Measurement of Space-Heating Emissions

Appendix A

PM2.5 Laboratory Results

Appliance:	Pellet Stove	**Burn Rate:**	High	**Run #:**	1
Fuel:	Alaskan Pellets	**Date:**	3/8/2011		

Filter Information:

T1 ID #:	A7518110
T1 Flow Rate [mL/min]:	4887
T1 Sample Volume [dsft^3]:	*20.67*
Q1 ID #:	A7518410
Q1 Flow Rate [mL/min]:	1026
Q1 Sample Volume [dsft^3]:	*4.34*

Run Information:

Test Duration [min]:	120
Tunnel Flow [dsft^3/min]:	470.8448
Barometric Pressure [in Hg]:	30.12
Temperature [℉]	73
Avg Delta H [in H2O]:	0.45

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**2422.00**	**3.311E+00**
K^+	876.88	1.199E+00
Na^+	7.53	1.030E-02
NH_4^+	0.00	0.000E+00
NO_3	25.38	3.469E-02
SO_4	299.55	4.095E-01
Silver	0.09	1.237E-04
Aluminum	0.00	0.000E+00
Arsenic	0.00	0.000E+00
Barium	0.07	9.242E-05
Bromine	0.14	1.893E-04
Calcium	2.13	2.912E-03
Cadmium	0.00	0.000E+00
Cerium	0.06	8.195E-05
Chlorine	36.28	4.960E-02
Cobalt	0.11	1.531E-04
Chromium	0.17	2.377E-04
Cesium	0.00	0.000E+00
Copper	0.69	9.416E-04
Iron	0.40	5.460E-04
Indium	0.00	0.000E+00
Potassium	922.77	1.261E+00
Magnesium	0.81	1.108E-03
Manganese	1.07	1.465E-03
Sodium	30.97	4.233E-02
Nickel	0.04	5.612E-05
Phosphorous	0.00	0.000E+00
Lead	0.16	2.126E-04
Rubidium	1.64	2.246E-03
Sulfur	106.04	1.449E-01
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.02	2.634E-05
Titanium	0.02	3.250E-05
Vanadium	0.00	0.000E+00
Zinc	39.89	5.453E-02
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	48.39	3.151E-01
Organic Carbon	59.09	3.847E-01

Appliance:	EPA Wood Stove	**Burn Rate:**	High	**Run #:**	2
Fuel:	Birch	**Date:**	3/9/2011		

Filter Information:

T1 ID #:	A751810N
T1 Flow Rate [mL/min]:	5697
T1 Sample Volume [dsft^3]:	*20.14*
Q1 ID #:	A751856I
Q1 Flow Rate [mL/min]:	1039
Q1 Sample Volume [dsft^3]:	*3.67*

Run Information:

Test Duration [min]:	101
Tunnel Flow [dsft^3/min]:	459.4511
Barometric Pressure [in Hg]:	30.09
Temperature [°F]	76
Avg Delta H [in H2O]:	0.44

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**1461.00**	**1.999E+00**
K^+	73.04	9.995E-02
Na^+	0.67	9.235E-04
NH_4^+	0.23	3.206E-04
NO_3	15.71	2.150E-02
SO_4	46.62	6.380E-02
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.00	0.000E+00
Barium	0.06	8.127E-05
Bromine	0.25	3.453E-04
Calcium	1.64	2.249E-03
Cadmium	0.01	1.547E-05
Cerium	0.00	0.000E+00
Chlorine	38.85	5.317E-02
Cobalt	0.05	7.001E-05
Chromium	0.08	1.065E-04
Cesium	0.00	0.000E+00
Copper	0.02	3.101E-05
Iron	0.41	5.546E-04
Indium	0.05	6.187E-05
Potassium	84.55	1.157E-01
Magnesium	1.43	1.959E-03
Manganese	0.21	2.908E-04
Sodium	29.74	4.071E-02
Nickel	0.04	4.871E-05
Phosphorous	0.00	0.000E+00
Lead	0.10	1.394E-04
Rubidium	0.14	1.919E-04
Sulfur	17.99	2.462E-02
Antimony	0.00	0.000E+00
Selenium	0.04	5.110E-05
Silicon	3.03	4.144E-03
Tin	0.00	0.000E+00
Strontium	0.00	4.644E-06
Titanium	0.03	4.222E-05
Vanadium	0.00	0.000E+00
Zinc	37.16	5.085E-02
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	155.30	1.165E+00
Organic Carbon	73.97	5.551E-01

Appliance:	EPA Wood Stove	**Burn Rate:**	High	**Run #:**	3
Fuel:	Spruce	**Date:**	3/10/2011		

Filter Information:

T1 ID #:	A751809U
T1 Flow Rate [mL/min]:	5445
T1 Sample Volume [dsft^3]:	*15.86*
Q1 ID #:	A7518550
Q1 Flow Rate [mL/min]:	1043
Q1 Sample Volume [dsft^3]:	*3.04*

Run Information:

Test Duration [min]:	83
Tunnel Flow [dsft^3/min]:	461.2901
Barometric Pressure [in Hg]:	29.93
Temperature [°F]	72
Avg Delta H [in H2O]:	0.45

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**728.00**	**1.271E+00**
K^+	62.52	1.091E-01
Na^+	0.77	1.340E-03
NH_4^+	0.01	2.552E-05
NO_3	14.41	2.516E-02
SO_4	41.13	7.179E-02
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.02	3.751E-05
Barium	0.02	3.574E-05
Bromine	0.09	1.540E-04
Calcium	1.27	2.221E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	18.44	3.219E-02
Cobalt	0.01	2.610E-05
Chromium	0.04	7.587E-05
Cesium	0.00	0.000E+00
Copper	0.06	1.126E-04
Iron	0.14	2.512E-04
Indium	0.00	0.000E+00
Potassium	72.61	1.267E-01
Magnesium	0.63	1.102E-03
Manganese	0.10	1.669E-04
Sodium	11.53	2.013E-02
Nickel	0.10	1.769E-04
Phosphorous	0.00	0.000E+00
Lead	0.03	4.540E-05
Rubidium	0.07	1.184E-04
Sulfur	16.56	2.890E-02
Antimony	0.00	0.000E+00
Selenium	0.00	3.949E-06
Silicon	1.24	2.161E-03
Tin	0.00	0.000E+00
Strontium	0.00	0.000E+00
Titanium	0.00	1.986E-06
Vanadium	0.00	0.000E+00
Zinc	15.21	2.655E-02
Zirconium	0.01	9.864E-06

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	31.19	2.842E-01
Organic Carbon	71.00	6.469E-01

Appliance:	EPA Wood Stove	**Burn Rate:**	Low	**Run #:**	5
Fuel:	Birch	**Date:**	3/17/2011		

Filter Information:

T1 ID #:	A751977 & A751801M
T1 Flow Rate [mL/min]:	2555
T1 Sample Volume [dsft^3]:	*22.45*
Q1 ID #:	A751853Y
Q1 Flow Rate [mL/min]:	1073
Q1 Sample Volume [dsft^3]:	*9.43*

Run Information:

Test Duration [min]:	248
Tunnel Flow [dsft^3/min]:	464.6459
Barometric Pressure [in Hg]:	30.11
Temperature [°F]	70
Avg Delta H [in H2O]:	0.44

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**4965.00**	**6.166E+00**
K^+	78.20	9.712E-02
Na^+	1.09	1.351E-03
NH_4^+	0.52	6.498E-04
NO_3	4.81	5.979E-03
SO_4	37.08	4.605E-02
Silver	0.00	0.000E+00
Aluminum	0.40	4.982E-04
Arsenic	0.00	0.000E+00
Barium	0.12	1.512E-04
Bromine	0.09	1.067E-04
Calcium	1.17	1.458E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	11.12	1.381E-02
Cobalt	0.03	3.350E-05
Chromium	0.13	1.565E-04
Cesium	0.07	8.628E-05
Copper	0.08	9.561E-05
Iron	0.61	7.536E-04
Indium	0.23	2.807E-04
Potassium	89.53	1.112E-01
Magnesium	0.64	7.975E-04
Manganese	0.17	2.160E-04
Sodium	9.15	1.137E-02
Nickel	0.05	6.823E-05
Phosphorous	0.00	0.000E+00
Lead	0.01	1.123E-05
Rubidium	0.15	1.910E-04
Sulfur	20.43	2.537E-02
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.08	9.825E-05
Strontium	0.03	3.370E-05
Titanium	0.00	0.000E+00
Vanadium	0.04	4.382E-05
Zinc	18.32	2.275E-02
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	396.68	1.173E+00
Organic Carbon	4408.43	1.304E+01

Appliance:	EPA Wood Stove	**Burn Rate:**	Low	**Run #:**	6
Fuel:	Spruce	**Date:**	3/18/2011		

Filter Information:

T1 ID #:	A751807S
T1 Flow Rate [mL/min]:	815
T1 Sample Volume [dsft^3]:	*5.98*
Q1 ID #:	A751842V
Q1 Flow Rate [mL/min]:	960
Q1 Sample Volume [dsft^3]:	*7.05*

Run Information:

Test Duration [min]:	210
Tunnel Flow [dsft^3/min]:	477.7275
Barometric Pressure [in Hg]:	29.94
Temperature [℉]	74
Avg Delta H [in H2O]:	0.42

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**351.00**	**1.681E+00**
K^+	2.60	1.247E-02
Na^+	0.21	1.021E-03
NH_4^+	0.06	2.808E-04
NO_3	1.49	7.149E-03
SO_4	1.73	8.295E-03
Silver	0.00	0.000E+00
Aluminum	0.10	4.904E-04
Arsenic	0.00	0.000E+00
Barium	0.01	4.878E-05
Bromine	0.01	5.251E-05
Calcium	0.41	1.982E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	0.82	3.912E-03
Cobalt	0.00	1.733E-05
Chromium	0.01	4.279E-05
Cesium	0.01	2.710E-05
Copper	0.00	0.000E+00
Iron	0.03	1.327E-04
Indium	0.00	0.000E+00
Potassium	2.84	1.359E-02
Magnesium	0.00	0.000E+00
Manganese	0.02	1.078E-04
Sodium	0.00	0.000E+00
Nickel	0.06	2.724E-04
Phosphorous	0.00	0.000E+00
Lead	0.01	3.789E-05
Rubidium	0.00	0.000E+00
Sulfur	0.84	4.047E-03
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.01	6.496E-05
Titanium	0.00	0.000E+00
Vanadium	0.00	0.000E+00
Zinc	0.29	1.397E-03
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	41.62	1.693E-01
Organic Carbon	321.87	1.309E+00

Appliance:	EPA OWHH	**Burn Rate:**	High	**Run #:**	8
Fuel:	Birch	**Date:**	3/22/2011		

Filter Information:

T1 ID #:	A751804P
T1 Flow Rate [mL/min]:	923.86
T1 Sample Volume [dsft^3]:	*7.98*
Q1 ID #:	A7518521X
Q1 Flow Rate [mL/min]:	1068.9
Q1 Sample Volume [dsft^3]:	*9.23*

Run Information:

Test Duration [min]:	243
Tunnel Flow [dsft^3/min]:	468.0051
Barometric Pressure [in Hg]:	30.1
Temperature [℉]	68
Avg Delta H [in H2O]:	0.45

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**3048.00**	**1.072E+01**
K^+	360.13	1.267E+00
Na^+	3.58	1.260E-02
NH_4^+	1.11	3.919E-03
NO_3	10.06	3.540E-02
SO_4	204.77	7.204E-01
Silver	0.07	2.387E-04
Aluminum	0.00	0.000E+00
Arsenic	0.00	0.000E+00
Barium	0.39	1.385E-03
Bromine	0.38	1.340E-03
Calcium	7.96	2.802E-02
Cadmium	0.25	8.752E-04
Cerium	0.00	0.000E+00
Chlorine	46.79	1.646E-01
Cobalt	0.07	2.575E-04
Chromium	0.10	3.373E-04
Cesium	0.00	0.000E+00
Copper	0.18	6.375E-04
Iron	0.31	1.081E-03
Indium	0.00	0.000E+00
Potassium	451.88	1.590E+00
Magnesium	4.07	1.433E-02
Manganese	1.02	3.573E-03
Sodium	32.70	1.150E-01
Nickel	0.02	8.393E-05
Phosphorous	0.35	1.226E-03
Lead	0.34	1.201E-03
Rubidium	0.80	2.798E-03
Sulfur	107.14	3.769E-01
Antimony	0.00	0.000E+00
Selenium	0.03	1.197E-04
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.07	2.550E-04
Titanium	0.00	0.000E+00
Vanadium	0.00	0.000E+00
Zinc	60.01	2.111E-01
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	297.08	9.034E-01
Organic Carbon	1688.39	5.134E+00

Appliance:	EPA OWHH	**Burn Rate:**	Low	**Run #:**	9
Fuel:	Birch	**Date:**	3/22/2011		

Filter Information:

T1 ID #:	A7518030
T1 Flow Rate [mL/min]:	780.85
T1 Sample Volume [dsft^3]:	*17.25*
Q1 ID #:	A751851W
Q1 Flow Rate [mL/min]:	875.09
Q1 Sample Volume [dsft^3]:	*19.33*

Run Information:

Test Duration [min]:	620
Tunnel Flow [dsft^3/min]:	494.703
Barometric Pressure [in Hg]:	30.05
Temperature [℉]	66
Avg Delta H [in H2O]:	0.44

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**8178.00**	**1.407E+01**
K^+	186.23	3.205E-01
Na^+	1.98	3.409E-03
NH_4^+	1.08	1.863E-03
NO_3	10.05	1.729E-02
SO_4	78.32	1.348E-01
Silver	0.02	3.890E-05
Aluminum	0.00	0.000E+00
Arsenic	0.00	0.000E+00
Barium	0.08	1.381E-04
Bromine	0.16	2.823E-04
Calcium	4.72	8.114E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	31.88	5.486E-02
Cobalt	0.04	6.895E-05
Chromium	0.09	1.463E-04
Cesium	0.00	0.000E+00
Copper	0.14	2.458E-04
Iron	0.31	5.383E-04
Indium	0.00	0.000E+00
Potassium	219.45	3.777E-01
Magnesium	1.47	2.538E-03
Manganese	0.21	3.639E-04
Sodium	14.91	2.566E-02
Nickel	0.01	1.386E-05
Phosphorous	0.00	0.000E+00
Lead	0.11	1.850E-04
Rubidium	0.24	4.087E-04
Sulfur	43.69	7.518E-02
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.05	8.563E-05
Titanium	0.01	9.871E-06
Vanadium	0.00	0.000E+00
Zinc	27.05	4.656E-02
Zirconium	0.02	3.113E-05

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	396.68	6.091E-01
Organic Carbon	4408.43	6.769E+00

Appliance:	EPA OWHH	**Burn Rate:**	High	**Run #:**	10
Fuel:	Spruce	**Date:**	3/23/2011		

Filter Information:

T1 ID #:	A7517988
T1 Flow Rate [mL/min]:	798
T1 Sample Volume [dsft^3]:	*6.65*
Q1 ID #:	A751850V
Q1 Flow Rate [mL/min]:	1051
Q1 Sample Volume [dsft^3]:	*8.76*

Run Information:

Test Duration [min]:	237
Tunnel Flow [dsft^3/min]:	462.0291
Barometric Pressure [in Hg]:	29.76
Temperature [℉]	68
Avg Delta H [in H2O]:	0.48

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**1228.00**	**5.120E+00**
K^+	248.29	1.035E+00
Na^+	2.72	1.135E-02
NH_4^+	-0.73	-3.054E-03
NO_3	10.25	4.272E-02
SO_4	150.09	6.258E-01
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.05	1.937E-04
Barium	0.87	3.617E-03
Bromine	0.25	1.025E-03
Calcium	32.02	1.335E-01
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	29.43	1.227E-01
Cobalt	0.05	1.938E-04
Chromium	0.57	2.357E-03
Cesium	0.00	0.000E+00
Copper	0.21	8.814E-04
Iron	1.10	4.577E-03
Indium	0.00	0.000E+00
Potassium	330.54	1.378E+00
Magnesium	4.27	1.781E-02
Manganese	1.25	5.192E-03
Sodium	14.19	5.916E-02
Nickel	0.01	4.222E-05
Phosphorous	1.48	6.157E-03
Lead	0.24	9.917E-04
Rubidium	0.35	1.454E-03
Sulfur	80.65	3.363E-01
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.20	8.541E-04
Titanium	0.00	0.000E+00
Vanadium	0.00	1.439E-05
Zinc	22.14	9.232E-02
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	78.28	2.478E-01
Organic Carbon	623.86	1.975E+00

Appliance:	EPA OWHH	**Burn Rate:**	Low	**Run #:**	11
Fuel:	Spruce	**Date:**	3/24/2011		

Filter Information:

T1 ID #:	
T1 Flow Rate [mL/min]:	914.5
T1 Sample Volume [dsft^3]:	*18.79*
Q1 ID #:	A751844X
Q1 Flow Rate [mL/min]:	1116.7
Q1 Sample Volume [dsft^3]:	*22.94*

Run Information:

Test Duration [min]:	582
Tunnel Flow [dsft^3/min]:	479.7847
Barometric Pressure [in Hg]:	29.72
Temperature [℉]	65
Avg Delta H [in H2O]:	0.43

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**2819.00**	**4.319E+00**
K^+	119.17	1.826E-01
Na^+	1.55	2.381E-03
NH_4^+	0.23	3.555E-04
NO_3	7.65	1.172E-02
SO_4	48.75	7.469E-02
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.00	0.000E+00
Barium	0.07	1.115E-04
Bromine	0.14	2.079E-04
Calcium	3.72	5.693E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	20.88	3.199E-02
Cobalt	0.02	3.802E-05
Chromium	0.05	7.213E-05
Cesium	0.00	0.000E+00
Copper	0.08	1.302E-04
Iron	0.17	2.627E-04
Indium	0.00	0.000E+00
Potassium	115.50	1.770E-01
Magnesium	0.75	1.145E-03
Manganese	0.24	3.691E-04
Sodium	11.05	1.693E-02
Nickel	0.02	3.488E-05
Phosphorous	0.00	0.000E+00
Lead	0.07	1.126E-04
Rubidium	0.15	2.252E-04
Sulfur	24.40	3.738E-02
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.01	1.731E-05
Strontium	0.03	5.196E-05
Titanium	0.00	7.000E-06
Vanadium	0.00	0.000E+00
Zinc	21.28	3.260E-02
Zirconium	0.01	2.078E-05

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	41.62	5.223E-02
Organic Carbon	321.87	4.038E-01

Appliance:	Conventional Wood Stove	**Burn Rate:**	High	**Run #:**	12
Fuel:	Spruce	**Date:**	3/30/2011		

Filter Information:

T1 ID #:	A751826V
T1 Flow Rate [mL/min]:	857.52
T1 Sample Volume [dsft^3]:	*1.61*
Q1 ID #:	A751840T
Q1 Flow Rate [mL/min]:	901.43
Q1 Sample Volume [dsft^3]:	*1.69*

Run Information:

Test Duration [min]:	53
Tunnel Flow [dsft^3/min]:	444.7836
Barometric Pressure [in Hg]:	30.32
Temperature [℉]	75
Avg Delta H [in H2O]:	0.62

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**174.00**	**2.890E+00**
K^+	22.40	3.719E-01
Na^+	0.28	4.692E-03
NH_4^+	0.00	0.000E+00
NO_3	2.74	4.548E-02
SO_4	17.49	2.904E-01
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.00	0.000E+00
Barium	0.04	6.582E-04
Bromine	0.03	5.631E-04
Calcium	2.90	4.824E-02
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	3.71	6.165E-02
Cobalt	0.01	1.521E-04
Chromium	0.01	2.424E-04
Cesium	0.00	0.000E+00
Copper	0.00	0.000E+00
Iron	0.63	1.039E-02
Indium	0.00	0.000E+00
Potassium	24.88	4.132E-01
Magnesium	0.54	8.915E-03
Manganese	0.08	1.386E-03
Sodium	2.77	4.593E-02
Nickel	0.01	2.159E-04
Phosphorous	0.00	0.000E+00
Lead	0.05	9.010E-04
Rubidium	0.01	1.126E-04
Sulfur	8.09	1.343E-01
Antimony	0.00	0.000E+00
Selenium	0.00	4.318E-05
Silicon	0.00	0.000E+00
Tin	0.15	2.440E-03
Strontium	0.04	6.194E-04
Titanium	0.00	0.000E+00
Vanadium	0.00	0.000E+00
Zinc	3.29	5.471E-02
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	23.96	3.785E-01
Organic Carbon	95.09	1.502E+00

Appliance:	Conventional Wood Stove	**Burn Rate:**	High	**Run #:**	13
Fuel:	Birch	**Date:**	3/31/2011		

Filter Information:

T1 ID #:	A751814R & A751825U
T1 Flow Rate [mL/min]:	644.48
T1 Sample Volume [dsft^3]:	*0.91*
Q1 ID #:	A751839O
Q1 Flow Rate [mL/min]:	802.76
Q1 Sample Volume [dsft^3]:	*1.13*

Run Information:

Test Duration [min]:	40
Tunnel Flow [dsft^3/min]:	433.3931
Barometric Pressure [in Hg]:	30.32
Temperature [℉]	76
Avg Delta H [in H2O]:	0.59

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**3308.00**	**9.456E+01**
K^+	30.31	8.663E-01
Na^+	0.76	2.175E-02
NH_4^+	0.20	5.730E-03
NO_3	5.10	1.457E-01
SO_4	15.79	4.513E-01
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.00	0.000E+00
Barium	0.02	6.475E-04
Bromine	0.06	1.755E-03
Calcium	0.78	2.217E-02
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	8.63	2.468E-01
Cobalt	0.05	1.442E-03
Chromium	0.04	1.008E-03
Cesium	0.00	0.000E+00
Copper	0.04	1.263E-03
Iron	0.35	9.923E-03
Indium	0.00	0.000E+00
Potassium	43.02	1.230E+00
Magnesium	0.30	8.620E-03
Manganese	0.06	1.756E-03
Sodium	4.87	1.391E-01
Nickel	0.07	1.859E-03
Phosphorous	0.00	0.000E+00
Lead	0.05	1.487E-03
Rubidium	0.03	7.432E-04
Sulfur	12.20	3.486E-01
Antimony	0.00	0.000E+00
Selenium	0.01	2.328E-04
Silicon	0.32	9.244E-03
Tin	0.00	0.000E+00
Strontium	0.02	6.786E-04
Titanium	0.00	0.000E+00
Vanadium	0.00	0.000E+00
Zinc	7.33	2.096E-01
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	23.96	5.498E-01
Organic Carbon	95.09	2.182E+00

Appliance:	Conventional Wood Stove	**Burn Rate:**	Low	**Run #:**	14
Fuel:	Spruce	**Date:**	4/1/2011		

Filter Information:

T1 ID #:	A751815S
T1 Flow Rate [mL/min]:	756
T1 Sample Volume [dsft^3]:	*1.40*
Q1 ID #:	A751832T
Q1 Flow Rate [mL/min]:	937
Q1 Sample Volume [dsft^3]:	*1.74*

Run Information:

Test Duration [min]:	53
Tunnel Flow [dsft^3/min]:	459.842
Barometric Pressure [in Hg]:	29.96
Temperature [°F]	74
Avg Delta H [in H2O]:	0.55

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**757.00**	**1.489E+01**
K^+	37.93	7.463E-01
Na^+	0.37	7.194E-03
NH_4^+	0.00	0.000E+00
NO_3	2.84	5.595E-02
SO_4	15.78	3.105E-01
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.01	2.224E-04
Barium	0.00	0.000E+00
Bromine	0.04	7.562E-04
Calcium	0.29	5.709E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	4.90	9.642E-02
Cobalt	0.01	2.004E-04
Chromium	0.00	3.568E-05
Cesium	0.00	0.000E+00
Copper	0.00	0.000E+00
Iron	0.04	8.732E-04
Indium	0.00	0.000E+00
Potassium	44.15	8.687E-01
Magnesium	0.01	1.241E-04
Manganese	0.02	4.725E-04
Sodium	1.98	3.896E-02
Nickel	0.00	0.000E+00
Phosphorous	0.00	0.000E+00
Lead	0.02	4.226E-04
Rubidium	0.01	1.112E-04
Sulfur	9.71	1.910E-01
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.00	0.000E+00
Titanium	0.00	0.000E+00
Vanadium	0.00	0.000E+00
Zinc	2.76	5.428E-02
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	131.11	2.081E+00
Organic Carbon	669.43	1.063E+01

Appliance:	Conventional Wood Stove	**Burn Rate:**	Low	**Run #:**	15
Fuel:	Birch	**Date:**	4/1/2011		

Filter Information:

T1 ID #:	A751816T
T1 Flow Rate [mL/min]:	783
T1 Sample Volume [dsft^3]:	*1.34*
Q1 ID #:	A751836X
Q1 Flow Rate [mL/min]:	997
Q1 Sample Volume [dsft^3]:	*1.70*

Run Information:

Test Duration [min]:	49
Tunnel Flow [dsft^3/min]:	446.1507
Barometric Pressure [in Hg]:	29.98
Temperature [°F]	77
Avg Delta H [in H2O]:	0.55

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**2242.00**	**4.492E+01**
K^+	36.48	7.310E-01
Na^+	0.30	5.926E-03
NH_4^+	0.00	-2.363E-05
NO_3	1.52	3.047E-02
SO_4	14.23	2.852E-01
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.01	1.587E-04
Barium	0.00	0.000E+00
Bromine	0.05	9.063E-04
Calcium	0.16	3.291E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	5.17	1.035E-01
Cobalt	0.01	2.067E-04
Chromium	0.00	0.000E+00
Cesium	0.00	0.000E+00
Copper	0.00	0.000E+00
Iron	0.00	7.500E-05
Indium	0.00	0.000E+00
Potassium	49.03	9.823E-01
Magnesium	0.15	3.028E-03
Manganese	0.06	1.242E-03
Sodium	4.63	9.271E-02
Nickel	0.01	1.930E-04
Phosphorous	0.00	0.000E+00
Lead	0.02	3.625E-04
Rubidium	0.05	9.061E-04
Sulfur	15.10	3.026E-01
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.00	0.000E+00
Titanium	0.00	0.000E+00
Vanadium	0.00	0.000E+00
Zinc	7.64	1.531E-01
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	455.07	7.160E+00
Organic Carbon	1970.65	3.101E+01

Appliance:	Oil Burner	**Burn Rate:**	Single	**Run #:**	17
Fuel:	No 2 Fuel Oil	**Date:**	4/12/2011		

Filter Information:

T1 ID #:	A751818V
T1 Flow Rate [mL/min]:	872.12
T1 Sample Volume [dsft^3]:	*15.93*
Q1 ID #:	A751833U
Q1 Flow Rate [mL/min]:	1086.6
Q1 Sample Volume [dsft^3]:	*19.84*

Run Information:

Test Duration [min]:	519
Tunnel Flow [dsft^3/min]:	487.5126
Barometric Pressure [in Hg]:	30.24
Temperature [°F]	76
Avg Delta H [in H2O]:	0.45

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**137.00**	**2.516E-01**
K^+	0.00	0.000E+00
Na^+	0.28	5.147E-04
NH_4^+	11.52	2.116E-02
NO_3	1.13	2.070E-03
SO_4	53.59	9.842E-02
Silver	0.00	0.000E+00
Aluminum	0.15	2.833E-04
Arsenic	0.00	0.000E+00
Barium	0.00	0.000E+00
Bromine	0.00	8.302E-06
Calcium	0.19	3.474E-04
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	0.08	1.397E-04
Cobalt	0.01	9.759E-06
Chromium	0.02	3.842E-05
Cesium	0.00	2.078E-06
Copper	0.06	1.156E-04
Iron	0.18	3.386E-04
Indium	0.00	0.000E+00
Potassium	0.07	1.374E-04
Magnesium	0.00	0.000E+00
Manganese	0.01	2.118E-05
Sodium	0.00	0.000E+00
Nickel	0.07	1.268E-04
Phosphorous	0.00	0.000E+00
Lead	0.00	0.000E+00
Rubidium	0.00	0.000E+00
Sulfur	19.56	3.592E-02
Antimony	0.00	0.000E+00
Selenium	0.00	0.000E+00
Silicon	0.09	1.673E-04
Tin	0.00	0.000E+00
Strontium	0.00	0.000E+00
Titanium	0.02	3.740E-05
Vanadium	0.00	0.000E+00
Zinc	0.02	2.844E-05
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	6.84	1.009E-02
Organic Carbon	44.60	6.574E-02

Appliance:	Waste Oil Burner	**Burn Rate:**	Single	**Run #:**	18
Fuel:	Waste Oil	**Date:**	4/14/2011		

Filter Information:

T1 ID #:	A751824T
T1 Flow Rate [mL/min]:	3754
T1 Sample Volume [dsft^3]:	*21.58*
Q1 ID #:	A751829Y
Q1 Flow Rate [mL/min]:	3699
Q1 Sample Volume [dsft^3]:	*21.27*

Run Information:

Test Duration [min]:	163
Tunnel Flow [dsft^3/min]:	445.7873
Barometric Pressure [in Hg]:	30.14
Temperature [°F]	72.95
Avg Delta H [in H2O]:	0.4752

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**8402.00**	**1.041E+01**
K^+	337.71	**4.185E-01**
Na^+	564.26	**6.993E-01**
NH_4^+	0.00	**0.000E+00**
NO_3	556.29	**6.894E-01**
SO_4	461.95	**5.725E-01**
Silver		No Data
Aluminum	6.66	**8.250E-03**
Arsenic		No Data
Barium		No Data
Bromine	1.83	**2.264E-03**
Calcium	181.47	**2.249E-01**
Cadmium		No Data
Cerium		No Data
Chlorine	1791.18	**2.220E+00**
Cobalt		No Data
Chromium		No Data
Cesium		No Data
Copper		No Data
Iron	43.96	**5.449E-02**
Indium		No Data
Potassium	370.56	**4.592E-01**
Magnesium	19.22	**2.381E-02**
Manganese		No Data
Sodium		No Data
Nickel		No Data
Phosphorous	700.04	**8.676E-01**
Lead	14.71	**1.823E-02**
Rubidium	0.00	**0.000E+00**
Sulfur	187.50	**2.324E-01**
Antimony		No Data
Selenium		No Data
Silicon	2.39	**2.966E-03**
Tin		No Data
Strontium		No Data
Titanium		No Data
Vanadium		No Data
Zinc	1349.93	**1.673E+00**
Zirconium		No Data

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	21.47	2.700E-02
Organic Carbon	79.42	9.989E-02

Appliance:	Coal Stove	**Burn Rate:**	High	**Run #:**	20
Fuel:	Dry Stoker Coal	**Date:**	5/6/2011		

Filter Information:

T1 ID #:	A751822R
T1 Flow Rate [mL/min]:	223
T1 Sample Volume [dsft^3]:	*1.62*
Q1 ID #:	A751828X
Q1 Flow Rate [mL/min]:	849
Q1 Sample Volume [dsft^3]:	*6.18*

Run Information:

Test Duration [min]:	208
Tunnel Flow [dsft^3/min]:	460.1363
Barometric Pressure [in Hg]:	30.14
Temperature [°F]	76.7
Avg Delta H [in H2O]:	0.4528

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**1027.00**	**1.745E+01**
K^+	0.17	**2.867E-03**
Na^+	0.21	**3.545E-03**
NH_4^+	0.82	**1.394E-02**
NO_3	0.83	**1.418E-02**
SO_4	3.09	**5.244E-02**
Silver	0.00	**0.000E+00**
Aluminum	0.09	**1.566E-03**
Arsenic	0.04	**6.724E-04**
Barium	0.00	**0.000E+00**
Bromine	0.10	**1.748E-03**
Calcium	0.13	**2.170E-03**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	5.76	**9.791E-02**
Cobalt	0.00	**0.000E+00**
Chromium	0.01	**1.290E-04**
Cesium	0.00	**0.000E+00**
Copper	0.00	**6.343E-05**
Iron	0.15	**2.566E-03**
Indium	0.00	**0.000E+00**
Potassium	0.19	**3.264E-03**
Magnesium	0.00	**0.000E+00**
Manganese	0.00	**0.000E+00**
Sodium	0.00	**0.000E+00**
Nickel	0.00	**0.000E+00**
Phosphorous	0.00	**0.000E+00**
Lead	0.48	**8.184E-03**
Rubidium	0.00	**0.000E+00**
Sulfur	8.99	**1.527E-01**
Antimony	0.40	**6.722E-03**
Selenium	0.04	**5.975E-04**
Silicon	0.06	**9.742E-04**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	0.89	**1.516E-02**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	693.05	3.094E+00
Organic Carbon	1620.49	7.234E+00

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	21
Fuel:	Dry Stoker Coal	**Date:**	5/9/2011		

Filter Information:

T1 ID #:	A751821Q
T1 Flow Rate [mL/min]:	780.81
T1 Sample Volume [dsft^3]:	*10.82*
Q1 ID #:	A751837Y
Q1 Flow Rate [mL/min]:	893.53
Q1 Sample Volume [dsft^3]:	*12.38*

Run Information:

Test Duration [min]:	391
Tunnel Flow [dsft^3/min]:	478.2646
Barometric Pressure [in Hg]:	30.2
Temperature [°F]	71.46
Avg Delta H [in H2O]:	0.442

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**655.00**	**1.737E+00**
K^+	0.00	**0.000E+00**
Na^+	0.17	**4.488E-04**
NH_4^+	2.32	**6.163E-03**
NO_3	0.92	**2.447E-03**
SO_4	6.48	**1.719E-02**
Silver	0.00	**0.000E+00**
Aluminum	0.01	**2.846E-05**
Arsenic	0.02	**4.796E-05**
Barium	0.00	**0.000E+00**
Bromine	0.02	**5.336E-05**
Calcium	0.01	**1.507E-05**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	0.50	**1.320E-03**
Cobalt	0.00	**1.020E-05**
Chromium	0.00	**0.000E+00**
Cesium	0.00	**0.000E+00**
Copper	0.04	**1.097E-04**
Iron	0.06	**1.689E-04**
Indium	0.01	**2.997E-05**
Potassium	0.00	**0.000E+00**
Magnesium	0.00	**0.000E+00**
Manganese	0.00	**0.000E+00**
Sodium	0.00	**0.000E+00**
Nickel	0.00	**0.000E+00**
Phosphorous	0.00	**0.000E+00**
Lead	0.04	**9.892E-05**
Rubidium	0.00	**0.000E+00**
Sulfur	3.60	**9.541E-03**
Antimony	0.00	**0.000E+00**
Selenium	0.01	**1.499E-05**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	0.06	**1.682E-04**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	267.46	6.199E-01
Organic Carbon	1417.80	3.286E+00

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	23
Fuel:	Wet Stoker Coal	**Date:**	5/11/2011		

Filter Information:

T1 ID #:	A751820P
T1 Flow Rate [mL/min]:	142.9
T1 Sample Volume [dsft^3]:	*1.47*
Q1 ID #:	A7518492
Q1 Flow Rate [mL/min]:	896.63
Q1 Sample Volume [dsft^3]:	*9.21*

Run Information:

Test Duration [min]:	294
Tunnel Flow [dsft^3/min]:	467.5876
Barometric Pressure [in Hg]:	29.97
Temperature [°F]	75.0131
Avg Delta H [in H2O]:	0.4214

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**582.00**	**1.113E+01**
K^+	**0.00**	0.000E+00
Na^+	0.23	4.325E-03
NH_4^+	0.75	1.431E-02
NO_3	3.60	6.891E-02
SO_4	3.06	5.854E-02
Silver	0.00	0.000E+00
Aluminum	0.04	6.797E-04
Arsenic	0.01	2.809E-04
Barium	0.00	0.000E+00
Bromine	0.00	6.481E-06
Calcium	0.07	1.411E-03
Cadmium	0.07	1.296E-03
Cerium	0.00	0.000E+00
Chlorine	0.46	8.799E-03
Cobalt	0.01	1.319E-04
Chromium	0.00	0.000E+00
Cesium	0.08	1.624E-03
Copper	0.00	0.000E+00
Iron	0.10	1.848E-03
Indium	0.08	1.512E-03
Potassium	0.08	1.521E-03
Magnesium	0.00	0.000E+00
Manganese	0.00	0.000E+00
Sodium	0.00	0.000E+00
Nickel	0.01	2.637E-04
Phosphorous	0.00	0.000E+00
Lead	0.01	1.728E-04
Rubidium	0.00	9.505E-05
Sulfur	1.65	3.163E-02
Antimony	0.00	0.000E+00
Selenium	0.00	7.779E-05
Silicon	0.00	0.000E+00
Tin	0.00	0.000E+00
Strontium	0.00	0.000E+00
Titanium	0.02	4.762E-04
Vanadium	0.01	2.164E-04
Zinc	0.07	1.346E-03
Zirconium	0.05	8.641E-04

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	167.08	5.090E-01
Organic Carbon	2367.08	7.212E+00

Appliance:	Non Qualified OWHH	**Burn Rate:**	High	**Run #:**	25
Fuel:	Spruce	**Date:**	5/27/2011		

Filter Information:

T1 ID #:	A7583519
T1 Flow Rate [mL/min]:	168.8
T1 Sample Volume [dsft^3]:	*0.70*
Q1 ID #:	A7518470
Q1 Flow Rate [mL/min]:	924.45
Q1 Sample Volume [dsft^3]:	*3.86*

Run Information:

Test Duration [min]:	118
Tunnel Flow [dsft^3/min]:	387.2835
Barometric Pressure [in Hg]:	29.99
Temperature [°F]	68.3866
Avg Delta H [in H2O]:	0.4198

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**3946.00**	**1.301E+02**
K^+	64.11	**2.113E+00**
Na^+	0.87	**2.868E-02**
NH_4^+	0.00	**0.000E+00**
NO_3	2.92	**9.614E-02**
SO_4	19.20	**6.328E-01**
Silver	0.00	**0.000E+00**
Aluminum	0.00	**0.000E+00**
Arsenic	0.00	**0.000E+00**
Barium	0.00	**0.000E+00**
Bromine	0.07	**2.312E-03**
Calcium	0.95	**3.136E-02**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	11.62	**3.831E-01**
Cobalt	0.01	**4.868E-04**
Chromium	0.01	**2.220E-04**
Cesium	0.00	**0.000E+00**
Copper	0.13	**4.258E-03**
Iron	0.20	**6.561E-03**
Indium	0.01	**3.726E-04**
Potassium	72.77	**2.399E+00**
Magnesium	0.29	**9.466E-03**
Manganese	0.06	**1.956E-03**
Sodium	7.71	**2.540E-01**
Nickel	0.01	**4.302E-04**
Phosphorous	0.00	**0.000E+00**
Lead	0.02	**5.594E-04**
Rubidium	0.05	**1.603E-03**
Sulfur	8.89	**2.931E-01**
Antimony	0.00	**0.000E+00**
Selenium	0.00	**0.000E+00**
Silicon	0.07	**2.343E-03**
Tin	0.31	**1.006E-02**
Strontium	0.01	**2.237E-04**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	6.26	**2.062E-01**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	1717.98	1.034E+01
Organic Carbon	7290.90	4.388E+01

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	26
Fuel:	Wet Stoker Coal	**Date:**	5/30/2011		

Filter Information:	
T1 ID #:	A7583508
T1 Flow Rate [mL/min]:	130.9
T1 Sample Volume [dsft^3]:	*0.57*
Q1 ID #:	A751838Z
Q1 Flow Rate [mL/min]:	1037.6
Q1 Sample Volume [dsft^3]:	*4.50*

Run Information:	
Test Duration [min]:	123
Tunnel Flow [dsft^3/min]:	424.9401
Barometric Pressure [in Hg]:	29.98
Temperature [°F]	69.9032
Avg Delta H [in H2O]:	0.4735

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**6564.00**	**2.946E+02**
K^+	4.62	**2.074E-01**
Na^+	0.48	**2.146E-02**
NH_4^+	1.03	**4.630E-02**
NO_3	0.75	**3.363E-02**
SO_4	16.02	**7.192E-01**
Silver	0.00	**0.000E+00**
Aluminum	0.32	**1.439E-02**
Arsenic	0.10	**4.523E-03**
Barium	0.00	**0.000E+00**
Bromine	0.17	**7.619E-03**
Calcium	0.82	**3.678E-02**
Cadmium	0.06	**2.537E-03**
Cerium	0.00	**0.000E+00**
Chlorine	1.53	**6.887E-02**
Cobalt	0.01	**5.771E-04**
Chromium	0.01	**4.627E-04**
Cesium	0.05	**2.339E-03**
Copper	0.23	**1.031E-02**
Iron	0.59	**2.655E-02**
Indium	0.00	**0.000E+00**
Potassium	6.76	**3.036E-01**
Magnesium	0.00	**0.000E+00**
Manganese	0.05	**2.297E-03**
Sodium	4.67	**2.094E-01**
Nickel	0.02	**8.568E-04**
Phosphorous	0.00	**0.000E+00**
Lead	0.20	**9.194E-03**
Rubidium	0.03	**1.422E-03**
Sulfur	21.57	**9.678E-01**
Antimony	0.00	**0.000E+00**
Selenium	0.00	**1.016E-04**
Silicon	0.00	**2.126E-04**
Tin	0.00	**0.000E+00**
Strontium	0.03	**1.168E-03**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	0.70	**3.141E-02**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon		No Data
Organic Carbon		No Data

Appliance:	Non-Qualified OWHH	**Burn Rate:**	Low	**Run #:**	27
Fuel:	Coal with Retrofit Catalyst	**Date:**	6/1/2011		

Filter Information:

T1 ID #:	A758338C
T1 Flow Rate [mL/min]:	178.21
T1 Sample Volume [dsft^3]:	*1.24*
Q1 ID #:	A751846Z
Q1 Flow Rate [mL/min]:	1017
Q1 Sample Volume [dsft^3]:	*7.08*

Run Information:

Test Duration [min]:	196
Tunnel Flow [dsft^3/min]:	426.929
Barometric Pressure [in Hg]:	30.15
Temperature [°F]	69.7107
Avg Delta H [in H2O]:	0.4826

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**5815.00**	**1.201E+02**
K^+	0.90	**1.852E-02**
Na^+	0.45	**9.383E-03**
NH_4^+	0.35	**7.138E-03**
NO_3	0.36	**7.417E-03**
SO_4	9.88	**2.041E-01**
Silver	0.00	**0.000E+00**
Aluminum	0.68	**1.399E-02**
Arsenic	0.06	**1.263E-03**
Barium	0.00	**0.000E+00**
Bromine	0.06	**1.239E-03**
Calcium	0.20	**4.083E-03**
Cadmium	0.10	**2.102E-03**
Cerium	0.00	**0.000E+00**
Chlorine	0.41	**8.453E-03**
Cobalt	0.00	**6.812E-05**
Chromium	0.02	**5.009E-04**
Cesium	0.00	**0.000E+00**
Copper	0.05	**9.681E-04**
Iron	0.27	**5.492E-03**
Indium	0.00	**0.000E+00**
Potassium	1.33	**2.757E-02**
Magnesium	0.00	**0.000E+00**
Manganese	0.00	**0.000E+00**
Sodium	1.52	**3.131E-02**
Nickel	0.01	**1.877E-04**
Phosphorous	0.00	**0.000E+00**
Lead	0.30	**6.102E-03**
Rubidium	0.01	**1.168E-04**
Sulfur	17.99	**3.716E-01**
Antimony	0.00	**0.000E+00**
Selenium	0.01	**2.572E-04**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	0.43	**8.902E-03**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon		No Data
Organic Carbon		No Data

Appliance:	Coal HH	**Burn Rate:**	Single, Cold Start	**Run #:**	28
Fuel:	Coal (typical moisture)	**Date:**	6/7/2011		

Filter Information:

T1 ID #:	A758349F
T1 Flow Rate [mL/min]:	183.52
T1 Sample Volume [dsft^3]:	*1.28*
Q1 ID #:	A751835W
Q1 Flow Rate [mL/min]:	979.11
Q1 Sample Volume [dsft^3]:	*6.84*

Run Information:

Test Duration [min]:	199
Tunnel Flow [dsft^3/min]:	427.5965
Barometric Pressure [in Hg]:	30.13
Temperature [°F]	74.98
Avg Delta H [in H2O]:	0.48

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**364.00**	**7.280E+00**
K^+	14.23	2.846E-01
Na^+	15.92	3.185E-01
NH_4^+	14.04	2.807E-01
NO_3	1.72	3.433E-02
SO_4	153.86	3.077E+00
Silver	0.00	0.000E+00
Aluminum	1.47	2.946E-02
Arsenic	0.10	2.080E-03
Barium	0.27	5.330E-03
Bromine	0.01	2.487E-04
Calcium	5.60	1.121E-01
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	0.14	2.819E-03
Cobalt	0.03	6.313E-04
Chromium	0.19	3.828E-03
Cesium	0.05	9.983E-04
Copper	0.98	1.957E-02
Iron	4.74	9.488E-02
Indium	0.00	0.000E+00
Potassium	13.00	2.600E-01
Magnesium	0.73	1.453E-02
Manganese	0.15	2.939E-03
Sodium	15.55	3.110E-01
Nickel	0.10	2.030E-03
Phosphorous	0.26	5.284E-03
Lead	1.73	3.452E-02
Rubidium	0.07	1.447E-03
Sulfur	47.50	9.499E-01
Antimony	0.00	0.000E+00
Selenium	0.03	6.783E-04
Silicon	1.90	3.791E-02
Tin	0.00	0.000E+00
Strontium	0.06	1.153E-03
Titanium	0.06	1.293E-03
Vanadium	0.00	9.067E-05
Zinc	2.53	5.058E-02
Zirconium	0.03	6.781E-04

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	39.95	1.497E-01
Organic Carbon	184.95	6.933E-01

Appliance:	Coal HH	**Burn Rate:**	Single	**Run #:**	29
Fuel:	Wet Stoker Coal	**Date:**	6/7/2011		

Filter Information:

T1 ID #:	A7583406
T1 Flow Rate [mL/min]:	160.56
T1 Sample Volume [dsft^3]:	*1.13*
Q1 ID #:	A751834V
Q1 Flow Rate [mL/min]:	1029.4
Q1 Sample Volume [dsft^3]:	*7.27*

Run Information:

Test Duration [min]:	202
Tunnel Flow [dsft^3/min]:	410.0643
Barometric Pressure [in Hg]:	30.13
Temperature [°F]	77.6453
Avg Delta H [in H2O]:	0.49

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**355.00**	**7.705E+00**
K^+	12.99	2.820E-01
Na^+	14.90	3.234E-01
NH_4^+	9.31	2.020E-01
NO_3	1.91	4.149E-02
SO_4	141.80	3.078E+00
Silver	0.00	0.000E+00
Aluminum	2.61	5.659E-02
Arsenic	0.23	5.006E-03
Barium	0.42	9.036E-03
Bromine	0.11	2.478E-03
Calcium	10.91	2.367E-01
Cadmium	0.00	0.000E+00
Cerium	0.00	2.460E-05
Chlorine	0.24	5.102E-03
Cobalt	0.05	1.130E-03
Chromium	0.21	4.475E-03
Cesium	0.00	0.000E+00
Copper	1.16	2.517E-02
Iron	7.81	1.695E-01
Indium	0.00	0.000E+00
Potassium	13.59	2.949E-01
Magnesium	1.41	3.055E-02
Manganese	0.18	4.006E-03
Sodium	16.67	3.617E-01
Nickel	0.15	3.200E-03
Phosphorous	0.20	4.392E-03
Lead	1.90	4.125E-02
Rubidium	0.09	1.938E-03
Sulfur	46.51	1.010E+00
Antimony	0.19	4.170E-03
Selenium	0.04	8.343E-04
Silicon	4.77	1.035E-01
Tin	0.00	0.000E+00
Strontium	0.11	2.355E-03
Titanium	0.16	3.374E-03
Vanadium	0.05	9.842E-04
Zinc	2.38	5.158E-02
Zirconium	0.15	3.189E-03

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	41.08	1.391E-01
Organic Carbon	187.91	6.361E-01

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	30
Fuel:	Spruce	**Date:**	6/30/2011		

Filter Information:

T1 ID #:	A7583417
T1 Flow Rate [mL/min]:	200.7
T1 Sample Volume [dsft^3]:	*0.82*
Q1 ID #:	A751831S
Q1 Flow Rate [mL/min]:	997.4
Q1 Sample Volume [dsft^3]:	*4.08*

Run Information:

Test Duration [min]:	117
Tunnel Flow [dsft^3/min]:	412.9687
Barometric Pressure [in Hg]:	30.16
Temperature [°F]	78.439
Avg Delta H [in H2O]:	0.4357

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**5514.00**	**1.666E+02**
K^+	27.50	**8.308E-01**
Na^+	1.20	**3.622E-02**
NH_4^+	0.25	**7.522E-03**
NO_3	1.53	**4.620E-02**
SO_4	6.79	**2.050E-01**
Silver	0.00	**0.000E+00**
Aluminum	0.00	**0.000E+00**
Arsenic	0.01	**2.736E-04**
Barium	0.00	**0.000E+00**
Bromine	0.08	**2.290E-03**
Calcium	0.60	**1.803E-02**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	4.34	**1.310E-01**
Cobalt	0.00	**1.477E-04**
Chromium	0.00	**0.000E+00**
Cesium	0.00	**0.000E+00**
Copper	0.28	**8.563E-03**
Iron	0.10	**2.903E-03**
Indium	0.00	**0.000E+00**
Potassium	36.99	**1.118E+00**
Magnesium	0.09	**2.737E-03**
Manganese	0.02	**6.479E-04**
Sodium	4.64	**1.402E-01**
Nickel	0.00	**1.441E-04**
Phosphorous	0.00	**0.000E+00**
Lead	0.04	**1.197E-03**
Rubidium	0.02	**5.809E-04**
Sulfur	3.06	**9.240E-02**
Antimony	0.02	**6.829E-04**
Selenium	0.01	**2.188E-04**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.02	**6.271E-04**
Vanadium	0.00	**1.387E-04**
Zinc	5.24	**1.582E-01**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon		No Data
Organic Carbon		No Data

Appliance:	Non Qualified OWHH	**Burn Rate:**	High	**Run #:**	31
Fuel:	Birch	**Date:**	7/1/2011		

Filter Information:

T1 ID #:	A758339D
T1 Flow Rate [mL/min]:	211.3
T1 Sample Volume [dsft^3]:	*0.86*
Q1 ID #:	A768262E
Q1 Flow Rate [mL/min]:	997.4
Q1 Sample Volume [dsft^3]:	*4.04*

Run Information:

Test Duration [min]:	115
Tunnel Flow [dsft^3/min]:	367.8844
Barometric Pressure [in Hg]:	30.21
Temperature [°F]	74.7845
Avg Delta H [in H2O]:	0.4263

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**4628.00**	**1.193E+02**
K^+	111.69	**2.880E+00**
Na^+	0.36	**9.180E-03**
NH_4^+	0.16	**4.000E-03**
NO_3	4.15	**1.071E-01**
SO_4	59.52	**1.535E+00**
Silver	0.15	**3.789E-03**
Aluminum	0.00	**0.000E+00**
Arsenic	0.01	**3.213E-04**
Barium	0.00	**0.000E+00**
Bromine	0.09	**2.335E-03**
Calcium	0.47	**1.222E-02**
Cadmium	0.03	**8.745E-04**
Cerium	0.00	**0.000E+00**
Chlorine	18.86	**4.864E-01**
Cobalt	0.01	**3.815E-04**
Chromium	0.00	**0.000E+00**
Cesium	0.00	**0.000E+00**
Copper	0.09	**2.214E-03**
Iron	0.05	**1.352E-03**
Indium	0.00	**0.000E+00**
Potassium	116.85	**3.013E+00**
Magnesium	0.60	**1.546E-02**
Manganese	0.08	**2.082E-03**
Sodium	25.62	**6.606E-01**
Nickel	0.00	**4.983E-05**
Phosphorous	0.00	**0.000E+00**
Lead	0.02	**4.963E-04**
Rubidium	0.08	**2.043E-03**
Sulfur	24.02	**6.193E-01**
Antimony	0.00	**0.000E+00**
Selenium	0.00	**0.000E+00**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.01	**3.501E-04**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	21.39	**5.516E-01**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	1632.88	8.920E+00
Organic Carbon	6724.69	3.674E+01

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	32
Fuel:	Birch	**Date:**	7/6/2011		

Filter Information:

T1 ID #:	A7583428
T1 Flow Rate [mL/min]:	159.34
T1 Sample Volume [dsft^3]:	*1.26*
Q1 ID #:	A768261D
Q1 Flow Rate [mL/min]:	1030.9
Q1 Sample Volume [dsft^3]:	*8.18*

Run Information:

Test Duration [min]:	231
Tunnel Flow [dsft^3/min]:	413.0445
Barometric Pressure [in Hg]:	30.16
Temperature [°F]	87.5733
Avg Delta H [in H2O]:	0.4869

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**2269.00**	**4.447E+01**
K^+	24.55	**4.812E-01**
Na^+	0.19	**3.694E-03**
NH_4^+	0.18	**3.604E-03**
NO_3	1.75	**3.434E-02**
SO_4	12.39	**2.428E-01**
Silver	0.00	**0.000E+00**
Aluminum	0.00	**0.000E+00**
Arsenic	0.01	**1.552E-04**
Barium	0.00	**0.000E+00**
Bromine	0.05	**1.020E-03**
Calcium	0.12	**2.377E-03**
Cadmium	0.23	**4.430E-03**
Cerium	0.00	**0.000E+00**
Chlorine	9.07	**1.779E-01**
Cobalt	0.00	**0.000E+00**
Chromium	0.03	**5.012E-04**
Cesium	0.00	**0.000E+00**
Copper	0.01	**2.730E-04**
Iron	0.09	**1.669E-03**
Indium	0.00	**0.000E+00**
Potassium	31.92	**6.256E-01**
Magnesium	0.14	**2.820E-03**
Manganese	0.00	**0.000E+00**
Sodium	5.45	**1.068E-01**
Nickel	0.00	**0.000E+00**
Phosphorous	0.00	**0.000E+00**
Lead	0.00	**0.000E+00**
Rubidium	0.04	**7.535E-04**
Sulfur	5.62	**1.102E-01**
Antimony	0.00	**0.000E+00**
Selenium	0.01	**1.352E-04**
Silicon	0.00	**0.000E+00**
Tin	0.17	**3.323E-03**
Strontium	0.01	**2.216E-04**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	8.34	**1.635E-01**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon		No Data
Organic Carbon		No Data

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	33
Fuel:	Birch, Cold Start	**Date:**	7/8/2011		

Filter Information:

T1 ID #:	A7583439
T1 Flow Rate [mL/min]:	145.4
T1 Sample Volume [dsft^3]:	*1.77*
Q1 ID #:	A768260C & A768259J
Q1 Flow Rate [mL/min]:	980.6
Q1 Sample Volume [dsft^3]:	*11.92*

Run Information:

Test Duration [min]:	346
Tunnel Flow [dsft^3/min]:	407.1146
Barometric Pressure [in Hg]:	30.26
Temperature [°F]	77.2133
Avg Delta H [in H2O]:	0.4393

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**2514.00**	**3.475E+01**
K^+	54.59	**7.546E-01**
Na^+	0.32	**4.455E-03**
NH_4^+	0.24	**3.267E-03**
NO_3	2.11	**2.914E-02**
SO_4	17.83	**2.465E-01**
Silver	0.02	**3.125E-04**
Aluminum	0.00	**0.000E+00**
Arsenic	0.00	**6.257E-05**
Barium	0.00	**0.000E+00**
Bromine	0.10	**1.423E-03**
Calcium	0.59	**8.195E-03**
Cadmium	0.07	**9.374E-04**
Cerium	0.02	**2.523E-04**
Chlorine	26.11	**3.610E-01**
Cobalt	0.05	**6.336E-04**
Chromium	0.27	**3.668E-03**
Cesium	0.00	**0.000E+00**
Copper	3.50	**4.831E-02**
Iron	2.92	**4.037E-02**
Indium	0.00	**0.000E+00**
Potassium	62.81	**8.681E-01**
Magnesium	0.64	**8.780E-03**
Manganese	0.09	**1.265E-03**
Sodium	14.91	**2.061E-01**
Nickel	0.12	**1.688E-03**
Phosphorous	0.00	**0.000E+00**
Lead	0.19	**2.690E-03**
Rubidium	0.04	**5.628E-04**
Sulfur	7.82	**1.081E-01**
Antimony	0.52	**7.186E-03**
Selenium	0.00	**6.263E-06**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.01	**1.094E-04**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	19.54	**2.700E-01**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	2563.52	5.254E+00
Organic Carbon	8579.16	1.758E+01

Appliance:	EPA OWHH	**Burn Rate:**	Low	**Run #:**	34
Fuel:	Birch w/ Retrofit Catalyst	**Date:**	7/27/2011		

Filter Information:

T1 ID #:	A758346C
T1 Flow Rate [mL/min]:	180.3
T1 Sample Volume [dsft^3]:	*3.35*
Q1 ID #:	A768275J
Q1 Flow Rate [mL/min]:	1108.1
Q1 Sample Volume [dsft^3]:	*20.59*

Run Information:

Test Duration [min]:	534
Tunnel Flow [dsft^3/min]:	502.8851
Barometric Pressure [in Hg]:	30.21
Temperature [°F]	81.5533
Avg Delta H [in H2O]:	0.4472

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**3754.00**	**3.382E+01**
K^+	32.81	**2.955E-01**
Na^+	0.58	**5.252E-03**
NH_4^+	0.14	**1.226E-03**
NO_3	4.33	**3.902E-02**
SO_4	14.90	**1.343E-01**
Silver	0.00	**0.000E+00**
Aluminum	0.00	**0.000E+00**
Arsenic	0.00	**0.000E+00**
Barium	0.00	**0.000E+00**
Bromine	0.09	**7.949E-04**
Calcium	0.51	**4.570E-03**
Cadmium	0.12	**1.120E-03**
Cerium	0.01	**1.338E-04**
Chlorine	12.69	**1.143E-01**
Cobalt	0.00	**2.454E-05**
Chromium	0.01	**1.325E-04**
Cesium	0.00	**0.000E+00**
Copper	0.12	**1.080E-03**
Iron	0.44	**3.952E-03**
Indium	0.27	**2.444E-03**
Potassium	35.44	**3.192E-01**
Magnesium	0.22	**1.977E-03**
Manganese	0.05	**4.265E-04**
Sodium	10.04	**9.043E-02**
Nickel	0.01	**5.517E-05**
Phosphorous	0.00	**0.000E+00**
Lead	0.04	**3.975E-04**
Rubidium	0.02	**1.936E-04**
Sulfur	5.79	**5.212E-02**
Antimony	0.00	**0.000E+00**
Selenium	0.00	**0.000E+00**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	8.50	**7.661E-02**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	717.01	1.051E+00
Organic Carbon	1736.87	2.546E+00

Appliance:	Coal Stove	**Burn Rate:**	High	**Run #:**	35
Fuel:	Wet Stoker Coal	**Date:**	8/10/2011		

Filter Information:

T1 ID #:	A758345B
T1 Flow Rate [mL/min]:	172.5
T1 Sample Volume [dsft^3]:	*1.30*
Q1 ID #:	A768267J
Q1 Flow Rate [mL/min]:	998.4
Q1 Sample Volume [dsft^3]:	*7.54*

Run Information:

Test Duration [min]:	220
Tunnel Flow [dsft^3/min]:	469.458
Barometric Pressure [in Hg]:	30.08
Temperature [°F]	86.3213
Avg Delta H [in H2O]:	0.4683

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**362.00**	**7.825E+00**
K^+	0.19	**4.040E-03**
Na^+	0.17	**3.624E-03**
NH_4^+	0.45	**9.657E-03**
NO_3	0.53	**1.154E-02**
SO_4	3.18	**6.880E-02**
Silver	0.00	**0.000E+00**
Aluminum	0.00	**0.000E+00**
Arsenic	0.00	**2.442E-05**
Barium	0.00	**0.000E+00**
Bromine	0.02	**5.008E-04**
Calcium	0.06	**1.323E-03**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	0.11	**2.361E-03**
Cobalt	0.00	**2.442E-05**
Chromium	0.00	**0.000E+00**
Cesium	0.00	**0.000E+00**
Copper	0.00	**0.000E+00**
Iron	0.04	**8.699E-04**
Indium	0.00	**0.000E+00**
Potassium	0.06	**1.398E-03**
Magnesium	0.00	**0.000E+00**
Manganese	0.00	**0.000E+00**
Sodium	0.00	**0.000E+00**
Nickel	0.00	**5.376E-05**
Phosphorous	0.00	**0.000E+00**
Lead	0.13	**2.834E-03**
Rubidium	0.00	**0.000E+00**
Sulfur	1.79	**3.875E-02**
Antimony	0.45	**9.770E-03**
Selenium	0.00	**6.106E-05**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.02	**3.908E-04**
Titanium	0.01	**2.690E-04**
Vanadium	0.00	**0.000E+00**
Zinc	0.12	**2.555E-03**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	513.67	1.918E+00
Organic Carbon	987.70	3.689E+00

Appliance:	Coal Stove	**Burn Rate:**	Low, Cold Start	**Run #:**	36
Fuel:	Wet Lump Coal	**Date:**	8/11/2011		

Filter Information:

T1 ID #:	A779727Z
T1 Flow Rate [mL/min]:	162.85
T1 Sample Volume [dsft^3]:	*2.82*
Q1 ID #:	A768258I
Q1 Flow Rate [mL/min]:	1064.4
Q1 Sample Volume [dsft^3]:	*18.46*

Run Information:

Test Duration [min]:	497
Tunnel Flow [dsft^3/min]:	488.8577
Barometric Pressure [in Hg]:	30.14
Temperature [°F]	78.739
Avg Delta H [in H2O]:	0.4488

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**1571.00**	**1.632E+01**
K^+	0.97	**1.012E-02**
Na^+	0.16	**1.675E-03**
NH_4^+	1.31	**1.361E-02**
NO_3	1.21	**1.257E-02**
SO_4	9.21	**9.565E-02**
Silver	0.00	**0.000E+00**
Aluminum	0.07	**7.065E-04**
Arsenic	0.06	**5.754E-04**
Barium	0.00	**0.000E+00**
Bromine	0.06	**5.754E-04**
Calcium	0.84	**8.775E-03**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	0.82	**8.556E-03**
Cobalt	0.00	**1.059E-05**
Chromium	0.02	**2.273E-04**
Cesium	0.00	**0.000E+00**
Copper	0.00	**0.000E+00**
Iron	0.15	**1.538E-03**
Indium	0.11	**1.174E-03**
Potassium	1.47	**1.524E-02**
Magnesium	0.02	**1.899E-04**
Manganese	0.08	**8.520E-04**
Sodium	0.00	**0.000E+00**
Nickel	0.01	**5.994E-05**
Phosphorous	0.00	**0.000E+00**
Lead	0.10	**1.045E-03**
Rubidium	0.01	**5.400E-05**
Sulfur	7.71	**8.004E-02**
Antimony	0.00	**0.000E+00**
Selenium	0.01	**1.186E-04**
Silicon	0.03	**2.808E-04**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.01	**1.298E-04**
Vanadium	0.00	**0.000E+00**
Zinc	0.59	**6.109E-03**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon		No Data
Organic Carbon		No Data

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	37
Fuel:	Wet Lump Coal	**Date:**	8/12/2011		

Filter Information:

T1 ID #:	A779726Y
T1 Flow Rate [mL/min]:	247.3
T1 Sample Volume [dsft^3]:	*3.37*
Q1 ID #:	A768266I
Q1 Flow Rate [mL/min]:	1002.9
Q1 Sample Volume [dsft^3]:	*13.67*

Run Information:

Test Duration [min]:	393
Tunnel Flow [dsft^3/min]:	488.5701
Barometric Pressure [in Hg]:	30.12
Temperature [°F]	81.5964
Avg Delta H [in H2O]:	0.4678

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**316.00**	**2.748E+00**
K^+	0.60	**5.223E-03**
Na^+	0.93	**8.102E-03**
NH_4^+	0.73	**6.348E-03**
NO_3	0.59	**5.092E-03**
SO_4	3.83	**3.328E-02**
Silver	0.00	**0.000E+00**
Aluminum	0.29	**2.552E-03**
Arsenic	0.02	**1.769E-04**
Barium	0.00	**0.000E+00**
Bromine	0.02	**1.327E-04**
Calcium	0.25	**2.217E-03**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	0.04	**3.262E-04**
Cobalt	0.00	**0.000E+00**
Chromium	0.00	**0.000E+00**
Cesium	0.00	**0.000E+00**
Copper	0.02	**1.327E-04**
Iron	0.13	**1.158E-03**
Indium	0.08	**6.879E-04**
Potassium	0.02	**2.071E-04**
Magnesium	0.00	**0.000E+00**
Manganese	0.00	**0.000E+00**
Sodium	0.00	**0.000E+00**
Nickel	0.01	**1.140E-04**
Phosphorous	0.00	**0.000E+00**
Lead	0.01	**9.828E-05**
Rubidium	0.00	**3.832E-05**
Sulfur	1.74	**1.511E-02**
Antimony	0.00	**0.000E+00**
Selenium	0.00	**0.000E+00**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.00	**0.000E+00**
Vanadium	0.00	**0.000E+00**
Zinc	0.05	**4.158E-04**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	203.26	4.359E-01
Organic Carbon	1041.70	2.234E+00

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	38
Fuel:	Dry Lump Coal	**Date:**	8/15/2011		

Filter Information:

T1 ID #:	A7797280
T1 Flow Rate [mL/min]:	170.9
T1 Sample Volume [dsft^3]:	*2.18*
Q1 ID #:	A768265H
Q1 Flow Rate [mL/min]:	990.81
Q1 Sample Volume [dsft^3]:	*12.66*

Run Information:

Test Duration [min]:	369
Tunnel Flow [dsft^3/min]:	515.7899
Barometric Pressure [in Hg]:	30.14
Temperature [°F]	82.773
Avg Delta H [in H2O]:	0.4588

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**578.00**	**8.191E+00**
K^+	0.21	**2.943E-03**
Na^+	0.16	**2.301E-03**
NH_4^+	1.04	**1.477E-02**
NO_3	0.93	**1.311E-02**
SO_4	4.60	**6.514E-02**
Silver	0.00	**0.000E+00**
Aluminum	0.16	**2.334E-03**
Arsenic	0.00	**0.000E+00**
Barium	0.00	**0.000E+00**
Bromine	0.02	**2.530E-04**
Calcium	0.09	**1.255E-03**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	0.19	**2.703E-03**
Cobalt	0.00	**1.443E-05**
Chromium	0.01	**8.336E-05**
Cesium	0.00	**0.000E+00**
Copper	0.00	**4.325E-05**
Iron	0.05	**7.195E-04**
Indium	0.00	**0.000E+00**
Potassium	0.12	**1.691E-03**
Magnesium	0.00	**0.000E+00**
Manganese	0.00	**0.000E+00**
Sodium	0.00	**0.000E+00**
Nickel	0.00	**0.000E+00**
Phosphorous	0.00	**0.000E+00**
Lead	0.06	**8.328E-04**
Rubidium	0.00	**1.601E-05**
Sulfur	2.47	**3.495E-02**
Antimony	0.00	**0.000E+00**
Selenium	0.00	**0.000E+00**
Silicon	0.08	**1.173E-03**
Tin	0.00	**0.000E+00**
Strontium	0.00	**0.000E+00**
Titanium	0.00	**1.604E-05**
Vanadium	0.00	**4.812E-05**
Zinc	0.09	**1.230E-03**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	69.56	1.700E-01
Organic Carbon	2238.03	5.470E+00

Appliance:	Coal Stove	**Burn Rate:**	Low, Cold Start	**Run #:**	39
Fuel:	Wet Stoker Coal	**Date:**	8/16/2011		

Filter Information:

T1 ID #:	A779725X
T1 Flow Rate [mL/min]:	198.37
T1 Sample Volume [dsft^3]:	*3.09*
Q1 ID #:	A768264G & A768263F
Q1 Flow Rate [mL/min]:	1583.7
Q1 Sample Volume [dsft^3]:	*24.67*

Run Information:

Test Duration [min]:	448
Tunnel Flow [dsft^3/min]:	522.0773
Barometric Pressure [in Hg]:	30.15
Temperature [°F]	80.853
Avg Delta H [in H2O]:	0.4557

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**1429.00**	**1.449E+01**
K^+	0.94	**9.488E-03**
Na^+	0.15	**1.508E-03**
NH_4^+	4.30	**4.358E-02**
NO_3	1.15	**1.163E-02**
SO_4	15.87	**1.609E-01**
Silver	0.00	**0.000E+00**
Aluminum	0.40	**4.040E-03**
Arsenic	0.02	**1.949E-04**
Barium	0.00	**0.000E+00**
Bromine	0.05	**5.387E-04**
Calcium	0.20	**1.983E-03**
Cadmium	0.00	**0.000E+00**
Cerium	0.00	**0.000E+00**
Chlorine	0.77	**7.769E-03**
Cobalt	0.04	**4.441E-04**
Chromium	0.00	**0.000E+00**
Cesium	0.00	**0.000E+00**
Copper	0.00	**0.000E+00**
Iron	0.14	**1.382E-03**
Indium	0.00	**0.000E+00**
Potassium	2.18	**2.206E-02**
Magnesium	0.00	**0.000E+00**
Manganese	0.00	**0.000E+00**
Sodium	0.03	**3.432E-04**
Nickel	0.00	**0.000E+00**
Phosphorous	0.00	**0.000E+00**
Lead	0.06	**6.189E-04**
Rubidium	0.00	**1.146E-05**
Sulfur	11.58	**1.174E-01**
Antimony	0.00	**0.000E+00**
Selenium	0.02	**2.017E-04**
Silicon	0.00	**0.000E+00**
Tin	0.00	**0.000E+00**
Strontium	0.02	**1.834E-04**
Titanium	0.00	**0.000E+00**
Vanadium	0.01	**1.495E-04**
Zinc	0.60	**6.043E-03**
Zirconium	0.00	**0.000E+00**

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	1951.90	2.479E+00
Organic Carbon	6351.17	8.066E+00

Appliance:	Oil Burner	**Burn Rate:**	Single	**Run #:**	40
Fuel:	No 1 Fuel Oil	**Date:**	8/7/2011		

Filter Information:

T1 ID #:	A779724W
T1 Flow Rate [mL/min]:	195.29
T1 Sample Volume [dsft^3]:	*6.01*
Q1 ID #:	A768268K
Q1 Flow Rate [mL/min]:	1020.9
Q1 Sample Volume [dsft^3]:	*31.42*

Run Information:

Test Duration [min]:	885
Tunnel Flow [dsft^3/min]:	518.3042
Barometric Pressure [in Hg]:	30.18
Temperature [°F]	81.12
Avg Delta H [in H2O]:	0.4344

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**60.00**	**3.104E-01**
K^+	0.16	8.367E-04
Na^+	0.16	8.286E-04
NH_4^+	4.22	2.183E-02
NO_3	0.73	3.769E-03
SO_4	11.48	5.941E-02
Silver	0.00	0.000E+00
Aluminum	0.21	1.110E-03
Arsenic	0.00	0.000E+00
Barium	0.00	0.000E+00
Bromine	0.00	2.514E-05
Calcium	0.29	1.480E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	0.01	6.440E-05
Cobalt	0.01	4.210E-05
Chromium	0.00	1.988E-05
Cesium	0.00	0.000E+00
Copper	0.03	1.368E-04
Iron	0.12	6.268E-04
Indium	0.14	7.015E-04
Potassium	0.05	2.633E-04
Magnesium	0.00	0.000E+00
Manganese	0.01	3.508E-05
Sodium	0.00	0.000E+00
Nickel	0.00	7.015E-06
Phosphorous	0.00	0.000E+00
Lead	0.00	0.000E+00
Rubidium	0.00	1.052E-05
Sulfur	3.92	2.026E-02
Antimony	0.03	1.754E-04
Selenium	0.00	0.000E+00
Silicon	0.06	3.343E-04
Tin	0.00	0.000E+00
Strontium	0.01	5.846E-05
Titanium	0.01	5.848E-05
Vanadium	0.00	0.000E+00
Zinc	0.01	3.566E-05
Zirconium	0.00	0.000E+00

Quartz Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Elemental Carbon	6.51	6.440E-03
Organic Carbon	157.78	1.561E-01

Appliance:	EPA Stove	**Burn Rate:**	Low, Cold Start	**Run #:**	41
Fuel:	Birch	**Date:**	8/18/2011		

Filter Information:

T1 ID #:	A779721T
T1 Flow Rate [mL/min]:	202.47
T1 Sample Volume [dsft^3]:	*2.04*
Q1 ID #:	A768269L
Q1 Flow Rate [mL/min]:	1022.3
Q1 Sample Volume [dsft^3]:	*10.32*

Run Information:

Test Duration [min]:	288
Tunnel Flow [dsft^3/min]:	477.4781
Barometric Pressure [in Hg]:	30.145
Temperature [°F]	76.5744
Avg Delta H [in H2O]:	0.448

Teflon Sample:	**Catch [µg]:**	**Emission Rate [g/hr]**
Total $PM_{2.5}$	**489.00**	**6.857E+00**
K^+	2.80	3.925E-02
Na^+	0.19	2.603E-03
NH_4^+	1.44	2.015E-02
NO_3	1.70	2.385E-02
SO_4	6.96	9.757E-02
Silver	0.00	0.000E+00
Aluminum	0.00	0.000E+00
Arsenic	0.01	1.791E-04
Barium	0.00	0.000E+00
Bromine	0.03	4.231E-04
Calcium	0.37	5.189E-03
Cadmium	0.00	0.000E+00
Cerium	0.00	0.000E+00
Chlorine	1.81	2.532E-02
Cobalt	0.07	9.133E-04
Chromium	0.01	9.994E-05
Cesium	0.00	0.000E+00
Copper	0.04	5.644E-04
Iron	0.12	1.633E-03
Indium	0.00	0.000E+00
Potassium	3.51	4.926E-02
Magnesium	0.00	0.000E+00
Manganese	0.00	1.903E-05
Sodium	0.00	0.000E+00
Nickel	0.00	3.646E-05
Phosphorous	0.00	0.000E+00
Lead	0.00	0.000E+00
Rubidium	0.00	0.000E+00
Sulfur	3.52	4.939E-02
Antimony	0.00	0.000E+00
Selenium	0.01	9.668E-05
Silicon	0.05	7.648E-04
Tin	0.00	0.000E+00
Strontium	0.01	1.585E-04
Titanium	0.00	0.000E+00
Vanadium	0.00	0.000E+00
Zinc	0.91	1.282E-02
Zirconium	0.05	6.339E-04

Quartz Sample:		**Emission Rate [g/hr]**
Elemental Carbon	111.51	3.097E-01
Organic Carbon	1016.51	2.823E+00

Measurement of Space-Heating Emissions

Appendix B

Analytical Laboratory Reports

Fuel Analysis: Pellets

Twin Ports Testing Inc.

1301 N. 3rd St. • Superior WI 54880 • 715-392-7114 • 800-373-2562 • F 715-392-7163 • www.twinportstesting.com

OMNI-Test Laboratories, Inc.
13327 NE Airport Way
Portland, OR 97230

Date Received: Apr 13, 2011
Date Tested: Apr 18, 2011
PO Number: OTL-11-029

Attn: Lyrik Pitzman

Sample Log No: 11C1231
Sample Designation: P1 Pellet Sample 1 4-7-11

	METHOD	UNITS	MOISTURE & ASH FREE	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM D3173	wt. %			7.09
Ash	ASTM D3174	wt. %		0.83	0.77
Volatile Matter	ASTM D3175	wt. %		------	------
Fixed Carbon By Difference	ASTM D3175	wt. %		------	------
Sulfur	ASTM D4239	wt. %		0.008	0.007
Gross Heating Value	ASTM D5865	BTU/lb	8664	8592	7984
Carbon	ASTM D5373	wt. %		50.36	46.79
Hydrogen	ASTM D5373	wt. %		6.41	5.96
Nitrogen	ASTM D5373	wt. %		< 0.14	< 0.13
Oxygen	ASTM D3176	wt. %		> 42.26	> 39.26
Chlorine	ASTM D6721	ug/g			
Fluorine	ASTM D3761	ug/g			
Mercury	ASTM D6722	ug/g			
Sodium Oxide in Ash	ASTM D3682	wt. %			
Hardgrove Grindability Index	ASTM D409	wt. /index			

Additional:

Prepared By: _____ **Date:** 4/18/11

Fuel Analysis: Birch Cordwood

Twin Ports Testing Inc.

1301 N. 3rd St. • Superior WI 54880 • 715-392-7114 • 800-373-2562 • F 715-392-7163 • www.twinportstesting.com

OMNI-Test Laboratories, Inc.
13327 NE Airport Way
Portland, OR 97230

Date Received: Apr 13, 2011
Date Tested: Apr 18, 2011
PO Number: OTL-11-029

Attn: Lyrik Pitzman

Sample Log No: 11C1232
Sample Designation: W1 Birch Cordwood 4-7-11

	METHOD	UNITS	MOISTURE & ASH FREE	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM D3173	wt. %			12.51
Ash	ASTM D3174	wt. %		0.73	0.64
Volatile Matter	ASTM D3175	wt. %		------	------
Fixed Carbon By Difference	ASTM D3175	wt. %		------	------
Sulfur	ASTM D4239	wt. %		0.080	0.070
Gross Heating Value	ASTM D5865	BTU/lb	8653	8590	7515
Carbon	ASTM D5373	wt. %		49.55	43.35
Hydrogen	ASTM D5373	wt. %		6.41	5.61
Nitrogen	ASTM D5373	wt. %		< 0.18	< 0.16
Oxygen	ASTM D3176	wt. %		> 43.05	> 37.66
Chlorine	ASTM D6721	ug/g			
Fluorine	ASTM D3761	ug/g			
Mercury	ASTM D6722	ug/g			
Sodium Oxide in Ash	ASTM D3682	wt. %			
Hardgrove Grindability Index	ASTM D409	wt. /index			

Additional:

Prepared By: _____ **Date:** 4/18/11

Fuel Analysis: Spruce Cordwood

Twin Ports Testing Inc.

1301 N. 3rd St. • Superior WI 54880 • 715-392-7114 • 800-373-2562 • F 715-392-7163 • www.twinportstesting.com

OMNI-Test Laboratories, Inc.
13327 NE Airport Way
Portland, OR 97230

Date Received: Apr 13, 2011
Date Tested: Apr 18, 2011
PO Number: OTL-11-029

Attn: Lyrik Pitzman

Sample Log No: 11C1233
Sample Designation: W2 Spruce Cordwood 4-7-11

	METHOD	UNITS	MOISTURE & ASH FREE	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM D3173	wt. %			15.01
Ash	ASTM D3174	wt. %		0.63	0.53
Volatile Matter	ASTM D3175	wt. %		------	------
Fixed Carbon By Difference	ASTM D3175	wt. %		------	------
Sulfur	ASTM D4239	wt. %		0.010	0.009
Gross Heating Value	ASTM D5865	BTU/lb	8804	8749	7435
Carbon	ASTM D5373	wt. %		50.30	42.75
Hydrogen	ASTM D5373	wt. %		6.40	5.44
Nitrogen	ASTM D5373	wt. %		< 0.11	< 0.09
Oxygen	ASTM D3176	wt. %		> 42.56	> 36.17
Chlorine	ASTM D6721	ug/g			
Fluorine	ASTM D3761	ug/g			
Mercury	ASTM D6722	ug/g			
Sodium Oxide in Ash	ASTM D3682	wt. %			
Hardgrove Grindability Index	ASTM D409	wt. /index			

Additional:

Prepared By: _____ **Date:** 4/18/11

Fuel Analysis: Lump Coal

Twin Ports Testing Inc.
1301 N. 3rd St. • Superior WI 54880 • 715-392-7114 • 800-373-2562 • F 715-392-7163 • www.twinportstesting.com

OMNI-Test Laboratories, Inc.
13327 NE Airport Way
Portland, OR 97230

Date Received: Apr 13, 2011
Date Tested: Apr 18, 2011
PO Number: OTL-11-029

Attn: Lyrik Pitzman

Sample Log No: 11C1234
Sample Designation: C1 Lump Coal 4-8-11

	METHOD	UNITS	MOISTURE & ASH FREE	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM D3173	wt. %			25.66
Ash	ASTM D3174	wt. %		6.12	4.55
Volatile Matter	ASTM D3175	wt. %		------	------
Fixed Carbon By Difference	ASTM D3175	wt. %		------	------
Sulfur	ASTM D4239	wt. %		0.086	0.064
Gross Heating Value	ASTM D5865	BTU/lb	11900	11171	8305
Carbon	ASTM D5373	wt. %		65.00	48.32
Hydrogen	ASTM D5373	wt. %		4.72	3.51
Nitrogen	ASTM D5373	wt. %		0.65	0.48
Oxygen	ASTM D3176	wt. %		23.42	17.41
Chlorine	ASTM D6721	ug/g			
Fluorine	ASTM D3761	ug/g			
Mercury	ASTM D6722	ug/g			
Sodium Oxide in Ash	ASTM D3682	wt. %			
Hardgrove Grindability Index	ASTM D409	wt. /index			

Additional:

Prepared By: _____ **Date:** 4/18/11

Fuel Analysis: Stoker Coal

Twin Ports Testing Inc.

1301 N. 3rd St. • Superior WI 54880 • 715-392-7114 • 800-373-2562 • F 715-392-7163 • www.twinportstesting.com

OMNI-Test Laboratories, Inc.
13327 NE Airport Way
Portland, OR 97230

Date Received: Apr 13, 2011
Date Tested: Apr 18, 2011
PO Number: OTL-11-029

Attn: Lyrik Pitzman

Sample Log No: 11C1235
Sample Designation: C2 Stoker Coal 4-8-11

	METHOD	UNITS	MOISTURE & ASH FREE	MOISTURE FREE	AS RECEIVED
Moisture Total	ASTM D3173	wt. %			25.94
Ash	ASTM D3174	wt. %		5.20	3.85
Volatile Matter	ASTM D3175	wt. %		------	------
Fixed Carbon By Difference	ASTM D3175	wt. %		------	------
Sulfur	ASTM D4239	wt. %		0.101	0.075
Gross Heating Value	ASTM D5865	BTU/lb	12253	11617	8602
Carbon	ASTM D5373	wt. %		66.75	49.44
Hydrogen	ASTM D5373	wt. %		4.95	3.67
Nitrogen	ASTM D5373	wt. %		0.72	0.53
Oxygen	ASTM D3176	wt. %		22.28	16.50
Chlorine	ASTM D6721	ug/g			
Fluorine	ASTM D3761	ug/g			
Mercury	ASTM D6722	ug/g			
Sodium Oxide in Ash	ASTM D3682	wt. %			
Hardgrove Grindability Index	ASTM D409	wt. /index			

Additional:

Prepared By: _____ **Date:** 4/18/11

Fuel Analysis: Ultimate and Proximate Analyses of Oil #1, Oil #2, and Waste Oil

Test Summary Report
December 13, 2011

Omni Test Laboratories

		No. 1 Heating Oil	No. 2 Heating Oil	Waste Oil
Lab ID		3173	3174	3175
ASTM D240 Net Heat of Combustion (Lower Heating Value)				
	BTU/lb	18483	18397	18024
	MJ/Kg	42.992	42.791	41.924
	Cal/g	10268	10220	10013
ASTM D240 Gross Heat of Combustion (Higher Heating Value)				
	BTU/lb	19721	19613	19237
	MJ/Kg	45.872	45.619	44.746
	Cal/g	10956	10896	10687
ASTM D482 Ash Content				
	wt%	<0.001	<0.001	0.88
ASTM D2622 Modified Chlorine Content				
Chlorine	ppm	<10	<10	8243.9
ASTM D5291 Carbon/Hydrogen Content				
Carbon	wt%	86.21	86.28	84.14
Hydrogen	wt%	13.57	13.33	13.3
ASTM D5291 Nitrogen Content				
Nitrogen	wt%	0.451	0.029	0.266
ASTM D6304 Water Content				
Water	ppm	86	58	398
Oxygen Content by Difference				
Oxygen	wt%	<1	<1	<1

Fuel Analysis: Elemental Analysis of Oil #1, Oil #2, and Waste Oil

Test Summary Report
December 13, 2011

Omni Test Laboratories

		No. 1 Heating Oil	No. 2 Heating Oil	Waste Oil
	Lab ID	3173	3174	3175
ASTM D5185 Elemental Analysis by ICP				
Aluminum	ppm	<1	<1	8
Barium	ppm	<1	<1	1
Boron	ppm	<1	<1	164
Calcium	ppm	<1	<1	1467
Chromium	Ppm	<1	<1	2
Copper	ppm	<1	<1	34
Iron	ppm	<1	<1	52
Lead	ppm	<1	<1	17
Magnesium	ppm	<1	<1	205
Molybdenum	ppm	<1	<1	82
Phosphorus	ppm	<1	<1	847
Sulfur	ppm	896	2566	3020
Silicon	ppm	<1	<1	14
Sodium	ppm	<5	<5	412
Zinc	ppm	<1	<1	974
Potassium	ppm	<5	<5	314
Titanium	ppm	<1	<1	44

Antimony, Manganese, Nickel, Silver, Tin, Strontium, Vanadium, Cadmium <1 ppm

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Ash Analysis: Ultimate Analysis, All Fuels

Columbia Analytical Services

September 22, 2011

Client: OMNI-Test Laboratories, Inc.
13327 NE Airport Way
P.O. Box 301367
Portland, OR 97230

Attn: Sebastian Button

Project: FNSB Ash

Date Received: August 12, 2011

Certificate of Analysis

Sample ID:	Sample Date and Time:	Lab #:	Moisture, Total D3173 Moist. Free wt%	Carbon Moist. Free wt%	Hydrogen D5373 Moist. Free wt%	Nitrogen Moist. Free wt%	Oxygen D5373 mod Moist. Free wt%	Sulfur D4239 Moist. Free wt%	Ash D482 Moist. Free wt%
Birch Ash	8/8/11	T1101099-001	1.87	61.81	0.85	0.58	10.20	<0.005	28.66
Coal Ash	8/8/11	T1101099-002	0.29	1.49	0.46	0.08	6.07	1.17	96.60
Pellet Ash	8/8/11	T1101099-003	4.14	72.99	1.33	0.57	14.03	0.01	9.90
Spruce Ash	8/8/11	T1101099-004	2.57	68.26	1.44	0.45	11.70	<0.005	18.04

3860 S. Palo Verde Rd.
Suite 302
Tucson, AZ 85714
520.623.3381

Page 1 of 3

Rpt-T1101099 OMNI FNSB Ash Button, 9/22/2011

Ash Analysis: pH, All Fuels

Columbia Analytical Services

September 22, 2011

Client: **OMNI-Test Laboratories, Inc.**
13327 NE Airport Way
P.O. Box 301367
Portland, OR 97230

Attn: **Sebastian Button**

Project: **FNSB Ash** ***Date Received:*** ***August 12, 2011***

Certificate of Analysis

Sample ID:	*Sample Date and Time:*	*Lab #:*		*pH* *D9045*					
Birch Ash	8/8/11	T1101099-001		11.66					
Coal Ash	8/8/11	T1101099-002		11.91					
Pellet Ash	8/8/11	T1101099-003		8.96					
Spruce Ash	8/8/11	T1101099-004		11.54					

Notes:

Wendy H. Cerda, Project Chemist

3860 S. Palo Verde Rd.
Suite 302
Tucson, AZ 85714
520.623.3381

B9

Ash Analysis: Total Metals, All Fuels

Columbia Analytical Services™

September 22, 2011

Client: **OMNI-Test Laboratories, Inc.**
13327 NE Airport Way
P.O. Box 301367
Portland, OR 97230
Attn: **Sebastian Button**
Project: **FNSB Ash** ***Date Received:*** ***August 12, 2011***

Certificate of Analysis

Total Metals by ICP-OES	*ID*	Birch Ash	Coal Ash	Pellet Ash	Spruce Ash
	Units	T1101099-001	T1101099-002	T1101099-003	T1101099-004
Aluminum	wt %	0.06	7.96	0.11	0.14
Antimony	wt %	< 0.20	< 0.20	< 0.20	< 0.20
Arsenic	wt %	0.06	0.04	0.03	0.02
Barium	wt %	0.24	0.55	0.06	0.09
Beryllium	wt %	< 0.001	< 0.001	< 0.001	< 0.001
Cadmium	wt %	< 0.001	0.003	0.002	0.002
Calcium	wt %	8.31	21.80	4.03	7.02
Chromium	wt %	< 0.01	0.01	< 0.01	< 0.01
Cobalt	wt %	0.02	0.01	0.01	0.01
Copper	wt %	0.01	0.02	< 0.01	< 0.01
Iron	wt %	0.07	8.06	0.08	0.18
Lead	wt %	< 0.02	< 0.02	< 0.02	< 0.02
Lithium	wt %	< 0.01	< 0.01	< 0.01	< 0.01
Magnesium	wt %	1.17	1.93	0.37	0.42
Manganese	wt %	0.51	0.11	0.11	0.11
Molybdenum	wt %	< 0.01	< 0.01	0.02	< 0.01
Nickel	wt %	< 0.01	< 0.01	< 0.01	< 0.01
Phosphorus	wt %	0.89	0.10	0.12	< 0.05
Potassium	wt %	5.07	0.71	1.76	2.65
Selenium	wt %	< 0.05	< 0.05	< 0.05	< 0.05
Silicon	wt %	1.62	11.97	0.58	0.23
Silver	wt %	< 0.01	< 0.01	< 0.01	< 0.01
Sodium	wt %	< 0.10	0.25	< 0.10	< 0.10
Strontium	wt %	0.05	0.19	0.02	0.03
Tin	wt %	0.03	0.02	0.02	0.01
Titanium	wt %	< 0.01	0.38	< 0.01	< 0.01
Vanadium	wt %	< 0.01	0.02	< 0.01	< 0.01
Zinc	wt %	0.14	< 0.05	< 0.05	< 0.05
Zirconium	wt %	< 0.01	0.02	< 0.01	< 0.01

Note: *Values reported on an as received basis.*
Approximately 50 mg of sample was digested with HNO3, HF, and HCl brought to50.0 mL with DI water and analyzed by ICP-OES.

W.H. Cerda

Wendy H. Cerda, Project Chemist

3860 S. Palo Verde Rd.
Suite 302
Tucson, AZ 85714
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Page 3 of 3

Rpt-T1101099 OMNI FNSB Ash Button, 9/22/2011

Ammonia Analysis: Runs 1-3

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client:	OMNI Environmental Services, Incorporated	**Service Request:**	K1102155
Project:	Fairbanks North Star/477-S-01-1	**Date Collected:**	3/8/2011
Sample Matrix:	Water	**Date Received:**	3/11/2011
		Date Extracted:	NA

Inorganic Parameters
Units: Total µg

Analyte:	Volume of Bottle	Ammonia as Nitrogen
Method	-	SM 4500-NH3 E
Method Reporting Limit:	-	-
Date Analyzed:	-	3/16/2011

Sample Name	Lab Code		
FNB 1-1	K1102155-001	250	101
FNB 1-2	K1102155-002	250	15
FNB 2-1	K1102155-003	250	39
FNB 2-2	K1102155-004	250	293
FNB 3-1	K1102155-005	250	152
FNB 3-2	K1102155-006	250	26
FNB - Blank	K1102155-007	250	<13
Method Blank	K1102155-MB	-	<13

3ADW/061694

K1102155wet.xls2 - 3_Tests 3/24/2011 Page No.:

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Ammonia Analysis: Runs 4-11

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: OMNI Environmental Services, Incorporated
Project: FNSB/477-S-01-1
Sample Matrix: Water

Service Request: K1102592
Date Collected: 3/17/11 - 3/25/11
Date Received: 3/25/11

Analysis Method: SM 4500-NH3 E

Units: mg/L
Basis: NA

Ammonia as Nitrogen

Sample Name	Lab Code	Result	Q	MRL	Dilution Factor	Date Extracted	Date Analyzed	Note
FNB 5-1	K1102592-001	4.31		0.050	1	NA	3/30/11 12:20	
FNB 5-2	K1102592-002	0.191		0.050	1	NA	3/30/11 12:20	
FNB 6-1	K1102592-003	1.75		0.050	1	NA	3/30/11 12:20	
FNB 6-2	K1102592-004	0.123		0.050	1	NA	3/30/11 12:20	
FNB 8-1	K1102592-005	24.5		0.050	1	NA	3/30/11 12:20	
FNB 8-2	K1102592-006	0.666		0.050	1	NA	3/30/11 12:20	
FNB 9-1	K1102592-007	10.8		0.050	1	NA	3/30/11 12:20	
FNB 9-2	K1102592-008	0.450		0.050	1	NA	3/30/11 12:20	
FNB 10-1	K1102592-009	6.13		0.050	1	NA	3/30/11 12:20	
FNB 10-2	K1102592-010	0.335		0.050	1	NA	3/30/11 12:20	
FNB 11-1	K1102592-011	12.0		0.050	1	NA	3/30/11 12:20	
FNB 11-2	K1102592-012	0.648		0.050	1	NA	3/30/11 12:20	
FNB Blank	K1102592-013	ND	U	0.050	1	NA	3/30/11 12:20	
Method Blank	K1102592-MB	ND	U	0.050	1	NA	3/30/11 12:20	

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SuperSet Reference: 11-0000173355 rev 00

8

Ammonia Analysis: Runs 12-18

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: OMNI Environmental Services, Incorporated
Project: FNSB/477-S-01-1
Sample Matrix: Water

Service Request: K1103389
Date Collected: 3/30/11 - 4/15/11
Date Received: 4/19/11

Analysis Method: SM 4500-NH3 H

Units: mg/L
Basis: NA

Ammonia as Nitrogen

Sample Name	Lab Code	Result	Q	MRL	Dilution Factor	Date Extracted	Date Analyzed	Note
FNB 12-1	K1103389-001	**1.05**		0.050	1	NA	4/20/11 12:00	
FNB 12-2	K1103389-002	**0.106**		0.050	1	NA	4/20/11 12:00	
FNB 13-1	K1103389-003	**6.84**		0.050	1	NA	4/20/11 12:00	
FNB 13-2	K1103389-004	**0.265**		0.050	1	NA	4/20/11 12:00	
FNB 14-1	K1103389-005	**3.36**		0.050	1	NA	4/20/11 12:00	
FNB 14-2	K1103389-006	**0.230**		0.050	1	NA	4/20/11 12:00	
FNB 15-1	K1103389-007	**7.80**		0.050	1	NA	4/20/11 12:00	
FNB 15-2	K1103389-008	**0.414**		0.050	1	NA	4/20/11 12:00	
FNB 16-1	K1103389-009	**0.215**		0.050	1	NA	4/20/11 12:00	
FNB 16-2	K1103389-010	**0.094**		0.050	1	NA	4/20/11 12:00	
FNB 17-1	K1103389-011	**0.186**		0.050	1	NA	4/20/11 12:00	
FNB 17-2	K1103389-012	**0.156**		0.050	1	NA	4/20/11 12:00	
FNB 18-1	K1103389-013	**0.172**		0.050	1	NA	4/20/11 12:00	
FNB 18-2	K1103389-014	**0.092**		0.050	1	NA	4/20/11 12:00	
Method Blank	K1103389-MB1	ND	U	0.050	1	NA	4/20/11 12:00	
Method Blank	K1103389-MB2	ND	U	0.050	1	NA	4/20/11 12:00	

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8

Ammonia Analysis: Runs 19-23

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: OMNI Environmental Services, Incorporated
Project: FNSB/477-S-01-1
Sample Matrix: Water

Service Request: K1104492
Date Collected: 5/ 5/11 - 5/11/11
Date Received: 5/19/11

Analysis Method: SM 4500-NH3 E

Units: mg/L
Basis: NA

Ammonia as Nitrogen

Sample Name	Lab Code	Result	Q	MRL	Dilution Factor	Date Extracted	Date Analyzed	Note
FNB 19-1	K1104492-001	**1.81**		0.050	1	NA	5/27/11 12:50	
FNB 19-2	K1104492-002	**0.262**		0.050	1	NA	5/27/11 12:50	
FNB 20-1	K1104492-003	**2.40**		0.050	1	NA	5/27/11 12:50	
FNB 20-2	K1104492-004	**0.245**		0.050	1	NA	5/27/11 12:50	
FNB 21-1	K1104492-005	**21.4**		0.050	1	NA	5/27/11 12:50	
FNB 21-2	K1104492-006	**0.645**		0.050	1	NA	5/27/11 12:50	
FNB 23-1	K1104492-007	**18.0**		0.050	1	NA	5/27/11 12:50	
FNB 23-2	K1104492-008	**5.57**		0.050	1	NA	5/27/11 12:50	
Method Blank	K1104492-MB	ND	U	0.050	1	NA	5/27/11 12:50	

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7

Ammonia Analysis: Runs 25-29

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: OMNI Environmental Services, Incorporated
Project: FNSB/477-5-01-1
Sample Matrix: Water

Service Request: K1105474
Date Collected: 5/27/11 - 6/ 7/11
Date Received: 6/17/11

Analysis Method: SM 4500-NH3 F

Units: mg/L
Basis: NA

Ammonia as Nitrogen

Sample Name	Lab Code	Result	Q	MRL	Dilution Factor	Date Extracted	Date Analyzed	Note
FNB 25-1	K1105474-001	**5.14**		0.050	1	NA	6/21/11 09:30	
FNB 25-2	K1105474-002	**0.532**		0.050	1	NA	6/21/11 09:30	
FNB 26-1	K1105474-003	**36.7**		0.050	1	NA	6/21/11 09:30	
FNB 26-2	K1105474-004	**0.776**		0.050	1	NA	6/21/11 09:30	
FNB 27-1	K1105474-005	**48.8**		0.050	1	NA	6/21/11 09:30	
FNB 27-2	K1105474-006	**1.54**		0.050	1	NA	6/21/11 09:30	
FNB 28-1	K1105474-007	**1.50**		0.050	1	NA	6/21/11 09:30	
FNB 28-2	K1105474-008	**0.716**		0.050	1	NA	6/21/11 09:30	
FNB 29-1	K1105474-009	**0.286**		0.050	1	NA	6/21/11 09:30	
FNB 29-2	K1105474-010	**0.214**		0.050	1	NA	6/21/11 09:30	
Method Blank	K1105474-MB1	ND	U	0.050	1	NA	6/21/11 09:30	
Method Blank	K1105474-MB2	ND	U	0.050	1	NA	6/21/11 09:30	

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Form 1A

SuperSet Reference: 11-0000181094 rev 00

7

Ammonia Analysis: Runs 30-33

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: OMNI Environmental Services, Incorporated
Project: FNSB/477-S-01-1
Sample Matrix: Water

Service Request: K1106544
Date Collected: 6/30/11 - 7/ 8/11
Date Received: 7/19/11

Analysis Method: SM 4500-NH3 E

Units: mg/L
Basis: NA

Ammonia as Nitrogen

Sample Name	Lab Code	Result	Q	MRL	Dilution Factor	Date Extracted	Date Analyzed	Note
FNB 30-1	K1106544-001	**8.28**		0.050	1	NA	7/27/11 10:55	
FNB 30-2	K1106544-002	**0.708**		0.050	1	NA	7/27/11 10:55	
FNB 31-1	K1106544-003	**26.7**		0.050	1	NA	7/27/11 10:55	
FNB 31-2	K1106544-004	**2.31**		0.050	1	NA	7/27/11 10:55	
FNB 32-1	K1106544-005	**18.0**		0.050	1	NA	7/27/11 10:55	
FNB 32-2	K1106544-006	**0.978**		0.050	1	NA	7/27/11 10:55	
FNB 33-1	K1106544-007	**49.6**		0.050	1	NA	7/27/11 10:55	
FNB 33-2	K1106544-008	**2.55**		0.050	1	NA	7/27/11 10:55	
Method Blank	K1106544-MB1	ND	U	0.050	1	NA	7/27/11 10:55	
Method Blank	K1106544-MB2	ND	U	0.050	1	NA	7/27/11 10:55	

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SuperSet Reference: 11 00000384702 rev 00

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Ammonia Analysis: Runs 34-41

COLUMBIA ANALYTICAL SERVICES, INC.

Analytical Report

Client: OMNI Environmental Services, Incorporated
Project: FNSB/477-S-01-1
Sample Matrix: Water

Service Request: K1107736
Date Collected: 7/27/11 - 8/18/11
Date Received: 8/19/11

Analysis Method: SM 4500-NH3 E

Units: mg/L
Basis: NA

Ammonia as Nitrogen

Sample Name	Lab Code	Result	Q	MRL	Dilution Factor	Date Extracted	Date Analyzed	Note
FNB 34-1	K1107736-001	**4.91**		0.050	1	NA	8/24/11 08:20	
FNB 34-2	K1107736-002	**0.389**		0.050	1	NA	8/24/11 08:20	
FNB 35-1	K1107736-003	**1.22**		0.050	1	NA	8/24/11 08:20	
FNB 35-2	K1107736-004	**0.119**		0.050	1	NA	8/24/11 08:20	
FNB 36-1	K1107736-005	**42.8**		0.050	1	NA	8/24/11 08:20	
FNB 36-2	K1107736-006	**14.6**		0.050	1	NA	8/24/11 08:20	
FNB 37-1	K1107736-007	**18.7**		0.050	1	NA	8/24/11 08:20	
FNB 37-2	K1107736-008	**1.05**		0.050	1	NA	8/24/11 08:20	
FNB 38-1	K1107736-009	**11.6**		0.050	1	NA	8/24/11 08:20	
FNB 38-2	K1107736-010	**0.274**		0.050	1	NA	8/24/11 08:20	
FNB 39-1	K1107736-011	**32.8**		0.050	1	NA	8/24/11 08:20	
FNB 39-2	K1107736-012	**1.65**		0.050	1	NA	8/24/11 08:20	
FNB 40-1	K1107736-013	**0.729**		0.050	1	NA	8/24/11 08:20	
FNB 40-2	K1107736-014	**0.424**		0.050	1	NA	8/24/11 08:20	
FNB 41-1	K1107736-015	**3.46**		0.050	1	NA	8/24/11 08:20	
FNB 41-2	K1107736-016	ND	U	0.050	1	NA	8/24/11 08:20	
Method Blank	K1107736-MB	ND	U	0.050	1	NA	8/24/11 08:20	

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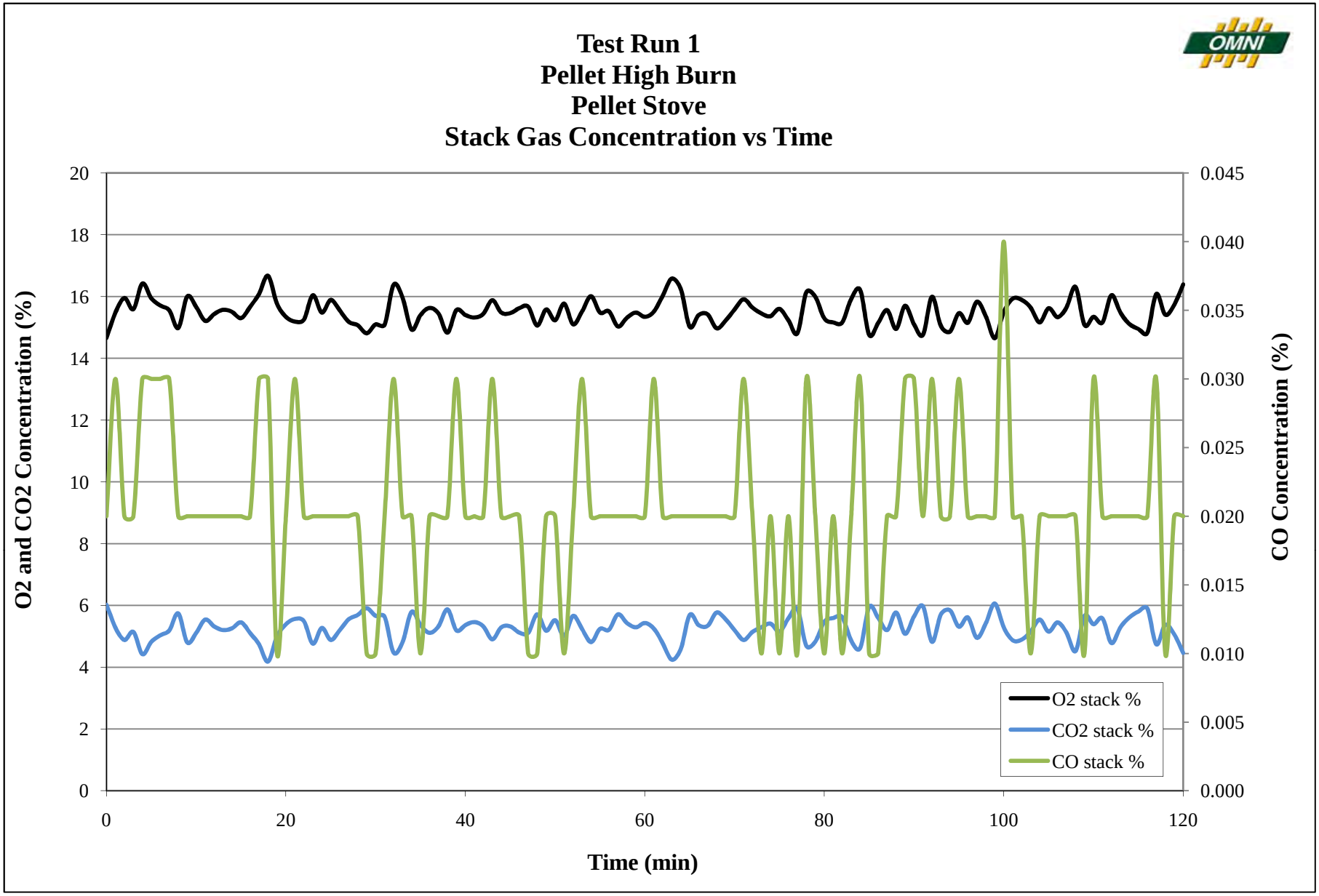
SuperSet Reference: 11-0000186903 rev 00

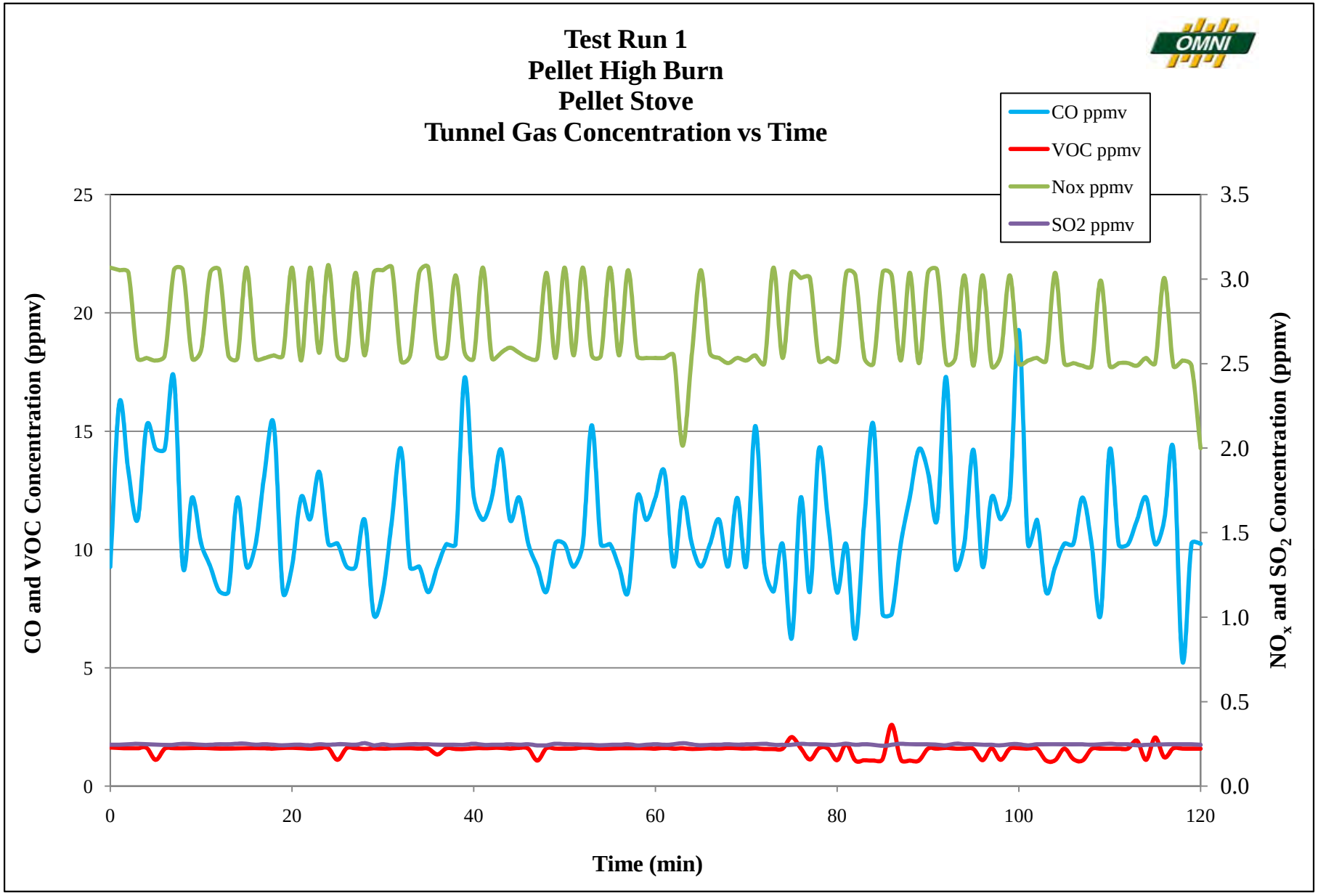
8

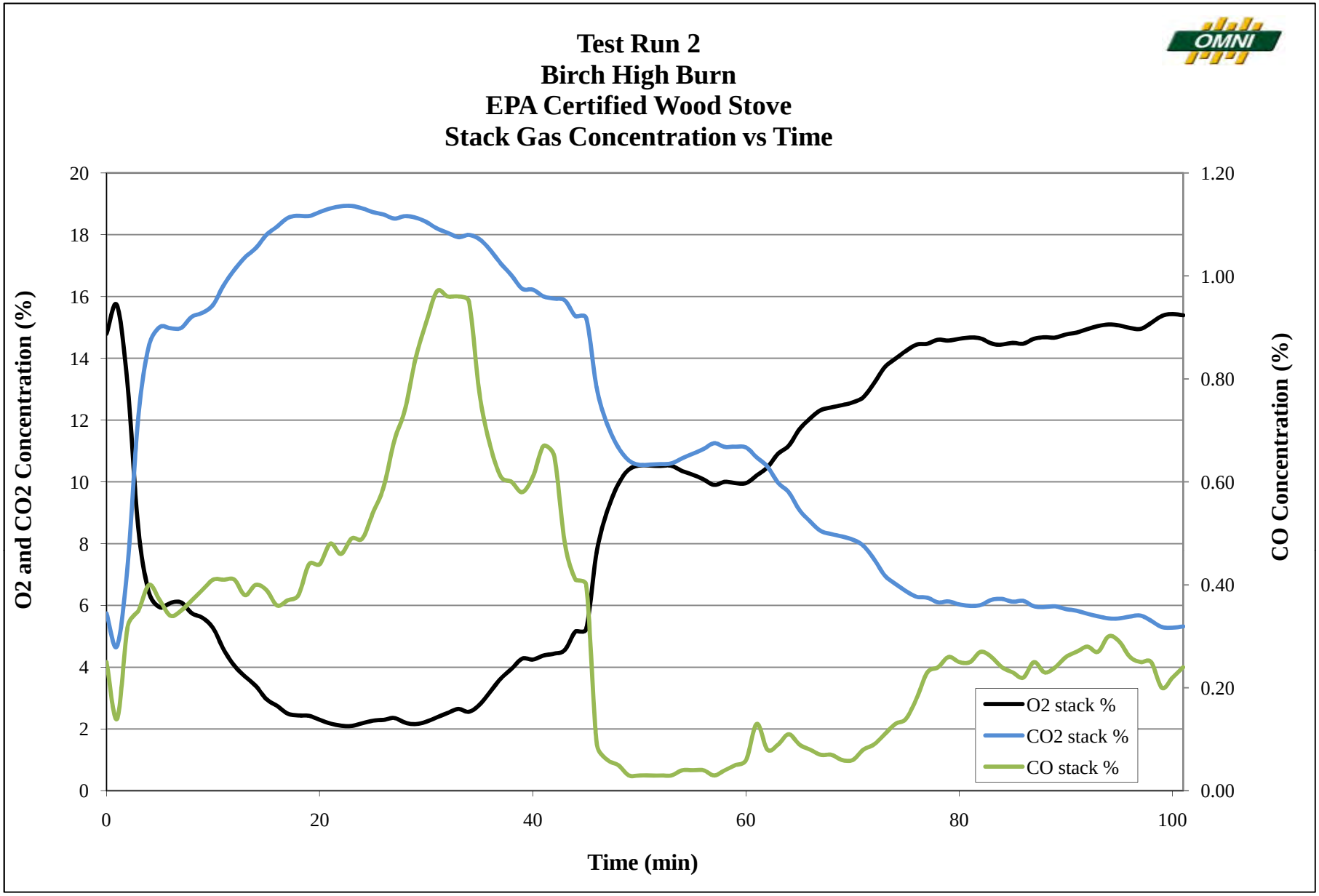
Measurement of Space-Heating Emissions

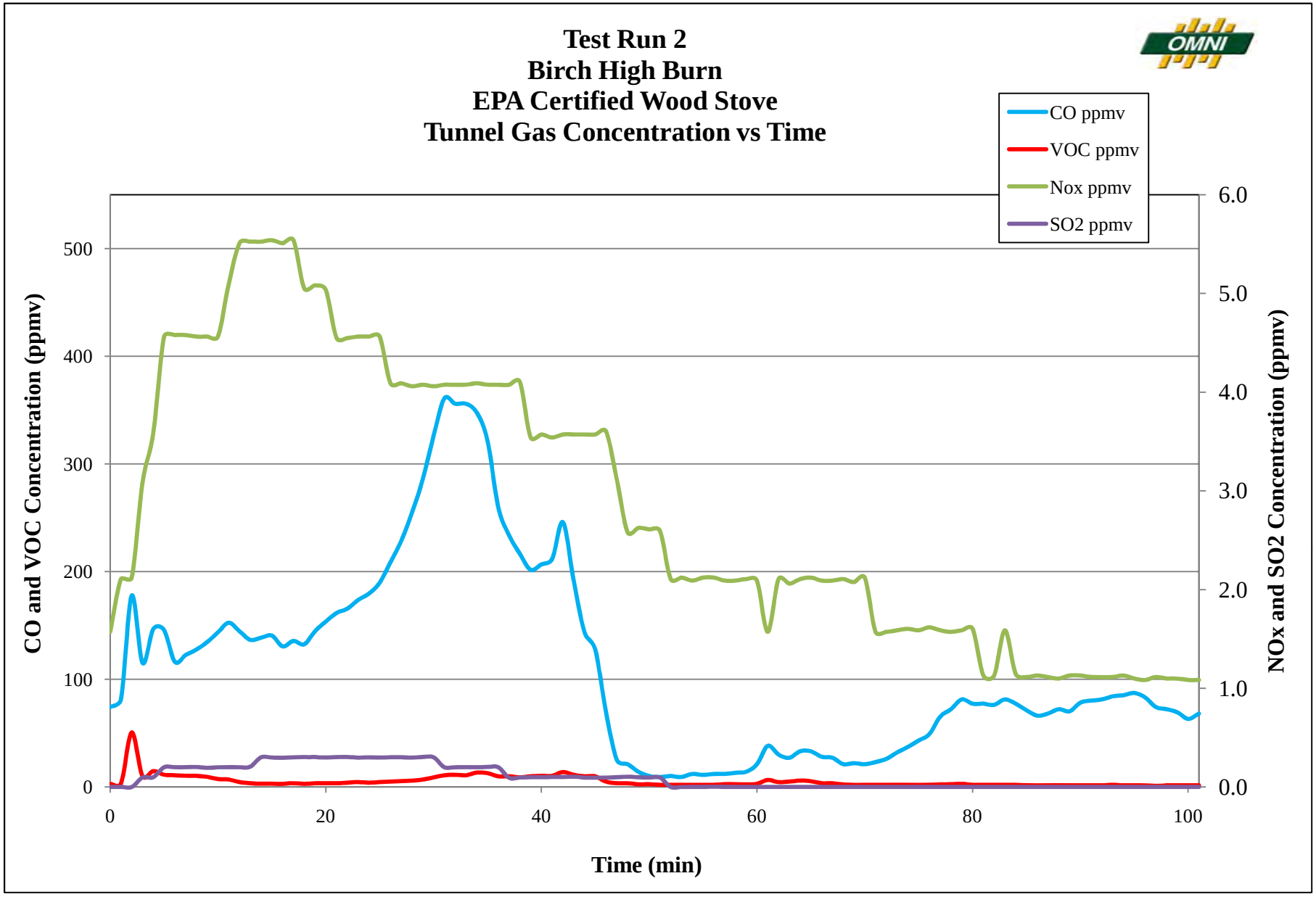
Appendix C

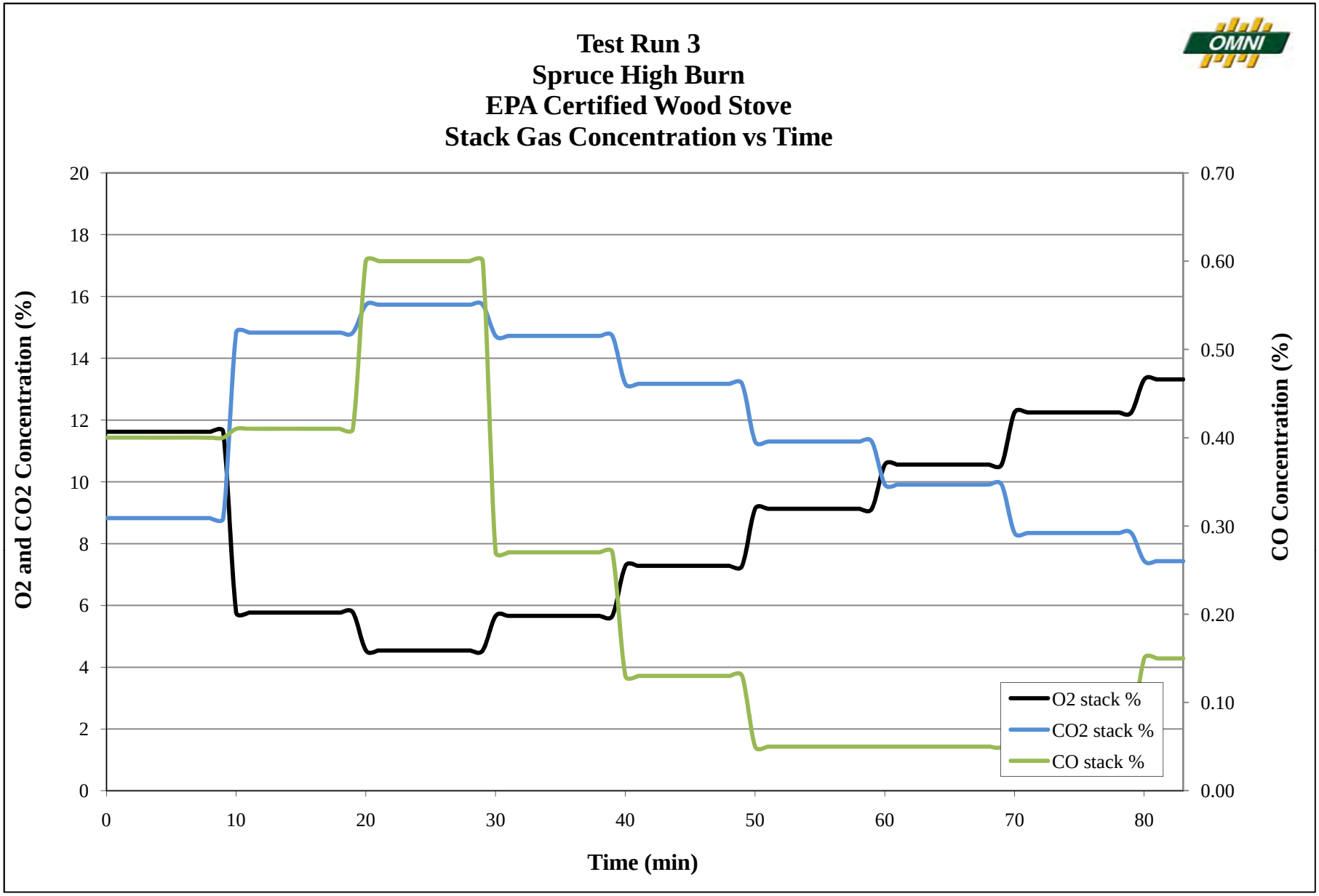
Real-Time Graphs

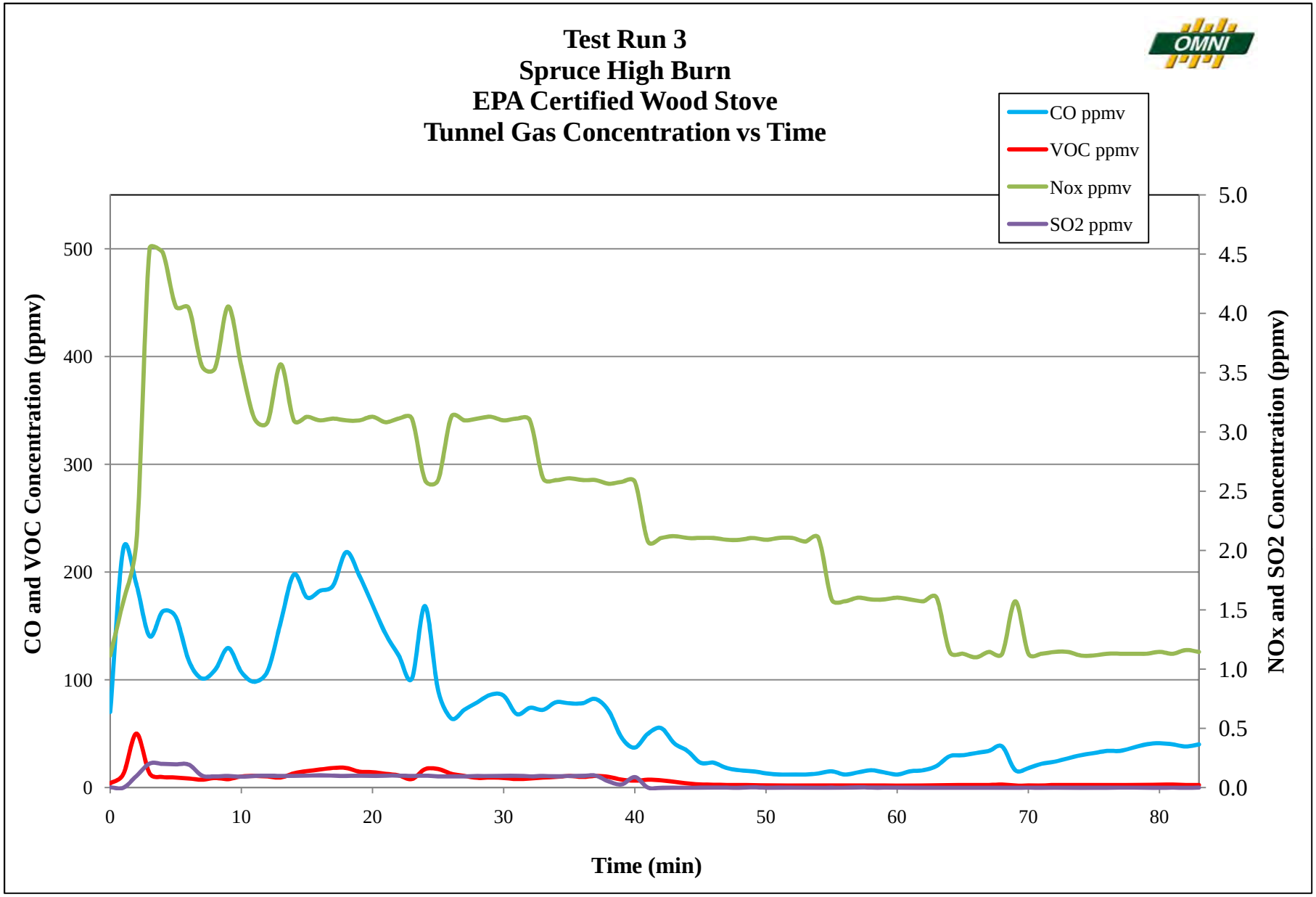

Test Run 1
Pellet High Burn
Pellet Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
0.045
0
20
40
60
80
100
120
O2 stack %
CO2 stack %
CO stack %

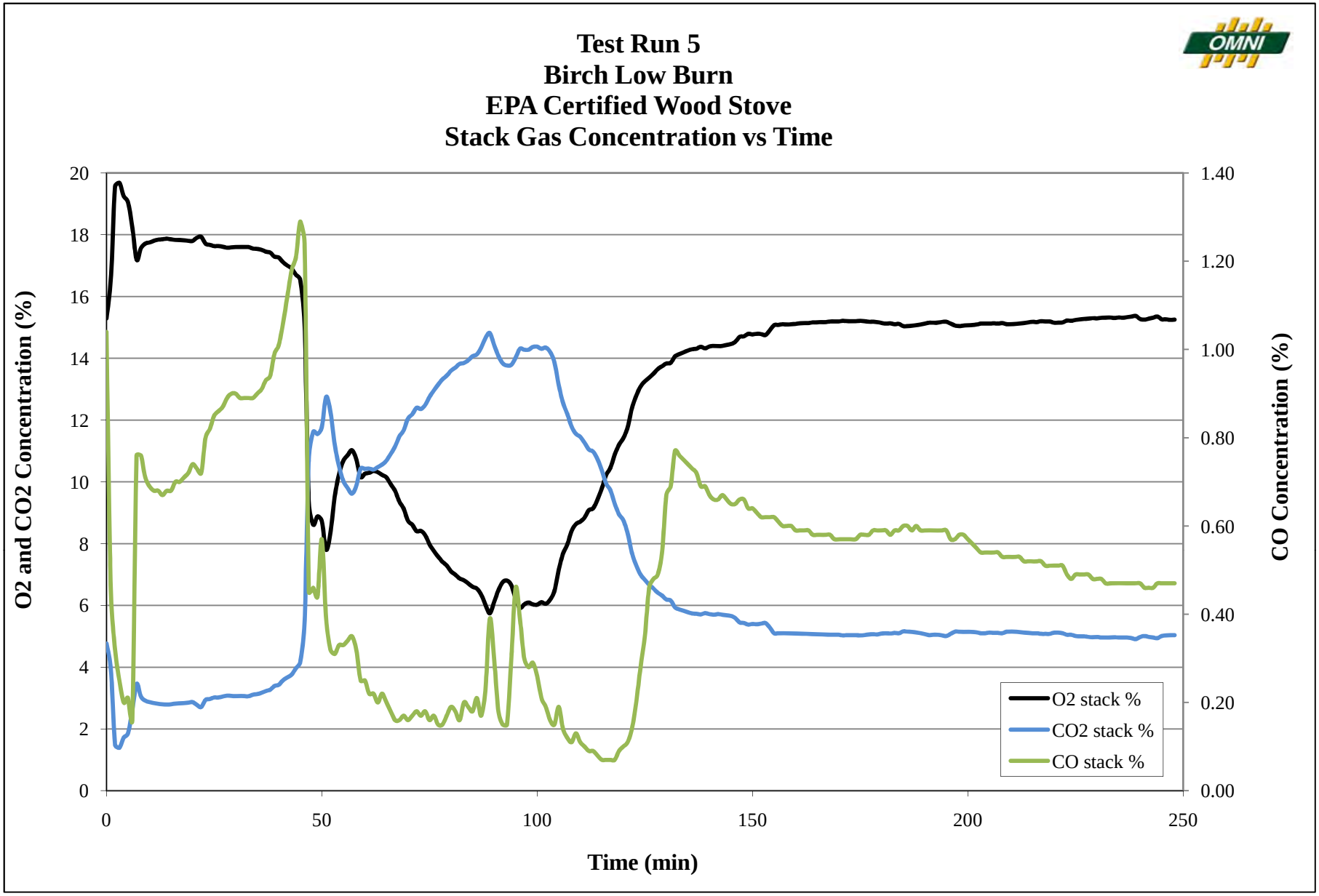

Test Run 1
Pellet High Burn
Pellet Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
5
10
15
20
25
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
20
40
60
80
100
120

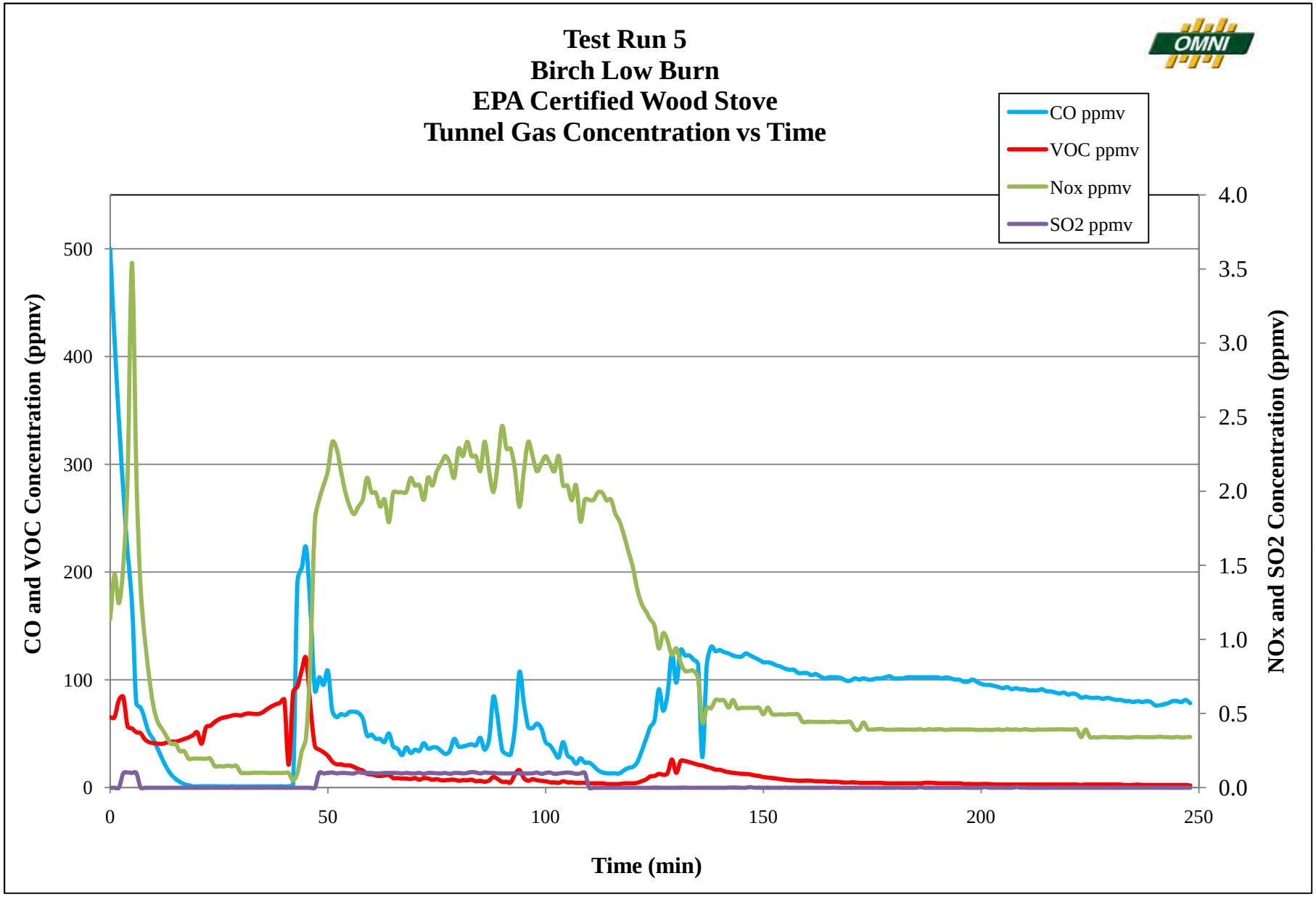

Test Run 2
Birch High Burn
EPA Certified Wood Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
0
20
40
60
80
100

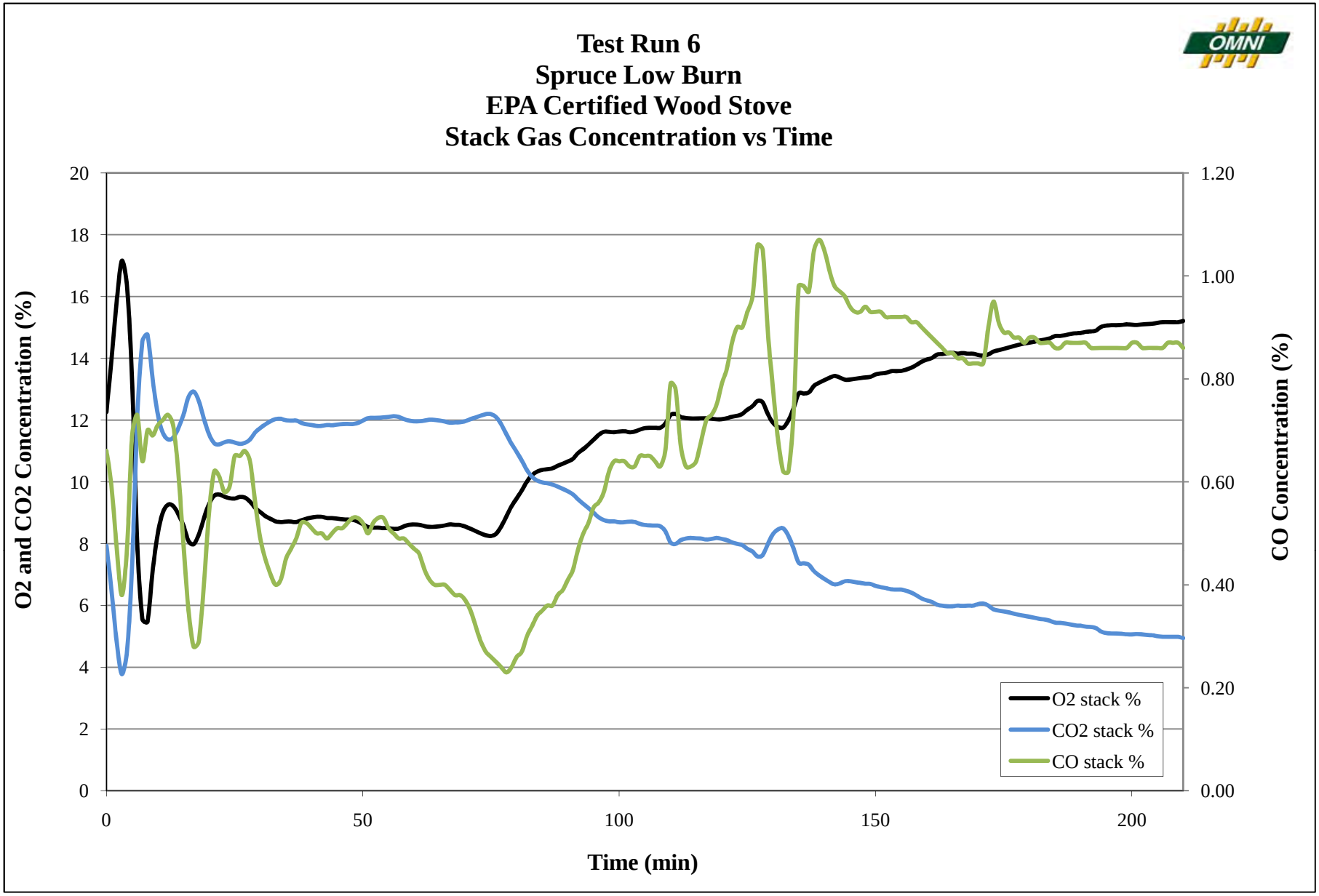

Test Run 2
Birch High Burn
EPA Certified Wood Stove
Tunnel Gas Concentration vs Time
OMNI
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
20
40
60
80
100

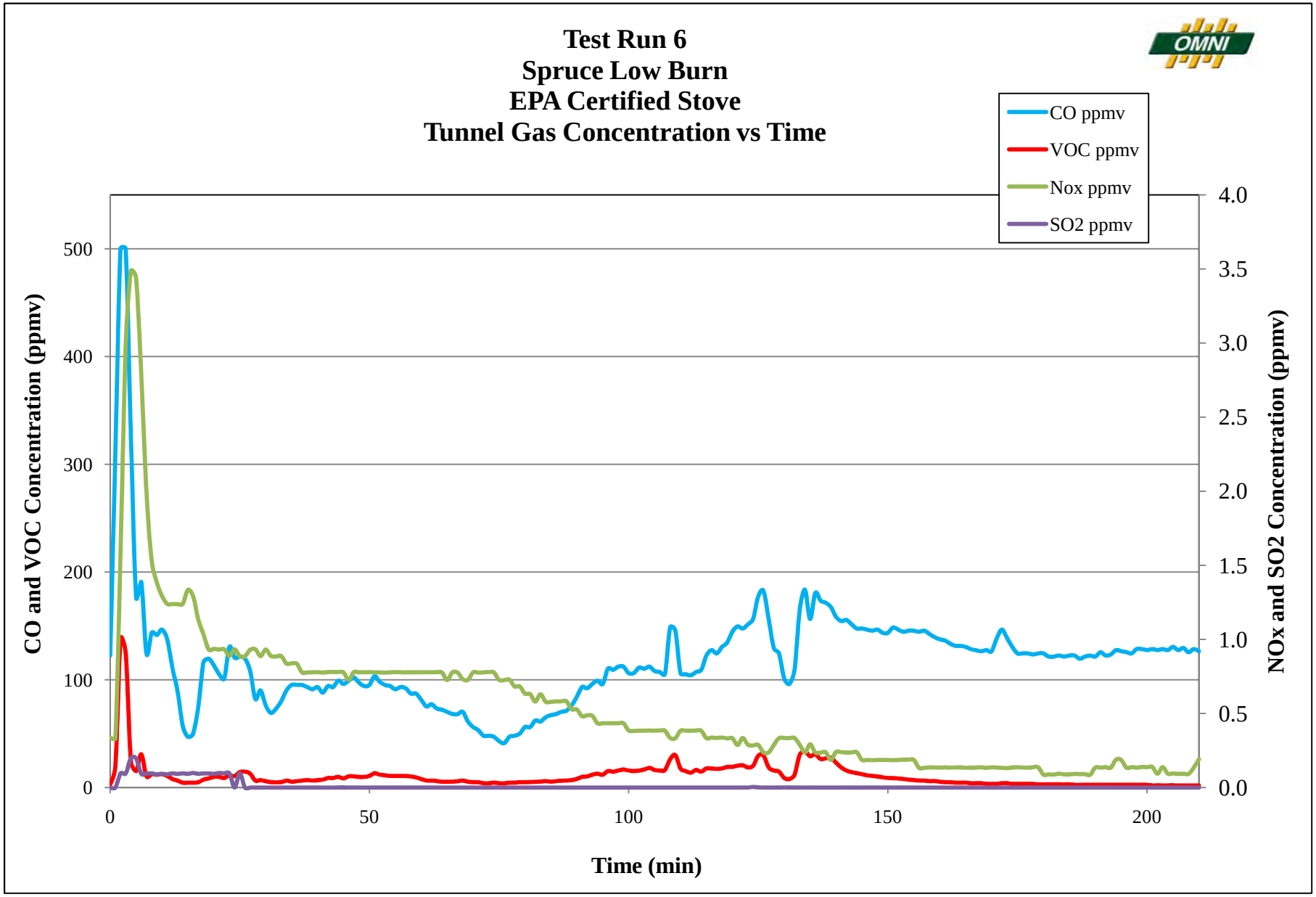

Test Run 3
Spruce High Burn
EPA Certified Wood Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0
10
20
30
40
50
60
70
80
O2 stack %
CO2 stack %
CO stack %

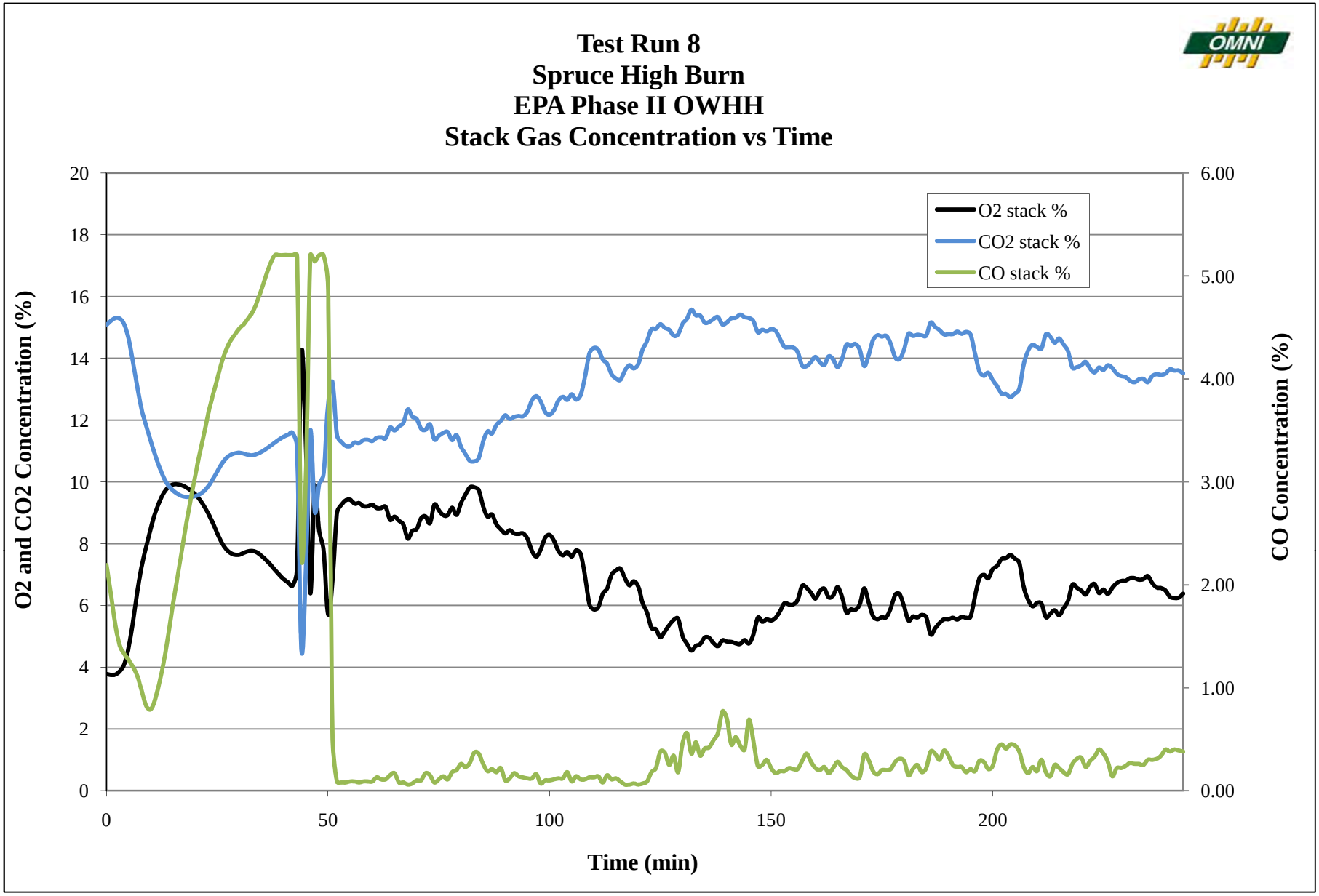

Test Run 3
Spruce High Burn
EPA Certified Wood Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
0
10
20
30
40
50
60
70
80

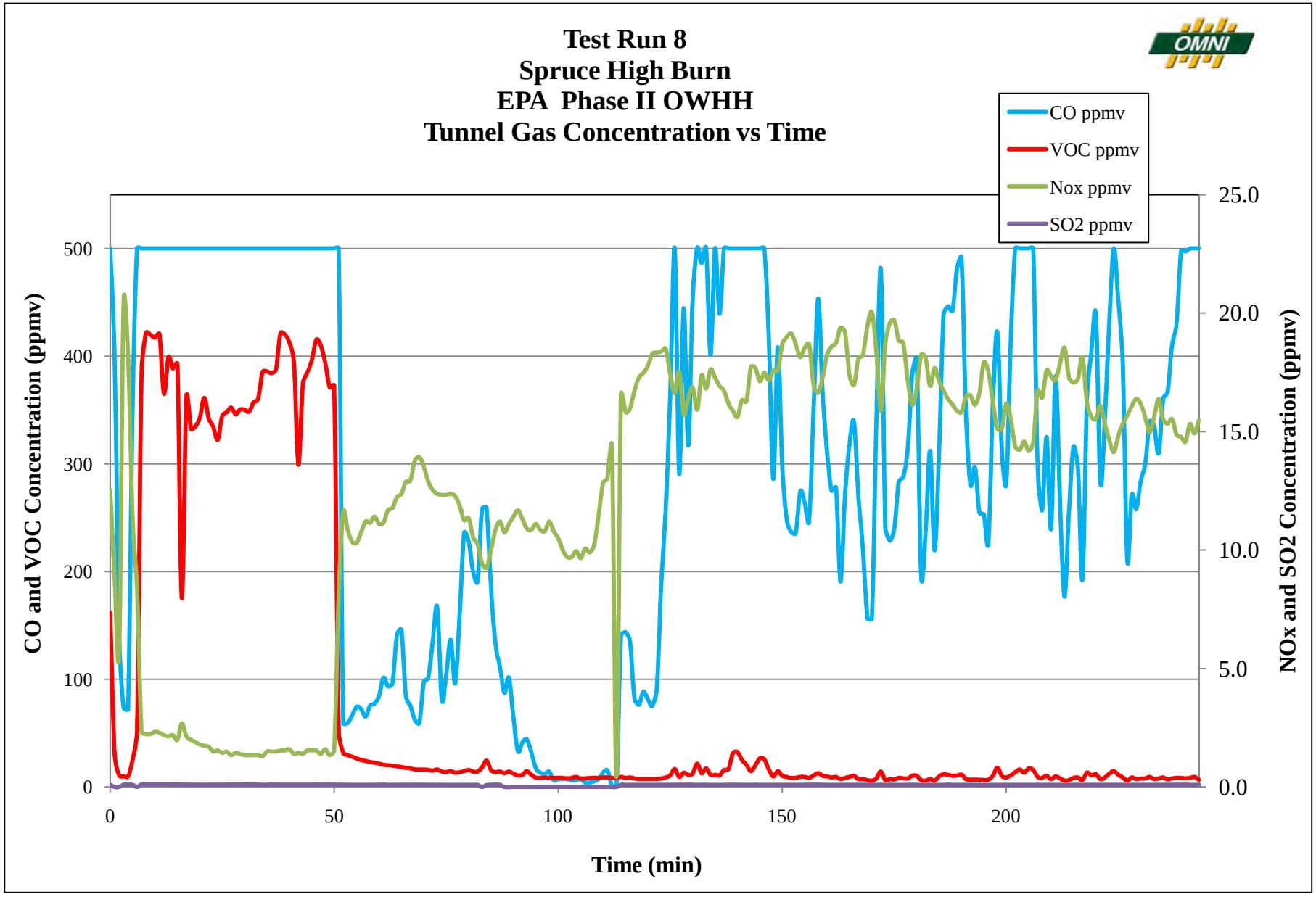

Test Run 5
Birch Low Burn
EPA Certified Wood Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
0
50
100
150
200
250
O2 stack %
CO2 stack %
CO stack %

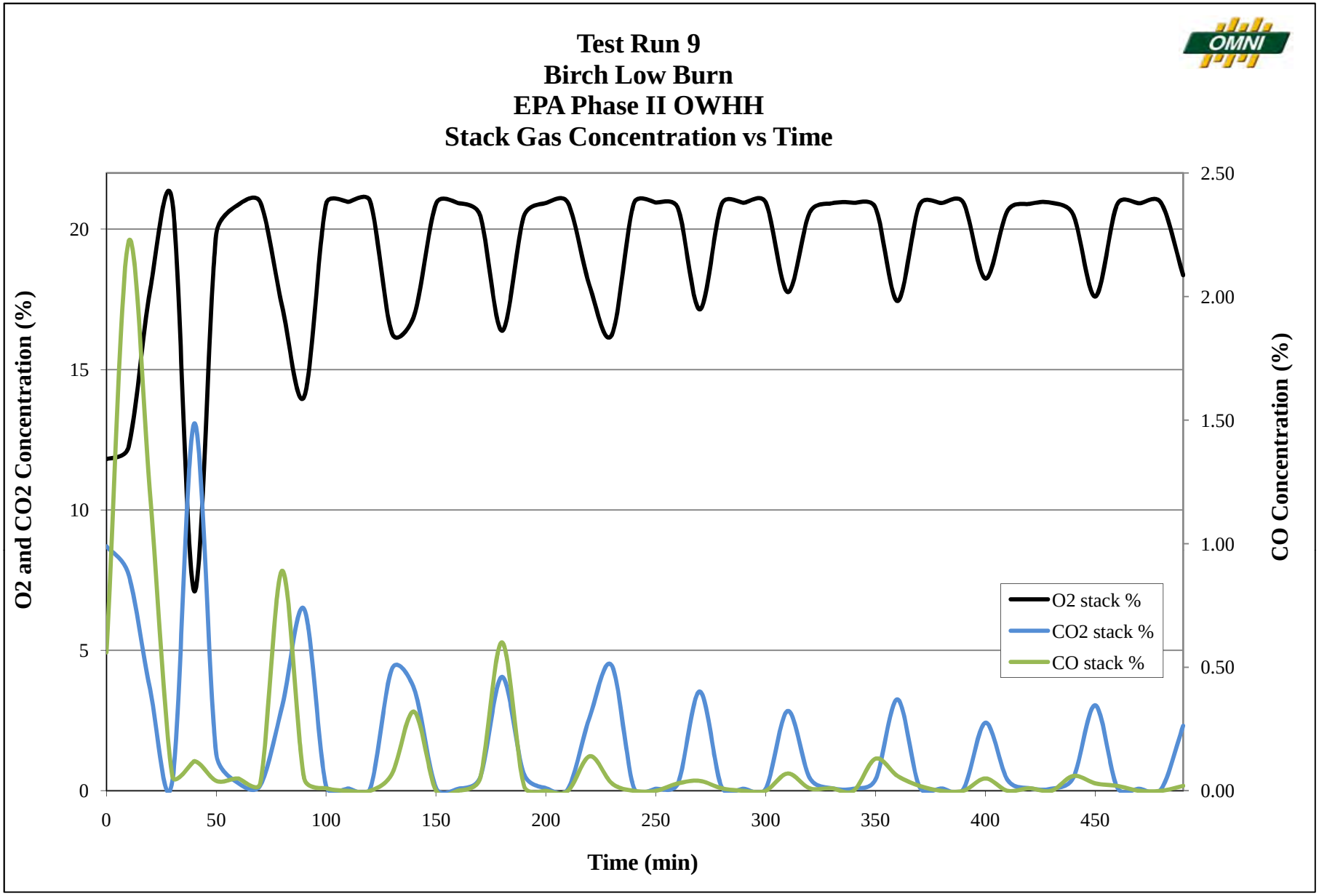

Test Run 5
Birch Low Burn
EPA Certified Wood Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
50
100
150
200
250

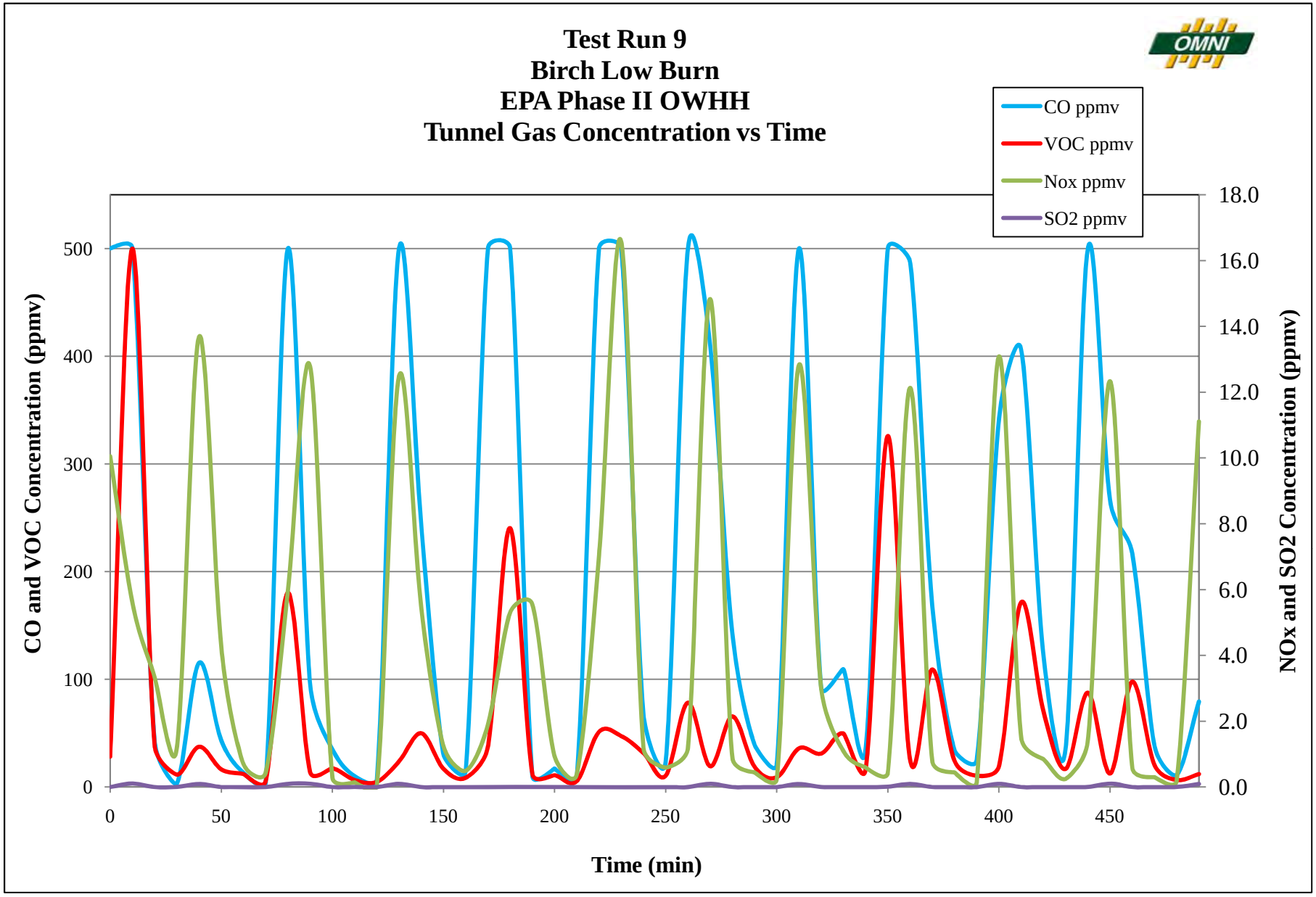

Test Run 6
Spruce Low Burn
EPA Certified Wood Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
0
50
100
150
200
O2 stack %
CO2 stack %
CO stack %

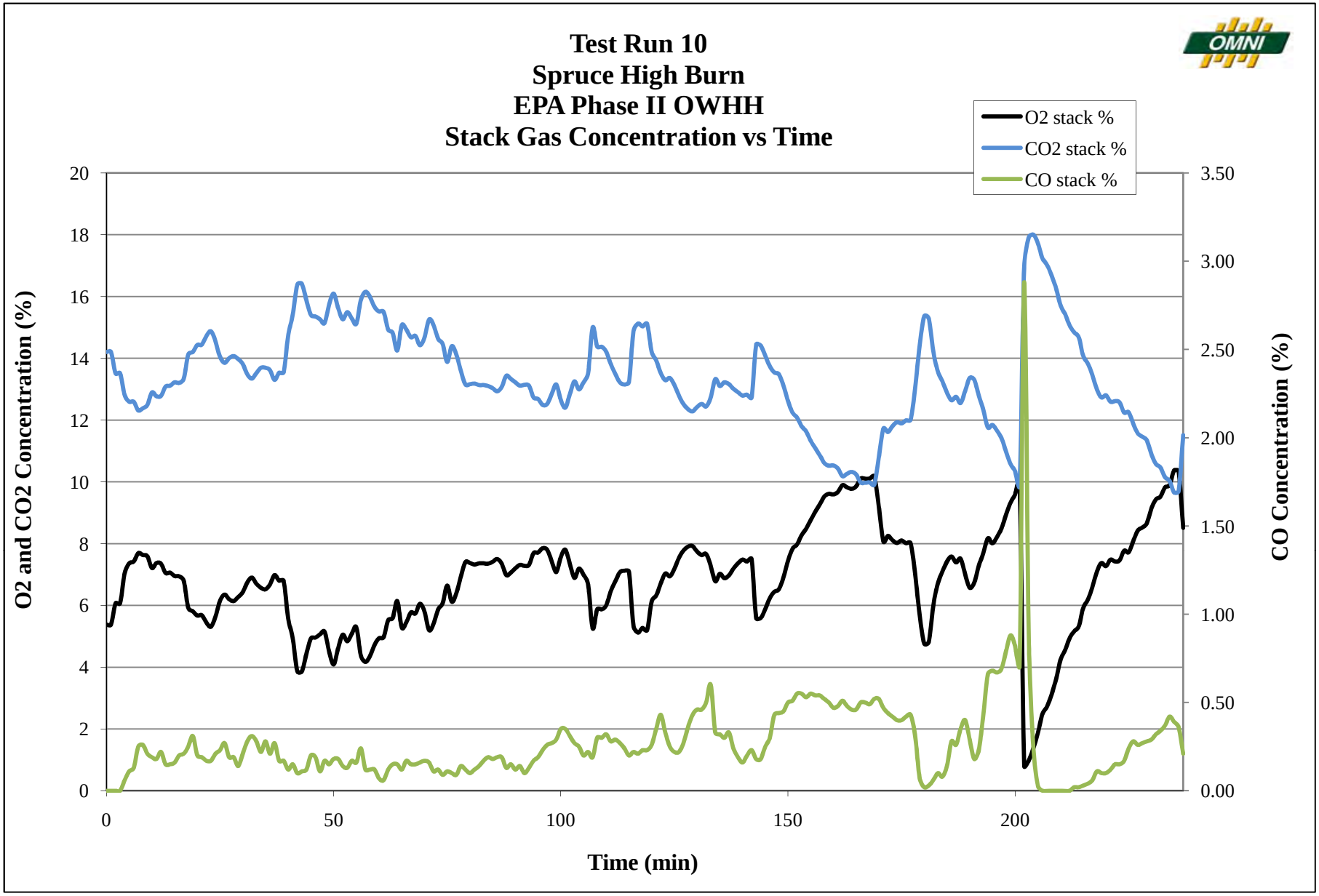

Test Run 6
Spruce Low Burn
EPA Certified Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
50
100
150
200

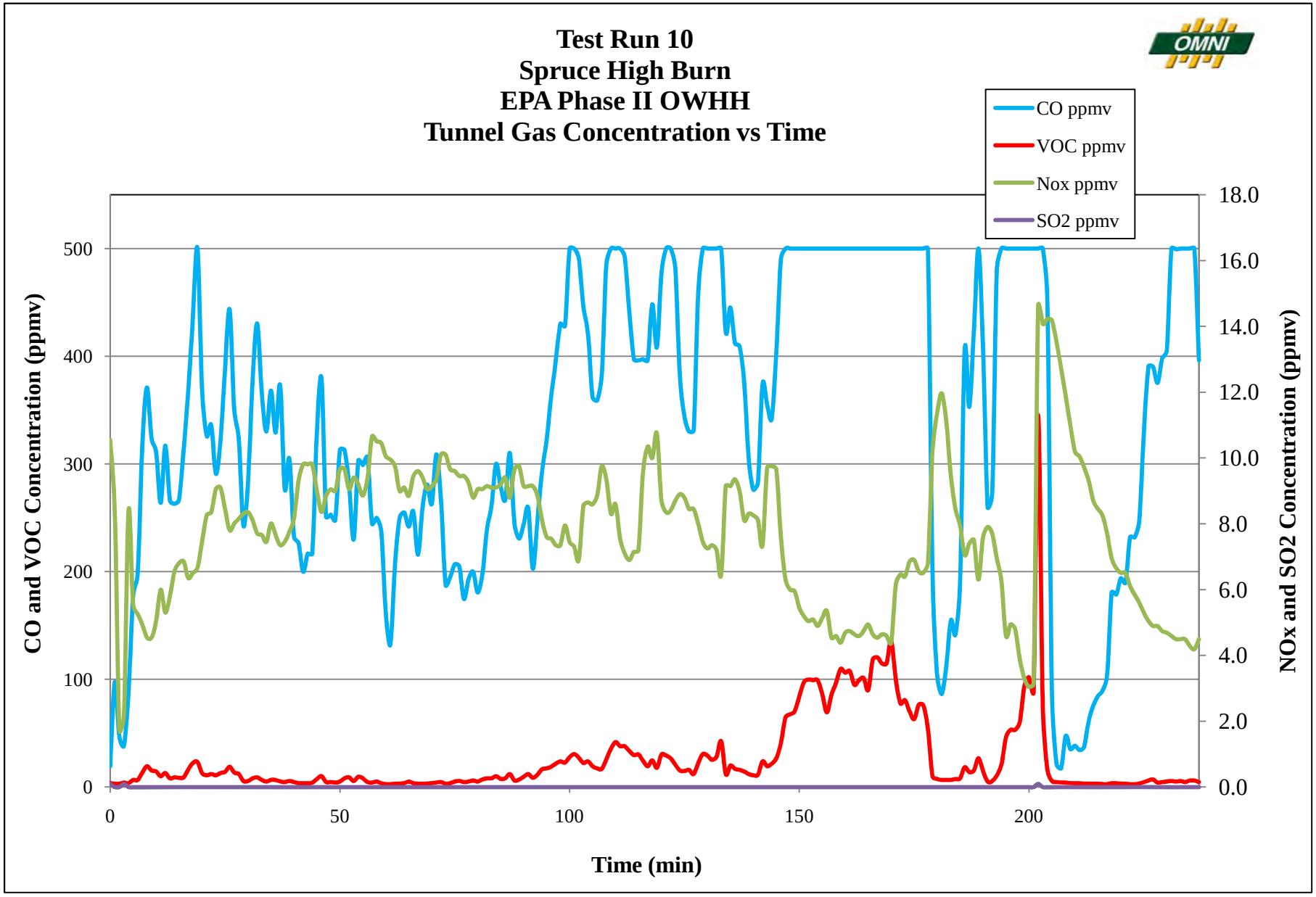

Test Run 8
Spruce High Burn
EPA Phase II OWHH
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200

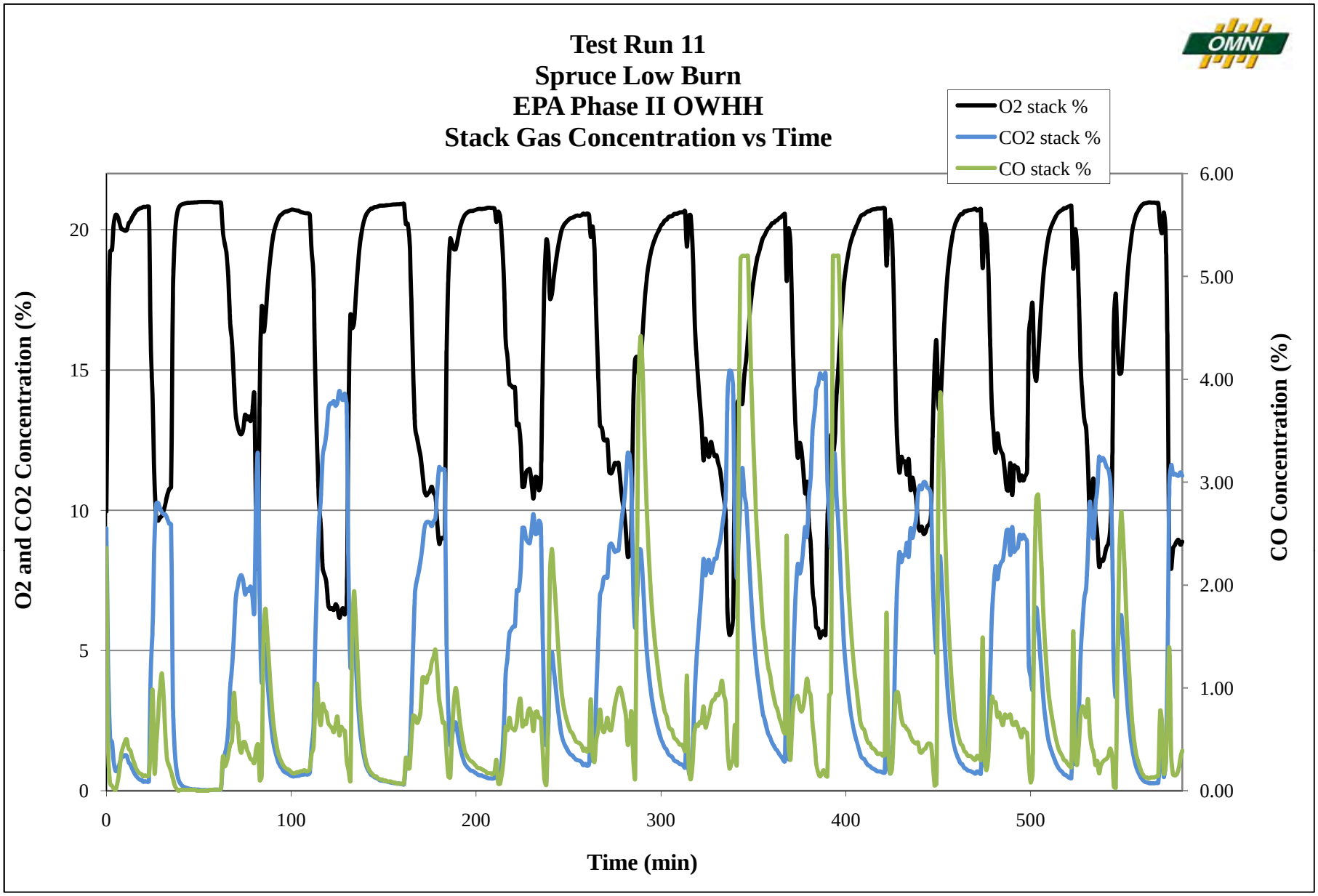

Test Run 8
Spruce High Burn
EPA Phase II OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
5.0
10.0
15.0
20.0
25.0
0
50
100
150
200

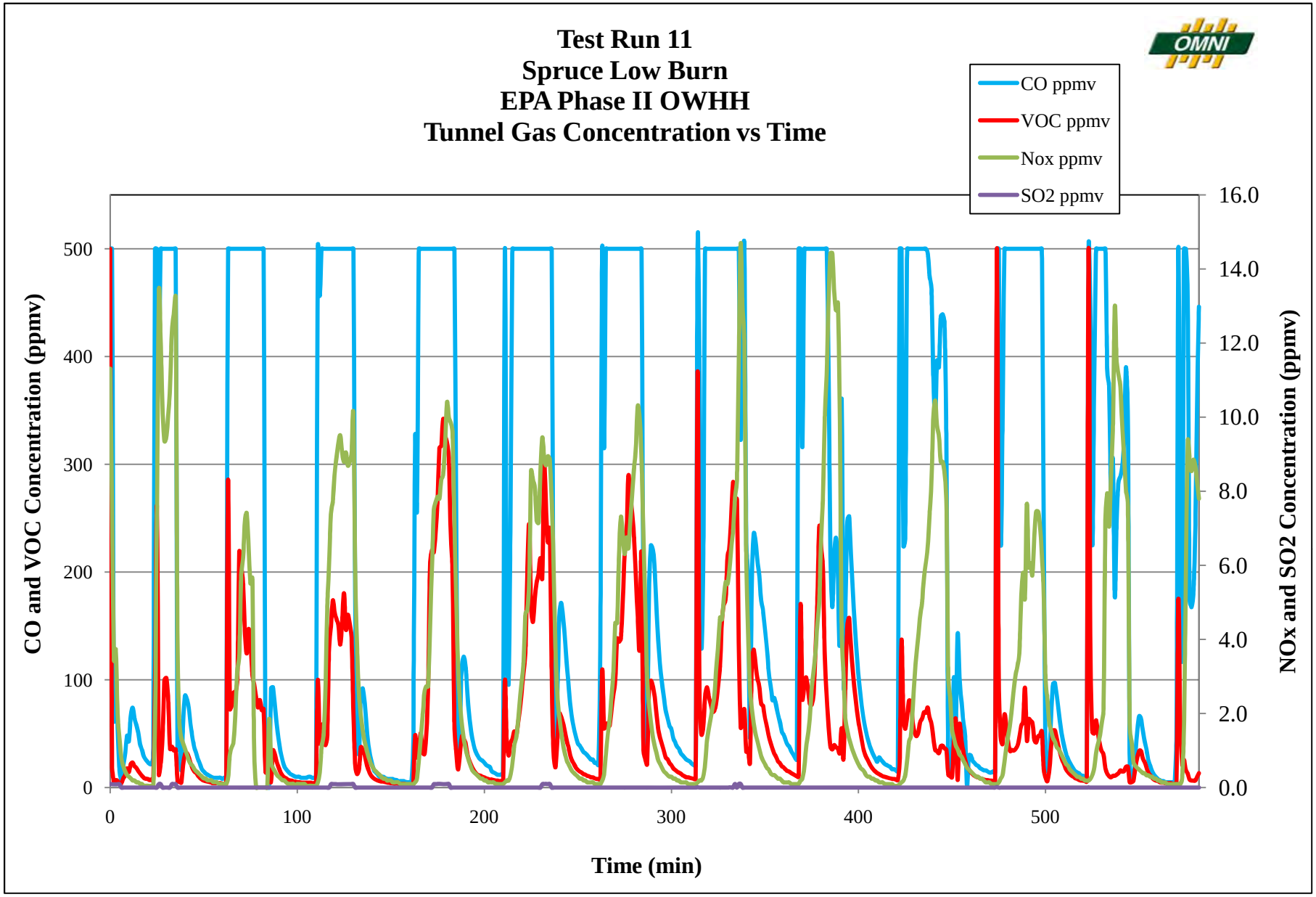

Test Run 9
Birch Low Burn
EPA Phase II OWHH
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
5
10
15
20
0.00
0.50
1.00
1.50
2.00
2.50
0
50
100
150
200
250
300
350
400
450

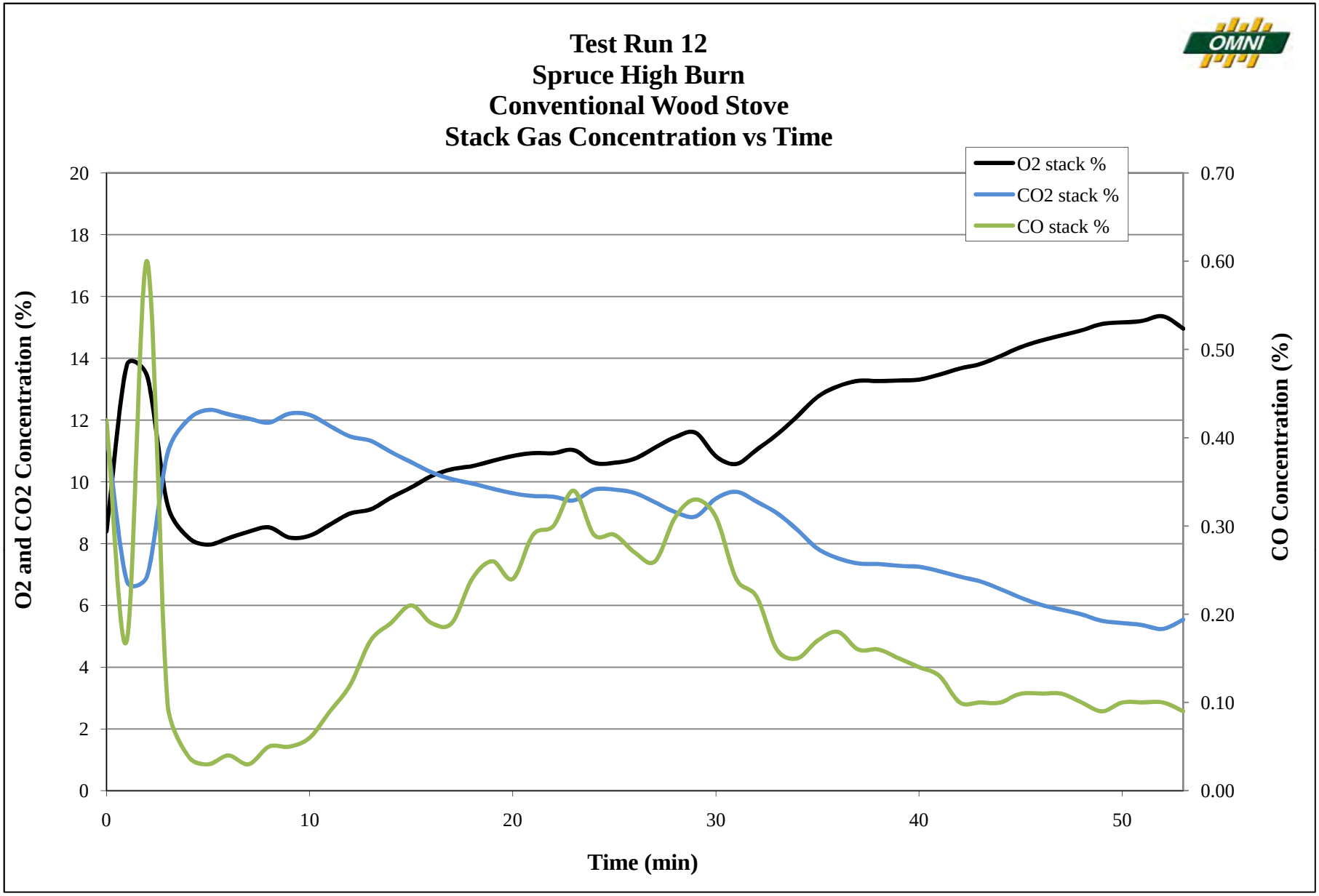

Test Run 9
Birch Low Burn
EPA Phase II OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
0
50
100
150
200
250
300
350
400
450

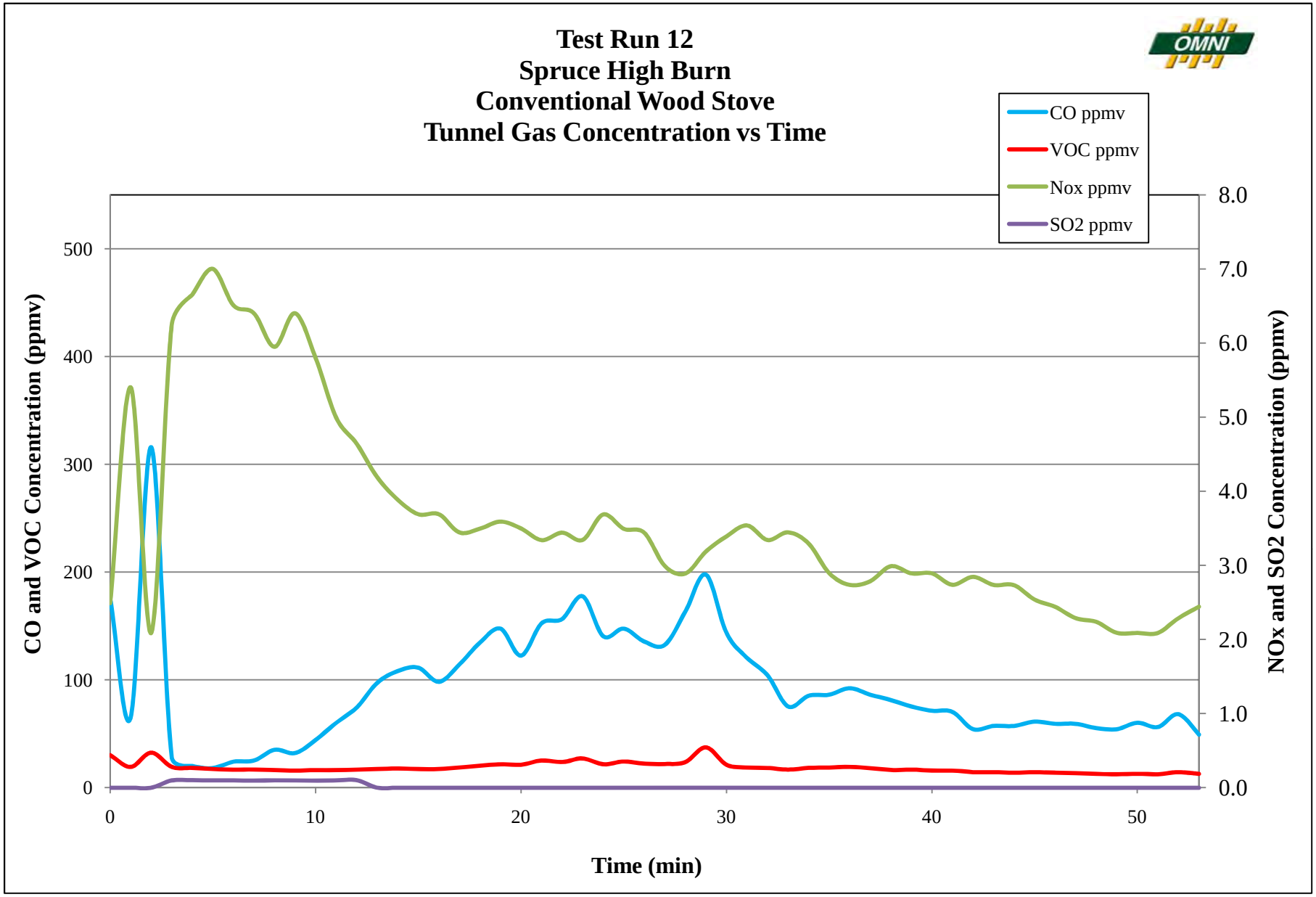

Test Run 10
Spruce High Burn
EPA Phase II OWHH
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
0
50
100
150
200

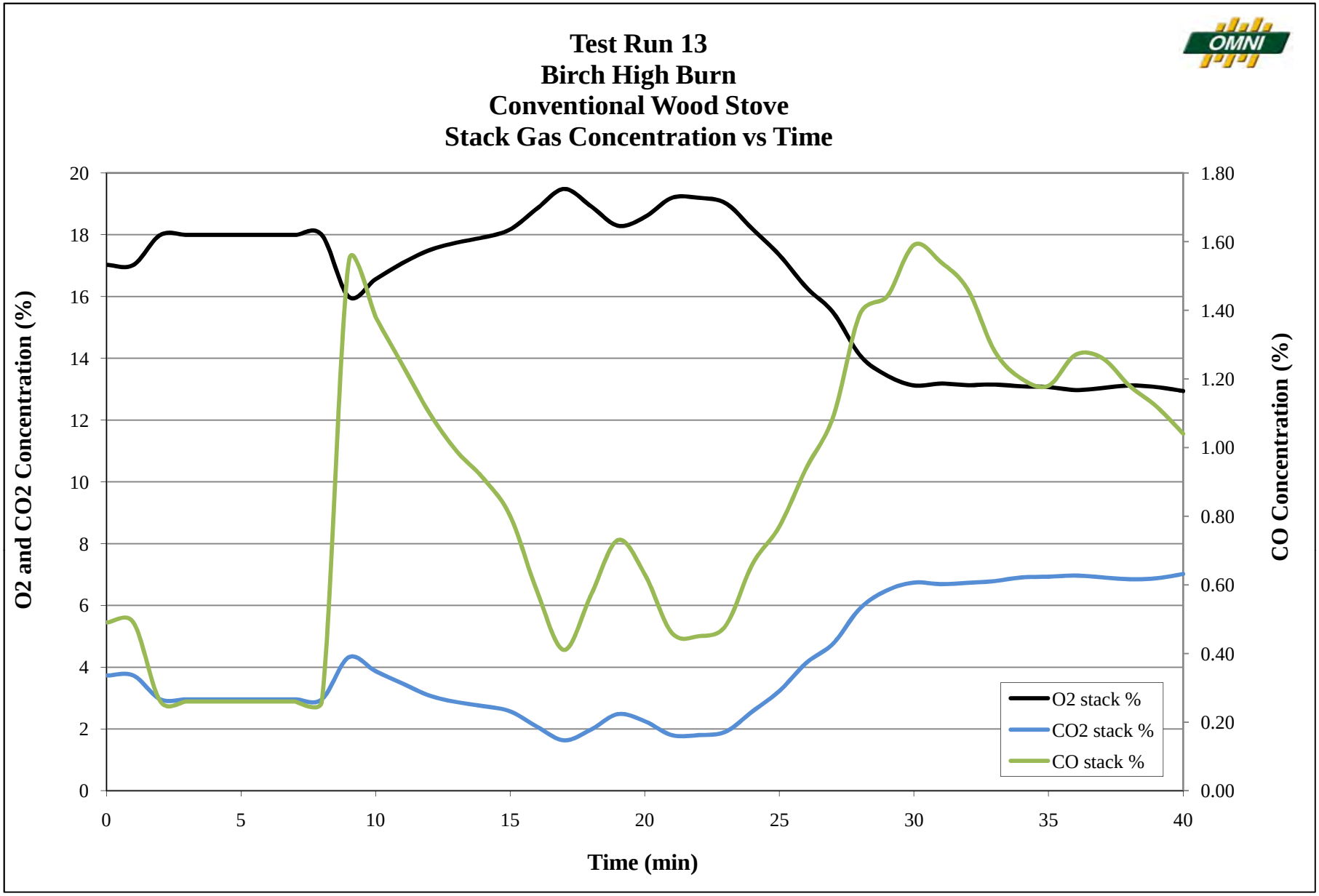

Test Run 10
Spruce High Burn
EPA Phase II OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
0
50
100
150
200

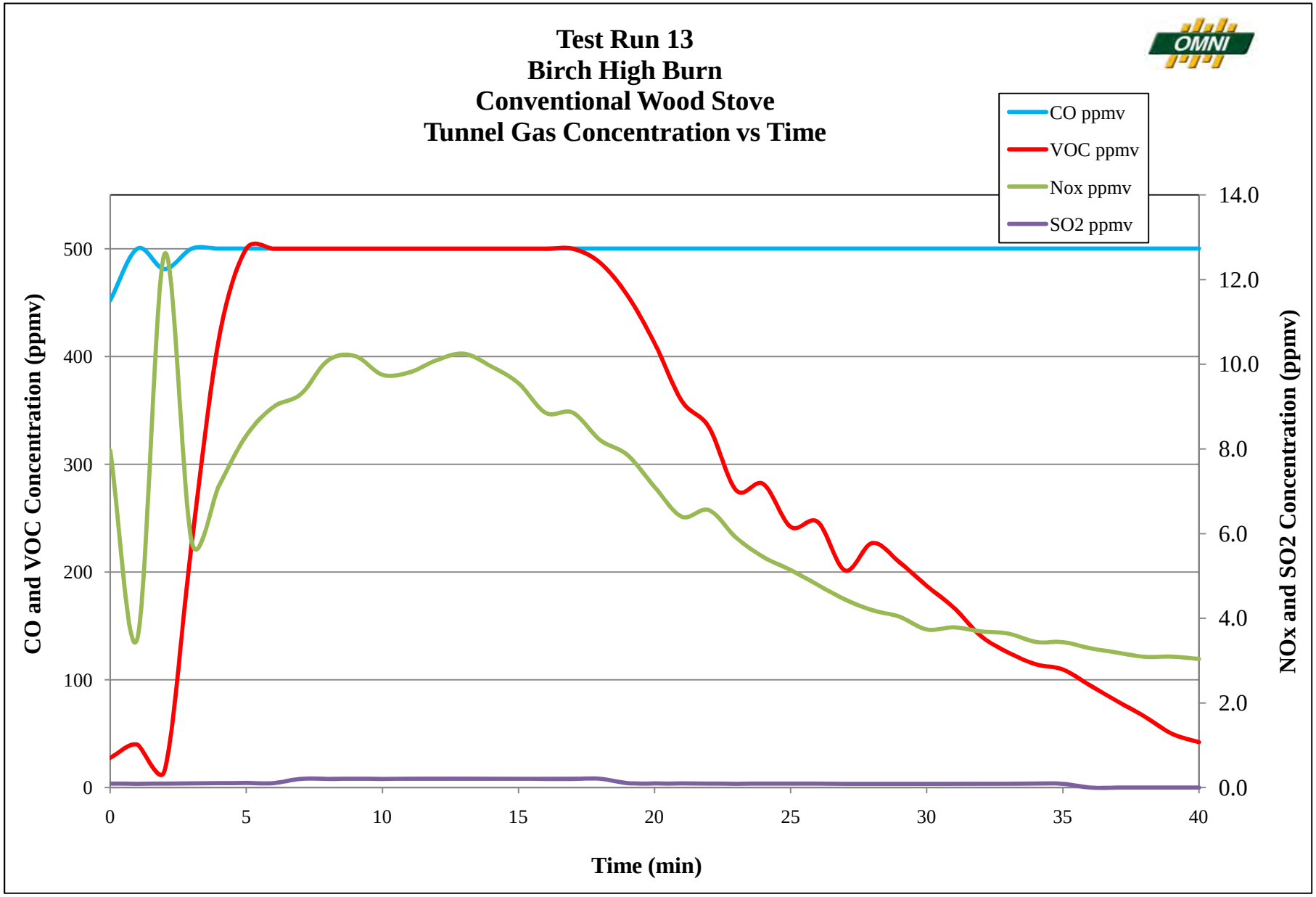

Test Run 11
Spruce Low Burn
EPA Phase II OWHH
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
100
200
300
400
500

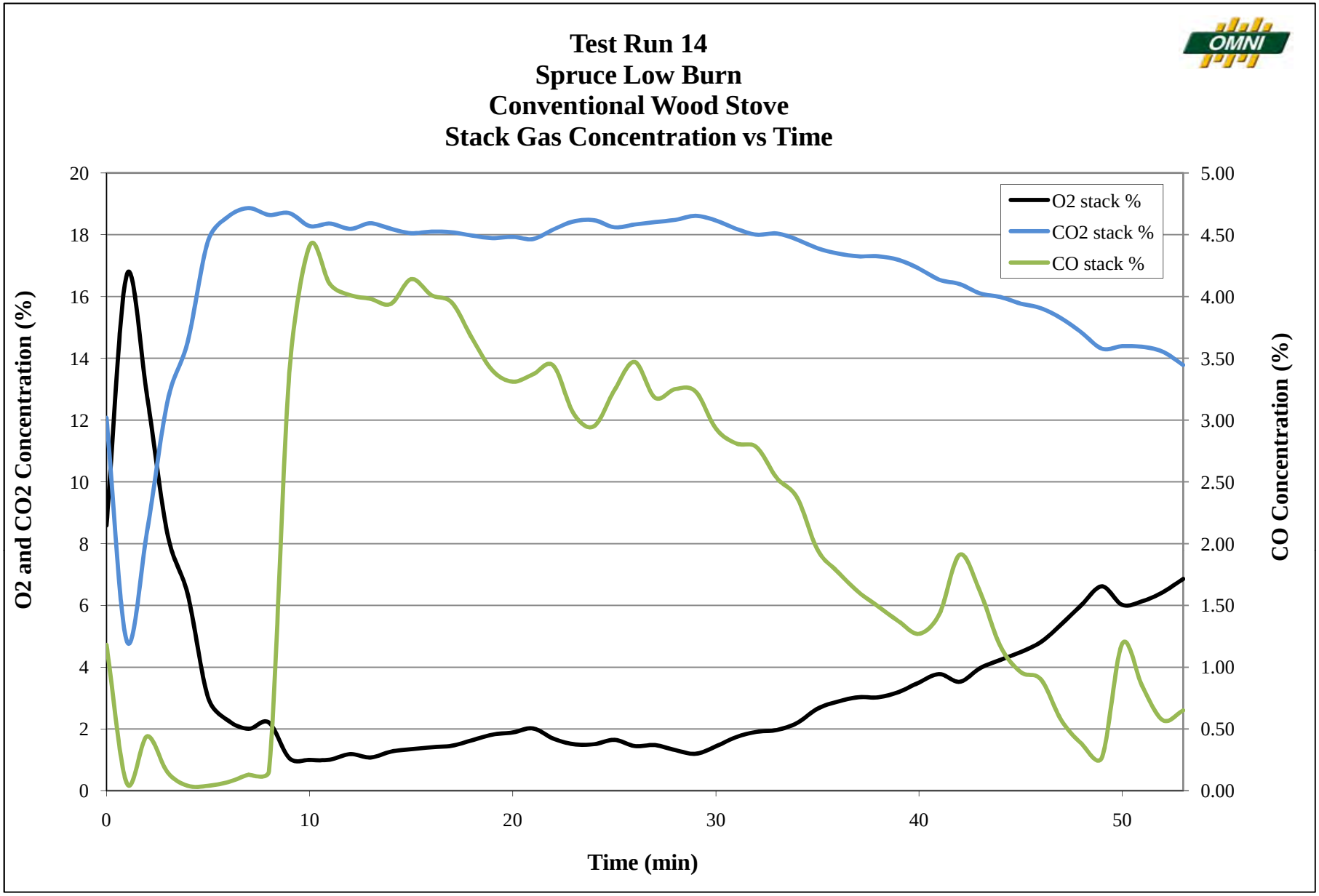

Test Run 11
Spruce Low Burn
EPA Phase II OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0

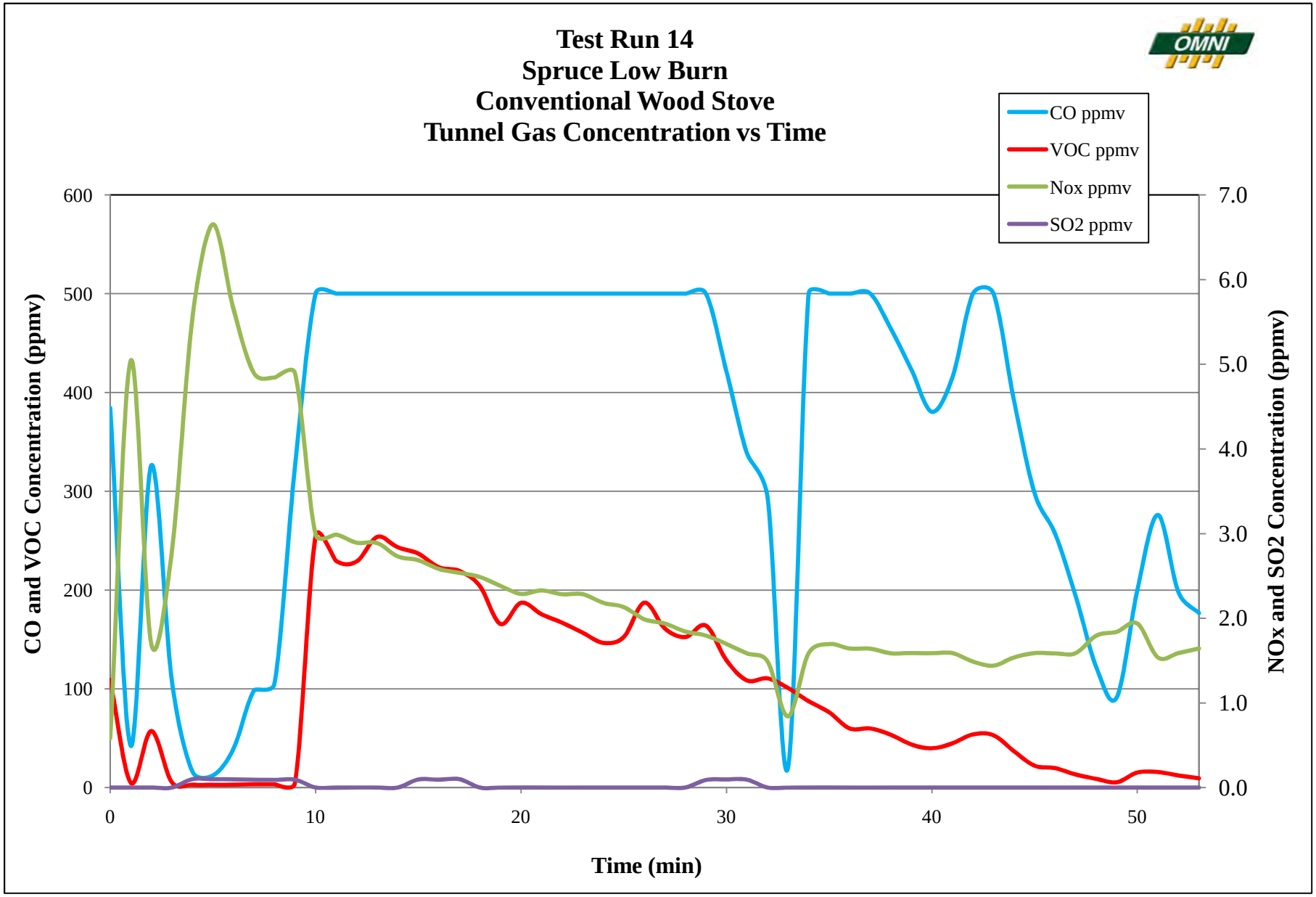

Test Run 12
Spruce High Burn
Conventional Wood Stove
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0
10
20
30
40
50

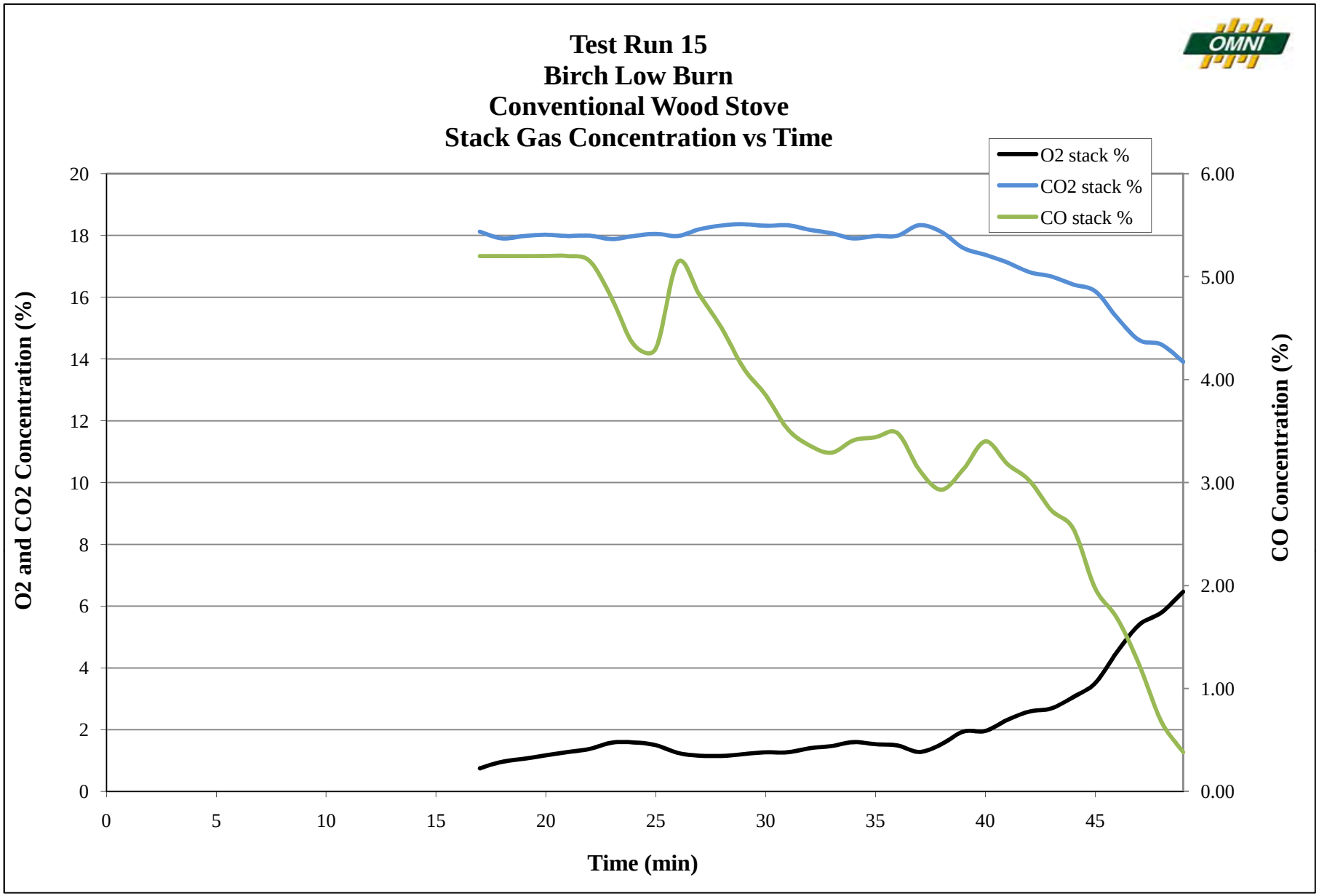

Test Run 12
Spruce High Burn
Conventional Wood Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
0
10
20
30
40
50

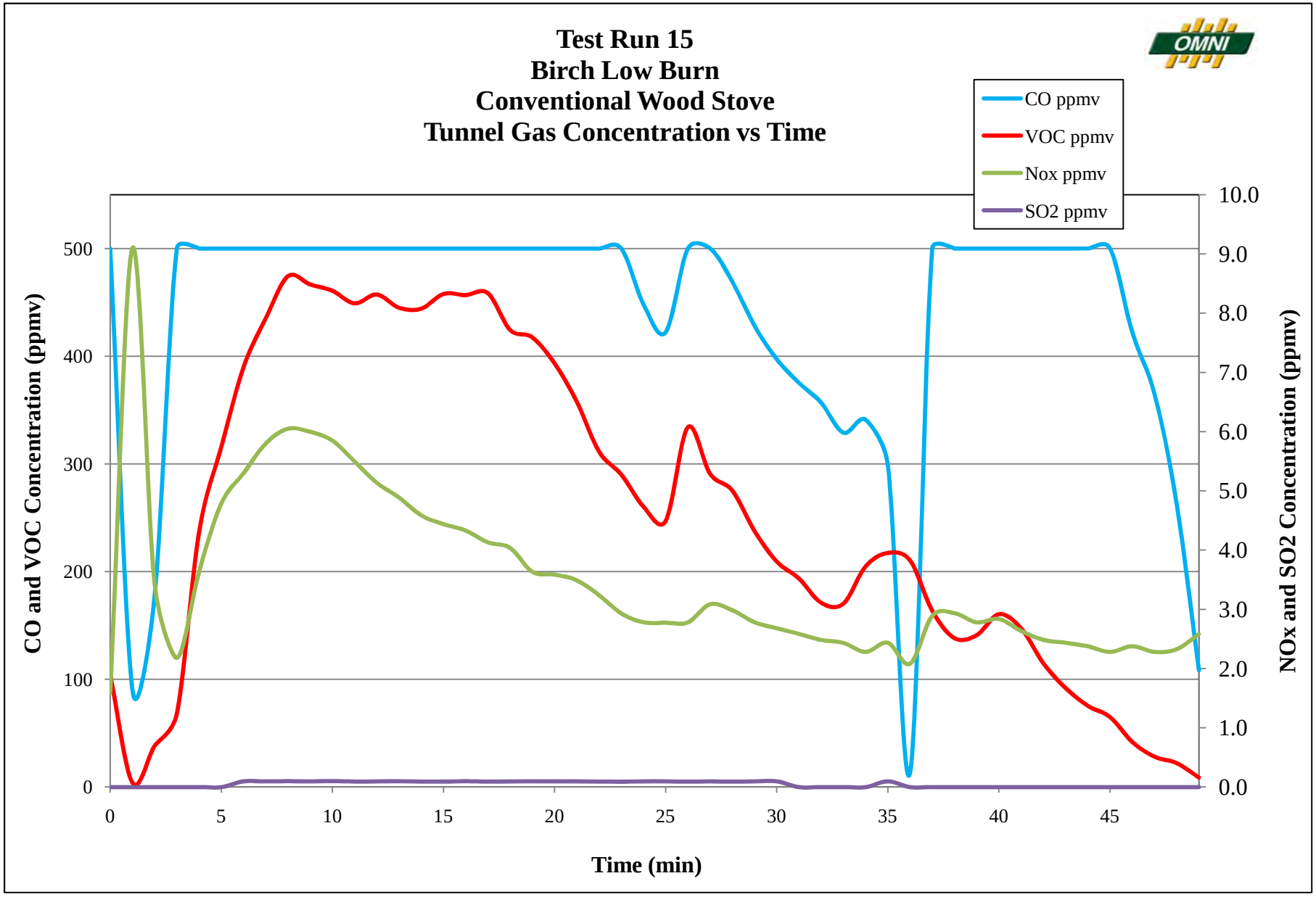

Test Run 13
Birch High Burn
Conventional Wood Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
0
5
10
15
20
25
30
35
40

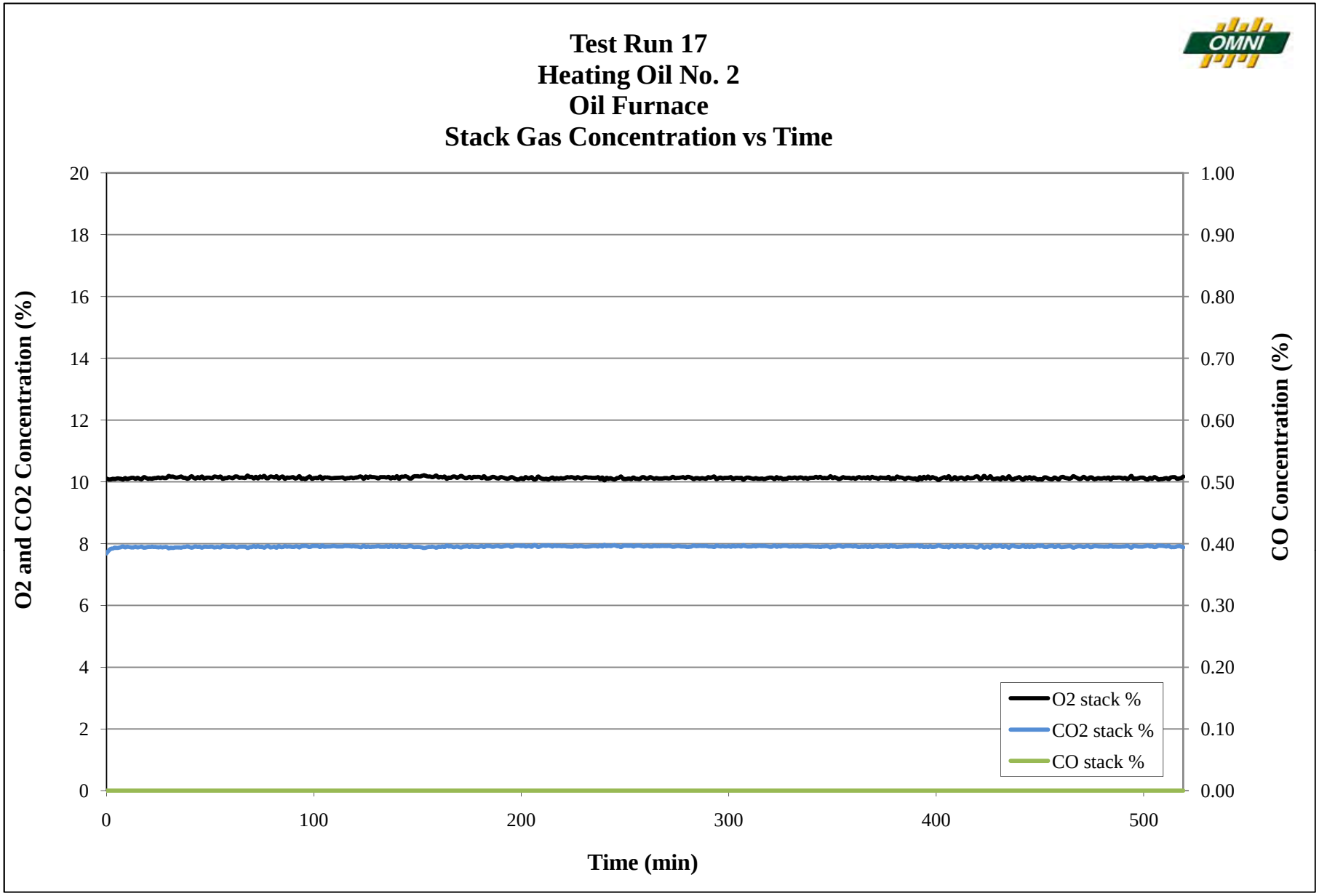

Test Run 13
Birch High Burn
Conventional Wood Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
0
5
10
15
20
25
30
35
40

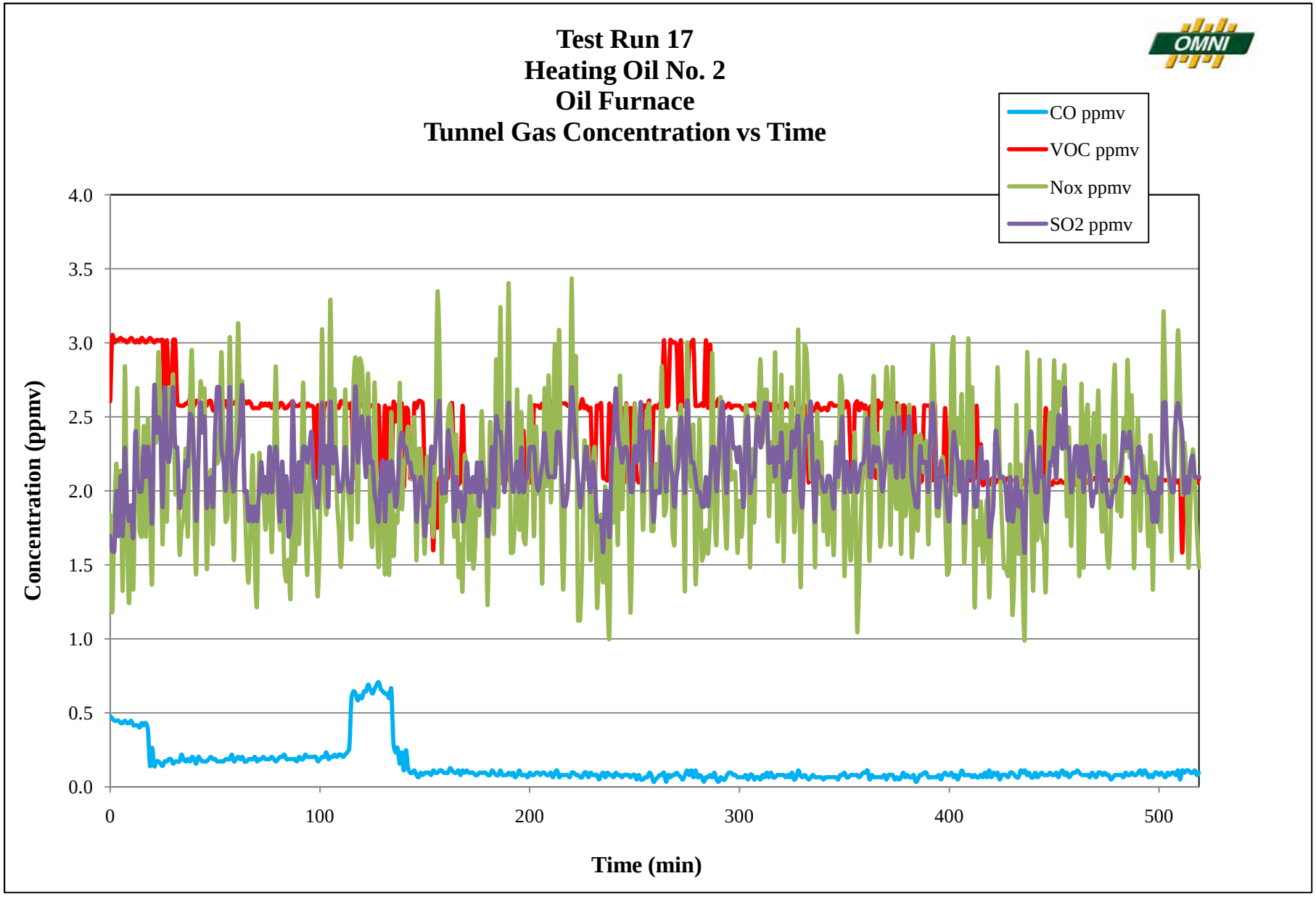

Test Run 14
Spruce Low Burn
Conventional Wood Stove
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
0
10
20
30
40
50

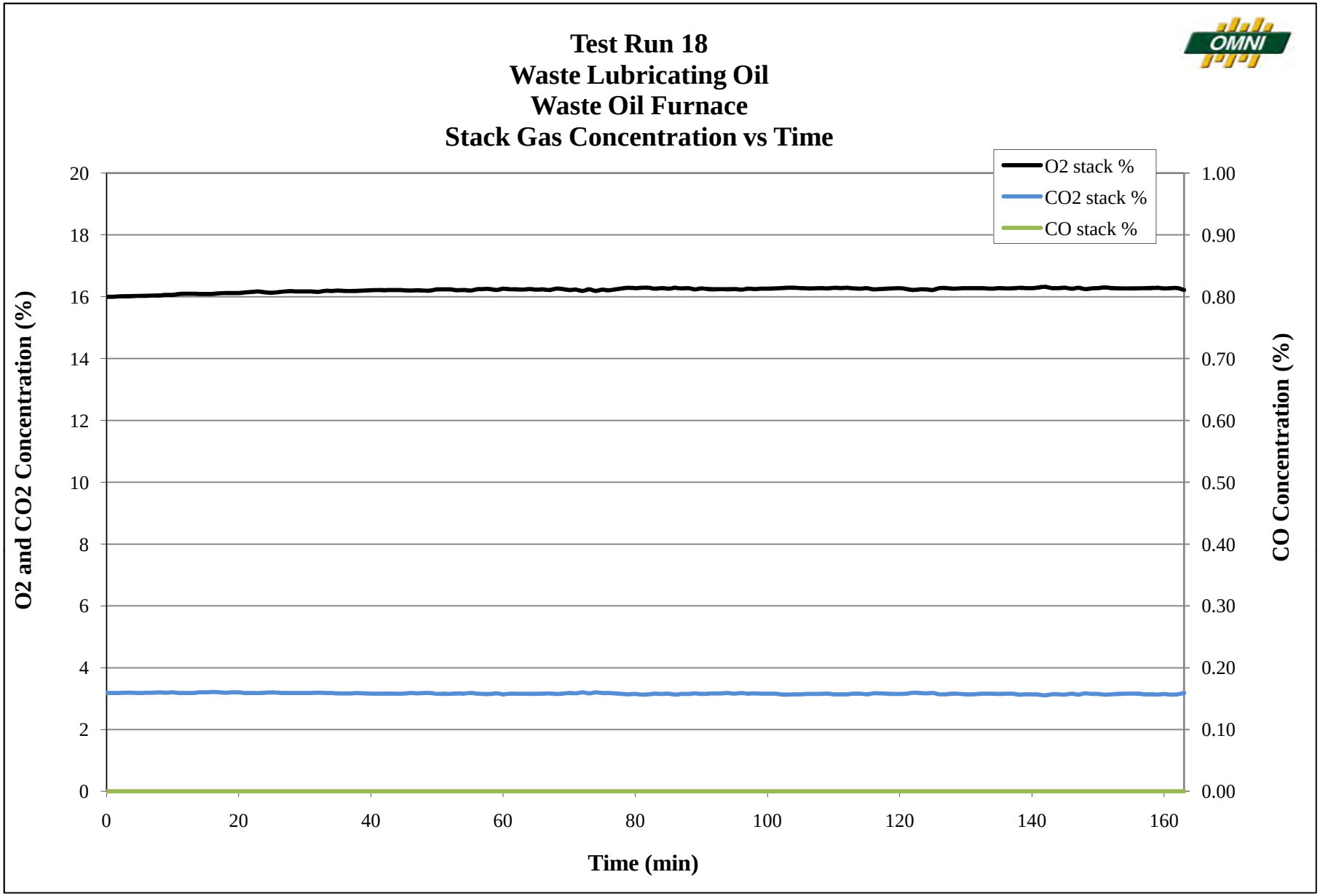

Test Run 14
Spruce Low Burn
Conventional Wood Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
600
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0
10
20
30
40
50

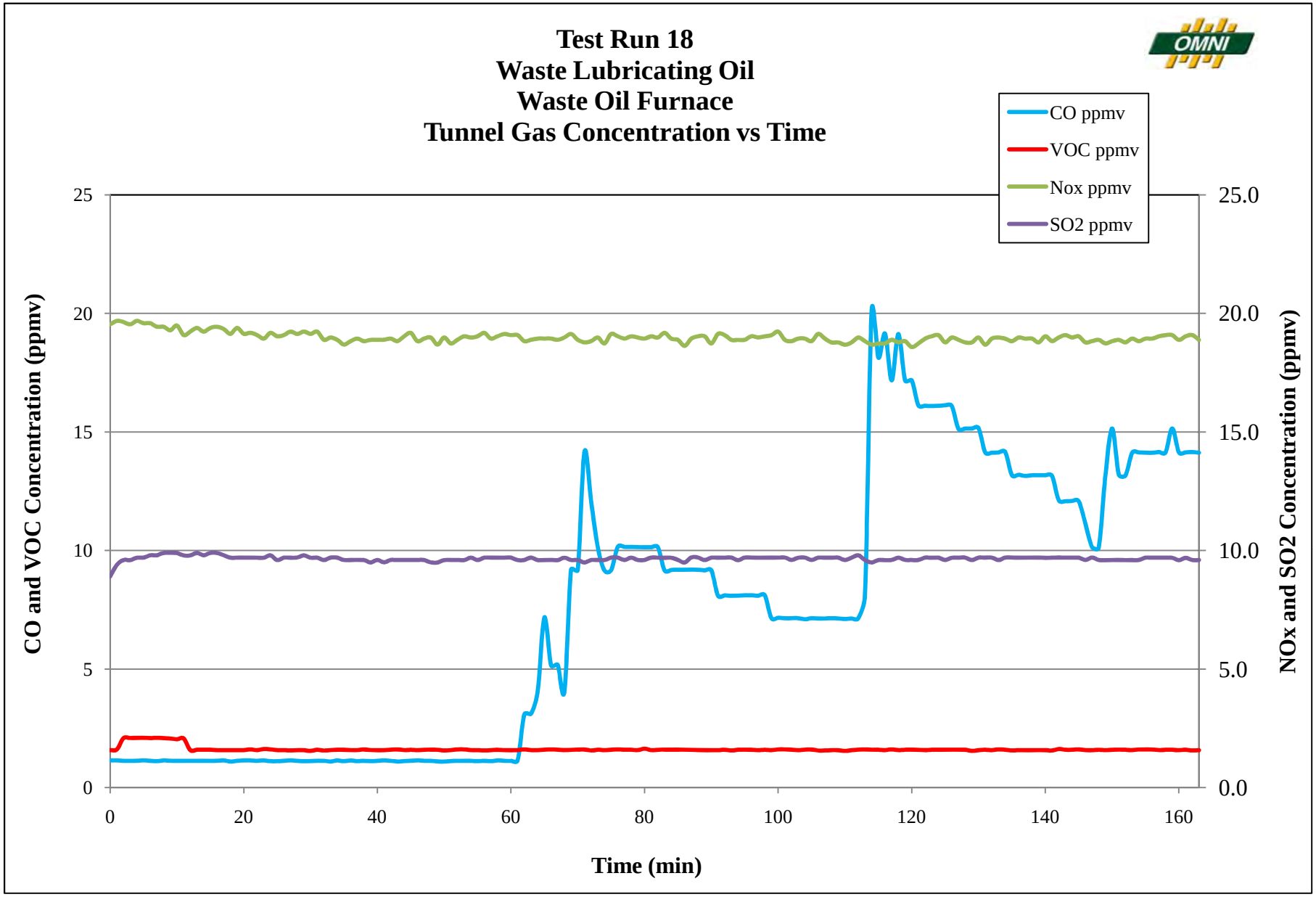

Test Run 15
Birch Low Burn
Conventional Wood Stove
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
5
10
15
20
25
30
35
40
45

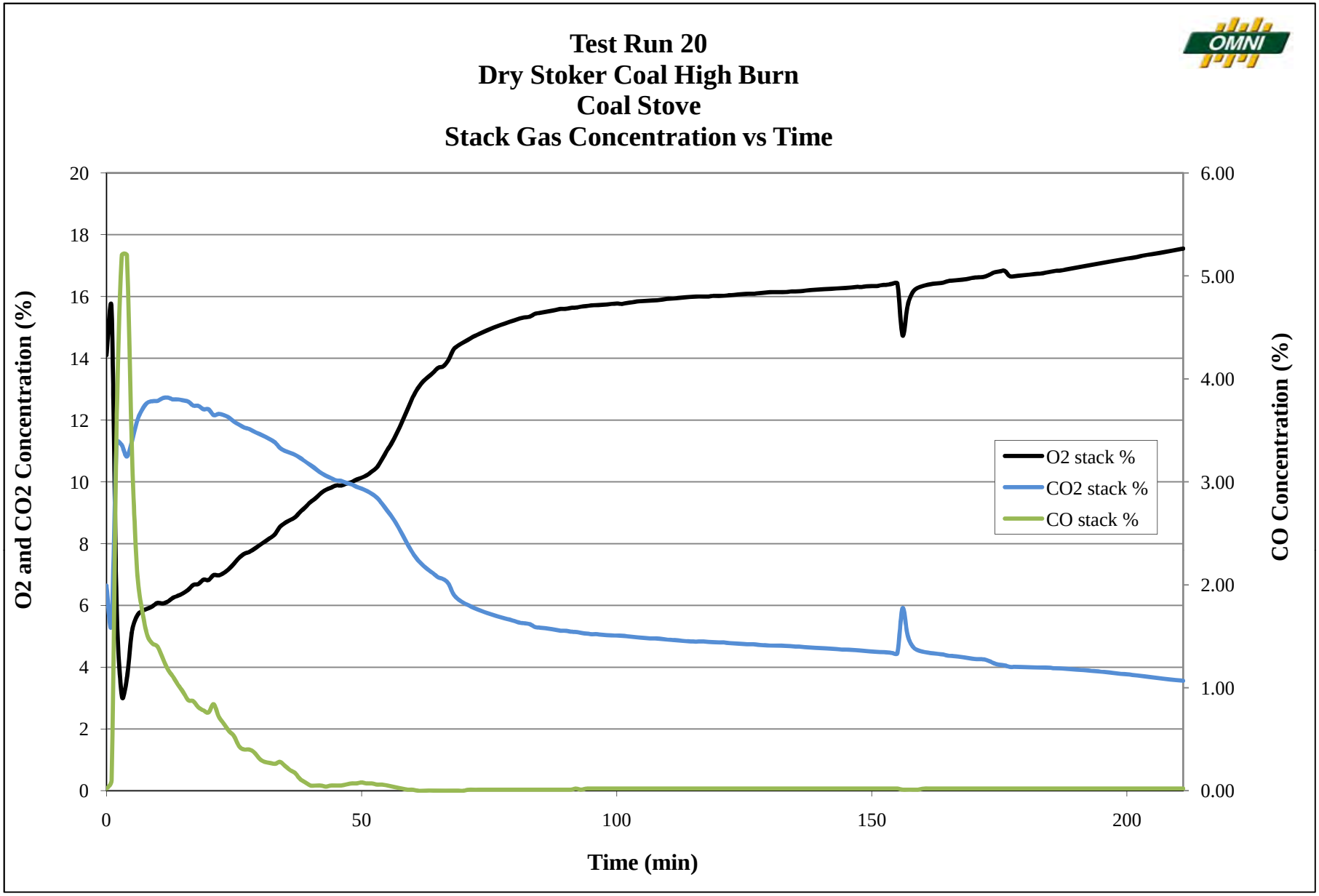

Test Run 15
Birch Low Burn
Conventional Wood Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0
5
10
15
20
25
30
35
40
45

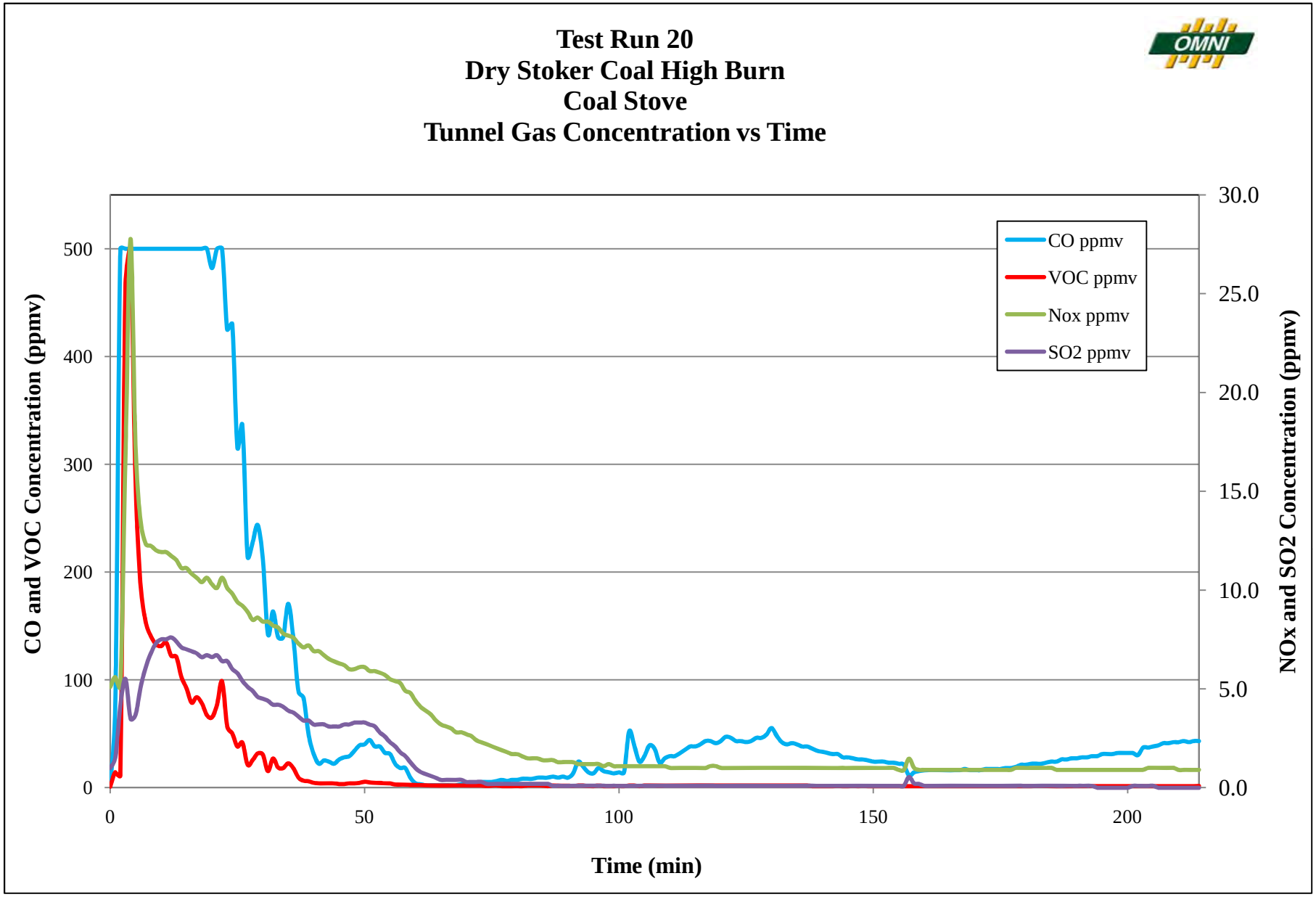

Test Run 17
Heating Oil No. 2
Oil Furnace
Stack Gas Concentration vs Time
OMNI
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
0
100
200
300
400
500
O2 stack %
CO2 stack %
CO stack %

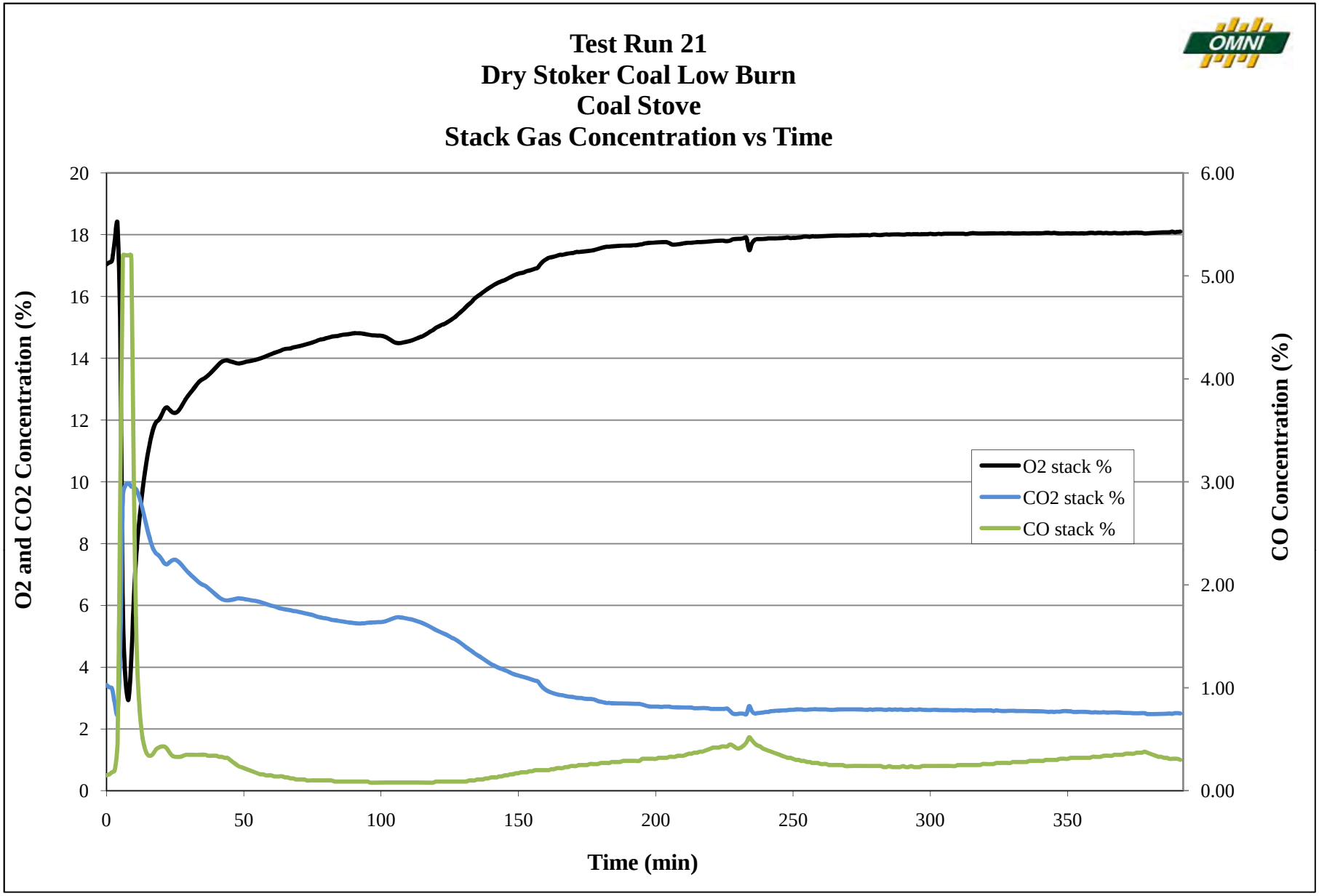

Test Run 17
Heating Oil No. 2
Oil Furnace
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
Concentration (ppmv)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
Time (min)

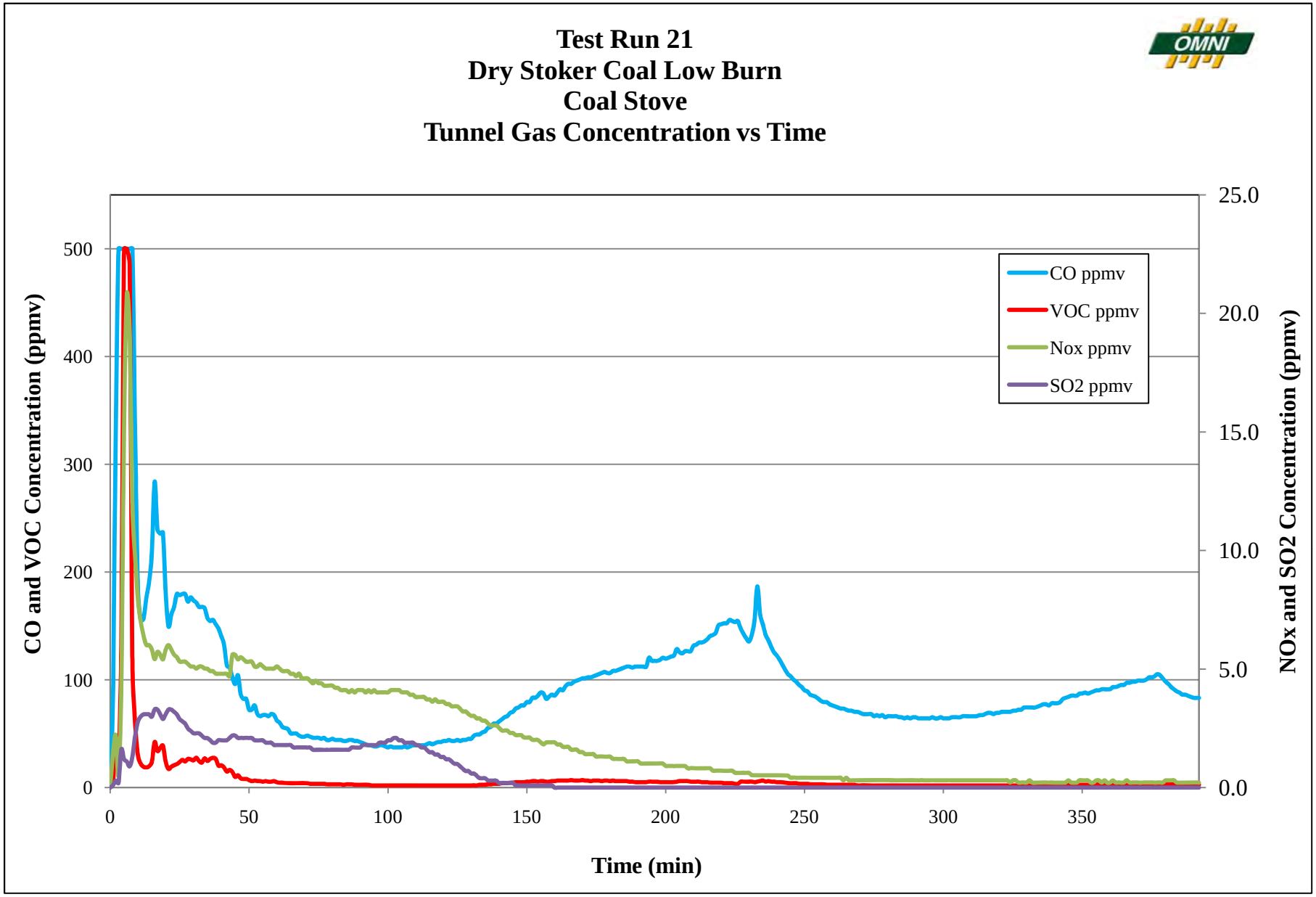

Test Run 18
Waste Lubricating Oil
Waste Oil Furnace
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
2
4
6
8
10
12
14
16
18
20
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
0
20
40
60
80
100
120
140
160

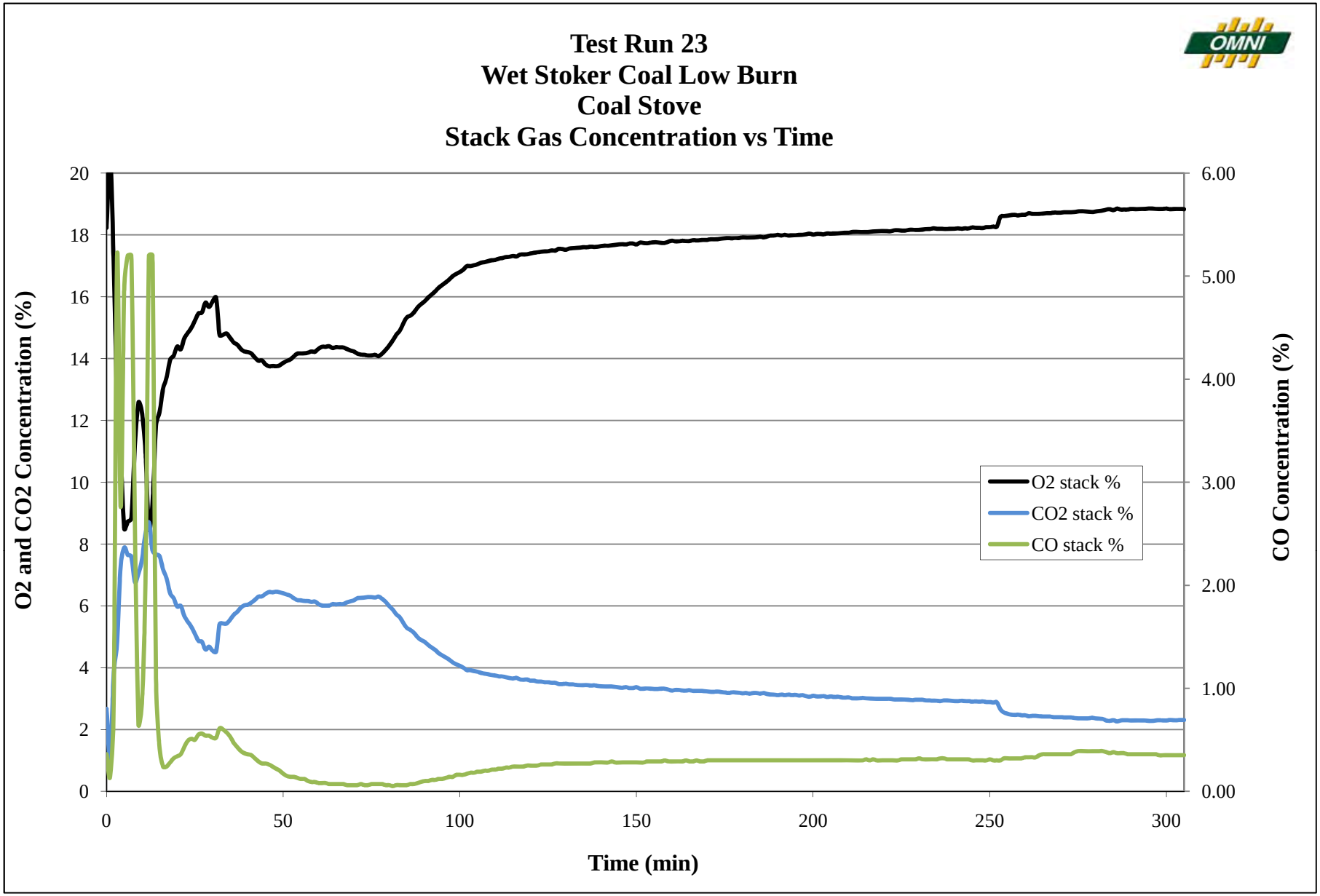

Test Run 18
Waste Lubricating Oil
Waste Oil Furnace
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
5
10
15
20
25
0.0
5.0
10.0
15.0
20.0
25.0
0
20
40
60
80
100
120
140
160

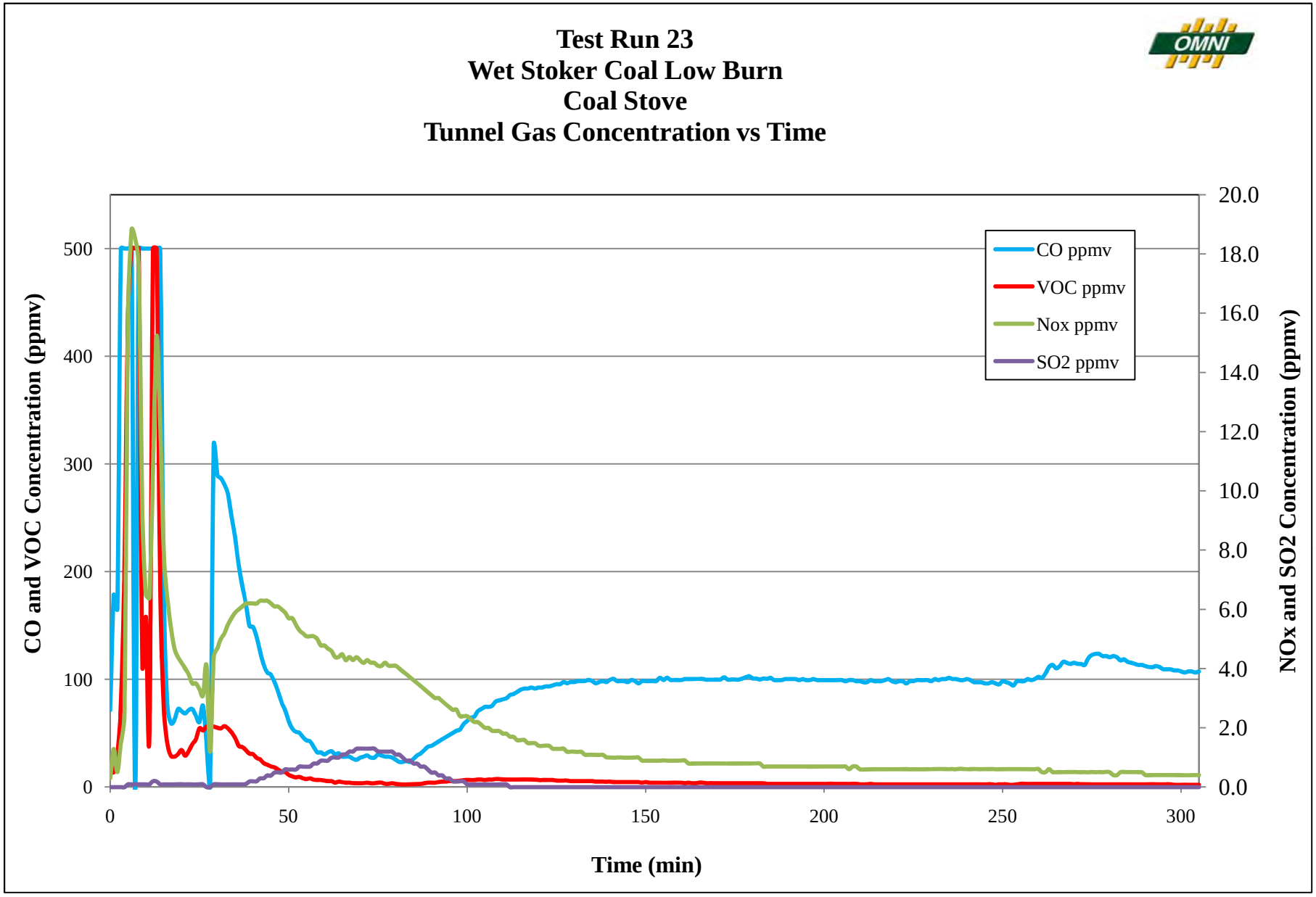

Test Run 20
Dry Stoker Coal High Burn
Coal Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200

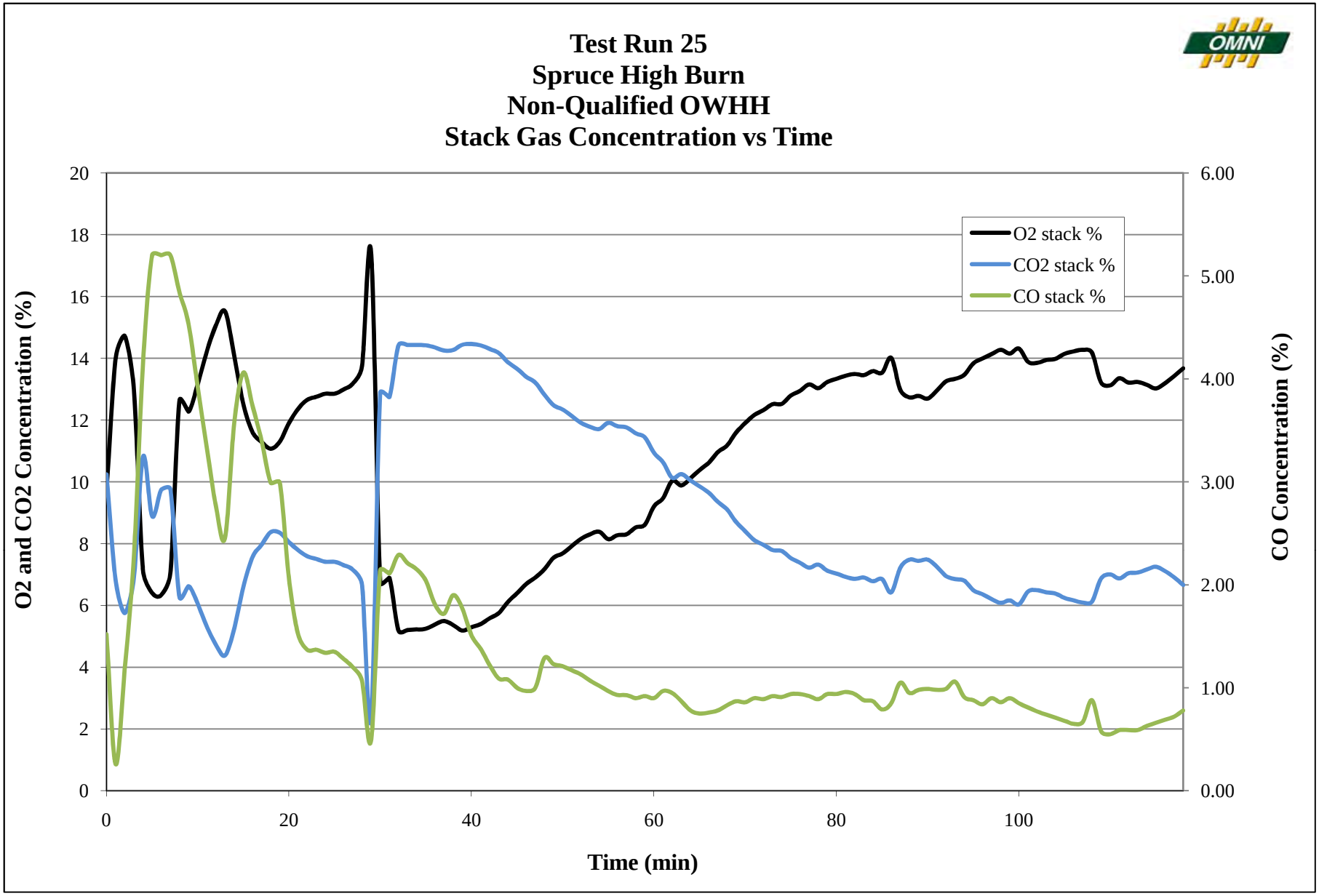

Test Run 20
Dry Stoker Coal High Burn
Coal Stove
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
5.0
10.0
15.0
20.0
25.0
30.0
0
50
100
150
200

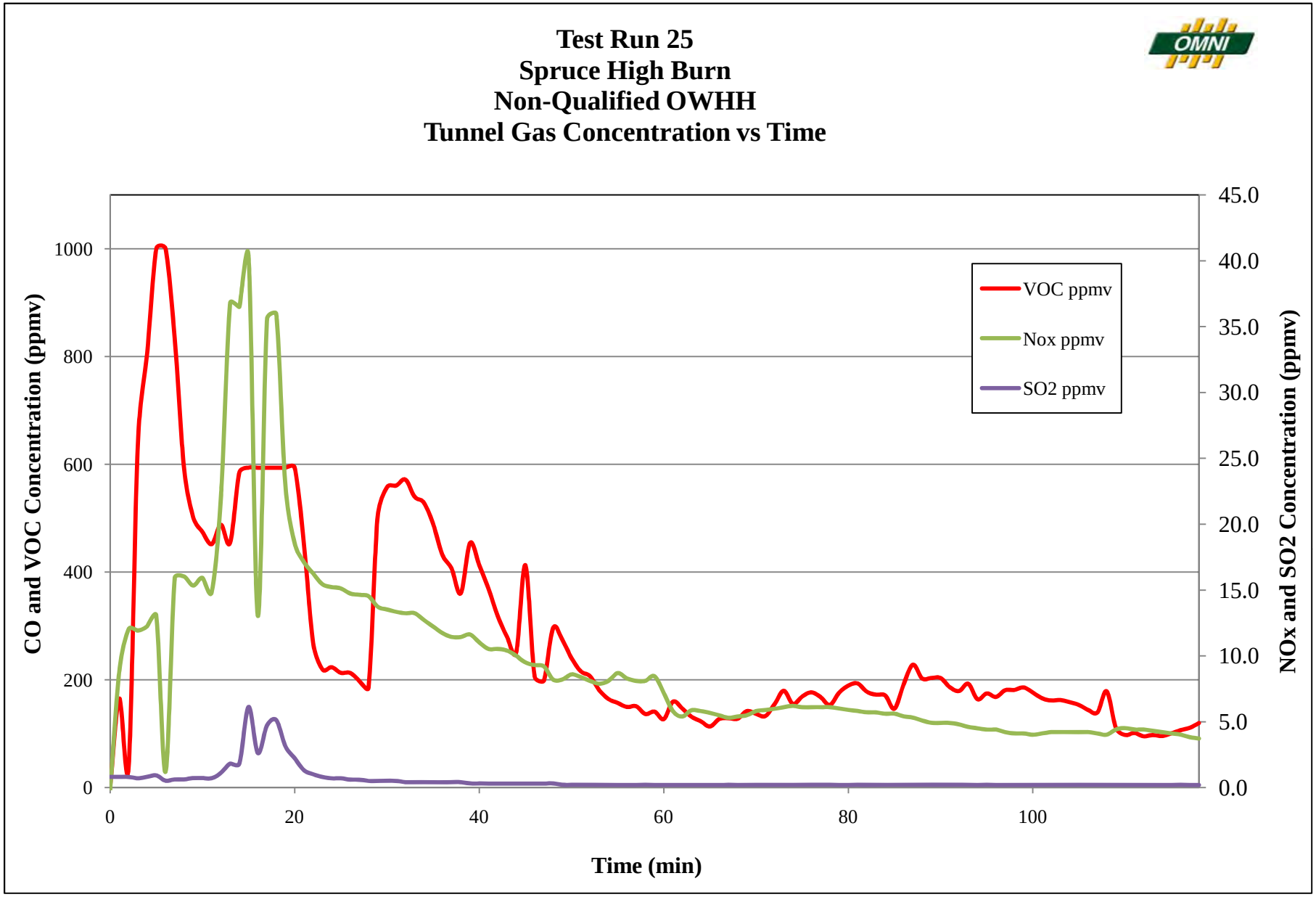

Test Run 21
Dry Stoker Coal Low Burn
Coal Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200
250
300
350

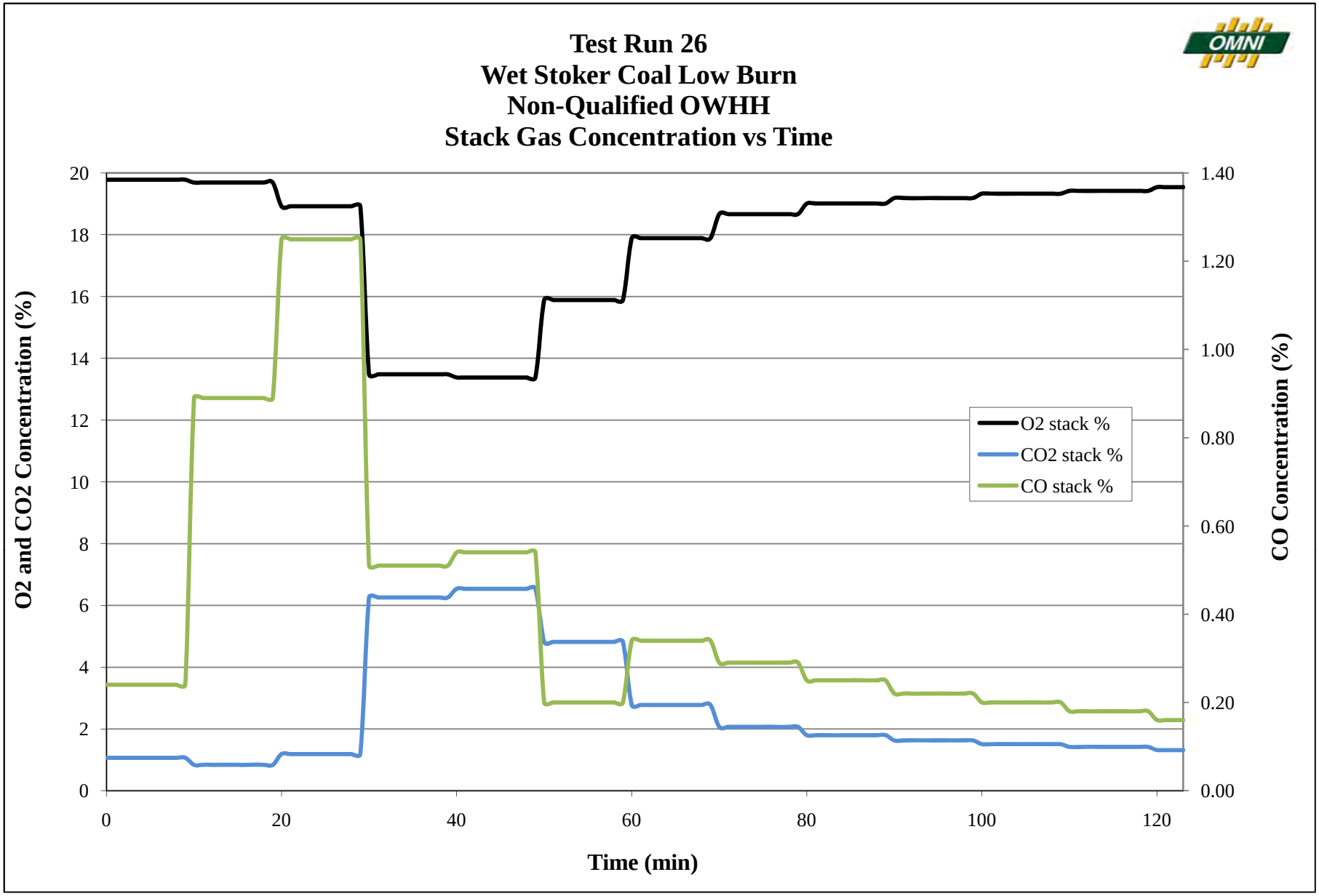

Test Run 21
Dry Stoker Coal Low Burn
Coal Stove
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
5.0
10.0
15.0
20.0
25.0
0
50
100
150
200
250
300
350

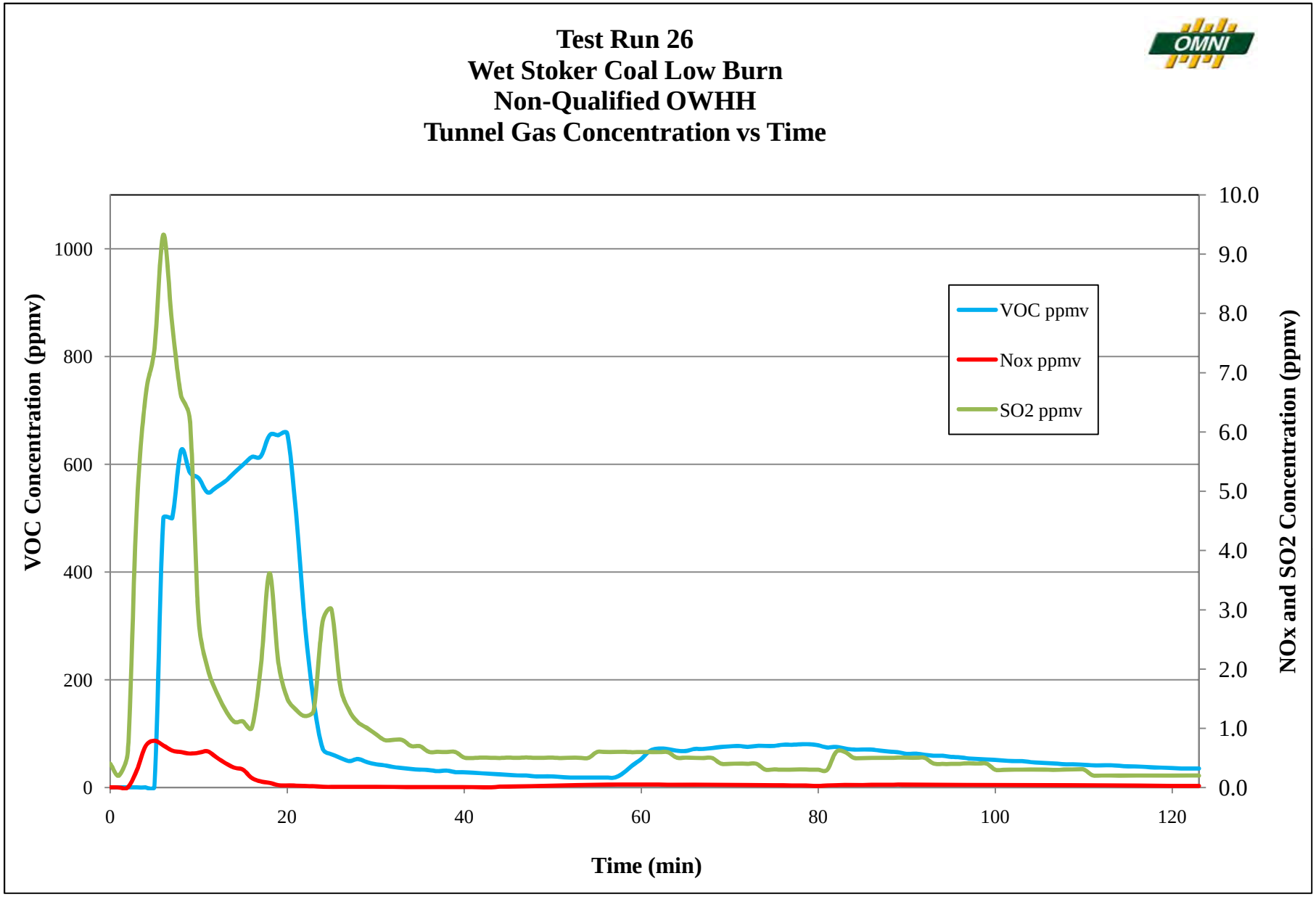

Test Run 23
Wet Stoker Coal Low Burn
Coal Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200
250
300


Test Run 23
Wet Stoker Coal Low Burn
Coal Stove
Tunnel Gas Concentration vs Time
OMNI
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
0
50
100
150
200
250
300

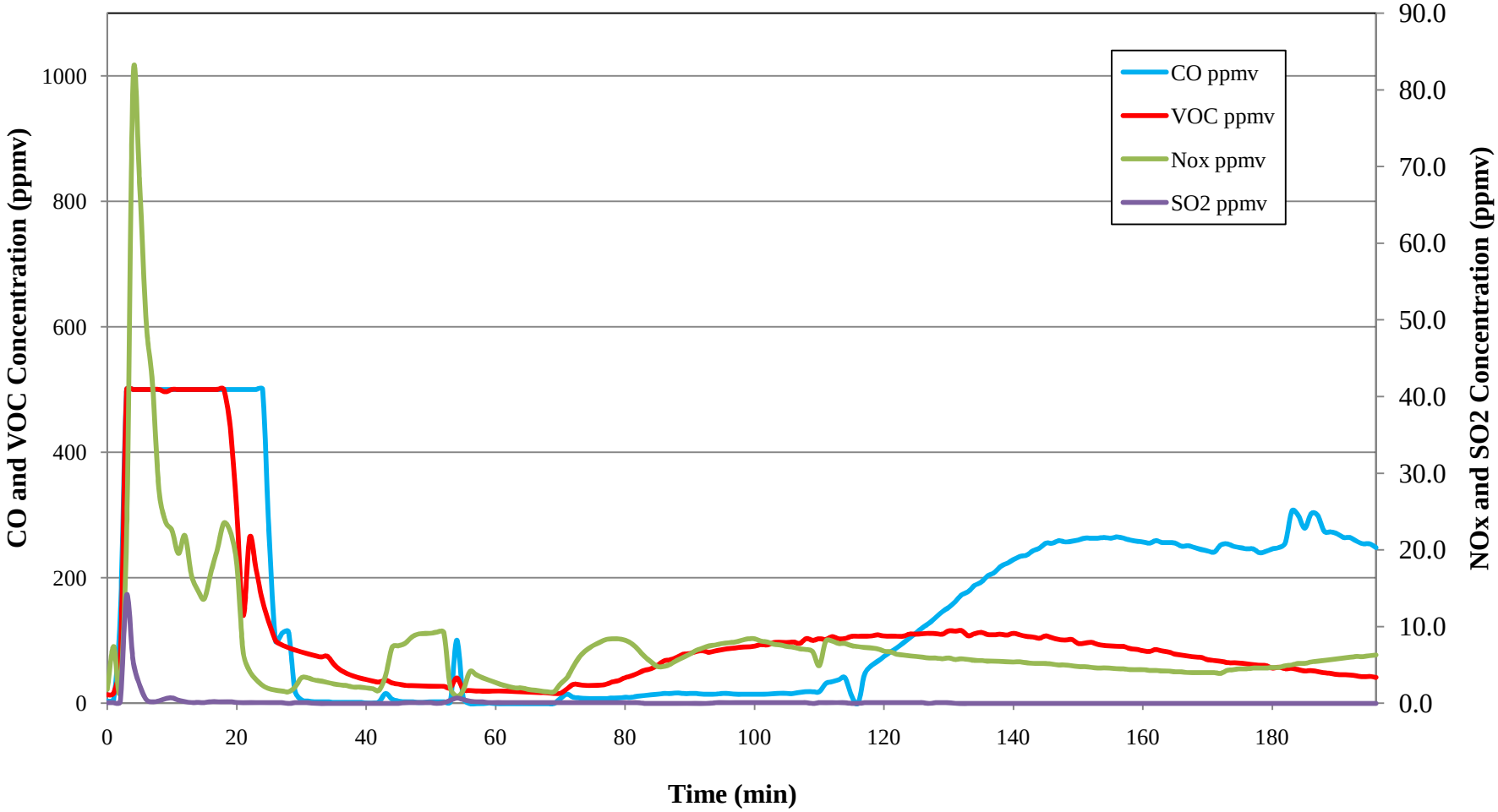

Test Run 25
Spruce High Burn
Non-Qualified OWHH
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
20
40
60
80
100

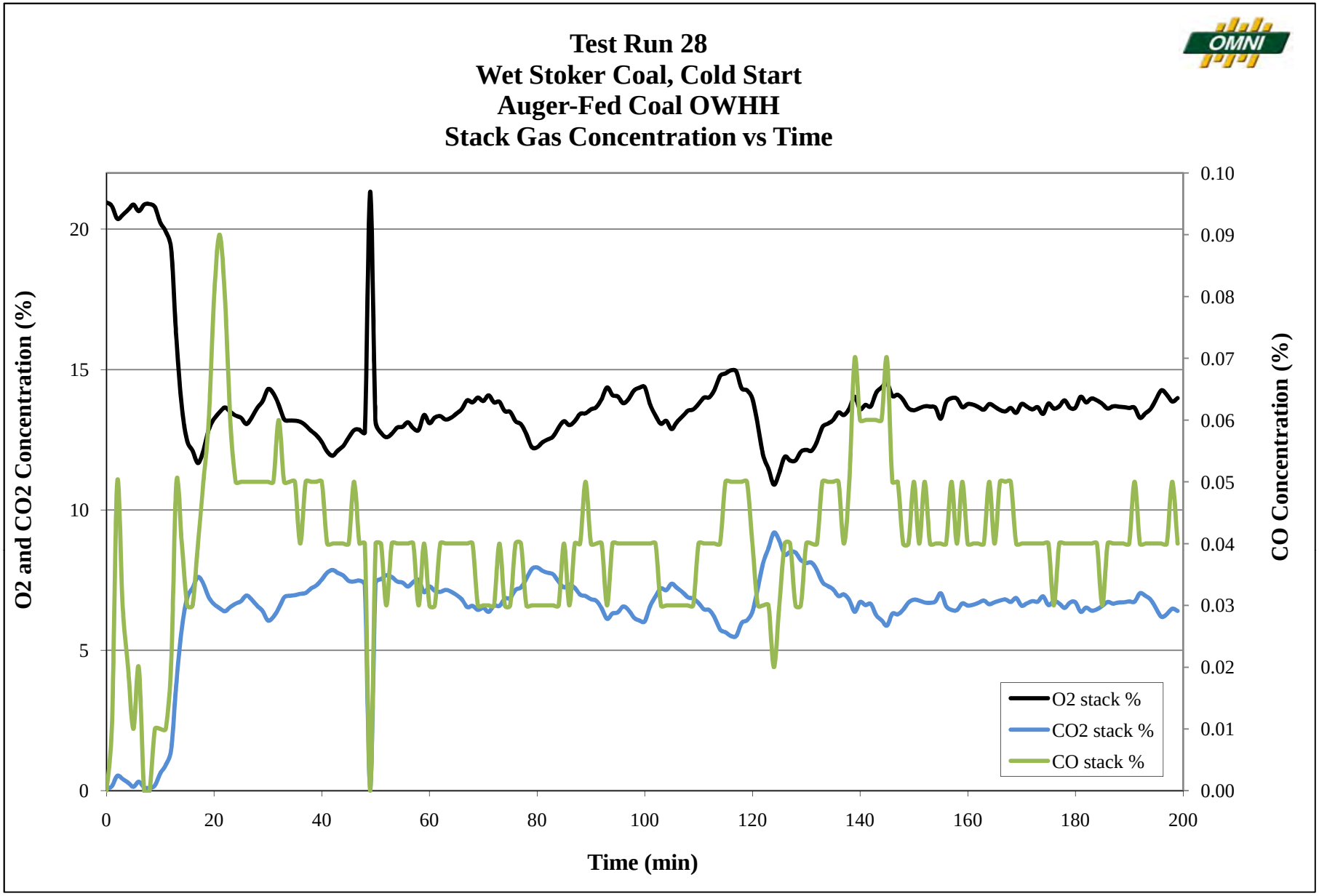

Test Run 25
Spruce High Burn
Non-Qualified OWHH
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
VOC ppmv
Nox ppmv
SO2 ppmv
0
200
400
600
800
1000
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
0
20
40
60
80
100

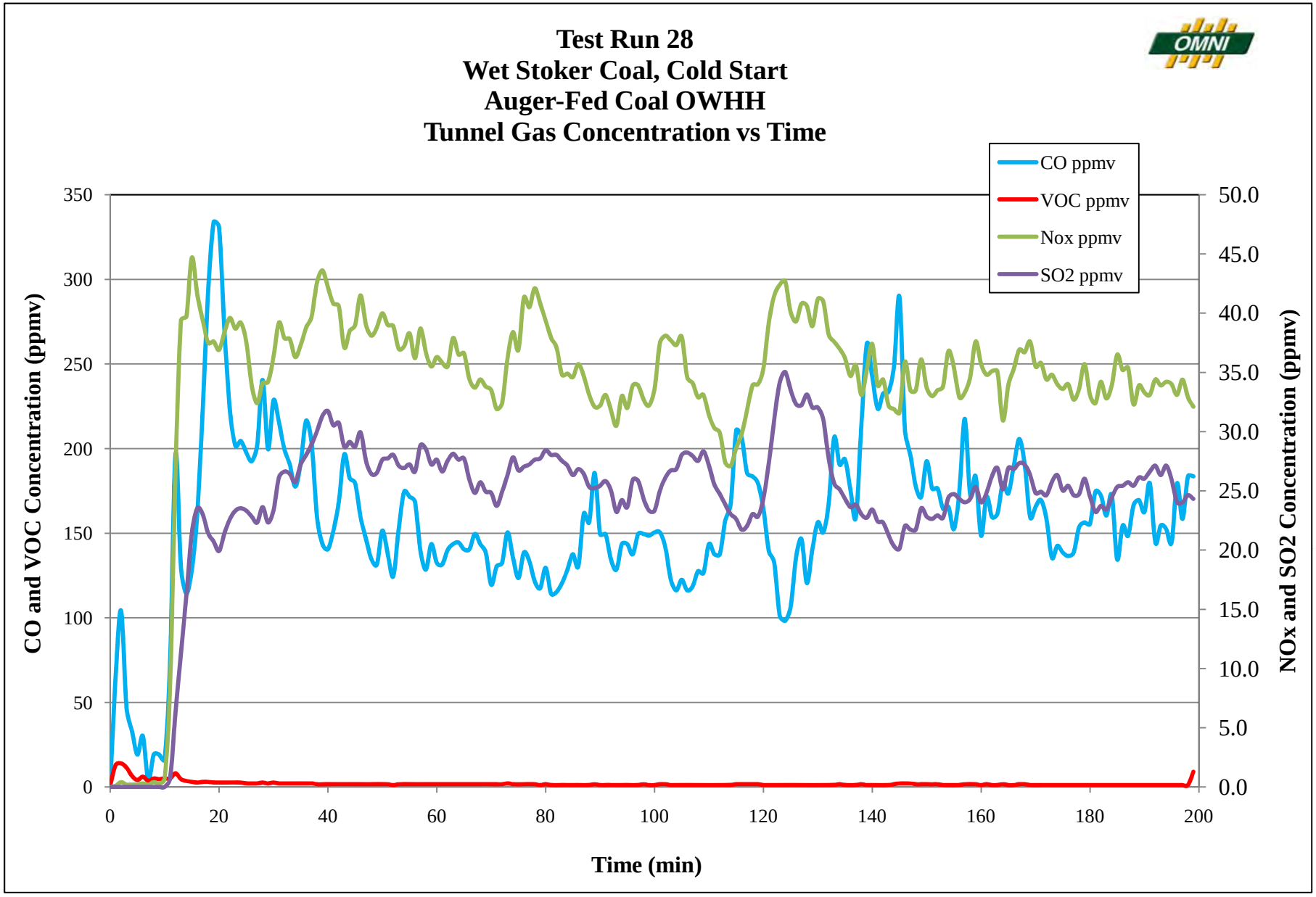

Test Run 26
Wet Stoker Coal Low Burn
Non-Qualified OWHH
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
0
20
40
60
80
100
120

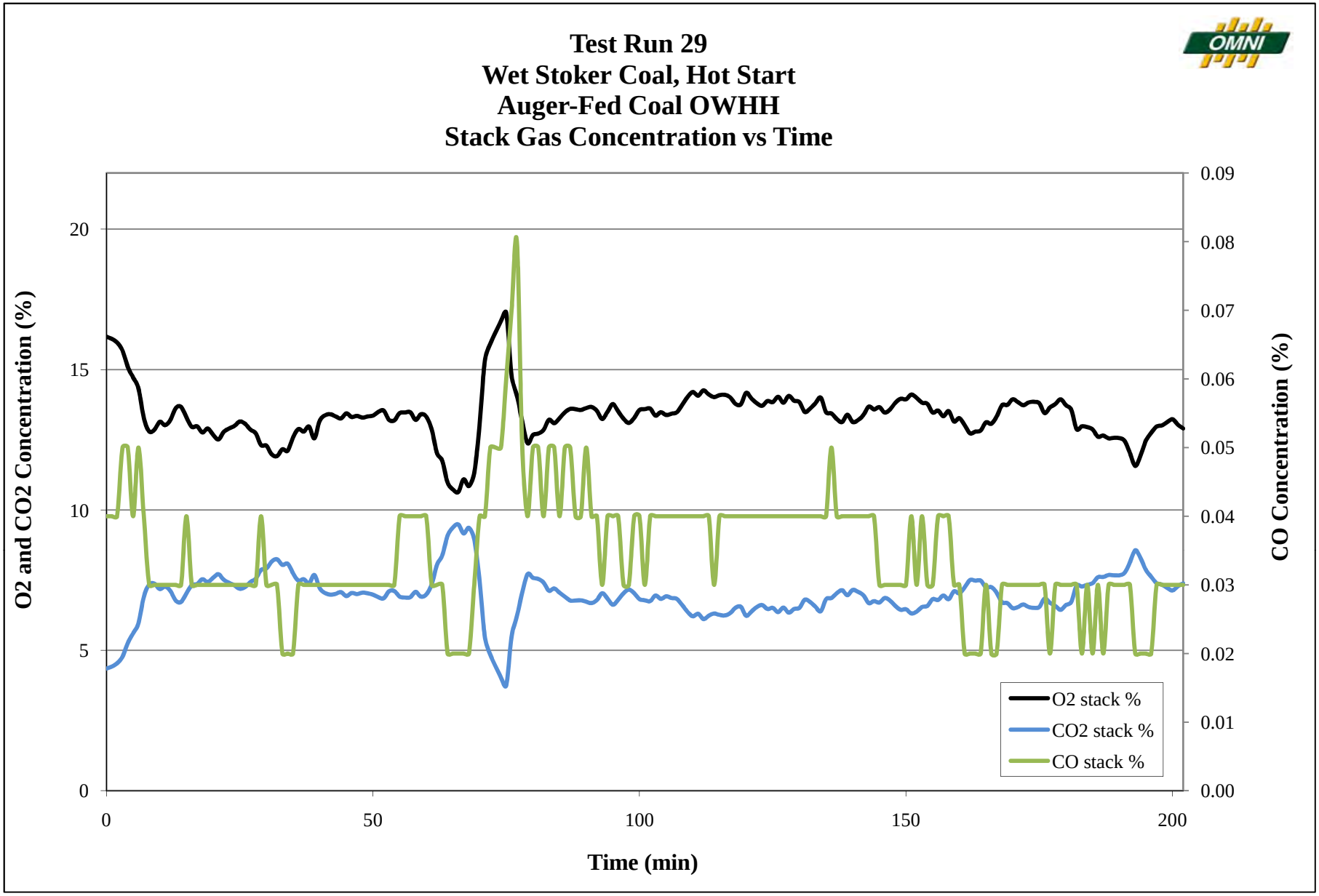

Test Run 26
Wet Stoker Coal Low Burn
Non-Qualified OWHH
Tunnel Gas Concentration vs Time
OMNI
VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
VOC ppmv
Nox ppmv
SO2 ppmv
0
200
400
600
800
1000
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0
20
40
60
80
100
120

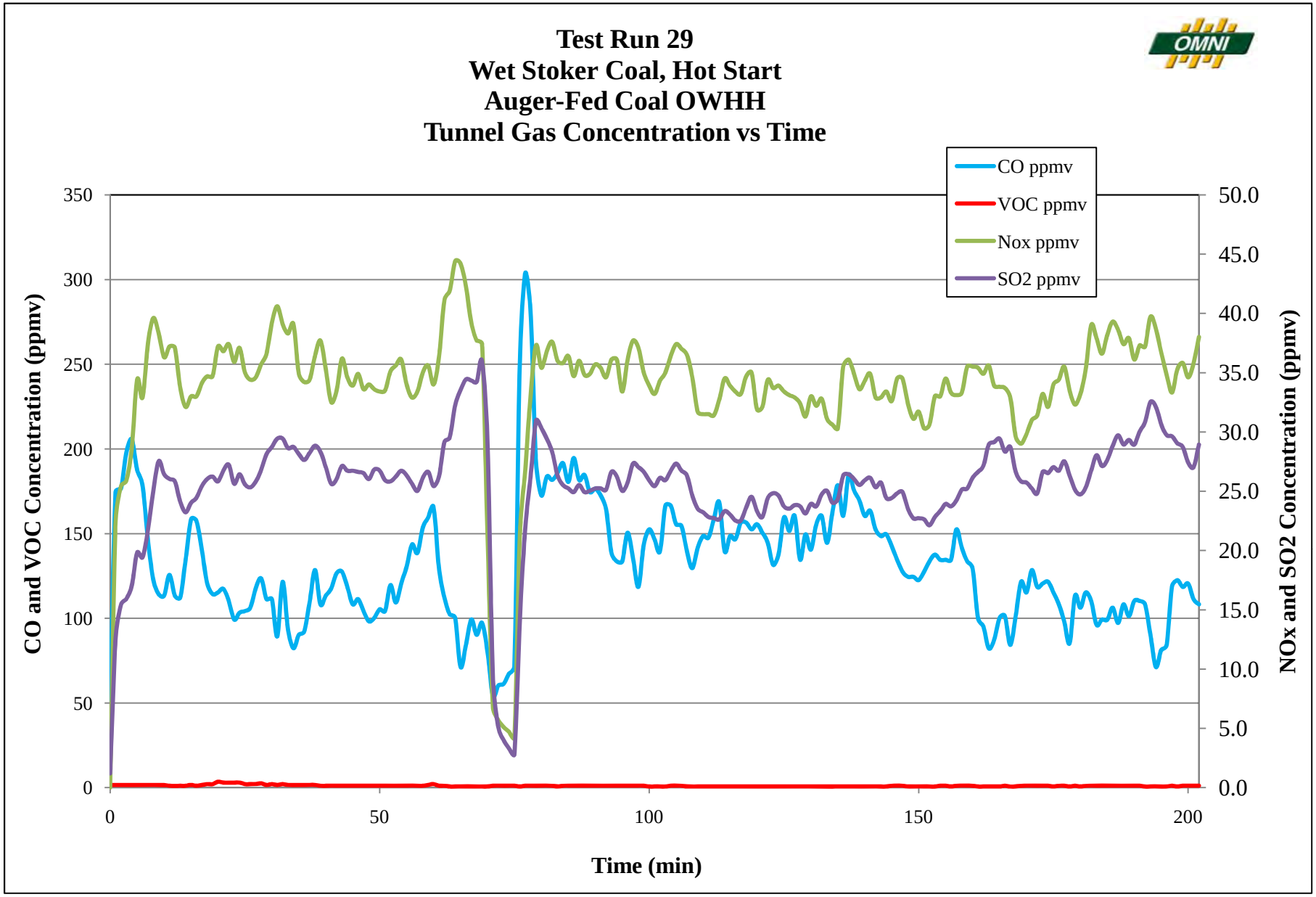
Test Run 27
Wet Stoker Coal, Low Burn, Cold Start
Non-Qualified OWHH with Retrofit Catalyst
Tunnel Gas Concentration vs Time

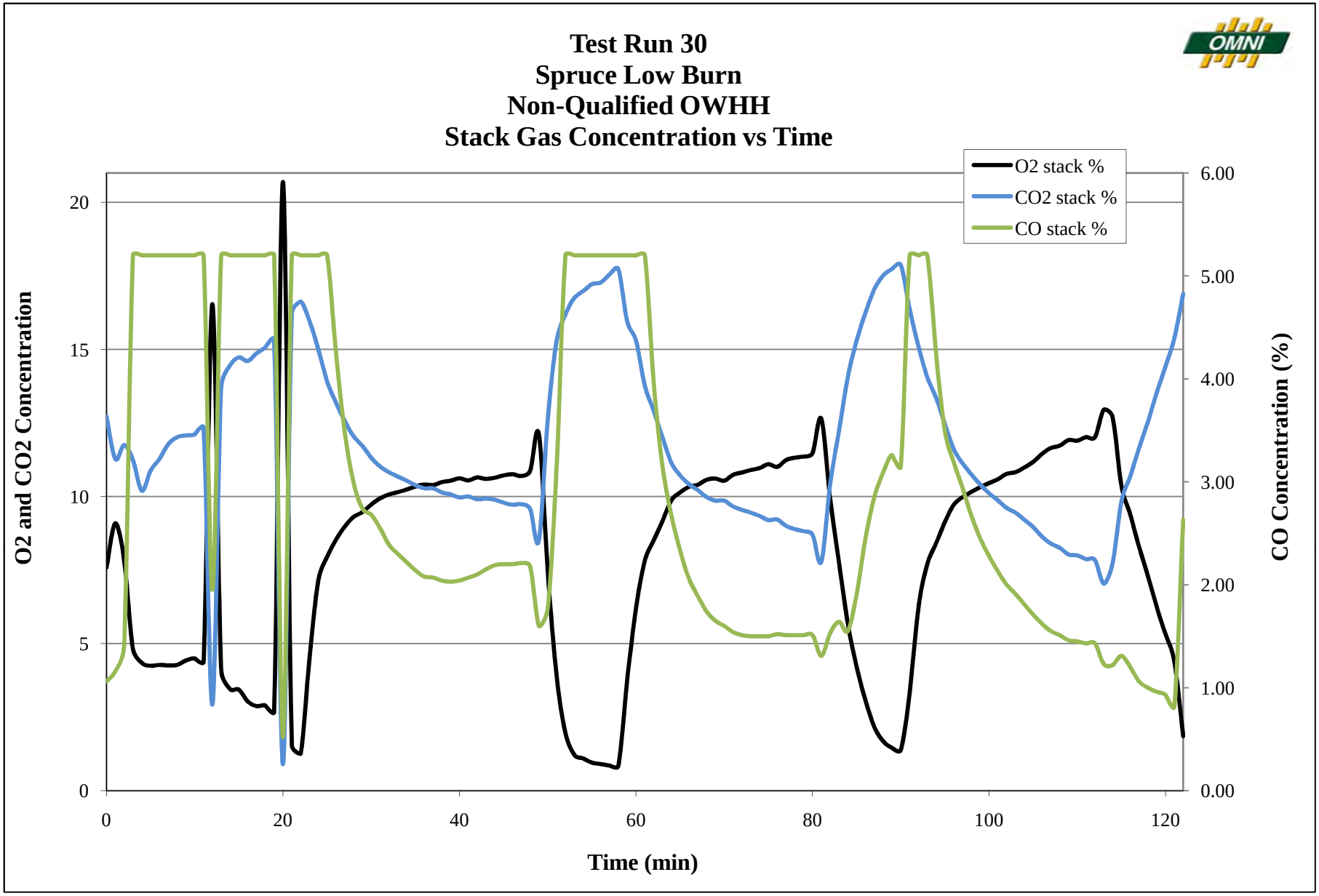


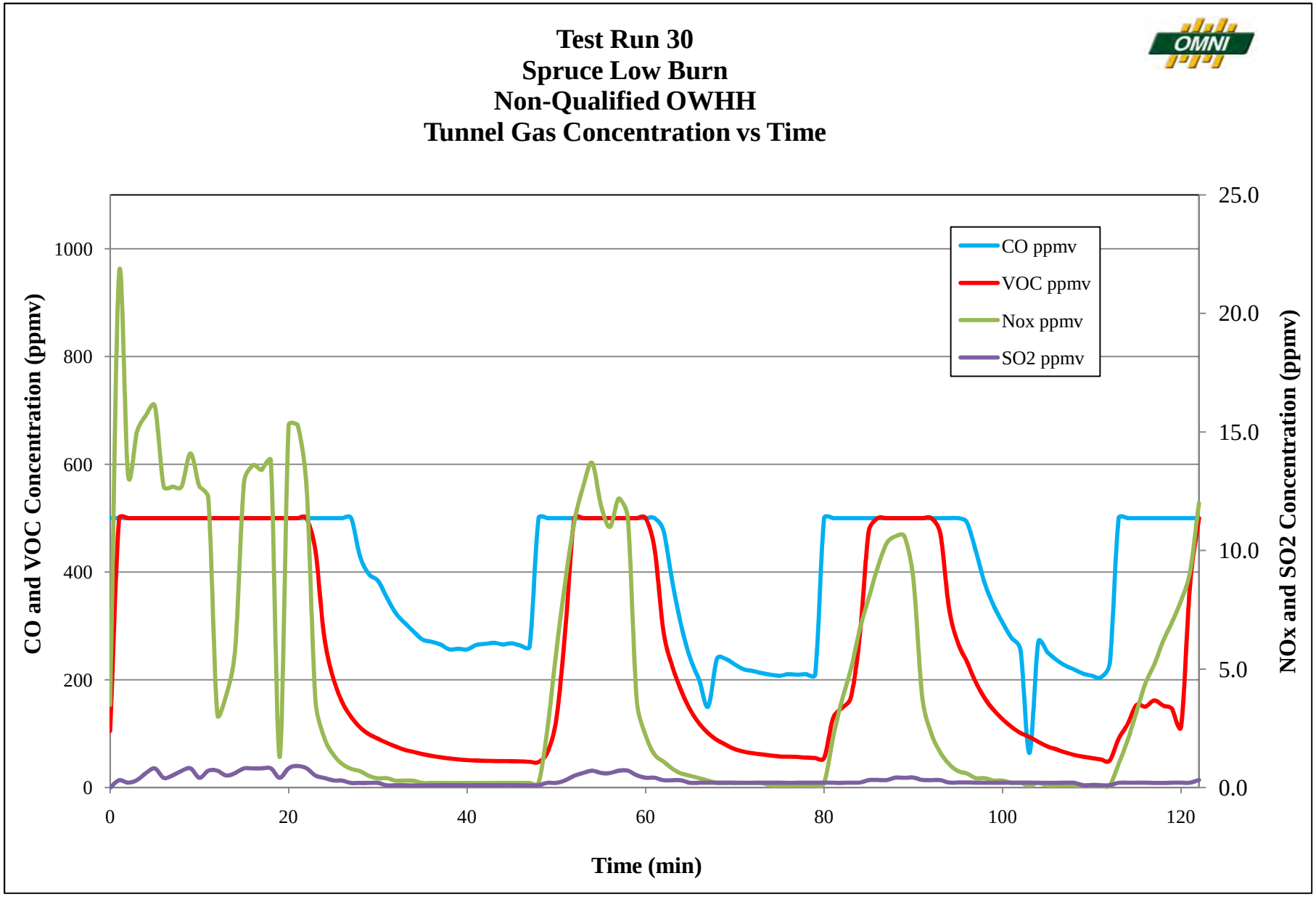

Test Run 28
Wet Stoker Coal, Cold Start
Auger-Fed Coal OWHH
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0
20
40
60
80
100
120
140
160
180
200
O2 stack %
CO2 stack %
CO stack %

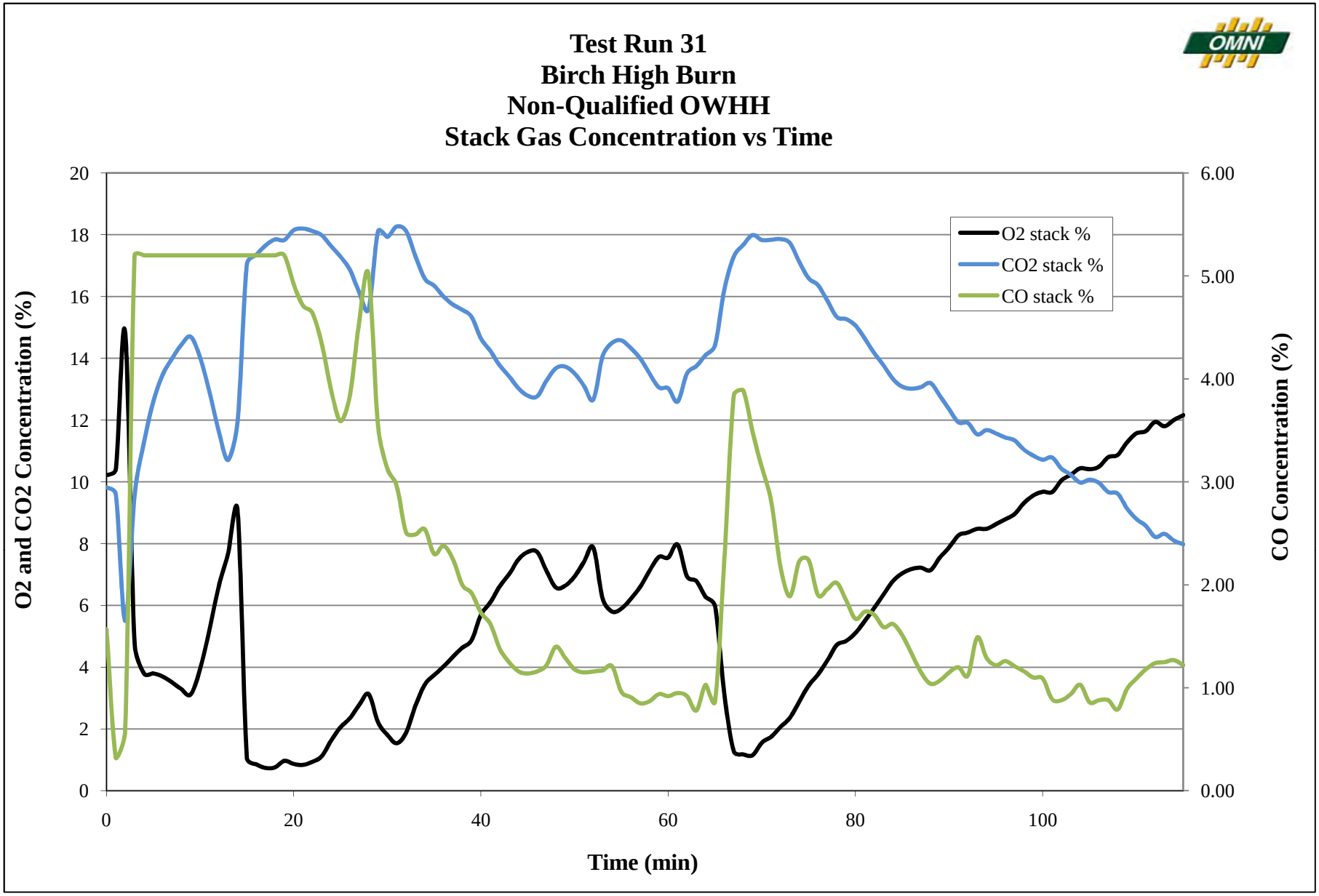

Test Run 28
Wet Stoker Coal, Cold Start
Auger-Fed Coal OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
20
40
60
80
100
120
140
160
180
200
0
50
100
150
200
250
300
350
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0

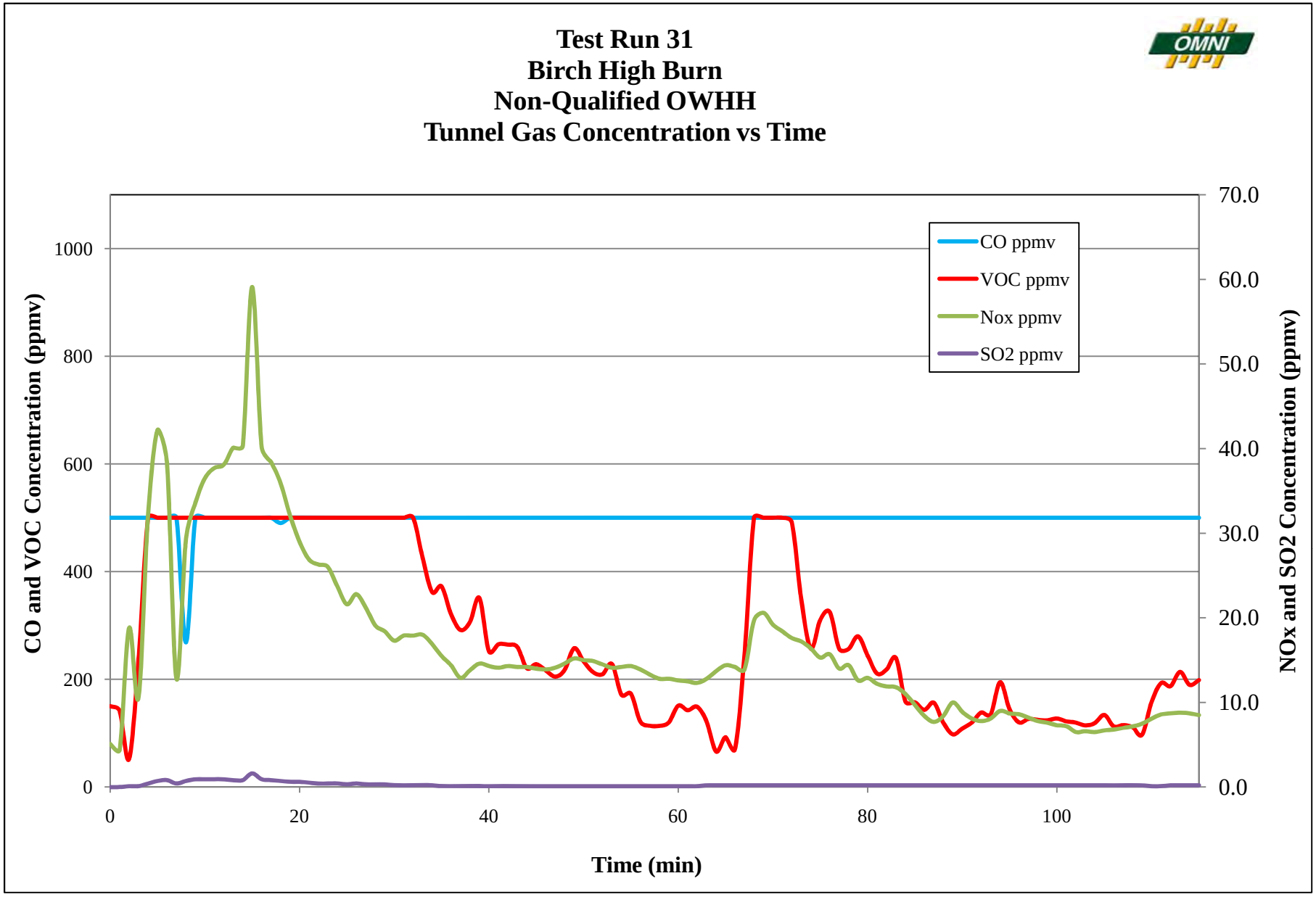

Test Run 29
Wet Stoker Coal, Hot Start
Auger-Fed Coal OWHH
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0
50
100
150
200
O2 stack %
CO2 stack %
CO stack %

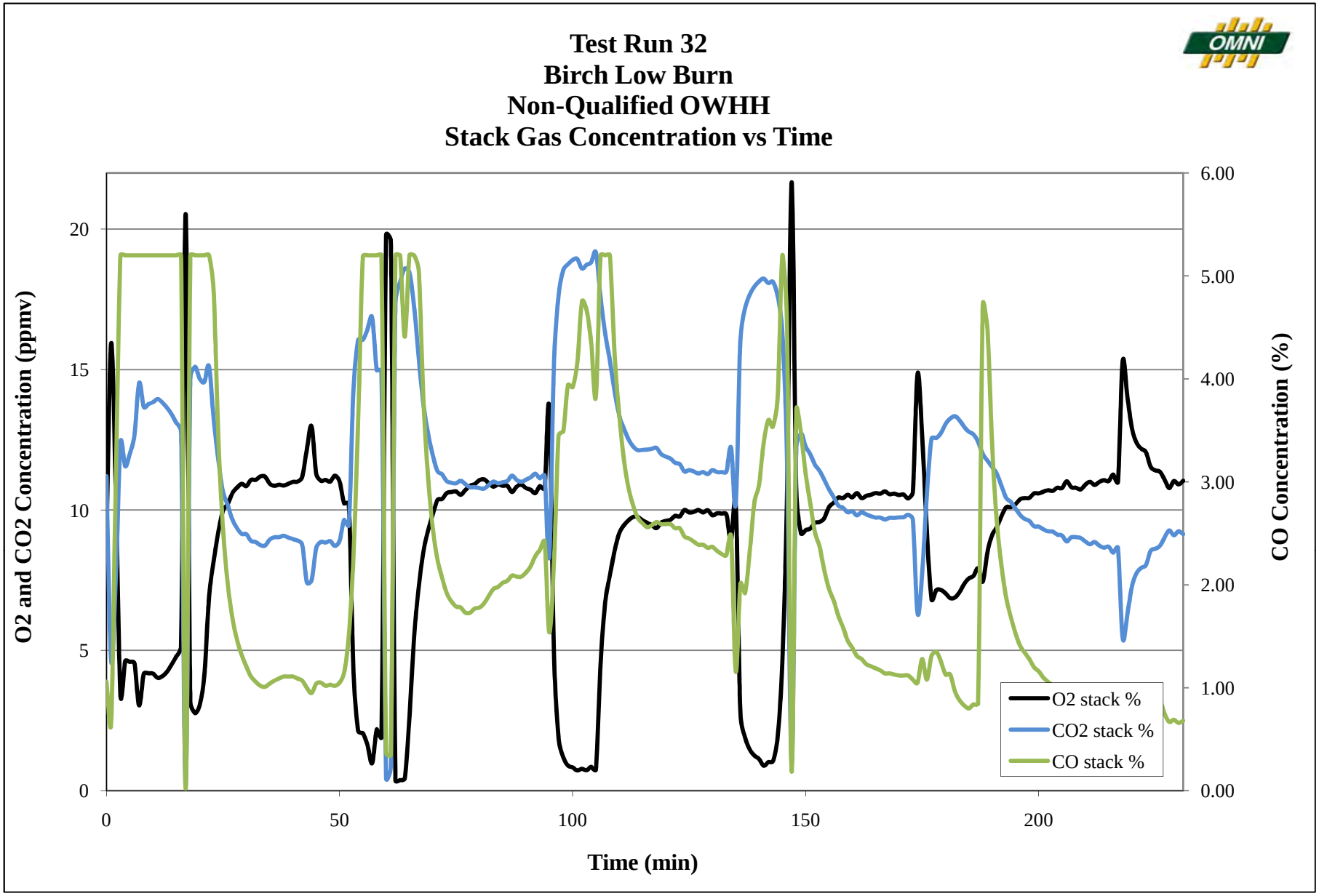

Test Run 29
Wet Stoker Coal, Hot Start
Auger-Fed Coal OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
50
100
150
200
250
300
350
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0

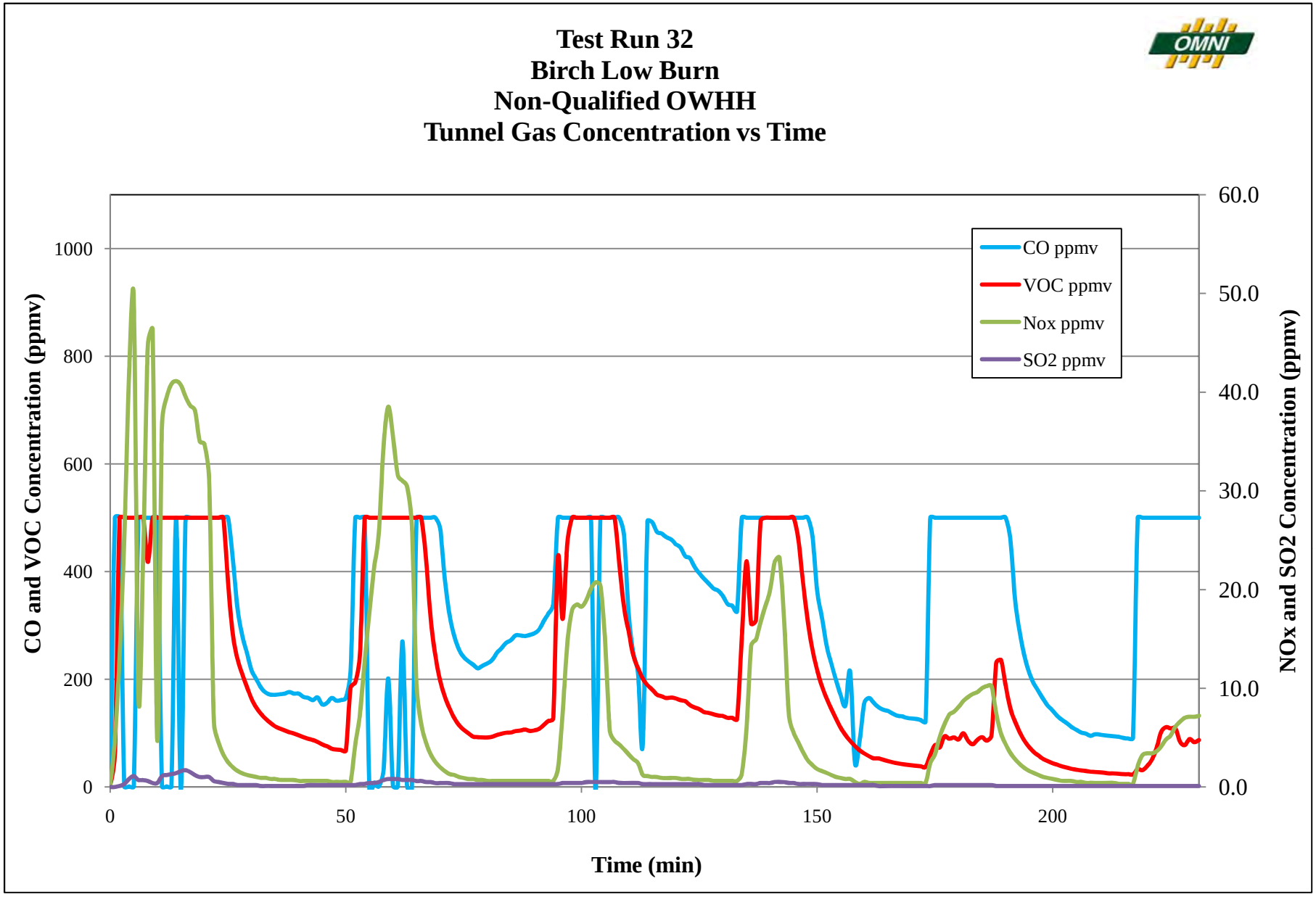

Test Run 30
Spruce Low Burn
Non-Qualified OWHH
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
20
40
60
80
100
120

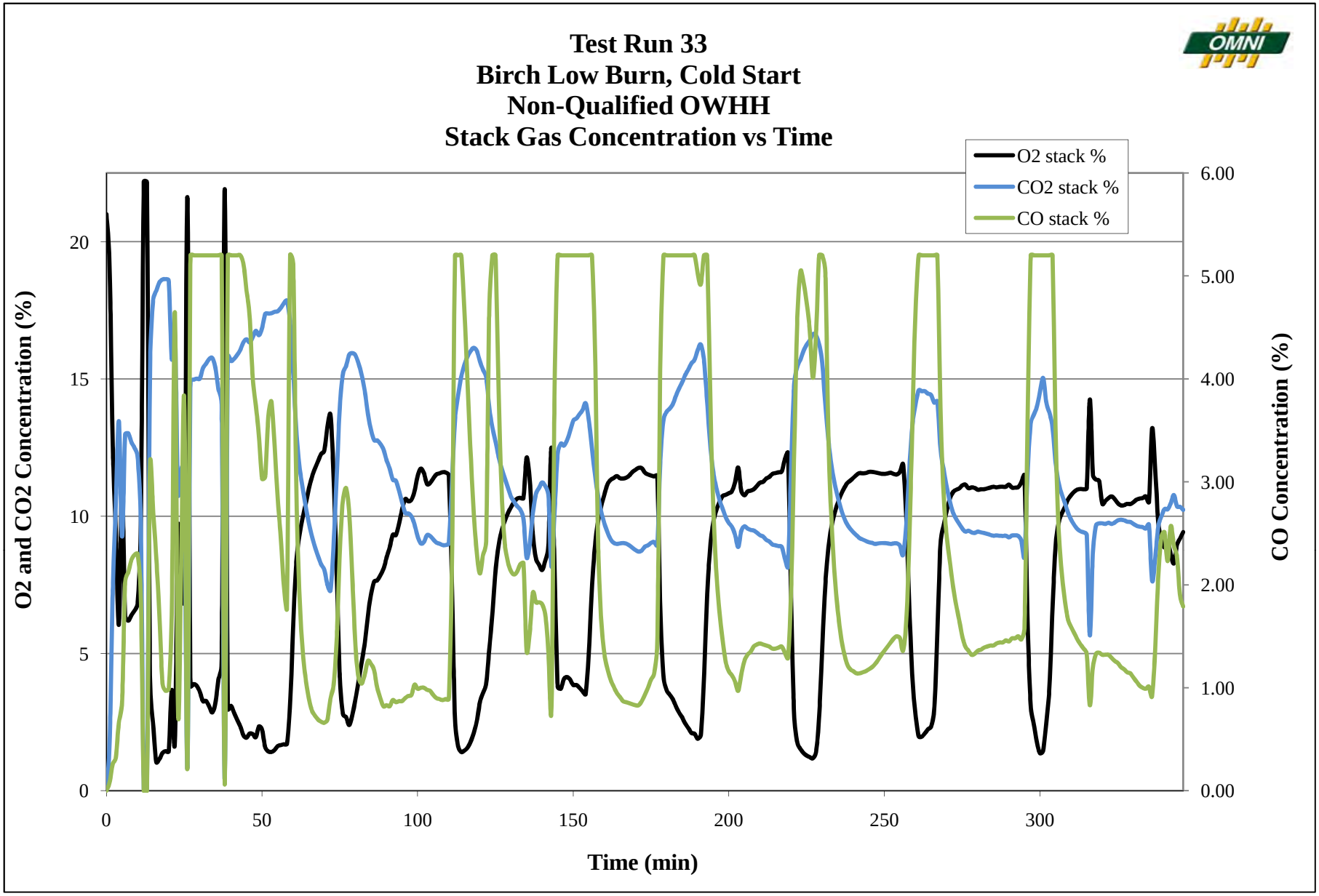

Test Run 30
Spruce Low Burn
Non-Qualified OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
200
400
600
800
1000
0.0
5.0
10.0
15.0
20.0
25.0
0
20
40
60
80
100
120

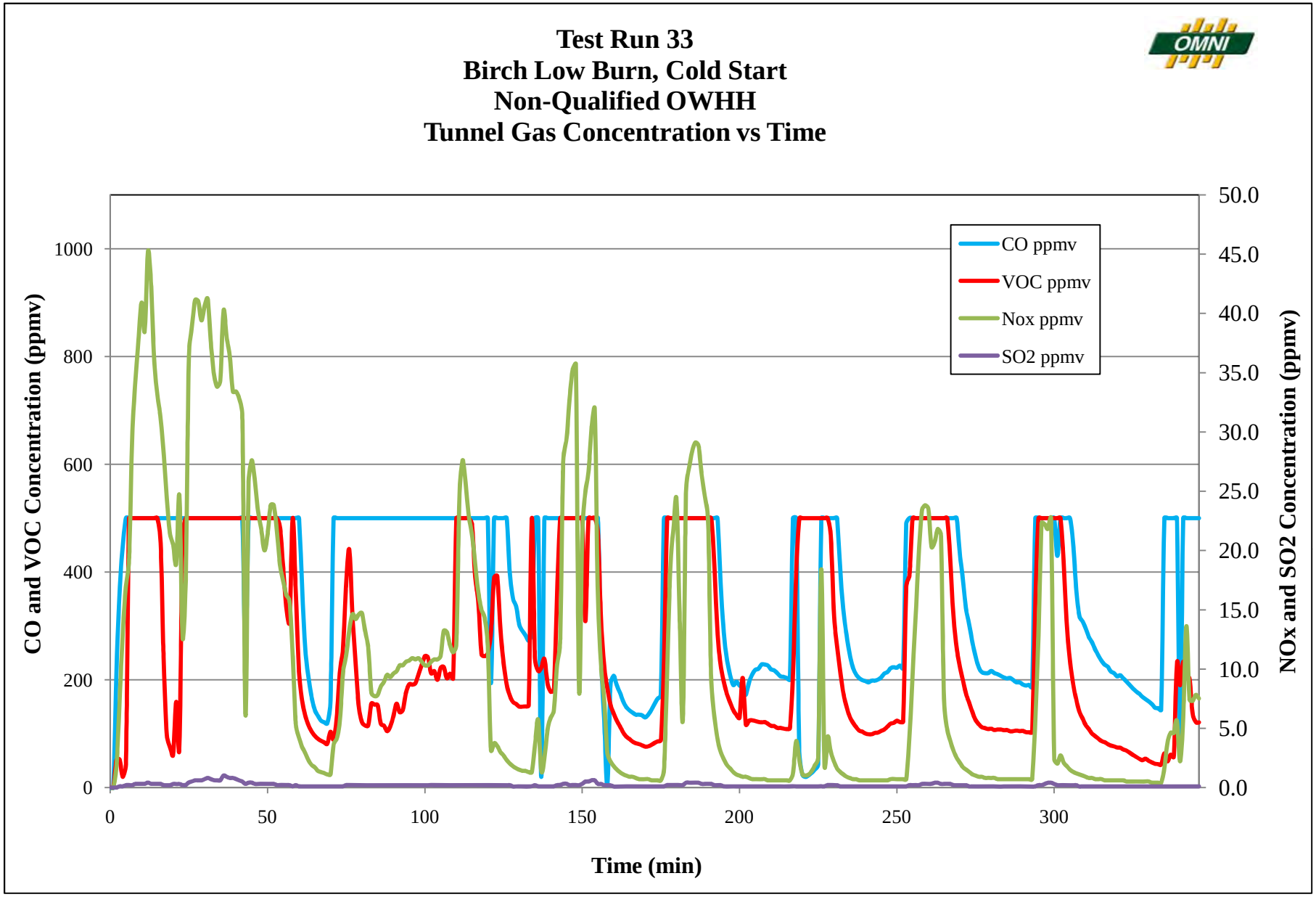

Test Run 31
Birch High Burn
Non-Qualified OWHH
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
20
40
60
80
100

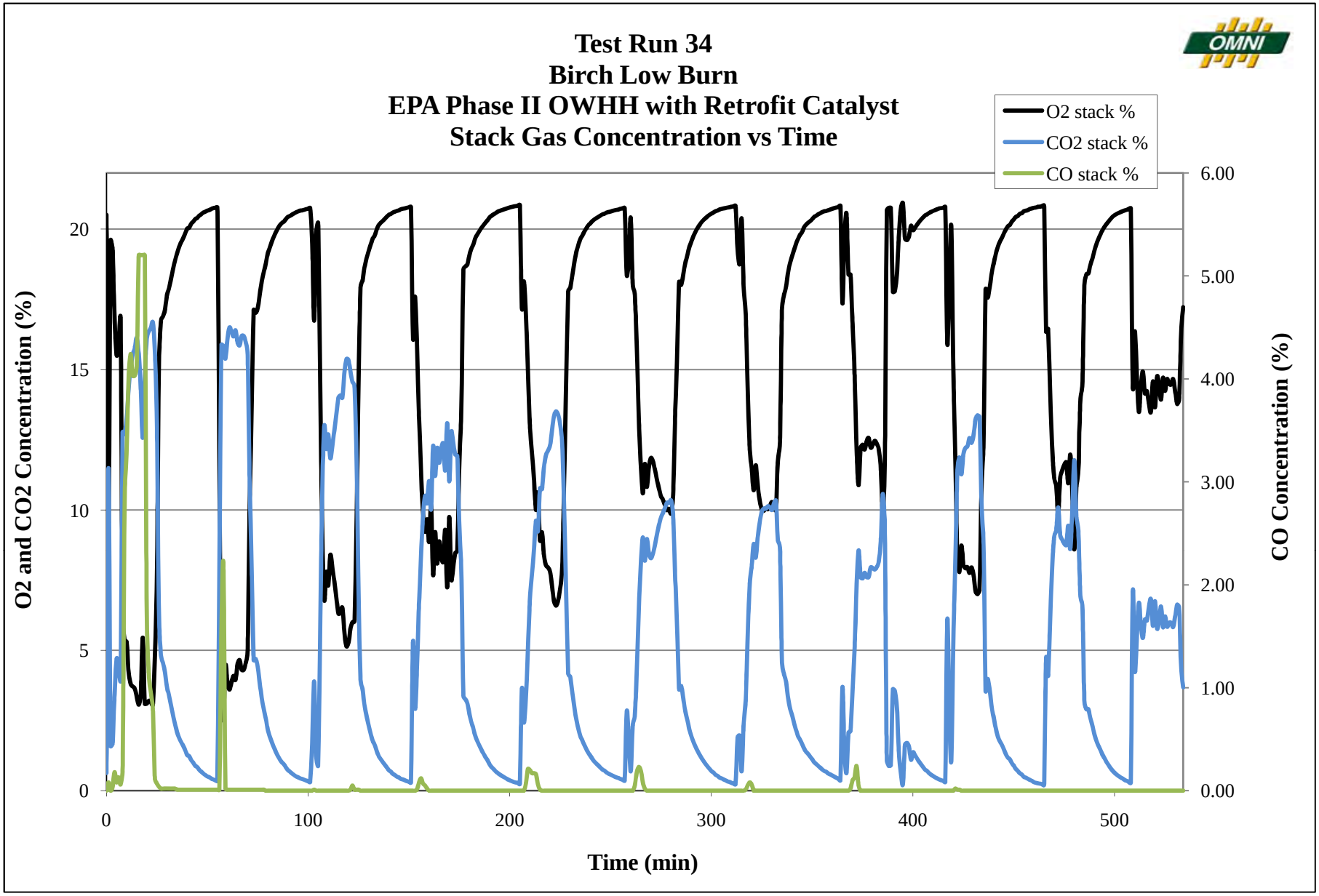

Test Run 31
Birch High Burn
Non-Qualified OWHH
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
200
400
600
800
1000
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
0
20
40
60
80
100

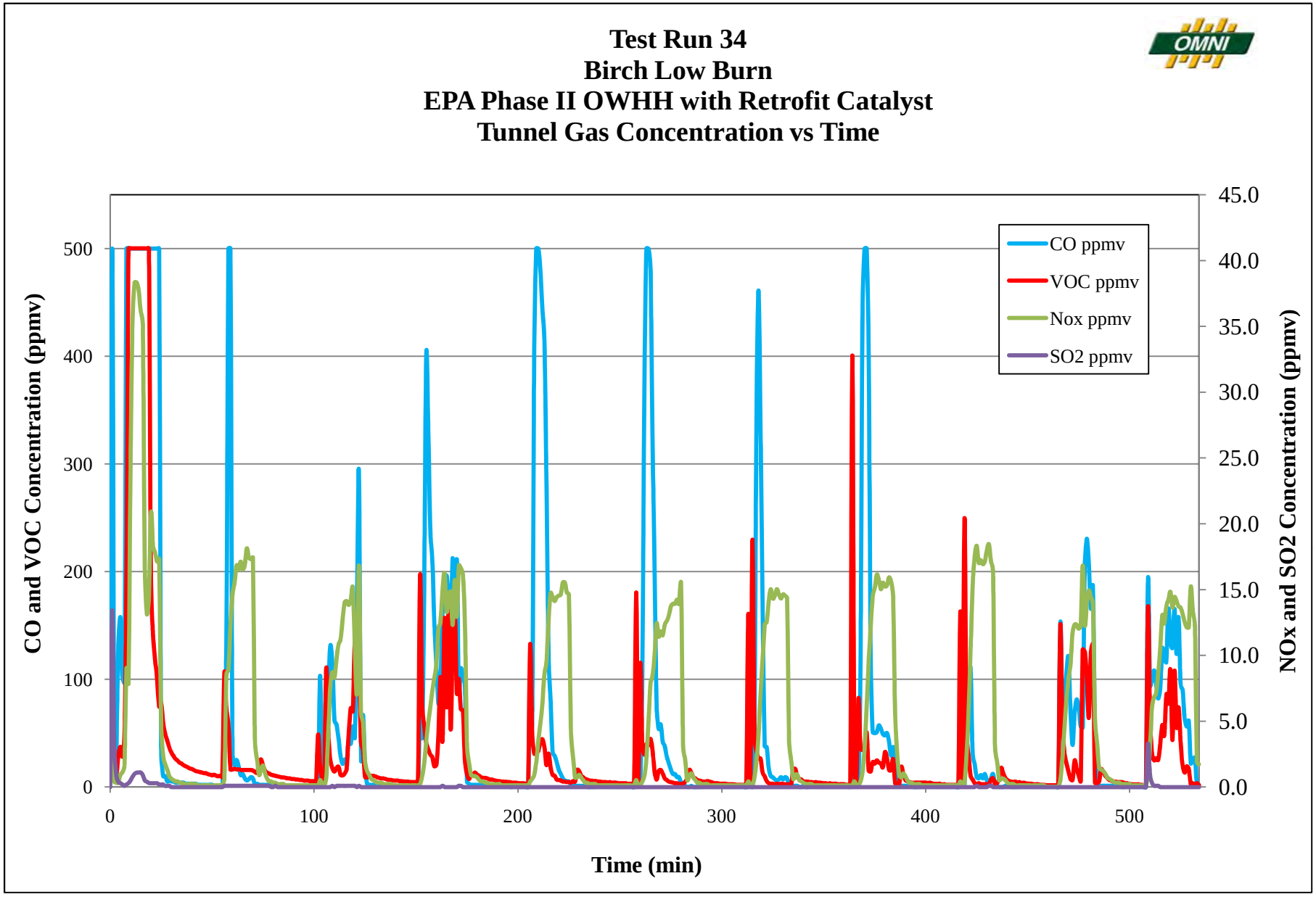

Test Run 32
Birch Low Burn
Non-Qualified OWHH
Stack Gas Concentration vs Time
O2 and CO2 Concentration (ppmv)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200
O2 stack %
CO2 stack %
CO stack %

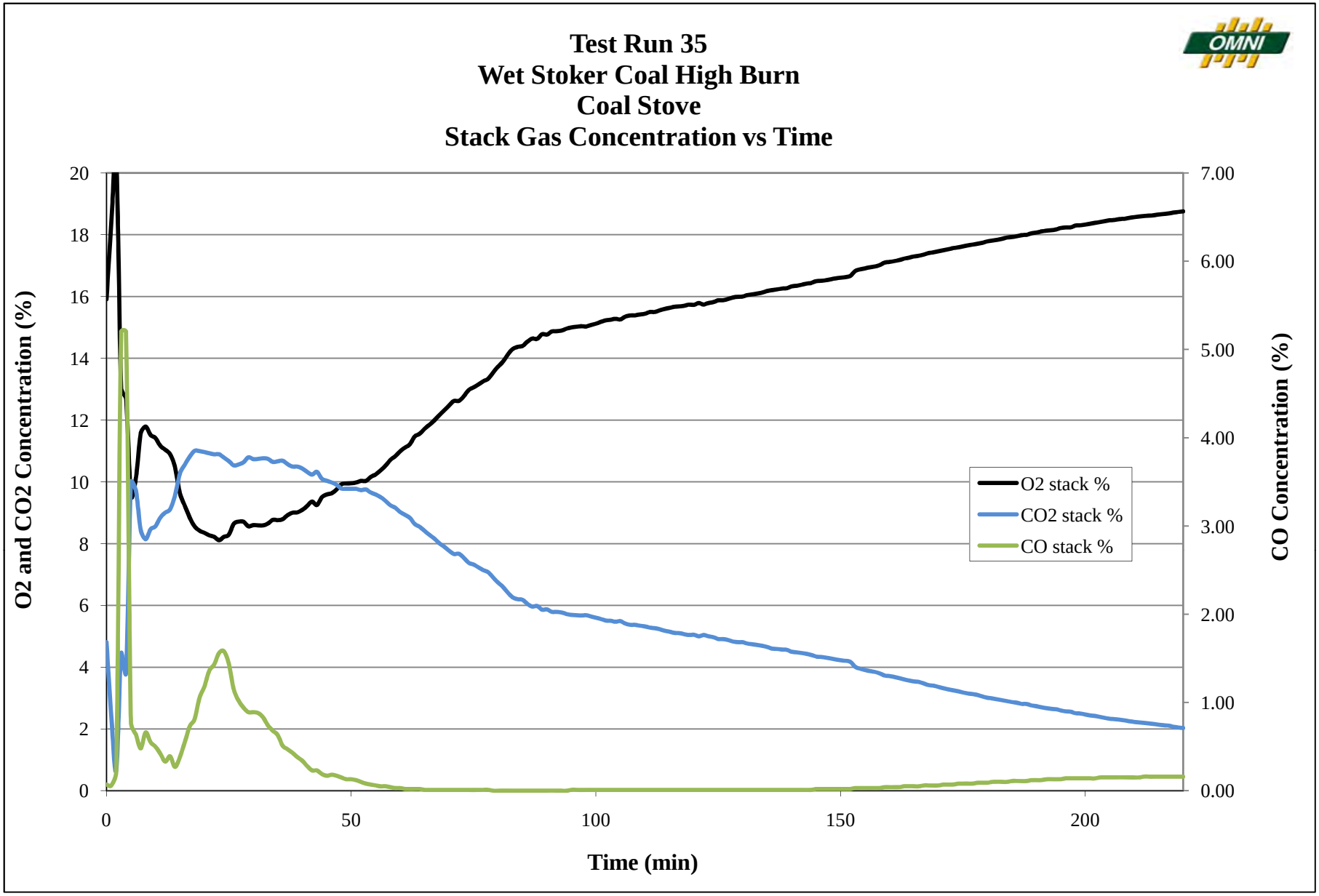

Test Run 32
Birch Low Burn
Non-Qualified OWHH
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
200
400
600
800
1000
0.0
10.0
20.0
30.0
40.0
50.0
60.0
0
50
100
150
200

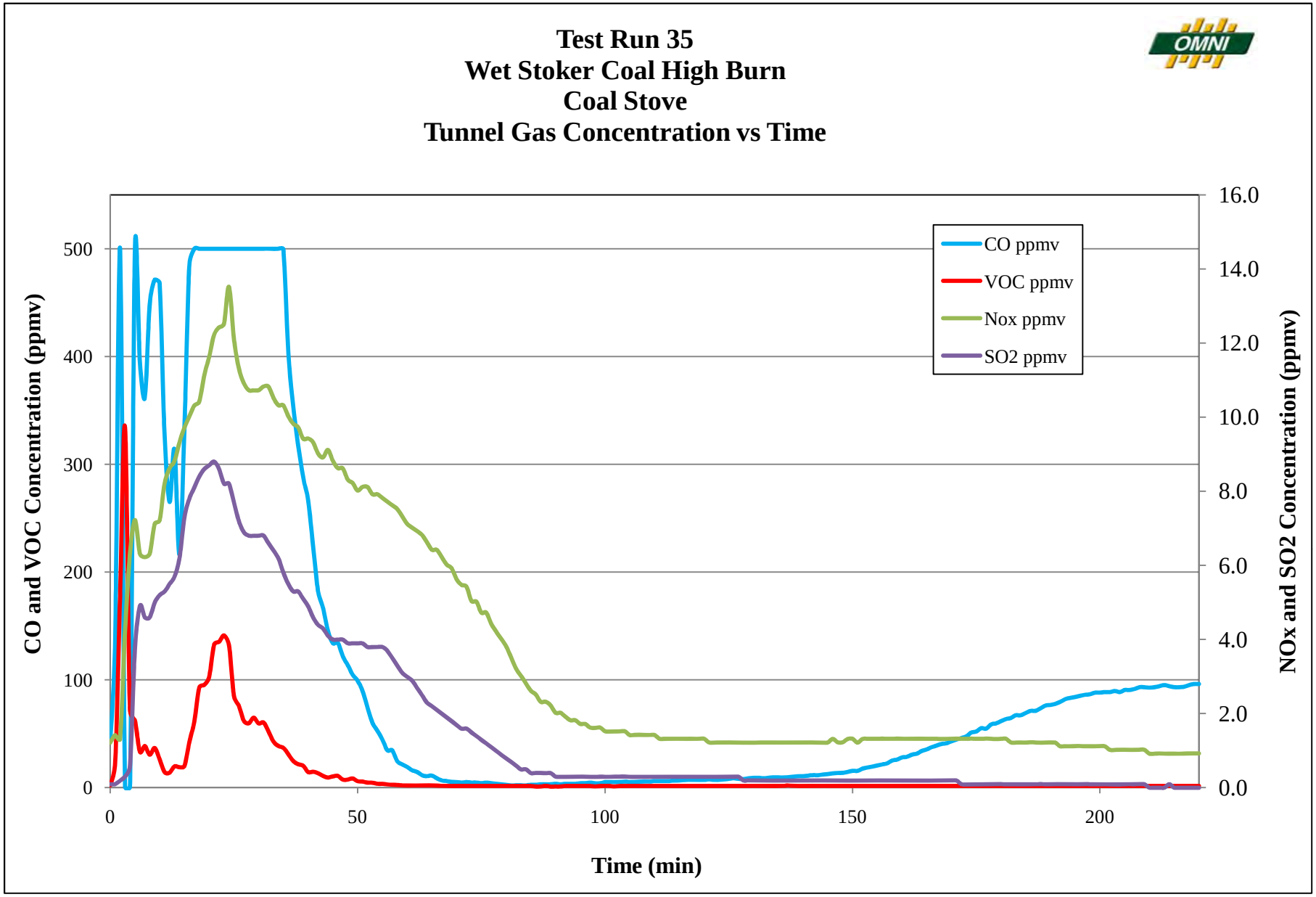

Test Run 33
Birch Low Burn, Cold Start
Non-Qualified OWHH
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200
250
300

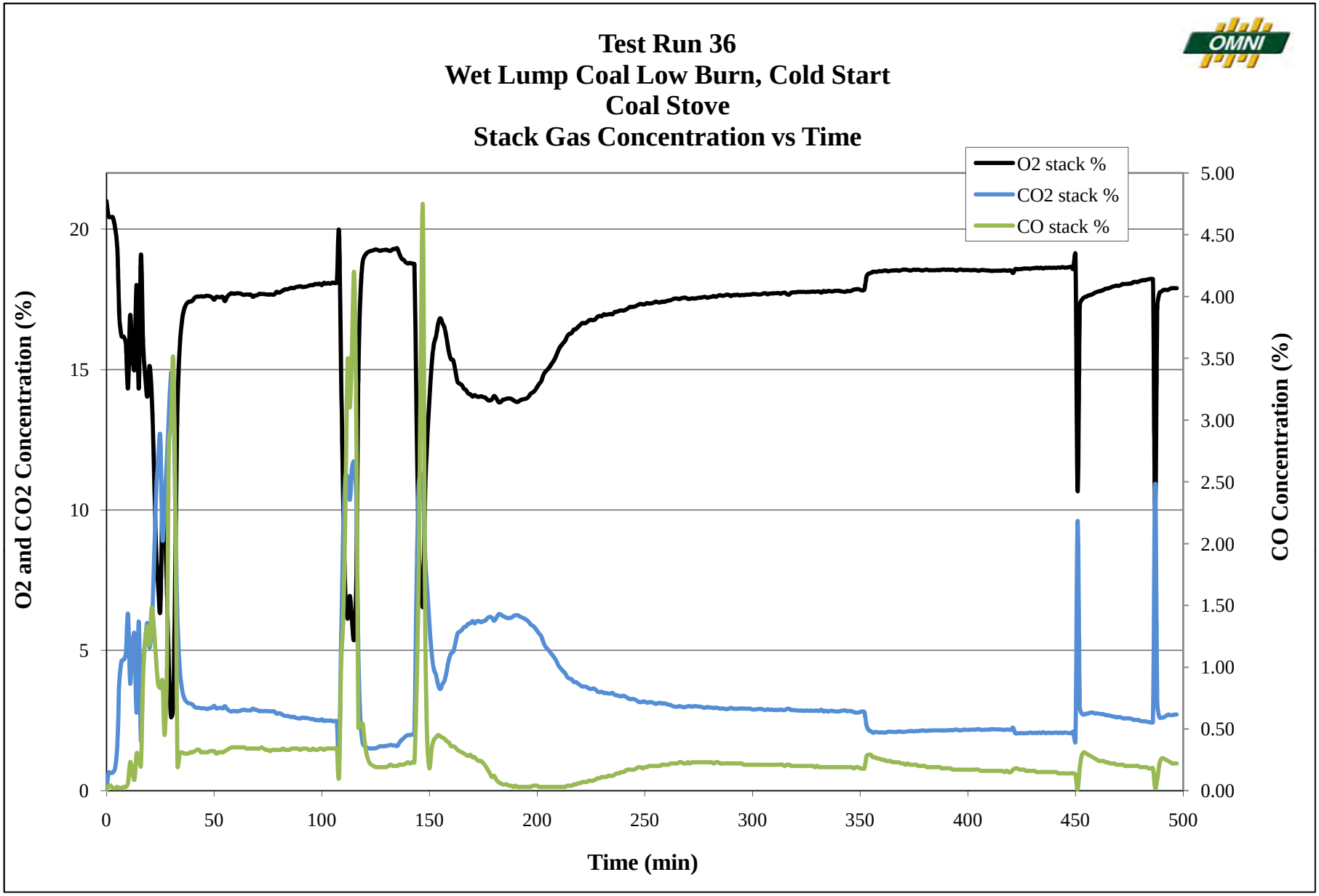

Test Run 33
Birch Low Burn, Cold Start
Non-Qualified OWHH
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
200
400
600
800
1000
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
0
50
100
150
200
250
300

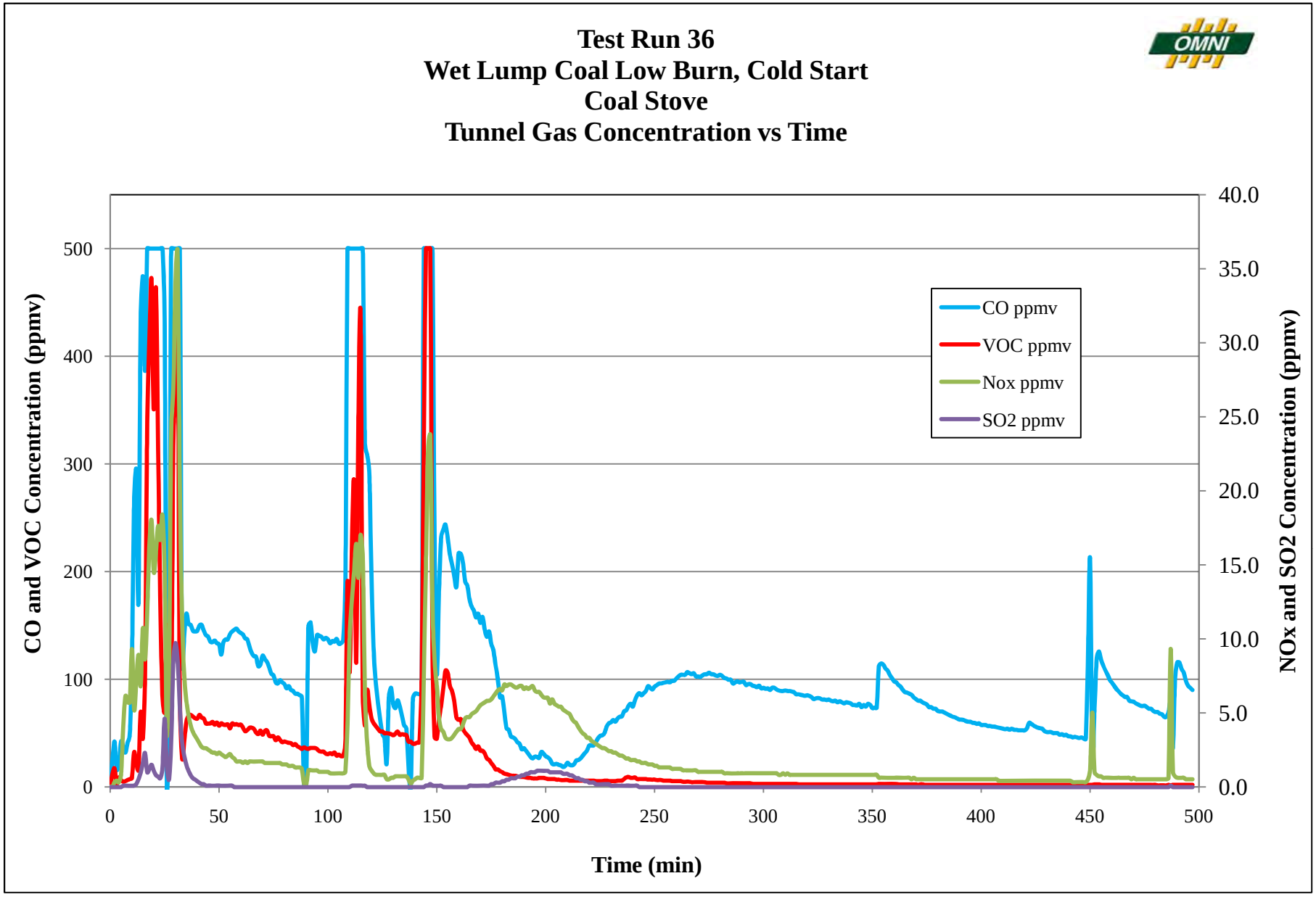

Test Run 34
Birch Low Burn
EPA Phase II OWHH with Retrofit Catalyst
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
100
200
300
400
500

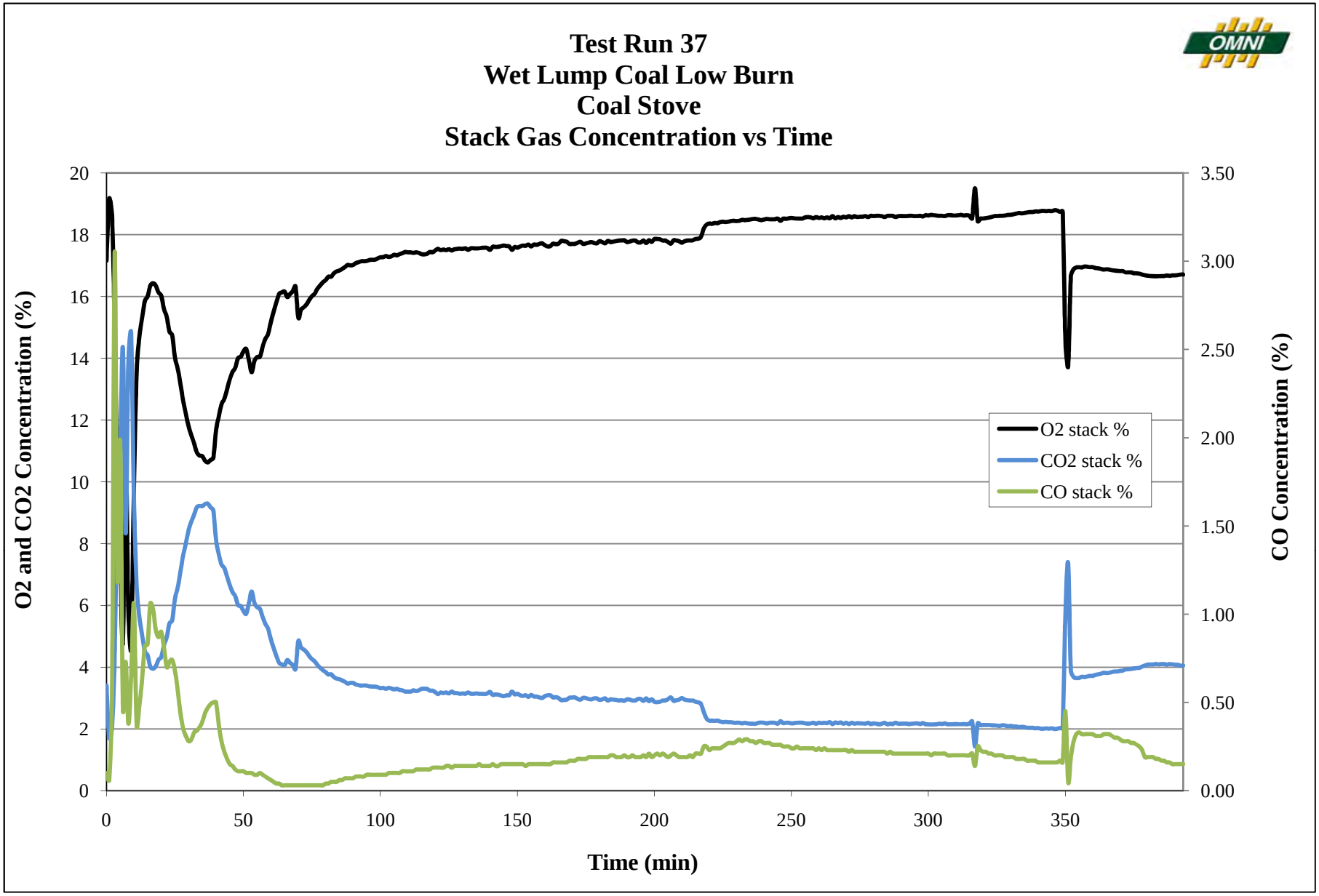

Test Run 34
Birch Low Burn
EPA Phase II OWHH with Retrofit Catalyst
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0

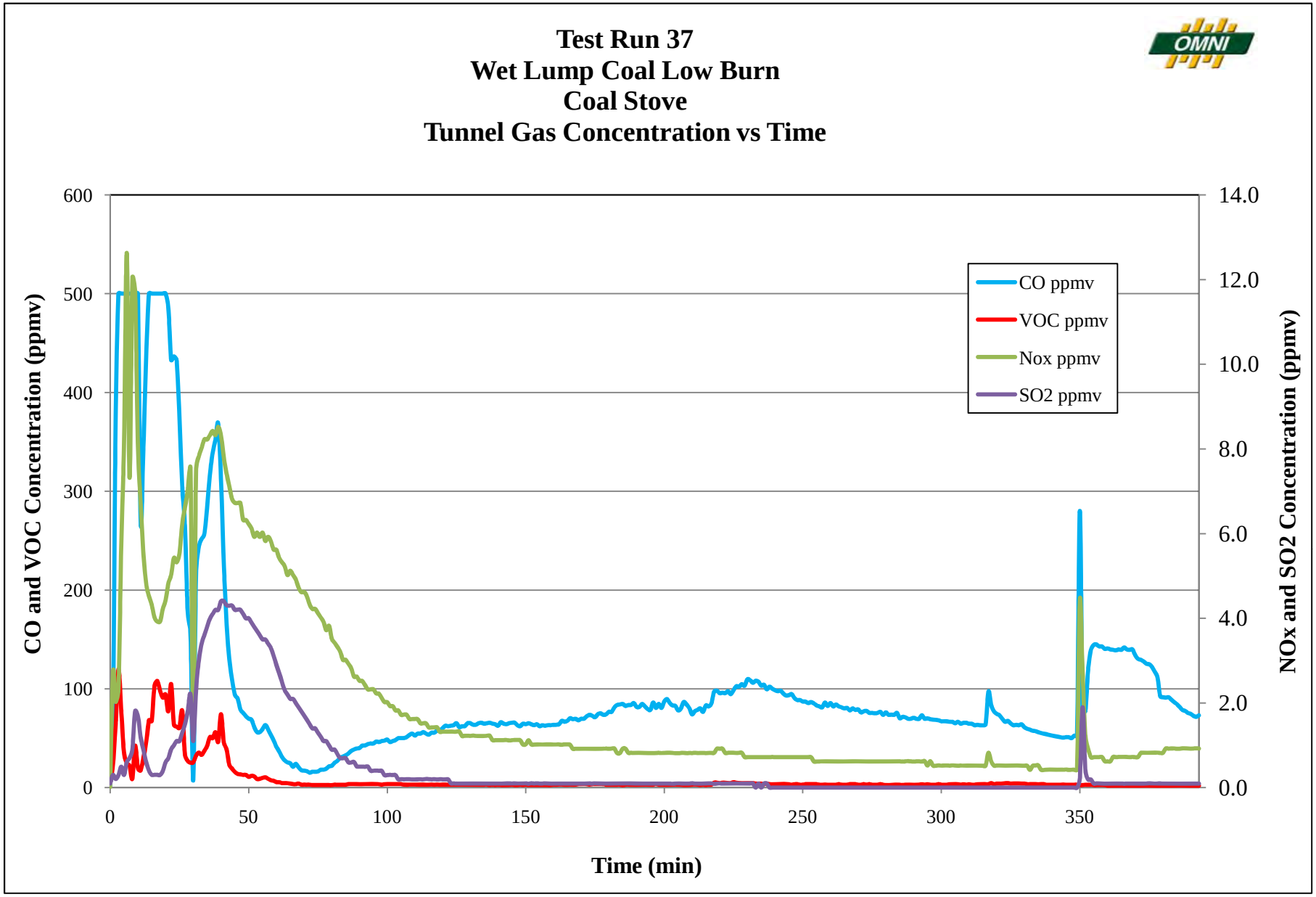

Test Run 35
Wet Stoker Coal High Burn
Coal Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
0
50
100
150
200

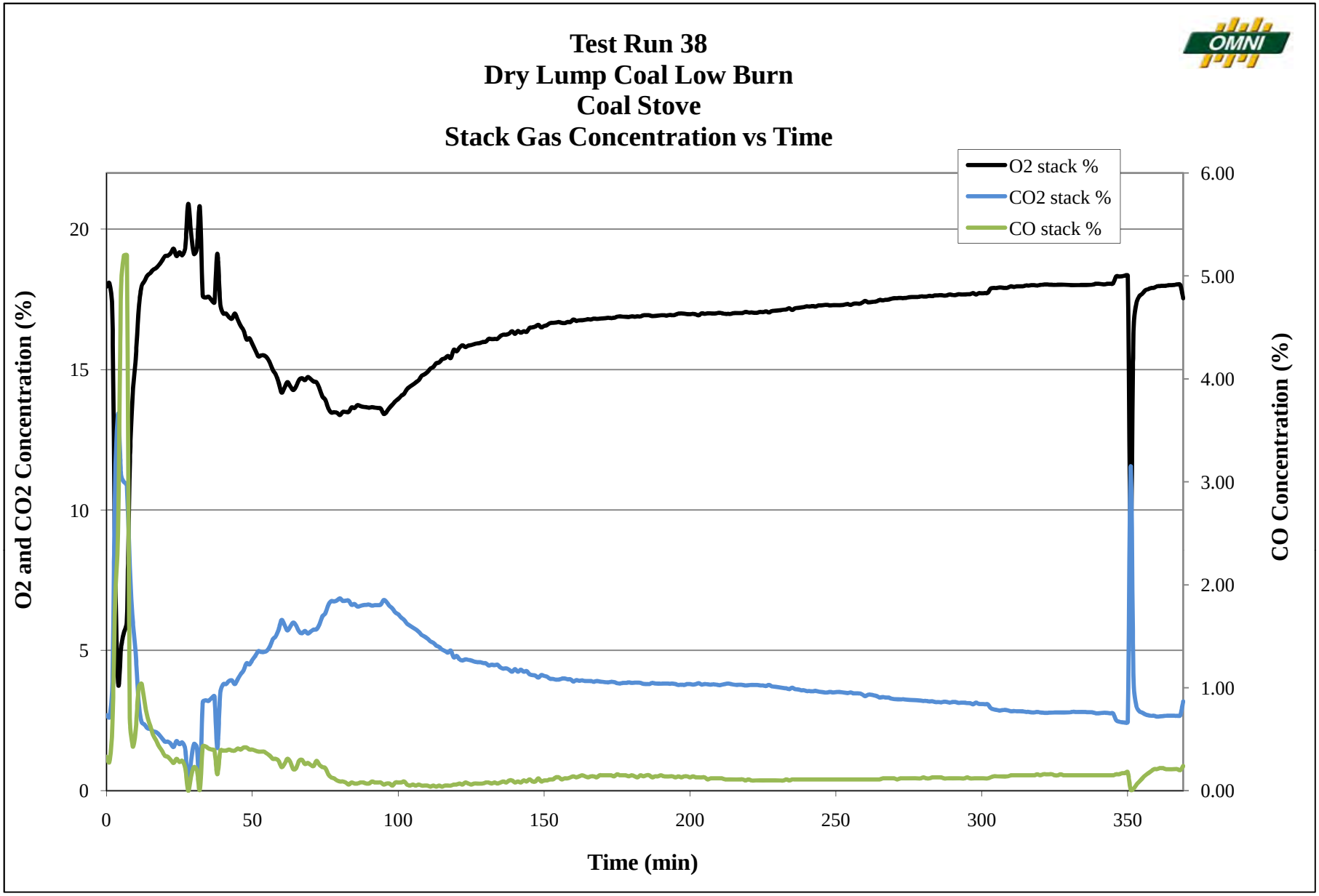

Test Run 35
Wet Stoker Coal High Burn
Coal Stove
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0
50
100
150
200

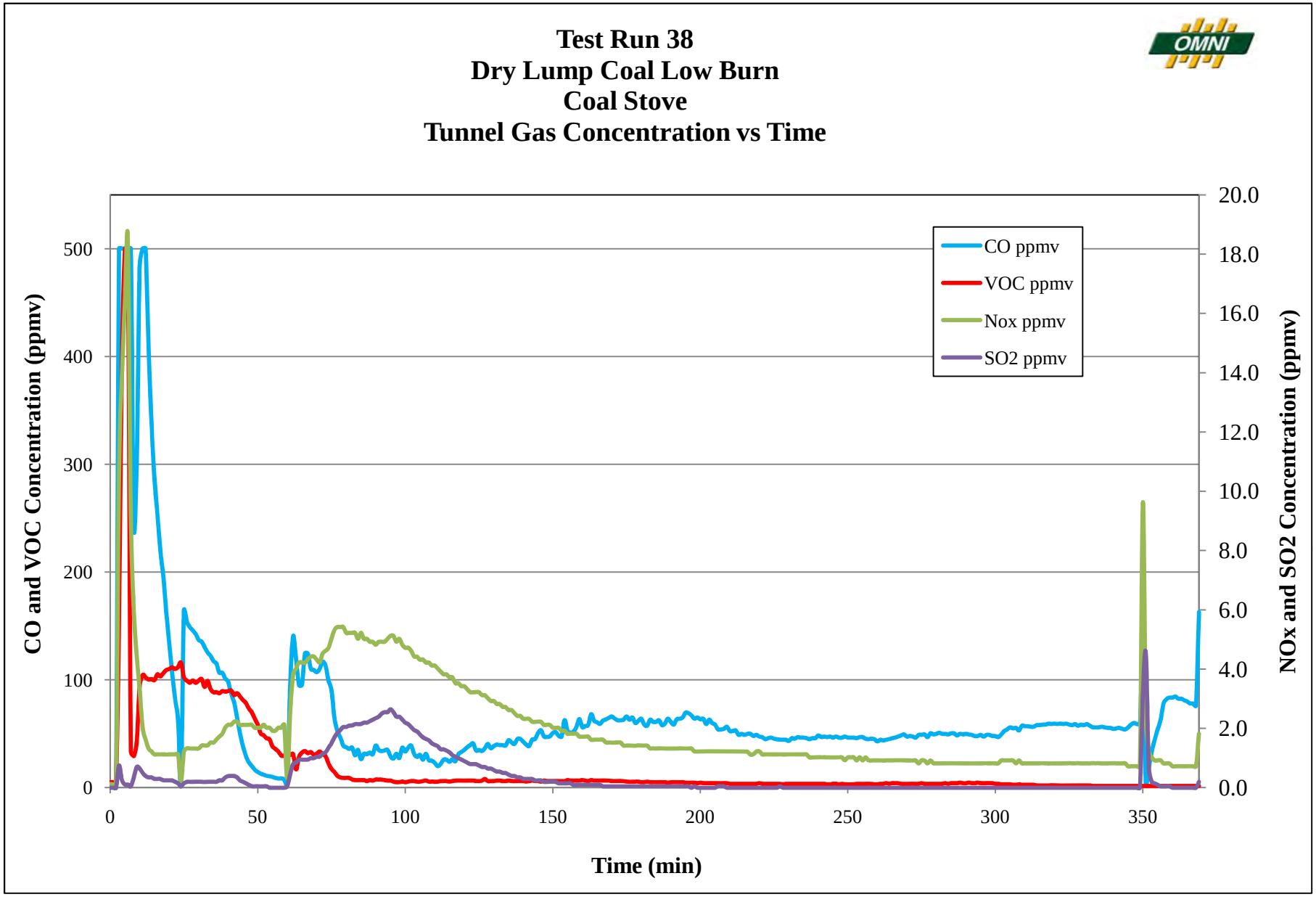

Test Run 36
Wet Lump Coal Low Burn, Cold Start
Coal Stove
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
0
50
100
150
200
250
300
350
400
450
500

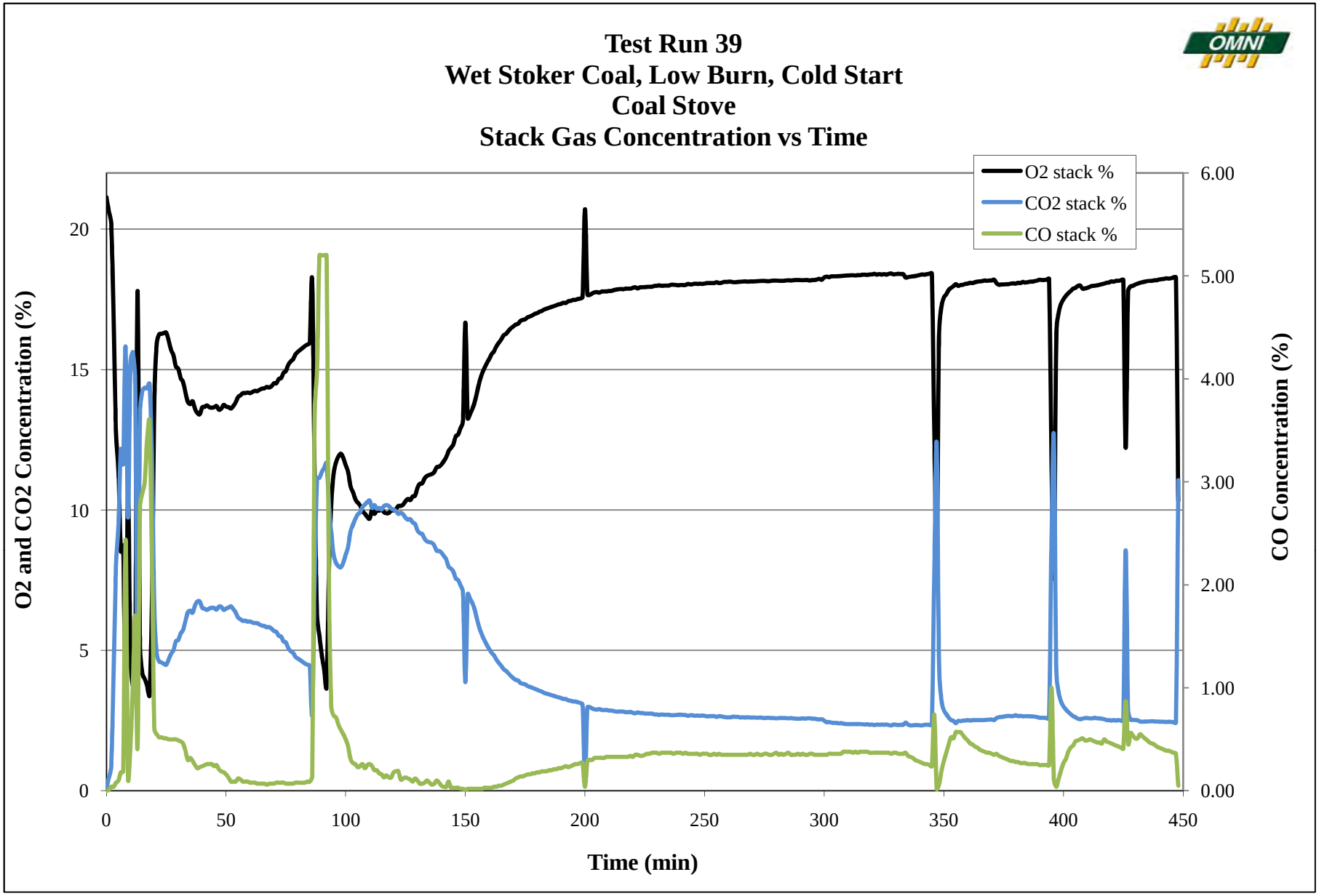

Test Run 36
Wet Lump Coal Low Burn, Cold Start
Coal Stove
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
0
50
100
150
200
250
300
350
400
450
500

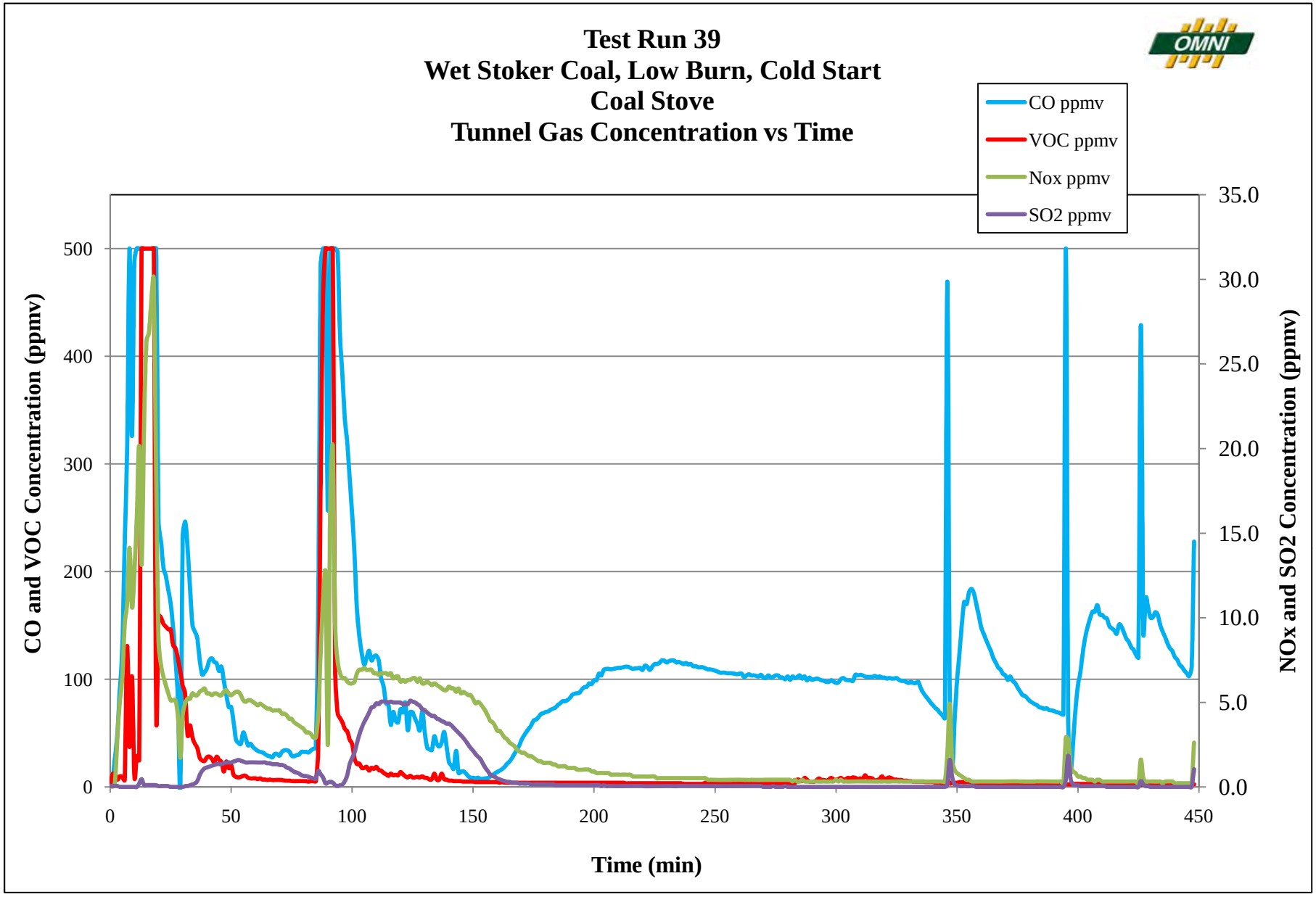

Test Run 37
Wet Lump Coal Low Burn
Coal Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
0
50
100
150
200
250
300
350

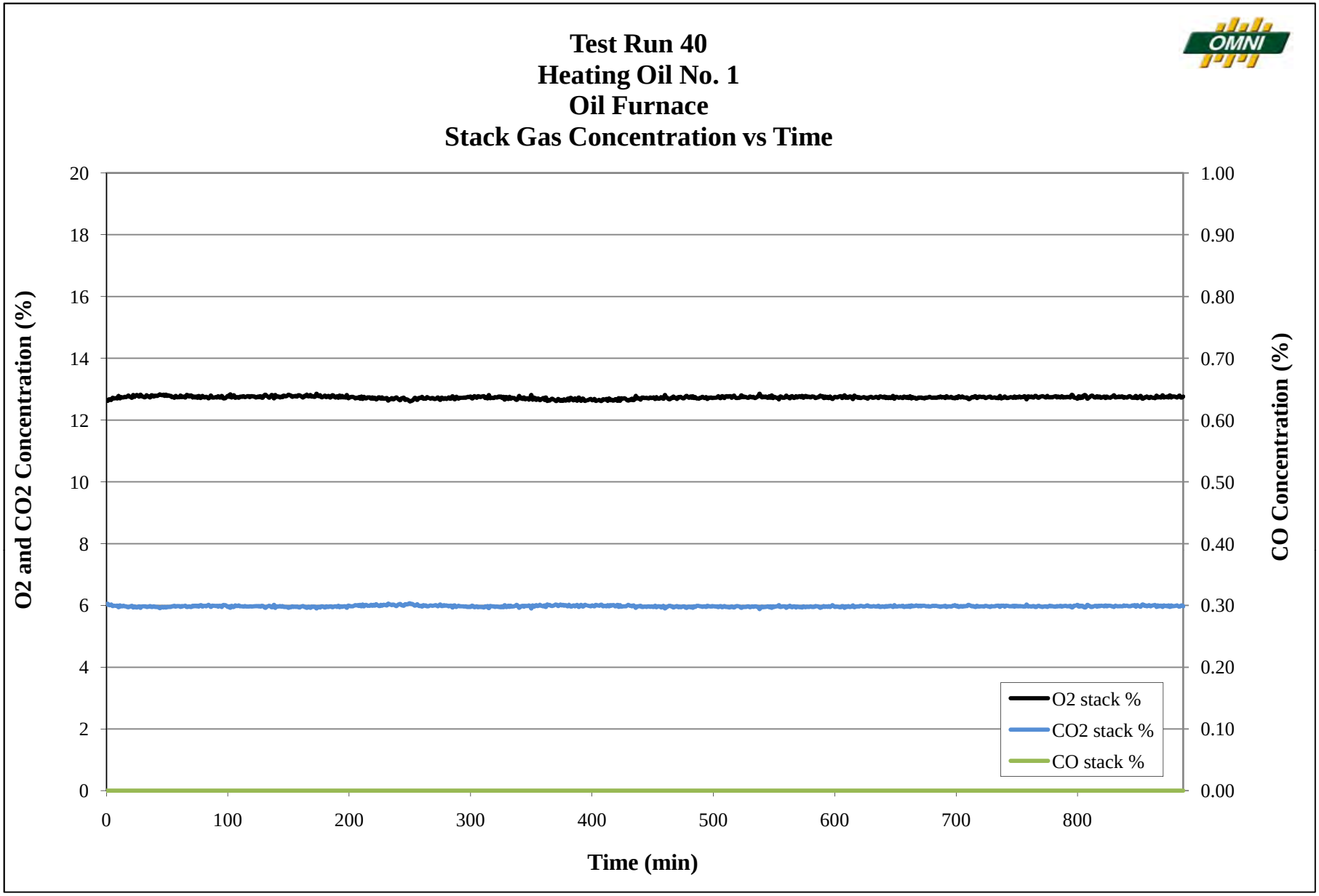

Test Run 37
Wet Lump Coal Low Burn
Coal Stove
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
600
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
0
50
100
150
200
250
300
350

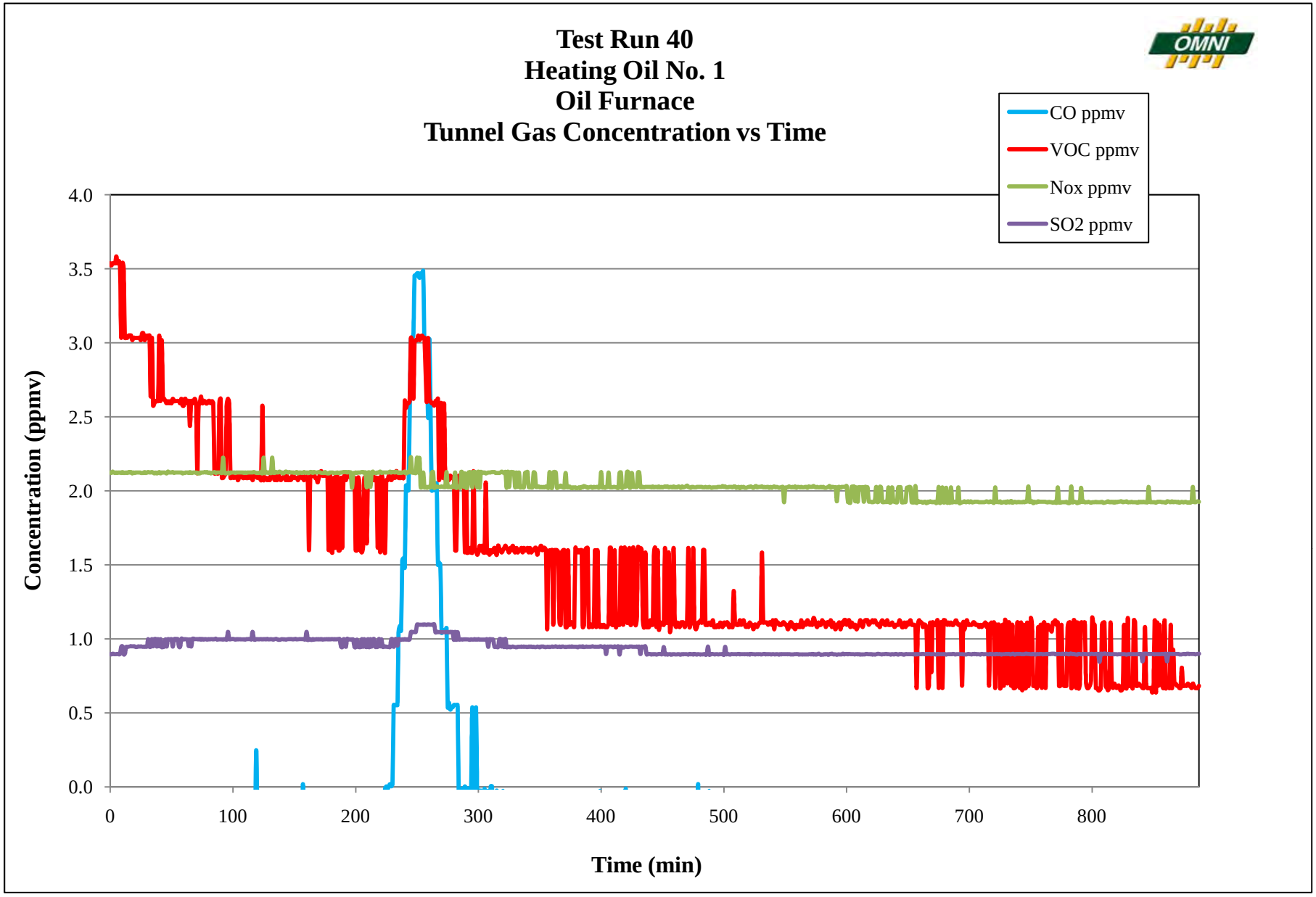

Test Run 38
Dry Lump Coal Low Burn
Coal Stove
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200
250
300
350

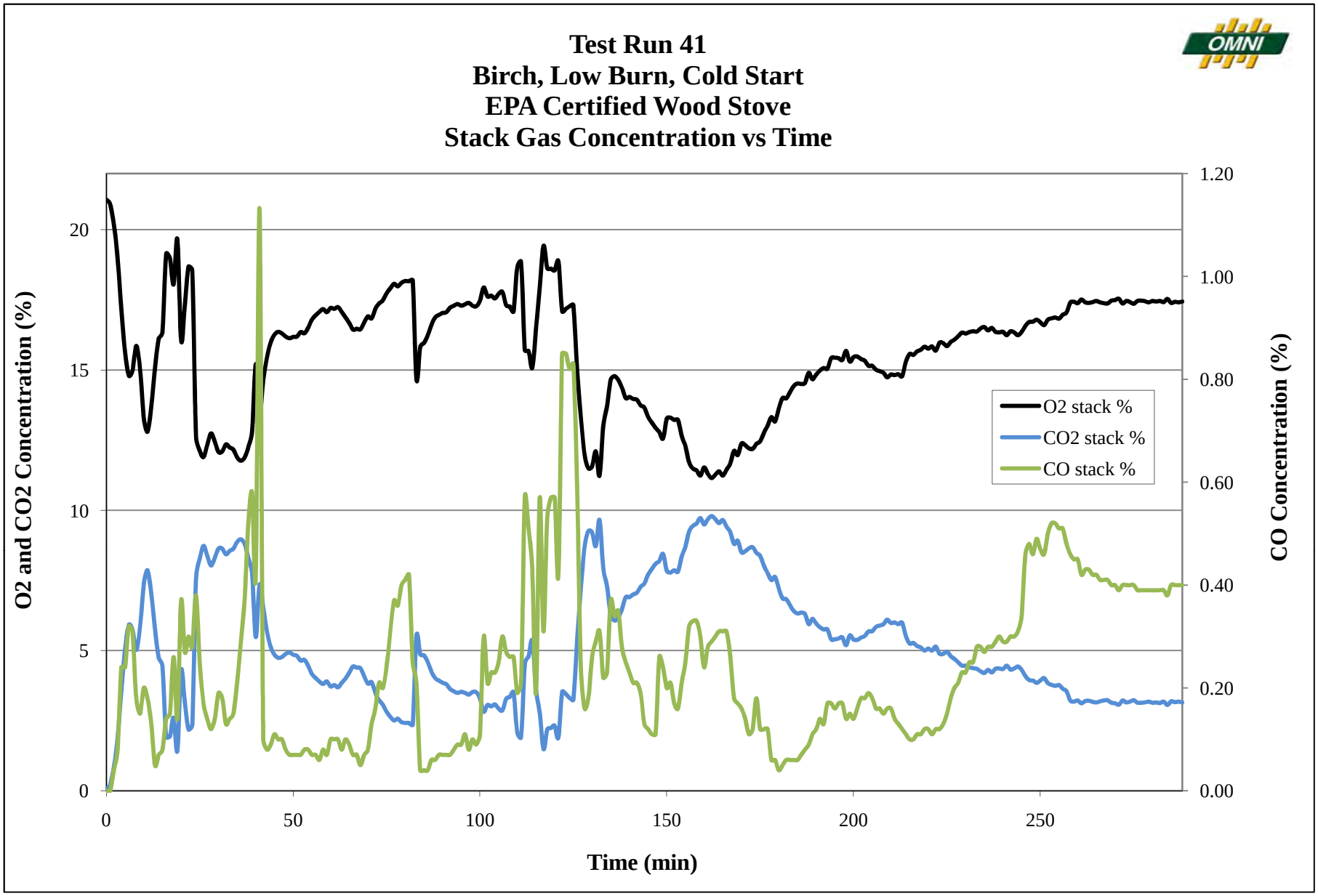

Test Run 38
Dry Lump Coal Low Burn
Coal Stove
Tunnel Gas Concentration vs Time
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
0
50
100
150
200
250
300
350

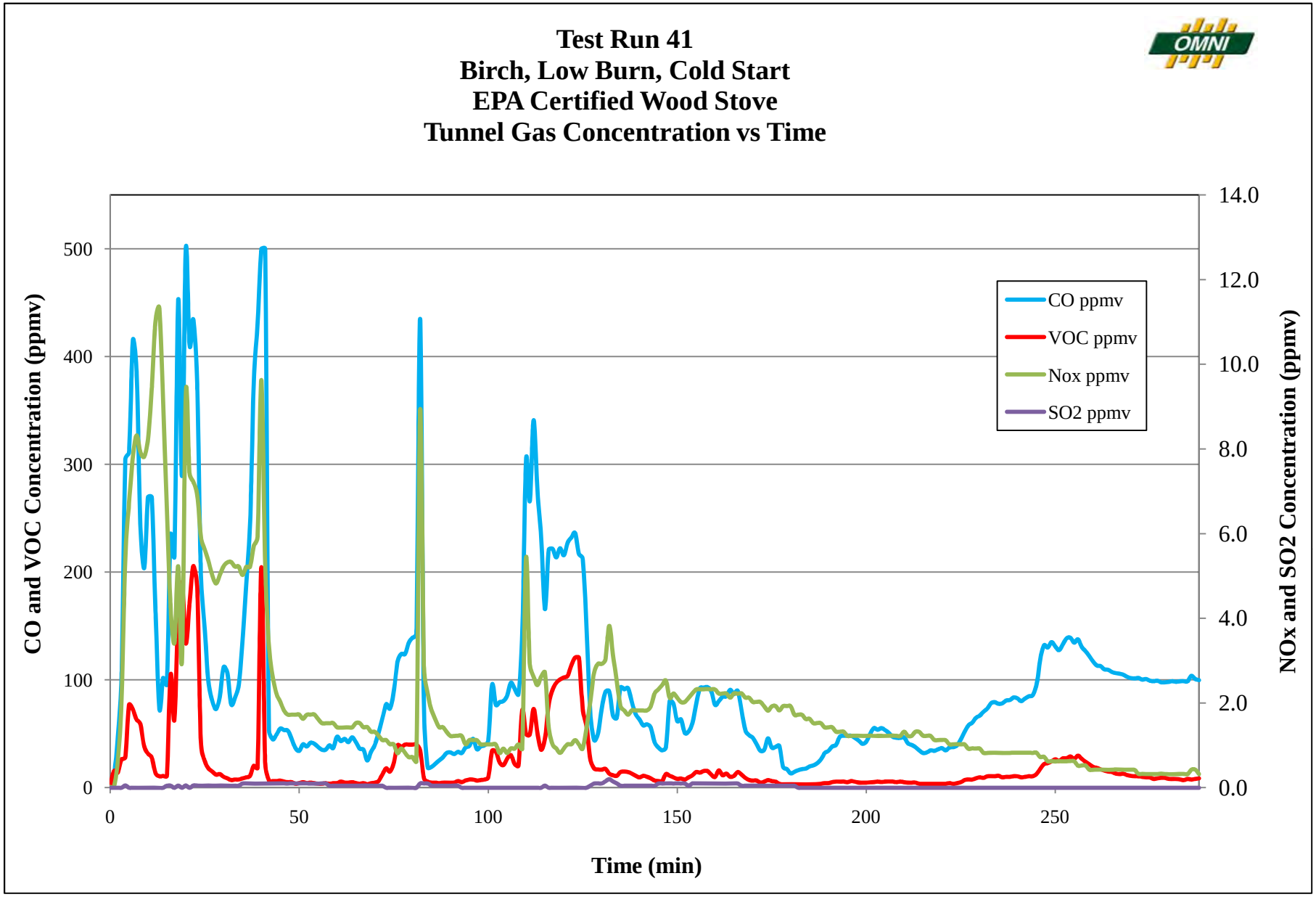

Test Run 39
Wet Stoker Coal, Low Burn, Cold Start
Coal Stove
Stack Gas Concentration vs Time
O2 stack %
CO2 stack %
CO stack %
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
0
5
10
15
20
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200
250
300
350
400
450


Test Run 39
Wet Stoker Coal, Low Burn, Cold Start
Coal Stove
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
0
100
200
300
400
500
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
0
50
100
150
200
250
300
350
400
450


Test Run 40
Heating Oil No. 1
Oil Furnace
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
2
4
6
8
10
12
14
16
18
20
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
0
100
200
300
400
500
600
700
800


Test Run 40
Heating Oil No. 1
Oil Furnace
Tunnel Gas Concentration vs Time
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
Concentration (ppmv)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
100
200
300
400
500
600
700
800
Time (min)


Test Run 41
Birch, Low Burn, Cold Start
EPA Certified Wood Stove
Stack Gas Concentration vs Time
O2 and CO2 Concentration (%)
CO Concentration (%)
Time (min)
O2 stack %
CO2 stack %
CO stack %
0
5
10
15
20
0.00
0.20
0.40
0.60
0.80
1.00
1.20
0
50
100
150
200
250


Test Run 41
Birch, Low Burn, Cold Start
EPA Certified Wood Stove
Tunnel Gas Concentration vs Time
OMNI
CO and VOC Concentration (ppmv)
NOx and SO2 Concentration (ppmv)
Time (min)
CO ppmv
VOC ppmv
Nox ppmv
SO2 ppmv
0
100
200
300
400
500
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
0
50
100
150
200
250

Measurement of Space-Heating Emissions

Appendix D

Ammonia Laboratory Results

Appliance:	Pellet Stove	**Burn Rate:**	High	**Run #:**	1
Fuel:	Alaskan Pellets	**Date:**	3/8/2011		

Reporting Units: ◉ Total ug ○ mg/L

Run Information:

	Catch (Total ug)	Volume (L)
Impinger 1	101	0.25
Impinger 2	15	0.25

Volume of Gas Sampled ($dsft^3$):	49.564
Tunnel Flow Rate ($dsft^3$/min):	470.8448005

Results:

Average Concentration (mg/L):	2.32E-01
Weight (as Nitrogen [g]):	1.16E-04
Weight (as NH_3, [g]):	1.41E-04
Total Concentraion of NH_3 (mg/L):	2.82E-01
Volume of Ammonia Gas Present (L):	9.41E-05
ppmV in Dilution Tunnel:	6.70E-02
Emissions Rate (g/hr):	8.03E-02
NH_3 Emissions Rate (g/hr) :	**0.08**

Appliance:	EPA Wood Stove	**Burn Rate:**	High	**Run #:**	2
Fuel:	Birch	**Date:**	3/9/2011		

Reporting Units: ◉ Total ug ○ mg/L

Run Information:

	Catch (Total ug)	Volume (L)
Impinger 1	293	0.25
Impinger 2	39	0.25

Volume of Gas Sampled ($dsft^3$):	62.31
Tunnel Flow Rate ($dsft^3$/min):	459.4510771

Results:

Average Concentration (mg/L):	6.64E-01
Weight (as Nitrogen [g]):	3.32E-04
Weight (as NH3, [g]):	4.03E-04
Total Concentraion of NH3 (mg/L):	8.06E-01
Volume of Ammonia Gas Present (L):	2.69E-04
ppmV in Dilution Tunnel:	1.53E-01
Emissions Rate (g/hr):	1.78E-01
NH3 Emissions Rate (g/hr) :	**0.18**

Appliance:	EPA Wood Stove	**Burn Rate:**	High	**Run #:**	3
Fuel:	Spruce	**Date:**	3/12/11		

Reporting Units: ◉ Total ug ○ mg/L

Run Information:

	Catch (Total ug)	Volume (L)
Impinger 1	152	0.25
Impinger 2	26	0.25

Volume of Gas Sampled ($dsft^3$):	51.64
Tunnel Flow Rate ($dsft^3$/min):	461.2901

Results:

Average Concentration (mg/L):	3.56E-01
Weight (as Nitrogen [g]):	1.78E-04
Weight (as NH3, [g]):	2.16E-04
Total Concentraion of NH3 (mg/L):	4.32E-01
Volume of Ammonia Gas Present (L):	1.44E-04
ppmV in Dilution Tunnel:	9.87E-02
Emissions Rate (g/hr):	1.16E-01
NH3 Emissions Rate (g/hr) :	**0.12**

Appliance:	EPA Wood Stove	**Burn Rate:**	Low	**Run #:**	5
Fuel:	Birch	**Date:**	3/17/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	4.31	0.25
Impinger 2	0.191	0.25

Volume of Gas Sampled (dsft^3):	158.1
Tunnel Flow Rate (dsft^3/min):	464.6458794

Results:

Average Concentration (mg/L):	2.25E+00
Weight (as Nitrogen [g]):	1.13E-03
Weight (as NH3, [g]):	1.37E-03
Total Concentration of NH3 (mg/L):	2.73E+00
Volume of Ammonia Gas Present (L):	9.12E-04
ppmV in Dilution Tunnel:	2.04E-01
Emissions Rate (g/hr):	2.41E-01

NH3 Emissions Rate (g/hr) :	**0.24**

Appliance:	EPA Wood Stove	**Burn Rate:**	Low	**Run #:**	6
Fuel:	Spruce	**Date:**	3/18/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	1.75	0.25
Impinger 2	0.123	0.25

Volume of Gas Sampled (dsft^3):	118.85
Tunnel Flow Rate (dsft^3/min):	477.7274609

Results:

Average Concentration (mg/L):	9.37E-01
Weight (as Nitrogen [g]):	4.68E-04
Weight (as NH3, [g]):	5.69E-04
Total Concentration of NH3 (mg/L):	1.14E+00
Volume of Ammonia Gas Present (L):	3.80E-04
ppmV in Dilution Tunnel:	1.13E-01
Emissions Rate (g/hr):	1.37E-01

NH3 Emissions Rate (g/hr) :	**0.14**

Appliance:	EPA OWHH	**Burn Rate:**	High	**Run #:**	8
Fuel:	Birch	**Date:**	3/22/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	24.5	0.25
Impinger 2	0.666	0.25

Volume of Gas Sampled ($dsft^3$):	138.65
Tunnel Flow Rate ($dsft^3$/min):	468.0051

Results:

Average Concentration (mg/L):	1.26E+01
Weight (as Nitrogen [g]):	6.29E-03
Weight (as NH3, [g]):	7.64E-03
Total Concentration of NH3 (mg/L):	1.53E+01
Volume of Ammonia Gas Present (L):	5.10E-03
ppmV in Dilution Tunnel:	1.30E+00
Emissions Rate (g/hr):	1.55E+00

NH3 Emissions Rate (g/hr) :	**1.55**

Appliance:	EPA OWHH	**Burn Rate:**	Low	**Run #:**	9
Fuel:	Birch	**Date:**	3/22/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	10.8	0.25
Impinger 2	0.45	0.25

Volume of Gas Sampled ($dsft^3$):	347.6
Tunnel Flow Rate ($dsft^3$/min):	494.7029817

Results:

Average Concentration (mg/L):	5.63E+00
Weight (as Nitrogen [g]):	2.81E-03
Weight (as NH3, [g]):	3.42E-03
Total Concentration of NH3 (mg/L):	6.83E+00
Volume of Ammonia Gas Present (L):	2.28E-03
ppmV in Dilution Tunnel:	2.32E-01
Emissions Rate (g/hr):	2.92E-01
NH3 Emissions Rate (g/hr) :	**0.29**

Appliance:	EPA OWHH	**Burn Rate:**	High	**Run #:**	10
Fuel:	Spruce	**Date:**	3/23/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	6.13	0.25
Impinger 2	0.335	0.25

Volume of Gas Sampled ($dsft^3$):	140.61
Tunnel Flow Rate ($dsft^3$/min):	462.0291086

Results:

Average Concentration (mg/L):	3.23E+00
Weight (as Nitrogen [g]):	1.62E-03
Weight (as NH3, [g]):	1.96E-03
Total Concentration of NH3 (mg/L):	3.93E+00
Volume of Ammonia Gas Present (L):	1.31E-03
ppmV in Dilution Tunnel:	3.29E-01
Emissions Rate (g/hr):	3.87E-01

NH3 Emissions Rate (g/hr) :	**0.39**

Appliance:	EPA OWHH	**Burn Rate:**	Low	**Run #:**	11
Fuel:	Spruce	**Date:**	3/24/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	12	0.25
Impinger 2	0.648	0.25

Volume of Gas Sampled ($dsft^3$):	359.12
Tunnel Flow Rate ($dsft^3$/min):	479.7847321

Results:

Average Concentration (mg/L):	6.32E+00
Weight (as Nitrogen [g]):	3.16E-03
Weight (as NH3, [g]):	3.84E-03
Total Concentration of NH3 (mg/L):	7.68E+00
Volume of Ammonia Gas Present (L):	2.56E-03
ppmV in Dilution Tunnel:	2.52E-01
Emissions Rate (g/hr):	3.08E-01

NH3 Emissions Rate (g/hr) :	**0.31**

Appliance:	Conventional Wood Stove	**Burn Rate:**	High	**Run #:**	12
Fuel:	Spruce	**Date:**	3/30/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	1.05	0.25
Impinger 2	0.106	0.25

Volume of Gas Sampled ($dsft^3$):	33.76
Tunnel Flow Rate ($dsft^3$/min):	444.7836106

Results:

Average Concentration (mg/L):	5.78E-01
Weight (as Nitrogen [g]):	2.89E-04
Weight (as NH3, [g]):	3.51E-04
Total Concentration of NH3 (mg/L):	7.02E-01
Volume of Ammonia Gas Present (L):	2.34E-04
ppmV in Dilution Tunnel:	2.45E-01
Emissions Rate (g/hr):	2.77E-01

NH3 Emissions Rate (g/hr) :	**0.28**

Appliance:	Conventional Wood Stove	**Burn Rate:**	High	**Run #:**	13
Fuel:	Birch	**Date:**	3/31/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	6.84	0.25
Impinger 2	0.265	0.25

Volume of Gas Sampled ($dsft^3$):	17.29
Dilution Factor (Qt/Qf):	17.3353
Tunnel Flow Rate ($dsft^3$/min):	433.3931235

Results:

Average Concentration (mg/L):	3.55E+00
Weight (as Nitrogen [g]):	1.78E-03
Weight (as NH3, [g]):	2.16E-03
Total Concentration of NH3 (mg/L):	4.31E+00
Volume of Ammonia Gas Present (L):	1.44E-03
ppmV in Dilution Tunnel:	2.94E+00
ppmV in Stack:	5.10E+01
Emissions Rate (g/hr):	3.24E+00

NH3 Stack Concentration (ppmV):	**51.01**
NH3 Emissions Rate (g/hr) :	**3.24**

Appliance:	Conventional Wood Stove	**Burn Rate:**	Low	**Run #:**	14
Fuel:	Spruce	**Date:**	4/1/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	3.36	0.25
Impinger 2	0.23	0.25

Volume of Gas Sampled ($dsft^3$):	37.47
Tunnel Flow Rate ($dsft^3/min$):	459.842048

Results:

Average Concentration (mg/L):	1.80E+00
Weight (as Nitrogen [g]):	8.98E-04
Weight (as NH3, [g]):	1.09E-03
Total Concentration of NH3 (mg/L):	2.18E+00
Volume of Ammonia Gas Present (L):	7.28E-04
ppmV in Dilution Tunnel:	6.86E-01
Emissions Rate (g/hr):	8.02E-01

NH3 Emissions Rate (g/hr) :	**0.80**

Appliance:	Conventional Wood Stove	**Burn Rate:**	Low	**Run #:**	15
Fuel:	Birch	**Date:**	4/1/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	7.8	0.25
Impinger 2	0.414	0.25

Volume of Gas Sampled ($dsft^3$):	36.66
Tunnel Flow Rate ($dsft^3$/min):	446.1506608

Results:

Average Concentration (mg/L):	4.11E+00
Weight (as Nitrogen [g]):	2.05E-03
Weight (as NH3, [g]):	2.49E-03
Total Concentration of NH3 (mg/L):	4.99E+00
Volume of Ammonia Gas Present (L):	1.67E-03
ppmV in Dilution Tunnel:	1.60E+00
Emissions Rate (g/hr):	1.82E+00

NH3 Emissions Rate (g/hr) :	**1.82**

Appliance:	Oil Furnace	**Burn Rate:**	Single	**Run #:**	17
Fuel:	No 2 Heating Oil	**Date:**	4/12/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	0.186	0.25
Impinger 2	0.156	0.25

Volume of Gas Sampled ($dsft^3$):	388.8511
Tunnel Flow Rate ($dsft^3$/min):	429.8975

Results:

Average Concentration (mg/L):	1.71E-01
Weight (as Nitrogen [g]):	8.55E-05
Weight (as NH3, [g]):	1.04E-04
Total Concentration of NH3 (mg/L):	2.08E-01
Volume of Ammonia Gas Present (L):	6.93E-05
ppmV in Dilution Tunnel:	6.30E-03
Emissions Rate (g/hr):	6.89E-03

NH3 Emissions Rate (g/hr) :	**0.01**

Appliance:	Waste Oil Burner	**Burn Rate:**	Single	**Run #:**	18
Fuel:	Waste Oil	**Date:**	4/15/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	0.172	0.25
Impinger 2	0.092	0.25

Volume of Gas Sampled ($dsft^3$):	103.44
Tunnel Flow Rate ($dsft^3$/min):	445.7873

Results:

Average Concentration (mg/L):	1.32E-01
Weight (as Nitrogen [g]):	6.60E-05
Weight (as NH3, [g]):	8.01E-05
Total Concentration of NH3 (mg/L):	1.60E-01
Volume of Ammonia Gas Present (L):	5.35E-05
ppmV in Dilution Tunnel:	1.83E-02
Emissions Rate (g/hr):	2.07E-02

NH3 Emissions Rate (g/hr) :	**0.02**

Appliance:	Coal Stove	**Burn Rate:**	High	**Run #:**	20
Fuel:	Dry Stoker Coal	**Date:**	5/6/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	2.4	0.25
Impinger 2	0.245	0.25

Volume of Gas Sampled ($dsft^3$):	100.3418
Tunnel Flow Rate ($dsft^3$/min):	460.1363

Results:

Average Concentration (mg/L):	1.32E+00
Weight (as Nitrogen [g]):	6.61E-04
Weight (as NH3, [g]):	8.03E-04
Total Concentration of NH3 (mg/L):	1.61E+00
Volume of Ammonia Gas Present (L):	5.36E-04
ppmV in Dilution Tunnel:	1.89E-01
Emissions Rate (g/hr):	2.21E-01

NH3 Emissions Rate (g/hr) :	**0.22**

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	21
Fuel:	Dry Stoker Coal	**Date:**	5/9/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	21.4	0.25
Impinger 2	0.645	0.25

Volume of Gas Sampled ($dsft^3$):	196.6714
Tunnel Flow Rate ($dsft^3$/min):	478.2646

Results:

Average Concentration (mg/L):	1.10E+01
Weight (as Nitrogen [g]):	5.51E-03
Weight (as NH3, [g]):	6.69E-03
Total Concentration of NH3 (mg/L):	1.34E+01
Volume of Ammonia Gas Present (L):	4.47E-03
ppmV in Dilution Tunnel:	8.03E-01
Emissions Rate (g/hr):	9.76E-01

NH3 Emissions Rate (g/hr) :	**0.98**

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	23
Fuel:	Wet Stoker Coal	**Date:**	5/11/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	18	0.25
Impinger 2	5.57	0.25

Volume of Gas Sampled ($dsft^3$):	162.0401
Tunnel Flow Rate ($dsft^3$/min):	467.5876

Results:

Average Concentration (mg/L):	1.18E+01
Weight (as Nitrogen [g]):	5.89E-03
Weight (as NH3, [g]):	7.16E-03
Total Concentration of NH3 (mg/L):	1.43E+01
Volume of Ammonia Gas Present (L):	4.78E-03
ppmV in Dilution Tunnel:	1.04E+00
Emissions Rate (g/hr):	1.24E+00

NH3 Emissions Rate (g/hr) :	**1.24**

Appliance:	Non Qualified OWHH	**Burn Rate:**	High	**Run #:**	25
Fuel:	Spruce	**Date:**	5/27/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	5.14	0.25
Impinger 2	0.532	0.25

Volume of Gas Sampled ($dsft^3$):	24.0723
Tunnel Flow Rate ($dsft^3$/min):	387.2835

Results:

Average Concentration (mg/L):	2.84E+00
Weight (as Nitrogen [g]):	1.42E-03
Weight (as NH3, [g]):	1.72E-03
Total Concentration of NH3 (mg/L):	3.44E+00
Volume of Ammonia Gas Present (L):	1.15E-03
ppmV in Dilution Tunnel:	1.69E+00
Emissions Rate (g/hr):	1.66E+00

NH3 Emissions Rate (g/hr) :	**1.66**

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	26
Fuel:	Wet Stoker Coal	**Date:**	5/30/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	36.7	0.25
Impinger 2	0.776	0.25

Volume of Gas Sampled ($dsft^3$):	48.8859
Tunnel Flow Rate ($dsft^3$/min):	424.9401

Results:

Average Concentration (mg/L):	1.87E+01
Weight (as Nitrogen [g]):	9.37E-03
Weight (as NH3, [g]):	1.14E-02
Total Concentration of NH3 (mg/L):	2.28E+01
Volume of Ammonia Gas Present (L):	7.60E-03
ppmV in Dilution Tunnel:	5.49E+00
Emissions Rate (g/hr):	5.93E+00

NH3 Emissions Rate (g/hr) :	**5.93**

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	27
Fuel:	Coal with Retrofit Catalyst	**Date:**	6/1/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	48.8	0.25
Impinger 2	1.54	0.25

Volume of Gas Sampled ($dsft^3$):	73.3998
Tunnel Flow Rate ($dsft^3$/min):	426.929

Results:

Average Concentration (mg/L):	2.52E+01
Weight (as Nitrogen [g]):	1.26E-02
Weight (as NH3, [g]):	1.53E-02
Total Concentration of NH3 (mg/L):	3.06E+01
Volume of Ammonia Gas Present (L):	1.02E-02
ppmV in Stack:	#REF!
Emissions Rate (g/hr):	5.33E+00

NH3 Emissions Rate (g/hr) :	**5.33**

Appliance:	Auger Fed HH	**Burn Rate:**	Single, Cold Start	**Run #:**	28
Fuel:	Wet Stoker Coal	**Date:**	6/7/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	1.5	0.25
Impinger 2	0.716	0.25

Volume of Gas Sampled ($dsft^3$):	85.68
Tunnel Flow Rate ($dsft^3$/min):	427.5965

Results:

Average Concentration (mg/L):	1.11E+00
Weight (as Nitrogen [g]):	5.54E-04
Weight (as NH3, [g]):	6.73E-04
Total Concentration of NH3 (mg/L):	1.35E+00
Volume of Ammonia Gas Present (L):	4.49E-04
ppmV in Dilution Tunnel:	1.85E-01
Emissions Rate (g/hr):	2.01E-01

NH3 Emissions Rate (g/hr) :	**0.20**

Appliance:	Auger Fed HH	**Burn Rate:**	Single	**Run #:**	29
Fuel:	Wet Stoker Coal	**Date:**	6/7/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	0.286	0.25
Impinger 2	0.214	0.25

Volume of Gas Sampled ($dsft^3$):	94.1
Tunnel Flow Rate ($dsft^3$/min):	410.0643

Results:

Average Concentration (mg/L):	2.50E-01
Weight (as Nitrogen [g]):	1.25E-04
Weight (as NH3, [g]):	1.52E-04
Total Concentration of NH3 (mg/L):	3.04E-01
Volume of Ammonia Gas Present (L):	1.01E-04
ppmV in Dilution Tunnel:	3.80E-02
Emissions Rate (g/hr):	3.97E-02
NH3 Emissions Rate (g/hr) :	**0.04**

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	30
Fuel:	Spruce	**Date:**	6/30/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	8.28	0.25
Impinger 2	0.708	0.25

Volume of Gas Sampled ($dsft^3$):	66.7505
Tunnel Flow Rate ($dsft^3$/min):	412.9678

Results:

Average Concentration (mg/L):	4.49E+00
Weight (as Nitrogen [g]):	2.25E-03
Weight (as NH3, [g]):	2.73E-03
Total Concentration of NH3 (mg/L):	5.46E+00
Volume of Ammonia Gas Present (L):	1.82E-03
ppmV in Dilution Tunnel:	9.64E-01
Emissions Rate (g/hr):	1.01E+00

NH3 Emissions Rate (g/hr) :	**1.01**

Appliance:	Non Qualified OWHH	**Burn Rate:**	High	**Run #:**	31
Fuel:	Birch	**Date:**	7/1/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	26.7	0.25
Impinger 2	2.31	0.25

Volume of Gas Sampled ($dsft^3$):	45.4303
Tunnel Flow Rate ($dsft^3$/min):	367.8844

Results:

Average Concentration (mg/L):	1.45E+01
Weight (as Nitrogen [g]):	7.25E-03
Weight (as NH3, [g]):	8.81E-03
Total Concentration of NH3 (mg/L):	1.76E+01
Volume of Ammonia Gas Present (L):	5.88E-03
ppmV in Dilution Tunnel:	4.57E+00
Emissions Rate (g/hr):	4.28E+00

NH3 Emissions Rate (g/hr) :	**4.28**

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	32
Fuel:	Birch	**Date:**	7/6/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	18	0.25
Impinger 2	0.978	0.25

Volume of Gas Sampled ($dsft^3$):	75.9649
Tunnel Flow Rate ($dsft^3$/min):	413.0445

Results:

Average Concentration (mg/L):	9.49E+00
Weight (as Nitrogen [g]):	4.74E-03
Weight (as NH3, [g]):	5.76E-03
Total Concentration of NH3 (mg/L):	1.15E+01
Volume of Ammonia Gas Present (L):	3.85E-03
ppmV in Dilution Tunnel:	1.79E+00
Emissions Rate (g/hr):	1.88E+00

NH3 Emissions Rate (g/hr) :	**1.88**

Appliance:	Non Qualified OWHH	**Burn Rate:**	Low	**Run #:**	33
Fuel:	Birch, Cold Start	**Date:**	7/8/2011		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	49.6	0.25
Impinger 2	2.55	0.25

Volume of Gas Sampled ($dsft^3$):	109.5025
Tunnel Flow Rate ($dsft^3$/min):	407.1146

Results:

Average Concentration (mg/L):	2.61E+01
Weight (as Nitrogen [g]):	1.30E-02
Weight (as NH3, [g]):	1.58E-02
Total Concentration of NH3 (mg/L):	3.17E+01
Volume of Ammonia Gas Present (L):	1.06E-02
ppmV in Dilution Tunnel:	3.41E+00
Emissions Rate (g/hr):	3.53E+00

NH3 Emissions Rate (g/hr) :	**3.53**

Appliance:	EPA OWHH	**Burn Rate:**	Low	**Run #:**	34
Fuel:	Birch w/ Retrofit Catalyst	**Date:**	7/27/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	4.91	0.25
Impinger 2	0.389	0.25

Volume of Gas Sampled ($dsft^3$):	153.4584
Tunnel Flow Rate ($dsft^3$/min):	502.8851

Results:

Average Concentration (mg/L):	2.65E+00
Weight (as Nitrogen [g]):	1.32E-03
Weight (as NH3, [g]):	1.61E-03
Total Concentration of NH3 (mg/L):	3.22E+00
Volume of Ammonia Gas Present (L):	1.07E-03
ppmV in Dilution Tunnel:	2.47E-01
Emissions Rate (g/hr):	3.16E-01

NH3 Emissions Rate (g/hr) :	**0.32**

Appliance:	Coal Stove	**Burn Rate:**	High	**Run #:**	35
Fuel:	Wet Stoker Coal	**Date:**	8/10/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	1.22	0.25
Impinger 2	0.119	0.25

Volume of Gas Sampled ($dsft^3$):	44.1109
Tunnel Flow Rate ($dsft^3$/min):	569.458

Results:

Average Concentration (mg/L):	6.70E-01
Weight (as Nitrogen [g]):	3.35E-04
Weight (as NH3, [g]):	4.06E-04
Total Concentration of NH3 (mg/L):	8.13E-01
Volume of Ammonia Gas Present (L):	2.71E-04
ppmV in Dilution Tunnel:	2.17E-01
Emissions Rate (g/hr):	3.15E-01

NH3 Emissions Rate (g/hr) :	**0.31**

Appliance:	Coal Stove	**Burn Rate:**	Low, Cold Start	**Run #:**	36
Fuel:	Wet Lump Coal	**Date:**	8/11/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	42.8	0.25
Impinger 2	14.6	0.25

Volume of Gas Sampled ($dsft^3$):	245.9403
Tunnel Flow Rate ($dsft^3/min$):	488.8577

Results:

Average Concentration (mg/L):	2.87E+01
Weight (as Nitrogen [g]):	1.44E-02
Weight (as NH3, [g]):	1.74E-02
Total Concentration of NH3 (mg/L):	3.49E+01
Volume of Ammonia Gas Present (L):	1.16E-02
ppmV in Dilution Tunnel:	1.67E+00
Emissions Rate (g/hr):	2.08E+00

NH3 Emissions Rate (g/hr) :	**2.08**

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	37
Fuel:	Wet Lump Coal	**Date:**	8/12/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	18.7	0.25
Impinger 2	1.05	0.25

Volume of Gas Sampled (dsft^3):	183.5963
Tunnel Flow Rate (dsft^3/min):	488.5701

Results:

Average Concentration (mg/L):	9.88E+00
Weight (as Nitrogen [g]):	4.94E-03
Weight (as NH3, [g]):	6.00E-03
Total Concentration of NH3 (mg/L):	1.20E+01
Volume of Ammonia Gas Present (L):	4.00E-03
ppmV in Dilution Tunnel:	7.70E-01
Emissions Rate (g/hr):	9.57E-01

NH3 Emissions Rate (g/hr) :	**0.96**

Appliance:	Coal Stove	**Burn Rate:**	Low	**Run #:**	38
Fuel:	Dry Lump Coal	**Date:**	8/15/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	11.6	0.25
Impinger 2	0.274	0.25

Volume of Gas Sampled (dsft^3):	181.931
Tunnel Flow Rate (dsft^3/min):	515.7899

Results:

Average Concentration (mg/L):	5.94E+00
Weight (as Nitrogen [g]):	2.97E-03
Weight (as NH3, [g]):	3.60E-03
Total Concentration of NH3 (mg/L):	7.21E+00
Volume of Ammonia Gas Present (L):	2.41E-03
ppmV in Dilution Tunnel:	4.67E-01
Emissions Rate (g/hr):	6.13E-01

NH3 Emissions Rate (g/hr) :	**0.61**

Appliance:	Coal Stove	**Burn Rate:**	Low, Coal Start	**Run #:**	39
Fuel:	Wet Stoker Coal	**Date:**	8/16/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	32.8	0.25
Impinger 2	1.65	0.25

Volume of Gas Sampled ($dsft^3$):	206.8815
Tunnel Flow Rate ($dsft^3/min$):	522.0733

Results:

Average Concentration (mg/L):	1.72E+01
Weight (as Nitrogen [g]):	8.61E-03
Weight (as NH3, [g]):	1.05E-02
Total Concentration of NH3 (mg/L):	2.09E+01
Volume of Ammonia Gas Present (L):	6.98E-03
ppmV in Dilution Tunnel:	1.19E+00
Emissions Rate (g/hr):	1.58E+00

NH3 Emissions Rate (g/hr) :	**1.58**

Appliance:	Oil Furnace	**Burn Rate:**	Single	**Run #:**	40
Fuel:	No. 1 Fuel Oil	**Date:**	8/17/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	0.729	0.25
Impinger 2	0.424	0.25

Volume of Gas Sampled ($dsft^3$):	545.9553
Tunnel Flow Rate ($dsft^3$/min):	518.3042

Results:

Average Concentration (mg/L):	5.77E-01
Weight (as Nitrogen [g]):	2.88E-04
Weight (as NH3, [g]):	3.50E-04
Total Concentration of NH3 (mg/L):	7.00E-01
Volume of Ammonia Gas Present (L):	2.34E-04
ppmV in Dilution Tunnel:	1.51E-02
Emissions Rate (g/hr):	1.99E-02

NH3 Emissions Rate (g/hr) :	**0.02**

Appliance:	EPA Wood Stove	**Burn Rate:**	Low, Cold Start	**Run #:**	41
Fuel:	Birch	**Date:**	8/18/11		

Reporting Units: ○ Total ug ◉ mg/L

Run Information:

	Catch (mg/l)	Volume (L)
Impinger 1	3.46	0.25
Impinger 2	0	0.25

Volume of Gas Sampled ($dsft^3$):	144.7273
Tunnel Flow Rate ($dsft^3$/min):	477.4781

Results:

Average Concentration (mg/L):	1.73E+00
Weight (as Nitrogen [g]):	8.65E-04
Weight (as NH3, [g]):	1.05E-03
Total Concentration of NH3 (mg/L):	2.10E+00
Volume of Ammonia Gas Present (L):	7.01E-04
ppmV in Dilution Tunnel:	1.71E-01
Emissions Rate (g/hr):	2.08E-01

NH3 Emissions Rate (g/hr) :	**0.21**

Measurement of Space-Heating Emissions

Appendix E

Lab Notes

Run Notes

Client: Fairbanks North Star Borough
Model: Pellet Stove ⇒ High
Project #: 477-S-1-1
Tracking #: _____
Run #: 1 Date: 3/8/11
Test Crew: S. Button, L. Pitzman
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

ON High

SECONDARY: _____

TERTIARY:

FAN:

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Pellets

START UP PROCEDURES

BYPASS: _____
FUEL LOADING _____
DOOR:
PRIMARY AIR:

OTHER:

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

on High

SECONDARY: _____

TERTIARY:

FAN:

Technician signature: _____ Date: 3/8/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/8/11

Appliance: Pellet stove *Fuel:* Pellets *Burn Rate:* High

Filter Data

T1: *ID:* *16790* A7518410 *D/T In Freezer:* 3/8/11 16:20 *Preliminary Weight:* —

Q1: *ID:* A7518410 *D/T In Freezer:* 3/8/11 16:20 *Preliminary Weight:* —

Q2: *ID:* FNB #1 *D/T In Freezer:* 3/8/11 16:20 *Preliminary Weight:* .1437

Q3: *ID:* FNB #2 *D/T In Freezer:* 3/8/11 16:20 *Preliminary Weight:* .1402

Q4: *ID:* FNB# 3 *D/T In Dessicator:* 3/8/11 16:20 *Preliminary Weight:* .1452

Q1 Weight record:	D/T: 3/14/11 10:30	D/T: 3/15/11 10:40	D/T:
	Audit: .5001	Audit: .5001	Audit:
	Temp: 72°	Temp: 74	Temp:
	Humidity: 5.4%	Humidity: 3.6%	Humidity:
	Weight: .1452	Weight: .1451	Weight:

Supplementary Data

Pre-test

Gas Analyzer Train: ϕ

Ammonia Train: 0.006 @ -8"

Box A: 0.010 @ -10"

Box B: 0.014 @ -5"

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

PRE	Zero	Span	Mid
O_2	-0.01	20.94	10.64
CO_2	0.00	16.75	10.08
CO	0.00	4.33	2.51

Post-Test

Gas Analyzer Train: ϕ

Box A: 010 @ -10"

Box B: 012 @ -5"

POST	Zero	Span	Mid
O_2	0.04	20.98	10.65
CO_2	0.03	16.78	10.12
CO	-0.00	4.30	2.50

Flow Rate Check:

T1: 4887 mL/min Q3: 1551 mL/min

Q1: 1026 mL/min Q4: — mL/min

Q2: 4029 mL/min

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

3/15/11

Run Notes

Client: Fairbanks North Star Borough
Model: EPA Stove - ~~Spruce~~ Birch - High
Project #: 477-S-1-1
Tracking #: ____
Run #: 2 Date: 3/9/11
Test Crew: A. Krantz, S. Butler, J. Clark
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

fully open

SECONDARY: fixed

TERTIARY: N/A

FAN: N/A

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
55:00	Added 3 lbs					
70:00	Added 5 lbs					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Front:

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 2:00
DOOR: Closed @ 2:00
PRIMARY AIR: Fully open
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

fully open

SECONDARY: Fixed

TERTIARY: N/A

FAN: N/A

Technician signature: _____ Date: 3/10/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/9/11

Appliance: EPA Stove *Fuel:* ~~Spruce~~ Birch JB *Burn Rate:* High

Filter Data

T1: *ID:* A75|810N - * 16791 * *D/T In Freezer:* 3/9/11 16:30

Q1: *ID:* A75|856| *D/T In Freezer:* 3/9/11 16:30

Q2: *ID:* FNB#4 *D/T In Freezer:* 3/9/11 16:30 *Preliminary Weight:* _____

Q3: *ID:* FNB#5 *D/T In Freezer:* 3/9/11 16:30 *Preliminary Weight:* _____

Q4: *ID:* FNB#6 *D/T In Dessicator:* 3/9/11 16:30 *Preliminary Weight:* _____

Q4 weight	D/T: 3/14/11 10:30	D/T: 3/15/11 10:40	D/T: _____
record:	Audit: .5001	Audit: .5001	Audit: _____
	Temp: 72°	Temp: 74°	Temp: _____
	Humidity: 5.4%	Humidity: 3.6%	Humidity: _____
	Weight: .1433	Weight: .1432	Weight: _____

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: ϕ

Ammonia Train: 0.008 @ ~12.5"

Box A: 0.004 @ ~7"

Box B: 0.013 @ ~9"

Post-Test

Leaks: Gas Analyzer Train: ϕ

Box A: 0.009 @ ~7"

Box B: 0.006 @ ~9"

PRE	Zero	Span	Mid
O_2	See other Sheet		
CO_2	↓	↓	↓
CO	↓	↓	↓

POST	Zero	Span	Mid
O_2	See other Sheet		
CO_2	↓	↓	↓
CO	↓	↓	↓

Flow Rate Check:

T1: 5697 mL/min Q2: 3991 mL/min

Q1: 1039 mL/min Q3: 1680 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 2-1 *D/T in Fridge:* 3/9/11 16:30

Impinger 2: *Bottle Number:* 2-2 *D/T in Fridge:* 3/9/11 16:30

Technician Signature/Date: 3/15/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

FUEL DATA

Client: Fairbanks North Star Borough
Model: EPA Stove - Spruce - SB - Birch - High
Project #: 477-S-1-1 Tracking #: ____
Date: 3/9/11 Test Crew: S. Button Run #: 2
OMNI Equipment ID #: ____
FUEL LOAD PREPARED BY: A. Knabe
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER:~~ SB Spruce, Birch, cordwood

PRE-BURN FUEL

MOISTURE CONTENT (METER -- DRY BASIS)

RM Hem: 5.5 lbs

CALIBRATION: Cal Value (1) = 12% Actual Reading 12%
Cal Value (2) = 22% Actual Reading 22%

Piece	Length	Readings			Type
1	____ ft	18.3	19	18.8	cordwood
2	____ ft	20.3	20.4	18	↓
3	____ ft	18	21.1	18.9	

16.0 lbs

Length of cut pieces: ≈16 inches Pre-Burn Fuel Average Moisture: 19.2%

Time (clock): ____ Room Temperature (F): 65 Initials: SB

TEST FUEL

FUEL TYPE AND AMOUNT: SB 2×4 cordwood 5 4 × 4 ____
CALCULATED LOAD WEIGHT: ____ ACTUAL LOAD WEIGHT: ____ (2 × 4)
____ (4 × 4)
FUEL PIECE LENGTH: x 16 inches 16.4 lbs Total

MOISTURE CONTENT (METER -- DRY BASIS)

PIECE	READINGS			TYPE
1	18.2	18.2	18.0	cordwood
2	14.0	15.7	13.7	↓
3	16.7	16.6	19	
4	17.5	16.7	14.9	
5	21.8	25.2	21.3	
6				
7				
8				
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: 17.83%

Time (clock): ____ Room Temperature (F): 65 Initials: SB

Technician signature: [signature] Date: 3/9/11

Run Notes

Client: Fairbanks North Star Borough
Model: EPA stove - Spruce - High
Project #: 477-S-1-1
Tracking #: _____
Run #: 3 Date: 3/10/11
Test Crew: S. Baxter, A. Krawitz, J. Clark
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Fully open

SECONDARY: Fixed

TERTIARY: N/A

FAN: N/A

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
4 min	Added 4.5 lbs of wood					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Cordwood

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Runs @ 20 sec
DOOR: closed @ 45 sec
PRIMARY AIR: Jet @ 0 sec
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Fully open

SECONDARY: Fixed

TERTIARY: N/A

FAN: N/A

Technician signature: _____ Date: 3/10/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/10/11

Appliance: Epa Stove *Fuel:* Spruce *Burn Rate:* High

Filter Data

T1: *ID:* *16792* A751809 *D/T In Freezer:* 3/10 2:30 *Preliminary Weight:* _____

Q1: *ID:* A758550 *D/T In Freezer:* 3/10 2:30 *Preliminary Weight:* _____

Q2: *ID:* FNB #7 *D/T In Freezer:* 3/10 2:36 *Preliminary Weight:* _____

Q3: *ID:* FNB #8 *D/T In Freezer:* 3/10 2:30 *Preliminary Weight:* _____

Q4: *ID:* FNB #9 *D/T In Dessicator:* 3/10 2:30 *Preliminary Weight:* .1451

Q1 Weight record:	D/T: 3/14/11 10:30	D/T: 3/15/11 10:40	D/T: _____
	Audit: .5001	Audit: .5001	Audit: _____
	Temp: 72°	Temp: 74°	Temp: _____
	Humidity: 5.4%	Humidity: 3.6%	Humidity: _____
	Weight: .1447	Weight: .1448	Weight: _____

Supplementary Data

Pre-test

Gas Analyzer Train: ϕ

Box A: 0.004 @ -13"

Ammonia Train: 0.005 @ -11

Box B: 0.013 @ -10"

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

PRE	Zero	Span	Mid
O_2	See other data sheet		
CO_2	↓	↓	↓
CO	↓	↓	↓

Post-Test

Gas Analyzer Train: ϕ

Box A: .004 @ -13"

Box B: .013 @ -10"

POST	Zero	Span	Mid
O_2	-0.10	21.10	10.66
CO_2	0.06	16.86	10.18
CO	-0.00	4.34	2.52

Flow Rate Check:

T1: 5445 mL/min Q3: 1563 mL/min

Q1: 1043 mL/min Q4: N/A mL/min

Q2: 3869 mL/min

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Technician Signature/Date: 3/15/11

FUEL DATA

Client: Fairbanks North Star Borough
Model: EPA Stove - Spruce - High Burn
Project #: 477-S-1-1 Tracking #: ____
Date: 3/10/11 Test Crew: S. Button Run #: 3
OMNI Equipment ID #: ____
FUEL LOAD PREPARED BY: A. Krawl
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER,~~ ~~DIMENSIONAL LUMBER.~~ SB Spruce, cordwood

PRE-BURN FUEL

Kindling: 4, 7 16s

MOISTURE CONTENT (METER – – DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading 12%
Cal Value (2) = 22% Actual Reading 22%

Piece	Length		Readings		Type
1	____ ft	21.9	20.9	15.4	cordwood
2	____ ft	16.6	15.2	20.7	"
3	____ ft	15.7	16.3	17.6	"

Length of cut pieces: ≈ 16" inches Pre-Burn Fuel Average Moisture:

Time (clock): ____ Room Temperature (F): 65 Initials: SB 16.0 16s

TEST FUEL

FUEL TYPE AND AMOUNT: ~~SB 2×4~~ cordwood - 4 4 × 4 ____
CALCULATED LOAD WEIGHT: ____ ACTUAL LOAD WEIGHT: ____ (2 × 4)
____ (4 × 4)
16.1 Total
FUEL PIECE LENGTH: ≈ 16"

MOISTURE CONTENT (METER – – DRY BASIS)

PIECE	READINGS			TYPE
1	28.3	21.7	28.2	cordwood
2	18.2	13.5	18.5	"
3	32.3	30.0	31.0	"
4	17.8	17.6	18.0	"
5				
6				
7				
8				
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: 23.75%

Time (clock): ____ Room Temperature (F): 65 Initials: SB

Technician signature: [signature] Date: 3/10/11

Run Notes

Client: Fairbanks North Star Borough
Model: EPA Birch Low 2
Project #: 477-S-1-1
Tracking #: ____
Run #: 5 Date: 3/17/11
Test Crew: A. Krantz, S. Button, J. Clark
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1/4" from fully closed

SECONDARY: N/A Fixed

TERTIARY: N/A

FAN: N/A

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
None						

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

cordwood (6 pcs.)

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 30 sec
DOOR: Closed @ 5 min
PRIMARY AIR: Set @ 7 min
OTHER:

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

1/4" from fully closed

SECONDARY: fixed

TERTIARY: N/A

FAN: N/A

Technician signature: _____ Date: 3/18/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/17/11

Appliance: EPA Stove *Fuel:* Birch *Burn Rate:* Low #2

Filter Data

T1: *ID:* A751977 + A751801M changed @ 28:00 *D/T In Freezer:* 3/17 4:00

Q1: *ID:* A751853Y *D/T In Freezer:* 3/17 4:00

Q2: *ID:* FNB #14 *D/T In Freezer:* 3/17 4:06 *Preliminary Weight:* .1508

Q3: *ID:* FNB #15 *D/T In Freezer:* 3/17 4:00 *Preliminary Weight:* .1482

Q4: *ID:* FNB #16 *D/T In Dessicator:* 3/17 4:00 *Preliminary Weight:* .1440
FNB #17 changed 24:00

Q4 weight	D/T:	3/25/11 2:00	D/T: 3/28/11	D/T:	3/29/11
record:	Audit:	.5002	Audit: .5001	Audit:	.5002
	Temp:	73.0	Temp: 73	Temp:	73
	Humidity:	5.1	Humidity: 2.2	Humidity:	6.1
	Weight:	.1689 .1434	Weight: .1688 .1432	Weight:	.1690 .1432

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: Ø

Ammonia Train: .007@-13"

Box A: .002 @-18"

Box B: .003 @-19"

PRE	Zero	Span	Mid
O_2	SEE GAS DATA		
CO_2			
CO			

Post-Test

Leaks: Gas Analyzer Train: Ø

Box A: .007 @-13"

Box B: .009 @-8"

POST	Zero	Span	Mid
O_2	See QFS Gas Data		
CO_2	↓	↓	↓
CO	↓	↓	↓

Flow Rate Check:

T1: 2555 mL/min Q2: 3150 mL/min

Q1: 1073 mL/min Q3: 1590 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 5-1 *D/T in Fridge:* 3/17 4:15

Impinger 2: *Bottle Number:* 5-2 *D/T in Fridge:* 3/17 4:15

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Technician Signature/Date: 3/29/11

Kindling: 5.0 lb
Preburn: 15.9 lb
Test load: 15.9 lb

FUEL DATA

Client: FNB
Model: EPA Birch Low 2
Project #: 477-S-01-1 Tracking #: ____
Date: 3/17/14 Test Crew: AH, SB, JC Run #: 5
OMNI Equipment ID #: ____
FUEL LOAD PREPARED BY: AH
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER.~~ Birch cordwood

PRE-BURN FUEL

MOISTURE CONTENT (METER – – DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading 12.0%
Cal Value (2) = 22% Actual Reading 22.0%

Piece	Length	Readings			Type	
1	____ ft	163	159	165	157	
2	____ ft	143	145	148	194	
3	____ ft	182	176	177	168	172

Length of cut pieces: ~16" inches Pre-Burn Fuel Average Moisture:

Time (clock): ____ Room Temperature (F): 68 Initials: AH

TEST FUEL

FUEL TYPE AND AMOUNT: 2 × 4 N/A 4 × 4 N/A
CALCULATED LOAD WEIGHT: 15.9 ACTUAL LOAD WEIGHT: ____ (2 × 4)
____ (4 × 4)
15.9 Total
FUEL PIECE LENGTH: ~16"

MOISTURE CONTENT (METER – – DRY BASIS)

PIECE	READINGS			TYPE
1	174	185	161	cord
2	153	154	156	
3	163	165	157	
4	170	184	178	
5	181	180	171	
6	156	160	155	
7				
8				
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: 16.7%

Time (clock): 8:30 Room Temperature (F): 68 Initials: AH

Technician signature: [signature] Date: 3/17/14

Run Notes

Client: FNB
Model: EPA Stove Spruce Low
Project #: 477-S-01-1
Tracking #: ___
Run #: 6 Date: 3/18/11
Test Crew: A. Knowitz, J. Clark, S. Button
OMNI Equipment ID #(s): ___

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1/4" from fully Closed

SECONDARY: fixed
TERTIARY: N/A
FAN: N/A

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

cordwood (4 pcs)

START UP PROCEDURES
BYPASS: N/A
FUEL LOADING: Door @ 1 min
DOOR: closed @ 4 min
PRIMARY AIR: set @ 5 min
OTHER: ___

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

1/4" from fully Closed

SECONDARY: fixed
TERTIARY: N/A
FAN: N/A

Technician signature: ___ Date: 3/18/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/18/11

Appliance: EPA Stove *Fuel:* Spruce *Burn Rate:* Low

Filter Data

T1: *ID:* A7518075 * 16794 * *D/T In Freezer:* 3/18/11 16:26

Q1: *ID:* A751842 V *D/T In Freezer:* 3/18/11 16:20

Q2: *ID:* FNB #18 *D/T In Freezer:* 3/18/11 16:20 *Preliminory Weight:* .1417

Q3: *ID:* FNB #19 *D/T In Freezer:* 3/18/11 16:20 *Preliminary Weight:* .1395

Q4: *ID:* FNB #20 *D/T In Dessicator:* 3/18/11 16:24 *Preliminary Weight:* .1454

Q4 weight	D/T:	3/25/11	D/T: 3/28/11	D/T:	3/29/11
record:	Audit:	.5002	Audit: .5001	Audit:	.5002
	Temp:	73.0	Temp: 73	Temp:	73
	Humidity:	5.1	Humidity: 2.2	Humidity:	6.1
	Weight:	~~.2048~~ .1447	Weight: .1451	Weight:	.1449

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: ϕ

Ammonia Train: .011 @ -12"

Box A: .010 @ -10"

Box B: .003 @ -7"

Post-Test

Leaks: Gas Analyzer Train: ϕ

Box A: .001 @ -8.8

Box B: .003 @ -7.0

PRE	Zero	Span	Mid
O_2	See ORS Data		
CO_2			
CO			

POST	Zero	Span	Mid
O_2			
CO_2			
CO			

Flow Rate Check:

T1: 815 mL/min Q2: 1565 mL/min

Q1: 960 mL/min Q3: 1490 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* G-1 *D/T in Fridge:* 3/18/11 16:30

Impinger 2: *Bottle Number:* G-2 *D/T in Fridge:* 3/18/11 16:30

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Technician Signature/Date: 3/29/11

Loading: 5 lb
Preburn: 16.1 lb
Test: 16.0 lb

FUEL DATA

Client: FNB
Model: EPA Stove Spruce Low
Project #: 477-S-01-1 Tracking #: ____
Date: 3/08/11 Test Crew: AH, SB, JC Run #: 6
OMNI Equipment ID #: 340
FUEL LOAD PREPARED BY: A. Krantz
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER.~~ spruce cordwood

PRE-BURN FUEL

MOISTURE CONTENT (METER – – DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading 12.0
Cal Value (2) = 22% Actual Reading 22.0

Piece	Length		Readings		Type
1	____ ft	21.9	14.4	16.6	23.0
2	____ ft	17.2	14.8	15.5	20.4
3	____ ft	15.9	21.9	14.1	19.4

Length of cut pieces: ~16 inches Pre-Burn Fuel Average Moisture:

Time (clock): ____ Room Temperature (F): ____ Initials: AH

TEST FUEL

FUEL TYPE AND AMOUNT: 2 × 4 N/A 4 × 4 N/A
CALCULATED LOAD WEIGHT: 16.0 ACTUAL LOAD WEIGHT: ____ (2 × 4)
____ (4 × 4)
FUEL PIECE LENGTH: ~16" 16.0 Total

MOISTURE CONTENT (METER – – DRY BASIS)

PIECE	READINGS			TYPE
1	14.1	14.2	14.9	cord
2	14.5	17.2	14.1	
3	22.3	22.5	21.0	
4	20.6	23.1	16.2	
5				
6				
7				
8				
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: 17.9%

Time (clock): 11:15 Room Temperature (F): 70 Initials: AH

Technician signature: [signature] Date: 3/18/11

Run Notes

Client: Fairbank North Star Borough
Model: Phase II Boiler Birch Hdg 2
Project #: 477-S-1-1
Tracking #: ____
Run #: 8 Date: 3/22/11
Test Crew: S, Buffan, J clark
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

ON high

SECONDARY: ____

TERTIARY: FIXED

FAN: ____

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
30 min	add 40 lbs of preburn fuel					
76 min	started coals					
125 min	started coals					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Card wood

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 90 sec
DOOR: close d 2 min
PRIMARY AIR: N/A
OTHER: ____

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

High

SECONDARY: ____

TERTIARY: fixed

FAN: ____

Technician signature: ____ Date: 3/22/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/22/11

Appliance: Phase II Boiler *Fuel:* Birch *Burn Rate:* High

Filter Data

T1: *ID:* A751804P *16797* *D/T In Freezer:* 3/22/11 15:00

Q1: *ID:* A751852 X *D/T In Freezer:* 3/22/11 15:00

Q2: *ID:* FNB #27 *D/T In Freezer:* 3/22/11 15:00 *Preliminary Weight:* .1455

Q3: *ID:* FNB#26 *D/T In Freezer:* 3/22/11 15:00 *Preliminary Weight:* .1685

Q4: *ID:* FNB#25 *D/T In* ***Dessicator:*** 3/22/11 15:00 *Preliminary Weight:* .1827

Q4 weight	D/T:	3/23/11	D/T: 3/23/11	D/T:	3/24/11
record:	Audit:	.5004	Audit: .5001	Audit:	.5002
	Temp:	73	Temp: 73	Temp:	73
	Humidity:	5.1	Humidity: 2.2	Humidity:	6.1
	Weight:	.1817	Weight: .1816	Weight:	.1816

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: Ø

Ammonia Train: .002 @ -10"

Box A: .005 @ -18"

Box B: .002 @ -10"

Post-Test

Leaks: Gas Analyzer Train: Ø

Box A: .006 @ -15"

Box B: .005 @ -17"

PRE	Zero	Span	Mid
O_2	See	OES	Mast
CO_2			
CO			

POST	Zero	Span	Mid
O_2			
CO_2			
CO			

Flow Rate Check:

T1: ~~415.4~~ 923.86 mL/min Q2: 1443.5 mL/min

Q1: 1068.9 mL/min Q3: 1332.3 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 8-1 *D/T in Fridge:* 3/22/11 15:00

Impinger 2: *Battle Number:* 8-1 *D/T in Fridge:* 3/22/11 15:00

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Technician Signature/Date: 3/24/11

Run 8

Boiler Fuel Moisture

Client: FNB
Model: EPA Boiler Birch High 2
Project Number: 477-S-01-1

Preburn Weight: 100.1 lb
Fuel Weight: 140.2 lb

Readings:

16.3	17.5	17.9	19.1	17.8
18.5	15.5	15.7	23.2	18.4
15.9	19.1	16.3	17.4	
17.6	18.1	16.0	13.1	
26.7	17.9	22.2	19.8	
18.7	17.3	17.5	17.6	
14.7	18.1	16.3	19.9	
18.4	14.1	18.0	19.7	
24.9	18.6	16.4	20.5	
16.9	23.8	18.1	13.9	
16.0	16.7	16.5	20.6	

Average: **18.11** % Dry Basis

4/26/11

OMNI-Test Laboratories, Inc.

Run Notes

Client: Fairbanks North Star Borough
Model: Phase II Boiler Birch Low
Project #: 477-S-1-1
Tracking #: ____
Run #: 9 Date: 3/22/11
Test Crew: A. Leavitt, S. Butler
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

On Low

SECONDARY: Fixed

TERTIARY:

FAN:

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
1:15:00	Coals Stirred					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Cordwood

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 2 min
DOOR: Closed @ 2 min
PRIMARY AIR:
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Low

SECONDARY: Fixed

TERTIARY:

FAN:

Technician signature: _____ Date: 3/23/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1
Date: 3/22/11
Appliance: Phase II OWHH *Fuel:* Birch *Burn Rate:* Low

Filter Data

T1: *ID:* A7518030 *16798* *D/T In Freezer:* 3/23 4:00
Q1: *ID:* A7518511W *D/T In Freezer:* 3/23 4:00
Q2: *ID:* FNB #28 *D/T In Freezer:* 3/23 4:00 *Preliminary Weight:* .1565
Q3: *ID:* FNB #29 *D/T In Freezer:* 3/23 4:00 *Preliminary Weight:* .1561
Q4: *ID:* FNB #30 *D/T In Dessicator:* 3/23 4:00 *Preliminary Weight:* .1626
FNB #31

Q4 weight record:	D/T: 3/25/11	D/T: 3/28/11	D/T: 3/29/11	4/5/11	4/11
	Audit: .5002	Audit: .5004	Audit: .5002	.5002	.5002
	Temp: 73	Temp: 73	Temp: 73	73	75.4
	Humidity: 5.1	Humidity: 2.2	Humidity: 6.1	5.1	8.1
	Weight: .2107 .1613	Weight: .2107 .1616	Weight: .2105 .1610	.2091 .1611	.2092 ~~.1611~~

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: 0
Ammonia Train: .010 @ -11"
Box A: .003 @ -10"
Box B: .004 @ -15"

PRE	Zero	Span	Mid
O_2	See other Data		
CO_2			
CO			

Post-Test

Leaks: Gas Analyzer Train: ~~0~~ Failed post test leak check
Box A: .006 @ -10
Box B: .005 @ -15"

POST	Zero	Span	Mid
O_2			
CO_2			
CO			

Flow Rate Check:

T1: 780.85 mL/min Q2: 1755.1 mL/min
Q1: 875.09 mL/min Q3: 1351.4 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 4-1 *D/T in Fridge:* 4:00 3/23
Impinger 2: *Bottle Number:* 9-2 *D/T in Fridge:* 4:00 3/23

Technician Signature/Date: 3/23

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Run 9

Boiler Fuel Moisture

Client: FNB
Model: EPA Boiler Birch Low
Project Number: 477-S-01-1

Preburn Weight: 100.0 lb
Fuel Weight: 140.2 lb

Readings:

22.8	14.0	14.5	19.1	15.6
15.5	16.8	15.8	16.6	18.7
11.6	14.1	18.1	14.7	18.4
18.5	16.7	16.7	15.5	
16.0	18.2	19.8	18.1	
14.0	17.8	17.9	14.5	
16.7	13.3	18.0	18.0	
13.1	17.0	17.9	13.6	
14.3	16.1	20.6	21.6	
13.9	13.5	15.4	15.0	
15.9	17.3	16.5	13.1	

Average: **16.40** % Dry Basis

3/22/11

November 14, 2014

Run Notes

Client: Fairbanks North Star Borough
Model: EPA OWHH Spruce high
Project #: 477-S-1-1
Tracking #: _____
Run #: 10 Date: 3/23/11
Test Crew: S. Button, J. Clark
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

on High

SECONDARY: _____

TERTIARY: fixed

FAN: _____

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Cord wood

START UP PROCEDURES

BYPASS: Closed @ 90 sec
FUEL LOADING: Closed @ 1 min 52 switch!
DOOR: Done @ 45 sec
PRIMARY AIR: N/A
OTHER: _____

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

on high

SECONDARY: _____

TERTIARY: fixed

FAN: _____

Technician signature: _____ Date: 3/23/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/23/11

Appliance: EPA OWHH *Fuel:* Spruce *Burn Rate:* High

Filter Data

T1: *ID:* A75179388 X17004 *D/T In Freezer:* 3/23/11 16:30

Q1: *ID:* A751850 V *D/T In Freezer:* 3/23/11 16:30

Q2: *ID:* FNB #34 *D/T In Freezer:* 3/23/11 16:30 *Preliminary Weight:* _____

Q3: *ID:* FNB #33 *D/T In Freezer:* 3/23/11 16:30 *Preliminary Weight:* _____

Q4: *ID:* FNB #32 +FNB #35 *D/T In Dessicator:* 3/23/11 16:30 *Preliminary Weight:* .1537 / .1512

Q4 weight	D/T: 3/25/11	D/T: 3/28	D/T: 3/29	4/5
record:	Audit: .5002	Audit: .5001	Audit: .5002	.5002
	Temp: 73	Temp: 73	Temp: 73	73
	Humidity: 5.1	Humidity: 2.2	Humidity: 6.1	5.1
	Weight: .1550 .1517	Weight: .1537 .1513	Weight: .1533 .1510	.1534 .1511

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: ∅

Ammonia Train: .004 @ .10"

Box A: .009 @ -11.5"

Box B: .001 @ -10"

Post-Test

Leaks: Gas Analyzer Train: ∅

Box A: .005 @ -10"

Box B: .008 @ ~9"

PRE	Zero	Span	Mid
O_2	See other data sheet		
CO_2			
CO			

POST	Zero	Span	Mid
O_2			
CO_2			
CO			

Flow Rate Check:

T1: 798 mL/min Q2: 1571 mL/min

Q1: 1051 mL/min Q3: 1640 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 10-1 *D/T in Fridge:* 16:45 3/23/11

Impinger 2: *Bottle Number:* 10-2 *D/T in Fridge:* 16:45 3/23/11

Technician Signature/Date: [signature] 4/5/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Run 10

Boiler Fuel Moisture

Client: FNB
Model: EPA Boiler Spruce High
Project Number: 477-S-01-1

Preburn Weight: 100 lb
Fuel Weight: 140 lb

Readings:

19.4	22.0	13.7	32.3
26.4	18.3	13.4	25.1
26.8	21.3	29.3	21.4
31.2	21.3	24.2	13.9
16.3	20.0	14.8	17.1
33.0	13.2	12.7	26.4
25.3	26.9	15.7	18.2
13.1	14.2	14.9	20.1
13.2	14.9	13.2	21.7
16.5	35.2	12.3	33.7
23.4	27.0	20.5	

Average: **20.78** % Dry Basis

4/26/11

Run Notes

Client: Fairbanks North Star Borough
Model: EPA OWHH Spruce Low
Project #: 477-S-1-1
Tracking #: _____
Run #: 11 Date: 3/24/11
Test Crew: S. Burton
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Cat II

SECONDARY: _____

TERTIARY: Fixed

FAN: _____

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
↓	N/A	↓				

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Cordwood

START UP PROCEDURES

BYPASS: Closed @ 1 min
FUEL LOADING: Done @ 4.5 sec
DOOR: Closed @ 1 min
PRIMARY AIR: _____
N/A
OTHER: _____

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Cat IV

SECONDARY: _____

TERTIARY: Fixed

FAN: _____

Technician signature: _____ Date: 3/24/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1
Date: 3/24/11
Appliance: EPA OWHH *Fuel:* Spruce *Burn Rate:* Low

Filter Data

T1: *ID:* A75100L * 17002 * *D/T In Freezer:* 3/24 9:15
Q1: *ID:* A751844X *D/T In Freezer:* 3/24 9:15
Q2: *ID:* FNB#36 *D/T In Freezer:* 3/24 9:15 *Preliminary Weight:* .1795
Q3: *ID:* FNB#37 *D/T In Freezer:* 3/24 9:15 *Preliminary Weight:* .1560
Q4: *ID:* FNB# 38 #39 *D/T In Dessicator:* 3/24 9:30 *Preliminary Weight:* .2361 .1569

						4/5	4/4
Q4 weight	D/T:	3/25	D/T:	3/28	D/T:	3/29		
record:	Audit:	.5002	Audit:	.5001	Audit:	.5002	.5002	.5002
	Temp:	73	Temp:	73	Temp:	73	73	73.4
	Humidity:	5.1	Humidity:	2.2	Humidity:	6.1	5.1	8.1
	Weight:	.2349 .1573	Weight:	.2338 .1567	Weight:	.2320 .1562	.2290 .1506	.2288

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: ϕ
Ammonia Train: .004@ 12"
Box A: .002 @ -10"
Box B: .007 @ -11"

Post-Test

Leaks: Gas Analyzer Train: ϕ
Box A: .006 @ -10"
Box B: .019 @ -12"

PRE	Zero	Span	Mid
O_2	See other data sheet		
CO_2			
CO			

POST	Zero	Span	Mid
O_2			
CO_2			
CO			

Flow Rate Check:

T1: .9145 L/min Q2: 4.7830 L/min
Q1: 1.1167 L/min Q3: 1.6122 L/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 11-1 *D/T in Fridge:* 3/24 9:00
Impinger 2: *Bottle Number:* 11-2 *D/T in Fridge:* 3/24 9:00

Technician Signature/Date: 3/27

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Run 11

Boiler Fuel Moisture

Client: FNB
Model: EPA Boiler Spruce Low
Project Number: 477-S-01-1

Preburn Weight: 100 lb
Fuel Weight: 141 lb

Readings:

29.1	28.6	15.4	19.8
29.0	15.8	26.0	17.4
24.6	17.9	23.6	21.8
21.1	20.4	20.4	22.3
27.0	15.4	16.1	28.1
15.3	13.8	15.3	19.8
16.6	14.5	15.3	17.4
24.2	14.8	14.9	21.3
20.2	25.4	18.8	18.7
15.0	21.8	21.4	
17.5	22.4	29.3	

Average: **20.32** % Dry Basis

3/24/1

Run Notes

Client: FNB
Model: Conventional Stove Spruce High
Project #: 477-S-01-1
Tracking #: ____
Run #: 12 Date: 3/30/11
Test Crew: AH, SB, JC
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Maxed out

SECONDARY: N/A

TERTIARY:

FAN:

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
36:00	Added 6.4 lb					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Maxed Out

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 30 sec
DOOR: Closed @ 30 sec
PRIMARY AIR: Fully open
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Cordwood

SECONDARY: N/A

TERTIARY:

FAN:

Technician signature: _____ Date: 3/30/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1
Date: 3/30/11
Appliance: Conventional Stove *Fuel:* Spruce *Burn Rate:* High

Filter Data

T1: *ID:* A751826V *D/T In Freezer:* 3/30/11
Q1: *ID:* A751840T *D/T In Freezer:* 3/30/11
Q2: *ID:* FNB #40 *D/T In Freezer:* 3/30/11 *Preliminary Weight:* N/A
Q3: *ID:* FNB #41 *D/T In Freezer:* 3/30/11 *Preliminary Weight:* N/A
Q4: *ID:* FNB #s 42+43 *D/T In Dessicator:* 3/30/11 *Preliminary Weight:* 42: .1402 43: .1432

Q4 weight record:	D/T: 4/5/11	D/T: 4/11/11	D/T: 4/12
	Audit: .5002	Audit: .5002	Audit: .5002
	Temp: 73	Temp: 75.4	Temp: 72.4
	Humidity: 5.1	Humidity: 8.1	Humidity: 9.5
	Weight: .1348/.1432	Weight: .1412/~~.1396~~ .1394	Weight: N/A/.1431

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: 0.002@10" AM
Ammonia Train: ϕ
Box A: 0.000@-11"
Box B: 0000@-11"

Post-Test

Leaks: Gas Analyzer Train: ϕ
Box A: .000 @ -11"
Box B: .000 @ -11"

PRE	Zero	Span	Mid
O_2	see	OES	Data
CO_2			
CO			

POST	Zero	Span	Mid
O_2			
CO_2			
CO	4	4	4

Flow Rate Check:

T1: 857.52 mL/min Q2: 3701.7 mL/min
Q1: 901.43 mL/min Q3: 1531.3 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 12-1 *D/T in Fridge:* 3/30/11
Impinger 2: *Bottle Number:* 12-2 *D/T in Fridge:* 3/30/11

Technician Signature/Date: 3/30/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

OMNI-Test Laboratories, Inc.

Kindling : 5 lb
Pre : 15 lb
Test : 14.7 lb

FUEL DATA

Client: FNB
Model: Conventional Stove Spruce High
Project #: 477-S-01-1 Tracking #: _____
Date: 3/30/16 Test Crew: _____ Run #: 12
OMNI Equipment ID #: _____
FUEL LOAD PREPARED BY: A. Hewitt
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER.~~ Spruce Cordwood

PRE-BURN FUEL

MOISTURE CONTENT (METER – – DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading _____
Cal Value (2) = 22% Actual Reading _____

Piece	Length		Readings			Type
1	____ ft	14.9	13.7	13.0		13.8
2	____ ft	14.1	12.2	14.7		15.4
3	____ ft	13.2	15.2			

Length of cut pieces: ~16 inches Pre-Burn Fuel Average Moisture:

Time (clock): _____ Room Temperature (F): 71 Initials: AH

TEST FUEL

FUEL TYPE AND AMOUNT: 2 × 4 N/A 4 × 4 N/A
CALCULATED LOAD WEIGHT: 14.7 ACTUAL LOAD WEIGHT: _____ (2 × 4)
_____ (4 × 4)
14.7 Total
FUEL PIECE LENGTH: ~16"

MOISTURE CONTENT (METER – – DRY BASIS)

PIECE	READINGS			TYPE
1	18.9	19.6	19.8	Cord
2	13.9	13.4	13.8	
3	19.1	19.0	20.1	
4	16.3	17.9	17.8	
5				
6				
7				
8				
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: 17.38

Time (clock): _____ Room Temperature (F): 71 Initials: AH

Technician signature: _____ Date: 3/30/16

OMNI-Test Laboratories, Inc.

15:00 Replace Q4 (FNB #47)
19:00 Replace G1 + T1 (A75(K)SW

Run Notes

Client: FNB
Model: Conventional Stove Birch High
Project #: 477-S-01-1
Tracking #: _____
Run #: 13 Date: 3/3/111
Test Crew: Aaron H, J Clark
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

On High

SECONDARY: N/A

TERTIARY:

FAN:

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
24:00	Added 8 lb					
45:00	Added 5.7 lb					
1:05:00	Added 6.7 lb					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

cordwood

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 1:00
DOOR: Closed @ 1:30
PRIMARY AIR:

OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

On high

SECONDARY:

TERTIARY: N/A

FAN:

Technician signature: Aaron Hunter Date: 3/3/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1
Date: 3/31/11
Appliance: Woodstream Stove *Fuel:* Birch *Burn Rate:* High

Filter Data

T1: *ID:* A751814R + A751825U *D/T In Freezer:* 3/31/11 13:00
Q1: *ID:* A751839O *D/T In Freezer:* 3/31/11 13:00
Q2: *ID:* FNB #44 *D/T In Freezer:* 3/31/11 13:00 *Preliminary Weight:* N/A
Q3: *ID:* FNB #45 *D/T In Freezer:* 3/31/11 13:00 *Preliminary Weight:* N/A
Q4: *ID:* FNB FH #6497 *D/T In Dessicator:* 3/31/11 13:00 *Preliminary Weight:* .1617 / .1530

Q4 weight record:	D/T: 4/5/11	D/T: 4/11/11	D/T: 4/12
	Audit: .5002	Audit: .5002	Audit: .5002
	Temp: 73	Temp: 75.4	Temp: 72.4
	Humidity: 5.1	Humidity: 8.1	Humidity: 9.5
	Weight: .1585/.1526	Weight: .1576/.1522	Weight: .1576/.1520

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: ~~.006 @ -15"~~ Ø
Ammonia Train: .006 @ -15"
Box A: .0103 @ -10"
Box B: .011 @ -10"

PRE	Zero	Span	Mid
O_2	N/A	N/A	N/A
CO_2			
CO			

Post-Test

Leaks: Gas Analyzer Train: ~~Ø~~ 5B failed post-test leak check
Box A: ~~Ø~~ @
Box B: ~~Ø~~ @

POST	Zero	Span	Mid
O_2			
CO_2			
CO			

Flow Rate Check:

T1: 644.48 mL/min Q2: 5187.0 mL/min
Q1: 8027.6 mL/min Q3: 1231.0 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 13-1 *D/T in Fridge:* 3/31/11 12:40
Impinger 2: *Bottle Number:* 13-2 *D/T in Fridge:* 3/31/11 12:40

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Technician Signature/Date: 4/12/11

FUEL DATA

Client: FNB
Model: Conventional Stove Birch High
Project #: 477-S-01-1 Tracking #: ____
Date: 3/31/11 Test Crew: AH, SB, JC Run #: 13
OMNI Equipment ID #: ____
FUEL LOAD PREPARED BY: AH
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER.~~ Birch cordwood

PRE-BURN FUEL

MOISTURE CONTENT (METER – – DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading ____
Cal Value (2) = 22% Actual Reading ____

Piece	Length	Readings			Type
1	____ ft	15.0	34.3	13.4	14.4
2	____ ft	12.9	12.4	18.4	16.5
3	____ ft	14.5	17.2	17.7	14.7

Length of cut pieces: ~16 inches Pre-Burn Fuel Average Moisture:

Time (clock): ____ Room Temperature (F): 71 Initials: AH

TEST FUEL

FUEL TYPE AND AMOUNT: 2 × 4 ____ 4 × 4 ____
CALCULATED LOAD WEIGHT: ____ ACTUAL LOAD WEIGHT: N/A (2 × 4)
N/A (4 × 4)
~~14.00~~ 14.9 Total

FUEL PIECE LENGTH: ____

MOISTURE CONTENT (METER – – DRY BASIS)

PIECE	READINGS			TYPE
1	14.6	12.5	15.3	Cold
2	16.3	16.8	12.4	
3	23.9	32.7	20.3	
4	16.5	16.5	13.2	
5	15.4	16.7	17.1	
6	13.2	15.3	13.1	
7				
8				
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: ____

Time (clock): ____ Room Temperature (F): 71 Initials: AH

Technician signature: [signature] Date: 3/31/11

Run Notes

Client: FNB
Model: Conventional Stove Spruce Low
Project #: 477-S-01-1
Tracking #: ____
Run #: 14 Date: ~~3/30/11~~ 4/1/11
Test Crew: MH, SA, JC
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

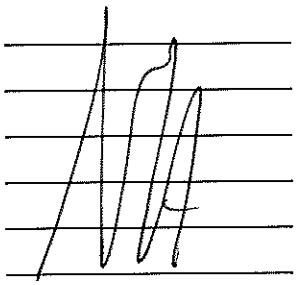
PRIMARY:

On Low

SECONDARY:

TERTIARY:

FAN:



PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
33:00	Added 6.1 15					
52:00	Added 7.1 15					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Cordwood (4 pc)

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Door @ ~~30sec~~ 30sec
DOOR: Closed @ 1min
PRIMARY AIR:
OTHER: N/A

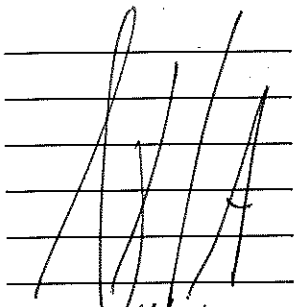
DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

On low

SECONDARY:

TERTIARY:

FAN:



Technician signature: _____ Date: 4/1/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 3/31/11

Appliance: Conventional Stove *Fuel:* Spruce *Burn Rate:* Low

Filter Data

T1: *ID:* A751855 #16786K *D/T In Freezer:* 4/1/11

Q1: *ID:* A751832T *D/T In Freezer:* 4/1/11

Q2: *ID:* FNB#48 *D/T In Freezer:* 4/1/11 *Preliminary Weight:* N/A

Q3: *ID:* FNB#49 *D/T In Freezer:* 4/1/11 *Preliminary Weight:* N/A

Q4: *ID:* FNB #50 *D/T In Dessicator:* 4/1/11 *Preliminary Weight:* .1499
FNB #51 .1451

Q4 weight	D/T: 4/5/11	D/T: 4/6/11	D/T: 4/12
record:	Audit: .5002	Audit: .5002	Audit: .5002
	Temp: 73	Temp: 75.4	Temp: 77.4
	Humidity: 5.1	Humidity: 8.1	Humidity: 9.5
	Weight: .1491/.1451	Weight: .1488/.1450	Weight: .1487/N/A

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: ∅

Ammonia Train: .005 @ -15"

Box A: .006 @ -11

Box B: .011 @ -9

Post-Test

Leaks: Gas Analyzer Train: ∅

Box A: .006 @ -7"

Box B: .015 @ -11"

PRE	Zero	Span	Mid
O_2	SEE	OES	DATA
CO_2			
CO			

POST	Zero	Span	Mid
O_2			
CO_2			
CO			

Flow Rate Check:

T1: 756 mL/min Q2: 3603 mL/min

Q1: 937 mL/min Q3: 1535 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 14-1 *D/T in Fridge:* 4/1/11 12:30

Impinger 2: *Bottle Number:* 14-2 *D/T in Fridge:* 4/1/11 12:30

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

Technician Signature/Date: [signature] 4/12/11

Preburn: 15 lb
Test: 14.8 lb

FUEL DATA

Client: FNB
Model: Conventional Stove Spruce Low
Project #: 477-S-01-1 Tracking #: ____
Date: 4/1/11 Test Crew: AH, SB, JC Run #: 14
OMNI Equipment ID #: ____
FUEL LOAD PREPARED BY: AH
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER.~~ spruce cordwood

PRE-BURN FUEL

MOISTURE CONTENT (METER – – DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading 12.0
Cal Value (2) = 22% Actual Reading 22.0

Piece	Length		Readings		~~Type~~
1	____ ft	27.6	14.5	24.1	32.1
2	____ ft	21.2	23.6	36.3	26.1
3	____ ft	21.3	24.1	____	____

Length of cut pieces: ~16 inches Pre-Burn Fuel Average Moisture:

Time (clock): ____ Room Temperature (F): 69 Initials: AH

TEST FUEL

FUEL TYPE AND AMOUNT: 2 × 4 N/A 4 × 4 N/A
CALCULATED LOAD WEIGHT: 14.8 ACTUAL LOAD WEIGHT: ____ (2 × 4)
____ (4 × 4)
FUEL PIECE LENGTH: ~16" 14.8 Total

MOISTURE CONTENT (METER – – DRY BASIS)

PIECE	READINGS			TYPE
1	19.0	21.5	20.2	____
2	14.3	21.9	19.4	____
3	15.0	14.9	14.9	____
4	15.1	15.3	15.2	____
5	____	____	____	____
6	____	____	____	____
7	____	____	____	____
8	____	____	____	____
9	____	____	____	____
10	____	____	____	____

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: ____

Time (clock): ____ Room Temperature (F): 69 Initials: AH

Technician signature: [signature] Date: 4/1/11

Run Notes

Client: FNB
Model: Conventional Stove Birch Low
Project #: 477-S-01-1
Tracking #: ~~478~~ 5
Run #: 15 Date: 4/11 4/1/11
Test Crew: _____
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

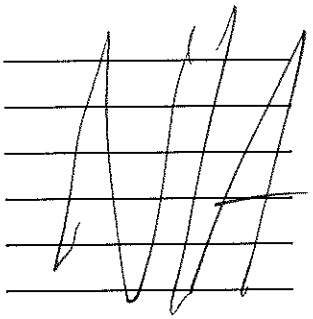
PRIMARY:

On low

SECONDARY:

TERTIARY:

FAN:



PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
32:00	Added 4/5 11/5					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Cordwood (6 pcs)

START UP PROCEDURES
~~BYPASS~~: Done @ 45 sec
FUEL LOADING: Closed @ Limit
DOOR:
PRIMARY AIR: Set Continuously
OTHER:

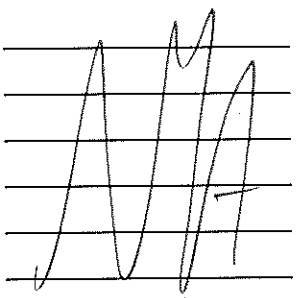
DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

On low

SECONDARY:

TERTIARY:

FAN:



Technician signature: _____ Date: 4/1/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 4/1/11

Appliance: Conventional Stove *Fuel:* Birch *Burn Rate:* Low

Filter Data

T1: *ID:* A751816T *D/T In Freezer:* 4/1/11

T1 (2): *ID:* N/A Changed @: _____ *D/T In Freezer:* _____

Q1: *ID:* A751836X *D/T In Freezer:* 4/1/11

Q2: *ID:* FNB #52 *D/T In Freezer:* 4/1/11

Q3: *ID:* FNB #53 *D/T In Freezer:* 4/1/11

Q4: *ID:* FNB #54 *D/T In Dessicator:* 4/1/11 Prelim: .1632

Q4 (2): *ID:* FNB # 55 Changed @: 21:00 *D/T In Dessicator:* 4/1/11 Prelim: .1436

Q4 weight	D/T: 4/5/11	D/T: 4/11	D/T: 4/12
record:	Audit: .5006	Audit: .5002	Audit: .5002
	Temp: 73	Temp: 75.4	Temp: 77.4
	Humidity: 51	Humidity: 8.1	Humidity: 9.5
	Weight: .1613/.1432	Weight: .1601/.1429	Weight: .1599/.1428

Supplementary Data

Pre-test

Leaks: Gas Analyzer Train: ϕ Ammonia Train: .004 @ -15"

Box A: .008 @ -11" Box B: .016 @ -11"

Post-Test

Leaks: Gas Analyzer Train: ϕ

Box A: .008 @ -11" Box B: .019 @ -11"

Flow Rate Check:

T1: 783 mL/min Q2: 3769 mL/min

Q1: 997 mL/min Q3: 1561 mL/min

Calibration Values:

Zero:	0.00% O_2	0.00% CO_2	0.000% CO
Span:	20.95% O_2	16.76% CO_2	4.327% CO
Mid:	10.56% O_2	10.17% CO_2	2.512% CO

Ammonia Sample:

Impinger 1: *Bottle Number:* 15-1 *D/T in Fridge:* 4/1/11

Impinger 2: *Bottle Number:* 15-2 *D/T in Fridge:* 4/1/11

Technician Signature/Date: [signature] 4/12/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Gas Bottles: AWC858 (Zero), CC337886 (Span), CC75242 (Mid)

FUEL DATA

Client: FNB
Model: Conventional Stove Birch Low
Project #: 477-S-01-1 Tracking #: ____
Date: 4/1/11 Test Crew: AH, SB, JC Run #: 15
OMNI Equipment ID #: ____
FUEL LOAD PREPARED BY: AH
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER.~~ Birch cordwood

PRE-BURN FUEL

MOISTURE CONTENT (METER -- DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading 12.6
Cal Value (2) = 22% Actual Reading 22.0

Piece	Length		Readings		~~Type~~	
1	____ ft	14.4	22.2	25.4	14.5	
2	____ ft	23.8	15.7	15.2	28.8	
3	____ ft	17.7	26.3	14.5	16.5	16.3

Length of cut pieces: ~16 inches Pre-Burn Fuel Average Moisture:

Time (clock): ____ Room Temperature (F): 70 Initials: AH

TEST FUEL

FUEL TYPE AND AMOUNT: 2 × 4 N/A 4 × 4 N/A
CALCULATED LOAD WEIGHT: ____ ACTUAL LOAD WEIGHT: ____ (2 × 4)
____ (4 × 4)
FUEL PIECE LENGTH: ~16" 14.4 Total

MOISTURE CONTENT (METER -- DRY BASIS)

PIECE	READINGS			TYPE
1	~~11.9~~	11.0	10.5	cord
2	~~11.9~~			
3	11.9	11.0	10.5	
4	11.9	11.8	11.9	
5	13.3	13.8	15.5	
6	15.3	16.6	15.2	
7	15.9	14.9	16.1	
8	14.4	17.4	14.7	
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: ____

Time (clock): ____ Room Temperature (F): 70 Initials: AH

Technician signature: [signature] Date: 4/1/11

Run Notes

Client: FNB
Model: No 2 Fuel Oil
Project #: 477-S-01-1
Tracking #: ____
Run #: 17 Date: 4/12/11
Test Crew: AH, SD
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Fixed

SECONDARY:

TERTIARY: Auto

FAN:

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

No. 2 Oil

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING
DOOR:
PRIMARY AIR:

OTHER:

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Fixed

SECONDARY:

TERTIARY: Auto

FAN:

Technician signature: _____ Date: 4/12/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 4/12/11 *Run #:* 17 *Appliance/Fuel/Burn Rate:* No 2 Fuel Oil

Filter Data

T1: *ID:* A751818V

T1 (2): *ID:* N/A

Time Changed:

Date/time Samples placed in freezer/dessicator: 4/12/11 9:22PM

Q1: *ID:* A751833U

Q2: *ID:* FMB #59

Q3: *ID:* FMB #60

Q4: *ID:* FMB #61 *Preliminary Weight:* .1452

Q4 (2): *ID:* N/A *Preliminary Weight:*

Time Changed:

Q4 weight record:	D/T: 4/7/11 14:00	D/T: 4/18/11 8:30	D/T:
	Audit: .5002	Audit: .5002	Audit:
	Temp: 74.0	Temp: 76.7	Temp:
	Humidity: 5.8	Humidity: 8.4	Humidity:
	Weight (1): .1458	Weight (1): .1458	Weight (1)
	Weight (2): N/A	Weight (2): N/A	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ

Ammonia Train: .0030 @ -15

Box A: .006 @ -7"

Box B: .001 @ -10"

Post-Test Leaks:

Gas Analyzer Train: ϕ

Box A: .008 @ -7"

Box B: .001 @ -10"

Flow Rate Check:

T1: 872.12 mL/min Q2: 3019.1 mL/min

Q1: 1086.6 mL/min Q3: 1567.3 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 17-1 *D/T in Fridge:* 4/12 9:40

Impinger 2: *Bottle Number:* 17-2 *D/T in Fridge:* 4/12 9:40

Technician Signature/Date: 4/18/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Run Notes

Client: FNSB
Model: Waste Oil Burner
Project #: 477-S-01-1
Tracking #: _____
Run #: 18 Date: 4/15/11
Test Crew: AK, SB
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

ON

SECONDARY: _____

TERTIARY:

FAN:

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

waste oil

START UP PROCEDURES

BYPASS:
FUEL LOADING
DOOR:
PRIMARY AIR:

OTHER:

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

ON

SECONDARY: _____

TERTIARY:

FAN:

Technician signature: _____ Date: 4/15/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 4/15/11 *Run #:* 18 *Appliance/Fuel/Burn Rate:* Waste Oil Burner

Filter Data

T1: *ID:* A751824T

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A751829Y

Q2: *ID:* FNB#62

Q3: *ID:* FNB#63

Q4: *ID:* FNB#64 *Preliminary Weight:* .1579

Q4 (2): *ID:* FNB#65 *Preliminary Weight:* .1511

Time Changed: 1:08:00

Date/time Samples placed in freezer/dessicator: 4/15/11 12:00

Q4 weight	D/T:	4/17/11 14:00	D/T: 4/18/11 8:30	D/T:	
record:	Audit:	.5002	Audit: .5002	Audit:	
	Temp:	74.0	Temp: 76.7	Temp:	
	Humidity:	5.8	Humidity: 8.9	Humidity:	
	Weight (1):	.1656	Weight (1): .1557	Weight (1)	
	Weight (2):	.1493	Weight (2): .1495	Weight (2)	

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0

Ammonia Train: .006 @ -12"

Box A: .003 @ -8"

Box B: .001 @ -11"

Post-Test Leaks:

Gas Analyzer Train: 0

Box A: .004 @ -12"

Box B: .008 @ -10"

Flow Rate Check:

T1: 3754 mL/min Q2: 4271 mL/min

Q1: 3699 mL/min Q3: 1728 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 18-1 *D/T in Fridge:* 4/15/11 12:00

Impinger 2: *Bottle Number:* 18-2 *D/T in Fridge:* 4/15/11 12:00

Technician Signature/Date: 4/18/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Fuel November 14, 2014

8.7 lb birch kindling
30 lb preburn
22.4 lb test fuel

Run Notes

Client: Fairbanks North Star Borough
Model: Coal Stove - Dry Stoker coal - High Burn
Project #: 477-S-1-1
Tracking #: _____
Run #: 20 Date: 5/6/11
Test Crew: J. Button
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Full open
(1 turn per manufacturing Instructions)

SECONDARY: N/A

TERTIARY: N/A

FAN: on

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Stoker Coal

START UP PROCEDURES

BYPASS: Ash Port, closed @ 3 min
FUEL LOADING: Door @ 2 min
DOOR: closed @ 2 min
PRIMARY AIR: _____
Set @ 0 sec
OTHER: _____

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Same as preburn

SECONDARY: N/A

TERTIARY: N/A

FAN: ON

Technician signature: _____ Date: 5/6/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 5/6/11 *Run #:* 20 *Appliance/Fuel/Burn Rate:* Coal Stove, Dry Stoker Coal, High Burn

Filter Data

T1: *ID:* A751822R

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A751828Y

Q2: *ID:* FNB # 69

Q3: *ID:* FNB# 70

Q4: *ID:* FNB #71 *Preliminary Weight:* .1690

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
5/6/11 15:20

Q4 weight record:	D/T: 5/17 15:00	D/T: 5/26/11 1400	D/T:
	Audit: .5000	Audit: .5001	Audit:
	Temp: 72.1	Temp: 73	Temp:
	Humidity: 16.7	Humidity: 13.1%	Humidity:
	Weight (1): .1683	Weight (1): .1681	Weight (1)
	Weight (2): N/A	Weight (2): N/A	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ

Ammonia Train: .004 @ -20"

Box A: .003 @ -11"

Box B: .000 @ -8"

Post-Test Leaks:

Gas Analyzer Train: ϕ

Box A: .004 @ -10"

Box B: .002 @ -8"

Flow Rate Check:

T1: 223 mL/min Q2: 3548 mL/min

Q1: 849 mL/min Q3: 1392 mL/min

Ammonia Sample:

Impinger 1: *Battle Number:* 20-1 *D/T in Fridge:* 5/6/11 1500

Impinger 2: *Bottle Number:* 20-2 *D/T in Fridge:* 5/6/11 1500

Technician Signature/Date: 5/6/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Run Notes

Client: Fairbanks North Star Borough
Model: Coal stove - Dry Stoker coal - Low Burn
Project #: 477-S-1-1
Tracking #: _____
Run #: 21 Date: 5/9/11
Test Crew: S. Button
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1/4 open from fully closed

SECONDARY: N/A

TERTIARY: N/A

FAN: ON

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Stoker Coal

START UP PROCEDURES

BYPASS: Ash door, closed @ 5min
FUEL LOADING: Done @ 2min
DOOR: Closed @ 2min
PRIMARY AIR: Set @ 5min

OTHER: NA

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Same as above

SECONDARY: N/A

TERTIARY: N/A

FAN: ON

Technician signature: [signature] Date: 5/9/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 5/9/11 *Run #:* 21 *Appliance/Fuel/Burn Rate:* (a) Stove / Dry Stacker Coal / Low Burn

Filter Data

T1: *ID:* A75182Q

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A751837Y

Q2: *ID:* FNB #72

Q3: *ID:* FNB #73

Q4: *ID:* FNB #74 *Preliminary Weight:* .1705

Q4 (2): *ID:* FNB #75 *Preliminary Weight:* .1487

Time Changed: 61 minutes into test

Date/time Samples placed in freezer/dessicator: 5/9 19:22

Q4 weight record:	D/T:	5/17 15:00	D/T: 5/26/11 14:10	D/T:	
	Audit:	.5000	Audit: .5001	Audit:	
	Temp:	72.1	Temp: 73	Temp:	
	Humidity:	16.9	Humidity: 13.1%	Humidity:	
	Weight (1):	.1651	Weight (1): .1649	Weight (1)	
	Weight (2):	.1447	Weight (2): .1448	Weight (2)	

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ

Ammonia Train: .010 @ ~20"

Box A: .005 @ 10"

Box B: .007 @ 15"

Post-Test Leaks:

Gas Analyzer Train: ϕ

Box A: .007 @ 10"

Box B: .007 @ 12"

Flow Rate Check:

T1: 780.81 mL/min Q2: 3917.1 mL/min

Q1: 893.53 mL/min Q3: 1446.7 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 21-1 *D/T in Fridge:* 5/9 19:35

Impinger 2: *Bottle Number:* 21-2 *D/T in Fridge:* 5/9 19:35

Technician Signature/Date: 5/9/2011

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Fuel
1.7 lb birch kindling
30 lb preburn
221 lb test fuel

Run Notes

Client: Fairbanks North Star Borough
Model: Coal Stove - wet stoker coal - Low Burn
Project #: 477-S-1-1
Tracking #: _____
Run #: 23 Date: 5/11/11
Test Crew: J. Button, J. Clark
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1/4 open from fully closed

SECONDARY: N/A

TERTIARY: N/A

FAN: ON

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

wet stoker coal

START UP PROCEDURES

BYPASS: NA
FUEL LOADING Done @ 2:00
DOOR: Closed @ 2:00
PRIMARY AIR: Set @ 5:00

OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Same as above

SECONDARY: N/A

TERTIARY: N/A

FAN: ON

Technician signature: [signature] Date: 5/11/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 5/11/11 *Run #:* 23 *Appliance/Fuel/Burn Rate:* Cord stove - wet stoker

Filter Data

T1: *ID:* A75182O8

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A75182492

Q2: *ID:* FNB 79

Q3: *ID:* FNB 80

Q4: *ID:* FNB 81 *Preliminary Weight:* .1853

Q4 (2): *ID:* FNB 82 *Preliminary Weight:* .1428

Time Changed: 1hr 40 min into test

Date/time Samples placed in freezer/dessicator:
5/11/11 17:00

Q4 weight record:	D/T: 5/17 15:00	D/T: 5/26/11 1400	D/T: 5/27/11 900
	Audit: .5000	Audit: .5001	Audit: .5001
	Temp: 72.1	Temp: 73	Temp: 73
	Humidity: 16.7	Humidity: 13.1%	Humidity: 12.4%
	Weight (1): .1834	Weight (1): .1826	Weight (1) .1828
	Weight (2): .1421	Weight (2): .1420	Weight (2) N/A

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0

Ammonia Train: .003 @ 15"

Box A: .003 @ 15"

Box B: .008 @ 10"

Post-Test Leaks:

Gas Analyzer Train: 0

Box A: .003 @ 15"

Box B: .010 @ 11"

Flow Rate Check:

T1: 142.90 mL/min Q2: 1850.27 mL/min

Q1: 846.63 mL/min Q3: 917.65 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 23-1 *D/T in Fridge:* 5/11 17:15

Impinger 2: *Bottle Number:* 23-2 *D/T in Fridge:* 5/11 17:15

Technician Signature/Date: 5/26/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

Run Notes

Client: Fairbank NorthStar Borough
Model: Non-a owHH Space Heat
Project #: 477-S-1-1
Tracking #: _____
Run #: 25 Date: 5/27/11
Test Crew: SJB Allen
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

ON High

SECONDARY: N/A

TERTIARY: N/A

FAN: N/A

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Cord wood

START UP PROCEDURES

BYPASS: Closed @ 5 m/h
FUEL LOADING: Done @ 2 m/h
DOOR: Closed @ 2 m/h
PRIMARY AIR: N/A
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

on high

SECONDARY: N/A

TERTIARY: N/A

FAN: N/A

Technician signature: _____ Date: 5/27/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 5/27/11 *Run #:* 25 *Appliance/Fuel/Burn Rate:* Non-Cat OWHH Spruce High

Filter Data

T1: *ID:* A75835l9

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7518476

Q2: *ID:* FMB #87

Q3: *ID:* FMB #28

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
5/27/11 13:00

Stack Gas Dilution
Total Flow: 1982.9 mL/min.
Dilution Air Flow: 1386.1 mL/min

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0

Ammonia Train: .005 @ -12"

Box A: .010 @ -15"

Box B: N/A

Post-Test Leaks:

Gas Analyzer Train: 0

Box A: .012 @ -15"

Box B: N/A

Flow Rate Check:

T1: 168.8 mL/min Q2: 771.1 mL/min

Q1: 924.45 mL/min Q3: 951.3 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 25-1 *D/T in Fridge:* 5/27/11 13:00

Impinger 2: *Bottle Number:* 25-2 *D/T in Fridge:* 5/27/11 13:00

Technician Signature/Date: 5/27/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Run 25
OWHHNQ - Spruce High
Fuel Moisture

OMNI 183 & 431 - 12.0%, 22.0%

15.4	15.4	Weight: 121.1 lb
16.8	16.1	Preburn: 122.7 lb
18.4	12.5	
13.8	14.3	
16.9	17.5	
~~18.5~~ 19.4	16.1	
13.6	20.1	
16.8	15.9	
14.5	18.1	
13.3	21.2	
14.3	14.9	
22.0	15.1	
16.8	14.8	
19.3	24.9	
18.8	15.3	
14.8	18.4	
12.1	21.5	
16.0	18.9	
16.8		
16.1	Avg = 16.91 %	

*/Min 30-31 gas train filter changed

Run Notes

Client: Fairbanks research Project
Model: NQ owHH - Coal
Project #: 477-S-1-1
Tracking #: ____
Run #: 26 Date: 5/30/11
Test Crew: SYBatton
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Low heat
6 mm

SECONDARY: NA

TERTIARY: N/A

FAN: AA

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	N/A					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Stoker Coal

START UP PROCEDURES

BYPASS: closed @ 5mm
FUEL LOADING: none @ 1mm
DOOR: closed @ 3mm
PRIMARY AIR: N/A
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Same as above

SECONDARY: N/A

TERTIARY: N/A

FAN: AuA

Technician signature: [signature] Date: 5/30/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 5/30/11 *Run #:* 26 *Appliance/Fuel/Burn Rate:* Non-Cat OWHH - Coal

Filter Data

T1: *ID:* A7583508

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7518387

Q2: *ID:* FMB# 89

Q3: *ID:* FMB ~~#90~~ TB #90

Q4: *ID:* ~~FMB# 90~~ TB *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
5/30/11 14:00

Stack Gas Dilution
Total Flow: 1347.0 mL/min
Dilution Air Flow: 721.19 mL/min

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: Ø

Ammonia Train: .006 @ -12"

Box A: .013 @ -16"

Box B: N@NA

Post-Test Leaks:

Gas Analyzer Train: Ø

Box A: .015 @ -16"

Box B: N@A

Flow Rate Check:

T1: 130.9 mL/min Q2: 1820.3 mL/min

Q1: 1037.6 mL/min Q3: 1002.0 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 26-1 *D/T in Fridge:* 5/30/11 14:15

Impinger 2: *Bottle Number:* 26-2 *D/T in Fridge:* 5/30/11 14:15

Technician Signature/Date: 5/30/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

Run Notes

Client: FNB
Model: N200WHH Coal w/ Retrofit Catalyst
Project #: 477-8-01-1
Tracking #: _____
Run #: 27 Date: 6/6/11
Test Crew: _____
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Low heat draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Stoker coal

START UP PROCEDURES

BYPASS:
FUEL LOADING Done @ 4:00
DOOR:
PRIMARY AIR:

OTHER:

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Low heat draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

Technician signature: _____ Date: 6/6/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 6/1/11 *Run #:* 27 *Appliance/Fuel/Burn Rate:* NQ OWHH Retrofit Catalyst

Filter Data

T1: *ID:* A7583380

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7518467

Q2: *ID:* FNB 91

Q3: *ID:* FNB 92

Q4: *ID:* ~~FNB 93~~ N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
6/1 15:30

~~Q4 weight~~	D/T:	D/T:	D/T:
record:	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

N/A

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ∅

Ammonia Train: .004 @ -15"

Box A: .010 @ -11"

Box B: ~~.000 @ -12"~~ N/A

Post-Test Leaks:

Gas Analyzer Train: ∅ - MELTED

Box A: .013 @ -11" PROBE

Box B: N/A @ N/A

Flow Rate Check:

T1: 178.82 mL/min Q2: 1835.1 mL/min

Q1: 1017.0 mL/min Q3: 757.28 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 27-1 *D/T in Fridge:* 6/1 15:30

Impinger 2: *Bottle Number:* 27-2 *D/T in Fridge:* 6/1 15:30

Technician Signature/Date: 6/1/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

Cold Start

2.0 lb kindling crib (doug fir)
Fuel weight = 150.0 lb
Approx. 10mL lighter fluid used

Run Notes

Client: Fairbanks North Star Borough
Model: _____
Project #: 477-S-1-1
Tracking #: _____
Run #: 25 Date: 6/7/11
Test Crew: AH, SB, JC
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

~~~~ Full burn Rate
Cold start

SECONDARY: N/A

TERTIARY:

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None (cold start)					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Auto-fed stoker
coal (wet)

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING N/A
DOOR: Closed @ 12:00
PRIMARY AIR: Auto

OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

~40% full burn

SECONDARY: N/A

TERTIARY:

FAN: Auto

Technician signature: _____ Date: 6/7/11
~~~~

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 6/7/11 *Run #:* 28 *Appliance/Fuel/Burn Rate:* Auger fed Coal Boiler - Cold Start

Filter Data

T1: *ID:* A758349F

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A751835W

Q2: *ID:* FNB #95

Q3: *ID:* FNB #94

Q4: *ID:* FNB #93 *Preliminary Weight:* .1547

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
6/7/11 13:20

Q4 weight record:	D/T: 6/15/11	D/T: 6/28/11	D/T: 6/29/11
	Audit: .5011	Audit: .5002	Audit: .5001
	Temp: 73.6	Temp: 74.1	Temp: 74.6
	Humidity: 8.6	Humidity: 10.9	Humidity: 10.0
	Weight (1): .1544	Weight (1): .1530	Weight (1) .1529
	Weight (2): N/A	Weight (2): N/A	Weight (2) N/A

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0

Ammonia Train: .012 @ -16"

Box A: .011 @ ~15"

Box B: .010 @ -12"

Post-Test Leaks:

Gas Analyzer Train: See Run 29

Box A: .009 @ -15"

Box B: _____ @ _____

Flow Rate Check:

T1: 183.52 mL/min Q2: 1778.8 mL/min

Q1: 979.11 mL/min Q3: 898.28 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 28-1 *D/T in Fridge:* 6/7/11 13:20

Impinger 2: *Bottle Number:* 28-2 *D/T in Fridge:* 6/7/11 13:20

Technician Signature/Date: _____

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

Run Notes

Fuel weight = 150.0 lb

Client: _____
Model: _____
Project #: _____
Tracking #: _____
Run #: 29 Date: 6/7/11
Test Crew: A. Kravitz
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

40% of max burn

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

150 lbs. coal
(wet stoker)

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING N/A
DOOR: N/A
PRIMARY AIR: Auto (40%)

OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

40% of max burn

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

Technician signature: _____ Date: 6/7/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 6/7/11 *Run #:* 29 *Appliance/Fuel/Burn Rate:* Auger Coal/Fed DWHH - Hot Start

Filter Data

T1: *ID:* A7583406

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7518347

Q2: *ID:* FNB 96

Q3: *ID:* FNB 97

Q4: *ID:* FNB 98 *Preliminary Weight:* .1522

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
6/7/11 17:50

Q4 weight record:	D/T: 6/15/11	D/T: 6/28/11	D/T:
	Audit: .5001	Audit: .5002	Audit:
	Temp: 73.6	Temp: 74.1	Temp:
	Humidity: 8.6	Humidity: 10.9	Humidity:
	Weight (1): .1516	Weight (1): .1518	Weight (1)
	Weight (2): N/A	Weight (2): N/A	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ∅

Ammonia Train: .008 @ -10"

Box A: .011 @ ~15"

Box B: .009 @ -10"

Post-Test Leaks:

Gas Analyzer Train: ∅

Box A: .011 @ -15"

Box B: .006 @ -11"

Flow Rate Check:

T1: 160.56 mL/min Q2: 1793.5 mL/min

Q1: ~~798~~ 1029.4 mL/min Q3: 194.06 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 29-1 *D/T in Fridge:* 6/7/11

Impinger 2: *Bottle Number:* 29-2 *D/T in Fridge:* 6/7/11

Technician Signature/Date: 6/7/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

Run Notes

Client: Fairbanks North Star Borough
Model: NQ2w HH Spruce Low
Project #: 477-S-1-1
Tracking #: ____
Run #: 30 Date: 6/30/11
Test Crew: A. Kravitz, S. Dutton, J. Clark
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Automatic (low burn)

SECONDARY: N/A

TERTIARY: N/A

FAN: On Low

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

(ordwood

START UP PROCEDURES

BYPASS: Open during loading
FUEL LOADING DOOR: Done @ 2 min
Closed @ 2 min
PRIMARY AIR: Auto
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Automatic (low burn)

SECONDARY: N/A

TERTIARY: N/A

FAN: On Low

Technician signature: _____ Date: 6/30/11

Appendix III.D.5.06 - 761

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 6/30/11 *Run #:* 30 *Appliance/Fuel/Burn Rate:* NQOWHH Spruce Low

Filter Data

T1: *ID:* A7583417

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7518315

Q2: *ID:* FNB 99

Q3: *ID:* FNB ~~100~~ 101

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
6/30/11 1636

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ∅

Ammonia Train: .010 @ -8"

Box A: .000 @ -12"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: ∅

Box A: .014 @ -10"

Box B: N/A @ N/A

Flow Rate Check:

T1: 200.7 mL/min Q2: 1979.3 mL/min

Q1: 997.4 mL/min Q3: 985.86 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 30-1 *D/T in Fridge:* 6/30/11 1630

Impinger 2: *Bottle Number:* 30-2 *D/T in Fridge:* 6/30/11 1630

Technician Signature/Date: 6/30/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

NQOWHH SPRUCE COW Run 30

118.1 lb
- 48.9 lbs

preburn: 114.5 lb

12.3 14.1
10.3 12.9
12.3 14.9
10.2 12.9
15.2 15.9
14.4
16.2 Avg = 14.00
14.8
14.7
14.9
14.2
16.1
13.5
16.1
14.3
16.4
14.2
12.9
13.7
15.4
16.5
11.4
11.1

OMNI-Test Laboratories, Inc.

Run Notes

Client: FNB
Model: NOUHH Birch high
Project #: _____
Tracking #: _____
Run #: 31 Date: 7/1/11
Test Crew: AH, SB, JC
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

High heat draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Birch cordwood

START UP PROCEDURES

BYPASS: Closed @ 3:00
FUEL LOADING: Done @ 2:30
DOOR: Closed @ 3:00
PRIMARY AIR: _____
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

High heat draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

Technician signature: _____ Date: 7/1/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 7/1/11 *Run #:* 31 *Appliance/Fuel/Burn Rate:* NQOWHH Birch ~~Low~~ High

Filter Data

T1: *ID:* A7583390

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A768262E

Q2: *ID:* FNB 102

Q3: *ID:* FNB 103

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
7/1/11 1300

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ @ 15"

Ammonia Train: .013 @ -18"

Box A: .011 @ -10"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: ϕ @ 16"

Box A: .012 @ -12"

Box B: N/A @ N/A

Flow Rate Check:

T1: 211.3 mL/min Q2: 1934.6 mL/min

Q1: 997.4 mL/min Q3: 1088.7 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 31-1 *D/T in Fridge:* 7/1/11 1245

Impinger 2: *Bottle Number:* 31-2 *D/T in Fridge:* 7/1/11 1245

Technician Signature/Date: 7/1/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

NQ OWHH Birch ~~low~~ High Run 31

Test Load = 100.4 lb

12.6	12.4
12.9	14.3
13.6	14.1
18.2	25.1
11.7	12.7
23.5	16.1
23.6	12.0
27.9	20.1
27.2	15.5
23.2	
14.5	AVG = 18.04
14.3	
22.6	
15.7	
14.5	
14.8	
19.8	
12.7	
23.2	
22.5	

Run Notes

Client: Fairbanks North Star Borough
Model: NQ OWHH Birch Low
Project #: 477-S-1-1
Tracking #: ____
Run #: 32 Date: 7/6/11
Test Crew: AH, SB, SC
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Low heat draw

SECONDARY: ~~Fixed~~ N/A

TERTIARY: N/A

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Birch Cordwood

START UP PROCEDURES
BYPASS: Closed @ 2:30
FUEL LOADING Door @ 2:00
DOOR: Closed @ 2:30
PRIMARY AIR: ____
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Low heat draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

Technician signature: [signature] Date: 7/6/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 7/6/11 *Run #:* 32 *Appliance/Fuel/Burn Rate:* NQ OWHH Birch Low

Filter Data

T1: *ID:* A7583428

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7682610

Q2: *ID:* FNB 104

Q3: *ID:* FNB 105

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
7/6/11 16:50

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0 @ -15"

Ammonia Train: .009 @ -11"

Box A: .000 @ -15"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: 0 @ -15"

Box A: .008 @ -15"

Box B: N/A @ N/A

Flow Rate Check:

T1: 159.34 mL/min Q2: 1779.5 mL/min

Q1: 1030.9 mL/min Q3: 975.29 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 32-1 *D/T in Fridge:* 7/6/11 16:46

Impinger 2: *Bottle Number:* 32-2 *D/T in Fridge:* 7/6/11 16:40

Technician Signature/Date: 7/6/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Run 32
NQOWHH Birch Low
7/6/11

Preburn: 102.0 lb
Test fuel: 100.2 lb

10.2	13.2
12.4	22.2
25.1	23.4
11.2	18.1
24.5	18.6
20.4	12.2
16.5	11.9
18.0	13.2
11.3	11.7
32.2	
31.0	AVG = 17.02
15.4	
12.1	
13.0	
11.3	
14.5	
17.2	
15.4	
15.0	
25.4	

Run Notes

Client: FNB
Model: NCOWFH Birch Low Cold Start
Project #: 477-S-01-1
Tracking #: _____
Run #: 33 Date: 7/8/11
Test Crew: AM, SB, JC
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Low Draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	See Attached					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Birch Cordwood

START UP PROCEDURES

BYPASS:
FUEL LOADING See
DOOR:
PRIMARY AIR: Attached
OTHER:

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Low Draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

Technician signature: _____ Date: 7/8/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 7/8/11 *Run #:* 33 *Appliance/Fuel/Burn Rate:* NQ OWHH Birch Low Cold Start

Filter Data

T1: *ID:* A7583439

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7682606 & A7682595

Q2: *ID:* FNB 106 & 108 & 110

Q3: *ID:* FNB 107 & 109

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
7/8/11 15:00

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0 @ -15"

Ammonia Train: .010 @ -13"

Box A: .011 @ -15"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: 0 @ -15"

Box A: .015 @ -16"

Box B: N/A @ N/A

Flow Rate Check:

T1: 145.4 mL/min Q2: 1903.8 mL/min

Q1: 980.6 mL/min Q3: 1018.3 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 33-1 *D/T in Fridge:* 7/8/11 14:40

Impinger 2: *Bottle Number:* 33-2 *D/T in Fridge:* 7/8/11 14:40

Technician Signature/Date: 7/8/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 44S

Run 33

NQ QWHH Cold Start

Knalling
40 lbs => load 20 lbs to start, Added Remaining 20 lbs @ 5 mins, bypass shut @ 8 mh

Preburn
100.2 lbs => loaded @ 22 mh

Test Fuel => loaded @ 2:20
100.1 lb

12.3	19.9
28.4	28.1
27.4	17.4
25.1	30.9
24.6	26.1
30.1	35.0
13.2	29.4
18.0	32.9
32.9	34.1
29.1	32.4
32.1	
32.2	
34.7	AVG = 20.78
24.8	
25.2	
24.5	
22.3	

OMNI-Test Laboratories, Inc.

Run Notes

Client: FNB
Model: EPA OWHH w/ Retrofit Catalyst
Project #: 477-SOL-1
Tracking #: ____
Run #: 34 Date: 1/27/11
Test Crew: AM, SB, JC
OMNI Equipment ID #(s): ____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Low Draw

SECONDARY: NA

TERTIARY: NA

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Birch cordwood

START UP PROCEDURES

BYPASS: Closed @ 1:30
FUEL LOADING: Done @ 1:00
DOOR: Closed @ 1:30
PRIMARY AIR: ____
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Low
Draw

SECONDARY: N/A

TERTIARY: N/A

FAN: Auto

Technician signature: [signature] Date: 1/27/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1
Date: 7/27/11 *Run #:* 34 *Appliance/Fuel/Burn Rate:* ~~EPACOWHH~~ EPACOWHH w/ Birch Low

Retrofit Catalyst

Filter Data

T1: *ID:* A758346C
T1 (2): *ID:* N/A
Time Changed: N/A
Q1: *ID:* A768275D
Q2: *ID:* FNB 111
Q3: *ID:* FNB 112
Q4: *ID:* N/A *Preliminary Weight:* N/A
Q4 (2): *ID:* N/A *Preliminary Weight:* N/A
Time Changed: N/A

Date/time Samples placed in freezer/dessicator: 7/27/11 12:30

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ
Ammonia Train: .008 @ -14"
Box A: .015 @ -20
Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: ϕ
Box A: .015 @ -20
Box B: N/A @ N/A

Flow Rate Check:

T1: 180.3 mL/min Q2: 190.3 mL/min
Q1: 1108.1 mL/min Q3: 996.9 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 34-1 *D/T in Fridge:* 7/27/11 12:15
Impinger 2: *Bottle Number:* 34-2 *D/T in Fridge:* 7/27/11 22:15

Technician Signature/Date: 7/27/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Run 34 Fuel Data
Phase II Boiler w/ Retrofit Catalyst - Birch

Preburn weight : 101 lbs
Test Fuel Weight : 125 lbs

Moisture:

	33.7
	33.5
	32.1
	34.4
	35.4
	23.9
	19.8
	25.3
	19.7
	25.8
	29.1
	27.6
	30.8
	18.6
	28.1
AVG	27.90%

OMNI-Test Laboratories, Inc.

Run Notes

Client: Fairbanks Northstar Borough
Model: Coal Stove - Wet stoker Coal - High Burn
Project #: 477-S-1-1
Tracking #: 1684
Run #: 35 Date: 8/10/11
Test Crew: AW, SB
OMNI Equipment ID #(s):

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1 full revolution open from finger tight

SECONDARY: N/A

TERTIARY: N/A

FAN: On High

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
90:00				-3.01b		

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Stoker coal

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING Done @ 1:30
DOOR: Closed @ 3:00
PRIMARY AIR: Set @ 5:00

OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Same as above

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

Technician signature: Date: 8/10/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 8/10/11 *Run #:* 35 *Appliance/Fuel/Burn Rate:* Coal Stove – Wet Stoker Coal -High

Filter Data

T1: *ID:* A758345B

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A768267J

Q2: *ID:* FNB 113

Q3: *ID:* FNB 114

Q4: *ID:* N/A *Preliminary Weight:* NA

Q4 (2): *ID:* NA *Preliminary Weight:* NA

Time Changed: NA

Date/time Samples placed in freezer/dessicator:
8/10/11 1830

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ

Ammonia Train: .010 @ 15"

Box A: .013 @ -20"

Box B: NA @ NA

Post-Test Leaks:

Gas Analyzer Train: ϕ

Box A: .015 @ -20"

Box B: NA @ NA

Flow Rate Check:

T1: 172.5 mL/min Q2: 1869.0 mL/min

Q1: 998.4 mL/min Q3: 934.2 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 35-1 *D/T in Fridge:* 18:45

Impinger 2: *Bottle Number:* 35-2 *D/T in Fridge:* 18:45

Technician Signature/Date:

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

Run Notes

Client: Fairbanks North Star Borough
Model: Coal Stove/Wet Lump Coal/Low Burn/Cold Start
Project #: 477-S-1-1
Tracking #: 1684
Run #: 36 Date: 8/11/11
Test Crew: SB, JC, AK
OMNI Equipment ID #(s):

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

¼ turn open from Fully closed

SECONDARY: N/A

TERTIARY: N/A

FAN: On High

Cold Start ~~PREBURN~~ SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
0:00:00	Ash door cracked		+4.0 - birch	kindling		Start up
0:03:30	Door open		4.5 - coal		kindling leveled	Propane torch used
0:10:00	Door open		5 - coal			
0:12:00	Door open		16.5 - coal			
0:15:30	Door open					
0:31:00	Doors closed					
1:47:00	Tared out scale, loaded fuel		25 - coal			

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Lump Coal (25.0 lb)

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done by 1:14:00
DOOR: Closed @ 1:54:00
PRIMARY AIR: Set the whole time

OTHER: 2:27:00 - fire out, ash door opened

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

¼ turn open from Fully Closed

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

Coals stirred @ 7:28:00 + @ 8:05:00

Technician signature: Date: 8/11/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 8/11/11 *Run #:* 36 *Appliance/Fuel/Burn Rate:* Coal Stove/Wet Lump Coal/Low Burn/Cold Start

Filter Data

T1: *ID:* ~~A768254E~~ A779727E

T1 (2): *ID:* _____

Time Changed: _____

Q1: *ID:* A768258I

Q2: *ID:* FNB 116

Q3: *ID:* FNB 117

Q4: *ID:* N/A *Preliminary Weight:* _____

Q4 (2): *ID:* _____ *Preliminary Weight:* _____

Time Changed: _____

Date/time Samples placed in freezer/dessicator: 8/11/11 18:00

Q4 weight record:	D/T: _____	D/T: _____	D/T: _____
	Audit: _____	Audit: _____	Audit: _____
	Temp: _____	Temp: _____	Temp: _____
	Humidity: _____	Humidity: _____	Humidity: _____
	Weight (1): _____	Weight (1): _____	Weight (1) _____
	Weight (2): _____	Weight (2): _____	Weight (2) _____

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: Ø

Ammonia Train: .010 @ -12"

Box A: .012 @ -15"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: Ø

Box A: Ø @ _____

Box B: N/A @ _____

Flow Rate Check:

T1: 162.85 mL/min Q2: 1847.8 mL/min

Q1: 1064.4 mL/min Q3: 1005.9 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 36-1 *D/T in Fridge:* 8/11 1800

Impinger 2: *Bottle Number:* 36-2 *D/T in Fridge:* 8/11 1800

Technician Signature/Date: [signature] 8/11/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Run Notes

Client: Fairbanks North Star Borough
Model: Coal Stove/Wet Lump Coal/ Low Burn/ Hot Start
Project #: 477-S-1-1
Tracking #: 1684
Run #: 37 Date: 8/12/11
Test Crew: SB, JC, AK
OMNI Equipment ID #(s):

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1/4 open from fully closed

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Wet lump coal
25.0 lb

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 1:00
DOOR: closed @ 9' Minutes
PRIMARY AIR: Set @ 9 min
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Same as above

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

Stirred coals @ 5:49 pm

Technician signature: [signature] Date: 8/12/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 8/12/11 *Run #:* 37 *Appliance/Fuel/Burn Rate:* Coal Stove/Wet Lump Coal/Low Burn/Hot Start

Filter Data

T1: *ID:* A7797267

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7682661

Q2: *ID:* FNB # 118

Q3: *ID:* FNB # 119

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
8/12/11 17:00

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ

Ammonia Train: .015 @ -17

Box A: .008 @ -16"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: ϕ

Box A: .011 @ -10

Box B: N/A @ N/A

Flow Rate Check:

T1: 247.3 mL/min Q2: 1881.7 mL/min

Q1: 1002.9 mL/min Q3: 1046.5 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 37-1 *D/T in Fridge:* 17:00

Impinger 2: *Bottle Number:* 37-2 *D/T in Fridge:* 17:00

Technician Signature/Date: 8/12/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

1) 0.010
2) 0.026
3) 0.032
4) 0.034
5) 0.034
6) 0.036

1) 0.031
2) 0.034
3) 0.034
4) 0.033
5) 0.031
6) 0.024

Run Notes

Client: FNB
Model: Dry Lump Coal Hot Start
Project #: 477-S-01-1
Tracking #: 1684
Run #: 38 Date: 8/15/11
Test Crew: AK, JC
OMNI Equipment ID #(s):

stable = 0.107

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY: 1/4 turn open

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
None						

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Dry lump coal
29.0 lb

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done @ 1:00
DOOR: Closed @ 5:00
PRIMARY AIR: Set the whole time
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY: 1/4 turn open

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

5:50 - stirred coals

Technician signature: [signature] Date: 8/15/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 8/15/11 *Run #:* 38 *Appliance/Fuel/Burn Rate:* Dry Lump Coal Hot Start

Filter Data

T1: *ID:* A7797280

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A7682658H

Q2: *ID:* FNB 120

Q3: *ID:* FNB 121

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
8/15/11 1815

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0

Ammonia Train: .015@-15"

Box A: .012 @ -15"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: 0

Box A: .015 @ -15"

Box B: N/A @ N/A

Flow Rate Check:

T1: 170.90 mL/min Q2: 1883.7 mL/min

Q1: 990.81 mL/min Q3: 1053.5 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 38-1 *D/T in Fridge:* 8/15

Impinger 2: *Bottle Number:* 38-2 *D/T in Fridge:* 8/15

Technician Signature/Date: 8/15/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

* Kindling: ~~6 lb~~ Birch 6.0 lb
Preburn = 25.0 lb coal
Test = 25.0 lb coal

Run Notes

* lit using propane torch
↳ 0:00:00 to 0:02:00

* Q2 replaced 1:13:00

Client: FNB ~~Wet~~ Stoker
Model: ~~Dry Lump~~ Coal Cold Start
Project #: 477-S-01-1
Tracking #: 1684
Run #: 39 Date: 8/16/11
Test Crew: AH, JC
OMNI Equipment ID #(s):

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1/4 turn open

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
0:08:30			11.0			Ash door open
0:12:00	Ash door closed, primary set		14.0			Ash door open
0:18:00						
1:25:00	Test fuel loaded					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Stoker coal
25.0 lb

START UP PROCEDURES

BYPASS: N/A
FUEL LOADING: Done by 1:28:06
DOOR: Closed @ 1:30:00
PRIMARY AIR: Set the Whole time
OTHER: N/A

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

1/4 turn open

SECONDARY: N/A

TERTIARY: N/A

FAN: On high

5:45:00 - stirred coals

Technician signature: Date: 8/16/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 8/16/11 *Run #:* 39 *Appliance/Fuel/Burn Rate:* ~~Dry lump~~ wet stoker coal cold start

Filter Data

T1: *ID:* A779725X

T1 (2): *ID:*

Time Changed:

Q1: *ID:* A768264G + A768263F

Q2: *ID:* FUB 122

Q3: *ID:* FNB 123

Q4: *ID:* N/A *Preliminary Weight:*

Q4 (2): *ID:* N/A *Preliminary Weight:*

Time Changed:

Date/time Samples placed in freezer/dessicator:
8/16/11 1700

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: ϕ

Ammonia Train: .006 @ -17"

Box A: .010 @ -15"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: ϕ

Box A: .009 @ -15"

Box B: NA @ NA

Flow Rate Check:

T1: 198.37 mL/min Q2: 1940.1 mL/min

Q1: 1583.7 mL/min Q3: 1048.0 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 39-1 *D/T in Fridge:* 8/16

Impinger 2: *Bottle Number:* 39-2 *D/T in Fridge:* 8/16

Technician Signature/Date: 8/16/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

OMNI-Test Laboratories, Inc.

Run Notes

Client: FNB
Model: No 1 Heating Oil 2`
Project #: 477-S-01-1
Tracking #: 1635
Run #: 40 Date: 8/17/11
Test Crew: AH, JC
OMNI Equipment ID #(s):

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

Auto

SECONDARY: NA

TERTIARY: NA

FAN: Auto

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
	None					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

No. 1 Fuel oil

START UP PROCEDURES

BYPASS:
FUEL LOADING DOOR:
PRIMARY AIR: NA

OTHER:

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

Auto

SECONDARY: NA

TERTIARY: NA

FAN: Auto

Technician signature: Date: 8/17/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 8/17/11 *Run #:* 40 *Appliance/Fuel/Burn Rate:* No. 1 Heating Oil 2

Filter Data

T1: *ID:* A779724W

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A768268K

Q2: *ID:* FNB 124

Q3: *ID:* FNB 125

Q4: *ID:* N/A *Preliminary Weight:*

Q4 (2): *ID:* N/A *Preliminary Weight:*

Time Changed:

Date/time Samples placed in freezer/dessicator:
8/14/11 0800

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: Ø

Ammonia Train: .014 @ -14"

Box A: .004 @ -15"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: Ø

Box A: .012 @ -15"

Box B: N/A @ N/A

Flow Rate Check:

T1: 1485.29 mL/min Q2: 1880.0 mL/min

Q1: 1020.9 mL/min Q3: 974.93 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 40-1 *D/T in Fridge:* 8/18

Impinger 2: *Bottle Number:* 40-2 *D/T in Fridge:* 8/18

Technician Signature/Date: 8/17/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

Run Notes

* propane torch used for startup.

Client: FNB
Model: EPA Stove Birch Low Cold Start
Project #: 477-S-01-1
Tracking #: _____
Run #: 41 Date: 8/18/11
Test Crew: AK, JC
OMNI Equipment ID #(s): _____

PREBURN

DESCRIBE OR SKETCH AIR OR THERMOMSTAT SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCABLE)

PRIMARY:

1/4" open from fully closed

SECONDARY: Fixed

TERTIARY: NA

FAN: NA

PREBURN SETTINGS AND ACTIVITIES

TIME	AIR (THERMO) CHANGES PRIMARY/SECONDARY/TERTIARY	FAN SETTING CHANGE	ADD FUEL + WT.	ADD FUEL - WT.	RAKE COAL	COMMENT
0:00:00			6.0			kindling
0:15:00			6.5			
0:18:00	Forced combustion air applied					Preburn
0:23:00	Door closed, primary opened wide					
0:40:00	Primary reduced to test setting					
1:21:00					stirred coals	
1:50:00	Test fuel loaded					

TEST

TEST FUEL CONFIGURATION SKETCH
(INDICATE VIEW ANGLE)

Birch cordwood

START UP PROCEDURES

BYPASS: NA
FUEL LOADING: Done by 1:51:00
DOOR: Closed @ 1:51:30
PRIMARY AIR: Set @ 1:55:00

OTHER: NA

DESCRIBE OR SKETCH TEST SETTINGS BELOW:
(SETTINGS MUST BE ACCURATE AND REPRODUCIBLE)
PRIMARY:

1/4" open from fully closed

SECONDARY: Fixed

TERTIARY: NA

FAN: NA

Technician signature: _____ Date: 8/17/11

Client: Fairbanks North Star Borough
Project #: 477-S-01-1

Date: 8/18/11 *Run #:* 41 *Appliance/Fuel/Burn Rate:* EPA Stove Birch Low Cold Start

Filter Data

T1: *ID:* A779721T

T1 (2): *ID:* N/A

Time Changed: N/A

Q1: *ID:* A768268L

Q2: *ID:* FNB 126

Q3: *ID:* FNB 127

Q4: *ID:* N/A *Preliminary Weight:* N/A

Q4 (2): *ID:* N/A *Preliminary Weight:* N/A

Time Changed: N/A

Date/time Samples placed in freezer/dessicator:
8/18/11 1600

Q4 weight record:	D/T:	D/T:	D/T:
	Audit:	Audit:	Audit:
	Temp:	Temp:	Temp:
	Humidity:	Humidity:	Humidity:
	Weight (1):	Weight (1):	Weight (1)
	Weight (2):	Weight (2):	Weight (2)

Supplementary Data

Pre-Test Leaks:

Gas Analyzer Train: 0

Ammonia Train: .007 @ -12"

Box A: .001 @ -14"

Box B: N/A @ N/A

Post-Test Leaks:

Gas Analyzer Train: 0

Box A: .006 @ -14"

Box B: N/A @ N/A

Flow Rate Check:

T1: 202.47 mL/min Q2: 1976.7 mL/min

Q1: 1022.3 mL/min Q3: 1041.5 mL/min

Ammonia Sample:

Impinger 1: *Bottle Number:* 41-1 *D/T in Fridge:* 8/18/11

Impinger 2: *Bottle Number:* 41-1 *D/T in Fridge:* 8/18/11

Technician Signature/Date: 8/18/11

OMNI Equipment: 23, 131, 343, 419, 289, 371, 372, 445

FUEL DATA

Client: FNB
Model: EPA Stove Birch Low Cold Start
Project #: 477-S-01-1 Tracking #: ____
Date: 8/18/11 Test Crew: AH, JC Run #: 41
OMNI Equipment ID #: 163, 431
FUEL LOAD PREPARED BY: AH
FUEL: ~~DOUGLAS-FIR SPECIES, UNTREATED, AIR-DRIED, STANDARD GRADE OR BETTER, DIMENSIONAL LUMBER.~~ Birch Cordwood

PRE-BURN FUEL

Kindling: 6.0 lb
Preburn: 16.5 lb

MOISTURE CONTENT (METER – – DRY BASIS)

CALIBRATION: Cal Value (1) = 12% Actual Reading 12.0
Cal Value (2) = 22% Actual Reading 22.0

Piece	Length		Readings		Type
1	____ ft	13.7	18.9	16.7	cord
2	____ ft	24.1	16.3	19.0	"
3	____ ft	15.7	13.2	13.1	"

Length of cut pieces: 12-20 inches Pre-Burn Fuel Average Moisture:

Time (clock): 1000 Room Temperature (F): 73 Initials: AH

TEST FUEL

FUEL TYPE AND AMOUNT: 2 × 4 N/A 4 × 4 N/A
CALCULATED LOAD WEIGHT: N/A ACTUAL LOAD WEIGHT: N/A (2 × 4)
(4 × 4)
FUEL PIECE LENGTH: 12-20" 16.9 lb Total

MOISTURE CONTENT (METER – – DRY BASIS)

PIECE	READINGS			TYPE
1	15.2	15.1	16.6	cord
2	14.2	24.7	25.1	"
3	14.3	14.8	15.2	"
4	20.5	21.2	20.6	"
5	13.2	13.1	14.7	"
6	12.8	19.4	20.6	"
7				
8				
9				
10				

OVERALL TEST FUEL LOAD MOISTURE AVERAGE: ~~17.5~~ 17.25 Coverall

Time (clock): 1000 Room Temperature (F): 73 Initials: AH

Technician signature: [signature] Date: 8/18/11

Coal Moisture worksheet

"Wet" Stoker Coal

Beaker: 527

Tare: 137.7 grams

5/9/11 Initial weight: 329.4 grams

5/12/11 Final weight: 281.3 grams

Initial weight = 329.4 - 137.7
⇒ 191.7 grams

Final weight ⇒ 281.3 - 137.7
⇒ 143.6 grams

DB Moisture ⇒

$\frac{191.7 - 143.6}{143.6}$ ⇒ 33.5%

5/12/11

Dry stoker coal

Beaker: 499

Tare: 136.0 grams

5/9/11 Initial weight: 391.3 grams

5/12/11 Final weight: 365.5 grams

Initial weight = 391.3 - 136
⇒ 255.3 grams

Final weight = ~~391.3~~
365.5 - 136
⇒ 229.5

DB Moisture ⇒

$\frac{255.3 - 229.5}{229.5}$

⇒ 11.2%

Coal Moisture ~~8/10/11~~ 8/31/11

Dry Lump

Beaker: 457	Initial: 232.4	216.1	8/1	0830
Tare: 130.3	In oven: 8/31/11 10:00	216.2	9/1	1430

Wet Lump

Beaker: 2062	Initial: 272.5	241.5	9/1	0830
Tare: 119.5	In oven: 8/31/11 10:00	241.5	9/1	1430

Dry Stoker (Batch 2)

Beaker: 583	Initial: 222.8	208.7	9/1	0830
Tare: 131.1	In oven: 8/31/11 10:00	208.6	9/1	1430

$$\text{Dry Lump} = \frac{(232.4 - 130.3) - (216.1 - 130.3)}{216.1 - 130.3} = 19.00\%$$

Wet Lump = 25.41%

Dry Stoker = 18.32%

9/1/11

Measurement of Space-Heating Emissions

Appendix F

Photographs

F.1 EPA Certified Wood Stove

Run 2 (birch high) test fuel

Run 2 test fuel loaded

Run 3 (spruce high) test fuel

Run 3 test fuel loaded

Run 5 (birch low) test fuel

Run 5 test fuel loaded

Run 6 (spruce low) test fuel

Run 6 test fuel loaded

Run 41 (birch low, cold start) fuel

Run 41 kindling loaded

Run 41 preburn loaded

Run 41 test fuel loaded

F.2 Conventional Wood Stove

Run 12 (spruce high) test fuel

Run 12 test fuel loaded

Run 13 (birch high) test fuel

Run 13 test fuel loaded

Run 14 (spruce low) test fuel

Run 14 test fuel loaded

Run 15 (birch low) test fuel

Run 15 test fuel loaded

F.3 EPA Phase II Certified OWHH

Run 8 (birch high) test fuel

Run 8 test fuel loaded

Run 9 (birch low) test fuel

Run 9 test fuel loaded

Run 10 (spruce high) test fuel

Run 10 test fuel loaded

Run 11 (spruce low) test fuel

Run 11 test fuel loaded

Run 34 (birch low, with retrofit catalyst) test fuel

Run 34 test fuel loaded

F.4 Coal Stove

Run 20 (dry stoker coal high) test fuel

Run 20 test fuel loaded

Run 21 (dry stoker coal low) test fuel

Run 21 test fuel loaded

Run 23 (wet stoker coal low) test fuel

Run 23 test fuel loaded

Run 35 (wet stoker coal high) test fuel

Run 35 test fuel loaded

Run 36 (wet lump coal low, cold start) test fuel-kindling, preburn, test fuel

Run 36 kindling/preburn loaded

Run 36 test fuel loaded

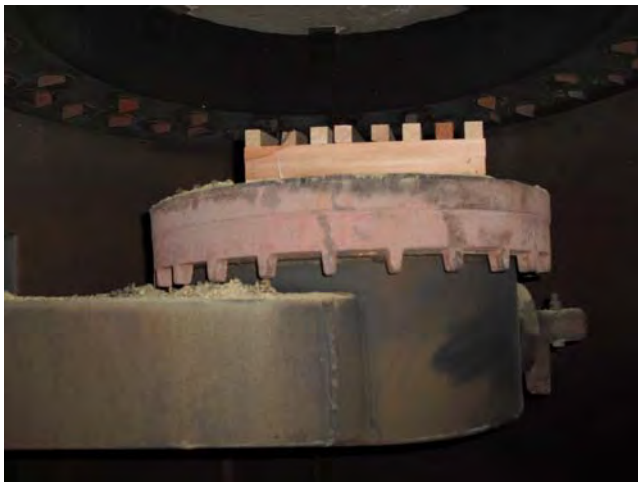
Run 37 (wet lump coal low) test fuel loaded

Run 38 (dry lump coal low) test fuel loaded

Run 39 (wet stoker coal low, cold start) test fuel loaded

F.5 Auger-fed Coal Hydronic Heater

Run 28 (cold start) kindling



Run 28 kindling on burner

Auger-fed HH hopper installation

F.6 Non-qualified OWHH

Run 25 (spruce high) test fuel

Run 25 test fuel loaded

Run 30 (spruce low) test fuel

Run 30 test fuel loaded

Run 31 (birch high) test fuel

Run 31 test fuel loaded

Run 32 (birch low) test fuel

Run 32 test fuel loaded

Run 33 (birch low, cold start) kindling loaded

Run 33 preburn loaded

Run 33 test fuel

Run 33 test fuel loaded

Measurement of Space-Heating Emissions

Appendix G

Equipment Calibration Documentation

Equipment Item	Equipment Number	Calibration Period
2000mg Balance	23	6 months
500mg Weight	131	5 years
10lb Weight	132	5 years
Delmhorst Wood Moisture Meter	183	Prior to use
APEX Sample Box	289	6 months
Omega Thermohygrometer	291	1 year
ThermoScientific CO PPM Analyzer	325	Prior to use
ThermoScientific VOC Analyzer	328	Prior to use
ThermoScientific SO2 Analyzer	329	Prior to use
Weightronix 500 lb Scale	353	Prior to use
Weightronix 5000 lb Scale	356	Prior to use
APEX Sample Box	371	6 months
California Analytic O2, CO2, CO % Analyzer	419	Prior to use
Delmhorst Moisture Meter Calibrator	431	6 months
Bios Air Flow Meter	445	1 year
Delmhorst Wood Moisture Meter	507	Prior to use
ThermoScientific NOx Analyzer	509	Prior to use

Public Review Draft

Certificate of Calibration

Certificate Number: **477037**

JJ Calibrations, Inc.
7007 SE Lake Rd
Portland, OR 97267-2105
Phone 503.786.3005
FAX 503.786.2994

OnSite

ACCREDITED 0723.01

Omni-Test Laboratories
13327 NE Airport Way
Portland, OR 97230

PO: TBD
Order Date: 5/16/2011
Authorized By: N/A

Property #: OMNI-00023
User: N/A
Department: N/A
Make: Mettler
Model: AE200
Serial #: E17657
Description: Scale 205g
Procedure: DCN 500818/500887
Accuracy: ±0.0004g ±1 LSD

Calibrated on: 5/16/2011
*Recommended Due: 11/16/2011
Environment: 25 °C 36 % RH
As Received: Out of Tolerance
As Returned: Within Tolerance
Action Taken: Calibrated
Technician: 53

Remarks: * Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired

Standards Used

Std ID	Manufacturer	Model	Nomenclature	Due Date	Trace ID
503A	Rice Lake	1mg-200g (Class O)	Mass Set	11/8/2011	460936

Measurement Data

Parameter / Measurement Description	Range	Unit	Reference	UUT	Variance	Min	Max	Uncertainty	
Before				× = OOT condition				Accredited = ✓	
Force									
		mg	1.00	1.0	0.00	0.50	1.50	2.6E-6	✓
		mg	10.00000	10.0000	0.00000	9.99950	10.00050	2.6E-6	✓
		mg	100.00000	100.0000	0.00000	99.99950	100.00050	2.6E-6	✓
		mg	500.00000	500.0000	0.00000	499.99951	500.00049	2.6E-6	✓
		g	1.00000	1.0000	0.00000	0.99950	1.00050	2E-6	✓
		g	20.00000	20.0002	-0.00020	19.99950	20.00050	2E-6	✓
		g	50.00000	50.0004	-0.00040	49.99950	50.00050	2E-6	✓
		g	100.00000	100.0006×	-0.00060	99.99950	100.00050	2E-6	✓
		g	150.00000	150.0007×	-0.00070	149.99950	150.00050	2E-6	✓
		g	185.00000	185.0009×	-0.00090	184.99950	185.00050	2E-6	✓
		g	200.00000	200.0009×	-0.00090	199.99950	200.00050	2E-6	✓
After								Accredited = ✓	
		g	20.00000	20.0000	0.00000	19.99950	20.00050	2E-6	✓
		g	50.00000	50.0000	0.00000	49.99950	50.00050	2E-6	✓
		g	100.00000	100.0000	0.00000	99.99950	100.00050	2E-6	✓
		g	150.00000	150.0000	0.00000	149.99950	150.00050	2E-6	✓
		g	185.00000	185.0000	0.00000	184.99950	185.00050	2E-6	✓
		mg	1.00	1.0	0.00	0.50	1.50	2.6E-6	✓
		mg	10.00000	10.0000	0.00000	9.99950	10.00050	2.6E-6	✓
		mg	100.00000	100.0000	0.00000	99.99950	100.00050	2.6E-6	✓
		mg	500.00000	500.0000	0.00000	499.99951	500.00049	2.6E-6	✓
		g	1.00000	1.0000	0.00000	0.99950	1.00050	2E-6	✓
		g	200.00000	200.0000	0.00000	199.99950	200.00050	2E-6	✓

JJ Calibrations, Inc. certifies that this instrument has been calibrated in accordance with the JJ Calibrations Quality Assurance Manual with the stated procedure using standards that are traceable to the National Institute of Standards and Technology (NIST), or other National Measurement Institutes (NMI's), or by using natural physical constants, intrinsic standards or ratio calibration techniques. The quality system and this certificate are in compliance with ANSI/NCSL Z540-1-1994, ISO/IEC 17025-2005, ISO 10012-1, the ISO 9000 family and QS 9000. The expanded uncertainties of measurements for this calibration are based upon 95% (2 sigma) confidence limits. Unless otherwise stated, a test accuracy ratio (TAR) of 4:1, if achievable, is maintained. The results reported herein apply only to the calibration of the item described above. This report may not be reproduced, except in full, without prior written consent of JJ Calibrations, Inc.
JJ Calibrations, Inc. quality system has been assessed and accredited to ISO/IEC 17025:2005.

Reviewer

5 Issued 5/16/2011 Rev # 14

Cynthia Calcote
Inspector

Certificate of Calibration

Certificate Number: **413631**

JJ Calibrations, Inc.
7007 SE Lake Rd
Portland, OR 97267-2105
Phone 503.786.3005
FAX 503.786.2994

Omni-Test Laboratories
13327 NE Airport Way
Portland, OR 97230

PO: **OTL-08-490**
Order Date: 11/04/2008

ACCREDITED
0723.01

Property #: OMNI-00131
User:
Department:
Make: Ohaus
Model: 500mg
Serial #: 27503
Description: 500mg WEIGHT
Procedure: DCN 500901
Accuracy: CLASS F

Calibrated on: 11/05/2008 MMH
*Recommended Due: 11/05/~~2009~~ 2013
Environment: 18 °C 43 % RH
As Received: Within Tolerance
As Returned: Within Tolerance
Action Taken: Calibrated
Technician: 92

Remarks:
Refer to attachment for measurement results.

Standards Used

Std ID	Manufacturer	Model	Nomenclature	Due Date	Trace ID
256A	Rice Lake	W0133K	WEIGHT SET	02/08/2010	406054
432A	Sartorius	C-44	Microbalance 5.1g	11/13/2008	384448

* Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired

JJ Calibrations, Inc. certifies that this instrument has been calibrated in accordance with the JJ Calibrations Quality Assurance Manual with the stated procedure using standards that are traceable to the National Institute of Standards and Technology (NIST), or other National Measurement Institutes (NMI's), or by using natural physical constants, intrinsic standards or ratio calibration techniques. The quality system and this certificate are in compliance with ANSI/NCSL Z540-1-1994, ISO/IEC 17025-2005, ISO 10012-1, the ISO 9000 family and QS 9000. The expanded uncertainties of measurements for this calibration are based upon 95% (2 sigma) confidence limits. The results reported herein apply only to the calibration of the item described above. This report may not be reproduced, except in full, without prior written consent of JJ Calibrations, Inc. JJ Calibrations, Inc. quality system has been assessed and accredited to ISO/IEC 17025:2005.

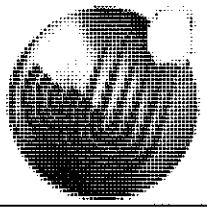
Reviewer

Inspector

5 Issued 11/05/2008 Rev # 13

Supplemental Calibration Report

Certificate Number: **413631**



November 14, 2014

JJ Calibrations, Inc.
7007 SE Lake Rd
Portland, OR 97267-2105
Phone 503.786.3005
FAX 503.786.2994

Customer:	Omni-Test Laboratories		
Property ID:	OMNI-00131	PO:	OTL-08-490
Make:	Ohaus	Order Date:	11/04/2008
Model:	500mg	Procedure:	DCN 500901
Serial #:	27503	Calibrated on:	11/05/2008
Description:	500mg WEIGHT	Technician:	92

Parameter Measurement Description	Range	Unit	Reference	UUT	Variance	Min	Max	Uncertainty	
Before/After								Accredited = ✓	
Mass									
		mg	500.0000	500.123	-0.1230	499.28	500.72	0.00011	✓

OMNI Environmental Service, Inc.
OMNI-Test Laboratories, Inc.
Beaverton, OR Phone (503) 643-3788

SCALE WEIGHT CALIBRATION DATA SHEET

Weight to be calibrated: 132

ID Number: 132

Standard Calibration Weight: 274

ID Number: 274

Scale Used: ~~185~~ 1K 288

ID Number: ~~185~~ 1K 288

Date: 2-07-08 By: K. Morgan

Standard Weight (A) (Lb.)	Weight Verified (B) (Lb.)	Difference (A - B)	% Error
10.0	10.0	0	0

*Acceptable tolerance is 1%.

This calibration is traceable to NIST using calibrated standard weights.

Technician signature: K. Morgan Date: 2-07-08

Thermal Metering System Calibration
Y and dH@

Manufacturer:	APEX
Model:	Model 533
Serial Number:	NA
OMNI Tracking No.:	289

Previous Calibration Comparision

Date	10/8/2010	Acceptable	
dH@ Value	NA	Deviation (5%)	Deviation
y Factor	0.99	0.0495	0.000
Acceptance	Acceptable		

Average Orifice Meter dH@	Average Gas Meter y Factor
3.006	0.990

Calibration Date:	04/12/11
Calibrated by:	S. Button
Calibration Frequency:	6 months
Next Calibration Due:	10/11/11
Instrument Range:	1.000 cfin
Standard Temp.:	68 oF
Standard Press.:	29.92 "Hg
Barometric Press.:	30.24 "Hg
Signature/Date:	4/12/11 4/12/11 SB

Current Calibration

Acceptable y Deviation	0.020
Maximum y Deviation	0.005
Acceptable dH@ Deviation	0.200
Maximum dH@ Deviation	1.838
Acceptance	~~Out of Limits~~ N/A SB

4/29/11 SB (MY MISTAKE WRONG PAPER)

Reference Standard *			
Standard Calibrator	Model	Standard Test Meter	
	S/N	1	
	Calib. Date	17-Jun-10	
	Calib. Value	0.9980	y factor (ref)

Calibration Parameters	Run 1	Run 2	Run 3
Vacuum ("Hg)	0.00	0.00	0.00
dH ("H2O)	2.57	1.44	0.67
Initial Reference Meter	133.515	139.512	146.685
Final Reference Meter	139.355	146.535	154.225
Initial DGM	0	0	0
Final DGM	5.883	7.09	7.705
Temp. Ref. Meter (°F), Tr	69.0	69.0	69.0
Temperature DGM (°F), Td	73.0	73.0	74.0
Time (Minutes)	7.0	11.5	27.3
Net Volume Ref. Meter, Vr	5.840	7.023	7.540
Net Volume DGM, Vd	5.883	7.09	7.705
Gas Meter y Factor =	0.992	0.993	0.984
Gas Meter y Factor Deviation (from avg.)	0.002	0.003	0.005
Orifice dH@	2.04	2.13	4.84
Orifice dH@ Deviation (from avg.)	0.966	0.873	1.838

where:

1. Deviation = |Average value for all runs - current run value|
2. y = [Vr x (y factor (ref)) x (Pb) x (Td + 460) / [Vd x (Pb + (dH / 13.6)) x (Tr + 460]
3. dH@ = 0.0317 x dH / (Pb (Td + 460)) x [(Tr + 460) x time) / Vr]^2

* Reference calibration is traceable to NIST through NIST Test # 40674, Kimble ASTM E1272

DIFFERENTIAL PRESSURE GAUGE CALIBRATION DATA SHEET
0-0.25" Magnehelic Gauge

Range: 0-0.25" WC ID Number: 289B (Stack Dept)

Calibration Instrument: ~~Microtector~~ Digital Manometer ID Number: OMNI- 315

Date: 4/29/2011 By: Aaron Kravitz

This form is to be used only in conjunction with Standard Procedure C-SPC.

Range of Calibration Point ("WC)	Digital Manometer (A) ("WC)	Magnehelic Gauge (B) ("WC)	Difference (A - B)	% Error of Full Span*
0.00 - 0.05	.036	.039	-.003	1.2%
0.05 - 0.10	.090	.095	~~.005~~ -.005	2%
0.10 - 0.15	.135	.141	-.006	2.4%
0.15 - 0.20	.157	.155	.002	0.8%
0.20 - 0.25	.214	.211	.003	1.2%

*Acceptable tolerance is 4%.

The uncertainty of measurement is ±0.01" WC. This is based on the reference standard having a TAR (Test Accuracy Ratio) of at least 4:1.

Technician signature: _____ Date: 4/29/11

Reviewed by: _____ Date: 4/29/11

OMNI Environmental Servi Inc.
OMNI-Test Laboratories, Inc.

DIFFERENTIAL PRESSURE GAUGE CALIBRATION DATA SHEET
0-0.25" Magnehelic Gauge

Range: 0-0.25" WC ID Number: 289D

Calibration Instrument: Microtector ID Number: OMNI- ~~3~~ 315

Date: 4/29/2011 By: Aaron Kravitz

This form is to be used only in conjunction with Standard Procedure C-SPC.

Range of Calibration Point ("WC)	Digital Manometer (A) ("WC)	Magnehelic Gauge (B) ("WC)	Difference (A - B)	% Error of Full Span*
0.00 - 0.05	~~.205~~ .048	~~.202~~ .042	.006	2.4%
0.05 - 0.10	.090	.092	-.002	0.8%
0.10 - 0.15	.117	.116	.001	0.4%
0.15 - 0.20	.180	.185	-.005	2.0%
0.20 - 0.25	.205	.202	.003	1.2%

*Acceptable tolerance is 4%.

The uncertainty of measurement is ±0.01" WC. This is based on the reference standard having a TAR (Test Accuracy Ratio) of at least 4:1.

Technician signature: _____ Date: 4/29/11

Reviewed by: _____ Date: 4/29/11

Temperature Calibration EPA Method 28 and 5G			
Booth:	**Temperature Monitor Type:**		**Identification Number:**
Emissions 2	National Instruments		289C/Booth 2
Reference Temperature Monitor Type:		**Identification Number:**	
OMEGA Calibrator Model CL20		**OMNI-** 117	
Calibration Performed By:	**Date:**	**Ambient Temperature:**	**Barometric Pressure:**
Aaron Kravitz	4/29/2011	70	30.43

Reference Point Source	Temperature Monitor (EF)					
		Method 5G Dilution Tunnel				
OMEGA Thermocouple Simulator Serial 117	Method 28 Room	Meter (Tm)	Filters (Tf)	Tunnel (Tt)	Stack (Ts)	DB
0	-2	-3	-1	-3	-1	
100	99	99	101	99	101	
300	299	299	299	299	299	
500	499	499	497	499	497	
700	699	699	695	699	695	

OMEGA Thermocouple Simulator Serial 117	Top	Bottom	Back	Left	Right
0	-3	-3	-3	-3	-3
100	99	99	99	99	99
300	299	299	299	299	299
500	499	499	499	499	499
700	699	699	699	699	699

4/29/11

Public Review Draft

Certificate of Calibration

Certificate Number: **466279**

JJ Calibrations, Inc.
7007 SE Lake Rd
Portland, OR 97267-2105
Phone 503.786.3005
FAX 503.786.2994

November 14, 2014

Omni-Test Laboratories
13327 NE Airport Way
Portland, OR 97230

RECENTERED
0723.01

PO: OTL-10-085
Order Date: 12/20/2010
Authorized By: N/A

Property #: OMNI-00291
User: N/A
Department: N/A
Make: Omega
Model: RH82
Serial #: 9190156
Description: Thermohygrometer
Procedure: DCN 401013/403410
Accuracy: REFER TO SPECIFICATIONS

Calibrated on: 12/22/2010
*Recommended Due: 12/22/2011
Environment: 22 °C 35 % RH
As Received: Within Tolerance
As Returned: Within Tolerance
Action Taken: Calibrated
Technician: 112

Remarks: * Any number of factors may cause the calibration item to drift out of calibration before the recommended interval has expired

Standards Used

Std ID	Manufacturer	Model	Nomenclature	Due Date	Trace ID
464A	General Eastern	M4-RH/D2	HUMIDITY STANDARD	03/21/2011	448210
497A	Hart Scientific	1502A	Precision Digital Thermometer	09/14/2011	459710
601A	Burns Engineering	200G05B085	INDUSTRIAL PRT	02/03/2012	444255

Measurement Data

Parameter / Measurement Description	Range	Unit	Reference	UUT	Variance	Min	Max	Uncertainty	Accredited = ✓
Before/After									
Relative Humidity									
		%	25.00	25.3	-0.30	22.00	28.00	2.03	✓
		%	50.0	51	-1.0	47.0	53.0	2.03	✓
		%	75.00	76.5	-1.50	72.00	78.00	2.03	✓
Temperature									
		°F	50.00	50.2	-0.20	48.20	51.80	1.2	✓
		°F	66.50	66.5	0.00	64.70	68.30	1.2	✓

JJ Calibrations, Inc. certifies that this instrument has been calibrated in accordance with the JJ Calibrations Quality Assurance Manual with the stated procedure using standards that are traceable to the National Institute of Standards and Technology (NIST), or other National Measurement Institutes (NMI's), or by using natural physical constants, intrinsic standards or ratio calibration techniques. The quality system and this certificate are in compliance with ANSI/NCSL Z540-1-1994, ISO/IEC 17025-2005, ISO 10012-1, the ISO 9000 family and QS 9000. The expanded uncertainties of measurements for this calibration are based upon 95% (2 sigma) confidence limits. Unless otherwise stated, a test accuracy ratio (TAR) of 4:1, if achievable, is maintained. The results reported herein apply only to the calibration of the item described above. This report may not be reproduced, except in full, without prior written consent of JJ Calibrations, Inc.
JJ Calibrations, Inc. quality system has been assessed and accredited to ISO/IEC 17025:2005.

Carolyn S Johansen
Reviewer

5 Issued 12/28/2010 Rev # 14

Inspector

Thermal Metering System Calibration
Y and dH@

Manufacturer:	Apex
Model:	XC-60-EP
Serial Number:	371
OMNI Tracking No.:	371

Average Orifice Meter dH@	Average Gas Meter y Factor
1.408	1.007

Calibration Date:	02/15/11
Calibrated by:	S Button
Calibration Frequency:	6 Month
Next Calibration Due:	08/16/11
Instrument Range:	1.000 cfm
Standard Temp.:	68 oF
Standard Press.:	29.92 "Hg
Barometric Press.:	29.72 "Hg
Signature/Date:	2/15/11

Previous Calibration Comparision

Date	7/14/2010	Acceptable	
dH@ Value	n/a	Deviation (5%)	Deviation
y Factor	0.996	0.0498	0.011
Acceptance	Acceptable		

Current Calibration

Acceptable y Deviation	0.020
Maximum y Deviation	0.019
Acceptable dH@ Deviation	0.200
Maximum dH@ Deviation	0.067
Acceptance	Acceptable

Reference Standard *			
Standard Calibrator	Model	Standard Test Meter	
	S/N	1	
	Calib. Date	17-Jun-10	
	Calib. Value	0.9980	y factor (ref)

Calibration Parameters	Run 1	Run 2	Run 3
Vacuum ("Hg)	0.00	0.00	0.00
dH ("H2O)	1.30	0.65	0.30
Initial Reference Meter	115.04	120.643	127.695
Final Reference Meter	120.138	127.375	133.255
Initial DGM	0	0	0
Final DGM	5.072	6.781	5.407
Temp. Ref. Meter (°F), Tr	69.0	69.0	69.0
Temperature DGM (°F), Td	70.0	71.0	69.0
Time (Minutes)	7.0	13.5	15.8
Net Volume Ref. Meter, Vr	5.098	6.732	5.560
Net Volume DGM, Vd	5.072	6.781	5.407
Gas Meter y Factor =	**1.002**	**0.993**	**1.025**
Gas Meter y Factor Deviation (from avg.)	0.005	0.014	0.019
Orifice dH@	**1.39**	**1.48**	**1.36**
Orifice dH@ Deviation (from avg.)	0.022	0.067	0.045

where:

1. Deviation = |Average value for all runs - current run value|
2. y = [Vr x (y factor (ref)) x (Pb) x (Td + 460) / [Vd x (Pb + (dH / 13.6)) x (Tr + 460]
3. dH@ = 0.0317 x dH / (Pb (Td + 460)) x [(Tr + 460) x time) / Vr]^2

* Reference calibration is traceable to NIST through NIST Test # 40674, Kimble ASTM E1272

DIFFERENTIAL PRESSURE GAUGE CALIBRATION DATA SHEET
0-1" Magnehelic Gauge

Range: 0-1" WC ID Number: 371 (B)

Calibration Instrument: Digital Manometer (A) ID Number: OMNI- 315

Date: 2/16/11 By: J. Buffum

This form is to be used only in conjunction with Standard Procedure C-SPC.

Range of Calibration Point ("WC)	Digital Manometer (A) ("WC)	Magnehelic Gauge (B) ("WC)	Difference (A - B)	% Error of Full Span*
0.0 – 0.2	.06	.07	.01	1%
0.2 – 0.4	.31	.33	.02	2%
0.4 – 0.6	.55	.57	.02	2%
0.6 – 0.8	.64	.66	.02	2%
0.8 – 1.0	.92	.93	.01	1%

*Acceptable tolerance is 4%.

The uncertainty of measurement is ±0.1" WC. This is based on the reference standard having a TAR (Test Accuracy Ratio) of at least 4:1.

Technician signature: _____ Date: 2/16/11

Reviewed by: _____ Date: _____

OMNI Environmental Services, Inc.
OMNI-Test Laboratories, Inc.
Beaverton, OR Phone (503) 643-3788

Public Review Draft

Thermocouple Readout Calibration Log

Date: 5-4-07 OMNI Meter Identification Number: OMNI- 00371 (A) Technician: B Dove

		Meter Response						Acceptable?		
		0	200	400	600	800	1000			
Date	Calibration Meter ID		± 3EF*	± 6EF	± 9EF	± 12EF	± 15EF	Yes	No	Initials
5-4-07	290	-1	201	399	602	803	1002	✓		BL
10-24-07	373	001	199	398	599	800	1001	✓		BR
5-01-08	373	002	200	397	596	796	996	✓		JL
11-11-08	373	001	200	399	599	798	1000	✓		BR
6/15/09	373	003	201	390	596	796	995	✓		SB
11/20/09	373	002	202	400	601	802	1002	✓		MO
5/17/10	373	1	201	401	601	801	1001	✓		SB
7/14/10	373	001	201	401	602	802	1001	✓		SB
2/15/11	373	001	201	401	601	802	1001	✓		SB
9/9/11	433	003	202	401	602	803	1003	✓		AG
10/6/11	433	003	203	402	602	802	1001	✓		JL

*Note: Acceptance Criteria are based on EPA Method 2 Section 4.3 (1.5% agreement of readings)

Technician signature: _____ Date: _____

OMNI Environmental, Inc.
OMNI-Test Laboratories, Inc.

WOOD MOISTURE CONTENT CALIBRATION WORKSHEET

Moisture Content Standard OMNI ID #: OMNI-00431 (8H0P)

Reference Moisture Content Standard: **OMNI # 00430**

Date	Temp.	Barometric Pressure	Fixed Moisture %	Fixed Moisture %	Observed Moisture % (#431)	Observed Moisture % (#430)	Initials
4/29/11	72	30.3	22%	12%	22% / 12%	22% / 12%	SW
8/10/11	85	29.2	22%	12%	22% / 12%	22% / 12%	SW
			22%	12%			
			22%	12%			
			22%	12%			
			22%	12%			
			22%	12%			
			22%	12%			
			22%	12%			
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			22%	12%			
			22%	12%			
			22%	12%			
			22%	12%			
			22%	12%			
			22%	12%			

Notes: _____

Technician signature: _____ Date: 4/29/11

NVLAP Lab Code 200661

Bios
Driving a Higher Standard in Flow Measurement℠

Calibration Certificate

Certificate No.	507987
Product	Defender 530 Medium Flow
Serial No.	120662
Cal. Date	9/7/2010
Sales Date	9/23/2010 *Calibration interval commences on sale date.*

All calibrations are performed in accordance with ISO 17025 at Bios International Corporation, 10 Park Place, Butler, NJ, 07405, 800-663-4977, an ISO 17025:2005 – accredited laboratory through NVLAP. This report shall not be reproduced except in full without the written approval of the laboratory. Results only relate to the items calibrated. This report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the Federal Government.

All units tested in accordance with Bios International Corporation test number PR17-13 using high-purity bottled nitrogen or dry filtered laboratory air.

Calibration Data

Technician Zenaida Ortiz

Lab. Pressure 755 mmHg
Lab. Temperature 22.2 °C

Instrument Reading	Lab Standard Reading	Deviation	Allowable Deviation	As Shipped
100.88 ccm	100.375 ccm	0.5 %	1.00%	In Tolerance
1,008.2 ccm	1007 ccm	0.12 %	1.00%	In Tolerance
5,014.1 ccm	5005.6 ccm	0.17 %	1.00%	In Tolerance
22.2 °C	22.2 °C	-	±0.8°C	In Tolerance
755 mmHg	755 mmHg	-	±3.5 mHg	In Tolerance

Bios International Standards Used

Description	Standard Serial Number	Calibration Date	Calibration Due Date
ML 500-24	113775	4/27/2010	4/27/2011
Precision Thermometer	305460	4/29/2010	4/29/2011
Precision Barometer	431/98-07	4/16/2010	4/16/2011

Calibration Notes

Bios is an ISO 17025-accredited metrology laboratory. Each Bios primary gas flow standard is dynamically verified by comparing it to one of our laboratory standards, which is a Proven DryCal® Technology volumetric piston prover of much higher accuracy but of similar operating principles. For this purpose, a flow generator of ±0.03% stability is used. Our laboratory standards are qualified by direct measurement of their dimensions (diameter, length and time) using NIST-traceable precision gauges and instruments, such as depth micrometers and laser micrometers. NIST numbers for these gauges and instruments are available upon request. Rigorous analyses of our laboratory standards' uncertainties have been performed, in accordance with The Guide to the Expression of Uncertainty in Measurement (the GUM), assuring their traceable accuracy.

Harvey Padden, President and Chief Metrologist

Gas Analyzers Calibrations

Date 3/8/2014
Project 477-S-01-1
Run # 1
Appliance/Fuel Harman / Pellet
Personnel LyP

Start of Test: 1:56
End test: 3:55 (8:57 on other computrs)

	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-500 ppm	80
NOx	0-500 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

END PSI

ZERO

			PRE-CAL		POST-CAL	
			Instrument		Instrument	
	Cylinder #	Standard Gas	Response	Time	Response	Time
VOC		0	0.66	8:42	0.1358	4:01
NO		0	0.169		0.1537	4:05
NOx		0	-0.1679		0.000	
SO2		0	0.2477		0.2447	
CO (ppm)		0	0.1679	9:00	0.1574	
CO2		0				
O2		0				
CO (%)		0				

SPAN

			Instrument		Instrument	
	Cylinder #	Standard Gas	Response	Time	Response	Time
VOC		451.7	454.7	9:19	453.9	4:13
NO		443.0	447.4			
NOx		—	—			
SO2		89.2	90.9		87.6	4:12
CO (ppm)		452.7	455.4	9:51		
CO2						
O2						
CO (%)						

LOW CHECK

			Instrument		Instrument	
	Cylinder #	Standard Gas	Response	Time	Response	Time
VOC		55.36	60.0	10:04	4443	
NO		5.037	5.6			
NOx		5.205	5.49			
SO2		10.99	11.4			4:12
CO (ppm)		73.28	69.4	10:10	64.2	4:22
CO2						
O2						
CO (%)						

Other Stds Run

NO	45.18	44.1	4:10
NOx	45.40	43.9	

Gas Analyzers Calibrations

Date 3/9/11
Project 477-S-01-1
Run # 2
Appliance/Fuel Drolet / Birch / High
Personnel JC

File Name: ~~FNSB_Gas Calibration (OES Booth)_2~~
FNSB_EPA Wood Stove Birch High_Gas ~~Analyzer~~ CAL

	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-500 ppm	80
NOx	0-500 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

Traverse

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	
VOC	~~CC33365~~	0	0.1491	9:47	0.1491	3:53	1)
NO	000000AWC858	0	0.1537	10:00	0.1385	3:54	2)
NOx		0	0.0610	10:00	0.0000	3:54	3)
SO2	CC33365	0	0.0009	9:51	0.0000	3:55	c)
CO (ppm)		0	0.1879	9:54	0.1421	3:55	
CO2		0	0.00	11:45	0.07	4:22	4)
O2		0	0.00	11:45	0.00	4:22	5)
CO (%)		0	0.00	11:45	0.00	4:22	

SPAN 6)

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	
VOC	CC33365	451.7	451.6485	10:14	453.9072	4:04	5)
NO	CC280202	442.7	442.822	10:24	428.614	4:09	
NOx	CC280202	443.0	443.7609	10:26	429.664	4:09	
SO2	CC33365	89.92	89.9716	10:08	89.1670	4:00	
CO (ppm)	CC280202	452.7	453.3016	10:28	453.2406	4:08	
CO2	CC337886	16.76	~~16.75~~ 16.33	11:48	13.80	~~13.80~~ 4:27	
O2	Amb. Air	20.946	20.94	11:50	20.80	4:30	
CO (%)	CC 337886	4.327	4.33	11:48	3.550	4:27	

LOW CHECK

			Instrument		Instrument	
	Cylinder #	Standard Gas	Response	Time	Response	Time
VOC	CC261974	55.36	59.9553	10:41	59.9460	4:15
NO	CC261974	5.037	5.1896	10:36	5.6169	4:14
NOx	CC261974	5.205	5.5093	10:36	5.9977	4:14
SO2	CC261974	10.99	11.0052	10:35	11.2010	4:14
CO (ppm)						
CO2	CC 75242	10.17	10.48	11:57	8.48	4:29
O2	CC 75242	10.56	10.64	11:57	12.68	4:29
CO (%)	CC 75242	2.512	2.61	11:57	2.09	4:29

Gas Analyzers Calibrations

Date 3/10/2011
Project 477-S-01-1
Run # 3
Appliance/Fuel EPA WS / ~~Birch/Low~~ Spruce/High
Personnel JC

Test Start Time 12:45 (actual) (12:43 gas file)
Test End Time 2:06 (gas file)

File Name FNSB_EPA Wood Stove Spruce High_Gas

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-500 ppm	80
NOx	0-500 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

		PRE-CAL		POST-CAL	
		Instrument		Instrument	
	Standard Gas	Response	Time	Response	Time
VOC	0	0.1643	8:52	0.1338	2:17
NO	0	~~0.1232~~ 0.1232	9:53	0.1232	2:38
NOx	0	0.0153	9:52	0.0485	2:37
SO2	0	0.0009	9:48 AM	0.6005	2:39
CO (ppm)	0	0.0963	9:51	0.0810	2:37
CO2	0	0.00	11:15	0.06	2:50
O2	0	0.00	11:15	-0.10	2:50
CO (%)	0	0.00	11:15	-0.00	2:50

SPAN

		Instrument		Instrument	
	Standard Gas	Response	Time	Response	Time
VOC	451.7	453.8003	8:57	450.9618	2:21
NO	442.7	442.822	10:58	442.303	2:42
NOx	443.0	444.8209	10:58	443.3406	2:42
SO2	89.92	90.0695	9:58	83.7674	2:34
CO (ppm)	452.7	452.2944	11:04	455.2552	2:44
CO2	16.76	16.76	11:20	16.86	2:51
O2	20.946	~~16.76~~ 20.95	11:20	21.09	2:53
CO (%)	4.327	4.33	11:20	4.34	2:57

LOW CHECK

		Instrument		Instrument	
	Standard Gas	Response	Time	Response	Time
VOC	55.36	59.0244	9:46	57.9714	2:24
NO	5.037	6.1815	11:09	5.2049	2:28
NOx	5.205	6.5471	11:09	5.0820	2:28
SO2	10.99	11.3172	11:09	9.8049	2:29
CO (ppm)					
CO2	10.17	10.11	11:24	10.18	2:52
O2	10.56	10.50	11:24	10.66	2:52
CO (%)	2.512	2.53	11:24	2.52	2:52

Tank Use	Cylinder #	Starting PSI	Ending PSI
Zero	AWC858		700
Span	CC33365/28202		1450 / 200
Low	CC261974/75242		1400/1600
H2/He	185695		300
Air			500

Gas Analyzers Calibrations

Date	3/17/2011
Project	477-S-01-1
Run #	5
Appliance/Fuel	EPA ws Birch Low
Personnel	JC
Background : 9:0[illegible] - 9:23 AM	
Test Start Time	11:37 AM
Test End Time	3:45 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_EPA wood stove Birch Low - Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1338	8:26	0.1491	3:50	1400
NO	AWC858	0	0.0000	8:30	0.0442	3:52	
NOx	AWC858	0	0.0000	8:30	0.0964	3:52	
SO2	AWC858	0	0.0000	8:31	0.0000	3:51	
CO (ppm)	AWC858	0	0.1268	8:30	0.1421	3:51	
CO2	AWC858	0	0.00	9:12	0.03	4:22	
O2	AWC858	0	0.00	9:12	-0.09	4:22	
CO (%)	AWC858	0	0.000	9:12	0.00	4:22	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	453.6324	8:39	452.6552	4:01	1300
NO	CC33365	45.18	44.9818	8:43	44.5299	3:58	1300
NOx	CC33365	45.40	45.7689	8:42	45.4132	3:58	1300
SO2	CC33365	89.92	89.9716	8:44	89.0722	3:56	1300
CO (ppm)	569161474	496.5	498.3398	8:50	500.0644	4:14	1600
CO2	CC337886	16.76	16.76	9:23	16.72	4:31	800
O2	Amb. Air	20.946	20.94	9:20	20.97	4:28	—
CO (%)	CC337886	4.327	4.33	9:23	4.33	4:28	800

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	58.4750	8:59	57.0252	4:03	1600
NO	CC261974	5.037	5.1906	8:54	4.9417	4:06	1600
NOx	CC261974	5.205	5.4006	854	5.1447	4:09	1600
SO2	CC261974	10.99	10.9073	8:55	10.7145	4:10	1600
CO (ppm)	CC287319	20.54	19.2196	9:03	18.2123	4:16	1300
CO2	CC75242	10.17	10.11	9:25	10.10	4:33	1500
O2	CC75242	10.56	10.67	9:25	10.60	4:33	1500
CO (%)	CC75242	2.512	2.518	9:25	2.52	4:33	1500

Gas Analyzers Calibrations

Date	3/18/2011
Project	477-S-01-1
Run #	6
Appliance/Fuel	EPA Wood Stove Spruce Low
Personnel	dc/SB/AK
Background	11:25 - 11:27
Test Start Time	11:39 AM
Test End Time	3:10 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_EPA Wood Stove_Spruce Low_Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1378	9:28	0.1338	3:56 PM	
NO	AWC858	0	0.000	9:22	0.000	3:29 PM	
NOx	AWC858	0	0.000	9:22	0.041	3:29 PM	
SO2	AWC858	0	0.000	9:17	0.000	3:26 PM	
CO (ppm)	AWC858	0	0.2337	9:21	0.2489	3:29 PM	
O2	AWC858	0	0.00	10:02	0.29	4:08 PM	
CO2	AWC858	0	-0.00	10:02	0.04	4:08 PM	
CO (%)	AWC858	0	-0.00	10:02	0.002	4:08 PM	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	453.199	9:50	457.417	4:00 PM	
NO	CC33365	45.18	45.3284	9:45	44.26	3:43 PM	
NOx	CC33365	45.40	45.7200	9:44	44.46	3:43 PM	
SO2	CC33365	89.92	89.9747	9:43	90.268	3:36 PM	
CO (ppm)	569161474	496.5	495.4858	9:36	492.37	3:32 PM	
O2	Amb. Air	20.946	20.95	10:05	21.00	4:17 PM	
CO2	CC337886	16.76	16.75	10:03	17.01	4:17 PM	
CO (%)	CC337886	4.327	4.33	10:03	4.37	4:17 PM	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	57.5796	9:52	58.44	4:02 PM	
NO	CC261974	5.037	5.0914	9:58	5.18	3:48 PM	
NOx	CC261974	5.205	5.1396	9:59	5.25	3:48 PM	
SO2	CC261974	10.99	10.7084	9:58	11.708	3:48 PM	
CO (ppm)	CC287319	20.54	20.3337	9:39	18.303	3:52 PM	
O2	CC75242	10.56	10.70	10:07	10.58	4:16 PM	
CO2	CC75242	10.17	10.06	10:07	10.24	4:16 PM	
CO (%)	CC75242	2.512	2.50	10:07	9.63	4:16 PM	

Gas Analyzers Calibrations

Date	3/22/2011
Project	477-S-01-1
Run #	8
Appliance/Fuel	OWHH Birch High 2
Personnel	JC/SB/AK
Background	8:20 – 8:36 AM
Test Start Time	10:20 AM
Test End Time	2:24 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_EPA OWHH Birch High2_Gas

(Note: Post-cal same as Run 9)

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1491	7:38			
NO	AWC858	0	0.0000	7:32			
NOx	AWC858	0	0.0000	7:32			
SO2	AWC858	0	0.0040	7:32			
CO (ppm)	AWC858	0	0.0963	7:31			
O2	AWC858	0	0.00	8:23			
CO2	AWC858	0	-0.00	8:23			
CO (%)	AWC858	0	-0.000	8:23			

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	454.3649	7:45			
NO	CC33365	45.18	45.2749	7:52			
NOx	CC33365	45.40	45.5170	7:52			
SO2	CC33365	89.92	89.8707	7:50			
CO (ppm)	569161474	496.5	496.2942	8:03			
O2	Amb. Air	20.946	20.95	8:10			
CO2	CC337886	16.76	16.75	8:28			
CO (%)	CC337886	4.327	4.33	8:28			

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	59.0549	8:16			
NO	CC261974	5.037	5.0379	8:11			
NOx	CC261974	5.205	5.0434	8:11			
SO2	CC261974	10.99	10.8094	8:10			
CO (ppm)	CC287319	20.54	20.1506	8:06			
O2	CC75242	10.56	10.45	8:32			
CO2	CC75242	10.17	10.14	8:32			
CO (%)	CC75242	2.512	2.52	8:32			

Gas Analyzers Calibrations

Date	3/22/2011
Project	477-S-01-1
Run #	9
Appliance/Fuel	OWHH Birch Low
Personnel	AK
Background	3:10 - 3:15 PM
Test Start Time	4:56 PM
Test End Time	3:16 AM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_EPA OWHH Birch Low_Gas

(Note: Pre-cal same as Run 8)

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0			.1491	3:27	
NO	AWC858	0			.0961	3:25	
NOx	AWC858	0			.1483	3:25	
SO2	AWC858	0			.0009	3:25	
CO (ppm)	AWC858	0			.2947	3:25	
O2	AWC858	0			-0.00	3:23	
CO2	AWC858	0			0.03	3:23	
CO (%)	AWC858	0			-0.009	3:23	

SPAN

466.4207

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7			~~466.4207~~	~~3:29~~ 3:34	
NO	CC33365	45.18			34.6020	~~3:29~~ 3:34	
NOx	CC33365	45.40			34.5393	~~3:29~~ 3:34	
SO2	CC33365	89.92			98.1667	~~3:29~~ 3:34	
CO (ppm)	569161474	496.5			483.4899	3:34	
O2	Amb. Air	20.946			21.01	3:34	
CO2	CC337886	16.76			16.63	3:51	
CO (%)	CC337886	4.327			4.320	3:51	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36			72.4232	3:40	
NO	CC261974	5.037			3.7433	3:43	
NOx	CC261974	5.205			3.6956	3:43	
SO2	CC261974	10.99			9.9099	3:43	
CO (ppm)	CC287319	20.54			16.3497	3:46	
O2	CC75242	10.56			10.81	3:56	
CO2	CC75242	10.17			10.02	3:56	
CO (%)	CC75242	2.512			~~2.502~~ 2.499	3:56	

Gas Analyzers Calibrations

Date	3/23/2011
Project	477-S-01-1
Run #	10
Appliance/Fuel	AWHH Spruce High
Personnel	JE
Background	10:08 - 10:14
Test Start Time	11:21 AM
Test End Time	3:18 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB-EPA AWHH Spruce High - Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1491	9:14	0.6374	3:30	900
NO	AWC858	0	0.0000	9:10	0.2365	3:28	
NOx	AWC858	0	0.0000	9:10	0.3879	3:28	
SO2	AWC858	0	0.0000	9:10	0.0000	3:27	
CO (ppm)	AWC858	0	0.1879	9:10	0.0000218	3:28	
O2	AWC858	0	-0.00	10:34	0.01	4:01	
CO2	AWC858	0	-0.00	10:34	-0.00	4:01	
CO (%)	AWC858	0	-0.00	10:34	-0.00	4:01	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	453.7545	9:21	451.6180	3:38	1000
NO	CC33365	45.18	45.2261	9:32	44.9772	3:36	
NOx	CC33365	45.40	45.4437	9:32	45.0744	3:36	
SO2	CC33365	89.92	90.0757	9:31	79.4630	3:40	
CO (ppm)	569161474	496.5	496.4932	9:39	464.5040	3:45	1000
O2	Amb. Air	20.946	20.95	10:38	21.13	3:44	—
CO2	CC337886	16.76	16.75	10:41	16.58	4:04	650
CO (%)	CC337886	4.327	4.33	10:41	4.27	4:04	650

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	61.4813	9:50	59.9400	3:54	1400
NO	CC261974	5.037	4.9952	9:46	5.0379	3:50	
NOx	CC261974	5.205	5.0327	9:46	5.1411	3:50	
SO2	CC261974	10.99	10.9065	9:46	9.3073	3:53	
CO (ppm)	CC287319	20.54	19.3112	9:41	19.3570	3:47	1150
O2	CC75242	10.56	10.76	10:43	10.73	4:05	950
CO2	CC75242	10.17	9.98	10:43	9.84	4:05	950
CO (%)	CC75242	2.512	2.50	10:43	2.46	4:05	950

Gas Analyzers Calibrations

Date	3/24/2011
Project	477-S-01-1
Run #	11
Appliance/Fuel	EPA OWHH, Spruce, Low
Personnel	JC/SB/AK
Background	9:51 - 10:05
Test Start Time	10:56 AM
Test End Time	8:38 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_EPA OWHH Spruce Low_Gas

VOC=.6679

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1491	8:50	~~.0293~~	8:45P	
NO	AWC858	0	0.0000	8:53	0.1312	8:43 P	
NOx	AWC858	0	0.0000	8:53	0.4352	8:43 P	
SO2	AWC858	0	0.0000	8:53	0.0000	8:43P	
CO (ppm)	AWC858	0	0.1421	8:53	1.1189	8:43P	
O2	AWC858	0	0.00	9:51	-0.100		
CO2	AWC858	0	0.00	9:51	-0.04		
CO (%)	AWC858	0	0.00	9:51	0.033		

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	453.5102	9:02	500.055	8:48	
NO	CC33365	45.18	45.3772	9:43	50.0000	8:51	
NOx	CC33365	45.40	45.5614	9:43	50.0000	8:51	
SO2	CC33365	89.92	90.0726	9:07	77.6549	8:51	
CO (ppm)	569161474	496.5	496.4327	9:11	413.1015	8:54	
O2	Amb. Air	20.946	20.95	9:54	20.94		
CO2	CC337886	16.76	16.76	9:56	16.66		
CO (%)	CC337886	4.327	4.33	9:56	4.311		

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	59.9705	9:31	67.5043	9:01	
NO	CC261974	5.037	5.3051	9:46	5.7005	9:00	
NOx	CC261974	5.205	5.3533	9:46	5.7990	9:00	
SO2	CC261974	10.99	10.9012	9:23	8.2488	9:00	
CO (ppm)	CC287319	20.54	8.2123	9:18	18.1513	8:57	
O2	CC75242	10.56	10.65	9:58	10.61		
CO2	CC75242	10.17	10.02	9:58	10.07		
CO (%)	CC75242	2.512	2.52	9:58	2.530		

Gas Analyzers Calibrations

Date	3/30/2011
Project	477-S-01-1
Run #	12
Appliance/Fuel	Conv. WS Spruce high
Personnel	AK/JC/SB
Background	12:20 - 12:22
Test Start Time	12:40
Test End Time	1:33P

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_Conventional Wood Stove Spruce High_Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1643	11:36	1.5687	1:40	
NO	AWC858	0	0.0000	9:33	10900	1:38	
NOx	AWC858	0	0.0000	9:33	1.1925	1:38	
SO2	AWC858	0	0.0000	9:31	10000	1:38	
CO (ppm)	AWC858	0	0.0000	9:31	.1879	1:38	
O2	AWC858	0	-0.00	10:37	0.13	2:02	
CO2	AWC858	0	-0.00	10:37	0.06	2:02	
CO (%)	AWC858	0	-0.00	10:37	0.000	2:02	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	451.9385	11:42	590.055	1:42	
NO	CC33365	45.18	45.1818	10:17	46.6764	1:44	
NOx	CC33365	45.40	45.4331	10:17	46.9762	1:44	
SO2	CC33365	89.92	89.9747	10:18	86.7655	1:46	
CO (ppm) CC89280	~~569161474~~	~~452.4 496.5~~	452.3859	10:10	459.270	1:49	
O2	Amb. Air	20.946	20.95	10:41	20.85	1:59	
CO2	CC337886	16.76	16.75	10143	16.69	2:04	
CO (%)	CC337886	4.327	4.33	10:43	4.234	2:04	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	57.5594	11:44	66.4105	1:57	
NO	CC261974	5.037	5.0410	10:22	6.4532	1:54	
NOx	CC261974	5.205	5.1426	10:22	~~6.0~~ 6.7087	1:54	
SO2	CC261974	10.99	10:22 ↔ 11.3111		10.9073	1:56	
CO (ppm)	CC287319	20.54	19.2501	10:27	21.2647	1:52	
O2	CC75242	10.56	10.68	10:45	10.57	~~2:0~~	
CO2	CC75242	10.17	10.12	10:45	10.10	2:06	
CO (%)	CC75242	2.512	2.52	10:45	2.455	2:06	

Gas Analyzers Calibrations

Date	3/31/2011
Project	477-S-01-1
Run #	13
Appliance	Conventional WS
Fuel/Burn Rate	Birch/High
Personnel	AK/JC/SB
Background	10:18 - 10:20 AM
Test Start Time	11:38 AM
Test End Time	12:18 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

Pitot tube not at center
11:38 - 11:57

File Name FNSB_Conventional Wood Stove Birch High_Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1491	9:00	0.1338	2:55	600
NO	AWC858	0	0.0000	8:53	0.0000	2:57	
NOx	AWC858	0	0.0000	8:53	0.0000	2:57	
SO2	AWC858	0	0.0000	8:53	0.0000	2:57	
CO (ppm)	AWC858	0	0.1268	8:57	1.1799	2:57	
O2	AWC858	0	-0.00	10:13	0.02	3:20	
CO2	AWC858	0	- 0.00	10:13	- 0.00	3:20	
CO (%)	AWC858	0	- 0.00	10:13	- 0.00	3:20	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	453.7392	9:16	462.9262	3:05	700
NO	CC33365	45.18	45.2704	10:04	44.3238	3:01	700
NOx	CC33365	45.40	45.5079	10:04	44.4592	3:02	700
SO2	CC33365	89.92	90.3742	9:12	88.5644	3:02	700
CO (ppm)	CC89280	452.4	453.2559	9:05	453.2252	3:14	1800
O2	Amb. Air	20.946	20.95	10:16	21.17	3:09	
CO2	CC337886	16.76	16.76	10:18	16.70	3:22	600
CO (%)	CC337886	4.327	4.33	10:18	4.33	3:22	600

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	60.4741	9:47	57.9561	3:07	900
NO	CC261974	5.037	5.1372	10:08	4.7845	3:09	900
NOx	CC261974	5.205	5.2510	10:08	4.7885	3:10	900
SO2	CC261974	10.99	10.9042	9:51	10.2985	3:11	900
CO (ppm)	CC287319	20.54	19.2501	9:55	20.1659	3:16	1050
O2	CC75242	10.56	10.76	10:21	10.77	3:23	750
CO2	CC75242	10.17	10.13	10:21	10.10	3:23	750
CO (%)	CC75242	2.512	2.52	10:21	2.51	3:23	750

Gas Analyzers Calibrations

Date	4/1/2011
Project	477-S-01-1
Run #	14
Appliance	Conventional WS
Fuel/Burn Rate	Spruce/Low
Personnel	AK/JC/SB
Background	9:39-9:41 AM
Test Start Time	11:17 AM
Test End Time	12:10 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_Conventional Wood Stove Spruce Low_Gas

(Note: Post-cal same as Run #15)

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1491	8:46 AM			
NO	AWC858	0	0.0000	8:53			
NOx	AWC858	0	0.0000	8:53			
SO2	AWC858	0	0.0927	8:53			
CO (ppm)	AWC858	0	0.1116	8:53			
O2	AWC858	0	-0.00	9:53			
CO2	AWC858	0	-0.00	9:53			
CO (%)	AWC858	0	-0.00	9:53			

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	453.3730	9:09			
NO	CC33365	45.18	45.1360	9:05			
NOx	CC33365	45.40	45.3628	9:05			
SO2	CC33365	89.92	90.4703	9:06			
CO (ppm)	CC89280	452.4	452.3702	8:57			
O2	Amb. Air	20.946	20.95	9:56			
CO2	CC337886	16.76	16.75	9:58			
CO (%)	CC337886	4.327	4.33	9:58			

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	56.5674	9:11			
NO	CC261974	5.037	4.9957	9:14			
NOx	CC261974	5.205	5.1899	9:14			
SO2	CC261974	10.99	10.8094	9:15			
CO (ppm)	CC287319	20.54	18.2734	8:59			
O2	CC75242	10.56	10.68	10:00			
CO2	CC75242	10.17	10.48	10:00			
CO (%)	CC75242	2.512	2.61	10:00			

NOx ILF change @ 11:50

Gas Analyzers Calibrations

Date	4/1/2011
Project	477-S-01-1
Run #	15
Appliance	Conventional WS
Fuel/Burn Rate	Birch/Low
Personnel	AK/JC/SB
Background	1:30 - 1:32 PM
Test Start Time	3:07 PM
Test End Time	3:56 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_Conventional Wood Stove Birch Low_Gas

(Note: Pre-cal same as Run # 14)

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0			1.5488	4:24	
NO	AWC858	0			.0320	4:21	
NOx	AWC858	0			.1330	4:21	
SO2	AWC858	0			.0001	4:21	
CO (ppm)	AWC858	0			1.2715	4:21	
O2	AWC858	0			.10	4:42	
CO2	AWC858	0			.01	4:42	
CO (%)	AWC858	0			.004	4:42	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7			467.9469	4:25	
NO	CC33365	45.18			43.0552	4:28	
NOx	CC33365	45.40			44.1692	4:28	
SO2	CC33365	89.92			64.5357	4:28	
CO (ppm)	CC89280	452.4			364.98	4:29	
O2	Amb. Air	20.946			20.94	4:20	
CO2	CC337886	16.76			16.85	4:47	
CO (%)	CC337886	4.327			4.721	4:47	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36			60.9283	4:30	
NO	CC261974	5.037			6.1936	4:32	
NOx	CC261974	5.205			6.4911	4:34	
SO2	CC261974	10.99			9.2052	4:34	
CO (ppm)	CC287319	20.54			19.7807	4:32	
O2	CC75242	10.56			10.37	4:51	
CO2	CC75242	10.17			10.22	4:51	
CO (%)	CC75242	2.512			2.641	4:51	

Gas Analyzers Calibrations

Date	4/12/2011
Project	477-S-01-1
Run #	17
Appliance	Oil Burner
Fuel/Burn Rate	No. 2 Fuel Oil
Personnel	AK/JC/SB
Background	
Test Start Time	7:05:50
Test End Time	~~11~~ 10:40:00

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name ENSB — No 2 Fuel Oil - 17

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1491	9:35	.1185	8:36	
NO	AWC858	0	~~10~~ 0.0000	9:40	.1281	8:35	
NOx	AWC858	0	0.0000	9:40	.1834	8:35	
SO2	AWC858	0	0.0004	9:40	.5944	8:35	
CO (ppm)	AWC858	0	0.0063	9:40	.1726	8:35	
O2	AWC858	0	0.00	11:14	-.11	8:41	
CO2	AWC858	0	0.00	11:19	0.11	8:41	
CO (%)	AWC858	0	0.000	11:14	0.000	8:41	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC33365	451.7	453.708	10:44			8
NO	CC33365	45.18	45.13	10:38			8
NOx	CC33365	45.40	47.0297	10:38			0
SO2	~~CC33365~~ CC89280	~~89.92~~ 86.77	89.6626	10:56	86.4582	8:44	
CO (ppm)	CC89280	452.4	452.37	10:56	454.4065	8:44	
O2	Amb. Air	20.946	20.94	11:28	20.91	8:36	
CO2	CC337886	16.76	16.76	11:14	16.86	9:00	
CO (%)	CC337886	4.327	4.327	11:14	4.342	9:00	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	60.9777	11:04	59.9400	8:50	
NO	CC261974	5.037	6.9081	11:03	8.4813	8:49	
NOx	CC261974	5.205	7.5070	11:03	9.5417	8:49	
SO2	CC261974	10.99	9.5061	11:03	11.9015	8:49	
CO (ppm)	CC287319	20.54	15.3481	11:09	16.3648	8:53	
O2	CC75242	10.56	10.71	11:20	10.67	9:01	
CO2	CC75242	10.17	10.22	11:28	10.14	9:01	
CO (%)	CC75242	2.512	2.534	11:20	2.509	9:01	

Gas Analyzers Calibrations

Date	4/15/2011
Project	477-S-01-1
Run #	~~477~~ 18
Appliance	Waste Oil
Fuel/Burn Rate	Waste Oil
Personnel	AK/JC/SB
Background	9:05 Am
Test Start Time	9:15 AM
Test End Time	11:58 Am
File Name	FNSB – Waste oil – 18

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-50 ppm	80
NOx	0-50 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1328	8:18	.1441	12:09	500
NO	AWC858	0	0.0000	8.14	.4884	12:06	
NOx	AWC858	0	0.0000	8:14	.4887	12:06	
SO2	AWC858	0	0.0000	8:14	.4934	12:06	
CO (ppm)	AWC858	0	.0963	8:14	6.1341	12:06	
O2	AWC858	0	0.00	8:24	-.04	12:13	
CO2	AWC858	0	0.00	8:24	.01	12:13	
CO (%)	AWC858	0	0.000	8:24	-.002	12:13	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC276183	225.4	225.77	8:34			1850
NO	CC276183	22.20	22.3609	8:40	.4884	12:06	1850
NOx	CC276183	22.27	22.6884	8:40	.4887	12:06	1850
SO2	CC89280	88.92	89.6718	8:46	.4934	12:06	1600
CO (ppm)	CC89280	452.4	453.37	8:46			1600
O2	Amb. Air	20.946	20.94	8:20	20.74	12:13	
CO2	CC337886	16.76	16.76	8:26	16.65	12:15	600
CO (%)	CC337886	4.327	4.327	8:26	4.300	12:15	600

234.92 @12:
26.9346 @ 12:
27.3420 @12:
16.4615@ 12:27
382.1800@12:2

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	57.0405	8:55	58.4597	12:37	500
NO	CC261974	5.037	7.7539	8:52	9.3466	12:31	500
NOx	CC261974	5.205	8.5037	8:52	11.0858	12:31	500
SO2	CC261974	10.99	9.2185	8:52	10.2006	12:31	500
CO (ppm)	CC287319	20.54	15.6549	8:54	14.1586	12:34	500
O2	CC75242	10.56	10.63	8:28	10.57	12:17	700
CO2	CC75242	10.17	10.12	8:28	10.08	12:17	700
CO (%)	CC75242	2.512	2.518	8:28	2.499	12:17	700

Gas Analyzers Calibrations

Date	5/6/2011
Project	477-S-01-1
Run #	20
Appliance	Coal Stove
Fuel/Burn Rate	Dry stoker / High
Personnel	AK/JC/SB
Background	10:42 – 10145
Test Start Time	11:25 AM
Test End Time	2:59 PM
File Name	FNSB_ Coal stove Dry coal High _ Gas

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	80
NOx	0-100 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWC858	0	0.1185	9:27	0.1491	3:06	2200
NO	AWC858	0	0.0185	9:43	0.1315	3:05	
NOx	AWC858	0	0.0031	9:43	0.2198	3:05	
SO2	AWC858	0	0.0000	9:42	0.1906	3:05	
CO (ppm)	AWC858	0	0.0810	9:42	0.0810	3:04	
O2	AWC858	0	0.01	10:23	0.08	3:35	
CO2	AWC858	0	0.00	10:23	-0.00	3:35	
CO (%)	AWC858	0	-0.00	10:23	-0.00	3:35	

AWB483

1) 10:13
2) 10:15
3) 10:17
4) 10:18
5) 10:21
6) 10:22
7) 10:23
8) 10:19

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2	454.2123	9:59	456.9897	3:10	1400
NO	CC5643	91.08	91.3548	9:50	92.7671	3:18	1750
NOx	CC5643	91.40	91.9387	9:50	93.4479	3:18	1750
SO2	CC89280	88.92	88.9682	9:55	87.3651	3:14	1400
CO (ppm)	CC89280	452.4	452.1723	9:55	448.1432	3:14	1400
O2	Amb. Air	20.946	20.95	10:26	21.01	3:32	
CO2	CC337886	16.76	16.77	10:28	16.68	3:37	400
CO (%)	CC337886	4.327	4.33	10:28	4.32	3:37	400

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	57.5136	10:05	59.5127	3:27	650
NO	CC261974	5.037	4.7034	10:08	5.0208	3:25	650
NOx	CC261974	5.205	4.9111	10:08	5.1980	3:25	650
SO2	CC261974	10.99	10.7023	10:09	10.9073	3:25	650
CO (ppm)	CC287319	20.54	18.1818	10:11	18.1971	3:20	650
O2	CC75242	10.56	10.66	10:30	10.70	3:39	550
CO2	CC75242	10.17	10.12	10:30	10.06	3:39	550
CO (%)	CC75242	2.512	2.51	10:30	2.51	3:39	550

Pbar = 30.14 in Hg

Gas Analyzers Calibrations

Date	5/9/2011
Project	477-S-01-1
Run #	21
Appliance	Coal Stove
Fuel/Burn Rate	Dry stoker / Low
Personnel	AK/JC/SB
Background	10:33-10:36 AM
Test Start Time	12:15 PM
Test End Time	6:47 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	80
NOx	0-100 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB - ~~Beg~~ Coal Stove Dry Stoker Coal Low - Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1185	9:53	.1185	~~6:50~~ 6:51	
NO	AWB483	0	0.0246	9:48	.0155	6:50	
NOx	AWB483	0	0.0122	9:48	.1091	6:50	
SO2	AWB483	0	0.0000	9:48	0.0000	6:50	
CO (ppm)	AWB483	0	0.0963	9:48	.0963	6:50	
O2	AWB483	0	-0.00	10:42	.02	6:53	
CO2	AWB483	0	-0.00	10:42	.02	6:53	
CO (%)	AWB483	0	-0.00	10:42	.000	6:53	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2	456.9282	10:01	477.5309	6:55	
NO	CC5643	91.08	91.0763	10:14	78.1295	7:02	
NOx	CC5643	91.40	91.4579	10:14	78.8124	7:02	
SO2	CC89280	88.92	88.8948	10:06	73.7543	6:59	
CO (ppm)	CC89280	452.4	452.2486	10:07	399.0916	6:59	
O2	Amb. Air	20.946	20.95	10:46	20.93	6:52	
CO2	CC337886	16.76	16.76	10:47	16.77	7:12	
CO (%)	CC337886	4.327	4.33	10:47	4.320	7:12	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	59.5280	10:26	59.5280	7:06	
NO	CC261974	5.037	4.6241	10:23	4.6949	7:05	
NOx	CC261974	5.205	4.8045	10:23	5.0088	7:05	
SO2	CC261974	10.99	11.0021	10:23	10.2006	7:05	
CO (ppm)	CC287319	20.54	18.1971	10:17	14.1624	~~7:05~~ 7:10	
O2	CC75242	10.56	10.64	10:49	16.71	7:13	
CO2	CC75242	10.17	10.11	10:49	10.15	7:13	
CO (%)	CC75242	2.512	2.51	10:49	2.510	7:13	

Traverse

1) 4:08
2) 4:10
3) 4:12
c) ~~4:13~~ 4:13
4) ~~4:15~~ 4:14
5) 4:15
6) 4:18
5) 4:20

Gas Analyzers Calibrations

Date	5/11/2011
Project	477-S-01-1
Run #	2 3
Appliance	Coal Stove
Fuel/Burn Rate	Wet coal / Low
Personnel	AK/JC/SB

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	80
NOx	0-100 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

Background 10:50 - 10:52 4M
Test Start Time ~~10:58~~ 10:57:30
Test End Time 4:02 PM

File Name FNSB_Coal Stove Wet Stoker Coal Low 2_Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1491	9:28	0.1338	4:07	1960
NO	AWB483	0	0.0216	8:00	0.0124	4:09	
NOx	AWB483	0	0.0031	8:00	0.1068	4:09	
SO2	AWB483	0	0.0000	8:00	0.0000	4:09	
CO (ppm)	AWB483	0	0.0810	8:00	0.0963	4:09	
O2	AWB483	0	-0.00	8:46	-0.00	4:41	
CO2	AWB483	0	-0.00	8:46	0.03	4:41	
CO (%)	AWB483	0	-0.00	8:46	0.00	4:41	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2	454.8380	9:16	462.3462	4:20	1050
NO	CC5643	91.08	91.1587	8:08	76.9331	4:25	1650
NOx	CC5643	91.40	91.5494	8:08	76.6178	4:25	1650
SO2	CC89280	88.92	88.9743	8:15	73.3383	4:13	1050
CO (ppm)	CC89280	452.4	453.3780	8:19	439.2380	4:12	1050
O2	Amb. Air	20.946	20.95	8:49	21.08	4:45	
CO2	CC337886	16.76	16.75	9:00	16.87	4:42	400
CO (%)	CC337886	4.327	4.33	9:00	4.33	4:42	400

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	55.5907	9:20	60.4589	4:33	650
NO	CC261974	5.037	4.2182	8:27	4.2151	4:28	
NOx	CC261974	5.205	4.2854	8:27	4.8989	4:28	
SO2	CC261974	10.99	8.8055	8:28	10.4056	4:27	
CO (ppm)	CC287319	20.54	20.2116	8:21	19.1586	4:27	500
O2	CC75242	10.56	~~10.86~~ 10.86 JC	~~9:03~~ 9:53 JC	10.87	4:44	400
CO2	CC75242	10.17	~~10.06~~ 10.06 JC	~~9:03~~ 9:53 JC	10.14	4:44	
CO (%)	CC75242	2.512	~~2.50~~ 2.50 JC	~~9:03~~ 9:53 JC	2.51	4:44	

Pbar @ 10:59 = 29.94 in Hg
Note: missed pt @ 11:04 AM, CO

NOx filter change
11:24 - 11:25

VOC filter change
12:00 PM

Note: Tunnel CO (ppm) out of operation

Gas Analyzers Calibrations

Date	5/27/2011
Project	477-S-01-1
Run #	25
Appliance	Non-Q OWHH
Fuel/Burn Rate	~~Birch / High~~ Spruce
Personnel	AK/JC/SB
Background	10:22
Test Start Time	10:22
Test End Time	

Pbar = 30.02 in Hg

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	80
NOx	0-100 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB_Non Q OWHH Spruce High-Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1796	7:50	4.4733	12:53	1700
NO	AWB483	0	0.0307	7:54	.1437	12:56	
NOx	AWB483	0	0.0122	7:54	.2350	12:56	
SO2	AWB483	0	0.0988	7:55	.1080	12:56	
CO (ppm)	AWB483	0	0.1421	7:59	5.1938	12:56	
O2	AWB483	0	0.00	8:52	-.07	12:58	
CO2	AWB483	0	0.00	8:52	.04	12:58	
CO (%)	AWB483	0	0.000	8:52	.004	12:56	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2	454.7769	10:05	493.248	1:10	850
NO	CC5643	91.08	91.2533	10:14	86.8400	1:16	1400
NOx	CC5643	91.40	91.5891	10:14	88.0684	1:16	1400
SO2	CC89280	88.92	88.9774	10:01	88.2676	1:14	850
CO (ppm)	CC89280	452.4					
O2	Amb. Air	20.946	20.95	8:54	20.89	1:02	
CO2	CC337886	16.76	16.76	8:58	16.82	1:05	150
CO (%)	CC337886	4.327	4.327	8:58	4.344	1:05	150

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC CC89280	~~CC261974~~	½ ~~55.36~~ 454.2	227.0586	10:07	214.6365	1:28	850
NO	CC261974	5.037	5.1155	10:18	5.6160	1:20	400
NOx	CC261974	5.205	5.2041	10:18	6.7164	1:20	400
SO2	CC261974	10.99	10.9073	10:17	13.0212	1:20	400
CO (ppm)	CC287319	20.54					
O2	CC75242	10.56	10.62	8:59	10.60	1:07	350
CO2	CC75242	10.17	10.10	8:59	10.18	1:07	350
CO (%)	CC75242	2.512	2.513	8:59	2.531	1:07	350

Note: @10:22, 50% dilution for VOC
@10:29, 80% dilution
@10:30, 8.0/9.5 dilution
@10:51, 5.0/9.5
@1120 ~~#~~: 0/9.5

Stack Gas Sample : 2/2.6

Filter Changes CO/NOx/SO2 @10:26 @10:38

Gas Analyzers Calibrations

Date	5/30/2011
Project	477-S-01-1
Run #	26
Appliance	NAOW114
Fuel/Burn Rate	Coal
Personnel	AK/JC/SB
Background	~~10:36~~ 10:37 - 10:52
Test Start Time	11:35
Test End Time	13:38
File Name	

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	80
NOx	0-100 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

11:43 - VOC Dilution
11:58 - Changed non-VOC filter

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	.1796	9:25	6.0244	14:15	
NO	AWB483	0	.0277	9:31	.0216	14:13	
NOx	AWB483	0	.0122	9:31	.8119	14:13	
SO2	AWB483	0	.0000	9:32	.2927	14:13	
CO (ppm)	AWB483	0	N/A				AM
O2	AWB483	0	0.00	8:49	0.09	13:59	
CO2	AWB483	0	0.00	8:49	0.00	13:59	
CO (%)	AWB483	0	0.000	8:49	-0.015	13:59	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2	454.7000	10:17	464.3160	14:17	
NO	CC5643	91.08	91.6836	10:11	88.7532	14:30	
NOx	CC5643	91.40	91.9768	10:11	94.4852	14:30	
SO2	CC89280	88.92	88.9774	10:25	75.9625	14:28	
CO (ppm)	CC89280	452.4	N/A				AM
O2	Amb. Air	20.946	20.95	8:52	20.88	14:03	
CO2	CC337886	16.76	16.76	8:55	16.73	14:01	~50
CO (%)	CC337886	4.327	4.329	8:55	4.299	14:01	~50

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	1/2 CC89280	227.1	227.546	10:31	243.2438	14:19	
NO	CC261974	5.037	4.5936	10:35	5.8291	14:33	
NOx	CC261974	5.205	4.6150	10:35	7.0080	14:33	
SO2	CC261974	10.99	9.9161	10:36	11.2101	14:33	
CO (ppm)	CC287319	20.54	N/A				AM
O2	CC75242	10.56	10.64	8:56	10.67	14:05	400
CO2	CC75242	10.17	10.10	8:56	10.03	14:05	400
CO (%)	CC75242	2.512	2.514	8:56	2477	14:05	400

@ 20 min
Turned off Stack Gas Dilution

Gas Analyzers Calibrations

Date	6/1/2011
Project	477-5-01-1
Run #	1dc 27
Appliance	NonQ OWHH w/ Catalyst
Fuel/Burn Rate	Coal/Low
Personnel	AK/JC/SB
Background	10:18-10:20
Test Start Time	11:45 AM
Test End Time	15:00 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	80
NOx	0-100 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name ENSB_Supplemental_NonQ OWHH w/ Catalyst Coal Low_Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1643	8:27	6.0244	3:09	1400
NO	AWB483	0	0.0277	8:33	0.1284	3:14	
NOx	AWB483	0	0.0092	8:33	3.0980	3:14	
SO2	AWB483	0	0.1049	9:33	0.0957	3:13	
CO (ppm)	AWB483	0	0.3252	9:36	-0.3158	3:13	
O2	AWB483	0	0.00	9:02	0.03	3:45	
CO2	AWB483	0	0.00	9:02	0.01	3:45	
CO (%)	AWB483	0	0.000	9:02	-0.00	3:45	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2	455.2958	9:49	~~482.48~~	3:24	500
NO	CC5643	91.08	91.1617	10:08	97.0461	3:31	
NOx	CC5643	91.40	91.7448	10:08	97.2389	3:31	
SO2	CC89280	88.92	88.6806	10:01	87.4691	3:21	500
CO (ppm)	CC89280	452.4	453.6832	10:00	481.4753	3:16	500
O2	Amb. Air	20.946	20.95	9:05	20.98	3:45	
CO2	CC337886	16.76	16.76	9:08	16.81	3:47	400
CO (%)	CC337886	4.327	4.327	9:08	4.29	3:47	<100

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC261974	55.36	56.0486	9:52	65.4949	3:28	500
NO	CC261974	5.037	6.0189	10:13	4.7034	3:37	500
NOx	CC261974	5.205	6.1076	10:13	5.2997	3:37	500
SO2	CC261974	10.99	10.8063	10:13	9.2063	3:39	500
CO (ppm)	CC287319	20.54	19.7385	10:10	19.7233	3:35	500
O2	CC75242	10.56	10.64	1:09	10.67	3:50	400
CO2	CC75242	10.17	10.08	9:09	~~10.39~~ 10.06	3:48	400
CO (%)	CC75242	2.512	2.511	9:09	~~2.67~~ 2.51	3:48	400

Filter Changes

VOC = 11:53

NOx = 11:50

11:56 - 12:00

1:33

Note: VOC over range 11:47 - 12:02

CO over 11:47 - 12:08

CO & SO_2 Disengaged 1:39 - 1:41 PM

Gas Analyzers Calibrations

Date	6/7/2011
Project	477-S-01-1
Run #	28
Appliance	Auger-fed OWHH
Fuel/Start	Coal/Cold
Personnel	AK/JC/SB
Background	8:50 – 8:52 AM
Test Start Time	9:29:40 AM (Supply) 9:30:30 (ambient)
Test End Time	12:49 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	80
NOx	0-100 ppm	80
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB Supplemental – Auger coal OWHH Cold Start – Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1491	8:05			
NO	AWB483	0	0.0000	7:28			
NOx	AWB483	0	0.0000	7:28			
SO2	AWB483	0	0.1110	7:30			
CO (ppm)	AWB483	0	0.0658	7:30			
O2	AWB483	0	0.00	8:38			
CO2	AWB483	0	0.00	8:38			
CO (%)	AWB483	0	0.00	8:38			

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2	455.7078	8:09			
NO	CC5643	91.08	91.1275	7:35			
NOx	CC5643	91.40	91.4201	7:35			
SO2	CC89280	88.92	89.8866	7:40			
CO (ppm)	CC89280	452.4	452.1338	7:44			
O2	Amb. Air	20.946	20.95	8:48			
CO2	CC53847	19.99	19.98	8:41			
CO (%)	CC53847	4.501	4.50	8:41			

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	1/2 CC89280	227.1	212.5485	8:12			
NO	CC287319	4.987	5.0991	7:47			
NOx	CC287319	5.022	5.2009	7:47			
SO2	CC261974	10.99	9.7142	7:52			
CO (ppm)	CC287319	20.54	19.1891	7:47			
O2	CC287205	10.00	10.35	8:52			
CO2	CC287205	10.07	10.02	8:52			
CO (%)	CC287205	2.266	2.26	8:52			

Pbar = 30.13 in Hg

Run 28 Post-Cal = Run 29 Post-Cal HE

Gas Analyzers Calibrations

Date	6/7/2011
Project	477-S-01-1
Run #	29
Appliance	Auger-fed OWHH
Fuel/Start	Coal/Hot
Personnel	AK/JC/SB
Background	1:46 – 1:48 PM
Test Start Time	1:51 PM
Test End Time	5:13 PM

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509 ~~80~~ JC
NOx	0-100 ppm	509 ~~80~~ JC
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB Supplemental_Auger coal OWHH Hot Start_Gas

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0			0.1643	5:17	1150
NO	AWB483	0			0.0999	5:19	
NOx	AWB483	0			0.0977	5:19	
SO2	AWB483	0			0.0087	5:20	
CO (ppm)	AWB483	0			0.0505	5:19	
O2	AWB483	0			0.04	5:43	
CO2	AWB483	0			0.07	5:43	
CO (%)	AWB483	0			-0.00	5:43	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC89280	454.2			457.2949	5:27	250
NO	CC5643	91.08			88.1241	5:33	1200
NOx	CC5643	91.40			87.8225	5:33	1200
SO2	CC89280	88.92			88.9927	5:23	250
CO (ppm)	CC89280	452.4			468.1363	5:23	250
O2	Amb. Air	20.946			20.84	5:45	
CO2	CC53847	19.99			19.97	5:48	1550
CO (%)	CC53847	4.501			~~-0.00~~ 4.49 JC	5:48	1550

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	1/2 CC89280	227.1			214.4382	5:29	250
NO	CC287319	4.987			5.0991	5:36	500
NOx	CC287319	5.022			5.2039	5:36	500
SO2	CC261974	10.99			10.3230	5:39	<200
CO (ppm)	CC287319	20.54			20.1048	5:35	500
O2	CC287205	10.00			10.12	5:50	2100
CO2	CC287205	10.07			10.03	5:50	2100
CO (%)	CC287205	2.266			2.25	5:50	2100

Pbar = 30.15 in Hg

JC Run 29 Pre-Cal = Run 28 Pre-Cal

Gas Analyzers Calibrations

Date	6/30/2011
Project	477-S-01-1
Run #	30
Appliance	Non Q OWHH
Fuel/Start	Spruce/Low/Hot start
Personnel	AK/JC/SB
Background	11:50-11:54
Test Start Time	2:18 PM
Test End Time	4:20 PM
File Name	

Pbar = 30.22 in Hg

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1491	8:53	0.1491	4:33	1000
NO	AWB483	0	0.0006	9:41	0.3991	4:25	
NOx	AWB483	0	0.0019	9:41	0.6926	4:25	
SO2	AWB483	0	0.3099	9:41	0.5118	4:25	
CO (ppm)	AWB483	0	0.1726	9:41	1.0883	4:28	
O2	AWB483	0	0.00	11:25	0.25	4:57	
CO2	AWB483	0	0.00	11:25	0.09	4:57	
CO (%)	AWB483	0	0.00	11:25	0.02	4:57	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	468.4652	9:10	467.2448	4:37	1400
NO	CC5643	91.08	91.2044	9:58	95.0115	4:47	1150
NOx	CC5643	91.40	91.7050	9:58	94.9026	4:47	1150
SO2	CC108971	89.8	89.8860	9:51	88.0841	4:41	1400
CO (ppm)	SG9161474	496.5	497.3020	10:02	491.1056	4:44	1000
O2	Amb. Air	20.95%	20.95	11:34	21.00	4:53	
CO2	ALM068058	17.10%	17.13	11:59	16.58	5:00	900
CO (%)	ALM068058	4.28%	4.28	11:34	4.15	5:00	900

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	1/2 CC108971	232.95	230.5380	9:33			JC (Dilution apparatus broken)
NO	CC287319	4.987	4.5027	11:00	5.3053	4:49	400
NOx	CC287319	5.022	4.5032	11:00	5.4063	4:49	400
SO2	CC277801	21.81	21.2324	11:10	21.9299	4:53	1900
CO (ppm)	CC287319	20.54	16.1977	11:00	21.0968	4:49	400
O2	ALM066210	5.03%	5.10	11:37	5.44	5:05	1250
CO2	ALM066210	5.06%	5:02	11:37	4.97	5:05	1250
CO (%)	ALM066210	2.50%	2.48	11:37	2.44	5:05	1250

NOx Filter changes:

2:22 - 2:25
2:26
2:30
2:36
3:25
4:01

VOC Filter changes:

3:10 - 3:11

Gas Analyzers Calibrations

Date	7/1/2011
Project	477-S-01-1
Run #	31
Appliance	Non-Cat Oil HH
Fuel/Burn Rate	Batch / High
Personnel	AK/JC/SB
Background	9:32
Test Start Time	10:36
Test End Time	12:32

File Name _____

Pbar = 30.24 in Hg

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1643	8:43	0.1643	1:20	890
NO	AWB483	0	0.0000	8:38	0.6956	12:49	
NOx	AWB483	0	0.0000	8:38	1.0043	12:49	
SO2	AWB483	0	0.3160	8:38	0.4904	12:48	
CO (ppm)	AWB483	0	0.0963	8:39	0.0353	12:48	
O2	AWB483	0	0.00	9:23	0.30	1:30	
CO2	AWB483	0	0.00	9:23	0.05	1:30	
CO (%)	AWB483	0	0.00	9:23	0.00	1:30	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	467.9623	8:50	467.4279	1:24	1400
NO	CC5643	91.08	91.1037	8:58	89.7068	12:52	1100
NOx	CC5643	91.40	91.4005	8:58	89.8050	12:52	1100
SO2	CC108971	89.8	90.1888	8:54	86.0802	1:08	1400
CO (ppm)	SG9161474	496.5	496.4626	9:04	485.0924	12:55	1000
O2	Amb. Air	20.95%	20.94	9:25	20.85	1:23	
CO2	ALM068058	17.10%	17.10	9:28	17.91	1:34	900
CO (%)	ALM068058	4.28%	4.28	9:28	4.49	1:34	900

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC277801	112.6	119.4105	9:14	116.4953	1:26	1850
NO	CC287319	4.987	4.8048	9:07	5.0001	1:13	350
NOx	CC287319	5.022	4.8998	9:07	5.2018	1:13	350
SO2	CC277801	21.81	21.2355	9:11	22.5326	1:11	1900
CO (ppm)	CC287319	20.54	19.2654	9:07	17.1287	1:13	350
O2	ALM066210	5.03%	5.23	9:30	4.77	1:36	800
CO2	ALM066210	5.06%	5.05	9:30	5.21	1:36	800
CO (%)	ALM066210	2.50%	2.56	9:30	2.57	1:36	800

NOx filter change
10:42

Pbar = 30.16 Mlg

Gas Analyzers Calibrations

Date	7/6/2011
Project	477-S-01-1
Run #	32
Appliance	Non Q OWHH
Fuel/Burn Rate	Birch / Low
Personnel	AK/JC/SB
Background	10:05 – 10:07
Test Start Time	12:26
Test End Time	16:17
File Name	FNSB – Non Q OWHH Birch Low Gas

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1491	8:50	13.3647	16:57	
NO	AWB483	0	0.0017	8:55	.2034	16:55	
NOx	AWB483	0	0.0171	8:55	.3147	16:55	
SO2	AWB483	0	0.0000	8:55	.8912	16:55	
CO (ppm)	AWB483	0	0.0505	8:55	.1047	16:53	
O2	AWB483	0	0.00	9:57	-.02	16:22	
CO2	AWB483	0	0.00	9:57	.20	16:22	
CO (%)	AWB483	0	0.00	9:57	.033	16:22	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	467.9468	9:36	406.1419	16:41	
NO	CC5643	91.08	91.1129	9:02	80.2143	16:50	
NOx	CC5643	91.40	91.4219	9:02	79.53186	16:50	
SO2	CC108971	89.8	89.8768	9:31	80.1635	16:46	
CO (ppm)	SG9161474	496.5	494.0970	9:25	448.81	16:53	
O2	Amb. Air	20.95%	20.94	10:03	20.80	16:21	
CO2	ALM068058	17.10%	17.09	10:01	17.11	16:26	
CO (%)	ALM068058	4.28%	4.28	10:01	4.285	16:26	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC277801	112.6	114.9849	9:38	112.421	17:00	
NO	CC287319	4.987	5.0062	9:50	3.2121	17:08	
NOx	CC287319	5.022	5.1255	9:50	3.2241	17:07	
SO2	CC277801	21.81	21.5200	9:42	16.9066	17:05	
CO (ppm)	CC287319	20.54	20.0438	9:44	12.8611	17:08	
O2	ALM066210	5.03%	5.06	10:05	5.01	16:24	
CO2	ALM066210	5.06%	4.99	10:05	5.08	16:24	
CO (%)	ALM066210	2.50%	2.47	10:05	2.481	16:24	

NOx Filter Changes:
12:31 – 12:32
12:36
12:48
12:48 – 2:20

VOC
12:34

Gas Analyzers Calibrations

Date	~~7/7/2011~~ 7/8/2011
Project	477-S-01-1
Run #	33
Appliance	NonQ OWHH
Fuel/Burn Rate	Birch/Low/Cold
Personnel	AK/JC/SB
Background	8:09 – 8:11
Test Start Time	8:36 AM
Test End Time	2:22 PM
File Name	

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

NOx Filter 9:18-9:19 10:36-10:37 10:53 11:05 11:12-11:14 11:40 12:22 1:37 2:16

VOC 11:56 – 11:57 2:15

			PRE-CAL Instrument Response	PRE-CAL Time	POST-CAL Instrument Response	POST-CAL Time	End PSI
	Cylinder #	Standard Gas					
VOC	AWB483	0	0.1491	7:12	1.0800	3:02	600
NO	AWB483	0	0.0017	7:06	0.1025	2:32	
NOx	AWB483	0	0.0171	7:06	0.3228	2:32	
SO2	AWB483	0	0.0000	7:06	1.2401	2:32	
CO (ppm)	AWB483	0	0.1726	7:08	0.0658	2:32	
O2	AWB483	0	0.00	8:05	0.00	3:13	
CO2	AWB483	0	0.00	8:05	0.12	3:13	
CO (%)	AWB483	0	0.00	8:05	0.01	3:13	

SPAN

			Instrument Response	Time	Instrument Response	Time	End PSI
	Cylinder #	Standard Gas					
VOC	CC108971	465.9	468.1299	7:17	473.9595	3:07	1100
NO	CC5643	91.08	91.1098	7:34	89.7127	2:36	800
NOx	CC5643	91.40	91.3212	7:34	89.8325	2:36	800
SO2	CC108971	89.8	90.2776	7:24	84.5689	2:45	1100
CO (ppm)	SG9161474	496.5	496.7678	7:42	495.1653	2:40	700
O2	Amb. Air	20.95%	20.94	8:06	20.82	3:15	
CO2	ALM068058	17.10%	17.09	8:08	17.08	3:17	900
CO (%)	ALM068058	4.28%	4.28	8:08	4.27	3:17	

LOW CHECK

			Instrument Response	Time	Instrument Response	Time	End PSI
	Cylinder #	Standard Gas					
VOC	CC277801	112.6	118.0523	7:57	121.8674	3:08	1700
NO	CC287319	4.987	4.9085	7:45	4.9116	2:48	700
NOx	CC287319	5.022	5.0248	7:45	5.0248	2:48	700
SO2	CC277801	21.81	21.8106	7:49	21.8167	2:56	1700
CO (ppm)	CC287319	20.54	19.5248	7:45	21.1274	2:48	700
O2	ALM066210	5.03%	5.07	8:10	5.06	3:18	1250
CO2	ALM066210	5.06%	5.04	8:10	5.07	3:18	
CO (%)	ALM066210	2.50%	2.47	8:10	2.47	3:18	

Gas Analyzers Calibrations

Date	7/27/2011
Project	477-S-01-1
Run #	34
Appliance	EPA OWHH w/ Catalyst
Fuel/Burn Rate	Birch Low
Personnel	AK/JC/SB
Background	9:00-9:02, 11:54-11:56
Test Start Time	13:26
Test End Time	22:20

P_{bar} = 30.21 in Hg

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2 (stack)	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419
CO2 (tunnel)	0-25 %	220

File Name FNSB_EPA OWHH ClearStak_Gas.xlsx; FNSB_EPA OWHH w/ Catalyst - Gas

NOx Filter:
13:44
15:26

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1338	8:35	0.1491	10:24	500
NO	AWB483	0	0.0000	7:49	0.2065	10:25	
NOx	AWB483	0	0.0202	7:49	0.2250	10:25	
SO2	AWB483	0	0.0000	7:49	0.0000	10:25	
CO (ppm)	AWB483	0	0.0658	7:50	0.0200	10:24	
CO2 (tunnel)	AWB483	0	0.0534	11:41	0.0992	10:25	
O2	AWB483	0	0.00	8:51	0.00	10:59	
CO2 (stack)	AWB483	0	0.00	8:51	0.00	10:59	
CO (%)	AWB483	0	0.00	8:51	0.00	10:59	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	467.7942	8:40	469.7476	10:43	900
NO	CC5643	91.08	91.1129	7:56	88.2118	10:27	
NOx	CC5643	91.40	91.4280	7:56	87.6208	10:27	
SO2	CC108971	89.8	89.8829	8:04	88.2707	10:41	900
CO (ppm)	SG9161474	496.5	497.1494	8:13	500.0064	10:37	1500
CO2 (tunnel)	CC53847	19.99%	19.9851	11:47	19.0084	10:33	2000
O2	Amb. Air	20.95%	20.94	8:53	20.92	11:05	
CO2 (stack)	ALM068058	17.10%	17.10	8:55	17.02	11:02	850
CO (%)	ALM068058	4.28%	4.28	8:55	4.26	11:02	850

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC277801	112.6	115.5190	8:42	115.9616	10:44	1400
NO	CC287319	4.987	4.8109	8:19	3.6 4.6126	10:52	300
NOx	CC287319	5.022	4.9272	8:19	4.7259	10:52	300
SO2	CC277801	21.81	21.1161	8:25	20.5135	10:49	1400
CO (ppm)	CC287319	20.54	19.2807	8:17	18.1360	10:52	300
CO2 (tunnel)	ALM066210	5.06%	5.0897	11:50	4.7845	10:57	1200
O2	ALM066210	5.03%	5.06	9:01	5.01	10:56	1200
CO2 (stack)	ALM066210	5.06%	4.94	9:01	4.92	10:56	1200
CO (%)	ALM066210	2.50%	2.47	9:01	2.45	10:56	1200

Gas Analyzers Calibrations

Date	8/10/2011
Project	477-S-01-1
Run #	35
Appliance	Coal Stove
Fuel/Burn Rate	Wet Stoker High 2
Personnel	AK/JC/SB
Background	1426-1430
Test Start Time	1447
Test End Time	1823 (6:46 elapsed)
File Name	FNSB - Wet Stoker Coal High 2 - 35

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	AWB483	0	0.1643	1147	0.1491	1831	300
NO	AWB483	0	0.0000	1143	0.0078	1830	
NOx	AWB483	0	0.0233	1143	0.0008	1830	
SO2	AWB483	0	0.0957	1143	0.0896	1830	
CO (ppm)	AWB483	0	0.0353	1143	0.5487	1830	
O2	AWB483	0	0.00	1150	0.03	1827	
CO2	AWB483	0	0.00	1150	0.01	1827	
CO (%)	AWB483	0	0.000	1150	0.006	1827	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	465.9170	1214	396.2670	1833	200
NO	CC5643	91.08	91.0092	1220	92.1074	1842	~~800~~ 800
NOx	CC5643	91.40	91.4249	1220	92.3248	1842	~~800~~ 800
SO2	CC108971	89.8	89.9900	1201	76.5867	1837	200
CO (ppm)	SG9161474	496.5	1158	493.7640	369.6964	1840	400
O2	Amb. Air	20.95%	20.49	1243	20.92	1826	
CO2	ALM068058	17.10%	17.10	1242	17.02	1854	100
CO (%)	ALM068058	4.28%	4.280	1242	4.260	1854	100

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC277801	112.6	118.5102	1234	61.8628	1848	1200
NO	CC287319	4.987	5.8091	1234	5.2407	~~5.2788~~ 1851	200
NOx	CC287319	5.022	5.9152	1238	5.3178	1851	200
SO2	CC277801	21.81	21.3119	1230	20.4156	1846	1200
CO (ppm)	CC287319	20.54	16.8701	1236	16.5645	1851	200
O2	ALM066210	5.03%	5.17	1245	5.06	1853	1200
CO2	ALM066210	5.06%	4.14	1245	4.97	1853	
CO (%)	ALM066210	2.50%	2.450	1245	2.446	1853	

Gas Analyzers Calibrations

Pbar = 30.14 in Hg

Date	8/11/2011
Project	477-S-01-1
Run #	36
Appliance	Coal Stove
Fuel/Burn Rate	Wet Lump / Low / Cold start
Personnel	AK/JC/SB
Background	9:04 - 9:07
Test Start Time	9:32
Test End Time	17:49
File Name	FNSB_Coal Stove Wet Lump Low_Cold_36

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2 (stack)	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419
CO2 (tunnel)	0-25 %	220

NOx filter 9:58 - 10:00
11:01 - 11:02
11:37 - 11:39
11:49 - 11:50

ZERO

			PRE-CAL Instrument Response	PRE-CAL Time	POST-CAL Instrument Response	POST-CAL Time	End PSI
	Cylinder #	Standard Gas					
VOC	AWB483	0	0.1796	8:06	0.6527	5:57	< 200
NO	AWB483	0	0.0108	8:25	0.0017	5:55	
NOx	AWB483	0	0.0263	8:25	0.1180	5:55	
SO2	AWB483	0	0.3955	8:26	0.0957	5:55	
CO (ppm)	AWB483	0	0.0200	8:26	-0.0460	5:55	
O2	AWB483	0	0.00	8:58	0.00	6:31	
CO2 (stack)	AWB483	0	0.00	8:58	0.03	6:31	
CO (%)	AWB483	0	0.00	8:58	0.00	6:31	

SPAN

			Instrument Response	Time	Instrument Response	Time	End PSI
	Cylinder #	Standard Gas					
VOC	CC108971	465.9	466.4513	8:14	464.3912	5:59	250
NO	CC5643	91.08	91.1129	8:30	90.1123	6:10	500
NOx	CC5643	91.40	91.4219	8:30	90.5280	6:10	500
SO2	CC108971	89.8	89.8799	8:37	82.2225	6:05	250
CO (ppm)	SG9161474	496.5	496.1726	8:43	500.0644	6:16	400
O2	Amb. Air	20.95%	20.94	9:03	20.86	6:30	
CO2 (stack)	ALM068058	17.10%	17.10	9:01	17.01	6:33	700
CO (%)	ALM068058	4.28%	4.28	9:01	4.26	6:33	700

LOW CHECK

			Instrument Response	Time	Instrument Response	Time	End PSI
	Cylinder #	Standard Gas					
VOC	CC277801	112.6	113.5352	8:17	120.3586	6:22	1200
NO	CC287319	4.987	4.9186	8:50	4.9116	6:26	200
NOx	CC287319	5.022	5.0279	8:50	4.9242	6:26	200
SO2	CC277801	21.81	21.7188	8:48	21.2140	6:21	1200
CO (ppm)	CC287319	20.54	~~21.0213~~	~~8:44~~ 8:51	18.5176	6:26	200
O2	ALM066210	5.03%	5.02	9:05	5.01	6:35	1200
CO2 (stack)	ALM066210	5.06%	4.98	9:05	4.97	6:35	1200
CO (%)	ALM066210	2.50%	2.46	9:05	2.45	6:35	1200

19.1128

Torch used 9:55 - 9:57

Gas Analyzers Calibrations

Date	8/12/2011
Project	477-S-01-1
Run #	37
Appliance	Coal Stove
Fuel/Burn Rate	Wet Lump/ Low/ Hot
Personnel	AK/JC/SB
Background	9:38 - 9:40
Test Start Time	10:05
Test End Time	16:38
File Name	FNSB_ Coal Stove Wet Lump Low Hot _ Gas

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-100 ppm	329
CO	0-500 ppm	325
CO2 (stack)	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

NOx Filter 10:35 BM#993

	Cylinder #	Standard Gas	PRE-CAL Instrument Response	PRE-CAL Time	POST-CAL Instrument Response	POST-CAL Time	End PSI
VOC	AWB483	0	0.1643	8:56	1.5988	4:45	2600
NO	AWB483	0	0.0078	7:57	0.0078	4:51	
NOx	AWB483	0	0.0141	7:57	0.0233	4:51	
SO2	AWB483	0	0.0000	7:56	0.1936	4:51	
CO (ppm)	AWB483	0	0.0047	7:56	-0.0716	4:52	
O2	AWB483	0	0.00	9:14	-0.05	5:24	
CO2 (stack)	AWB483	0	0.00	9:14	0.01	5:24	
CO (%)	AWB483	0	0.00	9:14	0.00	5:24	

SPAN

	Cylinder #	Standard Gas	Instrument Response	Time	Instrument Response	Time	End PSI
VOC	CC108971	465.9	466.9243	9:03	466.6344	5:12	200
NO	CC5643	91.08	91.1159	8:04	86.7140	4:55	600
NOx	CC5643	91.40	91.4310	8:04	86.6324	4:55	600
SO2	CC108971	89.8	90.4856	8:44	75.3543	5:16	200
CO (ppm)	SG9161474	496.5	495.2416	8:24	489.8499	5:19	400
O2	Amb. Air	20.95%	20.94	9:19	20.86	5:22	
CO2 (stack)	ALM068058	17.10%	17.10	9:16	17.10	5:28	800
CO (%)	ALM068058	4.28%	4.28	9:16	4.28	5:28	800

LOW CHECK

	Cylinder #	Standard Gas	Instrument Response	Time	Instrument Response	Time	End PSI
VOC	CC277801	112.6	116.5262	9:06	117.3198	5:04	1000
NO	CC287319	4.987	4.8140	8:49	4.8140	4:57	200
NOx	CC287319	5.022	4.9272	8:49	5.0218	4:57	200
SO2	CC277801	21.81	23.1169	8:47	21.1100	5:02	1000
CO (ppm)	CC287319	20.54	18.1055	8:49	19.0212	4:57	200
O2	ALM066210	5.03%	5.06	9:21	4.98	5:26	1150
CO2 (stack)	ALM066210	5.06%	4.98	9:21	4.93	5:26	1150
CO (%)	ALM066210	2.50%	2.51	9:21	2.56	5:26	1150

Gas Analyzers Calibrations

Date	8/15/2011
Project	477-S-01-1
Run #	38
Appliance	Coal Stove
Fuel/Burn Rate	Dry Lump / Low / Hot
Personnel	AK/JC/SB
Background	11:00 - 11:04
Test Start Time	11:51 AM
Test End Time	6:00 PM
File Name	FNSB_Coal StoveDry Lump Low Hot_38

Pbar = 30.14 in Hg

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-50 ppm	329
CO	0-500 ppm	325
CO2 (stack)	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

ZERO

NOx fill: 12:13 - 12:15; 12:49 - 12:51

VOC 12:54

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	BMH993	0	0.1643	9:16	0.1338	6:07	2500
NO	BMH993	0	0.0078	9:11	0.0078	6:04	
NOx	BMH993	0	0.0171	9:11	0.0233	6:04	
SO2	BMH993	0	0.1505	9:12	0.0000	6:04	
CO (ppm)	BMH993	0	0.0658	9:12	0.4931	6:05	
O2	BMH993	0	0.00	10:43	0.04	6:09	
CO2 (stack)	BMH993	0	0.00	10:43	0.05	6:09	
CO (%)	BMH993	0	0.00	10:43	0.00	6:09	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	467.7484	9:22	469.7782	6:13	200
NO	CC5643	91.08	91.1129	9:30	90.6492	6:20	600
NOx	CC5643	91.40	91.5195	9:30	91.1290	6:20	600
SO2	CC5643	40.98	40.9779	9:32	40.7237	6:21	600
CO (ppm)	SG9161474	496.5	498.2172	9:47	481.4448	6:24	400
O2	Amb. Air	20.95%	20.94	10:56	20.96	6:08	
CO2 (stack)	ALM068058	17.10%	17.10	10:54	17.05	6:39	
CO (%)	ALM068058	4.28%	4.28	10:54	4.27	6:39	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC277801	112.6	112.6806	9:24	116.4042	6:16	1200
NO	CC287319	4.987	4.9146	9:59	4.9177	6:28	200
NOx	CC287319	5.022	5.0218	9:59	5.0218	6:28	200
SO2	CC159390	10.77	10.3459	10:15	10.6440	6:30	1400
CO (ppm)	CC287319	20.54	19.1586	9:59	19.0670	6:29	200
O2	ALM066210	5.03%	5.06	11:00	5.07	6:37	1150
CO2 (stack)	ALM066210	5.06%	4.98	11:00	4.95	6:37	1150
CO (%)	ALM066210	2.50%	2.46	11:00	2.45	6:37	1150

Gas Analyzers Calibrations

Date	8/16/2011
Project	477-S-01-1
Run #	39
Appliance	Coal Stove
Fuel/Burn Rate	
Personnel	AK/JC/SB
Background	8:22
Test Start Time	8:45 (10:11 load)
Test End Time	16:12

Pbar = 30.15 in Hg

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-50 ppm	329
CO	0-500 ppm	325
CO2 (stack)	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name: FNSB_Coal Stove Wet stoker Low Cold

ZERO

NOx Filter 9:14 10:15

VOC

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	BMH993	0	0.1643	7:36	0.6527	4:23	2500
NO	BMH993	0	0.0078	7:29	0.0047	4:21	
NOx	BMH993	0	0.0274	7:29	0.1241	4:21	
SO2	BMH993	0	0.3981	7:32	0.0000	4:21	
CO (ppm)	BMH993	0	0.0810	7:29	-0.5600	4:21	
O2	BMH993	0	0.00	8:23	0.03	4:18	
CO2 (stack)	BMH993	0	0.00	8:23	0.04	4:18	
CO (%)	BMH993	0	0.00	8:23	0.00	4:18	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	468.2215	7:44	475.4245	4:25	200
NO	CC5643	91.08	91.1098	8:00	87.5224	4:31	550
NOx	CC5643	91.40	91.4219	8:01	87.2273	4:31	550
SO2	CC5643	40.98	40.9809	7:59	40.7681	4:33	550
CO (ppm)	SG9161474	496.5	495.8216	8:09	468.9752	4:37	300
O2	Amb. Air	20.95%	20.94	8:27	21.03	4:35	
CO2 (stack)	ALM068058	17.10%	17.10	8:26	16.99	4:53	
CO (%)	ALM068058	4.28%	4.28	8:26	4.25	4:53	

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC277801	112.6	113.0163	7:46	117.9302	4:27	1200
NO	CC287319	4.987	4.8170	8:04	4.6187	4:43	200
NOx	CC287319	5.022	4.9272	8:04	4.7198	4:43	200
SO2	CC159390	10.77	9.4000	8:17	10.2955	4:41	1400
CO (ppm)	CC287319	20.54	16.7014	8:12	17.0982	4:44	200
O2	ALM066210	5.03%	5.10	8:29	5.12	4:52	1100
CO2 (stack)	ALM066210	5.06%	4.99	8:29	4.93	4:52	1100
CO (%)	ALM066210	2.50%	2.47	8:29	2.45	4:52	1100

Gas Analyzers Calibrations

Date	8/17/2011
Project	477-S-01-1
Run #	40
Appliance	Central-heating indoor furnace
Fuel/Burn Rate	0.1 #1
Personnel	AK/JC/SB

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-50 ppm	329
CO	0-500 ppm	325
CO2 (stack)	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

Background 12:40 - 12:42 8/17/11
Test Start Time 12:54 8/17/11
Test End Time 3:41 8/18/11

File Name FNSB - Central - Heating Indoor Furnace 0.1 1_40

ZERO

	Cylinder #	Standard Gas	PRE-CAL Instrument Response	PRE-CAL Time	POST-CAL Instrument Response	POST-CAL Time	End PSI
VOC	BMH993	0	0.1338	12:19	0.1643	7:55	2300
NO	BMH993	0	0.0108	11:47	0.0108	8:02	2300
NOx	BMH993	0	0.0233	11:47	0.0202	8:02	
SO2	BMH993	0	0.0000	11:51	0.0000	8:02	
CO (ppm)	BMH993	0	0.0963	11:47	-0.3616	8:02	
O2	BMH993	0	0.00	11:22	0.00	7:54	
CO2 (stack)	BMH993	0	0.00	11:22	0.00	7:54	
CO (%)	BMH993	0	0.00	11:22	0.00	7:54	

SPAN

	Cylinder #	Standard Gas	Instrument Response	Time	Instrument Response	Time	End PSI
VOC	CC108971	465.9	465.6572	12:25	480.1095	8:40	2200
NO	CC5643	91.08	91.1129	11:54	87.4156	8:13	300
NOx	CC5643	91.40	91.4219	11:54	87.4195	8:13	300
SO2	CC5643	40.98	40.9763	12:00	39.0243	8:19	300
CO (ppm)	SG9161474	496.5	496.6610	12:04	497.8632	8:22	500
O2	Amb. Air	20.95%	20.94	11:26	20.99	8:07	
CO2 (stack)	ALM068058	17.10%	17.10	11:29	17.15	8:57	700
CO (%)	ALM068058	4.28%	4.28	11:29	4.29	8:57	700

LOW CHECK

	Cylinder #	Standard Gas	Instrument Response	Time	Instrument Response	Time	End PSI
VOC	CC277801	112.6	113.0623	12:27	108.1782	8:42	1050
NO	CC287319	4.987	4.8140	12:07	4.8170	8:33	300
NOx	CC287319	5.022	5.0248	12:07	4.9242	8:33	300
SO2	CC159390	10.77	10.7983	12:11	9.5956	8:29	1700
CO (ppm)	CC287319	20.54	20.6237	12:07	16.7777	8:34	300
O2	ALM066210	5.03%	5.08	11:33	5.11	8:56	900
CO2 (stack)	ALM066210	5.06%	5.00	11:33	5.01	8:56	900
CO (%)	ALM066210	2.50%	2.47	11:33	2.47	8:56	900

Gas Analyzers Calibrations

Date	8/18/2011
Project	477-S-01-1
Run #	41
Appliance	EPA Wood Stove
Fuel/Burn Rate	Birch/Low/Cold
Personnel	AK/JC/SB
Background	9:08 10:45-10:47
Test Start Time	10:57 (12:47 load)
Test End Time	15:45

Pbar = 30.25 in Hg

Instrument	Scale	OMNI #
VOC	0-500 ppm	328
NO	0-100 ppm	509
NOx	0-100 ppm	509
SO2	0-50 ppm	329
CO	0-500 ppm	325
CO2 (stack)	0-25 %	419
O2	0-25 %	419
CO (%)	0-5 %	419

File Name FNSB - EPA Stove Birch Low Cold - 41

ZERO

			PRE-CAL		POST-CAL		
			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	BMH993	0	0.1643	8:00	0.6832	3:54	2300
NO	BMH993	0	0.0078	8:04	0.0047	3:56	
NOx	BMH993	0	0.0171	8:04	0.0263	3:56	
SO2	BMH993	0	0.0481	8:04	0.0000	3:56	
CO (ppm)	BMH993	0	0.1726	8:06	0.0505	3:56	
O2	BMH993	0	0.00	7:59	0.08	3:54	
CO2 (stack)	BMH993	0	0.00	7:59	0.07	3:54	
CO (%)	BMH993	0	0.00	7:59	0.00	3:53	

SPAN

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC108971	465.9	466.8438	8:46	471.6240	4:21	<200
NO	CC5643	91.08	91.1129	8:19	89.6120	3:59	300
NOx	CC5643	91.40	91.4219	8:19	89.7257	3:59	300
SO2	CC5643	40.98	40.9763	8:20	37.7153	4:00	300
CO (ppm)	SG9161474	496.5	496.7526	8:24	492.1740	4:03	300
O2	Amb. Air	20.95%	20.94	8:07	20.90	3:58	
CO2 (stack)	ALM068058	17.10%	17.10	8:58	17.05	4:32	650
CO (%)	ALM068058	4.28%	4.28	8:58	4.26	4:32	650

LOW CHECK

			Instrument		Instrument		
	Cylinder #	Standard Gas	Response	Time	Response	Time	End PSI
VOC	CC277801	112.6	112.1007	8:49	111.0324	4:23	1050
NO	CC287319	4.987	4.8140	8:35	4.8170	4:06	250
NOx	CC287319	5.022	4.9272	8:35	4.9272	4:06	250
SO2	CC159390	10.77	9.7484	8:30	10.0983	4:14	1400
CO (ppm)	CC287319	20.54	16.7929	8:35	21.1274	4:05	250
O2	ALM066210	5.03%	5.12	8:59	5.12	4:28	900
CO2 (stack)	ALM066210	5.06%	5.02	8:59	4.98	4:28	900
CO (%)	ALM066210	2.50%	2.47	8:59	2.45	4:28	900

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E04NI99E15A4BQ4	Reference Number:	48-124250190-4
Cylinder Number:	CC276183	Cylinder Volume:	144 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	660
		Analysis Date:	Jan 31, 2011

Expiration Date: Jan 31, 2013

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
NOx	22.00 PPM	22.27 PPM	G1	+/- 1% NIST Traceable
NITRIC OXIDE	22.00 PPM	22.20 PPM	G1	+/- 1% NIST Traceable
SULFUR DIOXIDE	45.00 PPM	45.14 PPM	G1	+/- 1% NIST Traceable
PROPANE	225.0 PPM	225.4 PPM	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	080601	CC237959	50.60PPM SULFUR DIOXIDE/NITROGEN	Dec 15, 2011
NTRM	100603	CC280968	20.34PPM NITRIC OXIDE/NITROGEN	Feb 01, 2013
NTRM	100603NOx	CC280968	20.36PPM NOx/NITROGEN	Feb 01, 2013
NTRM	990605	XC012013B	248.9PPM PROPANE/	Oct 02, 2011

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
California Analytical NO	CLD NO	Jan 14, 2011
California Analitical NOx	CLD NOx	Jan 14, 2011
Nicolet 6700 AHR0801551 C3H8	FTIR	Jan 13, 2011
Nicolet 6700 AHR0801551 SO2	FTIR	Jan 15, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E03NI99E15A03N0	Reference Number:	48-124290510-3
Cylinder Number:	CC280202	Cylinder Volume:	144 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	660
		Analysis Date:	Nov 17, 2011

Expiration Date: Nov 17, 2013

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
NOx	9.000 PPM	8.897 PPM	G1	+/- 1% NIST Traceable
CARBON MONOXIDE	9.000 PPM	8.865 PPM	G1	+/- 1% NIST Traceable
NITRIC OXIDE	9.000 PPM	8.866 PPM	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	100603	CC253524	20.34PPM NITRIC OXIDE/NITROGEN	Feb 01, 2013
NTRM	100603	CC253524NOx	20.36PPM NOx/NITROGEN	Feb 01, 2013
NTRM	080609	CC255507	10.04PPM CARBON MONOXIDE/NITROGEN	Jun 15, 2012

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
Nicolet 6700 AHR0801551 CO	FTIR	Nov 07, 2011
Thermo 42i-LS	Chemiluminescence	Nov 12, 2011
Thermo 42i-LS NOx	Chemiluminescence	Nov 12, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E04NI77E15A0575	Reference Number:	48-124241253-1
Cylinder Number:	CC75242	Cylinder Volume:	151 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	590
		Analysis Date:	Nov 18, 2010

Expiration Date: Nov 18, 2013

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
CARBON MONOXIDE	2.500 %	2.512 %	G1	+/- 1% NIST Traceable
CARBON DIOXIDE	10.00 %	10.17 %	G1	+/- 1% NIST Traceable
OXYGEN	10.50 %	10.56 %	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	080614	CC267714	1.959% CARBON MONOXIDE/NITROGEN	Oct 15, 2012
NTRM	980510	SG9168397	12.05% OXYGEN/NITROGEN	Jan 15, 2012
NTRM	970510	SG9198971	10.818% CARBON DIOXIDE/NITROGEN	May 15, 2012

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
SIEMENS % CO2	NDIR	Oct 15, 2010
HORIBA % CO	NDIR	Nov 12, 2010
Siemens %O2	PARAMAGNETIC	Oct 15, 2010

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E04NI97E15A47Z4	Reference Number:	54-124196695-12
Cylinder Number:	CC287319	Cylinder Volume:	145 Cu.Ft.
Laboratory:	ASG - Chicago - IL	Cylinder Pressure:	2015 PSIG
PGVP Number:	B12011	Valve Outlet:	660
		Analysis Date:	Nov 13, 2009

Expiration Date: Nov 13, 2011

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
NOx	5.000 PPM	5.022 PPM	G1	+/- 1% NIST Traceable
NITRIC OXIDE	5.000 PPM	4.987 PPM	G1	+/- 1% NIST Traceable
CARBON MONOXIDE	20.00 PPM	20.54 PPM	G1	+/- 1% NIST Traceable
CARBON DIOXIDE	2.000 %	1.984 %	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM/NO	1	CC207744	10.08PPM NITRIC OXIDE/	Sep 01, 2011
NTRM/NOX	07060317NOX	CC207744	10.16PPM NOx/NITROGEN	Sep 01, 2011
NTRM/CO	51008	SG9154067	25.50PPM CARBON MONOXIDE/	Oct 02, 2010
NTRM/CO2	970507	SG9182105BAL	4.204% CARBON DIOXIDE/NITROGEN	May 01, 2010

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
(CO-1)HORIBA VIA-510	NDIR	Oct 21, 2009
(CO-1)HORIBA VIA-510	NDIR	Oct 21, 2009
(CH-1) CAI Model 600	Chemiluminescence	Oct 21, 2009
(CH-1) CAI Model 600	Chemiluminescence	Oct 21, 2009

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E04NI99E15A25V2	Reference Number:	48-124265918-3
Cylinder Number:	CC159390	Cylinder Volume:	144 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	660
		Analysis Date:	May 27, 2011

Expiration Date: Nov 27, 2011

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
NOx	5.000 PPM	4.916 PPM	G1	+/- 1% NIST Traceable
NITRIC OXIDE	5.000 PPM	4.832 PPM	G1	+/- 1% NIST Traceable
SULFUR DIOXIDE	11.00 PPM	10.77 PPM	G1	+/- 1% NIST Traceable
PROPANE	55.00 PPM	57.33 PPM	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	080610	CC263076	49.62PPM PROPANE/AIR	Jul 15, 2012
NTRM	100603	CC280968	20.34PPM NITRIC OXIDE/NITROGEN	Feb 01, 2013
NTRM	100603NOx	CC280968	20.36PPM NOx/NITROGEN	Feb 01, 2013
NTRM	100601	CC284502	14.82PPM SULFUR DIOXIDE/NITROGEN	Jul 13, 2013

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
California Analytical NO	CLD NO	May 19, 2011
California Analitical NOx	CLD NOx	May 19, 2011
Nicolet 6700 AHR0801551 C3H8	FTIR	May 23, 2011
Nicolet 6700 AHR0801551 SO2	FTIR	May 23, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E02NI99E15A03L6	Reference Number:	48-124155105-1
Cylinder Number:	SG9161474	Cylinder Volume:	144 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	590
		Analysis Date:	Oct 21, 2008

Expiration Date: Oct 21, 2011

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
CARBON MONOXIDE	490.0 PPM	496.5 PPM	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	05120506	CC180354	495.8PPM CARBON MONOXIDE/NITROGEN	Feb 02, 2009

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
SIEMENS CO LOW	NDIR	Oct 17, 2008

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS

Grade of Product: CERTIFIED STANDARD-SPEC

Part Number:	X05NI99C15AC524	Reference Number:	48-124231541-1
Cylinder Number:	CC5643	Cylinder Volume:	144.4 Cubic Feet
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
Analysis Date:	Aug 25, 2010	Valve Outlet:	660

Product composition verified by direct comparison to calibration standards traceable to NIST ASTM Class 1 weights and/or NIST gas mixture reference materials.

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration (Mole %)	Actual Concentration (Volume %)	Analytical Uncertainty
SULFUR DIOXIDE	40.00 PPM	40.98 PPM	40.98	+/- 5%
CARBON MONOXIDE	90.00 PPM	92.05 PPM	92.05	+/- 2%
NITRIC OXIDE	90.00 PPM	91.08 PPM	91.08	+/- 2%
PROPANE	90.00 PPM	93.56 PPM	93.56	+/- 2%
NITROGEN	Balance			
Total oxides of nitrogen		91.40 PPM	For Reference Only	

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E04NI99E15A2VF3	Reference Number:	48-124250190-2
Cylinder Number:	CC277801	Cylinder Volume:	144 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	660
		Analysis Date:	Feb 02, 2011

Expiration Date: Aug 02, 2011

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
NOx	10.00 PPM	10.53 PPM	G1	+/- 1% NIST Traceable
NITRIC OXIDE	10.00 PPM	10.53 PPM	G1	+/- 1% NIST Traceable
SULFUR DIOXIDE	22.00 PPM	21.81 PPM	G1	+/- 1% NIST Traceable
PROPANE	112.0 PPM	112.6 PPM	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	080605	CC208113	14.92PPM SULFUR DIOXIDE/NITROGEN	May 01, 2012
NTRM	090607	CC253474	9.90PPM NITRIC OXIDE/NITROGEN	Oct 02, 2011
NTRM	090607NOx	CC253474	9.90PPM NOx/NITROGEN	Oct 02, 2011
NTRM	090617	CC301753	97.82PPM PROPANE/AIR	Oct 02, 2013

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
California Analytical NO	CLD NO	Jan 14, 2011
California Analitical NOx	CLD NOx	Jan 14, 2011
Nicolet 6700 AHR0801551 C3H8	FTIR	Jan 13, 2011
Nicolet 6700 AMP0900118 SO2	FTIR	Jan 07, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E04NI61E15A0574	Reference Number:	54-124246819-1
Cylinder Number:	CC337886	Cylinder Volume:	101 Cu.Ft.
Laboratory:	ASG - Chicago - IL	Cylinder Pressure:	1310 PSIG
PGVP Number:	B12011	Valve Outlet:	590
		Analysis Date:	Jan 12, 2011

Expiration Date: Jan 12, 2014

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
CARBON MONOXIDE	4.250 %	4.327 %	G1	+/- 1% NIST Traceable
CARBON DIOXIDE	17.00 %	16.76 %	G1	+/- 1% NIST Traceable
OXYGEN	17.00 %	16.68 %	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM/O2	06060810	CC206131	22.51% OXYGEN/NITROGEN	May 01, 2016
NTRM/CO2	08061328	CC255569	20.09% CARBON DIOXIDE/	Jul 15, 2012
NTRM/CO	91508	CC269453	7.976% CARBON MONOXIDE/NITROGEN	Jul 15, 2012

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
(CO2-1)HORIBA VIA-510	NDIR	Dec 28, 2010
(CO-2)HORIBA VIA-510	NDIR	Dec 28, 2010
(O2-1)HORIBA MPA-510	Paramagnetic	Jan 04, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E04NI99E15A3LS0	Reference Number:	48-124265918-4
Cylinder Number:	CC108971	Cylinder Volume:	144 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	660
		Analysis Date:	Jun 02, 2011

Expiration Date: Jun 02, 2013

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
NITRIC OXIDE	45.00 PPM	46.25 PPM	G1	+/- 1% NIST Traceable
SULFUR DIOXIDE	90.00 PPM	89.80 PPM	G1	+/- 1% NIST Traceable
PROPANE	450.0 PPM	465.9 PPM	G1	+/- 1% NIST Traceable
NITROGEN	Balance			
Total oxides of nitrogen		46.45 PPM		For Reference Only

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	080615	CC255671	94.67PPM SULFUR DIOXIDE/NITROGEN	Oct 15, 2012
NTRM	100605	CC281711	495.3PPM PROPANE/NITROGEN	Feb 19, 2016
NTRM	100611	CC283982	49.73PPM NITRIC OXIDE/NITROGEN	Jul 23, 2016

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
Nicolet 6700 AHR0801551 NO	FTIR	May 23, 2011
Nicolet 6700 AHR0801551 C3H8	FTIR	May 25, 2011
Nicolet 6700 AMP0900118 SO2	FTIR	May 12, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

CERTIFICATE OF ANALYSIS
Grade of Product: EPA Protocol

Part Number:	E03NI99E15A0801	Reference Number:	48-124271954-2
Cylinder Number:	CC261974	Cylinder Volume:	144 Cu.Ft.
Laboratory:	ASG - Los Angeles - CA	Cylinder Pressure:	2015 PSIG
PGVP Number:	B32011	Valve Outlet:	660
		Analysis Date:	Jul 07, 2011

Expiration Date: Jul 07, 2013

Certification performed in accordance with "EPA Traceability Protocol (Sept. 1997)" using the assay procedures listed. Analytical Methodology does not require correction for analytical interferences. This cylinder has a total analytical uncertainty as stated below with a confidence level of 95%. There are no significant impurities which affect the use of this calibration mixture. All concentrations are on a volume/volume basis unless otherwise noted.
Do Not Use This Cylinder below 150 psig.i.e. 1 Mega Pascal

ANALYTICAL RESULTS

Component	Requested Concentration	Actual Concentration	Protocol Method	Total Relative Uncertainty
NOx	9.000 PPM	8.959 PPM	G1	+/- 1% NIST Traceable
NITRIC OXIDE	9.000 PPM	8.876 PPM	G1	+/- 1% NIST Traceable
CARBON MONOXIDE	18.00 PPM	18.24 PPM	G1	+/- 1% NIST Traceable
NITROGEN	Balance			

CALIBRATION STANDARDS

Type	Lot ID	Cylinder No	Concentration	Expiration Date
NTRM	100603	CC280968	20.34PPM NITRIC OXIDE/NITROGEN	Feb 01, 2013
NTRM	100603NOx	CC280968	20.36PPM NOx/NITROGEN	Feb 01, 2013
NTRM	090618	CC282592	24.35PPM CARBON MONOXIDE/NITROGEN	Oct 02, 2013

ANALYTICAL EQUIPMENT

Instrument/Make/Model	Analytical Principle	Last Multipoint Calibration
SIEMENS CO LOW	NDIR	Jun 28, 2011
Thermo 42i-LS	Chemiluminescence	Jun 14, 2011
Thermo 42i-LS NOx	Chemiluminescence	Jun 14, 2011

Triad Data Available Upon Request

Notes:

Signature on file

Approved for Release

AIR LIQUIDE Air Liquide America Specialty Gases LLC

Scott™

November 14, 2014

RATA CLASS

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD, LONGMONT, CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory - PGVP Vendor ID: A42011

AIR LIQUIDE AMERICA SPECIALTY GASES LLC
500 WEAVER PARK RD
LONGMONT, CO 80501

P.O. No.: OTL-11-036
Document # : 41897724-002

Customer
OMNI-TEST LABS

CINDI WARREN
18327 NE AIRPORT WAY
PORTLAND OR 97230
US

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure G-1; September, 1997.

Cylinder Number: ALM068058 **Certification Date:** 07Jun2011 **Exp. Date:** 06Jun2014
Cylinder Pressure*:** 2000 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ACCURACY**	TRACEABILITY
CARBON MONOXIDE	4.28	%	+/- 1%	Direct NIST and VSL
CARBON DIOXIDE	17.1	%	+/- 1%	Direct NIST and VSL
OXYGEN	17.0	%	+/- 1%	Direct NIST and VSL
NITROGEN		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is based on the requirements of EPA Protocol Procedure G1, September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2639	02Dec2011	KAL004146	0.974 %	CARBON MONOXIDE
NTRM 1800	01Mar2013	K022438	17.87 %	CARBON DIOXIDE
NTRM 2658	01Feb2016	K012175	10.03 %	OXYGEN

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HP/6890/US00034440	23May2011	TCD/FID
HPGC/5890/3115A34624	01Jun2011	TCD
OXYMAT/6E/W5-951	13May2011	PARAMAGNETIC

ANALYZER READINGS

(Z=Zero Gas R=Reference Gas T=Test Gas r=Correlation Coefficient)

First Triad Analysis

CARBON MONOXIDE
Date: 31May2011 Response Unit:AREA
Z1=0.00000 R1=1654120. T1=7242134.
R2=1645357. Z2=0.00000 T2=7248966.
Z3=0.00000 T3=7243511. R3=1642780.
Avg. Concentration: 4.277 %

CARBON DIOXIDE
Date: 11Jun2011 Response Unit:AREA
Z1=0.00000 R1=429828.0 T1=412982.0
R2=430386.0 Z2=0.00000 T2=411942.0
Z3=0.00000 T3=411738.0 R3=430391.0
Avg. Concentration: 17.11 %

OXYGEN
Date: 02Jun2011 Response Unit:VOLTS
Z1=0.00000 R1=10.14000 T1=17.08000
R2=10.10000 Z2=0.00000 T2=17.07000
Z3=0.00000 T3=17.04000 R3=10.08000
Avg. Concentration: 16.99 %

Second Triad Analysis

Date: 07Jun2011 Response Unit: AREA
Z1=0.00000 R1=1663220. T1=7328961.
R2=1668983. Z2=0.00000 T2=7335004.
Z3=0.00000 T3=7325979. R3=1661074.
Avg. Concentration: 4.283 %

Calibration Curve

Concentration=A+Bx+Cx2+Dx3+Ex4
r=0.999999
Constants: A=0.00193103
B=5.8855E-07 C=
D= E=

Concentration=A+Bx+Cx2+Dx3+Ex4
r=1.000000
Constants: A=-0.00272576
B=4.07397E-05 C=
D= E=

Concentration=A+Bx+Cx2+Dx3+Ex4
r=0.999998
Constants: A=0.00691632
B=0.998636028 C=
D= E=

APPROVED BY: JOHN ROZOF

AIR LIQUIDE Air Liquide America Specialty Gases LLC

Scott™

RATA CLASS

Dual-Analyzed Calibration Standard

500 WEAVER PARK RD, LONGMONT, CO 80501 Phone: 888-253-1635 Fax: 303-772-7673

CERTIFICATE OF ACCURACY: EPA Protocol Gas

Assay Laboratory - PGVP Vendor ID: A42011

AIR LIQUIDE AMERICA SPECIALTY GASES LLC
500 WEAVER PARK RD
LONGMONT, CO 80501

P.O. No.: OTL-11-036
Document # : 41897724-001

Customer
OMNI-TEST LABS

CINDI WARREN
13327 NE AIRPORT WAY
PORTLAND OR 97230
US

ANALYTICAL INFORMATION

This certification was performed according to EPA Traceability Protocol For Assay & Certification of Gaseous Calibration Standards; Procedure G-1; September, 1997.

Cylinder Number: ALM066210 **Certification Date:** 07Jun2011 **Exp. Date:** 06Jun2014
Cylinder Pressure*:** 2000 PSIG

COMPONENT	CERTIFIED CONCENTRATION (Moles)		ACCURACY**	TRACEABILITY
CARBON MONOXIDE	2.50	%	+/- 1%	Direct NIST and VSL
CARBON DIOXIDE	5.06	%	+/- 1%	Direct NIST and VSL
OXYGEN	5.03	%	+/- 1%	Direct NIST and VSL
NITROGEN		BALANCE		

*** Do not use when cylinder pressure is below 150 psig.
** Analytical accuracy is based on the requirements of EPA Protocol Procedure G1, September 1997.

REFERENCE STANDARD

TYPE/SRM NO.	EXPIRATION DATE	CYLINDER NUMBER	CONCENTRATION	COMPONENT
NTRM 2639	02Dec2011	KAL004146	0.974 %	CARBON MONOXIDE
NTRM 1800	01Mar2013	K022438	17.87 %	CARBON DIOXIDE
NTRM 2658	01Feb2016	K012175	10.03 %	OXYGEN

INSTRUMENTATION

INSTRUMENT/MODEL/SERIAL#	DATE LAST CALIBRATED	ANALYTICAL PRINCIPLE
HP/6890/US00034440	23May2011	TCD/FID
HPGC/5890/3115A34624	01Jun2011	TCD
OXYMAT/6E/W6-951	13May2011	PARAMAGNETIC

ANALYZER READINGS

(Z = Zero Gas R = Reference Gas T = Test Gas r = Correlation Coefficient)

CARBON MONOXIDE

First Triad Analysis
Date: 31May2011 Response Unit:AREA
Z1 = 0.00000 R1 = 1654120. T1 = 4244090.
R2 = 1645357. Z2 = 0.00000 T2 = 4226329.
Z3 = 0.00000 T3 = 4224092. R3 = 1642780.
Avg. Concentration: 2.499 %

Second Triad Analysis
Date: 07Jun2011 Response Unit: AREA
Z1 = 0.00000 R1 = 1663220. T1 = 4273573.
R2 = 1668983. Z2 = 0.00000 T2 = 4268895.
Z3 = 0.00000 T3 = 4269862. R3 = 1661074.
Avg. Concentration: 2.496 %

Calibration Curve
Concentration = A + Bx + Cx2 + Dx3 + Ex4
r = 0.999999
Constants: A = 0.00193103
B = 5.8855E-07 C =
D = E =

CARBON DIDXIDE

Date: 01Jun2011 Response Unit:AREA
Z1 = 0.00000 R1 = 429828.0 T1 = 123841.0
R2 = 430386.0 Z2 = 0.00000 T2 = 122887.0
Z3 = 0.00000 T3 = 123868.0 R3 = 430391.0
Avg. Concentration: 5.060 %

Calibration Curve
Concentration = A + Bx + Cx2 + Dx3 + Ex4
r = 1.000000
Constants: A = -0.00272576
B = 4.07397E-05 C =
D = E =

OXYGEN

Date: 02Jun2011 Response Unit:VOLTS
Z1 = 0.00000 R1 = 10.14000 T1 = 5.04800
R2 = 10.10000 Z2 = 0.00000 T2 = 5.05300
Z3 = 0.00000 T3 = 5.04300 R3 = 10.08000
Avg. Concentration: 5.030 %

Calibration Curve
Concentration = A + Bx + Cx2 + Dx3 + Ex4
r = 0.999998
Constants: A = 0.00691632
B = 0.998836028 C =
D = E =

APPROVED BY:
JOHN ROZOF

Measurement of Space-Heating Emissions

Appendix H

Sierra Research Critique & OMNI Response

By request of the Fairbanks North Star Borough, this report was subject to a third-party review by Sierra Research. A memorandum summarizing this review is included in this appendix. The critique includes an analysis of the testing data, an enumeration of minor errors and errata found in the report draft reviewed, and general criticisms about the testing and reporting process. The minor issues and errata have all been addressed in the final version of the report, but the broader criticisms warranted further response. This response, in the form of a letter to Dr. James Connor of FNSB, is also included in this appendix.

January 24, 2012

sierra research

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Memo to: Dr. James Conner, FNSB

From: Sierra Research

Subject: Critical Review of Draft Report "Measurement of Space-Heating Emissions," dated December 23, 2011, by OMNI-Test Laboratories, Inc.

Between March 8 and August 18, 2011, Omni-Test Laboratories, Inc., under contract to FNSB, conducted a series of 35 tests on nine space heating appliances, using six typical Fairbanks fuels. The main purposes of this study were to measure emissions and to provide detailed source profiles for chemical mass balance modeling. This memorandum summarizes the results of a review by Sierra Research of OMNI's draft report and data. Consistent with Borough priorities and SIP planning needs, our review has focused on $PM_{2.5}$ emission factors and the data collected by OMNI to develop those emission factors and corresponding source profiles.

Summary of Sierra's Findings and Recommendations

Testing, Analysis and Reporting Shortcomings

In several areas, OMNI's testing, analysis and/or reporting were, in our opinion, inadequate to meet Borough needs. These areas are outlined below and discussed in detail in the later sections entitled "Issues with OMNI Testing/Analysis/Reporting" and "Other Issues/Errata."

1. OMNI tested one emission control device installed on two different heating appliances. However, because of a failure to test the retrofit control device with the feedback air control attached, this supplemental control device testing did not meet the Borough's need for testing that is representative of Alaskan (or other "real world") conditions. Those test results, from run nos. 27 and 34, are of no use to the Borough.

2. OMNI's approach to measuring cold start effects using one integrated filter sample to capture ignition+kindling+coldstart preburn+hotstart testburn was flawed, in our opinion, because it did not provide the measurement of cold start emissions (only) required by the Borough. OMNI's initial analysis of its "cold start" test data was also flawed, in our opinion, for the same reason. Because of these problems, the results from OMNI's (5) cold start tests are of limited use.

3. OMNI found in its testing that the non-qualified (i.e., non-phase 2 certified) OWHH produced "an extreme amount of PM and heat in the flue…far beyond the capabilities of the sampling equipment." OMNI's steps to address the resulting problems were extensive. But OMNI did not, in our opinion, demonstrate that those measures were fully successful. Furthermore, in certain cases the test results were counterintuitive, raising further questions about their validity. For these reasons, Sierra does not believe that the results from nonqualified OWHH testing (run nos. 25-27 and 30-33) should be relied upon for regulatory purposes without further validation.

4. OMNI's analysis and review of its data and its reporting were insufficient to meet the Borough's needs. OMNI was selected by the Borough to perform this contract in part due to its anticipated understanding, experience, and qualifications in testing and interpreting test results for wood-burning and other space heating appliances. However, OMNI's analysis, interpretation, and reporting of test results, did not, in several areas, produce and properly identify much of what was critically needed by the Borough from the testing results. In particular, although OMNI's testing involved a specified matrix of fuels, appliance types, and other factors, and OMNI collected potentially valuable data, OMNI did little more than report the data—missing were the analysis and the insights.

Sierra has attempted to develop this information from an analysis of data in the report along with additional information provided by OMNI. Our summary of these insights is presented in the subsection below. Details are presented in the "Key Findings" section later in this memo, and reflected in the figures and tables appended to this memo.

Insights Gained from OMNI's Test Results

Notwithstanding the shortcomings described earlier, OMNI's testing of space heating appliances produced a dataset from which we were able to make several findings that should be useful to the Borough for its SIP planning and emission reduction strategy development. These include those outlined below.

1. EPA-certified wood stoves have a significantly lower PM emission factor (lbs of PM per ton of wood burned, dry basis) than non-certified stoves (see Figure 1, attached). This is important for two reasons. First, it confirms that the Borough's current strategy of providing incentives to remove non-certified wood stoves is an effective approach, even if such stoves are replaced by EPA-certified woodstoves (which were found to emit 70% less PM). Second, the developed emission factors allowed the quantification of the emission benefits per unit of fuel burned as well as per unit of useful heat output; this quantification provides support for the Borough's PM emissions inventory and for the evaluation of potential future emission reduction strategies that involve space heating.

2. EPA qualified (phase 2) OWHHs have a significantly lower emission factor than nonqualified OWHHs (see Figure 2). Although OMNI's testing of the

nonqualified OWHHs requires further validation in our opinion, a qualitative finding of much lower emissions is, we believe, supportable.

3. Emission factors for cordwood burned at" low" firing rate (about 35% of full load) are higher or much higher than at "high" (appliance maximum) firing rate, a result that has been reported by OMNI and others from previous measurement studies with other fuels. Emission factors were also found to be higher for birch than for spruce, which is contrary to the expectation of lower emissions for hardwoods compared to softwoods. These findings, which are detailed later and reflected in the 16 test runs shown in Figures 1 and 2, inform decisions about how and what to burn to minimize PM emissions and will assist both in the refinement of the Borough's emissions inventory and in providing guidance and technical support for the SIP.

4. Emission factors for coal in various forms (wet/dry, lump/stoker, low/high firing rate) resulted in a range of emission factors with no obvious systematic variation (results for six test runs, shown in Figure 3). While less satisfying than the simple, more systematic patterns observed for cordwood, these findings help to quantify the magnitude and variability of PM emissions from residential coal combustion. This is valuable because residential coal combustion is not explicitly represented in EPA's AP-42 emission factor compilation. The measurements shown also help to illustrate the substantial emission reduction possible when using augerfed coal compared to a conventional coal stove or coal-fired hydronic heater. (This and other comparisons of emission factors across fuel and appliance types are shown in Figures 4 and 5.)

5. The current OMNI study is the first systematic attempt to identify emission factors from Alaska-specific fuels and popular Alaska heating appliances, and results showed that emission factors with Alaska-specific fuels and appliances tend to be lower than EPA's AP-42 emission factors (see Attachment A). Better understanding and documenting the differences between the two will help guide the development of an effective and technically defensible SIP.

6. Firing with more homogeneously burned fuels—like oil, augerfed coal, and wood chips—tends to produce lower or dramatically lower PM emissions than cordwood. This observation, which was made by OMNI, lends credibility to the measurements because it is very reasonable to expect that more uniform fuel air mixtures will result in reduced emissions of unburned or partially burned fuel, which contribute to PM; more importantly, however, it is indicative of the large potential benefit of fuel switching. For example, on the basis of grams of PM emitter per megajoule of useful heat provided, OMNI's emission factors indicate that one conventional wood stove emits about 175 times as much PM as an oil burning appliance that produces the same amount of useful heat.

7. OMNI's speciated PM source profiles represent the first systematic sampling of the elemental composition of Alaska-specific fuels and space heating devices and, pending further review and comparisons with existing EPA profiles, they are expected to be used for CMB analysis as part of the SIP. However, at least one

profile (Run No. 1, the pellet stove test, which is discussed later) showed problems and should not, in our opinion, be relied upon without further analysis.

8. Waste lubricating oil, burned in a special purpose burner, was tested and found to have relatively low PM emissions compared to the non-homogenous fuels. However, the emissions profile for waste oil shows high concentrations of chlorine, phosphorous, potassium, and zinc, as well as a higher sulfur level than the conventional fuel oils, as shown later.

9. All of the mass profiles provided by OMNI have been compiled by Sierra into percentage mass profiles, and a subset of nine of those has been provided to the University of Montana for review. The subset was selected by Sierra to represent each major appliance type and fuels, as described in Table 1, below. In lieu of replicate tests (which are not available), the last two profiles were selected to provide backup for wood and coal burning in case problems were identified with the corresponding primary profiles above. All of these profiles are currently undergoing review.

Table 1
OMNI Profiles Selected to Represent Specified Source Categories

Run No.	Representation (and rationale)
5	EPA-certified Woodstove (low firing rate is most common, birch is highest emitting)
9	EPA-qualified OWHH (low firing rate, birch)
15	Conventional woodstove (low firing rate, birch)
17	Oil burner (no.2 fuel oil is most common)
18	Waste oil burner (only test of this source)
23	Coal stove (wet stoker coal and low firing rate are believed most common)
29	Coal OHH (wet stoker coal most common, augerfed showed low PM EF)
6	Backup profile for wood burning (EPA woodstove, spruce, low firing rate)
38	Backup profile for coal burning (coal stove, dry lump coal, low firing rate)

10. Emissions measurements for NH_3 collected by OMNI have no direct counterpart in EPA's AP-42 compilation of emission factors. However, Sierra has extracted the emission factor measurements from the OMNI testing and compared them (Table 2, below) with the most closely corresponding estimates contained in the preliminary emissions inventory for the SIP, which are based on estimates by Pechan[1] using molar ratios to CO. As the table shows, OMNI's emission factors, expressed as lbs of NH_3 per ton of fuel burned, tend to be less than the values estimated by Pechan but are generally within a factor of 4-5.

[1] Roe, Stephen*, et al*, "Estimating Ammonia Emissions from Anthropogenic Nonagricultural Sources - Draft Final Report)", prepared for Emission Inventory Improvement Program, by E.H. Pechan and Associates, Inc., April 2004.

Table 2
NH_3 Emission Factors by OMNI (draft report) Compared to Estimates by Pechan based on molar ratio to CO
(All emissions in lb/ton)

Pechan category and EF		OMNI description and EFs*	
Residential Wood, non-catalytic woodstoves, conventional	1.70	1 conventional, noncatalytic woodstove, avg (and range) of 4 tests: high and low firing rate, spruce and birch cordwood	0.386 (0.039 – 0.747)
Residential Wood, non-catalytic woodstoves, low-emitting	0.90	1 advanced (EPA-certified) noncatalytic woodstove, avg (and range) of 4 tests: high and low firing rate, spruce and birch cordwood	0.156 (0.053 – 0.322)
Residential wood, non-catalytic woodstoves, pellet fired	0.30	1 pellet stove, Alaskan wood pellets, low firing rate (~35%)	0.072
Residential wood, boilers and furnaces	1.8	1 non-qualified and 1 qualified OWHH, avg (and range) of 8 tests: 2 units, high and low firing rate, spruce and birch cordwood	0.202 (0.058 – 0.425)

* OMNI's measurements are based on M28 (hot start) tests and are expressed on the basis of dry tons burned; Pechan does not specify whether their measurements are on a dry basis.

The remainder of this memorandum provides additional background on the OMNI testing program and Sierra's review, including the limitations of our review; more detail about testing and reporting issues and about insights from the testing; and other issues/errata.

Background

Between March 8 and August 18, 2011, Omni-Test Laboratories, Inc., under contract to FNSB, conducted a series of 35 tests on nine space heating appliances, using six typical Fairbanks fuels. The testing matrix was specified by the Borough to meet its highest priority needs for preparation of the State Implementation Plan for $PM_{2.5}$. (A brief description and listing of results from each test is included in Attachment B.)

As specified by the Borough, filters were analyzed by RTI and liquid fuels were analyzed by SWRI. Solid fuels were analyzed by Twin Ports Testing. As of this writing, all of the planned testing has been completed, and essentially all test results have been received by Sierra[2] for review.

Previously, at the Borough's request, OMNI provided (partially complete) draft reports to the Borough dated September 1, 2011, and October 14, 2011, which described those

[2] As of this writing, we are still awaiting final minor formatting changes to the profiles for test runs that were reanalyzed by RTI and clarification of several items by OMNI and RTI.

portions of the test results from RTI and others that were available at the time. In November and December, OMNI provided the remainder of the test results and other requested information to Sierra, including a draft report dated December 23, 2011.

Limitations of This Review

Although Sierra received excellent cooperation from OMNI staff, our review has been limited by several factors, including the following: Sierra did not witness any of the testing; replicate testing was not conducted (or practical) for this limited test program; and, while OMNI performed many procedures and checks that are commonly a part of quality assurance, there was no quality assurance plan per se for the test program.

Issues with OMNI Testing/Analysis/Reporting

1. OMNI's supplemental testing of the retrofit control device did not meet the Borough's need for testing that is representative of Alaskan (or any other "real world") conditions.

A major focus of the Borough's contract with OMNI was to produce emissions measurements that represent typical Alaskan fuels, space heating appliances, and normal operations (consistent with standard measurement techniques, as specified). As part of this effort, OMNI received supplemental funding from the Borough in an amount of more than $25,000 to conduct two tests using a specified retrofit control device. Two supplemental tests were reported as reflected by the data and our conversations with OMNI, but there is essentially no description in the narrative portion of the report of either how tests were set up and conducted or what the results mean. Notably, the report does not state whether the feedback air control system for the retrofit control device was installed and operating during the tests.

It is Sierra's understanding, based on telephone conversations with both OMNI and the control device manufacturer,[3] that the control device manufacturer and/or its representative performed the control device installations and was present during both tests of the device, but that the feedback control system for the subject retrofit device was not connected or operating during the tests. If our understanding is correct that the air control system is, in fact, an integral part of the retrofit control device,[4] the associated test results would not be expected to represent any normal operating condition, nor would they be consistent with the pertinent objective of the project and OMNI's stated intent of measuring "real world" emissions. For these reasons, the results should not be used for emission inventory development, control technology assessment, or other regulatory purposes.

[3] Personal communications with OMNI and the control manufacturer, November and December 2011.
[4] The control device manufacturer has told Sierra that the furnace air control system is a part of the retrofit control system, and that they were instructed, either by the Borough directly or through OMNI, not to connect it. In contradiction, OMNI has told Sierra that the control device manufacturer was afforded all the time they required to install the control device completely and was present to witness the emissions testing that involved the control device.

2. OMNI's approach for measuring the effect of cold start on emissions represented a compromise between adherence to standard test methods, including Method 28 (which has no provision for cold-start testing) as specified by the Borough, and using a multi-test approach that, unavoidably, is subject to greater uncertainty. However, we believe the measurement as used and analyzed by OMNI to determine cold-start effect was flawed.

Briefly, OMNI used one integrated filter to capture emissions from four test phases: the cold start ignition, a kindling phase (which used a small charge of birch kindling), a high firing rate preburn charge (to prepare the hot coal bed for a Method 28 test), and a low firing rate test fuel charge. OMNI then used a modeling approach (initially suggested by Sierra after the testing was completed) of subtracting the emitted PM mass from the individual phases of the test to estimate the cold start effect. We view this approach as less than ideal because it requires taking differences from several tests, each of which unavoidably introduces additional (g/hr) uncertainties.

Subsequent to our most recent discussions with OMNI on this, we have a slightly revised, and we believe superior, approach to offer, whereby emissions for the ignition+kindling phase (together) are estimated by difference of the composite and two controlled (preburn and test) phases. However, neither this approach nor the one used by OMNI is able to fully compensate for the problematic integrated sampling approach used, which confounds the cold-start, high firing rate phase with the low firing rate main test phase.

Figure 6 provides an illustration of how we interpret the "cold start" tests. The two bars shown in the figure represent grams of PM emissions for the actual composite test (on the right), which had emissions of 38.73 grams, and an attempted reconstruction of that mass on the left, using emission factors from other low and high firing rate tests of the same unit and same fuel type, but using the fuel masses from the composite test. The difference of the reconstructed mass and the measured mass, which is shown lightly colored in the figure, is the mass attributed to the cold start—in this case, 4.67 grams out of the total of 38.73 grams, or 12.1% of the mass.

One may then ask, how do the mass emissions compare for a birch cordwood, low firing rate stove that is cold-started vs. one that is hot-started? The answer, from the figure, is that the hot start stove emits just 30.40 grams (time after time), whereas the cold started stove (after subtracting the preburn high firing rate charge, from the left hand bar), emits 35.07 (4.47+30.40) grams from start/kindling plus low firing rate test charge.

Similarly computed percentages are shown in Figure 7 for three other cold start tests, all of those 3 representing coal firing. The first two of those show relatively larger start effects, which may be real and caused by the relatively higher emission factor of the birch kindling compared to the coal pre-charge and test charge. In the case of augerfed coal (far right bar), the starting emissions are shown as negative, which is not true, but is a reflection of the uncertainty of the estimate showing them to be indistinguishable from zero. However, while not apparent from the figure, that also appears to be the case with the EPA certified wood stove (first bar), where the magnitude of the start effect is such that it likely is within the uncertainty of the measurement, and therefore indistinguishable from zero. This measurement is also far less than the several-fold difference suggested in

OMNI's 2009 report for Environment Canada.[5] OMNI's explanation of this to Sierra is that the Ontario report actually combines low firing rate and cold start and contrasts that result with high firing rate and hot start; thus, it too confounds the cold start effect. Sierra recommends that OMNI make a slight revision to its approach (as outlined above), include a more complete and detailed explanation in its report of how it analyzed the results, and provide a comparison of the current results with the results of Ontario (which appear to be the closest available comparison), explaining why the results are different.

One last interesting observation from Figure 6 is that it also permits an estimate of the effect of cold start upon mass emissions for a unit that burns birch cordwood at high (rather than low) firing rate. Here, we simply ignore (i.e., subtract out) the large contribution from the low firing rate main test charge and treat the preburn high firing rate phase as the main test charge. For this case, the mass emissions for a hot start are 3.66 grams and those for a cold start are 8.33 (4.67+3.66)—this represents a 128% increase, but results in relatively low emissions in either case because the relatively high emission factor associated with the low firing rate is eliminated.

3. Flow rates and filter loadings for the non-qualified OWHH testing (Run nos. 25-27 and 30-33, as listed in Attachment B) exceeded OMNI's testing system capabilities, requiring adaptations and non-standard test methods.

According to OMNI's assessment (p. 13):

> *The non-qualified OWHH used for testing required substantially modified procedures in order to generate meaningful results. This unit produced an extreme amount of particulate matter and heat in the flue. Combined with a low dilution factor, this resulted in excessively high particulate concentrations and temperatures in the dilution tunnel – far beyond the capabilities of the sampling systems described in Section 2.3*.

OMNI was required to take extraordinary steps (some, but not all of which are detailed in the report[6]) to address condensation problems, filter plugging, and filter overloading, yet, in the end, concluded that all of the provided test results, including those for the non-qualified OWHH, are valid.[7] We are less confident in this conclusion for the non-qualified OWHH results, in part because RTI found that filter overloading clearly did invalidate at least some of the XRF analyses (which had to be redone, as discussed in footnote 6), and also because of the somewhat surprising results for firing at low vs. high firing rate (discussed under the Cold Start issue, below), which tend to contradict the general pattern observed by OMNI and others in wood appliance testing.[8,9,10]

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[5] Pitzman, Lyrik, et al, "Verification of Emission Factors USEPA Certified Wood Heaters (Volume 1)", prepared for Environment Canada, by OMNI, September 8, 2009.

[6] OMNI should identify in the report which runs had filters that were overloaded to the point that RTI concluded that XRF analysis required calibration for individual elements. OMNI should also document in the report that spare duplicate filters were used for the reanalysis and which elements were reanalyzed. If not already done, the emission profile results for any elements that were not reanalyzed in this way for overloaded filters should be removed from the report.

[7] Personal communication with OMNI, December 2011.

[8] For example, in a 2005 study prepared for the Hearth and Patio Association ("PM2.5 Emission Reduction Benefits of Replacing Conventional Uncertified Cordwood Stoves with Certified Cordwood Stoves or

Accordingly, we recommend that test results for the non-qualified OWHH not be relied upon for regulatory purposes.

4. The amount of potassium in the PM emissions from the pellet burner was extraordinary—about 1/3 of the PM mass—and investigation into this by RTI revealed other significant problems with the pellet stove profile, namely "clearly low" mass reconstruction and "very poor" ion balance, according to RTI.[11]

These and other aspects of the Run 1 (pellet burner) test profile should be documented in a stand-alone section of the appendix that includes RTI's assessment. For the main report volume, it should suffice to say that quality control checks on the results for the pellet burner indicate that the profile cannot be relied upon for regulatory analysis, although the relatively high potassium measurement may be sound and is not without precedent, according to RTI.

Additional Detail on Insights Gained from OMNI's Test Results

1. Four tests were conducted with a conventional wood stove and four with an EPA-certified wood stove. Both were reported by OMNI to be popular and representative models in interior Alaska. Each model was tested with two permutations of firing rate (high and low) and with two fuels (birch and spruce), allowing for evaluation not only of the conventional vs. certified factor, but also the birch vs. spruce factor and low vs. high firing rate. A brief description of each test, and the corresponding emissions data are shown in Table 3.

Table 3
Summary of OMNI Test Results for Woodstoves

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lb/ton)
2	EPA Certified Woodstove	Birch	High	0.041	0.977
3	EPA Certified Woodstove	Spruce	High	0.021	0.549
5	EPA Certified Woodstove	Birch	Low	0.331	8.16
6	EPA Certified Woodstove	Spruce	Low	0.079	1.90
12	Conventional Woodstove	Spruce	High	0.051	0.89
13	Conventional Woodstove	Birch	High	1.246	21.79
14	Conventional Woodstove	Spruce	Low	0.197	4.22
15	Conventional Woodstove	Birch	Low	0.581	12.13

Modern Pellet Stoves"), Houck et al of OMNI, appeared to suggest an average increase in PM emission factors (g/kg) of 344% when comparing a high and low burn rate for ten studies.

[9] Differences of <5 g/hr in emission rates might be interpreted as test to test variation, but the high to low firing rate PM emission difference observed for the nonqualified OWHH with birch was 75 g/hr.

[10] Sierra believes that variation in emission factors with load may be one of the key factors contributing to the uncertainty in the emission inventory for woodburning in Fairbanks.

[11] Personal communication with Dr. James Flanagan, RTI, December 2011.

For the woodstoves, Figure 1 shows an average emission factor from the four conventional stoves of 9.76 lbs/ton (dry basis) and an average of 2.90 lbs/ton for EPA-certified stoves, which is a 70% reduction. From the eight tests, all four of the pairwise comparisons (e.g. birch low-firing rate conventional vs. birch low-firing rate EPA certified) show a significant reduction. Similarly, with regard to birch vs. spruce, all four of the pairwise comparisons (e.g. birch low conventional vs. spruce low conventional) show a significant reduction. And finally, for low vs. high firing rate, three of the four pairwise comparisons (e.g. spruce low conventional vs. spruce high conventional) show a significant reduction. The exception is birch low conventional vs. birch high conventional, which shows an inversion of the usual pattern of higher emissions at low firing rate. We see no definitive explanation for this difference, although OMNI noted that the conventional stove had significant air leakage (which OMNI considered typical for an older, conventional stove) and, as a result, it was difficult to maintain tight air control for the "low" firing rate. Thus, if air could be more effectively controlled, the "true" emission factor for birch low conventional (and spruce low conventional) may be higher than was measured.

2. Similar to the woodstoves, four tests were run for each of two popular and believed representative outdoor wood hydronic heaters, a non-EPA-qualified unit and a qualified (Phase 2) unit, with the resulting lb/ton emission factors shown in Table 4 and Figure 2. Although we note a caution about the four nonqualified OWHH tests shown, we see an overall reduction of 84% from the 14.3 lb/ton 4-test average of the nonqualified unit to the 2.32 lb/ton average of the EPA qualified OWHH. Also, the patterns of wood type and firing rate are essentially identical to those observed for the woodstoves, including the inversion of the emission factors for high and low firing rates with birch of the nonqualified OWHH. The reasons in this case are also unknown.

Table 4
Summary of OMNI Test Results for OWHHs

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lbs/ton)
8	EPA Qualified OWHH	Birch	High	0.057	1.61
9	EPA Qualified OWHH	Birch	Low	0.212	5.32
10	EPA Qualified OWHH	Spruce	High	0.027	0.769
11	EPA Qualified OWHH	Spruce	Low	0.065	1.576
25	Non Qualified OWHH	Spruce	High	0.789	10.89
30	Non Qualified OWHH	Spruce	Low	2.315	25.70
31	Non Qualified OWHH	Birch	High	0.757	11.85
32	Non Qualified OWHH	Birch	Low	0.757	8.82

3. There was no replicate testing performed that would permit rigorous statistical comparisons of the emission factors reported by OMNI. However, we view the

relative consistency of the results outlined above as a positive measure of their reliability. In addition, Sierra performed a simple multiple regression analysis of the above 16 emission factor test results using a log-linear model. The results, on average, showed the following:

- The lb/ton emission factor (EF) for conventional models was 390% compared to that for advanced (either qualified or certified), i.e., higher by nearly a factor of four;
- The EF for birch was 148% that of spruce;
- The EF for low firing rate vs. high was 134% (and only marginally significant statistically); and
- The EF for woodstove vs. OWHH was not statistically significant.

4. The emission factors for coal burning in a coal stove averaged 8.65 lbs/ton for the six tests shown in Table 5 and Figure 3. They ranged from a low of 2.3 lb/ton for dry stoker coal at low firing rate to 15.1 for wet stoker coal at a low firing rate. However, neither the effects of firing rate, nor pulverized vs. lump coal, nor even wet vs. dry coal were consistent. This may be due to high test variability, a more complex pattern of interactions than can be discerned by six tests, or other factors.

Table 5
Summary of OMNI Test Results for Coal Stoves and Augerfed HH

Run	Appliance	Fuel	Burn Rate	PM Emissions (g/MJ output)	PM Emissions (lbs/ton)
20	Coal Stove	Dry Stoker Coal	High	0.459	13.22
21	Coal Stove	Dry Stoker Coal	Low	0.085	2.32
23	Coal Stove	Stoker Coal	Low	0.589	15.07
29	Augerfed HH	Coal (hot start)	Single	0.030	0.96
35	Coal Stove	Stoker Coal	High	0.252	6.75
37	Coal Stove	Lump Coal	Low	0.142	3.98
38	Coal Stove	Dry Lump Coal	Low	0.377	10.57

This uncertainty in the emission factor for coal stoves is not, however, of much significance for the Borough's emission inventory, as the number of coal stoves is much smaller than the numbers of oil or wood-burning heating appliances. What the uncertainty does show, both for coal stoves and wood stoves, is that there is broad overlap of the two categories, i.e., despite the minor differences in average lb/ton values between woodstoves and coal stoves, there is no real difference between the two with regard to the amount of primary (i.e., direct) PM emissions per mass of fuel burned, and that both coal- and wood-burning produce far more PM than oil-burning.

The one exception to this pattern was the relatively low 0.96 lb/ton PM emission factor for the augerfed coal OHH (also shown in Table 5), which is nearly an order of magnitude below the average for the six coal stove test runs and only a factor of four greater than oil burning. Figure 4 illustrates these and other comparisons between emission factor test means, expressed as lbs/ton for the various fuel/appliance combinations. Figure 5, taken directly from OMNI's draft report, extends the comparison by showing, for each test, the g/MJ of heat output.

5. It would be difficult to overstate the significance of the OMNI study as the first systematic attempt to identify Alaska-specific emission factors representing both Alaska-specific fuel samples and heating appliances that were specifically selected to be popular and representative for interior Alaska. These two simple facts greatly increase the confidence associated with using the OMNI test results for Alaska's PM SIP.

It is also interesting to compare the OMNI test results, where possible, with EPA's compilation of emission factors as represented in EPA publication AP-42.
This comparison is attempted in Attachment A, where it may be seen that for six out of eight comparisons shown, the current OMNI lb/ton test results shown in column 1 are less than the AP-42 results shown in column 3. Exceptions are the coal stove (for which the AP-42 emission factor is really for a boiler, which is not directly comparable), and for the waste oil burner, where results depend (according to AP-42) on the specific ash content of the fuel.

6. There is, as demonstrated in Figure 5, a wide range of PM emissions from the various fuels and space heating appliances that represent Fairbanks. Furthermore, it's clear from the listing of these same emission factors in Attachment B that for the same useful heat output, the most extreme PM emitters can produce as much as 1,000 times higher PM emissions than at the cleaner end, and that even the next cleanest technology produces 3-4 times as much PM as fuel oil. The simple conclusion from this comparison is that a shift from burning wood to burning fuel oil would achieve PM emission reductions as soon as possible.

Other Issues/Errata

p. 3, Table 1. EPA Methods 28 and 28 OWHH are mentioned on subsequent pages but are not shown in Table 1. They should be.

p. 8, Section 2.4. It should be noted somewhere in the report, and this may be a logical place, that all tests with wood burning used cordwood of the specified types, which are popular in interior Alaska, rather than the crib wood of other types (which are specified in the respective test methods). Furthermore, birch kindling was used for the cold starts. Lastly, for reasons of practicality, the testing of each stove/fuel/condition used only one or two firing rates (low and high), as specified by the Borough, rather than four as specified in Method 28.

p. 9, Table 2. Run 27 is identified as a cold start, which is incorrect. It was a hot start (as implied in Table 10, pg 14).

p. 10, Section 2.4.2. The reference to Table 3 should be to Table 4, and in the same sentence, the word "load" should be inserted after "fuel." A sentence should also be added to describe briefly the cold start of Run 41, which is a deviation from Method 28 and is listed in the table.

p. 15, Sections 2.5 and 2.6. Two sections should be added to describe the retrofit control device testing and the cold start testing, respectively. For the retrofit control device, the report should document the conditions of the device setup and testing as described above.

p. 16, Section 3.3. Regarding the number 1 fuel oil and CO concentration below detection limit, it is suggested that the corresponding entries in Tables 12 and 16 be changed from "0" to "ND" (not detected), which matches the other tables and better describes the results, and that a footnote be added at the bottom of each table to describe "ND", "N/A" (not applicable), and ">" (exceeded instrument limit).

pp. 17-20, Tables 12-20. We understand that the data contained in the tables (and shown elsewhere in the report) used the initial (erroneous) lab analysis results for liquid fuels, and that these would be updated with the results from SWRI when available. Please confirm that the updated values have been incorporated throughout the report, including in the revised calculations of emission factors, etc. (and not just in Appendix B).

p. 25, Table 20. There is no reference or mention in the narrative of this important summary table. It should be referred to and briefly described in Section 3.1 (pg 16) in place of the reference to Appendix A. Similarly, the reference to Appendix B in Section 3.2 would be more useful if it referred instead to Tables 12 through 19.

p. 26, Section 4.1. It is stated here that "Emissions from eight appliances…were sampled…," whereas it was stated earlier (p. 1, Section 1), "…nine heating appliances were selected and operated…" There were nine, and p. 26 should be corrected.

p. 27. At Sierra's suggestion, OMNI provided graphs showing PM emissions per unit of useful heat output. Subsequently, EPA identified a problem with the measurements used to compute the efficiency of qualified OWHHs, and the agency removed the corresponding reported values from its website. OMNI should note this fact in its report, and state that it used the measurement and analysis procedures that were specified in Method 28 as of the time of its report.

On the same page, OMNI correctly notes that spruce generally burned cleaner (g/MJ) than birch, which Sierra also observed to be true on a lb/ton basis. This result is contrary to the general observation from prior testing that combustion of softwoods tend to have higher PM emissions than from hardwoods. OMNI should address this apparent contradiction between its test results and those in the literature.

p. 29. The reference to low amounts of particulate matter from waste oil needs to be qualified. In particular, the large fractions of chlorine, phosphorous, potassium and zinc on this filter, which are probably attributable to fuel oil additives, are noteworthy. The

resulting profile from this test (Run 18) appears to be limited to certain elements. (Is this a rerun of a previously overloaded filter? Are there no other filter results which are a rerun of a previous filter and therefore limited in the elements listed?)

p. 31. The emissions bars in Figure 12 should be labeled and, in Sierra's opinion, the results for the non-qualified OWHH should be identified as a subject to confirmatory testing.

pp. 32 and 33. Figures 13 and 14 should instead be labeled as Tables 21 and 22, respectively.

Appendix A. Several tests show blank fields for elemental and organic carbon for the quartz fiber filter sample. It is understood that these are due to filter overloadings that prevented the analyses. That explanation should be included in the report, and indicator, e.g. "NA" (not available) should be used in place of the blank on the pertinent test summary sheets. The same indicator should be used for those elements on the Teflon filter samples that were not reanalyzed by XRF when backup filters were reanalyzed by RTI due to filter overloading.

Appendix C. The real time graphs for several tests show results for several tests that are strongly modulated periodically. This is understood to be due to the automatic OWHH control of combustion air. For several other appliances, it is understood that combustion air was manually adjusted in an attempt to achieve the targeted burn rates. Both explanations should be included in the report.

Appendix E. There is conflicting information about how ignition was performed for the five cold start tests, with one source indicating that a propane torch was used for all, while another statement indicated that a lighter (butane) was used in at least one case. This should be clarified.

Figure 1

(Preliminary) $PM_{2.5}$ Emission Factors from OMNI Testing for Conventional and EPA-Certified Wood Stoves, Using Birch or Spruce and Low or High Firing Rates (lbs/ton of dry fuel)

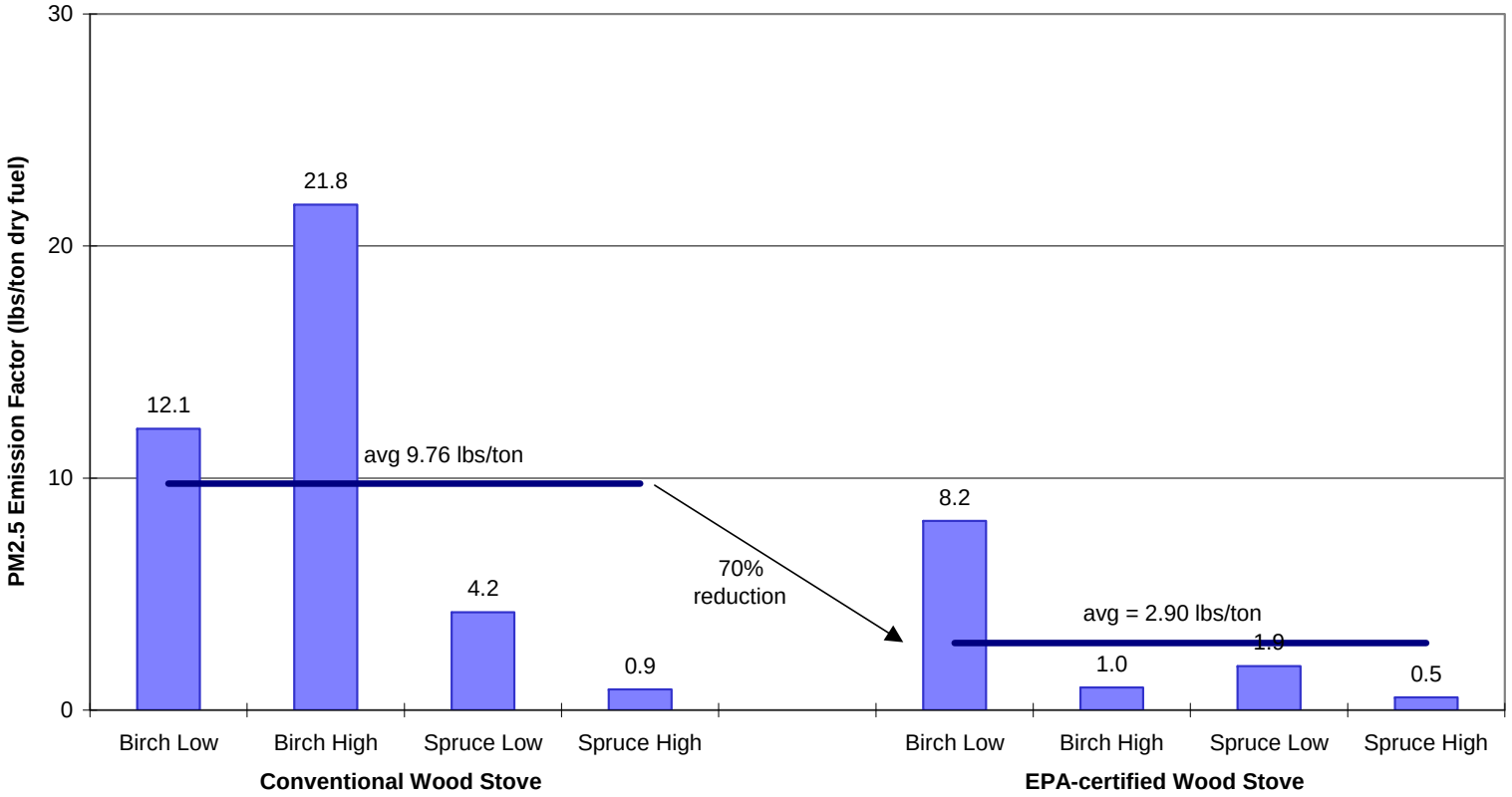


Figure 2

(Preliminary) Outdoor Wood Hydronic Heaters $PM_{2.5}$ Emission Factors from OMNI Testing for "Non-Qualified" and EPA-Qualified OWHHs using Birch or Spruce and Low or High Firing Rates (lbs/ton of dry fuel)

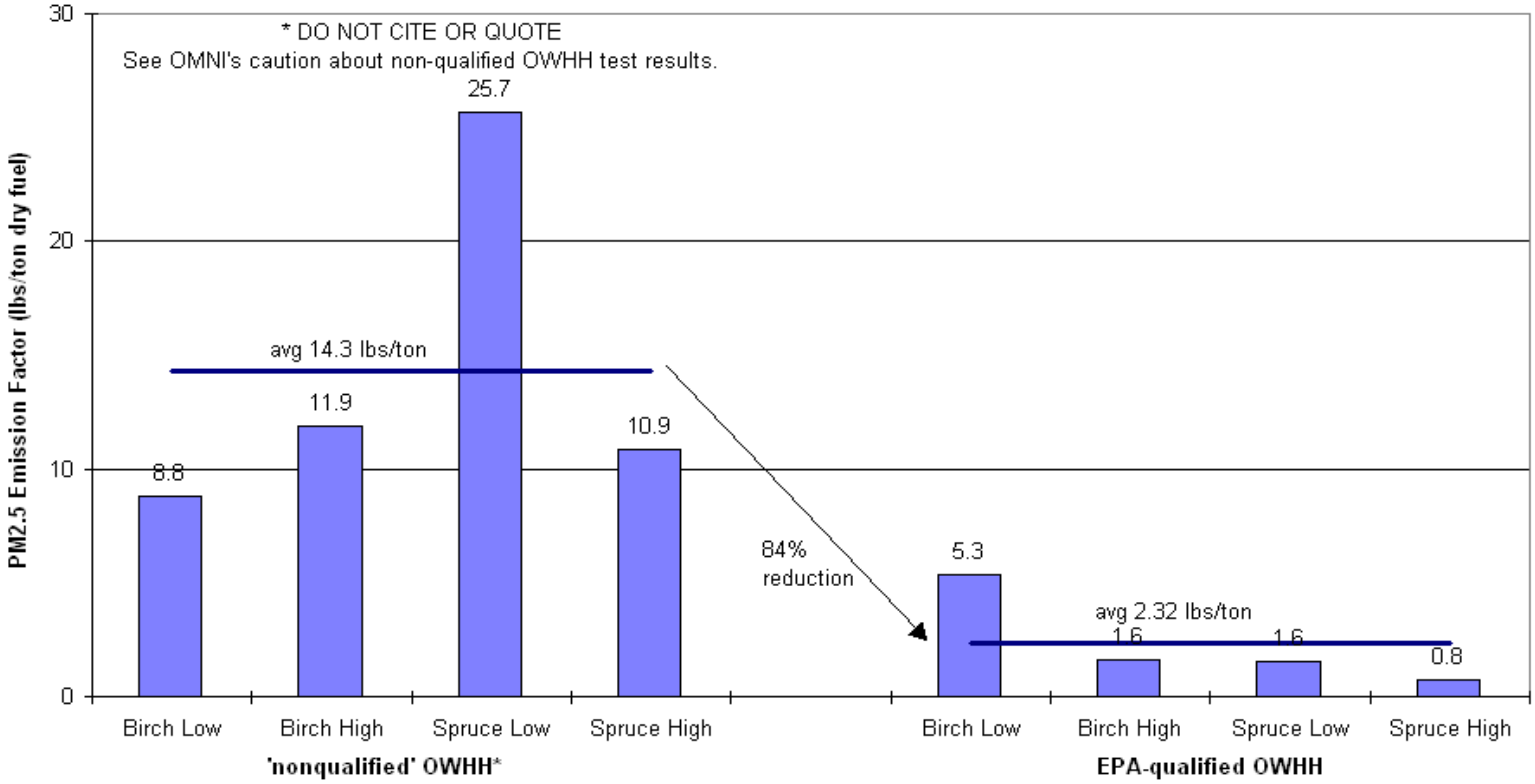


Figure 3

(Preliminary) Coal $PM_{2.5}$ Emission Factors from OMNI Coal Stove Testing for Wet or Dry Stoker and Lump Coal; Low and High Firing Rates; (lbs/ton of dry fuel)

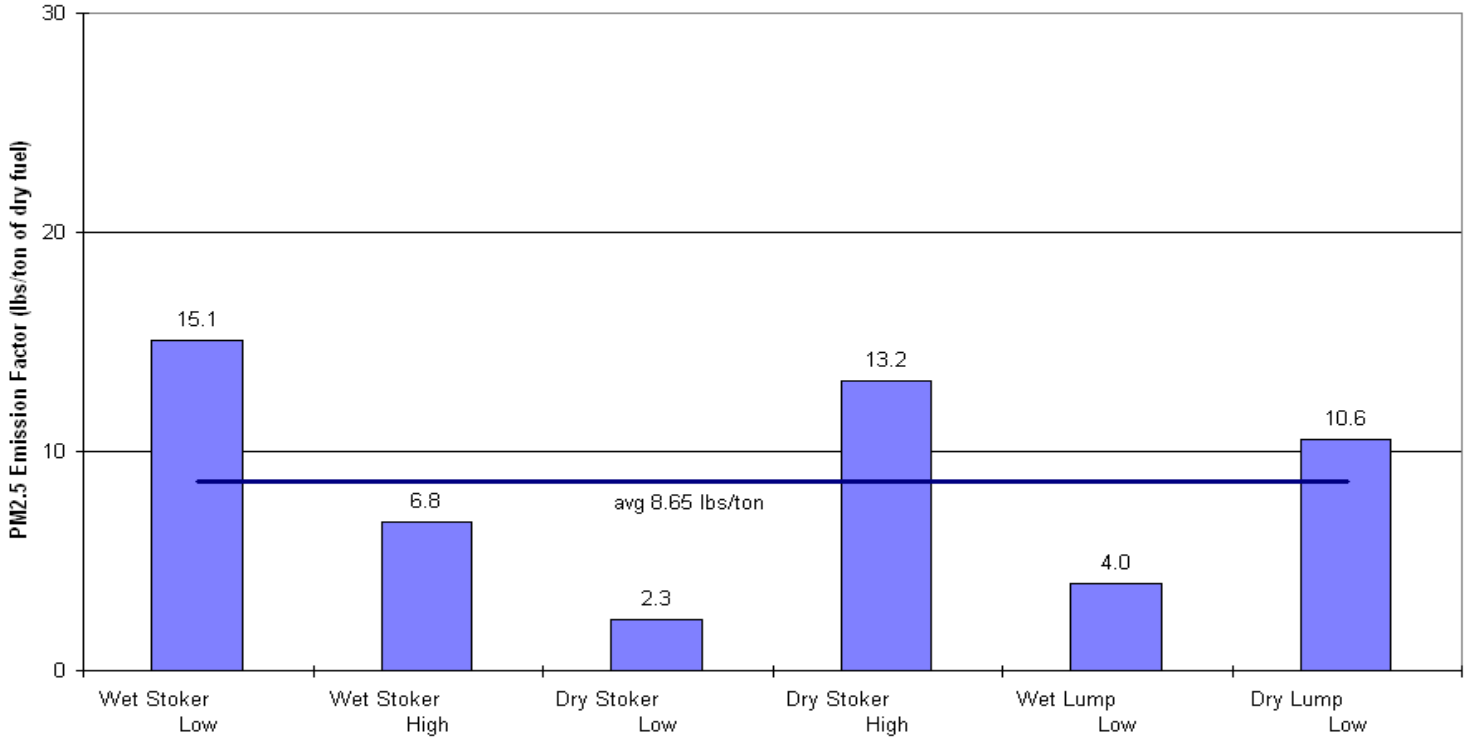


Figure 4

Preliminary Min, Max, and Average $PM_{2.5}$ Emission Factor by Appliance Type from OMNI Testing (lbs $PM_{2.5}$ emitted per ton of fuel burned)

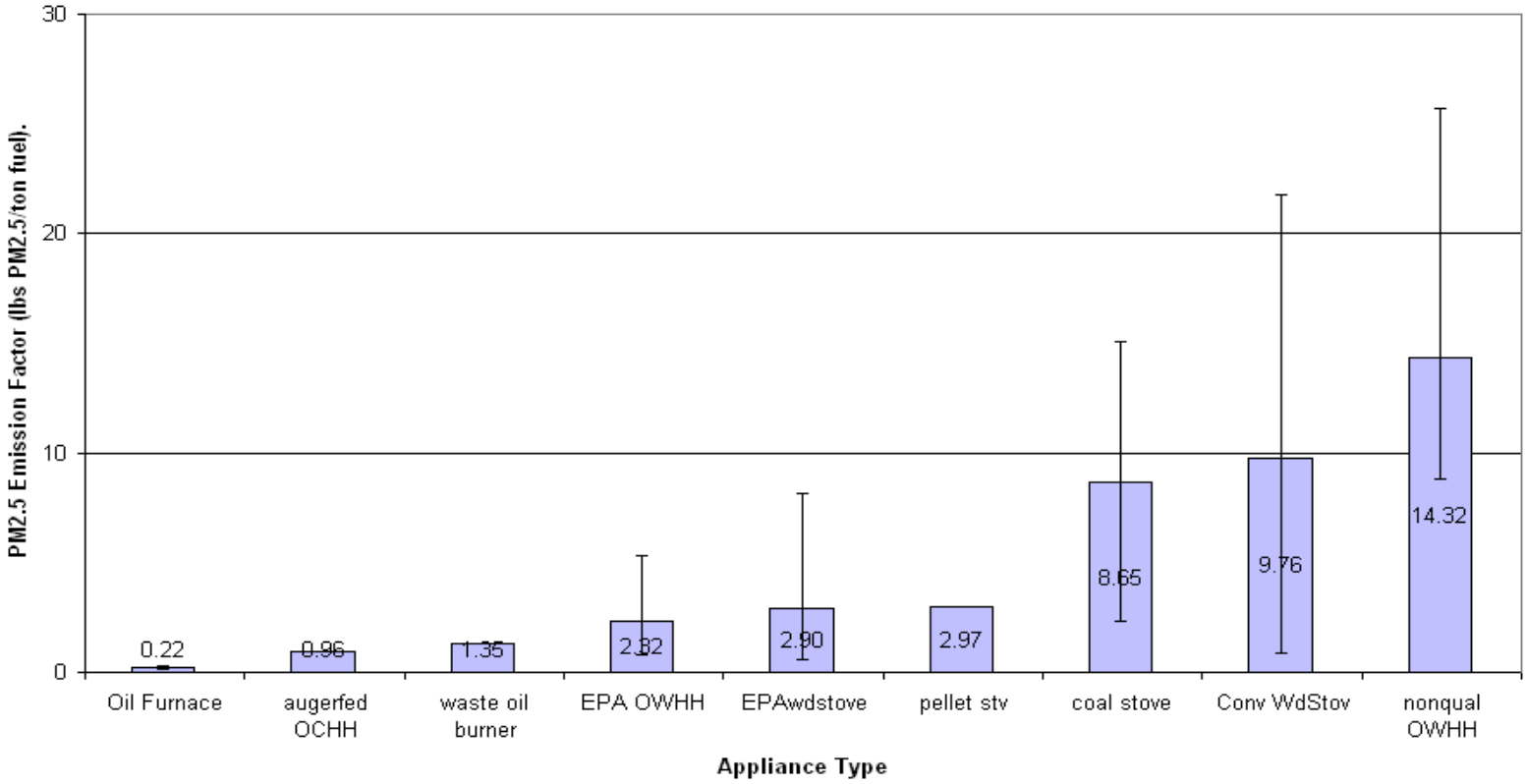


Figure 5

OMNI Preliminary Testing Results as $PM_{2.5}$ Emissions per Unit of Useful Heat Output (grams per megajoule)
(IMPORTANT – raw measurement results, see narrative for caveats)

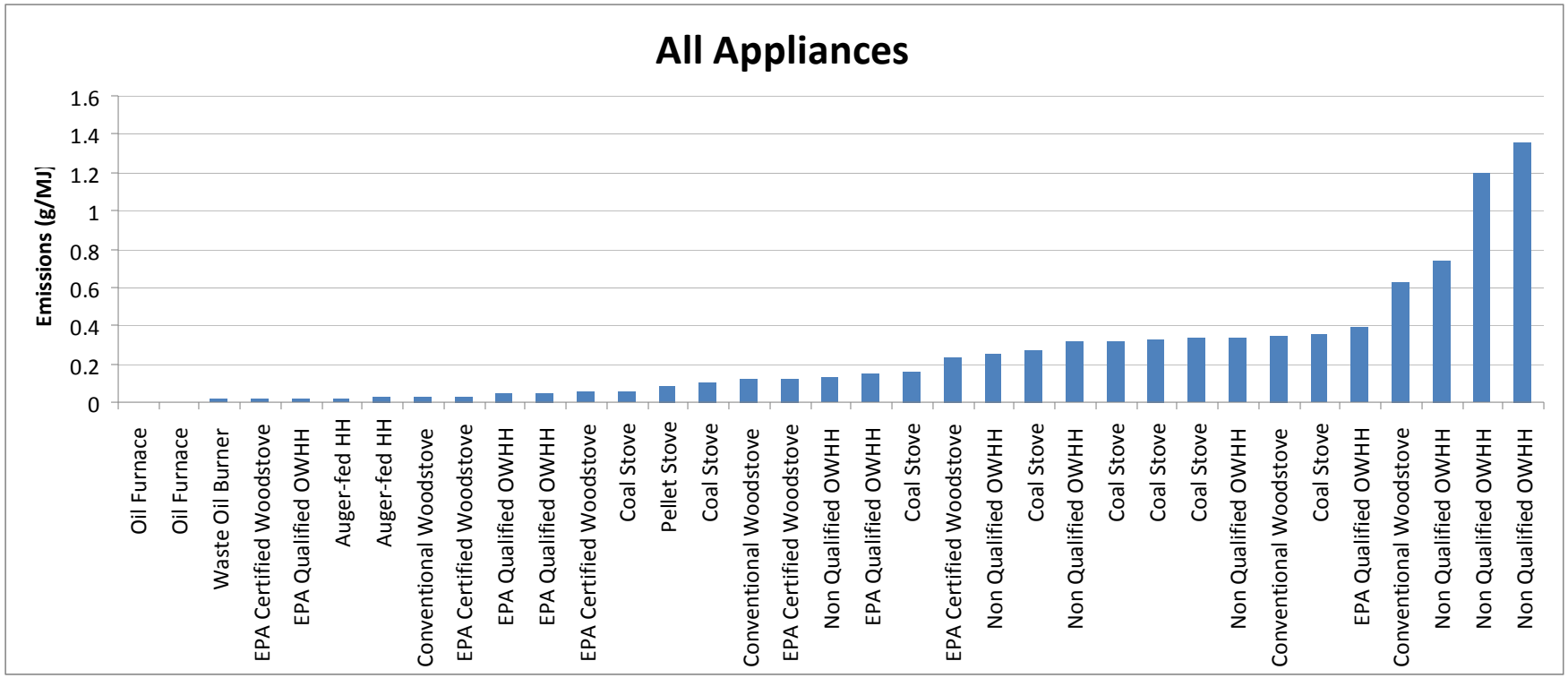


Figure 6

Cold Start Emissions for EPA Certified Wood Stove Burning Birch with Estimated Contribution from Each Test Phase

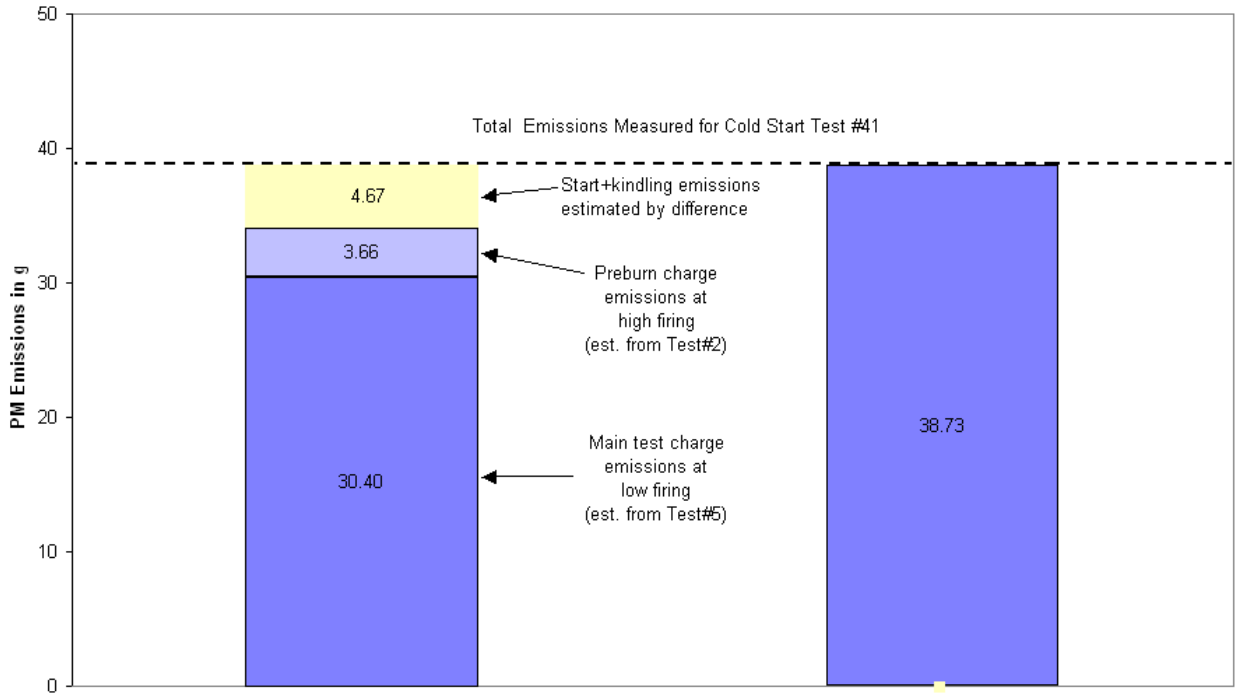
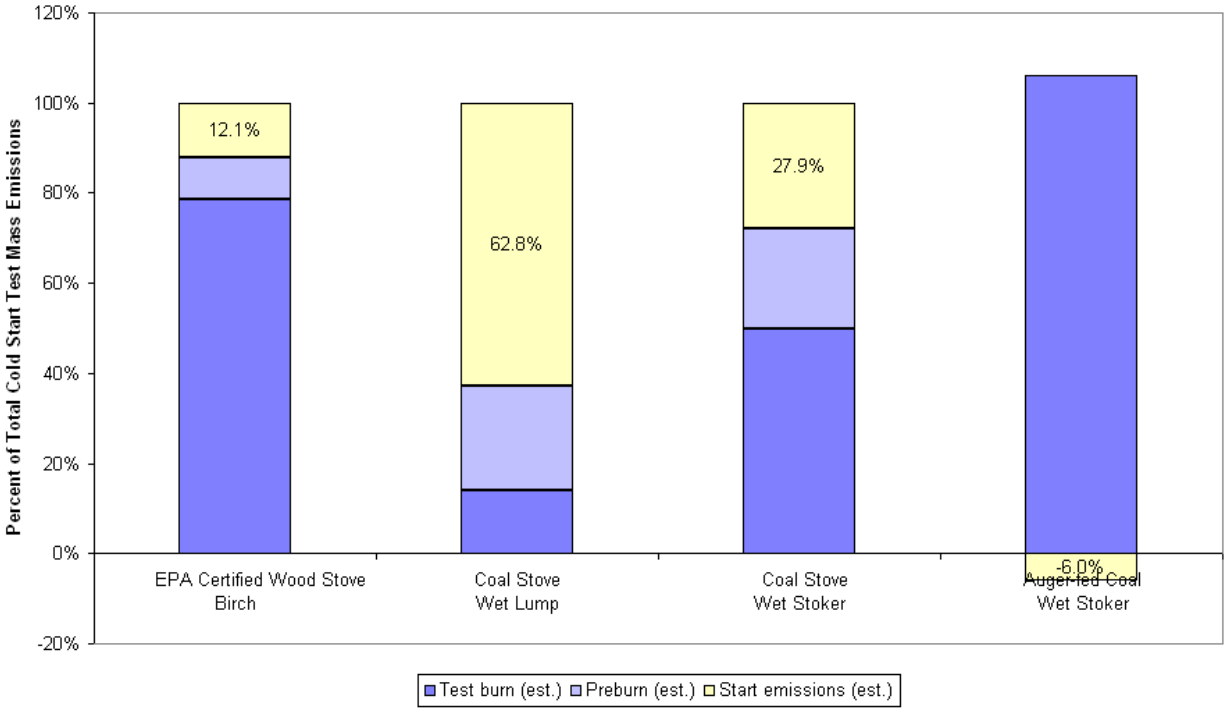


Figure 7

Estimated Contribution of Start+Kindling Emissions to Total Cold Start Test Emissions



Attachment A
Comparison of Selected OMNI PM Emission Factors Measurements (lbs/ton) with Prior Study Results & AP-42

Appliance Type	Current OMNI Testing Avg (range of conditions)	Earlier OMNI Testing of Same Model (fuel & method may vary)	AP-42 EFs (w. assumed or measured fuel properties)
Stove			
• Conventional, wood	9.8 (8.9 - 12.0)	7.1	30.6
• EPA-certified, wood	2.9 (2.4 - 5.3)	-	14.6 – 16.2
• Coal	8.7 (2.3 - 15.1)	-	-
OHH			
• Nonqualified, wood	14.3 (8.8 - 25.7)	-	-
• EPA Ph2 Qualified, wood	2.3 (0.77 – 5.3)	2.4	-
• Augerfed coal	0.96	-	3.8 (boiler)
Pellet Stove	3.0	-	4.2 - 8.8
Coal Stove	8.7 (2.3 – 15.1)	-	3.8 (boiler)
Oil burner			
• No. 1	0.33	-	0.55
• No.2	0.12	-	0.58
• Waste oil	2.97	-	0.17

Attachment B
List of Tests Performed by OMNI and Summary of Test Results

Run	Appliance	Fuel	Burn Rate	PM2.5 Emissions (g/hr)	Emissions (g/MJ output)	PM2.5 Emissions Factor (g/kg)
1	Pellet Stove	Alaskan Pellets	Single	3.31	0.111	1.48
2	EPA Certified Woodstove	Birch	High	1.84	0.041	0.49
3	EPA Certified Woodstove	Spruce	High	1.17	0.021	0.27
5	EPA Certified Woodstove	Birch	Low	6.12	0.331	4.08
6	EPA Certified Woodstove	Spruce	Low	1.68	0.079	0.95
8	EPA Qualified OWHH	Birch	High	10.72	0.057	0.81
9	EPA Qualified OWHH	Birch	Low	14.07	0.212	2.66
10	EPA Qualified OWHH	Spruce	High	5.12	0.027	0.38
11	EPA Qualified OWHH	Spruce	Low	4.32	0.065	0.79
12	Conventional Woodstove	Spruce	High	2.89	0.051	0.45
13	Conventional Woodstove	Birch	High	94.56	1.246	10.89
14	Conventional Woodstove	Spruce	Low	13.16	0.197	2.11
15	Conventional Woodstove	Birch	Low	44.02	0.581	6.06
17	Central Heating Indoor Furnace	No. 2 Heating Oil	Single	0.13	0.002	0.06
18	Waste Oil Burner	Waste Motor Oil	Single	10.41	0.021	0.67
20	Coal Stove	Dry Stoker Coal	High	17.45	0.459	6.61
21	Coal Stove	Dry Stoker Coal	Low	1.74	0.085	1.16
23	Coal Stove	Stoker Coal	Low	11.13	0.589	7.09
25	Non Qualified OWHH	Spruce	High	130.10	0.789	5.45
26	Non Qualified OWHH	Coal	Single	294.60	4.522	27.05
27	Non Qualified OWHH	Coal w/ retrofit control	Single	120.10	2.924	21.18
28	Augerfed HH	Coal (cold start)	Single	7.17	0.027	0.45
29	Augerfed HH	Coal (hot start)	Single	7.78	0.030	0.48
30	Non Qualified OWHH	Spruce	Low	174.00	2.315	12.85
31	Non Qualified OWHH	Birch	High	119.30	0.757	5.93
32	Non Qualified OWHH	Birch	Low	44.47	0.757	4.41
33	Non Qualified OWHH	Birch (cold start)	Low	34.75	0.376	2.33
34	EPA Qualified OWHH	Birch w/ retrofit control	Low	33.82	0.592	6.79
35	Coal Stove	Stoker Coal	High	7.83	0.252	3.18
36	Coal Stove	Lump Coal (cold start)	Low	16.32	0.453	6.48
37	Coal Stove	Lump Coal	Low	2.75	0.142	1.99
38	Coal Stove	Dry Lump Coal	Low	8.19	0.377	5.28
39	Coal Stove	Stoker Coal (cold start)	Low	14.49	0.431	6.36
40	Central Heating Indoor Furnace	No. 1 Heating Oil	Single	0.31	0.004	0.16
41	EPA Certified Woodstove	Birch (cold start)	Low	6.86	0.180	2.18

2/16/12

Dr. Jim Conner
Fairbanks North Star Borough

RE: Response to Sierra Critique

Dear Dr. Conner:

The following has been prepared by OMNI in response to the critical review submitted to you by Frank DiGenova of Sierra Research on January 25, 2012. Overall OMNI does not strongly disagree with any of the points made in the critique, but we would like to take this opportunity to comment on a couple of items.

Retrofit Device

The retrofit emissions control device was installed by representatives from its manufacturer. The decision not to enable feedback control was not made by OMNI and testing began only after the manufacturer's representatives indicated that their task had been completed. Any questions on the applicability of the tested installation to real-world usage should be directed to the device manufacturer.

Non-qualified OWHH

The uncertainly of data collected during the testing of the non-qualified OWHH was not reported. This is an oversight by OMNI, as it leads to the conclusion that despite the difficulties during testing, the data is as certain as that of other test runs. This is not the case. OMNI's calculations and comparisons to other data suggest that the reported particulate and gas emissions data sets for the non-qualified OWHH are only accurate to an order of magnitude. While this represents a large range, the results can still be of utility to the borough. Hypothetically, if reported emissions were reduced by a factor of ten, the results still show that emissions from the non-qualified unit are dramatically higher than those of the EPA Phase II certified OWHH. The report will be updated to include a description of the uncertainties in the data for the non-qualified OWHH.

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Lack of Analysis

OMNI was contracted to perform testing, report data, and perform quantitative analysis on those data. Neither the borough's proposal request, nor the proposal submitted by OMNI, included subjective analysis as a deliverable.

AP-42

OMNI urges caution when comparing data from OMNI's testing to the EPA's AP-42 emissions factors. The AP-42 report is intended to realistically report field-use emissions. Therefore, its sources are primarily field use studies that did not use standard operating methods. OMNI's testing relied primarily on EPA Method 28, the woodstove fueling and operation method. Method 28's intent is not to provide accurate field-use data; rather, its purpose is to ensure consistent results from one appliance to the next.

Replicate Testing

Though not discussed in the critique, OMNI's primary concern with the results of the study is the lack of repeated test runs. Many subjective conclusions can be drawn from the data, and much of the data makes intuitive sense. However, the fact that no two test runs were exactly the same means that the data has no scientific or statistical significance. The first step to improving the data for any appliance or fuel is to repeat the test runs performed.

In addition to the critical comments, Mr. DiGenova also pointed out some errors, as well as some opportunities for better clarification, which OMNI will work on addressing for a final draft. If you have any questions, please let don't hesitate to contact ***OMNI***.

Sincerely,

Sebastian Button
Emissions Testing Manager

Measurement of Space-Heating Emissions

Prepared for:

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May 23, 2013

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1. Introduction

OMNI-Test Laboratories, Inc. (OMNI) was contracted by Fairbanks North Star Borough (FNSB) to measure specific emissions from home heating appliances believed to be contributing to elevated levels of particulate matter smaller than 2.5 microns ($PM_{2.5}$). The objective of the study was to determine real-world emissions produced by devices commonly used in the borough's $PM_{2.5}$ nonattainment area, to use such data to develop source profiles and emission factors which can be used to model air quality within the nonattainment area, to evaluate possible $PM_{2.5}$ mitigation programs for emissions benefits, and to improve overall knowledge about local sources and source apportionment. To that end, nine heating appliances were selected and operated in a normal fashion during testing. This included: (1) tests with both hardwood and softwood cordwood, (2) tests with coal of varying moisture content, (3) tests with heating oils of differing composition, and (4) tests with both higher and lower burn rates. To provide insight into the possible range of emissions produced in the nonattainment area, a variety of appliances, with and without U.S. EPA certification and utilizing different fuels, were selected for the study.

All fuel samples were provided by FNSB and received in good condition. Testing was conducted at OMNI's facilities in Portland, Oregon by Mike Eisele, Lyrik Pitzman, Sebastian Button, Jeremy Clark, and Aaron Kravitz between March 8 and August 18, 2011.

Emissions of total particles (PM), particles with aerodynamic diameters of less than 2.5 microns ($PM_{2.5}$), nitrogen oxides (NO_x), carbon monoxide (CO), total volatile organic compounds (VOC), sulfur dioxide (SO_2), and ammonia (NH_3) were measured. In addition carbon dioxide (CO2), oxygen (O2), temperatures (chimney, room, meter boxes, particulate filters and dilution tunnel), fuel mass, and air and sample flow were measured to support the emission calculations. Moisture, elemental composition, and energy content were also measured for each fuel type. Standard methods were used to the extent feasible for all testing.

A detailed description of the testing program is provided as Section 2. The results of the testing are provided and discussed in Section 3. A summary is provided as Section 4. Real time graphs and analytical laboratory reports are provided as appendices.

2. Testing Program

2.1 Measurements

Measurements deemed appropriate for this study were selected based on consultations between OMNI and Fairbanks North Star Borough staff. Standard sampling methods were used to collect and monitor all parameters. Table 1 lists the methods used and the pollutants measured. Air emission samples were collected from a dilution tunnel. Supporting measurements were made in the heater chimney (stack) and in the surrounding laboratory. Selected background samples were collected from laboratory air. The pollutants measured included:

- Total particulate matter (PM) measured from the dilution tunnel
- Particles less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) measured from the dilution tunnel
- Nitrogen oxides (NO_x, reported as NO_2) measured from the dilution tunnel
- Carbon monoxide (CO) measured from the dilution tunnel
- Carbon monoxide (CO) measured from the stack
- Oxygen (O2) measured from the stack
- Carbon dioxide (CO_2) measured from the stack
- Sulfur dioxide (SO2) measured from the dilution tunnel
- Ammonia (NH_3) measured from the dilution tunnel
- Total volatile organic compounds (VOC) measured from the dilution tunnel. The total VOC emission factor was collected with a real-time gas analyzer incorporating a flame ionization detector (FID). This value includes methane and most non-methane VOCs, reported as carbon.

Table 1. Compounds, Parameters, Sampling and Monitoring Methods, Collection and Monitoring Devices, Analytical Laboratories, and Analytical Methods

Group	Analytical Compounds	Sampling Method	Collection Device	Analytical Laboratory	Analytical Method*
Particles	Particles less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$)	EPA Other Test Method 27 (In accordance with EPA proposed changes to method 201A)	47 mm Glass Fibre A/E Filter, Teflon coated glass A/E	Research Triangle Institute	Determined by RTI
Gases	Nitrogen Oxides (NO_x)	EPA Method 7E	Chemiluminescent gas analyzer	N/A	N/A
	Carbon Monoxide (CO)	EPA Method 10	Gas filter correlation analyzer	N/A	N/A
	Oxygen (O_2)	EPA Method 3A	Non-dispersive infrared analyzer (NDIR)	N/A	N/A
	Carbon Dioxide(CO_2)	EPA Method 3A	Non-dispersive infrared analyzer (NDIR)	N/A	N/A
	Sulfur Dioxide (SO_2)	EPA Method 6	Pulsed florescence UV analyzer	N/A	N/A
	Ammonia (NH_3)	EPA Conditional Test Method 27	Sulfuric acid-filled impinger series	Columbia Analytical Services, Inc.	EPA Method 350.1
	Total Volatile Organic Compounds (VOC's)	EPA Method 25A	Total hydrocarbon analyzer with flame ionizing detector (FID)	N/A	N/A
Efficiency	Flue Gas CO, CO_2, O_2	CSA B415.1-10	Non-dispersive infrared analyzer (NDIR)	N/A	N/A

*See appropriate laboratory reports in the appendices for modifications to analytical method

2.2 Standardized Methods

ASTM E 2515-07 further specifies the determination of TPM emissions collected in a dilution tunnel and includes specifications concerning the flow rate of the sampling equipment, the construction and proper operation of the dilution tunnel, and calculations for determining the total particulate emissions during a test.

EPA Method 201A pertains to the equipment, preparation, and analysis necessary to measure filterable particulate matter emissions equal to or less than 2.5 micrometers ($PM_{2.5}$).

EPA Method 28 pertains to the certification and auditing of wood heaters. This method prescribes the fueling protocol, conditions, and procedures for determining the particulate emissions and burn rate of a burn event.

EPA Method 28 WHH concerns the measurement of particulate emissions and heating efficiency of wood-fired hydronic heating devices. The method provides specifications for fueling, test facility conditions, and procedures for determining heat output rates and particulate emission rates, and for reducing data.

EPA Method 25A is used in the determination of the total gaseous organic concentration of vapors (i.e., VOCs) which are primarily composed of arenes, alkanes and/or alkenes. This method contains specifications for the type of analyzer to be used, the temperature of the heated sample line carrying gases from the source to the analyzer, the proper location for sampling, the appropriate concentrations for calibration gases, and calculations for determining the average organic concentration in terms of ppm_v as propane.

EPA Method 7E specifies the determination of the concentrations of nitrogen oxides emitted from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentration of NO_x.

EPA Method 10 is likewise used in the determination of the concentration of carbon monoxide emissions from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentration of CO.

EPA Method 3A is concerned with the determination of oxygen and carbon dioxide emissions from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentrations of O_2 and CO_2.

EPA Method 6 prescribes the measurement of sulfur dioxide emissions from stationary sources and specifies the type of analyzer and other equipment to be used, sampling locations, gas calibration values, and calculations for determining the average concentration of SO_2.

EPA Conditional Test Method 27 (CTM-027) addresses the collection of ammonia samples and, in conjunction with EPA Method 17, dictates the assembly and operation of the sample train and metering system as well as procedures for sample recovery.

CSA B415.1-10 specifies requirements for performance testing of solid-fuel-burning heating appliances, including appliance efficiencies via the stack-loss method.

2.3 Sampling Notes

2.3.1 Particulate Sampling

Particulate sampling was carried out in accordance with applicable portions of EPA method 201A. The particulate sampling system relied on a cyclone head attachment on the sample probe in order to sample only particulate smaller than 2.5 microns in diameter ($PM_{2.5}$). The cyclone head was placed in the dilution tunnel and the sample flow was split into 5 branches, each with a filter. The flow rate in each branch was individually controlled. One filter was composed of Teflon, three were quartz, and one was glass fiber. The Teflon filter and one quartz filter were sent to RTI for analysis, one quartz filter was sent to the University of Montana for analysis, and the final quartz filter was retained for OMNI's archive.

The glass fiber filter was used purely for bypass flow. In order to effectively separate particulate matter, a cyclone must be operated within a range of flow rates governed by sample temperature. The Teflon and quartz filters were set to their optimum sample rate and the flow through the glass filter was adjusted to achieve the proper cumulative sample flow.

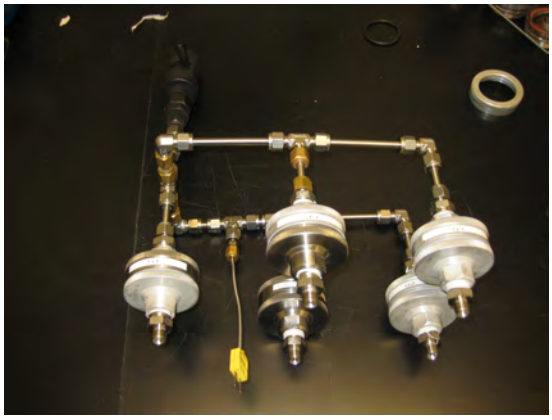


Figure 1. Cyclone and Filter Assembly

Figure 2. Cyclone Head Detail

2.3.2 Ammonia Sampling

Ammonia sampling was carried out in accordance with EPA CTM 27. The sampling system employed a glass impinger train behind a heated glass fiber particulate filter. The sample was collected in the first two impingers, which were each filled with 100 mL of 0.1 molar sulfuric acid prior to every test run. The sample rate was kept constant and proportional to the dilution tunnel flow throughout testing. Sample recovery was carried out by draining the impingers and rinsing with deionized water. The rinse water was then added to the sample, diluting each impinger's 100 mL to 250 mL.

Figure 3. Ammonia Sampling Probe and Impinger Train

2.3.3 Gas Sampling

Gas sampling system was divided into two trains: one used to measure CO, SO_2, NO, NO_2, and NO_x, and one dedicated solely to VOCs. Each train consisted of a ¼-inch stainless steel probe and a stainless steel 2-micron pore size in-line filter attached to a sample line heated to 215 °F to prevent gas condensation. Air samples for $CO/SO_2/NO_x$ analysis were pumped through a sample conditioner capable of removing water vapor without removing water soluble fractions from the gas sample, resulting in a dry gas sample which has the same composition on a dry basis before and after passing through the conditioner. The dried air was then conveyed to the respective analyzers at pressures dictated by their nominal operating conditions. The VOC analyzer, being an FID detector, required neither an external pump nor a cool, dry gas sample.

The in-line sample filters were replaced as needed, indicated by a drop in sample flow rate to the analyzers.

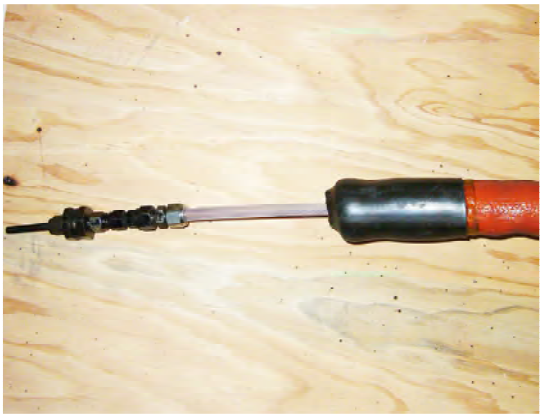


Figure 4. Probe, In-Line Filter, Heated Sample Line

Figure 5. In-Line Filter Detail

2.4 Operation and Run Notes

Testing adhered as closely as possible to the procedures found in standard EPA methods but for many of the units tested portions of those procedures are not applicable. Therefore, in many instances customized procedures were developed in order to generate repeatable, comparable results while still adhering to the intent of the methods. Table 2 presents a summary of all test runs including which type of common, Fairbanks sourced, fuels were used. The table also indicates which burn setting the appliance was tested at, either "high" or "low" to represent emissions over the range of a unit's possible controls. Appliances that indicate "single" burn rate operate at the single burn rate that particular unit is capable of, which is typically modulated by a thermostat or other similar devices. For all tests, with the exception of the "cold start" tests, the air controls were set at the beginning of the test, and not changed until testing was completed; see laboratory run notes in Appendix E for exact test settings. A unit-by-unit summary of the testing follows; it covers the operation procedures and deviations from the sample methods used for each run.

Supplementary "cold start" testing was conducted on several of the appliances. These test runs began sampling when the appliance was first lit or turned on, rather than while the appliance was operating. Standard methods were used where possible (e.g. a standard EPA Method 28 pre-burn was performed in the wood stove cold start test), and operation manuals were used where no method was available. Even ignition was achieved with the use of a propane torch for all appliances except the non-qualified hydronic heater, for which a butane lighter was sufficient.

Table 2. Summary of Test Runs

Run	Appliance	Fuel Type	Burn Rate	Hot/Cold Start
1	Pellet Stove	Pellets	Single	Hot
2	EPA Certified Wood Stove	Birch Cordwood	High	Hot
3	EPA Certified Wood Stove	Spruce Cordwood	High	Hot
5	EPA Certified Wood Stove	Birch Cordwood	Low	Hot
6	EPA Certified Wood Stove	Spruce Cordwood	Low	Hot
8	EPA Phase II OWHH	Birch Cordwood	High	Hot
9	EPA Phase II OWHH	Birch Cordwood	Low	Hot
10	EPA Phase II OWHH	Spruce Cordwood	High	Hot
11	EPA Phase II OWHH	Spruce Cordwood	Low	Hot
12	Conventional Wood Stove	Spruce Cordwood	High	Hot
13	Conventional Wood Stove	Birch Cordwood	High	Hot
14	Conventional Wood Stove	Spruce Cordwood	Low	Hot
15	Conventional Wood Stove	Birch Cordwood	Low	Hot
17	Oil Furnace	No. 2 Heating Oil	Single	Hot
18	Waste Oil Furnace	Waste Oil	Single	Hot
20	Coal Stove	Dry Stoker Coal	High	Hot
21	Coal Stove	Dry Stoker Coal	Low	Hot
23	Coal Stove	Wet Stoker Coal	Low	Hot
25	Non-Qualified OWHH	Spruce Cordwood	High	Hot
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot
28	Auger-Fed Coal HH	Wet Stoker Coal	Low	Cold
29	Auger-Fed Coal HH	Wet Stoker Coal	Low	Hot
30	Non-Qualified OWHH	Spruce Cordwood	Low	Hot
31	Non-Qualified OWHH	Birch Cordwood	High	Hot
32	Non-Qualified OWHH	Birch Cordwood	Low	Hot
33	Non-Qualified OWHH	Birch Cordwood	Low	Cold
34	EPA Phase II OWHH, Catalyst	Birch Cordwood	Low	Hot
35	Coal Stove	Wet Stoker Coal	High	Hot
36	Coal Stove	Wet Lump Coal	Low	Cold
37	Coal Stove	Wet Lump Coal	Low	Hot
38	Coal Stove	Dry Lump Coal	Low	Hot
39	Coal Stove	Wet Stoker Coal	Low	Cold
40	Oil Furnace	No. 1 Heating Oil	Single	Hot
41	EPA Certified Wood Stove	Birch Cordwood	Low	Cold

2.4.1 Pellet Stove

Operation of the pellet stove was carried out in accordance with EPA Method 28. A single run was completed, and no deviations from either Method 28 or any of the proscribed sampling methods were necessary.

Table 3. Pellet Stove Burn Characteristics

Fuel	Run	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Alaskan Pellets	1	6.60	120	2.23	10.5

2.4.2 EPA Certified Wood Stove

EPA Method 28 was used in the testing of the EPA Certified stove. The only deviation occurred in the fuel loads which, while of appropriate weight and length, were not dimensional Douglas fir but rather spruce and birch cordwood, as specified in the proposal. A summary of the fuel loads and burn rates can be found in Table 4. Otherwise, the firing procedures (e.g. preburn length, data collected) adhered to the method. Sampling, likewise, adhered to the methods and procedures specified in Section 2.3. Run 41 utilized a cold start procedure developed for this testing, which for this unit was simply an EPA Method 28 firing procedure, using birch kindling, with emissions sampled throughout the entire burn.

Table 4. EPA Certified Wood Stove Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	3	High	23.75	83	4.35	16.4
Spruce	6	Low	17.90	210	1.77	16.1
Birch	2	High	17.83	101	3.80	16.6
Birch	5	Low	16.70	248	1.50	15.9
Birch	41	Low, Cold Start	17.30	288	3.14	6.0 Kindling, 16.5 Preburn, 16.4 Test

2.4.3 EPA Phase II Qualified Outdoor Wood-Fired Hydronic Heater

As with the EPA stove, an applicable method was in place for operation of the Phase II outdoor wood-fired hydronic heater (OWHH). Again, this method was followed with the exception of the fuel requirements- the Alaskan fuels were used instead of the specified oak lumber.

In addition to the four high/low runs with birch and spruce, a fifth test was performed with a retrofit catalyst device, which consists of a catalyst and heating element, put on the exhaust gas stack while performing a low burn setting test with birch.

Table 5. EPA Phase II OWHH Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	10	High	20.78	237	13.31	140.0
Spruce	11	Low	20.32	582	5.48	141.0
Birch	8	High	18.11	243	13.29	140.2
Birch	9	Low	16.40	620	5.29	140.2
Birch	34	Low, with retrofit catalyst	27.90	534	4.98	125.0

2.4.4 Conventional Wood Stove

EPA Method 28 was applicable for the operation of the conventional wood stove tested. Testing was conducted in much the same fashion as with the EPA certified unit, however, controlling the burn rate was problematic. Despite performing high burns at the highest air setting, and low burns at the lowest air setting, very little difference in burn rate was observed. This is likely due to the age of the stove – over time many air leaks developed in the firebox, resulting in uncontrolled air supply to the fire. However, as any non-certified unit still in use in the field would be at least as old as the tested unit, the poorly-controlled air supply was considered typical for a unit of this type, and the data considered acceptable.

Otherwise, sampling was straightforward and as specified.

Table 6. Conventional Wood Stove Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	12	High	17.38	53	6.49	14.8
Spruce	14	Low	17.70	53	6.24	14.3
Birch	13	High	16.67	40	8.69	14.9
Birch	15	Low	13.95	49	7.26	14.9

2.4.5 Oil Furnace

No EPA standard is in place for oil-burning central air furnaces so the manufacturer's instructions were relied upon for operation. Test duration was dictated by the amount of time needed to acquire a measurable amount of particulate matter on the filters. No modifications to the sampling system or procedures were necessary.

Table 7. Oil Furnace Burn Characteristics

Fuel	Run	Higher Heating Value (BTU/lb)	Duration (min)	Fuel Usage (lb)
No. 1 Fuel Oil	40	19721	886	61.6
No. 2 Fuel Oil	17	19613	519	40.8

2.4.6 Waste Oil Furnace

Testing of the waste oil furnace was conducted in an identical manner to that of the conventional oil furnace. The furnace was run at its single output rate until sufficient particulate had been acquired by each of the sample filters.

Table 8. Waste Oil Furnace Burn Characteristics

Fuel	Run	Higher Heating Value (BTU/lb)	Duration (min)	Fuel Usage (lb)
Waste Oil	18	19237	163	26.5

2.4.7 Coal Stove

Due to the lack of an EPA method for coal stove operation, the manufacturer's instructions were used to determine fuel loads and operation procedures.

Table 9. Coal Stove Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Stoker Coal	35	High	33.50	220	2.46	25.0
Stoker Coal	23	Low	33.50	294	1.62	22.1
Dried Stoker Coal	20	High	11.20	208	2.64	22.4
Dried Stoker Coal	21	Low	11.20	391	1.50	24.0
Lump Coal	36	Low, Cold Start	25.40	497	2.23	4.0 Birch Kindling, 25.0 Preburn, 25.0 Test
Lump Coal	37	Low	25.40	393	1.38	25.0
Dried Lump Coal	38	Low	19.00	369	1.55	25.0
Stoker Coal	39	Low, Cold Start	33.50	448	2.28	6.0 Birch Kindling, 26.5 Preburn, 25.0 Test

2.4.8 Non-Qualified Outdoor Wood Fired Hydronic Heater

The non-qualified OWHH used for testing required substantially modified procedures in order to generate meaningful results. This unit produced an extreme amount of particulate matter and heat in the flue. Combined with a low dilution factor, this resulted in excessively high particulate concentrations and temperatures in the dilution tunnel – far beyond the capabilities of the sampling systems described in Section 2.3.

All of the sampling systems rely on filters for sample collection or conditioning, and all of the filters would become clogged almost immediately after test start. In addition to the high particulate concentrations, the elevated temperatures produced in the dilution tunnel caused large amounts of water to condense on the cooler filters. Regardless of material, a wet filter will not allow airflow. Solving this problem for the particulate sampling system required a two-pronged approach. The filters were first heated to prevent condensation. The filter holders were placed in a temperature-controlled box featuring a hole for the protuberance of the cyclone head. To solve the particulate problem, a larger bypass filter was used. A 102mm glass bypass filter was employed in place of the 47mm filter, allowing much higher flow through the bypass. The revised filter train is shown in Figure 6. The flow through the sample collection filters was greatly reduced, thus reducing the amount of particulate collected. The air from the bypass filter was cooled using a glass impinger train immersed in an ice bath; silica gel dryers were sufficient for cooling and drying the air from the sample filters.

Figure 6. Cyclone and Filter Assembly with 102 mm Glass Filter

Despite this, multiple filter changes were needed for each run. Most frequently changed was the glass bypass filter. Fortunately the effects of these changes were relatively minor, resulting only in a brief (approximately 1 minute) alteration in sample rate.

The gas sampling systems also required adjustment. A dilution system was attempted to reduce flow through the filter while maintaining the required sample rates. However, due to the difficulty in achieving a precise and constant dilution rate throughout each test, it was determined that the most robust technique was not to dilute but to simply closely monitor sample rates and change filters when needed. In some instances gas concentrations exceeded the maximum detection limits of the analyzers. For such cases, data are reported as being greater than the amount measured.

Similar to the EPA qualified OWHH, an additional test was performed on this unit with a retrofit catalyst exhaust stack. This extra test was done burning coal fuel with a low burn setting.

Table 10. Non-Qualified OWHH Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Spruce	25	High	16.91	118	18.57	93.9
Spruce	30	Low	14.00	117	14.12	69.2
Birch	31	High	18.04	115	20.13	100.4
Birch	32	Low	17.02	231	10.09	100.2
Stoker Coal	26	Low	33.50	123	10.89	62.0
Stoker Coal	27	Low, w/ Stack catalyst	33.50	196	6.45	62.0
Birch	33	Low, Cold Start	26.78	346	14.91	40.0 Kindling, 100.2 Preburn, 100.1 Test

2.4.9 Auger-Fed Coal Fired Hydronic Heater

The auger-fed coal burning hydronic heater was tested in accordance to Method 28 WHH for pellet boilers. Two tests were performed with this unit at the same heat output rate, which was approximately 35% of the maximum achievable heat output. The first test was a "cold start", meaning sampling started prior to a fire being lit. A fire was started in the burn pot with newspaper and small kindling wood prior to activating the auger. The second test was identical to the first with regards to burn rate and fuel consumption; however, it was a standard "hot start" per Method 28 WHH.

Table 11. Auger-Fed Coal HH Burn Characteristics

Fuel	Run	Burn Rate (Target)	Fuel Moisture (Avg. %)	Duration (min)	Burn Rate (Dry kg/hr)	Fuel Load (Actual lb)
Wet Stoker Coal	28	Low – Cold Start	33.5	199	15.37	150.0
Wet Stoker Coal	29	Low – Hot Start	33.5	202	15.14	150.0

3. Testing Results

3.1 Particulate Sampling Results

Results from particulate sampling are shown in Appendix A. Speciation was performed on the Teflon filter from each run, generating data for both elemental and ionic emissions. These are reported both as total filter catch and overall gram per hour emissions. For every run, there was no detectable catch for several of the compounds. These are reported as zero. Carbon emissions data were generated from the quartz filter and are broken down into elemental and organic carbon. These data are also reported both as total filter catch and emission rate per hour.

The contracted laboratory encountered difficulties analyzing several of the filters, as their equipment is used to analyze ambient samples, where particle loading is drastically lower. Even with the use of a dilution tunnel, some of the samples were "overloaded", making analysis impossible. The quartz filters, especially, proved difficult to properly analyze. For any instance where and analyte was not measurable, "No Data" is reported in Appendix A.

Total particulate results are summarized in Table 20. Also in Table 20, calculated efficiencies using CSA B415 and EPA M28 WHH (where applicable) are reported and used to compute particulate emissions per useful heat output.

3.2 Ammonia Sampling Results

Results from ammonia sampling are summarized in tables 12 through 19. Analytical lab results of the ammonia samples from each individual run are reported in Appendix B as total ammonia catch as nitrogen. These values were used to calculate the volumetric concentration of ammonia gas in the stack as well as the emission rate of ammonia by weight for each run.

3.3 Gas Sampling Results

Tables 12 through 19 contain air emissions measurements derived from the gas analyzers measuring SO_2, CO, VOCs (as C), NO, NO_2, and NO_x. Tables 12 and 16 compare gas emission rates by appliance type and by fuel type, respectively. Tables 13 and 17 compare gas emission factors (in g/kg of dry fuel) by appliance type and by fuel type, respectively. Tables 14 and 18 compare gas emission factors (in g/MJ input) by appliance type and by fuel type, respectively. Tables 15 and 19 compare gas emission factors (in g/MJ output) by appliance type and by fuel type, respectively. Refer to Appendix C for real time graphs of gas emissions measured during testing. With respect to Appendix C, it should be noted that some units are designed to periodically modulate its burn setting, specifically, the pellet stove and the OWHHs. All appliances with manual air adjustments where left at the same setting for the duration of the test.

Note that for the oil furnace burning fuel oil #1, CO concentration was below the detection limit. Also note that for two of the non-qualified OWHH test runs (runs 25 and 26) the CO analyzer was disconnected from the sampling train. Due to the fact that the filter for the analyzer was constantly plugging, and when it was not plugged the analyzer was far out of its calibration range, it was determined that no useful data could be collected for these runs.

Table 12. Emission Rate of Gas By-Products in g/hr, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Rate (g/hr)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.5681	11.09	1.986	5.050	0.1171	4.471	0.08029
3	EPA Wood Stove	Spruce	High	Hot	0.1113	70.36	9.269	2.889	0.7484	3.707	0.1158
6	EPA Wood Stove	Spruce	Low	Hot	0.02587	120.7	14.06	0.6780	0.1197	0.8919	0.1371
2	EPA Wood Stove	Birch	High	Hot	0.2107	108.7	6.613	3.095	1.082	4.556	0.1784
5	EPA Wood Stove	Birch	Low	Hot	0.05873	74.59	23.36	1.249	0.1808	1.544	0.2409
41	EPA Wood Stove	Birch	Low	Cold	0.07125	101.1	26.96	2.299	0.6377	3.368	0.2079
10	EPA OWHH	Spruce	High	Hot	0.002837	334.9	32.80	12.02	0.3301	12.51	0.3869
11	EPA OWHH	Spruce	Low	Hot	0.01611	230.9	77.30	3.320	0.7777	4.612	0.3078
8	EPA OWHH	Birch	High	Hot	0.1965	301.9	104.6	19.80	0.2983	20.23	1.547
9	EPA OWHH	Birch	Low	Hot	0.05227	207.5	75.77	6.042	0.6082	7.069	0.2916
34	EPA OWHH, Catalyst	Birch	Low	Hot	0.1701	63.31	44.29	7.162	0.8584	8.534	0.3163
12	Conventional Wood Stove	Spruce	High	Hot	0.03949	89.52	23.08	4.468	0.7336	5.702	0.2774
14	Conventional Wood Stove	Spruce	Low	Hot	0.04720	359.3	125.8	2.267	0.9782	3.884	0.8025
13	Conventional Wood Stove	Birch	High	Hot	0.2504	470.5	353.1	3.524	3.931	9.989	3.244
15	Conventional Wood Stove	Birch	Low	Hot	0.1100	422.5	313.8	2.130	2.062	5.554	1.821
40	Oil Furnace	Oil #1	Single	Hot	2.361	N/D	2.129	3.808	2.137E-04	3.673	0.01994
17	Oil Furnace	Oil #2	Single	Hot	4.502	0.1259	2.832	2.957	0.1905	3.140	0.006887
18	Waste Oil Burner	Waste Oil	Single	Hot	21.06	7.078	1.989	29.84	0.005961	29.74	0.02072
35	Coal Stove	Wet Stoker Coal	High	Hot	3.835	105.5	17.41	4.847	0.8117	6.197	0.3149
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.3705	107.0	24.89	2.220	0.9022	3.653	1.239
39	Coal Stove	Wet Stoker Coal	Low	Cold	1.706	128.7	33.54	3.537	0.8999	5.038	1.583
20	Coal Stove	Dry Stoker Coal	High	Hot	2.955	82.66	22.49	3.949	0.8896	5.362	0.2209
21	Coal Stove	Dry Stoker Coal	Low	Hot	1.466	98.44	12.99	2.236	0.8425	3.523	0.9764
37	Coal Stove	Wet Lump Coal	Low	Hot	1.212	107.3	11.68	2.597	0.4249	3.292	0.9573
36	Coal Stove	Wet Lump Coal	Low	Cold	0.4983	118.1	42.96	3.147	0.9102	4.663	2.078
38	Coal Stove	Dry Lump Coal	Low	Hot	0.9417	76.59	29.00	2.834	0.5006	3.673	0.6132
25	Non-Qualified OWHH	Spruce	High	Hot	0.9604	N/A	285.2	6.076	3.854	12.38	1.662
30	Non-Qualified OWHH	Spruce	Low	Hot	0.6206	>345.8	>269.3	2.841	1.923	5.991	1.013
31	Non-Qualified OWHH	Birch	High	Hot	0.5069	>392.6	>281.0	8.812	7.582	21.20	4.279
32	Non-Qualified OWHH	Birch	Low	Hot	0.6068	>275.3	>231.3	3.046	4.077	9.761	1.880
33	Non-Qualified OWHH	Birch	Low	Cold	0.3818	314.8	283.4	4.615	5.370	13.45	3.531
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	1.998	N/A	126.4	6.055	4.501	13.39	5.933
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.3524	139.1	124.2	5.859	2.963	10.64	5.333
28	Auger-Fed HH	Wet Stoker Coal	Low	Cold	49.91	143.1	2.218	36.82	8.197	50.27	0.2014
29	Auger-Fed HH	Wet Stoker Coal	Low	Hot	50.74	114.7	1.219	35.61	7.804	48.39	0.03969

N/D = Below detection limit
N/A = No data available
>[value] = Exceeded instrument limit

Table 13. Emission Factor of Gas By-Products in g/kg of Dry Fuel, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Factor (g/kg dry fuel)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.2543	4.966	0.88910	2.260	0.05244	2.002	0.03594
3	EPA Wood Stove	Spruce	High	Hot	0.02560	16.19	2.133	0.6647	0.1722	0.8531	0.02666
6	EPA Wood Stove	Spruce	Low	Hot	1.462E-02	68.23	7.942	0.3831	0.06766	0.5040	0.07749
2	EPA Wood Stove	Birch	High	Hot	0.05551	28.64	1.742	0.8152	0.2851	1.200	0.04698
5	EPA Wood Stove	Birch	Low	Hot	0.03928	49.89	15.62	0.8356	0.1209	1.033	0.1611
41	EPA Wood Stove	Birch	Low	Cold	0.02272	32.24	8.598	0.7332	0.2034	1.074	0.06632
10	EPA OWHH	Spruce	High	Hot	2.132E-04	25.16	2.464	0.9028	0.02480	0.9400	0.02907
11	EPA OWHH	Spruce	Low	Hot	0.002940	42.14	14.11	0.6058	0.1419	0.8416	0.05617
8	EPA OWHH	Birch	High	Hot	0.01478	22.71	7.868	1.489	0.02244	1.522	0.1164
9	EPA OWHH	Birch	Low	Hot	0.009038	35.87	13.10	1.045	0.1052	1.222	0.06380
34	EPA OWHH, Catalyst	Birch	Low	Hot	0.03415	12.71	8.891	1.438	0.1723	1.713	0.06350
12	Conventional Wood Stove	Spruce	High	Hot	0.002766	6.271	1.617	0.3130	0.05139	0.3995	0.01943
14	Conventional Wood Stove	Spruce	Low	Hot	0.007561	57.58	20.16	0.3634	0.1568	0.6226	0.1286
13	Conventional Wood Stove	Birch	High	Hot	0.02882	54.14	40.63	0.4056	0.4524	1.150	0.3733
15	Conventional Wood Stove	Birch	Low	Hot	0.01514	58.18	43.21	0.2933	0.2839	0.7647	0.2507
40	Oil Furnace	Oil #1	Single	Hot	1.249	N/D	1.126	2.015	1.131E-04	1.943	0.01055
17	Oil Furnace	Oil #2	Single	Hot	2.104	0.05885	1.324	1.382	0.08905	1.468	0.003219
18	Waste Oil Burner	Waste Oil	Single	Hot	4.759	1.600	0.4495	6.745	0.001347	6.721	0.004684
35	Coal Stove	Wet Stoker Coal	High	Hot	1.562	42.96	7.089	1.974	0.3305	2.524	0.1359
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.2366	68.33	15.89	1.418	0.5762	2.333	0.7912
39	Coal Stove	Wet Stoker Coal	Low	Cold	0.7496	56.57	14.74	1.555	0.3955	2.214	0.6960
20	Coal Stove	Dry Stoker Coal	High	Hot	1.153	32.26	8.778	1.541	0.3472	2.093	0.08622
21	Coal Stove	Dry Stoker Coal	Low	Hot	0.9785	65.70	8.666	1.492	0.5623	2.351	0.6516
37	Coal Stove	Wet Lump Coal	Low	Hot	0.8780	77.69	8.459	1.881	0.3078	2.385	0.6934
36	Coal Stove	Wet Lump Coal	Low	Cold	0.2238	53.05	19.29	1.413	0.4087	2.094	0.9331
38	Coal Stove	Dry Lump Coal	Low	Hot	0.6077	49.43	18.72	1.829	0.3231	2.371	0.3957
25	Non-Qualified OWHH	Spruce	High	Hot	0.04020	N/A	11.94	0.2543	0.1613	0.5181	0.06957
30	Non-Qualified OWHH	Spruce	Low	Hot	0.04583	>25.54	>19.89	0.2098	0.1420	0.4424	0.07480
31	Non-Qualified OWHH	Birch	High	Hot	0.02518	>19.50	>13.96	0.4378	0.3767	1.053	0.2126
32	Non-Qualified OWHH	Birch	Low	Hot	0.06015	>27.29	>22.93	0.3019	0.4041	0.9676	0.1863
33	Non-Qualified OWHH	Birch	Low	Cold	0.02561	21.12	19.01	0.3095	0.3602	0.9019	0.2369
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	0.1834	N/A	11.60	0.5559	0.4132	1.229	0.5447
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.06218	24.54	21.92	1.034	0.5229	1.878	0.9411
28	Auger-Fed HH	Wet Stoker Coal	Low	Cold	3.248	9.311	0.1444	2.396	0.5334	3.271	0.01311
29	Auger-Fed HH	Wet Stoker Coal	Low	Hot	3.352	7.576	0.08052	2.353	0.5155	3.197	0.002622

N/D = Below detection limit
N/A = No data available
>[value] = Exceeded instrument limit

Table 14. Emission Factor of Gas By-Products in g/MJ Input, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Factor (g/MJ input)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.01473	0.2876	0.05150	0.1309	0.003037	0.1159	0.002082
3	EPA Wood Stove	Spruce	High	Hot	0.001590	1.006	0.1325	0.04128	0.01070	0.05298	0.001656
6	EPA Wood Stove	Spruce	Low	Hot	9.078E-04	4.237	0.4932	0.02379	0.004202	0.03130	0.004812
2	EPA Wood Stove	Birch	High	Hot	0.003416	1.762	0.1072	0.05016	0.01755	0.07385	0.002891
5	EPA Wood Stove	Birch	Low	Hot	0.002417	3.070	0.9615	0.05142	0.007441	0.06355	0.009916
41	EPA Wood Stove	Birch	Low	Cold	0.001398	1.984	0.5291	0.04512	0.01252	0.06611	0.004081
10	EPA OWHH	Spruce	High	Hot	1.324E-05	1.562	0.1530	0.05607	0.001540	0.05838	0.001805
11	EPA OWHH	Spruce	Low	Hot	1.826E-04	2.617	0.8760	0.03762	0.008814	0.05227	0.003488
8	EPA OWHH	Birch	High	Hot	9.097E-04	1.397	0.4842	0.09164	0.001381	0.09365	0.007162
9	EPA OWHH	Birch	Low	Hot	5.561E-04	2.207	0.8062	0.06429	0.006472	0.07522	0.003926
34	EPA OWHH, Catalyst	Birch	Low	Hot	0.002102	0.7821	0.5471	0.08848	0.01060	0.1054	0.003907
12	Conventional Wood Stove	Spruce	High	Hot	1.718E-04	0.3895	0.1004	0.01944	0.003192	0.02481	0.001207
14	Conventional Wood Stove	Spruce	Low	Hot	4.696E-04	3.576	1.252	0.02257	0.009737	0.03867	0.007989
13	Conventional Wood Stove	Birch	High	Hot	0.001774	3.332	2.500	0.02496	0.02784	0.07074	0.02297
15	Conventional Wood Stove	Birch	Low	Hot	9.319E-04	3.580	2.659	0.01805	0.01747	0.04705	0.01543
40	Oil Furnace	Oil #1	Single	Hot	0.04707	N/D	0.04244	0.07591	4.261E-06	0.07322	3.974E-04
17	Oil Furnace	Oil #2	Single	Hot	0.08009	0.002240	0.05038	0.05261	0.003389	0.05586	1.225E-04
18	Waste Oil Burner	Waste Oil	Single	Hot	0.1839	0.06181	0.01737	0.2606	5.206E-05	0.2597	1.810E-04
35	Coal Stove	Wet Stoker Coal	High	Hot	0.08134	2.238	0.3693	0.1028	0.01722	0.1314	0.007079
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.01232	3.559	0.8278	0.07384	0.03001	0.1215	0.04121
39	Coal Stove	Wet Stoker Coal	Low	Cold	0.03905	2.946	0.7678	0.08098	0.02060	0.1153	0.03625
20	Coal Stove	Dry Stoker Coal	High	Hot	0.06008	1.680	0.4572	0.08029	0.01809	0.1090	0.004491
21	Coal Stove	Dry Stoker Coal	Low	Hot	0.05097	3.422	0.4514	0.07771	0.02929	0.1225	0.03394
37	Coal Stove	Wet Lump Coal	Low	Hot	0.04735	4.190	0.4562	0.1015	0.01660	0.1286	0.03739
36	Coal Stove	Wet Lump Coal	Low	Cold	0.01207	2.861	1.040	0.07619	0.02204	0.1129	0.05032
38	Coal Stove	Dry Lump Coal	Low	Hot	0.03277	2.665	1.009	0.09863	0.01742	0.1278	0.02134
25	Non-Qualified OWHH	Spruce	High	Hot	0.002497	N/A	0.7413	0.01580	0.01002	0.03218	0.004321
30	Non-Qualified OWHH	Spruce	Low	Hot	0.002846	1.586	1.235	0.01303	0.008820	0.02748	0.004645
31	Non-Qualified OWHH	Birch	High	Hot	0.001550	1.200	0.8590	0.02694	0.02318	0.06480	0.01308
32	Non-Qualified OWHH	Birch	Low	Hot	0.003701	1.679	1.411	0.01858	0.02487	0.05954	0.01146
33	Non-Qualified OWHH	Birch	Low	Cold	0.001576	1.299	1.170	0.01905	0.02216	0.05550	0.01458
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	0.009555	N/A	0.6043	0.02896	0.02152	0.06404	0.02837
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.003239	1.278	1.142	0.05385	0.02724	0.09781	0.04902
28	Auger-Fed HH	Wet Stoker Coal	Low	Cold	0.1692	0.4850	0.007519	0.1248	0.02779	0.1704	6.828E-04
29	Auger-Fed HH	Wet Stoker Coal	Low	Hot	0.1746	0.3946	0.004194	0.1225	0.02685	0.1665	1.366E-04

N/D = Below detection limit
N/A = No data available
>[value] = Exceeded instrument limit

Table 15. Emission Factor of Gas By-Products in g/MJ Output, by Appliance

Run	Appliance	Fuel	Burn Rate	Start	Emission Factor (g/MJ output)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellet Stove	Pellets	Single	Hot	0.02043	0.3989	0.07143	0.1816	0.004212	0.1607	0.002888
3	EPA Wood Stove	Spruce	High	Hot	0.002057	1.301	0.1714	0.05340	0.01384	0.06854	0.002142
6	EPA Wood Stove	Spruce	Low	Hot	1.299E-03	6.062	0.7056	0.03403	0.006011	0.04478	0.006884
2	EPA Wood Stove	Birch	High	Hot	0.005053	2.607	0.1586	0.07420	0.02596	0.1092	0.004277
5	EPA Wood Stove	Birch	Low	Hot	0.003433	4.361	1.366	0.07304	0.01057	0.09027	0.01409
41	EPA Wood Stove	Birch	Low	Cold	0.002012	2.854	0.7613	0.06492	0.01801	0.09512	0.005872
10	EPA OWHH	Spruce	High	Hot	1.633E-05	1.926	0.1887	0.06914	0.001899	0.07199	0.002226
11	EPA OWHH	Spruce	Low	Hot	2.597E-04	3.723	1.246	0.05351	0.01254	0.07435	0.004962
8	EPA OWHH	Birch	High	Hot	1.122E-03	1.723	0.5970	0.1130	0.001703	0.1155	0.008831
9	EPA OWHH	Birch	Low	Hot	7.734E-04	3.070	1.121	0.08942	0.009001	0.1046	0.005460
34	EPA OWHH, Catalyst	Birch	Low	Hot	3.204E-03	1.192	0.8340	0.1349	0.01616	0.1607	0.005956
12	Conventional Wood Stove	Spruce	High	Hot	3.416E-04	0.7744	0.1996	0.03865	0.006346	0.04932	0.002400
14	Conventional Wood Stove	Spruce	Low	Hot	7.599E-04	5.786	2.026	0.03652	0.01576	0.06257	0.01293
13	Conventional Wood Stove	Birch	High	Hot	0.003548	6.664	5.000	0.04992	0.05568	0.1415	0.04594
15	Conventional Wood Stove	Birch	Low	Hot	1.561E-03	5.997	4.454	0.03023	0.02926	0.07881	0.02585
40	Oil Furnace	Oil #1	Single	Hot	0.05826	N/D	0.05253	0.09395	5.273E-06	0.09062	4.919E-04
17	Oil Furnace	Oil #2	Single	Hot	0.09489	0.002654	0.05969	0.06233	0.004016	0.06619	1.452E-04
18	Waste Oil Burner	Waste Oil	Single	Hot	0.2620	0.08805	0.02474	0.3713	7.416E-05	0.3700	2.578E-04
35	Coal Stove	Wet Stoker Coal	High	Hot	0.1289	3.547	0.5853	0.1629	0.02729	0.2082	0.01122
23	Coal Stove	Wet Stoker Coal	Low	Hot	0.02047	5.912	1.375	0.1227	0.04985	0.2018	0.06846
39	Coal Stove	Wet Stoker Coal	Low	Cold	0.05298	3.998	1.042	0.1099	0.02795	0.1565	0.04919
20	Coal Stove	Dry Stoker Coal	High	Hot	0.08356	2.337	0.6359	0.1117	0.02516	0.1516	0.006246
21	Coal Stove	Dry Stoker Coal	Low	Hot	0.07507	5.040	0.6648	0.1144	0.04314	0.1804	0.04999
37	Coal Stove	Wet Lump Coal	Low	Hot	0.06504	5.755	0.6266	0.1394	0.02280	0.1767	0.05137
36	Coal Stove	Wet Lump Coal	Low	Cold	0.01631	3.866	1.406	0.1030	0.02978	0.1526	0.06800
38	Coal Stove	Dry Lump Coal	Low	Hot	0.04514	3.671	1.390	0.1358	0.02400	0.1761	0.02939
25	Non-Qualified OWHH	Spruce	High	Hot	0.006258	N/A	1.858	0.03960	0.02511	0.08065	0.01083
30	Non-Qualified OWHH	Spruce	Low	Hot	0.008866	4.941	3.847	0.04059	0.02748	0.08561	0.01447
31	Non-Qualified OWHH	Birch	High	Hot	0.003460	2.679	1.917	0.06013	0.05174	0.1446	0.02920
32	Non-Qualified OWHH	Birch	Low	Hot	0.01111	5.042	4.237	0.05580	0.07468	0.1788	0.03441
33	Non-Qualified OWHH	Birch	Low	Cold	0.004439	3.659	3.296	0.05366	0.06242	0.1563	0.04107
26	Non-Qualified OWHH	Wet Stoker Coal	Low	Hot	0.03196	N/A	2.021	0.09686	0.07197	0.2142	0.09488
27	Non-Qualified OWHH, Catalyst	Wet Stoker Coal	Low	Hot	0.008948	3.530	3.155	0.1488	0.07525	0.2702	0.1354
28	Auger-Fed HH	Wet Stoker Coal	Low	Cold	0.2071	0.5936	0.009203	0.1528	0.03401	0.2086	8.357E-04
29	Auger-Fed HH	Wet Stoker Coal	Low	Hot	0.2219	0.5014	0.005329	0.1557	0.03412	0.2116	1.736E-04

N/D = Below detection limit
N/A = No data available
>[value] = Exceeded instrument limit

Table 16. Emission Rate of Gas By-Products in g/hr, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Rate (g/hr)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.5681	11.09	1.986	5.050	0.1171	4.471	0.08029
40	Oil #1	Single	Hot	Oil Furnace	2.361	N/D	2.129	3.808	2.137E-04	3.673	0.01994
17	Oil #2	Single	Hot	Oil Furnace	4.502	0.1259	2.832	2.957	0.1905	3.140	0.006887
18	Waste Oil	Single	Hot	Waste Oil Burner	21.06	7.078	1.989	29.84	0.005961	29.74	0.02072
3	Spruce	High	Hot	EPA Wood Stove	0.1113	70.36	9.269	2.889	0.7484	3.707	0.1158
10	Spruce	High	Hot	EPA OWHH	0.002837	334.9	32.80	12.02	0.3301	12.51	0.3869
12	Spruce	High	Hot	Conventional Wood Stove	0.03949	89.52	23.08	4.468	0.7336	5.702	0.2774
25	Spruce	High	Hot	Non-Qualified OWHH	0.9604	N/A	285.2	6.076	3.854	12.38	1.662
6	Spruce	Low	Hot	EPA Wood Stove	0.02587	120.7	14.06	0.6780	0.1197	0.8919	0.1371
11	Spruce	Low	Hot	EPA OWHH	0.01611	230.9	77.30	3.320	0.7777	4.612	0.3078
14	Spruce	Low	Hot	Conventional Wood Stove	0.04720	359.3	125.8	2.267	0.9782	3.884	0.8025
30	Spruce	Low	Hot	Non-Qualified OWHH	0.6206	>345.8	>269.3	2.841	1.923	5.991	1.013
2	Birch	High	Hot	EPA Wood Stove	0.2107	108.7	6.613	3.095	1.082	4.556	0.1784
8	Birch	High	Hot	EPA OWHH	0.1965	301.9	104.6	19.80	0.2983	20.23	1.547
13	Birch	High	Hot	Conventional Wood Stove	0.2504	470.5	353.1	3.524	3.931	9.989	3.244
31	Birch	High	Hot	Non-Qualified OWHH	0.5069	>392.6	>281.0	8.812	7.582	21.20	4.279
5	Birch	Low	Hot	EPA Wood Stove	0.05873	74.59	23.36	1.249	0.1808	1.544	0.2409
41	Birch	Low	Cold	EPA Wood Stove	0.07125	101.1	26.96	2.299	0.6377	3.368	0.2079
9	Birch	Low	Hot	EPA OWHH	0.05227	207.5	75.77	6.042	0.6082	7.069	0.2916
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.1701	63.31	44.29	7.162	0.8584	8.534	0.3163
15	Birch	Low	Hot	Conventional Wood Stove	0.1100	422.5	313.8	2.130	2.062	5.554	1.821
32	Birch	Low	Hot	Non-Qualified OWHH	0.6068	>275.3	>231.3	3.046	4.077	9.761	1.880
33	Birch	Low	Cold	Non-Qualified OWHH	0.3818	314.8	283.4	4.615	5.370	13.45	3.531
35	Wet Stoker Coal	High	Hot	Coal Stove	3.835	105.5	17.41	4.847	0.8117	6.197	0.3149
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.3705	107.0	24.89	2.220	0.9022	3.653	1.239
39	Wet Stoker Coal	Low	Cold	Coal Stove	1.706	128.7	33.54	3.537	0.8999	5.038	1.583
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	1.998	N/A	126.4	6.055	4.501	13.39	5.933
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.3524	139.1	124.2	5.859	2.963	10.64	5.333
28	Wet Stoker Coal	Low	Cold	Auger-Fed HH	49.91	143.1	2.218	36.82	8.197	50.27	0.2014
29	Wet Stoker Coal	Low	Hot	Auger-Fed HH	50.74	114.7	1.219	35.61	7.804	48.39	0.03969
20	Dry Stoker Coal	High	Hot	Coal Stove	2.955	82.66	22.49	3.949	0.8896	5.362	0.2209
21	Dry Stoker Coal	Low	Hot	Coal Stove	1.466	98.44	12.99	2.236	0.8425	3.523	0.9764
37	Wet Lump Coal	Low	Hot	Coal Stove	1.212	107.3	11.68	2.597	0.4249	3.292	0.9573
36	Wet Lump Coal	Low	Cold	Coal Stove	0.4983	118.1	42.96	3.147	0.9102	4.663	2.078
38	Dry Lump Coal	Low	Hot	Coal Stove	0.9417	76.59	29.00	2.834	0.5006	3.673	0.6132

N/D = Below detection limit

N/A = No data available

>[value] = Exceeded instrument limit

Table 17. Emission Factor of Gas By-Products in g/kg of Dry Fuel, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Factor (g/kg dry fuel)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.2543	4.966	0.8891	2.260	0.05244	2.002	0.03594
40	Oil #1	Single	Hot	Oil Furnace	1.249	N/D	1.126	2.015	1.131E-04	1.943	0.01055
17	Oil #2	Single	Hot	Oil Furnace	2.104	0.05885	1.324	1.382	0.08905	1.468	0.003219
18	Waste Oil	Single	Hot	Waste Oil Burner	4.759	1.600	0.4495	6.745	0.001347	6.721	0.004684
3	Spruce	High	Hot	EPA Wood Stove	0.02560	16.19	2.133	0.6647	0.1722	0.8531	0.02666
10	Spruce	High	Hot	EPA OWHH	2.132E-04	25.16	2.464	0.9028	0.02480	0.9400	0.02907
12	Spruce	High	Hot	Conventional Wood Stove	0.002766	6.271	1.617	0.3130	0.05139	0.3995	0.01943
25	Spruce	High	Hot	Non-Qualified OWHH	0.04020	N/A	11.94	0.2543	0.1613	0.5181	0.06957
6	Spruce	Low	Hot	EPA Wood Stove	0.01462	68.23	7.942	0.3831	0.06766	0.5040	0.07749
11	Spruce	Low	Hot	EPA OWHH	0.002940	42.14	14.11	0.6058	0.1419	0.8416	0.05617
14	Spruce	Low	Hot	Conventional Wood Stove	0.007561	57.58	20.16	0.3634	0.1568	0.6226	0.1286
30	Spruce	Low	Hot	Non-Qualified OWHH	0.04583	>25.54	>19.89	0.2098	0.1420	0.4424	0.07480
2	Birch	High	Hot	EPA Wood Stove	0.05551	28.64	1.742	0.8152	0.2851	1.200	0.04698
8	Birch	High	Hot	EPA OWHH	0.01478	22.71	7.868	1.489	0.02244	1.522	0.1164
13	Birch	High	Hot	Conventional Wood Stove	0.02882	54.14	40.63	0.4056	0.4524	1.150	0.3733
31	Birch	High	Hot	Non-Qualified OWHH	0.02518	>19.50	>13.96	0.4378	0.3767	1.053	0.2126
5	Birch	Low	Hot	EPA Wood Stove	0.03928	49.89	15.62	0.8356	0.1209	1.033	0.1611
41	Birch	Low	Cold	EPA Wood Stove	0.02272	32.24	8.598	0.7332	0.2034	1.074	0.06632
9	Birch	Low	Hot	EPA OWHH	0.009038	35.87	13.10	1.045	0.1052	1.222	0.06380
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.03415	12.71	8.891	1.438	0.1723	1.713	0.06350
15	Birch	Low	Hot	Conventional Wood Stove	0.01514	58.18	43.21	0.2933	0.2839	0.7647	0.2507
32	Birch	Low	Hot	Non-Qualified OWHH	0.06015	>27.29	>22.93	0.3019	0.4041	0.9676	0.1863
33	Birch	Low	Cold	Non-Qualified OWHH	0.02561	21.12	19.01	0.3095	0.3602	0.9019	0.2369
35	Wet Stoker Coal	High	Hot	Coal Stove	1.562	42.96	7.089	1.974	0.3305	2.524	0.1359
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.2366	68.33	15.89	1.418	0.5762	2.333	0.7912
39	Wet Stoker Coal	Low	Cold	Coal Stove	0.7496	56.57	14.74	1.555	0.3955	2.214	0.6960
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	0.1830	N/A	11.60	0.5559	0.4132	1.229	0.5447
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.06218	24.54	21.92	1.034	0.5229	1.878	0.9411
28	Wet Stoker Coal	Low	Cold	Auger-Fed HH	3.248	9.311	0.1444	2.396	0.5334	3.271	0.01311
29	Wet Stoker Coal	Low	Hot	Auger-Fed HH	3.352	7.576	0.08052	2.353	0.5155	3.197	0.002622
20	Dry Stoker Coal	High	Hot	Coal Stove	1.153	32.26	8.778	1.541	0.3472	2.093	0.08622
21	Dry Stoker Coal	Low	Hot	Coal Stove	0.9785	65.70	8.666	1.492	0.5623	2.351	0.6516
37	Wet Lump Coal	Low	Hot	Coal Stove	0.8780	77.69	8.459	1.881	0.3078	2.385	0.6934
36	Wet Lump Coal	Low	Cold	Coal Stove	0.2238	53.05	19.29	1.413	0.4087	2.094	0.9331
38	Dry Lump Coal	Low	Hot	Coal Stove	0.6077	49.43	18.72	1.829	0.3231	2.371	0.3957

N/D = Below detection limit
N/A = No data available
>[value] = Exceeded instrument limit

Table 18. Emission Factor of Gas By-Products in MJ Input, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Factor (g/MJ input)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.01473	0.2876	0.05150	0.1309	0.003037	0.1159	0.002082
40	Oil #1	Single	Hot	Oil Furnace	0.04707	N/D	0.04244	0.07591	4.261E-06	0.07322	3.974E-04
17	Oil #2	Single	Hot	Oil Furnace	0.08009	0.002240	0.05038	0.05261	0.003389	0.05586	1.225E-04
18	Waste Oil	Single	Hot	Waste Oil Burner	0.1839	0.06181	0.01737	0.2606	5.206E-05	0.2597	1.810E-04
3	Spruce	High	Hot	EPA Wood Stove	0.001590	1.006	0.1325	0.04128	0.01070	0.05298	0.001656
10	Spruce	High	Hot	EPA OWHH	1.324E-05	1.562	0.1530	0.05607	0.001540	0.05838	0.001805
12	Spruce	High	Hot	Conventional Wood Stove	1.718E-04	0.3895	0.1004	0.01944	0.003192	0.02481	0.001207
25	Spruce	High	Hot	Non-Qualified OWHH	0.002497	N/A	0.7413	0.01580	0.01002	0.03218	0.004321
6	Spruce	Low	Hot	EPA Wood Stove	9.078E-04	4.237	0.4932	0.02379	0.004202	0.03130	0.004812
11	Spruce	Low	Hot	EPA OWHH	1.826E-04	2.617	0.8760	0.03762	0.008814	0.05227	0.003488
14	Spruce	Low	Hot	Conventional Wood Stove	4.696E-04	3.576	1.252	0.02257	0.009737	0.03867	0.007989
30	Spruce	Low	Hot	Non-Qualified OWHH	0.002846	1.586	1.235	0.01303	0.008820	0.02748	0.004645
2	Birch	High	Hot	EPA Wood Stove	0.003416	1.762	0.1072	0.05016	0.01755	0.07385	0.002891
8	Birch	High	Hot	EPA OWHH	9.097E-04	1.397	0.4842	0.09164	0.001381	0.09365	0.007162
13	Birch	High	Hot	Conventional Wood Stove	0.001774	3.332	2.500	0.02496	0.02784	0.07074	0.02297
31	Birch	High	Hot	Non-Qualified OWHH	0.001550	1.200	0.8590	0.02694	0.02318	0.06480	0.01308
5	Birch	Low	Hot	EPA Wood Stove	0.002417	3.070	0.9615	0.05142	0.007441	0.06355	0.009916
41	Birch	Low	Cold	EPA Wood Stove	0.001398	1.984	0.5291	0.04512	0.01252	0.06611	0.004081
9	Birch	Low	Hot	EPA OWHH	5.561E-04	2.207	0.8062	0.06429	0.006472	0.07522	0.003926
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.002102	0.7821	0.5471	0.08848	0.01060	0.1054	0.003907
15	Birch	Low	Hot	Conventional Wood Stove	9.319E-04	3.580	2.659	0.01805	0.01747	0.04705	0.01543
32	Birch	Low	Hot	Non-Qualified OWHH	0.003701	1.679	1.411	0.01858	0.02487	0.05954	0.01146
33	Birch	Low	Cold	Non-Qualified OWHH	0.001600	1.300	1.170	0.01900	0.0222	0.05550	0.01458
35	Wet Stoker Coal	High	Hot	Coal Stove	0.08134	2.238	0.3693	0.1028	0.01722	0.1314	0.007079
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.01232	3.559	0.8278	0.07384	0.03001	0.1215	0.04121
39	Wet Stoker Coal	Low	Cold	Coal Stove	0.03905	2.946	0.7678	0.08098	0.02060	0.1153	0.03625
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	0.009555	N/A	0.6043	0.02896	0.02152	0.06404	0.02837
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.003239	1.278	1.142	0.05385	0.02724	0.09781	0.04902
28	Wet Stoker Coal	Low	Cold	Auger-Fed HH	0.1692	0.4850	0.007519	0.1248	0.02779	0.1704	6.828E-04
29	Wet Stoker Coal	Low	Hot	Auger-Fed HH	0.1746	0.3946	0.004194	0.1225	0.02685	0.1665	1.366E-04
20	Dry Stoker Coal	High	Hot	Coal Stove	0.06008	1.680	0.4572	0.08029	0.01809	0.1090	0.004491
21	Dry Stoker Coal	Low	Hot	Coal Stove	0.05097	3.422	0.4514	0.07771	0.02929	0.1225	0.03394
37	Wet Lump Coal	Low	Hot	Coal Stove	0.04735	4.190	0.4562	0.1015	0.01660	0.1286	0.03739
36	Wet Lump Coal	Low	Cold	Coal Stove	0.01207	2.861	1.040	0.07619	0.02204	0.1129	0.05032
38	Dry Lump Coal	Low	Hot	Coal Stove	0.03277	2.665	1.009	0.09863	0.01742	0.1278	0.02134

N/D = Below detection limit
N/A = No data available
>[value] = Exceeded instrument limit

Table 19. Emission Factor of Gas By-Products in MJ Output, by Fuel Type and Burn Rate

Run	Fuel	Burn Rate	Start	Appliance	Emission Factor (g/MJ output)						
					SO_2	CO	VOC (as C)	NO	NO_2	NO_x	NH_3
1	Pellets	Single	Hot	Pellet Stove	0.02043	0.3989	0.07143	0.1816	0.004212	0.1607	0.002888
40	Oil #1	Single	Hot	Oil Furnace	0.05826	N/D	0.05253	0.09395	5.273E-06	0.09062	4.919E-04
17	Oil #2	Single	Hot	Oil Furnace	0.09489	0.002654	0.05969	0.06233	0.004016	0.06619	1.452E-04
18	Waste Oil	Single	Hot	Waste Oil Burner	0.2620	0.08805	0.02474	0.3713	7.416E-05	0.3700	2.578E-04
3	Spruce	High	Hot	EPA Wood Stove	0.002057	1.301	0.1714	0.05340	0.01384	0.06854	0.002142
10	Spruce	High	Hot	EPA OWHH	1.633E-05	1.926	0.1887	0.06914	0.001899	0.07199	0.002226
12	Spruce	High	Hot	Conventional Wood Stove	3.416E-04	0.7744	0.1996	0.03865	0.006346	0.04932	0.002400
25	Spruce	High	Hot	Non-Qualified OWHH	0.006258	N/A	1.858	0.03960	0.02511	0.08065	0.01083
6	Spruce	Low	Hot	EPA Wood Stove	0.001299	6.062	0.7056	0.03403	0.006011	0.04478	0.006884
11	Spruce	Low	Hot	EPA OWHH	2.597E-04	3.723	1.246	0.05351	0.01254	0.07435	0.004962
14	Spruce	Low	Hot	Conventional Wood Stove	7.599E-04	5.786	2.026	0.03652	0.01576	0.06257	0.01293
30	Spruce	Low	Hot	Non-Qualified OWHH	0.008866	4.941	3.847	0.04059	0.02748	0.0856	0.01447
2	Birch	High	Hot	EPA Wood Stove	0.005053	2.607	0.1586	0.07420	0.02596	0.1092	0.004277
8	Birch	High	Hot	EPA OWHH	0.001122	1.723	0.5970	0.1130	0.001703	0.1155	0.008831
13	Birch	High	Hot	Conventional Wood Stove	0.003548	6.664	5.000	0.04992	0.05568	0.1415	0.04594
31	Birch	High	Hot	Non-Qualified OWHH	0.003460	2.679	1.917	0.06013	0.05174	0.1446	0.02920
5	Birch	Low	Hot	EPA Wood Stove	0.003433	4.361	1.366	0.07304	0.01057	0.09027	0.01409
41	Birch	Low	Cold	EPA Wood Stove	0.002012	2.854	0.7613	0.06492	0.01801	0.09512	0.005872
9	Birch	Low	Hot	EPA OWHH	7.734E-04	3.070	1.121	0.08942	0.009001	0.1046	0.005460
34	Birch	Low	Hot	EPA OWHH, Catalyst	0.003204	1.192	0.8340	0.1349	0.01616	0.1607	0.005956
15	Birch	Low	Hot	Conventional Wood Stove	0.001561	5.997	4.454	0.03023	0.02926	0.07881	0.02585
32	Birch	Low	Hot	Non-Qualified OWHH	0.01111	5.042	4.237	0.05580	0.07468	0.1788	0.03441
33	Birch	Low	Cold	Non-Qualified OWHH	0.004507	3.661	3.295	0.05352	0.06254	0.1563	0.04107
35	Wet Stoker Coal	High	Hot	Coal Stove	0.1289	3.547	0.5853	0.1629	0.02729	0.2082	0.01122
23	Wet Stoker Coal	Low	Hot	Coal Stove	0.02047	5.912	1.375	0.1227	0.04985	0.2018	0.06846
39	Wet Stoker Coal	Low	Cold	Coal Stove	0.05298	3.998	1.042	0.1099	0.02795	0.1565	0.04919
26	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH	0.03196	N/A	2.021	0.09686	0.07197	0.2142	0.09488
27	Wet Stoker Coal	Low	Hot	Non-Qualified OWHH, Catalyst	0.008948	3.530	3.155	0.1488	0.07525	0.2702	0.1354
28	Wet Stoker Coal	Low	Cold	Auger-Fed HH	0.2071	0.5936	0.009203	0.1528	0.03401	0.2086	8.357E-04
29	Wet Stoker Coal	Low	Hot	Auger-Fed HH	0.2219	0.5014	0.005329	0.1557	0.03412	0.2116	1.736E-04
20	Dry Stoker Coal	High	Hot	Coal Stove	0.08356	2.337	0.6359	0.1117	0.02516	0.1516	0.006246
21	Dry Stoker Coal	Low	Hot	Coal Stove	0.07507	5.040	0.6648	0.1144	0.04314	0.1804	0.04999
37	Wet Lump Coal	Low	Hot	Coal Stove	0.06504	5.755	0.6266	0.1394	0.02280	0.1767	0.05137
36	Wet Lump Coal	Low	Cold	Coal Stove	0.01631	3.866	1.406	0.1030	0.02978	0.1526	0.06800
38	Dry Lump Coal	Low	Hot	Coal Stove	0.04514	3.671	1.390	0.1358	0.02400	0.1761	0.02939

N/D = Below detection limit
N/A = No data available
>[value] = Exceeded instrument limit

Table 20. Particulate Emissions and Efficiency, by Run

Run	Appliance	Fuel	Burn Rate	PM2.5 Emissions (g/hr)	PM2.5 Emissions Factor (g/kg)	Lower Heating Value Efficiency* (%)	Emissions (g/MJ input)	Emissions (g/MJ output)
1	Pellet Stove	Alaskan Pellets	Single	3.31	1.48	72.1	0.080	0.111
2	EPA Certified Woodstove	Birch	High	2.00	0.53	67.6	0.030	0.045
3	EPA Certified Woodstove	Spruce	High	1.27	0.30	77.3	0.017	0.022
5	EPA Certified Woodstove	Birch	Low	6.17	4.11	70.4	0.235	0.334
6	EPA Certified Woodstove	Spruce	Low	1.68	0.95	69.9	0.055	0.079
8	EPA Qualified OWHH	Birch	High	10.72	0.81	81.1**	0.046	0.057
9	EPA Qualified OWHH	Birch	Low	14.07	2.66	71.9**	0.152	0.212
10	EPA Qualified OWHH	Spruce	High	5.12	0.38	81.1**	0.022	0.027
11	EPA Qualified OWHH	Spruce	Low	4.32	0.79	70.3**	0.046	0.065
12	Conventional Woodstove	Spruce	High	2.89	0.45	50.3	0.026	0.051
13	Conventional Woodstove	Birch	High	94.56	10.89	50	0.623	1.246
14	Conventional Woodstove	Spruce	Low	14.89	2.39	61.8	0.138	0.223
15	Conventional Woodstove	Birch	Low	44.92	6.19	59.7	0.354	0.593
17	Central Heating Indoor Furnace	No. 2 Heating Oil	Single	0.25	0.12	78.5	0.003	0.003
18	Waste Oil Burner	Waste Motor Oil	Single	10.41	0.67	66.2	0.015	0.023
20	Coal Stove	Dry Stoker Coal	High	17.45	6.61	71.9	0.330	0.459
21	Coal Stove	Dry Stoker Coal	Low	1.74	1.16	67.9	0.058	0.085
23	Coal Stove	Stoker Coal	Low	11.13	7.09	60.2	0.354	0.589
25	Non Qualified OWHH	Spruce	High	130.10	7.01	51.5**	0.405	0.787
26	Non Qualified OWHH	Coal	Low	294.60	27.05	29.9**	1.352	4.522
27	Non Qualified OWHH	Coal w/ ClearStak	Low	135.60	23.92	36.2**	1.195	3.302
28	Auger-fed HH	Coal (cold start)	Low	7.28	0.45	81.7	0.023	0.028
29	Auger-fed HH	Coal (hot start)	Low	7.71	0.47	78.7	0.024	0.030
30	Non Qualified OWHH	Spruce	Low	166.60	12.30	33.1**	0.711	2.150
31	Non Qualified OWHH	Birch	High	119.30	5.93	44.8**	0.339	0.757
32	Non Qualified OWHH	Birch	Low	44.47	4.41	33.3**	0.252	0.757
33	Non Qualified OWHH	Birch (cold start)	Low	34.75	2.33	35.5**	0.133	0.376
34	EPA Qualified OWHH	Birch w/ ClearStak	Low	33.82	6.79	65.6**	0.389	0.592
35	Coal Stove	Stoker Coal	High	7.83	3.18	63.1	0.159	0.252
36	Coal Stove	Lump Coal (cold start)	Low	16.32	6.48	74	0.335	0.453
37	Coal Stove	Lump Coal	Low	2.75	1.99	72.8	0.103	0.142
38	Coal Stove	Dry Lump Coal	Low	8.19	5.28	72.6	0.274	0.377
39	Coal Stove	Stoker Coal (cold start)	Low	14.49	6.36	73.7	0.318	0.431
40	Central Heating Indoor Furnace	No. 1 Heating Oil	Single	0.31	0.16	80.2	0.004	0.004
41	EPA Certified Woodstove	Birch (cold start)	Low	6.86	2.18	69.5	0.125	0.180

*Efficiencies calculated using CSAB415.1-10 Stack Loss Method unless otherwise noted

**Efficiencies calculated per EPA Method 28 WHH, based on delivered heat output to the load side of the heat exchanger

4. Summary

4.1 Scope and Methods

A wide variety of source testing measurements were taken on a selection of home heating appliances. Emissions from nine appliances, each representative of a popular category, were sampled while burning fuel local to the Fairbanks North Star Borough area. Wood-burning appliances included a conventional wood stove, an EPA certified wood stove, and one each of EPA Phase-II qualified and non-qualified outdoor wood-fired hydronic heaters. The wood used for these tests was birch and spruce cordwood of typical moisture. A coal stove utilized local coal, both typical moisture and air-dried. A pellet stove used local wood pellets. Heating oil (both #1 and #2) was burned in an oil heater. Finally, used motor oil from local sources was used to fuel a waste oil burner.

Sampling was conducted using four separate systems, three of which sampled out of a dilution tunnel. The first was a gas sampling system which measured volatile organic compounds, SO_2, CO, NO, and NO_x. Combustion gas (O_2, CO_2, and CO) gas measurements were taken directly from the stack. The third system sampled ammonia as nitrogen by pulling the sample though sulfuric acid which was then recovered and analyzed for nitrogen. Finally, particulate matter was sampled using a single cyclone head to deliver particulate matter under 2.5 microns in diameter to four sample filters. All of the sampling performed was governed by applicable EPA methods.

4.2 Summary of Results

4.2.1 Comparison of Emissions per Useful Heat Output

In an effort to compare the performance of a wide variety of appliances, the following figures were created to provide some illustrations of the particulate matter emissions based on the amount of useful heat created.

Figure 7 shows the various single room heating, wood-burning appliances tested. The data shows that EPA certified stoves burn cleaner than the older, conventional stoves. Additionally, it appears that for these appliances spruce generally burns cleaner than birch.

Figure 7. Particulate Emissions per Useful Heat Output, Wood Burning Space Heaters

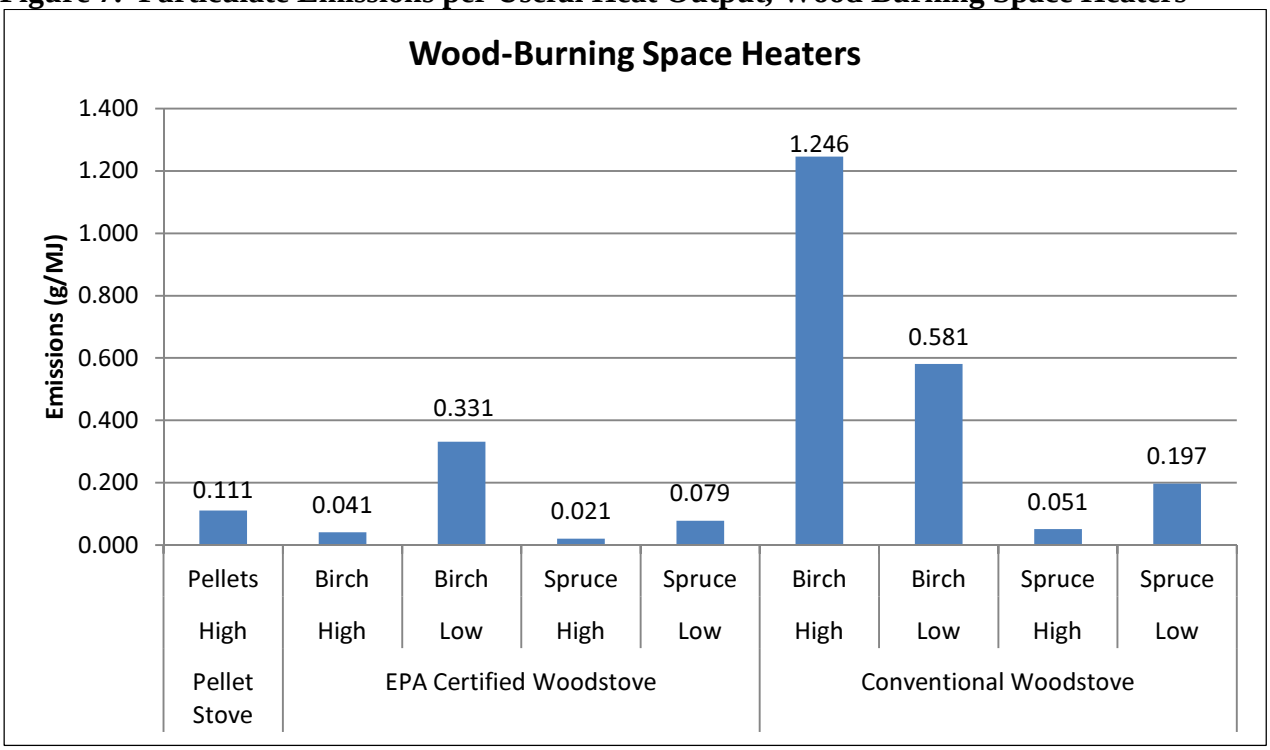


Figure 8 is a comparison of outdoor hydronic heaters, burning both wood and coal. Again, the EPA qualified model is significantly cleaner than the non-qualified unit, which produced extremely high emissions while burning coal. Due to difficulties encountered during testing (See section 2.4.8), the uncertainty of the results for that appliance is much higher than that of other appliances. However, OMNI is confident that the very high emissions of the unit are accurately reflected by the data, and therefore the data is still useful for comparative purposes. The auger-fed HH shows that coal can be burned in a clean manner. With regards to the wood burning devices, there does not appear to be a significant difference between birch and spruce.

Figure 8. Particulate Emissions per Useful Heat Output, Outdoor Hydronic Heaters

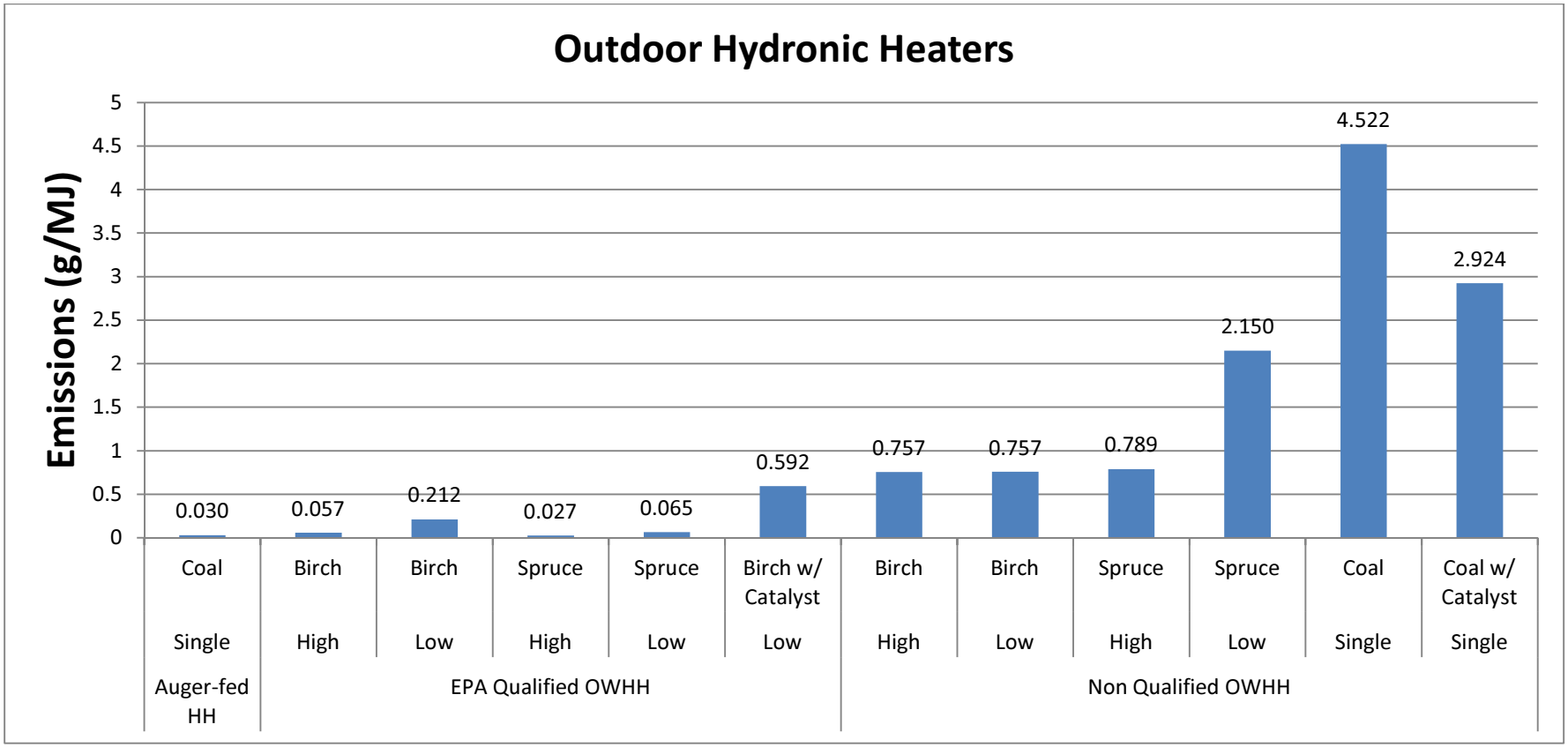


Figure 9 shows the results of the coal-fired room heater. There does not appear to be any particular pattern or favorable fuel based on the available data. Comparing it the wood-burning room heaters, the performance is similar to that of the conventional wood stove.

Figure 9. Particulate Emissions per Useful Heat Output, Coal Heater

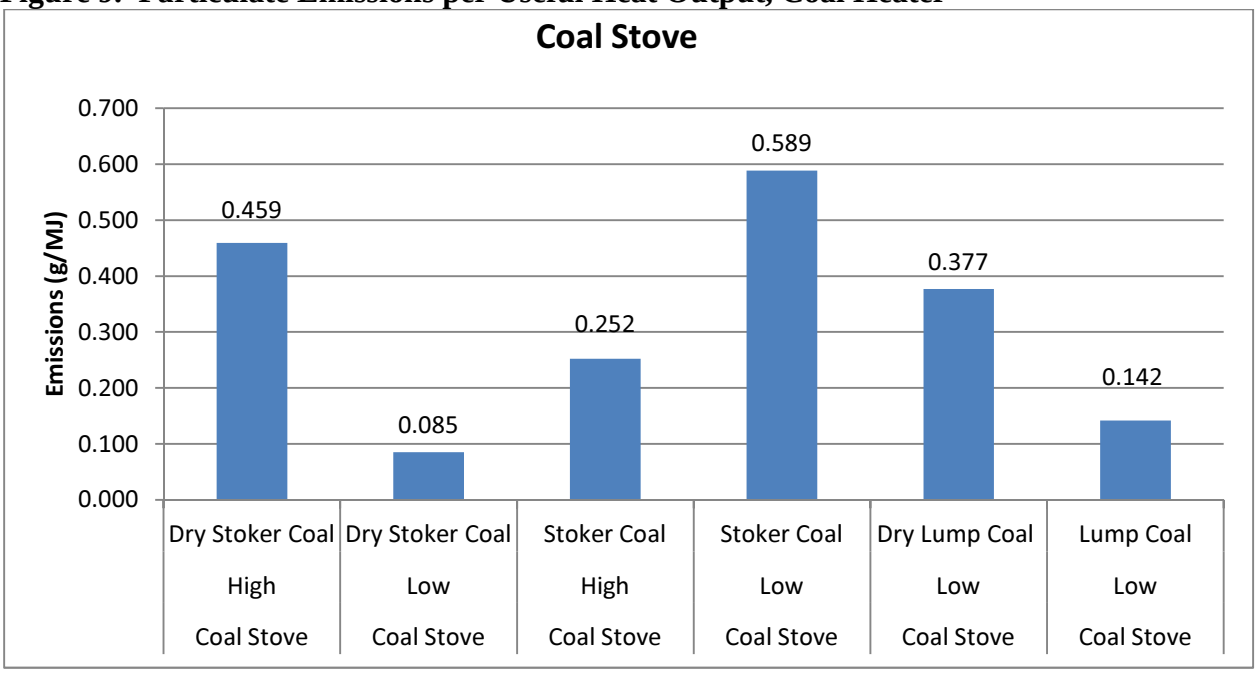
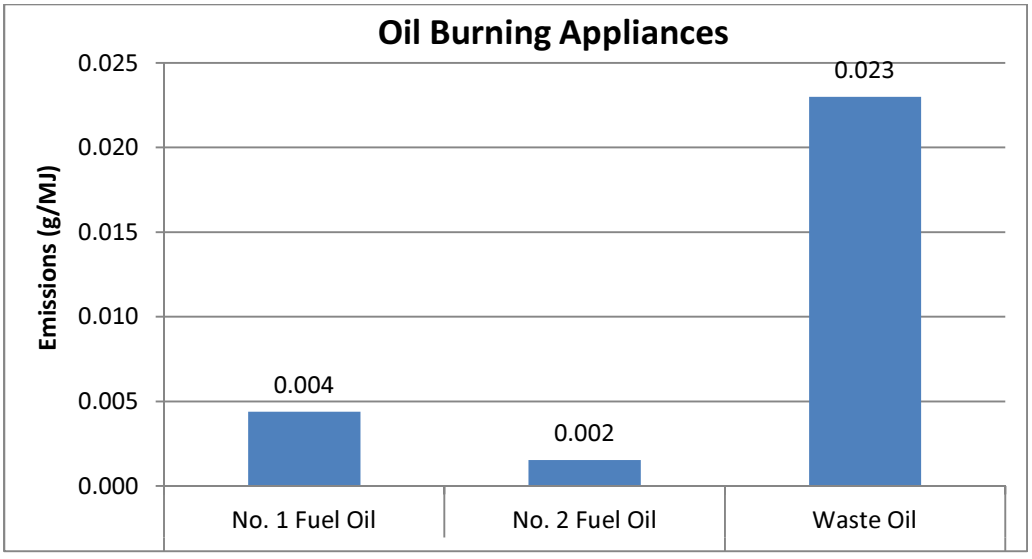


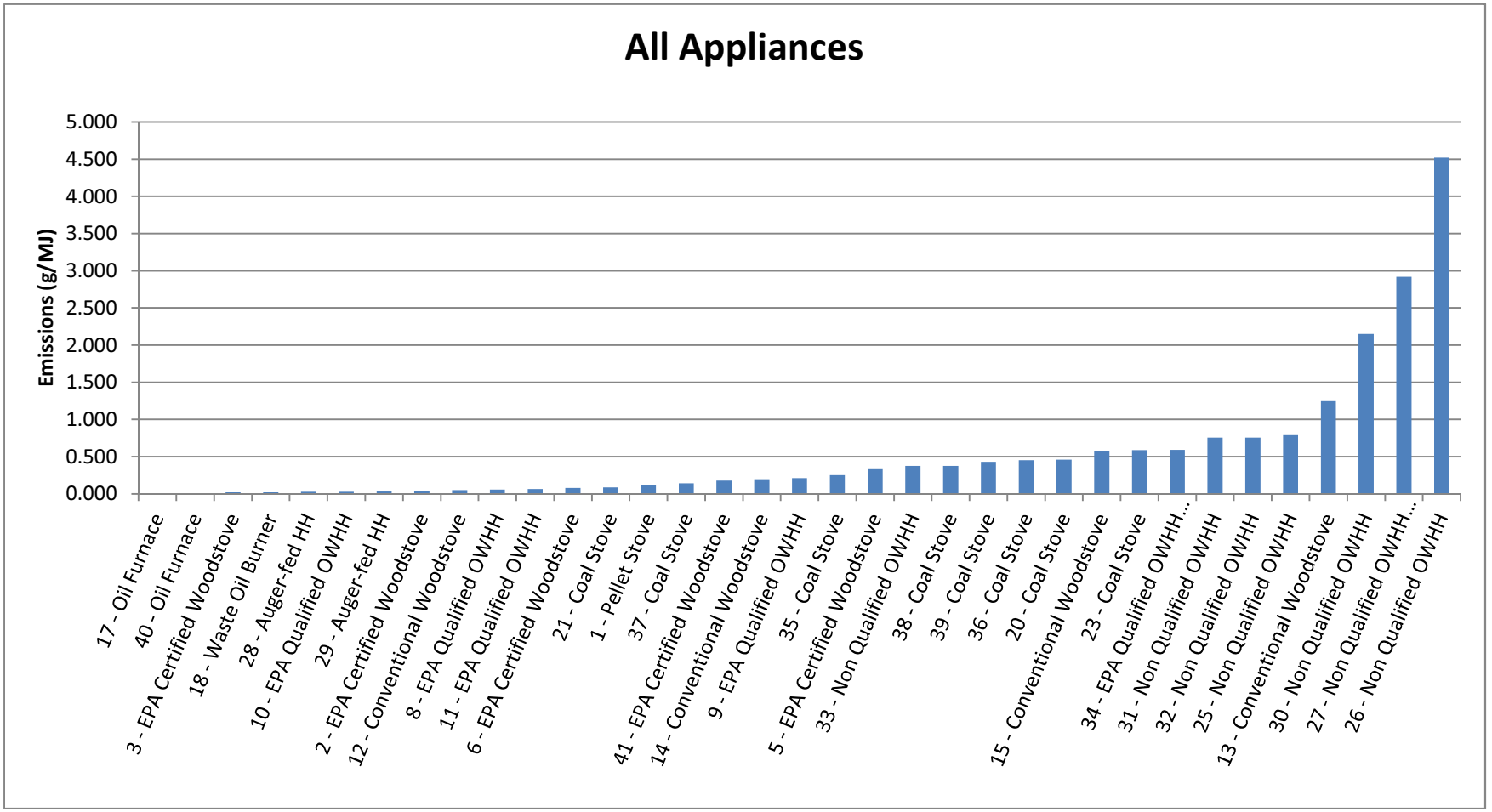
Figure 10 shows that all oil fuels produce low amounts of particulate matter. The makeup of the emissions from the waste oil burner is of particular note, however, due to additional compounds found in the fuel. Increased levels of chlorine, phosphorous, potassium and zinc were observed for this run. See Appendix A for a full analysis.

Figure 10. Particulate Emissions per Useful Heat Output, Oil-Burning Furnaces



Finally, Figure 11 shows a comparison of all appliances tested. With the exception of some overlap, there is a clear delineation between cleaner burning appliances and high emissions appliances. The models that are EPA certified or qualified are, in general, more efficient and cleaner burning. Additionally, all of the continuously fed units - the auger-fed HH, and the oil units - are designed for optimal burning conditions and efficiency, which is reflected in the data.

Figure 11. Particulate Emissions per Useful Heat Output, All Appliances



4.2.2 Cold Start Comparison

The emissions of a cold start test can be modeled as emissions from each phase (fuel load) of the test, that is, the kindling phase, the preburn phase, and the test fuel phase. Emissions (in terms of total particulate) from each phase are added together to generate total emissions for the run:

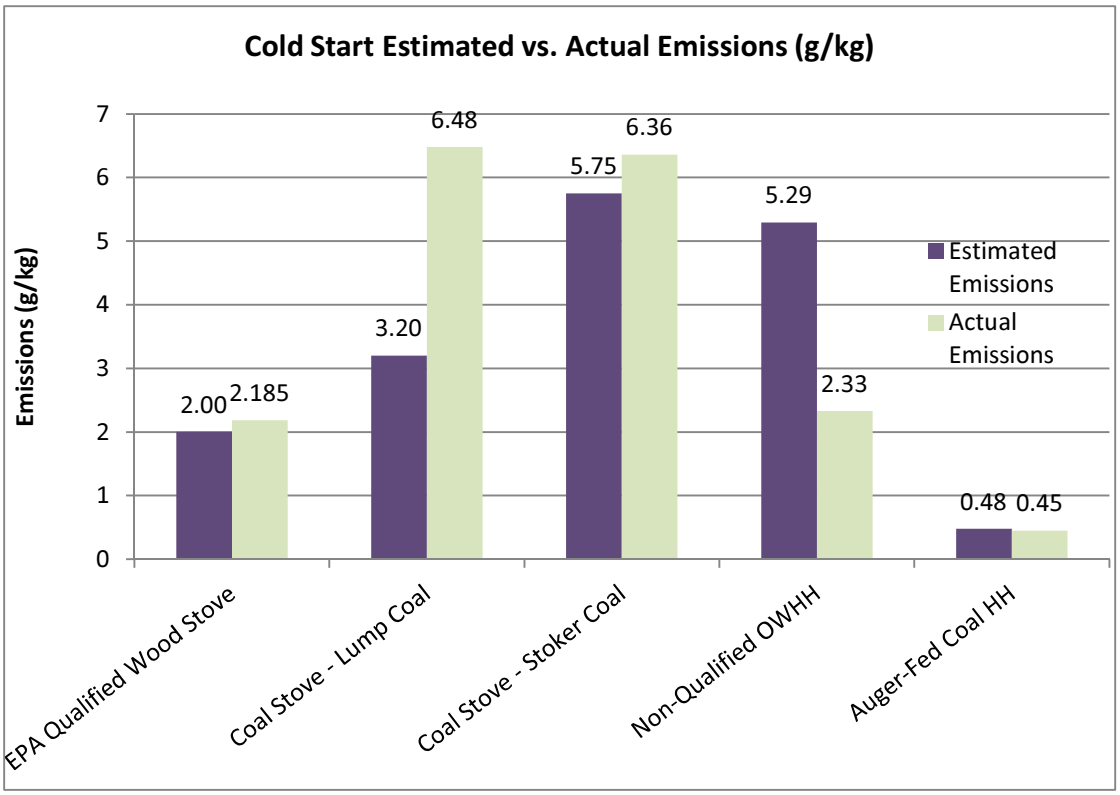
$$E_{Cold\ Start} = E_{Kindling} + E_{Preburn} + E_{Test\ Fuel}$$

Similarly, emissions factors (in grams per kilogram) can be added together to generate an estimated overall emissions factor for the run. These emissions factors come from tests performed earlier in the study. An example governing equation (for a birch low burn cold start) is shown below:

$$EF_{Cold\ Start} = \frac{EF_{Birch\ High}(m_{Kindling}) + EF_{Birch\ High}(m_{Preburn}) + EF_{Birch\ Low}(m_{Test\ Fuel})}{m_{Total}}$$

Using this method, expected emission rates were calculated for each cold start test. These data points were then compared to the actual emission rates for these runs, the difference between the estimated and actual values are presumably the effect of higher emissions from the cold start. Results are shown in Figure 12. The results for the Non-Qualified OWHH seem to be anomalous and are most likely the effect of high variability in a high emissions unit burning large quantities of fuel.

Figure 12. Comparison of Expected and Actual Cold Start Emissions



4.2.3 AP-42 Data Comparison

The issue has been raised that data generated by OMNI for this report are, in some cases, inconsistent with data from AP-42, *Compilation of Air Pollutant Emission Factors*. See Figure 13 for PM2.5 comparison data. This section of the report has been prepared to address the potential reasons for the discrepancy.

Table 21. PM2.5 Comparison of OMNI and AP42 Data

	PM 2.5 (lb/ton)	
	OMNI	**AP42 [1]**
Conventional Wood Stove	0.9-21.8	30.6
EPA-certified Wood Stove	0.6-8.2	14.6-20.0
Non-qualified OWHH	4.7-54.1	27.0*
EPA-qualified OWHH	0.8-5.3	4.3-8.1*
Pellet Stove	3.0	4.2-8.8
Oil Furnace	0.2-0.3	0.1*
Waste Oil	1.3	7.4*
Coal Stove	2.3-14.2	6.2

*Alaska emission inventory estimates (based on AP-42 or other sources, with assumed fuel properties)

While the coal stove and oil furnace data is similar in both the OMNI and AP-42 studies, for all other appliances the OMNI emissions rates are noticeably lower. The causes of this can be found in differences between the data collection procedures.

A primary goal of OMNI's testing was a high degree of consistency between runs due to small sample size. This was achieved by the use of EPA Method 28, which governs testing procedures for wood-fired appliances. Method 28 was written to assure consistent, comparable results across different appliances, making it ideal for this testing.

AP-42 is intended as a compendium of emissions data. The data collection procedure for wood stove emissions is described as follows in this excerpt from the 5th edition of the report, "The emission factors for PM and CO in Tables 1.10-1 and 1.10-2 are averages, derived entirely from field test data obtained under actual operating conditions." [2] The realism of the reported averages was achieved by virtue of the wide array of differences between the studies, and variability within those studies, which together create a large amalgam of field-use situations.

The data show that Method 28 results are moderately lower than field results. This is strongly supported by data from a field use study very similar to those cited by AP-42, *Long-Term Performance of EPA-Certified Phase 2 Woodstoves, Klamath Falls and Portland, Oregon: 1998/1999*. This study generated field emissions rate values for several stoves already certified by the EPA. A comparison between the emissions rates generated from certification testing and those from field testing is shown in Figure 14.

Table 22. Method 28 vs. Field Data

Appliance Name	Emissions Rate (Method 28 Certification) [g/hr] [3]	Emissions Rate (field) [g/hr][4]
Hearth and Home Quadrafire 2100	2.0	8.9
Pacific Energy Super 27	3.4	5.2
Waterford Stanley Limited 104 MK II	2.9	4.0
Country Stoves T-Top	5.7	9.9

This data shows that Method 28 results tend to have lower emissions rates than actual field testing. The differences in emission rates between OMNI and AP-42 data are primarily due to this discrepancy.

References

1. AP- 42 *Compilation of Air Pollutant Emission Factors,* United States Environmental Protection Agency, October 1996.

2. ibid.

3. *List of EPA Certified Wood Stoves,* United States Environmental Protection Agency, September 2011

4. L . H. Fisher, J. E. Houck, P. E. Tiegs, J. McGaughey, In *Long-Term Performance of EPA-Certified Phase 2 Woodstoves, Klamath Falls and Portland, Oregon: 1998/1999*, OMNI Environmental Services, Inc., Beaverton, OR, 1999.

Cold Climate Housing Research Center
CCHRC

Wood Storage Best Practices in Fairbanks, Alaska

June 27, 2011

A project report prepared by CCHRC for:
Sierra Research

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Executive Summary

It is a common notion that firewood takes multiple years to fully cure in Fairbanks, Alaska, however, there is a lack of documented evidence to refute or confirm this belief. To determine the storage methods and time necessary to fully cure firewood in Fairbanks, CCHRC studied the moisture content of firewood stored using a variety of methods for spring and fall tree harvests. The spring harvest was conducted in April and May 2010; the fall harvest was conducted in September 2010. All firewood was monitored for moisture content from the harvest until May 2011, unless a full cure (20% moisture content) was reached before that time.

This study shows that if firewood from a spring harvest is split, several firewood storage methods allow for rapid curing over the summer months, achieving moisture contents equal to or less than 20% in 6 weeks to 3 months. When firewood was kept as whole logs, it was unable to fully cure over the summer under any storage scenario. Whole logs contained between 21% and 43% moisture content by late summer 2010; however, some storage scenarios with whole spruce logs cured fully by May 2011. The type of wood and storage method were important variables, but less so than whether the firewood was split or unsplit. Aspen tended to dry more slowly than birch or spruce, and uncovered firewood was at risk of gaining moisture from rain.

In contrast, firewood harvested in fall did not cure fully by any means of storage or preparation throughout the study period. However, it is notable that split firewood stored in a simulated wood shed dried significantly throughout the winter.

The method of firewood storage was more significant during the winter than the summer. While all storage methods allowed for rapid drying of the spring-harvested firewood over summer, the tarp-covered and uncovered firewood dried slower than firewood stored in a simulated wood shed over the winter. Some tarp-covered and uncovered firewood accumulated a significant amount moisture over the winter. Firewood in a simulated wood shed from the spring harvest only showed a small increase of moisture content over the winter, while firewood from the fall harvest cured significantly.

The results of this study clearly demonstrate that it is possible to dry firewood cut in the spring in Fairbanks over a single summer to moisture content levels that optimize wood burning efficiency and minimize emissions. This finding deserves some caution in generalizing to all locations in the Fairbanks vicinity, as the wood was stored in an open field with minimal obstruction of solar radiation and air movement.

Introduction

The use of firewood for space heating is a significant contributing factor to winter-season PM2.5 in the Fairbanks airshed. Furthermore, it is suspected that burning inadequately cured firewood is a contributing factor that could be partially mitigated by changes in firewood storage and curing methods. Burning dry wood provides immediate benefit for homeowners by optimizing heat output while reducing the release of particulate air pollutants. However, ensuring an adequate supply of dry firewood requires preparation and planning, including knowledge of appropriate storage methods and duration of storage to achieve a full cure.

This project is designed to study the time necessary to achieve an adequate cure of firewood (i.e. 20% moisture content) for common storage scenarios in Fairbanks, Alaska. The data generated from this study are intended for use in an educational campaign to teach homeowners best practices for firewood storage.

Project Structure

This report documents work conducted by CCHRC from Spring 2010 through early Summer 2011. The primary phases completed for this project are summarized below:

Spring Harvest

This project phase simulates the practice of homeowners planning ahead for the winter by allowing the firewood to dry over the summer months.

a. Work plan preparation;
b. Spring harvest of trees;
c. Cutting trees to length and segregation of piles;
d. Initial moisture content sampling and analysis;
e. Splitting and stacking of firewood in various storage scenarios;
f. Interim reporting (June 30, 2010);
g. Periodic sampling of storage scenarios for moisture content.

Fall Harvest / Continuation of Spring Harvest Monitoring

The fall harvest simulates the practice of homeowners who have not planned ahead for the needs of the upcoming heating season, or are preparing for long-term storage for subsequent heating seasons.

a. Fall harvest of trees;
b. Fall firewood preparation and storage;
c. Cutting of trees to length and segregation of piles;
d. Initial moisture content sampling and analysis;

e. Splitting and stacking of firewood in various storage scenarios;

f. Periodic sampling of storage scenarios for moisture content over the winter and spring;

g. Interim reporting (April 18, 2011);

h. Final project reporting.

CCHRC expected the moisture content of birch and aspen trees to be at a relative maximum in the spring and early summer, and a relative minimum in fall. As discussed in the results below, this anticipated standing tree moisture content variation was not observed. White spruce trees were not expected to show a strong seasonal variation in moisture content, which was observed in the moisture content data.

Study Variables

The following variables in wood storage and preparation were included in this study to determine how homeowners can achieve a moisture content of 20% or less of from an initial green wood condition.

Wood species

- White spruce
- Birch
- Aspen

Storage condition

- Covered on top and stacked on pallets (a simulated wood shed)
- Covered completely and stacked on the ground (covered with a tarp)
- Uncovered and stacked on the ground
- Within a solar kiln and stacked on the ground

Preparation

- Whole logs
- Split at least once

Season

- Spring tree harvest
- Fall tree harvest
- Drying over summer
- Drying over winter

CCHRC chose multiple means of storing firewood to study the effect of different storage methods on drying rates. Because of the large number of variables identified above, only some combinations could be studied directly. A total of 16 storage scenarios were studied from the spring harvest, and 10 storage scenarios were studied from the fall harvest, as detailed below.

Each storage scenario from the spring and fall harvests are comprised of approximately 0.75 to 1.0 cords of firewood, respectively, where a cord is defined as 128 cubic feet of stacked wood. Each of the firewood storage scenarios have subsets for whole and split logs, stored together in roughly equal volumes. Photographs of the storage scenarios are provided in Appendix A.

While referred to as “aspen,” the poplar trees included in this study are a mix of white and black poplar trees. In common language, these trees are referred to as “aspen” and “cottonwood”, respectively. Both poplar trees are common in Fairbanks vicinity, are similar in their heat content, and are commonly less desired as a fuel wood.

Acquisition and Storage of Firewood

Spring Harvest

CCHRC obtained a firewood cutting permit from the Environmental Division of the Fort Wainwright Directorate of Public Works, U.S. Army Alaska on April 23, 2010. This permit allowed CCHRC to harvest trees from specified areas on base through April 23, 2011. From April 27 through May 7, CCHRC cut approximately 5 to 6 cords of white spruce, birch and aspen trees from Fort Wainwright, which were brought to CCHRC's Research and Testing Facility. The trees cut were in the base's northwest corner within the lowlands and hillsides close to Birch Hill. All trees harvested were live, standing trees.

CCHRC secured an additional firewood gathering permit from the U.S. Army Corps of Engineers, Chena Flood Control Project on May 20, 2010. Firewood freshly cut for maintenance of the Flood Control Project was made available to the public. The permit allowed for only a single truck load of firewood, which CCHRC acquired on May 20. Approximately 0.75 cords of white spruce was hauled to CCHRC's Research and Testing Facility.

From mid- to late-May 2010, CCHRC prepared, sampled, and established the storage scenarios for the spring firewood harvest. The 8 storage scenarios are summarized below in Table 1, and documented by photographs included in Appendix A.

Table 1 – *Spring Firewood Sample Scenarios**

Wood Storage Method	**Birch**	**Spruce**	**Aspen**
Simulated wood shed	X	X	X
Covered with a tarp	X	X	
On ground and uncovered	X	X	
In a solar kiln			X

**Each scenario consists of approximately 0.75 cords of firewood*

First, CCHRC cut the firewood into approximately 12 – 16 inch lengths and divided the accumulated firewood into 8 roughly equal piles. These piles were then sampled to characterize the initial wood moisture content. Approximately half of each pile was then split at least once with an electric log splitter. The split and remaining whole logs were then stacked to be comingled. Each pile was then covered in accordance with the storage scenario plan, comprising a total of 16 different storage scenarios within 8 piles.

Fall Harvest

Under the same permit acquired previously from the U.S. Army Alaska, in mid-September 2011 CCHRC harvested approximately 5 cords of white spruce, birch, and aspen from the hillside area of the former Birch Hill Tank Farm. All trees harvested were live, standing trees. From mid- to late-September, CCHRC prepared, sampled, and established storage scenarios for the fall firewood harvest. The 8 storage scenarios are summarized below in Table 2, and documented by photographs in Appendix A.

Table 2 – *Fall Firewood Sample Scenarios*			
Wood Storage Method	**Birch**	**Spruce**	**Aspen**
Simulated wood shed	X	X	X
Covered with a tarp	X	X	

**Each scenario consists of approximately one cord of firewood*

CCHRC cut the firewood into approximately 12 – 16 inch lengths and divided the accumulated firewood into 5 roughly equal piles. These piles were then sampled to characterize the initial wood moisture content. Approximately half of each pile was then split at least once with an electric log splitter. The split and remaining whole logs were then stacked to be comingled and covered in accordance with the storage scenarios, comprising a total of 10 different storage scenarios within 5 piles.

Deviations from Study Plan

The birch and spruce wood piles from the spring harvest intended to be fully covered were found in early May to be mostly uncovered due to the tarps being carried in the wind. The duration for which these 2 wood piles were uncovered is unknown, but potentially could have extended from mid-April through early-May 2011.

Sampling and Analysis

Sample Collection

Throughout the process of dividing the firewood into separate piles, whole logs were collected to characterize the initial wood moisture content. Each storage scenario was represented with a primary sample that filled a container approximately 4 cubic feet in volume, consisting of 4 to 8 whole logs, depending on log diameter.

Whereas the first sampling event for a harvest characterized the firewood's initial moisture content, all subsequent sampling events differentiated between split and whole logs stored under varying conditions. After the initial sampling event, each primary sample from a wood pile included 2 whole logs or 4 split logs. Final sampling events, such as August 2010 and May 2011 had larger primary samples (3 – 4 whole logs or 6 – 8 split logs). For each sampling event, logs were selected from throughout the pile.

When a monthly sampling event indicated that the moisture content of a specific storage scenario was at or under 20%, then the subsequent sampling event was conducted as a final sampling (i.e. more logs in the primary sample) to ensure accurate documentation of the final firewood condition.

During sampling of the firewood piles in winter, bulk snow and frost was brushed from the logs prior to subsampling and analysis; however, this sample preparation would not remove ice and hardened frost. This methodology was adopted to simulate the most probable user behavior in handling firewood.

Sample Preparation

The logs collected from the firewood piles constitute the primary samples, which require subsampling to allow for moisture content analysis. After collection, primary samples were stored as whole logs at CCHRC's Research and Testing Facility; subsamples were prepared from the primary samples within a few days of sample collection. Because firewood moisture content can vary within different zones of the wood, e.g. sapwood versus heartwood, cross-sectional discs approximately one inch thick were cut from the logs to ensure that each zone was represented proportionally in the analysis. Two cross-sectional discs were cut from each log in the primary sample: one from a log end and one from the log center. For large diameter logs, these discs were halved or quartered to facilitate subsequent drying and weighing. Subsamples were stored in a sealed plastic bag until ready for analysis. The determination of the wood disc mass before drying took place within 10 minutes to an hour after the discs were cut. Photographs of example firewood subsamples are provided in Appendix A.

Sample Analysis

CCHRC analyzed all firewood subsamples for moisture content following Method B of ASTM Standard Test Method D4442-07 (*Direct Moisture Content Measurement of Wood and Wood-Base Materials*). This method provides an absolute measure of firewood moisture content on a dry-weight basis. The drying oven used was a Quincy Lab convection oven model 40 GC. The mass balance used was an Acculab VICON with readability to 0.1 g. No attempt was made to differentiate the mass loss of water versus that of any other volatile constituents within the wood samples. All firewood moisture content

data presented are on a dry-weight basis. The moisture content results of individual subsamples, per ASTM D4442-07 Method B, are estimated to have a precision of ±1%.

The duration of oven time for each subsample varied based on practical considerations, such as drying overnight during the weekdays versus over weekends. Therefore drying time was not standardized for the subsamples, but was evaluated based on the stability of multiple mass measurements over time. When each subsample had changed approximately 0.5 grams or less in mass from the prior mass determination, the drying was considered complete. This provides a conservative determination of the drying endpoint following Method B of ASTM D4442-07.

Data Analysis

Because the goal of the primary sampling is to represent the entire firewood pile, and the intent of the subsampling is to represent the primary sample with a fraction amenable to analysis, the chosen method for calculating the average moisture content is:

$$Average\ moisture\ content_x = \frac{(\sum_{i=1}^{n} Initial\ mass_i) - (\sum_{i=1}^{n} Oven\ dry\ mass_i)}{\sum_{i=1}^{n} Oven\ dry\ mass} \ (100\%)$$

where $x = specific\ wood\ and\ storage\ scenario$

$$n = number\ of\ subsamples$$

This method accounts for the contribution of each subsample towards the total sample mass, and also allows for splitting large wood discs without over representing the disc as several subsamples. If it were practical to weigh the entire cord of stacked wood over time, that approach would be ideal (i.e. a census of the entire population available for sampling). Instead, the chosen approach was to collect a fragment of the entire pile mass to represent the whole mass. In other words, the moisture content of the individual subsamples isn't of interest, but rather the moisture content of the subsamples in aggregate as a representation of the entire wood pile.

Results for Firewood Moisture Content

The results from the moisture content monitoring for the spring firewood harvest are tabulated in Table 3 and illustrated in Figures 1a-d. The results for the fall firewood harvest are tabulated in Table 4 and illustrated in Figures 2a-b. The complete record of the moisture content data is contained in an electronic spreadsheet provided to Sierra Research.

The findings come with the caveat that the wood was stored in an open field with minimal obstruction of solar radiation and air movement. Wood piles stored in shade-covered areas will presumably require more time to cure, and large continuous firewood piles (e.g. multiple cords) may dry faster on the edges than within the pile.

Simulated Wood Shed

As shown in Figure 1a, the moisture content of spring harvest firewood stored in the simulated wood shed dropped rapidly over the summer months of 2010. Split firewood met the 20% moisture content criteria for a full cure within approximately 6 weeks to 3 months. Whole firewood logs dried less rapidly during the summer and did not dry over the winter. When grouped as “split” and “whole” logs, spruce dried most rapidly, followed by birch and aspen. The difference between the drying times for the different wood types was accentuated for whole logs.

The moisture content of the firewood from the fall harvest dropped steadily over the winter, but at a much slower rate than spring-harvested firewood over the summer (Figure 2a). As noted with the spring harvest, split wood dried substantially more than wood left as whole logs. However, none of the wood harvested in fall dried to 20% moisture content by the final sampling event in May 2011. The significance of wood types in the drying over the winter was much less distinct than for the spring harvest.

Fully (Tarp) Covered

The moisture content of the spring-harvest firewood covered by tarps lowered rapidly over the summer months (Figure 1b). Split firewood met the 20% moisture content criteria for a full cure within approximately 6 weeks to 3 months. The rate of drying was similar to the firewood stored in the simulated wood sheds, although it appears the wood covered by a tarp dried at a slightly lower rate. While the whole log moisture content remained approximately constant over the winter, the split spruce firewood gained some moisture by absorption or frost accretion. There is no data for the split birch covered with a tarp over winter, as that firewood reached a full cure by August 2010, therefore sampling was discontinued.

As shown in Figure 2b, the moisture content of fall-harvest firewood stored under tarps over the winter varied depending on wood type and preparation. Birch tended to decline in moisture content slowly, and without much difference in split and whole logs until the beginning of Summer 2011. Spruce firewood as whole logs dried over winter slightly, then regained some moisture content at the beginning of Summer 2011, whereas split spruce showed the opposite trend. None of the wood harvested in fall dried to 20% moisture content by the final sampling event in May 2011.

Uncovered

This storage method was studied only for the spring firewood harvest. The moisture content of the spring harvest firewood left uncovered fell rapidly over the summer months (Figure 1c). Split firewood met the 20% moisture content criteria for a full cure within approximately 6 weeks. The rate of drying was similar to the firewood stored in the simulated wood sheds. However, the uncovered firewood was highly susceptible to absorption of moisture from rain, snow, and frost. For example, the split birch had dried from an initial moisture content of 57% to 19% by early July, then had increased to 35% by late August, presumably due to rain immediately prior to the August sampling event. The moisture regained by the firewood over the late summer and winter had dissipated by the final sampling event in early summer 2011.

Solar Kiln

This storage method was studied only for the spring firewood harvest. The moisture content of the spring harvest firewood enclosed within a solar kiln dropped rapidly over the summer months (Figure 1d). The firewood stored in the solar kiln dried to lower moisture contents than the firewood stored in simulated wood sheds. However, due to heterogeneity of the moisture content amongst the various firewood piles, the initial condition of the aspen stored in the solar kiln was substantially lower than the aspen stored in the simulated wood shed. The rates of moisture loss in the aspen were very similar for the solar kiln and simulated wood shed storage methods.

Table 3 - Spring Wood Harvest, Summary of Moisture Content Data

Simulated Wood Shed						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Birch – split (PBS –S)	52%	20%	18%	Dry	Dry	Dry
Birch – whole (PBS – W)	52%	30%	25%	29%	28%	24%
Spruce – split (PSS – S)	86%	16%	17%	Dry	Dry	Dry
Spruce – whole (PSS – W)	86%	28%	21%	23%	24%	17%
Aspen – split (PAS – S)	76%	26%	20%	Dry	Dry	Dry
Aspen – whole (PAS – W)	76%	49%	44%	40%	--	26%

Tarp Covered						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Birch – split (TBS – S)	49%	21%	20%	Dry	Dry	Dry
Birch – whole (TBS – W)	49%	28%	31%	32%	--	25%
Spruce – split (TSS – S)	86%	22%	22%	35%	--	18%
Spruce – whole (TSS – W)	86%	67%	30%	29%	--	23%

Table 3 - Spring Wood Harvest, Summary of Moisture Content Data (continued)

Uncovered						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Birch – split (UBS – S)	57%	19%	35%	46%	38%	17%
Birch – whole (UBS – W)	57%	29%	32%	52%	39%	25%
Spruce – split (USS – S)	77%	17%	19%	Dry	Dry	Dry
Spruce – whole (USS – W)	77%	29%	27%	47%	29%	17%

Solar Kiln						
Wood Type	**Late May**	**Early July**	**Late Aug**	**Jan**	**March**	**May**
Aspen – split (KAS – S)	59%	24%	16%	Dry	Dry	Dry
Aspen – whole (KAS – W)	59%	38%	32%	34%	31%	27%

Table 4 - Fall Wood Harvest, Summary of Moisture Content Data

Simulated Wood Shed				
Wood Type	**Mid Sept**	**Jan**	**March**	**May**
Birch – split (PBF – S)	80%	49%	42%	30%
Birch – whole (PBF – W)	80%	55%	56%	47%
Spruce – split (PSF – S)	85%	63%	40%	37%
Spruce – whole (PSF – W)	85%	77%	72%	51%
Aspen – split (PAF – S)	83%	63%	51%	34%
Aspen – whole (PAF – W)	83%	65%	--	48%

Tarp Covered				
Wood Type	**Mid Sept**	**Jan**	**March**	**May**
Birch – split (TBF – S)	78%	63%	70%	49%
Birch – whole (TBF – W)	78%	67%	--	57%
Spruce – split (TSF – S)	92%	117%	--	84%
Spruce – whole (TSF – W)	92%	80%	--	89%

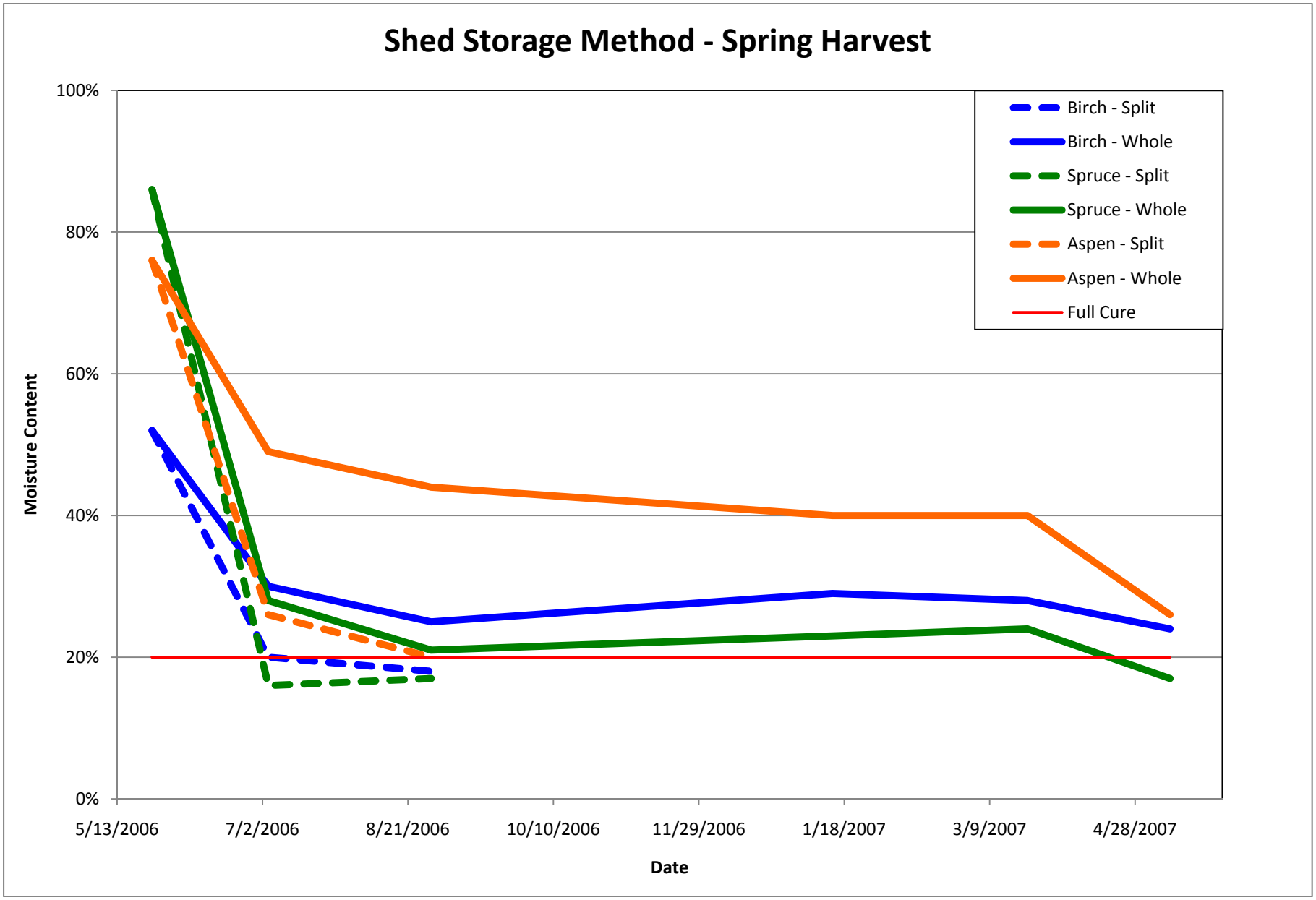


Figure 1a – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

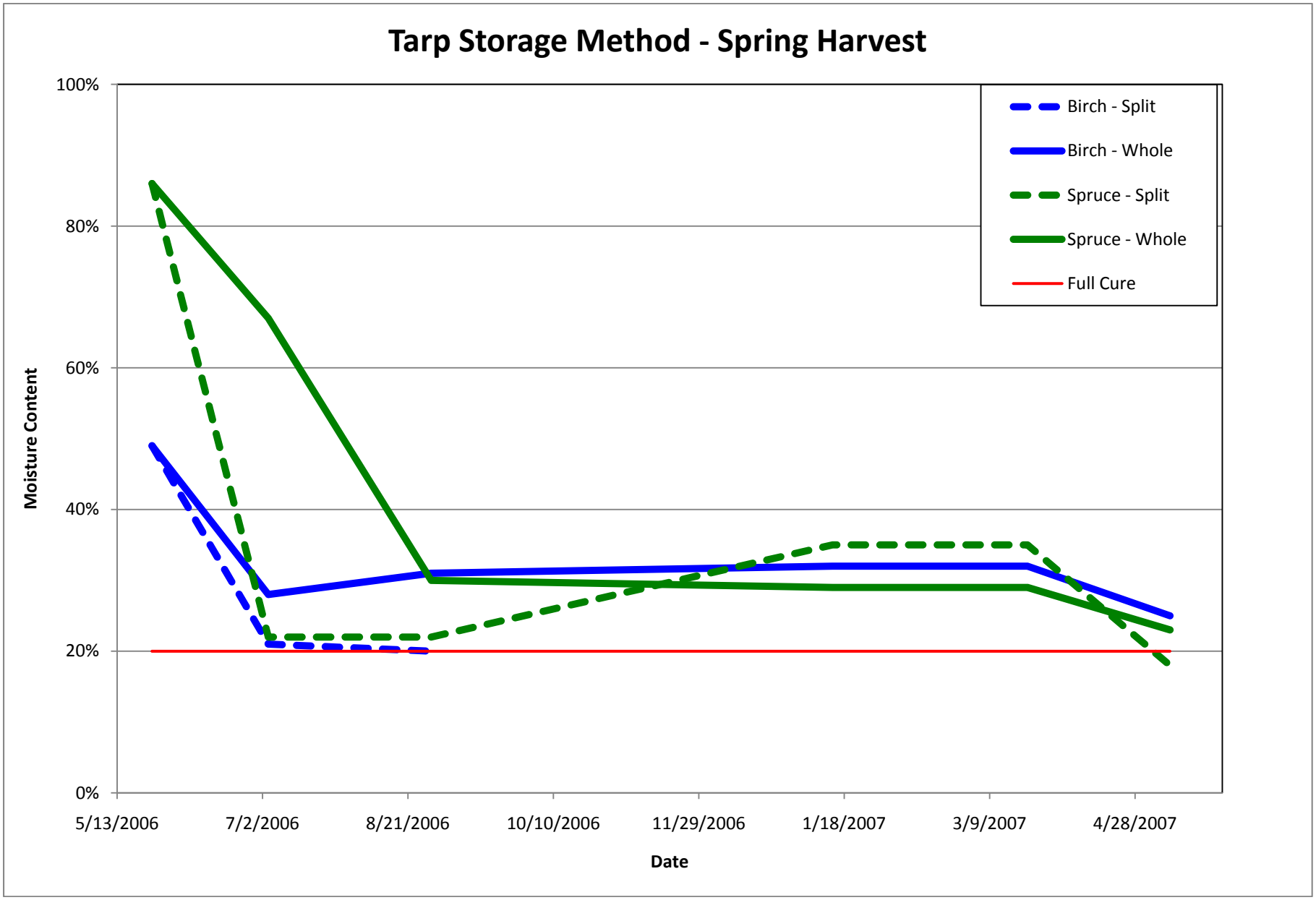


Figure 1b – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

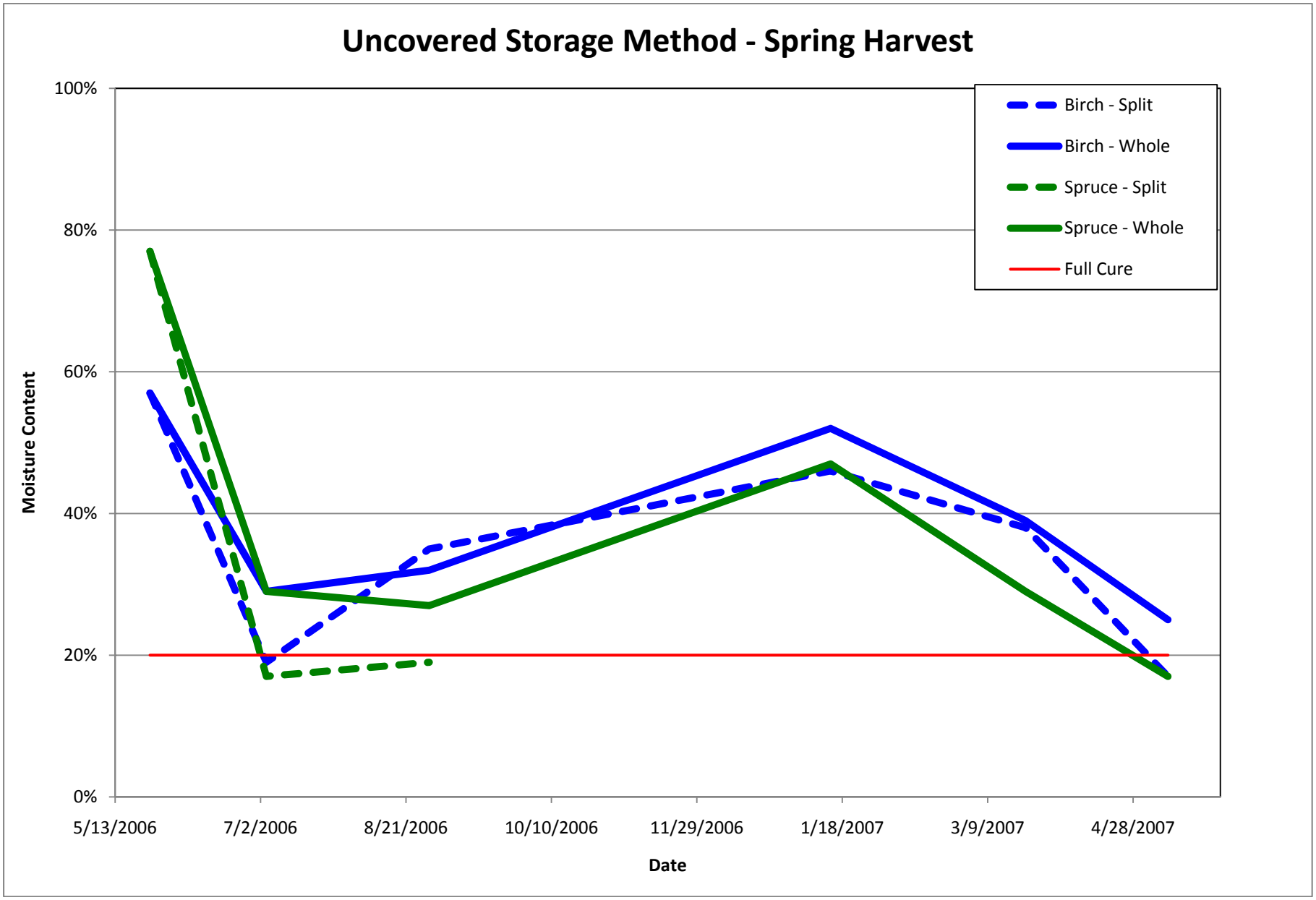


Figure 1c – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

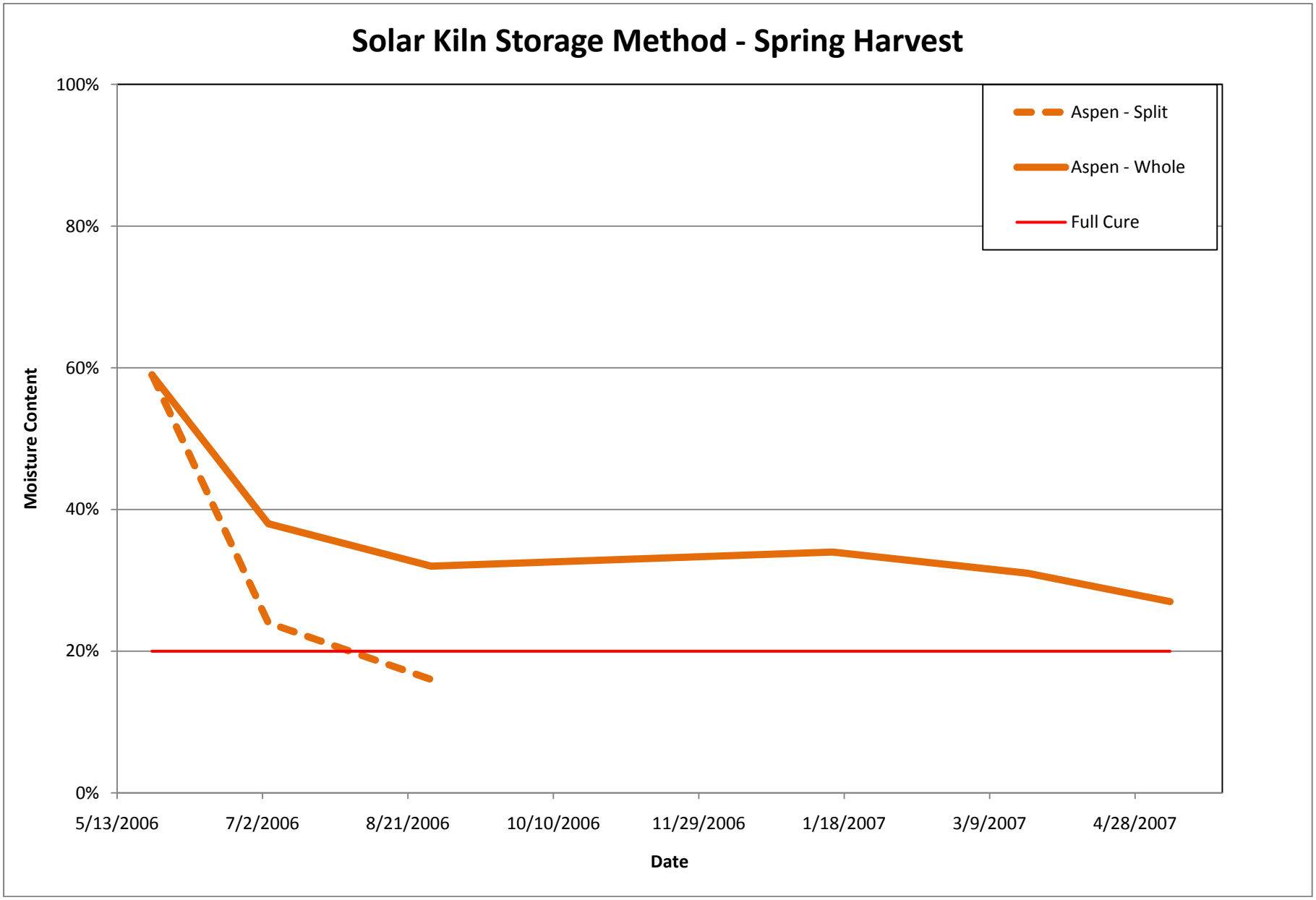


Figure 1d – Moisture content of spring harvest firewood over time for the different wood types and preparation methods.

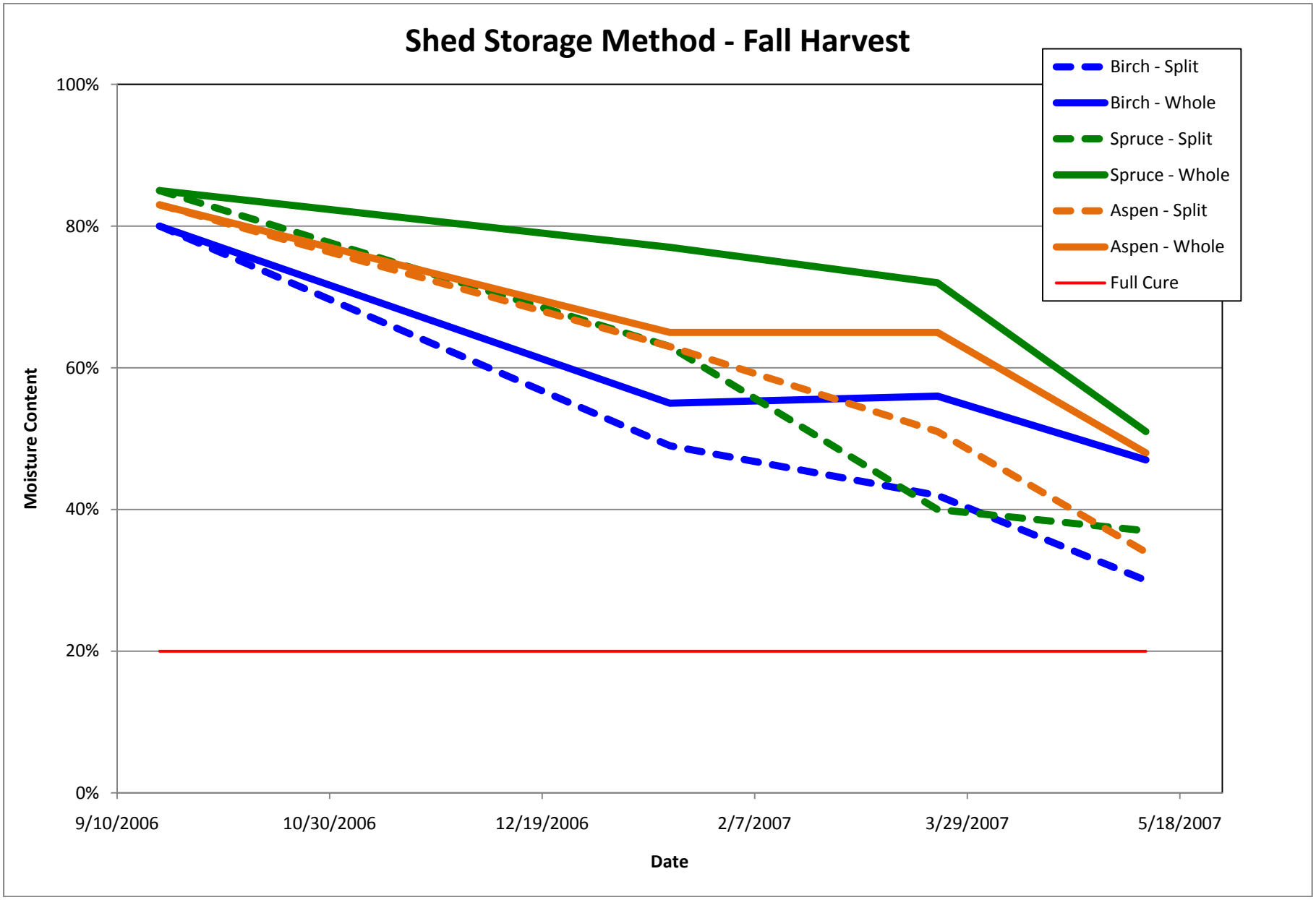


Figure 2a – Moisture content of fall firewood over time for the different wood types and preparation methods.

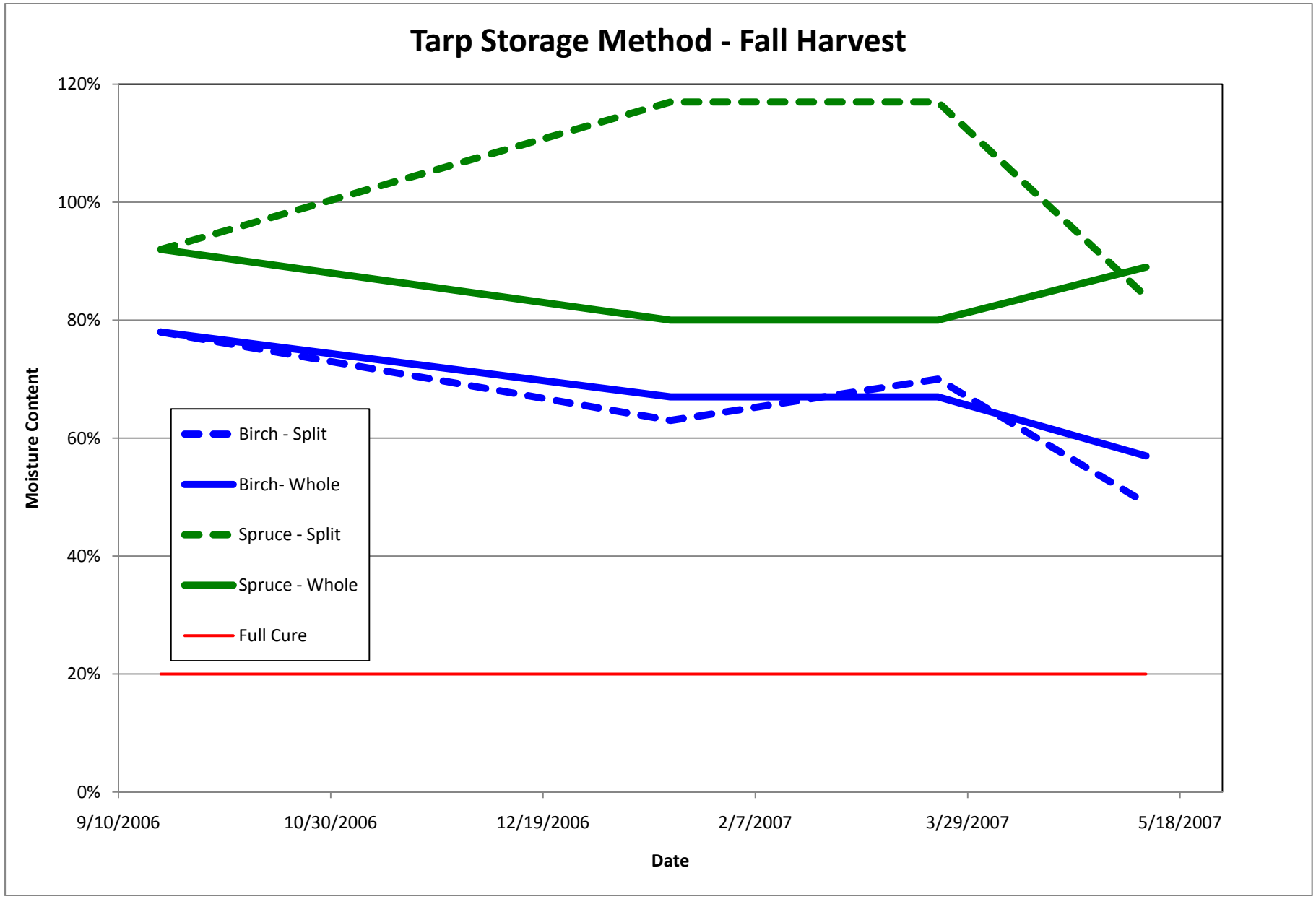


Figure 2b – Moisture content of fall firewood over time for the different wood types and preparation methods.

Appendix A – Photographs

The firewood storage scenarios initiated in May 2010 in the field west of the CCHRC Research and Testing facility.

The firewood storage scenarios initiated in May 2010.

Example of the simulated wood shed (top-covered and off-ground) storage scenario.

Example of the tarp-covered (fully-covered and on-ground) storage scenario.

Example of the uncovered and on-ground storage scenario.

Simple solar kiln storage scenario with wood placed on the ground.

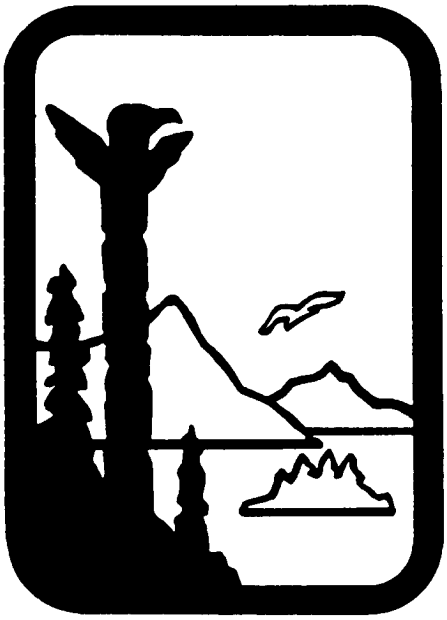
The firewood storage scenarios initiated in May 2010 (left side of picture) and September 2010 (right side of picture).

The firewood storage scenarios initiated in September 2010 (foreground) and May 2010 (background).

Firewood subsamples stored at CCHRC's Research and Testing Facility

Close-up of firewood subsamples.

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.07

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Public Review Draft

November 14, 2014

Sean Parnell
Governor

Larry Hartig
Commissioner

(This page serves as a placeholder for two-sided copying)

Appendix III.D.5.07

Reasonably Available Control Measures (RACT).

Addressing the precursor gases for Fairbanks PM2.5 State Implementation Plan.

Individual Emission Unit RACM Determinations.

Evaluation of Reasonably Available Control technologies (RACT) to Support the Development of the Fairbanks PM2.5 State Implementation Plan.

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Reasonably Available Control Measure (RACM) Analysis

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5.7. APPENDIX

5.7.1. BACKGROUND

In November 2009, Fairbanks was designated as a Moderate nonattainment area for the 2006 24-hour $PM_{2.5}$ National Ambient Air Quality standard.[1] The design value[2] is 44.7 µg/cubic meter.[3] The difference between this value and the ambient standard is 9.7 µg/cubic meter, which means that 98th percentile concentrations (the form of the standard) need to be reduced by 22% to demonstrate attainment.

The purpose of this document is to describe the process of identification and selection of Reasonably Available Control Measures (RACM) for the $PM_{2.5}$ Attainment Plan for the Fairbanks North Star Borough (FNSB, or Fairbanks) in Alaska.

5.7.1.1. Requirements for RACM Analysis

CAA section 172(c)(1) describes the general attainment plan requirement for reasonably available control measures (RACM). Attainment plan submissions must "provide for the implementation of all reasonably available control measures as expeditiously as practicable (including such reductions in emissions from existing sources in the area as may be obtained through the adoption, at a minimum, of reasonably available control technology) and shall provide for attainment" of the NAAQS.

Section 189 (a)(1)(C) requires that RACM measures in Moderate nonattainment areas be implemented no later than four years after designation.

Guidance on the steps to be followed in making RACM determinations for $PM_{2.5}$ were specified in the final Clean Air Fine Particulate Implementation Rule issued in 2007.[4] Additional guidance was provided in a subsequent EPA guidance document.[5] The rule was based on based on CAA Part D, Subpart 1. A court decision[6] in January 2013 remanded the $PM_{2.5}$ rule back to EPA to be re-promulgated to be consistent with Subpart 4. EPA withdrew the Subpart 1-based guidance document and new Subpart 4 based guidance has not been issued.

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[1] 74 FR 58688, November 13, 2009.
[2] The design value is a statistic that describes the air quality status of a given location, for purposes of comparison with the relevant NAAQS. The goal of the attainment plan is to bring the design value to a level at or below the standard.
[3] EPA, *$PM_{2.5}$ Detailed information;* available at http://www.epa.gov/airtrends/values.html (accessed September 8, 2014)
[4] 72 FR 20586, April 25, 2007
[5] Stephen Page, *Implementation Guidance for the 2006 24-Hour Fine Particulate (PM2.5) National Ambient Air Quality Standards,* March 2, 2012
[6] Natural Resources Defense Council (NRDC) v. EPA, No. 08-1250 (D.C. Cir., Jan. 4, 2013)

The steps in the RACM analysis followed in this report were developed based on a review of CAA provisions. In addition, this analysis incorporates the requirement in subpart 4[7] that RACM must be implemented within four years after designation. The RACM analysis steps are outlined below.

5.7.1.2. Process for Identification and Evaluation of Control Measures

Listed below are the steps that were followed in evaluating control measures.

- Step 1: Identify source categories with non-trivial emissions of $PM_{2.5}$ or its precursors.
- Step 2: **For each source category, source, or activity from Step 1**, develop a list of technologically feasible emission control technologies and/or measures
- Step 3: **For each technologically feasible control measure,** evaluate emission reductions and costs, identify and exclude economically infeasible measures.
- Step 4: Determine whether control measure can be implemented within four years of designation.
- Step 5: Identify Reasonably Available Control Measures.

5.7.2. Step 1: Identify Sources of $PM_{2.5}$ and Precursors in Fairbanks

The first step in the RACM identification and evaluation process is to identify candidate control measures. In this step, all source categories with non-trivial emissions of $PM_{2.5}$ or its precursors are identified. A list of control measures potentially applicable to each source category is then developed for consideration as RACM.

"Primary" particulates (i.e., directly emitted $PM_{2.5}$) are emitted directly into the air as a solid or liquid particle (e.g., elemental carbon from diesel engines or fire activities, or condensable organic particles from gasoline engines). "Secondary" particulates (e.g., sulfate and nitrate) form in the atmosphere as a result of various chemical reactions. The main precursor gases associated with secondary fine particle formation are SO_2, NOX, volatile organic compounds (VOC), and ammonia.

Evaluation of monitoring data indicates that directly emitted $PM_{2.5}$ is the principle contributor to exceedances of the $PM_{2.5}$ NAAQS in Fairbanks. Figure 5.7-1 shows that directly emitted $PM_{2.5}$ comprises 63.2% of the measured concentration. Sulfates comprise 29.1%, nitrates comprise 7.6%, and secondary organic aerosols (SOAs) comprise 0%.

[7] Clean Air Act Section 189(a)(1)(C)

The most current estimate of directly emitted $PM_{2.5}$ and precursor emissions in the nonattainment area is the 2015 emission inventory shown in Table 5.7-1. It shows the average daily emissions across the two episodes (Jan-Feb, 2008 and Nov 2008) selected to represent conditions associated with exceedances of the 24-hour ambient $PM_{2.5}$ standard in Fairbanks.

Pollutant emissions from a source category were used as a proxy for its contribution to the ambient $PM_{2.5}$ concentration[8] (e.g., a source category's contribution to the fraction of ambient $PM_{2.5}$ attributed to directly emitted $PM_{2.5}$ was assumed to be the same as its emissions, expressed as a percentage of the total regional $PM_{2.5}$ inventory). Table 5.7-2 shows the contributions of each source category to ambient concentrations on the average episode day using this simplified technique.

Source category contributions to ambient concentrations were also estimated using photochemical modeling, and the results are compared with the results using the simplified estimate described above in Table 5.7-3. The modeling indicates that the contribution of wood combustion to ambient concentrations is greater than would be estimated from emissions alone. Presumably, this is because wood smoke is emitted close to the ground, below the mixed layer and dispersed throughout the Borough. Similarly, the contribution of pollutants from the combustion of gasoline is greater than share of emissions would suggest. Point sources, on the other hand, typically have tall stacks that release emissions well above the inversion layer; as a result, their contribution to ambient pollutant concentrations is relatively low.

Point sources are subject to Reasonably Available Control Technology (RACT) requirements, which is a specialized subset of RACM. Point sources are evaluated for RACT in a different part of this report.

[8] This is a simplified approach, used only to identify and eliminate source categories and/or control measures with insignificant contributions to ambient $PM_{2.5}$ concentrations. The contribution of each RACM control measure to attainment is subsequently quantified using photochemical modeling.

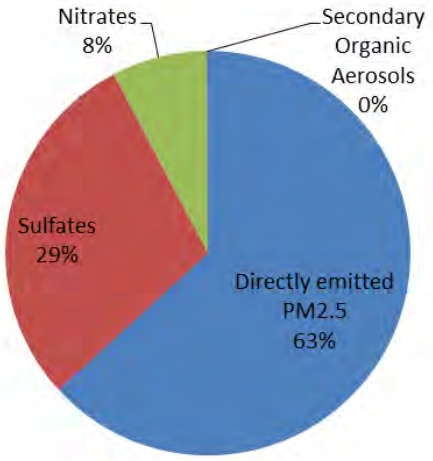

Figure 5.7-1. Constituents of Ambient $PM_{2.5}$ on High Concentration Days

Notes:
- Data are from the SANDWICH calculation spreadsheet that contains data over all winters from 2006- 2010 for the 98% days. They have been post processed through the SANDWICH method.
- Sulfates include primary and secondary sulfate + ammonium + particle bound water.
- Nitrates include primary + secondary nitrate + ammonium + particle bound water.
- Secondary organic aerosols were estimated from CMAQ.

Table 5.7-1. Average Daily Emissions by Source Category in 2015 for Episodes Selected for Fairbanks $PM_{2.5}$ Attainment Modeling

Source Category	Emissions (Tons per day)				
	Direct $PM_{2.5}$	SOx	NOx	VOC	NH_3
Point Sources					
Point Sources–all	1.59	22.97	27.39	1.15	0.00
Area Sources					
Space Heating–Wood	2.72	0.09	0.00	0.00	0.00
Central Oil–Residential	0.04	2.94	0.00	0.00	0.00
Central Oil–Commercial	0.02	1.14	0.00	0.00	0.00
Other Heating	0.05	0.12	0.00	0.00	0.00
Airport	0.01	0.08	0.76	0.26	0.00
Other Area Sources	0.06	0.00	0.00	0.60	0.00
Mobile Sources					
On-Road Vehicles (gasoline)	0.00	0.00	0.00	0.00	0.00
On-Road Vehicles (Diesel)	0.00	0.00	0.00	0.00	0.00
Non-Road Vehicles	0.01	0.01	0.30	0.15	0.00

Table 5.7-2. Estimated Source Category Contribution to Ambient $PM_{2.5}$ Concentration[a] (2015 Average Episode Day)

	$PM_{2.5}$			SOx			NOx			VOC			TOTAL
Source Category	%	Weighting[b] 63%	% of Ambient	%	Weighting[b] 29%	% of Ambient	%	Weighting[b] 8%	% of Ambient	%	Weighting[b] 0%	% of Ambient	% of Ambient[a]
Point Sources													
Point Sources–All	31%	63%	20%	84%	29%	24%	87%	8%	7%	19%	0%	0%	51%
Area Sources													
Space Heating–Wood	54%	63%	34%	0%	29%	0%	0%	8%	0%	0%	0%	0%	34%
Central Oil–Residential	1%	63%	1%	11%	29%	3%	0%	8%	0%	0%	0%	0%	4%
Central Oil–Commercial	0%	63%	0%	4%	29%	1%	0%	8%	0%	0%	0%	0%	1%
Other Heating	1%	63%	1%	0%	29%	0%	0%	8%	0%	0%	0%	0%	1%
Airport	0%	63%	0%	0%	29%	0%	2%	8%	0%	4%	0%	0%	0%
Other Area Sources	1%	63%	1%	0%	29%	0%	0%	8%	0%	10%	0%	0%	1%
Mobile Sources													
On-Road Vehicles (gasoline)	10%	63%	6%	0%	29%	0%	5%	8%	0%	60%	0%	0%	7%
On-Road Vehicles (Diesel)	1%	63%	1%	0%	29%	0%	5%	8%	0%	4%	0%	0%	1%
Non-Road Vehicles	0%	63%	0%	0%	29%	0%	1%	8%	0%	7%	0%	0%	0%
TOTAL													100%

Notes:

[a] No modeling involved. Estimated contributions of source categories to ambient concentrations were calculated by assuming that contribution to ambient PM subspecies ($PM_{2.5}$, nitrate, sulfate, VOC aerosol) concentration is proportional to emissions.

[b] Weighting factor for each PM subspecies ($PM_{2.5}$, nitrate, sulfate, VOC aerosol) is its measured fraction of the ambient $PM_{2.5}$ concentration across 2006 – 2010 winter period.

Table 5.7-3. Comparison of Estimated Source Category Contribution to Ambient $PM_{2.5}$ Concentration with Modeling Results (Projections to 2015)

Source Category	% of Ambient $PM_{2.5}$	
	Estimated[a]	Modeled
Point Sources		
Point Sources–All	51%	6%
Area Sources		
Space Heating–Wood	34%	66%
Central Oil–Residential	4%	3%
Central Oil–Commercial	1%	1%
Other Heating	1%	0%
Airport	0%	1%
Other Area Sources	1%	3%
Mobile Sources		
On-Road Vehicles (gasoline)	7%	18%
On-Road Vehicles (Diesel)	1%	2%
Non-Road Vehicles	0%	2%
TOTAL	100%	102%

Notes:
a. Estimated contributions of source categories to ambient concentrations were calculated by assuming that contribution to ambient PM subspecies ($PM_{2.5}$, nitrate, sulfate, VOC aerosol) concentration is proportional to emissions. The contribution of each subspecies is its measured fraction of the ambient $PM_{2.5}$ concentration on the episode day.

Based on the information in Table 5.7-2 and Table 5.7-3, the following source categories were evaluated for RACM.[9]

- Wood burning
  - Outdoor Wood-burning boilers (hydronic heater)
  - Wood Stoves
  - Fireplaces
  - Burn barrels
  - Open burning

- Residential Fuel Oil Combustion

[9] A number of control measures were not considered because emissions from this category of sources are *de minimis* in Fairbanks (either the number of such sources was too small to consider, or the seasonality of emissions means that reductions would not contribute to attainment). A list of such sources and control measures is provided in Appendix A.

- Transportation
  - Automobiles
  - Heavy-duty Vehicle

5.7.3. STEP 2: FOR EACH SOURCE CATEGORY, IDENTIFY TECHNOLOGICALLY FEASIBLE EMISSION CONTROL TECHNOLOGIES AND/OR MEASURES

An initial list was compiled that included all of the categories/measures identified by EPA in various guidance documents as likely candidates for RACM. To this list were added control measures that were suggested by public comments during Alaska's SIP development process. Some control measures on EPA's list (e.g., control of emissions from commercial charbroiling/cooking operations)[10] were eliminated because emissions from the source category make an insignificant contribution to PM concentrations in Fairbanks.

Additionally, $PM_{2.5}$ SIPs from other jurisdictions were reviewed for lists of control measures. Of the 35 areas originally designated to be nonattainment for the 2006 federal $PM_{2.5}$ standard, 23 also either had been or currently are an ozone nonattainment area; 6 of the remaining 12 have acquired a Clean Area Determination for $PM_{2.5}$, and therefore have not prepared a RACM analysis. The RACM analyses for each of the remaining six SIPs were reviewed for candidate control measures.

Controls applicable to stationary sources (large industrial facilities) were also eliminated because such facilities are subject to RACT review, and are addressed elsewhere in the SIP.

Table 5.7-4 lists the candidate control measures that were evaluated as potential RACM.

Table 5.7-4. Candidate Control Measures Considered for RACM

Source Category	Control Measure	Sources of Candidate Control Measure(s)[a]
Dry Wood Measures	Education and Outreach	1, 2, 4
	Regional kiln	7
	Ban on green wood sales	1

[10] The estimated $PM_{2.5}$ emission rate from conveyorized charbroilers in FNSB is about 0.0069 tons per day during the winter season. If all of these sources were controlled, the reduction (at an assumed 80%) would equal about 11 pounds per day.

Source Category	Control Measure	Sources of Candidate Control Measure(s)[a]
Hydronic Heaters	Education and Outreach	1, 2, 4
	Voluntary curtailment on air quality advisory days	1, 2
	Mandatory curtailment on air quality advisory days	1, 3, 5, 6
	All new units must be certified	7
	All units must be certified	7
	Ban new installations	5, 6
	Remove at time of home sale	3
	Subsidize heater change outs	2
	Ban use	7
Wood Stoves	Education and Outreach	1, 2, 3, 4
	Voluntary curtailment on air quality advisory days	1, 2
	Mandatory curtailment on air quality advisory days	1, 3, 5, 6
	All new units must be certified	2, 3, 4, 5, 6
	All new units must meet more stringent standards	7
	All units must be certified	3
	Replace uncertified stoves at time of home sale	3, 4
	Replace uncertified stoves in rental units	3
	Require alternate heat source in rental units	3
	Require alternate heat source in new construction	7
	Ban new installations	7
	Subsidize stove change outs	3, 4
	Ban use	3
	Use stove change outs to generate NSR offsets	3

Source Category	Control Measure	Sources of Candidate Control Measure(s)[a]
Fireplaces/Fireplace Inserts	Education and Outreach	1, 2, 3, 4
	Voluntary curtailment on air quality advisory days	1, 2, 5
	Mandatory curtailment on air quality advisory days	1
	Subsidize fireplace insert change outs	2
Open Burning	Reinstate open burning ban	1, 2, 3
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	7
Residential Fuel Oil Combustion	Provide economic incentives to switch to low-sulfur fuel	7
	Increase coverage of District heating systems	3
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	1, 3, 4, 5
Transportation	Improved public transit	1
	HOV lanes	1
	Traffic flow improvement programs	1
	Create non-motorized traffic zones	1
	Restrict truck idling	1
	Reduce cold start emissions	1
	Employer-sponsored flexible work schedules	1
	Retrofit diesel fleet (school buses, transit fleets)	1, 3
	Onroad vehicle I&M program	1
	Heavy-duty vehicle I&M program	1
	State LEV Program	1, 3

a. Control Measure Sources:
1 – EPA guidance
2 – FNSB programs and proposals
3 – Klamath Falls, Oregon SIP
4 – Oakridge, Oregon SIP
5 – Provo, Utah SIP
6 – Logan, Utah SIP
7 – Other

The identified control measures for area sources fall into four broad categories:

- Education and outreach;
- Voluntary curtailment;
- Mandatory curtailment; and
- Device upgrade and/or replacement.

Each control measure listed in Table 5.7-4 was evaluated for technological feasibility. Listed below are the criteria used. These criteria were developed based on a review of CAA provisions, past RACT and RACM guidance issued by EPA, the1992 general preamble for the implementation of Title of the 1990 CAA amendments and the addendum to the preamble..[11]

1. A measure is technologically infeasible if it is "absurd, unenforceable, or impractical."

2. A measure is technologically infeasible if it would cause severe socioeconomic impacts.

3. A measure is technologically infeasible if, considering the availability of mitigating adverse impacts of that control on other pollution media, the control would not, in the State's reasoned judgment, provide a net benefit to public health and the environment.

4. A measure may be determined to be technologically infeasible upon consideration of other relevant factors:

    a. The capability of effective implementation and enforcement of the measure; and

    b. Local circumstances, such as the condition and extent of needed infrastructure, population size, or workforce type and habits, which may prohibit certain potential control measures from being implementable.

The capability of effective implementation and enforcement are relevant considerations in the RACM analysis, even though public "unpopularity" is not. The General Preamble[12] states:

> *... the SIP submittal to EPA should contain a reasoned justification for partial or full rejection of any available control measures, including those considered or presented during the state's public hearing process, that explains, with appropriate documentation, why each rejected control measure is infeasible or otherwise unreasonable.*

[11] Federal Register, Vol. 57, No. 74, April 16, 1992.
[12] Page 13541 of the April 16, 1992 Preamble

5.7.3.1. Background Information

Education and Outreach Programs and Voluntary Curtailment

Education and outreach programs are necessary for successful implementation of curtailment programs. It is necessary that the target audience be aware of the reasons for, and means of implementing, curtailment of the specific behavior. Education and outreach should precede the implementation phase so that individuals may prepare for curtailment events. Education and outreach should continue through the program, to reinforce the message and to reach individuals who may have missed the previous outreach efforts.

Education and outreach efforts and voluntary curtailment programs may help increase community support for mandatory programs. Education and outreach increases the number of people who are aware of the air pollution problem, and explains the contribution that individuals can make to reduce the problem. Voluntary curtailment programs can help individuals understand the level of effort and cost needed to reduce the problem. Voluntary curtailment programs decrease opposition to mandatory programs by reducing the number of people who must change their behavior, and by demonstrating the feasibility of curtailment.

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions. Public outreach is an important component of the Fairbanks air quality program with respect to improving residents' use of solid-fuel heating devices, thereby reducing $PM_{2.5}$ emissions. Public outreach efforts focus on measures residents can take to protect themselves and to reduce $PM_{2.5}$ emissions from activities like wood and coal burning. For example, the Borough and DEC have developed and implemented an extensive outreach effort to encourage residents to employ "best burning" practices when using wood heating devices. The Borough has also developed and implemented a program to support and encourage voluntary efforts to encourage residents who can to shift away from wood burning on advisory days and use their primary fuel oil heating systems instead.

Emission reductions from voluntary curtailment are potentially significant. However, because the reductions are not enforceable, EPA policy limits the amount of credit that may be taken for planning purposes to 6% of the total reductions needed for attainment.[13]

Mandatory Curtailment Programs

Mandatory curtailment programs that affect home heating are currently not feasible in Fairbanks North Star Borough because the community has, on several occasions, indicated that it would not accept such a program. The community has indicated this by approving, and renewing, a referendum that prohibits the Borough from imposing or

[13] http://www.epa.gov/ttn/caaa/t1/memoranda/evm_ievm_g.pdf

enforcing any limits on fuels used to heat homes.[14] While this initiative failed in the most recent election in October 2014, it has not been feasible to implement a local mandatory curtailment program.

Under Alaskan laws, voter-approved ordinances cannot be amended by local officials for two years. In 2012, more than two years after the 2009 initiative passed, the Borough proposed "moderate" regulations affecting home heaters. In response, the proponents of the 2009 proposition circulated a new proposition, renewing and strengthening the previous measure. On October 2, 2012, the voters of the Fairbanks North Star Borough approved Proposition 3, the Home Heating Initiative:

> *The borough shall not, in any way, regulate, prohibit, curtail, nor issue fines or fees associated with, the sale, distribution, or operation of heating appliances or any type of combustible fuel.*
>
> *'Heating Appliances' is defined as, but not limited to: oil furnaces, gas furnaces, wood stoves, coal stoves, wood-fired hydronic heaters, wood-fired furnaces, coal-fired hydronic heaters, coal-fired furnaces, masonry heaters, pellet stoves, cook stoves, and fireplaces.*

Continuation of the four-year voter ban against Fairbanks North Star Borough regulation of air pollution from home heaters and fuels failed on October 14, 2014 when Proposition 2, the Home Heating Initiative, was defeated. The ban will be lifted when the vote is certified by the Borough Assembly. Since this information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

The Borough assembly interpreted the above language to require a repeal of its ban on open burning. This resulted in the DEC implementing its existing statewide open burning regulations within the nonattainment area.

This October, Fairbanks voters considered another initiative renewing the ban on local adoption of restrictions on combustion sources. And, although the initiative failed (giving the Borough the authority to establish local regulations for home heating devices) community opposition to limits on options for home heating is also grounded in the economics of home heating in the far north. Fairbanks experiences extremely and persistently cold temperatures during the winter, and the cold temperatures coincide with strong inversions that result in high 24-hour $PM_{2.5}$ concentrations.

While fuel oil is the dominant source of home heating in Fairbanks, with roughly two thirds of the market, many homes are equipped to burn multiple fuels to ensure that a

[14] FNSB Code 8.21.025 "The borough shall not, in any way, regulate, prohibit, curtail, nor issue fines or fees associated with, the sale, distribution, or operation of heating appliances or any type of combustible fuel."

backup is available in the event of a supply disruption in an arctic environment. The cost of fuel has risen from a low point of $2.25/gallon in Nov. 2006, to a high of $4.12 in January 2013. Current prices are roughly $4/gallon. The increase in fuel oil prices has stimulated a shift towards increase use of wood and coal as a way to conserve home heating expenses. Any perceived constraint on limiting the use of lower priced fuels is a significant concern in the community.

To illustrate the magnitude of home heating expenses in Fairbanks, information on the cost of living associated with energy use was assembled for PM nonattainment communities and northern tier (cold climate, high energy cost) communities located in states with wood burning controls. The Council for Community and Economic Research (C2ER) publishes a Cost of Living Index for 279 urban areas.[15] A total of 57 indices are provided for grocery items, housing, utilities, transportation, health care and miscellaneous goods and services. The utility categories include those described below.

- *Total Home Energy Cost* – monthly cost, at current rates, for average monthly consumption of all types over the previous 12 months for a 2,400 sq. ft. living area new house on an 8,000 sq. ft. lot (i.e., four bedrooms and two baths)

- *Electricity* – the average monthly cost for all electric homes

- *Other Home Energy* – average monthly cost, at current rates for natural gas, fuel oil, coal and any other forms of energy except electricity

- *Telephone* – not relevant to this discussion

It is important to note that these indices do not represent the average energy cost of all homes in each community and they do not include the cost of all fuels (e.g., wood is not included in the cost estimates). The collection of this level of detail across 279 communities on a quarterly basis is impractical. Instead, the indices provide a consistent metric to contrast utility- based energy costs of same size homes in each of the surveyed communities. The concept is that while smaller and larger homes may have different fuel use and fuel mixes, the relative cost observed in the indexes should provide a representative estimate of the cost of utility based fuels used in homes. Thus, the absolute value of the energy costs expressed in the index are less important the relative cost among participating communities.

A summary of the *Other Home Energy* and *Total Home Energy* indices for the second quarter of 2014 is presented below in Table 5.7-5 for 24 urban areas. The table also shows the percentage of each listed community's index relative to Fairbanks. It shows that Fairbanks had the highest energy costs of any of the listed urban areas. The C2ER data also show that Fairbanks has the highest home energy costs in the U.S. Juneau,

[15] Council for Community and Economic Research (C2ER),*Cost of Living Index, Comparative Data for 279 Urban Area, Second Quarter 2014, August 2014*

Alaska had home energy costs closest to those of Fairbanks at roughly 50% (i.e., one half). Outside of Alaska and Hawaii[16], the community with the highest energy costs

Table 5.7-5. Comparison of the Cost of Living Indices for *Other Home Energy and Total Home Energy* for Communities with Home Heating Particulate Control Measures

[16] Hilo and Honolulu, Hawaii have the second and third highest *Total Home Energy* cost in the U.S. (96.0% and 81.3%, respectively). While the State of Hawaii has outdoor burning restrictions, neither Hilo nor Honolulu community has wood burning restrictions and they have no PM nonattainment designations, so their values were not included in the Fairbanks comparisons.

Urban Area & State	Other Energy		Total Energy	
	Index	% Relative to Fairbanks	Index	% Relative to Fairbanks
Fairbanks, AK	426.93	100.0%	566.36	100.00%
Juneau, AK	223.11	52.3%	309.99	54.7%
Anchorage, AK	79.57	18.6%	162.30	28.7%
Phoenix, AZ	-	-	184.66	32.6%
Fresno, CA	79.30	18.6%	223.83	39.5%
Los Angeles, CA	70.71	16.6%	184.89	32.6%
Sacramento, CA	38.28	9.0%	215.80	38.1%
Denver, CO	69.21	16.2%	165.84	29.3%
Stamford, CT	129.19	30.3%	247.60	43.7%
Boise, ID	58.52	13.7%	148.85	26.3%
Boston, MA	122.55	28.7%	229.83	40.6%
Portland, ME	53.35	12.5%	136.28	24.1%
Detroit, MI	67.25	15.8%	183.32	32.4%
St. Paul, MN	71.76	16.8%	149.01	26.3%
Bozeman, MT	90.47	21.2%	154.02	27.2%
Manchester, NH	97.64	22.9%	205.55	36.3%
Newark, NJ	78.11	18.3%	206.39	36.4%
Buffalo, NY	70.01	16.4%	160.36	28.3%
Ithaca, NY	80.40	18.8%	179.24	31.6%
Manhattan, NY	148.24	34.7%	277.18	48.9%
Portland, OR	74.95	17.6%	158.73	28.0%
Burlington-Chittenden, VT	133.58	31.3%	234.60	41.4%
Salt Lake City, UT	76.03	17.8%	146.75	25.9%
Seattle, WA	-	-	173.47	30.6%
Tacoma, WA	79.94	18.7%	135.66	24.0%

(both categories) is Manhattan, NY, with 34.7% of the *Other Home Energy* index and 48.0% of the *Total Home Energy* index. Stamford, CT is second with 30.3% of the *Other Home Energy* index and 43.7.0% of the *Total Home Energy* index. Burlington-Chittenden, VT is third with 31.3% of the *Other Home Energy* index and 41.4.0% of the *Total Home Energy* index. Boston, MA is in fourth place, with 40.6% of the *Total Home Energy* index and 28.7% of the *Other Home Energy* costs.

Four communities (Fresno, Sacramento, Manchester, and Newark) had *Total Home Energy* indices falling between 33% and 40%. The rest of the listed communities had had energy costs that are one third or less than those incurred in Fairbanks. This

information demonstrates that home heating expenses are two to three times higher in Fairbanks than any other community with wood burning controls. The magnitude of this expense directly influences the public's willingness to comply with controls that increase the cost of home heating. The cost data also demonstrate the limited economic impact of wood burning controls in the other PM nonattainment areas, which influences public willingness to bear the cost of those controls.

Finally, in addition to the economic issues described above, some residences that are equipped with alternative sources of heat may find those sources inadequate on some of the coldest days of the year. In these cases, supplemental heating with a wood-fired device may be necessary when the fuel oil-fired heater does not provide enough heat.

For this reason, control measures that require the use of an alternative fuel source to wood have a much greater cost to the consumer in Fairbanks (a factor of two or three) than to consumers in other parts of the United States. The magnitude of this expense directly influences the public's willingness and ability to comply with controls that further increase the cost of home heating. A ban on use of woodstoves during high pollution days in Fairbanks has a dramatically different effect than such a ban in Sacramento.

As demonstrated by the Home Heating Initiative described above, the community resistance in Fairbanks to measures that would increase home heating costs has been carried over to other measures affecting the fuel supply, such as prohibitions on the use of wet wood.
While the initiative failed in October 2014, it will take some time to establish locally effective controls. For the reasons outlined above, such a program would still face resistance by many in the community, which remains opposed to limits on residential fuel use. Because of this opposition, candidate control measures that fall within the scope of the referendum's ban have been determined to be not practically enforceable at this time.

5.7.3.2. Dry Wood Programs

The Cold Climate Housing Research Center estimated in 2009 that residential wood burning accounted for slightly over 560 tons of $PM_{2.5}$ emissions per year in the FNSB.[17] As shown in Table 5.7-2, emissions from wood combustion are responsible for 2.99 tons per day of direct $PM_{2.5}$ emissions on episode days. Based on photochemical modeling, wood combustion is responsible for 66% of the ambient $PM_{2.5}$ concentration on episode days.

Dry wood programs reduce emissions from all categories of wood burning equipment by reducing the moisture content of the wood fuel mix. Reducing wood fuel moisture content reduces emissions of $PM_{2.5}$ and its precursors by (1) improving combustion, burning more cleanly and reducing emissions on a per pound of fuel basis; and (2) by burning more efficiently. Less moisture means less water needs to be evaporated, and

[17] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 14.

therefore more heat is available as useful heat. Because less fuel is required to provide the same amount of useful heat, emissions of all combustion pollutants is reduced. A secondary effect is that less energy is required to transport fuel, resulting in a modest reduction in onroad emissions.

Fuel wood can be dried actively in kilns. It can also be dried by letting cut wood season before being burned. Freshly cut "wet" wood may contain as much as 40% to 60% moisture, depending on the type of wood.[18] Wood that has been allowed sufficient time to dry (usually six months or more, for split wood that is air-dried) typically contains 20% moisture or less.[19] According to a 2008 report by the Northeast States for Coordinated Air Use Management (NESCAUM), for every 10 percentage point increase in the moisture content of wood, the $PM_{2.5}$ emissions increase by 65% to 167%.[20] Part of this increase is due to the increased amount of wood fuel needed to evaporate the extra water, but a larger part of this increase is due to poor combustion conditions that lead to reduced heat transfer efficiency and to more particulates in the smoke.

If only wet wood is burned, the total wood volume used for an entire winter may be as much as 100% more than if seasoned wood were used.[21]

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[22] The agencies publish a brochure, *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure, *Wet Wood is a Waste*, as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. Because it involves voluntary efforts on the part of the public, and is implemented as a state program, community resistance to the FNSB and Alaska DEC's outreach programs has been minimal.

A more comprehensive program that encourages the use of only dry wood, explains the methods for ensuring that wood is dry (seasoning after cutting, use of inexpensive moisture meters), and explains the benefits (less wood is needed, wood is lighter/easier to carry, less creosote is formed) has been developed and is in the process of being implemented.

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[18] EPA, *Subpart AAA—Standards of Performance for New Residential Wood Heaters, Revised Draft Review Document,* December 30, 2009, p. 35
[19] EPA, *Subpart AAA—Standards of Performance for New Residential Wood Heaters, Revised Draft Review Document,* December 30, 2009, p. 35
[20] NESCAUM, *Source Characterization of Outdoor Wood Furnaces,* September 9, 2008, p. 4-1
[21] Bureau of land Management, *Wood Heat as a Comparison* http://www.blm.gov/ca/st/en/fo/alturas/woodheatcomparison.html ("Wet wood alone can reduce the efficiency of a wood stove by an additional 50%.")
[22] As discussed in the introduction to this Section.

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public. Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Increased availability—regional kiln

Of the wood burned in FNSB, 26.2 % is purchased from firewood dealers (the rest is harvested by the user).[23] Less than 20% of the wood sold in FNSB is dry wood; the rest is sold green, or self-cut, and contains a considerable amount of moisture.[24]

As discussed above, wet wood does not burn as efficiently as dry wood. One of the barriers to use of dry wood is availability. Construction of a regional kiln is one way to increase the availability of dry wood. A regional kiln would allow wet firewood to be dried quickly. Depending on the source of heat[25] for drying, substantial reductions in PM emissions could be achieved. The source of drying heat would also affect the cost of the process, and therefore the premium charged for kiln-dried wood.

This measure would reach only a portion of the wood supply. More than 75% of the wood burned in residential heaters is self-cut or comes from unlicensed wood suppliers; this wood could not be processed in a regional kiln.

As discussed above, dry wood provides several advantages for the consumer: it burns hotter and cleaner, each log weighs less, and less fuel is needed for the same amount of heat. Depending upon the cost of drying heat, the premium for dry wood may be less than the consumer's savings due to the reduced need for fuel.[26] Economic incentives from government agencies may therefore be necessary to kickstart construction of a regional kiln.

There is no evidence that the current demand for sales of dry firewood is sufficiently high to require construction of a regional kiln.[27] As discussed below, adoption of a ban on the

[23] 2013 Tag survey.
[24] Most wood sold in the area comes from trees that have been cut down, but not sectioned and split until purchased by the consumer. As a result, the wood is still wet when sold.
[25] Sources of heat could include kiln-dried firewood produced in the facility, fuel oil or LNG, or low pressure steam or recovered heat from an industrial process.
[26] The current premium for dry vs. wet wood is $50 per cord ($375 per cord vs. $325 per cord). The moisture content of kiln-dried firewood must be similar to that of air-dried firewood in order for certified stoves to work properly.
[27] At least one firewood vendor is constructing a kiln, based either on current demand or anticipation of demand. If this venture is successful, other vendors may choose to do the

sale of green wood would increase demand, possibly justifying construction of a kiln; however, such a ban has not been feasible in FNSB. Furthermore, regional emissions from kiln-dried firewood are much higher than from air-dried firewood, because of the fuel needed to operate the kiln.

This measure is not technologically feasible.

Ban on green wood sales

A ban on the sale of green wood would require wood vendors to have access to facilities to dry wood. This would be either a kiln (such as a regional kiln described in the previous section) or sufficient storage space to store and dry all of the fuel wood to be sold in the following year. The amount of dry wood storage needed for one year of wood fuel sales in FNSB is 42,300 cords.[28]

This measure would reach only a portion of the wood supply. As discussed in the previous section, more than 70% of the wood burned in residential heaters is self-cut or comes from unlicensed wood suppliers; this would not be affected by a ban on sale of green wood.

As discussed above, the referendum prohibiting the Borough's regulation of home heating and fuels has prevented the Borough from implementing this program. Any such program would have to be implemented by the State, in the face of opposition from the local community.

This measure is not technologically feasible.

5.7.3.3. Residential Wood Burning: Outdoor Wood-burning Boilers (hydronic heaters)

A hydronic heater (also called an outdoor wood heater or outdoor wood boiler) burns wood to heat liquid flowing through pipes in the combustion chamber. The hot liquid is then piped to provide heat and hot water to occupied buildings. The number of units in FNSB has been estimated[29] at about 480: 380 are uncertified, and 100 are Phase 2 Qualified units (see below).

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same. A much larger unmet demand for dry wood would be needed to justify a regional kiln, however.

[28] A 2011 home heating survey (Sierra Research, June 10, 2011) indicated average wood fuel use of 3.57 cords/year per installation for stoves and inserts, and 1.80 cords/year for fireplaces. The SIP inventory for 2015 projects a total of 11,510 stoves, inserts, and hydronic heaters, and 660 fireplaces. Total estimated annual wood fuel consumption = 3.57 * 11,510 + 1.80 * 660 = 42,300 cords

[29] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

Emissions from wood boilers are currently not regulated at the national level, but EPA has initiated a voluntary program for manufacturers of hydronic heaters.[30] The program encourages manufacturers to produce and sell cleaner, more efficient devices. Hydronic heaters that are "Phase 2 Qualified" under the EPA program must meet an emissions limit of 0.32 lbs per million BTU output.[31] This represents a reduction of about 90% compared to unqualified units.

Direct $PM_{2.5}$ emissions from hydronic heaters are estimated to be 350 tons per year.[32]

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[33] The agencies publish a brochure, *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure*, Wet Wood is a Waste,* as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. In order to maximize the effectiveness of this control measure, additional materials that target hydronic heaters should be developed, containing the information currently available on the EPA website.[34]

Because it involves voluntary efforts on the part of the public, and is implemented as a state program, community resistance to the FNSB and Alaska DEC outreach programs has been minimal.

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public. Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

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[30] EPA, *EPA's Phase 2 Voluntary Partnership Program: Hydronic Heaters*
[31] Ibid.
[32] Cold Climate Housing Research Center, *Reducing $PM_{2.5}$ Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 14.
[33] As discussed in the introduction to this Section.
[34] http://www.epa.gov/burnwise/woodboilers.html.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them. FNSB has developed a voluntary burn cessation program that includes direct notification of participants when an advisory is called. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Under this control measure, the agencies will develop and distribute additional educational materials. They will increase efforts to publicize the program, beginning with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

In February, 2014, the FNSB adopted an ordinance[35] to create a voluntary burn cessation program with the following elements:

- Provide incentives (sign-up bonus, yard sign, or other form of public acknowledgment) to households that agree to voluntarily avoid use of wood-burning appliances during air quality advisories.

- Establish methods, such as automated phone calls, to notify participants when an advisory is called.

- Allow the Borough to contract with an agency to promote the program.

This control measure is technologically feasible.

Mandatory curtailment on air quality advisory days

Mandatory curtailment on air quality advisory days would prohibit use of some hydronic heaters on days of poor air quality. This prohibition could be implemented to affect all hydronic heaters, or only those that do not meet EPA qualification standards. An exemption from the ban for units that are the sole source of a residence's space heating would be included in either case. Approximately 4% of households in Fairbanks use wood as the sole source of heat.

State law currently prohibits the operation of wood-fired heating devices on episode days:

> *18 AAC 50.075 (b) A person may not operate a wood-fired heating device in an area for which the department has declared an air quality episode under 18 AAC 50.245.*

The criteria for declaring an air quality episode do not currently include $PM_{2.5}$ concentrations. Alaska DEC has proposed[36] to revise the criteria for declaring an air

[35] http://co.fairbanks.ak.us/meetings/ordinances/2014/2014-11.pdf
[36] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels,*

quality episode to include $PM_{2.5}$, but at a concentration well above the federal standard. At the same time, Alaska DEC proposed a revision to Section 50.075 to give the agency discretion about declaring an episode. The revision would benefit public health by reducing $PM_{2.5}$ concentrations on the worst episode days. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

As discussed above, the Borough has not been able to implement this measure because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community and would not be practically enforceable.

This measure is not technologically feasible.

All new units must be certified

Alaska DEC has already proposed a more stringent standard. See next section.

This control measure is technologically feasible.

All new units must meet a more stringent state standard of 2.5 gram/hour

EPA has initiated a voluntary program for manufacturers of hydronic heaters. EPA's primary intent is to first encourage manufacturers to produce cleaner hydronic heater models. EPA also wants those who buy a hydronic heater to buy the cleanest models available, which are those that qualify for the EPA voluntary program. EPA maintains a list of qualifying models, of which there are many.

Many local agencies have developed ordinances that ban unqualified hydronic heaters and establish minimum distances to neighbors and minimum stack heights. EPA has provided technical and financial support for the NESCAUM to develop a model rule that state and local agencies can use to regulate hydronic heater emissions.

Alaska DEC has proposed[37] to adopt a new regulation, 18 AAC 50.077(b)(1), that would require that all new hydronic heaters meet an emission limit of 2.5 gm/hr. While this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels, the State could implement the measure. Since it would only affect the supply of wood stoves offered for sale and not impact homeowner fuel choice decisions, enforceability limitations and concerns would not apply.

Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft, September 19, 2013.

[37] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

This measure is technologically feasible.

All units must be certified, requiring retrofits/replacement of existing units

Adoption of a performance standard for all hydronic heaters would require replacement or retrofit of existing heaters that do not meet the standard (e.g., qualified under the EPA program described above).

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community and would not be practically enforceable.

This control measure is not technologically feasible.

Ban on new installations

A ban on new installations would not reduce emissions from hydronic heaters in the near term, but would ultimately reduce emissions as hydronic heaters were retired. However, this approach could have the negative effect of prolonging the use of existing, dirty units because replacing them with newer, much cleaner units would not be allowed. As a result, this measure would not result in quantifiable reductions in the four years after designation.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community and would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Remove at time of home sale

A requirement to replace hydronic heaters at the time of home sale would not reduce emissions from hydronic heaters in the near term, but would ultimately reduce emissions as hydronic heaters were retired when residential property changed hands. As a result, this measure would not result in quantifiable reductions in the four years after designation. The cost of the measure would be borne by the seller, because the home's sale price would be diminished by the value of the heater that must be removed.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable.

This control measure is not technologically feasible.

Subsidize heater change outs

FNSB has a solid fuel burning appliance (SFBA) change out program. Qualifying residents can be reimbursed for replacing, removing, or repairing solid fuel burning devices (wood and coal-stoves, wood and coal-fired furnaces, hydronic heaters, fireplace inserts, etc.). FNSB offers reimbursement of 100% of the cost (up to $10,000) of a new qualifying hydronic heater. There is also a bounty program for dismantling an old device without replacement.

This control measure is technologically feasible.

Ban use

A ban on the use of hydronic heaters would require those with access to alternate heat sources to use them. Unless an exemption were offered, those with no alternate heat source would be required to install one. As discussed above, on very cold days some residences with alternate heat sources find those sources to be inadequate, and need to supplement with heat from wood combustion. An enforcement mechanism is required to implement this measure. Such a mechanism does not currently exist.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable.

This control measure is not technologically feasible.

5.7.3.4. Residential Wood Burning: Wood Stoves

The number of units in FNSB has been estimated[38] at about 11,000: 3,645 (33%) are uncertified; 3,811 (35%) are EPA-certified non-catalytic units; 2,497 (23%) are EPA-certified catalytic units; and 412 (4%) are pellet stoves

Direct $PM_{2.5}$ emissions from wood stoves are estimated to be 214 tons per year.[39]

[38] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

[39] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 14.

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[40] The FNSB and State of Alaska have programs focused on woodstoves. Program materials include brochures on woodstoves, catalytic woodstoves, and non-catalytic woodstoves; *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure, *Wet Wood is a Waste,* as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. Because it involves voluntary efforts on the part of the public, and is implemented as a state program, community resistance to the FNSB and Alaska DEC outreach programs has been minimal.

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public. Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them.

In February, 2014, the FNSB adopted an ordinance[41] to create a voluntary burn cessation program with the following elements:

- Provide incentives (sign-up bonus, yard sign, or other form of public acknowledgment) to households to agree to voluntarily avoid use of wood-burning appliances during air quality advisories.

- Establish methods, such as automated phone calls, to notify participants when an advisory is called

- Allow the Borough to contract with an agency to promote the program.

[40] As discussed in the introduction to this Section.
[41] http://co.fairbanks.ak.us/meetings/ordinances/2014/2014-11.pdf

This measure is technologically feasible.

Mandatory curtailment on air quality advisory days

Mandatory curtailment on air quality advisory days would prohibit use of some woodstoves. This prohibition could be implemented to affect all woodstoves, or only those that do not meet EPA certification standards. An exemption from the ban for units that are the sole source of a residence's space heating would be included in either case.

State law currently prohibits the operation of wood-fired heating devices on episode days:

> *18 AAC 50.075 (b) A person may not operate a wood-fired heating device in an area for which the department has declared an air quality episode under 18 AAC 50.245.*

The criteria for declaring an air quality episode do not currently include $PM_{2.5}$ concentrations. Alaska DEC has proposed[42] to revise the criteria for declaring an air quality episode to include $PM_{2.5}$, but at a concentration well above the federal standard. At the same time, Alaska DEC proposed a revision to Section 50.075 to give the agency discretion about declaring an episode. The revision would benefit public health by reducing $PM_{2.5}$ concentrations on the worst episode days.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such program would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

All new units must be certified

Alaska DEC has proposed a more stringent measure. Please see next section.
This control measure is technologically feasible.

Only stoves meeting more stringent state standards (2.5 gram/hr) may be sold

[42] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

Alaska DEC has proposed[43] to adopt a new regulation, 18 AAC 50.077(b)(2), that would require that all new woodstoves meet an emission limit of 2.5 gm/hr and be certified by EPA. The short-term effectiveness of this measure is low, as the turnover of wood stoves built before 1992 is very slow; however, the measure would stop the projected growth in the number of uncertified wood stoves (~1.3% per year).[44] Changeover to newer units could be accelerated with a wood stove change-out program.

This control measure is technologically feasible.

Replace uncertified stoves at time of home sale

A requirement to replace uncertified stoves at the time of home sale would not reduce emissions from wood stoves in the near term, but would ultimately reduce emissions as wood stoves were retired when residential property changed hands. As a result, this measure would not result in quantifiable reductions in the four years after designation. The cost of the measure would be borne by the seller, because the home's sale price would be diminished by the value of the stove that must be removed.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Replace uncertified stoves in rental units

A requirement to replace uncertified stoves in rental units would result in emission reductions upon replacement. The cost of the measure would be borne by the landlords, and presumably passed on to the renter.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the

[43] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.
[44] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Require alternate heat source in rental units

Emission reductions occur to the extent that the renter uses the alternate heat source during air pollution advisories. The availability of an alternate heat source allows the renter to participate in curtailment programs. It is not clear what fraction of the rental housing stock is physically able to install an alternate heat source. The cost of the measure would be borne by the landlords, and presumably passed on to the renter.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Require alternate heat source in new construction

A requirement to include alternate heat sources in new construction would not reduce emission; it would, however, potentially reduce the magnitude of new emissions associated with population growth. Emission minimization occurs to the extent that the resident uses the alternate heat source during air pollution advisories. The availability of an alternate heat source allows the resident to participate in curtailment programs. This measure would not result in quantifiable reductions in the four years after designation.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable.

This control measure is not technologically feasible.

Ban on new installations

A ban on new installations would not reduce emissions from wood stoves in the near term, but would ultimately reduce emissions as wood stoves were retired; however, this approach could have the negative effect of prolonging the use of existing, dirty units because replacing them with newer, much cleaner units would not be allowed. This measure would not result in quantifiable reductions in the four years after designation.

The short-term effectiveness of this measure is low, as the turnover of wood stoves built before 1992 is very slow. Changeover to newer units could be accelerated with a wood stove change-out program.

As discussed above, this measure cannot be implemented by the Borough because of the referendum prohibiting the Borough's regulation of home heating and fuels. Any such measure would have to be implemented by the State, in the face of opposition from the local community would not be practically enforceable. Since the measure has been recently defeated in October 2014. This information became available after the preparation of this document, there is insufficient time to prepare revisions and meet the schedule for delivering the SIP to EPA by the end of 2014. Moreover, the Borough has not had time to make decisions about any additional control measures to be implemented in the wake of the vote.

This control measure is not technologically feasible.

Subsidize woodstove change outs

FNSB has a SFBA change out program. Qualifying residents can be reimbursed for replacing, removing, or repairing solid fuel burning devices (wood and coal-stoves, wood and coal-fired furnaces, hydronic heaters, fireplace inserts, etc.). FNSB offers reimbursement of 100% of the cost (up to $4,000) of a new certified wood stove. There is also a bounty program for dismantling an old device without replacement.

This control measure is technologically feasible.

Ban on all use

A ban on the use of woodstoves would require those with access to alternate heat sources to use them. Unless an exemption were offered, those with no alternate heat source would be required to install one. As discussed above, on very cold days some residences with alternate heat sources find those sources to be inadequate, and need to supplement with heat from wood combustion.

An enforcement mechanism is required to implement this measure. The mechanism would need to be much larger than needed to enforce a ban on hydronic heaters, due to the larger number of stoves and the fact that stoves are less conspicuous. Such a mechanism does not currently exist.

This control measure is not technologically feasible.

Incentive program: use stove change outs to generate New Source Review (NSR) offsets

Incentive programs provide cash incentives to equipment owners to retire or replace old, dirty equipment. Proposals for incentive programs focus on the source of funds, the amount of subsidy per transaction, and the amount of funds available.

This measure would allow applicants for new major industrial sources to obtain emission offsets by funding stove change outs. Emissions from woodstoves would be reduced, and some fraction of the reduction would be made available to offset emissions from the new industrial source.

Based upon discussions with Alaska DEC permitting staff, the likelihood of an industrial project in FNSB triggering PM offset requirements is small. Because no projects have been proposed that might find this option useful, no reductions will occur in the four years following designation.

This measure is not technologically feasible.

5.7.3.5. Residential Wood Burning: Fireplaces

The number of units in FNSB has been estimated[45] at about 1,275; 610 (48%) do not have inserts; 234 (18%) have uncertified inserts; 245 (19%) are EPA-certified non-catalytic units; 160 (13%) are EPA-certified catalytic units; and 24 (2%) are pellet-burning inserts.

Education and Outreach

The State of Alaska and the FNSB have significant experience in educational programs that help citizens reduce their emissions.[46] The agencies publish a brochure, *Split Stack Store and Save!*, that encourages the use of only dry wood, explains methods for ensuring that wood is dry (seasoning after cutting,), and explains some of the benefits (less wood needed, cleaner burning). EPA publishes a similar brochure, *Wet Wood is a Waste,* as part of its Burn Wise program. Burn Wise materials are also available from the FNSB and Alaska DEC. Because it involves voluntary efforts on the part of the public, and is implemented as a State program, community resistance to the FNSB and Alaska DEC outreach programs has been minimal.

Overall effectiveness of voluntary measures as an emission reduction measure depends upon the extent of implementation, as well as the actual steps taken by the public.

[45] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

[46] As discussed in the introduction to this Section.

Education and outreach measures can reduce opposition to future efforts to implement mandatory measures.

This control measure is technologically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them.

In February 2014, the FNSB adopted an ordinance[47] to create a voluntary burn cessation program with the following elements:

- Provide incentives (sign-up bonus, yard sign, or other form of public acknowledgment) to households that agree to voluntarily avoid use of wood-burning appliances during air quality advisories.

- Establish methods, such as automated phone calls, to notify participants when an advisory is called.

- Allow the Borough to contract with an agency to promote the program.

This program is technologically feasible.

Mandatory curtailment on air quality advisory days

Mandatory curtailment on air quality advisory days would prohibit use of some fireplaces. This prohibition could be implemented to affect all fireplaces, or only those that do not meet EPA certification standards (e.g., certified inserts; chimney abatement systems). An exemption from the ban for units that are the sole source of a residence's space heating would be included in either case.

State law currently prohibits the operation of wood-fired heating devices on episode days:

> *18 AAC 50.075 (b) A person may not operate a wood-fired heating device in an area for which the department has declared an air quality episode under 18 AAC 50.245.*

[47] http://co.fairbanks.ak.us/meetings/ordinances/2014/2014-11.pdf

The criteria for declaring an air quality episode do not currently include $PM_{2.5}$ concentrations. Alaska DEC has proposed[48] to revise the criteria for declaring an air quality episode to include $PM_{2.5}$, but at a concentration well above the federal standard. At the same time, Alaska DEC proposed a revision to Section 50.075 to give the agency discretion about declaring an episode. The revision would benefit public health by reducing $PM_{2.5}$ concentrations on the worst episode days. However, because the proposed threshold for calling an advisory is well above the federal standard, this revision will not result in emission reductions on many violation days, and therefore will not contribute to attainment in FNSB.

This control measure is not technologically feasible.

Subsidize fireplace insert change outs

FNSB has an SFBA change out program. Qualifying residents can be reimbursed for replacing, removing, or repairing solid fuel burning devices (wood and coal-stoves, wood and coal-fired furnaces, hydronic heaters, fireplace inserts, etc.). FNSB offers reimbursement of 100% of the cost (up to $4,000) of a new certified fireplace insert. There is also a bounty program for dismantling an old device without replacement.

This control measure is technologically feasible.

5.7.3.6. Residential Wood Burning: Burn Barrels, Open Burning

Reinstate seasonal open burning ban

Open burning is currently banned between November 1 and March 31 in Wood Smoke Control Areas (18 AAC 50.065(f)). FNSB is not currently a Wood Smoke Control Area. Alaska DEC has proposed adding $PM_{2.5}$ non-attainment areas to the areas covered by this regulation as a proactive measure to prevent additional smoke during winter months.[49]

Alaska DEC's regulation 18 AAC 50.065(e) prohibits open burning during an air quality advisory. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Since the 1970s, the Fairbanks North Star Borough had an ordinance to restrict wintertime open burning. In 2013, the Borough Assembly repealed that ordinance in

[48] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

[49] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

response to a voter initiative that restricted the Borough's authority to regulate fuel burning.

Although the voters of FNSB have clearly indicated opposition to local regulations affecting home heating, there is no indication of similar widespread opposition to the FNSB's historical open burning control program.

The cost of such a program is the increased administrative cost of enforcing the ban. Most of this cost can be recovered through fines imposed on violators.

This control measure is technologically feasible.

Burn barrel prohibition

Although the voters of FNSB have clearly indicated opposition to local regulations affecting home heating, there is no indication of similar widespread opposition to the FNSB's historical open burning control program. Burn barrels are used by some residents to dispose of combustible waste, not to provide useful heat.

Many states and localities ban the use of burn barrels, mostly because these devices are prone to creating a nuisance. If used only to burn clean, dry wood, they can be operated in a smokeless, odor-free manner. Combustion of almost any other materials will result in both smoke and odors.

Burn barrels are covered by the State's open burning regulation, which bans open burning between November 1 and March 31 in Wood Smoke Control Areas (18 AAC 50.065(f)). FNSB is not currently a Wood Smoke Control Area. Alaska DEC has proposed adding $PM_{2.5}$ nonattainment areas to the areas covered by this regulation as a proactive measure to prevent additional smoke during winter months.[50]

Alaska DEC's regulation 18 AAC 50.065(e) also prohibits open burning during an air quality advisory. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

This control measure is technologically feasible.

5.7.3.7. Residential Fuel Oil

The number of units in FNSB has been estimated at about 27,000.[51] Direct $PM_{2.5}$ emissions from fuel oil combustion in residential heaters are estimated to be 42 tons per

[50] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

[51] Sierra Research, projected 2015 (attainment year) inventory based on 2011 home heating survey

year.[52] Additionally, fuel oil combustion contributes to secondary particulate formation because virtually all (99%) of the sulfur in fuel oil is oxidized to SO_2 when combusted, and a portion of the SO_2 reacts to form sulfate aerosols, a form of $PM_{2.5}$. SOx emissions from fuel oil combustion are estimated to be about 770 tons per year,[53] equivalent to 130 tons per year of direct $PM_{2.5}$ emissions.

Economic incentives to switch to low sulfur fuel

The most effective strategy for reducing SO_2 emissions from residential oil use is lowering the sulfur content of heating oil. Currently in the U.S. (and in the FNSB), heating oil for residential use has an average sulfur content of about 0.20–0.25% (about 2,500 ppm). Switching to low sulfur content fuel (500 ppm) could eliminate 75–80% of the SO_2 emissions generated by residential oil heating systems, as well as 80% of direct $PM_{2.5}$ emissions.

The American Society for Testing and Materials (ASTM), an international voluntary standards development organization, has approved a Low-Sulfur No. 2 Heating Oil specification. Also, the Oilheat Manufacturers Association has been promoting low-sulfur heating oil, both to improve air quality and to reduce equipment maintenance costs. Low-sulfur heating oil reduces the level of residue build-up on the surfaces of boilers and furnaces, improving equipment performance and reducing maintenance costs.

The control measure would consist of providing an economic incentive (in the form of a cash rebate[54]) to consumers to purchase low-sulfur fuel oil instead of their current supply. Because participation in the program would be voluntary, it would not conflict with the fuel regulation ban in the Home Heating Initiative.

This control measure is technologically feasible.

5.7.3.8. District Heating System

Many residential, commercial, and institutional buildings within the FNSB are connected to district heating systems that supply low pressure steam or hot water for space heating and domestic hot water use. Use of the district heating systems allows for the widespread use of energy produced by a central steam generating unit that is well controlled. These systems essentially eliminate the need for the operation of individual fuel combustion units by the facilities connected to them.

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[52] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 15.
[53] Cold Climate Housing Research Center, *Reducing PM2.5 Emissions from Residential Heating Sources in the Fairbanks North Star Borough*, February 23, 2009. p. 15. SOx emissions are calculated by dividing the reported sulfate formation (232 TPY) by the assumed conversion rate (30%).
[54] Because Alaska has no state income or sales tax, a tax credit or exemption would not work as a mechanism for implementing this program. A property tax offset is another possible mechanism, but would not be available to renters.

Even considering transmission losses, a well maintained and operated central unit can be much more efficient that individual combustion units, especially those that burn wood, coal, or oil. Pollutants from a central unit are emitted at a much higher elevation, and as a result are more dispersed.

Increased usage/coverage of district heating systems

Individual combustion units—especially those that burn wood, coal, or oil—are often much less efficient than a well maintained and operated central power plant. Individual combustion units also produce pollutants that are emitted to the atmosphere very near ground level, rather than from tall stacks. Because of the difference in release points, pollutants from individual combustion units have a greater impact on ground-level $PM_{2.5}$ concentrations.

An increase in the coverage of the district heating systems would therefore result in a decrease in measured $PM_{2.5}$ concentrations.

This control measure is technologically feasible.

5.7.3.9. Energy Efficiency and Weatherization

Home Improvement Rebate Program

EPA recognizes the benefits of including energy efficiency programs in SIPs as a low cost means of reducing emissions.

The Alaska Housing Finance Corporation (AHFC) implements several energy programs that are designed to make homes more energy efficient. As homeowners make energy efficiency improvements, they reduce the amount of fuel and electricity needed for power and heat, leading to corresponding air quality benefits due to the reduced fuels being burned for space heating and power generation.

This control measure is technologically feasible and already implemented.

5.7.3.10. Transportation

Listed below are the transportation-related programs currently being implemented in Fairbanks.

- Expanded availability of plug-ins; electrical outlets were installed on 1,500+ parking spaces between 2008 & 2015

- Ordinance mandating—for employers with 275+ parking spaces—electrification of outlets at temps < 21° F between November 1 and March 31

- Public education focused on the benefits of plugging-in and using the transit program called Metropolitan Area Commuter System (MACS)

- Expanded transit service includes improved service frequency on high ridership routes, new routes and better bus stop facilities; ridership increased 61% between 2008 & 2013

- Commuter Van Pool program, includes Van Tran program for elderly and disabled

- Anti-idling program for heavy-duty diesel vehicles started as a ADOT&PF program focused on dump trucks and tractors and has been expanded to a CMAQ-funded pilot program focused on the purchase and installation of auxiliary heaters to reduce idle time

- Federal Motor Vehicle Control Program

With the exception of the anti-idling program, the programs listed above have been in place for well over a decade and are working to reduce motor vehicle emissions under extreme winter operating conditions.

Measures focused on reducing traffic congestion offer limited benefits as the Fairbanks road network has few roads operating at Level of Service (LOS) levels D, E, or F.

Community-wide ridesharing programs offer few potential emission reduction benefits because of the low population and employment density in the nonattainment area (employer programs are operated where sufficient density supports participation).

Travel reduction programs have been found to have limited benefits on a national basis, with principal reductions coming from commute trips, which require high density employment to be successful.

EPA's motor vehicle emissions model MOVES, including the recently released version MOVES2014, does not provide a PM benefit for either light- or heavy-duty I/M programs. Thus, there is no way to quantify a particulate benefit from I/M, and EPA clearly does not recognize I/M as an appropriate PM control measure.

Given these constraints, no additional TCMs appear viable for Fairbanks. Because TCMs are not expected to provide additional reductions, all TCMs are classified as "not technologically feasible."

5.7.3.11. Measures Deemed Technologically Infeasible

A summary of the assessment of technological feasibility for candidate control measures is presented below in Table 5.7-6. It shows that a number of candidate control measures are not technologically feasible at this time: two of those—construction of regional kilns and use of stove change outs to generate NSR credits—are not feasible because there is

no evidence of demand, so no emission reductions are expected; the remainder are infeasible because they are not practically enforceable in the Borough at this time.

Table 5.7-6. Candidate Control Measures Considered for RACM

Source Category	Control Measure	Technologically Feasible?	
Dry Wood Measures	Education and Outreach	Yes	
	Regional kiln		No
	Ban on green wood sales		No
Hydronic Heaters	Education and Outreach	Yes	
	Voluntary curtailment on air quality advisory days	Yes	
	Mandatory curtailment on air quality advisory days		No
	All new units must be certified	Yes	
	All new units must meet more stringent standards	Yes	
	All units must be certified		No
	Ban new installations		No
	Remove at time of home sale		No
	Subsidize heater change outs	Yes	
	Ban use		No
Wood Stoves	Education and Outreach	Yes	
	Voluntary curtailment on air quality advisory days	Yes	
	Mandatory curtailment on air quality advisory days		No
	All new units must be certified	Yes	
	All new units must meet more stringent standards	Yes	
	All units must be certified		No
	Replace uncertified stoves at time of home sale		No
	Replace uncertified stoves in rental units		No
	Require alternate heat source in rental units		No
	Require alternate heat source in new construction		No
	Ban new installations		No
	Subsidize stove change outs	Yes	
	Ban use		No
	Use stove change outs to generate NSR offsets		No

Source Category	Control Measure	Technologically Feasible?	
Fireplaces/Fireplace Inserts	Education and Outreach	Yes	
	Voluntary curtailment on air quality advisory days	Yes	
	Mandatory curtailment on air quality advisory days		No
	Subsidize fireplace insert change outs	Yes	
Open Burning	Reinstate open burning ban	Yes	
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	Yes	
Residential Fuel Oil Combustion	Provide economic incentives to switch to low-sulfur fuel	Yes	
	Increase coverage of District heating systems	Yes	
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	Yes	
Transportation	Improved public transit	Yes	
	HOV lanes		No
	Traffic flow improvement programs		No
	Create non-motorized traffic zones		No
	Restrict truck idling	Yes	
	Reduce cold start emissions	Yes	
	Employer-sponsored flexible work schedules		No
	Retrofit diesel fleet (school buses, transit fleets)		No
	Onroad vehicle I&M program		No
	Heavy-duty vehicle I&M program		No
	State LEV Program		No

5.7.4. STEP 3: EVALUATE EMISSION REDUCTIONS AND COSTS FOR EACH TECHNOLOGICALLY FEASIBLE CONTROL MEASURE

In this section, technologically feasible control measures are evaluated for emission benefits and cost effectiveness. Measures with negligible potential for emission reductions were screened out in previous steps.

The process used to evaluate the economic feasibility of candidate control measures is outlined below. Some of the control measures determined to be RACM in this analysis are already implemented in the FNSB. Because the economic feasibility of these measures does not need to be established, a qualitative analysis has been performed.

1. **For each technologically feasible emission control technology or measure**, provide best estimates of the following:

a. the control efficiency by pollutant;
b. the possible emission reductions by pollutant;
c. the estimated cost per ton of pollutant reduced; and
d. the date by which the technology or measure could be reasonably implemented.

2. Determine if any technologically feasible control measures are economically infeasible:

   a. Consider the cost of reducing emissions and the difference between the cost of an emissions reduction measure at a particular source and the cost of emissions reduction measures that have been implemented at other similar sources.

   b. Economic feasibility of RACM/RACT is thus largely determined by evidence that other sources in a source category have in fact applied the control technology, process change, or measure in question.

   c. For each technologically feasible control measure or technology, a state must determine the capital costs, annualized costs, and cost effectiveness (i.e., cost per ton of pollutant reduced by that measure or technology).

   d. A state may not reject a technologically feasible control measure or technology as being economically infeasible if such a measure or technology has been implemented at other similar sources, unless the state provides a detailed justification that clearly explains the specific circumstances of the source or sources in the nonattainment area that make such a measure or technology economically infeasible.

Table 5.7-7 presents the list of candidate control measures that were determined to be technologically feasible.

Table 5.7-7. Technologically Feasible Control Measures

Source Category	Control Measure	Economically Feasible?	RACM?	Potential Implementation Date
Dry Wood Measures	Education and Outreach	Yes	RACM	Already in place
Hydronic Heaters	Education and Outreach	Yes	RACM	Already in place
	Voluntary curtailment on air quality advisory	Yes	RACM	1st Qtr 2016

Source Category	Control Measure	Economically Feasible?	RACM?	Potential Implementation Date
	days			
	All new units must be certified to more stringent standards	Yes	RACM	1st Qtr 2016
	Subsidize heater change outs	Yes	RACM	Already in place
Wood Stoves	Education and Outreach	Yes	RACM	Already in place
	Voluntary curtailment on air quality advisory days	Yes	RACM	Already in place
	All new units must be certified	Yes	RACM	1st Qtr 2016
	Subsidize stove change outs	Yes	RACM	Already in place
Fireplaces/Fireplace Inserts	Education and Outreach	Yes	RACM	Already in place
	Voluntary curtailment on air quality advisory days	Yes	RACM	Already in place
	Subsidize fireplace insert change outs	Yes	RACM	Already in place
Open Burning	Reinstate open burning ban	Yes	RACM	1st Qtr 2016
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	Yes	RACM	1st Qtr 2016
Residential Fuel Oil Combustion	Provide economic incentives to switch to low-sulfur fuel	No	No	Not cost effective
	Increase coverage of District heating systems	No	No	Not cost effective
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	Yes	RACM	Already in place
Transportation	Improved Public Transit	Yes	RACM	Already in place

Source Category	Control Measure	Economically Feasible?	RACM?	Potential Implementation Date
	Restrict Truck Idling	Yes	RACM	Already in place
	Reduce Cold Start Emissions	Yes	RACM	Already in place

5.7.4.1. Dry Wood Programs

As shown in Table 5.7-2, residential wood combustion in Fairbanks is responsible for 2.72 tons per day, or 60% of total direct $PM_{2.5}$ emissions on episode days. About 60% of the wood burned in residential wood combustion units is green wood, on a volume basis.[55] According to a 2008 NESCAUM report, for every 10 percentage point increase in the moisture content of wood the $PM_{2.5}$ emissions increase by 65% to 167%.[56] If dry wood (20% moisture content) is burned instead of all of the wet wood, a reduction of between 1.2 and 1.8 ton/day of $PM_{2.5}$ could result.

Education and Outreach

The overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Actual quantification of emission reduction is difficult to do. However, these programs are considered pivotal to the acceptance of any wood smoke control program.[57]

Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed) and the cost to homeowners to store wood for a season. (In order to have dry wood all year, a full year's supply of wood would need to be purchased at least six months before it is to be used, and split and stored in a manner that would allow it to dry. The average amount of wood burned per year in Fairbanks is 3.57 cords/year per household,[58] which would require 460 cubic feet of storage. Although construction of this much storage would not be a trivial expense, the cost would

[55] Based on a 2011 sample of 20 households, 40% of the households sampled had moisture contents at or below 20%.
[56] NESCAUM, *Source Characterization of Outdoor Wood Furnaces,* September 9, 2008, p. 4-1
[57] Hearth, Patio and Barbecue Association, *Clearing the Smoke: The Wood Stove Changeout in Libby, Montana*, January 2008, p. 20; see also Canadian Council of Ministers of the Environment, Code of Practice for Residential Wood Burning Applicances, 2012, p. 28.
[58] A 2011 home heating survey (Sierra Research, June 10, 2011) indicated an average wood fuel use of 3.57 cords/year per installation for stoves and inserts, and 1.80 cords/year for fireplaces.

go down after the first year by as much as 30% because less dry wood is needed for the same useful heat production.[59])

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

5.7.4.2. Residential Wood Burning: Outdoor Wood-burning Boilers (hydronic heater)

Education and Outreach

Overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed).

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor.

[59] Useful heat energy from a typical wood fuel is 5,000 btu/lb at 20% moisture, and 3,500 btu/lb at 40% moisture (the difference is due to the heat required to evaporate the extra water). The fuel savings due to burning dry wood (20% moisture) is 30% [(5,000-3,500)/5,000].

Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them

Under this control measure, the agencies will develop and distribute additional educational materials. They will increase efforts to publicize the program, beginning with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: not estimated because already implemented
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

All new units must meet 2.5 gm/hr

This control measure reduces the rate of growth of emissions due to the increased number of installations by minimizing the emissions from new equipment. In addition, it reduces emissions as old units are retired and replaced by new ones.

Because of the small rate of projected growth, and the low rate of replacement of old units, emission reductions from this measure are small. Cost of control is also small, because there is no incremental cost between a certified unit and a non-certified unit.

Alaska DEC has proposed[60] to adopt a new regulation, 18 AAC 50.077(b)(2), that would require that all new woodstoves meet an emission limit of 2.5 gm/hr and be certified by EPA.

- Control efficiency by pollutant: small
- Possible emission reductions by pollutant: small.
- Estimated cost per ton of pollutant reduced: small

[60] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

Subsidize hydronic heater change outs

The FNSB's hydronic heater change out program is a voluntary program initiated by FNSB to promote the use of cleaner-burning heating appliances. It uses a cash rebate, combined with public outreach and education, to encourage consumers to replace their old, inefficient, and high-polluting woodstoves with new clean-burning EPA-certified woodstoves, or other heating appliances such as pellet stoves or gas/electric stoves.[61] EPA has provided estimates of control effectiveness and costs for such a program.[62] These are summarized below.

- Control efficiency by pollutant: 60%
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: $10,000
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

5.7.4.3. Residential Wood Burning: Wood Stoves

Education and Outreach

Overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed).

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

[61] Guidance for Quantifying and Using Emission Reductions from Voluntary Woodstove Changeout Programs in State Implementation Plans.
[62] EPA, *Menu of Control Measures* (8/6/2013), p. 52

Voluntary curtailment on air quality advisory or alert days

Under a voluntary curtailment program, owners of wood-burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Under this control measure, the agencies will develop additional educational materials. They will increase efforts to publicize the program, beginning with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Only certified stoves may be sold

This control measure reduces the rate of growth of emissions due to the increased number of installations by minimizing the emissions from new equipment. In addition, it reduces emissions as old units are retired and replaced by new ones.

Because of the small rate of projected growth, and the low rate of replacement of old units, emission reductions from this measure are small. Cost of control is also small, because there is no incremental cost between a certified unit and a non-certified unit.[63]

Alaska DEC has proposed[64] to adopt a new regulation, 18 AAC 50.077(b)(2), that would require that all new woodstoves meet an emission limit of 2.5 gm/hr and be certified by EPA.

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[63] An analysis of the 2012 List of EPA Certified Wood Stoves shows there is essentially no correlation between retail price and the EPA certification emission rate, with a R2 of 0.023. The List was accessed at (www.lrapa.org/downloads/publications/**certifiedwood**.pdf *)*

[64] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels,*

- Control efficiency by pollutant: small
- Possible emission reductions by pollutant: small.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

Subsidize stove change outs

The FNSB's woodstove change out program is a voluntary program initiated by FNSB to promote the use of cleaner-burning heating appliances. It uses a cash rebate, combined with public outreach and education, to encourage consumers to replace their old, inefficient, and high-polluting woodstoves with new clean-burning EPA-certified woodstoves, or other heating appliances such as pellet stoves or gas/electric stoves.[65] EPA[66] has provided estimates of control effectiveness and costs for such a program, as summarized below.

- Control efficiency by pollutant: 60%
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: $9,900 (2010$)
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

5.7.4.4. Residential Wood Burning: Fireplaces

Education and Outreach

Overall effectiveness of voluntary measures depends upon the extent of implementation, as well as the actual steps taken by the public. Costs associated with this measure are small. Costs include the cost to the State and/or Borough to develop educational materials (small, because educational materials for this purpose have already been developed).

- Control efficiency by pollutant: N/A

- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.

Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft, September 19, 2013.

[65] Guidance for Quantifying and Using Emission Reductions from Voluntary Woodstove Changeout Programs in State Implementation Plans.

[66] EPA, *Menu of Control Measures* (8/6/2013), p. 52

- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Voluntary curtailment on air quality advisory days

Under a voluntary curtailment program, owners of wood burning devices are asked to voluntarily reduce or avoid operation of the devices on days when air quality is poor. Such a program relies on agency efforts to predict poor air quality days, agency efforts to make the public aware of predictions, agency efforts to educate the public about reducing emissions, and public cooperation with requests to minimize emissions.

The FNSB Air Quality Division provides daily air quality information on its website and by telephone. Alaska DEC also provides air quality advisories when circumstances call for them. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Under this control measure, the agencies will develop additional educational materials. They will increase efforts to publicize the program, beginning with links on the existing Air Quality Index webpages to the FNSB's existing AQ Advisory program webpages.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: Potentially large. However, EPA guidance allows only a small amount of SIP credit for voluntary measures.
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

Subsidize fireplace insert change outs

The FNSB's fireplace change out program is a voluntary program initiated by FNSB to promote the use of cleaner-burning heating appliances. It uses a cash rebate, combined with public outreach and education, to encourage consumers to retrofit fireplaces with devices that reduce emissions.

EPA[67] has provided estimates of control effectiveness and costs for such a program, as summarized below.

[67] EPA, *Menu of Control Measures* (8/6/2013), p. 43

- Control efficiency by pollutant: 70%
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: $9,500 (2012$)
- Date by which the measure could be reasonably implemented: already implemented

This measure is economically feasible.

5.7.4.5. Residential Wood Burning: Burn barrels, open burning

Open burning (including the use of burn barrels) is currently banned between November 1 and March 31 in Wood Smoke Control Areas (18 AAC 50.065(f)). FNSB is not currently a Wood Smoke Control Area. Alaska DEC has proposed adding $PM_{2.5}$ nonattainment areas to the areas covered by this regulation as a proactive measure to prevent additional smoke during winter months.[68]

Alaska DEC's regulation 18 AAC 50.065(e) prohibits open burning (including the use of burn barrels) during an air quality advisory. Advisories are called when $PM_{2.5}$ concentrations above 35 micrograms per cubic meter are predicted.

Open burning ban

Open burning is not considered a large contributor to air pollution episodes. However, a ban on open burning on air quality advisory days could prevent such activities from contributing to unhealthful air, and is relatively inexpensive to implement. Because the expected reductions are small and variable, they are difficult to quantify.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

Burn barrel prohibition

Burn barrels are not considered a large contributor to air pollution episodes. However, a ban on burn barrels could prevent such activities from contributing to unhealthful air, could avoid nuisance situations, and is relatively inexpensive to implement. Because the expected reductions are small and variable, they are difficult to quantify.

[68] Alaska DEC, *Proposed Regulation changes Pertaining to: Open Burning, Wood-fired Heating Device Visible Emission Standards, Solid Fuel-Fired Heating Device Fuels, Wood Fired Heating Device Standards, & Fine Particulate Matter (PM-2.5) Air Episode and Advisories, Public Review Draft*, September 19, 2013.

- Control efficiency by pollutant: N/A
- Possible emission reductions by pollutant: small
- Estimated cost per ton of pollutant reduced: small
- Date by which the measure could be reasonably implemented: 1st Qtr 2016

This measure is economically feasible.

5.7.4.6. Residential Fuel Oil

Economic incentives to switch to low sulfur fuel

The sulfur in fuel oil is emitted as SOx when the fuel is burned. SOx emissions contribute to the formation of secondary particulate matter in the form of sulfate aerosols. Ambient sampling and modeling in FNSB indicates that reduction of six tons of SOx emissions result in the same reduction in ambient $PM_{2.5}$ concentration as the reduction of one ton of directly emitted $PM_{2.5}$.[69] Additionally, fuel oil combustion contributes to secondary particulate formation because virtually all (99%) of the sulfur in fuel oil is oxidized to SO_2 when combusted, and a portion of the SO_2 reacts to form sulfate aerosols, a form of $PM_{2.5}$.

Reducing six tons of SOx emissions results in the same ambient PM concentration that would result from about a one ton reduction of directly emitted PM. SOx emissions from fuel oil combustion are estimated to be about 770 tons per year,[70] equivalent to 130 tons per year of direct $PM_{2.5}$ emissions.

Using low-sulfur fuel (500 ppm sulfur) instead of current fuel oil (2,000 ppm sulfur) would reduce SOx emissions from this source category by 1500/2000 = 75%, or 580 tons per year. This is equivalent to 96 tons per year of $PM_{2.5}$ reductions.

The incremental cost of low sulfur fuel oil is assumed to be $0.10 per gallon;[71] the resulting reduction in SO_2 emissions is 0.011 lb/gal. The cost effectiveness of control is therefore $0.10/0.011 lb of SO_2, or $18,000 per ton of SO_2. Because SO_2 reductions are 1/6 as effective as $PM_{2,5}$ reductions as a control measure, this is equivalent to more than $100,000 per ton of $PM_{2.5}$.

In addition to the increased cost of fuel, there are potentially capital costs involved in switching fuels as well. Because the physical characteristics of low-sulfur fuel oil are different, changes may be needed to storage, pumps, and burners to accommodate the new fuel.

- Control efficiency by pollutant: 75% reduction of SO_2
- Possible emission reductions by pollutant: 580 tons per year of SO_2
- Estimated cost per ton of pollutant reduced: $18,000

[69] Appendix III.D.5.7 Precursors
[70] Ibid.
[71] Personal communication, Sourdough Fuel, October 2, 2014

- Date by which the measure could be reasonably implemented: Not cost effective

This control measure is not cost effective, and is therefore not RACM.

5.7.4.7. District Heating System

Increased usage/coverage of district heating systems

The costs and benefits of potential increases in the coverage of the district heating systems are highly variable and depend on the number and types of individual combustion units replaced.

Aurora Energy operates a coal-fired power plant that cogenerates steam for heating use. Aurora Energy also provides district heating (in the form of low-pressure steam or hot water) to approximately 180 customers. Customers range in size from small residential to large commercial/institutional loads. In the last nine years, Aurora Energy has added 35 new district heat customers, with a total load of approximately 45 million btu/hr.

Aurora Energy has prepared a study of the feasibility of increasing the size of the district heat program by 210 MMBtu/hr, to serve an additional 1,989 individual buildings.[72] The increased cost associated with this measure is the capital cost of constructing the steam distribution infrastructure; no additional capital costs are needed for the heating plant. The total cost of the expanded distribution system and building conversions to hot water heat exchanger is estimated to be $238 million. The resulting cost per connection is estimated to be $120,000.

The average amount of wood used for home heating in a home that relies on a wood stove for home heating in Fairbanks is 3.57 cords/year.[73] The emission factor for burning air-dried wood in an uncertified wood stove is 20.3 lb $PM_{2.5}$ per cord. The emissions from each household would therefore average 72.5 lb/year. Over 30 years, the emissions would total 2175 lb, or 1.1 tons.

Even without taking into consideration increased emissions at the power plant, the cost effectiveness of this proposal would be no less than $120,000/1.1 tons, or $109,000/ton of $PM_{2.5}$.

This control measure is not cost effective.

5.7.4.8. Transportation

Improved Public Transit

[72] PDC, Inc. Engineers, *Aurora Energy District Heat Capacity Study, Phase 2,* December 2008

[73] A 2011 home heating survey (Sierra Research, June 10, 2011) indicated an average wood fuel use of 3.57 cords/year per installation for stoves and inserts, and 1.80 cords/year for fireplaces.

While Fairbanks has expanded its transit service in recent years and continues to experience increased ridership, a review of the MOVES-based emission factors for transit buses and motor vehicles operating in Fairbanks conditions shows that PM and NOx emissions from buses are higher than passenger vehicles. Thus, new bus routes need to take enough passenger vehicles off the road to offset the emissions associated with increased bus operations. Information on the transit program operations obtained from the Borough[74] indicates that current average winter ridership over the entire transit system is 1,725 passengers per day at a cost of $16,370 per day (this cost includes the cost of both bus service operation and ADA-required para-transit services).[75] Using an estimated average trip length of 6.9 miles per trip replaced (i.e., for passenger vehicles trips), an average 1,800 miles of transit VMT per day, and 2014 MOVES-based emission factors, it is estimated that 1 lb of $PM_{2.5}$ is eliminated through transit operations each winter day service is provided (i.e., Monday through Saturday, transit service is not provided on Sundays). The cost per ton of this reduction is $32.7 million dollars.

The control measure is not cost effective.

Restrict Truck Idling

Alaska DEC recently received approval for a CMAQ program that is intended to reduce heavy-duty diesel emissions through anti-idling, maintenance, and other emission reduction opportunities. The focus of the program is to expand the use of auxiliary heaters to reduce idle time, thereby reducing emissions and providing an associated cost savings due to less diesel fuel needed. The program has the following elements:

- Provide support for the existing anti-idling pilot project currently underway at DOT in Fairbanks by assisting with Telemetric purchase and installation, installing additional heaters, and assisting with education and training. With assistance from this program, the DOT pilot program will be fully functional and will be able to provide additional information to assist in expanding anti-idling programs to others.

- Expand anti-idling to other heavy-duty vehicles within the FNSB nonattainment area: state fleets, local government fleets, private fleets, and commercial fleets. This includes working with the heavy-duty fleet owners by providing education material and training; contracting for installations of auxiliary heaters; and providing incentives for participation, including purchasing of heaters and auxiliary equipment.

- During installation of program auxiliary heaters, conduct an inspection of the vehicle to identify where implementation of additional emission reductions may be possible, such as maintenance (filter, tune-up), retrofit technologies or

[74] Email communication from Glenn Miller to Bob Dulla, October 7, 2014.
[75] *http://www.ecfr.gov/cgi-bin/text-idx?SID=3387a7533c3134e09c52ac1170a185d7&tpl=/ecfrbrowse/Title49/49tab_02.tp*l

repower, and/or additional emission reduction equipment (particulate matter traps). Partnership and incentive opportunities with vehicle fleet owners will be explored to further emission reduction benefits while the vehicle is in shop.

CMAQ funding in the amount of $750,000 has been approved for the program, which will be implemented by Alaska DEC. While CMAQ funding will not support continued operation of a project, the bulk of the funding cover the cost of procurement and installation of equipment which can continue to operate after the project has ended.

This program is economically feasible.

Reduce Cold Start Emissions

The Borough recently received approval for CMAQ project funding that continues a long-standing practice of expanding the number of parking spaces in both public and private lots equipped with electrical outlets. This program will add a total of 975 outlets to four community facility parking lots.

CMAQ funding in the amount of $2,912,000 has been approved and the Borough will implement the program.

Since the project will cover the cost of the outlet installation and the Borough Plug-In Ordinance[76] requires parking lot owners with 275+ parking spaces to supply electricity to outlets at temperatures below 21° F, the outlets will continue to operate after the CMAQ project has ended.

This program is economically feasible.

5.7.5. STEP 4: DETERMINE WHETHER CONTROL MEASURES CAN BE IMPLEMENTED WITHIN FOUR YEARS OF DESIGNATION

Five of the technologically feasible and cost effective control measures have not already been implemented.

- Hydronic heaters: voluntary curtailment on air quality advisory days
- Hydronic heaters: All new units must be certified to 2.5 gm/hr
- Wood stoves: All new units must be certified to 2.5 gm/hr
- Open burning: Reinstate open burning ban
- Burn barrels: Prohibit use of burn barrels (seasonal or year-round)

All of these measures may be implemented within four years of designation, with a target implementation date of 1st Qtr 2016.

[76]http://yosemite.epa.gov/r10/airpage.nsf/283d45bd5bb068e68825650f0064cdc2/fa36e96da9630a5588256da20070d1c1/$FILE/Ordinance%20No.%202001-17.pdf

5.7.6. STEP 5: IDENTIFY REASONABLY AVAILABLE CONTROL MEASURES

Table 5.7-8. Reasonably Available Control Measures

Source Category	Control Measure	Potential Implementation Date
Dry Wood Measures	Education and Outreach	Already in place
Hydronic Heaters	Education and Outreach	Already in place
	Voluntary curtailment on air quality advisory days	1st Qtr 2016
	All new units must be certified to 2.5 gm/hr	1st Qtr 2016
	Subsidize heater change outs	Already in place
Wood Stoves	Education and Outreach	Already in place
	Voluntary curtailment on air quality advisory days	Already in place
	All new units must be certified to 2.5 gm/hr	1st Qtr 2016
	Subsidize stove change outs	Already in place
Fireplaces/Fireplace Inserts	Education and Outreach	Already in place
	Voluntary curtailment on air quality advisory days	Already in place
	Subsidize fireplace insert change outs	Already in place
Open Burning	Reinstate open burning ban	1st Qtr 2016
Burn Barrel	Prohibit use of burn barrels (seasonal or year-round)	1st Qtr 2016
Energy Efficiency Measures	Subsidize heating upgrades and weatherization	Already in place
Transportation	Restrict truck idling	Already in place
	Reduce cold start emissions	Already in place

Note:
a. Implementation dates are targets for planning purposes, not commitments.

APPENDIX A

CONTROL MEASURES NOT CONSIDERED

- Stationary Diesel Engine (prime) retrofits (insignificant contribution to ambient concentrations)
- Charbroilers (insignificant contribution to ambient concentrations)
- Reduced solvent usage or solvent substitution (insignificant contribution to ambient concentrations)

ADEC

DRAFT Addressing the precursor gases for Fairbanks $PM_{2.5}$ State Implementation Plan

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Deanna Huff

9/25/2014

As part of requirements for subpart 4 Non-Attainment Area (NAA) PM2.5 State Implementation Plan (SIP), all of the precursor gases that contribute to PM2.5 (NOx, SO2,NH3 and VOCs) are addressed for potential controls in addition to the primary PM2.5 components (organic carbon, elemental carbon, ammonium, sulfate, nitrate, other).

Executive Summary

This document explains how the precursor gases (sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds) contribute to $PM_{2.5}$ in the Fairbanks, Alaska NAA. The Clean Air Act (Subpart 4 of Part D of Title I, id. 7513-7513b (Subpart 4)) calls upon states to develop an analysis called RACM (Reasonable Available Control Technologies) for all source sectors for $PM_{2.5}$ including all precursor gases. The major source sectors are points, area (home-heating), and road and non-road vehicles. The precursor gases that must be addresses as part of the analysis are nitrogen oxides, sulfur dioxide, ammonia and Volatile Organic Compounds (NO_x, SO_2, NH_3 and VOCs). Fairbanks is designated a non-attainment area for exceeding the $PM_{2.5}$ 24-hour NAAQS of 35 $\mu g/m^3$. The designation was calculated from the 98%-tile of 3 years of data from 2006-2008 and 2008 is the design year. The baseline design value of 44.7 $\mu g/m^3$, that the attainment demonstration is based on, was derived from 5 years (2006-2010) of FRM monitor data at the State Office Building, monitored data is found in Appendix III.D.5.4.

Particulate Matter ($PM_{2.5}$) is directly emitted into the atmosphere or formed by secondary chemical reactions from precursor gases. The largest component of $PM_{2.5}$ in the Fairbanks area is organic carbon, primarily from direct emission with less resulting from secondary formation. The major components of atmospheric aerosols formed by secondary chemistry are nitrate (NO^{-3}), sulfate (SO_2^{-4}) and ammonium (NH_4^+). These species are formed mostly from chemical reactions in the atmosphere involving the precursor's nitrogen oxides (NO_x), sulfur dioxide (SO_2) and ammonia (NH_3).

SO_2: ADEC's analysis shows that sulfates comprise approximately 18% of the total mass of Fairbanks $PM_{2.5}$. Direct emissions and atmospheric formation of particulate sulfate contribute to measured sulfate concentrations. Most of the sulfate is in the form of ammonium sulfate and the total mass contribution including particle bound water is 8.69 $\mu g/m^3$. Comparing SO_2 controls that lead to a reduction in ammonium sulfate would be 3.2 times less effective than wood stove controls.

NO_x: Aerosol processes play a dominant role in the formation of nitrate. Most nitrate is formed in the atmosphere from NO_x emissions that transform into from secondary processes. Assuming that all of the moles of nitrate are balanced by any equivalent molar amount of ammonium the observations show that ammonium nitrate accounts for 4% of the total $PM_{2.5}$. In order to reduce NO_x emissions effectively, it is necessary to understand the formation of nitrate in the atmosphere and how NO_x controls influence nitrate formation in $PM_{2.5}$. The total amount of nitrate that can be removed as ammonium nitrate including particle bound water, according to filter-based measurements is 3.39 $\mu g/m^3$ $PM_{2.5}$. Comparing NO_x controls to reduce ammonium nitrate, wood stove controls are 13.2 times more effective.

NH_3: The processes that emit ammonia (biomass burning, mobile, home heating) differ in Fairbanks from those in the lower 48, where ammonia from agricultural activities, vehicles, and other industrial activities form ammonium nitrate. In the Fairbanks nonattainment area, there is only a limited about of PM-nitrate formed from on the measurement filters. The maximum reductions of the 2.44 $\mu g/m^3$ of ammonium in the $PM_{2.5}$ would come from the reductions in nitrate and sulfate in the form of ammonium nitrate and ammonium sulfate that were formed from precursor gases NO_x and SO_2 (some ammonium is associated with primarily emitted sulfate that is not from precursor gases).

VOCs: The VOCs emissions contribute to $PM_{2.5}$ by condensing after being emitted from a high temperature stack and through photochemistry forming secondary organic aerosols (SOA). The VOC emissions are 14.8 TPD, but according to model results on 0.00062 $\mu g/m^3$ are from SOA. The model performance shows good agreement between organic carbon observed and organic carbon + SOA modeled. For this reason we believe the contribution from VOCs to $PM_{2.5}$ is very small.

Fairbanks Chemistry Overview

Addressing the precursor gases and how they are related to $PM_{2.5}$ requires understanding the Fairbanks wintertime characteristics that lead to the formation of $PM_{2.5}$ from both direct and secondary formations. Precursor gases form secondary $PM_{2.5}$ and this component of $PM_{2.5}$ is addressed through reviewing current knowledge of the chemistry involved in the secondary formation in the Fairbanks airshed

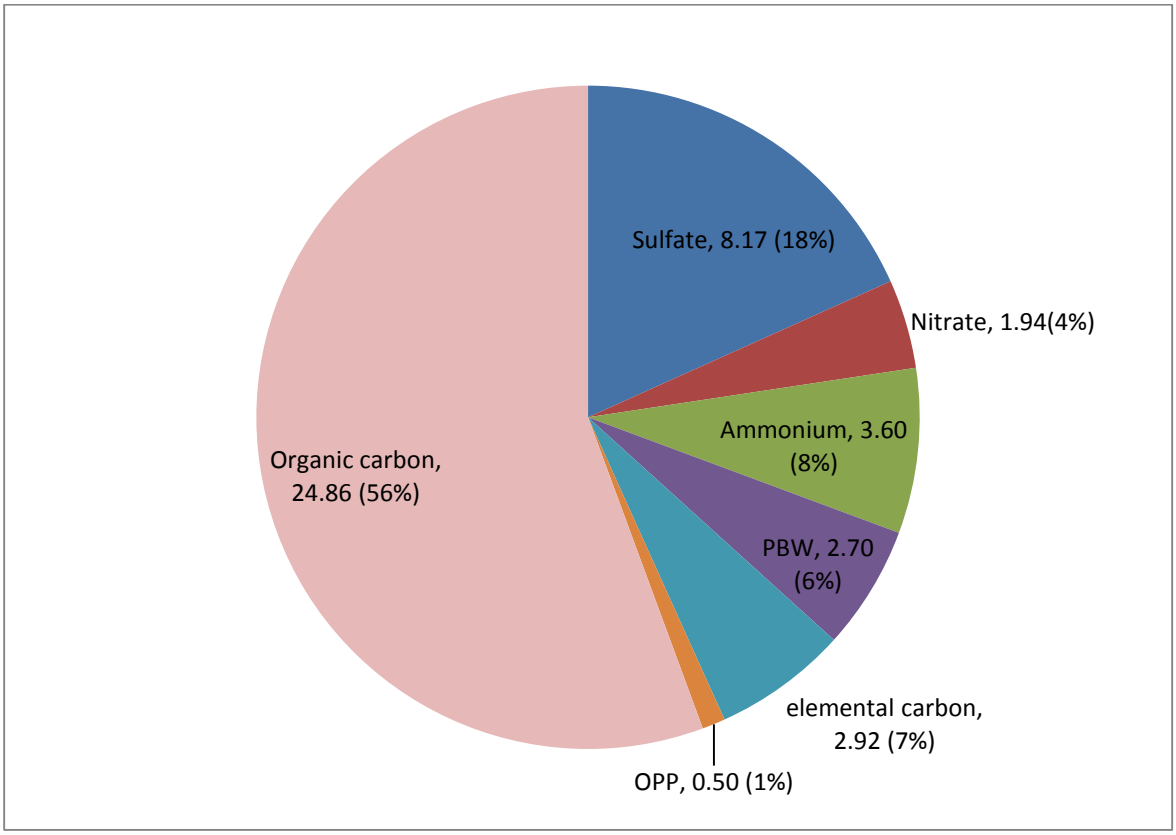

Figure 1: 24-hr average FRM-derived PM $_{2.5}$ speciation concentrations based on the design value (DV) of 44.7 µg/m^3 for the top 25% of wintertime days from the years 2006 -2010 at the Fairbanks State Office Building.

Particulate Matter ($PM_{2.5}$) is directly emitted into the atmosphere or formed by secondary chemical reactions from precursor gases. The major components of atmospheric aerosols formed by secondary chemistry are nitrate (NO^{-3}), sulfate (SO_2^{-4}) and ammonium (NH_4^+). These species are formed primarily from chemical reactions in the atmosphere involving the gas-phase precursors, nitrogen oxides (NO_x), sulfur dioxide (SO_2) and ammonia (NH_3). The major component of Fairbanks $PM_{2.5}$ is organic carbon and is directly emitted as particles, condenses to existing particles, or contributes to the formation of new particles from gaseous molecules.

Speciation of the Fairbanks winter $PM_{2.5}$ components (Figure 1) are derived from the top 25% of wintertime high $PM_{2.5}$ days from the years 2006-2010. The speciation concentrations that represent the

breakdown of the components of $PM_{2.5}$ in the Fairbanks area are measured from the SASS speciation instrument. The two different instruments both measure $PM_{2.5}$ but have different measurement artifacts. The goal is to derive concentrations of chemical species as they would be found on the official Federal Reference Method (FRM) monitor filter, not as they are found through the SASS instrument. To convert the concentrations of each chemical species from the measurement by the SASS to what would have been found on the FRM filter, we use the SANDWICH method (Frank, 2006). A detailed account of the adjustments made to compare speciation measurements to FRM total $PM_{2.5}$ measurements are found in Appendix III.D5.8. The speciation results in Figure 1 are post-SANDWICH and thus represent speciation on the FRM filter that is used to calculate regulatory design values.
Conversion of precursor gas emissions of nitrogen oxides (NO_x) and sulfur dioxides (SO_2) are constrained by atmospheric conditions including photochemical reactions from sunlight, the pH and the ambient temperature.

pH is an important aspect of atmospheric chemistry and has strong baring on the formation of ammonium sulfate and ammonium nitrate in particulate matter. One method to estimate the pH of the particulate matter is to balance the charge of major ions including ammonium (NH4+, Na+, K+, nitrate $(NO_3)^-$, Sulfate $(SO_4)^{2-}$ and Chloride (Cl^-). Figure 2 was completed by an ion mass balance approach using NH_4^+, Na^+, K^+ for the cations and NO_3^- , SO_4^{2-} and Cl^- as the anions for the Fairbanks State Office Building speciation data for 2006-2010. The net equivalent charge of all the speciation days from 2006-2010 are plotted verses the total FRM $PM_{2.5}$. If the net charge is 0, greater than 0 or less than 0; then the particulate matter is neutral, basic or acidic, respectively.

Our analysis finds neutral to basic aerosol pH on high $PM_{2.5}$ days, which is in general agreement with Dr. Peltier's analysis (2011, 2012) of Fairbanks $PM_{2.5}$. His 2011 white paper compares net charge in $\mu eq/m^3$ for observed winter speciation from 2007-2010 from the State Office Building, using only sulfate, nitrate and ammonium. Peltier found basic conditions during the winter, but did not break down the speciation data by high $PM_{2.5}$ days. In his 2012 analysis, he obtained a more time resolved analysis of two months of hourly sampling for aerosols using a PILS (Particle In Liquid Sampler) instrument, which collects airborne particles into a liquid vial for analysis on hourly speciation, and was used for net equivalent charge comparison. Peltier used the ion molar ratio method using the anions, cations and organic acid measurements to calculate a resulting net particle charge. The results showed that the aerosol is slightly acidic to neutral at high organic carbon hours. The hourly data is only representative of 280 hours during the time period from February 11- March 11th, 2011. There were only two $PM_{2.5}$ days greater than $30\mu g/m^3$during the study and no days were at or above the design value of $44.7\mu g/m^3$.

Although the first Peltier analysis concludes Fairbanks $PM_{2.5}$ is basic and the second analysis finds slightly acidic to neutral particles, they agree that particles on less polluted days are neutral. Both data sets have net equivalence charges between -0.1 and 0.1, which is considered to be in the category of neutrally charged (Peltier, 2012). The basic conditions in the first Peltier analysis occurred at high $PM_{2.5}$ loadings not experienced during collection of the second dataset. It is possible that the denuder on the SASS instrument used at the State Office Building could allow for excess ammonia gas penetration and an overrepresentation of ammonium. Another factor to consider is the presence of sulfur in non-sulfate forms, but Peltier (2012) found only 10% non-sulfate sulfur in Fairbanks $PM_{2.5}$. To within the degree we

can trust the measurement techniques and compare datasets across time, the three analyses are in reasonably good agreement that $PM_{2.5}$ in Fairbanks is not noticeably acidic.

In addition to the net equivalence charge using observed data, a modeling study was conducted in the Fairbanks area using local NO_x, O_3 and particulate matter data to understand the formation of ammonium (Joyce et. al., 2012). The results indicated that ammonium nitrate would only form downwind of downtown and no secondary formation of nitrate or sulfate occurred in the downtown Fairbanks area. Figure 3 shows the process analysis results from a CMAQ model run for the Jan. 23th- Feb. 10th representative episode for the formation of nitrate. "Aerosol Processes" play a dominant role in the formation of nitrate, which means that nitrate is being formed from NO_x precursors rather than being directly emitted from emission sources. It is not possible to understand control strategies for nitrate without understanding the emissions and fate of NO_x.

Forming nitrate downwind from the Fairbanks area has important implications for whether ammonia controls would reduce $PM_{2.5}$ or not. With neutral to basic pH in the particles, this suggests there may be enough ammonium to neutralize the sulfate and excess ammonium to form ammonium nitrate under the right conditions. For nitrate, the excess ammonium denoted by the neutral particles suggests that we are limited by nitrate formation under the dark and cold conditions and by fresh injection of NO hindering the nitrate production. For the sulfate secondary formation, reductions in SO_2 will yield a proportional reduction in $PM_{2.5}$ rather than simply replace ammonium sulfate with ammonium nitrate. The photochemistry in downtown Fairbanks due to the low to no sunlight and cold conditions during the winter, limits the photochemical production of nitric acid from the daytime processes of OH and NO_2. In addition at night, NO titrates the ozone removing the main oxidant to form nitrate (Joyce et. al, 2012). Joyce showed that ammonium nitrate is formed downwind of downtown, adding to the probability that aerosol nitrate from nitric acid is not being formed in downtown Fairbanks. Heterogeneous nighttime chemistry from N_2O_5 is thought to be responsible for 80% of the nitric acid formation at high latitudes (Crutzen et al, 2000), but in polluted areas the fast reaction of excess NO with the nitrate radical, nitric acid formation is hindered at night (Seinfeld and Pandis, 1999).

The largest component of $PM_{2.5}$ in the Fairbanks area is organic carbon. Organic carbon is primarily due to direct emission with very little resulting from secondary formation. The CMAQ modeling results show the fraction of secondary organic aerosols formed are 6.2 x 10^-4 $\mu g/m^3$ for the State Office Building grid cell. The observed organic carbon mass is in good agreement with modeled organic carbon mass (Table 1) at 17.1 observed and 25.1 $\mu g/m^3$ of organic carbon modeled for the average of the two modeling episodes (details can be found in Appendix III.D.5.8).

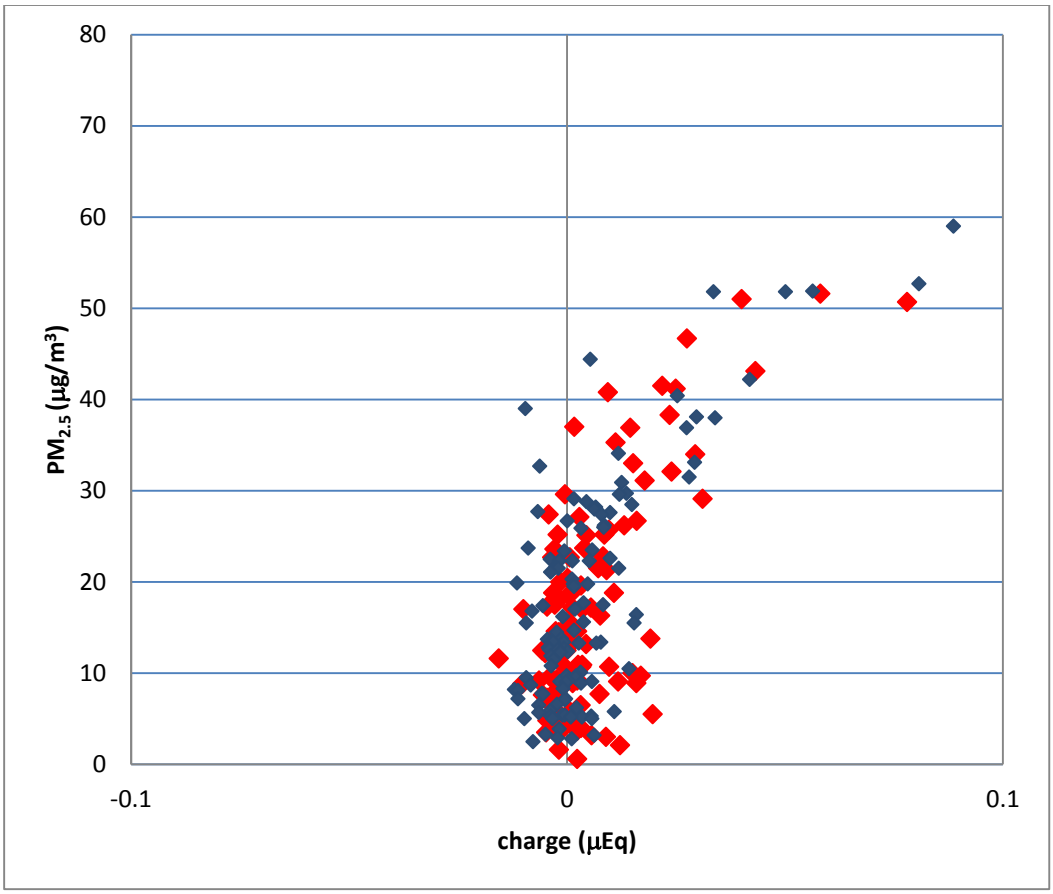

Figure 2: Aerosol charge vs. high $PM_{2.5}$ concentrations measured by FRM from 2006-2010 concentrations. Charge less than zero is acidic and greater than zero is basic.

Table 1. CMAQ and Observed Species Comparison from the State Office Building Monitor-FRM days Averaged for both modeling episodes.

Species	**Observed** (µg/m^3)	**Modeled** (µg/m^3)
$PM_{2.5}$ Total	36.1	35.7
OC	17.0	24.5
EC	2.3	4.3
SO_4	6.2	2.1
NO_3	1.6	1.3

NH_4	3.1	1.2
OTH	6.3	2.3

The CMAQ model run for Fairbanks performs well for nitrate and is in agreement with the State Office Building observed concentrations of nitrate and the modeled state office building grid cell concentration. Table 1 represents the observed verses simulated concentrations for the chemical components of $PM_{2.5}$ during two representative design episodes, episode 1 (Jan. 23-Feb 11th) and episode 2 (Nov. 2nd to the 17th) used for simulated control strategy model runs for the impracticability demonstration. The observed and modeled speciation components are 24-hr averages of the FRM days only and when speciation measurements were available.

The model adequately represents the organic carbon, elemental carbon and nitrate components. The CMAQ model runs do not well represent ammonium, sulfate or other primary particulates. Details on the model performance are found in Section 5.8.

Satisfying the EPA guideline for RACM requires the validation of all controls to advance attainment for year. In the case of Fairbanks, an estimate of 2 $\mu g/m^3$ per year is needed to advance attainment by 1 year. The design value of 45 mg/m^3 minus the $PM_{2.5}$ NAAQS of 35.0$\mu g/m^3$ is a 10 $\mu g/m^3$ reduction needed to reach attainment. If we have 5 years to reach attainment then a 10 $\mu g/m^3$ reduction over 5 years is estimated to be 2 $\mu g/m^3$. After each precursor discussion section, RACM applicability follows.

Nitrogen oxide precursors and nitrates

Nitrogen oxides are referred to as the chemical family NO_x (NO_2+NO), NO and NO_2 with primary emissions coming from combustion processes, home heating, vehicles and industry. Typically, during the day, NO_x is oxidized by reacting with ozone and OH radical chemistry and forms nitric acid (HNO_3) and during the night NO_x is oxidized to form $N_2O_{5\ (g)}$, which reacts on aerosol surfaces to form $HNO_{3\ (aq)}$ and deposition to snowpack. Particles containing nitrate are neutralized via reaction with ammonia gas (NH_3) to form ammonium nitrate.

Winter time chemistry is well represented by the model from a comparison of simulated to observed concentrations of nitrates. The modeled 24-hr mean NO_x concentration for both episodes near the surface at the State Office Building is 30ppm or 51$\mu g/m^3$. The State Office Building simulated grid cell mean 24-hr average NO_x of 51 $\mu g/m^3$ and simulated 1.3 $\mu g/m^3$ for the nitrate mass concentrations on FRM days (FRM days are a 1/3 schedule and used to compare observed filters directly to modeled days, not the same concentrations that are used for model performance all modeled days) only and converted to molar concentrations leads to a nitrate/ NO_x molar ratio of 0.031. The production of nitrate compared to NO_x emissions is very low at 3.1%. The molar ratio of 0.031 assumes that the NOx at the State Office Building

grid cell has not undergone chemical reactions (some NO has already converted to NO_2), but equivalent observed 24-hr nitrate measurement on FRM days used for performance evaluation of CMAQ is 1.6 µg/m^3, meaning that the simulated nitrate mass concentration of 1.3 µg/m^3 is in good agreement with the observed measurement almost all of the NO_x converting to nitrate is captured by the model (Table 1). This is good model agreement and gives weight to CMAQ's analysis of nitrogen chemistry during polluted wintertime episodes. The aerosol process or secondary formation of nitrate is the driving process (Figure 3) from our modeled analysis and shows that CMAQ is representing nitrate with an acceptable bias and error (section 5.8.4 "Basecase Model Performance"). All of the PM-nitrate is considered secondary and primary emitted nitrate quantity is very small (10^ (-5) µg/m^3).

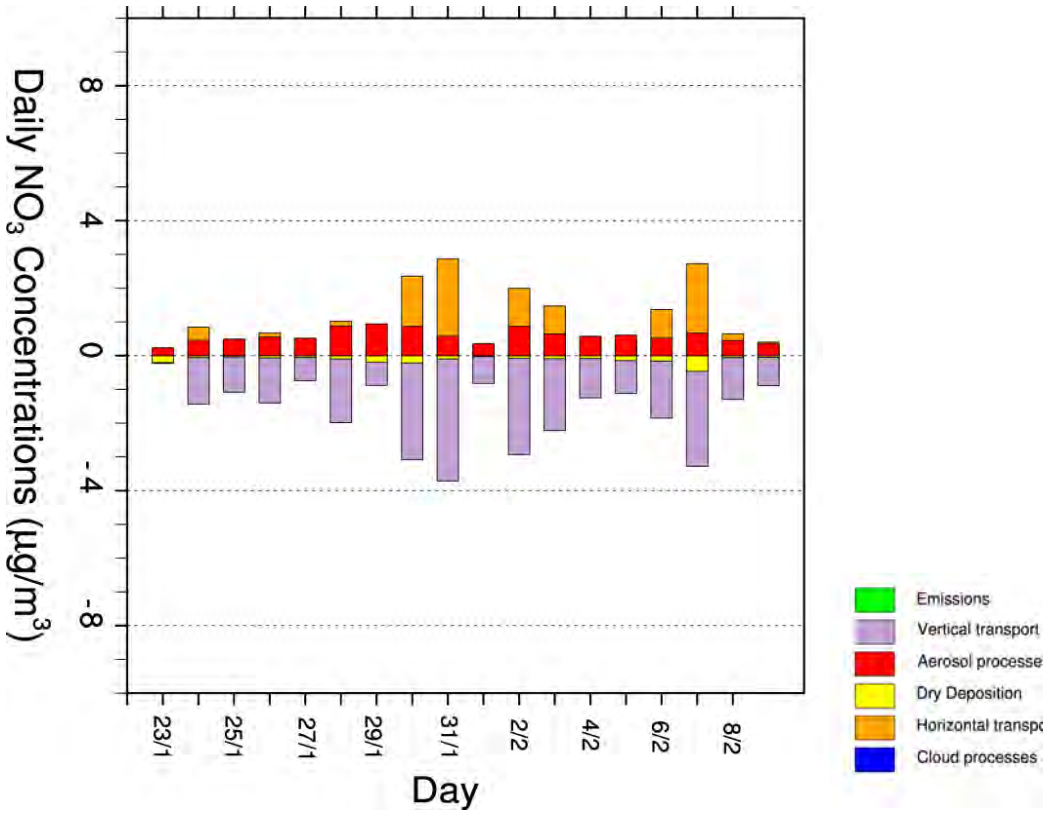

Figure 3. Process analysis results for nitrate from CMAQ for Jan. 23rd to Feb. 10th from the State Office Building grid cell.

The contribution from point sources is an important factor for NO_x emissions, because they contribute to the nitrate component of $PM_{2.5}$. The NO_x emissions by source category are 60% point sources, 20% mobile, 15% area, 4% non-road and less than 1% for all other sources combined. The total NO_x emissions from point sources are 13.45 Tons per Day (TPD).

In the winter, nitrate composes 4.33% (Figure 1) of the total $PM_{2.5}$ at the Fairbanks State Office Building on the top 25% most polluted days. For Fairbanks' baseline design value of 44.7 µg/m^3, this corresponds to 1.93 µg/m^3 of nitrate. In the CMAQ modeling, nitrate is 3.6% whereas the nitrate was 4.33 % of the observed $PM_{2.5}$.

Assuming that all of the moles of nitrate are balanced by any equivalent molar amount of ammonium the observations show that ammonium nitrate accounts for 4% of the total $PM_{2.5}$. This percentage is calculated based on an observed 1.94 $\mu g/m^3$ nitrate (Figure 1) and equivalent to 2.5 $\mu g/m^3$ ammonium nitrate (1.94 x (80 g/mol NH_3NO_3/ 62 g/mol NO_3). The observed ammonium nitrate originates from 13.45 TPD of NO_x emitted by point sources and we are assuming that all the nitrate is formed from point source emissions alone for this example. In addition to ammonium nitrate, a certain amount of water is associated with the ammonium nitrate, called particle bound water. The amount of water depends the acidity of the aerosol, the components, relative humidity and temperature. These parameters are hard to measure of an individual aerosol and there is an assumption that the water is bound in a 1/3 to 2/3 ratio, 1/3 for ammonium nitrate and 2/3 for ammonium sulfate (Frank, 2006). Taking the particle bound water (PBW) into account as part of the ammonium nitrate, then 0.89 $\mu g/m^3$ addition to the 2.5 $\mu g/m^3$ ammonium nitrate, for total of 3.39 $\mu g/m^3$ of ammonium nitrate + PBW. The 0.89 $\mu g/m^3$ (2.70 x 0.33) estimate is from the Frank (2006) paper where the ratio of PBW of 0.12 for ammonium nitrate or 1/3 (0.33) of the 2.70 $\mu g/m^3$ that is PBW (Figure 1).

Next, the observed ammonium nitrate and emitted NO_x are translated into a \$/ton NO_x metric to assess the NO_x control reduction. Dividing through the emitted tons by the observed ammonium nitrate (13.45 TPD / 3.39 $\mu g/m^3$ ammonium nitrate + PBW) it is determined that 3.97 Tons of NO_x makes 1 $\mu g/m^3$ of $PM_{2.5}$. Assuming that the conversion of NO_x to nitrate is linear throughout the range of nitrate concentrations, every ton of NO_x controls would reduce $PM_{2.5}$ nitrate by 1/3.97 $\mu g/m^3$, or 0.295 $\mu g/m^3$. In comparison, the total emissions for woodstoves are 3.18 TPD and the modeled reduction of $PM_{2.5}$ from woodstoves is 10.62 $\mu g/m^3$ (details on the emissions inventory and modeling for wood stoves can be found in Appendix III.D.5.6). Every ton of wood smoke emissions yields, by dividing the through the emitted tons by the modeled wood smoke $PM_{2.5}$ (3.18 Tons/ 10.62 $\mu g/m^3$), 0.3 tons of wood smoke $PM_{2.5}$ emissions makes 1 $\mu g/m^3$ of $PM_{2.5}$. Recalling that 3.97 tons of emissions makes 1 $\mu g/m^3$ of $PM_{2.5}$, wood smoke emissions are 13.2 (3.97/0.3) times more efficient at producing 1 $\mu g/m^3$ $PM_{2.5}$ than NO_x emissions are.

When it comes to the economic feasibility of various control strategies, NO_x controls will need to be 13.2 (3.97/0.30) times less expensive to be cost effective relative to controls on wood stove emissions. If wood stove emissions reductions are \$10,000/ton (from pg 41, EPA wood stove change outs), NO_x controls would need to be less than ~\$758/ton (\$10,000/13.2) to be considered cost effective relative to wood stove change outs.

Sulfur Dioxide precursor gas and Sulfate

Sulfates are a major component of the $PM_{2.5}$ mass; estimates show that sulfates comprise approximately 18% (8.17 $\mu g/m^3$) of the total mass of Fairbanks $PM_{2.5}$. Direct emissions and atmospheric formation of particulate sulfate contribute to measured sulfate concentrations. The bulk of the primary sulfate results from the combustion of fossil fuels, and to a lesser extent wood combustion also contribute. The speciation profiles used for the different emission categories show that primary sulfate is emitted by point,

area (home heating) and mobile sources. Direct emissions of sulfate are not enough to account for the amount of sulfate observed at the State Office Building. It is very likely that SO_2 is converted into sulfate in the atmosphere after being emitted and thus accounts for the remainder of the observed sulfate. The direct emissions of sulfate do not account for all of the sulfate found on the filters and even though the mechanism is not known, secondary sulfate formation is important. As control strategies are adopted, for example to reduce wood stove use by switching to fuel oil, fuel oil has higher SO_2 and primary sulfate emissions. Due to the complex nature of the sulfate chemistry a white paper on sulfur chemistry was written by Rick Peltier of UMass, Division of Environmental Health Science (Peltier, 2011). As discussed in the introduction, the white paper concludes that the lack of oxidants available in the dark and cold conditions would impede production of sulfate by the most common photochemical pathways(Peltier, 2011), and the chemical mechanisms to convert SO_2 to sulfate under the Fairbanks wintertime conditions are unknown. Unlike nitrate, the CMAQ model does not capture the sulfate concentrations found at the State Office Building speciation filters resulting in a need to parameterize the conversion of SO_x to sulfate with a blend of observations and model results.

The CMAQ inventory for point and area sources reveal that point sources are a majority of primary sulfate (Dulla, 2010c, Elleman, 2010) emissions. After further refinements based on source apportionment modeling and locally derived emissions factors (Appendix III.D.5.6), the latest emissions inventory break down shows 65.4 % of SO_2 is linked to point sources and 42.1% of SO_2 is linked to area-space heating fuel oil sources of . Fairbanks total $PM_{2.5}$ speciation at the surface is composed of 18% sulfates by mass or 8.17 $\mu g/m^3$ (Figure 1).

Sulfate and sulfur dioxide as precursor gas are significant when addressing sulfate in the attainment demonstration as well as in the RACM analysis. In the case of sulfate, the modeled concentrations of primary and secondary sulfate are 2.03 $\mu g/m^3$ from both episodes, 24-hr average concentration at the State Office Building grid cell on modeled FRM days (Table 1). The observed FRM values from the representative modeling episodes are 5.25 $\mu g/m^3$, leaving an unexplained secondary sulfate contribution not represented by the model of 3.22 $\mu g/m^3$ (Table 2).

Table 2. Sulfate Average ($\mu g/m^3$) from FRM days for our two representative modeling episodes

	Episode 1	Episode 2	Weighted Average
Observed	5.38	5.08	5.25
Modeled	2.03	2.03	2.03
Remainder	3.35	3.04	3.22

The modeled concentrations in Table 2 are the sulfate average days from the two representative episodes. Evaluating the reduction in PM-sulfate for RACM, the design value, a 5-yr rolling average of the 98%-tile concentrations from years 2006-2010 of 44.7 $\mu g/m^3$ is used instead the modeling episode days which are only 14 day periods. Taking the weighted average column of observed, modeled and remainder concentrations in Table 2, multiplying by the ratio of design value observed sulfate (8.17 $\mu g/m^3$) by the

observed sulfate during the episodes (5.25 μg/m^3) the sulfate fraction from all sources modeled is 3.16 μg/m^{3}and 5.01μg/m^3 is the unexplained sulfate remainder:

2.03 (modeled sulfate μg/m^3) * (8.17/5.25) = 3.16 μg/m^3
3.22 (remainder sulfate μg/m^3) *(8.17/5.25) = 5.01 μg/m^3

The model runs have very little secondary sulfate (average of 0.2 μg/m^{3}of secondary sulfate formed for both episodes), but the main chemical reactions in the model are photochemical and a function of OH and H_2O_2 (Molders, 2012). There are no observed measurements of OH or H_2O_2 for daytime winter conditions to prove that the mechanism is not favorable, but background OH concentrations at high latitudes in remote areas are measured to be extremely low even in the summertime (Mao et al., 2010). Sulfate is not well represented in the CMAQ model runs (Table 2). The observed average sulfate concentrations at the State Office Building during all days in both episode 1 and episode 2 is 6.2μg/m^3 and the simulated concentration is 2.1 μg/m^3 (Table 1).

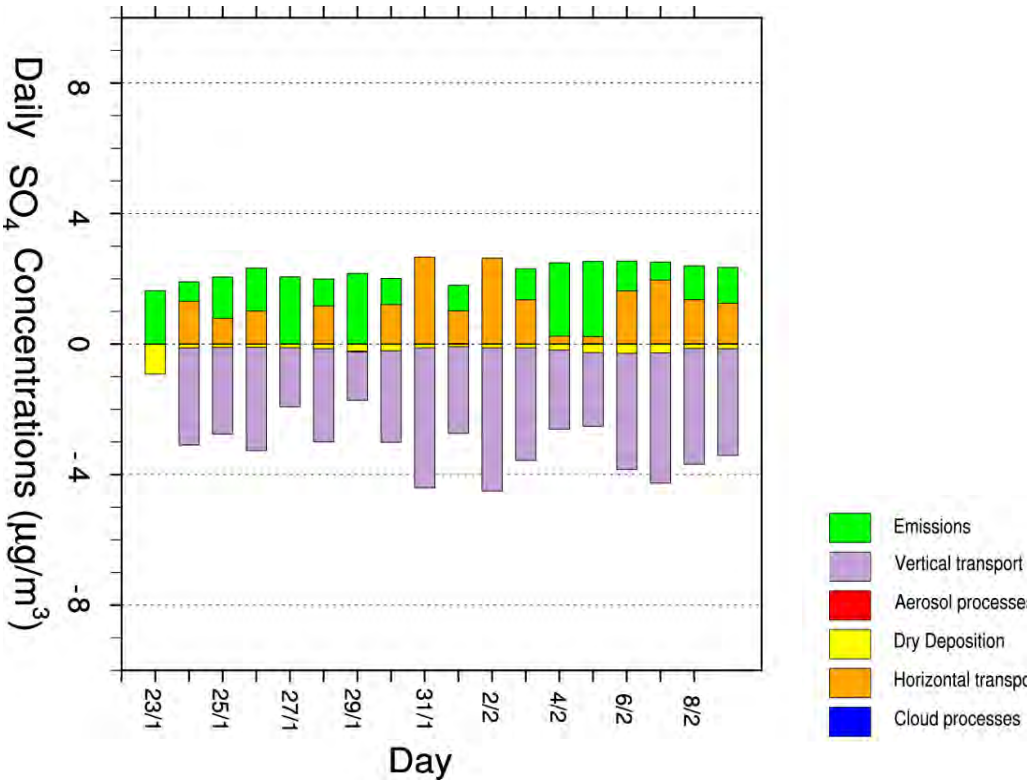

Figure 4. Process analysis for SO_4 concentrations from the CMAQ model for Jan. 23rd to Feb. 10th at the State Office Building grid cell (Molders, 2012).

The CMAQ process analysis results for sulfate show the sulfate emissions are nearly entirely primarily emitted and no aerosol processes are responsible for secondary formation of sulfate (Figure 4) in the model. CMAQ under predicts sulfate formation when compared to the total sulfate of the $PM_{2.5}$ speciation concentrations (Figure 1).

Understanding why CMAQ performs poorly for secondary sulfate in Fairbanks, several changes were made to the CMAQ model to investigate secondary sulfate, from increasing the water available for the Fe/Mn catalyst conversion reaction of SO_2 to SO_4, changing the pH and combining meteorological inputs of ice and water (Molders, 2012). The percentage of sulfate increased from 4.2 to 5.3% and from 3.9 to 5.0% for the November and January episodes. The increase in the percentage of SO4 increased NH4 and the percentage of NO3 and organic compounds decreased. The increase of sulfur dioxide and sulfate affected the thermodynamic equilibrium of the aerosol and allowed further neutralization of the sulfate and nitrate into ammonium sulfate and ammonium nitrate (Seinfeld, 2006). The 1% increase in sulfate in the model results did not account for 34% missing secondary sulfate from the observed sulfate to the modeling sulfate (Table 1) and sulfate model performance is still poor.

In order for the Fe/Mn catalyst reaction to take the place, the pH and the amount of water available are important. One idea for the underrepresentation of sulfate in the model is that the anthropogenic water not represented in the model that comes from the point sources could be enough to initialize the conversion of Fe/Mn catalyst reaction. This chemical mechanism was presented by Grgic et al. (1993) in a laboratory setting and she found that under the right pH and available water that the conversion to sulfate could be accounted for by Fe/Mn. The anthropogenic water that is not represented in the model has not been calculated and an additional box model study is needed to predict if this mechanism is responsible for the under representation in the CMAQ model. Since this study is not conducted, we currently parameterized the upper and lower bound of the sulfate conversion. The CMAQ inventory SO_2 precursor gas and primary sulfate emission estimates are total emissions into the entire modeling domain, not specifically what sources contribute to the high $PM_{2.5}$ surface concentrations.

Another determination for SO_2 precursor gas benefits is the possibility of forming ammonium nitrate and in fact increasing the $PM_{2.5}$. We have evidence from the understanding of wintertime Fairbanks chemistry that this would not occur and the details are in the ammonia precursor gas section. A total of 8.38 TPD of SO_2 are emitted. After source elimination CMAQ model results (Hixson, 2012c), it is estimated that 5% of primary emitted sulfate is from the point sources and up to 15% of secondary sulfate (assuming the entire unexplained sulfate portion is formed from point source emissions). These CMAQ model results were corroborated by running CALPUFF, a dispersion model. The CALPUFF model (Huff, 2012) results showed minimal impact for directly emitted PM2.5, less than 5%. The CALPUFF model was also run for SO_2 emissions from point sources and found 21% of the SO_2 at the State Office Building was from point sources for the November modeling episode. More detailed calculations on the SO_2 forming sulfate predications are discussed below.

CMAQ has been used in a series of source elimination runs to determine the contributions of different source sectors to the primary SO_4 and SO_2 gas at the monitor grid cell. It was found that 22% of the SO_2 originates from points, 78% from central oil and <1% is from mobile source. Using the design value day unexplained sulfate remainder and assuming that each source contributes linearly to the unexplained sulfate remainder of 5.01 $\mu g/m^3$ ((8.17 obs sulfate design value/5.25) *3.22 remainder sulfate on FRM days), then an estimate of the secondary SO_4 attributable to point sources would be calculated to be 1.10 $\mu g/m^3$ as shown below.

> 5.01 $\mu g/m^3$ Unexplained SO_4 Total x 0.22 (fractional SO_2 from point sources) = 1.10 $\mu g/m^3$ Unexplained SO_4 from point sources

The sulfate reduction of 1.10 μg/m^3 is a mid-range estimated benefit of 100% SO_2 controls on all point sources based on the modeled source contributions to SO_2 at the monitor assuming a linear relationship between SO_2 reductions and unexplained, measured sulfate. This sulfate reduction benefit was calculated only for our model episodes, but this secondary sulfate reduction can also be calculated on a design value basis. In the context of the design value of 5.01μg/m^3 of unexplained (secondary) sulfate in question as a portion of the total design concentration of 44.7μg/m^3. There are three scenarios for the unexplained sulfate (Hixson, 2013, sulfate elimination):

1) 61.3% (5.01 μg/m^3) Upper bound - All of the unexplained sulfate is from point sources
2) 13.5% (1.10 μg/m^3) Middle/Estimated - 22% of modeled contribution from points
3) 0% (0 μg/m^3) Lower bound- None of the unexplained sulfate is from the point sources

In addition to CMAQ modeling results, the CALPUFF dispersion model was run for the same November episode when SO_2 measurements were available at the State Office Building and used to corroborate the CMAQ model results. Hourly SO_2 measurements for Nov. 2-17th were averaged to 24-hour measurements and then to an episode average of 46 μg/m^3. The CALPUFF surface layer at the State office Building grid cell for all point sources combined was 9.7 μg/m^{3}of SO_2. Comparing the CMAQ total point source apportionment results for SO_2 above to actual SO_2 measurements for the November episode using CALPUFF:

> 9.7 μg/m^3 SO_2 modeled concentration at SOB / 46 μg/m^3 SO_2 OBS at the SOB = 21 % point source contribution of total SO_2 (Huff, 2012).

Considering the cost effectiveness for SO_2, the most conservative scenario 1) was used or all of the unexplained sulfate remainder of 5.01 μg/m^3 is from the point sources. Adding in the mass of ammonium that provides the charge balance within the particles, the concentration of ammonium sulfate is calculated to be 6.89 μg/m^3 (5.01 + 1.89 μg/m^3 (using the ratio132 g/mol of ammonium sulfate/96 g/mol ammonium). Using the same methodology as for comparing SO_2 emissions to $PM_{2.5}$ sulfate, it takes 1.21 TPD (8.38 SO_2 TPD / 6.89 μg/m^3 sulfate) of SO_2 to form each 1 μg/m^{3}of $PM_{2.5}$. Assuming the SO_2 to sulfate to be linear and a source the total that could be removed by SO_2 controls is 1.22 Tons (8.38 TPD/6.89 ammonium sulfate). Recalling that 0.3 tons of wood smoke $PM_{2.5}$ emissions makes 1 μg/m^3 of $PM_{2.5}$, SO_2 controls would need to be 4.1 times (1.22 / 0.3) cheaper than wood stove controls in order to provide the same air quality benefit as wood stove controls.

If we take particle bound water (PBW) into account as part of the ammonium sulfate, then 1.8 μg/m^3 addition to the 6.89 μg/m^3 for total ammonium sulfate and particle bound water of 8.69 μg/m^3 would be included in the cost effectiveness. The 1.8 μg/m^3 estimate is from the Frank (2006) paper where the ratio of PBW of 0.12 for ammonium nitrate or 1/3 of the PBW and therefore 2/3rds is bound to ammonium sulfate (2.70 x 0.66 = 1.8).Using the above equations there are 0.96 Tons of SO_2 removed (8.38 SO_2 TPD emitted/ (6.89 μg/m^3 ammonium sulfate + 1.8 μg/m^3 PBW)). The SO_2 control cost effectiveness would then be 3.2 (0.96/0.30) or less than $3,125/ton ($10,000/3.2).

In conclusion if the RACT controls for point sources and woodstoves are the same at $10,000/ton and all of the secondary sulfate is from point sources, then SO_2 controls would need to be 3.2 times more

efficient (than primary $PM_{2.5}$ in wood stoves) to be cost effective (0.96/0.30). SO_2 controls would need to be less than $3,125/ton ($10,000/3.2) to be considered cost effective.

Ammonia precursor gas and ammonium

Ammonia gas (NH_3) reacts with acid aerosols containing nitrate (NO_3^-) and sulfate (SO_4^{2-}) to from ammonium nitrate (NH_4NO_3) and ammonium sulfate ($(NH_4)_2SO_4$). Nitrate is assumed to be all ammonium nitrate. Sulfates are partially neutralized to form ammonium sulfate and are associated with a degree of neutralization. Speciation data shows that 3.6 µg/m^3 (8 %) of total PM $_{2.5}$ mass 44.7 µg/m^3 on violation days is ammonium (Figure 1). In locations that are ammonium limited, reductions in sulfate make an ammonium available to nitrate. Controls on sulfate have the net effect of decreasing ammonium sulfate but increasing ammonium nitrate. Since nitrate is heavier on a per mole basis than sulfate, sulfate controls in an ammonium-limited environment increase $PM_{2.5}$ mass. There is no indication this would occur in Fairbanks since the observed $PM_{2.5}$ appears to be well-balanced in charge and because we have other evidence that nitrate does not readily form from NO_x in Fairbanks in the winter. With an approximately neutral particle acidity in Fairbanks, there is no indication that particle formation is ammonia limited. If sulfate is reduced in Fairbanks, $PM_{2.5}$ is reduced by the weight of the sulfate reduced and also by the weight of the ammonium.

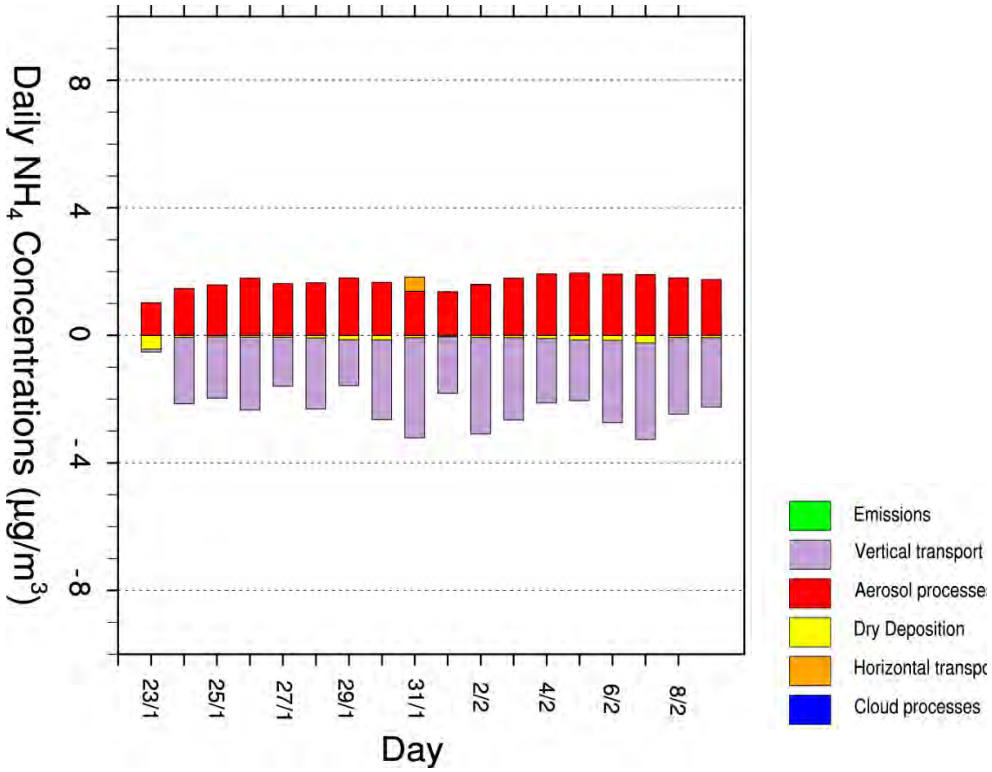

Figure 5. Ammonium concentration process analysis for episode 1 using the CMAQ model (Molders, 2012) at the State Office Building grid cell.

The modeling process analysis Figure 5 shows that the driving process for the production of ammonium is aerosol processes. The model does not accurately represent ammonium and is linked to the under prediction of secondary formation of sulfate and possible missing chemical mechanisms to convert SO_2 to sulfate. In addition, the ammonia emissions are measured and observed poorly due to measurement techniques. Figure 5 shows that there is enough ammonium to neutralize the sulfate, but in the model the amount of secondary ammonium sulfate production is very low, approximately 0.4 $\mu g/m^3$ of 2 $\mu g/m^3$ of sulfate (Molders, 2012).

Ammonia as a precursor gas is emitted from area sources at 60.7% (mostly home heating), mobile is 38.7% and non-road is 0.7%. Because ammonium in the Fairbanks $PM_{2.5}$ is dictated by the availability of sulfate and nitrate, this analysis accounts for ammonium decreases as part of sulfate and nitrate control strategies. If control strategies were to remove all 6.89 $\mu g/m^3$ of ammonium sulfate (1.88 $\mu g/m^3$ is ammonium) and 2.5 $\mu g/m^3$ of ammonium nitrate (0.56 $\mu g/m^3$ is ammonium), 2.45 $\mu g/m^3$ of ammonium (1.89 + 0.56 = 2.45) would be removed. The remainder of ammonium of 1.15 $\mu g/m^3$ (3.6 observed – 2.45 removed = 1.15) is associated with sulfate that is primarily emitted and not formed from the precursor gas emissions of SO_2.

Volatile Organic Compounds

The emissions of Volatile Organic Compounds (VOCs) are precursor gas emissions that contribute to the secondary formation of $PM_{2.5}$ by forming particulate organic carbon through condensing in the cold air after emission and through photochemistry to form secondary organic aerosols (SOA). The VOC emissions for home heating are 14.8 TPD. The condensable fraction of PM from point sources, gases that are emitted and form particles right out of the high temperature stack could be a significant from the condensation due to low temperature. After analyzing the CMAQ modeling results from the VOC emitted tons per day, the VOC fraction of secondary organic aerosols formed are 6.2 x 10^-4 $\mu g/m^3$ for the State Office Building grid cell. Some VOCs are temperature driven by higher temperatures and greater vaporization, but in Fairbanks winter the temperatures are routinely as low -40 with a winter time average temperature of -10° F, this pathway is not expected to add VOC emissions. As mentioned in the introduction, the observed organic carbon mass (particles primarily emitted and those formed from VOCs) is in good agreement with modeled organic carbon mass (Table 1) at 17.1 observed and 25.1 $\mu g/m^3$ of organic carbon modeled for the average of the two modeling episodes. The observed organic carbon mass is mostly accounted by primary particle contribution with no unexplained secondary organic aerosol. The relationship between modeled vs. observed concentrations and the very small modeled SOA leads us to believe that VOCs forming SOA are miniscule in the Fairbanks area and will be not be dealt with in detail in further RACT or RACM analysis.

The largest contributor to $PM_{2.5}$ in Fairbanks is organic carbon mass (OCM) at 21.47 $\mu g/m^3$ or 48% (Figure 1). Both organic carbon (OC) and elemental carbon (EC) are from combustion processes. Elemental carbon (EC) is a primary particulate emitted and is 17% of total. Elemental carbon is not involved in precursor chemistry and will not be addressed. Organic carbon is a primary and secondary particulate and calculated as the organic mass fraction of the total using the SANDWICH method (Frank, 2006) for the design value on high days (Figure 1). The major sources for EC/OC components are home heating. This includes wood stoves, fireplaces, inserts and wood boilers as the main component of OC and EC. Primary $PM_{2.5}$ emitted from point sources is 1.38 tons/day, not considering what fraction reaches the surface. The wood home heating primary $PM_{2.5}$ emitted is 3.18 tons/day and is emitted near the surface. Woodsmoke is found to be a major source contributor to $PM_{2.5}$ in Fairbanks and from the receptor model CMB (chemical mass balance), woodsmoke is shown to have 60-80% of total $PM_{2.5}$ (Ward, 2013). Carbon-14 testing can identify the aging of the carbon particles. Newer particles are associated with wood burning and aged carbon with fossil fuels (34-62%) (Ward, 2013).

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Appendix III.D.5.7

Individual Emission Unit RACT Determinations

Introduction

This appendix provides the detailed Reasonably Available Control Technology (RACT) analyses performed to support the RACT determinations contained in the Fairbanks $PM_{2.5}$ SIP. All facilities with emissions exceeding 100 TPY of $PM_{2.5}$, or one of its precursors SO_2 and NOx, were included. An individual RACT determination was made for each emission unit with emissions equal to or exceeding 5 TPY of one of these pollutants, for that pollutant.

The U.S. EPA has defined RACT as "the lowest emission limitation that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility."[1] EPA has also defined "presumptive RACT" as the norm achievable by the source category.[2] EPA interprets the term "reasonably available" to allow consideration of both the costs and benefits of applying the measure.[3]

> *RACT and RACM are those measures that a State finds are both reasonably available and contribute to attainment as expeditiously as practical in the specific nonattainment area.*[4]

The individual RACT analysis in this document follows the steps outlined below.

1. Identify baseline RACT[5] for the source category. This involves a review of current practice within the category.
2. Determine whether the emission unit meets baseline RACT.
3. If the emission unit does not meet baseline RACT, determine whether site-specific considerations preclude implementation of baseline RACT.

The emission units, and affected pollutants, are shown in Table 1.

[1] 44 FR 53762 (September 17, 1979)
[2] 72 FR 20610 (April 25, 2007)
[3] 72 FR 20610 (April 25, 2007)
[4] 72 FR 20612 (April 25, 2007)
[5] "Baseline RACT," as used in this analysis, is intended to be conceptually similar to "presumptive RACT"—it is the norm achievable by the source category, and serves as the starting point for the individual RACT evaluation. However, because it has not been established with the rigor utilized by EPA to determine presumptive RACT in the ozone and NO_2 programs, the term "presumptive RACT" is not utilized in this report.

Table 1. Emission units, located at major stationary sources, with actual emissions of $PM_{2.5}$, or a precursor, greater than 5 TPY.

Facility	Source	Source Category	Unit Size[a]	Actual Emissions[b]			Current Controls	Proposed RACT
				$PM_{2.5}$	SO_2	NOx		
Fort Wainwright	Boiler 3	Coal-fired boiler	230 MMBtu/hr	2	**109**	**101**	Baghouse	Baghouse
Fort Wainwright	Boiler 4	Coal-fired boiler	230 MMBtu/hr	2	**101**	**99**	Baghouse	Baghouse
Fort Wainwright	Boiler 5	Coal-fired boiler	230 MMBtu/hr	2	**126**	**117**	Baghouse	Baghouse
Fort Wainwright	Boiler 6	Coal-fired boiler	230 MMBtu/hr	1	**87**	**91**	Baghouse	Baghouse
Fort Wainwright	Boiler 7	Coal-fired boiler	230 MMBtu/hr	3	**171**	**197**	Baghouse	Baghouse
Fort Wainwright	Boiler 8	Coal-fired boiler	230 MMBtu/hr	2	**122**	**168**	Baghouse	Baghouse
Aurora Energy, Chena	Boiler 1, 2, 3, 5[c]	Coal-fired boiler	5 MW each (Boilers 1,2,3); 20 MW (Boiler 5)	**7.81 (total)**	**838.9 (total)**	**792.7 (total)**	Baghouse	Baghouse
North Pole Refinery	H-2001 Crude Heater	Liquid Fuel Fired Process Heater	325.6 MMBtu/hr	5.1	3.3	**62.0**	Ultra low NOx burners	No additional controls
North Pole Refinery	H-241 Crude Heater	Liquid Fuel Fired Process Heater	120 MMBtu/hr	2.0	1.0	**44.6**		Note (d)
North Pole Refinery	H-1001 Crude Heater	Liquid Fuel Fired Process Heater	62.5 MMBtu/hr	0.3	0.8	**20.6**		Note (d)
North Pole Refinery	B-401 Steam Generation	Liquid Fuel Fired Boiler	25 MMBtu/hr	0.3	0.1	**11.8**		Note (d)
North Pole Power Plant	Gas Turbine #1	Gas Turbine	60.5 MW	**15.5**	**42.3**	**50.3**		Continued use of HAGO
	Gas Turbine #2	Gas Turbine	60.5 MW	**131**	**326**	**464**		Continued use of HAGO
	GT #3	Gas Turbine	43 MW	**16.8**	**1.86**	**367**		Continued use of naptha and LSR
Zehnder	GT#1	Gas Turbine		**16.05**	**39.83**	**54.3**		Continued use of HAGO
	GT#2	Gas Turbine		**10.77**	**25.73**	**36.4**		Continued use of HAGO
UofA, Fairbanks	Boiler #1	Coal-fired boiler	84.5 MMBtu/Hr	3.62	**123.8**	**250**	Baghouse	Baghouse
	Boiler #2	Coal-fired boiler	84.5 MMBtu/Hr	3.77	**128.93**	**260**	Baghouse	Baghouse
	Boiler #3	Dual Fuel-fired Boiler	180.9 MMBtu/Hr	2	**17.7**	**5.72**		Continued use of No. 2 Distillate
	Boiler #4	Dual Fuel-fired Boiler	180.9 MMBtu/Hr	1.27	**11.23**	3.63		Continued use of No. 2 Distillate

NOTES:
[a]From each facility's Title V Permit Application.
[b]Actual emissions are based on information submitted in by facility operators 2013 for operations in 2011. The information was requested by Alaska Department of Environmental Conservation to satisfy the requirement to prepare a statewide point-source emission inventory (40 CFR 51.30). The inventory report has not been completed.
[c]Emissions shown for the Chena boilers, which share a common stack, are the combined emissions for all four boilers.
[d]No RACT determined for this source because the only pollutant above the threshold is NOx.

The emission units for which determinations were made fall into three source categories:

- Coal-fired boilers (12; excludes dual fuel-fired boilers), evaluated for $PM_{2.5}$ (1), SO_2 (12)
- Dual Fuel-fired Boilers (2), evaluated for SO_2 (2)
- Gas Turbines (5), evaluated for $PM_{2.5}$ (5), SO_2 (5)

Control of NOx as a $PM_{2.5}$ Precursor

NOx is a precursor for $PM_{2.5}$ in the form of nitrates, especially ammonium nitrate. Atmospheric phenomena involving NOx are very complex. Dispersion and transport of NOx emissions, atmospheric chemistry, and other factors affect the ultimate fate of NOx emissions.

NOx is widely controlled in many parts of the United States as a precursor for ozone. Current and former ozone nonattainment areas have NOx control requirements for many source categories. Some of these regulations reflect RACT, while others go beyond RACT.

The definition of RACT includes consideration of both costs and benefits of candidate controls. A control technique that is widely used for some other purpose because the emission reduction contributes towards attainment or maintenance of the standard (as an ozone precursor, for example) may still not be RACT for PM control, if the costs of control greatly outweigh the benefits of control.

EPA's policy towards control of NOx as a precursor for $PM_{2.5}$ includes a strong presumption in favor of requiring controls; this presumption may be overcome, however, if controls are very expensive, and the local conditions are such that NOx reductions are will not advance attainment by one year. The cost/benefit element of RACT review is commonly expressed as cost effectiveness for a proposed control. Cost effectiveness is expressed in units of dollars per ton of emissions avoided. A lower value for cost effectiveness means that the control technology is more efficient from a cost perspective at reducing emissions.

No threshold has been set for acceptable cost effectiveness for RACT review.[6] Instead, cost effectiveness is used as an indicator of the relative value of the costs and benefits of control. A very high cost effectiveness value may mean that a candidate control technology, even if commonly used and affordable, is not RACT for a specific emission unit because the costs of control outweigh the benefits from control. Whether a particular control technology is cost-effective as RACT for a specific emission unit is a case-by-case determination made by states and EPA.

As part of this analysis, the effectiveness of NOx emission reduction as a strategy to reduce ambient $PM_{2.5}$ concentrations in Fairbanks has been evaluated relative to reductions of directly emitted $PM_{2.5}$. The evaluation was based on the contribution that nitrates make to $PM_{2.5}$ concentrations in the design case for the region's attainment demonstration, and the regional NOx emissions that contribute to them.[7]

Based upon ambient sampling, nitrates comprise about 4% of the measured $PM_{2.5}$ concentrations in Fairbanks.[8] This corresponds to hydrated ammonium nitrate concentration of 3.4 $\mu g/m^3$. This represents the theoretical upper-bound of $PM_{2.5}$ reductions that could be achieved by elimination of NOx emissions.

Regional emissions of NOx from point sources are 13.45 TPD.[9] Assuming that all of the ambient nitrate $PM_{2.5}$ can be attributed to emissions from point sources establishes an upper bound for the effectiveness of NOx reductions as a strategy for reducing $PM_{2.5}$ concentrations.[10] Using this assumption, a reduction of 13.45 TPD of NOx would result in a reduction, at most, of 3.4 $\mu g/m^3$, or 0..25 $\mu g/m^3$ (= 3.4/13.45) per TPD.

For comparison, a wood stove change out program implemented by Fairbanks North Star Borough to reduce directly emitted $PM_{2.5}$—is expected to achieve a reduction in ambient $PM_{2.5}$ of 10.62 $\mu g/m^3$ through a reduction of 3.18 TPD of $PM_{2.5}$ emissions, or 3.34

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[6] Some states and local agencies use cost effectiveness thresholds when evaluating the economic feasibility of controls that have been proposed as Best Available Control Technology (BACT). Some states and some local agencies, notably several in California, establish "bright line" thresholds above which controls are considered too costly to apply. Current typical practice at Alaska DEC from reviewing BACT analyses is to deem any control that costs more than $10,000 per ton of reduction it may be too expensive to require for BACT. EPA has not established such cost-effectiveness thresholds. Both states and EPA also may use cost effectiveness in prioritizing post-RACT control measures for plans to attain and maintain National Ambient Air Quality Standards. For this reason, any control technique deemed too expensive for RACT may still be required as part of the attainment demonstration.

[7] This analysis is not as precise as one based, for example, on atmospheric modeling. However, the results are being used here as an indicator of the relative cost/benefit of requiring reduced emissions of a given pollutant. For this limited purpose, the level of approximation provided by the analysis is reasonable.

[8] Appendix III.D.5.7 Precursors

[9] Fairbanks PM 2.5 SIP Chapter III.D.5.8

[10] This is a conservative assumption. Region-wide, 60% of all NOx emissions are from point sources (the other 40% come from mobile, area, non-road, and miscellaneous other sources). It would therefore be reasonable to apportion 60% of the NOx-originated PM2.5 to point sources. This apportionment would still be conservative because the plumes from industrial sources frequently penetrate the inversion layer that is a common feature of local meteorology, and as a result the NOx in those plumes does not contribute as significantly to local $PM_{2.5}$ concentrations as the emission inventory would suggest. However, neither of these adjustments is necessary to demonstrate that NOx control is not an effective strategy for reducing ambient $PM_{2.5}$ concentrations in Fairbanks.

(=10.62/3.18) µg/m^3 per TPD. Based on this measure, control of a ton of directly emitted $PM_{2.5}$ is about 13 times more effective[11] than control of a ton of NOx.

Survey of NOx Controls in $PM_{2.5}$ SIPs

In order to ensure that the RACT determinations in this analysis are consistent with those made by other jurisdictions in similar circumstances, a survey of $PM_{2.5}$ SIPs was performed.

All areas designated nonattainment for the 2006 $PM_{2.5}$ standard[12] were identified. Areas that are currently nonattainment for ozone were eliminated from further review. This was done because control requirements for NOx in current ozone nonattainment areas are already well beyond RACT levels. PM SIPs in such areas cannot provide insight into NOx RACT in ozone attainment areas.

Next, areas that have been redesignated attainment for the 2006 $PM_{2.5}$ standard, or that have Clean Area determinations, were eliminated from further review. The plans for these areas were not expected to include NOx control measures as strategies for attaining the PM standard because the standard has already been attained.

Six jurisdictions, including Fairbanks, were left. SIPS for these other areas were reviewed for information useful in establishing RACT. The results of this review were:

- Klamath Falls, Oregon: Klamath Falls point sources emit a total of 755 lb/day (138 TPY). Point source control measures identified as RACT: 20% opacity limitation (direct PM control). No NOx control measures were identified as RACT.
- Oakridge, Oregon: Nitrates contribute less than 0.4% of the PM mass on exceedance days. As a result, Oakridge did not evaluate RACT for NOx sources in its plan.
- Logan, Utah: Total NOx inventory from point sources = 7.3 TPY. [13] No NOx RACT proposed.
- Provo, Utah: Unlike Fairbanks, secondary particulate is most responsible for Provo's PM exceedances.[14] However, due to previous efforts to attain the federal PM_{10} standard, most point sources were already controlled at RACT/BACT levels. Additional control measures for point sources are listed with Salt Lake City, below.

[11] 13.2 = 3.97 tons of NOx emissions / 0.3 tons of woodsmoke emissions
[12] EPA, *Area Designations for 2006 24-Hour Fine Particle ($PM_{2.5}$) Standards,* http://www.epa.gov/airquality/particlepollution/designations/2006standards/state.htm
[13] *Utah State Implementation Plan, Control Measures for Area and Point Sources, Fine Particulate Matter, PM2.5 SIP for the Logan, UT-ID Nonattainment Area* (November 6, 2013), p. 24
[14] *Utah State Implementation Plan, Control Measures for Area and Point Sources, Fine Particulate Matter, PM2.5 SIP for the Provo, UT Nonattainment Area* (November 6, 2013), p. 43

- Salt Lake City, Utah: Unlike Fairbanks, secondary particulate is most responsible for Provo's PM exceedances.[15] However, due to previous efforts to attain the federal PM_{10} standard, most point sources were already controlled at RACT/BACT levels. The State identified the following additional point source control measures:[16]
    - Ultra-Low NOx Burners (liquid fuel-fired process heaters), $1,813-$7,200 per ton
    - Low NOx Burners and Flue Gas Recirculation (FGR): $8,340 per ton
    - Combustion Controls, $1,357 per ton

The methodology used by Utah to establish the levels that it characterized as RACT went beyond RACT requirements.[17] Utah identified feasible control methods for each source it reviewed; it then evaluated expected reductions in its air quality model, in an effort to achieve attainment of the NAAQS as expeditiously as practicable. Finally, it determined which control measures would be included in the overall control strategy for the SIP.

The last two steps utilized by Utah are not part of a RACT analysis. They are the steps used in evaluating and prioritizing control measures for attainment. In other words, Utah blended the RACT evaluation process and the attainment planning process. Utah skipped making RACT determinations and efficiently proceeded directly to identification of the controls needed to demonstrate attainment. These control requirements are certainly *at least stringent as* RACT would be for the affected sources. In many cases, however, the controls go beyond RACT, as indicated by the cost effectiveness calculations included in the analysis.

For this reason, Utah's RACT determinations were considered, but in the end not used, in the RACT determinations for Fairbanks.

Methodology

As discussed above, NOx controls are not an efficient method for reducing PM concentrations in Fairbanks. This conclusion is based upon the relatively small contribution that secondary particulate (specifically nitrates) make to ambient PM concentrations on episode days, and the relatively large reductions in NOx emissions needed to have the same benefit (as measured by ambient PM concentrations) as a modest reduction in PM emissions.

Because the purpose of this analysis is to determine whether expenditures are reasonable for reduction of ambient $PM_{2.5}$ concentrations, the cost-effectiveness threshold for this analysis has been selected by taking the relative effectiveness of NOx control for PM reductions into account. This adjustment is necessary in order to ensure that control dollars are spent effectively. As discussed elsewhere in this report, a NOx reduction of 13 tons was determined to have the same effect as reduction of a single ton of directly-

[15] *Utah State Implementation Plan, Control Measures for Area and Point Sources, Fine Particulate Matter, PM2.5 SIP for the Provo, UT Nonattainment Area* (November 6, 2013), p. 43
[16] *PM2.5 Technical Support Documentation For the Salt Lake City and Provo PM2.5 Nonattainment Areas*
[17] *PM2.5 Technical Support Documentation For the Salt Lake City and Provo PM2.5 Nonattainment Areas*, p. 5.c.i-1

emitted PM, for the purposes of reducing ambient concentrations of PM. After reviewing several past ADEC BACT determinations for various pollutants, staff determined that $10,000 per ton was a representative threshold for BACT for all pollutants. For this analysis, the RACT cost-effectiveness threshold for PM was set at the same level as the BACT threshold.

In order to maximize the environmental benefit for the amount of money spent, the cost RACT cost-effectiveness for NOx reductions for the purpose of reducing ambient PM concentrations was derived by taking into account the relative benefits of reducing NOx and direct PM. As discussed above, a reduction of PM emissions is about 13 times more effective than a reduction of the same amount of NOx emissions.

In order to be conservative, a cost effectiveness threshold of $1,000 per ton of NOx has been used in this RACT review. Any technology with a lower bound of more than $1,000 per ton of NOx reduction was eliminated from further consideration.

Control technologies considered

All of the point sources under review emit NOx as a combustion product. There are two approaches to the control of NOx from combustion: combustion controls, and post-combustion controls. Combustion controls include use of water injection, low NOx burners, and other combustion modifications to reduce the formation of NOx during combustion. Post-combustion controls include catalyst systems that convert NOx to nitrogen in the stack.

The control techniques evaluated are presented in Table 1, along with the estimated cost effectiveness.

Table 1 shows that the screening estimate of the cost effectiveness[18] (based on the low end of the dollar-per-ton range, if one was provided) of all identified control technologies except one is higher than (i.e., less cost-effective than) the $1,000 per ton threshold established above. As a result, none of these control technologies are considered cost effective for the control of NOx as a precursor of $PM_{2.5}$ in Fairbanks.

The exception is the use of low NOx burners and flue gas recirculation (FGR) to control NOx emissions from oil-fired process heaters. The only oil-fired process heaters under review are the heaters at the North Pole refinery. The largest of these units, the H-2001 Crude Heater, is already equipped with ultra low-Nox burners. The other three heaters are not currently equipped with low NOx burners. Installation of low NOx burners was considered as a possible RACT measure for these units. However, the cost effectiveness value shown in Table 1 is the low end of the range of estimated costs, and it is just barely below the RACT threshold. Installation costs in Alaska are not expected to be at the low

[18] The values shown in Table 1 are the low values in the range, if a range was given in *EPA Menu of Control Options*. The cost of controls in Fairbanks is expected to be above the middle of the range of costs in the lower 48 states. Additionally, some of the cost effectiveness values do not take equipment size into account. Many of the sources are relatively small, at or below the range for which cost estimates are valid. Smaller units generally cost more per ton than larger units. As a result, the values shown are conservatively low. Actual costs would be expected to be much higher.

end of the range of costs; additionally, the costs of installation on small units are almost never at the low end of the range—economies of scale usually result in the low end of the cost scale being associated with large units. For these reasons, the cost effectiveness of installation of low NOx burners at North Pole Refinery are expected to be sufficiently higher than the value shown in Table 1 to be above the cost effectiveness threshold, and installation of low-NOx burners was determined to not be RACT for these units.

Because none of the identified NOx control measures will result in a cost-effective reduction of ambient PM concentrations, existing controls are deemed to meet RACT requirements for NOx for each of the identified sources.

Table 1. NOx Control Techniques[a]

Source Category	Control Technique	Cost Effectiveness ($/ton of NOx removed)[b]	Additional Information
Coal-Fired Boilers (and Dual Fuel-Fired Boilers)[c]			
Industrial Boilers firing coal (stoker)	Low NOx burner	$1,526	<250 MMBtu/hr
Industrial Boilers firing coal (stoker)	Low NOx burner and overfire air	$1,077	
EGU boiler firing coal	SCR	$1,550	
EGU Boilers firing coal	SNCR	$1,370	
Liquid Fuel-Fired Process Heaters[d]			
Industrial Fuel Oil Combustion	Low NOx Burner	$1,894	
Process Heaters	Low NOx burner and FGR	$915	
Oil combustion in Process Heaters	Low NOx burner retrofit & SNCR	$3,691	
Gas Turbines[e]			
Turbines, oil fired	Water Injection & SCR	$3,691	
Turbines, oil fired	Water Injection	$2,070	

[a]Data from *EPA Menu of Control Options* (Updated 4/12/2012). The values shown are the bottom of the range, if a range was provided.
[b]2006 dollars
[c]Fort Wainwright Boilers 3-8; Chena Power Plant Boilers 1,2,3,5; UofA Fairbanks Boiler 1-2.
[d]North Pole Refinery Crude Heaters and Steam Generation.
[e]North Pole Power Plant GT1-3; Zehnder GT 1-2.

Conclusion: Reducing NOx emissions is a relatively inefficient strategy for reducing $PM_{2.5}$ in Fairbanks. Using the analysis discussed and cited above, our assessment of the cost and effectiveness of NOx controls concludes that available controls are not cost effective and would not advance attainment of the $PM_{2.5}$ standard by a year. Based on the fact that controlling for direct $PM_{2.5}$ is approximately 13 times more effective, on a per-pound basis, than controlling for NOx emissions, any cost effectiveness analysis for NOx control equipment would need to reflect this factor and still be shown to be cost effective.

Our analysis did not find any NOx controls that are cost effective for reducing $PM_{2.5}$ emissions in the nonattainment area.

For this reason, NOx reductions, for the purposes of $PM_{2.5}$ reductions within the context of RACM and RACT, will not be considered at this time.

Coal-Fired Boilers

The following is considered baseline RACT for coal-fired boilers in Fairbanks:

- $PM_{2.5}$: Fabric Filters
- SO_2: Use of low-sulfur coal

The basis for each baseline RACT determination is described below.

$PM_{2.5}$ (Direct Emissions)

Candidate Control Technologies – The following control technologies were considered for this source category:

- Fabric Filters;
- Electrostatic Precipitators; and
- Wet Scrubbers.

All of the coal-fired boilers under evaluation are currently equipped with fabric filters. If properly designed and maintained, fabric filters generally reflect the best performing control technology available for emissions of PM from coal-fired boilers.

Conclusion: RACT for PM for each of the coal-fired boilers is a properly designed and operated fabric filter system. A design review will be conducted for each boiler to confirm that the existing baghouses are properly designed and operated.

SO_2

Candidate Control Technologies – The following control technologies were considered for this source category:

- Scrubber (Wet, Spray Dry, and Dry); and
- Fuel sulfur content reduction.

Scrubbers[19] – Scrubbers are used extensively to control emissions of inorganic contaminants, including acid gases such as sulfur dioxide (SO_2). Scrubbers are capable of reduction efficiencies in the range of 50% to 90%. In a wet system, the exhaust gas is contacted in a scrubber with a wet solution. Acid components (SO_2 and HCl) are absorbed into the liquid, and a liquid waste must be disposed of. Dry systems involve injection of dry alkali substances (usually some form of lime), which is removed from the exhaust by a fabric filter or ESP. Spray dry systems introduce the absorbent in a slurry that is fully evaporated by the exhaust stream, resulting in particulates that are removed by fabric filter or ESP. Approximately 85% of the Flue Gas Desulfurization (FGD) systems installed in the U.S. are wet systems, 12% are spray dry, and 3% are dry systems.

[19] Information in this section is from: EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034

SO_2 scrubbers have been applied to combustion units as small as 5 MW (~50 MMBtu/Hr). Dry and spray dry scrubbers are generally applied to units less than 300 MW (~3,000 MMBtu/Hr).[20] However, there are relatively few installations on units smaller than 300 MMBtu/hr. All 14 of the units in Fairbanks are smaller than 300 MMBtu/hr; 6 of them are smaller than 100 MMBtu/hr. See Table 1. The strategy for control of SO_2 emissions under the Acid Rain program provides an incentive to invest in controls for large to very large sources while leaving smaller sources without controls. EPA has characterized the range of "realistic values" for unit size for scrubber installations as between 100 and 2000 MW_e.[21]

Capital costs for all SO_2 scrubbers were reported to be approximately $100/kW in 2001.[22] Retrofit costs vary significantly between sites and depend on space limitations, requirements for duct modifications, and operating conditions (temperature, flow rate); retrofit of scrubbers on existing units can increase the capital costs up to 30%.

The addition of a scrubber to an existing combustion device causes a loss of energy due to evaporation of water and the energy required to drive the reaction.[23] New scrubber designs result in energy penalties of less than 1% of total plant energy.

Wet scrubbers rely primarily on the absorption process to remove these soluble contaminants from the exhaust gas stream. Wet scrubbing devices that are based on absorption principles include packed towers, plate (or tray) columns, venturi scrubbers, and spray chambers. Removal efficiencies for gas absorbers vary for each pollutant-solvent system and with the type of absorber used. Pollutant removal may also be enhanced by manipulating the chemistry of the absorbing solution so that it reacts with the pollutant(s), e.g., caustic solution for acid-gas absorption vs. pure water as a solvent. Chemical absorption may be limited by the rate of reaction, although the rate-limiting step is typically the physical absorption rate, not the chemical reaction rate.

Most absorbers have removal efficiencies in excess of 90%, and packed tower absorbers may achieve efficiencies as high as 99.9% for some pollutant-solvent systems.

EPA considers dry scrubbers to be a promising emerging technology.

> *Dry scrubbers have significantly lower capital and annual costs than wet systems because they are simpler, demand less water and waste disposal is less complex. Dry injection systems install easily and use less space, therefore, they are good candidates for retrofit applications. SO_2 removal efficiencies are significantly*

[20] For the purposes of this analysis, a nominal plant heat rate of 10,000 Btu/kwhr is assumed for boilers producing steam for electricity where a heat rate is required site specific information is not available.
[21] Srivastava, *Controlling SO_2 Emissions: A Review of Technologies, EPA/600/R-00/093* (November 2000) , p. 44.
[22] Smith, *SO_2 Controls: Cost of SO_2 Scrubbers Down to $100/kW,* Power Engineering (September 2001).
[23] Although there is no evaporation, there is still an energy penalty associated with the use of dry scrubbing. EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034, p. 2.

> *lower than wet systems, between 50% and 60% for calcium based sorbents. Sodium based dry sorbent injection into the duct can achieve up to 80% control efficiencies (Srivastava 2001). Dry sorbent injection is viewed as an emerging SO_2 control technology for medium to small industrial boiler applications. Newer applications of dry sorbent injection on small coal-fired industrial boilers have achieved greater than 90% SO_2 control efficiencies.*[24]

The available information for cost effectiveness for scrubbers is summarized below.

Table 2. Cost of SO_2 Scrubbers

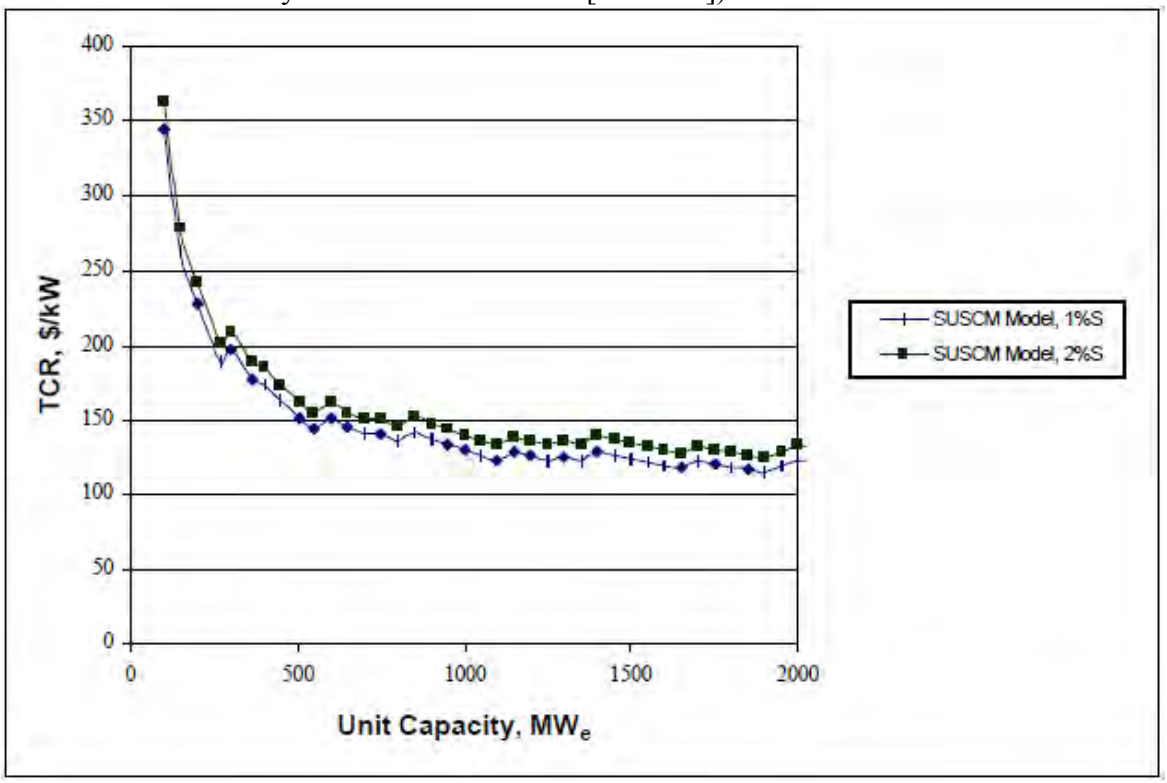
Scrubber Type	Unit Size (MW)	Cost per Ton of Pollutant Removed ($\$_{2001}$/ton)
Wet	>400	200-500
	<400	500-5000
Spray Dry	>200	150-300
	<200	500-4000
Dry Scrubbers	All	Not Available

Source: EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034. EPA does not provide cost information for dry scrubbers.

By far the most significant factor determining cost effectiveness of controls is the size of the unit. This is illustrated in Figure 1.

[24] EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034

Figure 1. Total Capital Requirement for Lime Spray Drying System (as calculated by State-of-the-Art Utility Scrubber Cost Model [SUSCM])[25]



NOTE: 100 $MW_e \approx$ 1,000 MMBtu/hr

In order to better refine this cost estimate, EPA's tool for estimating the cost of controls for coal-fired boilers, CUECost,[26] was utilized to estimate the cost of wet scrubbers for coal-fired equipment in Fairbanks. CUECost is the Coal Utility Environmental Cost workbook, an interrelated set of spreadsheets that "produces rough-order-of-magnitude cost estimates (+/- 30% accuracy) of the installed capital and annualized operating costs for air pollution control systems installed on coal-fired power plants."[27] As noted above, EPA has determined realistic values for unit size for scrubber installations as between 100 and 2000 MW_e. Consistent with this determination, the minimum unit size for which CUECost is valid is 100 MW_e whereas the largest example in the nonattainment area are the 40 MWe associated with the combines exhaust from the Chena power plant.

Default values were used for most user-specified inputs. Non-default values, and the basis for their selection, are shown in Table 3. The analysis was performed using values for the largest boiler under review (the combined emissions of the four boilers at Aurora Energy's Chena facility). This exhaust stream was selected because it is expected to have the best cost effectiveness value for capital costs; operating costs for sulfur controls are roughly

[25] Taken from Srivastava, *Controlling SO_2 Emissions: A Review of Technologies, EPA/600/R-00/093* (November 2000) , p. 74.
[26] CUECost Model Version 3.0, downloaded from *http://www.epa.gov/ttn/catc/products.html*. This is the most current version of CUECost available.
[27] Yelverton, *Coal Utility Environmental Cost (CUECost) Workbook User's Manual, Version 1.0,* p. 1. This is the version of the user's manual that accompanies CUECost Version 3.0.

proportional to actual throughput, so unit size does not affect overall operating costs as strongly.

Table 3
CUECost Estimate of Cost of Sulfur Scrubbers for 100 MW Coal-fired Boiler—Input

Description	Units	Range	Default	Case 2
Location - State	Abbrev.	All States	PA	AK
MW Equivalent of Flue Gas to Control System	MW	100-2000	500	100[a]
Net Plant Heat Rate (w/o APC)	Btu/kWhr		10,500	10,500
Plant Capacity Factor	%	40-90%	65%	40%[b]
Percent Excess Air in Boiler	%		120%	120%
Air Heater Inleakage	%		12%	12%
Air Heater Outlet Gas Temperature	°F		300	300
Inlet Air Temperature	°F		80	26.7[c]
Ambient Absolute Pressure	In. of Hg		29.4	29.4
Pressure After Air Heater	In. of H2O		-12	-12
Moisture in Air	lb/lb dry air		0.013	0.0026[d]
Ash Split:				
Fly Ash	%		80%	80%
Bottom Ash	%		20%	20%
Seismic Zone	Integer	1-5	1	4[e]
Retrofit Factor (1.0 = new, 1.3 = medium, 1.6 = difficult)	Dimensionless	1.0-3.0	1.3	1.3 – 3
Coal Cost	$/MMBtu		1.50	3.30[f]
Coal Moisture	wt%		30.24	30.00[g]
Coal Carbon	wt%		48.18	45.00[g]
Coal Sulfur	wt%		0.37	0.13[h]
Ash	wt%		5.32	9.23[h]
Electricity cost	mills/kwh		25	60[i]
2013 Chemical Engineering Price Index			388 (1998)	585.7 (2012)

NOTES:
[a] Largest boiler in the study is 37 MW (combined exhaust of boilers at Aurora Energy's Chena Facility). Used minimum value in the tool's range (i.e., 100 MW).
[b] The analysis was run using the lowest value for capacity factor within the tool's allowed range (i.e., 40%)
[c] U.S. Climate Data *http://usclimatedata.com/climate.php?location=USAK0083*, accessed 9/19/13.
[d] Vapor pressure of water over ice at 32F.
[e] Seismic zone = 4 ("Areas within Zone 3 close to major fault systems"), based on information from this website: *http://seismic.alaska.gov/seismic_hazards_earthquake_risk.html*
[f] Cost of coal ~$50/st
[g] Adjusted from default to compensate for ash content.
[h] From Emission Inventory 2011
[I] Source: Alaska Electric Light and Power Company, Large Commercial Tariff

Information about the estimates is provided in Table 4. Based on the model, the cost effectiveness of wet scrubbers and spray dryer systems to control SO_2 from these boilers is

between $24,000 and $58,000 per ton of SO_2. This is much higher than the cost effectiveness values provided by the EPA Fact Sheet, shown in Table 2. However, this outcome is expected, given the small size and low sulfur content of the unit being evaluated. Furthermore, it is important to bear in mind that the definition of "small" for coal-fired units is 500 MWe, and that EPA considers installation of scrubbers on units smaller than 100 MW_e to be "unrealistic."

Table 4
CUECost Estimate of Cost of Sulfur Scrubbers for 100 MW Coal-fired Boiler—Output

Description	Units	Limestone Forced Oxidation[a]	Lime Spray Dryer[b]
Total Capital Requirements	$2012	$77-176 million	$57-131 million
Levelized Constant Dollars			
Fixed O&M	$2012/year	$4.0 million/year	$3.0 million/year
Variable O&M	$2012/year	$0.6 million/year	$0.8 million/year
Fixed Charges	$2012/year	$9.0-20.6 million/year	$6.7-15.3 million/year
Total	$2012/year	$13.6-25.0 million/year	$10.4-19.1 million/year
Total	$2012/ton SO_2	$29,600-57,600/ton	$23,900-46,100/ton

[a]Limestone Forced Oxidation is a type of wet scrubber.
[b]Lime Spray Dryer is a type of spray dryer.

In summary, available cost information for wet scrubbers and spray dry systems indicate that these systems are not cost effective for small units (smaller than 500 MW_e).

As for dry scrubbers, the most recent EPA guidance indicates that EPA considers dry scrubbers to be a promising, but still emerging, technology, with potentially lower capital costs, particularly for medium to small installations. An emerging technology may be a candidate for evaluation in a top-down BACT analysis, but cannot be considered to be the "norm." Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[28] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

The Sargent & Lundy report compares capital and operating costs for power plants of two sizes: 400 MW and 500MW. The report also evaluated the effect of fuel sulfur content on cost. The cost calculations were developed for the purpose of comparing the relative cost effectiveness of the various technologies on power plants of the selected sizes. The report cautions that costs should not be used to plan the cost of a FGD project. Taking these cautions into account, the report still contains information relevant to the RACT analysis. What follows is an attempt to scale the cost data for a 400 MW plant down to the 20-40 MW units in Fairbanks.

[28] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.

Effect of fuel sulfur content on cost

Table 5 presents the cost information from the Sargent & Lundy report (Cases 1-6), as well as an extrapolation of the costs to a hypothetical 400 MW power plant burning Alaska coal. The costs shown are retrofit costs.

The defining characteristic of Alaska coal is very low sulfur content. For this reason, uncontrolled sulfur emissions are 4 times lower than occur at a plant burning "low sulfur" coal in the lower 48 states.

Table 5. Cost of Circulating Dry Scrubber for SO_2 Controls (400 and 500 MW Coal-fired Power Plant)

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Unit Size	MW	400	500	400	500	400	500
boiler fuel capacity	MMBtu/hr	4000	5000	4000	5000	4000	5000
Coal HHV	btu/lb	8,335	8,335	13,100	13,100	13,100	13,100
Sulfur content	wt%	0.6	0.6	1.3	1.3	2	2
SO2 generation	lb/MMBtu	1.44	1.44	2.0	2.0	3.1	3.1
Annual fuel use	ton/year	1,681,584	2,101,980	1,069,924	1,337,405	1,069,924	1,337,405
Capacity Factor		80%	80%	80%	80%	80%	80%
Control efficiency		97.2%	97.2%	98%	98%	98%	98%
Capital Cost	M$	110.2	139.3	107.9	135.9	111.9	140.6
Annualized Cap Cost	M$/year	10.40	13.15	10.18	12.83	10.56	13.27
Fixed Operating Cost	M$/year	2.08	2.45	2.05	2.40	2.11	2.47
Variable Operating Cost	M$/year	5.13	6.41	7.03	8.79	10.46	13.07
Total Operating Cost	M$/year	7.21	8.86	9.08	11.19	12.57	15.54
Total cost	M$/year	17.61	22.00	19.27	24.02	23.13	28.81
Cost per kwh	¢/kwh	0.63	0.63	0.69	0.69	0.83	0.82
SO2 removed	ton/year	19,614	25,224	27,818	34,773	42,797	53,496
Cost effectiveness	$/ton SO2	898	872	693	691	540	539

Notes:
[a]All data from Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.
[b]Annual capital cost calculated using a 7% discount rate and a 20-year equipment life.

A direct result of this is that the cost effectiveness of any sulfur emission reduction strategy is much poorer for facilities firing Alaskan coal. The estimated cost effectiveness of retrofitting a 400 MW baseload (80% capacity factor) firing Alaskan coal is $2,800 per ton; this is more than 3 times the cost of retrofitting a similar unit in the lower 48 states. This value is based on an assumption that the control efficiency of the control device will be 95%. It is likely that the control efficiency will be lower, because a lower inlet pollutant loading usually results in a lower overall control efficiency.

Effect of unit size on cost

Extrapolating costs from data at 400-500 MW to units that are 5-40 MW in size is unreliable, at best. Generally, economies of scale result in capital costs (expressed as dollars per unit of capacity) being higher for smaller units.

The Sargent & Lundy capital cost data were evaluated to determine a capital cost factor of $0.276 million per MW for scrubber units applied to boilers in the 400-500 MW range

The linear factor above does not take into account economies of scale. Small units are more expensive (on a dollar per unit capacity basis) than larger units. A scaling equation to account for the non-linearity of construction costs, adjusting equipment cost estimates for size, is provided by the National Energy Technology Library.[29]

$$SC = RC * (\frac{SP}{RP})^{Exp}$$

Where

SC = Scaled Cost
RC = Reference Cost
SP = Scaling Parameter
RP = Reference Parameter
Exp = exponent

For the components comprising the desulfurization system (sorbent handling, injection, collection, etc.) the exponents range from 0.5 to 0.72. An exponent value of 0.64 was used to calculate the costs presented in Table 4. Costs were calculated by scaling the estimated cost of a 400 MW unit burning Alaska coal (Case 7 in Table 4) by the ratio of the boiler capacity (in MW) to 400 MW, raised to the power of 0.64.

Operating and maintenance (O&M) costs can be separated into two components: fixed costs (overhead costs that are insensitive to usage; these include labor and maintenance materials) and variable costs (costs that are tied to production, including cost of consumable, by-product management, water and power). Fixed costs were estimated by evaluating the Sargent & Lundy cost data to get a fixed cost factor of $5,036 per MW. Variable costs were based on a variable cost factor of $252 per ton of SO_2 recovered.

[29] US Department of Energy, *Capital Cost Scaling Methodology*, January 2013.

Results of Cost Calculations

Table 6 presents the cost estimates for dry scrubbers using the methodology described above. Estimated site-specific cost effectiveness are $2,200 per ton of SO_2 removed (Chena power plant); $2,200 per ton of SO_2 removed (University of Alaska 1 & 2); and over $5,000 per ton of SO_2 removed (Wainwright, University of Alaska 3 & 4).

Table 6. Cost of Circulating Dry Scrubber for SO_2 Controls (Fairbanks Facilities)

		Case 7 (Alaska coal)	Wainwright 3-8	U of A 1, 2[c]	Chena (combined)[d]
Unit Size	MW	400	23	8.5	42
boiler fuel capacity	MMBtu/hr	4000	230	85	420
Coal HHV	btu/lb	7,545	7,545	7,545	7,545
Sulfur content	wt%	0.14	0.14	0.18	0.14
SO2 generation	lb/MMBtu	0.4	0.4	0.5	0.4
Annual fuel use	ton/year	1,857,654	50,391	36,950	234,251
Capacity Factor		80%	38%	75%	96%
Control efficiency		95%	95%	95%	95%
Capital Cost	M$	110.4	12.0	4.5	22.0
Annualized Cap Cost	M$/year	10.42	1.14	0.42	2.08
Fixed Operating Cost	M$/year	2.01	0.12	0.04	0.21
Variable Operating Cost	M$/year	1.24	0.04	0.03	0.16
Total Operating Cost	M$/year	3.26	0.15	0.08	0.37
Total cost	M$/year	13.68	1.29	0.50	2.45
Cost per kwh	¢/kwh	0.49	1.70	0.89	0.69
SO2 removed	ton/year	4,941	141	133	656
Cost effectiveness	$/ton SO2	2,769	9,140	3,734	3,732

Notes:

[A]All costs are estimates based on cost factors derived from Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007. The values in this table are extrapolated from 400 and 500 MW examples.

[b]Annual capital cost calculated using a 7% discount rate and a 20-year equipment life.

[c]University of Alaska Units 3 & 4 are not included. These dual fuel-fired units did not burn coal in the inventory year.

[d]Chena Units are combined because they share a common stack. Unit 4 capacity was adjusted upward (from 20 MW to 27 MW) to match actual physical capacity as demonstrated by historical firing rate data.

In interpreting these values, it is important to note that they are very likely low estimates. They are based on cost factors for much larger facilities, and do not take economies of scale into account. The Wainwright boilers have relatively low capacity factors, which contributes to poor cost effectiveness. All of them use low-sulfur Alaska coal, which also contributes to poor cost effectiveness. Additionally, the low sulfur loading may result in much lower abatement efficiencies than assumed in this analysis, further increasing the cost per ton of SO_2 controlled, and reducing the effectiveness of the control strategy.

Other observations

The Sargent & Lundy report indicates that the cost of a circulating dry scrubber is very similar to that of a spray dryer.[30]

Information in the Sargent & Lundy report creates concerns about cost estimates using older sources.

> FGD prices have seen a minimum of 25% inflation in the last year [CY2006]. Some recent contracts have been signed at prices over 300% higher than the market of 5 years ago.[31]

The EPA fact sheet used to describe and estimate costs for other SO_2 removal technologies uses cost data from 2000 and 2001.

Sargent & Lundy indicated that, at least in 2007, the scrubber marketplace was a "seller's market."

> [E]ven when the seller's costs agree with the costs that these tables were based on, the seller's price may include a factor of 20% that reflects his diminished desire to capture the contract. This diminished desire may alternatively be exp0ressed as a refusal to offer any price. Many suppliers are declining to bid on contracts they deem too small, too different from their experience base, to short a schedule, too difficult a labor environment, or too commercially risky.[32]

Conclusions

The cost effectiveness of controlling SO_2 from coal-fired units in Fairbanks using dry scrubbing technology has been estimated. The estimated costs exceed $3,700 per ton for all facilities, and range as high as $9,100 per ton. For a number of reasons, these cost estimates are considered to be underestimates of the actual costs.

- The capital cost per unit capacity is extrapolated from 400 MW examples to units smaller than 40 MW.
- A control efficiency of 90% was assumed. However, this level of control may not be achievable due to the much lower inlet sulfur loading.
- Actual vendor costs may be higher, or even unavailable, because the projects are too small or too challenging to be attractive.

These control costs are too high for this technology to be considered RACT for the small units operated in Fairbanks.

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[30] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007, p. 53.

[31] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007, p. 33.

[32] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007, p. 33.

The Sargent & Lundy report indicates that the cost of dry scrubbing is very similar to that of a spray dryer, characterizing them as a "tie" from a cost standpoint. The report also indicates that the costs of controls have increased substantially since the EPA guidance on sulfur control technologies was issued, and the costs in that guidance may underestimate control costs by a factor of 3 or more.

For the reasons presented above, the use of scrubbers (wet, spray-dry, or dry) on boilers smaller than 100 MW_e cannot be considered to be the norm for SO_2 control, and therefore scrubbers are not considered RACT for these units

Reduced Sulfur in Fuels – Perhaps the simplest and, in many cases, the most cost effective SO_2 emission reduction technology that can be employed for fuel combustion sources is to switch to a lower sulfur content fuel. Reducing the sulfur content in the fuel will reduce the sulfur emissions linearly.

For coal-fired boilers, this means either cleaning the coal to remove sulfur, or switching to a coal source with a lower sulfur content.

Alaskan coal has very low sulfur content.[33] As a result, switching to a coal with a lower sulfur content is not an option. The low sulfur content makes fuel cleaning uneconomical as well, because of the higher volume of fuel that must be cleaned to achieve a given reduction in sulfur.

Conclusion: In order to establish baseline RACT for this source category, data collected by EPA during development of the Boiler NESHAPS were reviewed. Very few coal-fired boilers are currently equipped with exhaust gas SO_2 controls—certainly not enough to be able to say that exhaust gas scrubbers are the norm for this source category. EPA guidance states that use of scrubbers on units smaller than 100 MW is unrealistic. Wet scrubbers and spray dry scrubbers are too expensive to be cost effective. Dry scrubbers may be less expensive than other scrubbers, but the available information on control costs is extremely sparse, and extrapolation to estimate the cost of very small units is unreliable. However, costs have been estimated using available information, and the result appears to indicate that dry scrubbers are too costly to be deemed RACT.

Alaskan coal has a very low fuel content, making fuel switching ineffective and fuel cleaning uneconomical. For these reasons, baseline RACT for SO_2 for each of the coal-fired boilers is use of low-sulfur coal, with no additional controls.

[33] "Alaskan coal resources have a lower sulfur content (averaging 0.3 percent) than most coals in the conterminous United States and are within or below the minimum sulfur value mandated by the 1990 Clean Air Act Amendments." USGS, *Alaska Coal Geology, Resources, and Coalbed Methane Potential* ,(2004) p. 1.

Individual RACT: Fort Wainwright Boilers 3-8

Fort Wainwright has a Central Heat and Power Plant (CHPP) that generates steam and electricity to meet the heating and electricity demands of the base. The CHPP has six identical 230 MMBtu/hr coal-fired boilers (identified as boiler 3 through 8). The boilers were built in 1953 and each is controlled with a full stream baghouse.

$PM_{2.5}$ – Actual PM emissions from each of these boilers were less than the 5 TPY threshold used to screen sources for inclusion in this analysis.

Conclusion: RACT for PM for each boiler is properly designed and operated fabric filters. A design review will be conducted to confirm that the existing fabric filter controls are properly designed.

SO_2 – Actual emissions from each of these boilers was between 87 and 171 tons in 2011. The boilers are currently not equipped with SO_2 controls.

Each boiler's capacity of about 23 MW is above the size of the smallest commercial scrubber installations, yet is below the bottom of the size range (i.e., 100-2,000 MW) for cost estimates. The capacity of each boiler is well below the "realistic range" EPA has determined for scrubbers. As explained above, Aurora Energy's Chena Facility was selected for detailed cost calculations because it was expected to be the most economical to control. Based on the CUECost evaluation of the larger boiler exhaust stream at the Chena facility, the cost effectiveness of wet or spray dry sulfur scrubbing is expected to be higher than $24,000/ton. Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[34] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

Conclusion: RACT for SO_2 for each boiler is use of low-sulfur coal, with no additional controls. The boilers are already using low-sulfur coal.[35]

Individual RACT: Aurora Energy Chena Boilers 1, 2, 3, 5

The Chena facility has four coal-fired boilers: three overfeed traveling grate stokers and one spreader stoker. The three traveling grate boilers (identified as Chena 1, 2, and 3) were installed in the 1950s and the maximum design power production of each is 5 megawatts (MW); fuel capacity is 76 MMBtu/Hr.[36] The spreader stoker unit (identified as Chena 5) was installed in 1970 and has a maximum power production rating of 20 MW; fuel capacity is 269 MMBtu/hr. The four coal-fired boilers are controlled with a single

[34] Sargent & Lundy, *Flue Gas Desulfurization Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.
[35] 0.14 wt% sulfur content (Data submitted to ADEC for 2011 Emission Inventory).
[36] Aurora Energy Company, *Application, Title V Permit No. AQ0315TVPO2 Revision 1* (October 2010) Table 2-1

full stream baghouse (installed in 2007) through which all of the combined exhaust gas flows.

Because the four boilers share a common stack and exhaust control system, the RACT analysis will be based on the combined capacity and exhaust characteristics.

$PM_{2.5}$ – Actual emissions from all four of these boilers combined was 7.81 TPY in 2011.

Conclusion: RACT for PM for each boiler is properly designed and operated fabric filters. A design review will be conducted to confirm that the existing fabric filter controls are properly designed.

SO_2 – Actual emissions from all four of these boilers combined was 838.9 TPY in 2011. The boilers are currently not equipped with SO_2 controls.

The combined capacity of 35 MW (500 MMBtu/hr) is above the size of the smallest commercial scrubber installations, yet is below the bottom of the size range (i.e., 100-2,000 MW) for cost estimates. The capacity of each boiler is well below the "realistic range" EPA has determined for scrubbers. Based on the CUECost evaluation of this facility, described above, the cost effectiveness of wet or spray dry sulfur scrubbing is expected to be higher than $24,000/ton. Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[37] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

Fuel sulfur content is very low (0.13 weight%). As discussed above, this makes fuel switching ineffective and fuel cleaning uneconomical.

Conclusion: RACT for SO_2 for each boiler is use of low-sulfur coal, with no additional controls.

Individual RACT: University of Alaska, Fairbanks Campus Power Plant
Boilers 1, 2, 3 and 4

The University of Alaska's Utilities Division operates a combined heat and power plant that provides electric power, steam heat, domestic water, and chilled water to campus. The power plant has two 140 MMBtu/Hr coal-fired boilers (identified as Boilers 1 and 2) that were installed in 1962 and two 181 MMBtu/Hr dual-fired (gas, liquid, or coal slurry) boilers (identified as Boiler 3, installed in 1970, and Boiler 4, installed in 1987) that generate the steam that powers the three turbines. The coal-fired boilers are controlled by a multi-cyclone separator that came as part of the unit followed by an add-on baghouse installed in 1982. The dual-fired boilers both have low NOx burners. The University is

[37] Sargent & Lundy, *Flue Gas Desulfurization Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.

planning to construct a new coal-fired boiler and that will be controlled with lime injection and a fabric filter.[38] The new boiler will replace boilers 1 and 2 while greatly reducing the need for boilers 3 and 4. It is scheduled to start operations in 2017.

$PM_{2.5}$ – Actual PM emissions from each of these boilers were less than the 5 TPY threshold used to screen sources for inclusion in this analysis.

Conclusion: RACT for PM for each boiler is properly designed and operated fabric filters. A design review will be conducted to confirm that the existing fabric filter controls are properly designed.

SO_2 – Actual emissions from all four of these boilers combined was 281.7 TPY in 2011. The boilers are currently not equipped with SO_2 controls.

The individual boiler capacity (~14-18 MW) is above the size of the smallest commercial scrubber installations, yet is below the bottom of the size range (i.e., 100-2,000 MW) for cost estimates. The capacity of each boiler is well below the "realistic range" for scrubbers. Based on the CUECost evaluation of the larger boiler exhaust stream at Aurora Energy's Chena facility, the cost effectiveness of wet or spray-dry sulfur scrubbing is expected to be higher than $24,000/ton. Efforts to find cost data for dry scrubbers were largely unsuccessful. After searching various literature sources and vendor websites, one article comparing circulating dry scrubbers with other wet scrubber systems was found.[39] The report compared units designed for 400-500 MW coal-fired power plants. The report concluded that, for that size at least, the cost of a dry scrubber was essentially a tie with the cost of a lime spray-dry system.

Fuel sulfur content is very low (0.18 weight%). As discussed above, this makes fuel switching ineffective and fuel cleaning uneconomical.

Conclusion: RACT for SO_2 for each boiler is use of low-sulfur coal, with no additional controls.

Dual Fuel-fired Boilers

Because only two identical units are included in this category, baseline RACT was not established. Instead, the relevant factors were considered as part of the individual emission unit analysis, presented below.

Individual RACT: U of Alaska, Fairbanks Boilers 3, 4

Boilers 3 and 4 are 181 MMBtu/Hr dual-fired (gas, liquid, or coal slurry) boilers. The dual-fired boilers both have low NOx burners. The University is planning to construct a new coal-fired boiler and that will be controlled with lime injection and a fabric filter.

[38] The University has obtained permits to construct two units; however, only one has been scheduled for construction.

[39] Sargent & Lundy, *Flue Gas Desulfurizaiton Technology Evaluation: Dry Lime vs. Wet Limestone FGD,* March 2007.

The new boiler will replace boilers 1 and 2 while greatly reducing the need for boilers 3 and 4. It is scheduled to start operations in 2017. See the previous section for more details.

$PM_{2.5}$ – Actual PM emissions from each of these boilers were less than the 5 TPY threshold used to screen sources for inclusion in this analysis.

Conclusion: RACT for PM was not determined for these boilers, because emissions are below the threshold for evaluation.

SO_2 – Actual emissions from combustion of fuel oil were 17.7 tons (Boiler 3) and 11.2 tons (Boiler 4) in 2011.[40] Based on the analyses prepared for the coal-fired boilers, use of wet or spray-dry scrubbers to control SO_2 from the dual-fuel fired boilers is not expected to be cost-effective. Since the only available cost information for dry scrubbers indicates that the costs are similar to those for spray dry scrubbers, dry scrubbers are not expected to be cost-effective.

The fuel used in these boilers is #2 Distillate Oil. The fuel sulfur content of this fuel, 0.43 wt%, is considered typical for this fuel. The feasibility of achieving cost-effective SO_2 reductions at this facility by replacing this fuel with a low-sulfur alternative is discussed below.

Table 5 shows fuel characteristics of the fuels included in this analysis. Information in this table was provided by Golden Valley Electric Association in a site specific analysis prepared by CH2MHill to evaluate the costs associated with fuel switching at GVEA North Pole and Zehnder Peaker Units.[41] HAGO is Heavy Atmospheric Gas Oil, a relatively inexpensive heavy fuel oil produced at the North Pole refinery.

Table 5
Fuel Characteristics

Fuel Type		HAGO	No. 2 fuel oil	Naphtha	ULSD
Sulfur[a]	wt%	1	0.5	0.05	0.0015
Density	lb/gal	7.12	7.05	6.43	7.1
Heat value	BTU/gal	141,000	138,000	116,000	138,500
Cost	$/gal	$2.79	$3.28	$2.41	$3.66
$PM_{2.5}$ emissions	lb/MMBtu	0.043	0.012	0.012	0.012
SO2 emissions	lb/MMBtu	1.01	0.51	0.06	0.00
Cost	$/MMBtu	$19.79	$23.77	$20.78	$26.43

Notes:
[a]Fuel sulfur content is based on fuel specifications rather than actual current fuel content.

Tables 6 and 7 show the fuel costs associated with switching fuels. This is just the cost of buying the new fuel instead of the old one. Capital investment will be required for some

[40] Data submitted to ADEC for 2011 Emission Inventory.
[41] CH2MHill, *Evaluation of Fuel Switching for Potential PM2.5 Reduction for GVEA North Pole and Zehnder Peaker Units*, January 2014

units to be able to switch fuels due to fuel physical characteristics such as viscosity. Additionally, some units will require onsite storage in order to meet system reliability requirements.

Table 6
Fuel Cost of Switching Fuels ($/ton $PM_{2.5}$ Reduced)

	To this fuel		
From this fuel	No. 2 fuel oil	Naphtha	ULSD
HAGO	$25,683.11	$6,378.25	$42,830.70
No. 2 fuel oil		no benefit	no benefit
Naphtha			no benefit

Table 7
Fuel Cost of Switching Fuels ($/ton SO_2 Reduced)

	To this fuel		
From this fuel	No. 2 fuel oil	Naphtha	ULSD
HAGO	$15,951.27	$2,071.36	$13,166.10
No. 2 fuel oil		-$13,140.10	$10,436.72
Naphtha			$209,679.08

Table 6 shows that the cost of fuel, by itself, is above ADEC's $10,000/ton BACT cost effectiveness threshold for $PM_{2.5}$ for all fuels except naphtha. Table 7 shows that the cost of fuel, by itself, is above typical ADEC's $10,000/ton BACT cost effectiveness threshold for SO2 for all fuels except naphtha. For this reason, fuel switching to fuels other than naphtha is ruled out as RACT.

Switching from #2 distillate to naphtha would significantly reduce fuel costs for these units. However, naphtha has significantly different combustion characteristics that would require substantial equipment modification. Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. Although the costs of these modifications would be very site-specific, and are not currently available, it is clear that switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel.

Conclusion: Use of low-sulfur naphtha as a fuel would result in PM and SO_2 emission reductions. However, because of the relatively low use/low emissions of these boilers, and the fact that usage is expected to be even lower in 2017 when the new boiler begins operating, the significant capital investment needed to convert Boilers 3 and 4 to naphtha is not justified. RACT is continued use of #2 distillate.

Gas Turbine

Because only five units are included in this category, baseline RACT was not established. Instead, the relevant factors were considered as part of the individual emission unit analysis, presented below.

Individual RACT: North Pole Power Plant GTs 1, 2, and 3

The North Pole Power Plant has three generating units. One unit (GT#3) is a base load unit and operates continuously except for periods of repair or maintenance. This unit was installed in 2006 and is a 455 MMBtu/hr GE Gas Turbine fueled with low sulfur naphtha and LSR fuel and equipped with water injection for NOx control and a CO oxidation catalyst. The other two units at the North Pole Power Plant are 672 MMBtu/hr GE fuel oil-fired regenerative Gas Turbines, installed in 1976 and 1977, and are now operated in peak load periods only. The fuel used in Units 1 and 2 is HAGO. The two units operated a combined total of about 123 days during 2011. This facility also has a permit to install a fourth gas turbine similar to the base unit, but the unit has not yet been installed.

$PM_{2.5}$ – Actual PM emissions from the gas turbines were 16 TPY for GT #1, 131 TPY for GT#2, and 16 TPY for GT#3.[42]
SO_2 – Actual SO_2 emissions from the gas turbines were 42 TPY for GT #1, 326 TPY for GT#2, and 1.9 TPY for GT#3.[43]

Candidate Control Technologies – The following control technologies were considered for this source category:

- Use of gaseous fuels
- Use of low sulfur liquid fuels

Gaseous fuels such as natural gas or propane have much lower sulfur content than liquid distillate fuels. Gas turbines burning gaseous fuels have lower particulate emissions than those burning liquid fuels. However, none of the gas turbines under evaluation are currently capable of burning gaseous fuels. Furthermore, a supply of pipeline natural gas is not available in Fairbanks. The only natural gas currently used in Fairbanks is brought in by truck for supply to a network of 1100 customers. This network does not extend to North Pole. For this reason, use of gaseous fuel is not an option.

Table 5 shows fuel characteristics of the fuels included in this analysis. Information in this table was provided by Golden Valley Electric Association in a site specific analysis prepared by CH2MHill to evaluate the costs associated with fuel switching at GVEA North Pole and Zehnder Peaker Units.

[42] Data submitted to ADEC for 2011 Emission Inventory.
[43] Data submitted to ADEC for 2011 Emission Inventory.

Tables 6 and 7 show the fuel costs associated with switching fuels. This is just the cost of buying the new fuel instead of the old one. Capital investment will be required for some units to be able to switch fuels due to fuel physical characteristics such as viscosity. Additionally, some units will require onsite storage in order to meet system reliability requirements.

Table 6 shows that the cost of fuel, by itself, is above the typical ADEC $10,000/ton BACT cost effectiveness threshold for $PM_{2.5}$ for all fuels except naphtha. Table 7 shows that the cost of fuel, by itself, is above typical ADEC BACT cost effectiveness for SO2 for all fuels except naphtha. For this reason, fuel switching to fuels other than naphtha is ruled out as RACT.

Switching from HAGO to naphtha would significantly reduce fuel costs for Units 1 and 2 (Unit 3 already uses naphtha). However, naphtha has significantly different combustion characteristics that may require substantial modification before it can be used as a fuel. Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. Switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel. GVEA has stated that, due to the age of its turbines, a requirement to retrofit the turbines to use naphtha would likely result in replacement of the turbines. Additionally, GVEA has indicated that it would probably need to demolish and rebuild structures in order to meet safety requirements. Finally, GVEA has indicated that it would need to replace all fuel systems.

Conclusion: Use of low-sulfur naphtha as a fuel would result in PM and SO_2 emission reductions from Units 1 and 2. However, because of the relatively low use/low emissions of these boilers, the significant capital investment needed to Units 1 and 2 to naphtha is not justified. RACT for directly emitted $PM_{2.5}$ and SO_2 control is continued use of current fuels: HAGO in Units 1 and 2, and naphtha and LSR in Unit 3.

Individual RACT: Zehnder, GTs 1 and 2

The Zehnder Power Plant has two GE Frame 5 fuel oil-fired gas turbines, which were installed in 1971 and 1972. The two gas turbines ran a combined total of about 53 days during 2011.

$PM_{2.5}$ – Actual PM emissions from the gas turbines were 16 TPY for GT #1 and 11 TPY for GT#2.[44]

SO_2 – Actual SO_2 emissions from the gas turbines were 40 TPY for GT #1 and 26 TPY for GT#2.[45]

[44] Data submitted to ADEC for 2011 Emission Inventory.
[45] Data submitted to ADEC for 2011 Emission Inventory.

Candidate Control Technologies – The following control technologies were considered for this source category:

- Use of gaseous fuels
- Use of low sulfur liquid fuels

Gaseous fuels such as natural gas or propane have much lower sulfur content than liquid distillate fuels. Gas turbines burning gaseous fuels have lower particulate emissions than those burning liquid fuels. However, none of the gas turbines under evaluation are currently capable of burning gaseous fuels. Furthermore, a supply of pipeline natural gas is not available in Fairbanks. The only natural gas currently used in Fairbanks is brought in by truck for supply to a network of 1100 customers. This network does not extend to Zehnder. For this reason, use of gaseous fuel is not an option.

Table 5 shows fuel characteristics of the fuels included in this analysis. Information in this table was provided by Golden Valley Electric Association in a site specific analysis prepared by CH2MHill to evaluate the costs associated with fuel switching at GVEA North Pole and Zehnder Peaker Units.

Tables 6 and 7 show the fuel costs associated with switching fuels. This is just the cost of buying the new fuel instead of the old one. Capital investment will be required for some units to be able to switch fuels due to fuel physical characteristics such as viscosity. Additionally, some units will require onsite storage in order to meet system reliability requirements.

Table 6 shows that the cost of fuel, by itself, is above the typical ADEC's $10,000/ton BACT cost effectiveness (based on reviewing BACT analyses) threshold for $PM_{2.5}$ for all fuels except naphtha. Table 7 shows that the cost of fuel, by itself, is above ADEC's $10,000/ton BACT cost effectiveness threshold for SO_2 for all fuels except naphtha. For this reason, fuel switching to fuels other than naphtha is ruled out as RACT.

Switching from HAGO to naphtha would significantly reduce fuel costs for Units 1 and 2. However, naphtha has significantly different combustion characteristics that may require substantial modification before it can be used as a fuel. Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. Switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel. GVEA has stated that, due to the age of its turbines, a requirement to retrofit the turbines to use naphtha would likely result in replacement of the turbines. Additionally, GVEA has indicated that it would probably need to demolish and rebuild structures in order to meet safety requirements. Finally, GVEA has indicated that it would need to replace all fuel systems.

Conclusion: Use of low-sulfur naphtha as a fuel would result in PM and SO_2 emission reductions from Units 1 and 2. However, because of the relatively low use/low emissions of these boilers, the significant capital investment needed to Units 1 and 2 to naphtha is

not justified. RACT for directly emitted $PM_{2.5}$ and SO_2 control is continued use of current fuels: HAGO in Units 1 and 2.

Process Heater, Oil-fired

The only emission units at the facility with emissions above the screening level are the Crude Heaters at the North Pole Refinery. NOx emissions from these units are already controlled using an Low NOx Burners. As discussed above, NOx controls are not an effective way to reduce $PM_{2.5}$ in Fairbanks.

SO_2 emissions for these units are less than 5 TPY each, and are therefore below the threshold used in this analysis for RACT determinations for SO_2.

At 5.1 TPY $PM_{2.5}$ emissions for one unit (H-2001 Crude Heater) are just above the threshold for evaluation for RACT. This unit burns a very low sulfur distillate fuel and refinery fuel gas. In fact, particulate emissions from oil combustion are below the 5 TPY threshold; emissions from natural gas combustion bring the unit's emissions above 5 TPY. The unit is equipped with ultra low-NOx burners.

Control of PM emissions from units firing gas and/or distillate fuels is accomplished by improving burner servicing and improving oil atomization and combustion aerodynamics (i.e., burner design).[46]

The H-2001 Crude heater is already equipped with ultra low-NOx burners. The burner design incorporates features that improve combustion dynamics, with the result that the uncontrolled PM emissions (as measured by source test) are very low (0.5 lb/thousand gallons,[47] compared with the uncontrolled emission factor of 2.0 lb/thousand gallons in AP-42). It is not expected that further PM reductions can be achieved through design changes.

Based on the low uncontrolled emission factor; the small amount of particulate to be controlled (less that 5 TPY from oil combustion); the type of oil burned (low sulfur distillate fuel); and commonly applied controls as described in AP-42, RACT for $PM_{2.5}$ for H-2001 Crude Heater is best practices for burner maintenance.

[46] AP-42 (May 2010) p. 1.3-6
[47] 2011 Emission Inventory

State of Alaska Department of Environmental Conservation

Evaluation of Reasonably Available Control Technologies (RACT) to Support the Development of the Fairbanks $PM_{2.5}$ SIP

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I. Executive Summary

The purpose of this report is to present an evaluation of emission control technologies that are candidates for selection as reasonably available control technologies (RACT) that could be implemented to advance the timeframe for attaining the annual Fine Particulate Matter ($PM_{2.5}$) National Ambient Air Quality Standard (NAAQS)[1] in the Fairbanks North Star Borough (FNSB). Section I (this section) provides a brief discussion of the results of the evaluation. Section II discusses FNSB's designation by the U.S. Environmental Protection Agency (EPA) as a nonattainment area for $PM_{2.5}$ and refers to the statutory requirements that Alaska must meet in response to this designation. Section III describes the major point source facilities found in the FNSB. Section IV provides additional information on individual emission units at these facilities as well as the control technologies currently in use. Section V describes the control technologies that were considered to be candidates for RACT for each source category, and analysis discussion of the estimated costs and benefits of each candidate technology. Section VI presents the recommended RACT for each emission source type. Detailed individual RACT determinations are provided in Appendix III.D.5.7

Information supplied by the Alaska Department of Environmental Conservation (ADEC) was used to identify individual emission units that comprise the significant sources of $PM_{2.5}$, SO_2, and NO_x emissions at the FNSB major point source facilities. These emission units were grouped by source category types (i.e., coal-fired boilers, gas turbines, process heaters, etc.). For each of the source category types, emission control technologies were identified that could be potential candidates for selection as RACT. A review of available literature, including RACT analyses performed by other States, was performed to gather information on the expected efficiency, capital cost, and cost-effectiveness for each of the candidate technologies. Other site-specific factors, such as the availability of various types of clean fuel in Fairbanks, were also considered in evaluating the candidate technologies.

RACT determinations were made for those emission units at major point source facilities having actual emissions greater than 5 tons per year of any one of the following pollutants: $PM_{2.5}$, NOx, or SO_2. Emission units at area sources were not included in this RACT analysis; such units will be addressed, if necessary, during the development of Reasonably Available Control Measures (RACM). Emission units with actual emissions below 5 TPY were not evaluated, because EPA guidance, described below, indicates that that further control of such sources, individually, is inefficient in reducing area-wide concentrations of PM.

[1] 40 CFR 50.13

The emission units for which RACT determinations were made include boilers, process heaters, and turbines. The $PM_{2.5}$ RACT is a fabric filter system for boilers. Additional $PM_{2.5}$ controls are considered unreasonable for process heaters and turbines. RACT for the SO_2 emissions is the use of low sulfur fuel for all of the fuel combustion sources. RACT controls were not recommended for NOx because control of NOx is not an efficient method for reducing ambient $PM_{2.5}$ in Fairbanks.

All of the emission units that were reviewed are already implementing the emission control techniques identified as RACT. All of the coal-fired units are already equipped with fabric filters, and Alaskan coal has a very low sulfur content. The costs associated with switching from high- to low-sulfur liquid fuels were too high to be deemed to be source specific RACT for those sources currently using liquid fuels.

II. Background

On November 13, 2009 the U.S. Environmental Protection Agency (EPA) designated a portion of the FNSB as a nonattainment area[2] for the 2006 24-hour $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS). This designation obligates the State to develop an approvable State Implementation Plan (SIP) to demonstrate attainment of the NAAQS. Requirements for the preparation, adoption, and submittal of a SIP are outlined under 40 CFR 51, Subpart Z. Paragraph (a) of section 51.1010 states:

> *(a) For each $PM_{2.5}$ nonattainment area, the State shall submit with the attainment demonstration a SIP revision demonstrating that it has adopted all reasonably available control measures (including RACT for stationary sources) necessary to demonstrate attainment as expeditiously as practicable and to meet any RFP requirements. The SIP revision shall contain the list of the potential measures considered by the State, and information and analysis sufficient to support the State's judgment that it has adopted all RACM, including RACT.*

As defined in 40 CFR 51.100(o), RACT "means devices, systems, process modifications, or other apparatus or techniques that are reasonably available taking into account: (1) The necessity of imposing such controls in order to attain and maintain a national ambient air quality standard, and (2) The social, environmental, and economic impact of such controls." The State's SIP for demonstrating attainment with the $PM_{2.5}$ NAAQS must, therefore, include analyses of the emission control technologies currently in use at the applicable stationary sources and whether there are additional emissions reductions that could be achieved by applying other controls that are found to be reasonable. This report presents the results of these analyses.

As described in more detail in Section III, there are six major point source facilities in the FNSB. These six major point source facilities are all operating under Title V permits. A modeling analysis[3] was performed by the State using a dispersion model to evaluate the impact of the point source facilities on the observed $PM_{2.5}$ values at the monitor located at the Fairbanks state office building. Cumulatively, according to information provided by ADEC, these six major point source facilities are estimated to contribute approximately 5 percent of the direct $PM_{2.5}$ on the state office building monitor filter[4] and up to an additional 15 percent of the secondary sulfate.[5] Nitrates account for less than 5

[2] 74 FR 58688 (November 13, 2009); Designations effective December 14, 2009.
[3] Appendix III.D.5.8 Weight of Evidence/ Using the CALPUFF dispersion model to characterize Fairbanks power plant plumes.
[4] Appendix III.D.5.7 Precursors.
[5] Fairbanks PM 2.5 SIP Chapter III.D.5.8 Modeling

percent of the overall mass collected on the filters.[6] Therefore, although NO_x control technologies are discussed in this analysis, the installation of additional NO_x controls on the point source facilities would have little impact on ambient $PM_{2.5}$ concentrations.

Some of the FNSB major point source facilities include numerous small, low emitting sources of $PM_{2.5}$, SO_2, and NO_x.[7] Several other emission units that would have large uncontrolled emissions are already so well controlled that their potential emissions of $PM_{2.5}$ are very low.[8] Additional PM controls for these emission units would not be cost effective because of the very low emission reductions that could be achieved. For example, an annualized capital cost of as low as $30,000 to reduce particulate emissions from a small oil-fired process heater that emits 3 tons of $PM_{2.5}$ per year would have a cost effectiveness of over $10,000 per ton even without considering any operating cost for the controls. Most viable emissions control techniques actually cost at least an order of magnitude more than the $30,000 used in the hypothetical example. In its 2006 Regulatory Impact Analysis for the Particulate Matter National Ambient Air Quality Standards, EPA stated that sources emitting less than 5 tons per year "were likely to have existing controls in place, and further control was typically not cost-effective and inefficient in reducing area-wide concentrations of PM." [9] In light of this statement by EPA, only those emission units having the potential to emit greater than 5 tons per year of $PM_{2.5}$ (or one of its precursors, SO_2 or NOx, for which the same rationale applies) were evaluated individually for RACT.[10]

[6] Appendix III.D.5.7 Precursors.
[7] Title V Permit applications for Fort Wainwright, North Pole Refinery, and University of Alaska. See Section IV below.
[8] Title V Permit applications for Fort Wainwright, Chena Power Plant, Zehnder Power Plant, and University of Alaska. See Section IV below.
[9] EPA, *Regulatory Impact Analysis for 2006 National Ambient Air Quality Standards for Particle Pollution* (October 2006). p. 1-12
[10] This conclusion does not rule out the possibility that the cumulative impact of numerous small sources may be considerable, and worth controlling as a group. For example, reduction of SO_2 emissions from area combustion sources by means of stringent limit on fuel sulfur content may be a cost effective control technique. Evaluation of such measures is beyond the scope of this analysis.

III. Description of Major Point Source Facilities

As mentioned earlier, the FNSB includes six major point source facilities that are estimated to contribute approximately 5 percent of the direct $PM_{2.5}$ and an additional 15 percent of the secondary sulfate measured at the Fairbanks state office building monitoring site. Of the six major point source facilities, five are operating power plants that produce electricity and, in some cases, provide steam and hot water for comfort heating in nearby commercial/residential buildings. The sixth facility is a refinery that has numerous emission points related to its process operations. The following paragraphs present brief descriptions of each of the six major point source facilities. Additional information on the major point source facilities' emissions and emission controls is presented in Section IV of this report.

Discussion and assessment of non-major point source facilities (also known as "area sources") is beyond the scope of this analysis.

A. Aurora Energy, LLC, Chena Power Plant[11]

Aurora Energy, LLC, owns and operates the Chena Power Plant, which provides steam and electrical power to the City of Fairbanks. The facility not only produces electricity for the Fairbanks area but also operates two district heat systems (one steam and the other hot water) to provide heat to nearby commercial/residential buildings. The Chena facility has four coal-fired boilers, with three being overfeed traveling grate stokers and one being a spreader stoker. The three traveling grate boilers (identified as Chena 1, 2, and 3) were installed in the 1950s and the maximum design power production of each is 5 megawatts (MW_e). The spreader stoker unit (identified as Chena 5) was installed in 1970 and has a maximum power production rating of 20 MW_e. The four coal-fired boilers are controlled with a single full stream baghouse (installed in 2007) through which all of the combined exhaust gas flows.[12]

B. Doyon Utilities, LLC, Ft. Wainwright Power Plant

Fort Wainwright has a Central Heat and Power Plant (CHPP) that generates steam and electricity to meet the heating and electricity demands of the base. The CHPP has six identical 230 MMBtu/hr (23 MW_e) coal-fired boilers (identified as Boiler 3 through 8).[13] The boilers were built in 1953 and each is controlled with a full stream baghouse.[14] The

[11] The following information comes from *Title V Statement of Basis, Revision 1* (October 9, 2006) p. 2.
[12] *Renewal Application for Title V Permit* (October 2010). p. 2.
[13] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 4
[14] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 8

facility also operated a coal preparation plant that prepares the coal for the boilers.[15] The emission units at the coal preparation plant are controlled by baghouses. [16] Fort Wainwright's CHPP also has a 2 megawatt Black Start generator that meets the EPA Tier II requirements.[17]

Fort Wainwright also has several insignificant sources that emit $PM_{2.5}$, NO_x, and SO_2. The insignificant sources are not controlled and are spread out across the base. The insignificant units include 16 generator sets, 5 lift stations, 4 well pumps, and wind erosion and drop loading at the coal pile.[18]

C. Flint Hills Resources, North Pole Refinery

The North Pole Refinery processes North Slope crude oil and supplies gasoline, jet fuel, heating oil, diesel, gasoil and asphalt to Alaska markets. Most of the current combustion emission units at the facility were installed either in the mid-1980s or during renovations in 1998.[19] There are four combustion devices with actual emissions greater than 5 TPY (three crude heaters and one steam generator), as well as a number of smaller combustion devices..[20] The combustion units burn light straight run (LSR)[21], fuel gas, waste gas, or diesel depending on the unit. In addition, the refinery has numerous VOC sources.

D. Golden Valley Electric Association (GVEA)

Golden Valley Electric Association (GVEA) operates two electric generating facilities within the Fairbanks North Star Borough; the North Pole Power Plant and the Zehnder Power Plant.

D.1. The North Pole Power Plant has three generating units. One unit is a base load unit and operates continuously except for periods of repair or maintenance.[22] This unit was installed in 2005 and is a GE LM6000 Gas Turbine fueled with low sulfur naphtha and LSR fuel and equipped with water injection for NO_x control and a CO oxidation

[15] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 4
[16] 2011 Emission Inventory
[17] 2011 Emission Inventory
[18] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 42
[19] *Department of Environmental Conservation Air Quality Operating Permit No. AQ0071TVP02* (April 23, 2010) Section 2, Table A
[20] 2011 Emission Inventory
[21] LSR is a very low sulfur (0.0025 wt. percent sulfur) liquid fuel, with properties similar to gasoline. See 2011 Emission Inventory
[22] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A3

catalyst.[23] The other two units at the North Pole Power Plant are GE Frame 7 fuel oil-fired regenerative Gas Turbines, installed in 1976 and 1977, and are now operated in peak load periods only.[24] This facility also has a permit to install a fourth gas turbine similar to the base unit, but the unit has not yet been installed.[25]

D.2. The Zehnder Power Plant has four units. Two of the units are GE Frame 5 fuel oil-fired gas turbines installed in 1971 and 1972.[26] The other two units are GE fuel oil-fired electro-motive diesel engines, installed in 1970, that are used for emergency power and also serve as black start engines for the GVEA generation system.

E. University of Alaska, Fairbanks Campus Power Plant

The University of Alaska's Utilities Division operates a combined heat and power plant that provides electric power, steam heat, domestic water and chilled water to campus. The power plant has two 84.5 MMBtu/hr coal-fired boilers (identified as Boilers 1 and 2) that were installed in 1962 and two 181 MMBtu/hr dual-fired (gas, liquid, or coal slurry) boilers (identified as Boiler 3, installed in 1970, and Boiler 4, installed in 1987) that generate the steam that powers the three turbines.[27] The coal-fired boilers are controlled by a multi cyclone separator that came as part of the unit followed by an add-on baghouse installed in 1982.[28] The dual-fired boilers both have low NO_x burners.[29] The power plant also has one 13,226 hp diesel generator, two backup 125 kW diesel generators, and one backup oil-fired boiler.[30] The generator was originally designed to burn a coal slurry and was installed with an SCR unit.[31] The SCR is still in operation; however, the generator burns diesel fuel instead of the coal slurry.[32]

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[23] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A2
[24] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A3
[25] *Application for Renewal of Title V Permit AQ0110TVP02, Golden Valley Electric Association North Pole Power Plant* (May 2013), Form A2
[26] *Revision to Application for Renewal of Title V Permit AQ0109TVP02, Golden Valley Electric Association Zehnder Power Plant* (October 2013), Form B
[27] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 5, Table A
[28] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 1, Table 1-1
[29] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Page 21
[30] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table A
[31] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant,* Section 4, Table A, Note 3
[32] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table A, Note 3

The University is planning to construct two new coal and biomass-fired boilers that will be controlled with lime injection and a fabric filter.[33] The new boilers will replace boilers 1 and 2 while greatly reducing the need for boilers 3 and 4.[34] They are scheduled to start operations in 2017.[35]

The University also operates a diesel fired medical waste incinerator that is mostly used for pathological waste.[36] The University also has several insignificant sources that emit $PM_{2.5}$, NO_x, and SO_2. The insignificant sources are not controlled and are spread out across the campus. The insignificant units include fifteen (15) boilers, two (2) generators, three (3) furnaces, one (1) grain dryer, one (1) hot water heater, one (1) classroom engine.[37] All of the insignificant sources burn diesel fuel. The sulfur content in the fuel is not regulated directly and the facility does not burn low sulfur diesel fuel, but SO_2 emissions from these sources are limited to 500 ppm averaged over three hours.[38]

[33] *Application for a Prevention of Significant Deterioration Air Quality Construction Permit* (January 2013), p. 1
[34] *Application for a Prevention of Significant Deterioration Air Quality Construction Permit* (January 2013), p. 1.
[35] *Application for a Prevention of Significant Deterioration Air Quality Construction Permit* (January 2013), p. 8.
[36] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table 2-4
[37] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant* (June 2012), Section 4, Table 2-4
[38] *Application for Renewal of an Air Quality Control Operating Permit, University of Alaska--Fairbanks Campus Power Plant, Section 4* (June 2012), Permit Conditions13 and 24

IV. Emission Units and Current Emission Levels

This section presents information on the significant emission units (defined in this analysis as those that have the potential to emit greater than 5 tons of $PM_{2.5}$, SO_2, or NOx emissions per year) found at each of the FNSB major point source facilities. In the first subsection, each facility is addressed in a separate table that shows the facility's emission units current control technology, control efficiency, and the actual and potential emissions of $PM_{2.5}$, NO_x and SO_2. All of this information except the actual reported emissions was taken from the facilities' Title V permits and applications. The actual emissions are those reported by the facilities in their 2011 annual emissions inventory report. In a few cases, the reported actual emissions are higher than the calculated potential to emit (PTE) in the Title V permit information.

For some emission units, the PTE is the maximum allowable emissions, and reflects enforceable emission limits. For such units, actual emissions cannot exceed the PTE without being out of compliance. However, there are many units for which the PTE is an estimate, not an enforceable limit, calculated for the sole purpose of determining applicability of certain programs, including the Title V permit program. One option recommended by EPA to calculate PTE is to use of average emission rates from agency references such as AP-42, and assume continuous operation at full capacity. See, e.g., EPA Potential to Emit: A Guide for Small Businesses, (October 1998).

If subsequent source tests indicate that the actual emission factor is higher than the one used to calculate PTE, then the actual emissions may exceed the PTE without resulting in noncompliance. This is the situation for all but one of the emission units where actual emissions exceed PTE.

The one exception is Chena Boiler #5, which reported an actual annual average firing rate 20% above the boiler's rated capacity. After investigation, it was determined that this unit has not been modified. The boiler's rated capacity is simply much lower than its actual physical capacity.

The second subsection presents the emission units grouped by source category types. This allows a comparison of the different control technologies for the existing sources in the FNSB.

EMISSION UNITS BY FACILITY

A. Aurora Energy, LLC, Chena Power Plant

Description	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Coal-fired boilers (units 1, 2, 3, & 5, combined)	Baghouse	99.9%[f]	7.81[e]	5.0[d]	None	792.7[e]	744.6[c]	None	838.9[e]	1,294.7[a,c]
Coal preparation plant	Baghouse	99.9%[f]	0.28[e]	0.34[d]	NA[b]	NA	NA	NA	NA	NA
Ash vacuum pump exhaust	Baghouse	99.9%[f]	0.197[e]	0.23[d]	NA	NA	NA	NA	NA	NA

[a] Based on average sulfur content of coal of 0.26 wt. percent (Title V Permit Application Table 2-8); reported sulfur content in 2011 emission inventory was 0.13 wt. percent

[b] NA means that the pollutant is not emitted by the source type

[c] Data from 2010 Title V Permit Application Table 2-2.

[d] Data from 2010 Title V Permit Application Table 2-6d.

[e] Data from 2011 Emission Inventory (2011 EI SS-315_Chena)

[f] $PM_{2.5}$ Control Efficiency is from Chapter 6, OAQPS Control Cost Manual (Sixth Edition), EPA, Office of Air Quality Planning and Standards, Emissions Standards Division, January 2002 (EPA 452/B-02-001).

Note that actual 2011 emissions exceed the reported PTE for the coal-fired boilers. This discrepancy is due to two things. First, the PTE calculations are based on emission factors developed from a 2007 source test, while the actual emissions are based on emission factors developed from a 2011 source test. Second, Unit 5, the largest boiler, reported an annual average firing rate 20% above its rated capacity. After investigation, it was determined that this unit has not been modified. The boiler's rated capacity is simply much lower than its actual physical capacity.

B. Doyon Utilities, LLC, Ft. Wainwright Power Plant

Description	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Coal-fired boiler 3	Baghouse	99.9%[a]	2[d]	5.4[c]	None	101[d]	767.9[c]	None	109[d]	2,352.0[c]
Coal-fired boiler 4	Baghouse	99.9%[a]	2[d]		None	101[d]		None	99[d]	
Coal-fired boiler 5	Baghouse	99.9%[a]	2[d]		None	117[d]		None	126[d]	
Coal-fired boiler 6	Baghouse	99.9%[a]	1[d]		None	91[d]		None	87[d]	
Coal-fired boiler 7	Baghouse	99.9%[a]	3[d]		None	197[d]		None	171[d]	
Coal-fired boiler 8	Baghouse	99.9%[a]	2[d]		None	168[d]		None	122[d]	
Coal Preparation Plant South	Baghouse	99.9%[a]	0.596[d]	14[c]	NA[b]	NA	NA	NA	NA	NA
Ash Handling	Baghouse	99.9%[a]	None reported[d]	11.8[c]	NA	NA	NA	NA	NA	NA

[a] $PM_{2.5}$ Control Efficiency is from Chapter 6, OAQPS Control Cost Manual (Sixth Edition), EPA, Office of Air Quality Planning and Standards, Emissions Standards Division, January 2002 (EPA 452/B-02-001).

[b] NA means that the pollutant is not emitted by the source type

[c] *Revised Title V Renewal Permit Application Package for Fort Wainwright, Alaska* (March 2008), p. 9.

[d] 2011 Emission Inventory

Note that actual 2011 $PM_{2.5}$ emissions exceed the reported PTE for the coal-fired boilers. This discrepancy is because, the PTE calculations are based on emission factors developed from a 2005 source test, while the actual emissions are based on emission factors from EPA's WebFIRE database.

C. Flint Hills Resources, North Pole Refinery

Description	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
H-241 Crude Heater (120 MMBtu/hr)		None	2.0[b]	3.0[c]	None	44.6[b]	65.4[c]	None	1.0[b]	1.5[c]
H-1001 Crude Heater (70 MMBtu/hr)		None	0.3[b]	0.5[c]	None	20.6[b]	38.6[c]	None	0.9[b]	1.6[c]
B-401 Steam Generator		None	0.3[b]	0.6[c]	None	11.8[b]	23.5[c]	None	0.1[b]	0.2[c]
H-2001 Crude Heater[a]	ULNB	None	5.1[b]	6.7[c]	None	62.0[b]	81.5[c]	None	3.3[b]	4.3[c]

[a] The crude heater was grouped with H-3700 Asphalt Heater which had an actual NO_x emissions of 0.81 tpy compared to 52.2 tpy from H-2001. In the analysis we assumed that the crude heater was the significant unit and included in the RACT analysis.

[b] 2011 Emission Inventory

[c] PTE Calculations based on rated capacity and emission factors in Emission Inventory, and operation at full capacity for 8760 hours per year.

D.1 Golden Valley Electric Association (GVEA), North Pole Plant

Description	Control Device	$PM_{2.5}$[a]			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
GT#2 Gas Turbine	None		131[c]	141[d]	Limited to 7,992 hr/yr	464[c]	3,733[d]	Combined limit of 24,500 lb/day[e]	326[c]	4079[d]
GT#1 Gas Turbine	None		15.5[c]	290[d]		50.3[c]			42.3[c]	
GT#3 Gas Turbine	NO_x - Water Injection CO - Oxidation Catalyst[f]		16.8[c]	25.6[d]	Limited to 1,600 tpy[d]	367[c]	1,600[d]	Limited to naphtha or LSR to .05%S[e]	1.86[c]	192[d]
GT#4 Gas Turbine[b]	NO_x - water injection[f]		--	1.2[d]		--		Limited to Jet A to 0.3%S[e]	--	31[d]

[a] Assume that PM_{10} equals $PM_{2.5}$ since no other data is available in the permit application.

[b] This unit is included in the pending permit application but had not yet been installed in 2011.

[c] 2011 Emission Inventory

[d] *Application for Renewal of Air Quality Operating Permit North Pole Power Plant* (2007), Attachment 1, Table 1.

[e] *Application for Renewal of Air Quality Operating Permit North Pole Power Plant* (2007), Attachment 1, Table 5.

[f] *Application for Renewal of Air Quality Operating Permit North Pole Power Plant* (2007), Attachment 2, Table 1.

D.2 Golden Valley Electric Association (GVEA), Zehnder Power Plant

Description	Control Device	$PM_{2.5}$[a]			NO_x			SO_2		
		Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Diesel Generator #2	None	None	0.007[c]	8.5[b]	None	0.393[c]	392[b]	None	0.012[c]	580 TPY total facility permit limit
Diesel Generator #1	None	None	0.028[c]	8.5[b]	None	1.58[c]	392[b]	None	0.048[c]	
Combustion Gas Turbine #1	None	None	16.05[c]	14.1[b]	None	54.3[c]	1033[b]	None	39.83[c]	
Combustion Gas Turbine #2	None	None	10.77[c]	14.1[b]	None	36.4[c]	1033[b]	None	25.73[c]	

[a] Assume that PM_{10} equals $PM_{2.5}$ since no other data is available in the permit application.

[b] *Application for Renewal of Air Quality Operating Permit Zehnder Power Plant (2007),* Attachment 1, Table 1

[c] 2011 Emission Inventory

E. University of Alaska, Fairbanks Campus Power Plant

Description:	Control Device	$PM_{2.5}$			NO_x			SO_2		
		Control Efficiency [a]	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)	Control Efficiency	2011 Actual (tpy)	Potential (tpy)
Coal-fired Boiler #1	Multicyclone with a Baghouse	99.9%	3.62[g]	7.3[c]	None	250[g]	212.9[b]	Limited to 500ppm S[e]	123.8[g]	220.1[d]
Coal-fired Boiler #2	Multicyclone with a Baghouse	99.9%	3.77[g]	7.3[c]	None	260[g]	212.9[b]		128.9[g]	220.1[d]
Dual Fuel-Fired Boiler #3	Low NO_x Burners	None	2[g]	11.6[c]	30-50%[f]	5.72[g]	138.8[b]		17.7[g]	410.6[d]
Dual Fuel-Fired Boiler #4	Low NO_x Burners	None	1.27[g]	11.6[c]	30-50%[f]	3.63[g]			11.23[g]	410.6[d]

[a] $PM_{2.5}$ Control Efficiency is from Chapter 6, OAQPS Control Cost Manual (Sixth Edition), EPA, Office of Air Quality Planning and Standards, Emissions Standards Division, January 2002 (EPA 452/B-02-001).

[b] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Table 2-4

[c] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Table 2-6c

[d] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Table 2-8

[e] *Application for Renewal of an Air Quality Control Operating Permit* (June 2012) Permit Condition 13

[f] EPA, *Technical Bulletin: Nitrogen Oxides (NOx), Why and How They Are Controlled* (November 1999), Table 16

[g] 2011 Emission Inventory

V. Candidates for Reasonably Available Control Technology

This section presents discussions of the various control technologies that were considered as candidates for selection as RACT for the applicable source categories. The first subsection (A) presents those technologies that primarily control emissions of direct $PM_{2.5}$. Subsections B and C present technologies that primarily control emissions of $PM_{2.5}$ and precursors SO_2 and NO_x, respectively.

A. $PM_{2.5}$ Control Technologies

The $PM_{2.5}$ control technologies that were identified as potentially applicable to the sources being evaluated for RACT are presented below in a top down order: the technology with the theoretically highest potential $PM_{2.5}$ reduction being first and the remaining technologies in descending order of reduction effectiveness:

- Fabric Filters
- Electrostatic Precipitators
- Wet Scrubbers
- Controls for Stationary Diesel Engines

Provided below is a general description of each of these technologies, as well as a rough assessment (~+/- 30%) of the associated costs. The technical feasibility of each control device, as it specifically applies to the Fairbanks area will be discussed in Section VI. The cost and cost effectiveness values presented below were taken from EPA publications available on the Clean Air Technology Center at EPA's website: www.epa.gov/ttn/catc/products.[39] The cost information presented here is intended to be representative of the typical costs of the control technologies but does not account for numerous variables that may be encountered by a specific facility. In addition, the cost effectiveness values are typical of those that would be expected when applying the control technologies to an uncontrolled source. For these reasons, a more detailed assessment was made, as appropriate, for each of the emission units being evaluated for RACT. This detailed assessment is provided in Appendix XXX.

[39] *Chemical Engineering*, May 2012, p. 64. Costs were first determined using the methods described in the EPA publications, then adjusted to 2012 dollars using the ratio of the CE Composite Index for 2012 and the reference year for the cost calculations. The index in 2002 (most of the costs in the EPA references were reported in 2002 dollars) was 395.6. The index value used for 2012 was 584.6. Costs in 2002 dollars were adjusted to 2012 dollars using a factor of 584.6/395.6 = 1.48.

A1. Fabric Filters[40]

Fabric filters consist of one or more isolated compartments containing rows of fabric bags in the form of round, flat, or shaped tubes, or pleated cartridges. Particle laden gas passes through the fabric, particles are retained on the upstream face of the bags, and the cleaned gas stream is vented to the atmosphere. Fabric filters collect particles with sizes ranging from submicron to several hundred microns in diameter at efficiencies generally in excess of 99 percent. Fabric filter removal efficiency is relatively level across the particle size range, so that excellent control of PM_{10} and $PM_{2.5}$ can be obtained. The layer of dust, or dust cake, collected on the fabric is primarily responsible for such high efficiency. Gas temperatures up to about 500°F, with surges to about 550°F can be accommodated routinely in some configurations. Most of the energy used to operate the system appears as pressure drop across the bags and associated hardware and ducting. Typical values of system pressure drop range from about 5 to 20 inches of water.

Fabric filters are used where high efficiency particle collection is required. Limitations are imposed by gas characteristics (temperature and corrosivity) and particle characteristics (primarily stickiness) that affect the fabric or its operation and that cannot be economically accommodated. Fabric filter costs vary depending on the type of fabric filter, the air to cloth ratio, and the filter type used. According to cost information presented in EPA publications "EPA-452/F-03-025 and EPA-452/F-03-026," typical capital costs for pulse jet and reverse air fabric filters range from $9 to $128 per standard cubic feet per minute (scfm) of air flow. Annualized costs range from $9 to $75 per scfm and the cost effectiveness ranges from $63 to $508 per ton of PM controlled.

A2. Electrostatic Precipitators[41]

Electrostatic precipitators (ESPs) use electrical fields to remove particulate from flue gas. In an ESP, an electric field is maintained between high-voltage discharge electrodes, typically wires or rigid frames, and grounded collecting electrodes, typically plates. A corona discharge from the discharge electrodes ionizes the gas passing through the precipitator, and gas ions subsequently ionize particles in the gas stream. The electric field then drives the negatively charged particles to the collecting electrodes. Because ESPs act only on the particulate to be removed and only minimally hinder flue gas flow, they have very low pressure drops and low energy requirements and operating costs. While several factors determine ESP removal efficiency, size is of paramount

[40] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Fabric Filter – Pulse-Jet Cleaned Type (EPA-452/F-03-025)* and *Air Pollution Control Technology Fact Sheet: Fabric Filter – Reverse Air Cleaned Type (EPA-452/F-03-026).*
[41] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Dry Electrostatic Precipitator (ESP) –Wire-Plate Type (EPA-452/F-03-028).*

importance. Size determines treatment time: the longer a particle spends in the ESP, the greater its chance of being collected, other things being equal.

Factors limiting ESP performance are flow non-uniformity and re-entrainment. More uniform flow will ensure that there are no high gas velocities, short treatment time paths through the ESP. Attaining flow uniformity also will minimize gas flows bypassing the electrical fields.

ESP overall (mass) collection efficiencies can exceed 99.9%, and efficiencies in excess of 99.5% are common. ESPs with high overall collection efficiencies will have high collection efficiencies for particles of all sizes, so that excellent control of PM_{10} and $PM_{2.5}$ will be achieved with well-designed and operated ESPs. According to EPA publication "EPA-452/F-03-028," typical ESP capital costs range from $15 to $50 per scfm of exhaust gas. The annualized cost ranges from $6 to $57 per scfm and the cost effectiveness for PM control ranges from $57 to $355 per ton. In general, smaller units controlling a low concentration waste stream will be towards the high end of the cost range.

A3. Wet Scrubbers[42]

Wet scrubbers control particulates by bringing them in contact with a liquid (in the form of droplets, foam, or bubbles) and then collecting the liquid along with the adhering particulates. There are several wet scrubber designs available commercially, including the venturi, spray tower, packed bed, and impingement plate scrubbers. Collection efficiencies for wet scrubbers are highly variable. Most conventional scrubbers can achieve high collection efficiencies for particles greater than 5-10 micrometers in diameter but they are generally much less effective for particles less than 5 micrometers. Properly designed venturi scrubbers, however, are capable of controlling fine particulate matter and typically provide high removal efficiencies of particles between 0.5 and 5.0 micrometers in diameter. In most applications, venturi scrubbers achieve reductions of 80 to 90% of $PM_{2.5}$ emissions. Although the capital cost for venturi scrubbers is much lower than the costs for fabric filters and ESPs, the high pressure drop through venturi scrubber systems typically results in relatively high energy use. In addition, the operation of scrubbers generates large volumes of water that must be properly treated or disposed.

EPA publication "EPA-452/F-03-017" indicates that the capital costs of venturi scrubbers range from $4 to $32 per scfm. Annualized costs range from $9 to $291 per scfm, and the cost effectiveness values range from$105 to $3600 per ton of PM.

[42] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*

EPA publication "EPA-452/F-03-015" indicates that the capital costs of packed bed scrubbers range from $17 to $83 per scfm. Annualized costs range from $26 to $117 per scfm, and the cost effectiveness values range from $166 to $828 per ton of PM.

B. SO_2 Control Technologies

There are limited SO_2 control technologies options available for consideration for the Fairbanks Area. The control technologies considered are:

- Wet scrubber
- Dry scrubber
- Spray dry scrubber
- Fuel sulfur reduction

Provided below is a general description of each of these options. The technical feasibility of each control device, as it specifically applies to the Fairbanks area will be discussed in Section VI.

B1. Wet Scrubbers[43]

In addition to their use as particulate control devices (discussed above), wet scrubbers are used extensively to control emissions of inorganic contaminants, including acid gases such as sulfur dioxide (SO_2). Wet scrubbers rely primarily on the absorption process to remove these soluble contaminants from the exhaust gas stream. Wet scrubbing devices that are based on absorption principles include packed towers, plate (or tray) columns, venturi scrubbers, and spray chambers. Removal efficiencies for gas absorbers vary for each pollutant-solvent system and with the type of absorber used. Pollutant removal may also be enhanced by manipulating the chemistry of the absorbing solution so that it reacts with the pollutant(s), e.g., caustic solution for acid-gas absorption vs. pure water as a solvent. Chemical absorption may be limited by the rate of reaction, although the rate limiting step is typically the physical absorption rate, not the chemical reaction rate.

Most absorbers have removal efficiencies in excess of 90%, and packed tower absorbers may achieve efficiencies as high as 99.9% for some pollutant-solvent systems. As discussed above, typical capital costs for wet scrubbers average from about $4 to $83 per scfm. Operating costs for wet scrubbers used to control SO_2 are somewhat higher than for scrubbers used strictly for PM control because of the added cost of the caustic

[43] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*

solution that is typically added and because of the additional treatment that may be required for the wastewater.

B2. Dry Scrubbers[44]

Dry systems involve injection of dry alkali substances (usually some form of lime), which is removed from the exhaust by a fabric filter or ESP. Sorbent may be mixed with the fuel or injected in the exhaust. Dry scrubbing is not commonly used for coal-fired power plants. EPA considers dry scrubbers to be a promising technology, but one that becomes less cost effective as the boiler size decreases.

An even distribution of sorbent across the reactor and adequate residence time at the proper temperature are critical for high SO_2 removal rates.

> "Dry scrubbers have significantly lower capital and annual costs than wet systems because they are simpler, demand less water and waste disposal is less complex. Dry injection systems install easily and use less space, therefore, they are good candidates for retrofit applications. SO_2 removal efficiencies are significantly lower than wet systems, between 50% and 60% for calcium based sorbents.
>
> "Sodium based dry sorbent injection into the duct can achieve up to 80% control efficiencies (Srivastava 2001). Dry sorbent injection is viewed as an emerging SO_2 control technology for medium to small industrial boiler applications.[45] Newer applications of dry sorbent injection on small coal-fired industrial boilers have achieved greater than 90% SO_2 control efficiencies."[46]

Cost information for dry scrubbers is not readily available.

B3. Spray Dry Scrubbers[47]

Spray dry systems introduce the absorbent in a slurry that is fully evaporated by the exhaust stream, resulting in dry particulates that are removed by fabric filter or ESP. They differ from dry systems because the absorbent is introduced in liquid form. They differ

[44] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*
[45] Although this statement is based on EPA guidance that is 11 years old, it remains EPA's current guidance.
[46] EPA, *Air Pollution Control Technology Fact Sheet: Flue Gas Desulfurization (FGD) - Wet, Spray Dry, and Dry Scrubbers*, EPA-452/F-03-034
[47] Information in this section is from EPA, *Air Pollution Control Technology Fact Sheet: Packed-Bed/Packed Tower Wet Scrubber (EPA-452/F-03-015)* and *Air Pollution Control Technology Fact Sheet: Venturi Scrubber (EPA-452/F-03-017).*

from wet systems because the water is fully evaporated, so the absorbed sulfur is removed from the exhaust as a sold by a fabric filter or ESP.

The capital and operating cost for spray dry scrubbers are typically lower than the costs for similarly-sized wet scrubbers because equipment for handling wet waste products is not required. However, the operation of a spray dry scrubber is more sensitive than a wet scrubber to operating conditions. Excess moisture causes wet solids to deposit on the absorber and downstream equipment. .

B4. Reduced Sulfur in Fuels

Perhaps the simplest and, in many cases, the most cost effective SO_2 emission reduction technology that can be employed for fuel combustion sources is to switch to a lower sulfur content fuel. Reducing the sulfur content in the fuel will reduce the sulfur emissions linearly.

The emission units subject to this evaluation burn a variety of fuels. The sulfur content of these each fuel is limited either by regulation or by permit condition. Additionally, some of the emission units are subject to mass emission limits; others are subject to limitations on exhaust SO_2 concentration.

Current limits on liquid fuel sulfur content range from 500 ppm (for naphtha/LSR burned in GT#3 at the North Pole power plant) to 10,000 ppm (for other liquid fuels burned in the same gas turbines).[48]

In recent years, EPA has reduced the permissible level of sulfur in highway diesel fuel to 15 ppm.[49] This ultra-low sulfur fuel is becoming increasingly available on a widespread basis. Tables available on the EIA website (www.eia.gov) show that the average price differential (not including taxes) in Alaska between No. 2 heating oil and ultra-low sulfur No. 2 diesel fuel was about 25 cents per gallon in 2010.[50] Reducing the fuel sulfur content from 500 ppm to 15 ppm results in reduction of 0.0067 lb SO_2 emissions per gallon. Thus, switching from heating oil to an ultra-low sulfur fuel oil would cost about $75,000/ton. This is clearly not a cost-effective strategy for reduction of ambient PM concentrations.

[48] North Pole Power Plant Title V Operating Permit, Condition 12.
[49] USEPA, Heavy-Duty Highway Diesel Program, http://www.epa.gov/oms/highway-diesel, accessed October 25, 2013
[50] Annual Average No. 2 Fuel Oil (residential) price in 2010 in Alaska was $2.95/gal (EIA website http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPD2_PRT_SAK_DPG&f=M accessed October 28, 2013).
Annual Average No. 2 Diesel Fuel price in 2010 in Alaska was $3,20/gal (EIA website http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPD2D_PTC_SAK_DPG&f=M accessed October 28, 2013).

Fuel switching to low sulfur liquid fuels was evaluated as a strategy for reducing both direct PM emissions and SO_2. Switching from high sulfur fuel oil to any fuel but naphtha will increase fuel costs well beyond ADEC's threshold for acceptable costs. Switching from high sulfur fuels to naphtha would significantly reduce fuel costs. However, naphtha has significantly different combustion characteristics from currently used fuels Naphtha is significantly more flammable than heavier fuels, potentially requiring significant construction costs for storage and structures. Fuel systems would need to be modified or replaced. The combustion units themselves would require significant modifications or possibly retirement and replacement. Switching to naphtha is a costly effort for a facility not currently equipped to burn this fuel.

As a result, fuel switching was ruled out as RACT for all combustion sources.

C. NOx Control Technologies

Based upon ambient sampling, nitrates comprise about 4% of the measured PM2.5 concentrations in Fairbanks.[51] Atmospheric conditions in Fairbanks do not lead to a high rate of conversion from NOx emissions to ambient $PM_{2.5}$. As a result, the installation of additional NO_x controls on the point source facilities would have little impact on ambient $PM_{2.5}$ concentrations. Controlling for direct PM2.5 is approximately 13 times more effective, on a per-pound basis, than controlling for NOx emissions.[52] Any cost effectiveness analysis for NOx control equipment would need to reflect this factor and still be shown to be cost effective. This is extremely unlikely.

For this reason, NOx controls are not being considered as RACT for $PM_{2.5}$ planning for Fairbanks.

[51] Appendix III.D.5.7 Precursors.
[52] See Appendix III.D.5.7 Precursors, for supporting calculations.

VI. Recommended RACTs for each Source Category Type

The following paragraphs present the recommendations for baseline RACT for the source category types found in the FNSB. RACT is addressed for each of the pollutants of concern ($PM_{2.5}$ and SO_2) for each source category type. NOx controls are not discussed because NOx reduction is not an especially effective method for reducing ambient $PM_{2.5}$ in Fairbanks. As a result, these controls are not considered to be economical or reasonable for the purposes of the RACT analysis.

The baseline RACT determinations below are the starting point for the individual emission unit RACT determinations, details of which are provided in Appendix III.D.5.7.

A. Boilers

$PM_{2.5}$ emissions from coal and dual-fuel fired boilers can be most effectively controlled by the installation and operation of a properly sized fabric filter system. While other types of control devices such as electrostatic precipitators (ESPs) and high pressure drop venturi wet scrubbers may achieve comparable control efficiencies, there are drawbacks to their selection as RACT in the FNSB geographical area. ESPs typically require a larger initial investment than fabric filters and often require more space for installation than a fabric filter system. Venturi scrubbers are less costly than fabric filters but they typically achieve lower control efficiencies unless they are designed to operate at very high pressure drops, which increases the operating costs and, therefore, the total annualized costs to levels exceeding the costs for fabric filters. Also, freezing is a potential disadvantage of any type of wet scrubber in a location where ambient temperatures are well below freezing for many months of the year.[53] Although in-stack temperatures are elevated and would accommodate wet scrubber systems, the auxiliary piping that is required for the operation of a wet system would require heating or greatly increased amounts of insulation, which would further increase the operating cost. Wet scrubbers also typically generate a dense plume of water vapor, which could lead to downstream icing issues. Because fabric filter systems achieve emission reductions comparable to ESPs, and because they tend to be less costly to purchase and install and they typically require less space, they are considered to be RACT for $PM_{2.5}$ control for coal-fired boilers. Fabric filter systems have been used to control PM emissions from large coal-fired boilers in a range of geographical setting, including Alaska, for many years and there is significant precedent for selecting the technology as RACT for the control of $PM_{2.5}$.

While effective control of SO_2 emissions from boilers can be accomplished through the use of wet scrubbers, the cost per pound of sulfur removal rises dramatically as boilers

[53] The Stationary Source Control Techniques Document for Fine Particulate Matter (EPA, 1998), p. 5.4-1

get smaller, and as the sulfur content of the fuel gets lower. Because all of the coal-fired boilers in Fairbanks are relatively small (i.e., below 300 MW capacity) and because they already use very low sulfur coal, the use of scrubbers for SO_2 control unreasonably expensive for the sources being reviewed. See Appendix III.D.5.7 for more details.

The use of low sulfur content fuel is, therefore, recommended as baseline RACT for controlling emissions of SO_2 from combustion devices. For coal-burning units, this means use of low-sulfur Alaskan coal. For the oil-burning units in Fairbanks, the cost of switching to low-sulfur liquid fuels is not cost effective, because of complex physical changes that must be made in order to accommodate a fuel which the equipment cannot currently utilize. Case-by-case evaluations of the effectiveness of SO_2 emission reductions by switching to a lower sulfur fuel are provided in Appendix III.D.5.7.

B. Process Heaters

Process heaters are combustion devices that heat process materials. All of the units included in this analysis are refinery heaters that are fired with diesel fuel or a high grade of fuel oil (such as No. 2 fuel oil or kerosene). One process heater has actual PM emissions slightly above the review threshold (at 5.1 TPY). This process heater burns a very low sulfur distillate fuel.[54] The commonly applied PM control for boilers that burn distillate fuel is best operating practices for boiler maintenance. The combination of best operating practices and the use of very low sulfur distillate fuel constitutes RACT for this source category.

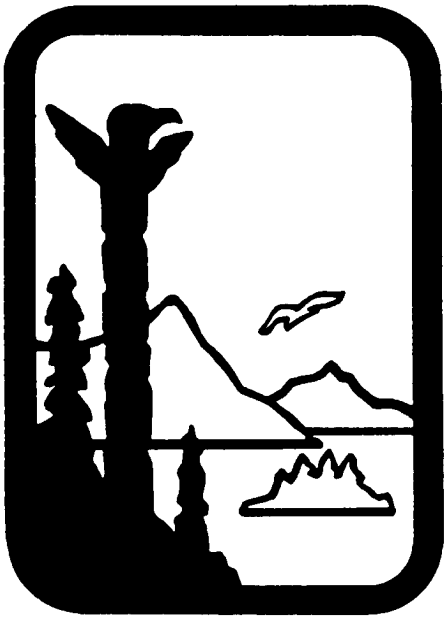
None of the other process heaters included in this evaluation have PM or SO_2 emissions above the review threshold, and NOx control is not effective for reducing ambient PM. For these reasons, no controls are proposed for process heaters.

C. Turbines

Combustion turbines used to generate electricity generally emit relatively low levels of particulate matter and have very high exhaust gas flow rates. AP-42 states: “PM emissions are negligible with natural gas firing and marginally significant with distillate oil firing because of the low ash content.”[55] Consequently, direct PM controls are not considered feasible for existing turbines. For the reasons discussed above, the cost of switching to more expensive low-sulfur fuels is not cost-effective; use of current fuels is recommended as RACT for SO_2 controls.

[54] Fuel sulfur content = 0.00146 wt%
[55] EPA, *Compilation of Air Pollutant Emission Factors (AP-42),* p. 3.1-4

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.08

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Public Review Draft

November 14, 2014

Sean Parnell
Governor

Larry Hartig
Commissioner

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Appendix III.D.5.08

Modeling Appendix

Speciated Modeled Attainment Test (SMAT).

Aerosol Chemistry in Fairbanks: A summary of prevailing conditions, May 27, 2011, by Richard E. Peltier (MPH, PhD), Dirigo Consulting LLC, Amherst, MA.

Using the CALPUFF dispersion model to characterize the Fairbanks Power Plant Plumes.

Fairbanks PM2.5 Non-Attainment Area WRF-ARW, Final Report, Reporting Period March 8, 2011- January 31, 2012, by Dr. Brian J. Gaudet, PI and Dr. David R. Stauffer, co-PI, Department of Meteorology, The Pennsylvania State University, University Park, PA.

Fairbanks Alaska PM2.5 Organic Composition and Source Apportionment Research Study, Final Report August 10, 2012, by Dr. Christopher P. Palmer (PhD), Department of Chemistry and Biochemistry, University of Montana, Missoula, MT.

Exploratory Research of Wintertime Aerosol Chemical Composition at a Ground Location in Fairbanks, Alaska, February 10, 2012, by Dr. Richard E. Peltier (PhD), University of Massachusetts.

Final Report to the U.S. Environmental Protection Agency, Stable Boundary Layers Representation in Meteorological Models in Extremely Cold Wintertime Conditions, Reporting Period September 1, 2008- January 31, 2010, by Dr. Brian J. Gaudet, PI and Dr. David R. Stauffer, co-PI, Department of Meteorology, The Pennsylvania State University, University Park, PA.

CMAQ Final Report- Phase I: “Fairbanks PM2.5 Non-Attainment Area CMAQ Modeling”, December 1, 2011, reporting period March 1, 2011- October 31, 2011, by Dr. Nicole Molders (PhD) and Ketsiri Leelasakultum, Department of Atmospheric Sciences, College of Natural Science and Mathematics, Geophysical Institute, University of Alaska at Fairbanks.

Investigation of means for PM2.5 mitigation through atmospheric modeling, April 2011 Final Report Phase I, reporting period December 1, 2008-December 31, 2010, prepared by Dr. Nicole Molders (PhD), Huy N.Q. Tran and Ketsiri Leelasakultum, Department of Atmospheric Sciences, College of Natural Science and Mathematics, Geophysical Institute, University of Alaska at Fairbanks.

CMAQ Final Report- Phase II: “Fairbanks PM2.5 Non-Attainment Area CMAQ Modeling”, reporting period January 1, 2012- December 31, 2012, by Dr. Nicole Molders (PhD) and Ketsiri Leelasakultum, Department of Atmospheric Sciences, College of Natural Science and Mathematics, Geophysical Institute, University of Alaska at Fairbanks.

Fairbanks PM2.5 Source Apportion Estimates, Winter 2008-2009.

Reconciling Trends in Carbon Measurements for Fairbanks, 2006-2010.

CMAQ First Quarterly Report- Phase II: “Fairbanks PM2.5 Non-Attainment Area CMAQ Modeling”, reporting period January 1, 2012- April 30, 2012, by Dr. Nicole Molders (PhD) and Ketsiri Leelasakultum, Department of Atmospheric Sciences, College of Natural Science and Mathematics, Geophysical Institute, University of Alaska at Fairbanks.

The Fairbanks, Alaska PM2.5 Source Apportionment Research Study Winters 2005/2006-2012/2013 and Summer 2012, Final Report, Amendments 6 &7, December 23, 2013, by Tony J. Ward, PhD., Center for Environmental Health Sciences, University of Montana, Missoula, MT.

Characterization of PM2.5 from Fairbanks, AK: Organics Analysis for Residential Oil Burner Emissions, Interim Report June 2011, by Dr. Christopher P. Palmer (PhD), Department of Chemistry and Biochemistry, University of Montana, Missoula, MT.

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5.8. Modeling Appendix

Introduction

This appendix provides the supplemental details of the photochemical transport modeling required as part of the Species Modeled Attainment Test (SMAT). Modeling efforts using PMF and CMB describe the early efforts to quantify the contributions to particulate matter concentrations in Fairbanks. Dispersion modeling results are presented to quantify the potential influence of point sources. Scientific analysis of sulfur formation and organic components of ambient aerosols provide further understanding related to contributing activities and atmospheric processes to $PM_{2.5}$ formation. The photochemical transport modeling sections provide the methodology for converting meteorological model outputs and emission inventories to model-ready inputs. Photochemical model outputs are then presented in the form of episode averaged concentrations of $PM_{2.5}$ components and gaseous SO_2. The resulting future design value concentrations are then calculated for the attainment tests.

Emissions Processing

Emission inventories were processed through the Sparse Matrix Operator Kernel Emissions (SMOKE) model version 2.7.5. The emissions sources were grouped into 8 different source sectors: point, home heating, onroad rate per vehicle (starting exhaust), onroad rate per distance (running exhaust, tire, and brake), onroad rate per profile (evaporative), nonroad including railroad, airport, and other area. All source sectors with the exception of the onroad mobile sources were processed through the following SMOKE program workflow: SMKINVEN, GRDMAT, SPCMAT, TEMPORAL, and SMKMERGE. An additional layer step is needed for point, home heating and airport sources with vertical distributions above the ground level.

Before the emissions processing can be initiated the meteorological data from the WRF model and the emissions inventory are converted to inputs for both the SMOKE and CMAQ models. The meteorological outputs from WRF are used to define the modeling grid (GRIDDESC) for both SMOKE and CMAQ. The Meteorology-Chemistry Interface Processor (MCIP) program version 3.6 was used to prepare the WRF outputs for use with SMOKE and CMAQ. The SMOKE model as configured in 5.8.4 was used to process episodic inventories for the 2008 baseline, 2015 projected baseline, 2015 control scenario, 2019 projected baseline, and 2019 control scenario.

SMOKE Processing Outline

- Meteorological input processing
- Point
    - Actuals
    - PTE
    - Vertical Layering
- Home Heating

    - Processing as Point Sources
        - Spatial Allocations
        - Temporal Allocations
    - Speciation Changes
        - AP42
        - Omni
    - Vertical Layering
- Nonroad
    - Spatial Allocations
    - Temporal Allocations
- Other Area
    - Spatial Allocations
    - Temporal Allocations
- Airport
    - Spatial Allocations
    - Temporal Allocations
    - Vertical Layering
- Rate-Per-Vehicle
    - MOVES Lookup Tables
    - Activity Inputs
    - Spatial Allocations
    - Plugins Adjustments
- Rate-Per-Distance
    - MOVES Lookup Tables
    - Activity Inputs
    - Spatial Allocations
- Rate-Per-Profile
    - MOVES Lookup Tables
    - Activity Inputs
    - Spatial Allocations
    - Maintained year to year

SMOKE Emissions Processing Modifications for Fairbanks, AK $PM_{2.5}$ SIP

In support of $PM_{2.5}$ SIP modeling efforts in Fairbanks, Alaska, Sierra Research has created a modified version of the SMOKE-model. Model modifications were made in order to generate highly resolved home heating emissions and address bugs in the processing of onroad mobile source emissions from the MOVES model. The baseline source codes used in these projects were SMOKE version 2.7.5, MOVES 2010a, and SMOKE-MOVES 0.20 and 0.31. Processed emissions were evaluated using Verdi 1.31, custom NCL scripts, custom BASH and CSH SHELL scripts, and NCO programs on a custom-built computer (Intel i7 950 4 core/8 thread, 8 GB system memory, 1 TB hard disk drive) running Ubuntu 10.04 OS.

The modeling episodes span January 23 through February 11 and November 7 through November 22. The modeling domain covers 199x199 grid cells of 1.33x1.33km size comprising the bulk of the Fairbanks North Star Borough and 38 vertical layers up to 20km.

Area Source Modifications

Home heating emissions inputs to the SMOKE model were generated using a Fairbanks-specific heating demand model developed by Sierra Research. The home heating model is informed by multiyear phone surveys, in-home instrumentation data, device measurement studies, local land parcel data, census records and local day-specific meteorology. The home heating model can produce highly spatially resolved, hourly emissions for the 199x199 gridded model domain. To best preserve the temporal and spatial resolution of this inventory, an alternative approach to the standard SMOKE area source processing via spatial and temporal surrogates schemes was developed. The most efficient approach was to treat the home heating source input file as a large point source emissions inventory with hourly specified emissions.

Both an inventory input and hourly emissions input file were created to meet SMOKE's point source processing requirements: PTINV[1] and PTHOUR. The PTINV input was formatted per the ORL formatting guidelines[2]. Descriptive, dummy text was applied to the facility information fields with the exception of the FIPS, SCC codes, pollutant CAS number, X location and Y location. In this instance, the PTINV file ultimately serves as a spatial allocation file. The PLANTID field is given a name specific to the grid cell where the home heating activity is located and which corresponds to the latitude and longitude specified by the X and Y location fields. Since hourly emissions data are imported with PTHOUR, the emission levels in the PTINV file are set to dummy values and not ultimately used. PTHOUR follows the EMS95 Wide format per the SMOKE guidelines.[3]

Changes to the SMOKE code were made to allow for the home heating sources to be processed using the PTINV and PTHOUR inputs while preserving the sector's identity as an area source. Code sections that received changes are noted below and comments were added within the source code. The initial code changes were made to the inventory importing routines within the smkinven[4] program. Lines of code were added to read the HOUR_SPECIFIC_YN environment variable on lines 201 to 205 within the area source subsection of smkinven.f. Modifications were subsequently required on lines 249, 256, 273, 275, 401, and 424 related to the source category variable CATEGORY. For simplicity when the hour-specific emissions variable was set to true, the source category was changed from AREA to POINT before calling certain subroutines. The old category was stored in a separate variable and then recalled after these subroutines were completed. This category swapping was preferable to rewriting each of the subroutines to allow both POINT and AREA categories to use the PTHOUR emissions and PTINV inventory files. Subroutines impacted by this category swapping were the following:

[1] Variables, subroutines, and inputs are presented in all capitalized form for clarity.
[2] SMOKE v2.7 User's Manual: section 8.2.8.3 pages 408-412
[3] SMOKE v2.7 User's Manual: section 8.2.7.2 pages 300-401
[4] Executable programs and their source code files are presented in lowercase to distinguish them from variables, subroutines, and inputs.

RDINVSRCS, PROCINVSRCS, PROCINVEN, OPENINVOUT, WRINVCHR, SRCMEM, and WRINVEMIS.

Several other subroutines were impacted by the point as area and hourly emissions changes. The INITFINFO subroutine in file initinfo.f was modified on lines 61, 67 and 76 to read the hourly emissions flag. Conditional statements were placed or modified to correctly initialize variables associated with processing the hourly area source emissions and inventory data as for the treatment of the hourly area source emissions on lines 77, 112, 120, 166, 176, 187, 201, 203, 219, and 237.

The OPENINVIN subroutine was altered on line 121 to allow for hourly specified emissions outside of POINT sources. Conditional statements were added on lines 340 and 347 to avoid opening certain point source related files that were not required for the area source category. RDINVDATA was updated to add logic around the instances where hourly specific emissions were to be used and area source category inventories were being read. Line 225 was modified to determine whether the hourly specific emissions flag was set. Lines 362, 669, 691, 795, 855, 1171, 1188, 1389, 1393, 1458, 1460, 1479, and 1495 received modifications to their conditional statement logic to have the hourly specific area source files process more like point source files when the hourly specific emissions flag was set.

Due to the 8-character, SCC length limitations of the EMS95 Wide Format, the RDEMSPD subroutine in rdemspd.f had to be altered to extend the SCC size from 8 to 10 characters for EMS95 Wide emission files. Extending the SCC field width requires shifting all of the proceeding fields by the number of characters added to the SCC field. Changes occurred on lines 273 and 274 where the position of the field following the SCC code is defined: DATNAM. Both the start and end positions of the DATNAM field were increased by two, 381 to 383 and 396 to 398. There are no other fields that follow these in the EMS95 Wide format. Lines 680 and 721 are responsible for reading the SCC code from each line in the PTHOUR file. The values indicating the ending position of the SCC code were increased by two digits from 380 to 382.

Additional precision was also sought in the reading of the latitude and longitude entries, XLOC and YLOC, of the PTINV file. The RDINVDATA subroutine was modified to accept two additional digits of precision when reading latitude and longitude, line 214 in the file rdinvdata.f. Lines 1502 and 1503 were revised to preserve the desired precision of the XLOC and YLOC by using a formatted read statement instead of the existing code's usage of the function STR2REAL. Subroutine RDDATAORLPT in file rddatantipt.f was modified on lines 75 and 76 to extend the LAT and LON dimensions from 9 to 11.

A section of the subroutine WRPDEMIS that checks for missing emissions data and fills in those data with values based on annual emissions data was modified since the area emissions are now using hourly data only. An error would result due to the inability of the code to differentiate between missing emissions data and a zero emissions value. Line 319 was modified to set null emissions to zero.

Following changes to the smkinven source code, the smkinven program was compiled and tested with PTINV and PTHOUR area source inputs. Debug statements, log files for the smkinven program, and intermediate data files were inspected as part of the QA process to address any coding errors and resolve any bugs. The resulting intermediate files from the imported inventory and emission files were then passed to the grdmat, spcmat, and temporal programs.

The gridding program, grdmat, was updated to use the latitude and longitude information from the imported inventory file to grid the emissions. Sections of code were added on lines 172 and 199 to read the hourly-specific emissions flag and conditionally branch into point source spatial allocation subroutines even when the area category was being processed. Conditional statements were modified on lines 254, 299, 303, 641, 706, 726, and 756 to allocate sufficient memory for the number of sources and to call subroutines to convert the latitude and longitude to gridded outputs. Source code in opengmat.f was modified on lines 87, 110 and 120 to setup the correct headers for the area source as points gridding matrix. Grdmat was then compiled and tested similarly to the smkinven program.

The speciation program, spcmat, received updates to the correct for problems with processing the hourly area sources. Changes occurred on lines 152 and 166 to add reading of the hourly specified flag and a temporary variable for storing the source category. A line of code was added on line 186 to read the hourly emissions environment flag. Source code was added on line 271 to artificially switch the source code to POINTS before running the RDINVCHR subroutine that reads inventory characteristics. This is a more efficient solution than modifying the RDINVCHR code. A conditional statement in file asgntag.f line 179 was changed to allow both hourly point and area sources to use a set of SCC storage arrays required for the number of sources being processed. The profile assignment subroutine in asgnspro.f was modified on lines 129, 190, 224, 234, 242, 314 and 361 to accommodate the changes to the rest of the spcmat program. Spcmat was compiled and tested using the existing intermediate files from smkinven.
No modifications were required to the temporal allocation program within SMOKE. Temporal was tested as is with some additional debug statements to ensure clean processing of the hourly area sources. Intermediate files and log files were also checked to determine the successful operation of the program.

With the completion of the smkinven, grdmat, spcmat, and temporal programs some minor changes to the smkmerge program was made to merge together the spatial, temporal, and speciated intermediate data files. Code was written on lines 206 and 219 to determine if hourly specific data were being merged. Next conditional statements on lines 393, 401, 404, 419, 429, 433, 452, 561, 565, 625, 657, 661, 666, 719, 720, 761, 766, 795, 924, 925, 939, and 951 were written to correctly call point source or area source subroutines depending on the state of the hourly specific data variable. The resulting code was compiled and extensively bug tested using intermediates generated from the previously mentioned intermediate programs. The outputs from smkmerge were plotted using the Verdi program and exported to both Excel and ArcGIS compatible file formats for spatial and temporal assessments. NCO software, ncl scripts, and BASH scripts were utilized in creating data summaries of the inventories generated from this process.

SMOKE-MOVES code changes, bug fixes, daily meteorology

The MOVES 2010a model was used to create onroad emissions inventory lookup tables for the Fairbanks $PM_{2.5}$ nonattainment area. Local data was used for the configuration of the MOVES model for the two separate modeling episodes. Details on the operation of MOVES and post processing are described in the Emission Inventory Data CMAQ/SMOKE 2008 sections.
The meteorological processing routines in the MET4MOVES code was changed to allow for daily processing of meteorology for use in the MOVES model and the MOVESMRG program. Lines 293 and 312 of met4moves.f were modified to indicate daily averaging methods were being used. Lines 163, 262, 266, and 269 of rdmetmoves.f were modified to allow for day specific averaging and storing of minimum and maximum while reading the MCIP processed meteorology fields.

Revisions to the SMOKE source code were made for the processing of the MOVES mobile source emissions inventory. These changes were necessary due to bugs from the preliminary nature of the releases of the software available at the time: SMOKE 2.7.5b and the SMOKE-MOVES processing tools version 0.20 – 0.31.

The MOVESMRG source code was modified to correct for errors that occurred during the reading and processing of the mobile source emissions inventory. These errors included the exceeding of arrays. The BLDSRCCELL subroutine in file bldsrccell.f allocates the source fractions to each grid cell. Conditional statements were added on line 82 and 87 to ensure the SRC variable falls between 1 and NSRC (the maximum number of sources) to prevent the NSRCCELLS array from exceeding its bounds.

For the core MOVESMRG source code a bug was addressed with the discrepancy between county codes used in movesmrg.f and in other subroutines resulting in an error in the arrays AVGMIN and AVGMAX. Parameter CNTYCOD was added on line 78 and used on line 546 to correctly address the county number for determining MINVAL and MAXVAL. Additional debug statements and warning messages were added to movesmrg.f on lines 546, 717 and 720.

Photochemical Modeling

Model outputs were extracted for the State Office Building grid cell in the modeling domain for all episode days. The episode averages and multi-episode averages are shown in tables below for the 2008 baseline, 2015 projected baselines, 2015 control scenarios. The 2015 year emissions are presented both with actual point source emissions (Actuals) and PTE-level point source emissions (PTE). Outputs are shown as for $PM_{2.5}$ total, OC (organic carbon), EC (elemental carbon), SO_4 (sulfate), NO_3 (nitrate), NH_4 (ammonium), OTH (other), SOA (secondary organic aerosol), and SO_2 (gaseous sulfur dioxide).

Table 5.8-1. 2015 PM Species Concentrations Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	$PM_{2.5}$ ($\mu g/m^3$)	OC ($\mu g/m^3$)	EC ($\mu g/m^3$)	SO_4 ($\mu g/m^3$)	NO_3 ($\mu g/m^3$)	NH_4 ($\mu g/m^3$)	OTH ($\mu g/m^3$)	SOA ($\mu g/m^3$)	SO_2 (ppm)
2008 Baseline	Ep1 & Ep2	35.72	24.47	4.34	2.13	1.30	1.17	2.31	0.01	0.02
	Ep1	42.01	29.24	5.13	2.40	1.25	1.25	2.73	0.01	0.02
	Ep2	28.53	19.01	3.44	1.83	1.35	1.07	1.83	0.01	0.01
2015 Baseline Actuals	Ep1 & Ep2	33.91	23.36	3.82	2.20	1.23	1.17	2.13	0.01	0.02
	Ep1	39.59	27.66	4.52	2.48	1.20	1.27	2.47	0.01	0.02
	Ep2	27.42	18.44	3.01	1.88	1.27	1.07	1.73	0.00	0.01
2015 Baseline PTE	Ep1 & Ep2	36.90	23.48	3.91	2.72	1.26	1.35	4.18	0.01	0.02
	Ep1	42.82	27.81	4.65	3.02	1.21	1.44	4.69	0.01	0.02
	Ep2	30.12	18.53	3.07	2.37	1.32	1.25	3.59	0.01	0.02
2015 Controls Actuals	Ep1 & Ep2	30.80	20.70	3.46	2.18	1.18	1.15	2.13	0.01	0.02
	Ep1	36.04	24.61	4.11	2.46	1.15	1.24	2.47	0.01	0.02
	Ep2	24.82	16.23	2.72	1.86	1.22	1.05	1.73	0.00	0.01
2015 Controls PTE	Ep1 & Ep2	33.77	20.82	3.56	2.70	1.20	1.32	4.18	0.01	0.02
	Ep1	39.24	24.76	4.25	2.99	1.14	1.40	4.69	0.01	0.02
	Ep2	27.51	16.32	2.78	2.36	1.26	1.22	3.58	0.01	0.02

Relative response factors for each of the components of $PM_{2.5}$, gaseous SO_2, and SO_4* are calculated for 2015. SO_4* RRF represents the combined impacts of primary and secondary sulfate on $PM_{2.5}$ using both modeled and measured estimates of sulfur. The method for calculating SO_4* is explained below. $PM_{2.5}$ and SO_2 RRFs are calculated by dividing the modeled concentrations in the 2015 multi-episode 24-hour averaged concentration of a species by the 2008 multi-episode 24-hour averaged concentration:

$$RRF_i = \frac{[i_{2015}]}{[i_{2008}]}$$

where *RRF* is the relative response factor of species *i* and [*i*] is the concentration of *i* for 24-hours averaged over all episode days in 2008 and 2015.

The SO_4* RRF is calculated as the weighted average of the SO_4 and SO_2 RRFs. A process analysis study of the CMAQ-model for both the modeling episodes by Leelasakultum and Mölders found that nearly all of the sulfate is derived from primary emissions.[5] Any RRF derived from the modeled SO_4 concentrations would overestimate the impacts of changes to primary SO_4 while ignoring the impacts of changes to gaseous SO_2. In order to estimate the likely impacts of changes to SO_2 emissions on $PM_{2.5}$ a method was developed to account for the secondary formation of sulfate:

$$RRF_{SO_4{}^*} = \frac{([SO_{4(FRM)}] - [SO_{4(CMAQ)}]) \times RRF_{SO_2}}{[SO_{4(FRM)}]} + \frac{[SO_{4(CMAQ)}] \times RRF_{SO_4}}{[SO_{4(FRM)}]}$$

Where the variables are defined as follows:

- $RRF_{SO_4{}^*}$ is the relative response factor for both primary and secondary sulfate
- $[SO_{4(FRM)}]$ is the measured concentration of SO_4 averaged over FRM days for both episodes in µg/m^3
- $[SO_{4(CMAQ)}]$ is the modeled concentration of SO_4 averaged over FRM days for both episodes in µg/m^3
- RRF_{SO_2} is the relative response factor of gaseous SO_2
- RRF_{SO_4} is the relative response factor of primary SO_4.

This method assumes that the sulfate concentrations calculated by CMAQ are due only to primary emissions and transport of sulfate. This assumption seems reasonable given the results of the process analysis study by Leelasakultum and Mölders.[6]

Table 5.8-2. 2015 PM and SO_2 Relative Response Factors - Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	OC	EC	SO_4	NO_3	NH_4	OTH	SO_2	SO_4*
2008 Baseline	Ep1 & Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep1 & Ep2	0.95	0.88	1.03	0.95	1.00	0.92	1.06	1.05

[5] *Fairbanks North Star Borough PM 2.5 Non-Attainment Area CMAQ Modeling Final Report Phase II* DEC 2012 By Prof. Nicole Mölders (PhD, PhD) and Ketsiri Leelasakultum (MS) University of Alaska Fairbanks, Geophysical Institute, College of Natural Science and Mathematics, Department of Atmospheric Sciences

[6] IBID

2015 Baseline Actuals	Ep1	0.95	0.88	1.03	0.96	1.01	0.90	1.06	1.05
	Ep2	0.97	0.88	1.03	0.94	1.00	0.95	1.06	1.04
2015 Baseline PTE	Ep1 & Ep2	0.96	0.90	1.27	0.97	1.15	1.80	1.29	1.28
	Ep1	0.95	0.91	1.26	0.97	1.15	1.72	1.26	1.26
	Ep2	0.97	0.89	1.30	0.97	1.16	1.96	1.33	1.32
2015 Controls Actuals	Ep1 & Ep2	0.85	0.80	1.02	0.91	0.98	0.92	1.05	1.04
	Ep1	0.84	0.80	1.02	0.92	0.99	0.90	1.05	1.04
	Ep2	0.85	0.79	1.02	0.90	0.98	0.95	1.05	1.04
2015 Controls PTE	Ep1 & Ep2	0.85	0.82	1.26	0.92	1.13	1.80	1.28	1.27
	Ep1	0.85	0.83	1.25	0.92	1.12	1.72	1.26	1.25
	Ep2	0.86	0.81	1.29	0.93	1.13	1.96	1.33	1.31

Ammonium and particle bound water RRFs are calculated based on the changes to sulfate and nitrate RRFs. Calculated future ammonium concentrations are fixed at 0.29*[NO_3] + 0.37*[SO_4]. The ratios of 0.29 for NH_4:NO_3 and 0.37 for NH_4:SO_4 are fixed based on the 2006 – 2010 winter average (quarters 1 and 4) values used for SANDWICH. Particle bound water RRFs are calculated by attributing 1/3rd of the PBW to ammonium nitrate and 2/3rd of the PBW to ammonium sulfate as discussed in the precursors document in Appendix III.D.5.7. The equation to calculate the PBW RRF is shown below:

$$RRF_{PBW} = \frac{2}{3} \times RRF_{SO_4} + \frac{1}{3} \times RRF_{NO_3}$$

Where RRF_{PBW}, RRF_{SO4}, and RRF_{NO3} are the relative response factors for PBW, SO_4 and NO_3 respectively. The RRFs from model outputs averaged over both episodes are used to calculate the future design values for 2015 emissions scenarios.

Future design values calculated from the RRFs above with a 0.5 µg/m^3 credit for voluntary measures are presented in table 5.8-3. Scenarios for the baseline projections and controls were simulated with actual point source emissions (Actual) and potential to emit levels (PTE). Three sets of design values are shown for each scenario depending on the treatment of sulfate: FDV, FDV SO_4, and FDV SO_4*. The FDV column calculates the design value based on RRFs for OC, EC, NO_3 and OTH with PBW and NH_4 RRFs derived as stated above. Per discussions with EPA regarding the model performance of SO_4 the sulfate RRF is held to 1.0. FDV SO_4 and FDV SO_4* present scenarios where the sulfate RRF is used in the design value calculations. FDV SO_4 uses the RRF calculated from the model outputs for [SO_4] with no modifications. Based on the model performance and process analysis assessment this approach likely does not account for secondary sulfate. FDV SO_4* uses the RRF for SO_4* in the design value calculation. This treatment of the design value should more accurately capture the influence of both secondary and primary sulfate on $PM_{2.5}$ concentrations.

Voluntary measure benefits are calculated as the weighted average of a 3% credit in onroad mobile source contributions and a 6% reduction in the remaining sources. The total needed

reductions based on the baseline design value of 44.7 µg/m^3 and 24-hour $PM_{2.5}$ NAAQS of 35 µg/m^3 would be calculated as 44.7 – 35 = 9.7 µg/m^3. Using the inventory for the 2008 baseline onroad mobile sources contribute 13.7% of the direct $PM_{2.5}$ in the nonattainment area with all other sources contributing 86.7%. A 3% voluntary measure credit from mobile source would yield a reduction of 3%*13.7%*9.7 µg/m^3 = 0.04 µg/m^3. A 6% voluntary measure benefit from all other sources would yield a reduction of 6%*86.7%*9.7 µg/m^3 = 0.5 µg/m^3. A total voluntary credit of 0.5 µg/m^3 is taken when rounding to the first decimal.

Table 5.8-3. Future Design Values for 2015 baselines (Actual and PTE) and Control Scenarios (Actual and PTE)

Scenario	FDV (µg/m^3)	FDV SO_4 (µg/m^3)	FDV SO_4* (µg/m^3)
2015 Baseline Actual	42.4	42.8	43.0
2015 Baseline PTE	43.2	46.6	46.8
2015 Control Scenario Actual	39.6	39.8	40.1
2015 Control Scenario PTE	40.1	43.4	43.5

The treatment of Actual and PTE point sources along with the influence of sulfate can produce a range of results for the control run between 39.6 µg/m^3 and 43.5 µg/m^3. The PTE bias alone can cause the results to shift by 0.5 µg/m^3 to 3.6 µg/m^3 depending on the treatment of sulfate. This range of bias is caused by the significant contributions of sulfate and sulfur dioxide from point sources. The most realistic approximation of the FDV in 2015 would be 40.1 µg/m^3 from the 2015 Control Scenario Actual with SO_4*.

CMAQ-modeled outputs for 2019 baseline and control scenarios are shown in tables 5.8-4. Similar to 2015 the outputs are shown as averaged over both episodes and for individual episodes across $PM_{2.5}$ total, OC, EC, SO_4, NO_3, NH_4, OTH, SOA, and SO_2. Simulations for 2019 are presented only for the case where point sources are held to PTE levels. A 2019 baseline and control scenario are shown along with the 2008 baseline for comparison. The control scenario package contains the ARA OHH, WSCO, State standards, natural gas expansion, dry wood, and natural turnover. Credit for voluntary measures is taken following the RRF calculations below.

Table 5.8-4. 2019 PM Species Concentrations Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	$PM_{2.5}$ ($\mu g/m^3$)	OC ($\mu g/m^3$)	EC ($\mu g/m^3$)	SO_4 ($\mu g/m^3$)	NO_3 ($\mu g/m^3$)	NH_4 ($\mu g/m^3$)	OTH ($\mu g/m^3$)	SOA ($\mu g/m^3$)	SO_2 (ppm)
2008 Baseline	Ep1 & Ep2	35.72	24.47	4.34	2.13	1.30	1.17	2.31	0.01	0.02
	Ep1	42.01	29.24	5.13	2.40	1.25	1.25	2.73	0.01	0.02
	Ep2	28.53	19.01	3.44	1.83	1.35	1.07	1.83	0.01	0.01
2019 Baseline PTE	Ep1 & Ep2	37.16	23.84	3.79	2.76	1.26	1.36	4.15	0.02	0.01
	Ep1	43.02	28.14	4.49	3.07	1.21	1.46	4.64	0.02	0.01
	Ep2	30.47	18.91	2.99	2.41	1.31	1.26	3.59	0.02	0.00
2019 Controls PTE	Ep1 & Ep2	26.87	14.70	2.57	2.78	1.29	1.39	4.13	0.02	0.00
	Ep1	31.29	17.80	3.12	3.08	1.19	1.47	4.62	0.03	0.00
	Ep2	21.81	11.16	1.95	2.43	1.40	1.30	3.57	0.02	0.00

Relative response factors for 2019 are calculated in the same manner as for 2015 using 2008 as the base year with 2019 as the future year. Again no Actual level point source outputs are presented here.

Table 5.8-5. 2019 PM and SO_2 Relative Response Factors - Episode Averages and Multi-Episode Averages

Scenario	Averaging Period	OC	EC	SO_4	NO_3	NH_4	OTH	SO_2	SO_4*
2008 Baseline	Ep1 & Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Ep2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2019 Baseline PTE	Ep1 & Ep2	0.97	0.87	1.29	0.97	1.17	1.79	1.32	1.31
	Ep1	0.96	0.88	1.28	0.97	1.17	1.70	1.30	1.29
	Ep2	1.00	0.87	1.32	0.97	1.17	1.96	1.37	1.35
2019 Controls PTE	Ep1 & Ep2	0.60	0.59	1.30	0.99	1.19	1.79	1.43	1.38
	Ep1	0.61	0.61	1.28	0.95	1.17	1.69	1.39	1.35
	Ep2	0.59	0.57	1.33	1.03	1.21	1.95	1.50	1.43

Design values for 2019 are derived from the above RRFs with the same considerations for sulfate presented for each scenario in Table 5.8-6: FDV, FDV SO_4, and FDV SO_4*. The bias from PTE emissions is not calculated in the 2019 scenarios, but the influence is again expected to range from 0.5 $\mu g/m^3$ to 3.6 $\mu g/m^3$ depending on the sulfate RRF calculations. The previously calculated voluntary measure credit of 0.5 $\mu g/m^3$ is also applied to the FDV values for 2019 in the table below.

Table 5.8-6. Future Design Values for 2019 baseline (PTE) and Control Scenarios (PTE)

Scenario	FDV ($\mu g/m^3$)	FDV SO_4 ($\mu g/m^3$)	FDV SO_4* ($\mu g/m^3$)
2019 (PTE)	43.4	47.1	47.4
2019 Control Scenario (PTE)	33.5	37.3	38.3

Unmonitored Area Analysis

Areas in the nonattainment region away from the monitor sites require additional analysis to show attainment under a control scenario. These unmonitored areas are reviewed using a technique described as unmonitored area analysis (UMAA). The UMAA methodology blends photochemical model predicted concentrations of $PM_{2.5}$ with interpolated ambient monitor data to produce a map of future concentrations throughout the nonattainment area. This approach takes advantage of modeled $PM_{2.5}$ gradients between grid cells while making use of the existing monitor network's spatial fields. Three steps are recommended for UMAA; 1) interpolate ambient data, 2) adjust ambient spatial fields with modeled outputs, 3) adjust model-modified spatial fields with modeled cell-by-cell RRFs. [7]

1) Interpolation of Measured Ambient Concentrations

The interpolation of ambient monitored $PM_{2.5}$ concentrations relies on data from monitor sites over the design period of 2006 – 2010 to produce a five year weighted average design value as described in the SMAT section of the SIP (Chapter 5.8.9.2). The only available monitor with FRM-derived speciated concentrations covering all winters for 2006 through 2010 was the State Office Building monitor. Several other temporary monitor sites were operated during that period. The measurements from these sites were compared against the total $PM_{2.5}$ at the State Office Building monitor site during severe winter episodes to establish a ratio. These sites were then used in lieu of more permanent monitors to spatially interpolate $PM_{2.5}$ concentrations. Since the data from these sites were not all speciated the total $PM_{2.5}$ was used to establish the ratios between the State Office Building and the rest of the sites in the nonattainment area.

2) Adjusting Ambient Spatial Fields with Modeled Outputs

The spatial information from the monitors is adjusted with modeled outputs using the Voronoi Neighbor Averaging (VNA) technique. The VNA technique was applied in Excel as described in the BenMAP: Environmental Benefits Mapping and Analysis Program User's Manual.[8]

[7] Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5 , and Regional Haze U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Air Quality Analysis Division Air Quality Modeling Group Research Triangle Park, North Carolina - EPA -454/B-07-002 April 2007

[8] BenMAP: Environmental Benefits Mapping and Analysis Program User's Manual, September 2008, Prepared for Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency by Abt Associates Inc.

BenMAP software was not used due to the limited monitor availability during the modeling episodes. VNA operates as an inverse-distance weighted average of monitor values. The VNA method was coded to match the default options in BenMAP with no distance cutoff or maximum number of monitors. The $PM_{2.5}$ weighted average is calculated in a given grid cell as follows,

$$PM_{2.5_i} = \frac{\frac{1}{d_1} * \frac{[obs_1]}{[model_1]} + \frac{1}{d_2} * \frac{[obs_2]}{[model_2]} + \cdots + \frac{1}{d_n} * \frac{[obs_n]}{[model_n]}}{\frac{1}{d_1} + \frac{1}{d_2} + \cdots + \frac{1}{d_n}} * [model_i]$$

Where $PM_{2.5i}$ is the adjusted $PM_{2.5}$ concentration in a grid cell i; d_1, d_2, and d_n are the distances between the grid cell i and 1st, 2nd, and nth monitors; obs_1, obs_2, and obs_n are the observed $PM_{2.5}$ concentrations at the 1st, 2nd, and nth monitors; $model_1$, $model_2$, and $model_n$ are the modeled concentrations at the 1st, 2nd, and nth monitor grid cells; $model_i$ is the modeled concentration in the grid cell i. The adjusted grid cells are calculated over the nonattainment area grid cells using the 2008 baseline model outputs.

3) Relative Response Factor Adjustments of Spatial Fields

Cell by cell RRFs were calculated for total $PM_{2.5}$ in the modeling domain for the 2015 and 2019 control scenarios. The total $PM_{2.5}$ RRF was used instead of the individual components due to the lack of speciated measurements away from the State Office Building monitor site. To be consistent with the methodology used in the FDV calculations the total $PM_{2.5}$ RRF in each grid cell was calculated as follows:

$$RRF_{PM} = \frac{OC_{future} + EC_{future} + NO3_{future} + NH4_{future} + OTH_{future} + SO4_{baseline}}{OC_{baseline} + EC_{baseline} + NO3_{baseline} + NH4_{baseline} + OTH_{baseline} + SO4_{baseline}}$$

Where the RRF_{PM} is the relative response factor for $PM_{2.5}$ for a future year control scenario in a grid cell; OC, EC, NO3, NH4, OTH, and SO4 are concentrations of individual $PM_{2.5}$ species for either the future year or the baseline year. Note the SO_4 contribution to the RRF is held constant to match the RRF_{SO4} calculation used in the attainment demonstration.

SMAT (Speciated Modeled Attainment Test)

EPA model guidance, "Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze" (USEPA, 2007), recommends the Species Modeled Attainment Test (SMAT) to estimate future concentrations of daily $PM_{2.5}$ concentration. The method combines monitoring data with outputs from simulation models to estimate future $PM_{2.5}$ concentrations. It can be used to determine whether emission reductions will bring ambient concentrations to or below the National Ambient Air Quality Standard (NAAQS) (<=35 $\mu g/m^3$ for 24-hr $PM_{2.5}$). The SMAT is combined with other modeling techniques and relevant supplemental evidence to develop a technically-sound, weight-of-evidence recommendation on whether the proposed control strategies will meet the goal of pollution levels below the NAAQS.

SMAT recommends a nine-step process to take historically-measured $PM_{2.5}$ concentrations, apply factors to represent changes from the historical period to a future year, and estimate the future $PM_{2.5}$ design value (DV). The historically-measured $PM_{2.5}$ concentrations are sampled from the top 25% of polluted wintertime days within a five-year period. For each major chemical component of $PM_{2.5}$ (sulfates, nitrates, ammonium, organic carbon, elemental carbon; particle bound water, other primary particulate matter (Figure 1)), an air pollution model projects the change in concentration from the historical period to the future year. For instance, if the organic carbon concentration is projected to be in 2014 half of what it was in 2008, then the organic carbon concentration from the polluted days in the historical period is divided by two. The process is done for each chemical species and then summed across species to the get the projected future $PM_{2.5}$ after implementation of control strategies.

One important aspect of SMAT is how speciated $PM_{2.5}$ measurements from the Speciated Trends Network (STN) monitor are melded with the standard federal reference method (FRM) measurement of total $PM_{2.5}$ concentration. Care must be taken in this step because the STN monitor and FRM monitor use different measurement techniques. As the NAAQS are based on FRM monitored values, the speciated data from the STN monitor must be transformed into the values that would have been recorded by the FRM monitor. EPA modeling guidance in Section 5.1.4 describes this transformation technique, called Sulfate, Adjusted Nitrate, Derived Water, Inferred Carbonaceous material balance approach (SANDWICH), which follows the peer-reviewed, scientific methodology of Frank (2006) and references therein.

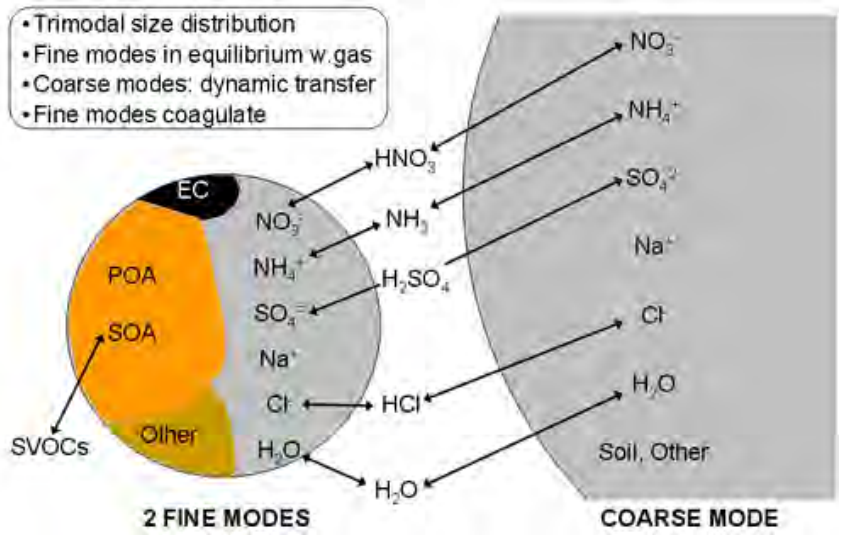

Figure 1: Major Components of $PM_{2.5}$
http://www.epa.gov/AMD/ModelDevelopment/aerosolModule.html

STEP 1:

The first step in the SMAT analysis is to identify the high observed $PM_{2.5}$ days at each monitoring site for each year used for the baseline design value (DV). The baseline design value represents the pollution levels at the time the area violated the NAAQS and was designated nonattainment. In Fairbanks, the State Office Building is the only monitoring station that was used to determine a non-attainment area (NAA). Following the EPA emission inventory guidance (USEPA, 2005), 2008 was chosen as the base year, and following Section 3.1 of the EPA modeling guidance the baseline design value was calculated as an average of the 2006-2008, 2007-2009, and 2008-2010 three-year design values. The three-year design value is the same one as in the calculation of compliance with the PM2.5 NAAQS: an average of three consecutive years' worth of 98th percentiles. The baseline design value for the Fairbanks non-attainment area the design value is 44.7μg/m^3 (Table 1).

The baseline design value is not directly used in the calculation of the future year design value. Rather, the species-specific changes from the base (historical) year to the future year are applied to all the individual 24-hour averages in the 2006-2010 period and then the same procedure as used to calculate the baseline design value (98th percentiles for each year, three year design values, average of three year design values) is used to calculate the future design value (USEPA Update to the 24 hour PM2.5 NAAQS model attainment test, 2011). The baseline design value is not useless, however. The difference between the baseline design value and the NAAQS determines the overall reductions needed to reach attainment. After the amount of pollution reduction needed to reach attainment (9.2 μg/m^3) is divided by the number of years between designation of nonattainment and the Moderate Area attainment date (5), we arrive at the one year's worth of progress value relevant for Reasonable Further Progress and Contingency Measures (1.84 μg/m^3).

Table 1: The 98%-tile $PM_{2.5}$ (μg/m^3) concentration days and resulting 5-year rolling average DV for Fairbanks, excluding Exceptional Events[1].

Year	High Concentrations	98th Percentile	3- year design value
2006	51.9	42.2	
	42.2		
2007	51.6	33.1	
	34.1		
	33.1		
2008	114.5	46.7	40.7
	50.7		
	46.7		
2009	59.0	51.0	43.6
	52.7		
	51		
2010	83.2	51.8	49.8
	57.1		
	51.8		
5-yr Baseline Design Value			44.70

[1]Exceptional Events for the 2009 data have been flagged by DEC and concurred by EPA. 2010 Exceptional Events have been flagged by DEC and are in the EPA concurrence process. If the 2010 data is not concurred on by EPA, the baseline design value will be 51.8 $\mu g/m^3$. These Exceptional Events become official when EPA acts on them in the Federal Register, which will come when the EPA acts upon this SIP revision.

STEP 2:

The intent of Step 2 to is to develop the average $PM_{2.5}$ chemical speciation for representative polluted days. For Fairbanks we designated the top 25% of winter days during Quarter 1 and 4 of 2006-2010—as indicated by the $PM_{2.5}$ concentration from the FRM filter -- for this task as a balance of choosing the relevant polluted days and having a statistically strong dataset to use (Table 2). We develop a post-SANDWICH average speciation for Quarter 1 (January, February, and March) and Quarter 4 (October, November, and December) separately, according to EPA modeling guidance. We then use the average of the Quarter 1 and Quarter 4 speciated concentration because Fairbanks experiences polluted days across all winter months.

We developed the species concentration fractions from the STN monitor located at the same State Office Building location as the violating FRM monitor. As mentioned previously, the speciated concentration from the STN measurement cannot be directly used as the speciated concentration from the FRM. The speciated concentration must be converted into the concentration that would have been measured by the FRM monitor after accounting for the differences between the instruments. For example, the FRM measurements do not capture all ambient particles, loss of ammonium nitrate, and addition of particle bound water (PBW) from the STN speciation measurement. The SANDWICH method (Frank, 2006) carries out this conversion process and is described briefly below. We followed the SANDWICH method described from Frank and by EPA modeling guidance exactly in most cases, but made a couple changes specific to woodsmoke-dominated areas in consultation with the EPA Regional Office and in collaboration with other states with woodsmoke issues.

Table 2: The top 25% of high $PM_{2.5}$ ($\mu g/m^3$) days at the State Office Monitor for the years 2006-2010 for Quarter 4 (Q4) and Quarter 1 (Q1).

Q4 Date	Q4 FRM Concentration ($\mu g/m^3$)	Q1 Date	Q1 FRM Concentration ($\mu g/m^3$)
20081229	114.5	20100126	83.2
20071220	51.6	20090107	59
20091209	51	20090110	52.7
20081114	50.7	20060117	51.9
20081202	46.7	20100102	51.8
20091230	43.1	20100105	51.8
20091221	41.5	20100108	44.4
20101201	41.2	20060111	42.2
20091212	40.8	20080209	40.4
20081214	38.3	20090104	39
20081108	37	20100120	38.1
20101207	36.9	20060105	38
20091124	35.3	20100111	36.9
20081217	34	20070205	34.1
20071223	33	20070223	33.1
20061219	32.1	20060129	32.7
20061125	31.1	20100204	31.5
20071129	29.6	20100213	30.9
20081223	29.1	20070220	29.7
20081111	27.4	20070127	29.6
20081205	27.1	20090113	29.1
20071217	26.7	20100201	28.8
20091121	26.2	20100123	28.5
20081220	25.7	20070301	28.2
20091227	25.2	20090215	28
20101210	25.2	20090101	27.7
20091206	25.1	20060123	27.6
20061119	23.7	20100129	27.4
20081123	23.6	20070112	26.7
20061207	22.8	20090125	26.2
20071111	22.7	20100216	26

SANDWICH addresses the 7 major measured components of $PM_{2.5}$:

- Measured sulfate [SO_{4STN}]
- Adjusted nitrate [NO_{3FRM}] (retained on the FRM filter)
- Adjusted ammonium [NH_4FRM] (retained on the FRM filter)
- Measured elemental carbon [EC_{STN}] (corrected IMPROVE to NIOSH analysis)
- Organic carbonaceous mass estimated from a mass balance [OCMmb]
- Estimated particle bound water [PBW]
- Estimated other primary $PM_{2.5}$ components [OPP]

Measured sulfate

There are no major differences in how the STN and FRM instruments measure sulfate. It is assumed that the sulfate measured by the STN is equal to what was captured by the FRM.

Retained Nitrate Mass

Nitrate volatilizes from the FRM filter but not the STN measurement. SANDWICH calculates the amount that would have volatilized if the amount of nitrate measured by STN had been deposited on the FRM filter. The volatilized nitrate mass concentration, delta NO_3, in units of μg/m^3 is

$$\Delta NO_3 = \frac{745.7}{T_R(K)} x \frac{1}{24} \sum_{i=1}^{24} K_i^{1/2}$$ Eq. 5.2 (USEPA, 2007) ;(Eq. 5, (Frank, 2006)).

The dissociation constant for ammonium nitrate (K_i) is evaluated for every hour of every day of nitrate measurements we are using for the analysis. The hourly temperature and relative humidity data used for the associated equations (Frank, 2006) in determining K_i are from the Fairbanks Airport (PAFA). The reference temperature T_R in Eq. 5.2 is the daily average ambient temperature and then ΔNO_3 averaged to 24-hour. The retained nitrate [NO_{3FRM}] is estimated by

$NO_{3FRM} = NO_{3STN} - \Delta NO_3$.

A limit was applied to NO_{3FRM} as follows,

If $NO_{3FRM} < 0$, then $NO_{3FRM} = 0$.

The potential nitrate loss using local Fairbanks meteorology is shown in Figure 2. The graph is labeled as potential nitrate loss, because the loss of nitrate is bound by the nitrate on the filter (NO_{3FRM}). The amount of nitrate volatilization during the winter in Fairbanks is low. The maximum nitrate loss of all the days analyzed from 2006-2010 was 1.2 μg/m^3 and was during the summer on exceptional event day.

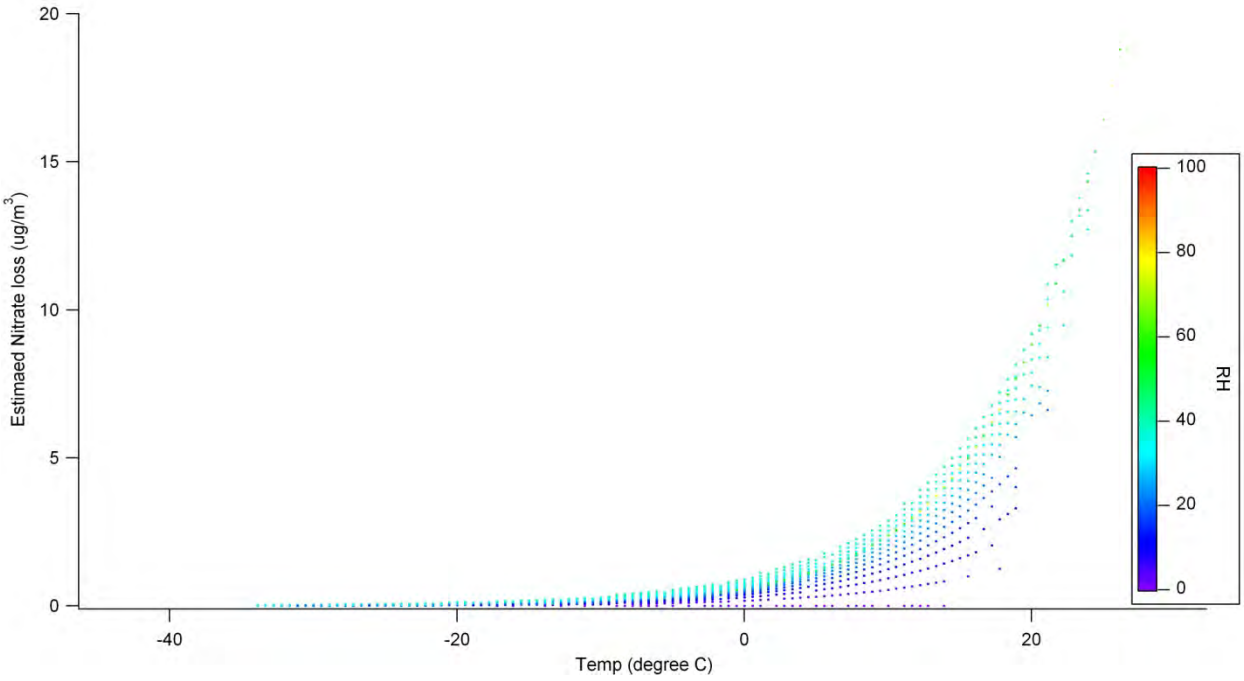

Figure 2: Fairbanks Potential 1-hr NO_3 loss as a function of temperature and relative humidity.

Adjusted Ammonium Mass

EPA modeling guidance recommends using the measured STN ammonia (NH_4) as the measured FRM ammonia. Many of the questions raised in the guidance about the validity of such a recommendation are not problems in Fairbanks because Fairbanks winters are very cold and the amount of ammonium nitrate volatilization is very small. Thus,

$[NH_{4FRM}] \cong [NH_{4STN}]$.

In cases where the ammonia concentration exceeds the amount necessary to neutralize the FRM sulfate and nitrate, the ammonia concentration was adjusted to ensure charge balance. This is a deviation from the USEPA recommended adjustment, but has been noted in other adjusted ammonium concentration calculations (Turner, 2010). The adjustment used was:

$NH_{4FRM} = 2 \times SO_4^{2-} + NO_{3FRM} - H^+$ when $H^+ > 0$ or else $H^+ = 0$

The hydrogen ion concentration results from the calculation of particle bound water, as described below.

Elemental Carbon Mass

Elemental carbon (EC) concentrations as measured by the STN instrument are used directly as the concentrations for the FRM measurement. In October 2009, the STN instrument at the Fairbanks State Office Building changed its technique for measuring elemental and organic carbon; the MetOne SASS using the NIOSH analysis method was replaced with the URG 3000N using the IMPROVE analysis method. Since most of the measurements were made on the SASS sampler and NIOSH method and evidence of high wood smoke $PM_{2.5}$ areas are more accurately measured by the NIOSH method, the EC

measurements from October 2009 on were corrected to reflect the NIOSH method (Hixson, 2011). Traditionally in the Lower 48 the NIOSH data is corrected to reflect the IMPROVE method, but the opposite makes sense for the particular case of a wood smoke dominated area with primarily NIOSH data in the 2006-2010 analysis timeframe.

$EC_{FRM} = EC_{SASS/NIOSH}$ (Before October 2009)
$EC_{FRM} = (EC_{URG/IMPROVE}*0.5722) + 0.2509$ (After October 2009)

Other primary $PM_{2.5}$ components

We calculate the other primary $PM_{2.5}$ (OPP) directly as recommended by EPA modeling guidance:

OPP= 3.73 x [*Si*] + 1.63 x [*Ca*] + 2.42 [*Fe*] + 1.94 x [*Ti*].

Particle Bound Water Mass

Because the STN speciation does not measure the particle bound water (PBW) that would be present in the $PM_{2.5}$ if it were being measured by a FRM monitor, we calculate the PBW with the Aerosol Inorganic Model II (http://www.aim.env.uea.ac.uk/aim/model2/model2a.php). Inputs to the model are using the ammonia, nitrate, and sulfate concentrations as calculated above. As suggested by Frank (2006), the model is evaluated at 295K and 35% RH because these are the equilibrium atmospheric conditions under which the FRM filter is weighed in the laboratory. In the model we assume there is no ammoniated compound solid formation and us the following ion mass balance equation:

$H^+ = [2 \times SO_4^{2-}] + NO_3^- - NH_4^+$.

The measured sulfate, retained nitrate mass and adjusted ammonium mass allowed an estimated hydronium ion proton molar concentration and a PBW water mass was directly calculated from the AIM model.

Organic Carbonaceous Mass

SANDWICH estimates organic carbonaceous mass, [OCMmb], as the amount that is not explained by other chemical species:

$OCMmb = [PM2.5_{FRM}] - \{[SO_{4STN}] + [NO_{3FRM}] + [NH_{4FRM}] + [EC_{FRM}] + [OPP] + [PBW] + 0.5$

The STN instrument measures organic carbon directly, but the techniques to quantify the organic mass have considerable uncertainties. The mass balance technique is reasonable since all other species can be well-quantified and it is likely the remaining mass is organic carbon. As a benefit mass closure is assured. To guard against spurious results, the organic carbon mass is bound on the lower end by 70% of the measured organic carbon and on the upper end by 80% of the total mass. As with the elemental carbon concentration, organic carbon concentrations obtained with the URG/IMPROVE method were converted using the correlation in Hixon (2011) to the SASS/NIOSH method. When a bound is applied, the speciated concentration no longer adds up to the total concentration. When this happens all species are adjusted proportionally such that they add up to the total measured concentration by the FRM instrument. The upper bound was never invoked by the Fairbanks data set, while the lower bound was used on three

occasions (5% of the total dataset). The concentration closure adjustment in these three cases modified the sum of the species' concentration by less than 10%.

Quarterly average FRM-derived species concentration fractions

The SANDWICH process is done separately for every 24-hour measurement in the dataset. The top 25% polluted days in 2006-2010 for Quarter 1 and Quarter 4 represent 31 and 27 samples, respectively. The average speciation for Quarter 1 and Quarter 4 is presented in Table 3 and Figures 4-5. These values represent the chemical composition of $PM_{2.5}$ on polluted wintertime days in Fairbanks for the baseline 2006-2010 period.

Table 3: Quarterly average percentage of SANDWICH'ed $PM_{2.5}$, calculated from the top 25% of $PM_{2.5\ days}$ for years 2006-2010

	SO_{4STN}	NO_{3FRM}	NH_{4FRM}	PBW	$EC_{URG/IM>SASS/NI}$	OPP	$OCMmb_{URG/IM>SASS/NI}$
Q4	17.40%	3.64%	7.57%	5.82%	6.89%	1.25%	57.43%
Q1	19.15%	5.0%	8.54%	6.27%	6.19%	1.01%	53.82%

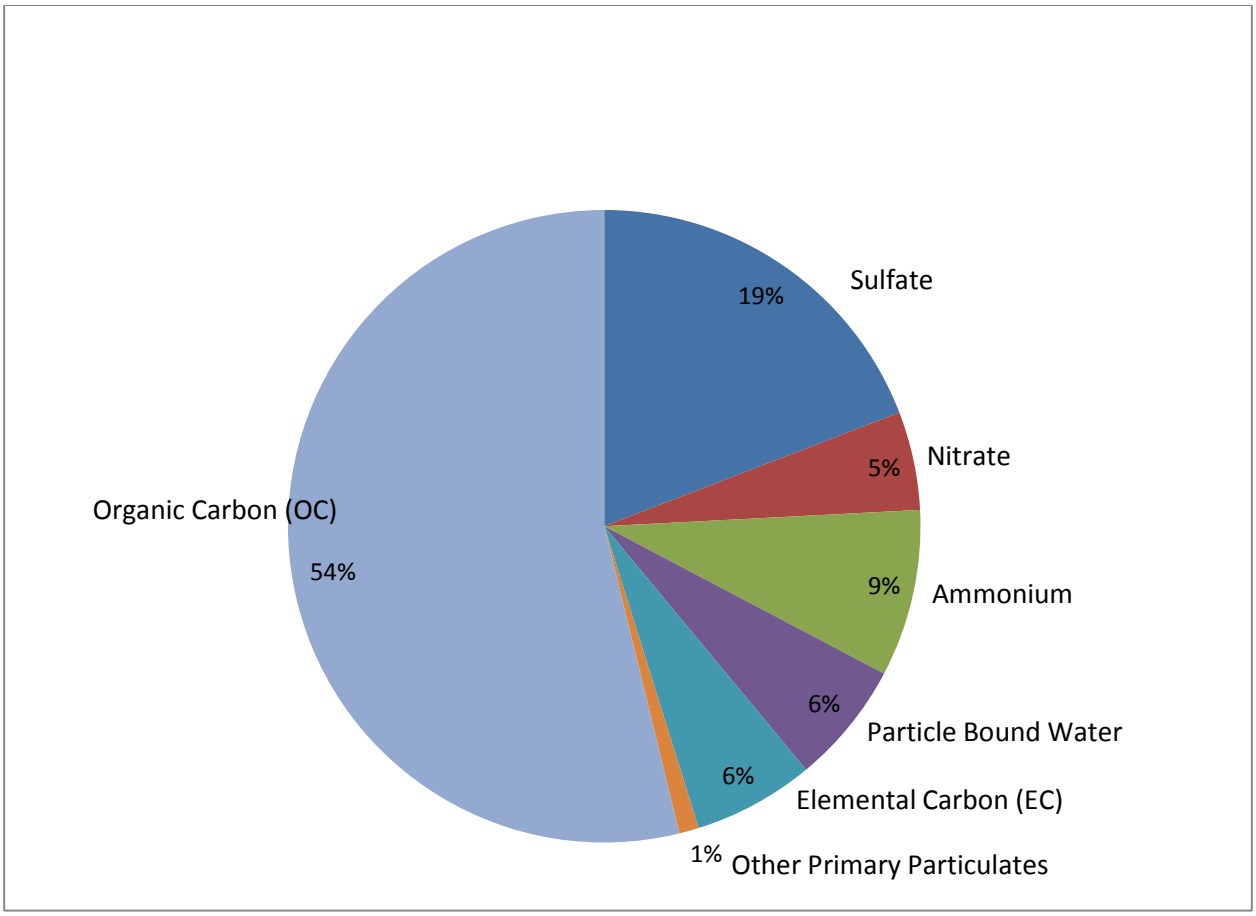

Figure 4: Quarter 1, FRM-derived species percentage of high 24-hr average $PM_{2.5}$ days from the Fairbanks State Office Building for years 2006-2010.

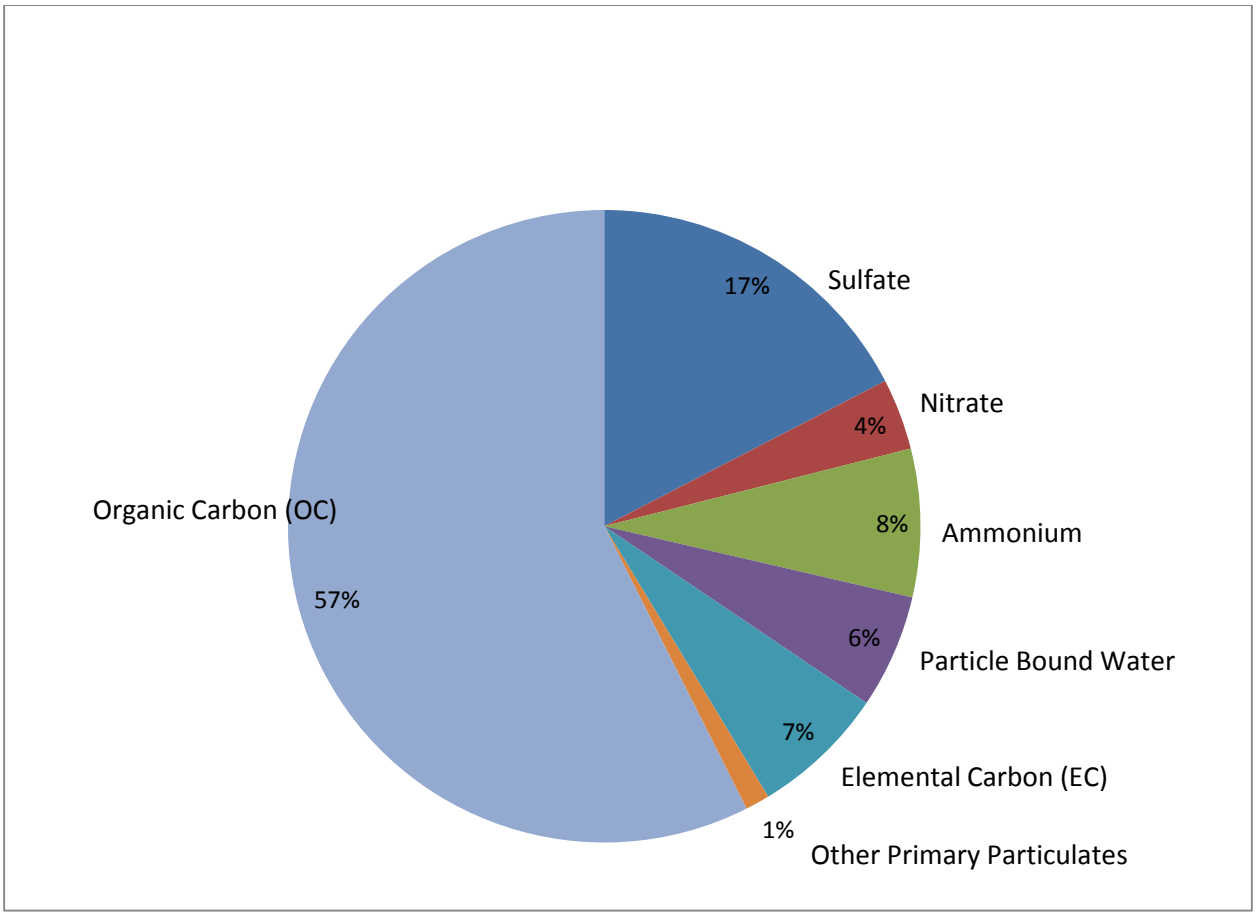

Figure 5: Quarter 4, FRM-derived species percentage of high 24-hr average $PM_{2.5}$ days from the Fairbanks State Office Building for years 2006-2010.

After SANDWICH was complete and the Q1 and Q4 average species concentrations and percentages were calculated (Table 4), the average species percentage was multiplied by the baseline design value of 44.7 $\mu g/m^3$ from Step 1. While not necessary for the model attainment test, this information has been helpful in guiding other parts of the attainment plan.

Table 4: Averaged Quarter 1 and 4, FRM-derived species percentage of high $PM_{2.5}$ days and average concentration based on the baseline design value (DV) of 44.7$\mu g/m^3$.

Species	Sulfate	Nitrate	Ammonium	Water	elemental carbon	OPP	Organic carbon
Q4 %	17.40	3.64	7.57	5.82	6.89	1.25	57.43
Q1 %	19.15	5.03	8.54	6.27	6.19	1.01	53.82
Average of Q1 and Q4 %	18.28	4.34	8.05	6.05	6.54	1.13	55.62
Average DV($\mu g/m^3$)	8.17	1.94	3.60	2.70	2.92	0.50	24.86

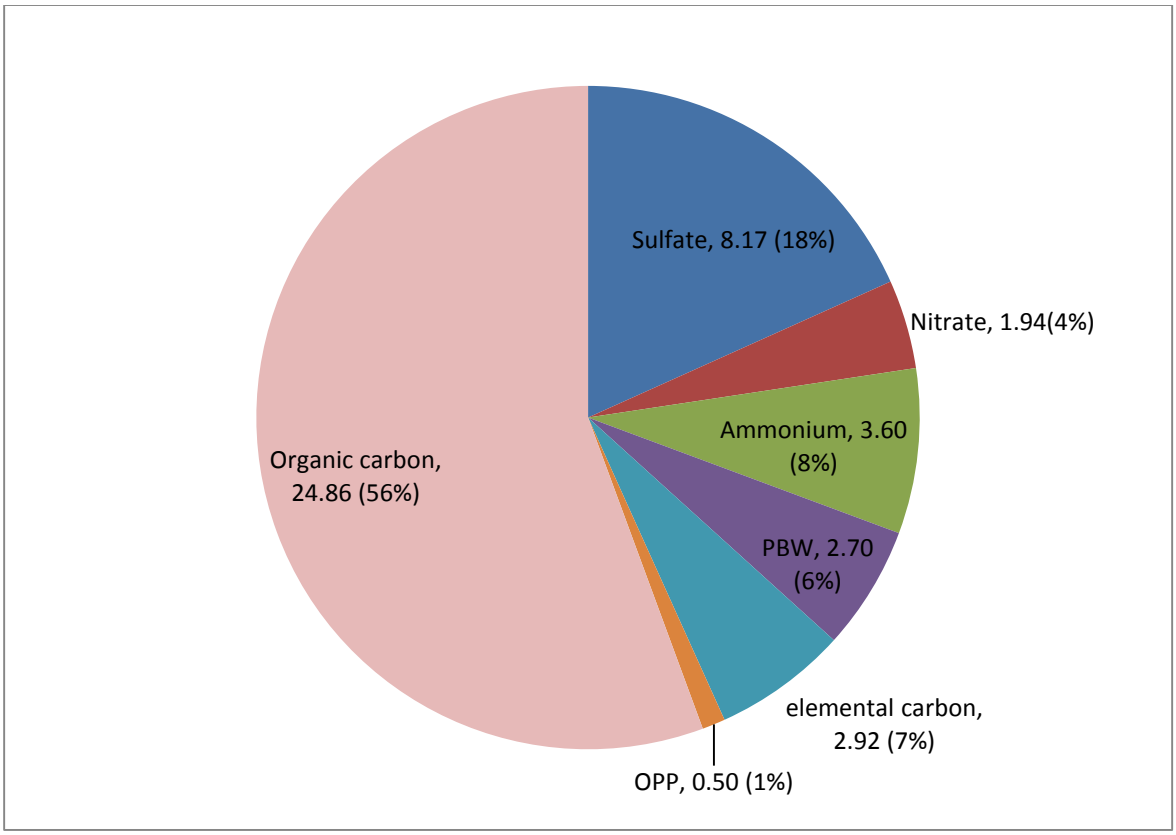

Figure 6: Averaged Quarter 1 and 4, FRM-derived species percentage of high PM2.5 days from years 2006-2010 and average concentration based on the baseline design value (DV) of 44.7 μg/m^3.

Step 3: Calculate species concentration for each of the high ambient days

Step 3 calculates the concentration of chemical species on each of the high ambient days in 2006-2010. For example, the highest $PM_{2.5}$ from 2006 was 51.9 μg/m^3 on January 17th (see Table 1,STEP1), Using the Quarter 1 average speciation percentages (Table 4), we calculate the species concentrations in μg/m^{3}on that day at the Fairbanks State Office Building in Table 5:

Example for sulfate:

51.9 μg/m^3 - 0.5 μg/m^3 (blank filter) = 51.4 μg/m^3 x 0.1915 (SO4, Q1 % from Table 3) = 9.84 μg/m^3

Table 5: $PM_{2.5}$ Species concentrations in μg/m^3 for the highest day in the year 2006

Date	FRM PM2.5	Blank	Non blank FRM	Sulfate	Nitrate	Ammonium	Water	Elemental Carbon	OPP	Organic Carbon
1/17/06	51.9	0.50	51.40	9.84	2.58	4.39	3.22	3.18	0.52	27.66

The same process is done for the top 25% of high days during the winter (Quarter 1 and 4) and all of these high days are listed in Table 2, STEP 2.

STEP 4: Calculate the component specific RRFs (Relative Response Factor)

The relative response factor is a ratio between the modeled projected concentrations divided by the present baseline modeled concentration for each species. Two episodes from 2008 are modeled using emissions from 2008 (present baseline) and then using emissions from 2015 (future baseline) plus emission reductions from emission reduction strategies (future control). The modeled concentrations from the 2015 future control case are divided by the modeled concentrations from the 2008 present baseline. This is done for each chemical species and for every grid cell of the modeling domain. The result is a table of RRFs similar to Table 5, which is just an illustration for explanatory purposes. The RRFs for the emission reductions proposed in this attainment plan are presented in Chapter 5.9. Concentrations in the both the present and future model runs are calculated as 24-hour average values for each component of PM for the baseline and each component of the future. Then the future components were divided by the baseline for the episode-long 24-hour PM species averages for all episode days except for the two model spin up days at the start of each episode. The resulting RRFs for the modeled State Office Building grid cell are in Table 6. Table 7 shows an example of data from the high days of 2008 with the species-specific RRFs applied in order to calculate the concentration of each $PM_{2.5}$ chemical species in 2015 given a scenario of emission controls.

Example calculation:

Sulfate RRF = 2015 future modeled concentration x 2008 baseline modeled concentration = 0.89 RRF

Sulfate RRF = 8.78/9.82 = 0.89 RRF

Table 6: Relative Response Factor (RRF) example averaged over days in episode 1 and 2 derived from a present baseline 2008 simulation and future year control strategies.

Species	Sulfate	Nitrate	Ammonium	Water	Element Carbon	OPP	Organic Carbon
RRF	0.89	0.95	0.94	1.00	0.88	0.99	0.77

There are no RRFs for particle bound water or the blank, they do not change as control strategies changes. For example, in Table 6, the OCMmb (organic carbon mass balance) RRF is 0.77 and a large decrease in OC is observed from controls that largely only affect organic carbon.

STEP 5-6: Apply the component specific RRFs to the observed air quality by quarter

Step 5-7 are represented as an example in Table 7 for the year 2008, high $PM_{2.5}$ days and the species are added together to calculate the future year $PM_{2.5}$ species (step6). The left side of the Table 7 follows the exact same method as shown in Table 5 for January 17th, 2006. The FRM derived species concentrations based on the Sandwich method on the left and the right side is the future species concentrations based on the example RRFs in Table 6.

Example calculation for future sulfate:

Future Sulfate = 2008 FRM-derived species concentration x 2015 sulfate RRF = 17.66 μg/m^3

Future Sulfate = 19.84 x 0.89 = 17.66 μg/m^3

Table 7: Example RRF future year concentrations based on the RRFs in Table 5 and the top high days in year 2008.

Observed FRM PM 2.5	Blank	Non blk FRM	Observed Sulfate	Observed Nitrate	Observed Ammonium	Water	Observed Elemental Carbon	OPP	Observed Organic Carbon		Future Sulfate	Future Nitrate	Future Ammonium	Water	Future Elemental Carbon	Future OPP	Future Organic Carbon	Blank	Future FRM
114.5	0.50	114.00	19.84	4.16	8.62	6.64	7.85	1.42	65.47		17.66	3.95	8.11	6.64	6.91	1.41	50.41	0.50	95.58
50.7	0.50	50.20	8.74	1.83	3.80	2.92	3.46	0.63	28.83		7.78	1.74	3.57	2.92	3.04	0.62	22.20	0.50	42.37
46.7	0.50	46.20	8.04	1.68	3.50	2.69	3.18	0.58	26.53		7.16	1.60	3.29	2.69	2.80	0.57	20.43	0.50	39.03
40.4	0.50	39.90	7.64	2.01	3.41	2.50	2.47	0.40	21.47		6.80	1.91	3.20	2.50	2.17	0.40	16.54	0.50	34.02
40.4	0.50	39.90	6.94	1.45	3.02	2.32	2.75	0.50	22.91		6.18	1.38	2.84	2.32	2.42	0.49	17.64	0.50	33.78
38.3	0.50	37.80	6.58	1.38	2.86	2.20	2.60	0.47	21.71		5.86	1.31	2.69	2.20	2.29	0.47	16.72	0.50	32.03
37	0.50	36.50	6.35	1.33	2.76	2.13	2.51	0.46	20.96		5.65	1.26	2.60	2.13	2.21	0.45	16.14	0.50	30.94
34	0.50	33.50	5.83	1.22	2.53	1.95	2.31	0.42	19.24		5.19	1.16	2.38	1.95	2.03	0.41	14.81	0.50	28.44
32.6	0.50	32.10	5.59	1.17	2.43	1.87	2.21	0.40	18.43		4.97	1.11	2.28	1.87	1.95	0.40	14.19	0.50	27.27
25.9	0.50	25.40	4.86	1.28	2.17	1.59	1.57	0.26	13.67		4.33	1.21	2.04	1.59	1.38	0.25	10.53	0.50	21.84
23.7	0.50	23.20	4.44	1.17	1.98	1.45	1.44	0.23	12.49		3.95	1.11	1.86	1.45	1.26	0.23	9.61	0.50	19.99
23.5	0.50	23.00	4.40	1.16	1.96	1.44	1.42	0.23	12.38		3.92	1.10	1.85	1.44	1.25	0.23	9.53	0.50	19.82
23.4	0.50	22.90	4.39	1.15	1.96	1.44	1.42	0.23	12.32		3.90	1.09	1.84	1.44	1.25	0.23	9.49	0.50	19.74
21.5	0.50	21.00	4.02	1.06	1.79	1.32	1.30	0.21	11.30		3.58	1.00	1.69	1.32	1.14	0.21	8.70	0.50	18.14
19.8	0.50	19.30	3.70	0.97	1.65	1.21	1.19	0.19	10.39		3.29	0.92	1.55	1.21	1.05	0.19	8.00	0.50	16.71
19.5	0.50	19.00	3.64	0.96	1.62	1.19	1.18	0.19	10.23		3.24	0.91	1.53	1.19	1.03	0.19	7.87	0.50	16.46
14.4	0.50	13.90	2.22	0.00	0.80	0.77	0.76	2.07	7.28		2.22	0.00	0.80	0.77	0.76	2.07	7.28	0.50	14.40

Step 7: Sum the species components to get total $PM_{2.5}$ concentrations for each day

The species concentrations from the future year are added together to arrive at the modeled projected concentrations given changes in emissions between 2015 and 2008 plus changes from emission controls. Table 7 is the result of this process for when or example RRFs (from Step5) are applied to our high ambient days (from Step1). It is an estimate of the $PM_{2.5}$ concentration that would have been observed in 2006-2010 if the area had the pollutant emissions from 2015 and from the proposed emission control strategy. The result of this process for the emission controls proposed in this attainment plan is in Section Chapter 5.6 and Appendix 5.6.

Step 8: Determine future year 98th percentile concentrations for each site year.

The 98th percentile concentration is usually the 3rd highest concentration from a year for the sampling schedule followed in 2006-2010 but it depends on how many valid samples were obtained from the year [Appendix N reference]. For the 2006 $PM_{2.5}$ data, the 2nd highest concentration is the 98th percentile and is the 3rd highest for 2007 through 2010. Table 8 identifies the 98th percentile for the future year control case.

Step 9: Calculate future 5 year 24-hr DV.

The future year control design value is calculated as an average of the 3-year design values from 2006-2008, 2007-2009, and 2008-2010. For our example case:

Table 8: Baseline and Future 5-year Design Values based example RRFs (Table 5)

Year	**98%-tile**	**98%-tile**
2006	42.2	36.6
2007	33.1	28.7
2008	46.7	39.0
2009	51.0	45.6
2010	51.8	44.9
Design Values	**44.70**	**38.6**

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Aerosol Chemistry in Fairbanks: A Summary of Prevailing Conditions

May 27, 2011

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1. Introduction

Atmospheric particulate matter (PM) is comprised of a variety of chemicals across a range of sizes and is nearly ubiquitous in the environment. It is also a dynamic component of the atmosphere that can undergo rapid chemical or physical transformation from a variety of stimuli. This leads to highly complex aerosol climatology that is dependent on a variety of contextual variables and therefore must be characterized with high precision and specificity.

The Fairbanks region in Alaska is a region of specific concern because of the relatively high concentrations of PM, especially in the winter. In recent years, the Fairbanks community has experienced a number of exceedances in which PM concentrations were above the federally-mandated standard. This paper will describe the current state of understanding of the conditions observed in the Fairbanks region. A specific focus of this document entails a detailed discussion of a specific component of PM – sulfur-containing aerosol – that is found in significant quantities of aerosol measured in this community.

2. General Overview on Particulate Matter

Ambient PM is ubiquitous in the lower troposphere and results from a variety of physical and chemical transformations. It can be formed as a primary pollutant from combustion and biogenic sources, as well as by resuspension of dust from crustal surfaces [2-4]. Secondary aerosol sources, i.e. those formed by precursor gases and/or particles, are substantially more complex, however. PM has also been shown to form as a secondary product from a variety of chemical reactions in the atmosphere [3, 5], with the most important reactions involving the secondary formation from petroleum combustion exhaust, biomass burning, and coal fired emissions. The diversity of possible atmospheric reactions makes unequivocal identification of aerosol sources quite complex, and thus, our understanding of aerosol formation is also incomplete. PM is chemically complex in different regions of the world. Figure 1, adapted from Jimenez et al [1] confirms significant spatial variability of aerosol chemical components at the global and continental scale. In general, ammonium, sulfate, and secondary fractions of organic carbon comprise the majority of observed $PM_{2.5}$ mass near the East coast of North America. In contrast, aerosol on the West Coast is more chemically variable, but is driven by nitrate, ammonium, and more volatile fractions of organics. Thus on continental scales,

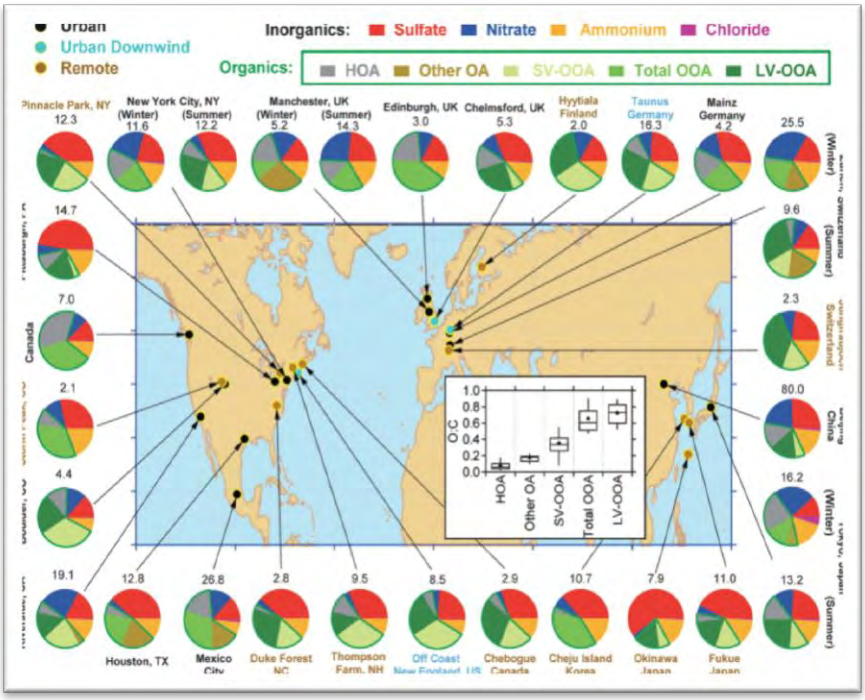

Figure 1: Measured worldwide distribution of aerosol composition, including differences in inorganic and organic components. Figure adapted from Jimenez, et al [1]

significant spatial variability is observed in aerosol chemical composition. This implies that when assessing aerosol chemical exposure in different regions of North America, a $PM_{2.5}$ measure of exposure in one region is chemically different from a $PM_{2.5}$ measure of exposure in another region.

In general, particulate matter in Fairbanks is comprised of a mixture of ions, crustal material, and carbonaceous components, with relative levels of each component dependent, in part, on prevalent local sources and sinks, long-range transport of chemicals, and chemical processing. However, because of its geography and prevailing meteorology, we currently lack a full understanding of the chemical processing that typically occurs, especially during the winter months when there is a high demand for residential heating, strong inversions, and extremely cold temperatures. This white paper attempts to provide a summary of the current state of knowledge, provides an initial analysis of some of the existing data, and proposes some mechanisms for future study. A specific focus of this paper expands the understanding of sulfur chemistry, which drives a significant fraction of the aerosol composition in Fairbanks.

2 Sources of Aerosol Sulfur in Fairbanks

2.1 Sulfur Precursors

Sulfur is emitted into the atmosphere typically as gas-phase constituents from both biogenic and anthropogenic sources. Biogenic sources of sulfur include hydrogen sulfide (H_2S), carbonyl sulfide, dimethyl sulfide and a variety of mercaptans, all of which contain sulfur in the lowest oxidation state (-2). Anthropogenic sources of sulfur are extensive, though the largest source (by mass) is the release of sulfur dioxide stemming from the combustion of petro-fuels such as heating oil, diesel, and coal.

Observed particulate sulfur in Fairbanks comprises a significant fraction of total PM, though our understanding of sulfur sources remains incomplete. Sulfur can be present in three broad forms: as part of an organosulfur compound, as a sulfate salt, or other sulfur-metal or sulfur–metalloid complexes. The latter complexes are atypical and usually only found as a result of specific industrial sources and are often only of limited consequence for an urban community.

Atmospheric processing of these sulfur sources is equally diverse and includes a number of relevant pathways the lead to sulfur-containing particulate matter. There are a number of primary emission sources, such as the release of sea spray laden with sulfate, that do contribute to primary sources of sulfur to the atmosphere, though these are likely to have an insignificant impact on the Fairbanks regions since few sources are located nearby. This leaves secondary formation mechanisms that lead to the bulk of observed sulfur in particulate matter.

Specific sources of sulfur in Fairbanks are thought to include emissions from the three coal-fired power generation facilities (Atkinson Power Plant at UAF, the Chena Power Plant, and the Fort Wainwright Power Plant – a fourth plant in Eielson AFB also exists), on-road diesel fuel, and home heating oil. Long-range transport is not thought to contribute significantly to sulfur loading in Fairbanks because there are very few upwind regional sources of sulfur. Wood-burning does contribute to the overall loading of particulate matter, but it is not likely to directly contribute to the sulfate burden typically observed in Fairbanks. Thus, the available sulfur sources in Fairbanks are probably limited to these three main categories, though recent regulations have sharply reduced the quantity of sulfur in on-road diesel; the mechanisms of formation are also not yet fully understood, and thus a discussion of these mechanisms follows.

2.2 Secondary Sources of Sulfur: Homogeneous nucleation

Gas-to-particle conversion of precursor sulfur-containing gases can be a significant source of particulate laden with sulfate. Briefly, this process is initiated when a gas, such as SO_2, is present in supersaturated conditions and spontaneously forms agglomerates (e.g. molecular clusters). These agglomerations, which are inherently unstable and continuously disintegrate, can interact with one another if an adequate number of agglomerates are formed. In a process similar to coagulation, these agglomerates can form larger particles that exceed (albeit briefly) a critical diameter that allows for vapor equilibrium between the newly-formed particle and the surrounding vapor. In this case, condensation is encouraged and allows for rapid growth of the particle governed by Kelvin theory, a complex ratio of saturation vapor pressure over a flat plane compared to that over a spherical particle.

Homogeneous nucleation typically depends on point sources of sulfur (usually SO_2) that are emitted in high concentrations in order for optimal conditions to be present for gas-to-particle formation to occur. Such sources might include coal- or residual oil-fired power generation facilities, high sulfur fuel use (mainly for heating purposes) or fugitive sulfur emissions from refining activities. This is relevant for Fairbanks because all of these sources are thought to have an impact on local aerosol climatology, though these processes are not yet fully understood. Even less empirical data are available on nucleation in extremely cold environments such as what Fairbanks experiences each winter, though nucleation events at cold temperatures would require higher vapor pressures than an equivalent event at warmer temperatures; essentially, this makes this process less likely a player in aerosol formation in Fairbanks. However, an open mind would be prudent in future assessment of homogeneous nucleation in this community because of the unusual and unique environmental conditions (rapid cooling, ice fog formation, rapid sublimation) that these gases meet soon after emission.

2.3: Heterogeneous nucleation

Heterogeneous nucleation, that is, the formation of sulfur-containing particles that involves precursor gases and other reactants, is a far more complex formation mechanism and likely to be a significant source of particulate-bound sulfur. Heterogeneous reactions are usually mediated by compounds that can either directly oxidize sulfur, or participate as catalysts in oxidation processing. Though gas-phase heterogeneous chemistry involving common oxidants (e.g. hydroxyl radical, ozone, organic peroxides, etc.) is typically quite slow, aqueous phase reactions are greatly accelerated and contribute to the bulk of the observed heterogeneous chemistry. Thus, the importance of available water is crucial for facilitating the formation of particle-bound sulfur compounds.

Heterogeneous formation of sulfur-containing particles likely plays at least some role in the climatology of aerosol chemistry in Fairbanks, however, this formation mechanism is poorly, if not at all, understood. Under more typical conditions, water droplets, or seed particles coated with liquid water (from vapor condensation, deliquescence, etc) serve as the reactor vessels that lead to sulfate aerosol formation. Sulfur dioxide, a common emission source of sulfur, is dissolved in these droplets and allows for much more rapid rates of conversion compared to typical gas-phase reactions. Oxidants, either formed in-situ or directly released, play an important role in mediating this oxidation, and they include ozone, peroxyradicals, hydroxyl groups, formaldehyde, oxides of nitrogen, and some metals and are summarized in Table 1.

Table 1: Possible oxidant reactions that may play a role in sulfur chemistry in Fairbanks

Oxidant component	Likely Local Source of oxidant in Fairbanks	Estimated relative reaction efficiency in Fairbanks winter	Consideration of future measurement to better understand sulfur conversion?
Ozone	Photochemical production of ozone	low	Perhaps. Easy to do with instrumentation already in place.
Hydrogen peroxide	Mainly found dissolved in clouds/fog resulting from photochemistry	Unknown, likely moderate	yes
Organic Peroxides	VOC oxidation due to NO3 radical chemistry	low	Yes, surveys of representative organic peroxides might yield important information on sulfur conversion pathway.
Dissolved Oxygen	Naturally-occurring	Probably trivial	No, yield not likely to be significant and O2 concentration already known.
Metal catalysis (Fe^{3+}, Cu^{2+}, and Mn^{2+})	Direct emission of metals	Unknown, possible synergy in presence of both metals.	Yes, but these metals already measured in speciation network; consider additional study of metal oxidation states.
Hydroxyl radical	Photochemical production from water vapor/droplets/crystals	Probably low	No, technically challenging to directly measure OH
Oxides of nitrogen	Direct emission	Low	Yes, despite low theoretical yield, research infrastructure already in place by investigators at UAF. Also, many local sources, especially in winter.
Formaldehyde (and other aldehydes)	Direct emission and secondary formation from VOC oxidation	unknown	Yes

Of these typical oxidant pathways, most are pH dependent, with lower sulfur conversion yields at higher pH [6]. They also vary depending on the precursor chemical concentrations present in the ambient environment. An exception to this is the pathway involving hydrogen peroxide which is relatively insensitive to changes in acidity, and maintains a high sulfur conversion yield independent of pH (assuming typical urban concentrations of constituent gases).

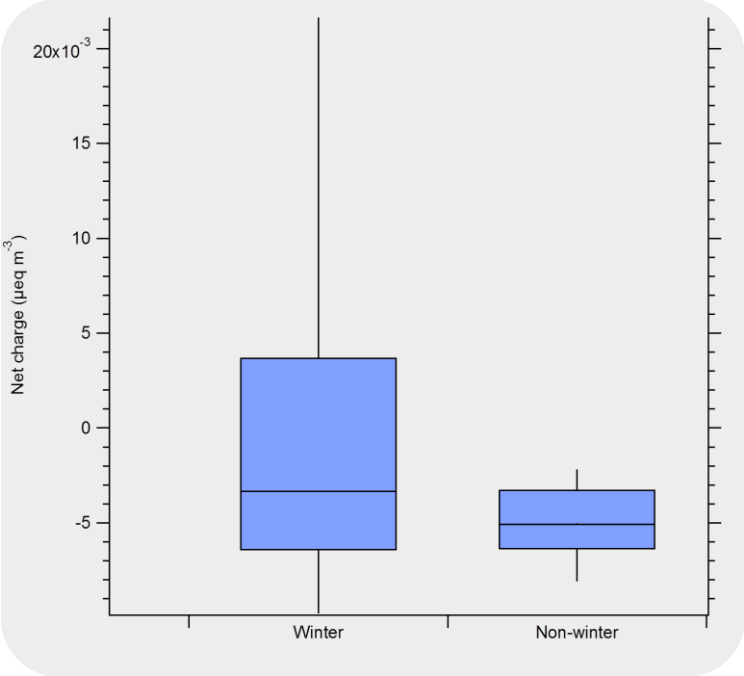

Figure 2: Net charge on aerosol resulting from sulfate (-2), nitrate (-1), and ammonium (+1) by season. Winter is defined as November- March; non-winter is all other months. Measurements less than zero suggest an apparently acidic aerosol.

Using data of fine sulfate, ammonium, and nitrate collected by FNSB from 2007-2010, we observe a somewhat different apparent aerosol acidity profile in the winter compared to the non-winter periods (Figure 2). While this approach only includes a fraction of the components that comprise a molar balance of aerosol (e.g. other aerosol species may change this balance), it appears that aerosol is generally acidic in both the winter periods (defined as November – March) and the non-winter periods (April – October). There is no significant difference between the two seasons, though there is a skewing of data during the winter towards more alkaline conditions that is not observed in the summer. This indicates an apparent excess of positively-charged components (e.g. ammonium ion) during the winter. In the case of positively charged aerosol, previous work [7, 8] has shown this to likely be a result of biomass burning influence and suggests the presence of unmeasured organic acids as the anionic pair.

The majority of the scientific understanding on sulfur chemistry has been studied under acidic conditions. Only limited information on heterogeneous chemistry is available and seems to suggest that typical sulfur conversion reactions are not highly favored. Nonetheless, sulfur (mainly as sulfate) is most certainly observed in significant quantities in Fairbanks. Most research has investigated alkaline sulfate formation of sea salt in the presence of ozone, though this process is not expected to play any significant role in Fairbanks. Thus at present, the mechanism of heterogeneous sulfate formation in the winter in Fairbanks is not understood.

Of the mechanisms described in Table 1, the most likely candidates to play a significant role in sulfur conversion in Fairbanks appears to be that induced by hydrogen peroxide, organic peroxides, metal catalysis, oxides of nitrogen, and formaldehyde. This does not exclude the other sources of sulfur conversion chemistry, but they are not likely to play a large role in contributing to the observed sulfur in the region. While there are plausible primary sources of these components, there may also be unusual secondary chemistry at play that forms these reagents in-situ. A number of arctic studies [9-11] (and references therein) have suggested that halide chemistry, specifically interactions with chlorine and bromine species, play an important role in catalyzing oxidant formation, specifically in the presence of snowpack. Most existing studies, again, have taken place in remote areas (e.g. Barrow, AK, northern Finland, Greenland, etc), and have centered on investigating the fundamental mechanistic chemistry principles under pristine conditions and may not be fully transferable to a more complex urban

environment characterized by multiple sources of aerosol. However, this pathway may still be an important determinant in the formation of atmospheric constituents that can lead to sulfur conversion.

A unique possibility for further study of sulfur chemistry in the Fairbanks area relates to the widespread presence of ice fog in the vicinity of the Chena River during the winter. With low winter temperatures, most water bodies in the region freeze to solid ice (surfaces at least). The Chena River, which winds through the central downtown region, is injected by waste heat produced by the Chena Power Plant, a 29MW coal-fired facility. Coupled with winter dew points well below zero and low ambient temperatures, artificially warm river water rapidly evaporates, condenses, and freezes each day. This represents a significant mass transfer of water and dissolved components into the air, and may suggest a possible source for direct formation of aerosol from this process [12-14]. It also likely provides a large number of small particles, which in total, create a large surface area suitable for reactive chemistry. This is particularly important because it occurs in the immediate vicinity of the power plant; in the presence of a looping or fumigating plume, there is the potential for significant sulfur chemistry.

2.4 Sulfur losses

Particulate sulfur is lost through one of two ways: via transport out of the measurement domain (e.g. long-range meteorological transport), or loss to the surface by deposition (through direct contact with surfaces or induced by precipitation). Because it is very stable, sulfur bound as sulfate aerosol generally does not undergo further chemical processing that reduces concentration. Other sulfur species (e.g. organosulfur components) may be subjected to further chemical processing though this mechanism is not understood and depends on the initial chemical conditions, aerosol sources, and available atmospheric reactants. Because the region has relatively low annual precipitation, it is likely that sulfur losses in Fairbanks are most likely a result of long range transport out of the region.

3. Current Investigations and Open Questions

The Fairbanks region is characterized by almost entirely locally-generated particulate matter, with relatively low concentrations in summer and much higher concentrations in winter. For much of the United States, this seasonal pattern is reversed (with highest PM concentrations observed in the summer) and reflects the importance of photochemistry in the formation of PM. Fairbanks, however, lacks significant photochemistry in the winter suggesting that unique, alternative formation mechanisms drive the chemistry. While a number of studies have looked at atmospheric chemistry in arctic regions, to our knowledge, no studies have examined in detail the processing of urban pollutants in arctic regions. This is, in part, because there are relatively few cities located in arctic regions and there are comparatively few opportunities to conduct such investigations.

The Division of Air Quality of Fairbanks North Star Borough, has had a presence monitoring ambient particulate matter since 1999. It currently operates 4 monitoring stations, and includes measurements of PM_{10} and $PM_{2.5}$, as well as measurements of carbon monoxide, SO_2, and chemical speciation. Recent efforts have begun the attempt to characterize the chemistry conditions prevalent in the Fairbanks region beyond the scope and capacity of the FNSB borough, and these are now summarized. As of the date of this document, many of the results summarized below are in progress and final data and analyses are not yet completed.

3.1 Measurements by FNSB

Measurements of elemental sulfur and particulate sulfate have been collected in Fairbanks since 2003. Figure 3 shows a simple time series of sulfate concentration. Of note, significant wintertime spikes in sulfate are apparent, with summer minima more typical. Also plotted on this figure is the ratio of directly measured elemental sulfur that is predicted stoichiometrically by sulfate (e.g. removal of four moles of oxygen per mole of sulfate), including a box-plot smoothed line to more clearly identify any patterning in the data. Despite the seasonal spikes in sulfate concentration, no

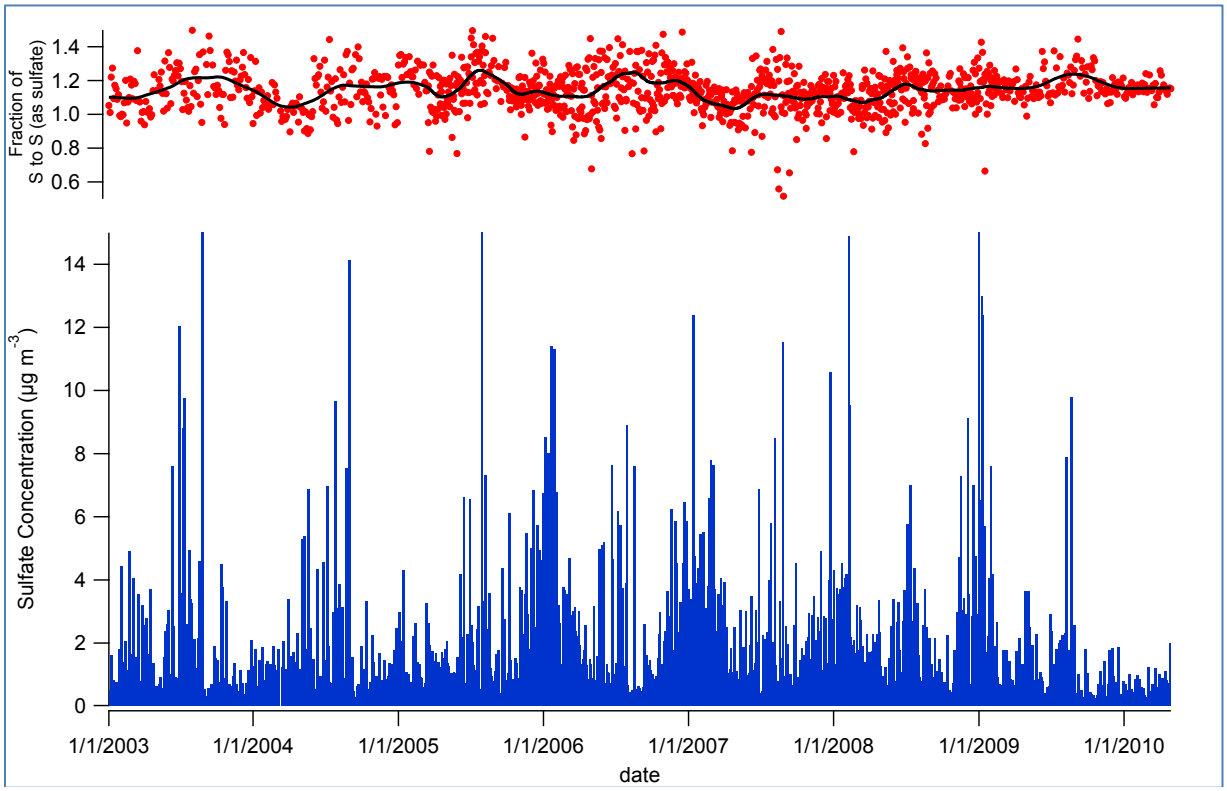

Figure 3: Time series of sulfate concentration (lower frame) and sulfur-to-sulfur ratio (upper frame, including box-smoothed line for visual aid) from Jan 2003-Jan 2010, as collected by FNSB.

pattern in this ratio is apparent, although it appears there is an unmeasured source of sulfur in Fairbanks that is not measured as sulfate. On the whole, the sulfur-to-sulfur (as sulfate) ratio is 1.15 and suggests an addition ~15% of sulfur cannot be attributed to sulfate. The ratio and sulfate concentration measurements are not correlated, suggesting that an independent factor is associated with this additional sulfur. Possible sources for this include organosulfur compounds or sulfur gases preferentially-adsorbed and reacted onto elemental filters. Additional work is continuing to understand this process.

3.2 Modelling approaches

Investigators from the University of Montana, Center for Environmental Health have recently concluded an intensive effort to characterize aerosol chemistry from 2008-2009 using modeling approaches. This study, which employs a Chemical Mass Balance model to identify relative sources of aerosol, utilized existing data provided by FNSB from five monitoring locations in the region. A secondary approach used archived filters for a chemical analysis of isotopes of carbon as well as levoglucosan, a marker for

biomass burning. Their results were recently summarized in a final report by Dr. Tony Ward (Ward, 2010).

Their CMB analysis identified 5 prevailing source profiles of aerosol representative of the Fairbanks region. While there was some site-to-site variability, winter time aerosol loading was most significantly impacted by woodsmoke (range: 62.7%-79.8%, depending on location). Sulfate aerosol was the second most prevalent component of PM (range: 9.8%-20.0%). Their findings also suggest that ammonium nitrate was also substantial (range: 5.1%-10.5%), with lesser contributions from automobile exhaust (range: not detected to 6.8%), diesel exhaust (range: not detected to 7.3%), and Unexplained (range: 0.5%-1.2%). While CMB modeling does not provide insight into specific chemistry, is does provide information towards the more important chemical processes that might be at play in the Fairbanks region.

This study also provided an analysis of 14C carbon isotope ratio analysis that provides information on the sources of the observed carbon. 14C analyses are particularly powerful because they can identify, at the atomic level, the likely age of the carbon elements. In this case, Ward's investigation provides confirmatory evidence that woodsmoke, or 'modern carbon' is a significant contributor to the aerosol loading in the Fairbanks region. This project investigated an additional dataset of levoglucosan, a sugar associated with woodsmoke. Their results were, again, consistent with the notion that woodsmoke contributes significantly to the aerosol mass loading for the Fairbanks airshed.

3.3 Denuder studies

Work at the Washington University in St Louis has begun to investigate the nature of denuder function in cold-weather environments. This study explores three main objectives: whether extreme cold temperate allows for SO_2 penetration through a denuder, whether water vapor interferes with denuder functionality, and whether long-term denuder loading plays a deleterious role in denuder efficiency. This work is still under development and not yet completed, but early results suggest that there is no significant effect on denuder function based on cold-temperate operating conditions, and that water vapor does, in fact, inhibit the denuder from efficient functioning.

3.4 Winter intensive characterization

In February and March of 2011, investigators from the University of Massachusetts established an intensive field monitoring site to provide a broad spectrum of chemical characterization measurements at a fast time resolution. This was an effort to establish more advanced chemical measurements throughout typical wintertime conditions in Fairbanks, and to capture both typical and atypical PM climatology in the region. The study collected hourly aqueous samples of dissolved $PM_{2.5}$ (including all typical ions), daily high-volume filter samples (for trace metal analysis), and hourly measurements of organic carbon and elemental carbon.

Preliminary data, which has not yet been validated, shows a time series of organic and elemental carbon during the study period (Figure 4). The data are characterized by highly distinct spikes of both organic and elemental carbon, with a good correlation between the two measurements ($r^2 = 0.53$). This suggests that a periodic event that leads to this chemistry consistently occurs and lowers the likelihood of industrial sources of OC or EC (such as power plant emissions or refinery effluent, which normally do not have a significant diurnal emissions profile). Ion measurements and trace metal results are still

pending.

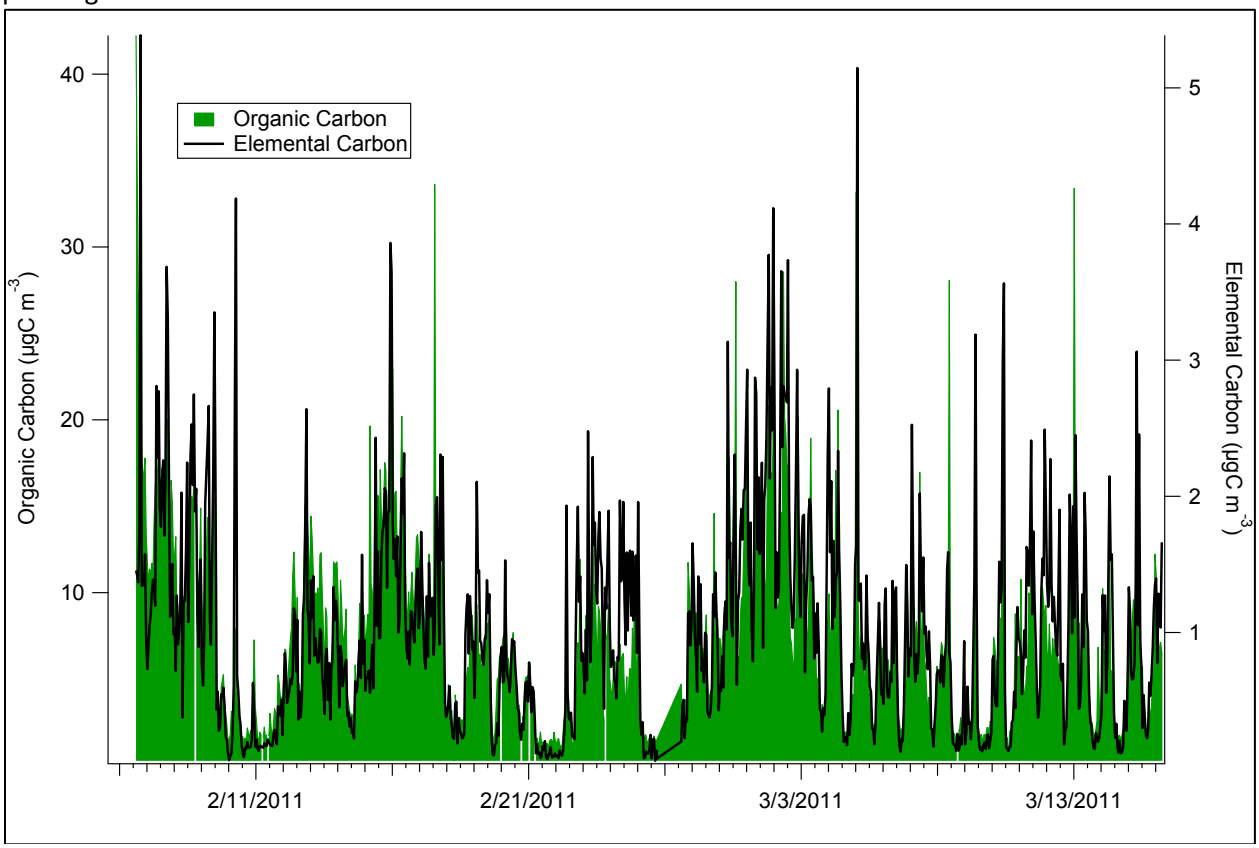

Figure 4: Time series of organic carbon and elemental carbon measured during this study in Feb-Mar 2011 in Fairbanks.

There appears to be a wintertime pattern of highly enhanced EC and OC, as well as a precipitous drop in the same concentration. Figure 5 presents the same data in an alternative approach, with all of the OC and EC data presented as box plots across each hour of the day. Both EC and OC exhibit a clear bimodal distribution, with apparent spikes in the late morning and the hours before midnight during the study period. There are several possible explanations for this finding, though the most probable one involves a link to residential heating using wood and/or oil. The latter possibility is important in the context of sulfur chemistry, since wood burning does not normally emit significant quantities of sulfur, and these data may be useful for further study of home heating oil use in that this emits both sulfate precursor as well as organic and elemental carbon, and thus their variability is likely to have a high degree of association.

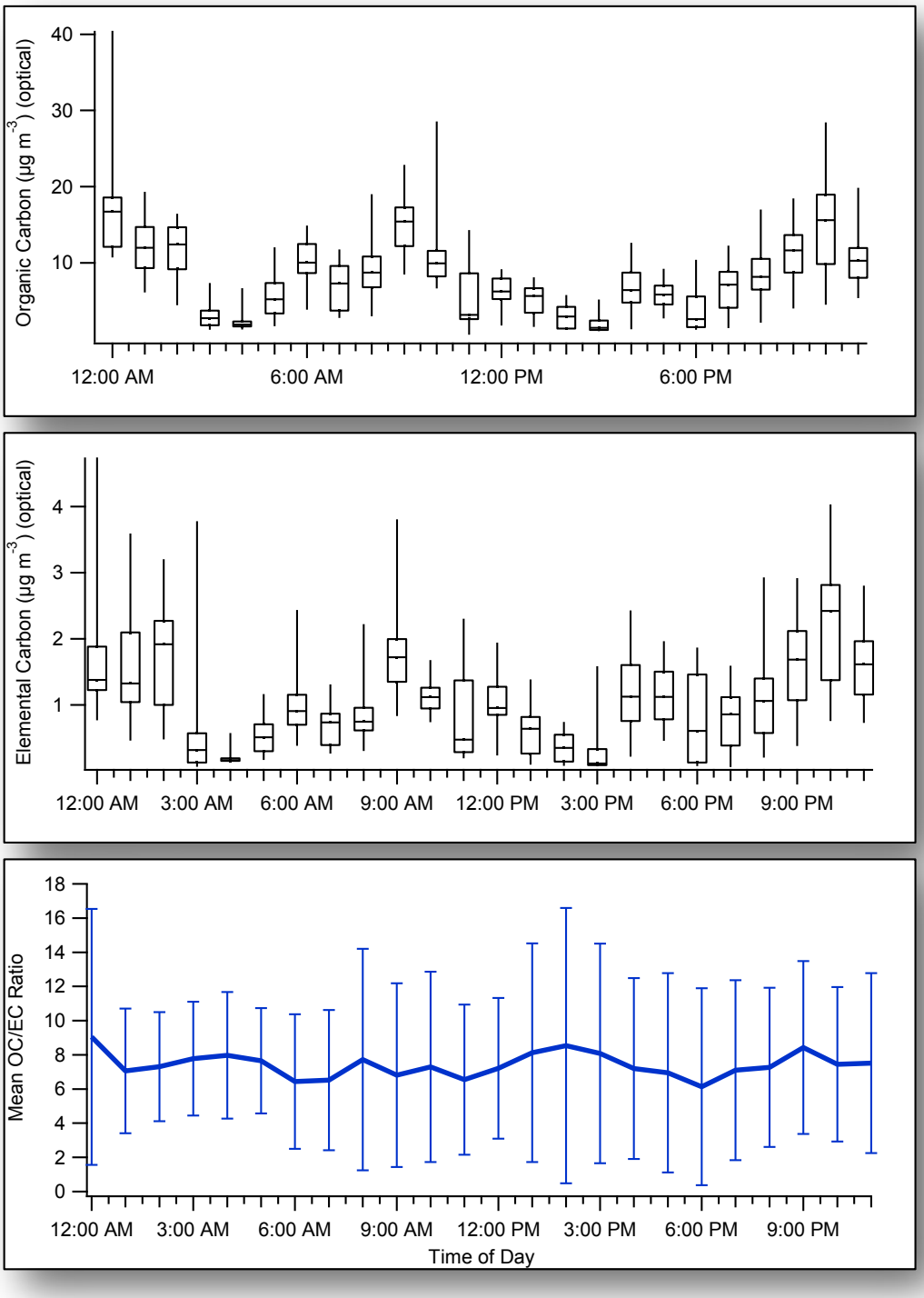

Figure 5: Hourly measurements of organic carbon (top), elemental carbon (middle), and mean OC/EC ratio (bottom). Box plots consist of median and 25th and 75th percentile; whiskers denote 10th and 90th percentiles. Data was collected over approximately 40 days in Feb-Mar 2011 in Fairbanks.

The data also include the mean OC-to-EC ratio for each hour. Overall, these ratios are quite large, with mean ratios approaching 8. The included error bars denote that there is no significant patterning in the data across the diurnal profile, which is inconsistent with the concentration plots of OC and EC. The EC

tracer method of estimating secondary organic aerosol [15, 16], which is an admittedly imperfect analytical approach, would suggest that the majority of the observed OC in the atmosphere is primarily emitted since the ratios are much higher than typical environments with active secondary organic aerosol formation mechanisms. It should be noted that the primary emissions profile of wood and oil burning, on-road diesel combustion, and other local sources of particulates in Fairbanks is not yet known. Additional work (described below) will inform whether the empirically measured ratio is entirely consistent with primary emissions, or if, in fact, secondary formation processes have an important role.

3.5 Fuel feedstock characterization studies

FNSB has recently contracted with Omni Environmental (Portland, OR) to chemically characterize a variety of local fuel feedstocks, including firewood, local on-road and heating oil fuel, and coal. By doing so, it is hoped that a chemical signature profile can be developed for each source indigenous to Fairbanks which, in turn, can be used to study and better understand the observed ambient conditions. As of the date of this paper, no results are yet available.

3.6 Open Questions

Several specific open questions remain that have not yet been addressed by the current efforts. It would be worthwhile to investigate the approaches to answering these questions, and to determine whether these efforts would inform FNSB in the best approach to establishing attainment status. These questions include:

1) To what degree does wintertime ice fog play a role in secondary aerosol chemistry?
2) Can the current emissions inventory of sulfur account for the observed sulfur (as sulfate or non-sulfate sulfur-containing components?)
3) Can PM be better apportioned to on-road diesel, home heating fuel oil, home heating biomass, and coal-fired power plant emissions, which likely comprise the bulk of PM emissions in Fairbanks?
4) How does extreme cold temperatures influence gas-to-particle conversion in the context of stack emissions (e.g. how does a rapidly cooling wet emissions stack perform)?
5) Can existing (or new) air quality models be better calibrated to on-the-ground observations? Are these model assumptions valid?

4.0 Future Plans on Attainment in Fairbanks

Currently, Sierra Research is working with FNSB staff to develop a comprehensive Implementation Plan to ensure compliance with federal air quality standards. Data from these, and future, investigations will provide significant guidance in the best approaches to developing efficient, and effecting plans to reduce the burden of particulate matter.

There are two complimentary approaches to a better understanding of air quality issues in the Fairbanks region, and both are equally important. The first approach includes better empirical understanding of local aerosol conditions through additional field characterization studies. This approach will result in a direct understanding of the critical mechanisms at play in this unique environment, and will do so with the least amount of scientific uncertainty. However, over the long term, additional field studies are probably unsustainable in that they are technically challenging, often limited to answering only a few, specific questions, and can be cost-prohibitive. Thus, computational chemistry modeling is an outstanding extension to field studies. They are cost-effective, highly repeatable, and can be adapted to changing conditions. By themselves however, models – especially those developed to operate in an

atypical aerosol milieu such as that of Fairbanks – need to be compared with on-the-ground measurements to provide operational efficacy and validation to ensure high confidence in their results. A number of these possible future studies are listed in Appendix A, though not all are specific to improving model guidance.

5.0 Summary and Conclusions

This paper has summarized the current state of the science associated with aerosol chemistry during the winter in Fairbanks, Alaska. It has also provided a brief summary of the studies to-date, and these results appear to be consistent with significant issues related to sulfur chemistry, as well as chemistry related to carbon (organic and elemental). Further, it identified likely and unlikely oxidation mechanisms for secondary formation (mainly in the context of sulfur conversion, though this process is not necessarily limited to this element).

Attainment of the National Ambient Air Quality Standards in Fairbanks will only be achieved with a better understanding of aerosol formation chemistry specific to the winter in Fairbanks. Without this understanding, most attempts to reduce emissions – e.g. through regulatory action – may be misguided and not achieve the intended targets. At his point, the understanding of chemical conditions in Fairbanks, specifically related to sulfur chemistry, is quite poor and needs significant improvement.

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Appendix A

Future Research Initiatives: Fairbanks North Star Borough Region

Ice Fog Sample Collection

Method Summary: Develop highly mobile, high volume TSP samplers suitable for quick deployment to collect and characterize ice fog samples for a chemical analysis of potential aerosol formation processes. Samples could be collected and compared across periods of local wood- and fuel-burning influence, when gas-phase power plant emissions have a stronger downwelling impact, or when relatively clean air advects through the region. Samples would be taken in the immediate vicinity of the fog formation near the Chena River, as well as downwind of this fog after the crystals have phase sublimation.

Rationale: Because the chemical processing and formation mechanisms are, at this point, not fully understood, it has been hypothesized that ice fog crystals provide suitable reactive surface area for heterogeneous nucleation in the absence of known oxidant components. Collecting in-situ measurements with newly-formed fog crystals (and pre-existing particles and gases near the river), we can provide baseline concentration measurements of sulfur-containing fine particles. Additional measurements may provide insight into sulfur oxidation processes by assessing differential sulfur-containing particle concentrations downwind of the aerosol/fog mixture.

Spatial profiling of aerosol composition: Stationary Approaches

Method Summary: Develop and simultaneously deploy a set of 15-20 (or more) autonomous filter samplers capable of unattended, low-flow PM2.5 aerosol collection on Teflon filter media. Typical deployment schemes include weekly (or bi-weekly) filter changes with a ½ hour on, ½ hour off cycle that collects samples at low flow (4 lpm) throughout the week. Alternative approaches include more frequent filter changes (e.g. every 48 hours) with a continuous sample collected during each time period. Spatially distributed measurements can be scaled against 2-3 reference site measurements for components thought to have limited local variation (TBD) in order to account for instrument variability, instrument precision, or local emission effects. Study length will be 6-8 weeks during the winter, and can be coupled with 6-8 weeks during the summer for comparative purposes. Filter analysis by gravimetry and high resolution XRF for ~35 metals.

Rationale: The ability to discern spatial and temporal characteristics of particle composition, coupled with meteorological data, may provide important insight into the specific sources of aerosols in the region. Further, it will provide a dense dataset which may inform spatial models currently under production and use in the region with improved chemistry profiles and temporal variations.

Model Validation Studies

Method Summary: Chemical speciation measurements guided by the chemical modeling currently used by FNSB to identify predicted PM concentrations and future attainment. Speciation measurements depend on elements identified by the model as predictive of model efficacy and uncertainty and would be measured in different locations and across different times (e.g. different seasons, diurnal variations). Measurements could include chemical elements such as those measured by XRF, PM2.5 mass, or gas-

phase tracers. Both high spatial resolution models (e.g. smallest grid cells) and low spatial resolution models can be validated.

Rationale: Because of increased reliance on models to efficiently provide estimates or predictions of current and future aerosol climatology, it is essential to characterize the performance of these models in terms of precision and uncertainty through robust field measurements. This approach will provide either a) a mechanism to assess and possibly improve model performance for local conditions; b) provide evidence to invalidate model results based on field testing; or c) provide insight into reasons and locations where model predictions and field measurements are de-coupled.

Spatial profiling of aerosol composition: Mobile Approaches

Method Summary: Expand and enhance the analytical capabilities of the FNSB "Sniffer" vehicle with a wider range of chemical and physical characterization capacity (either permanently or for a specific study period). Relevant instruments for such an application might include high time resolution measurements of carbon monoxide, sulfur dioxide, particle size distribution (by SMPS and/or aerosol laser spectrometer), and short time integrated, high volume filter samplers.

Rationale: Expansion of analytical capacity provides FNSB staff with the capacity to better investigate aerosol chemical characteristics across a wide range of conditions, often in response to short-term prevailing environmental conditions (e.g. presence of strong or weak inversion, periodically located downwind of specific sources of interest, etc). The current Sniffer vehicle has yielded important findings, but is currently limited by analytical capacity and specificity.

Characterizing Organic Carbon (and tracers of combustion) in Fairbanks

Method Summary: Simultaneously characterize carbonaceous aerosol at three or more locations to provide chemical evidence describing multiple facets of carbon. A set of instrumentation will be established at each site, and will include aethelometers, Sunset Labs EC/OC (field instruments), and a custom-built filter sampler capable of multiple sample collections on quartz filters through either denuded or undenuded sample lines. The latter would be collected and analyzed (after extraction) by suitable speciation methods (e.g. GC/MS) for organic speciation, ^{14}C isotopic dating, and levoglucosan analysis. Measurements to be conducted in the winter and summer.

Rationale: Organic carbon accounts for a large fraction of $PM_{2.5}$ (and is even larger when converted to organic matter) and thus represents an important subject of study in order to move FNSB towards attainment. By undertaking more comprehensive chemical analyses with a specific focus on carbon-containing aerosol, FNSB is likely to better understand source contributions to this complex component, whether from fuel oil combustion, on-road diesel/gasoline, or wood-burning.

Using the CALPUFF Dispersion Model to Characterize the Fairbanks Power Plant Plumes.

Fairbanks has a significant $PM_{2.5}$ nonattainment problem with design values increasing, in excess of 50 µg/m^3 in recent years. Chemical speciation shows organic carbon (OC) levels amount to approximately 60% and sulfate levels of about 20% of the mass of $PM_{2.5}$. The dominant source of CO is thought to be from the wood burning and sources of sulfur from space heating oil, power plant fuel oil and coal. Upon analysis of the monitoring site filters, it is not clear whether the SO_2 and sulfate emissions are from fuel oil or from the coal because of the presence of winter time inversion layers.

The air quality model CMAQ, configured with the Penn State developed meteorological model WRF runs showed approximately 20% of the particulate matter composed of sulfate. It was not known whether the sulfur contribution to the $PM_{2.5}$ was from fuel oil or from the coal. EPA region 10 suggested running a dispersion model to assess the plumes from the point sources located at the adjacent areas. ADEC and EPA agreed that CALPUFF would be an appropriate model to run to characterize the plumes from the power plants located within the vicinity of the nonattainment area.

CALPUFF is a non-steady-state meteorological and air quality modeling system used by the EPA for studies that include long range transport of pollutants. The model was configured with WRF inputs using mesoscale model interface program (MMIF) and was modified to handle 38 vertical layers representing Fairbanks with the lowest layer being 4 meters above ground level on a 1.33 x 1.33 km grid cell. Six point sources that are in the Fairbanks $PM_{2.5}$ nonattainment area were modeled for the design episode January 23- February 10, 2008. These six point sources were:

1- Fort Wainwright (Facility ID 1121) – Coal is the fuel source, hourly emissions provided.
2- University of Alaska Fairbanks (Facility ID 315) Coal is the base fuel and distillate fuel oil is the secondary fuel used to satisfy increased loads, hourly emissions were provided.
3- GVEA is the electric utility and has two facilities Zehnder (Facility ID 109). Zehnder peaking facility north of downtown which burns high sulfur distillate fuel oil on an intermittent basis.
4- North Pole (Facility ID 110). North Pole is a larger facility and burns a mixture of high sulfur distillate fuel oil and naptha (very low sulfur), hourly emissions provided for both.
5- Aurora Energy (Facility ID 315) is a power plant owned by the coal company, located in downtown Fairbanks, which burns a mixture of coal and distillate fuel oil. They sell the power to GVEA and they sell hot water and steam to office buildings and a limited number of homes in the downtown area. Only constant yearly emissions were provided.
6- Flint Hills Refinery (Facility ID 71) – is located in North Pole. It is a distillation refinery, no cracking; all heavy ends go back into the pipeline. Hourly emissions were provided.

Figure XX represents the modeling domain 201 x 201 in the X and Y direction with a grid cell size of 1.33 x 1.33 km. In addition to the gridded receptors, the model used discretely placed receptors at specific locations with vertical resolution of the WRF data's first 12 layers to obtain the average surface concentration of the entire domain. Summary of the six major point sources average surface concentration of $PM_{2.5}$and SO_2 is tabulated below.

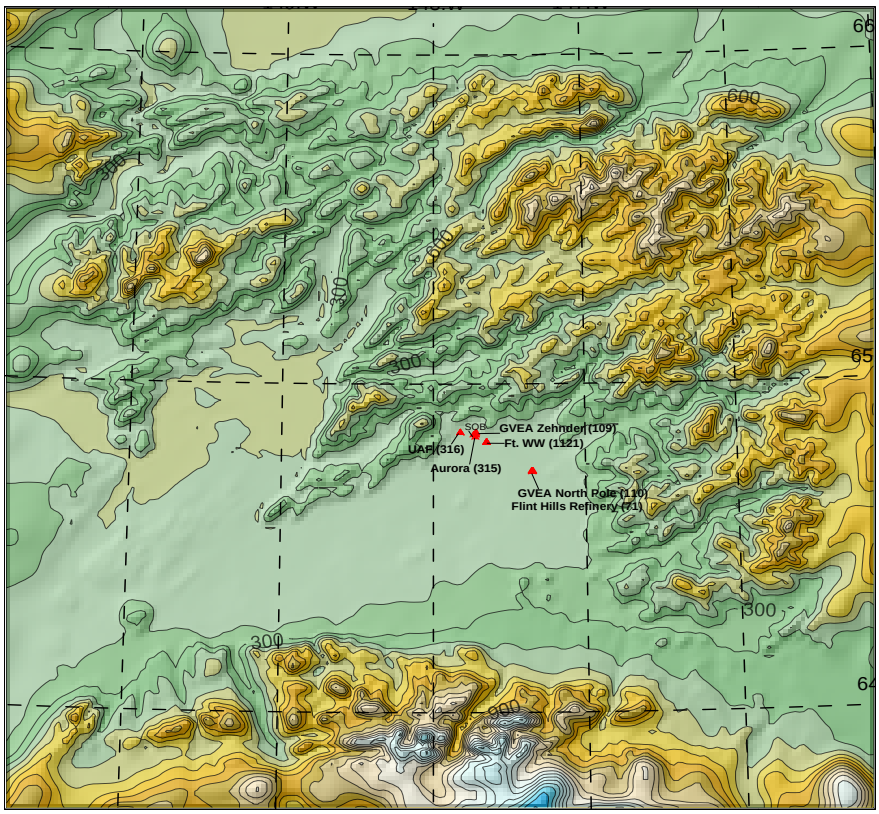

Figure XX: Fairbanks point source locations are represented by red triangles and are labeled by facility ID number and abbreviated name. The SOB (state office building) that houses the FRM (Federal Reference Method) monitor is labeled with a red triangle. The domain represented is 201 x 201, 1.33 km grid cells.

Table 1. Summary of six major Fairbanks point source plumes from CALPUFF for the episode (Jan. 23rd to Feb. 9th, 2008) average surface concentrations of $PM_{2.5}$ and SO_2 in $\mu g/m^3$.

Power Plant	Episode average SO_2 ($\mu g/m^3$)	Episode average $PM_{2.5}$ ($\mu g/m^3$)
UAF- 316	2.75	0.16
Aurora- 315	0.75	0.02
Zehnder-109	0.48	0.19
Flint Hills-071	0.016	0.38
GVEA NP-110	3.8	1.45
Ft. WW- 1121	14	1.6
Total surface concentration	21.8	3.8

CALPUFF modeling showed two largest sources that influence $PM_{2.5}$ concentration at the downtown state office building site were, the GVEA North Pole and Ft. Wainwright power plants. Monitoring data from the state office building was selected for comparison because it was the only location for which January 2008 episode data was available. Average SO_2 concentration from all sites for the entire episode was 4.4 $\mu g/m^3$ and the highest were from the two sources aforementioned. The cumulative effect of all six plants according to model output is estimated to be less than 10% of the $PM_{2.5}$ surface concentration. In overall, whether use of vertical profiles, episode surface concentration averages for all power plants, or SOB specific concentrations, there was not more than 10% influence on the surface concentrations from the six power plants.

Final Report

To

Alaska Department of Environmental Conservation (ADEC)

Grant Number 127617

Reporting Period: 8 March 2011 – 31 January 2012

'Fairbanks, North Star Borough AK PM2.5 Non-Attainment Area WRF-ARW'

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2 Apr 2012

EXECUTIVE SUMMARY

This final report describes work performed by the Department of Meteorology at the Pennsylvania State University under Grant Number 127617, 'Fairbanks North Star Borough PM2.5 Non-Attainment Area WRF-ARW Modeling', supported by the Alaska Department of Environmental Conservation (ADEC) and the Fairbanks / North Star Borough. The purpose of this project was to perform meteorological modeling of the region around Fairbanks and North Pole, AK, as part of the State Implementation Plan for fine particulate matter (PM2.5) analysis of the region. The Fairbanks / North Star region was designated a non-attainment area for the daily National Ambient Air Quality Standard (NAAQS) for PM2.5 by the Environmental Protection Agency (EPA); high PM2.5 concentrations for the area predominantly occur within stable boundary layers during periods of extreme cold and weak winds during the winter season. The air quality modeling component of the SIP utilizes atmospheric analyses generated by a meteorological model; therefore it is important to select a meteorological model configuration that can properly represent the structure and evolution of the local stable boundary layer in these conditions.

The simulations were to be performed with the Weather Research and Forecasting (WRF), Advanced Research WRF (WRF-ARW) model, a globally used and freely-available meteorological model. Initial WRF-ARW simulations for a period in Jan. – Feb. 2008 were performed by Penn State under the Regional Applied Research Effort (RARE) project funded by the EPA. During the RARE project an optimal set of physics options, grid configuration, and data assimilation strategy was developed and tested. For physics sensitivity tests data assimilation was only performed on the coarser two domains (12-km and 4-km horizontal grid spacing), while the finest domain (1-km horizontal grid spacing) was used for assessing sensitivity. It was concluded, however, that a final meteorological analysis to be provided to EPA should also have data assimilation on the finest domain, to provide a better fit to the observations.

For the current contract, the model setup from the RARE project was to be applied to the production of a new meteorological analysis covering the period 2-17 Nov. 2008. As in the final meteorological analysis of the RARE project, data assimilation for the current project uses data assimilation on all three domains. However, a few modifications to the data assimilation procedure were implemented to take advantage of data and source code not used in the RARE project: 1) the effective vertical resolution of the observations as seen by the data assimilation modules was increased; 2) a more vertically-consistent objective analysis procedure was used; 3) additional surface observations from non-standard sources (i.e., stations not present in the standard METAR-format database typically used for hourly meteorological reporting) were used

both for verification and in the data assimilation, in order to supplement the METAR observations in this relatively data-sparse region.

A test period (5 – 9 Nov 2008) was used to perform some initial evaluations of possible modified procedures. In particular, during the RARE project the data assimilation on Grid 3 for the final meteorological analysis only used the temperatures from the METAR surface stations, and not the winds. For the RARE project it was thought that, since the surface winds during the coldest episode would be expected to be weak and poorly sampled, and since the surface winds in these conditions might be expected to be thermally-driven, the best chance of accurately reproducing existing flows would be to only use the temperature (and moisture) fields from surface observations in data assimilation, while relying on the model itself to generate the proper wind fields. This led to realistic low-level flow patterns and generally satisfactory wind error statistics at non-calm locations. There did tend to be a positive near-surface temperature bias during periods of extreme cold and weak winds, which could have been a result of overestimated vertical mixing due to the model's positive near-surface wind speed bias. The extended surface dataset used in the current study provided an opportunity to determine if improved statistics could result if 1-km grid data assimilation of near-surface winds was included. This was one of the initial sensitivity tests performed for the test period.

The major findings of the current project are as follows:

- The use of near-surface winds in data assimilation during the test period, when compared to a control simulation, led to about a 20 degree improvement in the mean absolute error (MAE) of wind direction. Temperature and wind speed statistics were also improved, but the improvements were modest. The modest size of these improvements was hypothesized to be due to either insufficient horizontal resolution of the model topography, or too large of a region of influence of particular observations in the data assimilation procedure.

- A new simulation was performed in which the radius of influence of observations on the 1-km grid was reduced from 75 km to 30 km, and the strength of the relaxation coefficient was doubled. These experiments produced slightly better temperature statistics on average, but slightly worse wind speed statistics. Wind direction errors, however, were further reduced by the new simulation procedure by a substantial amount (about 19 degrees in MAE). It was decided to make this model configuration (experiment TWIND2X30) the basis of a simulation of the entire 2-17 Nov. 2008 episode.

- Previous experiments did not make use of calm wind observations in the data assimilation procedure; the possible presence of missing data or high instrument response thresholds imply that it might be preferable to retain model-generated flows in weak-

wind conditions rather than relax the flows towards a zero-magnitude wind vector by data assimilation. However, because it was desired to further reduce the model positive wind speed bias, an additional set of simulations over the 2-17 Nov. 2008 episode was performed, for which data assimilation did make use of calm wind reports (henceforth experiment TWIND2X30CALM). While the use of calm wind reports did reduce the positive near-surface wind bias of the model, the improvement was only on the order of 0.1 m s^{-1}. Meanwhile, TWIND2X30CALM had wind direction MAE scores that were about 14 degrees worse. Since wind direction by necessity can only be verified with non-calm wind observations, the implication was that the use of near-surface calm wind observations in data assimilation was degrading wind direction statistics at other observation locations without making a substantial improvement in wind speed statistics. Therefore, it was decided to deliver the results of TWIND2X30, rather than TWIND2X30CALM, to ADEC for use in subsequent air quality modeling.

- The Jan-Feb 2008 episode simulated during the RARE study was re-simulated using the TWIND2X30 procedure, and compared with corresponding statistics using the RARE configuration. Little statistical difference was found between the RARE and TWIND2X30 for variables other than wind direction, for which the TWIND2X30 configuration was about 12 degrees better in terms of MAE.

- Qualitatively, it was found that the meteorological analysis produced realistic topographical flows, and was capable of reproducing observed surface temperatures below -40 °C in locations such as Woodsmoke. However, the model did tend to have a positive near-surface temperature bias during the coldest episodes at valley locations that could not be well-resolved by the model (e.g., Goldstream Creek). This was counteracted by periods when the model had a negative temperature bias, such as during the initial precipitation event of the 2-17 Nov. 2008 episode, such that the overall model temperature bias was quite small (less than a degree Celsius) for both simulated episodes.

1. INTRODUCTION

The region around Fairbanks and North Pole, AK, was designated by the Environmental Protection Agency (EPA) as a non-attainment area for fine particulate matter (PM2.5, referring to particles with aerodynamic diameters equal to or less than 2.5 microns). This designation required that a State Implementation Plan (SIP) be developed. The violations occur predominantly during the cold season, when the meteorological conditions frequently become ideal for achieving high concentrations of any tracer released into the atmosphere. These ideal conditions, often present in combination, include the presence of extremely strong inversions capping a shallow layer of extremely cold air, light and variable winds, and very weak, intermittent turbulence (e.g., Benson 1970; Serreze et al. 1992; Mölders and Kramm 2010). These conditions, which frequently occur in the winter over inland Alaska, can be exacerbated in the region around Fairbanks, where a rough semicircle of ridges tends to isolate the airflow around Fairbanks from its surroundings, restricting the dispersal of pollutants.

2. EPA RARE STUDY BACKGROUND

The Regional Applied Research Effort (RARE) study was sponsored by the EPA to help the Fairbanks North Star Borough and the Alaska Department of Environmental Conservation (ADEC) develop a State Implementation Plan for the Fairbanks / North Pole PM2.5 non-attainment area. This project included meteorological modeling, meteorological observational, and trace gas and aerosol analysis modeling components. Penn State conducted the meteorological modeling component of this study from 1 Sep 2008 – 31 Jan 2010, with the specific focus being the extremely cold stable boundary layers in winter in the Fairbanks region. The meteorological portion of the project consisted of selecting and performing two twenty-day simulations down to 1-km horizontal grid spacing for two episodes from the 2007-2008 winter season characterized by high PM2.5 exceedance events in the Fairbanks region. One episode was to be characterized by near total darkness, while the second was to contain partial sunlight.

There were two components of the atmospheric modeling portion of the study. One was to produce the best possible analysis of the atmosphere (at approximately 1-km grid spacing) that could be used in conjunction with the parallel chemical and emissions modeling efforts to better understand the nature of the PM2.5 exceedance events of the Fairbanks / North Star Borough area. The other was to perform physics sensitivity studies on turbulence and land surface model parameterizations to determine the best-performing modeling configuration and physics suite for representing the stable atmospheric boundary layers in these conditions.

The tool used for the meteorological modeling component of the RARE project was the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008), more specifically, the Advanced Research WRF dynamic core (WRF-ARW, henceforth simply called WRF). WRF contains separate modules to compute different physical processes such as surface energy budgets and soil interactions, turbulence, cloud microphysics, and atmospheric radiation. Since turbulent eddies in the SBL are typically much smaller than mesoscale model horizontal grid spacing (e.g., ten meters vs. a thousand or more meters), they cannot be modeled directly (e.g., Wyngaard 2004), but typically their effect is parameterized by a planetary boundary layer (PBL) scheme that predicts turbulent kinetic energy (TKE). Within WRF the user has many options for selecting the different schemes for each type of physical process. There is also a WRF Preprocessing System (WPS) that generates the initial and boundary conditions used by WRF, based on topographic datasets, land use information, and larger-scale atmospheric and oceanic models.

The RARE simulations used three one-way nested horizontal grids with horizontal grid spacing of 12 km, 4 km and 1.3 km, respectively. Grid 1 covers the entirety of Alaska and extends from Siberia to the northwestern continental United States (Figure 1). Grid 2 closely coincides with the extent of the Alaskan landmass south of the Brooks range; it includes the Anchorage region and the Gulf of Alaska in the south (Figure 2). Grid 3, centered around Fairbanks and extending south to the Alaska Range and north past the White Mountains and other uplands just north of Fairbanks, includes all of the non-attainment area within the Fairbanks North Star Borough (Figure 3 - Figure 4).

Many of the WRF namelist parameters used in the RARE study were taken directly from modeling studies performed by Penn State for studying the nocturnal stable boundary layers of central Pennsylvania (Stauffer et al. 2009; Seaman et al. 2012) using version 3.1 of WRF-ARW. Many of the grid-independent parameters are listed in Table 1. In particular, the extremely fine vertical grid spacing of the model levels near the surface is in order to adequately resolve the depth of stable boundary layers that may be only tens of meters deep, and within which the scale of the turbulent eddies may be even less. However, the near-surface vertical grid spacing in the RARE study was coarsened slightly from that of the central Pennsylvania studies both in order to prevent numerical instabilities from occurring over the extremely steep elevation gradients on the north edge of the Alaska Range, and to alleviate concerns about the model atmospheric grid spacing being on the order of the vegetation canopy height. The final near-surface vertical grid spacing was 4 m, increasing gradually with height above the surface (refer to Gaudet and Stauffer 2010).

Grid-dependent namelist parameters and WRF Preprocessing System (WPS) namelist parameters are listed in Table 2 and Table 3, respectively.

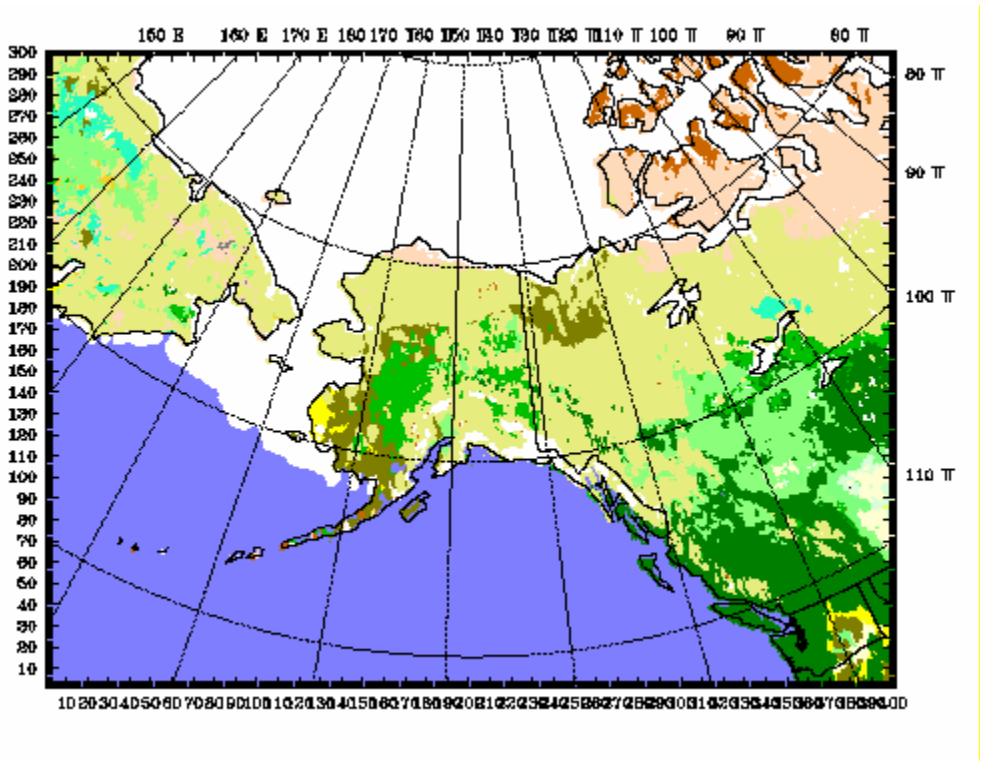


Figure 1: Grid 1 domain, showing land use variation. Colors indicate: light green – cropland/woodland mosaic; yellow – grassland; dark yellow – shrubland; mustard – mixed shrubland/grassland; leaf green – deciduous broadleaf forest; dark green – deciduous or evergreen needleleaf forest; forest green – mixed forest; light blue – water body; brown – herbaceous wetland; surf green – wooded wetland; tan – barren or sparsely vegetated; light gray – herbaceous tundra; avocado – wooded tundra; peach – mixed tundra; medium gray – bare ground tundra; white – snow or ice.

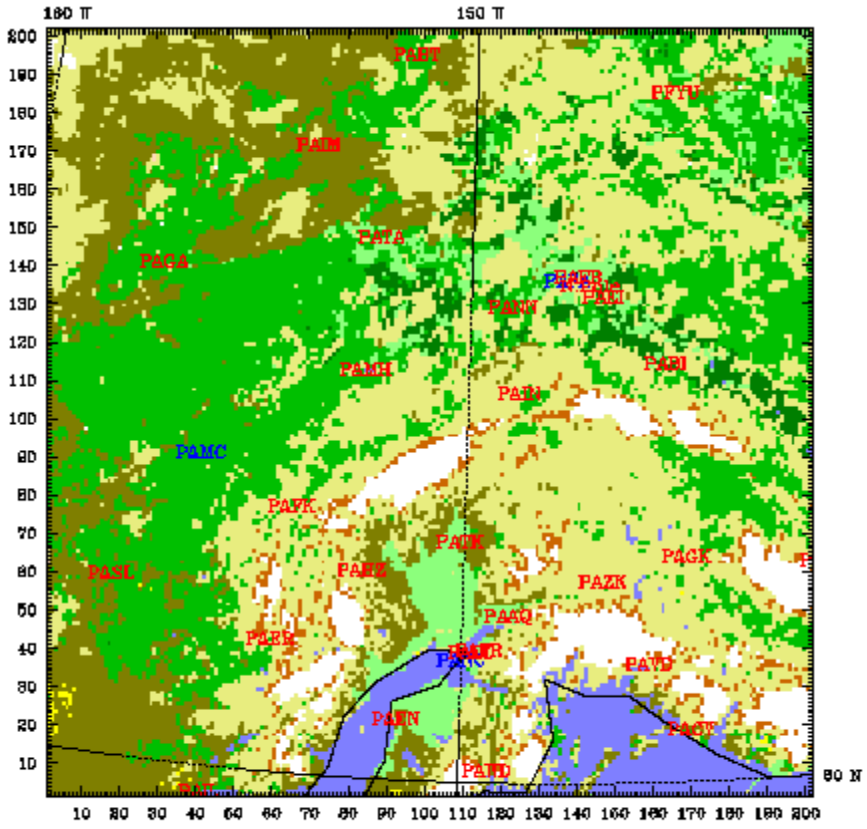


Figure 2: Grid 2 domain, showing land use variation. Color scale same as in Figure 1.

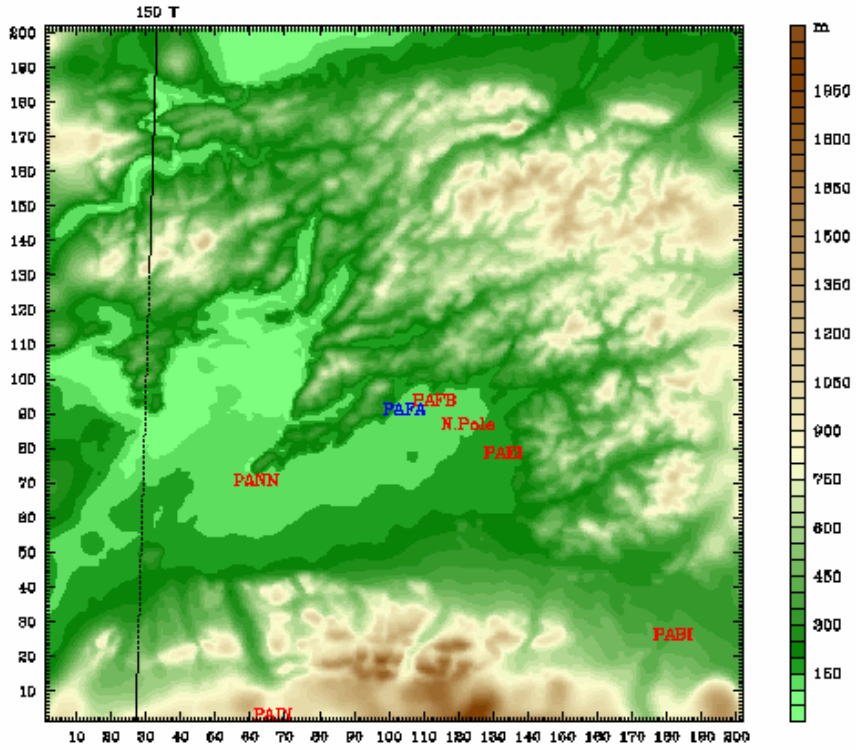


Figure 3: Grid 3 domain, showing topographic relief. METAR stations are shown in red; rawinsonde stations are shown in blue. Eielson AFB is denoted by PAEI; Fort Wainwright is denoted by PAFB. Location of community of North Pole is also indicated.

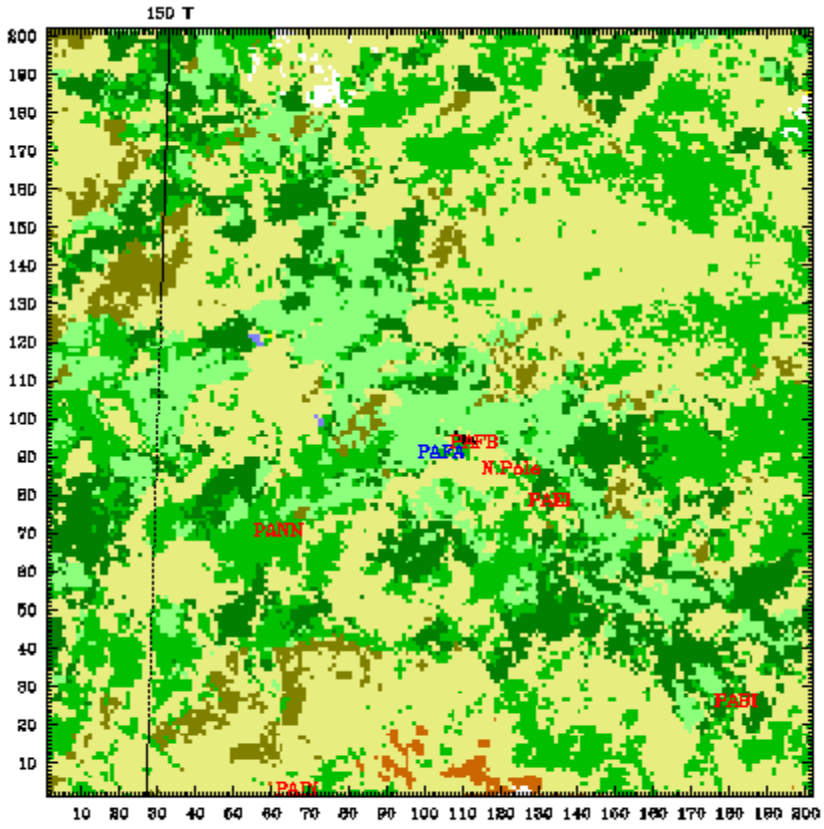


Figure 4: Grid 3 domain, showing land use variation. Color scale same as in Figure 1.

Table 1: Grid-independent features of WRF simulations.

nesting procedure	one-way concurrent
model top (hPa)	50
number of vertical layers	39
eta value of full levels	1.0, 0.9995, 0.999, 0.9984, 0.99705, 0.99415, 0.99155, 0.986, 0.78, 0.966, 0.95, 0.034, 0.918, 0.902, 0.886, 0.866, 0.842, 0.814, 0.78, 0.74, 0.694, 0.648, 0.602, 0.556, 0.51, 0.464, 0.418, 0.372, 0.326, 0.282, 0.24, 0.2, 0.163, 0.128, 0.096, 0.066, 0.04, 0.018, 0
approximate height above ground level of half levels (m)	2.0, 6.0, 10.5, 18.4, 35.5, 57.8, 90.9, 146.2, 228.3, 344.5, 478.7, 614.8, 752.7, 892.5, 1052.3, 1251.1, 1491.2, 1785.4, 2148.4, 2587.7, 3079.8, 3598.2, 4146.0, 4727.3, 5346.7, 6010.4, 6725.8, 7502.6, 8333.4, 9208.6, 10135.5, 11190.6, 12139.8, 13234.2, 14408.4, 15652.1, 16921.7, 18193.7
exclude nudging from the boundary layer	no
G for analysis nudging, when used (s^{-1})	0.0003
G for obs nudging, when used (s^{-1})	0.0004
obs nudging half-time window (hr)	2
specified, relaxed zone width	1, 9

Table 2: Grid-Dependent features of baseline model configuration

	Grid 1	Grid 2	Grid 3
horizontal extent	401 x 301	202 x 202	202 x 202
horizontal Δx (km)	12	4	1.33
i parent start	-	156	103
j parent start	-	106	106
time step (s)	24	8	4
sound step ratio	8	8	4
dampcoef	0.0	0.0	0.0
analysis nudging	yes	no	no
obs nudging	yes	yes	yes
surface obs nudging xy radius (km)	100	100	75
topographic dataset	USGS 10 m	USGS 2 m	USGS 30 s

Table 3: Grid-independent WRF Preprocessor System (WPS) features

projection	Lambert conformal
reference latitude, longitude	64.8, -148.0
true latitudes	50.0, 70.0
standard longitude	-148.0
initial conditions	0.5 degree GFS analyses
analysis interval (hr)	6

Two twenty-day episodes from the 2007-2008 winter season were selected in the RARE study. One episode was from 14 Dec 2007 to 03 Jan 2008, a time of year when there is little solar radiation in the Fairbanks area (approximately three hours of daylight per day near the solstice). During this episode the temperature rapidly decreased to near -40°C by 21 Dec, accompanied by rapid increases in PM2.5 concentrations, and then temperatures generally increased and PM2.5 decreased for the remainder of the episode. The second episode was from 23 Jan 2008 to 12 Feb 2008, when solar insolation was more significant (between five and eight hours of sunlight per day), and provides an example of 'partial sunlight' conditions. During this episode temperatures were initially relatively warm (near 0°C), decreased briefly to near -35°C by 27 Jan, rebounded slightly, and then decreased during the most extensive period of sub -35°C weather of the season. Consistent with the prolonged period of cold temperatures were recurring violations of the PM2.5 standard in the Fairbanks area.

In the initial period of a regional model simulation there is generally a period of several hours when the atmospheric state, whose initial conditions are usually provided by a global or coarser regional model, is still dynamically adjusting to the finer scale resolution and topography of the regional model. Therefore the model output from this initial 'spin-up' period is not completely reliable as an indicator of the true atmospheric state. However, if a regional model simulation is allowed to progress for too long without re-initialization (normally several days), it tends to drift away from the actual observed atmospheric state. Therefore, our method of obtaining realistic regional atmospheric analyses over an entire twenty-day episode was to divide each episode into four overlapping simulation segments. Each segment was around five days long with a twelve-hour overlap between each segment to avoid spin-up effects. (Specifically, the near total darkness episode was divided into successive segments of 6 days, 5.5 days, 5.5 days, and 4.5 days; the partial sunlight episode was divided into successive segments of 5 days, 5.5 days, 5.5 days, and 5.5 days). Initial conditions and most of the Grid 1 lateral boundary conditions were obtained from the half-degree Global Forecast System (GFS) zero-hour analyses (except for a few particular times during the near total darkness episode when the half-degree GFS product was unavailable, when one-degree GFS analysis was used).

Even with the overlapping simulation segment strategy, it is difficult to ensure that the interior of a regional model simulation remains close to observations for simulations of more than a day or so. Therefore, dynamic analyses of historical cases are often performed, in which a Four-Dimensional Data Assimilation (FDDA) strategy is applied throughout the model integration. Relaxation terms based on the differences between actual observations and the corresponding model fields at the observation sites (also known as the 'innovations') are added to the model's predictive equations. In this way the model error is constrained based on available observations while the model still provides dynamic consistency and finer mesoscale structure not present in the observations. The version of FDDA used in these simulations is the multiscale, multigrid

nudging FDDA strategy developed by Stauffer and Seaman (1994) for the MM5 mesoscale model, and implemented in WRF as described in Deng et al. (2009). Nudging is also known as Newtonian relaxation, where the nudging relaxation terms are proportional to the innovation divided by a characteristic e-folding time inversely proportional to a nudging coefficient *G*. Nudging does not perform a direct insertion of observational information at a single point in space and time, but rather it applies the correction or innovation gradually in time and space based on the model terrain influences and prescribed / assumed weighting functions. For example, when a well-mixed PBL is present, one would generally want the influence of surface observations to be extended throughout the PBL, because in these conditions there is high correlation between errors in atmospheric fields at the surface and those anywhere within the PBL.

The multiscale multigrid FDDA method uses a combination of two forms of nudging: analysis nudging and observation ('obs') nudging. Analysis nudging is performed in model grid space where an objective analysis of observations (e.g., a modified Cressman scheme, Benjamin and Seaman 1985) is performed using the interpolated global analyses (e.g., from the GFS) as a background field. The resultant 'enhanced analysis' can then be used as the basis for analysis nudging. Analysis nudging is generally applied on coarser model domains where synoptic data can be used to produce a reasonable gridded analysis. Obs nudging is more attractive for finer-scale domains and asynoptic data. It is particularly effective where observational data density is sparse and corrections are applied only in the neighborhood of the observations, allowing the model to still add value in regions without any data by advecting observation information into the data-sparse regions and creating mesoscale structure not in the observations. In this case the nudging is performed in observation space, and the model field is interpolated to the observation site to compute the innovation that is then analyzed back to the model grid over some three-dimensional neighborhood in space, and over some time window. Quality control (QC) of observations is critically important for the success of both analysis nudging and observation nudging.

In the multiscale multigrid FDDA method applied in the RARE study, 3D-analysis nudging, as well as surface analysis nudging using higher temporal frequency surface data within the PBL (e.g., Stauffer et al. 1991), were performed on the outermost 12-km domain. Obs nudging is applied on at least the 12-km and 4-km domains. (Obs nudging is not applied on the finest 1.33-km model nest for the physics sensitivity studies described further below.) The finer domains thus have the benefit of improved lateral boundary conditions from the coarsest 12-km domain using both types of nudging, as well as the obs nudging performed directly on the 4-km nested domain. This project was one of the first applications of the multiscale FDDA strategy of Stauffer and Seaman (1994) in WRF. The newly developed OBSGRID module was used to produce gridded objective analyses similar to those produced by Rawins / Little_r in the MM5 system. The output files of OBSGRID can be used for 3D and surface analysis nudging and obs

nudging within WRF. OBSGRID takes as input raw WMO observations (both surface and upper air) and the output from WPS, which consists of large-scale gridded data (e.g., GFS output) horizontally interpolated to the model grid to be used in WRF. The outputs of OBSGRID relevant to this study include 1) pressure-level and surface objective analyses of the WMO observations (passing internal QC checks) using the GFS output interpolated to the model grid as background fields; the resultant analyses are then vertically interpolated to the WRF terrain-following "sigma" layers to be used for 3D analysis nudging; 2) surface analysis nudging files that can be directly used by WRF; 3) observation nudging files usable by WRF, and 4) files of the WMO observations including those passing the QC tests for use in the statistical verification software.

As mentioned above, for the physics sensitivity portion of the RARE study, 3D analysis nudging, surface analysis nudging, and obs nudging were performed on the 12-km domain (Grid 1); obs nudging was performed on the 4-km domain (Grid 2); and no nudging was performed on the 1.33- km domain (Grid 3). Thus Grid 3 has no direct FDDA tendencies and could be used to determine physics sensitivities, while still benefiting from improved lateral boundary conditions derived from the coarser grids that did have FDDA.

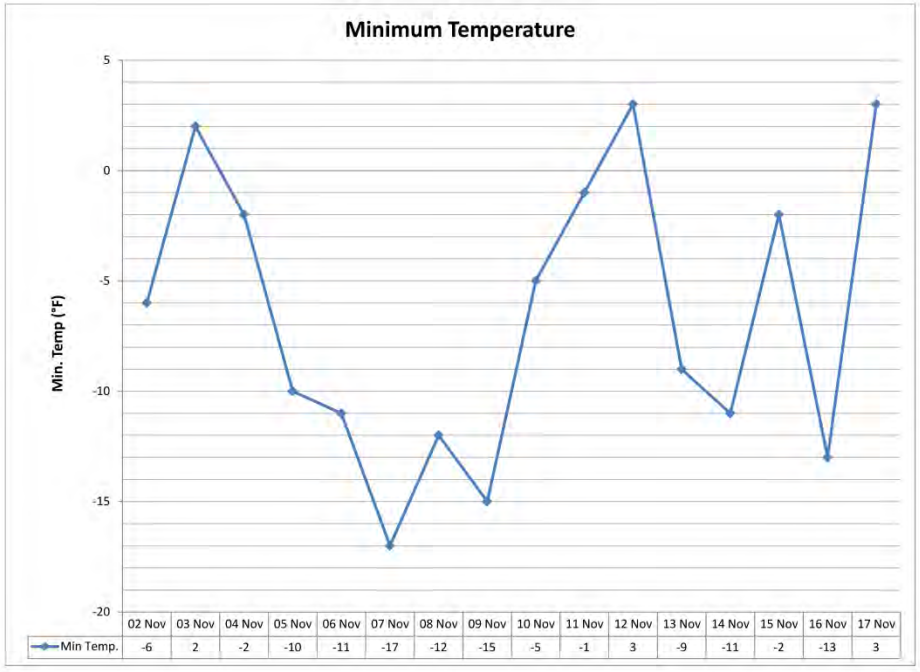
The following modifications were made to the WRF FDDA schemes for use in the baseline Alaska simulations. 1) The verification software was rewritten so that surface wind observations are verified against the third model half-layer from the ground (level closest to the 10-m observation level), while surface moisture and temperature observations are verified against the lowest model half-layer (level closest to the 2-m observation level). 2) A portion of the verification software that uses an assumed lapse rate to adjust model temperatures based on the difference between modeled and actual elevation was disabled, because this can lead to large errors in very stable conditions. 3) The surface analysis nudging and obs nudging codes were modified so that surface innovations for wind are computed and applied directly at the third model level. 4) Because surface wind observations directly relate to the third model layer and surface temperature and moisture observations directly relate to the lowest model layer, the similarity-based adjustments normally performed on model output for surface innovation computation was also disabled. 5) Hardwired vertical weighting functions for surface innovations were implemented into the surface analysis nudging and obs nudging codes, replacing the default functions that extend surface corrections to the model-predicted PBL height. The new functions had a vertical extent hardwired at about 150 m, which is a reasonable order of magnitude estimate for the maximum depth of nocturnal radiatively-driven stable boundary layers (SBL).

As a result of the physics sensitivity studies, the selected physics parameterizations included the Morrison cloud microphysics scheme (specifically designed for high-latitude simulations; Morrison et al. 2005), the RRTMG longwave / shortwave radiation package (Mlawer et al. 1997; Chen and Dudhia 2001), the Mellor-Yamada-Janjic PBL turbulence parameterization

(Janjic 2002) (as modified to be appropriate for the weak-turbulence conditions of very stable boundary layers), and the Rapid Update Cycle (RUC) land surface model (Smirnova et al. 2000). In particular, this physics suite seemed to have the best (least positive) temperature bias and best statistics during the periods when the surface temperatures were coldest and PM2.5 concentrations were the greatest. However, even with this physics configuration, the model's positive temperature bias could not be completely removed; furthermore, during other periods (such as the falling temperature periods in advance of a number of extremely cold episodes) the selected model physics suite seemed to have a negative temperature bias. It was thus strongly suggested that the actual meteorological analysis provided to the EPA be obtained from a final dynamic analysis simulation in which FDDA was also used to constrain the 1.33-km Grid 3 to the observations. However, there was concern that data assimilation of wind fields on Grid 3 would produce spurious low-level circulations in the model; furthermore, it was expected that the low-level circulations in both the actual atmosphere and the model would be driven by the low-level temperature fields. Thus, it was decided that in the delivered final dynamic analysis, that FDDA on Grid 3 would be done within all layers for temperature and moisture fields, but only within layers more than 150 m above the surface for wind fields. Also, the radius of influence for obs nudging on Grid 3 was reduced from the 100 km used on Grids 1 and 2 to 75 km. This value was obtained by computing the characteristic Grid 3 surface temperature innovation length scale through a correlation procedure that will be described in more detail in the next section.

3. WORK PLAN FOR NOV 2008 EPISODE

The current study covers the period 2-17 Nov 2008. Temperatures were relatively mild during the initial portion of this period (Figure 5), but then decreased to -17 °F (-27.2 °C) by the 7th, as recorded by a portable Beta Attenuation Mass (BAM) monitoring unit in the Fairbanks / North Star Borough region. Temperatures then rebounded for about 5 days before the next cold outbreak which bottomed out again at (-11 °F) (-24 °C)by the 14th. The low temperature periods corresponded to high PM2.5 concentrations as expected, especially towards the end of the study episode. However, the extremely cold temperatures, below (-22 °F) -30 °C, recorded during the Jan-Feb 2008 RARE episode did not occur during the Nov 2008 episode, and so the extreme effect of ice fog was not a factor. The final simulation of the episode was divided into four overlapping segments (12 UTC 01 Nov – 00 UTC 05 Nov; 12 UTC 04 Nov – 12 UTC 09 Nov; 00 UTC 09 Nov – 00 UTC 14 Nov; 12 UTC 13 Nov – 12 UTC 18 Nov). In order to facilitate the performance of initial sensitivity studies, an initial test period of 00 UTC 05 Nov – 12 UTC 09 Nov, encompassing one of the colder times during the Nov 2008 episode, was chosen.



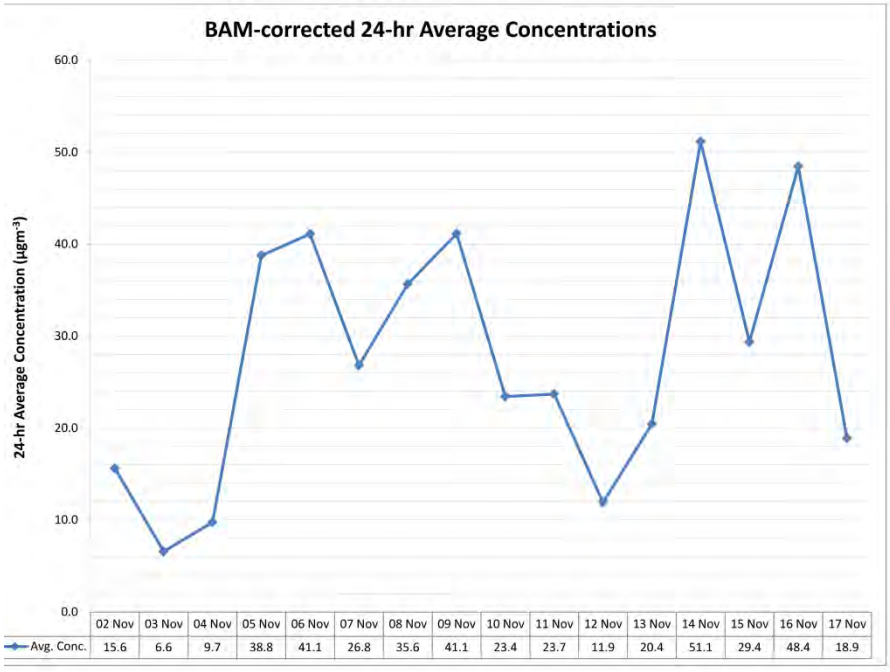


Figure 5 – Plot showing the daily minmun temperatures for the November episode in the Fairbanks region in Farenheit (top) and the BAM-corrected 24-hr average concentration of PM2.5 (bottom). Courtesy Bob Dulla, Sierra Research.

The grid configuration was taken directly from the EPA RARE study, although there are a few modifications relating to the use of observations for the November case as compared to the RARE study. The first involves the effective vertical resolution of the quality control procedure performed on the observations. The OBSGRID pre-processing software package compares point observations of a field such as temperature (either at a single level such as the surface or at multiple levels such as in a sounding) to the background analysis values of that field. For surface observations a direct comparison is performed between observed values of temperature and the background surface values. For sounding observations, if a vertical pressure level of the background analysis does not correspond to one of the pressure levels of that sounding, the observed sounding is interpolated in pressure space to the background pressure levels prior to the objective analysis and the values at the original observed sounding pressure levels are not retained. The result of this procedure is that the effective vertical resolution of sounding observations in the verification dataset and as used in the model is limited by the vertical resolution of the background analysis. In the GFS background fields the pressure levels are spaced 25 hPa apart near the surface, which corresponds to a distance in physical space of approximately 250 m. To alleviate this issue for the current study, a modified version of the GFS decoder, obtained from NCAR, permitted the generation of a background analysis with enhanced vertical resolution, with pressure levels spaced 5 hPa (~50 m) apart near the surface. It was hoped that the increased vertical resolution would improve the representation of the extremely shallow stable boundary layers characteristic of the winter season.

Another modification dealt with the specific objective analysis procedure used by OBSGRID. During the RARE project OBSGRID used either a Cressman scan procedure or a multiquadric analysis (Nuss and Titley 1994) depending on the number of observations at each vertical level. Since the RARE project, NCAR modified the OBSGRID code to provide the user with more flexibility in the objective analysis procedure. It was decided to use the Cressman method at each vertical level in order to produce more vertical consistency in the analysis; furthermore, each successive scan radius was set using the same method present in the Mesoscale Model version 5 (MM5) developed by the co-PI and others at Penn State.

Finally, a decision was made to make use of observations beyond those from the standard METAR observational dataset, in order to enhance the sparse local observational dataset. The total number of surface METAR stations within the Grid 3 domain is eight: Fairbanks (code PAFA), Eielson Air Force Base (PAEI), Ft. Wainwright (PAFB), Nenana (PANN), Delta Junction / Ft. Greely (PABI), McKinley Park (PAIN), Healy (PAHV), and Manley Hot Springs (PAML). Of these, only three could be said to lie in the focus region of the non-attainment area (Fairbanks, Eielson AFB, Ft. Wainwright). However, data from non-METAR surface stations for the period of Nov 2008 were located in the focus region during this project. The data quality from these stations is sometimes uncertain, and often standard METAR meteorological fields

(such as dewpoint) may be absent, but some of the data may be quite valuable, and many of them are used in the Meteorological Assimilation Data Ingest System (MADIS) that is run operationally by the National Weather Service. Stations from the non-METAR database are shown in Table 4.

Table 4: Non-METAR stations used for data assimilation and verification in current study. APRSWXNET – Automatic Position Reporting System as a WX NETwork; RAWS – Remote Automated Weather Station; AKDOT – AK Department of Transportation; MADIS – Meteorological Assimilation Data Ingest System

Station	Database	Latitude	Longitude	Elevation (m)
Woodsmoke	Other MADIS	64.781	-147.284	145
Goodpasture	RAWS	64.238	-145.267	463
Healy (near Otto Lake Rd.)	APRSWXNET	63.839	-149.068	594
Two Rivers	APRSWXNET	64.873	-147.174	229
Fairbanks, near Farmer's Loop Rd. & Ballaine Rd.	APRSWXNET	64.879	-147.824	152
Goldstream Creek	APRSWXNET	64.894	-147.876	176
Livengood	RAWS	65.424	-148.722	137
Ester Dome	APRSWXNET	64.879	-148.055	708
Parks Hwy at Antler Creek	AKDOT	63.810	-148.965	462

A qualitative examination of the data from the non-METAR stations suggested that the temperature data are quite reasonable, although data gaps are more common than for most of the METAR stations. Most of these stations also provide wind data; while the actual values often seem quite plausible, the non-METAR stations overwhelmingly report zero wind speeds during the time period of this study. This is probably due to the relatively high start-up measurement threshold of the instruments used, making them inadequate to measure the very weak winds in the stable meteorological conditions. The one exception to this is Ester Dome, located 710 m above sea level on a ridge to the west of Fairbanks, which normally records a stronger flow. Many of the non-METAR stations also report pressure, but it was discovered that in some cases the pressure seemed to be reduced to the 1000-hPa level, whereas in other cases actual pressure was used. The value of pressure has some significance in that WRF uses potential temperature

as an internal variable, which is the temperature that would result if an air parcel is adiabatically compressed or expanded from its current pressure to the standard sea level pressure. An incorrect or misinterpreted pressure would lead to an erroneous potential temperature and thus an erroneous sense of the 'warmth' of a station. Thus, a decision was made to disregard any reported pressures from the non-METAR surface stations, and effectively use the model-predicted surface pressures to generate a self-consistent potential temperature field from the surface observations.

4. NEAR-SURFACE WIND ASSIMILATION

In the original RARE project a decision was made not to assimilate low-level wind data from surface stations on the 1.33-km (Grid 3). The reasoning was that the near-surface flow in these conditions was weak and predominantly thermally-forced (i.e., much of the existing wind circulation likely consists of topographically-forced drainage flows induced by air masses of varying temperatures). Thus, a numerical model may actually do a better job at capturing these flows than an observational network, especially a sparse observational network, and any data assimilation of observed near-surface winds within the model may erroneously override the development of these flows. The use of this data assimilation strategy in the RARE project did lead to realistic low-level flow patterns and produced generally satisfactory wind error statistics. However, the reported wind speed and wind directions statistics excluded cases where the observation wind report was calm. Including calm wind reports in the wind speed verification, by necessity, makes the wind speed bias more positive, because the model generated wind is never exactly zero. On the one hand, calm or near-calm conditions are common in extremely cold stable boundary layers, so representing them properly is of importance to this study. On the other hand, it is not clear how much of the positive model wind speed bias during calm wind reports is an artifact of insufficient instrument sensitivity. (More discussion on this issue will appear in the next section.) The reported surface temperature biases in the RARE project were also reasonable, but did tend to be positive during the periods of the weakest winds, which could be a direct consequence of positive model wind speed biases leading to too much turbulent mixing in the model. Because the extended dataset to be used in Nov 2008 case provided the potential for more surface data coverage over the Fairbanks region than that used in the Jan-Feb 2008, the possible use of near-surface wind data assimilation was revisited.

A comparison for the 5-9 Nov test period was performed between a simulation that used the RARE FDDA strategy on Grid 3, only nudging temperature and moisture near the surface (henceforth experiment T), and a simulation where additionally nudging of winds near the surface was performed (henceforth experiment TWIND). Statistics for the three local METAR stations are shown in Table 5. The wind speed statistics here include calm wind observations, but the wind direction statistics still do not, because wind direction cannot be defined in calm conditions. It can be seen that in experiment TWIND the wind speed RMSE statistics for all stations are reduced in comparison with experiment T; the reduction is modest but is about 10%

for Ft. Wainwright. The positive wind speed biases are also reduced, though their reduction is even more modest (no more than 0.02 m s^{-1}). Temperature statistics show a small sensitivity, although again Ft. Wainwright shows the greatest improvement in RMSE score. The biggest statistical difference between experiments T and TWIND resides in the wind direction RMSE scores, for which there is a 20 degree improvement for TWIND relative to T when the statistics for all stations are combined.

Table 5: Surface METAR statistics for experiments T and TWIND

Temperature (°C)	T RMSE (MAE for wind direction)	TWIND RMSE (MAE for wind direction)	T Bias	TWIND Bias
Fairbanks	1.71	1.72	-0.07	-0.15
Eielson AFB	1.83	1.80	1.20	1.18
Ft. Wainwright	1.36	1.32	0.05	-0.05
Three Stations	1.70	1.68	0.42	0.36
Relative Humidity (%)				
Fairbanks	4.21	4.31	-0.54	-0.59
Eielson AFB	7.39	7.50	3.59	3.70
Ft. Wainwright	17.55	17.89	-16.59	-16.96
Three Stations	9.31	9.49	-2.06	-2.11
Wind Speed (m s^{-1})				
Fairbanks	0.98	0.95	0.54	0.16
Eielson AFB	1.20	1.16	0.71	0.70
Ft. Wainwright	0.82	0.75	0.18	0.53
Three Stations	1.05	1.01	0.54	0.53
Wind Direction (degrees)				
Fairbanks	49.1	32.6	26.2	22.4
Eielson AFB	66.2	37.6	42.0	16.7
Ft. Wainwright	93.1	74.2	35.8	36.2
Three Stations	73.1	53.8	33.2	28.4

This statistical improvement in wind direction statistics suggested that using near-surface wind FDDA on the 1.33-km Grid 3 should be recommended, once a subjective analysis of the wind field in simulation TWIND revealed no irregularities.

Though the wind direction improvement in experiment TWIND was encouraging, the relatively small improvement in surface wind speed statistics, and the lack of substantial improvement in surface temperature statistics, was puzzling. An examination of the time series of the statistics during the test period (Figure 6 - Figure 13) suggests that while at Eielson AFB positive temperature biases are the norm during the early morning hours, this is not true at Fairbanks on 06 Nov, within one of a couple of prolonged periods of negative surface temperature biases at Fairbanks. (The time axes on the plots are in Coordinated Universal Time (UTC), so 00 UTC is 1500 Alaska Standard Time while 12 UTC is 0300 Alaska Standard Time, which correspond closely to the typical times of daily maximum and minimum temperatures, respectively.) Note that the location of the Fairbanks METAR is at the airport near the west end of the semi-circular topographical bowl in the region, while Eielson AFB is at the east end of this bowl and somewhat more distant from the neighboring ridges (Figure 3). If the time series of actual observed and modeled surface temperatures at the METARs are examined (Figure 14), it can be seen that for Eielson AFB and apparently for Ft. Wainwright the model is significantly too warm during the night (approximately -22 °C versus the observed -25 °C), consistent with the findings from the RARE study. (The gap during the night in the Ft. Wainwright observations is due to the fact that observations from that location are not typically reported during the night or on weekends.) However, on 06 Nov the Fairbanks observation reports a much warmer temperature (near -18 °C) than the other stations, and it shows significant oscillations but no trend of decreasing temperatures during the night. The modeled temperature time series in Figure 14 shows much less variability among the three stations; however, there is a warm spike in the modeled temperature at Fairbanks near 12 UTC 06 Nov that is reflective of the observations.

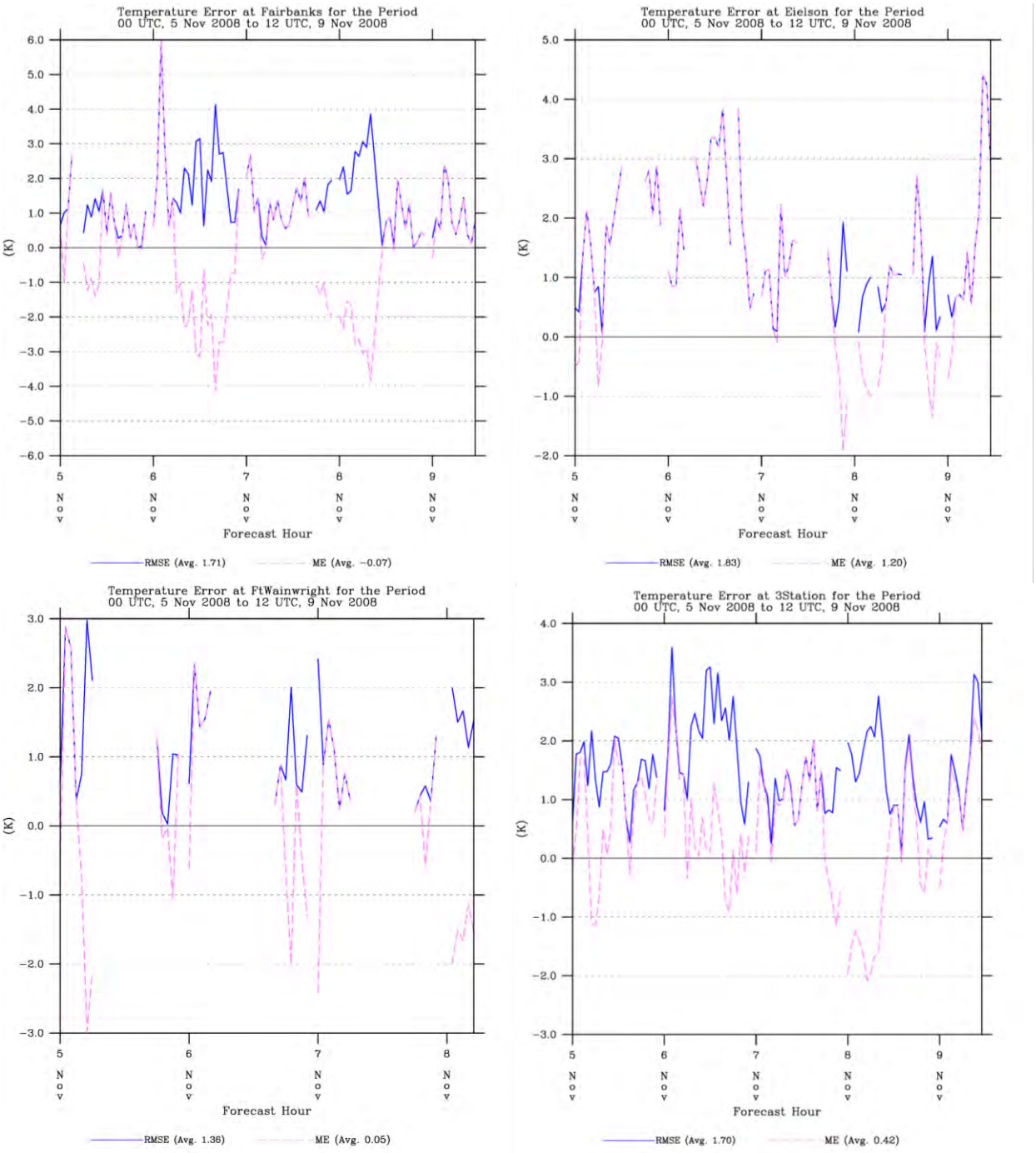


Figure 6: Temperature root mean square error (RMSE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

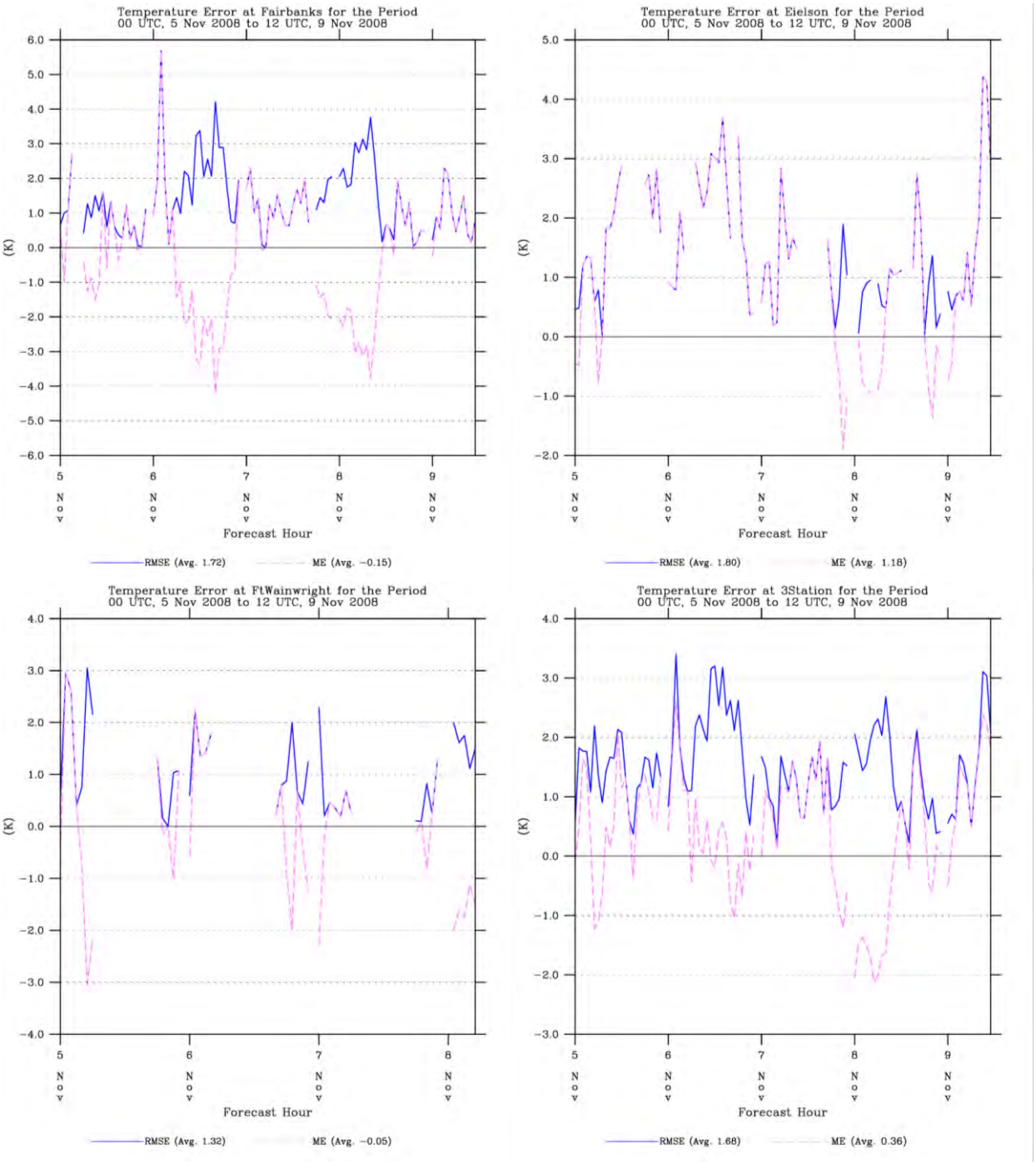


Figure 7: Same as Figure 6, but for experiment TWIND.

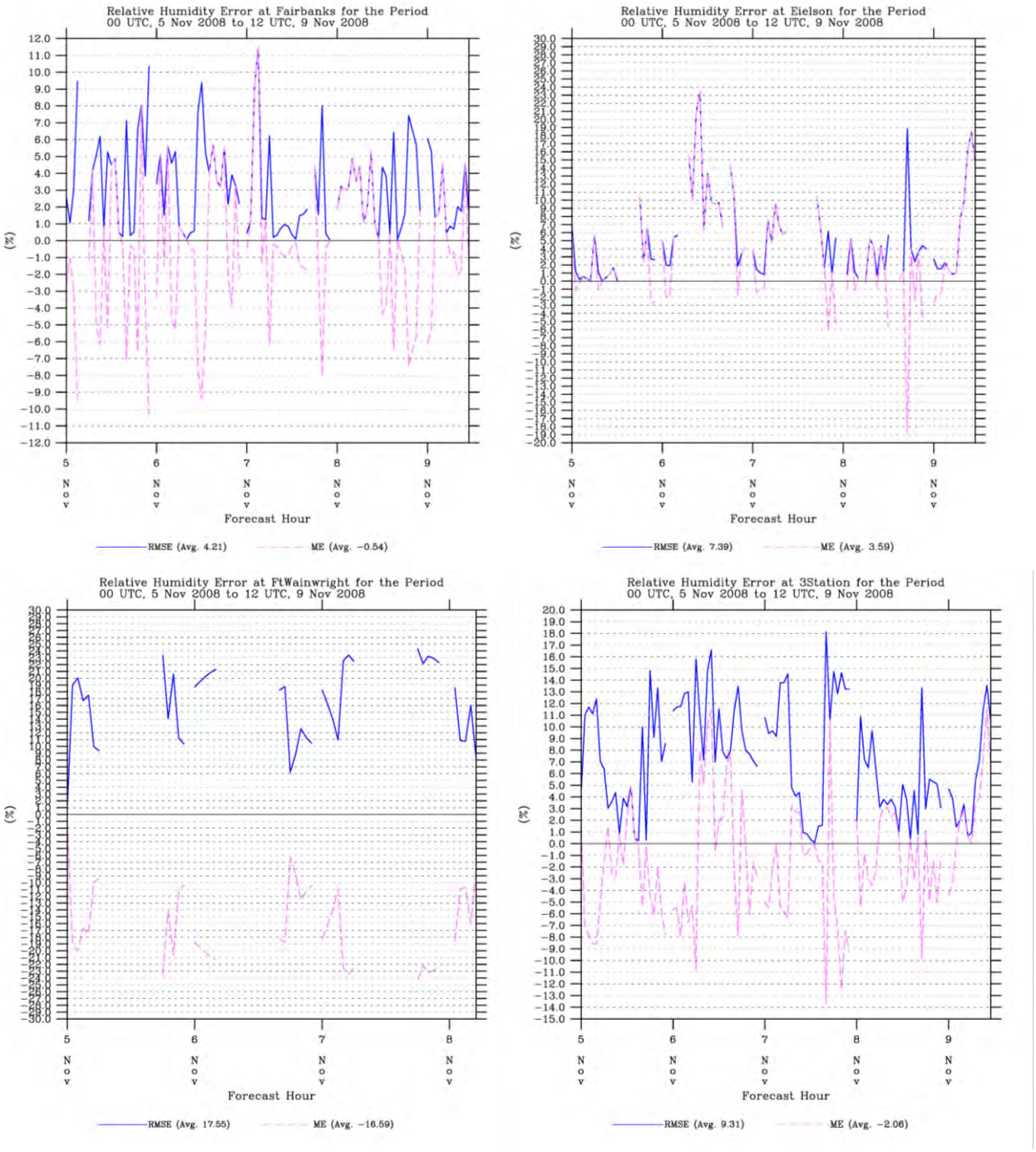


Figure 8: Relative humidity root mean square error (RMSE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

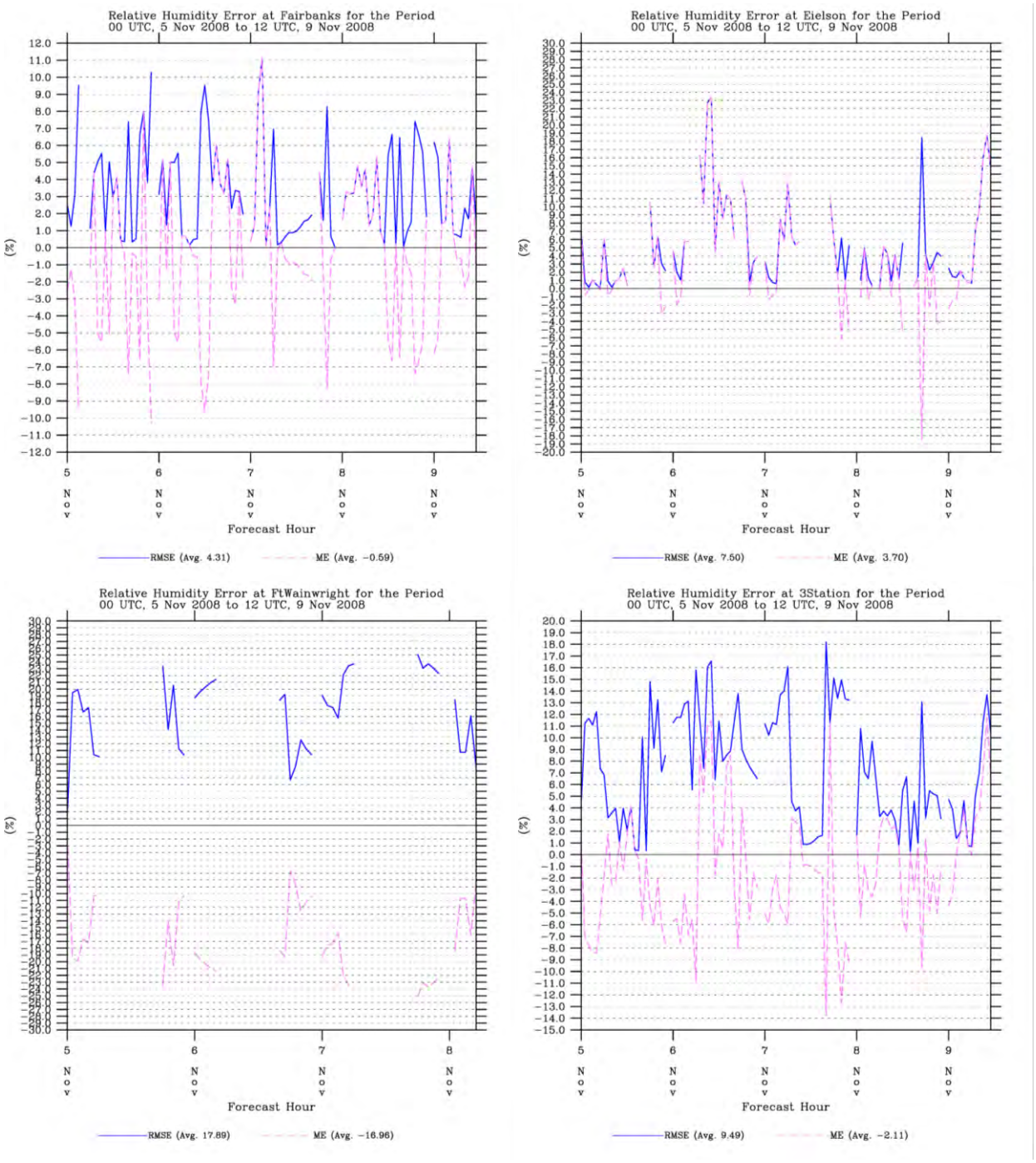


Figure 9: Same as Figure 8, but for experiment TWIND.

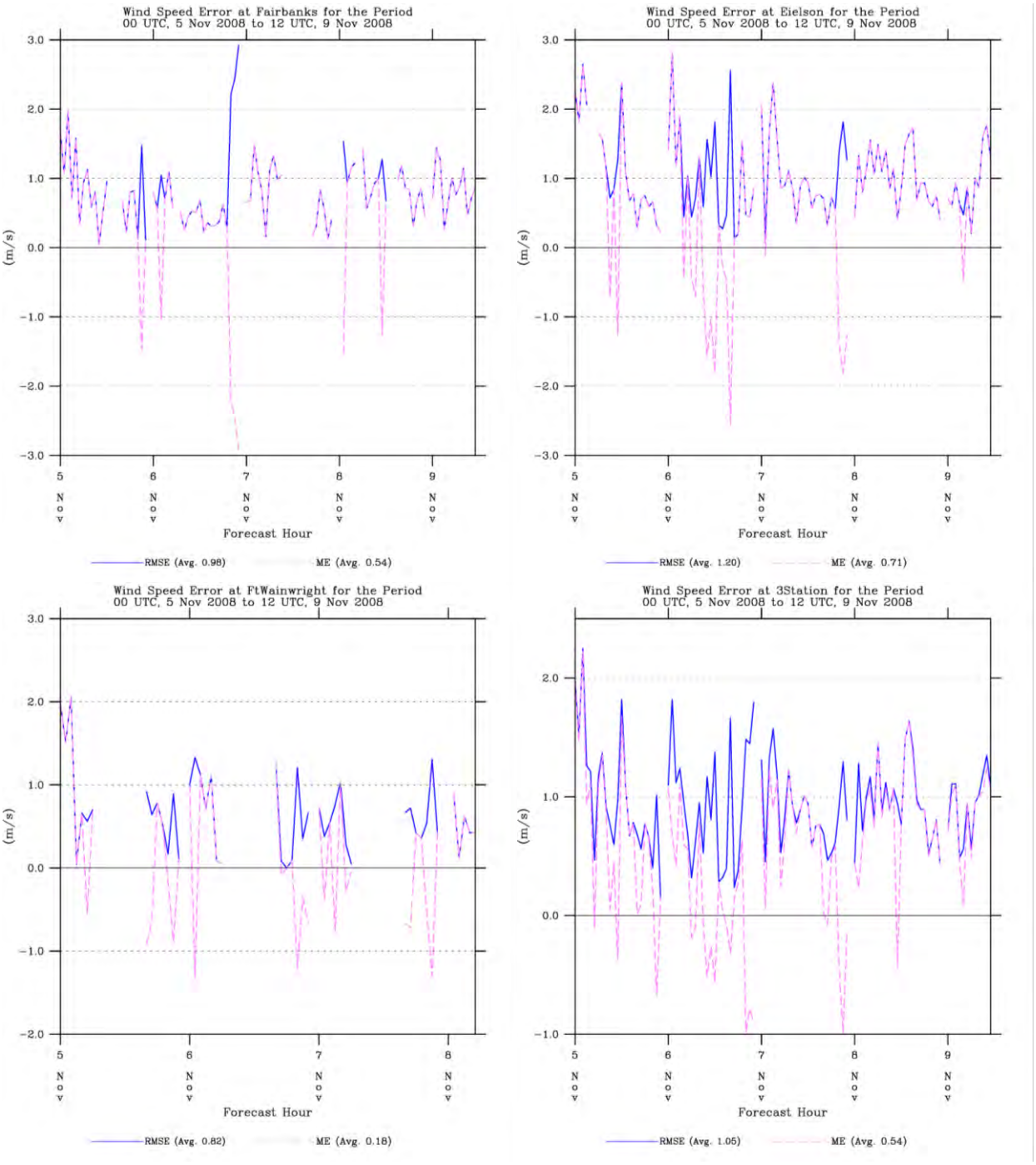


Figure 10: Wind speed root mean square error (RMSE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

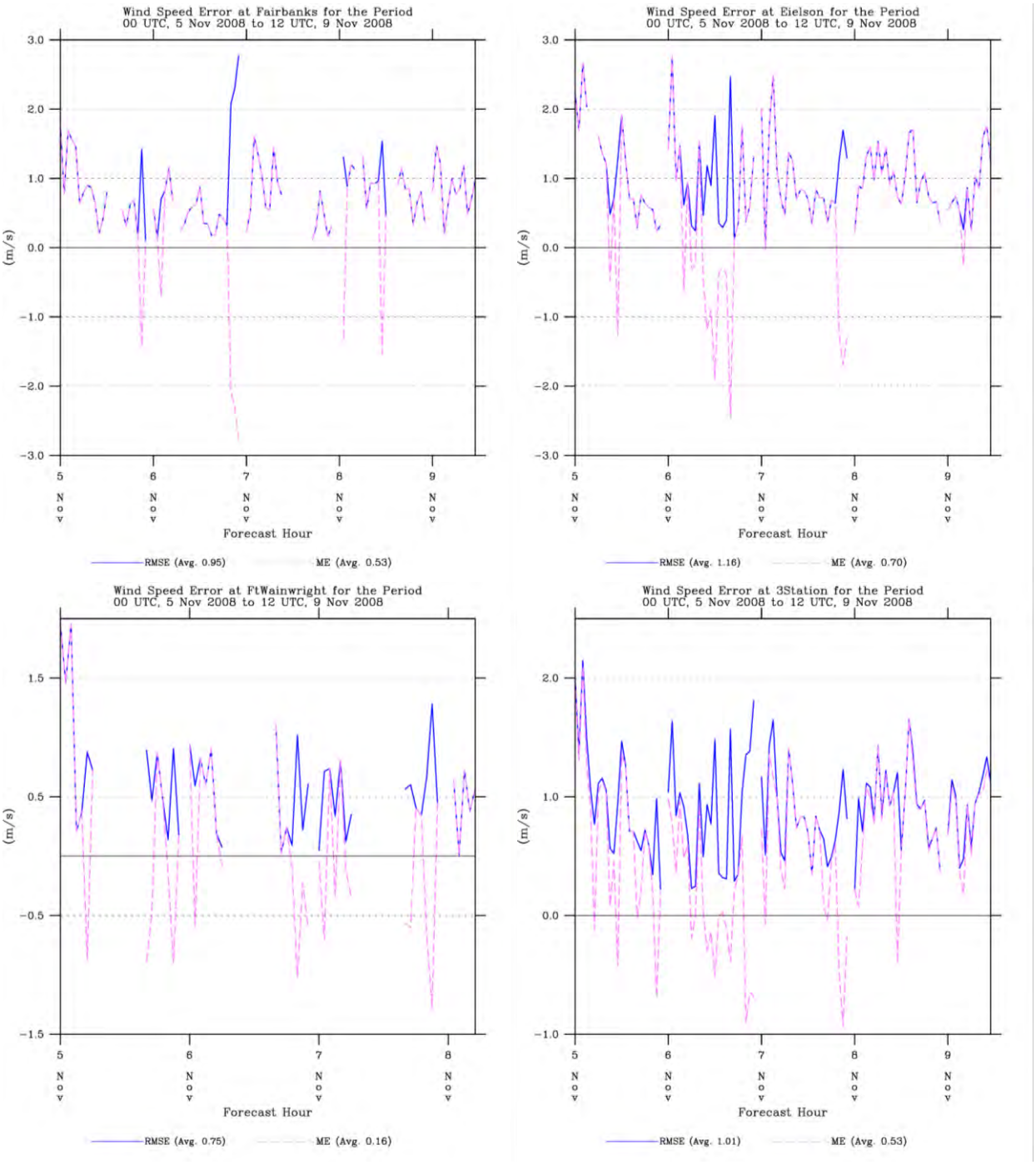


Figure 11: Same as Figure 10, but for experiment TWIND.

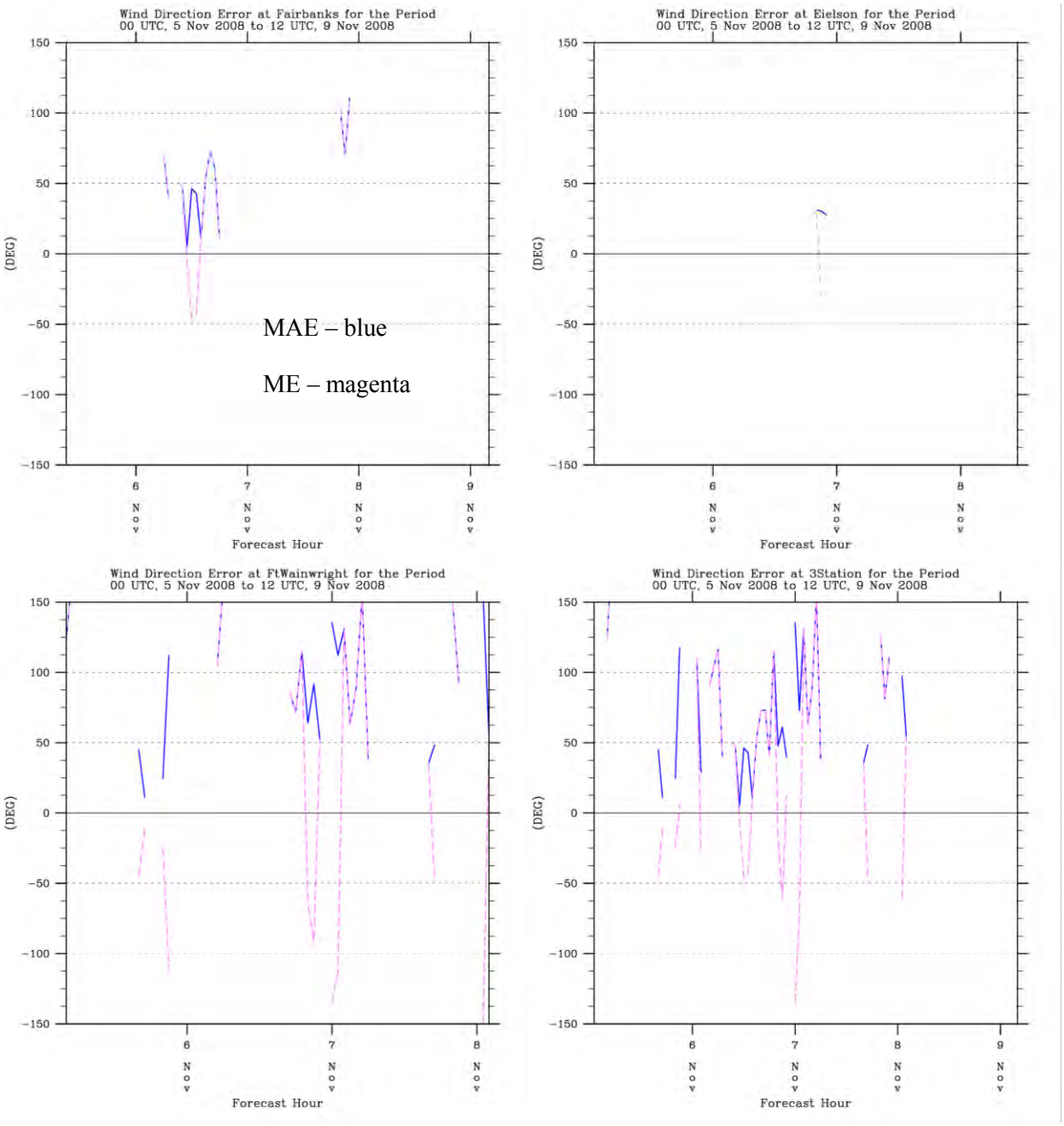


Figure 12: Wind direction mean absolute error (MAE) and bias or mean error (ME) statistics for experiment T during the 00 UTC 5 Nov 2008 – 12 UTC 9 Nov 2008 test period at the local METAR surface stations. Statistics are for Fairbanks (top left), Eielson AFB (top right), Ft. Wainwright (bottom left) and all three stations combined (bottom right).

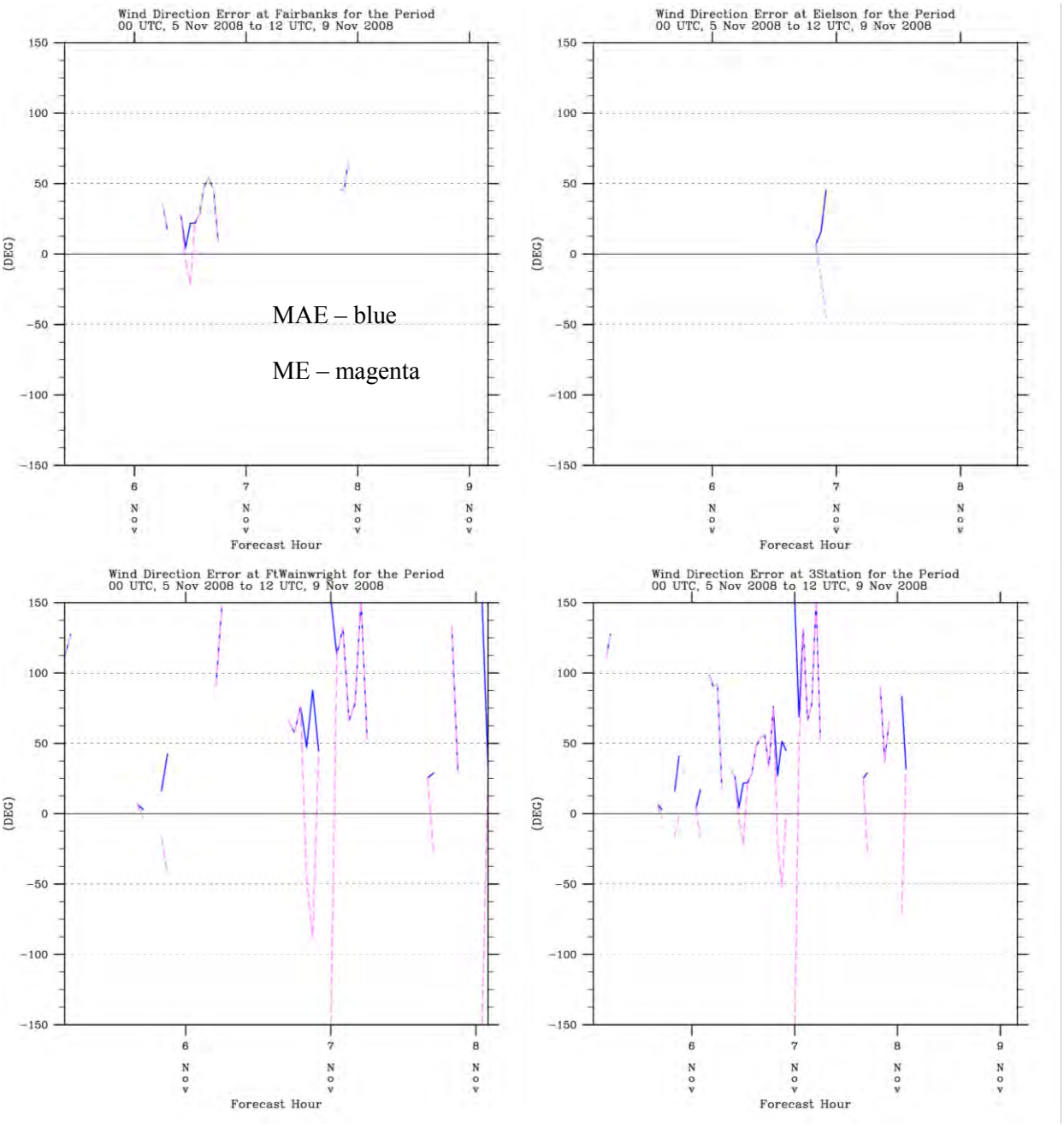


Figure 13: Same as Figure 12, but for experiment TWIND.

The corresponding time series of observed and modeled wind speeds (Figure 15) reveal that 06 Nov exhibits fairly strong wind speeds at Fairbanks (to about 4 m s^{-1} or about 8 knots), especially compared to the other stations, which is probably due to the fact that the Fairbanks station is

closest to the perimeter of the stagnant air within the topographic semicircle. The model successfully reproduces some of the increased wind speed at Fairbanks at this time (2.2 – 2.8 m s^{-1}), but the maximum wind speed of 4.0 m s^{-1} is underestimated. It is plausible that the anomalously warm temperatures at Fairbanks for this case are a direct consequence of increased wind speeds at this location, which lead to increased turbulent mixing and prevent the occurrence of the cold surface temperatures shown at the more stagnant locations at Ft. Wainwright and Eielson AFB. A plausible explanation of the errors in the model predictions is that the model is insufficiently resolving the differences in topography and location among the three stations, and effectively blending the effects of the observations of all three stations. The conclusion, then, is that surface wind data assimilation on Grid 3 seems to be beneficial, especially for wind direction, but that the radius of influence of wind observations should probably be reduced.

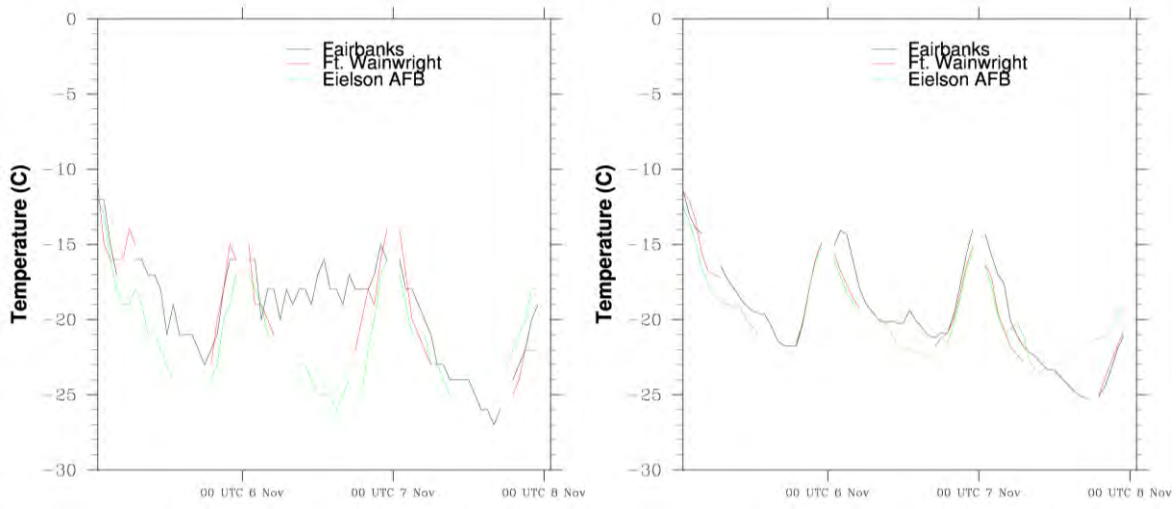


Figure 14: Time series of temperature for Fairbanks, Ft. Wainwright, and Eielson AFB from observations (left) and experiment TWIND (right)

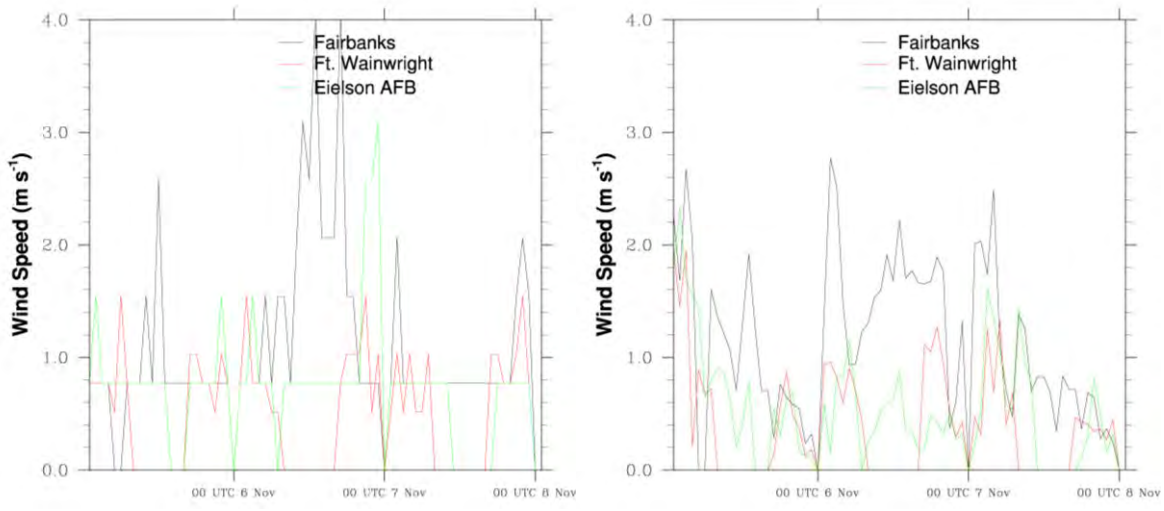


Figure 15: Same as Figure 14, but for wind speed

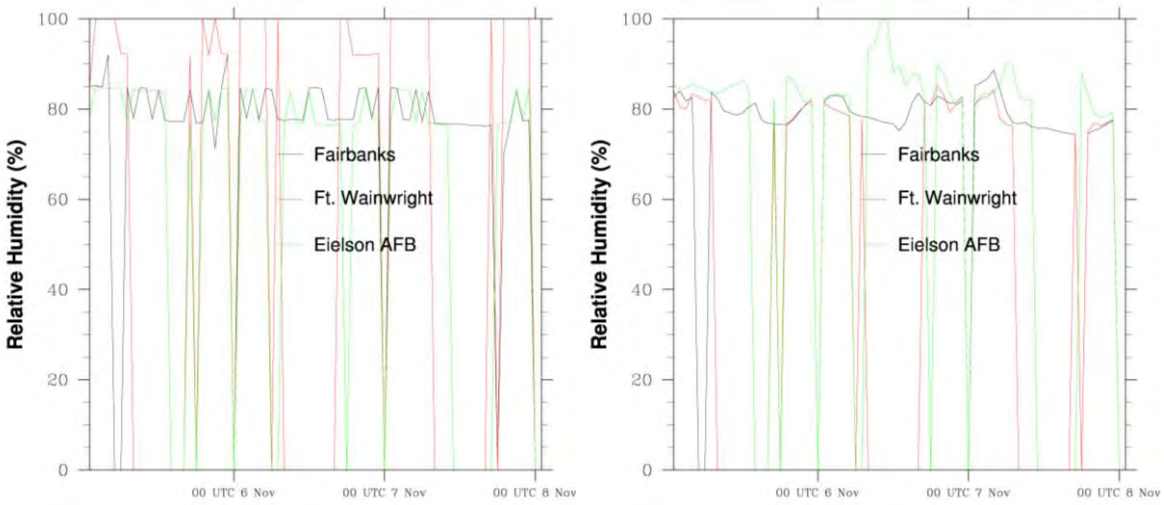


Figure 16: Same as Figure 14, but for relative humidity

Some insight into the characteristics of the relative humidity statistics can be found in Figure 16. The observations for stations other than Ft. Wainwright indicate relative humidity values are consistently near 80%. This is consistent with conditions near saturation with respect to ice but with relative humidity reported with respect to water saturation, when temperatures are on the order of -20 °C. However, Ft. Wainwright always reports relative humidity near 100% in these conditions. The model output at the Ft. Wainwright location tends to be closer to 80%, leading to the large positive relative humidity bias found in the Ft. Wainwright relative humidity

statistics. This could reflect the fact that Ft. Wainwright is erroneously reporting 100% relative humidity, based on the occurrence of ice crystals and other water condensate in the atmosphere, when in reality the atmosphere is ice saturated. However, it is interesting that the model does in fact produce conditions closer to water saturation near Eielson AFB during the day of 07 Nov, though the observations do not reflect this. Water saturation at temperatures as cold as -20 °C is difficult to maintain because of the large numbers of ice nuclei at these temperatures; after nucleation, ice crystals tend to deplete all water vapor above the ice saturation value and deplete all remaining liquid water via the Bergeron-Findeisen process. However, it is possible to maintain water saturation at these temperatures if the air is pristine. So a full explanation of these differences is not known at present.

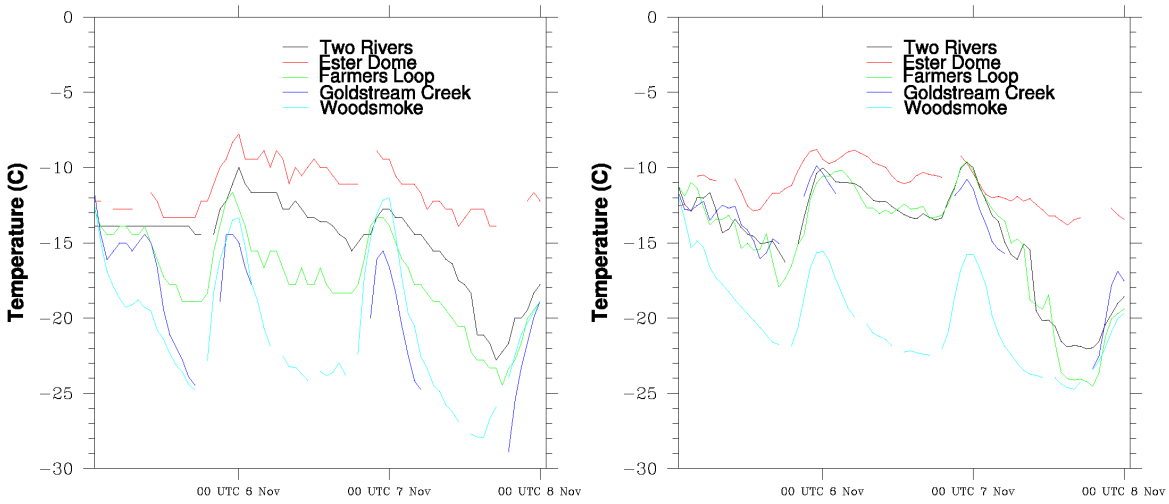


Figure 17: Time series of temperature for the local non-METAR surface stations from observations (left) and experiment TWIND (right).

Figure 17 shows the time series of observed and TWIND temperature at five non-METAR surface stations in the immediate Fairbanks region. The observed temperatures show that Woodsmoke and presumably Goldstream Creek behave like Eielson AFB and Ft. Wainwright, approaching -25 °C at night. The location near Farmer's Loop Rd. behaves somewhat like the Fairbanks METAR station in that it has temperatures decreasing to only about -18 °C at night. Two Rivers has even less of a nocturnal decrease of temperature, while Ester Dome remains near -10 °C for most of the period. This seems to confirm that the warmest temperatures during these episodes occur on the ridges while the coldest temperatures occur within the low spots of local valleys. Of these stations, Ester Dome is predicted very well by the model, helping corroborate the model skill for the atmosphere above the near-surface stable boundary layer. Two Rivers and Woodsmoke are also fairly well predicted by the model; the latter performance is notable because it confirms that the model configuration is capable of reproducing observed surface

temperatures at least as low as about -23 °C. These two stations also happen to be located at the east end of the Fairbanks / North Star Borough valley, near Eielson AFB. The model predicts approximately the same temperatures at Goldstream Creek and Farmer's Loop Rd. as at Two Rivers, but for Farmer's Loop Rd. and Goldstream Creek the resultant temperature is much too warm. It should be pointed out that these two stations are only about 2 km apart in physical distance, so it cannot be expected that a numerical model with 1.33-km horizontal grid spacing would be able to differentiate the temperature behavior between the two. All of the results considered together suggest that the model is able to predict the temperature evolution well in places both along the ridges and in the valley, but in other places the model is insufficiently resolving the actual difference in meteorological conditions between stations, whether the insufficient resolution is in the model terrain or in the way the model is treating observations in the data assimilation.

Statistics for wind speed are shown in Figure 18 for the non-METAR stations. This is an example of the fact that, other than Ester Dome, the wind instrumentation at these stations is generally not capable of recording what little wind is present. For Ester Dome itself, however, the magnitude of the wind speed peaks are well represented at the beginning of the test period. It can be seen that at the Woodsmoke station, the appropriately low model temperatures are accompanied by model wind speeds generally about 1 m s^{-1} or less, while the other stations have model wind speeds that are usually above 1 m s^{-1}.

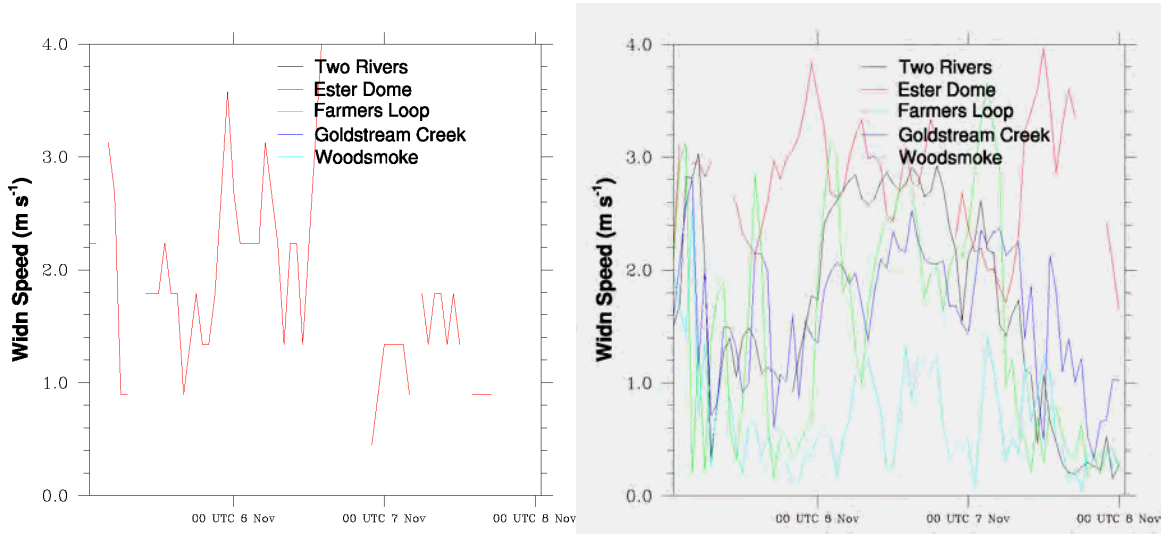


Figure 18: Same as Figure 17, but for wind speed.

Based on these results, it was decided to re-apply a procedure performed during the RARE study to derive an observation nudging correlation length scale based on the near-surface temperature field, and to use that radius of influence in subsequent model simulations. The procedure

consists of repeating the simulation with the same configuration, but with no FDDA of any sort performed on Grid 3. For each station on Grid 3, the temperature innovation (value of the observation minus the value of the model at that location) is computed at one hour increments. The correlation coefficient was then calculated between pairs of stations separated by known horizontal distances. Since the innovation for a variable is proportional to the nudging tendency for that variable, the typical distance over which innovations are correlated gives an indication of what the radius of influence should be. When this analysis was performed for the November case, it was discovered that the typical correlation distance was on the order of 30 km, substantially smaller than the 75 km value derived in the RARE project. (The ability to calculate a smaller radius of influence for the current study was aided by the presence of a denser surface observational network after the inclusion of the non-METAR stations.) It was thus decided to try a combination of a reduced radius of influence from 75 km to 30 km on Grid 3, along with a doubled value of the wind nudging strength on Grid 3 (from 4×10^{-4} s^{-1} to 8×10^{-4} s^{-1}). The temperature nudging strength was left unaltered, because the extreme horizontal variability in the temperature field and its strong dependence on the local topography argue for a more conservative approach.

When the new experiment (henceforth TWIND2X30) was run on the test period, the results (Table 6 and Figure 19 - Figure **22**) showed even more improvement in surface wind direction errors for the three local METAR stations, with an average decrease in MAE of 19 degrees. Temperature RMSE scores were slightly better for Fairbanks, somewhat worse for Ft. Wainwright, but substantially better for Eielson AFB. Since Eielson AFB is relatively distant from most of the other stations, this is an indication that the reduced radius of influence was in fact an improvement. Relative humidity errors are also generally improved. On the other hand, wind speed RMSE scores were made slightly worse, by up to 0.16 m s^{-1} for Ft. Wainwright.

Though there was no completely unambiguous choice, based on the test period results, for the optimal model configuration to produce the dynamic analysis for the entire 2-17 Nov 2008 episode, it was decided that, since the degradation in wind speed errors was slight while the improvement in wind direction errors was substantial, we would select the TWIND2X30 setup as the basis for further simulations.

Table 6: Surface METAR statistics for experiments TWIND and TWIND2X30

Temperature (°C)	TWIND RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND Bias	TWIND2X30 Bias
Fairbanks	1.72	1.68	-0.15	0.33
Eielson AFB	1.80	1.45	1.18	0.95
Ft. Wainwright	1.32	1.43	-0.05	0.63
Three Stations	1.68	1.55	0.36	0.62
Relative Humidity (%)				
Fairbanks	4.31	4.46	-0.59	-0.61
Eielson AFB	7.50	5.43	3.70	2.49
Ft. Wainwright	17.89	16.22	-16.96	-15.33
Three Stations	9,49	8.36	-2.11	-2.26
Wind Speed ($m\ s^{-1}$)				
Fairbanks	0.95	1.01	0.16	0.60
Eielson AFB	1.16	1.24	0.70	0.82
Ft. Wainwright	0.75	0.91	0.53	0.27
Three Stations	1.01	1.10	0.53	0.63
Wind Direction (degrees)				
Fairbanks	32.6	21.0	22.4	9.5
Eielson AFB	37.6	19.3	16.7	3.1
Ft. Wainwright	74.2	48.9	36.2	10.7
Three Stations	53.8	34.5	28.4	9.2

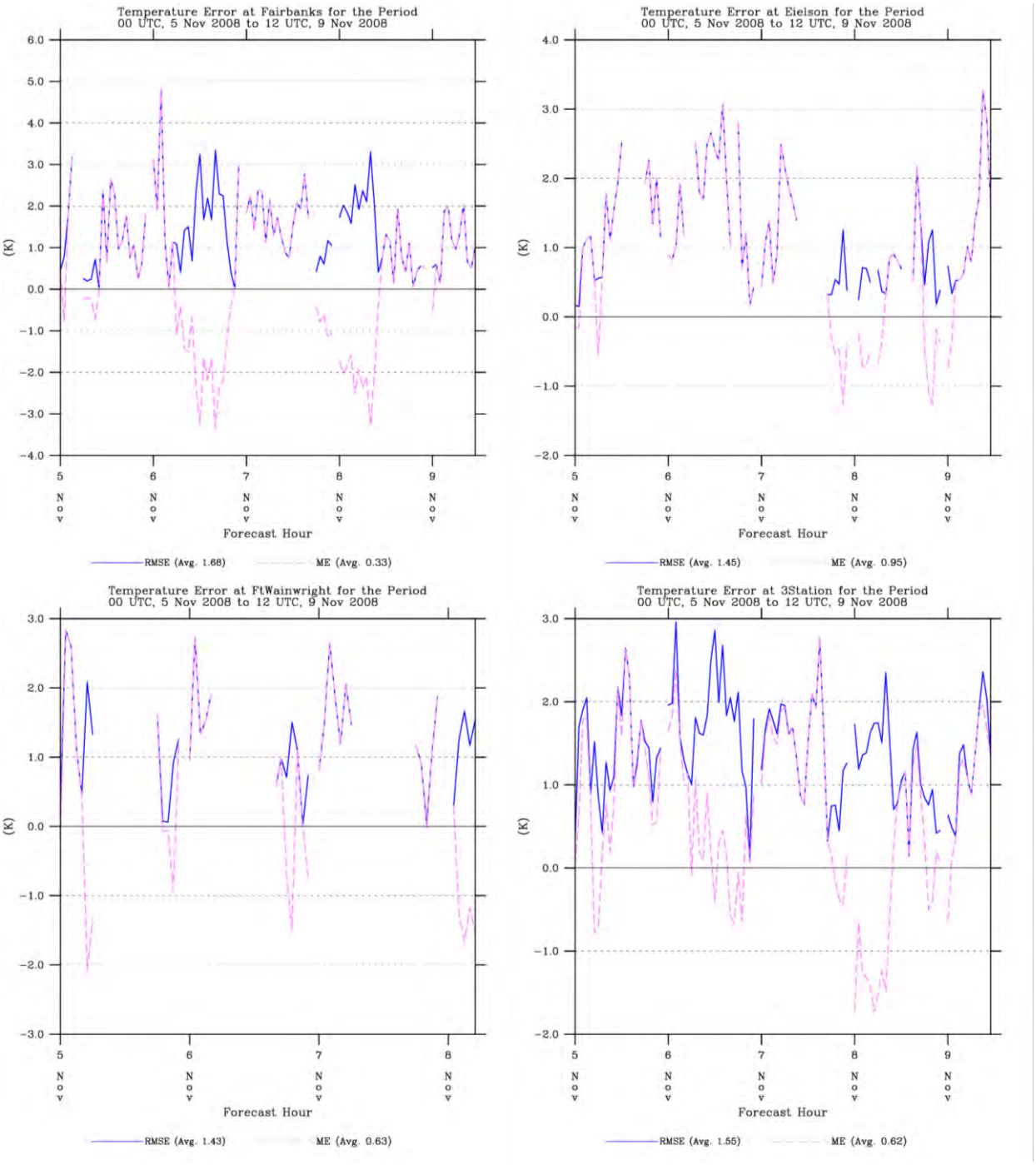


Figure 19: Same as Figure 6, but showing temperature statistics for experiment TWIND2X30.

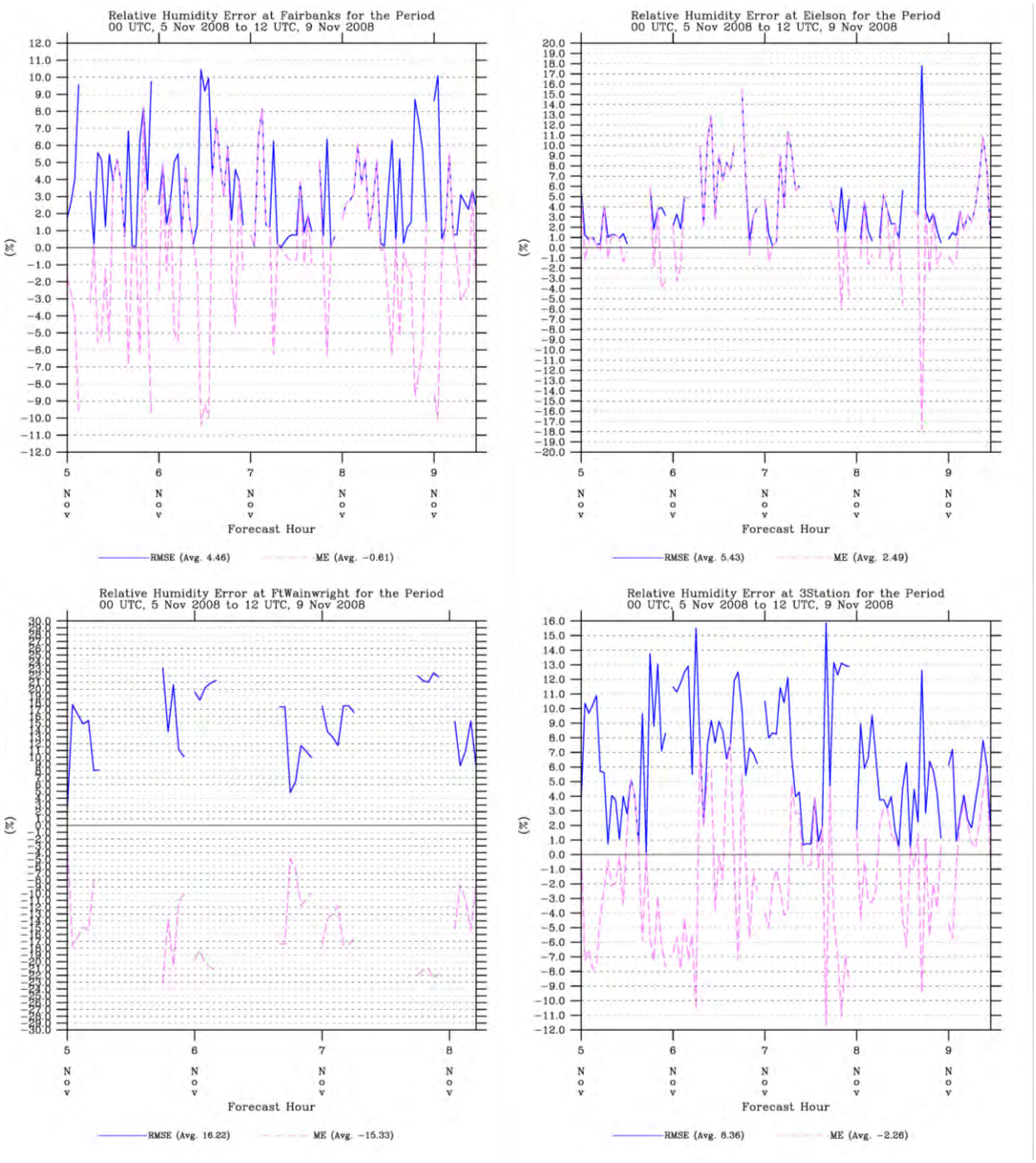


Figure 20: Same as Figure 8, but showing relative humidity statistics for experiment TWIND2X30.

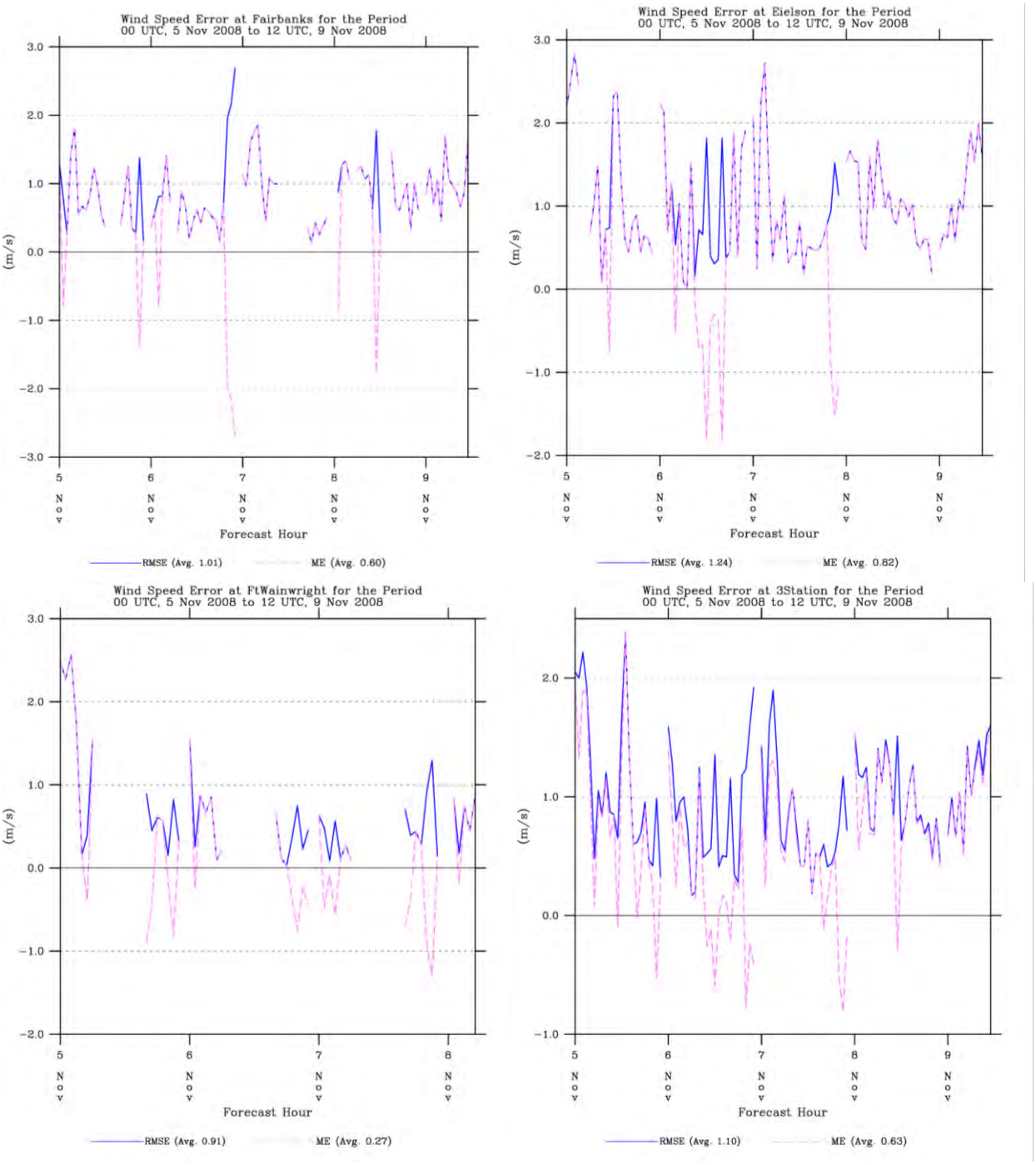


Figure 21: Same as Figure 10, but showing wind speed statistics for experiment TWIND2X30.

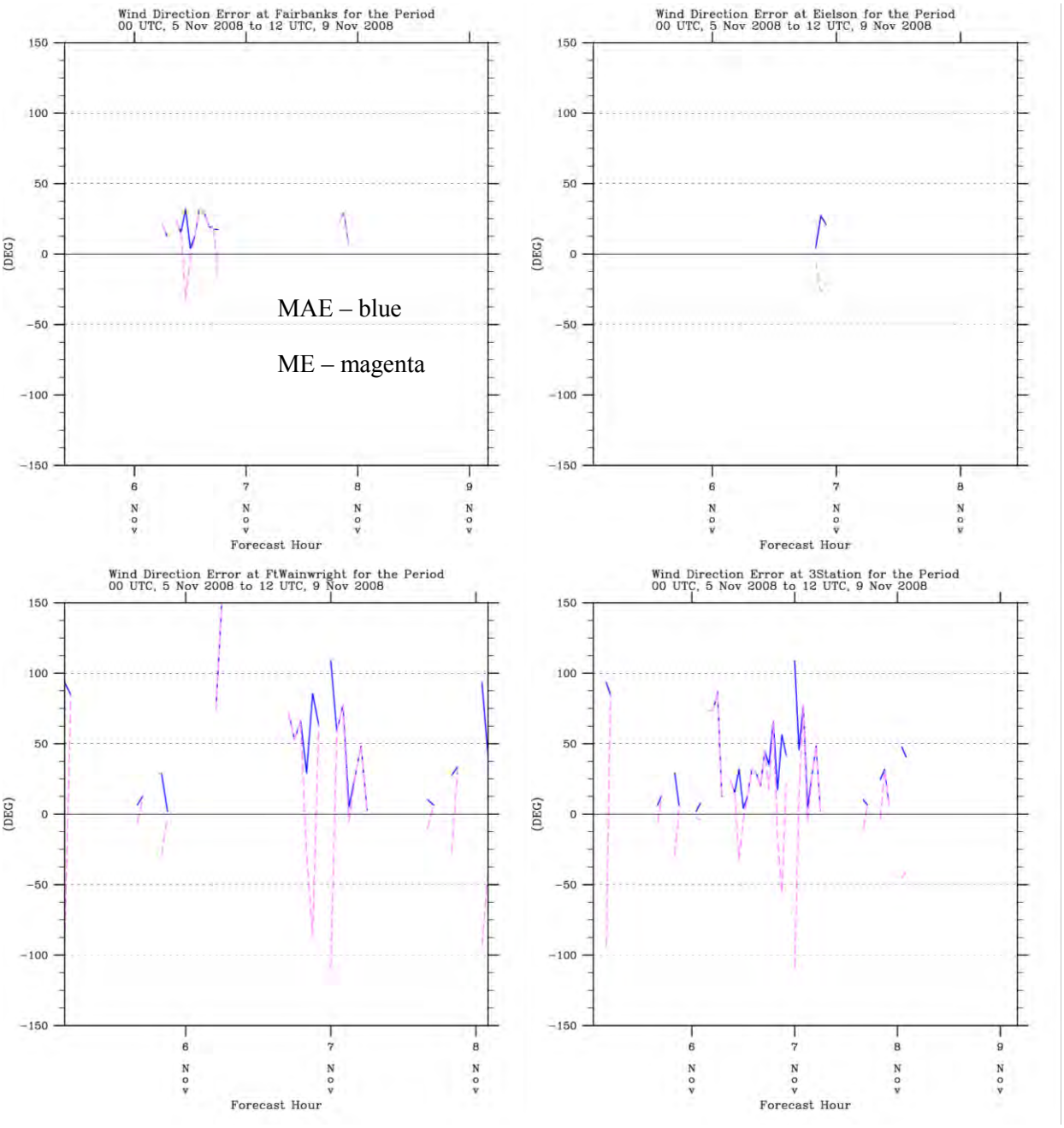


Figure 22: Same as Figure 12, but showing wind direction MAE and ME statistics for experiment TWIND2X30.

5. USE OF CALM WIND OBSERVATIONS

One issue of particular importance lies in the treatment of observations that report zero wind speed. It is often not clear, especially for non-METAR data, whether a report of zero wind speed indicates calm conditions, or indicates missing or faulty data. Furthermore, even if it is accepted that the data correctly represents calm conditions, in practice a report of calm generally indicates an actual wind speed that could have any value up to some minimum detection threshold. For automated METAR surface stations such as Fairbanks this threshold is 3 knots (=1.543 m s^{-1}). This is on the order of the model positive wind speed biases, which suggests that a (not-well-known) component of the model positive wind speed bias may be due to the model capturing actual atmospheric flows that are below the observational threshold. Furthermore, observations of calm winds do not provide usable guidance on the direction of the flow that does exist, which is of great importance for dispersion applications, and for which the model may be the only reliable source of information.

Because of these considerations, the default obs nudging data assimilation strategy is not to use calm wind reports. For the typical case of dense surface observing networks and non-stagnant meteorological conditions, this is entirely satisfactory. However, in the particular application of near-surface transport under very stable conditions, when only a few meters per second of flow can have a great effect on the transport of pollutants, and where the presence of non-calm surface wind observations are infrequent, the assimilation of near-surface calm winds should be considered.

As noted above, the great majority of the surface wind observations for these stable episodes are calm reports. Since the model appears to have a positive wind speed bias in these conditions, nudging towards a zero velocity wind vector near the surface may have a beneficial effect on reducing a positive wind speed bias. On the other hand, also as noted above, an unknown portion of the positive wind speed bias in near-calm conditions is an artifact of the model always having a wind speed above zero while observations indicate a wind speed of exactly zero when the wind speed is below the instrument threshold. Furthermore, since a calm wind observation does not provide guidance as to the wind direction, within the radius of influence of a calm surface observation there is the potential to degrade model predictions of wind direction at locations where the wind speed is not actually calm.

Table 7: Surface METAR statistics for experiments TWIND2X30CALM and TWIND2X30 for the November test period.

Temperature (°C)	TWIND2X30CALM RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND2X30CALM Bias	TWIND2X30 Bias
Fairbanks	1.51	1.68	0.22	0.33
Eielson AFB	1.43	1.45	0.93	0.95
Ft. Wainwright	1.50	1.43	0.70	0.63
Three Stations	1.48	1.55	0.57	0.62
Relative Humidity (%)				
Fairbanks	4.55	4.46	-0.87	-0.61
Eielson AFB	5.44	5.43	2.46	2.49
Ft. Wainwright	16.21	16.22	-15.30	-15.33
Three Stations	8.37	8.36	-2.38	-2.26
Wind Speed ($m\ s^{-1}$)				
Fairbanks	0.97	1.01	0.54	0.60
Eielson AFB	1.18	1.24	0.72	0.82
Ft. Wainwright	0.96	0.91	0.29	0.27
Three Stations	1.07	1.10	0.57	0.63
Wind Direction (degrees)				
Fairbanks	31.4	21.0	20.9	9.5
Eielson AFB	31.0	19.3	4.97	3.1
Ft. Wainwright	83.7	48.9	5.9	10.7
Three Stations	57.1	34.5	11.3	9.2

A final sensitivity test to the effect of including calm wind reports in the data assimilation procedure of experiment TWIND2X30, henceforth experiment TWIND2X30CALM, was performed. Statistics for the two experiments performed over the test period are shown in Table 7. The assessment of the comparison is mixed. Overall temperature biases and wind speed biases are improved by about 10% in experiment TWIND2X30CALM (note however that a 10% improvement of wind speed bias in this case amounts to less than 0.1 m s^{-1} which is certainly less than the instrumentation precision), and temperature RMSE scores are improved by about 5%. However, both statistics are actually degraded for the Ft. Wainwright station. Furthermore, overall wind direction MAE statistics are over 20 degrees worse in experiment TWIND2X30CALM than in experiment TWIND2X30. Recall that in wind direction statistics calm wind observations are excluded from the verification dataset; therefore, a degradation of wind direction statistics in experiment TWIND2X30CALM means that the inclusion of calm wind reports in the data assimilation is having an adverse affect on the model-generated winds at other locations that are not reporting calm winds.

The decision between using simulation TWIND2X30CALM and TWIND2X30 was even more challenging than the decision between simulation TWIND and TWIND2X30. However, despite the beneficial reduction in the positive wind speed bias in TWIND2X30CALM, because of the importance of wind direction prediction to dispersion calculations in these conditions, and because wind direction was the variable that showed the most statistical variability between different experiments, a final decision was made to simulate the whole 2-17 Nov 2008 episode using the TWIND2X30 setup (although a parallel simulation of the entire episode using TWIND2X30CALM was also performed). The time series of the entire episode are presented in Figure 23 - Figure **26**. It appears that the statistics for the whole 2-17 Nov 2008 episode are somewhat worse than the statistics for just the test period, particularly for the temperature statistics during 2-5 Nov, 13-14 Nov, and 17-18 Nov. These three periods of greater-than-typical temperature RMSE scores are actually characterized by negative temperature biases, and meteorologically are characterized by extensive cloudiness and frequent reports of snow. Failure of the model to properly represent these events and the cloudiness in particular could explain the negative temperature biases. The periods of coldest temperatures adjacent to these events have positive temperature biases at these stations, but these are generally of the order of 2 °C or less. The overall three-station temperature bias for the whole episode is negative (-0.9 °C), and the overall temperature RMSE of 2.4 °C is comparable to what was obtained in the RARE project. The overall wind speed bias for the whole Nov 2008 episode for the three METAR stations is almost exactly the same as it is for just the test period (+1.0 m s^{-1}). The overall wind direction MAE of 41 degrees for these stations is slightly better than what we have observed in SBLs over central Pennsylvania using unfiltered wind data. These results give us confidence that our general model configuration is performing as intended, though possibilities for improvement still exist.

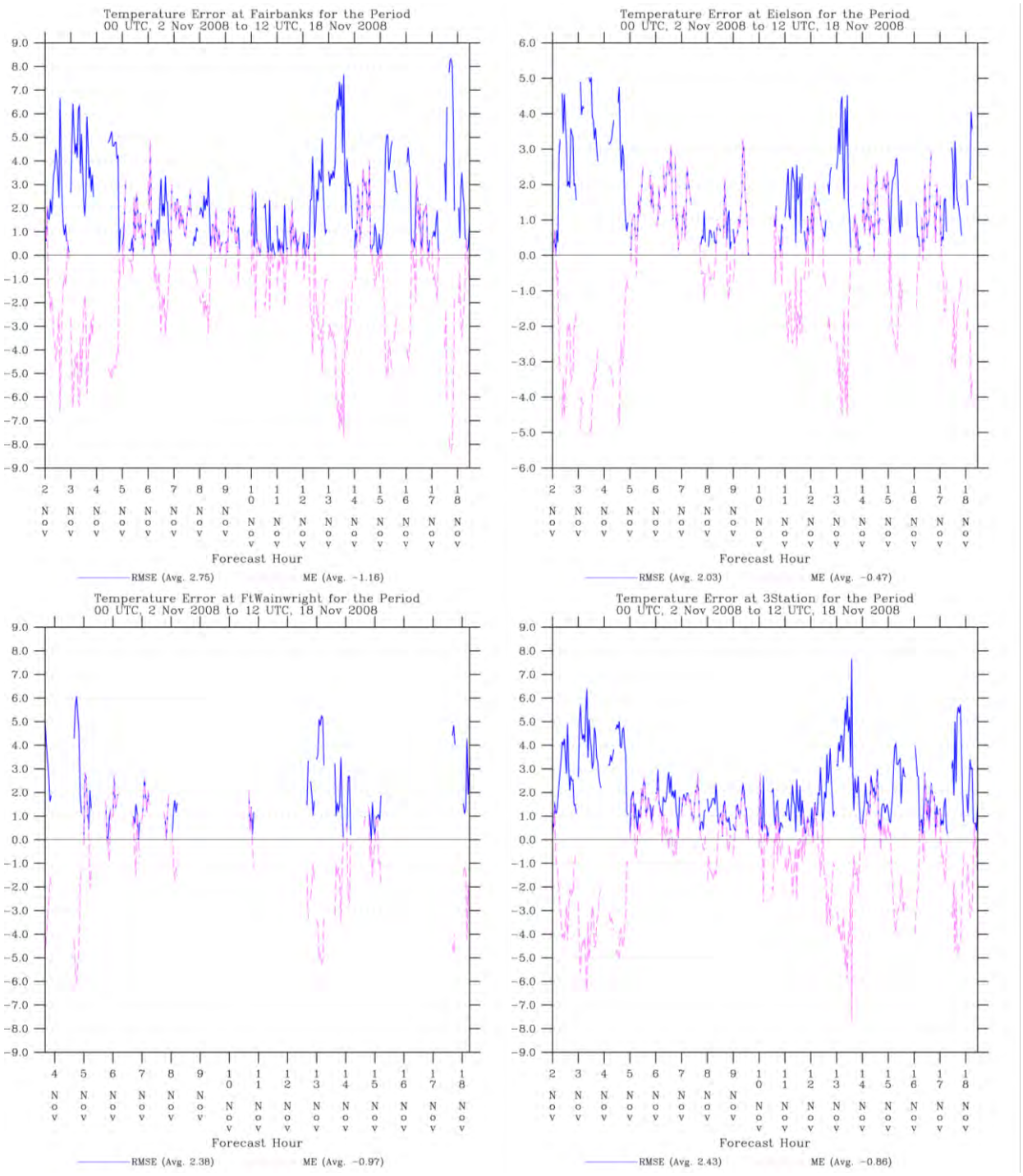


Figure 23: Temperature statistics for experiment TWIND2X30 over the entire 00 UTC 2 Nov 2008 – 12 UTC 18 Nov 2008 test episode at the local METAR surface stations.

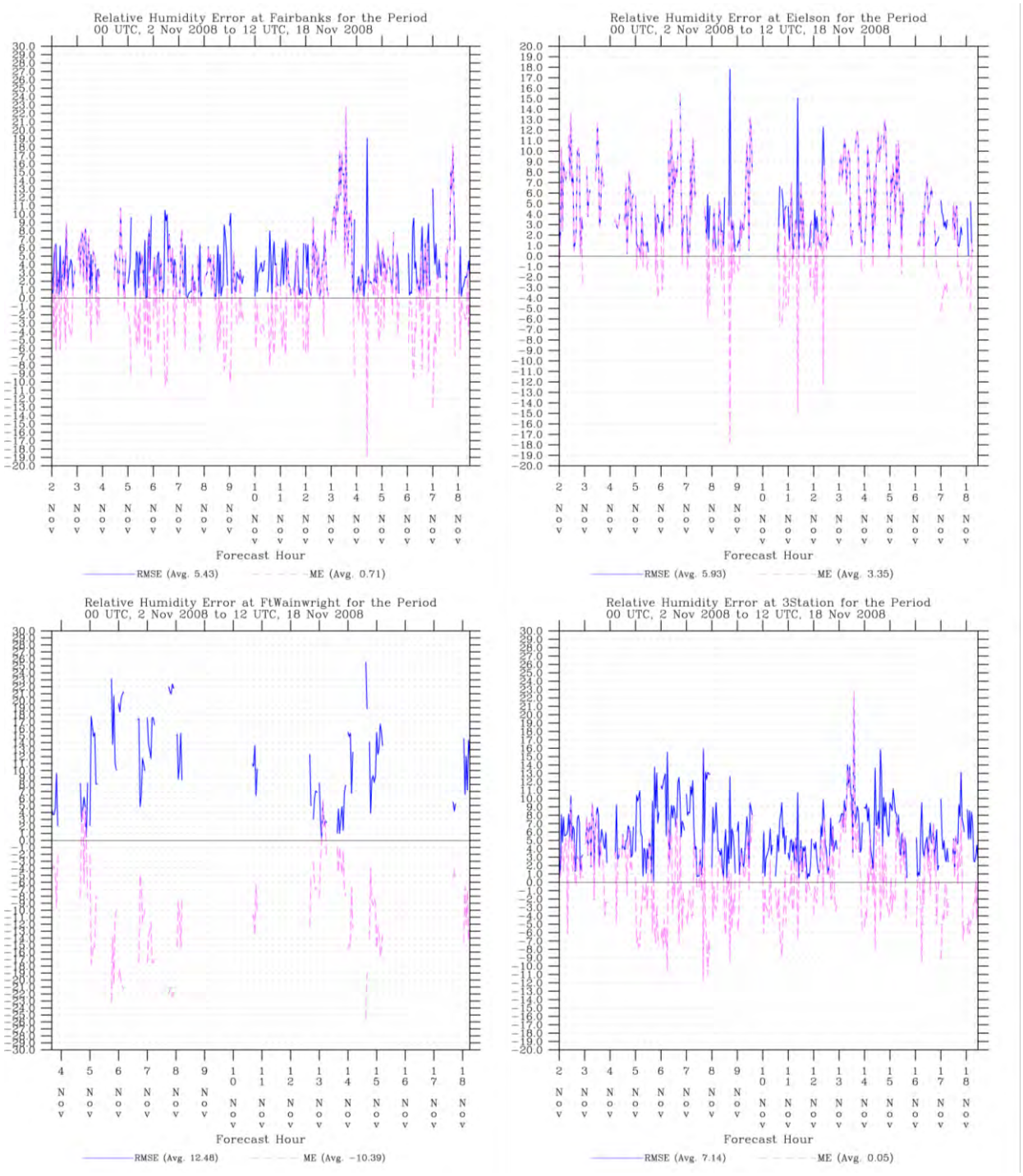


Figure 24: Same as Figure 23, but showing relative humidity statistics.

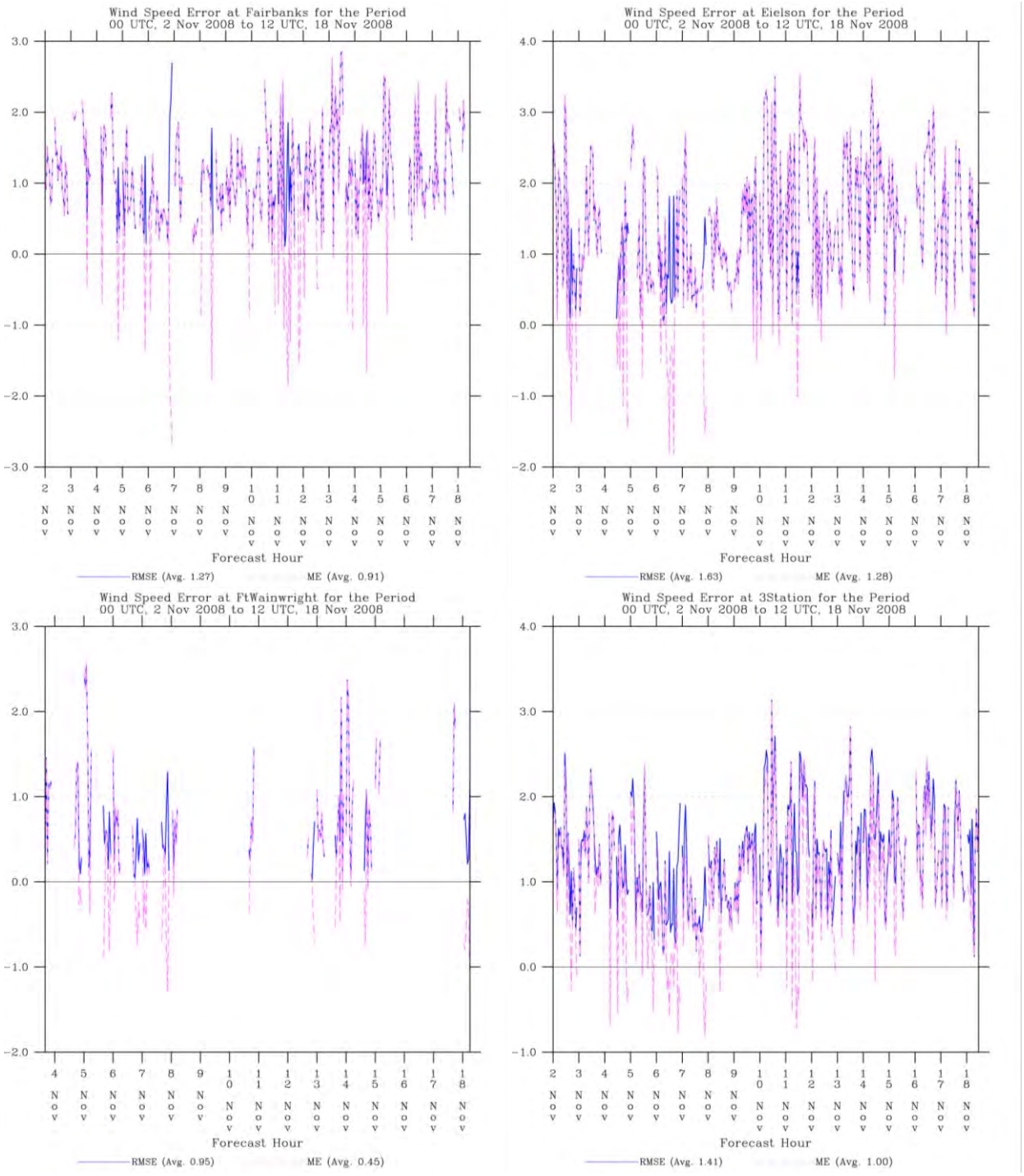


Figure 25: Same as Figure 23, but showing wind speed statistics.

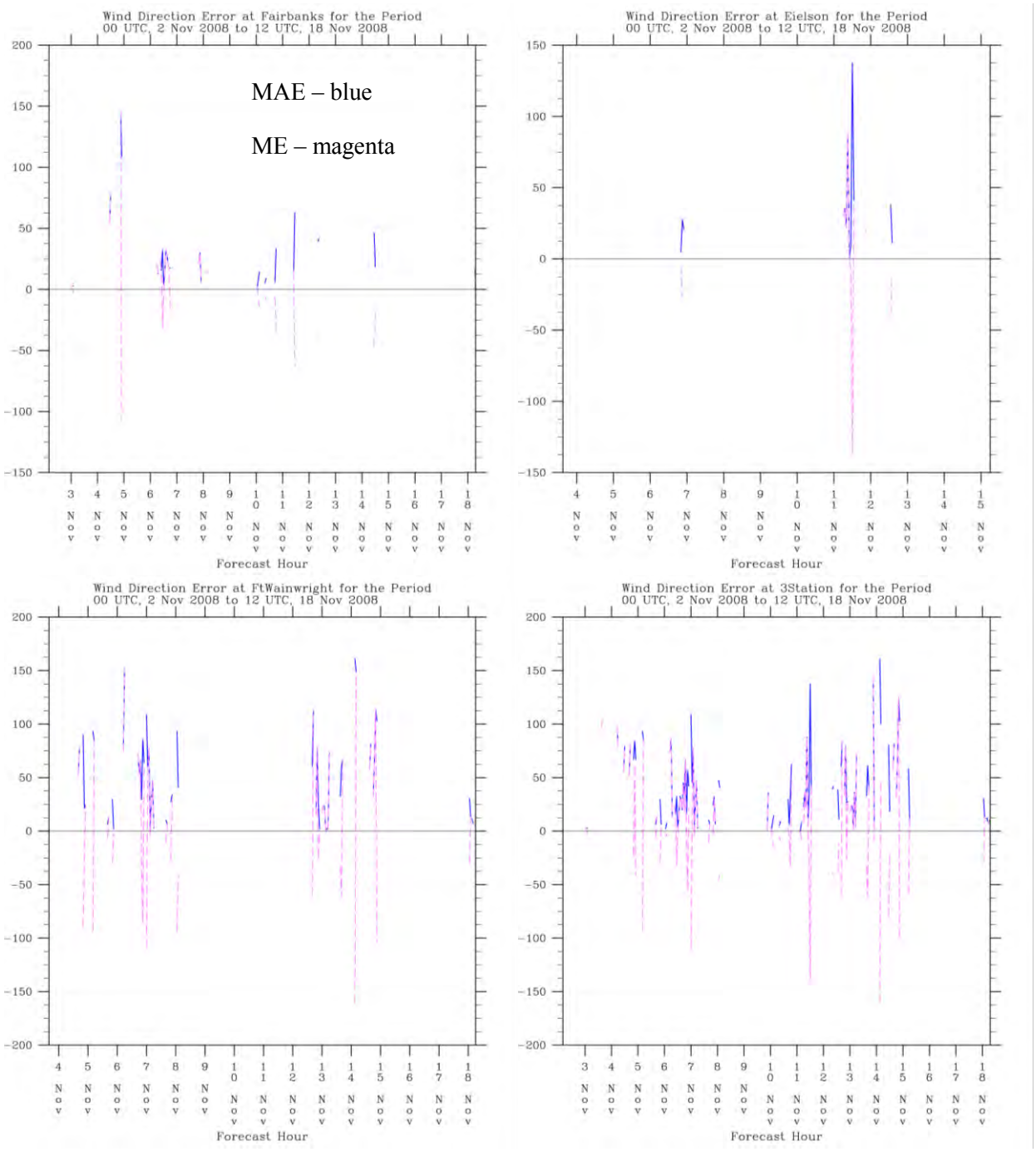


Figure 26: Same as Figure 23, but showing wind direction statistics.

For reference, a comparison between the statistics for the TWIND2X30CALM and TWIND2X30 model configurations for the entire November episode are presented in Table 8. Essentially, the same tendencies found for the November test period apply to the entire November episode as a whole. The superior configuration for temperature depends on statistic and station, and in all cases the sensitivity to calm wind inclusion is never more than about 0.15 °C. Positive wind speed biases are reduced by the inclusion of calms by on the order of 0.1 m s^{-1} for Fairbanks and Eielson, but are actually increased at Ft. Wainwright. Again, the one substantial sensitivity is in wind direction error, for which TWIND2X30 has the better performance.

Finally, detailed time series of the statistics and modeled and observed values of surface meteorological variables, for both METAR and non-METAR stations, are presented in Appendix A for the TWIND2X30 simulation of the November episode that was provided to ADEC.

Table 8: Same as Table 7, but over entire November episode.

Temperature (°C)	TWIND2X30CALM RMSE (MAE for wind direction)	TWIND2X30 RMSE (MAE for wind direction)	TWIND2X30CALM Bias	TWIND2X30 Bias
Fairbanks	2.64	2.75	-1.30	-1.16
Eielson AFB	2.03	2.03	-0.46	-0.47
Ft. Wainwright	2.44	2.38	-0.94	-0.97
Three Stations	2.38	2.43	-0.92	-0.86
Relative Humidity (%)				
Fairbanks	5.49	5.43	0.75	0.71
Eielson AFB	6.01	5.93	3.42	3.35
Ft. Wainwright	12.39	12.48	-10.40	-10.39
Three Stations	7.17	7.14	0.10	0.05
Wind Speed (m s^{-1})				
Fairbanks	1.22	1.27	0.84	0.91
Eielson AFB	1.51	1.63	1.16	1.28
Ft. Wainwright	1.00	0.95	0.49	0.45
Three Stations	1.33	1.41	0.93	1.00
Wind Direction (degrees)				
Fairbanks	46.6	32.8	6.5	6.1
Eielson AFB	45.7	38.6	22.0	18.2
Ft. Wainwright	69.7	50.8	17.1	17.9
Three Stations	55.7	41.3	14.2	13.6

6. JAN-FEB 2008 EPISODE

The episode from 23 Jan – 12 Feb 2008 was re-simulated using the final model setup used for the 2-17 Nov 2008 episode (i.e., model configuration TWIND2X30, using the supplemental surface stations and enhanced vertical resolution in data assimilation). As mentioned previously, the Jan-Feb 2008 episode was considerably colder than the Nov 2008 case, with an extended period of temperatures reaching -35°C (see Figure 27**)**. A comparison between the METAR station statistics for the TWIND2X30 re-simulation with the statistics from the original RARE project simulation is shown in Table 9. Generally the difference between the re-simulated and original statistics were slight for temperature, wind speed, and relative humidity (although at Ft. Wainwright the temperature RMSE increased by 0.5 °C in the re-simulated case). Wind direction errors were substantially reduced in the re-simulated Jan – Feb 2008 episode, though, because in the original RARE configuration there was no assimilation of any surface wind observations on the finest domain. It appears that either model configuration has little, if any, overall temperature bias for the Jan-Feb episode. However, this reflects a cancellation between periods of positive temperature bias (generally the coldest temperature episodes) and periods of negative temperature bias (generally before the coldest episodes, often when precipitation is occurring).

A comparison of the METAR statistics between the TWIND2X30 versions of the Nov 2008 and Jan-Feb 2008 episodes (Table 10) shows that the TWIND2X30 version of the Jan-Feb 2008 episode arguably has better statistics than the Nov 2008 episode, despite the more extreme cold present in the former. However, the more negative temperature bias in the Nov 2008 versus the Jan-Feb 2008 episode is consistent with the relative absence of extreme cold periods in Nov 2008 and the configurations general tendency to have a negative temperature bias in milder winter conditions for the Fairbanks region. While the model tends to be too warm during the periods of the coldest temperatures, the coldest temperature periods also tend to be of short duration.

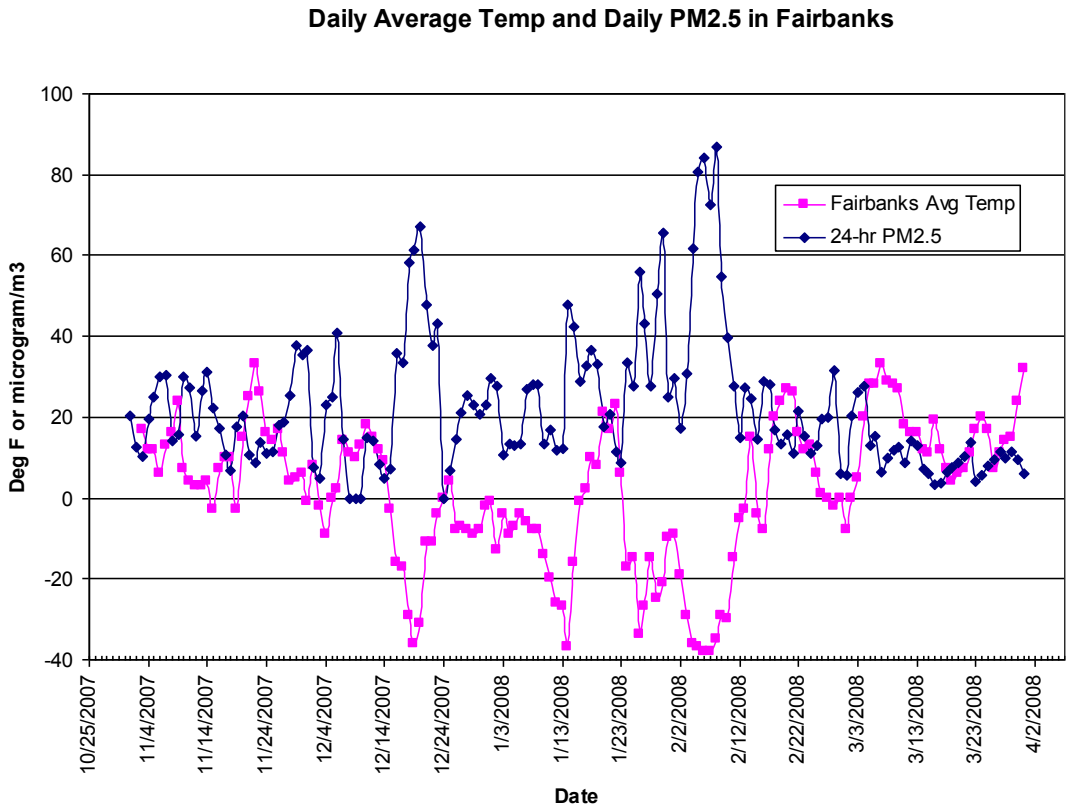


Figure 27: Measured daily average temperature (Fahrenheit) and 24-hr PM2.5 concentration in Fairbanks region during 2007-2008 winter season. Courtesy Robert Dulla, Sierra Research.

Temperatures for some of the local non-METAR stations are shown in Figure 28. Although the data record is a bit erratic, it is apparent that for the coldest period between 00 UTC on the 4th and 00 UTC on the 9th, the temperatures in Woodsmoke can be 10 °C or more colder than those in Two Rivers, which in turn can be 10 °C colder than those on Ester Dome. While the model surface temperature forecasts are not perfect (daytime temperatures at Two Rivers in particular seem to be too warm) the model configuration is certainly capturing a large part of the temperature variability and magnitude across these stations

Time series of statistics for the METAR stations for the rerun of the Jan – Feb 2008 case are shown in Figure 29 – Figure **32**. While there are significant gaps in the data, it seems clear that the period from about 28 January through 31 January, as well as from about 4 – 11 February, exhibit positive temperature bias, corresponding to periods of low actual temperatures, while other periods tend to have a negative temperature bias (Figure 29). The largest temperature RMSE values for the positive and negative temperature bias periods are roughly comparable (exceeding 4 °C at times, but usually less than 3 °C). Wind speed biases tend to be positive

(Figure 31), but wind speed RMSE values seem to vary little on average between the warm and cold periods. These results are broadly consistent with those from the RARE project.

Appendix B contains more detailed time series of the statistics and modeled and observed surface field values for the Jan-Feb 2008 episode.

Table 9: Comparison of statistics for Jan-Feb 2008 between RARE configuration and TWIND2X30 configuration.

Temperature (°C)	Jan-Feb RARE RMSE (MAE for wind direction)	Jan-Feb RARE Bias	Jan-Feb TWIND2X30 RMSE (MAE for wind direction)	Jan-Feb TWIND2X30 Bias
Fairbanks	2.20	-0.03	2.22	-0.12
Eielson AFB	1.81	-0.07	2.05	-0.23
Ft. Wainwright	1.33	0.23	1.83	0.51
Three Stations	1.87	0.02	2.07	0.00
Relative Humidity (%)				
Fairbanks	8.07	2.74	8.15	2.55
Eielson AFB	11.45	-1.38	12.45	-2.49
Ft. Wainwright	16.85	-13.87	17.09	-13.67
Three Stations	11.98	-2.89	12.44	-3.32
Wind Speed (m s^{-1})				
Fairbanks	1.58	0.87	1.51	0.86
Eielson AFB	1.17	0.69	1.18	0.69
Ft. Wainwright	1.31	0.32	1.21	0.25
Three Stations	1.38	0.69	1.34	0.68
Wind Direction (degrees)				
Fairbanks	43.6	0.3	21.6	-5.6
Eielson AFB	55.7	-19.4	26.0	-10.3
Ft. Wainwright	66.4	18.9	40.3	3.4
Three Stations	54.6	1.9	29.2	-3.6

Table 10: Comparison of statistics for Nov 2008 and Jan-Feb 2008 episodes for TWIND2X30 model configuration.

Temperature (°C)	Nov 2008 RMSE (MAE for wind direction)	Nov 2008 Bias	Jan-Feb 2008 RMSE (MAE for wind direction)	Jan-Feb 2008 Bias
Fairbanks	2.75	-1.16	2.22	-0.12
Eielson AFB	2.03	-0.47	2.05	-0.23
Ft. Wainwright	2.38	-0.97	1.83	0.51
Three Stations	2.43	-0.86	2.07	0.00
Relative Humidity (%)				
Fairbanks	5.43	0.71	8.15	2.55
Eielson AFB	5.93	3.35	12.45	-2.49
Ft. Wainwright	12.48	-10.39	17.09	-13.67
Three Stations	7.14	0.05	12.44	-3.32
Wind Speed (m s^{-1})				
Fairbanks	1.27	0.91	1.51	0.86
Eielson AFB	1.63	1.28	1.18	0.69
Ft. Wainwright	0.95	0.45	1.21	0.25
Three Stations	1.41	1.00	1.34	0.68
Wind Direction (degrees)				
Fairbanks	32.8	6.1	21.6	-5.6
Eielson AFB	38.6	18.2	26.0	-10.3
Ft. Wainwright	50.8	17.9	40.3	3.4
Three Stations	41.3	13.6	29.2	-3.6

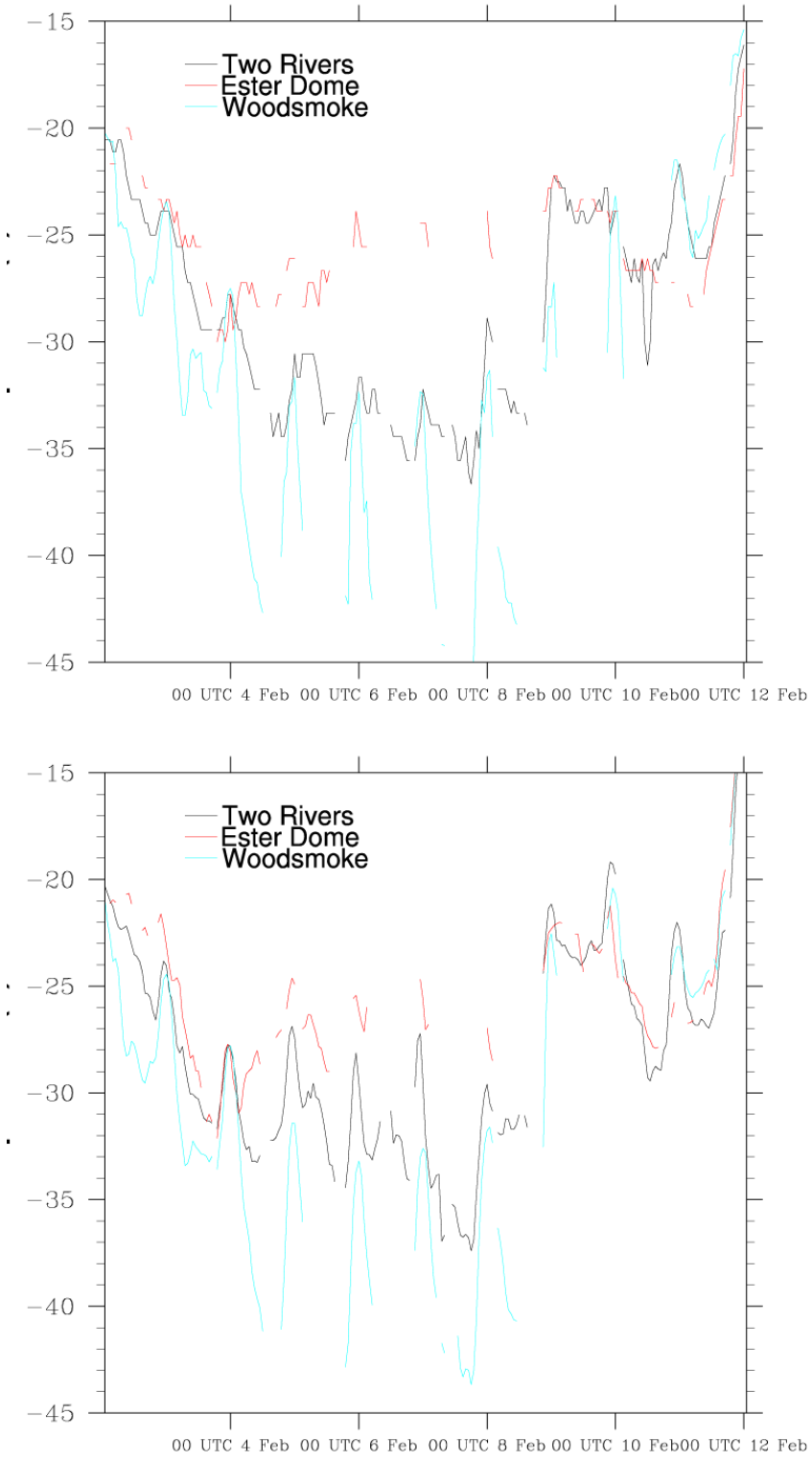


Figure 28: Observed (top) and model (bottom) surface temperatures (degrees Celsius) at non-METAR stations for 00 UTC 3 Feb -- 00 UTC 12 Feb

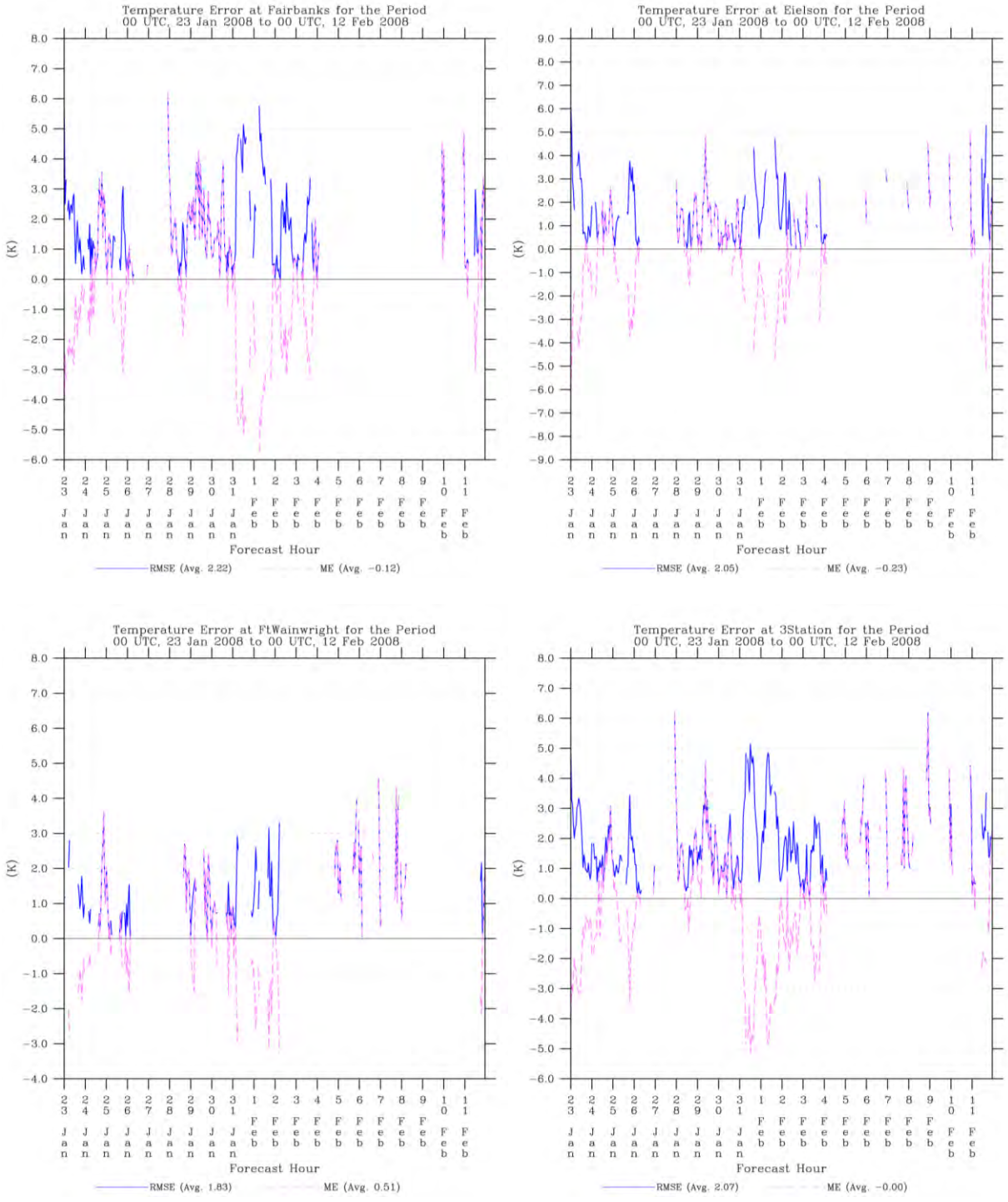


Figure 29: Temperature RMSE and Bias statistics for Jan-Feb 2008 episode at the local METAR surface stations using TWIND2X30 configuration.

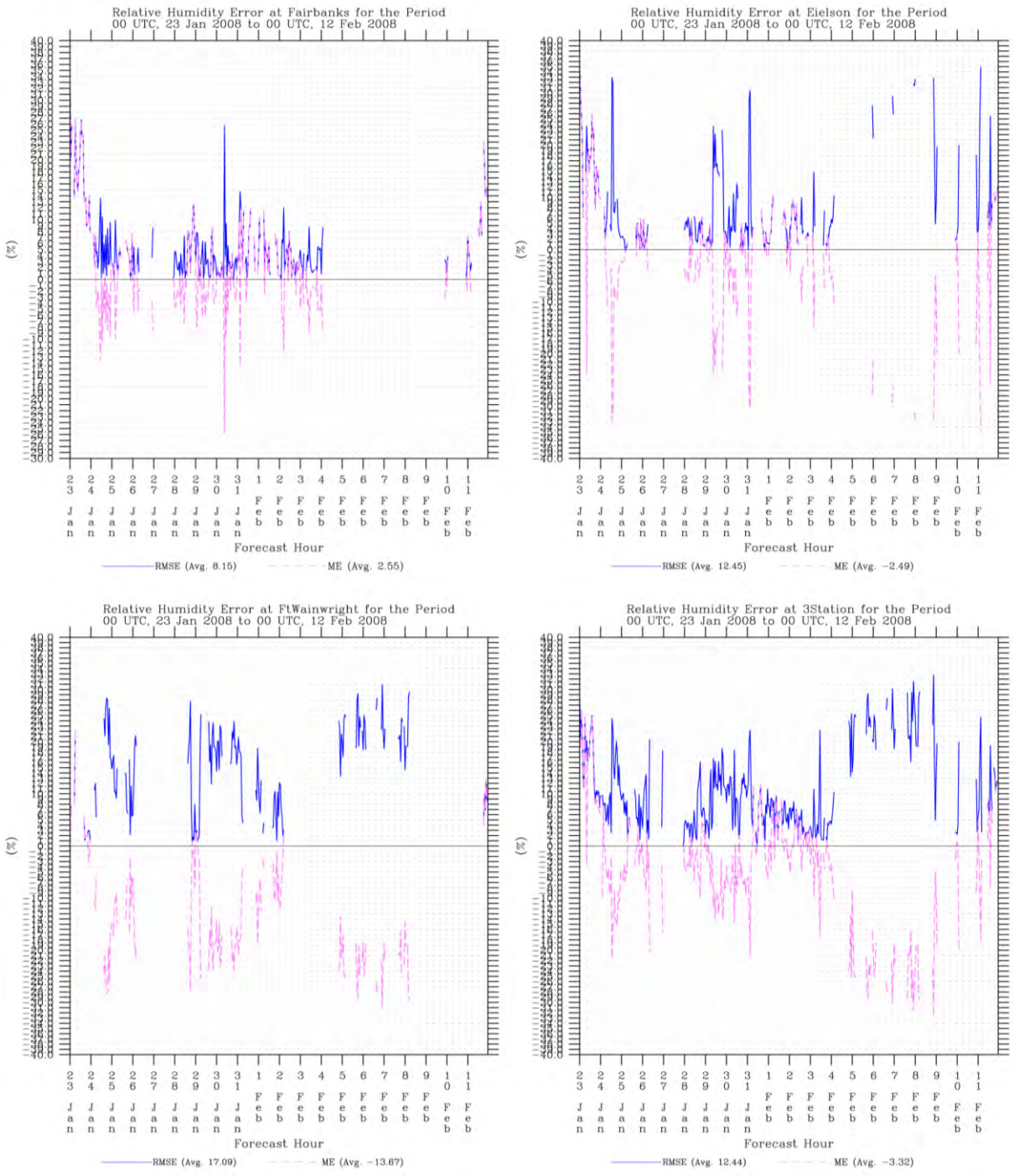


Figure 30: Same as Figure 29, but for relative humidity.

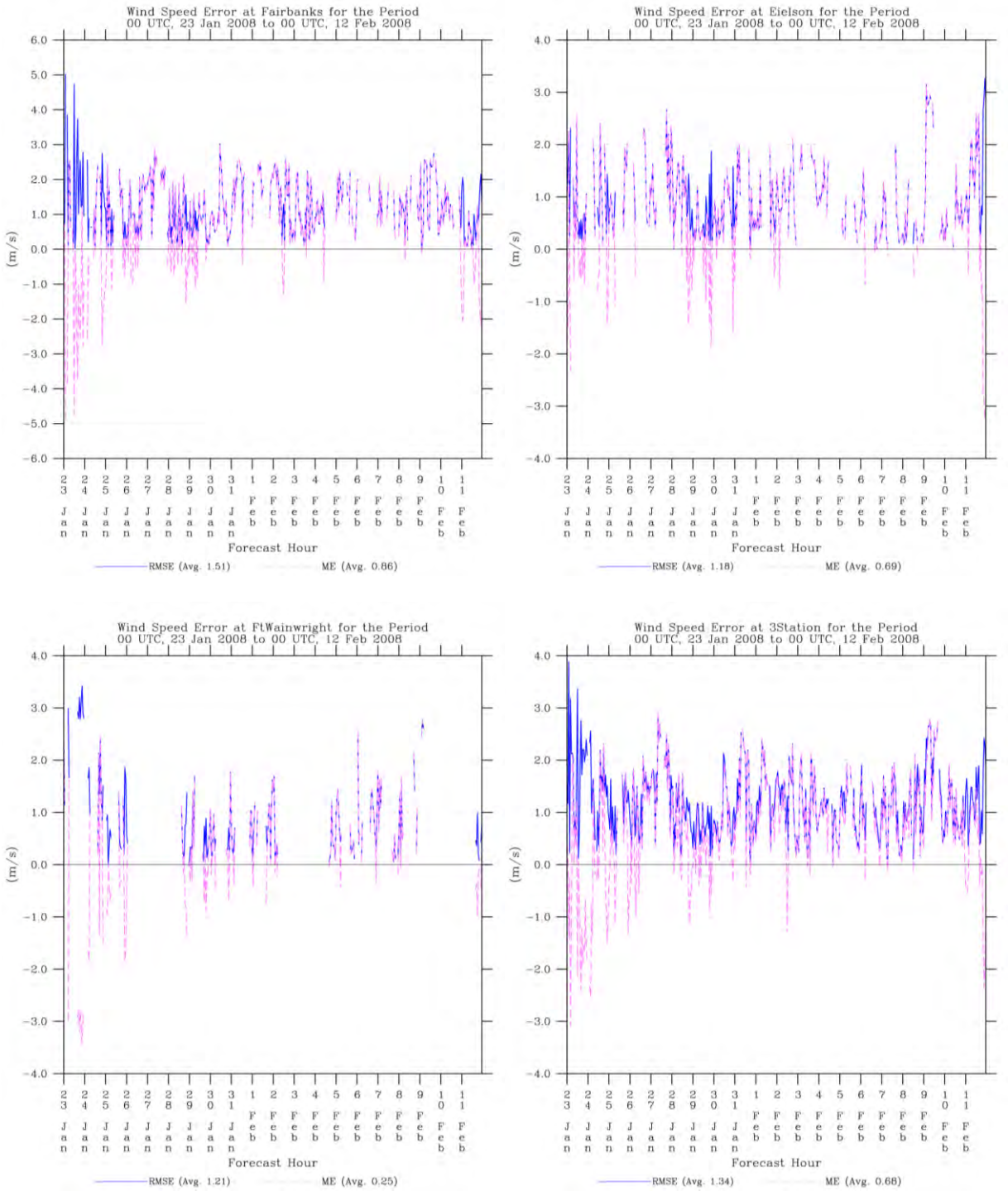


Figure 31: Same as Figure 29, but for wind speed.

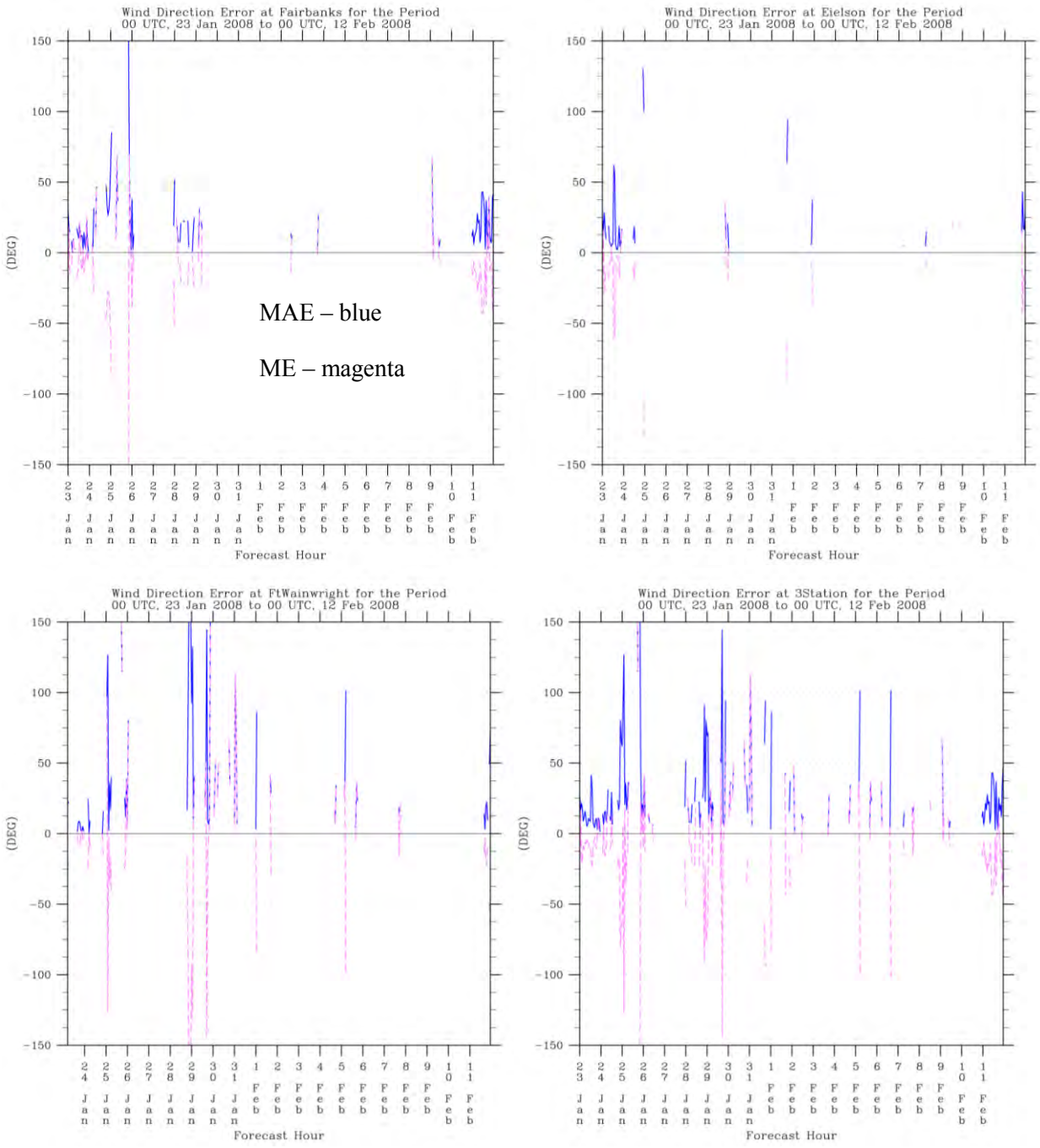


Figure 32: Same as Figure 29, but for wind direction MAE and ME statistics.

7. CONCLUSIONS

An episode extending from 2-17 November 2008 was simulated as part of the State Implementation Plan for the Fairbanks / North Star non-attainment region. The simulations were performed using the WRF-ARW model with essentially the same configuration as that used in the preliminary RARE study. However, initial decisions were made to increase the effective vertical resolution of the data assimilation near the surface, to use observation nudging towards surface wind observations even on the 1.33-km finest grid, and to make use of both standard METAR and non-METAR surface observations that were available for the period. These alterations to the procedure of the RARE study were made because, even though the statistics from that study were reasonably good, the model displayed a warm bias during the coldest, most stagnant conditions from that study, and concurrently the model wind speed bias was consistently positive. It was felt that these modifications would lead to the creation of a dynamic analysis that would be a closer fit to the actual state of the atmosphere.

The November episode was divided into four overlapping simulation segments using the discussed model configuration. A test period from 5-9 November was chosen for model sensitivity tests, including a comparison between the RARE study methodology and the proposed method of enhancing the data assimilation capabilities. Statistics indicated the benefits of the new data assimilation configuration, especially for wind direction. This configuration was then used for all subsequent simulations. However, the statistics also suggested that the model data assimilation was effectively blending the influence of neighboring observations in the Fairbanks region, leading to model simulations that did not possess all of the horizontal variability of the observations. A procedure taken from the RARE study was performed to determine an effective correlation length scale for surface temperature observation innovations; this led to new simulations in which the radius of influence was reduced from 75 km to 30 km, while the strength of the nudging coefficients was doubled. The new configuration (indicated by the label TWIND2X30) was then used to simulate the entire November episode, and generated the atmospheric analysis delivered to ADEC.

A positive wind speed model bias remained during stagnant, cold temperature conditions, though a portion of that bias is an artifact of the threshold of instrument detection, causing observations to frequently report dead calm conditions while model simulations produce non-zero wind speeds near the surface. While one procedure to reduce the positive wind speed bias would be to explicitly nudge towards the calm wind observations, it was found that this led to only minimal reductions in the wind speed bias, and using these reports in nudging had the undesirable effect of creating large increases in wind direction error at nearby stations not reporting dead calm conditions. Therefore, the decision was made to use the default procedure of not making explicit use of calm surface wind observations in the data assimilation procedure.

The Jan-Feb 2008 episode was then re-simulated using the TWIND2X30 configuration. Wind direction statistics for the METAR stations were improved with respect to the original simulations from the RARE project. Other fields did not show much change statistically. While model output at the location of the non-METAR station at Woodsmoke confirmed that the model could produce temperatures (nearly) as cold as observed temperatures around -45 °C, at other locations the model had difficulty producing sufficient cooling, especially if the horizontal resolution was insufficient (e.g., Goldstream Creek).

At the METAR stations, overall temperature bias for both episodes was quite low (less than a degree Celsius), while the temperature RMSE was on average 2 – 2.5 °C, which seemed reasonable given the occasionally extreme meteorological conditions. Wind speed RMSE values seemed to be fairly consistent at 1.3 – 1.4 m s^{-1}, while wind direction MAE values were on the order of 30 – 40 degrees with the TWIND2X30 configuration.

APPENDIX A – Detailed Time-Series Figures of 2-17 November 2008 Episode, for TWIND2X30 Configuration

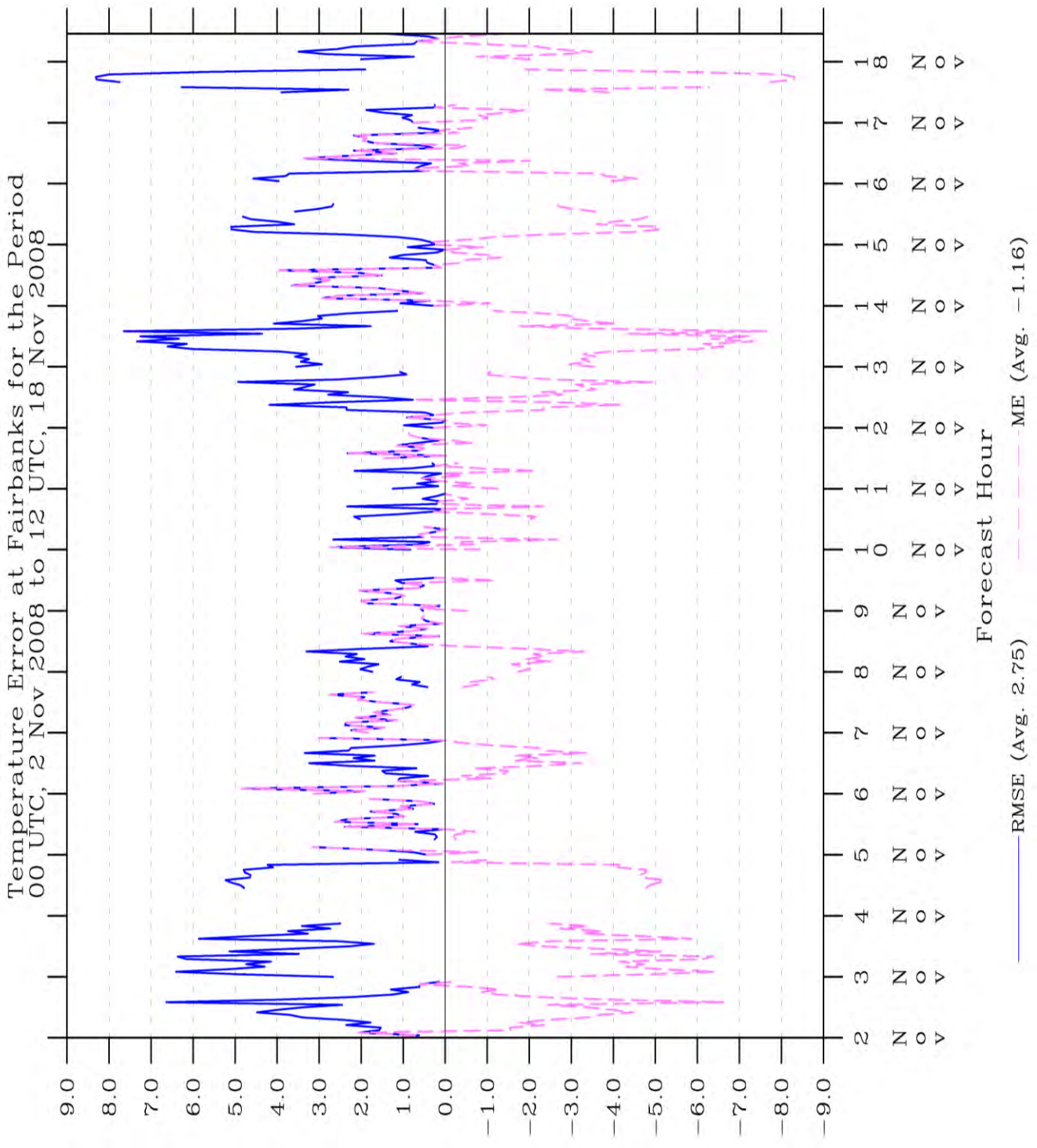


Figure 33: Time series of temperature statistics for Fairbanks in TWIND2X30.

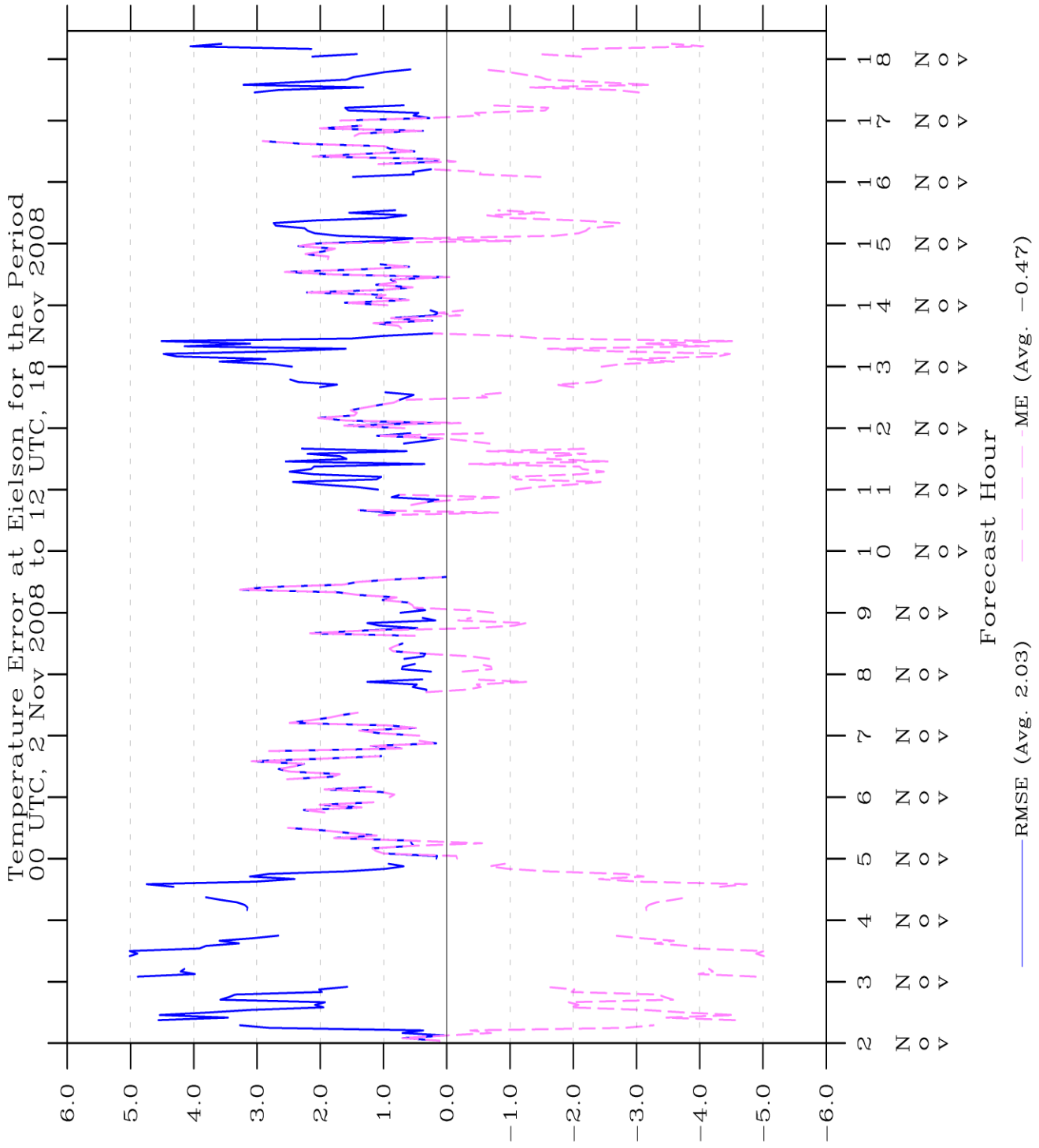


Figure 34: Time series of temperature statistics for Eielson in TWIND2X30.

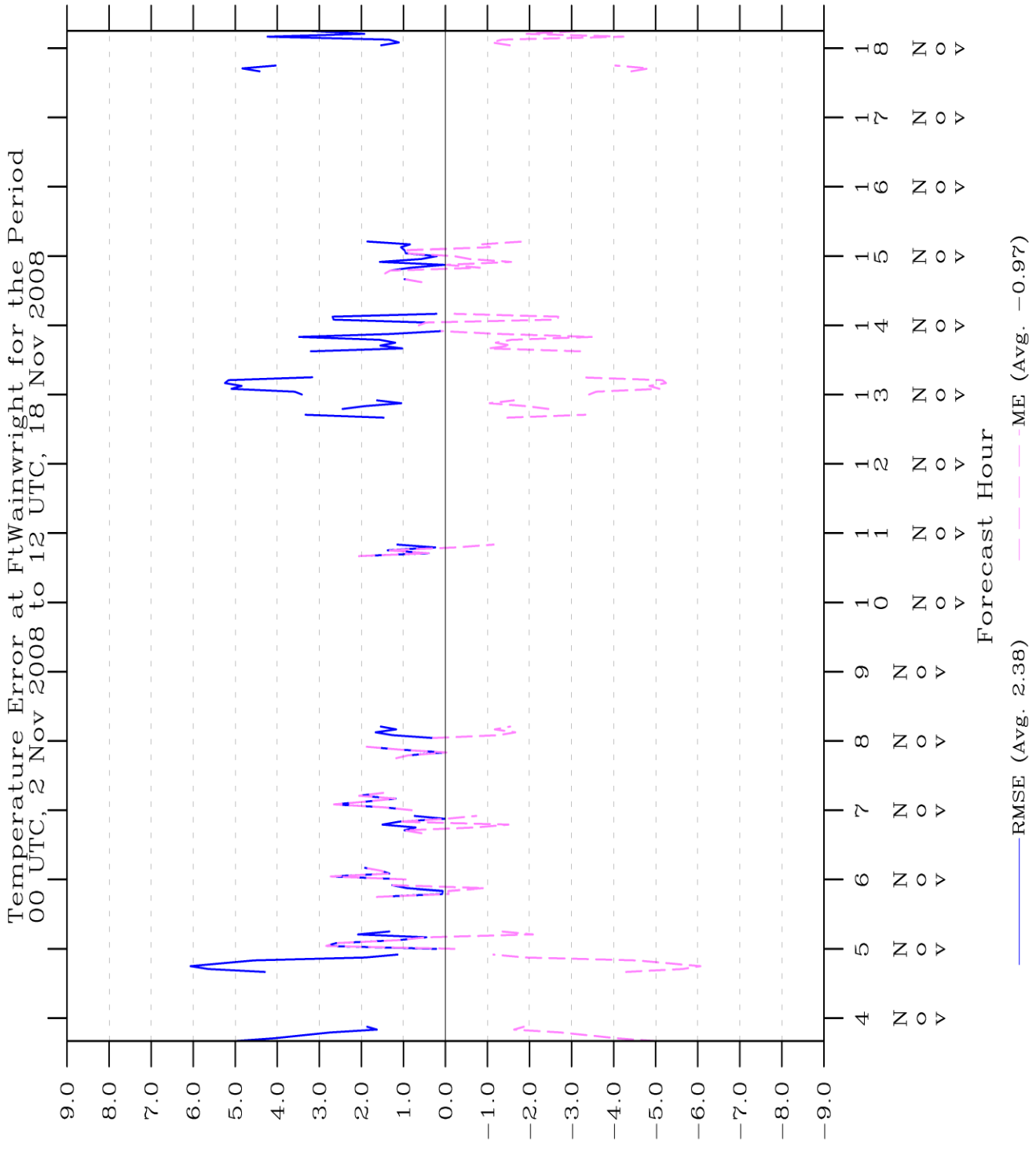


Figure 35: Time series of temperature statistics for Ft. Wainwright in TWIND2X30.

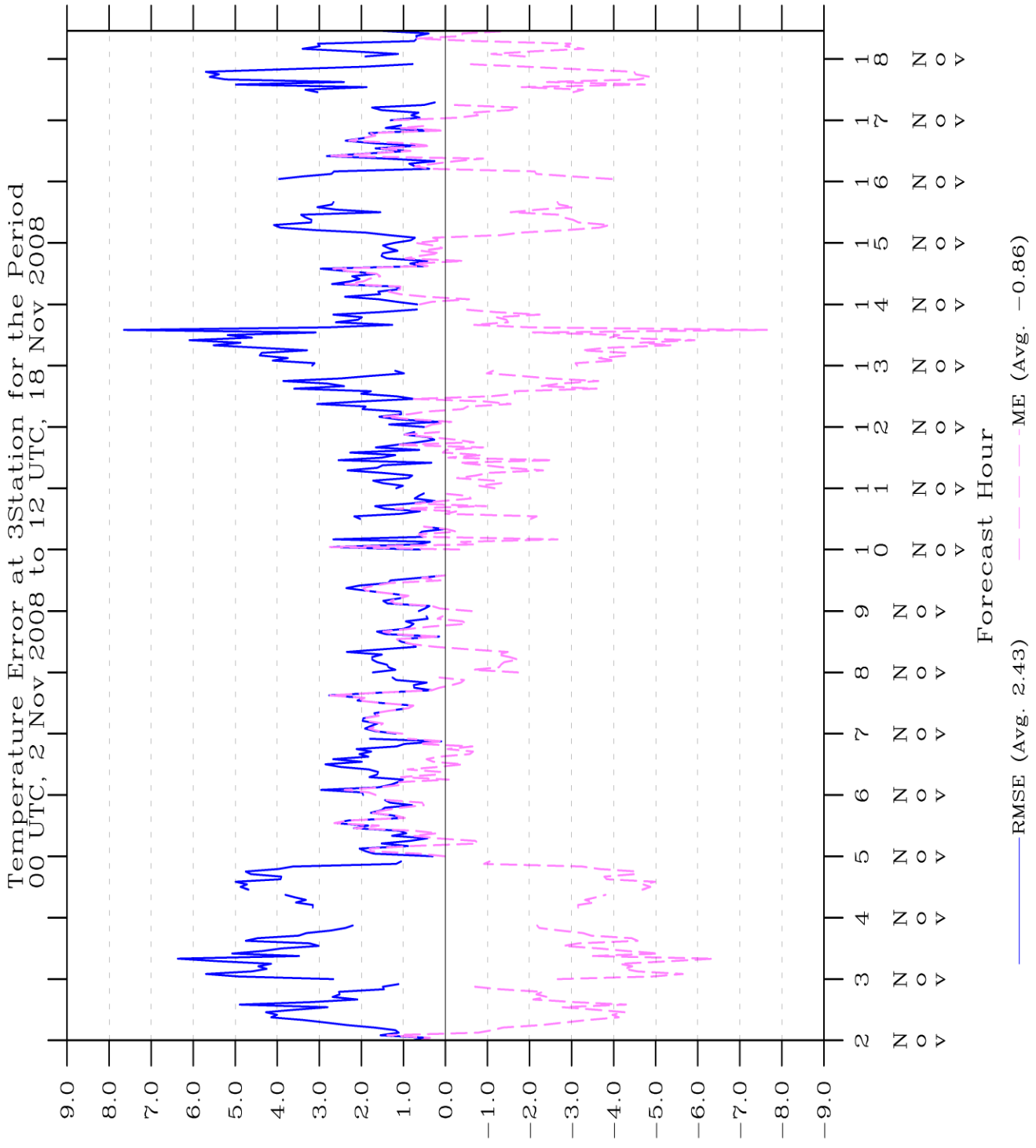


Figure 36: Time series of temperature statistics for all three stations in TWIND2X30.

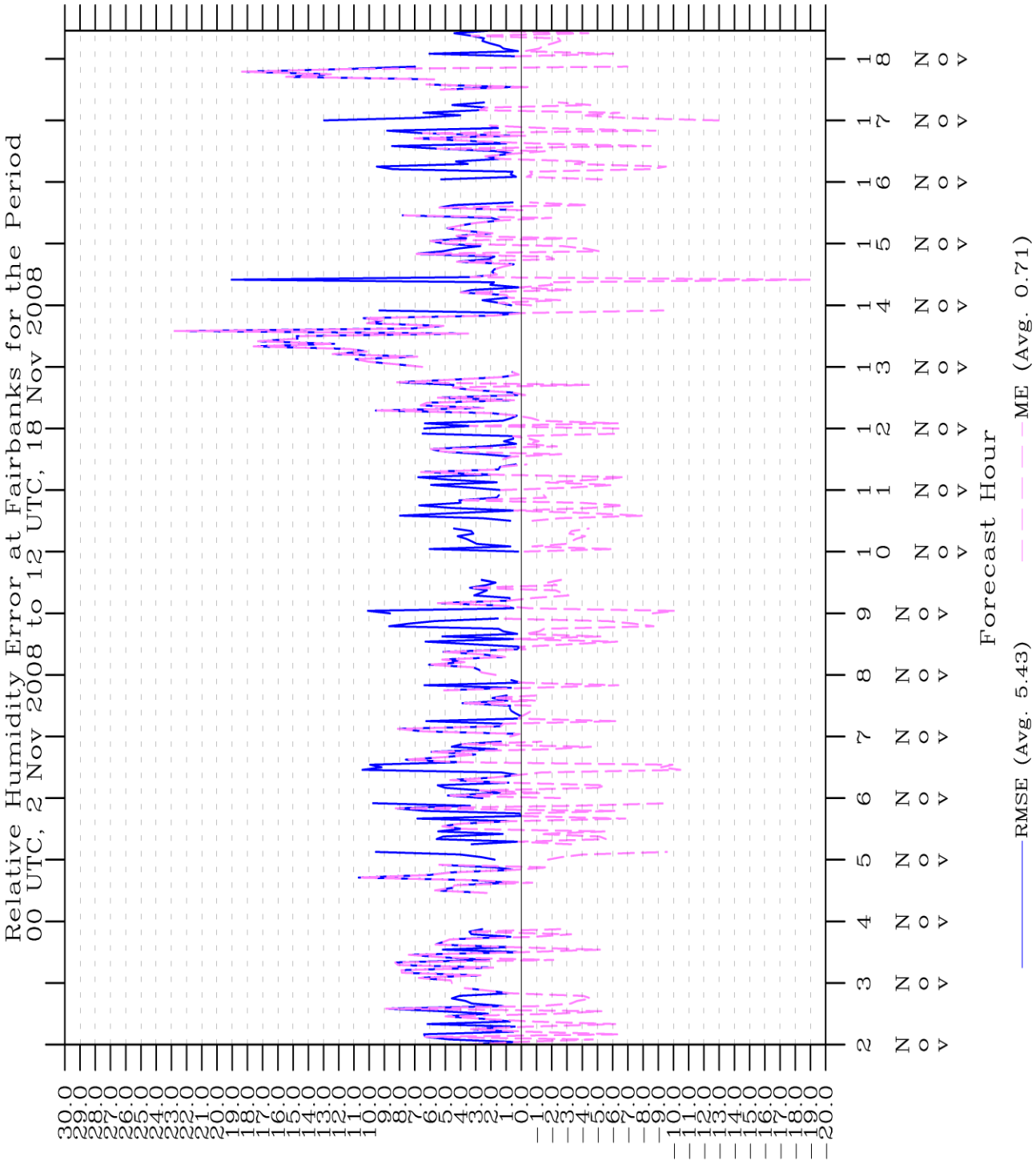


Figure 37: Time series of relative humidity statistics for Fairbanks in TWIND2X30.

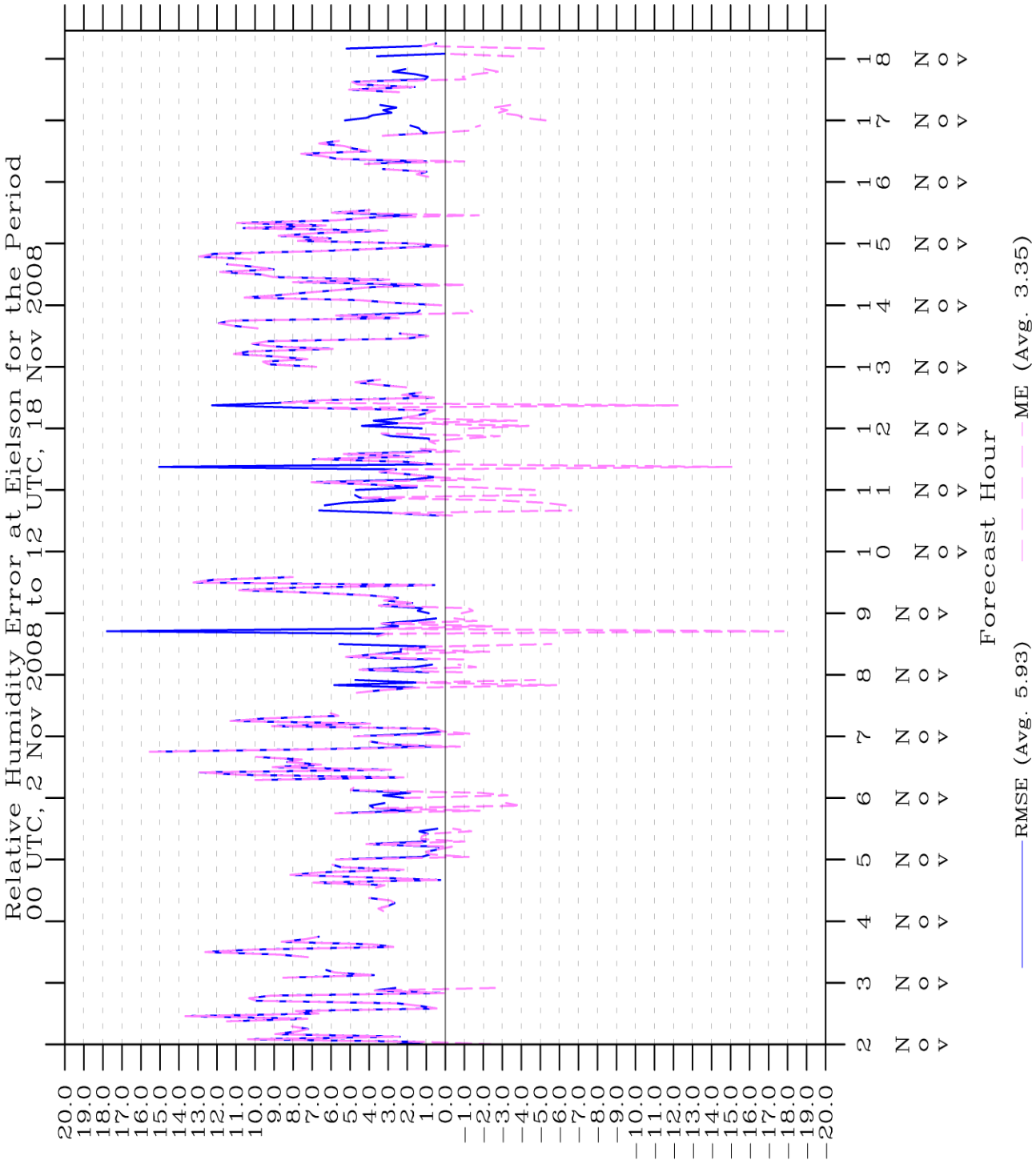


Figure 38: Time series of relative humidity statistics for Eielson in TWIND2X30.

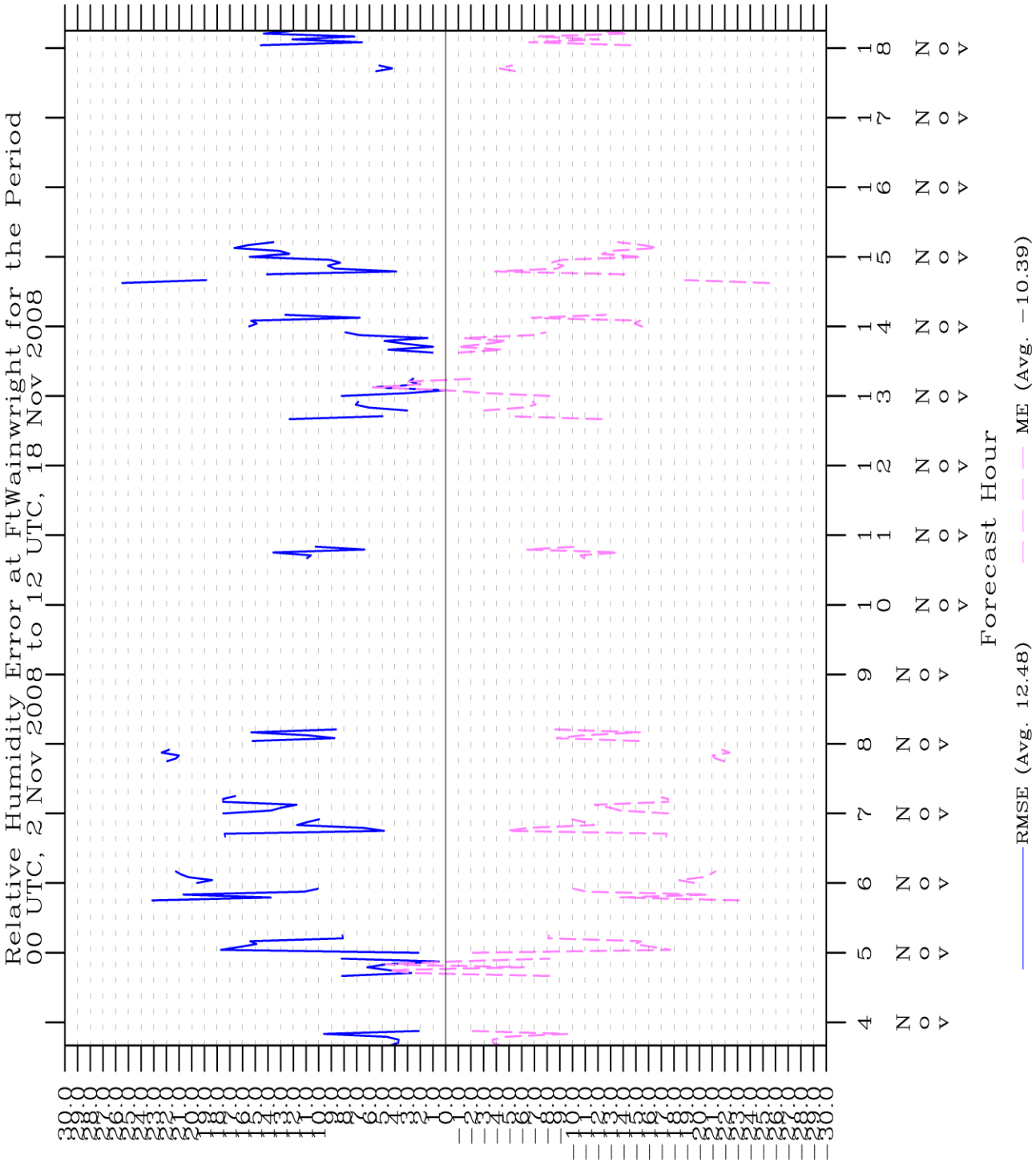


Figure 39: Time series of relative humidity statistics for Ft. Wainwright in TWIND2X30.

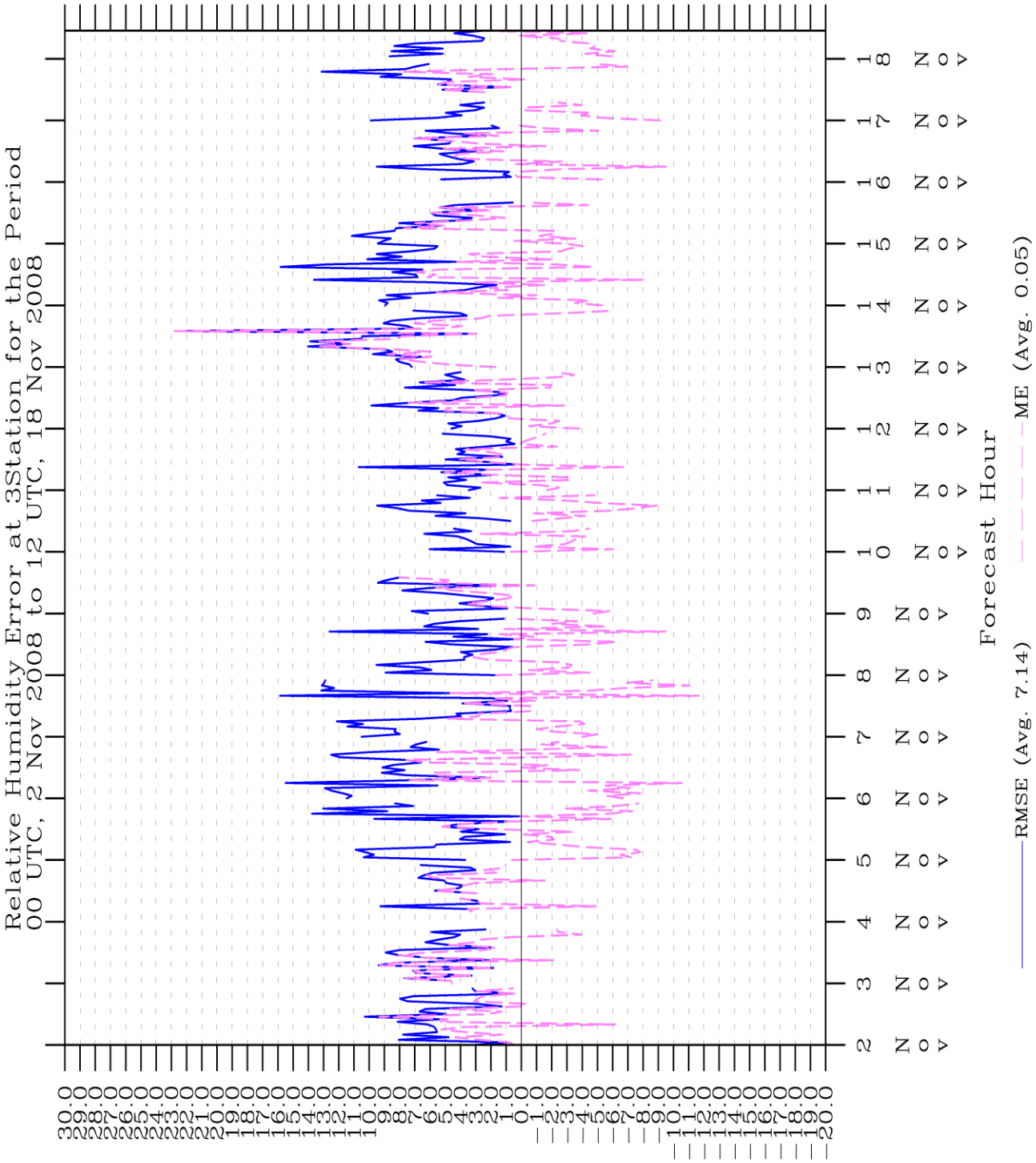


Figure 40: Time series of relative humidity statistics for all three stations in TWIND2X30.

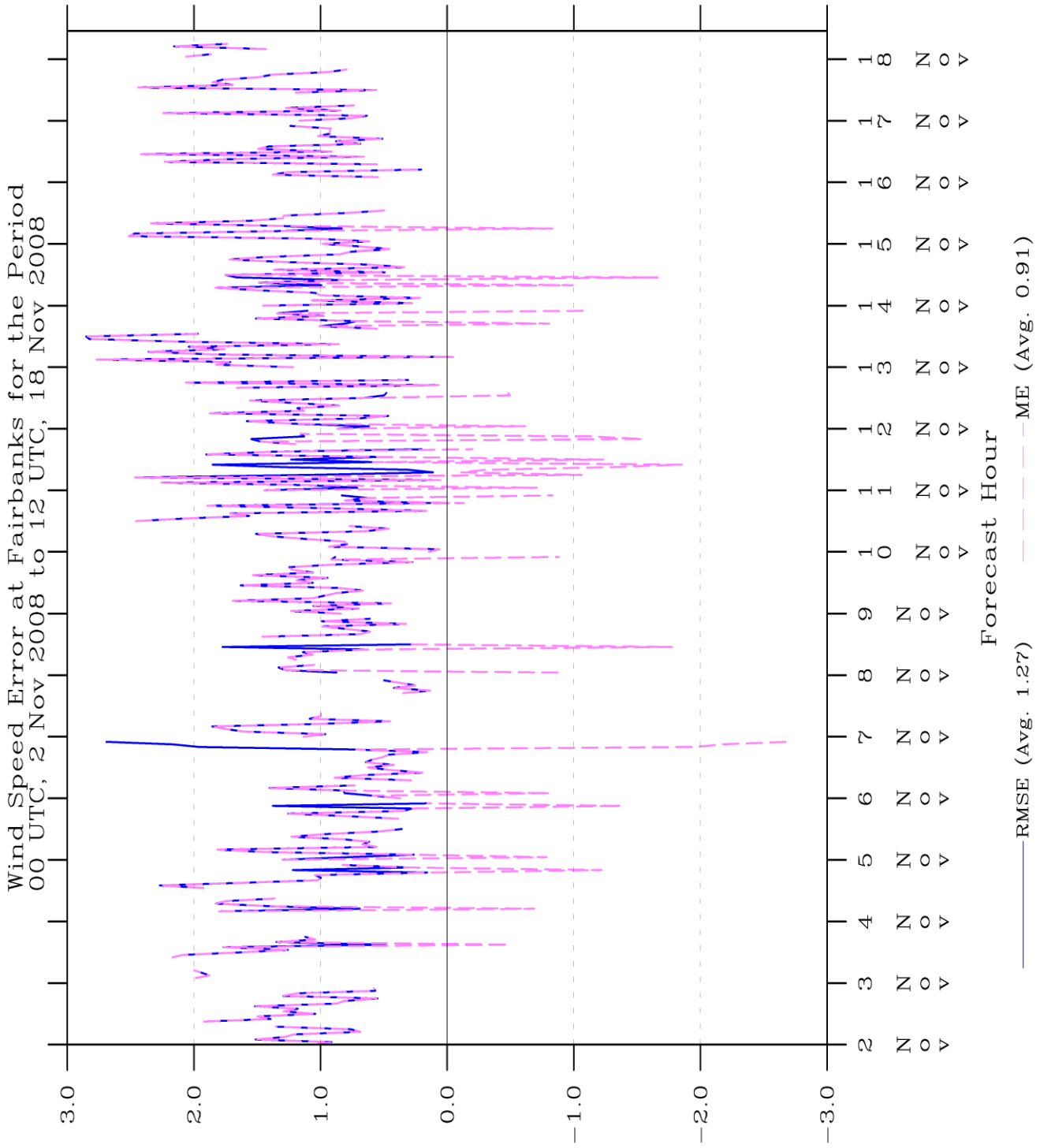


Figure 41: Time series of wind speed statistics for Fairbanks in TWIND2X30.

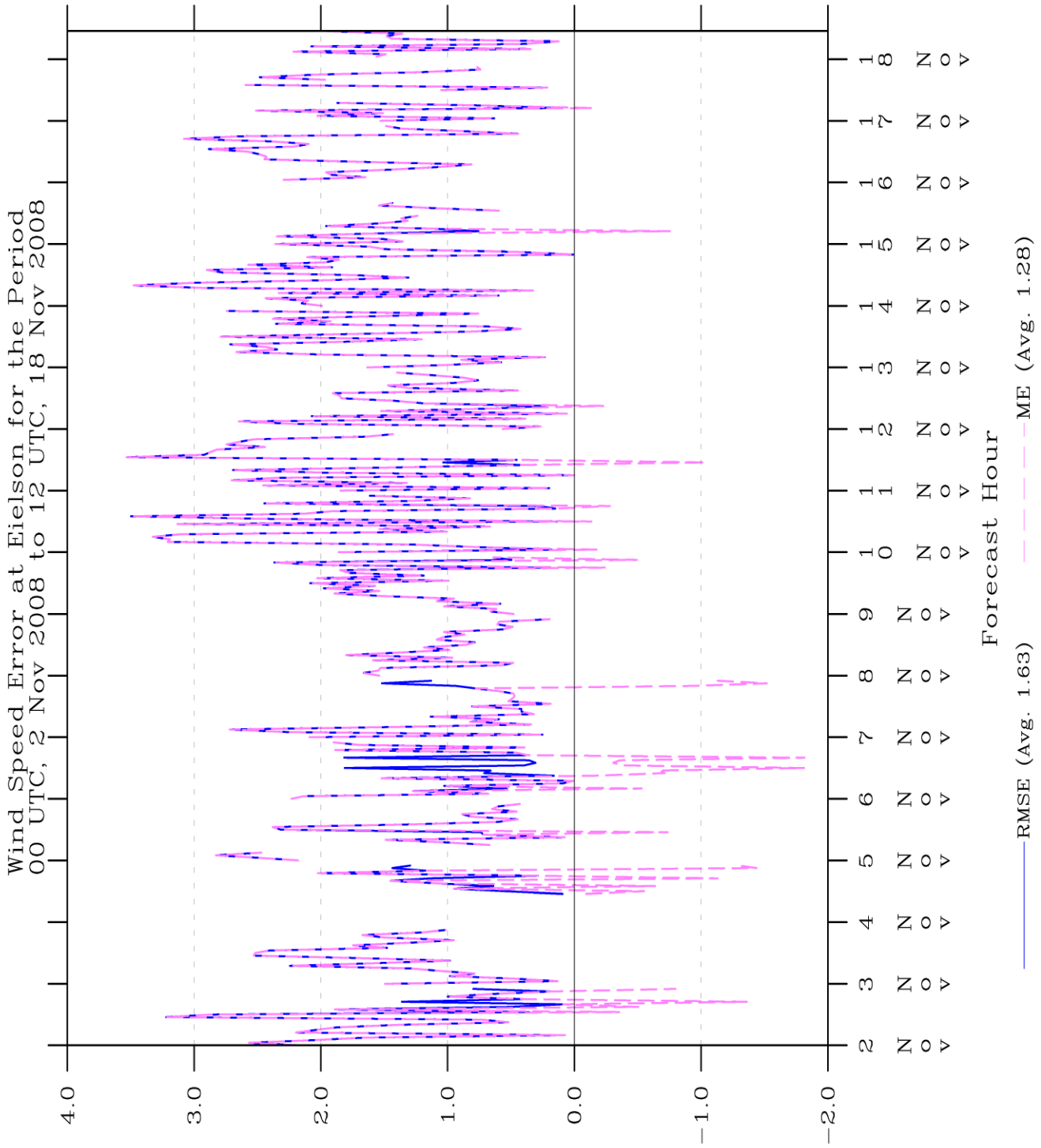


Figure 42: Time series of wind speed statistics for Eielson in TWIND2X30.

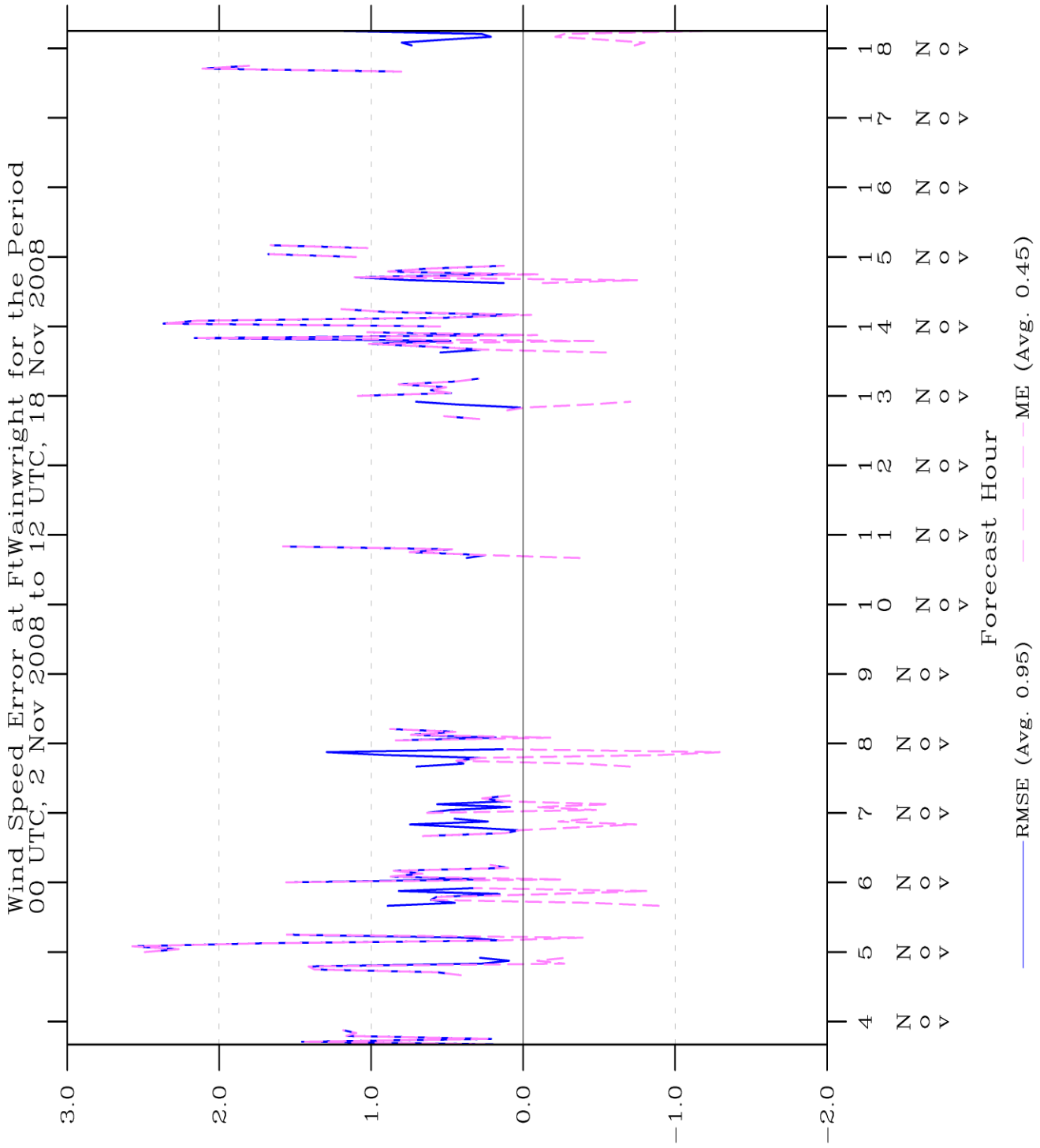


Figure 43: Time series of wind speed statistics for Ft. Wainwright in TWIND2X30.

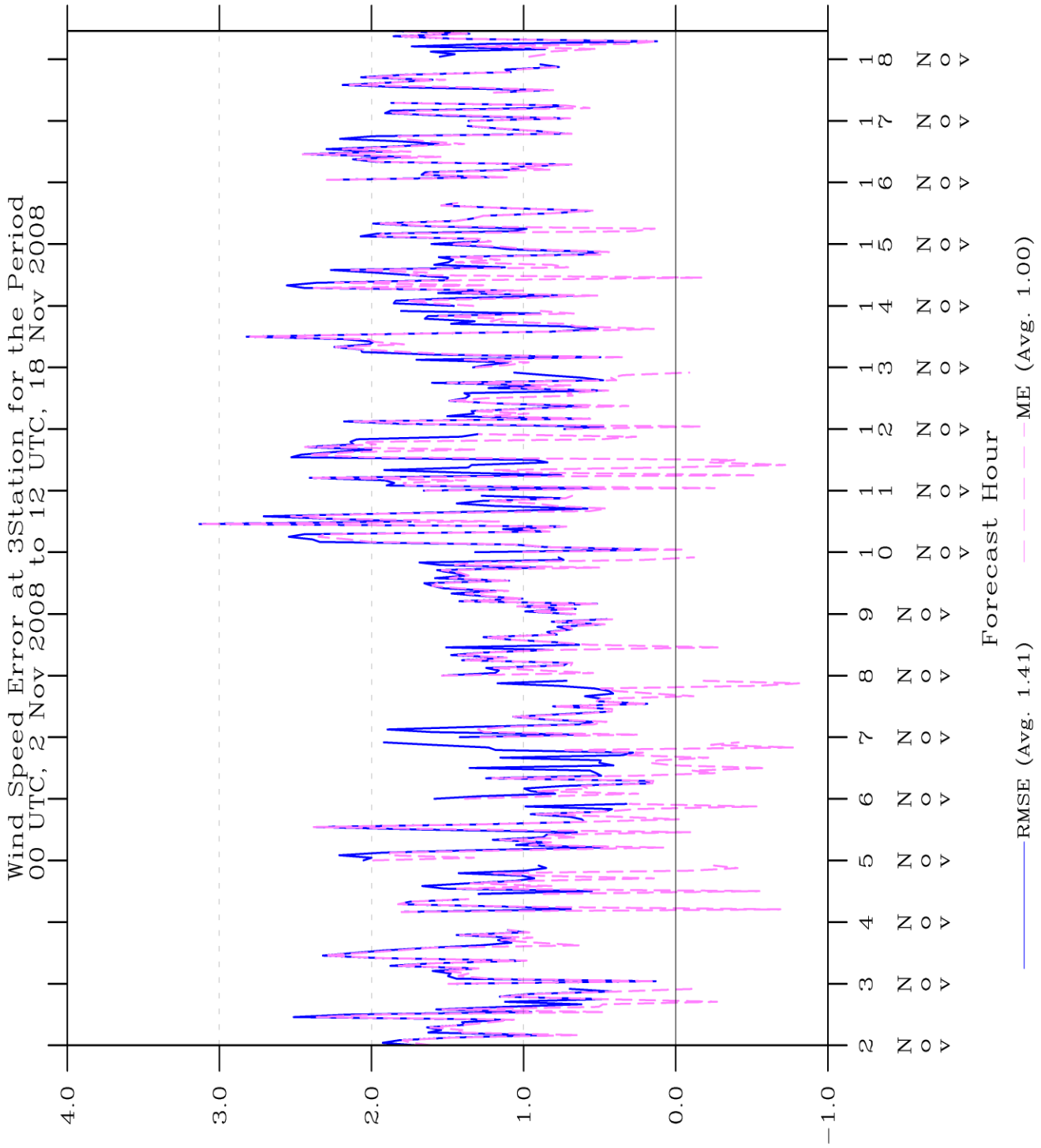


Figure 44: Time series of wind speed statistics for all three stations in TWIND2X30.

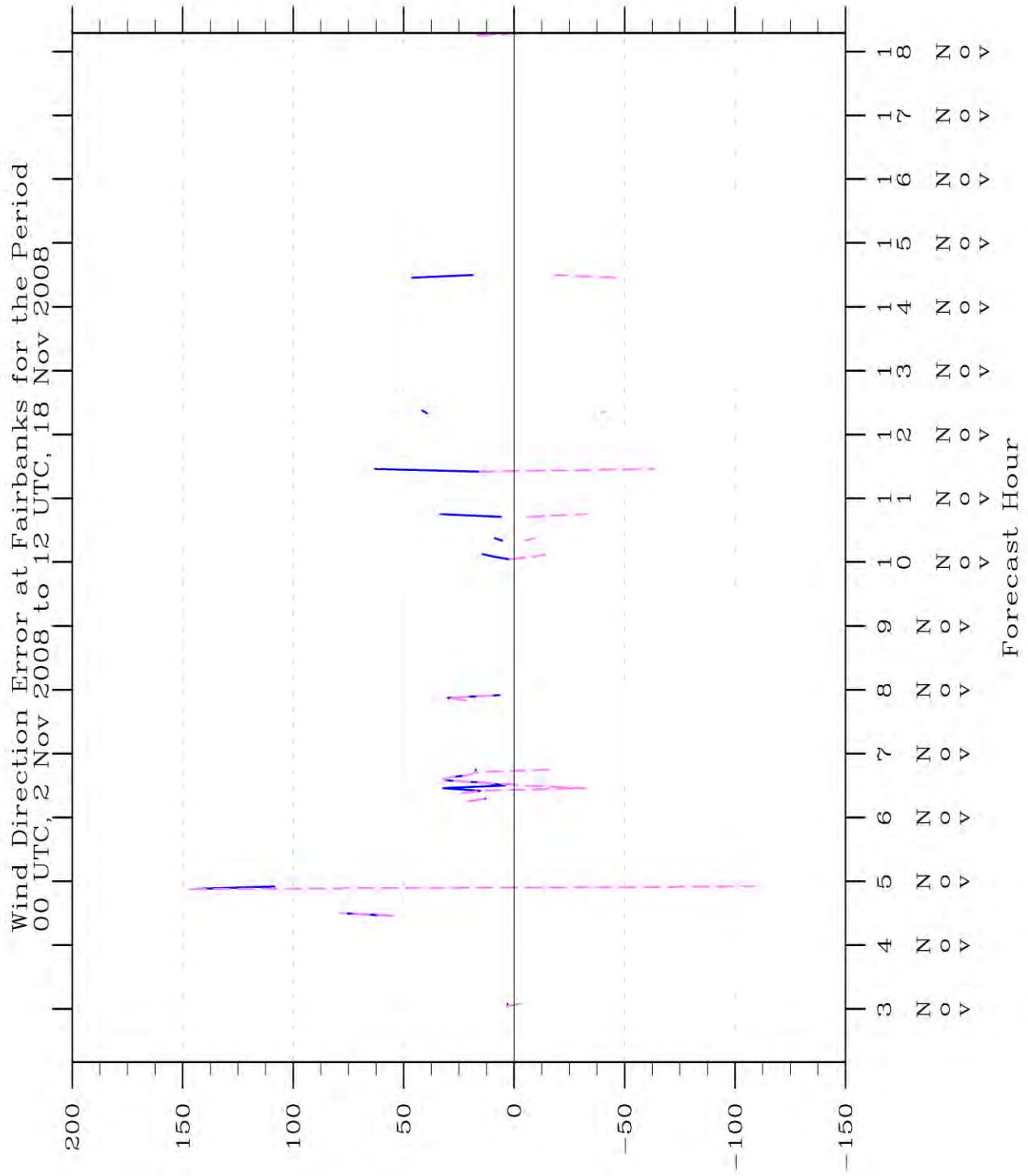


Figure 45: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Fairbanks in TWIND2X30.

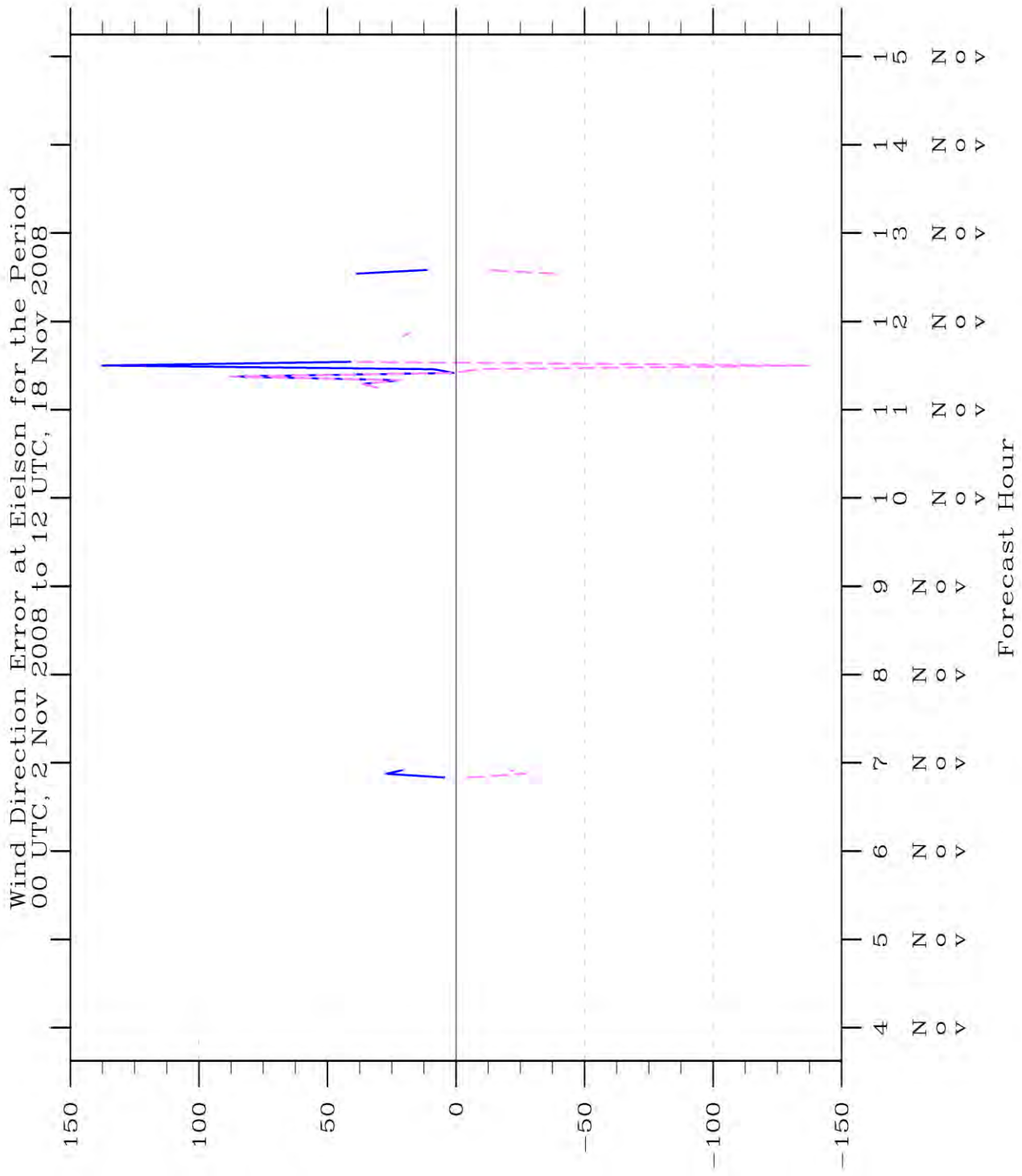


Figure 46: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Eielson in TWIND2X30.

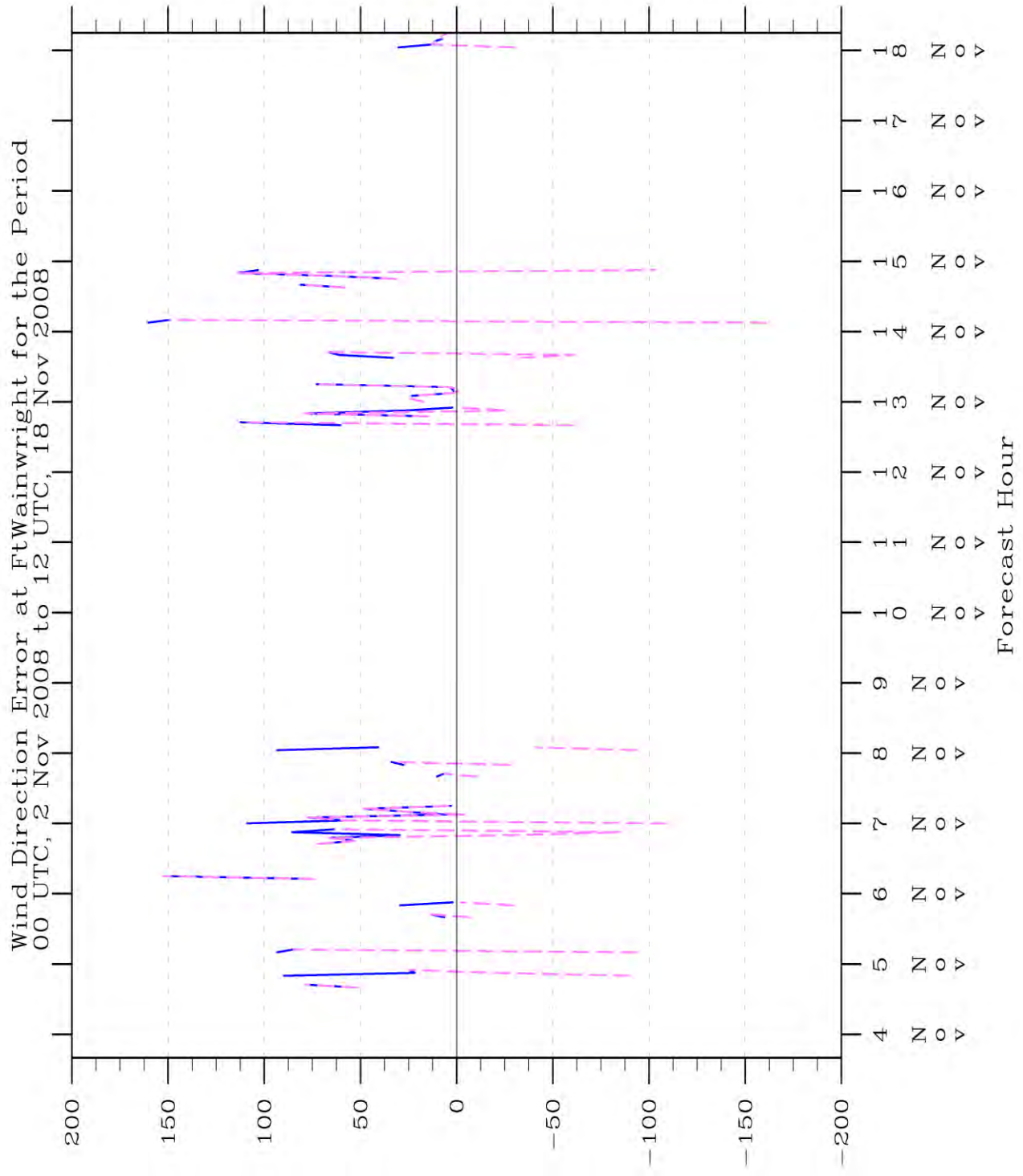


Figure 47: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Ft. Wainwright in TWIND2X30.

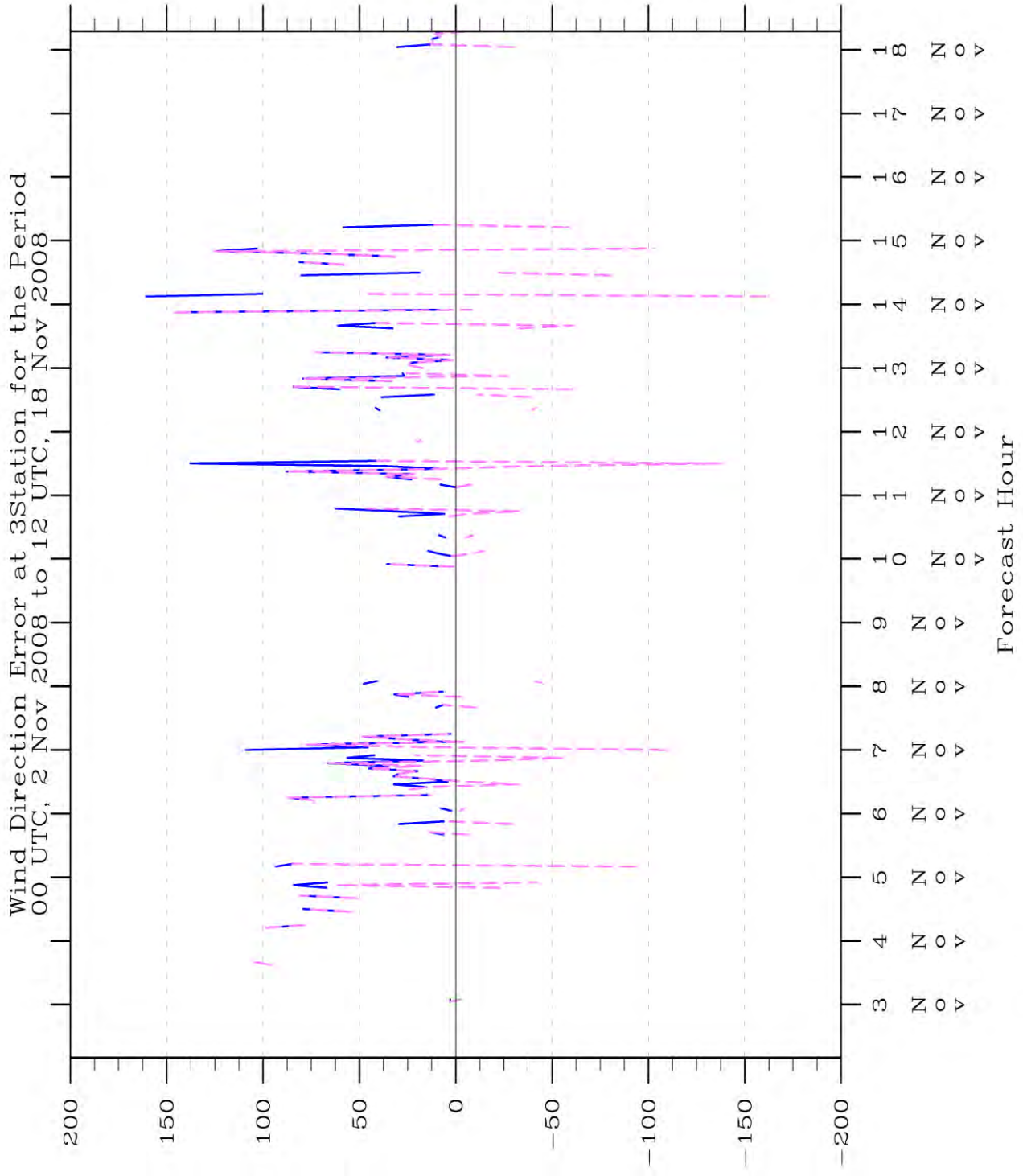


Figure 48: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for all three stations in TWIND2X30.

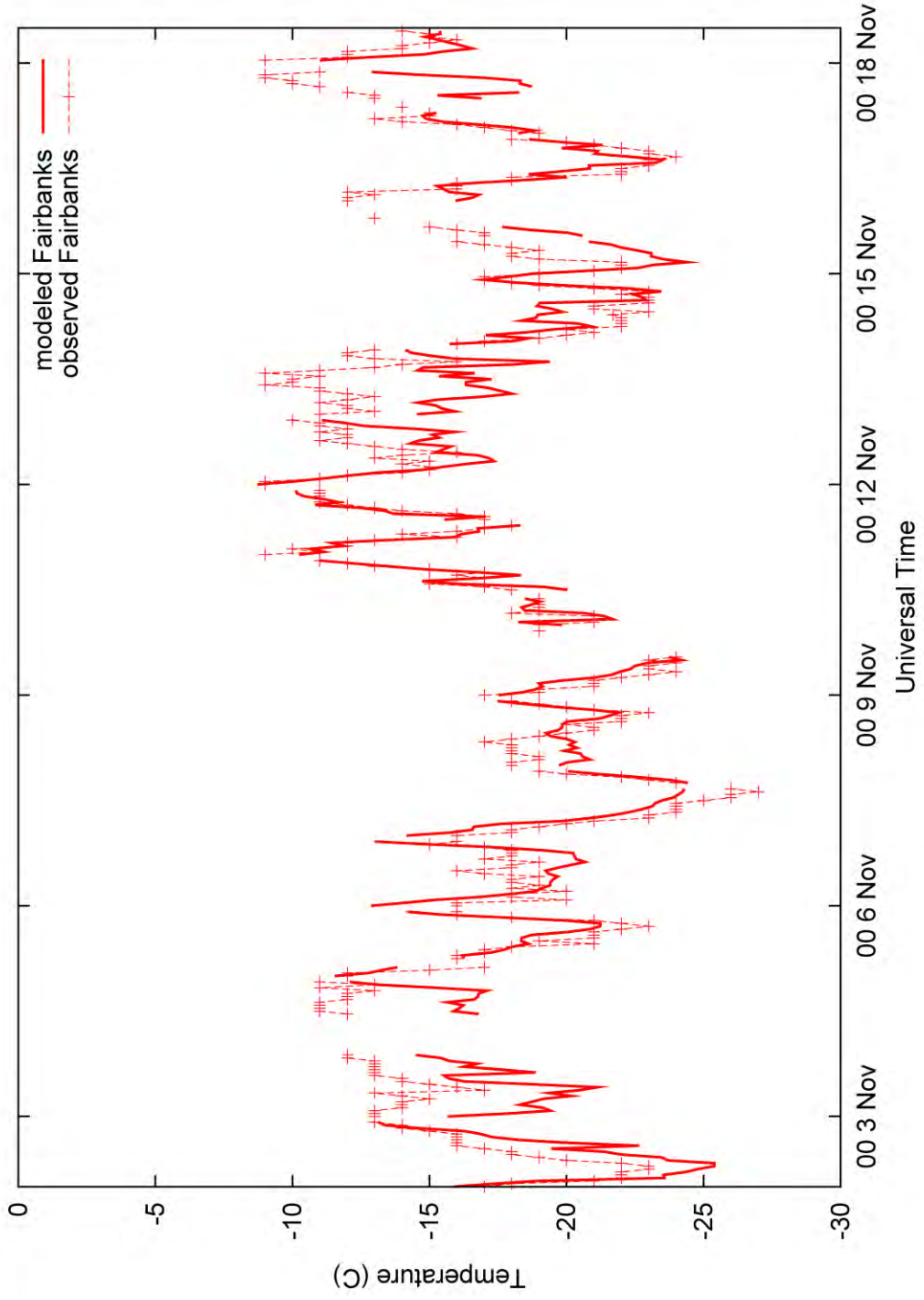


Figure 49: Time series of modeled and observed temperature for Fairbanks in TWIND2X30.

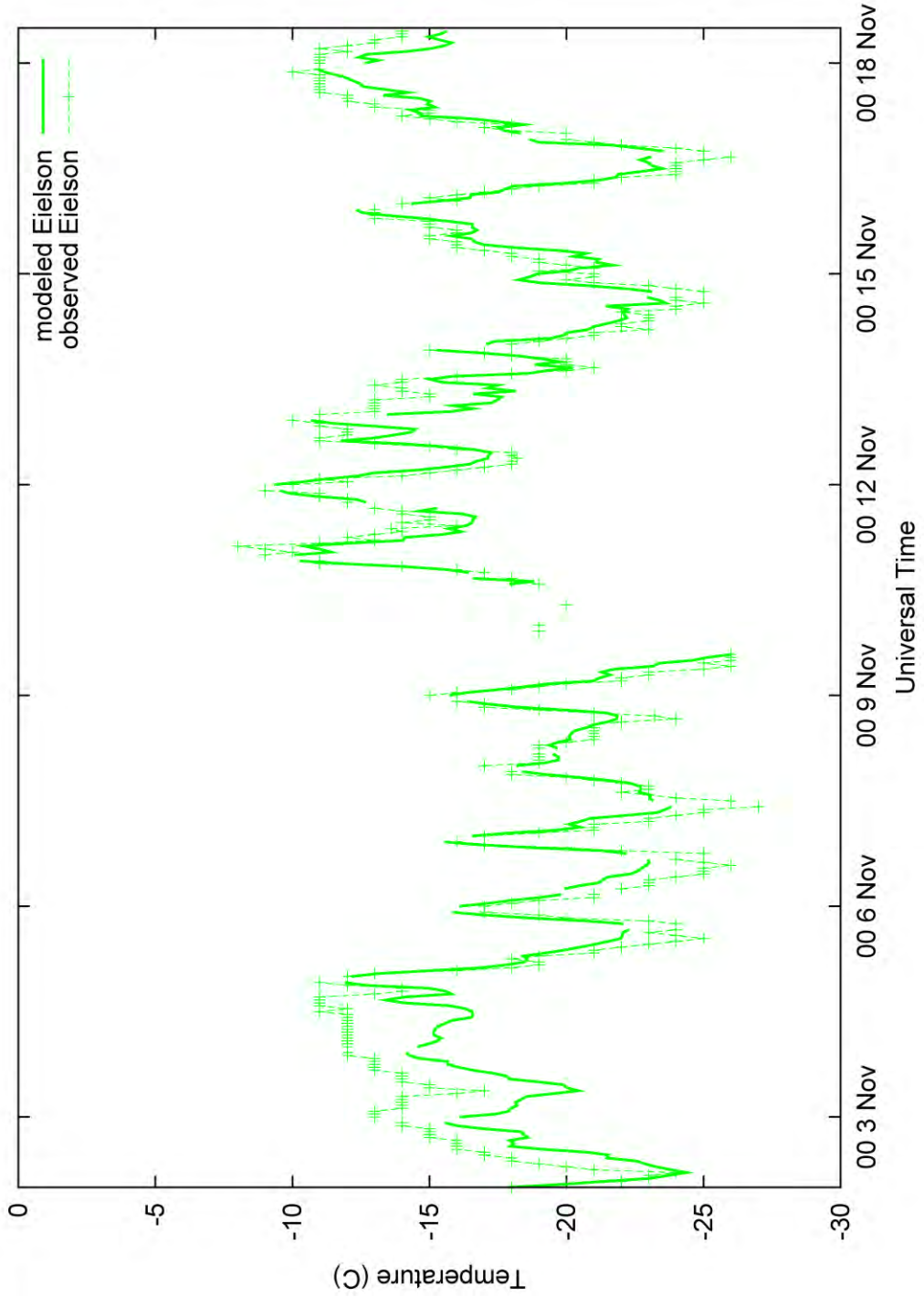


Figure 50: Time series of modeled and observed temperature for Eielson in TWIND2X30.

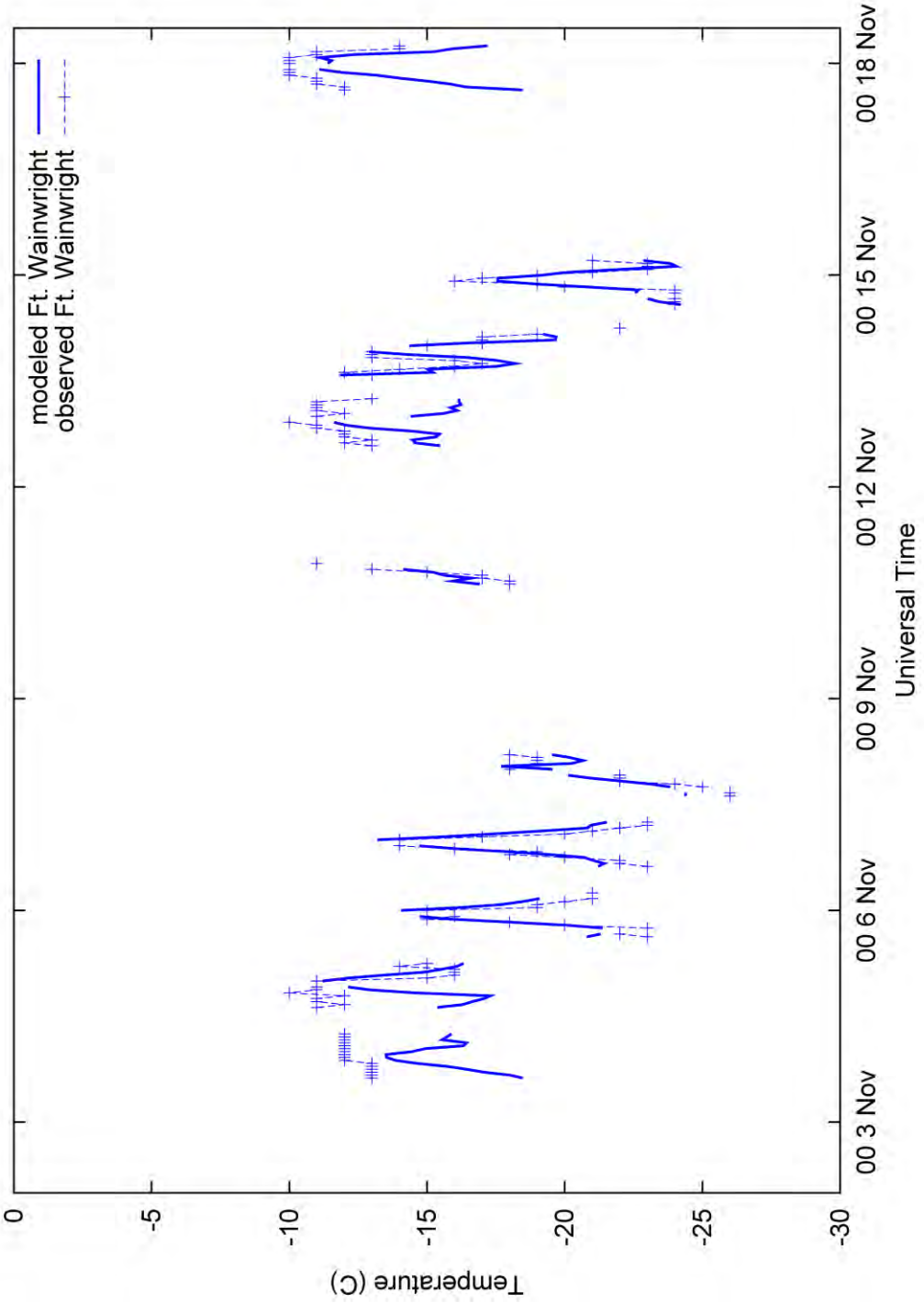


Figure 51: Time series of modeled and observed temperature for Ft. Wainwright in TWIND2X30.

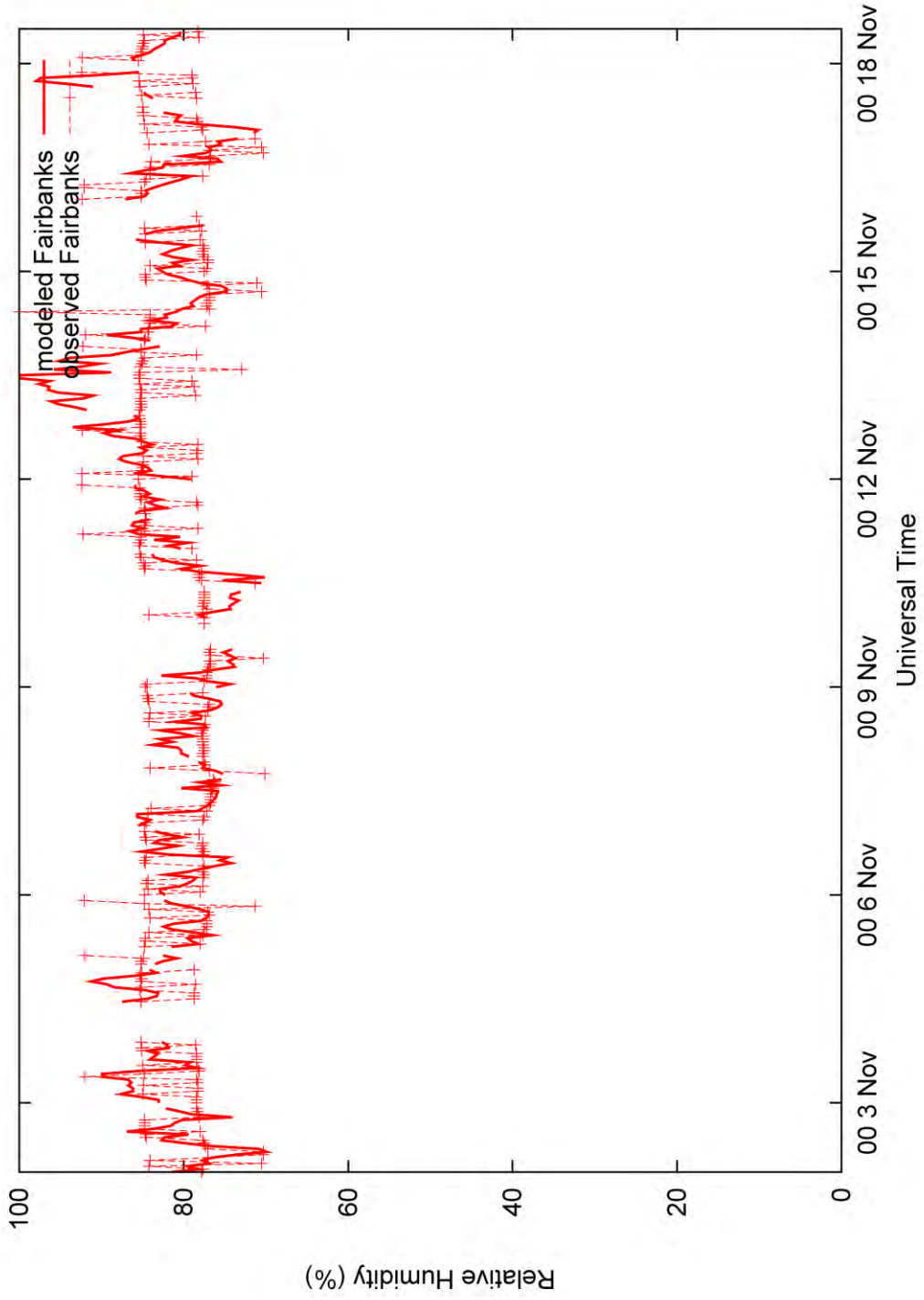


Figure 52: Time series of modeled and observed relative humidity for Fairbanks in TWIND2X30.

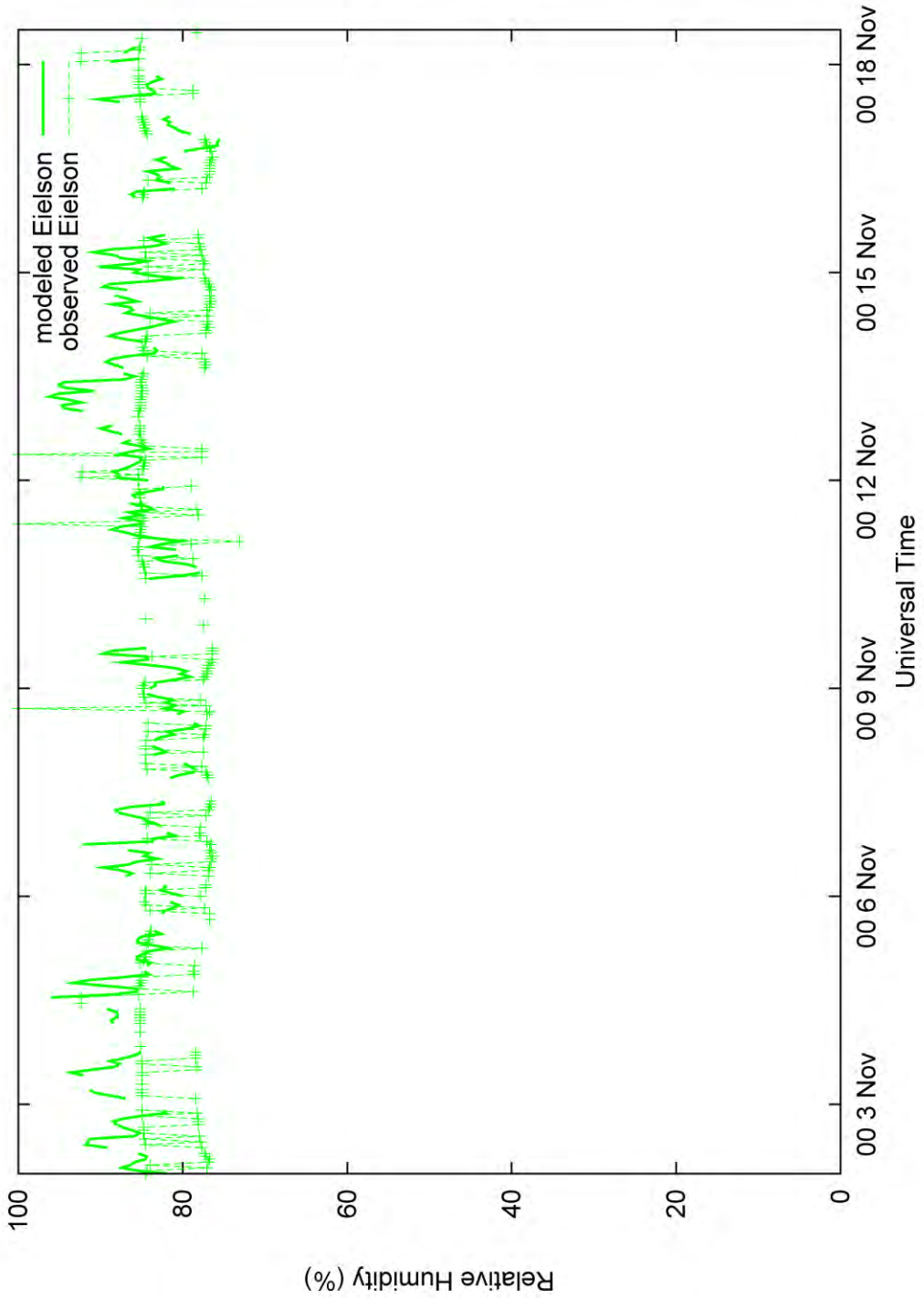


Figure 53: Time series of modeled and observed relative humidity for Eielson in TWIND2X30.

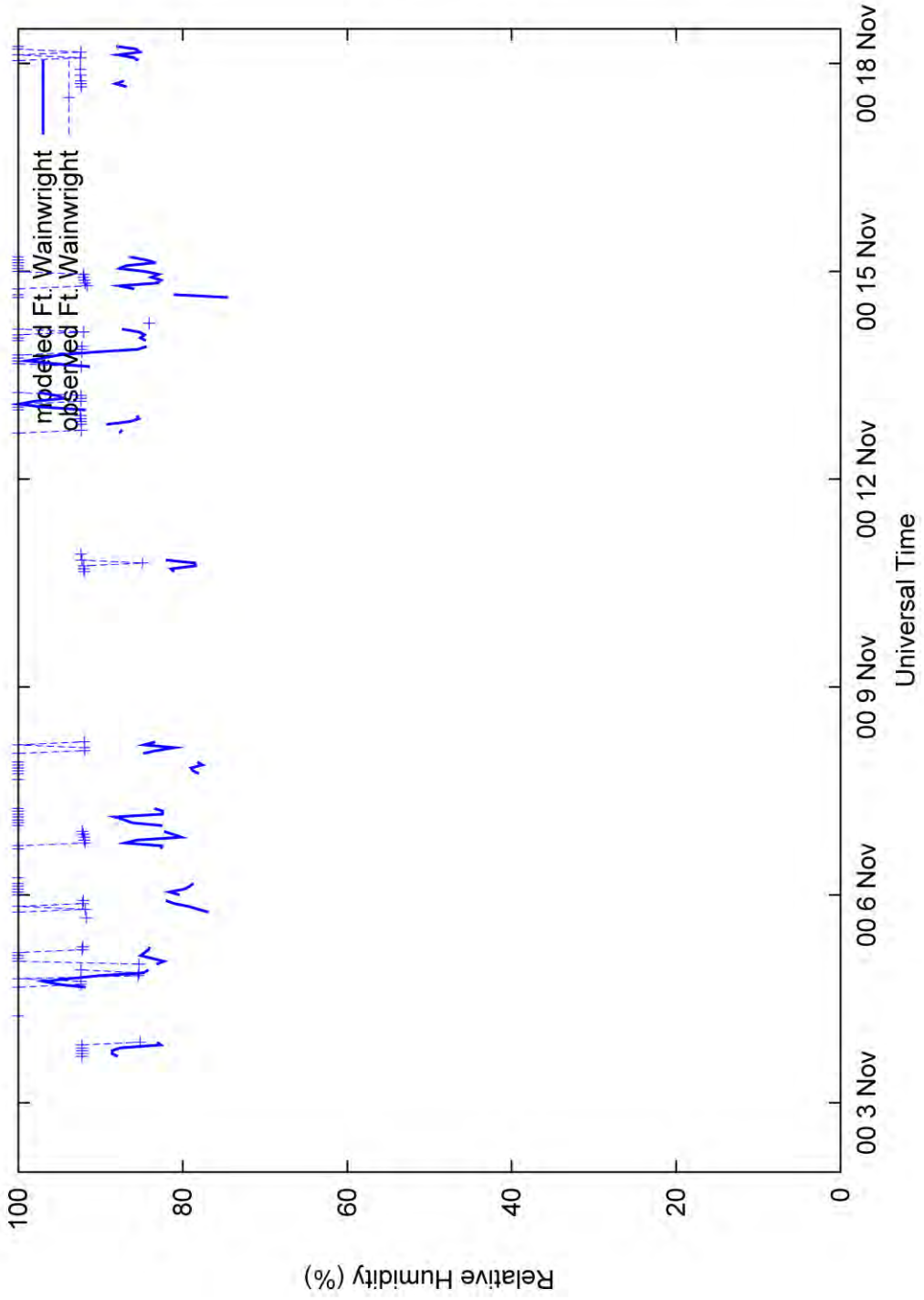


Figure 54: Time series of modeled and observed relative humidity for Ft. Wainwright in TWIND2X30.

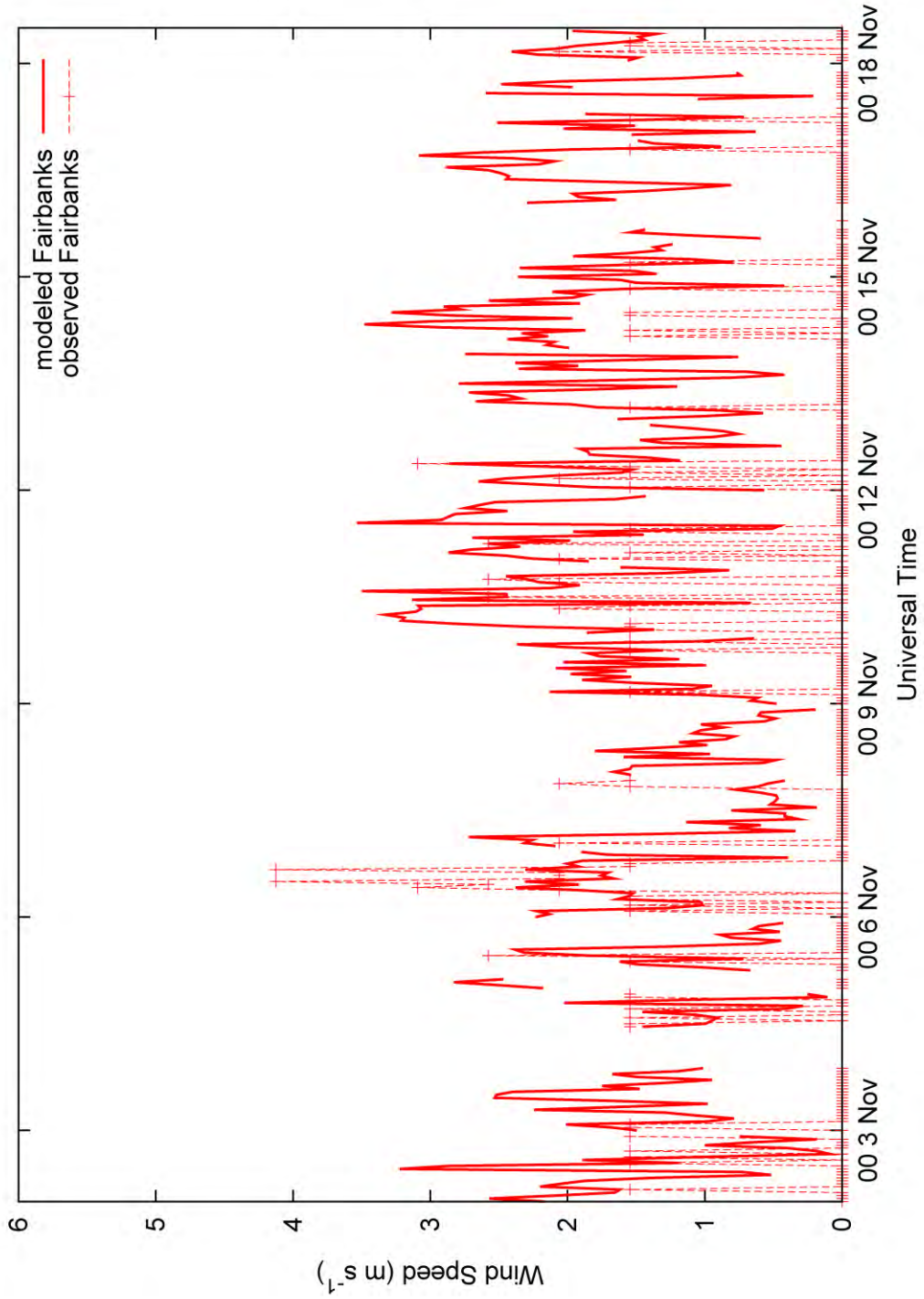


Figure 55: Time series of modeled and observed wind speed for Fairbanks in TWIND2X30.

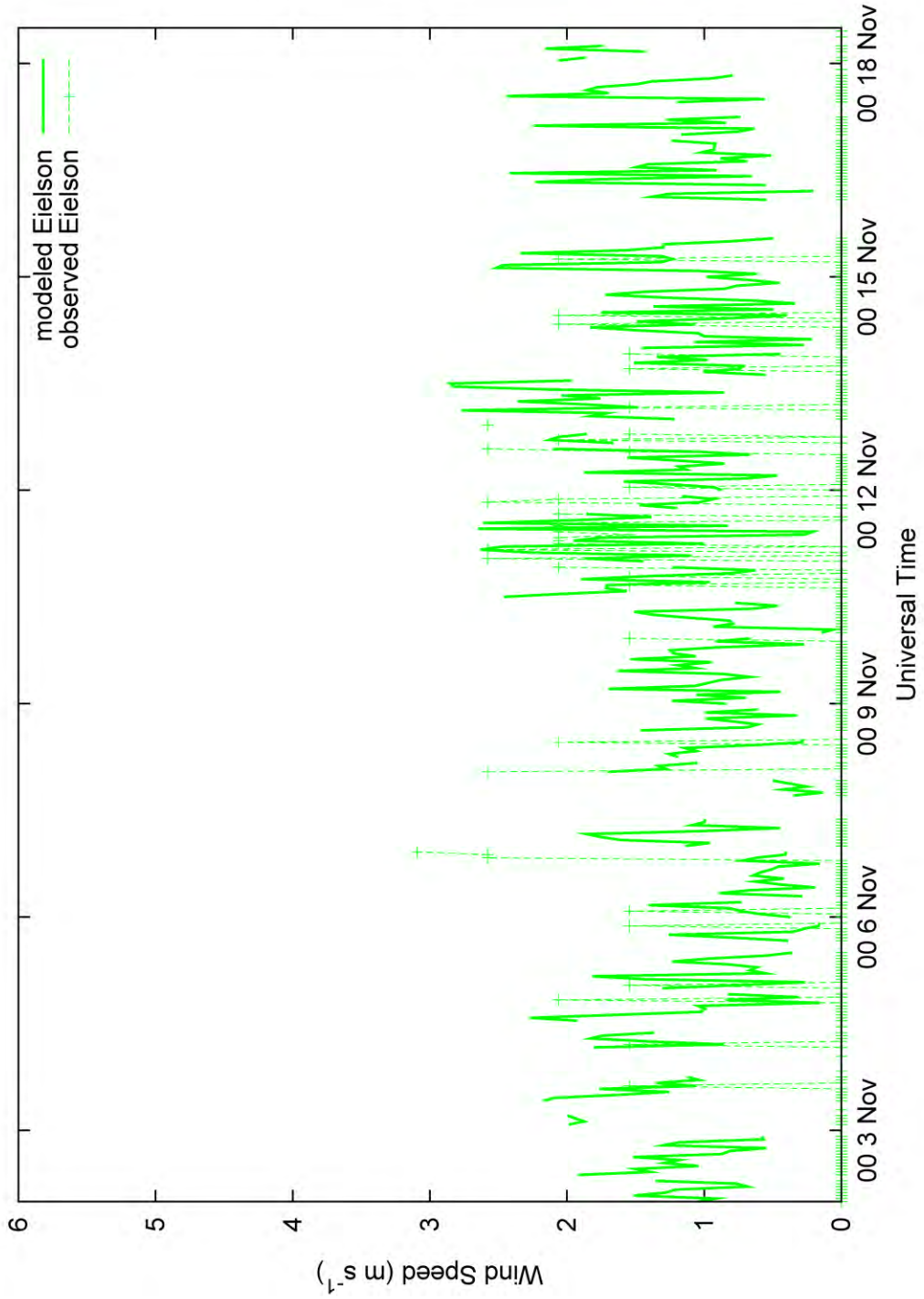


Figure 56: Time series of modeled and observed wind speed for Eielson in TWIND2X30.

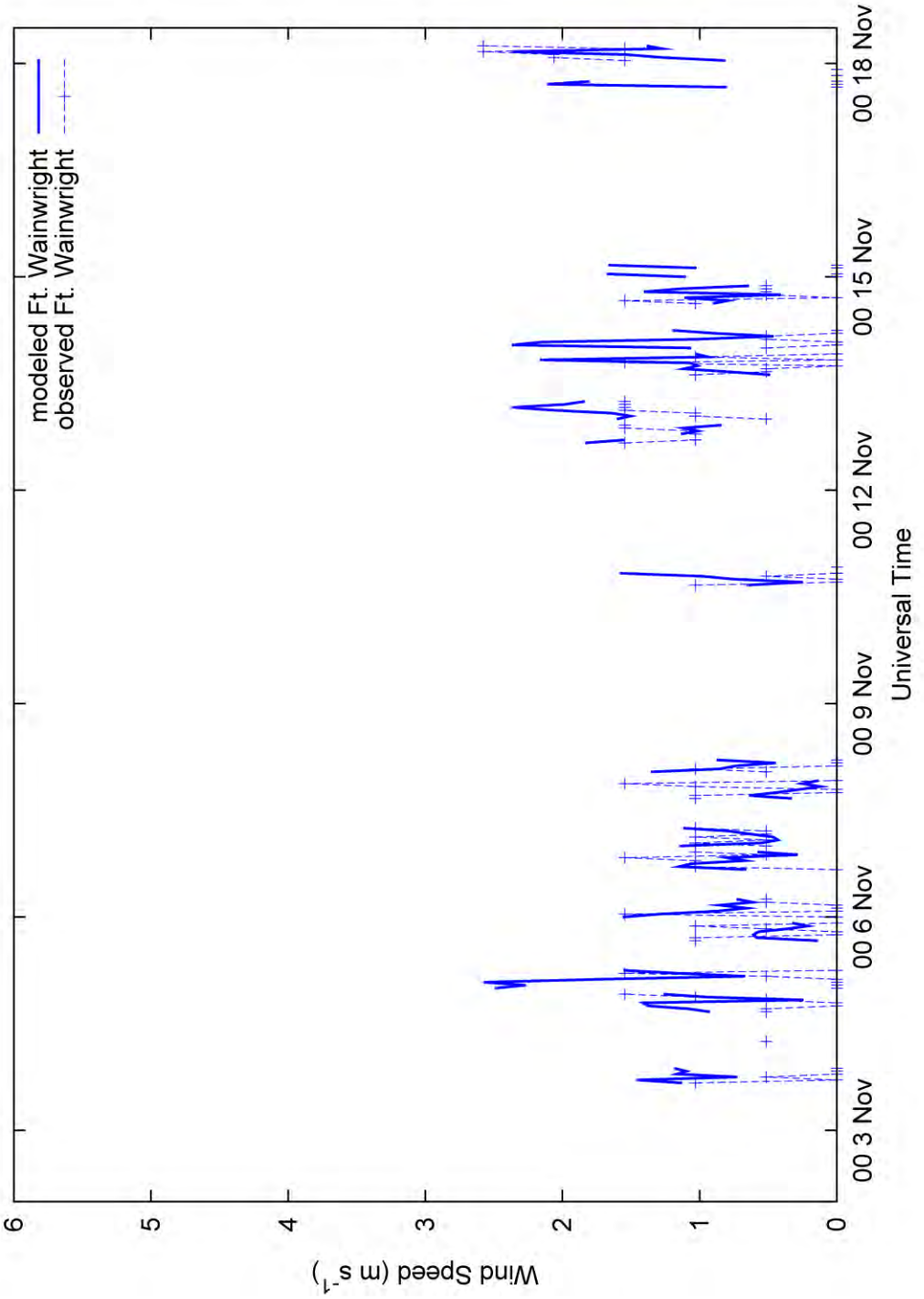


Figure 57: Time series of modeled and observed wind speed for Ft. Wainwright in TWIND2X30.

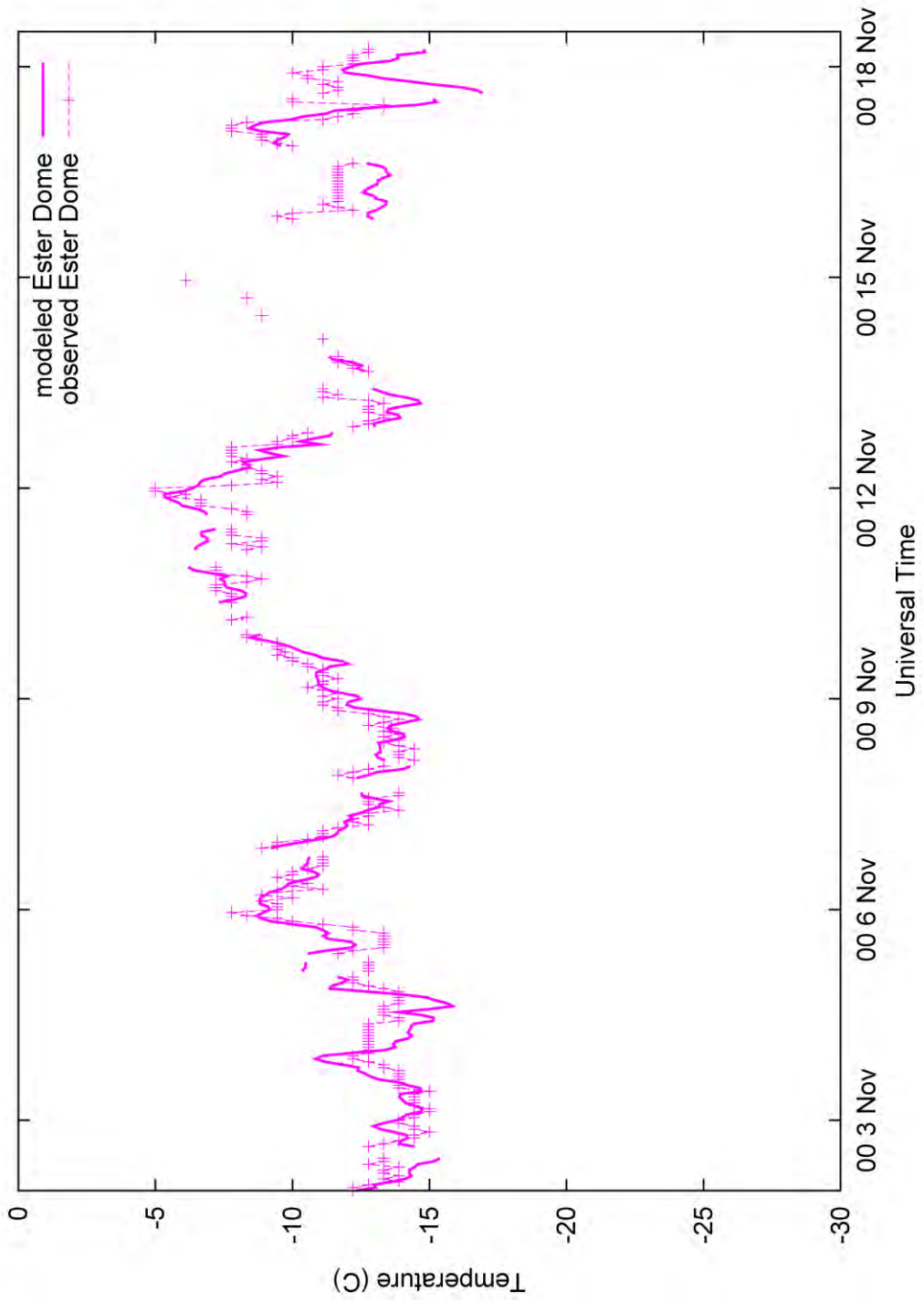


Figure 58: Time series of modeled and observed temperature for Ester Dome in TWIND2X30.

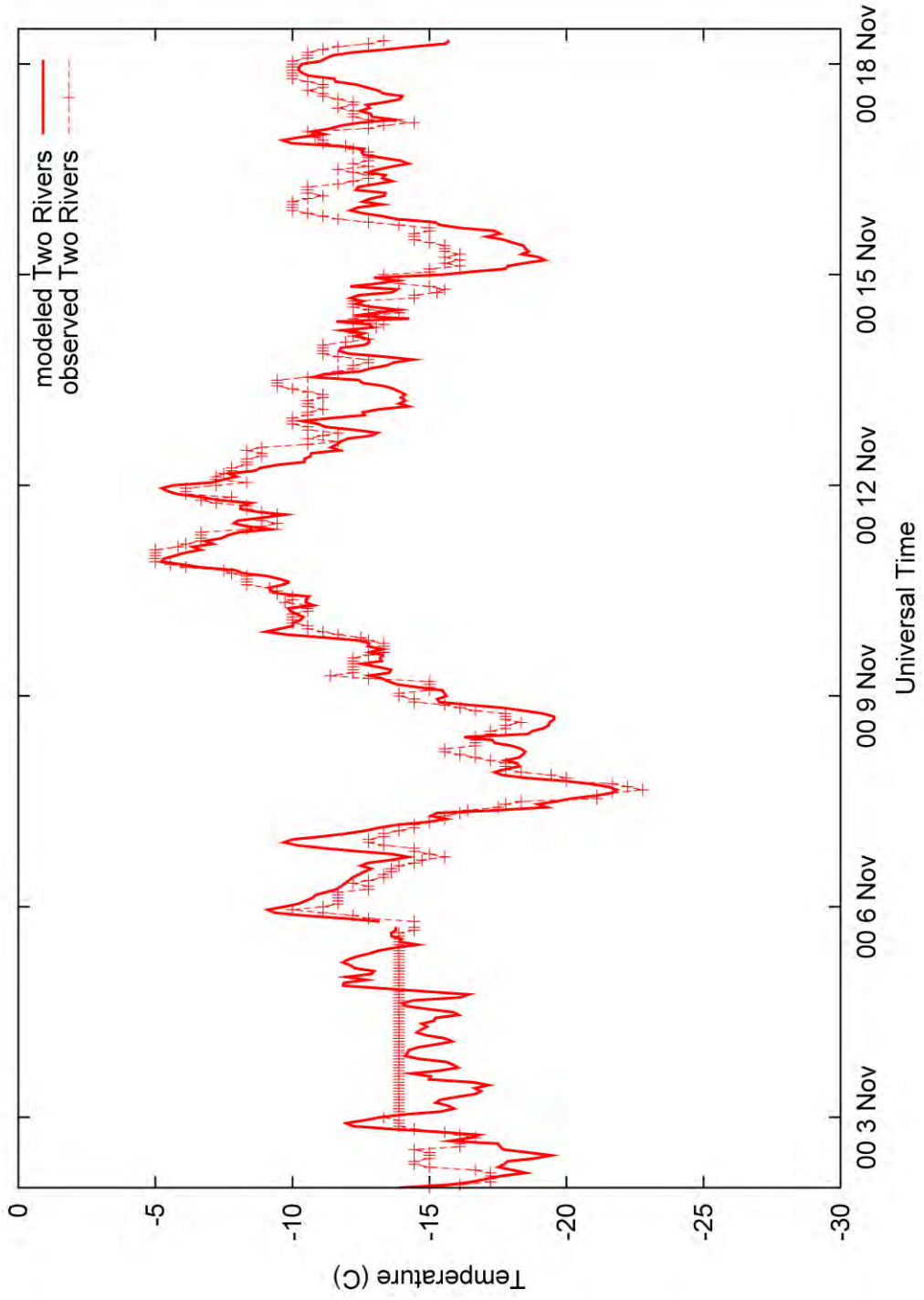


Figure 59: Time series of modeled and observed temperature at Two Rivers in TWIND2X30.

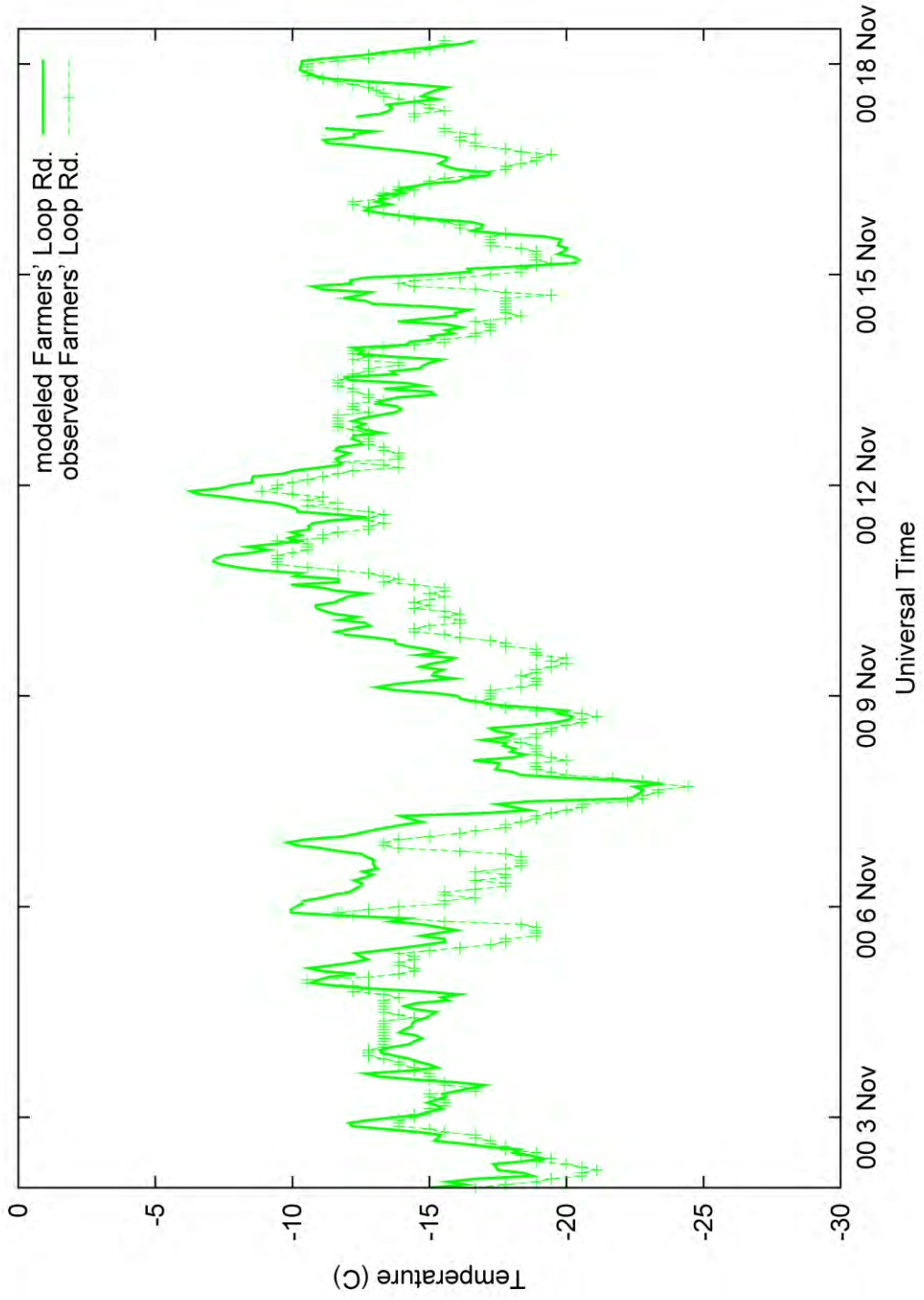


Figure 60: Modeled and observed time series of temperature for Farmers' Loop Rd. in TWIND2X30.

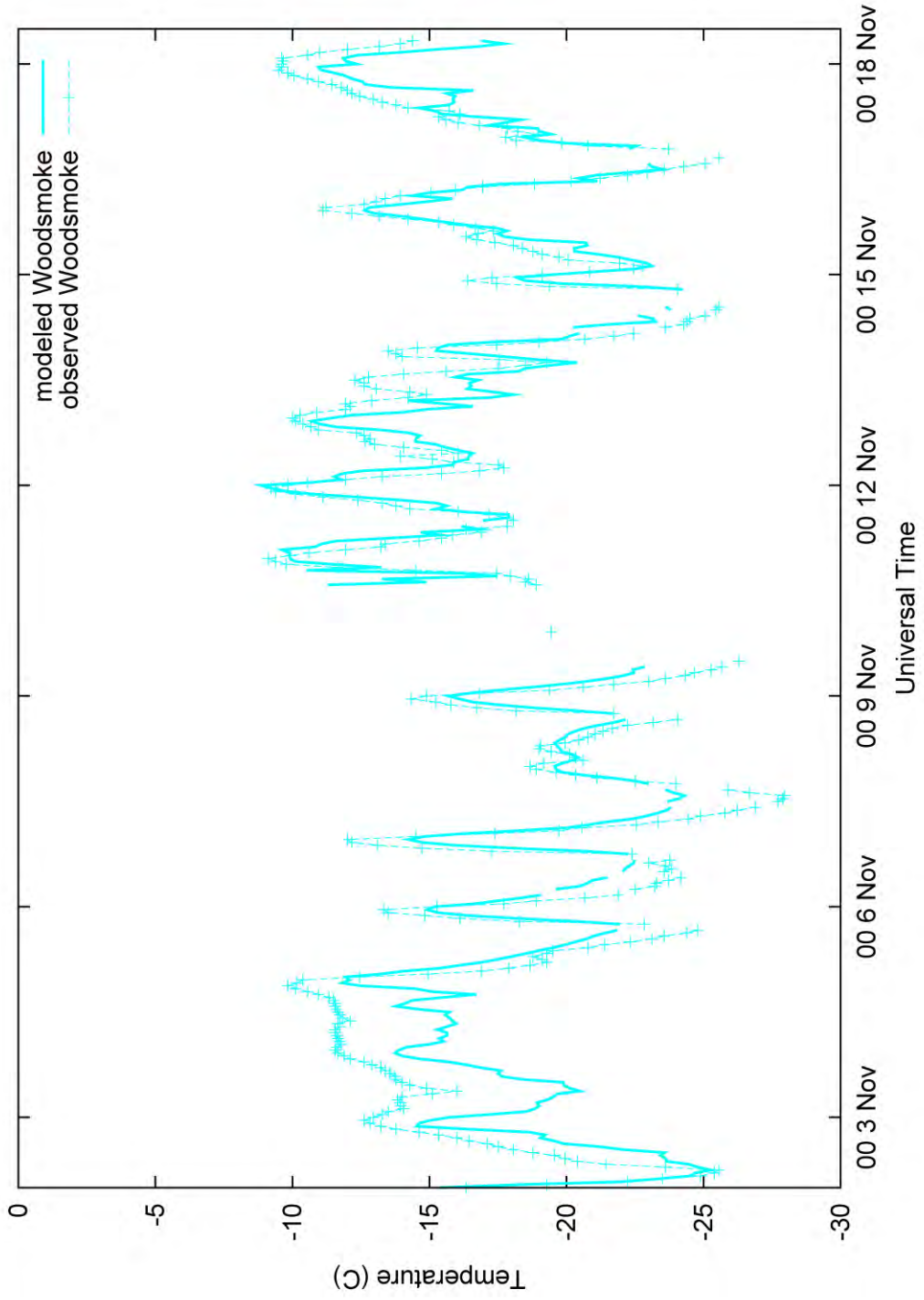


Figure 61: Time series of modeled and observed temperature for Woodsmoke in TWIND2X30.

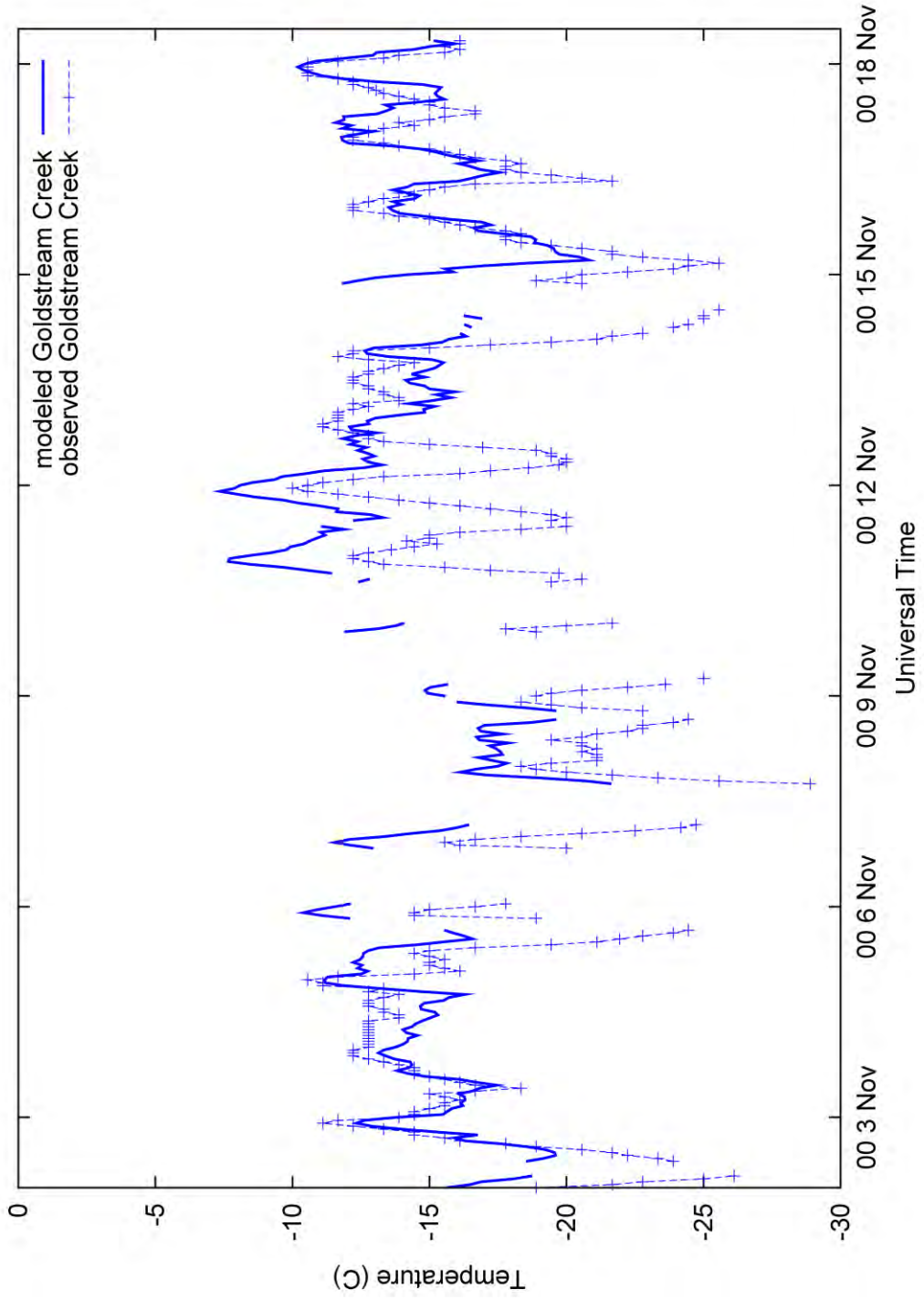


Figure 62: Time series of modeled and observed temperature for Goldstream Creek in TWIND2X30.

APPENDIX B – Detailed Time-Series Figures of 23 Jan – 12 Feb 2008 Episode, for TWIND2X30 Configuration

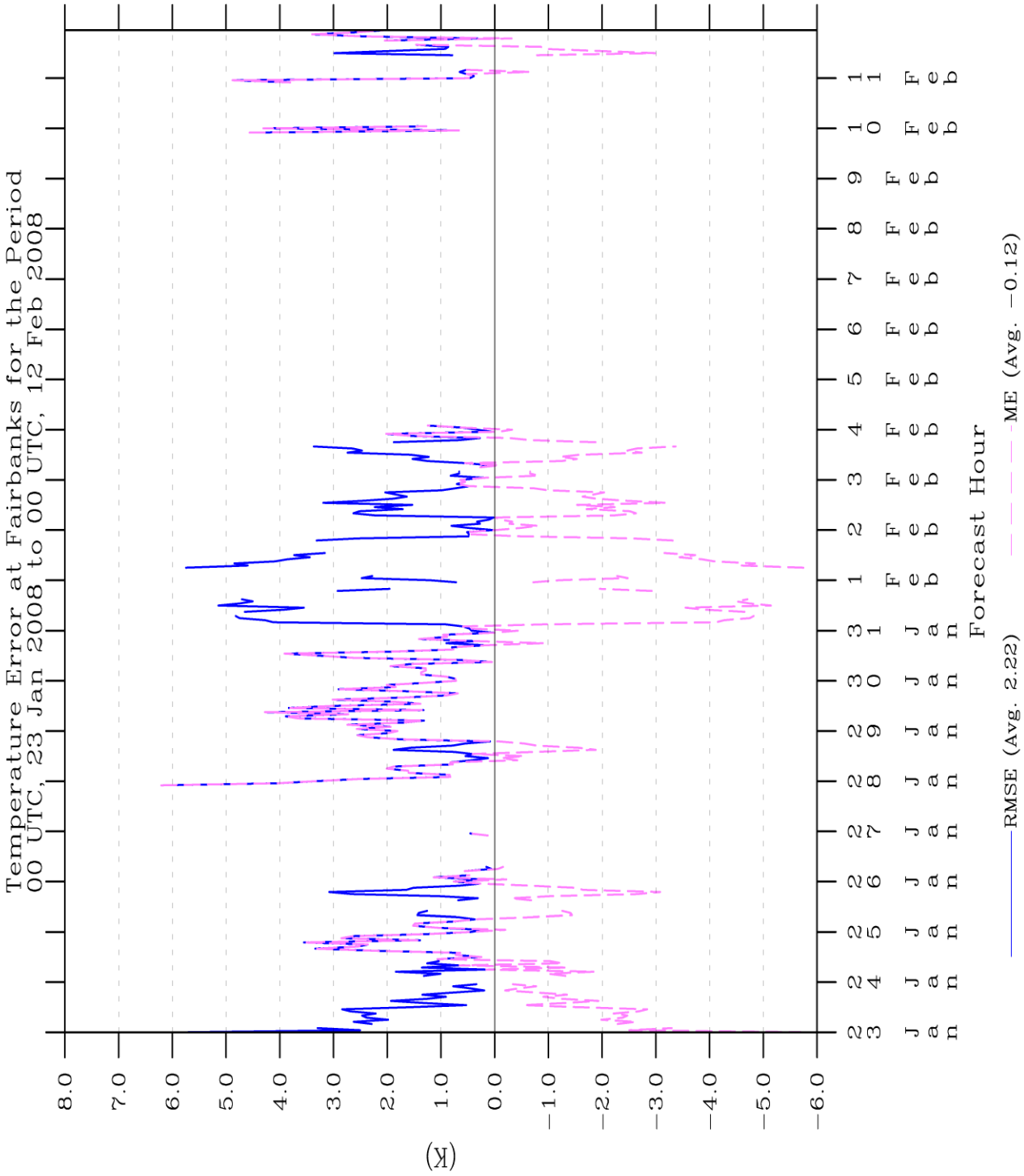


Figure 63: Time series of temperature statistics for Fairbanks in TWIND2X30

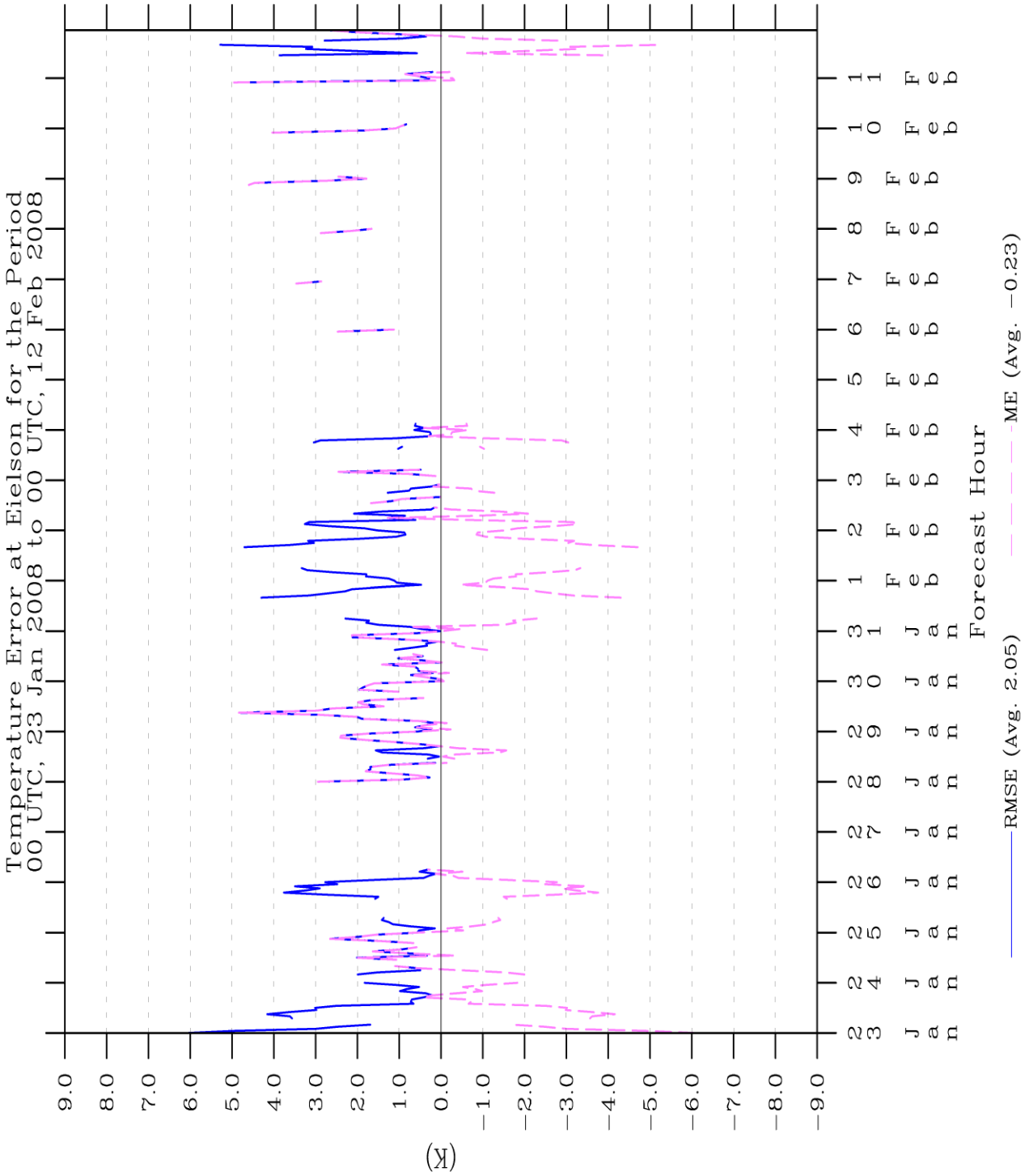


Figure 64: Time series of temperature statistics for Eielson in TWIND2X30.

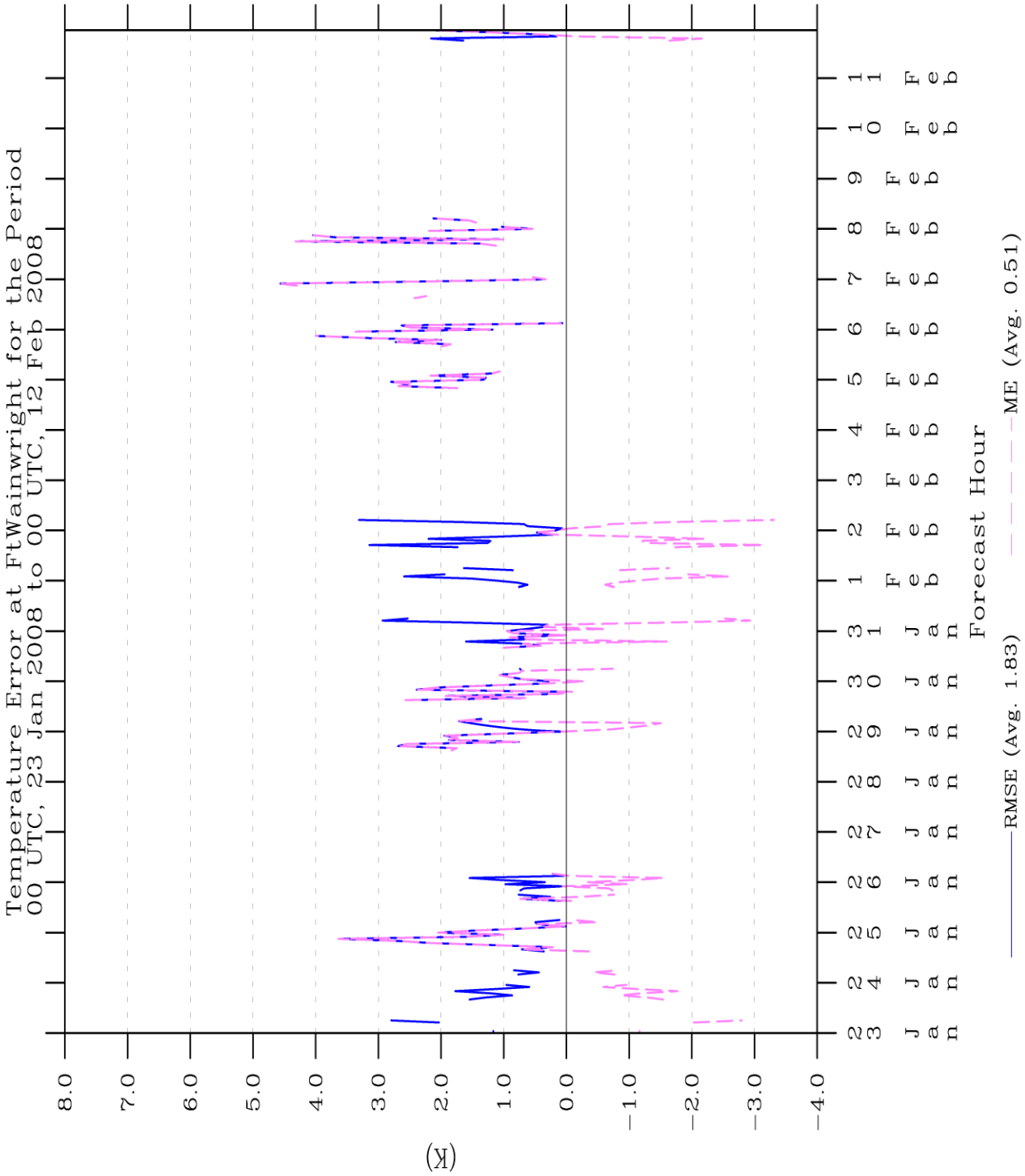


Figure 65: Time series of temperature statistics for Ft. Wainwright in TWIND2X30.

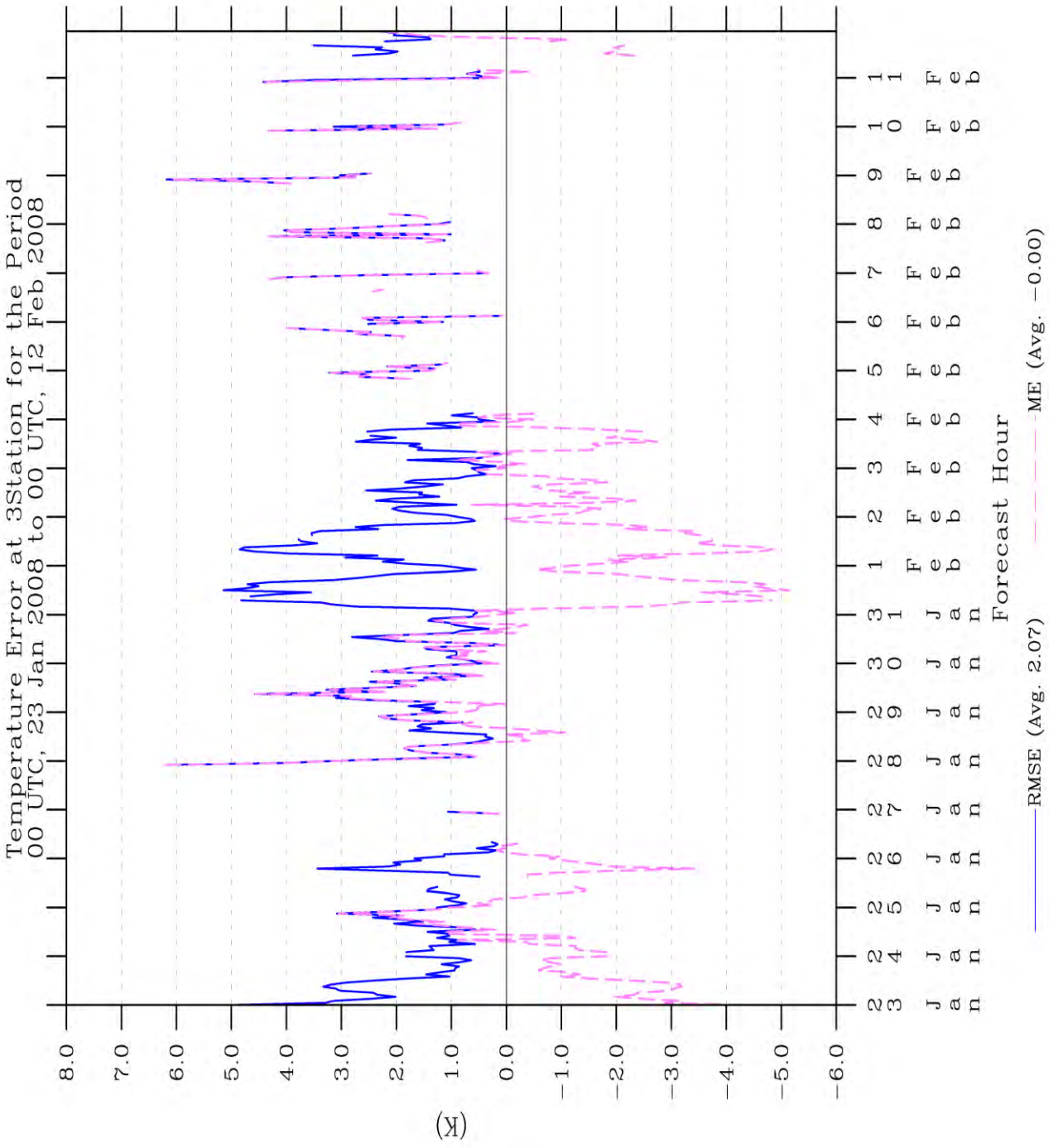


Figure 66: Time series of temperature statistics for all three stations in TWIND2X30.

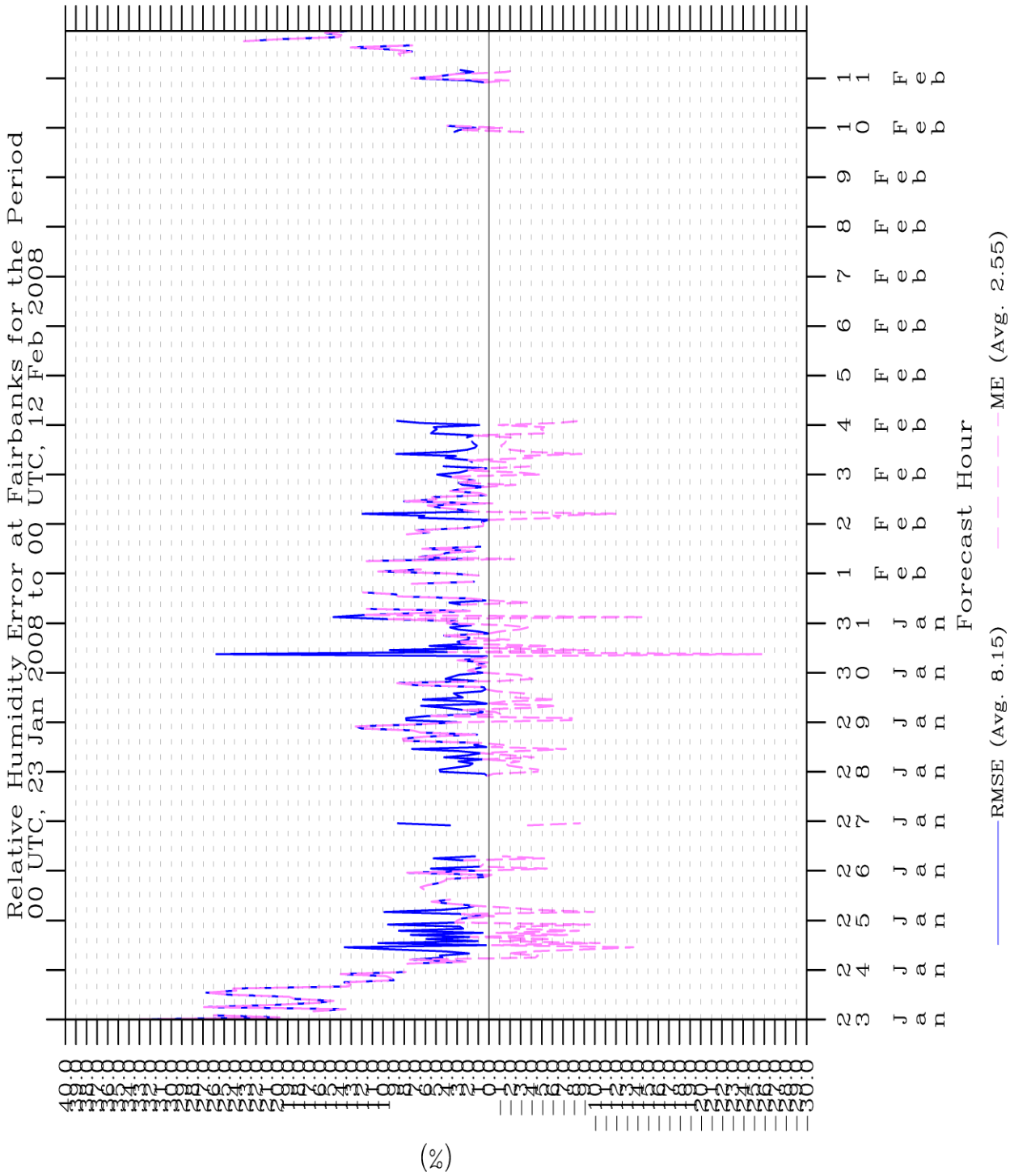


Figure 67: Time series of relative humidity statistics for Fairbanks in TWIND2X30.

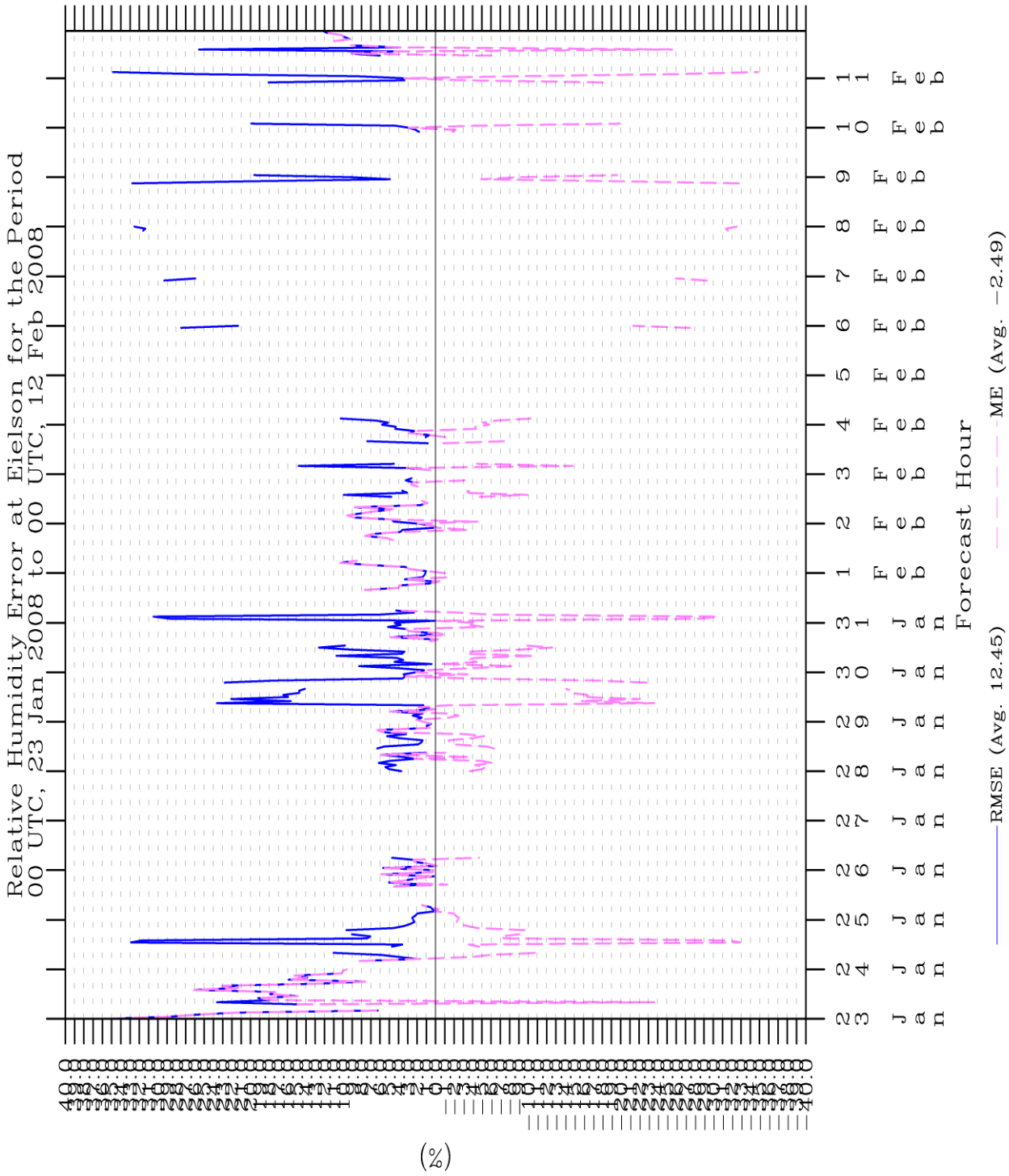


Figure 68: Time series of relative humidity statistics for Eielson in TWIND2X30.

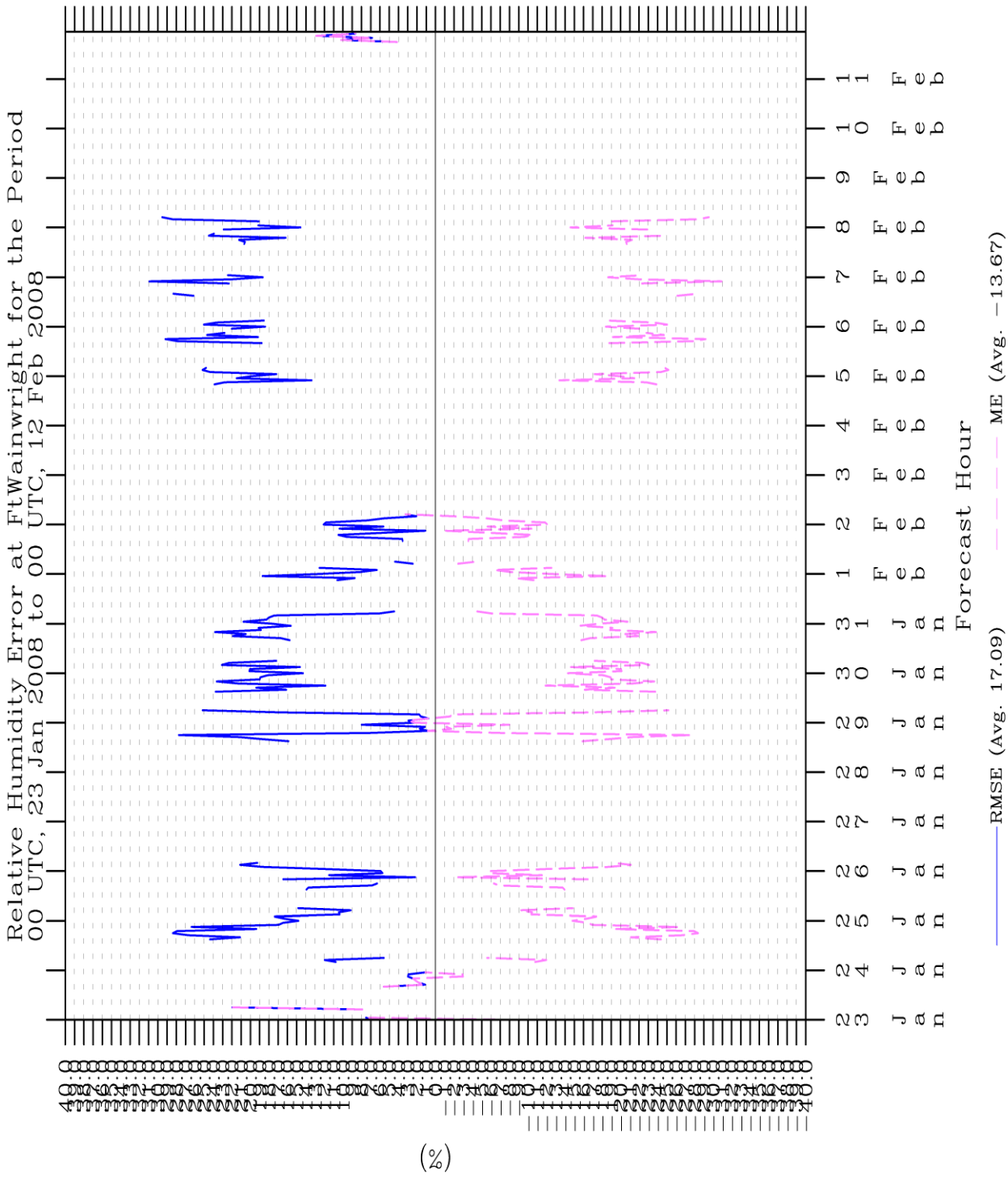


Figure 69: Time series of relative humidity statistics for Ft. Wainwright in TWIND2X30.

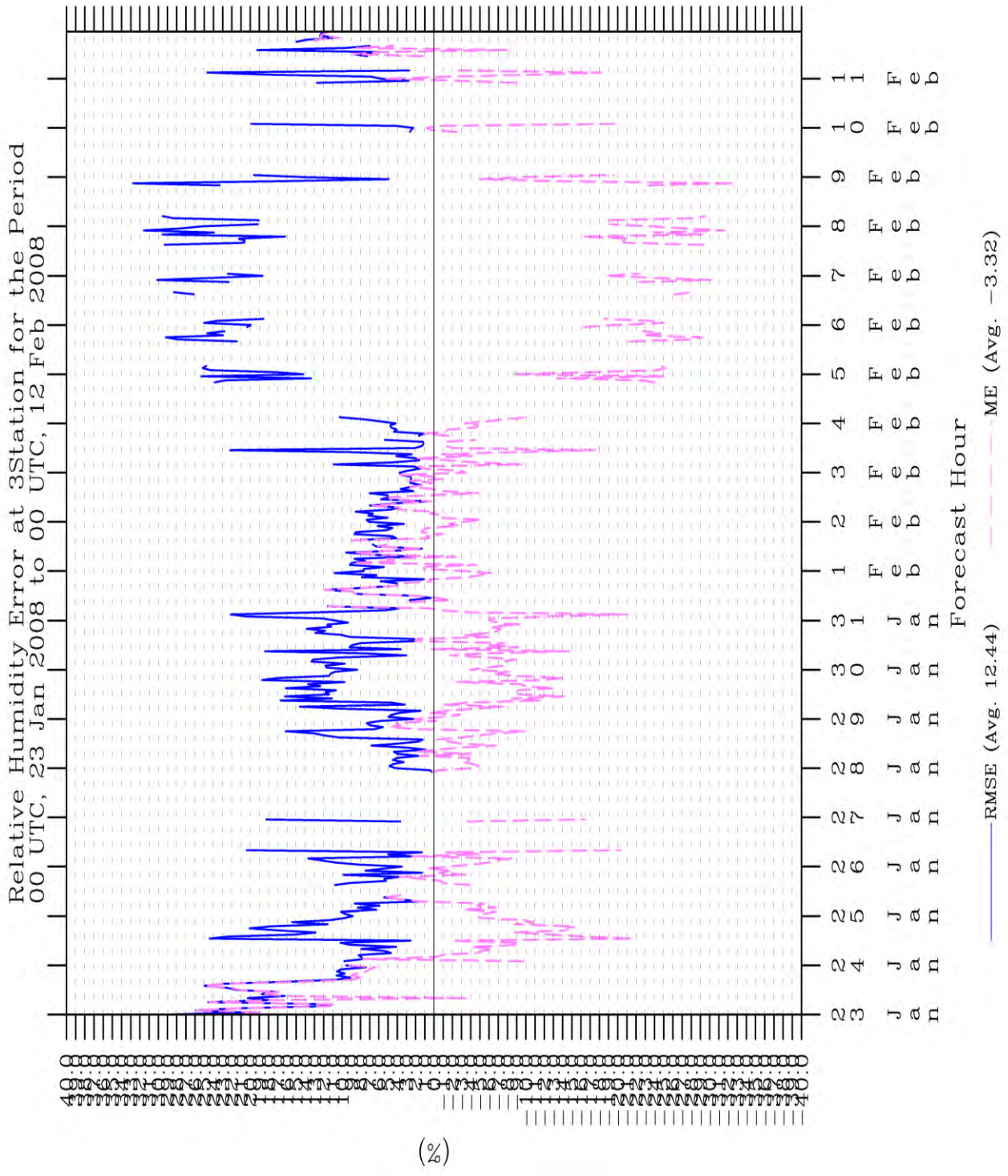


Figure 70: Time series of relative humidity statistics for all three stations in TWIND2X30.

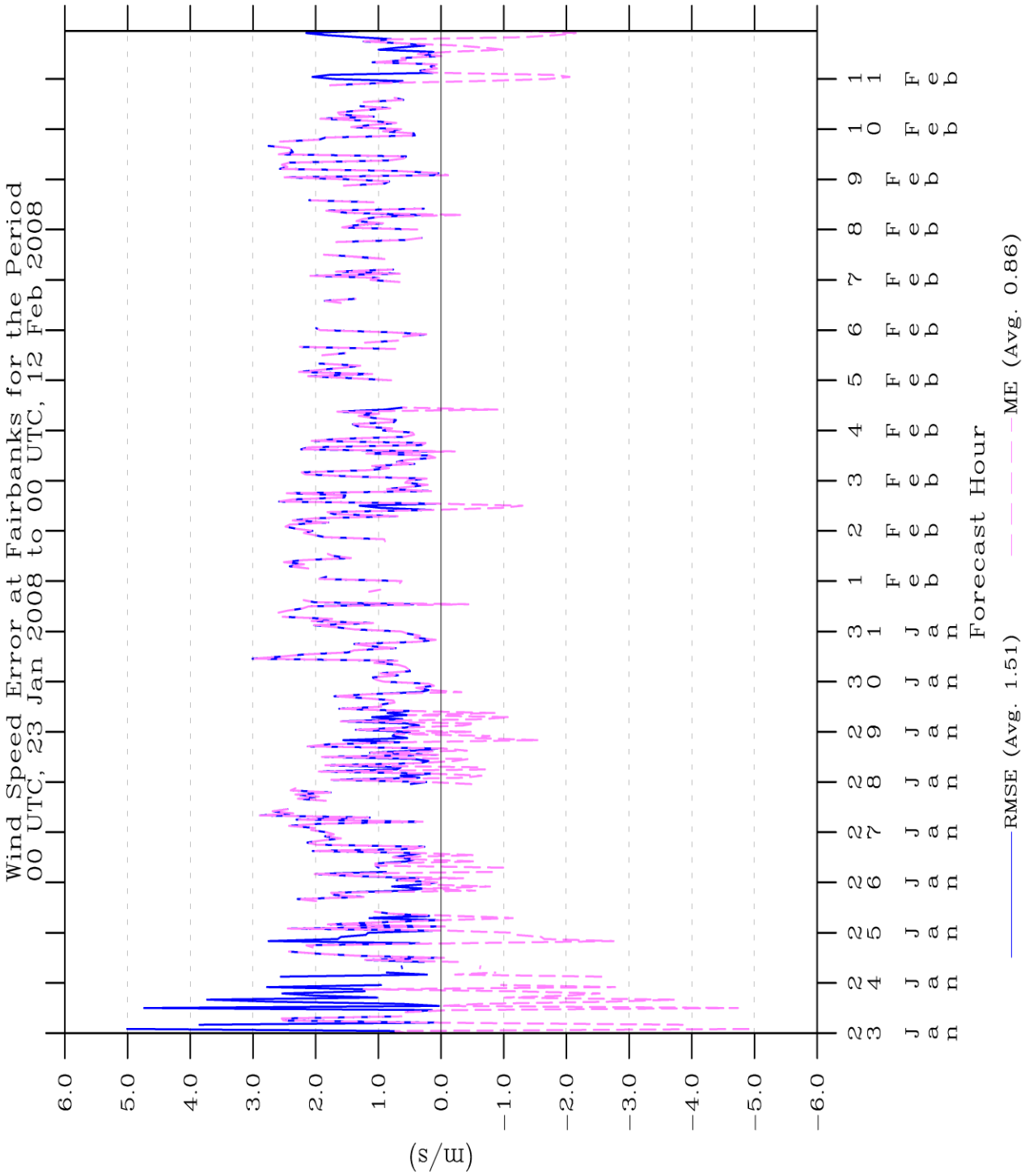


Figure 71: Time series of wind speed statistics for Fairbanks in TWIND2X30.

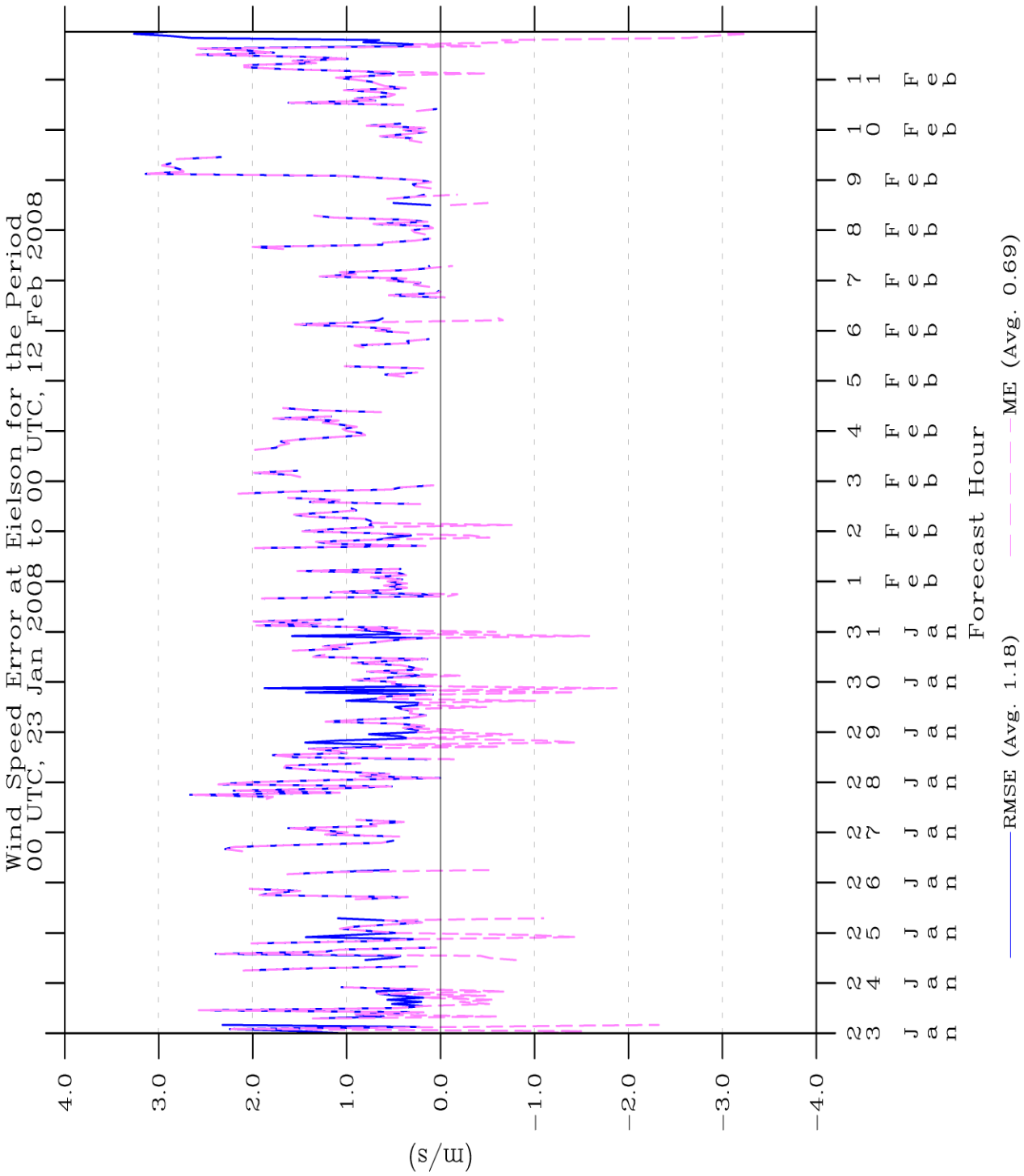


Figure 72: Time series of wind speed statistics for Eielson in TWIND2X30.

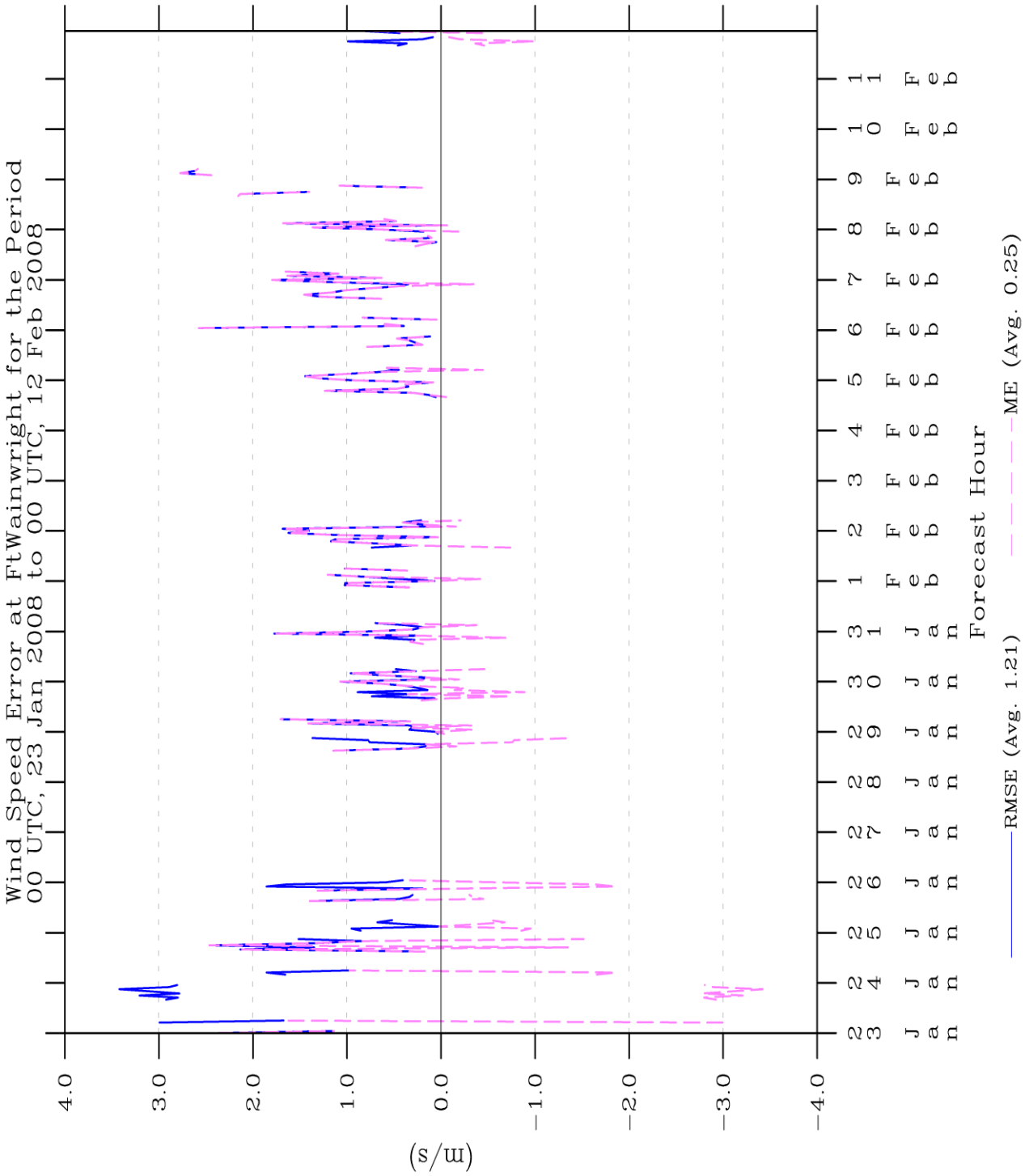


Figure 73: Time series of wind speed statistics for Ft. Wainwright in TWIND2X30.

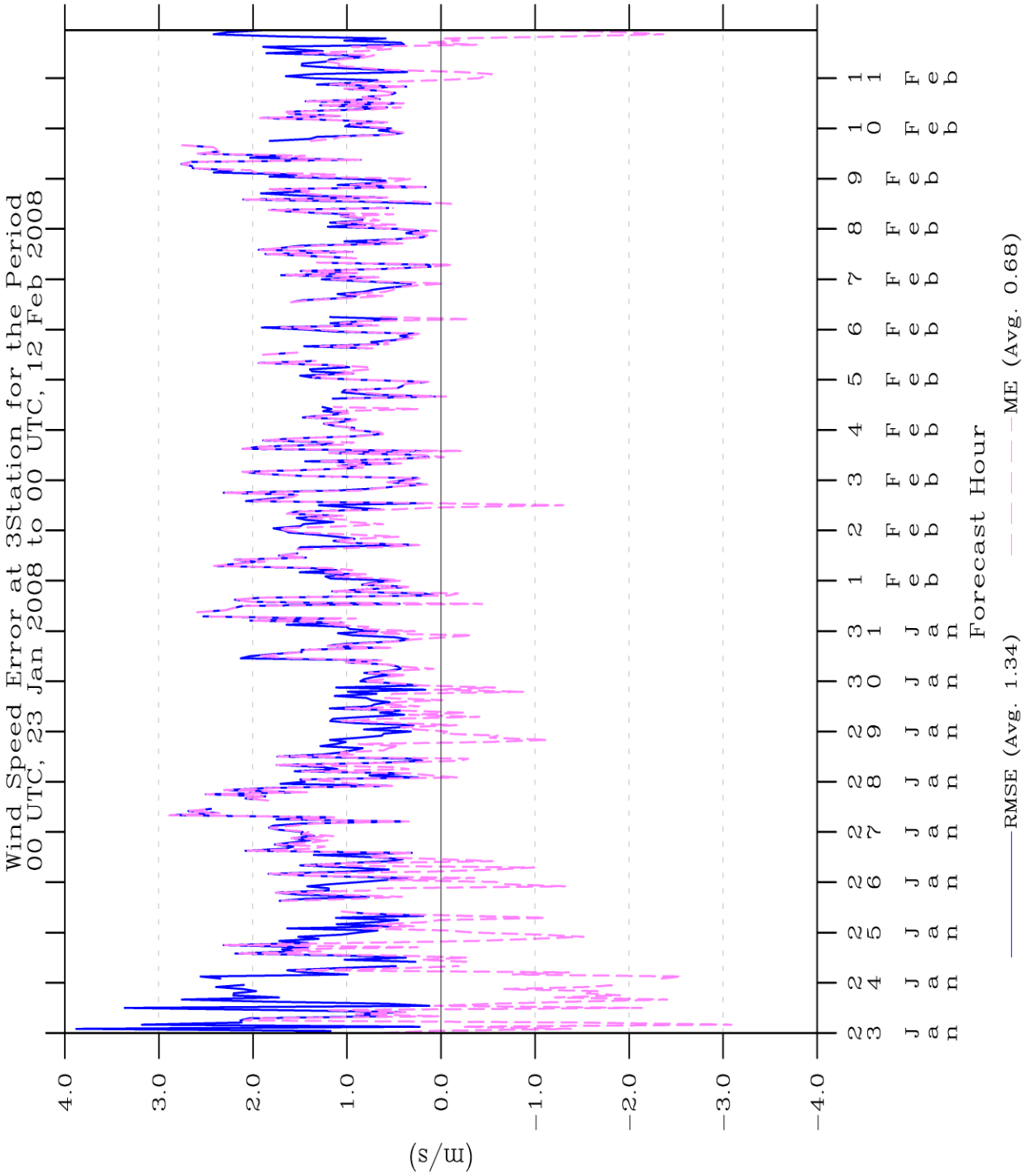


Figure 74: Time series of wind speed statistics for all three stations in TWIND2X30.

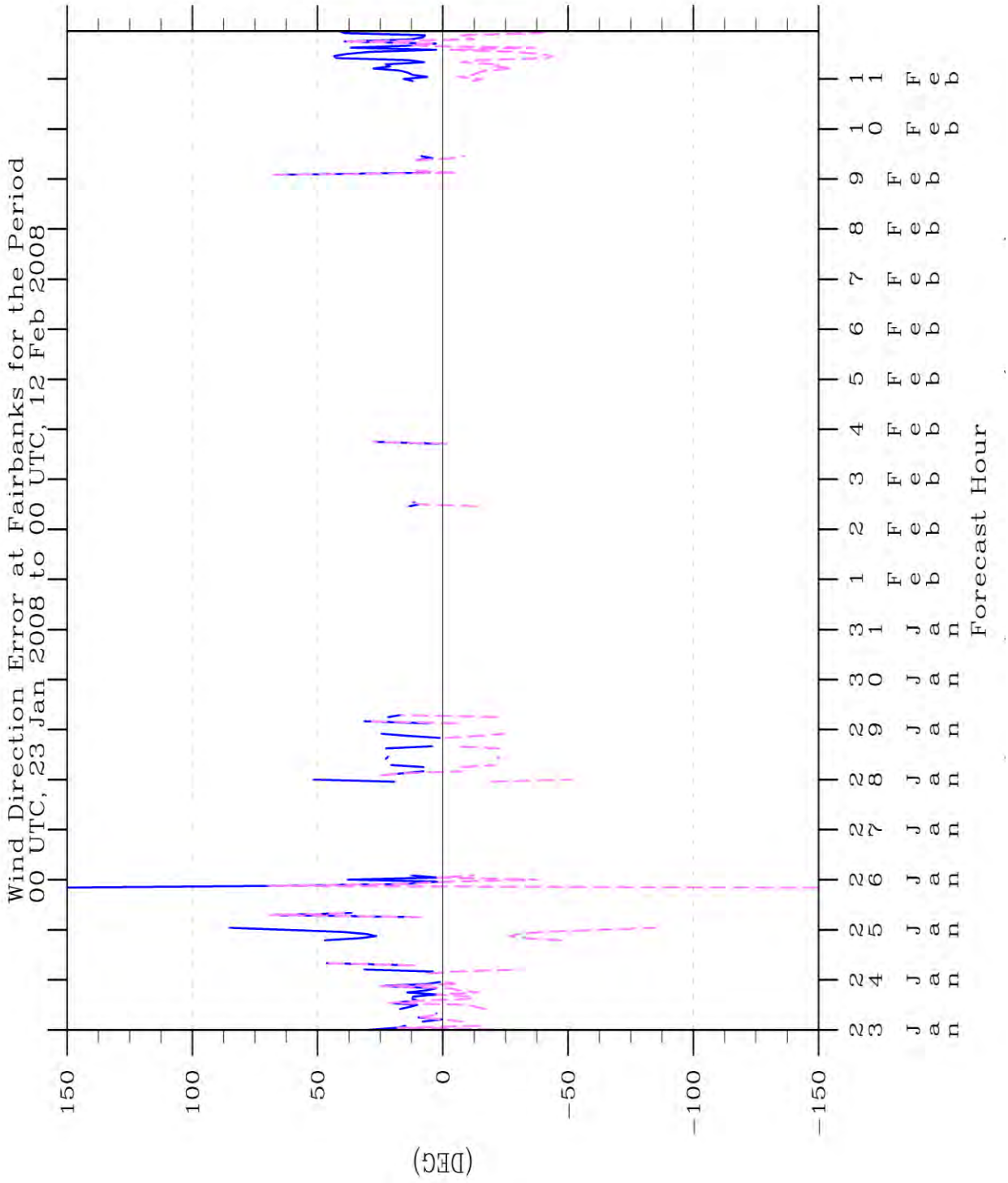


Figure 75: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Fairbanks in TWIND2X30.

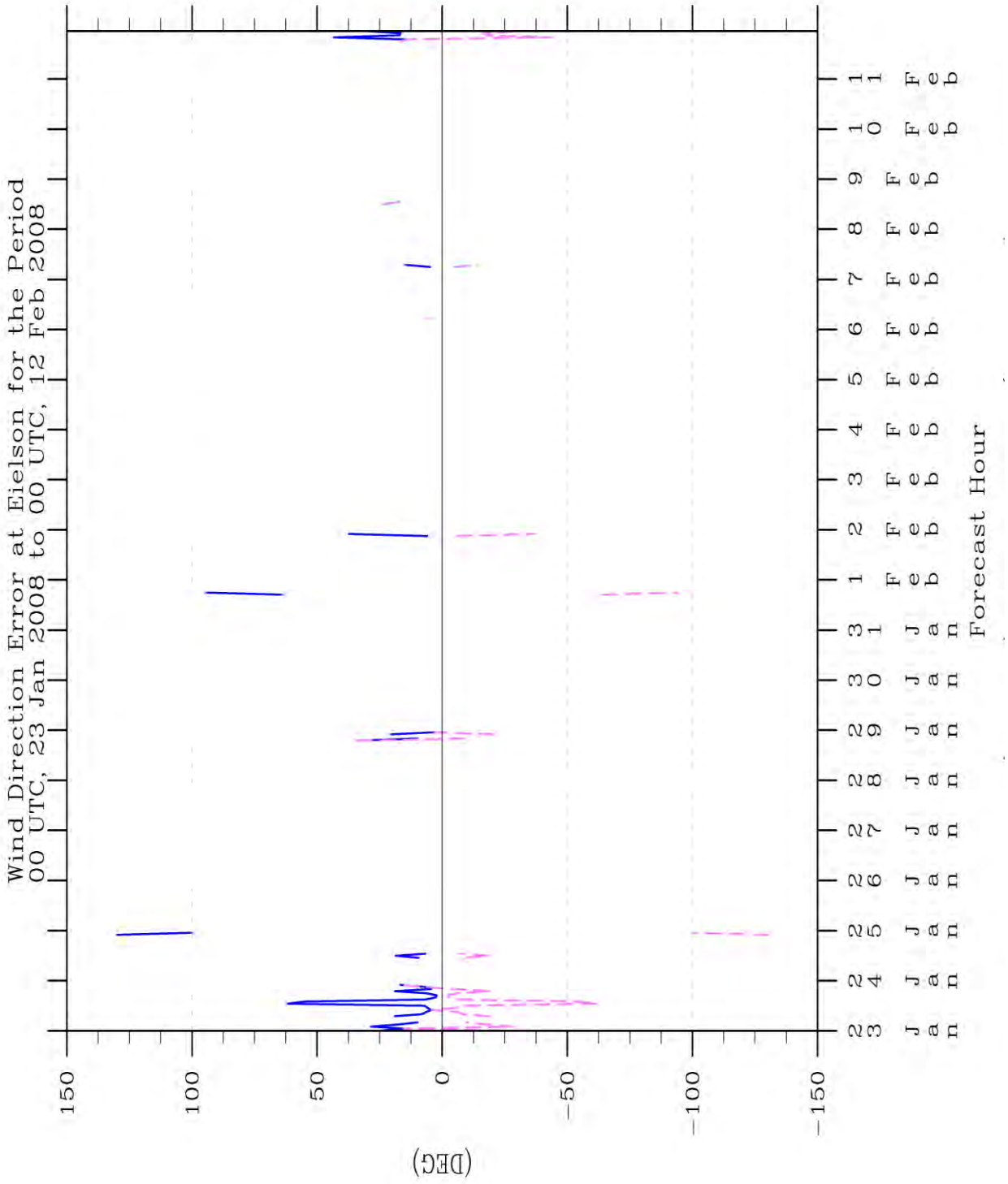


Figure 76: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Eielson in TWIND2X30.

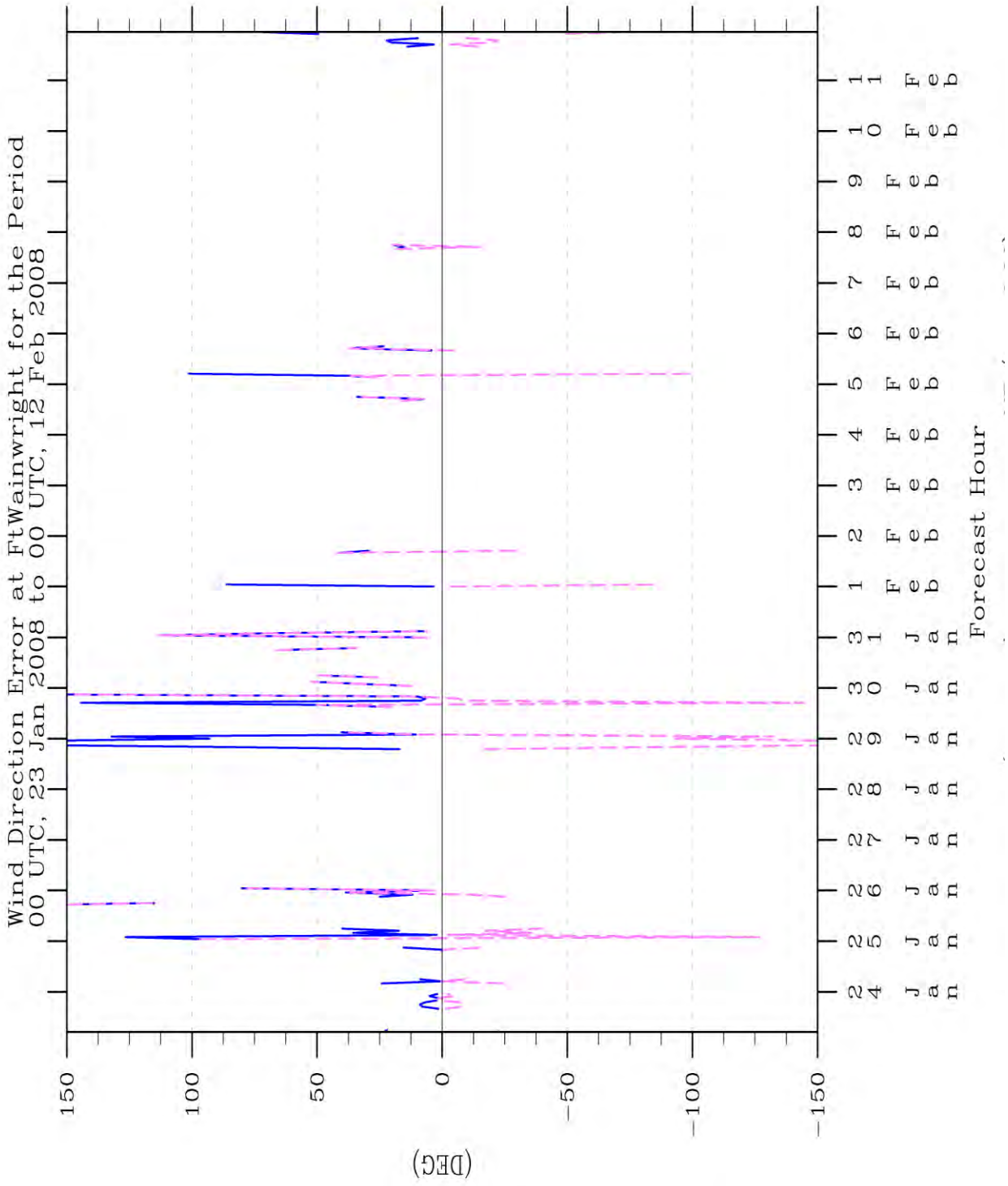


Figure 77: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for Ft. Wainwright in TWIND2X30.

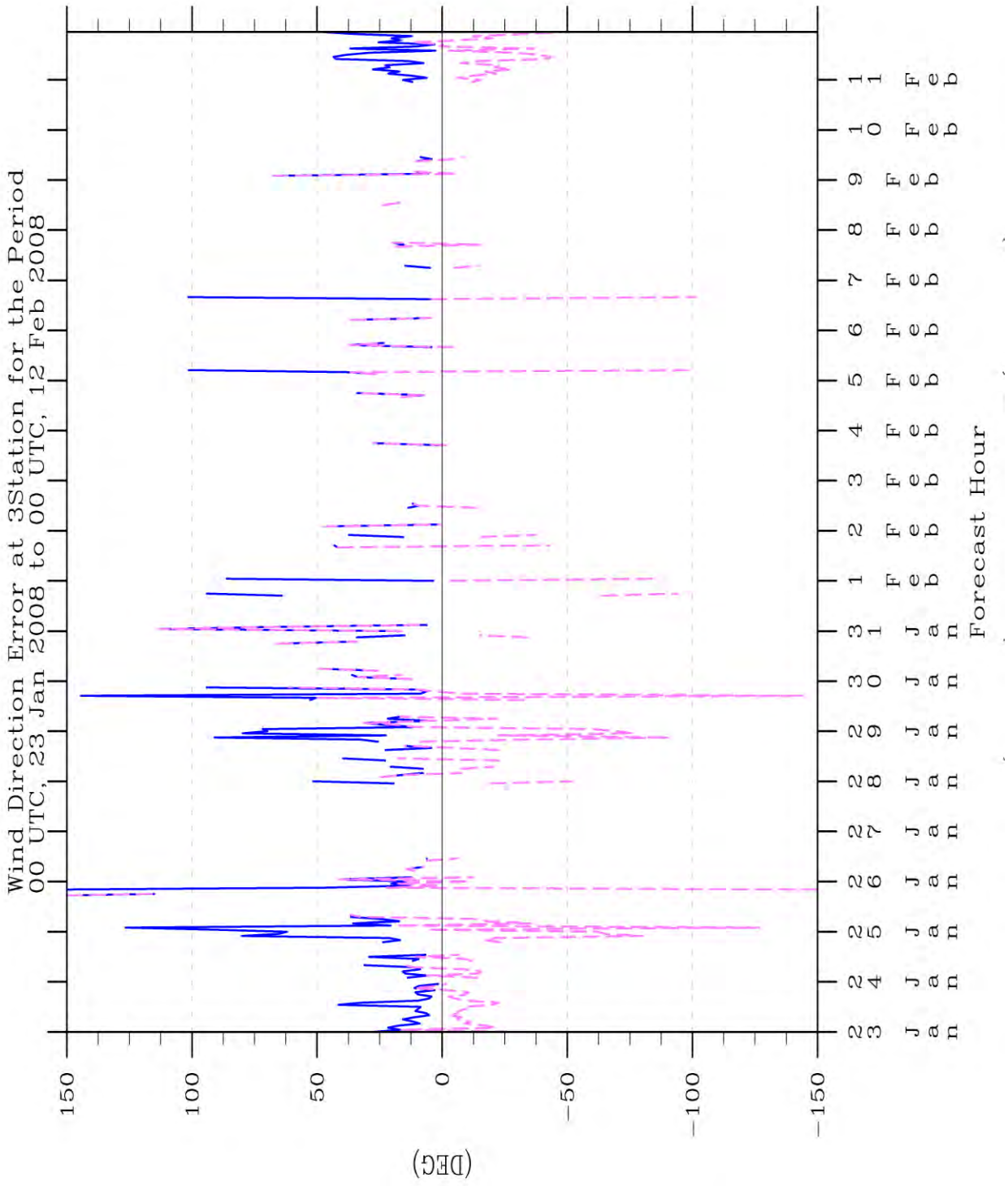


Figure 78: Time series of wind direction mean absolute error (blue) and mean error (magenta) statistics for all three stations in TWIND2X30.

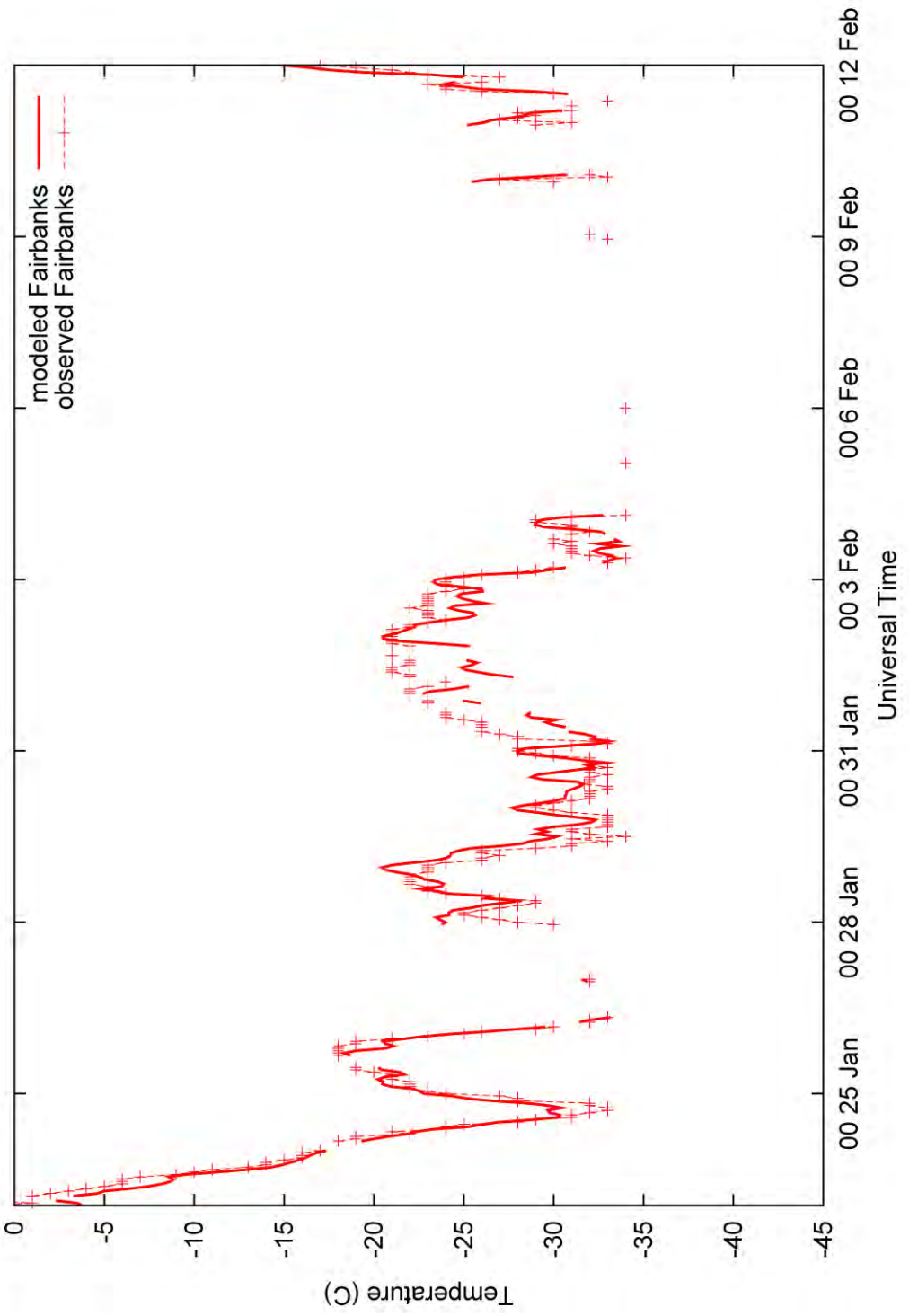


Figure 79: Time series of modeled and observed temperature for Fairbanks in TWIND2X30.

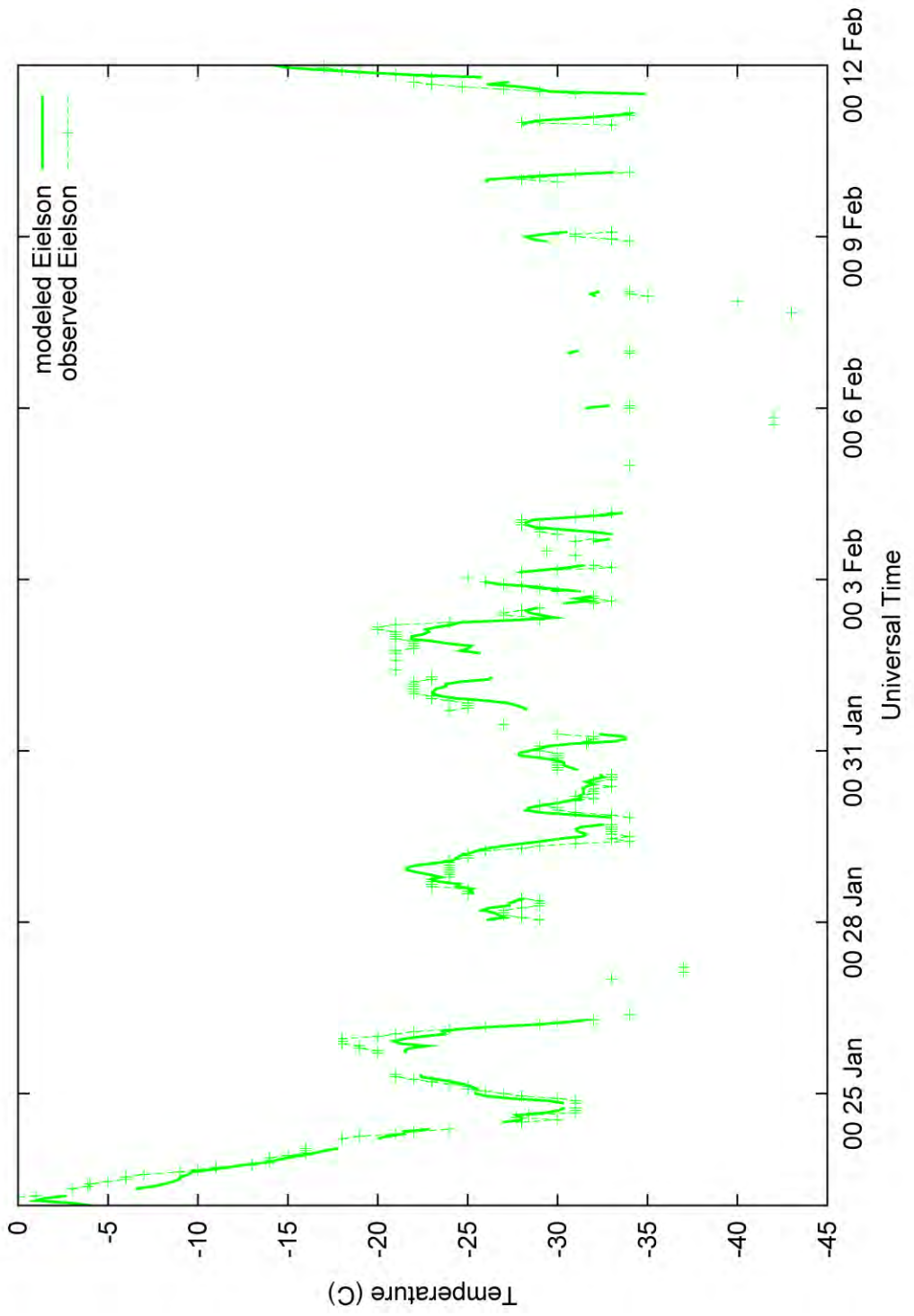


Figure 80: Time series of modeled and observed temperature for Eielson in TWIND2X30.

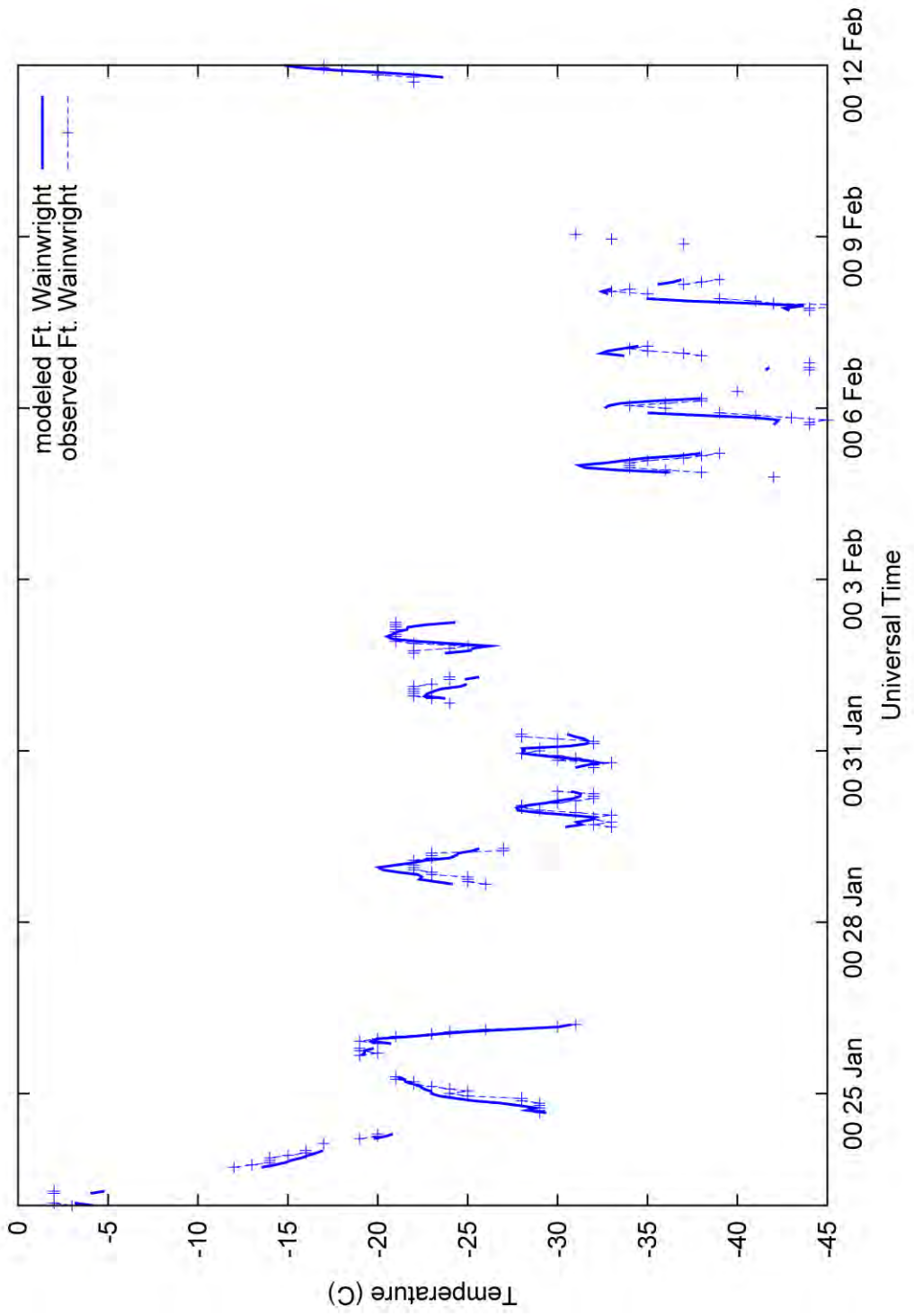


Figure 81: Time series of modeled and observed temperature for Ft. Wainwright in TWIND2X30.

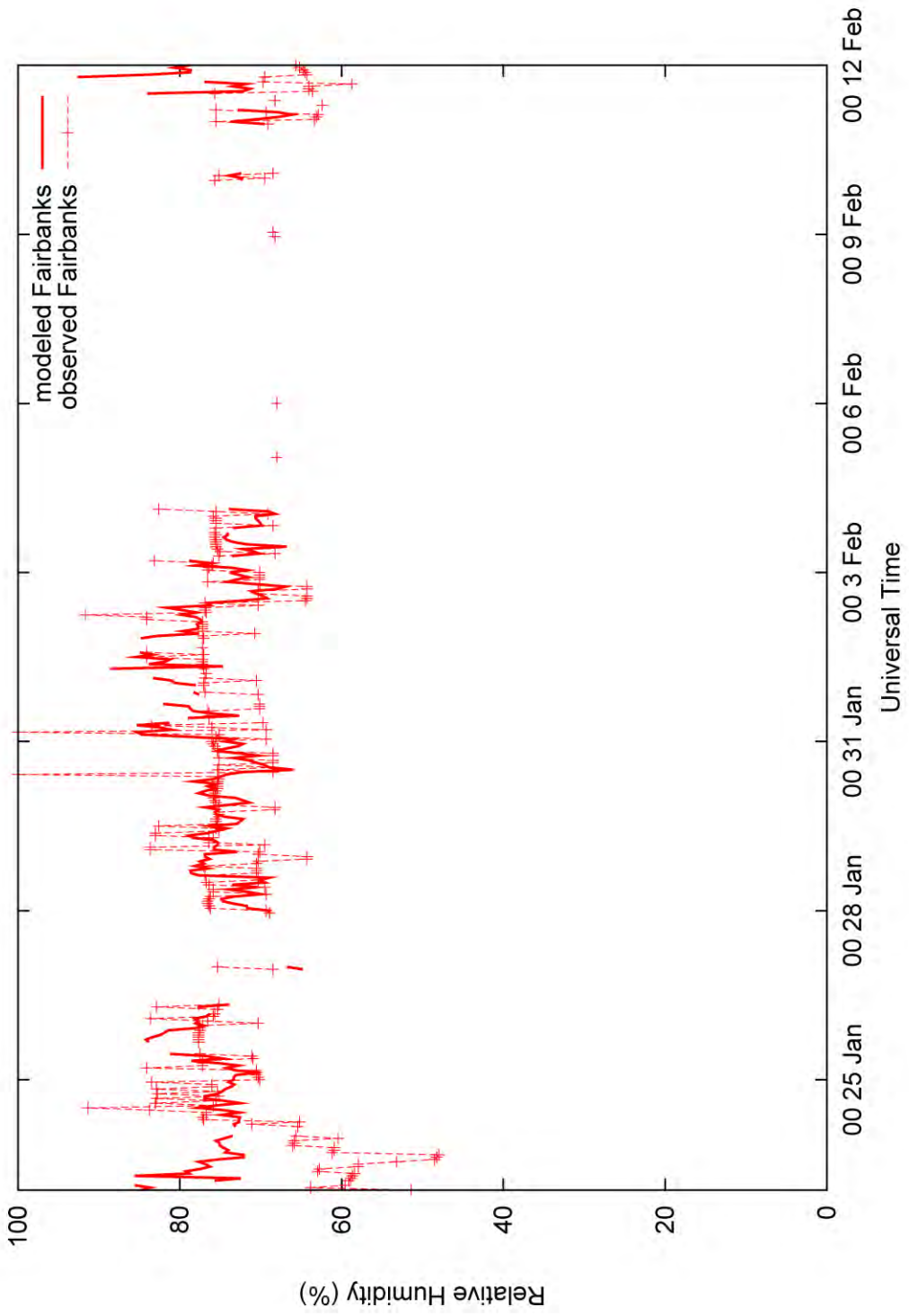


Figure 82: Time series of modeled and observed relative humidity for Fairbanks in TWIND2X30.

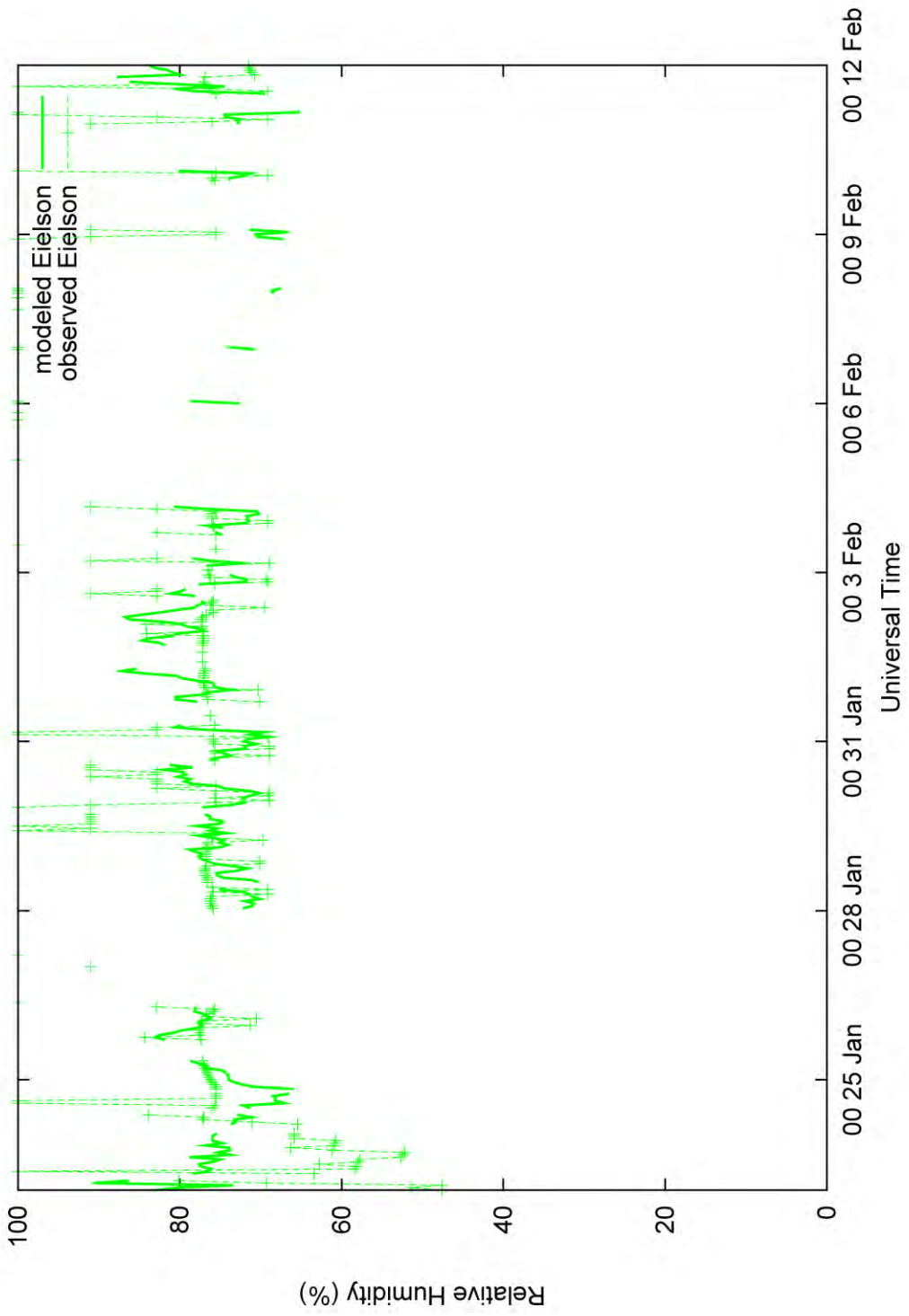


Figure 83: Time series of modeled and observed relative humidity for Eielson in TWIND2X30.

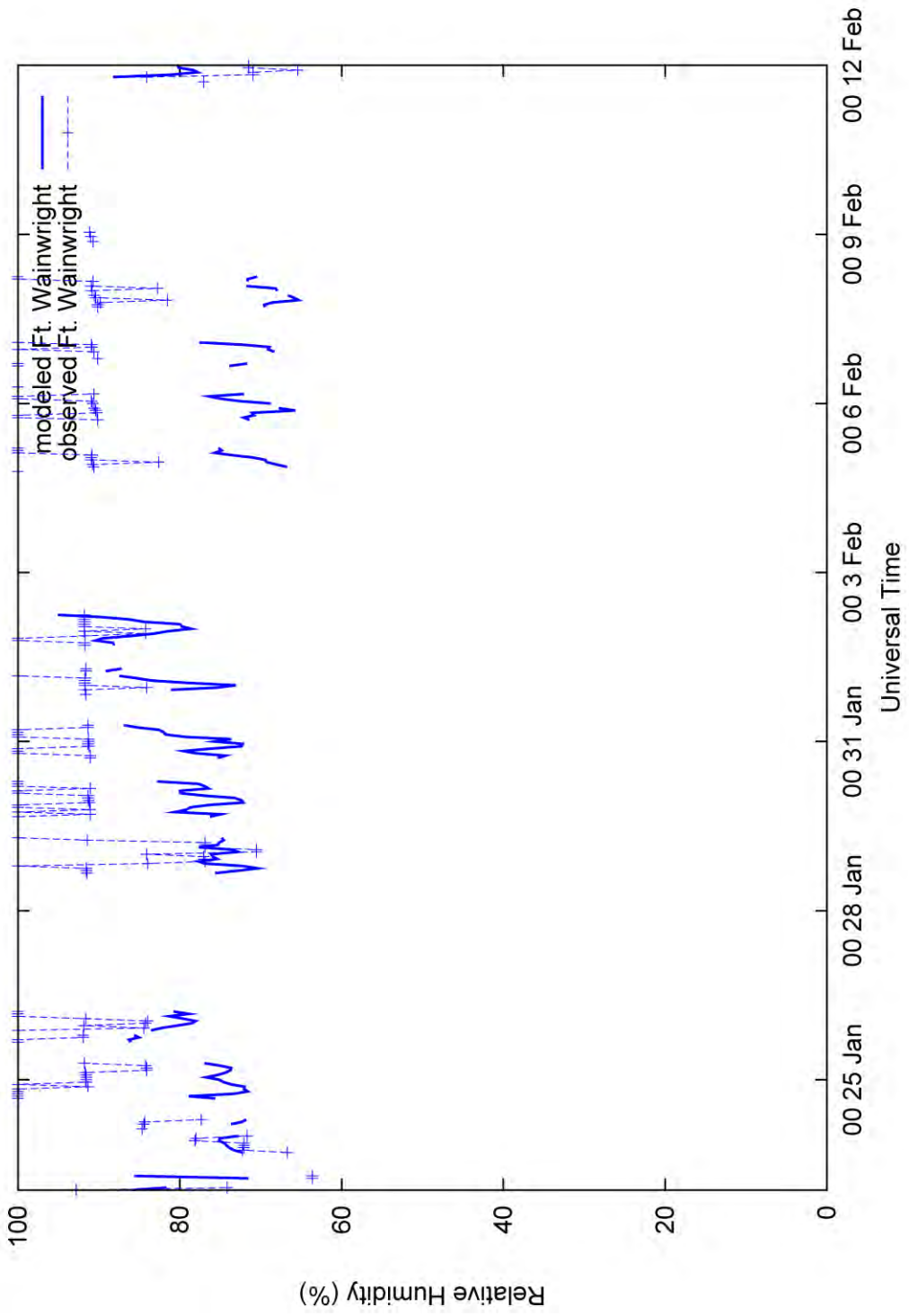


Figure 84: Time series of relative humidity for Ft. Wainwright in TWIND2X30.

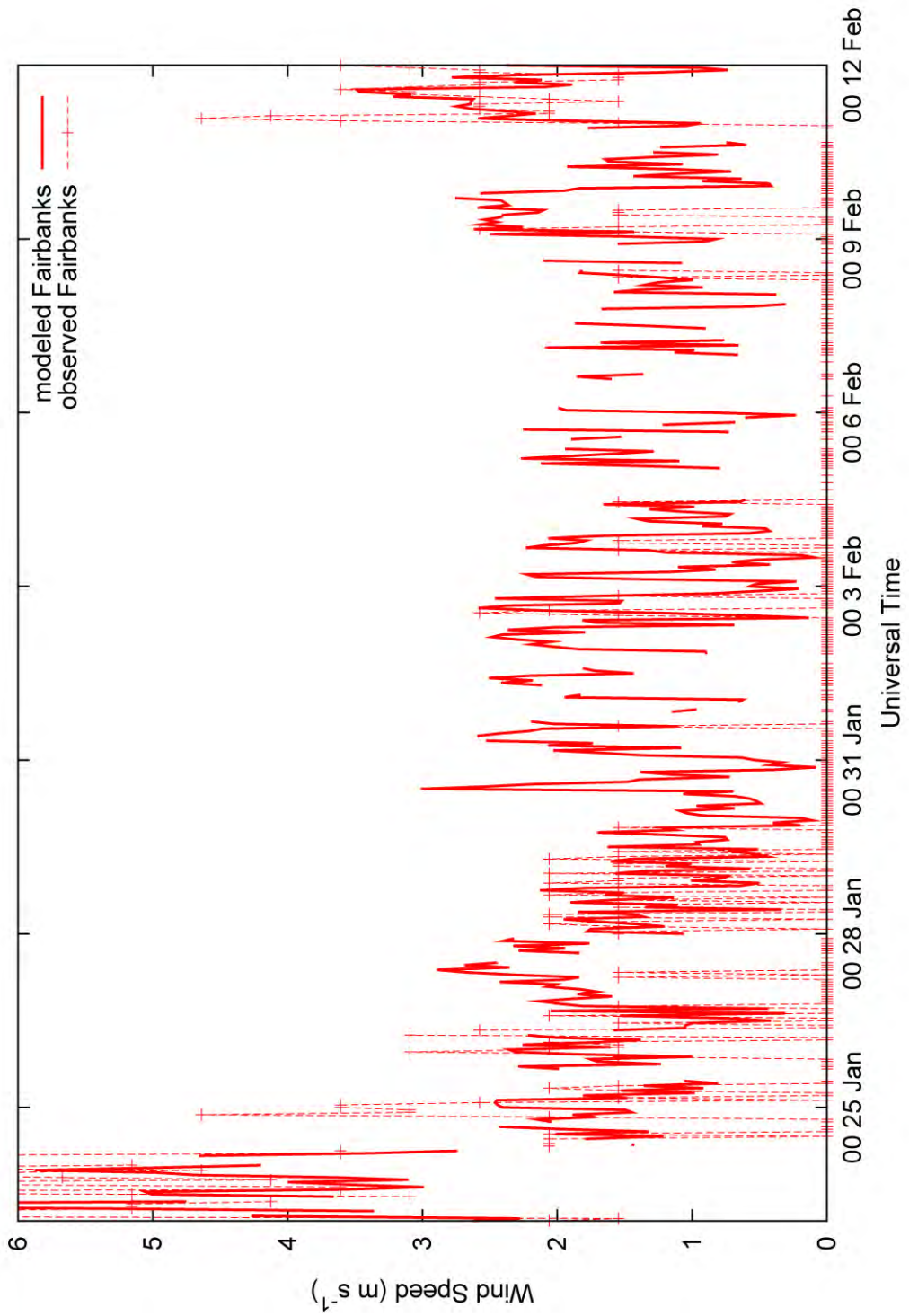


Figure 85: Time series of modeled and observed wind speed for Fairbanks in TWIND2X30.

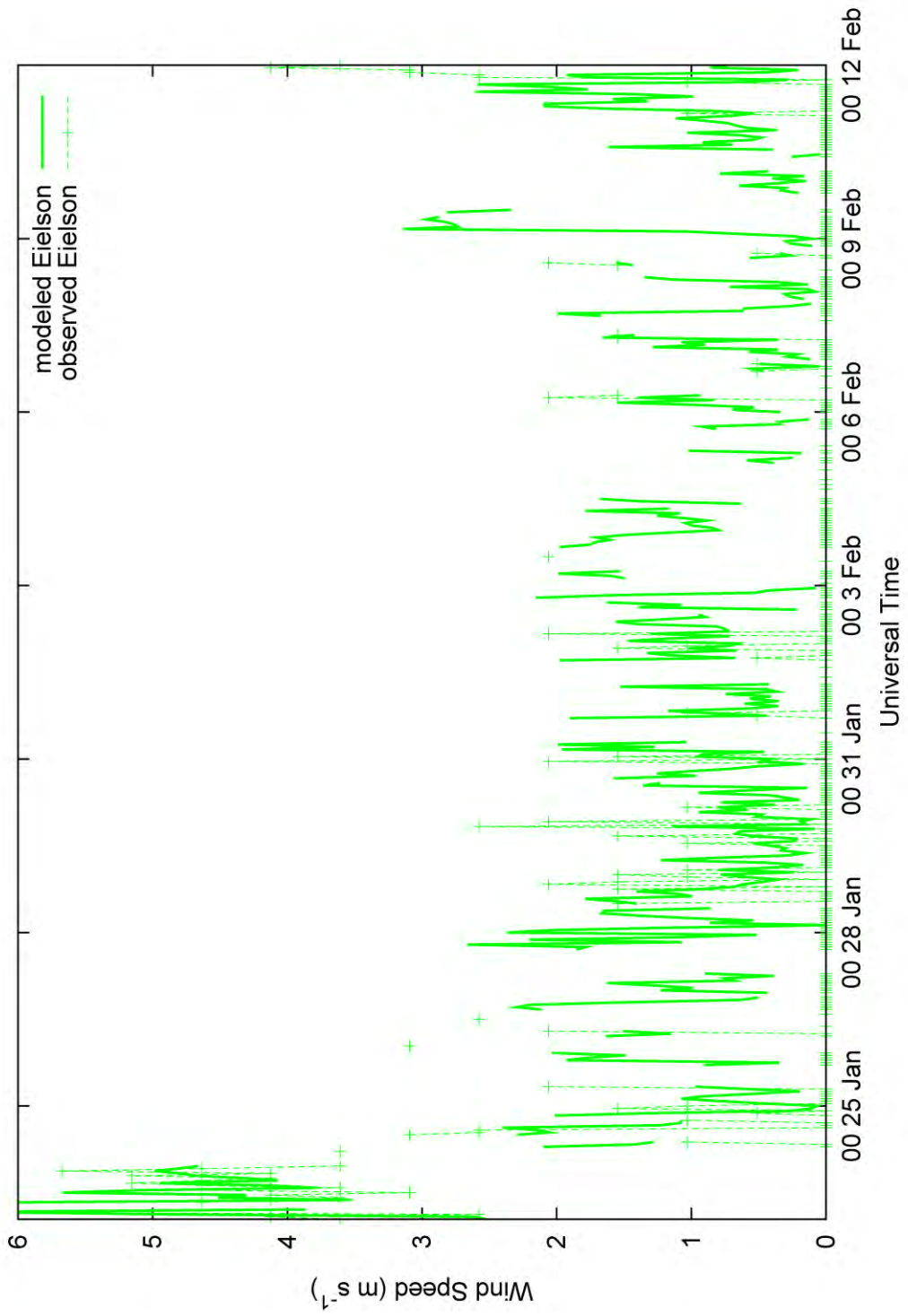


Figure 86: Time series of modeled and observed wind speed for Eielson in TWIND2X30.

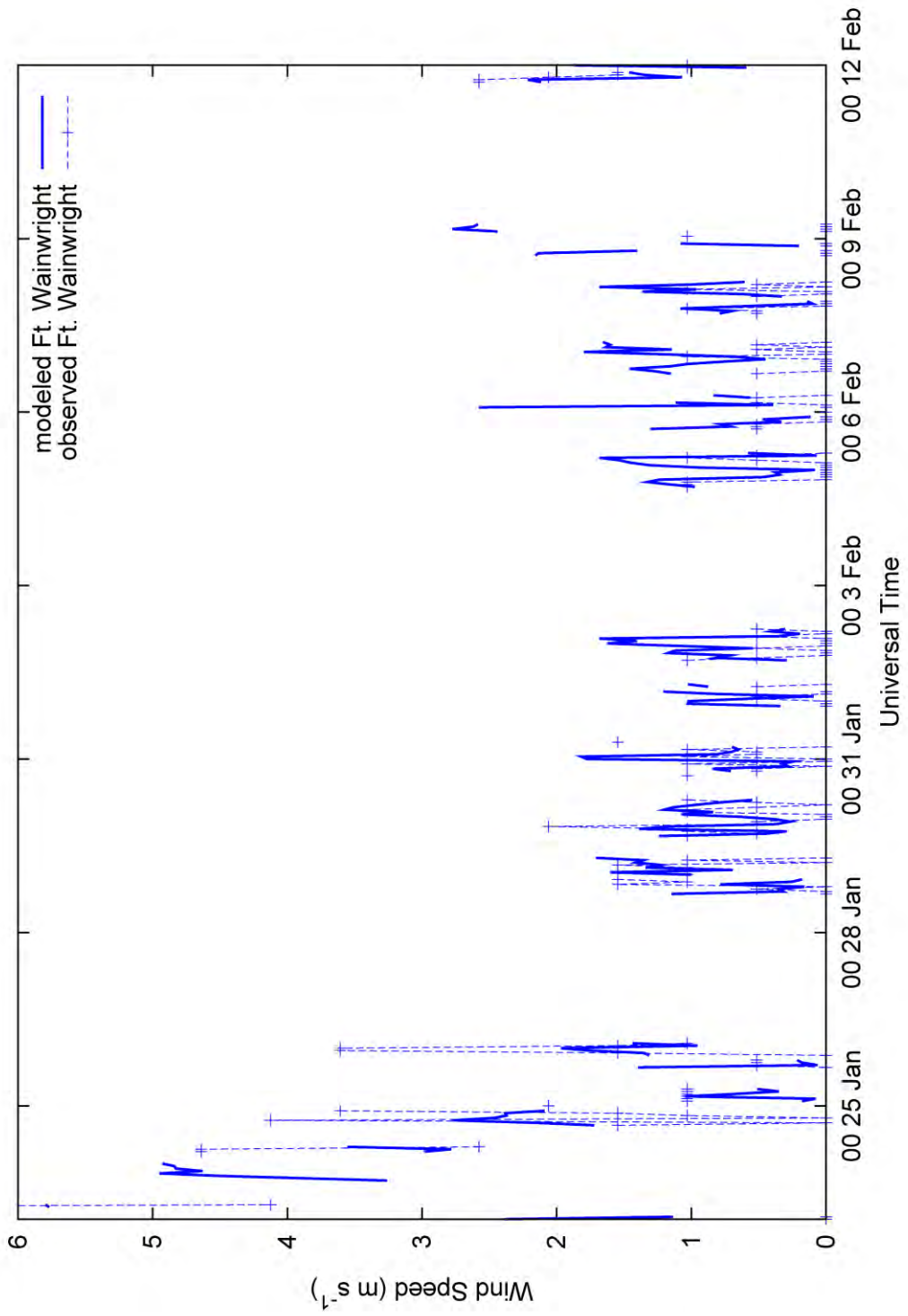


Figure 87: Time series of modeled and observed wind speed for Ft. Wainwright in TWIND2X30.

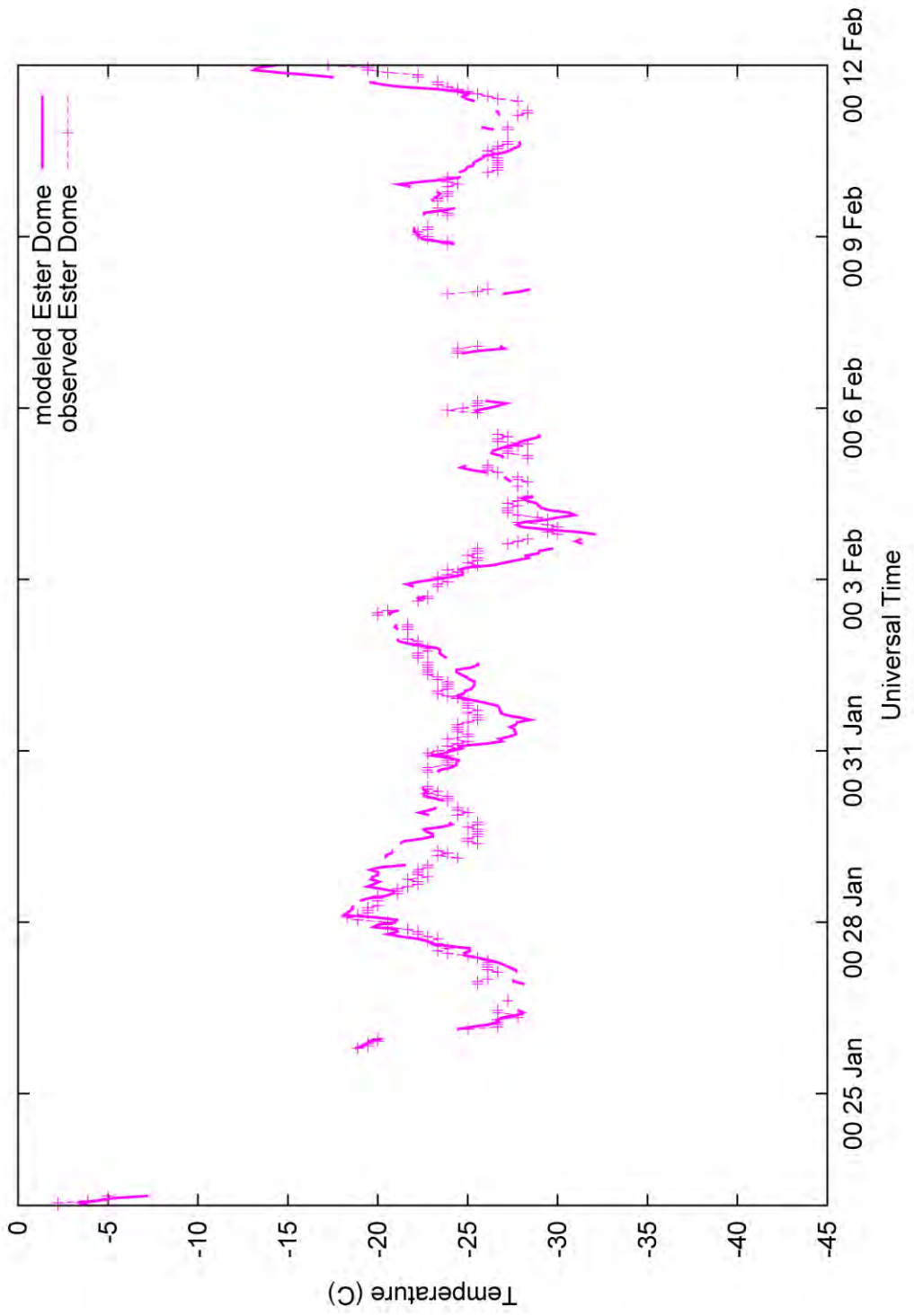


Figure 88: Time series of modeled and observed temperature for Ester Dome in TWIND2X30.

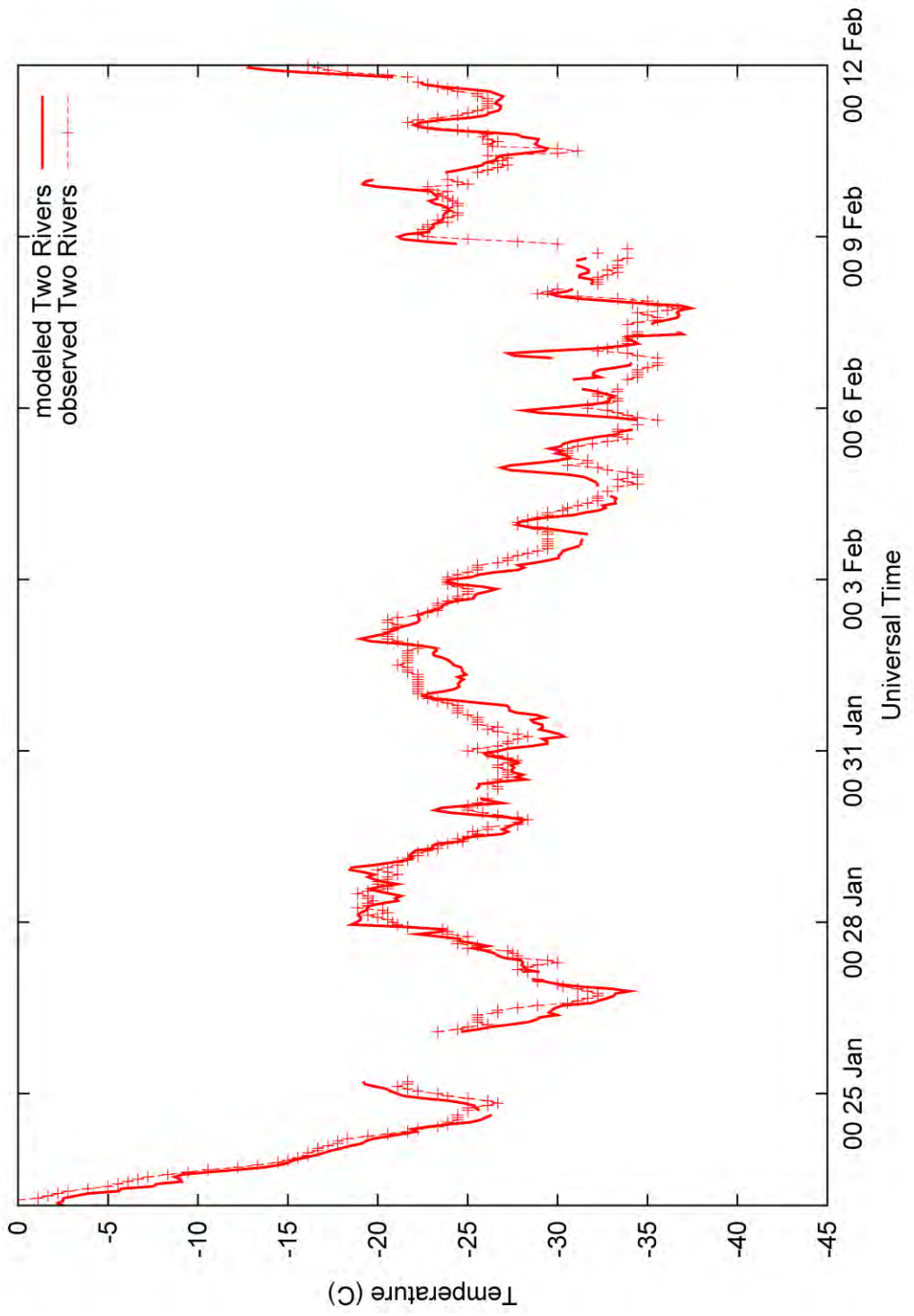


Figure 89: Time series of modeled and observed temperature for Two Rivers in TWIND2X30.

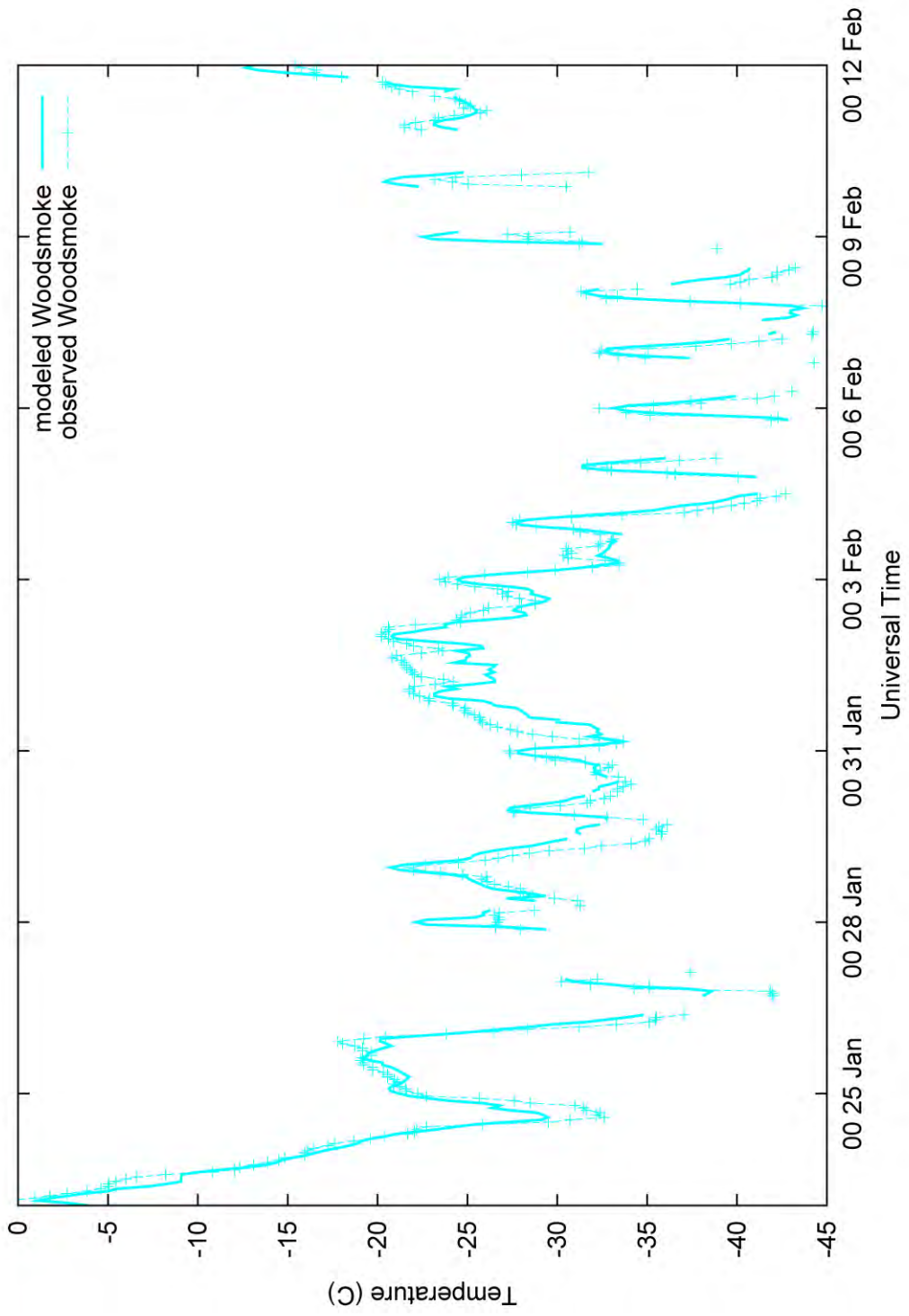


Figure 90: Time series of modeled and observed temperature for Woodsmoke in TWIND2X30.

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Fairbanks, Alaska $PM_{2.5}$ Organic Composition and Source Apportionment Research Study

Final Report

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by

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1. Executive Summary

Fairbanks, AK experiences very high levels of ambient $PM_{2.5}$ during the winter months. Studies are currently under way to determine the sources of the $PM_{2.5}$ so that the issue might be addressed. Possible sources of the $PM_{2.5}$ include residential heating (wood, fuel oil, and/or natural gas combustion), transportation (diesel and gasoline engines), and coal combustion.

The current project is to provide a more complete characterization of the organic chemical composition of $PM_{2.5}$ from Fairbanks with the goal of identifying and quantifying chemical species that can be used to calculate and apportion ambient $PM_{2.5}$, particularly from wood and fossil fuel combustion.

Comprehensive chemical analyses for levoglucosan, hopanes, steranes and PAHs have been performed on up to33 ambient $PM_{2.5}$ samples from Fairbanks. Analyses have also been performed on $PM_{2.5}$ generated at OMNI scientific using representative fuels and devices. The results of these analyses have been examined with special attention to compounds reported by previous authors as emissions from wood (levoglucosan) and fossil fuel sources. Emphasis has been placed on sulfur-containing compounds (dibenzothiophene and benzonaphthothiophene) which are known emissions of diesel vehicles and were hypothesized to be markers of residential oil burners and a polynuclear aromatic hydrocarbon (picene) which has been reported as a unique marker for coal combustion. A second polynuclear aromatic hydrocarbon, bibenzyl, has been identified as a potential marker for residential oil combustion.

In general, the results show that the ambient levels of levoglucosan and selected hopanes, steranes, picene and thiophenes, measured either as a concentration in air or as a fraction of $PM_{2.5}$, are high relative to previous studies. Levoglucosan results provide a reasonable estimate of the wood smoke contribution to ambient $PM_{2.5}$, and other markers provide a sense of upper bounds for the contribution of residential oil burners and coal combustion.

Levoglucosan results indicate that wood smoke contributes 26-35% of the $PM_{2.5}$ at the State Building site, 42-62% at the North Pole site, and 20-30% at the Peger Road site. These values are significantly lower than those reported by CMB analysis and similar to somewhat lower than those determined by ^{14}C analysis. The results show that wood smoke is a substantial contributor to ambient $PM_{2.5}$. The contribution of wood smoke to ambient $PM_{2.5}$ varies substantially within a season, but has had a fairly constant seasonal average or median over the past three seasons.

Polynuclear aromatic hydrocarbon results indicate that residential oil combustion is likely a minor contributor to ambient $PM_{2.5}$ levels with a median contribution of less than 1%. Sterane analysis indicates that the upper bound for the contribution from residential oil combustion is 15%, but this is likely to be an overestimate. There is significant but unquantifiable uncertainty in these results, which rely on a single sample of no. 2 fuel oil $PM_{2.5}$.

Analysis of picene levels indicates that coal combustion also contributes a minor fraction to ambient $PM_{2.5}$ of 2.7% or less. Analysis of hopanes suggests an upper bound for coal contribution of 13%, which is likely to be an overestimate. The picene and hopane shares of coal $PM_{2.5}$ are highly variable with device, however, and the contribution of coal combustion to ambient $PM_{2.5}$ could be less than 1% from coal stoves or much higher if from HH systems.

Thiophene analysis shows that these compounds are not present in residential oil emissions, and thus cannot be used as markers of residential oil combustion. The compounds do appear in the emissions from coal combustion at shares that result in estimated coal contributions to ambient $PM_{2.5}$ of 6.7% to over 100%. It is clear from this analysis that there is another significant source of thiophenes, particularly dibenzothiophene, other than residential heating. The most likely source is transportation, since thiophenes have been reported at significant levels in diesel fuel and gasoline emissions.

2. Levoglucosan

Levoglucosan, a product of incomplete cellulose combustion, has been recognized for many years as a marker of biomass combustion in $PM_{2.5}$. In winter urban environments such as Fairbanks, this can be equated with smoke from wood-fired residential heating devices.

The University of Montana has been analyzing ambient filters from Fairbanks for levoglucosan content since beginning in the 2008-2009 heating season and continuing through the 2010-2011 heating season. Measurements have been made on over 225 filters from four separate sampling sites during that period. This report will summarize these results, providing both the raw results and interpretation of those results in terms of the fractional contribution of wood smoke to total PM in Fairbanks.

2.1 Analytical Method and Quality Control

The Fairbanks ambient $PM_{2.5}$ sampling program is described in detail in "The Fairbanks, Alaska PM2.5 Source Apportionment Research Study Final Report," July 23, 2012, by Tony Ward. Levoglucosan analyses were performed on quartz filters obtained through this sampling program as described in this report for the ^{14}C analyses.

Ambient filters received from Fairbanks are stored at -10 C until analysis is performed. Each filter is halved before analysis to allow for a second half to be archived or analyzed for ^{14}C or other analytes. The filter half was placed in a 30 mL vial and spiked with deuterated levoglucosan as in internal standard. The vials were left at room temperature to allow the standard to be absorbed onto the filter. After half an hour or until the standard solvent had evaporated, 20 mL of ethyl acetate with 3.6 mM triethylamine (TEA) was added and the samples were sonicated for half an hour to extract the desired compounds. After sonication, the filter was removed and the extract was filtered through a Whatman 0.45 µm nylon filter to remove particulates. The volume of the solvent was adjusted to 0.5 mL through evaporation under a stream of air in a sand bath at 45 °C. The sample was evaporated to dryness under a stream of air at room temperature and then derivatized with 75 µL N-*O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA), 10 µL trimethylchlorosilane (TMCS), and 10 µL trimethylsilylimidazole (TMSI). The samples were heated in a sand bath at 70 °C for 1 hour to allow the derivatization to go to completion. Upon removal from the sand bath, the samples were diluted to 500 µL with ethyl acetate containing 3.6 mM TEA and were transferred to a GC vial for analysis.

Analysis was performed on an Agilent 6890N Gas Chromatograph with an Agilent 5973 Mass Spectrometer. An HP-5MS column ((5%-Phenyl)-methylpolysiloxane) was used with dimensions of 0.25 mm ID x 30 m length x 0.25 μm film thickness. A volume of 2 μL was injected for each analysis into a Split/Splitless FocusLiner^{TM} for HP, single taper p/w quartz wool liner. Split injection was used to analyse for levoglucosan with a split ratio of 50:1. The inlet temperature was set to 250°C and the auxiliary transfer line temperature was set at 280°C. The temperature programme was started at 40˚C for 1.5 minutes, ramped at 30°C/min to 190°C, 20°C/min to 210°C, and then 50°C/min to a final temperature of 300°C, which was held for 1.5 minutes. The mass spectrometer was operated with a solvent delay of

4.00 minutes and the mass range from 40-450 was scanned. Single ion monitoring was also used during detection. Highly selective quantitation was performed using the signal for representative ions for levoglucosan (217 m/e) and D-levoglucosan (220 m/e) extracted from the total ion chromatogram.

Calibration standards were prepared containing variable concentrations of levoglucosan and a fixed concentration of D-levoglucosan internal standard. The fixed concentration of deuterated internal standard (20 ppm) was selected to match the concentration expected from extraction of internal standard spiked on the filters, assuming 100% recovery. The standards were derivatized and analysed on the GCMS. The ratio of the peak area of levoglucosan to the peak area of D-levoglucosan standard was found for each calibration standard. A calibration curve was prepared by plotting the ratio of the two peak areas versus the concentration of the levoglucosan. Linearity was determined for each calibration curve, and all had R^2 values of at least 0.95. The concentration of levoglucosan extracted from sample filters was determined by measuring the ratio of the peak area for the analyte to that of D-levoglucosan, and reading the concentration from the calibration curve. Filter blanks and spiked filters were analysed on a regular basis, at least once for every 10 filters. Recoveries were determined for blank filters spiked with the analytes at known amounts corresponding to typical levels seen in actual sample filters. Recovery was consistently in the range of 95-105%, and blank filters did not give significant signals.

Wood smoke particulate obtained from OMNI Scientific was also analysed for levoglucosan content using essentially the same procedure. These filters had very high loads of $PM_{2.5}$, which required adaptations to the method. Smaller portions of the filters, typically 1/8 rather than ½, and extracts were often diluted before derivatization. In each case where additional dilution was necessary, the filters were spiked before extraction with sufficient deuterated levoglucosan such that the final diluted concentration would match that of other samples and standards. This ensured that the area ratios could be interpreted using the same standard curve.

In order to interpret the results for levoglucosan as a share of wood smoke $PM_{2.5}$ on the OMNI-generated filters, it was necessary to estimate the total $PM_{2.5}$. OMNI reported total $PM_{2.5}$ for quartz filter 1 (PM_{Q1}) and flow rates for quartz filters 1 (FR_{Q1}) and 2 (FR_{Q2}) for each sampling event. Quartz filter 2 was sent to UM for levoglucosan analysis. We calculated total $PM_{2.5}$ on quartz filter 2 using these data:

$$PM_{Q2} = PM_{Q1}\frac{FR_{Q2}}{FR_{Q1}}$$

This calculation assumes that the sampling time and that the $PM_{2.5}$ level in the sampling region for the two quartz filters were the same for each experiment.

2.2 Results

Raw results for all measured levoglucosan levels in ambient air (in ng/m^3) and as levoglucosan share of total $PM_{2.5}$ (in %) are provided in a spreadsheet. These data are organized by sampling site and sampling date, and total reported $PM_{2.5}$ (in $\mu g/m^3$) are also included. Based on replicate measurements, typical relative error for reported levoglucosan levels is ± 10%.

Table 1 presents averages and 95% confidence intervals for levoglucosan levels and shares by sampling site and year. Data for the RAMS site is presented only for the 2009-2010 season since other seasons have either no or insufficient data. Confidence intervals in these results are affected by actual variations in levoglucosan levels and shares as well as variations due to analytical reproducibility.

Table 1: Average levoglucosan (LG) levels and shares for four sites over the three year study period.

	State Building		Peger Road		North Pole		RAMS	
	LG Level (ng/m^3)	LG Share (%)	LG Level (ng/m^3)	LG Share (%)	LG Level (ng/m^3)	LG Share (%)	LG Level (ng/m^3)	LG Share (%)
2008-09	573 ±203	3.1 ±1.1	628 ±120	2.18 ±0.24	833 ±480	3.8 ±1.2	NA	NA
2009-10	671 ±288	2.33 ±0.63	312 ±131	1.60 ±0.41	1720 ±470	4.80 ±0.51	NA	NA
2010-11	671 ±157	2.96 ±0.32	763 ±195	2.30 ±0.36	1150 ±490	4.85 ±0.53	2680 ±1160	4.67 ±0.70
3 yr	632 ±118	2.80 ±0.46	628 ±120	2.18 ±0.24	1400 ±300	4.59 ±0.40		

Levoglucosan levels range from 600 to 2700 ng/m^3 with levels at the State Building and Peger Road at the lower end and those at North Pole averaging 1400 ng/m^3.

Table 2: Levoglucosan shares for various devices, fuels and burn rates.

Filter ID	Burner Type	Fuel Type	Burn Rate	Levoglucosan Share (%)
FNB 1	pellet	Pellet	single	0.24
FNB 44	conv. WS	Birch	high	1.08
FNB 40	conv. WS	Spruce	high	0.88
FNB 52	conv. WS	Birch	low	1.18
FNB 48	conv. WS	Spruce	low	0.35
FNB 4	Cert. WS	Birch	high	0.27
FNB 7	Cert. WS	Spruce	high	1.80
FNB14	Cert. WS	Birch	low	6.12
FNB 18	Cert. WS	Spruce	low	6.05
FNB 87	NQ OWHH	Spruce	high	5.86
FNB 27	EPA OWHH	Birch	high	7.46
FNB 34	EPA OWHH	Spruce	high	2.48
FNB 28	EPA OWHH	Birch	low	5.73
FNB 36	EPA OWHH	Spruce	low	11.73

The RAMS site, with an average of 2700 ng/m^3 is very high, but the $PM_{2.5}$ levels are also very high at that site. Levoglucosan share range from 1.6 to 4.7%, with the State Building and Peger Road sites averaging 2.2-2.8% and the North Pole and RAMS sites averaging 4.6-4.7%. Significant differences in levoglucosan levels and shares are observed between sampling sites, with the North Pole and RAMS sites showing higher levels and shares and the State Building and Peger Road sites having lower levels and shares. There are no significant differences or trends in levoglucosan levels or shares for any given site as a function of heating season. Variability in the levoglucosan levels, expressed as relative 95% confidence intervals, are high, often exceeding 40%. This variation reflects the fact that levoglucosan levels increase

and diminish with $PM_{2.5}$ levels, which also vary significantly. Relative variations in levoglucosan as share of $PM_{2.5}$ are lower, and are typically 15% or less.

Fourteen filters generated by OMNI Scientific utilizing wood burning devices and two wood species representative of those from Fairbanks, and generated at different burn rates, were also analyzed for levoglucosan content and share. The results for levoglucosan share of the wood smoke $PM_{2.5}$ for these filters are presented in Table 2. Based on replicate analyses of some filters, the relative uncertainty in these numbers is estimated to be ±10%.

In general, these results indicate a relatively low share of levoglucosan in the wood smoke (3.7%) compared to published values[1-3]. No significant differences were observed in levoglucosan share based on wood species, which is also not consistent with previous studies[1-3]. Significant differences are observed as a function of burner type and within burner types as a function of burn rate.

2.3 Interpretation and Discussion

The levoglucosan results in Tables 1 and 2 have been analyzed in an effort to provide a quantitative measure of the contribution of residential wood combustion to ambient $PM_{2.5}$. Recent studies have made similar efforts[1]. The basic approach is to establish an experimental levoglucosan share in wood smoke, and to use this to convert levoglucosan share of ambient $PM_{2.5}$ to wood smoke fraction of ambient $PM_{2.5}$. Dividing the levoglucosan share of ambient $PM_{2.5}$ by the levoglucosan share of pure wood smoke generated using representative heating appliances and wood species should provide the fractional wood smoke contribution to the ambient PM. The levoglucosan share of wood smoke is established by analysis of PM from wood heaters and wood species used in the region of study. The levoglucosan share is generally observed to vary between wood species[1-3], so a representative value for the region is calculated as a weighted average based on a survey of the amount or fraction of each wood species consumed in the region[1].

There are several difficulties, however, in establishing the best conversion factor to apply to Fairbanks ambient levoglucosan results. The most relevant data for levoglucosan share of wood smoke $PM_{2.5}$ should be those reported in Table 2. However, those data include results only for spruce and birch, and a survey of wood consumption in Fairbanks has indicated 43% aspen, 52% birch, and 6% spruce. Further, average levoglucosan share reported in Table 2 is 3.7%, which is significantly lower than typical and average levoglucosan shares measured in ambient $PM_{2.5}$ at the North Pole and RAMS sites. Calculation of wood smoke contribution to ambient PM using these average numbers would result in average values of 124-126% for these two sites. This is clearly not a reasonable result.

There are experimental levoglucosan shares of PM reported in the literature for wood smoke from various species, including aspen, birch and spruce (Fine). These published data are generally accepted and have been used in multiple studies to interpret ambient PM levoglucosan results. The published numbers are generally higher than those reported in Tables 1 and 2, and employing them would result in more acceptable average wood smoke contributions of less than 100%. However, the published results are not specific for appliances and practices in Fairbanks, and their use thus introduces

significant uncertainty. Other published results for levoglucosan share do not include the same species as those burned in Fairbanks and/or are for PM_{10} rather than $PM_{2.5}$.

We have investigated multiple approaches to generate a conversion factor to allow the calculation of wood smoke contributions from levoglucosan fractions of ambient $PM_{2.5}$. Each of our conversion factors is a weighted average based on the survey data for wood species consumption in Fairbanks:

$$CF = \frac{1}{0.43L_A + 0.52L_B + 0.06L_S}$$

where CF is the desired conversion factor and L_A, L_B, and L_S are the levoglucosan share for aspen, birch and spruce wood smoke respectively. A value calculated from results published by Caseiro et al. (CF=11) was rejected because those published results did not include all of the species of interest and because they were for PM_{10}. The value calculated from the published results of Fine et al. (CF=9.01) is considered the industry standard, and is based only on the assumption that the Fine results are valid for Fairbanks devices and conditions. This "Fine conversion factor" was the lowest of the calculated conversion factors and is used here as a lower limit. Two conversion factor values were calculated using, in part, the results in Table 2 for the OMNI-generated filters. The first is calculated using the average values for L_B and L_S from Table 2 under all burn conditions and the value for aspen reported by Fine et al. (L_A=0.125). The resulting "OMNI conversion factor" (CF=13.3) is strongly influenced (43%) by the published value for aspen. Working with a lower value for aspen more in line with those measured for OMNI-generated filters would result in a larger conversion factor and in many days for which wood smoke contributions in North Pole would exceed 100%. The OMNI conversion factor as calculated results in only one day for which wood smoke contribution in North Pole exceeds 100%, and three days that exceed 90%. It is thus a reasonable upper limit for the conversion factor. Finally, device type data by zip code was utilized together with wood species survey data to generate site-specific conversion factors weighted for both wood species and device type. These conversion factors were calculated using L_A from Fine et al., and L_B and L_S from Table 2 and ranged from 12.2-12.4. There was significant concern that these conversion factors were based on too many data with significant uncertainties. Because of this, and because the values are intermediate, they were rejected and were not used for additional calculations.

Using the two conversion factors it is possible to calculate a low and a high estimate of wood smoke contribution to ambient $PM_{2.5}$ in Fairbanks. The high end estimates are nearly 48% higher than the low end estimates. Table 3 presents these results by site and season, along with results for the same sites and seasons from ^{14}C and CMB analysis. The levoglucosan results include analyses for many sampling periods when ^{14}C analysis was not performed. Average values are reported, but these do not differ significantly from median values. Errors are reported as presented in previous reports or as 95% confidence intervals for levoglucosan results. The results for ^{14}C analysis are based on a subset of the samples that were analyzed for levoglucosan, and those results may thus be biased if those samples were not selected at random. Still, results calculated using the OMNI conversion factor (which includes the published Fine result for Aspen) are within the range or are not significantly different from the

results reported from the ^{14}C results. Results calculated using the conversion factor generated using only the published Fine numbers are generally lower than, and often significantly lower than, the minimum value reported from the ^{14}C results. All of the results based on levoglucosan analysis are significantly lower than those reported using CMB modeling. It should be noted that some data were eliminated for a few low PM days, where the results for levoglucosan are either below the detection limit or near the detection limit and thus have considerable error. No more than two data points were eliminated for any heating season.

Table 3: Wood smoke contributions to ambient $PM_{2.5}$ as determined by ^{14}C analysis, levoglucosan analysis

	WS % $PM_{2.5}$ ^{14}C Minimum	**WS % $PM_{2.5}$ ^{14}C Maximum**	**WS % $PM_{2.5}$ Levoglucosan (Fine CF=9.01)**	**WS % $PM_{2.5}$ Levoglucosan (OMNI CF=13.3)**	**WS % $PM_{2.5}$ CMB Model (OMNI)**	**WS % $PM_{2.5}$ CMB Model**
State Bldng						
2008/2009	31.6 ± 8.0	38.0 ± 9.6	28.1±10.0	34.7±5.9	56.0	66.3 ± 10.1
2009/2010	36.7 ± 7.5	44.2 ± 9.1	21.0±5.6	31.0±8.3		69.9 ± 7.8
2010/2011	28.7 ± 4.3	34.5 ± 5.1	26.7±2.9	39.4±4.3		72.0 ± 6.3
3-yr avg	33.6 ± 7.7	40.4 ± 9.3	25.6±4.1	35.2±3.5		68.5 ± 8.6
North Pole						
2008/2009	42.9 ± 9.8	51.7 ± 11.8	36.8±10.0	54.3±14.7	73.4	72.1 ± 4.7
2009/2010	56.7± 6.3	68.3 ± 7.6	43.3±4.6	63.8±6.8		83.3 ± 10.3
2010/2011	58.4 ± 6.9	70.4 ± 8.3	43.7±4.8	64.3±7.0		73.8 ± 17.0
3-yr avg	55.0 ± 8.3	66.2 ± 10.0	42.0±3.4	61.8±5.1		79.4 ± 11.8
Peger Road						
2008/2009	23.6	28.4	14.3±3.7	21.1±5.4	51.0	62.9
2009/2010	33.9 ± 4.8	40.9 ± 5.8	21.5±2.9	31.7±4.3		69.9 ± 13.1
2010/2011	28.7 ± 6.6	34.6 ± 8.0	22.5±3.4	33.1±5.0		68.5 ± 11.3
3-yr avg	31.8 ± 5.6	38.3 ± 6.7	20.0±2.0	29.5±3.0		69.0 ± 12.1

The relatively low per sample cost of levoglucosan analysis allows multiple analyses to be run a single site in a single season and over several seasons. This, in turn, provides a means to monitor wood smoke contributions as a function of time as well as during and after efforts to reduce wood smoke emissions. A major caveat with this approach, however, is that source profiles would also need to be monitored if significant changes in fuels or devices are implemented. As an example of the approach, the wood smoke contribution to $PM_{2.5}$ at two sampling sites in Fairbanks as a function of time are presented in Figure 1. These plots show clearly that there is significant variability in the results, which is a combination of actual variability and random error in the measurements (if relative error in PM and levoglucosan measurements are each ±10%, the calculated levoglucosan share can be expected to be ±14%). The plots show no observable trend within any heating season. The data show a weak but

statistically insignificant trend of increasing contribution from wood smoke over time. Neither these plots nor the average seasonal data in Table 3 provide significant evidence of any trend of increased or diminished wood smoke contribution over this time period.

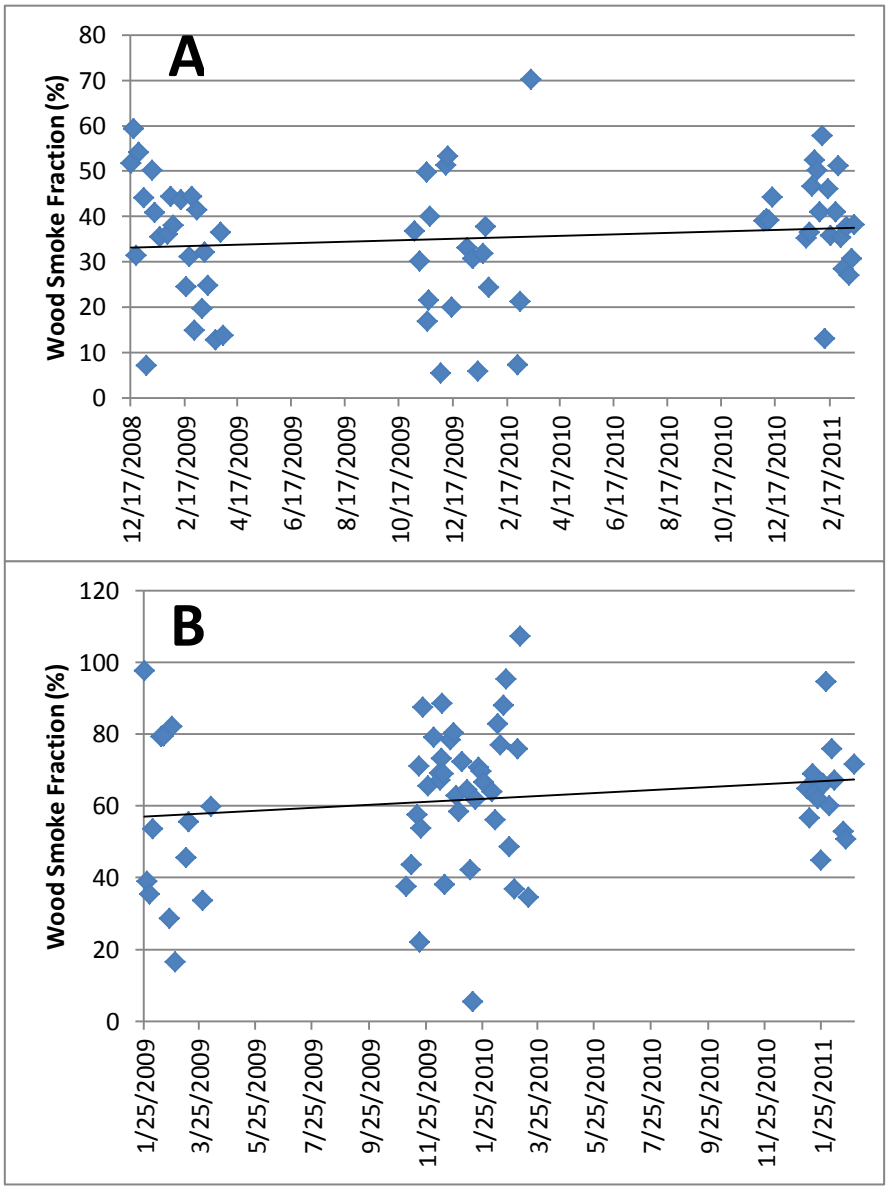

Figure 1: Wood smoke contribution to ambient $PM_{2.5}$ in Fairbanks North Star Borough, based on levoglucosan measurements and the OMNI conversion factor, at A. State Building and B. North Pole sites as a function of time.

2.4 Conclusions

Measurement of levoglucosan shares in ambient $PM_{2.5}$ in Fairbanks as well as in wood smoke particulate using representative devices and fuels allows an estimate of the residential wood smoke contribution to ambient $PM_{2.5}$. The final estimates include significant uncertainty due to both random measurement errors and lack of knowledge concerning the chemical composition of wood smoke. The effect of random measurement errors is reduced somewhat by the large number of measurements that can be made to generate averages. The effect of errors in estimation of the conversion factor is not diminished by making multiple measurements. Two conversion factors were generated that can be

reasonably expected to yield minimum and maximum wood smoke contributions, but as an indication of the uncertainty these two values differ by nearly 45%.

The resulting values for wood smoke contribution are similar to those determined from ^{14}C analysis. This lends some level of credence to both of these methods. Both of the approaches, however, yield results that are significantly lower than those obtained from CMB analysis.

Levoglucosan analysis is relatively inexpensive in comparison to either ^{14}C analysis or CMB analysis. This allows the wood smoke fraction of $PM_{2.5}$ to be determined and monitored many times over the course of a heating season or intervention program. Inspection of the data for the past three years in the Fairbanks area indicates that wood smoke contribution has not diminished but may have increased.

3. Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAH) are found in the $PM_{2.5}$ from most combustion processes. Although the PAH are generally associated with combustion, certain PAH are reported to be strongly associated with combustion of specific fuels. Examples include retene, picene, and thiophenes, which are often associated with wood, coal and diesel fuel combustion, respectively.

Ambient and OMNI Scientific-generated $PM_{2.5}$ samples on quartz filters were submitted to the Desert Research Institute for analysis of PAH, including two thiophenes (dibenzothiophene and benzonaphthothiophene), on two dates. In the first round of analyses, eight ambient samples were analyzed for 62 PAH. In the second set, 25 ambient samples and 11 OMNI-generated samples were analyzed for 96 PAH. All of the ambient $PM_{2.5}$ samples are from the State Building site. The first eight samples were selected to be relatively high $PM_{2.5}$ days to ensure detection of the PAH, but the subsequent 25 ambient samples were selected considering meteorological conditions and represent a range of low to high $PM_{2.5}$ days. Most of the ambient samples are from the 2009-10 season. All of the raw and calculated results discussed in this report are provided in a spreadsheet.

The results for OMNI Scientific samples have been used to identify those PAH that appear at relatively high levels and shares of $PM_{2.5}$ in samples for specific fuels and devices. Those fuel-specific share data have then been used to set upper bounds on the contribution to ambient $PM_{2.5}$ from the combustion of those fuels.

3.1 OMNI Fuel and Device-Specific Samples

OMNI Scientific supplied UM with eleven quartz filter samples generated using various burners and fossil fuels. The identity of the filters, fuel and burner type are provided in Table 4. The $PM_{2.5}$ catch for each filter was calculated as described for OMNI-generated wood smoke filters as described in section 2.1. Unfortunately, no data were available to allow calculation of the $PM_{2.5}$ catch for two of the filters. Full PAH results for these filters, with analytical uncertainties, are provided in a spreadsheet.

Unfortunately, no replicate filters were provided for any fuel type or device, so it is not possible to estimate the repeatability of these experiments.

Table 4: OMNI Scientific-generated filters analyzed for PAHs.

Filter ID	Fuel	Device	$PM_{2.5}$ Catch (µg)
FNB56	No. 1 Fuel Oil	CHIF	NA
FNB59	No. 2 Fuel Oil	CHIF	474
FNB62	Waste Oil	Waste Oil Burner	9559
FNB66	Coal	Stove	NA
FNB69	Dry Coal	Stove	16340
FNB72	Dry Coal	Stove	2950
FNB79	Coal	Stove	7536
FNB89	Coal	OWHH	93786
FNB91	Coal	OWHH	59879
FNB95	Coal	HH Cold Start	3431
FNB96	Coal	HH Hot Start	3965

3.2 Fuel and Waste Oil

Insufficient data were provided by OMNI Scientific to calculate $PM_{2.5}$ catch for the filter generated with no. 1 fuel oil. The filter provided for no. 2 fuel oil has a relatively low catch of $PM_{2.5}$, and analysis was able to detect significant quantities and shares of only bibenzyl and 9-flourenone. Bibenzyl appears at a relatively high share of no. 2 fuel oil $PM_{2.5}$, at 0.2%. Although a higher quantity of $PM_{2.5}$ was caught for waste oil, analysis of this filter detected only 9-fluorenone and at a much lower share (0.0001%) compared with no. 2 fuel oil. The results for waste oil and no. 1 fuel oil do not identify any potential $PM_{2.5}$ markers for these fuels. It is possible, however, to consider 9-fluorenone and bibenzyl as markers of no. 2 fuel oil combustion.

9-Fluorenone made up a significant but small share (0.013%) of no. 2 fuel oil $PM_{2.5}$, but was also detected in the OMNI generated coal $PM_{2.5}$ samples at 0.0002% to 0.004% share. 9-Fluorenone was detected in ambient samples at similar to higher shares than in the no. 2 fuel oil $PM_{2.5}$ sample, implying that there is another significant source of this compound in ambient $PM_{2.5}$. This compound was thus not considered to be a unique or useful marker for no. 2 fuel oil $PM_{2.5}$.

Bibenzyl, however, was not detected in any other OMNI-generated fossil fuel $PM_{2.5}$ samples but was detected as a significant share (0.2%) in no. 2 fuel oil $PM_{2.5}$. Bibenzyl was not determined in the first set of eight ambient filter samples but was detected in 24 of the 25 samples submitted in the second set. Bibenzyl is found at much lower shares in ambient $PM_{2.5}$ than in $PM_{2.5}$ for no. 2 fuel oil. Bibenzyl was thus considered a potentially unique and useful marker for no. 2 fuel oil combustion.

An upper boundary for the contribution of no. 2 fuel oil $PM_{2.5}$ to the ambient $PM_{2.5}$ samples was calculated using the bibenzyl results for ambient shares and the experimental bibenzyl share in no. 2 fuel oil $PM_{2.5}$. **This analysis provided a median of 0.6% and a mean of 0.6 ± 0.4% (±1σ) contribution, suggesting that no. 2 fuel oil combustion is responsible for only a minor fraction of ambient $PM_{2.5}$.**

This is considered an upper boundary since the analysis does not take into consideration any other potential sources of bibenzyl. Further, there is significant but unquantifiable uncertainty in this result, since it is based on a single collection and analysis of $PM_{2.5}$ from no. 2 fuel oil.

3.3 Coal

OMNI Scientific provided $PM_{2.5}$ samples for coal combustion in various residential devices. These results provide some useful results for these devices. However, there are still no measured values for any PAH in coal emissions from power plants or other commercial facilities.

Inspection and analysis of the results for the OMNI coal $PM_{2.5}$ samples suggests eight possible PAH markers for coal combustion. These compounds were selected because they were detected in more than half of the OMNI coal $PM_{2.5}$ samples and because they showed at least a 200 ppm share for one or more coal $PM_{2.5}$samples. Table 5 lists the selected PAH with their median and average ± 1σ shares of $PM_{2.5}$ over the seven usable OMNI coal $PM_{2.5}$ samples. The very high standard deviations in these data reflect the large variability between different coal burning devices tested by OMNI scientific. In each case, $PM_{2.5}$ from the HH systems had the lowest shares of PAH compounds. Previous studies have identified picene as a unique marker for coal combustion,[4-6] and this compound is observed at relatively high shares in most of the coal $PM_{2.5}$ samples in this study (although not for the HH systems).

Table 5: PAH compound shares of coal $PM_{2.5}$ in OMNI Scientific-generated samples, and contributions of coal $PM_{2.5}$ to Fairbanks ambient $PM_{2.5}$ calculated using these shares.

Compound	Share of Coal $PM_{2.5}$ (ppm)		Median Coal Fraction of Ambient $PM_{2.5}$ (%)	
	Median	Mean ± 1σ	by Median	by Mean
Picene	1000	1000 ± 1200	2.7	2.7
Retene	56	250 ± 400	72	16
Indeno[1,2,3]pyrene	320	370 ± 350	19	16
Benzo[g,h,i]perylene	440	460 ± 430	26	24
Anthanthrene	210	190 ± 160	12	13
Dibenzo[a,l]pyrene	150	130 ± 120	4.4	4.9
Coronene	160	160 ± 150	21	21
Dibenzo(b,k)fluoranthene	160	160 ± 150	5.7	5.8
Dibenzothiophene	2.2	11 ± 14	234[1]	48[1]
Benzonaphthothiophene	6.4	19 ± 33	20[1]	6.7[1]

[1]Based on second set of 25 ambient $PM_{2.5}$ samples only.

Also included in Table 5 are the median percent contributions of coal $PM_{2.5}$ for the Fairbanks ambient $PM_{2.5}$ samples based on either the median or the mean share of that compound in OMNI-generated coal $PM_{2.5}$ samples. Most of these are determined for the full set of 33 ambient samples, but thiophene results are reported for only the latter 25 samples analyzed (this is discussed in detail below).

The results for coal $PM_{2.5}$ fraction based on the PAHs are highly variable, ranging from a median contribution of 2.7% to 72%. In fact, because these compounds are also produced by other combustion processes, each of the reported values is an upper boundary for coal $PM_{2.5}$ contribution. Retene, for example, is known to be emitted during wood combustion. Thus, the lowest of these calculated

contributions, 2.7%, which is based on picene shares, is most likely to be valid. Picene has been reported as unique to coal combustion emissions[7,8], lending additional confidence to this result.

Defining a coal PM fraction based on any of the markers is complicated, however, by the wide range of $PM_{2.5}$ shares observed for each marker with different coal burning devices. Picene is no exception; picene shares range from below the detection limit (5 ppm share of $PM_{2.5}$) for HH systems to 3300 ppm share of $PM_{2.5}$ for coal stoves. This suggests that the median coal $PM_{2.5}$ contribution to ambient $PM_{2.5}$ could range from 0.8% if the contribution were exclusively from coal stoves to >100% if the $PM_{2.5}$ were exclusively from HH systems. A value of greater than 100% indicates a substantial contribution from a separate source, although other sources of picene have not been reported. It is possible that a single coal stove in the vicinity of the sampling site contributing less than 1% to the sampled $PM_{2.5}$ could account for all of the observed picene.

3.4 Ratiometric Analysis

Another commonly used measure for sourcing PAH emissions is the ratio of indeno[123-cd]pyrene to the sum of indeno[123-cd]pyrene and benzo[ghi]perylene (IP/(IP+BghiP)).[6,9,10] Typical values for this ratio from various fossil fuel sources, woodsmoke, and for Fairbanks are reported in Table 6. No published value is available for residential oil combustion $PM_{2.5}$. The ratio for OMNI-generated coal $PM_{2.5}$ (average ± 1σ) is also included in Table 6. No value could be determined for oil burner samples since these PAH compounds were not detected. The ratio for Fairbanks ambient $PM_{2.5}$ is reasonably consistent between samples, and is most similar to that reported for diesel fuel emissions. The observed ratio is lower than all reported ratios except gasoline autos, which suggests a significant contribution from transportation.

Table 6: Ratio of indeno[123-cd]pyrene to sum of indeno[123-cd]pyrene and benzo[ghi]perylene for various sources.

Source	IP/(IP+BghiP)
Gasoline autos	0.18
Diesel autos	0.37
Coal combustion	0.56
Wood combustion[9]	0.54
OMNI-Coal	0.42 ± 0.05
Fairbanks $PM_{2.5}$	0.33 ± 0.05

3.5 Thiophenes

The thiophenes are unique sulfur-containing compounds related to the PAHs that have been reported in the emissions of fossil fuel combustion. Preliminary studies of Fairbanks ambient $PM_{2.5}$ showed high levels of these compounds. Thus, there was interest in further study of these compounds in ambient $PM_{2.5}$ and in $PM_{2.5}$ from fossil fuel sources.

Dibenzothiophene, benzonapthothiophenes and alkylated derivatives of these compounds are reported to be representative of diesel fuel vehicle emissions.[7,8] These compounds make up a significant fraction of the sulfur content of diesel fuel. Low sulfur diesel fuel has lower concentrations, and vehicles utilizing low sulfur diesel fuel emit reduced quantities of these compounds[7,8]. Rogge *et al.*[11] did not report thiophenes in the emissions from residential fuel oil combustion, but Huffman *et al.* did report that typically 25-35% of the sulfur in residential fuel oil particulate is thiophenic sulfur.[12] Analysis of no. 2 fuel oil from Fairbanks at the University of Montana detected dibenzothiophene at 443 ppm, a

level that is higher than that reported previously for high sulfur diesel fuel. Given the similar composition of # 2 fuel oil and diesel fuel, and the fact that the sulfur content of # 2 fuel oil is not regulated with respect to sulfur content, it was hypothesized by us that these compounds would be found in the $PM_{2.5}$ emissions from #2 fuel oil. Dibenzothiophene has also been reported in the emissions from gasoline vehicles[13]. In this and one report on diesel emissions[8], dibenzothiophene was found primarily in the gas phase. Given the ambient temperatures in Fairbanks, it seems likely that the compound would be found in the particulate phase. These sulfur compounds are not present in wood smoke $PM_{2.5}$.

Preliminary results for eight Fairbanks ambient $PM_{2.5}$ samples showed very high levels and shares of thiophenes when compared with published results for diesel emissions[7] or with ambient concentrations in European urban environments[14]. Results for the second set of 25 Fairbanks ambient $PM_{2.5}$ samples are much lower, however, and there is a large, statistically significant ($p<10^{-9}$), and inexplicable difference in thiophene shares of ambient $PM_{2.5}$ between the first eight and latter 25 samples. The share results for the latter 25 samples are lower than those reported for diesel emissions[7]. However, the ambient concentration results for the latter samples remain a factor of two to three higher than those reported for European cities[14]. This may be explained by different $PM_{2.5}$ concentrations and local environments. There is concern, therefore, that the thiophene results for the initial eight samples are invalid.

It is important to note that thiophenes were not detected in the OMNI-generated $PM_{2.5}$ from fuel oil samples. Our hypothesis that dibenzothiophene and benzonaphthothiopene might serve as markers for $PM_{2.5}$ from no. 2 fuel oil combustion is not supported by the results, and is invalidated.

Results for two thiophenes in OMNI-generated coal $PM_{2.5}$ are included in Table 5 and are used in subsequent calculations of coal contributions to ambient $PM_{2.5}$. Coal contributions based on thiophenes range from 6.7% to more than 100%. A value of greater than 100% indicates a substantial contribution from a separate source of dibenzothiophene, such as diesel or gasoline vehicle emissions.

It remains unclear what the sources of the thiophenes observed in Fairbanks ambient $PM_{2.5}$ are. None of the OMNI samples for residential oil heating devices had detectable levels of either thiophene, so this cannot be considered a significant source. Some fraction of the thiophene shares of Fairbanks ambient $PM_{2.5}$ may be explained by coal emissions, but these cannot explain all of the observed thiophenes. Previous studies have attributed thiophenes to diesel emissions, but this should be minimized with low sulfur diesel fuel. Previous studies have also reported relatively high concentrations of these thiophenes in the vapor phase emissions from gasoline automobiles[13]. It is possible in the winter climate in Fairbanks that these normally vapor phase emissions are associated with the $PM_{2.5}$, explaining a substantial fraction of the observed levels.

3.6 Conclusions

Polynuclear aromatic hydrocarbon and thiophene analysis of $PM_{2.5}$ generated using representative fuels and devices as well as ambient $PM_{2.5}$ does provide useful information regarding

potential contributions of fuel oil, coal and potentially other fossil fuels to Fairbanks $PM_{2.5}$. The results indicate no substantial contributions of fuel oil or coal combustion to ambient $PM_{2.5}$.

No. 2 fuel oil emissions and waste oil filters had low amounts of $PM_{2.5}$ and the levels of nearly all compounds were below the detection limits. Bibenzyl was identified as a potential marker based on its relatively high fraction in no. 2 fuel oil $PM_{2.5}$ and its absence in coal $PM_{2.5}$. Using this as a marker leads to the conclusion that combustion of no. 2 fuel oil contributes a negligible fraction to ambient $PM_{2.5}$ of less than 1% for the 33 samples analyzed.

Picene is accepted as a unique marker for coal combustion. Zhang *et al.* reported picene as being "unique to the organic carbon emissions from coal combustion," although picene was not detected in all coal particulate and was notably absent from bituminous coal emissions from industrial boilers.[6] Zhang *et al.* did report picene in brown and mixed coal emissions from industrial boilers (3.7 and 2.0 ppm shares respectively) as well as much higher levels in the emissions from residential coal burners (72-284 ppm shares).[6] Oros *et al*. reported picene and methyl picenes as bituminous coal smoke markers, and C_2 substituted picenes as more general coal-specific markers.[4] As a large PAH, picene can be expected to be found primarily in the particulate phase.

The current results for picene support its use as a specific marker for coal combustion. Picene appears as a relatively large share of coal $PM_{2.5}$ for certain devices. Other compounds found in the coal $PM_{2.5}$ were detected at lower $PM_{2.5}$ share and suggested higher contributions of coal combustion to ambient $PM_{2.5}$. These compounds are very likely found in the emissions of other combustion sources.

Using a median value of picene share in the various devices leads to 2.7% coal contribution to $PM_{2.5}$. The picene shares, however, are highly variable depending on the device. If coal combustion were primarily from devices that have a much lower $PM_{2.5}$ share of picene, then coal $PM_{2.5}$ would represent a much higher fraction of ambient $PM_{2.5}$. Alternatively, the observed picene share of ambient $PM_{2.5}$ could result from less than a 1% contribution from devices that generate high picene shares.

The OMNI Scientific $PM_{2.5}$ samples do not show detectable levels of thiophenes for fuel oil samples, and show only low shares for coal samples. Thiophenes are observed in ambient $PM_{2.5}$ at levels that cannot be explained using coal combustion sources alone. It remains unclear what the sources or these thiophenes are. A fraction of the observed thiophenes might be associated with coal emissions, but it seems likely that the majority is from transportation sources.

4. Hopanes and Steranes

The hopanes and steranes are typically found and reported in distillate fossil fuel emissions, but have also been reported in coal emissions. The highest levels reported are for diesel auto emissions, and the lowest are for coal emissions. The hopanes and steranes are not present in emissions from biomass combustion, and thus provide a general indication of the extent to which an air shed is affected by fossil fuel emissions. Unfortunately, however, none of the compounds have been reported to be a specific marker of any particular fossil fuel source.

Analytical results for 23 hopane and sterane compounds have been obtained for eight Fairbanks ambient $PM_{2.5}$ samples, and generally show high levels and shares (5-60 ppm) of certain compounds. These results, with analytical uncertainties, are presented in a separate spreadsheet. Levels of hopanes and steranes in Fairbanks are typically higher than those reported for ambient air in other airsheds[5,15], and Fairbanks hopane and sterane shares are greater than those reported for most specific fuel emissions[4,6,8,11,13]. Analytical results for the same hopanes and steranes were also obtained for fossil fuel $PM_{2.5}$ samples provided by OMNI Scientific. These results are also presented in a separate spreadsheet.

4.1 Coal

Of the compounds analyzed, several hopanes were selected as potentially useful markers of coal combustion. Compounds were considered potential markers if they were detected in all of the coal $PM_{2.5}$ samples, if shares of three or more of the seven samples exceeded 100 ppm, and if the compounds did not have comparable shares in fuel oil $PM_{2.5}$. These selected hopanes, and their median and mean shares of coal $PM_{2.5}$, are presented in Table 7. Shares of coal $PM_{2.5}$ are highly variable between devices, with the HH systems showing low shares and the coal stoves generally showing high shares. In comparison, previous studies have reported hopane shares of diesel $PM_{2.5}$ of 5-60 ppm[7,8] .

Table 7: Hopane compound shares of coal $PM_{2.5}$ in OMNI Scientific-generated samples, and contributions of coal $PM_{2.5}$ to Fairbanks ambient $PM_{2.5}$ calculated using these shares.

Compound	**Share of Coal $PM_{2.5}$ (ppm)**		**Median Coal Fraction of Ambient $PM_{2.5}$ (%)**	
	Median	**Mean ± 1σ**	**by Median**	**by Mean**
17α(H),21ß(H)-29-Norhopane	83	122 ± 133	50	34
17α(H),21ß(H)-Hopane	111	126 ± 121	23	21
22S-17α(H),21ß(H)-30-Homohopane	45	132 ± 135	39	13
22R-17α(H),21ß(H)-30-Homohopane	90	137 ± 156	26	17
22S-17α(H),21ß(H)-30,31-Bishomohopane	41	65 ± 62	21	13

The share data presented in Table 7 can be used to estimate coal contributions to the ambient $PM_{2.5}$ samples. These results are also presented in Table 7, and show median coal contributions to ambient $PM_{2.5}$ of 13 to 50%. Because the hopanes are not specific to coal emissions, these should be considered upper bounds to coal contribution. Further, the hopane shares are highly variable with coal burning device. Thus, ambient levels of $PM_{2.5}$ could suggest an upper bound of as little as 6% contribution of $PM_{2.5}$ from coal stoves that produce high hopane shares. Coal emissions from HH systems, on the other hand, cannot explain the shares observed in Fairbanks ambient $PM_{2.5}$.

4.2 Fuel Oil

The results for hopane and sterane shares of no. 2 fuel oil and waste oil $PM_{2.5}$ were also examined for potentially useful selective markers. Hopane and sterane shares of waste oil $PM_{2.5}$ were all less than 1.3 ppm and were equivalent or higher in coal $PM_{2.5}$, and thus could not be used to estimate waste oil contributions to ambient $PM_{2.5}$. One sterane, 20S-5α(H),14ß(H),17ß(H)-cholestane, did appear at a relatively high share of no. 2 fuel oil $PM_{2.5}$ (13 ppm) and at lower shares of coal $PM_{2.5}$ (0-6 ppm). Using this compound as a marker for no. 2 fuel oil generates an extreme upper bound of 15% for the contribution of no. 2 fuel oil combustion to ambient $PM_{2.5}$. This is very clearly an overestimate to fuel oil contribution, since substantial quantities of this sterane would also be produced by combustion of other fossil fuels, including coal. Further, there is significant but unquantifiable uncertainty in this result, since it is based on a single collection and analysis of $PM_{2.5}$ from no. 2 fuel oil.

4.3 Ratiometric Analysis

An alternative approach for the analysis of hopane results is to calculate the ratio of 17α (H) 21β (H) hopane to 22R-17α (H), 21β (H) homohopane.[4,6,16] This value has been reported to be 3.7 for gasoline emissions and 2.5 for diesel emissions.[16] Unfortunately, conflicting results have been reported for coal combustion emissions, with Oros *et al.*[4] reporting values of 0.1-2.6 and Zhang *et al.*[6] reporting values of 4.28-9.19. In the current study, the ratio for OMNI-generated coal emissions over all devices ranged from 0.76 to 1.63 with a median of 1.15 and an average ± 1σ of 1.13 ± 0.33. The ratios for no. 2 fuel oil and waste oil emissions were found to be 0.57 and 1.01 respectively, but the ratio for no. 1 fuel oil emissions could not be determined because 22R-17α (H), 21β (H) homohopane was not detected. The average value observed for Fairbanks is 1.2 ± 0.4. This relatively low result for Fairbanks is not significantly different from that observed for the OMNI-generated coal filters and is within the range reported by Oros *et al.* for coal. This analysis implies that coal or other low ratio emissions such as fuel oil may be a more substantial contribution to the hopanes in Fairbanks ambient $PM_{2.5}$ than the analyses above suggest.

4.2 Conclusions

Hopane and sterane analysis of Fairbanks ambient $PM_{2.5}$ shows levels and shares that are indicative of substantial contribution from fossil fuel combustion sources. Unfortunately, however, none of these compounds can be considered specific markers of any individual combustion source. This means that any simple calculations of contributions from a given source will overestimate the value and must be considered upper bounds. Upper boundaries for the contributions of coal and no. 2 fuel oil combustion to ambient $PM_{2.5}$ by this approach are estimated to be 13% and 15% respectively.

Analysis based on the ratio of levels for two specific hopanes indicate that a substantial share of hopanes in ambient Fairbanks $PM_{2.5}$ are from a low ratio source such as fuel oil or coal. This is inconsistent with the results based on hopane and sterane shares of $PM_{2.5}$.

A more comprehensive approach of source apportionment using full profiles of all sources and ambient $PM_{2.5}$ is much more appropriate for this analysis. This is not recommended with the limited data available for Fairbanks sources and ambient $PM_{2.5}$.

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Exploratory Research of Wintertime Aerosol Chemical Composition at a Ground Location in Fairbanks, Alaska

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EXECUTIVE SUMMARY

This report summarizes quantitative chemical composition data of ambient particulate matter of less than 2.5 μm (PM2.5) aerosol collected during a month-long study in Fairbanks, Alaska in February and March, 2011. The data collected include hourly measures of ions commonly found in aerosol, as well as hourly measurements of organic and elemental carbon. Daily filter samples were also collected for alternative chemical analyses. Data were collected in a small, insulated trailer that was located near the Fairbanks Borough North Star Administrative Office near 809 Pioneer Road.

Approximately 283 sets of ion samples were collected during this study, and just over 500 measurements of organic and elemental carbon were collected. 37 pairs of filters were collected as well, with one set consumed by analytical techniques and a second set collected for long-term storage and post-hoc analyses. Aerosol chemical composition appears to be dominated by organic carbon (mean = 6.5 $\mu gC\ m^{-3}$) and estimated organic matter, as well as elemental carbon (mean = 0.9 $\mu gC\ m^{-3}$and sulfate (mean = 2.02 $\mu g\ m^{-3}$). Lesser measurements included ammonium, nitrate, potassium, and several light organic acids.

The data show a clear diurnal profile that is likely attributed to anthropogenic activities. Wood burning appears the be a significant contributor to the high particle loading observed during the winter in Fairbanks as indicated by the enhanced levels of organic carbon and in the relative absence of other compounds that would indicate other emission sources of PM2.5. Ion information provides some confirmation of this, and a preliminary look at high time resolution XRF data provides additional confirmatory evidence in support of this hypothesis.

A particular focus of this work involved improving the understanding of sulfur in the Fairbanks airshed. Particulate sulfur (as sulfate) was detected throughout the study indicating that mechanisms that promote sulfur conversion (from gas phase to particle phase) are, in fact, present. We also examined chemical composition by complementary analytical methods – first by X-Ray Fluorescence (XRF) followed by ion chromatography for two measures of sulfur from the same filter. Results show that sulfur is measured at the same levels no matter the analytical method, which is in contrast to results reported by the United States Environmental Protection Agency (EPA) for chemical speciation measurements in Fairbanks. It is likely that a methodological difference explains the disagreement between the two methods of sulfur measurement used by the EPA speciation network.

INTRODUCTION AND RATIONALE FOR RESEARCH

Ambient fine particles are ubiquitous in the lower troposphere, and result from a variety of physical and chemical transformations. They can be formed as a primary pollutant through, among others, combustion and biogenic sources, as well as by resuspension of dust from crustal surfaces [1-3]. Secondary aerosol sources – that is, aerosol formed by a variety of secondary gas-phase chemical reactions in the atmosphere - are substantially more complex and can represent a significant fraction of ambient aerosol [2, 4]. The diversity of possible atmospheric reactions makes unequivocal identification of aerosol sources quite complex, and thus, our understanding of aerosol formation is also incomplete.

The Fairbanks region is an excellent example of unique and diverse chemical conditions that result in ambient particulates. The region is known to routinely exceed the National Ambient Air Quality Standards during the winter heating season. This is thought to arise both from significant local emissions, but also by meteorological enhancement due to strong inversions and poor regional ventilation. Aerosol source hypotheses include emissions from wood and fuel oil burning, and the formation of sulfur-containing particles from local coal-fired power generation. Because of its relatively remote location, regional transport of particle pollution is generally insignificant suggesting that most of the ambient pollution was generated within the local area. Thus, because of this unique complexity and the absolute need to maintain safe temperatures through residential heating during the winter, Fairbanks represents an excellent case for further study of ambient aerosol composition and formation.

Because of a history of demonstrated non-attainment for PM2.5 in the Fairbanks area, there exists a need for substantially increased expansion of fundamental understanding of aerosol chemical climatology for the community. This information will be useful in identifying suggested pathways to reduce air pollution levels in the most efficient and cost-effective manner, as well as reduce aerosol components of known health hazards for the citizens of the borough. Without this information, mitigation attempts are likely to be ineffective.

INSTRUMENTATION

A state-of-the-art instrumentation package was installed in a small, insulated utility trailer, which was situated near the NCORE site in Fairbanks, Alaska. Instrument integration was completed on February 6, 2011, and field data collection began on February 9th, 2011 at approximately 13:00 AST. The instrumentation package, described below, operated with periodic user intervention and maintenance, as described below. FNSB staff were immensely helpful in performing these duties for the duration of the study. The study continued until March 16th, 2011 at 07:05 AST when instruments were powered down and removed from the trailer.

PILS-IC

The Particle-Into-Liquid Sampler (PILS) is a device that captures all particles greater than ~10-15 nm by employing condensational growth of the particle in a supersaturated environment of water vapor. Prior to entering the PILS, a particle passes through a set of denuders which strip out gas phase organics, and any acidic or basic gases present in the aerosol stream. The particles and water vapor are adiabatically cooled, which promotes rapid particle growth to a size of 1-3 μm; these are then accelerated and collected on an impaction wall. This wall is continuously washed with a small amount of purified water, and the effluent is then diverted by syringe pump to any number of

analytical processes. Typical detection limits are described in Table 1, and a schematic representation of the PILS system is show in Figure 1. Rather than *in-situ* analytical chemistry, aqueous samples were collected in a semi continuous manner in 1.8ml plastic aliquots which were

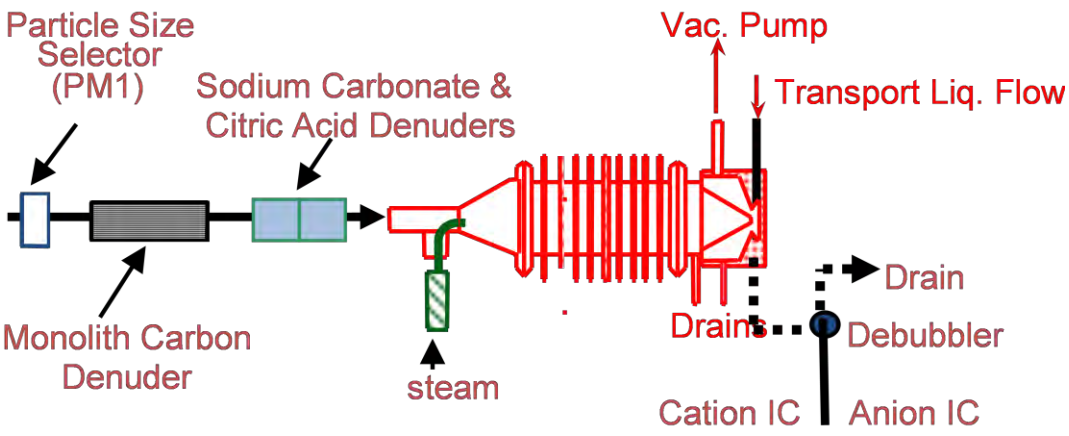

Figure 1: Schematic of Particle-Into-Liquid sampler. Aerosol enters from the leftm, is denuded and mixed with steam, abiabatically cooled, and collected on an impactor. Sample is then deposited into vials (not shown).

mounted on a computer-controlled rotating carousel. Filled aliquots were periodically collected and frozen by local assisting staff.

Maintenance activities performed by local staff included emptying of wastewater tanks (containing a non-hazardous dilute solution), replacement of purified water, retrieval and storage of samples and replacement of new plastic vials, and inspection and removal of any ice buildup at the pump exhaust. The instruments were checked daily for normal operation. Collected samples were organized according to unique barcodes, and shipped to the investigator's lab in Massachusetts for chemical analysis.

Table 1: This is a summary of analyses of aerosol chemical composition useful for this study. Data include typical concentrations in Fairbanks, estimated liquid concentration in the PILS effluent, and typical detection limits by a variety of analytical techniques.

Compound	Typical Winter Air Concentration at Fairbanks (Jan-Feb, 2006-2009), μg m^{-3}	Estimated Liquid Concentration (μg L^{-1})	Typical Detection Limit (μg L^{-1})
Sulfate	4.498	3748.33	0.01[a]
Elemental sulfur	1.63	1358.33	0.1[b]
Ammonium	2.021	1684.17	0.1[a]
Sodium	0.093	77.50	0.1[a]
Nitrate	1.121	934.17	0.5[a]
Potassium	0.150	125.00	0.2[a]
As	0.0015	1.25	0.1[c]
Se	0.0010	0.83	1.0[c]
Oxalate	n/a	n/a	0.2[a]
Zn	0.0520	43.33	0.2[c]

[a] by ion chromatography
[b] by ICP-MS
[c] by Flame ionization/ Atomic Absorption

Once defrosted, collected aliquots were removed from field vials and diluted to 4ml with precision pipettes and placed into 5ml autosampler vials (Environmental Express, Model K4300). Dilution matrix was 18.2M-Ohm or better purified water. The samples were then analyzed by ion chromatographic separation for 18 ion species (as a total of 13 anion and 5 cation peak) using a Dionex ICS-3000 Ion Chromatography System. In order of elution, the anion peaks are fluoride, acetate, formate, methanesulfonate, chlorite, chloride, nitrite, sulfate, bromide, oxalate, nitrate, chlorate, and phosphate. The 5 cation peaks are sodium, ammonium, potassium, magnesium, and calcium.

SUNSET LABS EC AND OC

Because of the multicomponent complexity of aerosol in Fairbanks, we also operated a Sunset Labs Model 4 semi continuous Organic Carbon and Elemental Carbon (OC/EC) analyzer. This instrument simultaneously and directly measures fine particle organic and elemental carbon at hourly integrated measurements and is a standalone instrument that requires almost no user support.

The instrument includes a sharp-cut cyclone to remove particles greater than 2.5 μm. The inlet also includes a parallel plate denuder consisting of laminar paper sheets impregnated with activated carbon which effectively removes organic vapors. The sample cycle typically includes 45 minutes of sample collection that begins on the hour, and a 12-13 minute analysis cycle. The instrument goes through a cooling cycle and then repeats an analysis at the next hour. With typical operating parameters, the detection limits of this analyzer are approximately 0.3 $\mu g\ m^{-3}$ for both organic carbon and elemental carbon. It requires several certified compressed gases for analysis, and this method is consistent with the NIOSH [5-7] method of OC and EC determination.

FILTER SAMPLES

37 filters samples (collected in duplicate, a total of 74 filters) were also collected for the duration of this study. The samples were collected over a nominal 24 hours (with filter changes initiated at approximately 13:00 AST), and were collected at ambient temperature and pressure and corrected to standard temperature and pressure. Samples were collected in conductive plastic filter holders than contained 37 mm ringed Teflon filters (Pall Corporation, model R2PJ037) that were sequentially labeled. Sample passed through a sharp-cut cyclone with a cut size of 2.5 μm, and through two stainless steel annular denuders in series, one of which was coated with a sodium carbonate/bicarbonate solution, and second coated with a citric acid solution. Sample flow was achieved by a 1/4hp vane pump that applied a strong vacuum to a critical orifice calibrated for choked flow at 15.0 $l\ min^{-1}$. After sampling, filters were returned to their original petri dish containers and sent to the investigator's lab in Massachusetts.

Filters were analyzed by high resolution X-ray Fluorescence Spectroscopy using analytical methods consistent with EPA speciation approaches. The method used in this analysis conforms to EPA Compendium Method IO-3.3: For the Determination of Metals in Ambient Particulate Matter Using X-Ray Fluorescence (XRF) Spectroscopy.

Filters were then returned to the lab and sent for further analysis by ion chromatography. This is a destructive technique that renders the remaining filters unusable for any further testing. Chromatographic separation methods were consistent with those described above, but filters were first digested in a vial of purified water under sonication, and then cooled for an hour to room temperature prior to analysis.

RESULTS AND DISCUSSION

AEROSOL IONS

Approximately 280 unique, hourly samples were collected over the course of this study. A number of samples were invalidated due to issues of contamination and instrument failure.

Table 2: Univariate statistics for the range of ions measured during this study. Reported values include mean, median, standard deviation, range, and the number of measurements collected during this study. Llod denotes measurements below the limit of detection.

	Mean, μg m^{-3}	Median, μg m^{-3}	Std Dev, μg m^{-3}	Range, μg m^{-3}	n
Ammonium	0.39	0.24	0.46	(llod, 3.22)	278
Potassium	0.75	0.63	0.42	(0.24, 3.5)	278
Magnesium	0.17	0.07	0.39	(0.03, 2.65)	278
Calcium	0.93	0.56	1.16	(0.17, 7.37)	273
Acetate	1.06	0.51	1.23	(llod, 8.8)	285
Formate	0.21	0.09	0.25	(0.02, 1.55)	285
Chloride	0.83	0.28	2.12	(0.08, 25.1)	285
Nitrite	0.08	0.03	0.12	(llod, 0.62)	285
Sulfate	2.02	1.55	1.56	(0.12, 12.25)	285
Oxalate	0.03	0.01	0.08	(llod, 0.56)	285
Nitrate	0.59	0.41	0.51	(llod, 2.9)	285

Table 2 shows univariate statistics describing the data collected at this location. Dominant ions throughout this study included ammonium, calcium, and potassium, as well as sulfate, nitrate and some chloride. All ions were detected at times over the course of this study. A number of light organic acids were detected, including acetate and formate; these are discussed further in the next section.

Aerosol chemical composition during this study could be characterized by high variability, as seen in relatively high reported standard deviations (Table 2) and graphically as in Figure 2. Figure 2 plots sulfate, one of the more dominant ions measured during this campaign, plotted on hourly intervals. Superimposed on this graph are measured sulfate concentrations determined from collocated 24-hour filter samples which were also analyzed by ion chromatography. Of particular note, sulfate appears with a quasi-diurnal cycle (more discussion of this follows) with minima typically in the 1-2 μg m^{-3} range, and short term maxima in the 4-5 μg m^{-3} range; there are notable deviations from this with clear spikes in sulfate approaching 10-12 μg m^{-3}. 24 hour filter measures show some variability in concentration data, but they lack substantial texture clearly seen with the higher time resolution data.

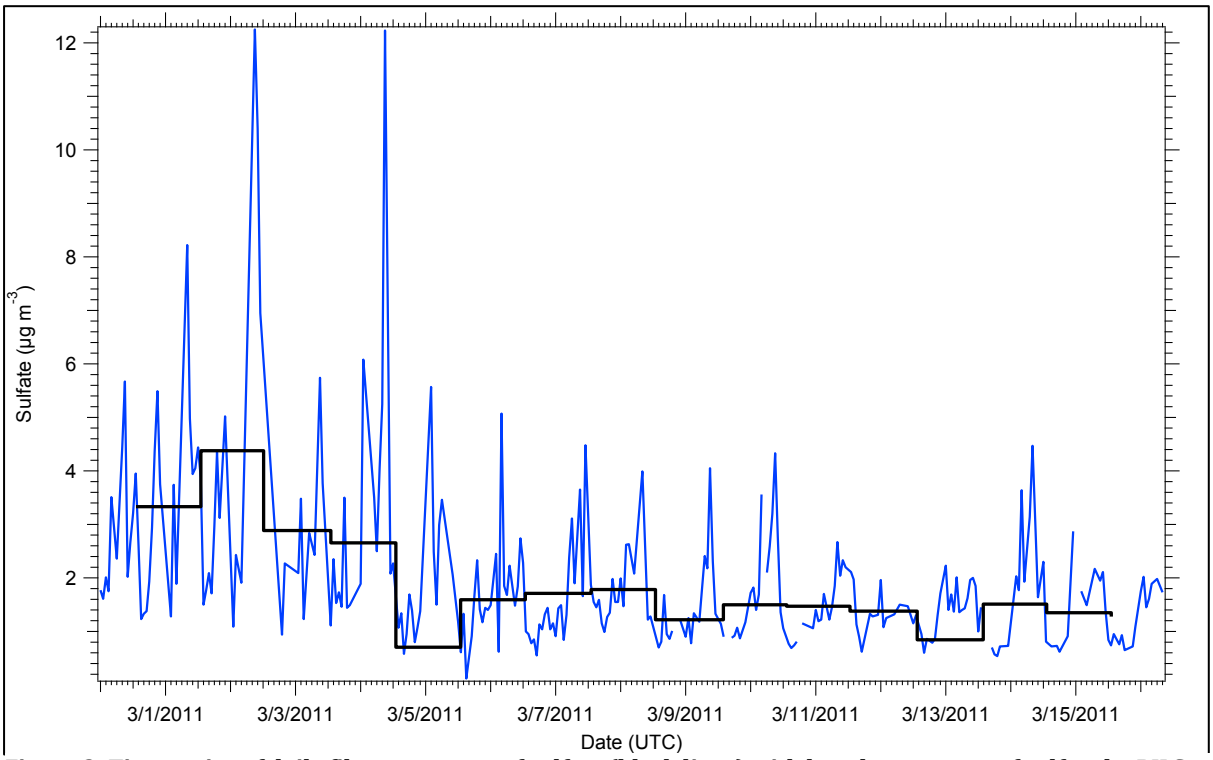

Figure 2: Time series of daily filter measures of sulfate (black lines) with hourly measures of sulfate by PILS (blue) superimposed on the figure.

Figure 3 depicts available ion data coupled with measured organic carbon, plotted against apparent charge, in microequivalents. Charge is calculated by taking the net valence charge for each measured ion, adjusted for molar concentration, and summing the positive and negative charges. This approach also includes (when available) the net charge resulting from a variety of measured light organic acids (including oxalate, formate, and acetate). If all elements are measured, one would expect a balanced charge of zero. Deviations towards a net negative charge indicate a missing cation; deviations towards a net positive charge indicate a missing anion. In typical studies, this missing cation (e.g. conditions with net negative charge) is presumed to be a hydrogen proton which can accompany acidic aerosol.

In the case of Figure 3, both positive and negative conditions appear in the data. While acidic conditions are often observed in air sheds that have significant influence from coal combustion (which normally leads to sulfuric acid formation in the aerosol), it is notable that these deviations occurred throughout a range of concentrations of OC – both high and low – and suggest that acidic influence is independent of OC concentration. Charge balance contributed by the measured light organic acids also appears to be relatively low during these periods suggesting that the aerosol climatology lacks a substantial light organic acid profile and further suggestion this acidity is linked more closely inorganic acids, such as sulfuric or nitric acid, rather than light organic acids. This does provide some weak evidence that inorganic acids are playing a role in determining aerosol charge in Fairbanks, but these results are not yet determinative; there are a number of possible explanations for this, though it does appears likely that the modest acidity results from a source unrelated to the source of organic carbon. It should also be noted that apparent acidity determined here is quite modest in the context of other studies which examined particle acidity arising from coal combustion. For example, in communities on the East Coast of the US, net charges are typically -0.25 µEq and lower [8, 9], which is twice as acidic as conditions observed here.

In contrast, a surprising result was that there were a number of cases where there were significant positive charges observed in the data, suggesting missing cations. This tended to occur during

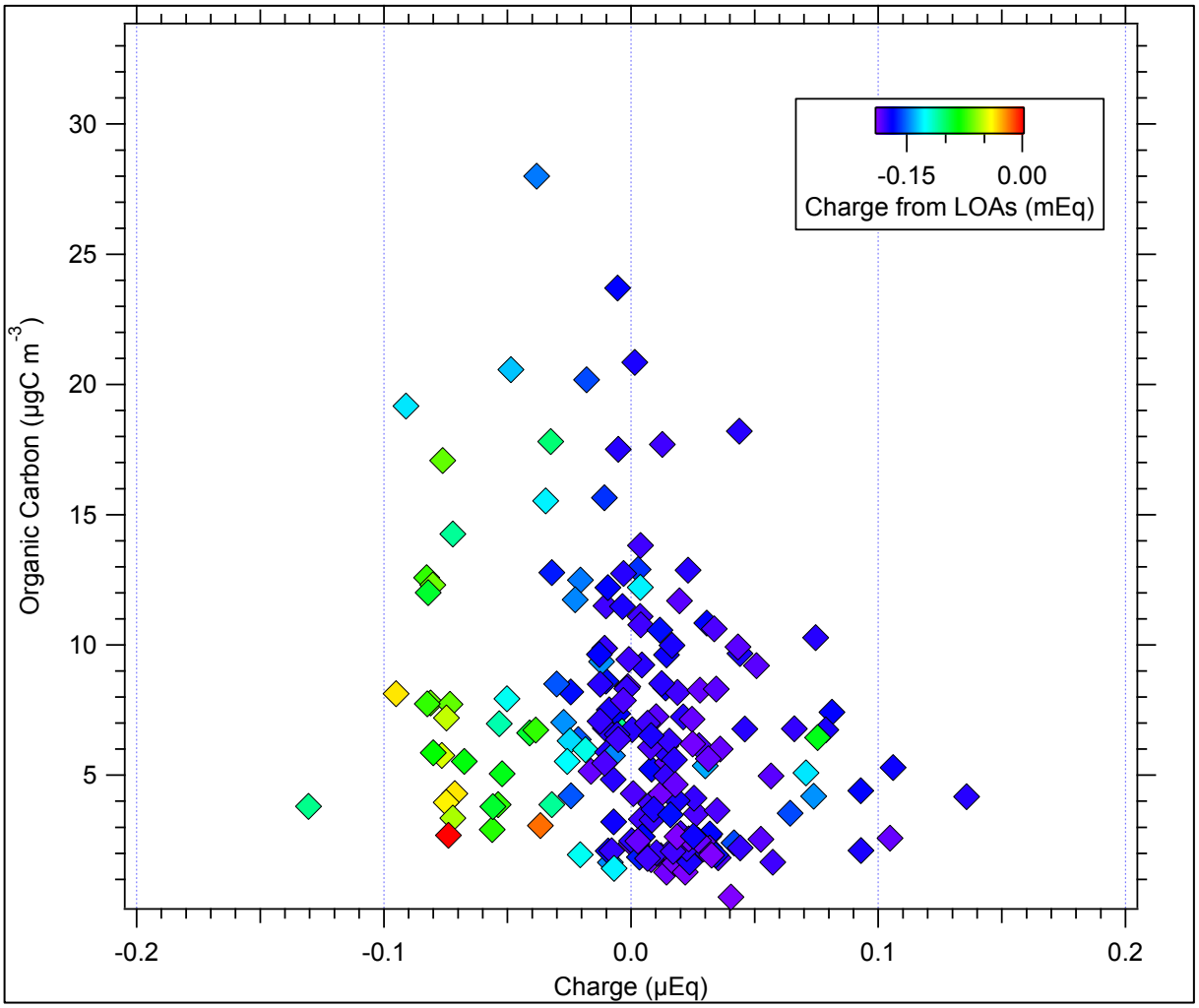

Figure 3: Net charge on aerosol plotted against organic carbon concentration. Markers are colored by apparent net charge resulting from three measured light organic acids, which include acetate, formate, and oxalate.

periods of lowest measured OC. While not yet determined, there are several possible explanations for this. For example, one explanation would be contamination of the system by a cation such as ammonium, though one would expect to see a systematic bias rather than only occasional influence. Another more likely explanation is that a negatively charged species, such as a light organic acid, may be present in aerosol only under conditions of limited OC, which is not accounted for in the charge calculation.

SULFUR STUDIES

Investigating the possible sources of sulfur was an a priori interest in this study and stems from the observation that local speciation measurements, which measure sulfate by chromatography and sulfur by XRF, suggest that there may be a non-sulfate source of sulfur present in the Fairbanks air shed. Of note, as illustrated by Figure 4, existing sulfate and sulfate data shows a substantially noisy

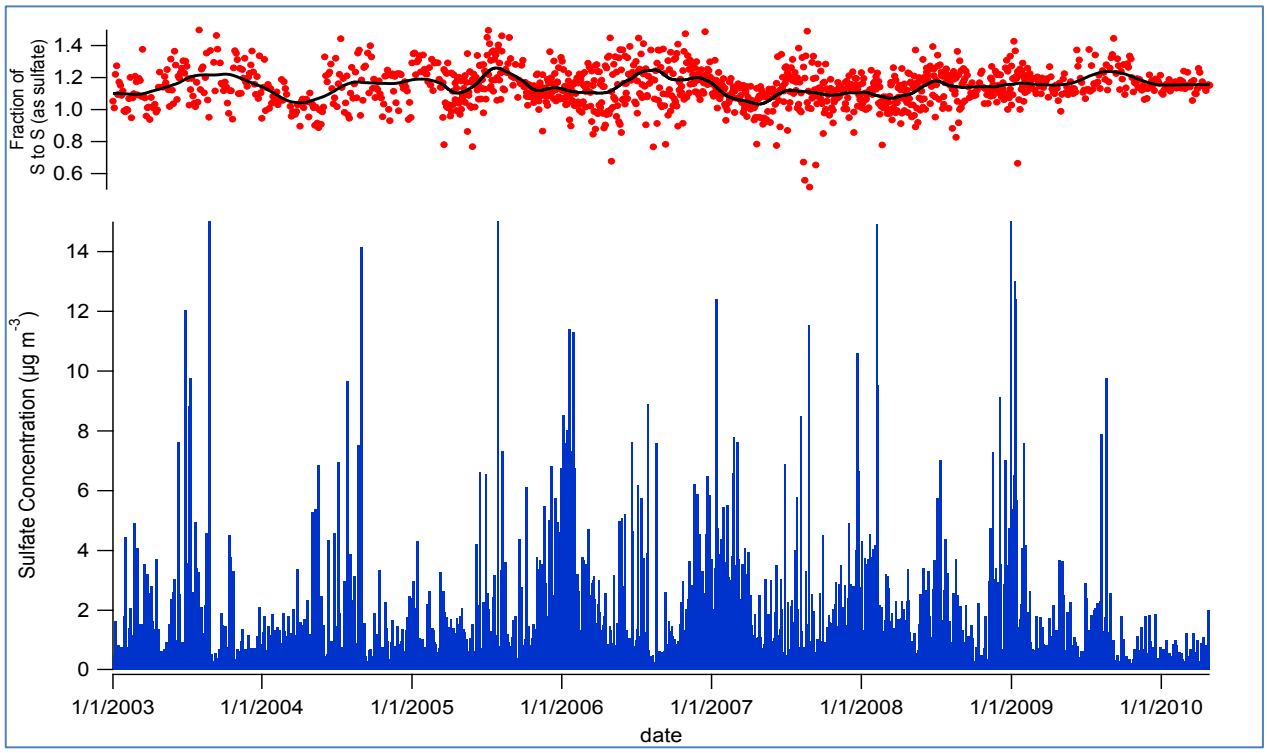

Figure 4: Time series of speciation data collected by FNSB staff since 2003. Data on bottom is daily sulfate measurements, and plot at top represents the fraction of total sulfur to sulfur calculated from measured sulfate. Total sulfur is measured directly by XRF, and sulfate is measured directly by ion chromatography.

pattern in the ratio of sulfur to sulfur (as sulfate). A clear divergence from unity can be observed suggesting that there is a possible unmeasured, stoichiometrically-adjusted sulfur source not captured in a collocated measure of sulfate. This ratio does have broad trends, but they do not appear to correspond with measured sulfate, which appears as highly variable in concentration and time.

Because this study collected its own filter measurements, we can empirically investigate the possibility of 'missing sulfur' by sequential analysis by non-destructive X-Ray Fluorescence Spectroscopy, followed by filter processing and chemical analysis of dissolved ions. The methods

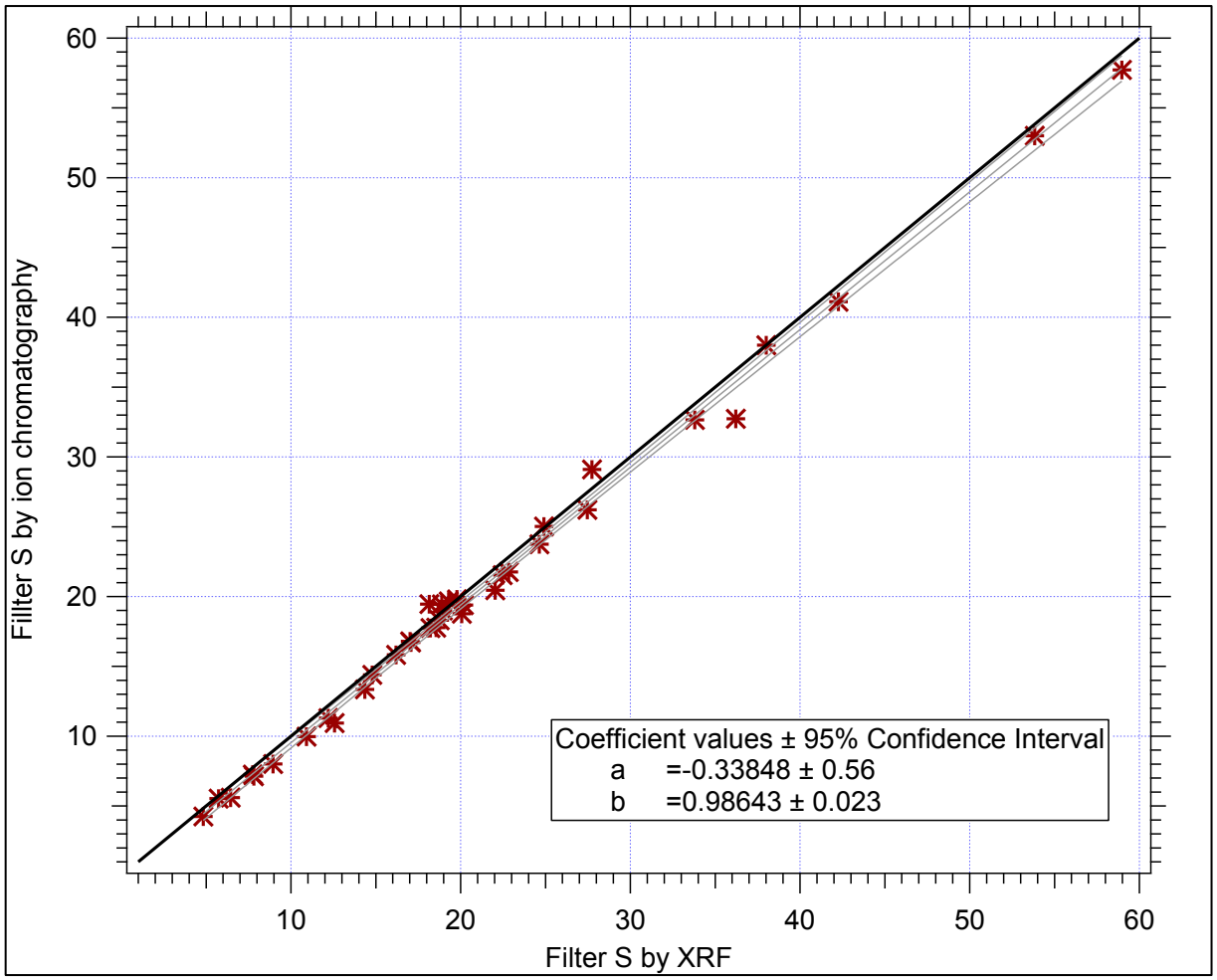

Figure 5: Regression plot of sequentially analyzed filters for sulfur concentration. Filters were first analyzed by XRF followed by ion chromatography for a measure of sulfate. Linear fit coefficients are also included and report a correlation coefficient of 0.97.

for this process were similar to the method used to analyze the aliquots collected by the PILS. The results, as shown in Figure 5, show a very high degree of correlation between measured S as sulfate and directly measured S by XRF. Regression slope approaches statistical unity, with a statistically insignificant intercept. These findings clearly suggest that any bias seen in the presence of sulfur across different measurements are not likely because of a unmeasured sources of ambient sulfur; the most likely explanation is that there is some bias introduced because of methodological reasons such as differential absorption related to different filter materials, systemic bias introduced by post-collection filter processing, or gas-phase intrusion resulting from the extreme cold experienced in Fairbanks. While the answer to this problem is still elusive, it should be noted that sulfur comprises a relatively small fraction of overall PM loading and this small bias, on average, may represent just a few tenths of percent of aerosol (by mass) in the Fairbanks region.

Further analysis follows in the section on preliminary analysis of XRF data.

EC AND OC

By mass, OC was one of the largest contributors to PM2.5 mass observed at this location during the study. EC, which was a much smaller fraction by mass, was well correlated with OC suggesting common sources. Of particular note as illustrated in Figure 6, OC and EC are generally well correlated with one another during this study. The OC to EC ratio was generally between 4-5,

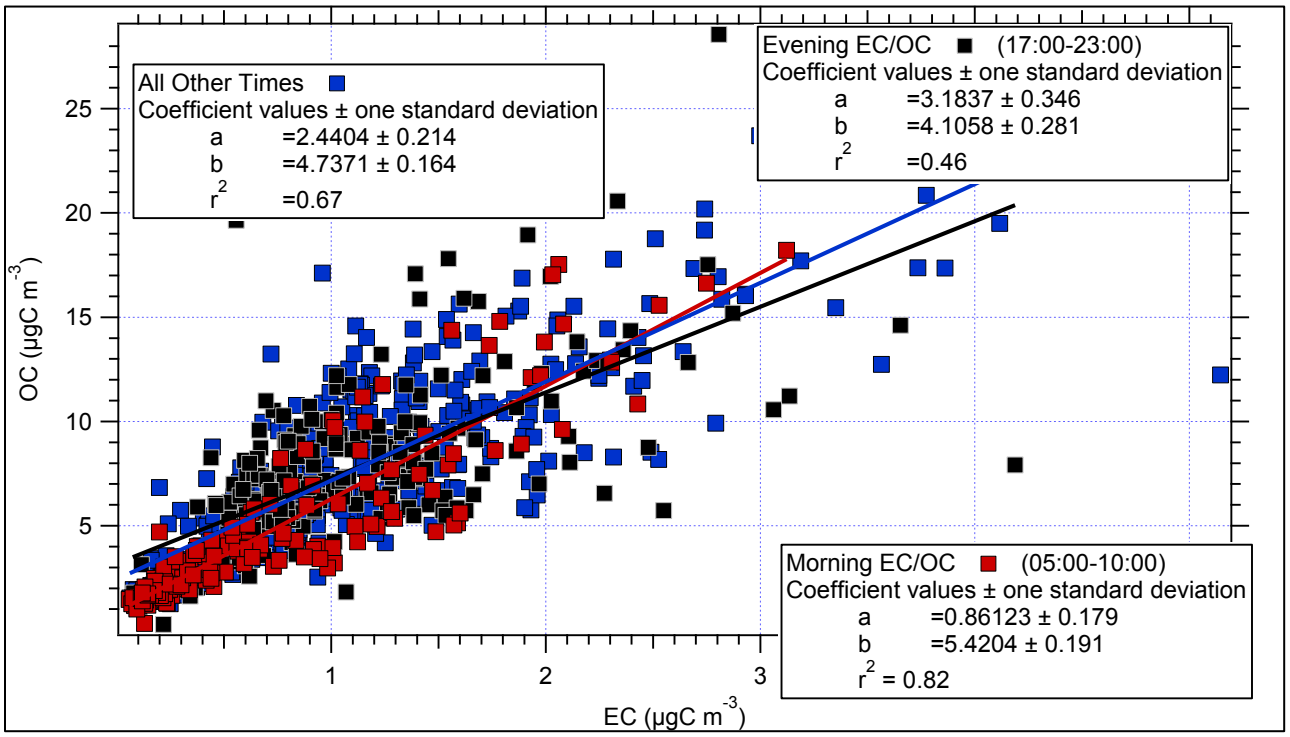

Figure 6: Measured organic carbon compared to measured elemental carbon (collected at same time). Data are binned to different time periods to show comparison between morning, evening, and all other times. Regression statistics are for a linear fit.

which is somewhat higher than urban values reported in the literature [10-14] and is more consistent with the higher values observed in biomass burning plumes [15-18], though this is an overly simplified analysis. More work is indicated to investigate these ratios further. A somewhat different regression was observed when the data were binned between morning, evening, and all other times. Tighter correlations and higher ratios were observed (Figure 6) in the morning compared to the evenings, suggested a different source process is occurring at this time. The lowest ratios and the less correlated data are observed in the evenings, with data from all other times falling between the two. This finding suggests that during morning periods, sources that are attributed to OC and EC (which themselves are tightly correlated) are more likely to emit OC per unit of EC than observed in the evenings. Possible explanations for this may include different combustion characteristics that emit OC and EC that are more conducive for OC formation in the morning compared to the evening. Likewise, combustion conditions in the evening appear to emit less OC per unit EC, providing another line of evidence suggesting different formation mechanisms.

Table 3: Univariate statistics for organic and elemental carbon measured during this study. Reported values include mean, median, standard deviation, range, and the number of measurements collected during this study. Llod denotes measurements below the limit of detection.

	Mean, µg m^{-3}	Median, µg m^{-3}	Std Dev, µg m^{-3}	Range, µg m^{-3}	n
Organic Carbon	6.47	5.92	4.62	(0.03, 33.4)	505
Elemental Carbon	0.90	0.78	0.69	(llod, 3.86)	509

While much remains to be analyzed, it appears that OC and EC in the Fairbanks region are most likely associated with biomass burning. A substantial residential heating demand is required in this community during the winter, and wood burning remains an economically efficient fuel source for the community. Unfortunately, this has resulting in a preponderance of OC and EC in the Fairbanks

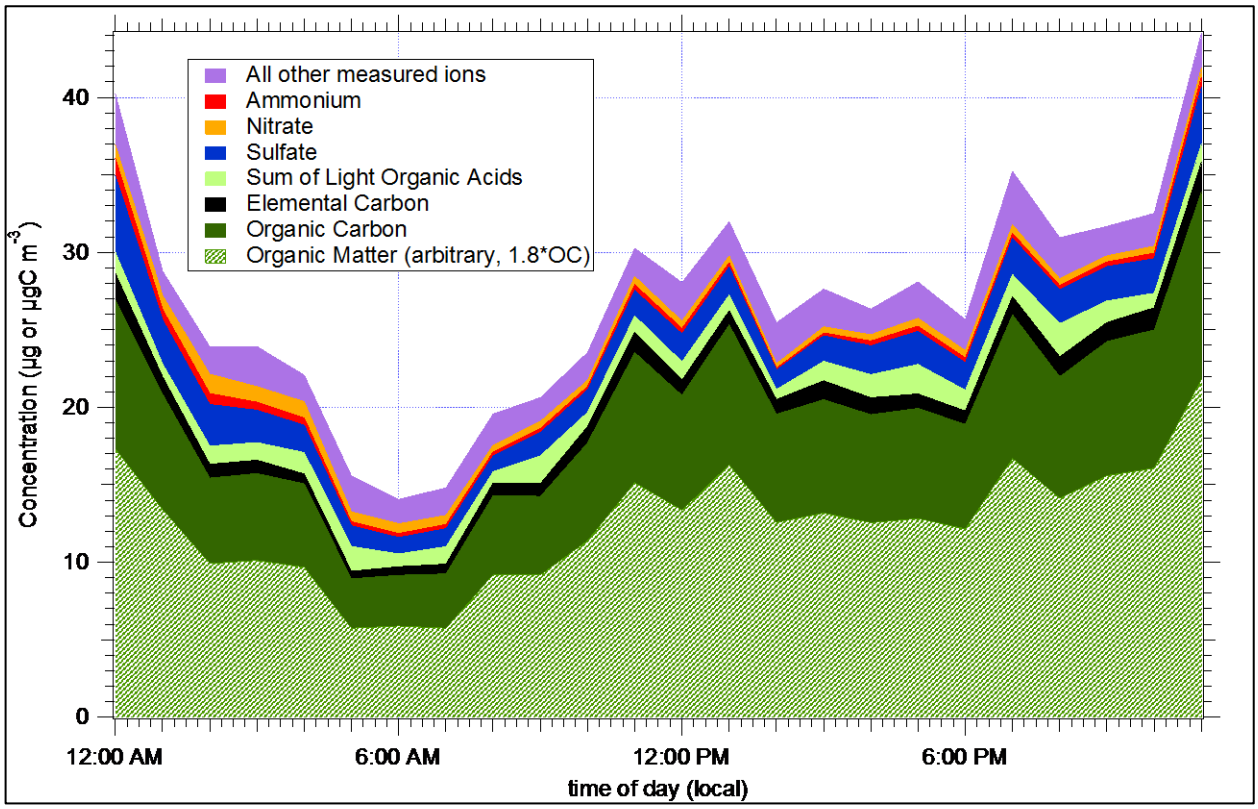

Figure 7: A composite diurnal profile for ~270 hourly measurements of OC, EC, and most ions. Organic matter is estimated as 1.8 times the measured OC value. Data are binned to each hour of the day and the mean value is presented here. Several lesser ions are binned into a separate composite group ('all other measured ions') to simplify this plot

air shed linked to these fuels, and it would be wise to investigate this issue further in hopes to better identify the mechanistic conditions leading to these different emissions profiles.

The data from this study were concatenated into a single, diurnal profile and plotted in Figure 7. While a number of components were measured during this study, organic matter – that is, the functional groups that are part of the organic particle, but not accounted for in the measure of carbon – is only estimated here. We use an arbitrary, but reasonable, value of 1.8 for the OM-to-OC ratio, and included this in the profile. Figure 7 shows a clear drop in concentration in the early

morning, with distinct peaks occurring around noon, 7PM, with highest observations around midnight local time. Ion composition is generally uniform throughout the day with some deviations in sulfate apparent throughout the day. Notable, however, is the dominance of OC and OM across the entire day, with these components reaching a minima around 6AM and a maxima at midnight.

This profile, at least subjectively, is consistent with wood burning as the dominant source of aerosol in this community. One might expect to see a declining emission rate between the evening and early morning as wood burning devices start to self-extinguish; a rapid increase in emissions follows in the morning as there is an increased demand for residential heating. The spike near midnight may be attributed to residential space heaters which are typically refueled to ensure continuous heating through the night and early morning.

XRF (PRELIMINARY)

As part of additional measurement efforts, the Borough has initiated a longer term study in the winter/spring of 2012 using a novel speciation instrument that provides hourly measurements of metal composition from PM2.5. This method is accomplished by way of a newly developed semicontinuous XRF installed at a ground location in Fairbanks. An initial look at this data is enclosed here, but does not represent a full analysis. Univariate statistics describing the dataset, as of 06 Jan 2012 are included in Table 4.

Table 4: Univariate statistics for the range of metals measured during the ongoing field study. Reported values include mean, standard deviation, max, and min values. All data are reported as nanograms per cubic meter, adjusted for standard temperature and pressure. Total number of measurements is 261 as of January 6, 2012, with data collection currently ongoing.

	Average	Stdev	Min	Max		Average	Stdev	Min	Max
SULFUR	868.169	760.360	0.076	3348.000	**ZINC**	42.448	42.982	0.116	254.743
POTASSIUM	158.202	100.821	0.941	568.123	**GERMANIUM**	0.129	0.102	*LLOD*	0.777
CALCIUM	24.719	93.944	*LLOD*	834.172	**ARSENIC**	0.117	0.500	*LLOD*	3.642
SCANDIUM	0.127	0.249	*LLOD*	1.486	**SELENIUM**	0.052	0.065	*LLOD*	0.372
TITANIUM	0.949	0.877	*LLOD*	4.754	**BROMINE**	3.291	3.250	0.049	24.975
VANADIUM	0.084	0.133	*LLOD*	0.729	**RUBIDIUM**	0.220	0.196	*LLOD*	1.122
CHROMIUM	0.087	0.240	*LLOD*	2.242	**STRONTIUM**	2.177	8.863	0.203	127.562
MANGANESIUM	0.525	0.821	*LLOD*	8.083	**SILVER**	54.473	178.273	0.204	1378.000
IRON	27.536	32.076	2.400	280.647	**CADMIUM**	19.157	52.453	1.096	588.461
COBALT	0.020	0.054	*LLOD*	0.504	**BARIUM**	0.930	1.547	*LLOD*	15.086
NICKEL	0.220	0.177	*LLOD*	1.645	**MERCURY**	0.001	0.010	*LLOD*	0.157
COPPER	3.997	3.263	0.918	46.591	**LEAD**	4.443	4.740	0.719	37.569

Transition metals are useful for source identification initiatives to provide quantitative information on elements that are released by specific sources, even if the overall concentrations of the elements are quite small. Figure 8 depicts a time series of concentration following elements with tracers through to mainly derive from coal combustion, although the important caveat that these

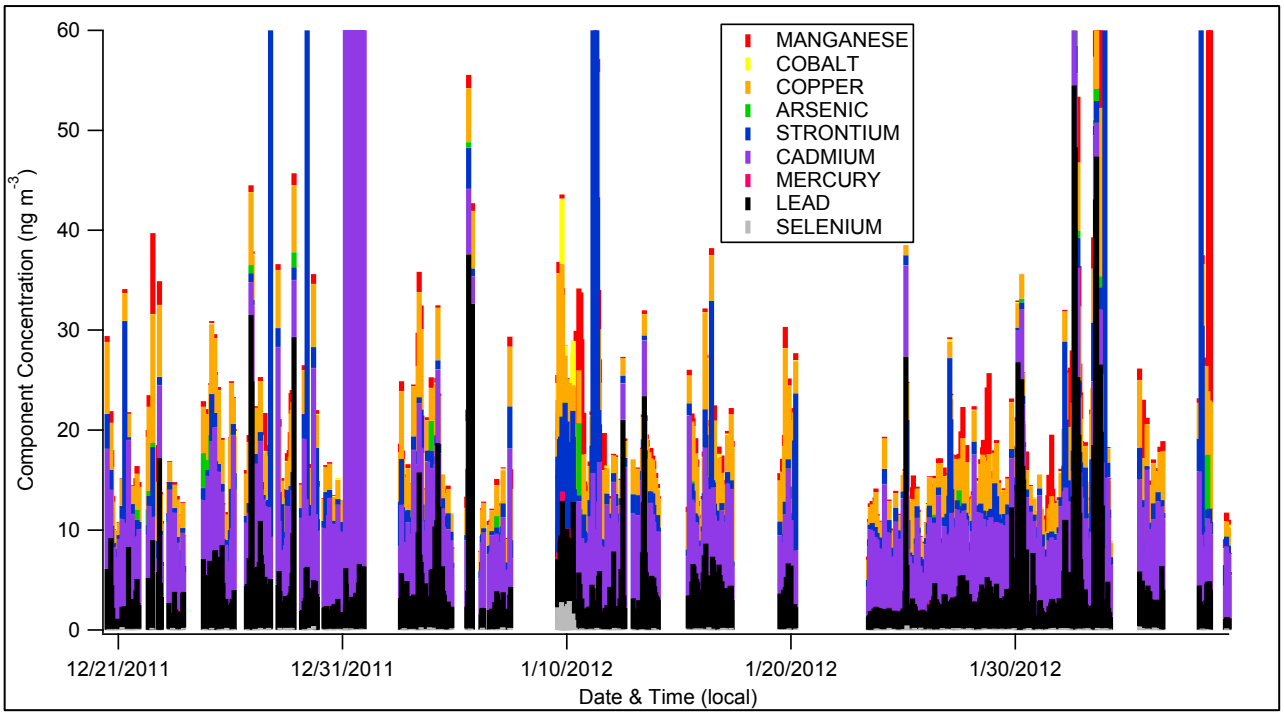

Figure 8: Time series of preliminary XRF data for selected metals thought to be linked to coal emissions. Gaps in data represent periods where the instrument was not reporting data.

components have not yet been confirmed as markers of coal combustion; further analyses to this effect are continuing.

Substantial texture in these elements suggests highly variable influence from coal combustion sources at this location. While overall elemental concentrations are in the single to 10's of nanogram per cubic meter range, some notable trends do appear in the data. For example, strontium has been anecdotally linked to spikes in PM concentration during times when air advection would suggest influence from the nearby coal power plant. Mercury and selenium also appear infrequently, but do so at clearly detectable levels well above a background concentration of less than ~0.5 ng m^{-3} and are generally throughy to be markers of coal combustion.

At least three distinct events are shown in this figure, occurring on January 1, January 12, and Feb 2-3 that warrant greater investigation. The event on January 1 was characterized by nearly 1 microgram per cubic meter of cadium; other elements were also substantially elevated during this time period. Because this event occurred just after midnight, it is likely that this is linked to local fireworks celebrations in the community. While this anecdote has little relevance for the broader air quality problems experienced by the borough, it does show the specificity and power of these measurements in the context of a complex aerosol setting. The other events are characterized by increases in strontium concentration, which is thought to be linked to coal emissions, though other sources may also be responsible for this emission.

It is important to point out that Figure 8 depicts a time series of densely-packed concentration for only a fraction of the elements. Though this approach provides a measure of concentration magnitude and temporal time scales, a more robust approach would be to use statistical modeling techniques to refine this data; such techniques include PMF, PCA, or other source apportionment approaches. It should also be noted that information on 13 additional elements (not plotted here) are also available, and these data are expected to be collected until the end of winter 2012. These approaches are forthcoming and not included in this report.

High time resolution data for sulfur was also exploited to begin investigating sulfur emissions and sulfate formation processes. The time period of study for this was from December 20th, 2011 through January 13th, 2012 and included 417 hourly data points measuring particulate sulfur by

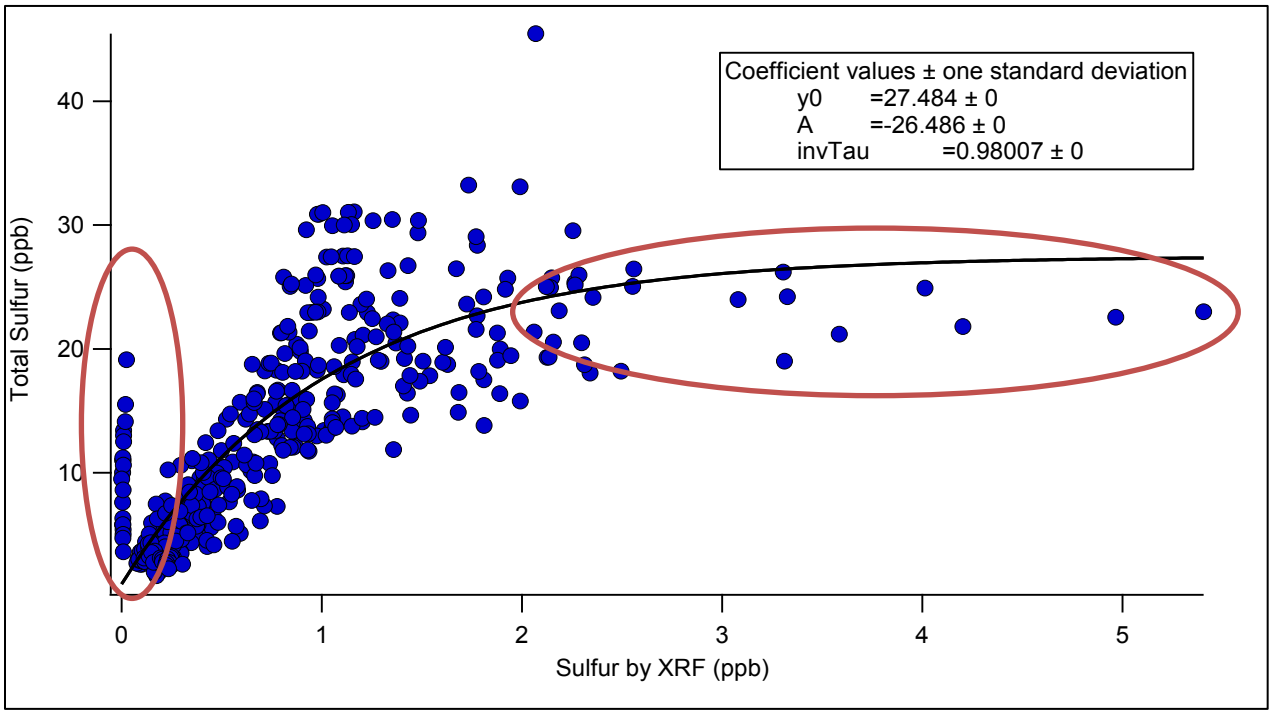

Figure 9: Total sulfur compared to sulfur measured by XRF. Total sulfur is defined as the sum of particulate sulfur by XRF with the sulfur observed in the gas phase as sulfur dioxide. Measurements are collocated. Circled regions highlight two distinct regimes; the left being a regime where particulate sulfate is absent even in the presence of gas-phase sulfur and the second regime (right) where total sulfur appears with a higher fraction in the particulate phase. This second regime may represent the most advantageous conditions for gas-to-particle conversion processes. Fit line is a simple exponential decay function.

XRF and sulfur as sulfur dioxide. Figure 9 plots total sulfur as defined by the sum of particulate sulfur by XRF and sulfur from SO2 compared against total particular sulfur by XRF. At least two different regimes are immediately apparent from this data; one that shows conditions where no aerosol is detected (presumably during precipitation events) and a second where sulfur conversion to particles is effective. In the latter case, an exponential decay appears to describe the latter where SO2 concentrations were generally limited to 25-30 ppb. An exponential curve fit to the data appears reasonable, but greater investigation is warranted. Under most conditions, sulfur conversion is a widely understand chemical process that occurs it he presence of sulfur dioxide, water vapor, and sunlight. The region lacks strong sunlight, and thus the typical mechanism for sulfate conversion is probably quite weak. Nonetheless, the presence of sulfate in the aerosol

stream in Fairbanks confirms that this conversion process exists, and appears to limit SO2 concentration to less than ~30ppb.

In terms of identification of sulfur sources, it is not yet clear where these sources can be attributed. Likely sources include coal power generation, coal residential heating, or combustion of fuel oils for residential heating. Much greater analysis is indicated to develop a more robust profile.

CONCLUSIONS AND FUTURE DIRECTIONS

While data from these studies continues to be collected at the time of writing this report, it is clear from the winter 2011 studies that aerosol chemical composition is complex and unlike any other air shed in the United States. With the exception of occupational environments, it is relatively rare that greater than 20 $\mu gC\ m^{-3}$ are observed at any time in US, yet this is typical on cold winter days in Fairbanks. Thus, Fairbanks is subjected to unique and important stressors on its airshed.

The data are consistent with a profile that fits a primary influence from biomass burning. High levels of OC and EC are routinely observed, and follow a pattern one might expect from a community that relies on wood burning to meet sizeable demands for residential heating. EC is well correlated with OC suggesting common sources, and the OC to EC ratio is consistent with sources derived from biomass combustion.

High temporal resolution measurements of ion concentrations showed relatively low (when compared with OC and EC) levels and suggest only a limited influence. Measured ions were dominated by sulfate, ammonium, and nitrate, but only at levels of approximately 10-20% of observed PM2.5 mass. While ions derive from a number of sources, sulfate is mainly derived from coal and non-road distillate combustion, the latter being defined mainly by home heating oil. Because we observed modest concentrations of sulfate (typically 2-4 $\mu g\ m^{-3}$), we cannot exclude these sources as contributors to the air quality concerns in Fairbanks, but they likely play only a minor role in PM2.5 loading in the community.

Combining these measurements, a strong diurnal profile was observed providing further evidence of anthropogenic influence on aerosol composition in Fairbanks. While there was some hour-to-hour variability in ion concentration, the vast majority of the diurnal profile was driven by OC, and the estimated organic material component that was not measured in this study. Further limited analysis examined sulfur concentrations in both gas and particle forms and suggest that there are at least two regimes related to sulfur conversion: one where sulfur remains in the gas phase with only trivial particulate sulfur, and another where sulfur conversion to particulate form appears to follow an exponential decay pattern. This suggests that the conditions necessary for this conversion are, in fact, present.

Future work on this data is extensive. One project includes a comparative analysis with fuel source profiles collected during another investigation by FNSB. By incorporating updated fuel profiles, which provide detailed chemical component information from each type of fuel used in the region, we hope to be able to statistically connect those profiles with the observations in Fairbanks. Another project will incorporate these results into the Chemical Mass Balance modeling currently performed by investigators at the University of Montana. Additional planned analyses include investigating the high time resolution XRF data in much greater detail, with a focus on chemical mass balance and positive matrix factorization modeling, as well as coupling this data with in-progress modification of the CMAQ model for purposes of refining and validation.

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Final Report

To

Environmental Protection Agency (EPA)

Purchase order EP08D000663

Reporting Period: 1 September 2008 – 31 January 2010

'Stable Boundary Layers Representation in Meteorological Models in Extremely Cold Wintertime Conditions'

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12 May 2010

EXECUTIVE SUMMARY

This final report describes work performed by Penn State for the EPA-funded Purchase Order EP08D000663 titled 'Stable Boundary Layers Representation in Meteorological Models in Extremely Cold Wintertime Conditions'. The purpose of the project was to develop, adapt, and test a methodology for stable boundary layer representation (initial onset, space/time evolution, dissipation) in three-dimensional numerical models, with a specific focus on the dark, extremely cold environments such as those in the winter in the Fairbanks, AK region. A particular concern is the frequent occurrence of very high fine particular matter (PM2.5) concentrations within the stable boundary layers that form in these conditions.

Ten tasks were defined in the Statement of Work (SOW) for this project. A summary of these tasks and a brief overview of the work completed can be found in the Appendix to this report. Two twenty-day episodes were selected from the 2007-2008 winter season to study periods of extremely cold temperatures and high PM2.5 concentrations and to evaluate model performance: one in near total darkness (14 Dec 2007 – 03 Jan 2008), and the other in partial sunlight (23 Jan 2008 – 12 Feb 2008). One baseline physics configuration and three physics sensitivity experiments were performed for each episode. The physics sensitivity experiments were used to assess the impact of different planetary boundary layer (PBL) parameterizations, land surface models, and atmospheric radiation schemes on the simulations. Each simulation used three nested grids: Grid 1 (12-km horizontal grid spacing) and Grid 2 (4-km) utilized the multiscale multigrid data assimilation strategy of Stauffer and Seaman (1994) in order to ensure the model and observations remain close over the extended duration of the simulations, and Grid 3 (1.3-km) did not use any direct data assimilation, and so was best-suited for quantifying the physics sensitivity. Grid 3, which is centered over the Fairbanks region, also possesses sufficient horizontal resolution to be used by the EPA as meteorological input to chemical and air transport and dispersion models. From the different physics packages one was to be recommended to the EPA for further mesoscale modeling of the region.

The major findings and impacts of this project are as follows:

- The use of the three-grid configuration with a multiscale, multigrid four-dimensional data assimilation (FDDA) strategy on the outer two grids and no direct FDDA on Grid 3 consistently produced qualitatively plausible atmospheric fields throughout the variety of meteorological conditions found in the episodes, despite the relatively sparse data density. Quantitatively, the multiscale, multigrid FDDA strategy led to improved root-mean-square-error (RMSE) scores for both wind and temperature on all grids. The FDDA on the outer domains had the desired effect of improving the simulations of Grid 3 without FDDA and used for physics sensitivity tests, by providing improved lateral boundary conditions.

- The best RMSE scores for the combination of both surface and sounding data required modification of the default FDDA procedure. These modifications included applying surface wind observational data to the third model vertical level instead of the lowest model level because wind observations are normally taken at a height of 10 m which is the height of the third level in the high vertical resolution configuration used here. The influence of surface observations was also restricted to approximately the lowest 100 m, instead of the top of the PBL, because the model-predicted PBL height in these simulations, based on the turbulent kinetic energy profile, was often found to be 1 km or higher. This correction applied the surface innovation (observation minus model value) in these predominantly stable boundary layers over a much shallower layer and produced improved statistical results in the lower troposphere.

- All model physics combinations tended to have a positive temperature bias on Grid 3, especially during the most extremely cold periods. All of the physics sensitivity tests tended to reduce the warm bias in comparison with the selected baseline physics package.

- Switching from the RRTM longwave / Dudhia shortwave radiation package to the RRTMG longwave and shortwave radiation package led to significantly reduced warm biases and better RMSE statistics. RRTMG was then used in all future physics sensitivity tests. The reduced warm bias seemed to be due to the longwave component, both because of direct examination of surface fluxes in the partial sunlight case, and due to the fact that the difference was more pronounced in the near total darkness episode.

- The simulation with the Rapid Update Cycle (RUC) land surface model, the Mellor-Yamada-Janjić (MYJ) PBL model, and the RRTMG radiation package was the coldest of the four physics suites tested, and had the lowest positive temperature bias and best statistics during those periods when the temperature was coldest. It was thus selected as the physics configuration of choice, since the coldest temperature conditions are those with the potential for the highest PM2.5 concentrations. However, there were periods in each episode, generally when the temperature was steadily decreasing in advance of an extremely cold period, during which the models had a cold bias. During these periods the RUC/MYJ/RRTMG configuration would usually be even colder and thus have worse magnitude temperature biases and RMSE scores. Thus, while this configuration was recommended, we also strongly recommended that the final fine-scale atmospheric data (i.e., from Grid 3) to be provided to EPA should come from an additional simulation in which FDDA is performed directly on Grid 3, in order to reduce some of this error.

- Wind component and wind speed statistics generally showed much less variability among the model physics sensitivity experiments than that seen for temperature. The MYJ/RUC/RRTMG (MRR) configuration usually produced slightly better wind statistics than the other configurations.

- Use of obs nudging for temperature and humidity (and not surface wind) on Grid 3 produced large improvements in the mass fields as expected, and also improvements in the wind fields

above the surface. Results were very encouraging and suggested that a smaller (larger) time window should be used for the surface (above-surface) data assimilation. This capability present in the Penn State MM5 FDDA system has been added to the new-release version of WRF.

- In addition to this final report, deliverables to the EPA will include the full three-dimensional output at relatively fine temporal resolution (every 1 hour for Grid 1; every 12 minutes for Grids 2 and 3) for the final Grid 3 nudging simulation as well as all the baseline and physics sensitivity simulations. Model namelists, initialization files, and modifications to the model source code will also be provided.

- The development and refinement of WRF FDDA capabilities and supporting software, including the surface analysis nudging, observation nudging and the OBSGRID objective analysis and obs-nudging pre-processing code, occurred concurrently with this project. This separate development effort led by PI Dave Stauffer and funded by the Defense Threat Reduction Agency (DTRA) allowed us rapid access to the most recent and robust versions of the WRF FDDA code, and this greatly benefited this project.

- The results of the default FDDA procedures not performing well in this high vertical resolution modeling study of stable boundary layer environments motivated an additional FDDA code development effort to make the vertical influence functions of surface observations within the FDDA be a function of stability regime type, as well as to provide the user with greater flexibility in specifying the vertical influence functions. These modifications were not finalized in time to be used for this project but are scheduled to appear in the next official release of the WRF model.

- An extended abstract and oral presentation were made at the 13th Conference on Mesoscale Processes (Gaudet et al. 2009), and a manuscript based on the project is in preparation.

- Since the first draft of the final report, the Grid 3 FDDA design and simulations have been completed for both twenty-day episodes. The results showed that the use of obs nudging for temperature and humidity (but not surface wind) on Grid 3 produced large improvements in the mass fields (as expected), and also improvements in the wind fields above the surface. Results were very encouraging and suggested that a smaller (larger) time window should be used for the surface (above-surface) data assimilation. This capability present in the Penn State MM5 FDDA system has been added to the new-release version of WRF.

1. INTRODUCTION

Fine particulate matter (PM2.5, referring to particles with aerodynamic diameters equal or less than 2.5 microns) has been implicated in a variety of health problems, including respiratory disease. With the recent decrease in the allowable 24-hour PM2.5 concentration to 35 micrograms per cubic meter, there is now an even greater need to be able to determine the sources primarily responsible for exceedance events when they occur, as well as to predict the potential impact of source emission changes. Modeling the behavior of fine particulate matter typically involves coupling between an inventory of emissions sources, chemical and air transport and dispersion models, and synoptic and mesoscale atmospheric models. (Synoptic atmospheric models are designed to represent features with characteristic horizontal scales greater than about 2000 km; mesoscale atmospheric models represent features with scales of approximately 2 – 2000 km.) The purpose of the meteorological models is to use physical predictive equations and assimilation of available meteorological data to capture the evolution of the local atmospheric state over sufficiently long periods for use by the other models.

During the winter season the part of interior Alaska consisting of Fairbanks and the surrounding Fairbanks North Star Borough often have extremely cold temperatures due to the strong longwave radiative cooling, the absence of moderating marine influences, and the generally weak winds. Although this region often has a clean, relatively pristine atmosphere, the periods of coldest temperatures are often accompanied by some of the strongest low-level temperature inversions that have been observed, with temperature increases up to 20°C as one ascends from the surface (Benson 1970). The inversions cap stable boundary layers (SBLs) that can be as shallow as tens of meters in clear nocturnal conditions (Sereze et al. 1992; Vickers and Mahrt 2004). Emissions from vehicular traffic, power plants, and home heating (mostly diesel and wood fuels) remain trapped within the SBL, leading to high concentrations of particulates and other pollutants. In the extremely cold conditions of interior Alaska an additional problem that arises is ice fog that can be triggered by combustion-generated water vapor at temperatures below approximately -25°C (Benson 1970; Girard and Blanchet 2001). The dispersal of pollutants is further hindered by the fact that winds and turbulence are quite weak in these conditions. The winds and turbulence that do exist in the SBL are strongly modulated by drainage flows, gravity waves, and other less understood phenomena (Hanna 1983; Mahrt 2009). Thus predicting the behavior of SBLs becomes a complex problem involving synoptic weather patterns, topography, turbulence, surface energy budgets, and precipitation.

The tool used for the meteorological modeling component of this project is the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008), more specifically, the Advanced Research WRF dynamic core (WRF-ARW, henceforth simply called WRF). WRF contains separate modules to compute different physical processes such as surface energy budgets and soil interactions, turbulence, cloud microphysics, and atmospheric radiation. Since turbulent eddies in the SBL are typically much smaller than mesoscale model horizontal grid spacing (e.g., ten meters vs. a thousand or more meters), they cannot be modeled directly (e.g., Wyngaard 2004), but typically their effect is parameterized by a Planetary Boundary Layer (PBL) scheme that predicts turbulent kinetic energy (TKE). Within WRF the user has many options for selecting the different schemes for each type of physical process. There is

also a WRF Preprocessing System (WPS) that generates the initial and boundary conditions used by WRF, based on topographic datasets, land use information, and larger-scale atmospheric and oceanic models. New software associated with objective analysis and data assimilation will be discussed later.

The goal of this project was to select and perform two twenty-day simulations down to 1-km horizontal grid spacing for two episodes from the 2007-2008 winter season characterized by high PM2.5 exceedance events in the Fairbanks region. One episode was to be characterized by near total darkness, while the second was to contain partial sunlight. From a set of modeling experiments including a baseline physics configuration and a series of physics sensitivity tests, modified as appropriate to be suitable to the unique Alaskan atmospheric conditions, a best performing physics suite was to be selected and delivered to the EPA, along with source code and the model output. The project had two main components: (1) creating the best possible representation of the atmosphere through the use of a mesoscale model with continuous data assimilation, and (2) determining the best set of physics parameterizations by performing a series of sensitivity tests without the direct effects of data assimilation. Both components are included in a multiscale, multigrid data assimilation procedure, which will be described in more detail below.

2. METHODOLOGY AND BASELINE EXPERIMENTAL DESIGN

2.1 Grid Configuration

The simulations presented in this report involve three one-way nested horizontal grids with horizontal grid spacing of 12 km, 4 km and 1.3 km, respectively (Table 1 and Fig. 1). Grid 1 covers the entirety of Alaska and extends from Siberia to the northwestern continental United States. Grid 2 closely coincides with the extent of the Alaskan landmass south of the Brooks range; it includes the Anchorage region and the Gulf of Alaska in the south. Grid 3, centered around Fairbanks and extending south to the Alaska Range and north past the White Mountains and other uplands just north of Fairbanks, includes all of the proposed non-attainment area within the Fairbanks North Star Borough (Fig. 2). It can be seen in the figure that Fairbanks is located next to a semicircle of low mountains that are generally a few hundred meters above the city; this tends to restrict airflow near the city and further reduce the dispersion of pollutants in stable conditions.

Grid	Dimensions	Horizontal Grid Spacing
1	401 x 301	12 km
2	202 x 202	4 km
3	202 x 202	1.3 km

Table 1: Specifications of model grids.

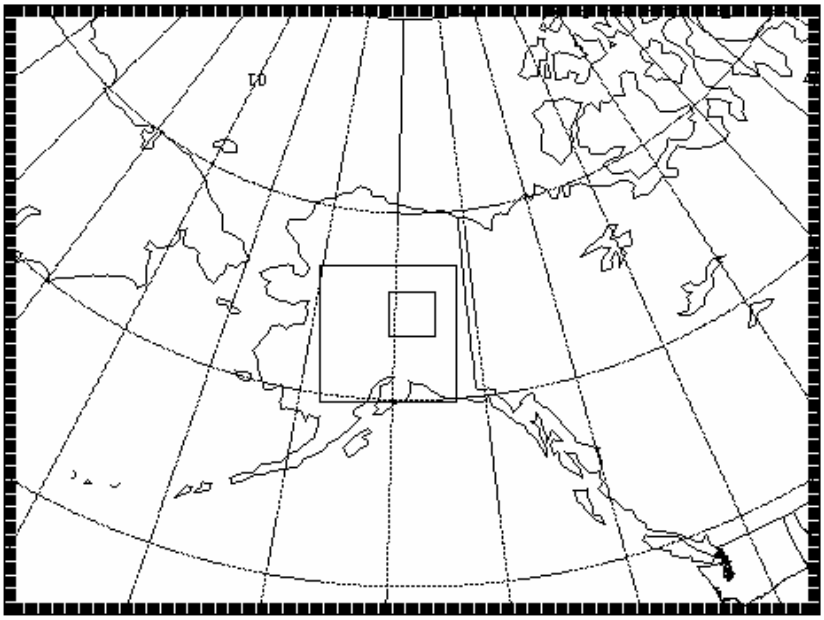


Fig. 1: Nested grid configuration of WRF, showing the 12-km Grid 1, the 4-km Grid 2, and the 1.3-km Grid 3 described in the text.

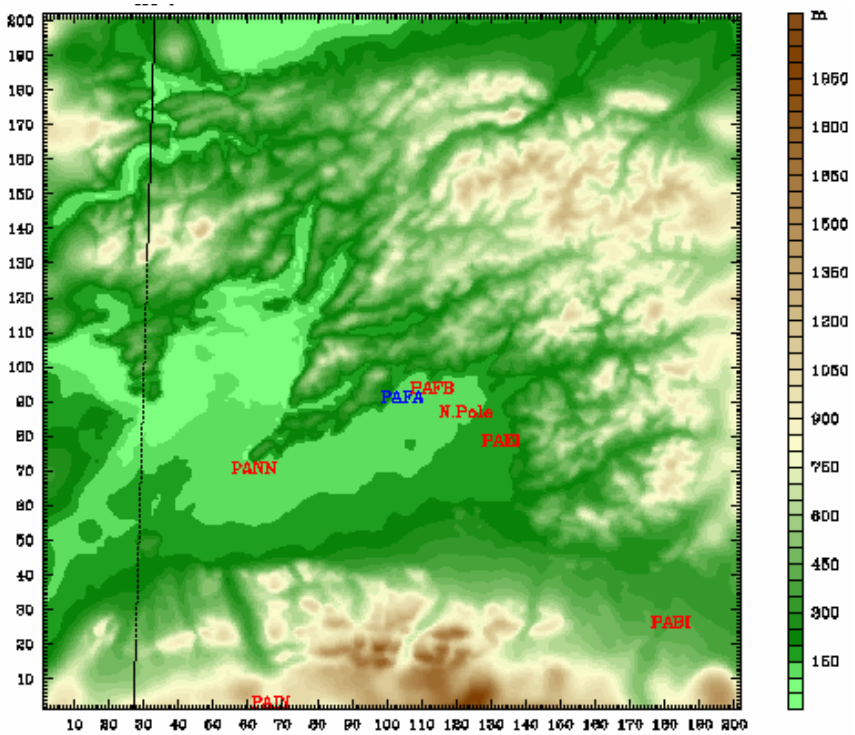


Fig. 2: Elevation on Grid 3 used in study. The location of the Fairbanks sounding is labeled in blue; other local METAR stations are shown in red.

The vertical grid spacing needed to be fine enough to resolve the structure of SBLs that can be only tens of meters deep, but not so fine that numerical instabilities arise in regions of steep topography (in particular the Alaska Range). After a series of initial tests a vertical grid configuration with 38 half layers (39 full levels) was defined, with a minimum vertical grid spacing of 4 m near the surface (see Fig. 3). Numerical stability was achieved through the use of time steps of 24 s, 8 s, and 4 s on the 12-km, 4-km and 1.3-km grids, respectively. These parameters are comparable to those used over central PA in the Seaman et al. (2008) SBL study. but with 4-m rather than 2-m vertical resolution near the surface, and slightly shorter timesteps.

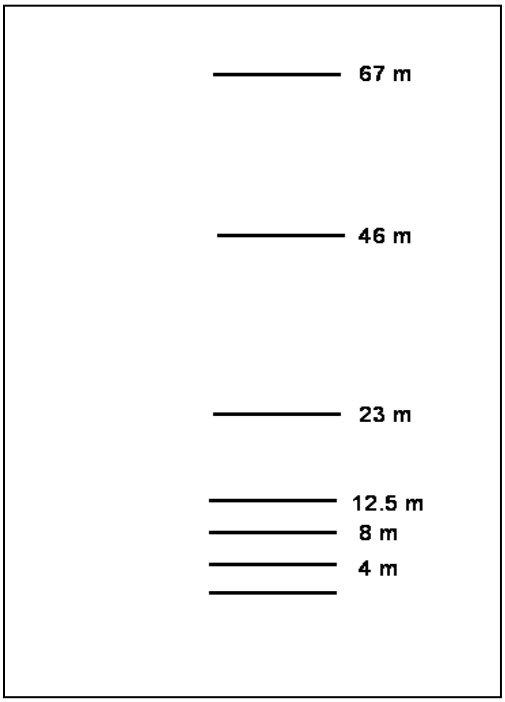


Fig. 3: Lowest few vertical full levels (i.e., locations where vertical velocity is calculated) in WRF model configuration, roughly to scale.

Two twenty-day episodes from the 2007-2008 winter season were selected for study. One episode was from 14 Dec 2007 to 03 Jan 2008, a time of year when there is little solar radiation in the Fairbanks area (approximately three hours of daylight per day near the solstice). During this episode the temperature rapidly decreased to near -40°C by 21 Dec, accompanied by rapid increases in PM2.5 concentrations, and then temperatures generally increased and PM2.5 decreased for the remainder of the episode (Fig. 4). The second episode was from 23 Jan 2008 to 14 Feb 2008, when solar insolation was more significant (between five and eight hours of sunlight per day), and provides an example of 'partial

sunlight' conditions. During this episode temperatures were initially relatively warm (near 0°C), decreased briefly to near -35°C by 27 Jan, rebounded slightly, and then decreased during the most extensive period of sub -35°C weather of the season. Consistent with the prolonged period of cold temperatures were recurring violations of the PM2.5 standard in the Fairbanks area.

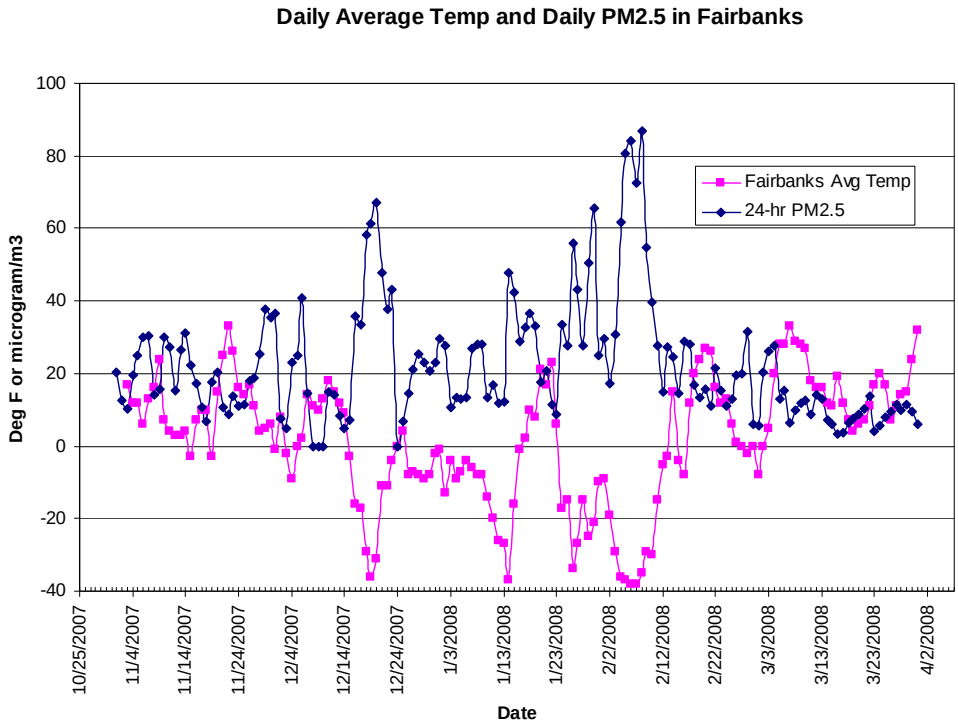


Fig. 4: Observations of daily average temperature and 24-hr PM2.5 concentrations taken in Fairbanks during 2007-2008 winter season. Courtesy Robert Dulla, Sierra Research, Inc.

In the initial period of a regional model simulation there is generally a period of several hours when the atmospheric state, whose initial conditions are usually provided by a global or coarser regional model, is still dynamically adjusting to the finer scale resolution and topography of the regional model. Therefore the model output from this initial 'spin-up' period is not completely reliable as an indicator of the true atmospheric state. However, if a regional model simulation is allowed to progress for too long without re-initialization (normally several days), it tends to drift away from the actual observed atmospheric state. Therefore, our method of obtaining realistic regional atmospheric analyses over an entire twenty-day episode was to divide each episode into four overlapping simulation segments. Each segment is around five days long with a twelve-hour overlap between each segment to avoid spin-up effects. (Specifically, the near total darkness episode was divided into successive segments of 6 days, 5.5 days,

5.5 days, and 4.5 days; the partial sunlight episode was divided into successive segments of 5 days, 5.5 days, 5.5 days, and 5.5 days).

Initial conditions and most of the Grid 1 lateral boundary conditions were obtained from the half-degree Global Forecast System (GFS) zero-hour analyses that were obtained from the NOAA National Operational Model Archive and Distribution System (NOMADS) website maintained by the National Climatic Data Center. The exceptions were some analysis times during the near total darkness episode when the half-degree GFS product was unavailable; in these instances the one-degree GFS analysis was used. All simulation segments for the near total darkness episode were selected such that all initial conditions could be obtained from half-degree global analyses.

The simulations were performed on one of two Linux clusters: one local cluster with 128 available processor cores, and the other cluster with 512 processor cores maintained by the Research Computing and Cyberinfrastructure High Performance Computing Group (RCC HPCG) at Penn State. Each 5.5 day simulation segment took 1-2 days to complete. The full 3D model output from each simulation was saved at a frequency of one hour for the 12-km Grid 1, and at a frequency of 12 minutes for the 4-km Grid 2 and 1.3-km Grid 3. For our configuration as shown in Table 1, the file size at each model output time is 500 MB for Grid 1 and 170 MB for each of Grids 2 and 3 (although this size can be approximately halved through file compression).

2.2 Four-Dimensional Data Assimilation (FDDA)

Even with the overlapping simulation segment strategy, it is difficult to ensure that the interior of a regional model simulation remains close to observations for simulations of more than a day or so. Therefore, dynamic analyses of historical cases are often performed, in which a Four-Dimensional Data Assimilation (FDDA) strategy is applied throughout the model integration. Relaxation terms based on the differences between actual observations and the corresponding model fields at the observation sites (also known as the 'innovations') are added to the model's predictive equations. In this way the model error is constrained based on available observations while the model still provides dynamic consistency and finer mesoscale structure not present in the observations. The version of FDDA used in these simulations is the multiscale, multigrid nudging FDDA strategy developed by Stauffer and Seaman (1994) for the MM5 mesoscale model. Nudging is also known as Newtonian relaxation, where the nudging relaxation terms are proportional to the innovation divided by a characteristic e-folding time inversely proportional to a nudging coefficient G. Nudging does not perform a direct insertion of observational information at a single point in space and time, but rather it applies the correction or innovation gradually in time and space based on the model terrain influences and prescribed / assumed weighting functions. For example, when a well-mixed PBL is present, one would generally want the influence of surface observations to be extended throughout the PBL, because in these conditions there is high correlation between errors in atmospheric fields at the surface and those anywhere within the PBL.

The multiscale multigrid FDDA method uses a combination of two forms of nudging: analysis nudging and observation ('obs') nudging. Analysis nudging is performed in model grid space where an objective

analysis of observations (e.g., with a modified Cressman scheme (Benjamin and Seaman 1985)) is performed using the interpolated global analyses (e.g., from the GFS) as a background field. The resultant 'enhanced analysis' can then be used as the basis for analysis nudging. Analysis nudging is generally applied on coarser model domains where synoptic data can be used to produce a reasonable gridded analysis. Obs nudging is more attractive for finer-scale domains and asynoptic data. It is particularly effective where observational data density is sparse and corrections are applied only in the neighborhood of the observations, allowing the model to still add value in regions without any data by propagating observation information into the data-sparse regions and creating mesoscale structure not in the observations. In this case the nudging is performed in observation space, and the model field is interpolated to the observation site to compute the innovation that is then analyzed back to the model grid over some three-dimensional neighborhood in space, and over some time window. Quality control (QC) of observations is critically important for the success of both analysis nudging and observation nudging.

In the multiscale multigrid FDDA method applied in this study, 3D-analysis nudging, as well as surface analysis nudging using higher temporal frequency surface data within the PBL (e.g., Stauffer et al. 1991), are performed on the outermost 12-km domain. Obs nudging is applied on at least the 12-km and 4-km domains. (Obs nudging is not applied on the finest 1.3-km model nest for the physics sensitivity studies described further below.) The finer domains thus have the benefit of improved lateral boundary conditions from the coarsest 12-km domain using both types of nudging, as well as the obs nudging performed directly on the 4-km nested domain.

This project was one of the first applications of the multiscale FDDA strategy of Stauffer and Seaman (1994) in WRF. It is important to note that many of the WRF FDDA capabilities were not available and still under development via a contract from the Defense Threat Reduction Agency (DTRA) to Penn State at the time that this project was proposed. In fact, the WRF 3D / surface analysis nudging and obs nudging capabilities were still being developed during this contract period. The WRF end-to-end FDDA system is shown in Fig. 5 and described in more detail in Deng et al. (2009). This contract was able to take advantage of the fact that the WRF FDDA developers at Penn State were also working on this contract.

The new OBSGRID module in the WRF end-to-end FDDA system produces gridded objective analyses and observation files similar to those produced by Rawins / Little_r in the MM5 system. These files can be used for 3D/surface analysis nudging and obs nudging within WRF. OBSGRID takes as input raw WMO observations (both surface and upper air) and the output of WPS, which consists of atmospheric initial and boundary gridded data (e.g., GFS output) horizontally interpolated to the model grid to be used in WRF. The outputs of OBSGRID relevant to this study include 1) pressure-level and surface objective analyses of the WMO observations (passing internal QC checks) using the WPS GFS output as background fields; the resultant analyses are then vertically interpolated to the WRF terrain-following "sigma" layers to be used for 3D analysis nudging; 2) surface analysis nudging files that can be directly used by WRF; 3) observation nudging files usable by WRF, and 4) files of the WMO observations including those passing the QC tests for use in the statistical verification software.

As mentioned above, for the physics sensitivity part of this study, 3D analysis nudging, surface analysis nudging, and obs nudging are performed on the 12-km Grid 1; obs nudging is performed on the 4-km Grid 2; and no nudging is performed on the 1.3 km Grid 3. Thus Grid 3 has no direct FDDA tendencies and can be used to determine physics sensitivities, while still benefitting from improved lateral boundary conditions derived from the coarser grids that do have FDDA.

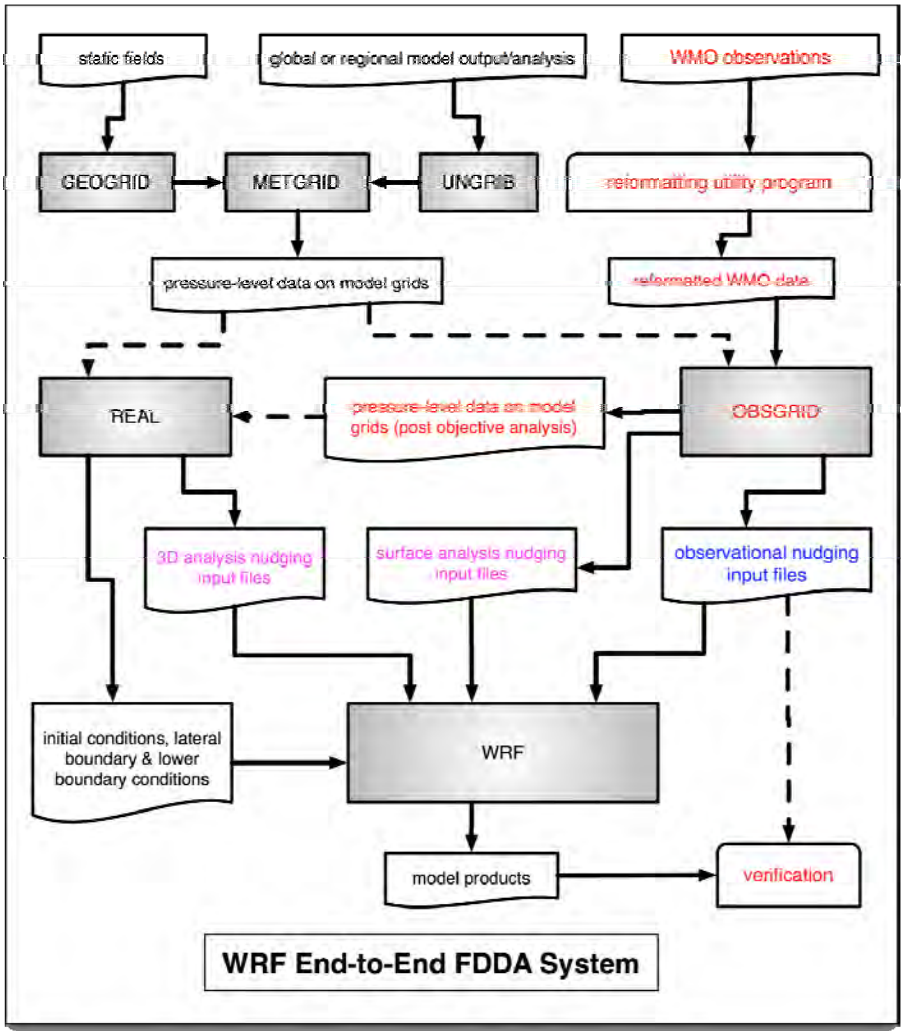


Fig. 5: Diagram of the WRF End-to-End FDDA system used for this study (from Deng et al. 2009). Items in magenta apply to analysis nudging; items in blue apply to obs nudging; items in red apply to both.

For the generation of the final dynamic analysis, obs nudging was performed on Grid 3, but with a reduced horizontal radius of influence (from 100 to 75 km), a reduced vertical pressure difference within the terrain-modified radius of influence function used for surface obs nudging (from 75 hPa to 37.5 hPa),

and obs nudging of surface data was performed on mass fields only (i.e., not winds). The values of FDDA-related WRF namelist parameters for these simulations can be found in Table 2.

	3D/Sfc Analysis Nudging			OBS Nudging		
Parameter	Grid 1 12-km	Grid 2 4-km	Grid 3 1.3-km	Grid 1 12-km	Grid 2 4-km	Grid 3 1.3-km
G (1/sec)	$3*10^{-4}$	**Not Used**	**Not Used**	$4*10^{-4}$	$4*10^{-4}$	$(4*10^{-4})$
Wind field	Yes	**Not Used**	**Not Used**	Yes	Yes	No
Mass field	Yes	**Not Used**	**Not Used**	Yes	Yes	(Yes)
RINXY (km)	N/A	N/A	N/A	100	100	(75)
TWINDO (hours)	N/A	N/A	N/A	2	2	(2 – but see Section 5)
Time Frequency of Data (hours)	6 / 3 (Sfc)	**Not Used**	**Not Used**	1	1	(1)

Table 2: List of WRF FDDA namelist parameter values used in this study. Analysis nudging parameters apply to both surface and 3D versions unless otherwise specified. Values in parentheses for Grid 3 do not apply to the physics sensitivity studies, which have no FDDA on Grid 3, but do apply to the final dynamic analysis performed in this study.

2.3 Baseline Physics Suite

Two of the most important controls on the evolution of SBLs in mesoscale models are the PBL scheme and the Land Surface Model (LSM). The former is critical for determining the effects of vertical mixing both within and outside of the PBL, and thus helps regulate how rapidly pollutants can disperse. The LSM helps to determine the details of the surface energy balance and thus the thermal tendency and stability of air near the surface. In addition to these, other physical processes that are important in these conditions are the atmospheric radiation scheme (because of the impact on the thermal cooling and temperature structure of the lower atmosphere) and the microphysics scheme (because of the interactions between radiation, latent heat, and quantities of water vapor and condensate, as well as the value of predicting such features as ice fog).

The baseline physics suite used for these simulations was originally derived from that of Seaman et al. (2008) for central Pennsylvania, but with some modifications. To determine the longwave component of radiation, the RRTM scheme of Mlawer et al. (1997) was used, whereas the Dudhia (1989) scheme was used to determine the shortwave component. The PBL scheme used was a version of the Level 2.5 Mellor Yamada scheme as modified by Janjić (2002); henceforth this will be referred to as the Mellor-Yamada-Janjić (MYJ) scheme. A Level 2.5 scheme explicitly predicts the evolution of turbulent kinetic energy (TKE) at each grid point, and uses the predicted TKE to compute the magnitude and vertical extent of mixing. The MYJ scheme used is that available in version 3.1 of WRF; however, based on subsequent work from the central Pennsylvania study, the threshold of minimum TKE within the MYJ scheme was reduced to 0.01 $m^2 s^{-2}$, due to the extremely weak winds and turbulence expected in these stable conditions.

The LSM for the baseline was originally the 5-layer thermal diffusion model used in Seaman et al. (2008). However, we performed a series of preliminary tests with the Alaska grid configuration using the Noah LSM, originating from NCEP, Oregon State University and AFWA (Chen and Dudhia 2001). This was done because the Noah LSM includes a number of features that are potentially important in the central Alaska environment, including time-dependent snow cover, time-dependent snow density, and snow-dependent emissivities and ground conduction. Some properties of the Noah LSM that had just been incorporated into standard WRF (e.g., a more rigorous treatment of latent heat release in the presence of ice) were based on the 'Polar-WRF' and 'Polar-MM5' versions of Noah used for high latitude simulations (Bromwich et al. 2001; Hines and Bromwich 2008). A number of other features of the polar-modified Noah were not in the standard WRF at the time, but not directly relevant to central Alaska (e.g., modification of sea ice properties). Preliminary tests in the relatively mild conditions immediately prior to the partial sunlight episode revealed that the use of the Noah LSM initialized directly from the soil levels of the half-degree GFS resulted in smaller surface temperature biases. Thus, based on our preliminary favorable results, we used the version of Noah in WRF v3.1 as the LSM for the baseline simulation.

The microphysics model selected for the baseline was the Morrison et al. (2005) scheme, also new to WRF v3.1. This scheme was developed specifically for high-latitude cold temperature microphysics, and includes the prediction of two moments (mixing ratio and number concentration) for rain, snow, graupel, and cloud ice, in addition to single moment prediction of cloud water. We thus felt it was worth using this scheme in the baseline even though file sizes and computational costs were significantly increased (by 50% in time) from the simple ice scheme used previously.

3. Initial Baseline Testing and FDDA Modifications

Initial testing of the baseline WRF configuration for the two episodes began in January 2009. The purpose of the 'pre-baseline' testing was to confirm that the proposed WRF grid configuration would remain numerically stable and physically realistic for simulation segments of several days, to determine the resource and timing requirements of the simulations, and to confirm that the WRF FDDA features were working as expected. Furthermore, a number of key WRF system features to be used in this study

were still under development at the beginning of 2009; in particular, surface analysis nudging, OBSGRID, and the official WRF v3.1 release itself, which included the QNSE PBL scheme and a modified version of the Noah LSM. Thus all of these new features had to be tested and evaluated when they became available.

At the beginning many of these tests were performed on the first segment of the partial sunlight episode (23 – 28 Jan 2008). Not only was this a convenient place to begin, but it began as a time of relatively warm temperatures in central Alaska, allowing the model configurations to be evaluated in relatively mild conditions before being used in the extreme cold conditions of the high exceedance episodes. Nonetheless, a brief period of colder temperatures occurred toward the end of the 23-28 Jan 2008 period, so some evaluation of model performance in different temperature regimes could be determined.

A preliminary assessment of the skill of the FDDA components of the WRF end-to-end system for the baseline simulation of the 23-28 Jan 2008 period, made in April 2009, is shown in Table 3 for the 12-km (Grid 1) and 4-km (Grid 2) domains. Raw WMO observations from both surface METAR and rawinsonde stations were given QC codes within OBSGRID, and only those observations of sufficient quality to be used in the objective analysis were retained for verification. The table compares a simulation without FDDA, a simulation using only analysis nudging on Grid 1; a simulation using only obs nudging on Grids 1 and 2; and a simulation combining the analysis nudging and obs nudging features, corresponding to the proposed multiscale multigrid FDDA procedure. Furthermore, since the surface analysis nudging feature of WRF had only just become available from Penn State, two versions of each simulation including analysis nudging were performed: one with and one without surface analysis nudging.

The table confirms that, for virtually every grid, observation station type, and variable, the best root-mean-square error (RMSE) scores occur for multiscale multigrid FDDA, and the worse RMSE scores occur for the simulation without any FDDA. However, a more careful analysis of the table revealed a few puzzling results. While surface analysis nudging led to expected improvements in temperature on Grid 1 (vs. analysis nudging without surface analysis nudging) when verified against surface METAR stations, the RMSE scores of METAR winds and relative humidity actually became slightly worse. Furthermore, when the verification was performed against rawinsondes on Grid 1, surface analysis nudging made temperature RMSEs considerably worse, and wind RMSEs far worse, than the corresponding runs without surface analysis nudging.

For Grid 2 verified against rawinsonde data, we see the expected result that a simulation with only obs nudging improves the RMSE scores more than either version of the analysis nudging only simulation. (Since analysis nudging is always applied to Grid 1 only, the analysis-nudging-only simulations have only indirect FDDA improvements on Grid 2, through the lateral boundary conditions from Grid 1; the obs nudging simulations do have direct FDDA on Grid 2.) However, when surface METARs are used for Grid 2 verification, we have the puzzling result that obs nudging only is outperformed by analysis nudging only (except for temperature).

Verification Domain	Verification Field and Station Type	Simulation FDDA Method (O – Obs Nudging; 3DA – 3D Analysis Nudging; SA – Surface Analysis Nudging; No – No Nudging)			
Grid 1 (12 km)		Grid 1: No Grid 2: No	Grid 1: O Grid 2: O	Grid 1: 3DA / 3DA + SA Grid 2: No / No	Grid 1: 3DA + O / 3DA + SA + O Grid 2: O / O
	Surface U-Component	3.2	2.6	2.3 / 2.4	**2.1** / 2.2
	Surface V-Component	3.2	2.7	2.1 / 2.3	**2.0** / 2.1
	Surface Temperature	5.6	2.9	2.9 / 2.4	2.5 / **2.1**
	Surface Rel. Humidity	21.0	18.7	17.7 / 18.2	**17.0** / 17.5
	Sounding U-Component	4.6	2.2	1.5 / 3.3	**1.1** / 2.0
	Sounding V-Component	4.2	2.3	1.5 / 2.9	**1.1** / 1.9
	Sounding Temperature	3.5	1.4	1.4 / 2.0	**1.0** / 1.3
	Sounding Rel. Humidity	21.2	10.2	11.2 / 16.0	**8.3** / 10.5
Grid 2 (4 km)	Surface U-Component	3.8	3.3	**2.2** / 2.3	2.5 / 2.7
	Surface V-Component	**2.5**	3.1	2.7 / 2.8	2.9 / **2.5**
	Surface Temperature	5.0	2.5	3.1 / 3.0	1.9 / **1.8**
	Surface Rel. Humidity	23.8	22.0	20.7 / 20.7	19.6 / **19.3**
	Sounding U-Component	4.5	2.2	2.6 / 2.8	**1.7** / 1.8
	Sounding V-Component	4.5	3.2	3.4 / 3.8	**2.8** / 3.4
	Sounding Temperature	3.1	1.3	2.2 / 2.2	**0.9** / 1.4
	Sounding Rel. Humidity	27.0	14.1	21.7 / 24.5	**12.5** / 13.1

Table 3: Root-mean-square error (RMSE) values of u-component wind (m s^{-1}), v-component wind (m s^{-1}), temperature (°C) and relative humidity (%) as verified within Grids 1 and 2 during test FDDA simulation of 23-28 Jan 2008 for various FDDA combinations. Verification was performed against METAR stations for the surface and rawinsonde stations for the sounding data. The best value for each row is in bold.

Investigations into the cause of these puzzling results led to the realization that a number of the components of the WRF end-to-end FDDA system probably needed to be modified to adapt the system to the special conditions of the Alaska configuration. First, in most mesoscale model simulations it can be assumed that surface wind observations, normally made at a height of 10 m above ground level (AGL), and surface temperature and moisture observations, normally made at 2 m AGL, are located within the lowest model layer. In fact, normally the problem is that the midpoint of the lowest model layer (or first half-layer height above the surface) is often tens of meters in height and still well above the height of the surface observations. A proper interpolation of model values to the height of the surface observations usually requires using similarity theory or some similar procedure. For the Alaska configuration, however, a 10-m wind would actually be located within the *third* model layer from the surface, while 2-m temperature essentially corresponds to the height of the lowest model half layer (midway between the surface and the lowest model full level). There are at least two consequences of this. The first is that, for the default procedure of verifying surface wind observations with model output from the lowest model half layer, observed 10-m winds are actually being compared to modeled 2-m winds whereas they should be verified against the modeled 10-m winds of the third model half layer. The second consequence is that the surface wind innovations used in the WRF FDDA code are by default based on the difference between 10-m observed winds and 2-m modeled winds in this case, which is wrong and may introduce erroneous biases into the FDDA simulation.

An additional issue was revealed by examining fields of PBL height produced by the PBL turbulence parameterization in various test simulations. Though, as expected, PBL heights are very low over many large areas within the model domains, especially during the colder periods, some patches of unexpectedly high PBL height values can be seen at times (Fig. 6). PBL heights of 1500 m or greater are more typical of convective boundary layers than of the nocturnal SBL conditions found in interior Alaska. Model soundings taken in the proximity of these patches (Fig. 7) confirm that the atmosphere is certainly rather stable and not well mixed in potential temperature (although some layers above show potential temperatures close to a saturated adiabat). The high PBL height zones appear to be associated with regions of elevated shear-generated TKE and cloudiness, since it is the TKE profile in the MYJ scheme that determines the PBL height. The issue is that the default WRF surface analysis and obs nudging schemes spread the influence of surface innovations throughout the depth of the PBL, but in these stable conditions this may overestimate the vertical error correlation length scale for surface innovations. This helped explain why the use of surface analysis nudging on Grid 1 made the rawinsonde-verified statistics worse.

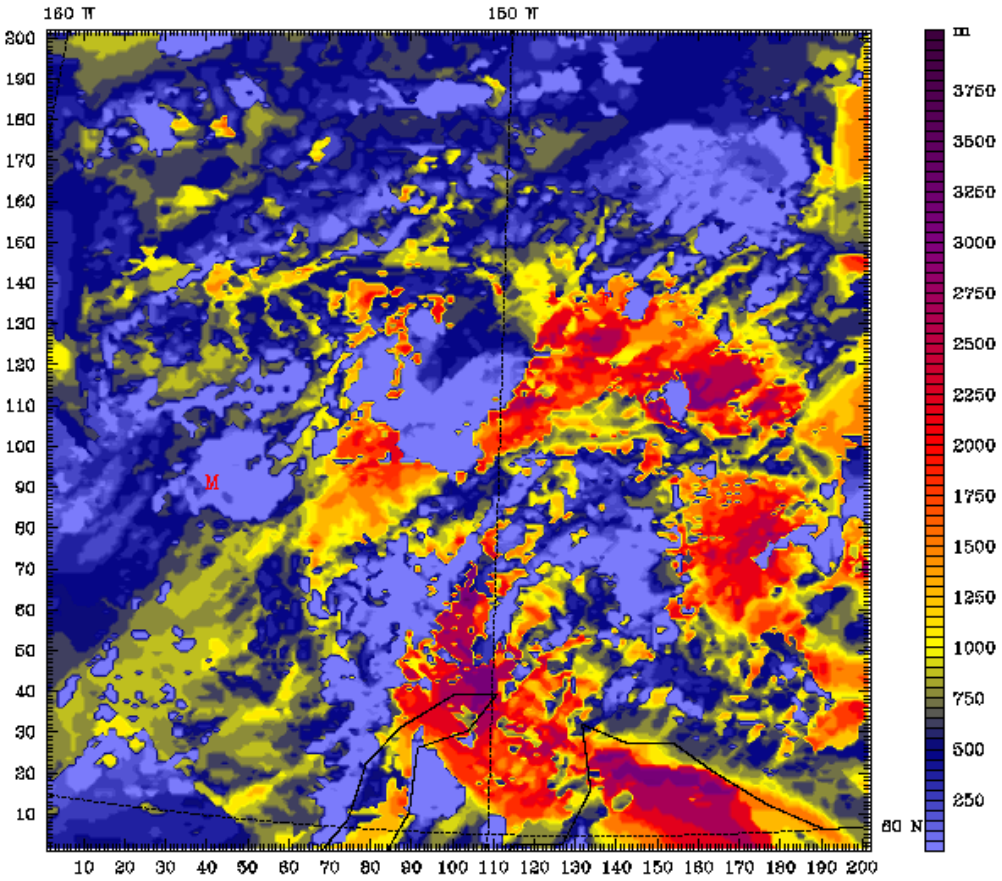


Fig. 6: WRF-predicted PBL height at 1200 UTC 25 Jan 2008 (60-hour simulation time) within the 4-km Grid 2. Simulation does not include FDDA.

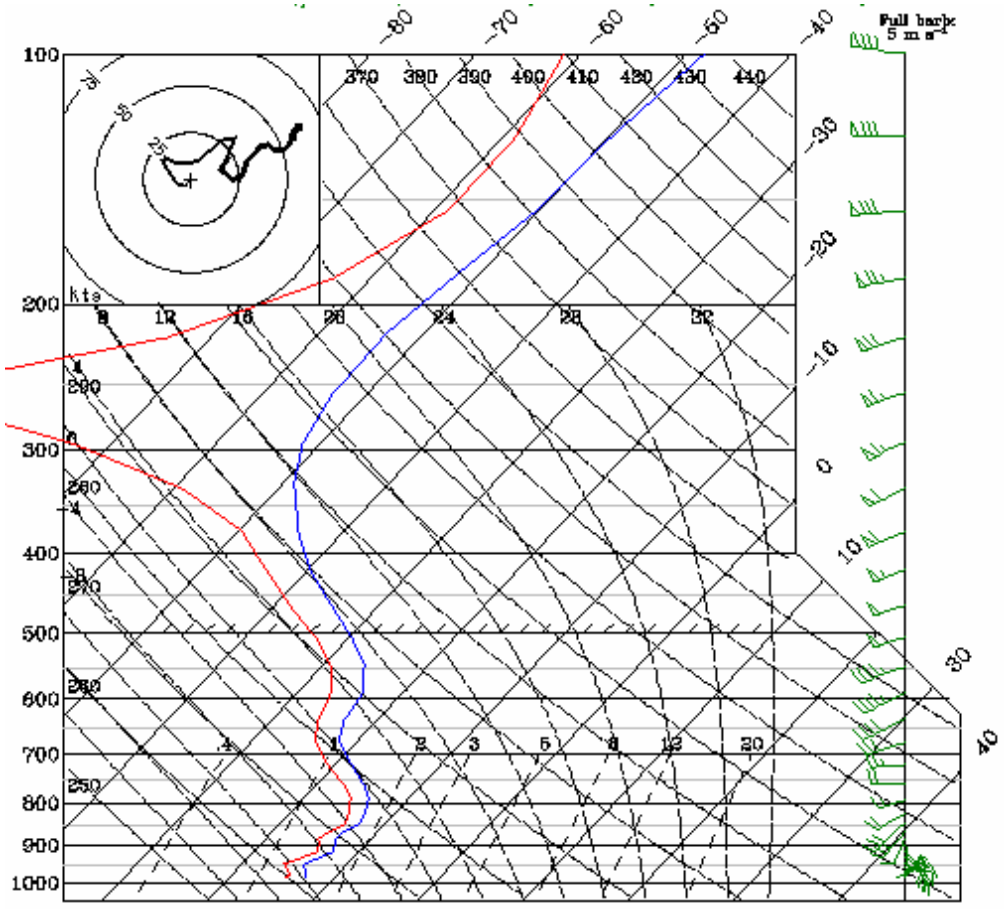


Fig. 7: WRF-predicted model sounding at Fairbanks for same time and simulation as Fig. 6.

Based on a series of similar tests, the following modifications were made to the WRF FDDA schemes for use in the baseline Alaska simulations. 1) The verification software was rewritten so that surface wind observations are verified against the third model half-layer from the ground, while surface moisture and temperature observations are verified against the lowest model half-layer. 2) A portion of the verification software that uses an assumed lapse rate to adjust model temperatures based on the difference between modeled and actual elevation was disabled, because this can lead to large errors in very stable conditions. 3) The surface analysis nudging and obs nudging codes were modified so that surface innovations for wind are computed and applied directly at the third model level. 4) Because surface wind observations directly relate to the third model layer and surface temperature and moisture observations directly relate to the lowest model layer, the similarity-based adjustments normally performed on model output for surface innovation computation was also disabled. 5) Hardwired vertical weighting functions for surface innovations were implemented into the surface analysis nudging and obs nudging codes, replacing the default functions that extend surface corrections to the model-predicted PBL height. Trial and error established that the functions shown in Fig. 8 for surface obs

nudging and analysis nudging extend the surface innovations in the vertical enough to improve surface statistics but without degrading rawinsonde-verified RMSE scores; furthermore, the vertical extent of

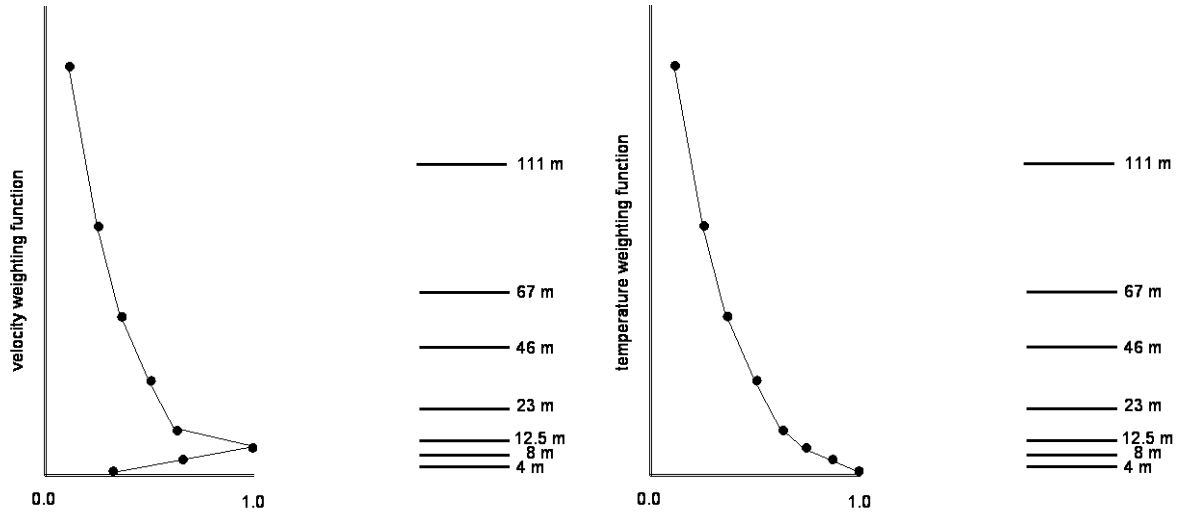


Fig. 8: Vertical weighting functions at model half-layers for wind components (left) and temperature and moisture (right), as used by modified surface analysis nudging and obs nudging FDDA procedures for Alaska simulations. Heights of model full layers are shown to the right, roughly to scale.

these functions (about 150 m) is a reasonable order of magnitude estimate for the maximum depth of nocturnal radiatively-driven SBLs.

Results from this phase of the project were presented at an oral presentation at the 13th AMS Conference on Mesoscale Processes in Salt Lake City, UT, from 17-20 Aug 2009. (Gaudet et al. 2009).

4. PHYSICS SENSITIVITY EXPERIMENTS

4.1 Experimental Design

Three modifications of the baseline physical parameterizations were evaluated in the physics sensitivity component of this project. The first involved modifying the atmospheric radiation schemes so that both the longwave and shortwave components used the new RRTMG radiation package, which uses the RRTM methodology but in a more efficient form adaptable to global climate models. This particular radiation package first became available in WRF v3.1. Though the RRTM and RRTMG longwave radiation schemes should produce very similar clear-sky fluxes, when mult-layered condensate is present the RRTMG makes use of the Monte Carlo Independent Column Approximation (McICA) to take into account 3D scattering effects.

The second involved changing the PBL parameterization from MYJ to the Quasi-Normal Scale Elimination (QNSE) scheme (Sukoriansky et al. 2005; Galperin et al. 2007). The theory behind the scheme is quite

advanced, but it is specifically designed for stable conditions, and allows both turbulent mixing and gravity wave motions to be represented in a unified framework. Dr. Boris Galperin was invited to Penn State University to give a seminar on the theory of the QNSE scheme in October 2008 before it was officially made public in WRF v3.1. The implementation of the QNSE scheme in WRF is actually similar to that of the MYJ, but with the values of vertical mixing parameters derived from the theory as a function of Richardson number (i.e., essentially the ratio of atmospheric stability to the square of the wind shear).

The third modification involved changing the LSM model from Noah to the Rapid Update Cycle (RUC) LSM. Among the features of the RUC LSM that suggest its use for this study is the presence of a snow model that potentially can have multiple layers depending on the snow depth (Smirnova et al. 2000). Other users have reported favorable results from using the RUC LSM in simulations of the Arctic (Mölders and Kramm 2010). The RUC LSM can also be initialized using soil information from the half-degree GFS after minor modification of the WRF source code. By default WRF can use either 6 or 9 soil levels, but we chose 6 because it is closer to the 4 levels of Noah and because it is the typical number of soil levels used in the RUC (e.g, Hines and Bromwich 2008).

4.2 Model Initialization and Setup

The objective analyses used for model initialization and analysis nudging were performed using the multi-quadric method within the OBSGRID software designed for WRF. The background analysis files were derived from the half-degree GFS and topographic and land use dataset through the WPS. The background fields also served as the basis for performing QC on the WMO rawinsonde and surface METAR data used for verification and obs nudging, through 'buddy-check' (excluding obs too different from their neighbors) and 'err-max' (excluding obs too different from the background) procedures. A consequence of the current QC methodology is that all observations were located at the surface or at the standard pressure levels of the GFS model.

For the baseline and sensitivity experiments the model setup was the same except for the choice of physics options. Both the near total darkness and the partial sunlight episodes were simulated in their entirety using the four overlapping simulation segments referred to above. The FDDA procedure (using the modified vertical weighting functions) was defined to use surface and 3D analysis nudging on the 12-km Grid 1, obs nudging on both the 12-km Grid 1 and the 4-km Grid 2, and no FDDA on the 1.3-km Grid 3. Physics sensitivities on Grid 3 would thus be given greater weight than sensitivities on the other grids (which would not be expected to be as large due to the influence of FDDA). (However, we left open the possibility of performing a final dynamic-analysis simulation with obs nudging also performed on Grid 3 once a best-choice physics suite was selected; this final simulation would then have our best available model analysis of the atmospheric state during the episodes, and would be appropriate for use in atmospheric chemistry or transport and dispersion models. These results have been added to the report in Section 5 below.)

For each sensitivity experiment verification was performed using model output every 3 hours (excluding the initial time). For the periods of overlapping simulation segments, the model output from the segment at the larger forecast time was used, so all of the verification model output was at least 12 hours after a model initialization (except of course for the first 12 hours of an episode). All three grids were verified against only those stations located within the boundaries of Grid 3, to ensure that statistical differences between grids are not due to the different set of stations available on each domain. As previously discussed, verification of surface METAR data is performed directly with the third model level from the surface for winds, and the lowest model level for temperature and moisture.

The first physics sensitivity test involved changing the radiation to the RRTMG scheme for both longwave and shortwave components. We all agreed that if this produced favorable results we could simply retain the RRTMG radiation scheme rather than the Dudhia shortwave / RRTM longwave radiation suite of the baseline simulation in future sensitivity experiments. An initial three-day test (23-26 Jan) was performed without FDDA on any grid so as to maximize physics sensitivity. It was indeed found that the surface METAR temperature RMSE scores were consistently improved by the use of RRTMG (Fig. 9), although winds and relative humidity were little affected (not shown). The improvement seemed to be related to reduced downward longwave fluxes beneath patches of ice condensate. Thus, the decision was made that all future physics sensitivity tests, this time with FDDA on Grids 1 and 2 as described above, would make use of the RRTMG scheme.

The combinations of physics parameterizations used in the physics sensitivity tests are summarized in Table 4. To facilitate the comparison of different physics sensitivity experiments, the baseline simulation, with the combination of MYJ PBL scheme, Noah LSM, and Dudhia shortwave / RRTM longwave radiation, will henceforth be denoted as experiment MND. Another experiment, with MYJ PBL / Noah LSM / RRTMG radiation, will be noted as MNR, and another with QNSE PBL / Noah LSM / RRTMG radiation will be denoted as QNR. Finally, the experiment with MYJ PBL / RUC LSM / RRTMG radiation will be denoted as MRR.

Experiment Name	Planetary Boundary Layer (PBL)	Land Surface Model (LSM)	Radiation
MND (Baseline)	Mellor-Yamada-Janjić (MYJ)	Noah	Dudhia Shortwave / RRTM Longwave
MNR	Mellor-Yamada-Janjić (MYJ)	Noah	RRTMG Shortwave / RRTMG Longwave
QNR	Quasi-Normal Scale Elimination (QNSE)	Noah	RRTMG Shortwave / RRTMG Longwave
MRR	Mellor-Yamada-Janjić (MYJ)	Rapid Update Cycle (RUC)	RRTMG Shortwave / RRTMG Longwave

Table 4: Names and physical parameterizations used for physics sensitivity studies.

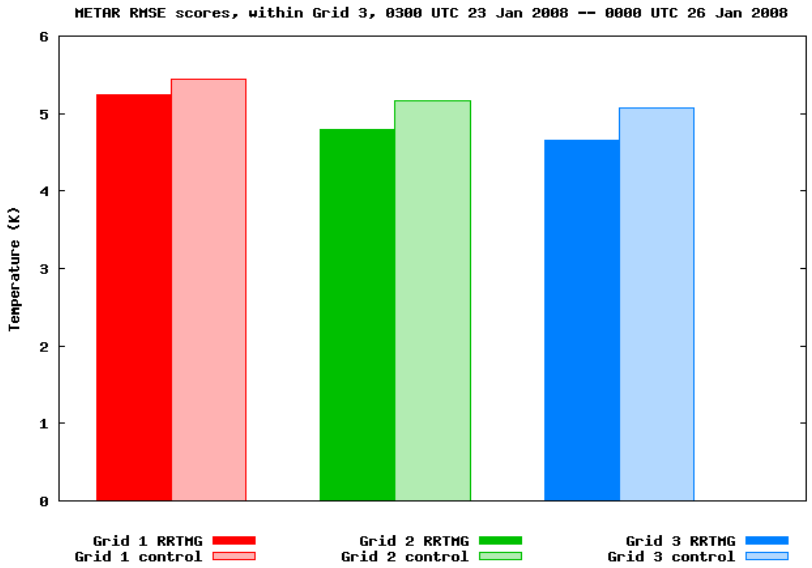


Fig. 9: Surface METAR RMSE scores for temperature compiled for those stations located within Grid 3 for simulations from 00 UTC 23 Jan 2008 – 00 UTC 26 Jan 2008. Verification statistics are computed every three hours during the period. 'Control' denotes baseline physics configuration; 'RRTMG' denotes baseline physics configuration but with the RRTMG longwave and shortwave radiation schemes. All simulations shown were performed without FDDA.

4.3 Results of Physics Sensitivity Experiments

Figures 10 and 11 present the temperature RMSE and bias scores, respectively, for Grid 3 surface METAR stations for both the partial sunlight and near total darkness episodes. First, it can be seen that the RMSE score increases from Grid 1 to Grid 2 to Grid 3, which can be explained by the fact that less FDDA forcing is being applied from Grid 1 (both analysis and obs nudging) to Grid 2 (obs nudging) to Grid 3 (no nudging). These RMSE scores are large compared to typically reported surface meteorological values (e.g., Seaman and Michelson 2000), but of course the large temperature range through the period (about 40°C for both episodes) and extreme conditions make these challenging forecasts for a numerical model. Second, we see the previously discussed result that switching the radiation to RRTMG (compare MND and MNR) leads to improved temperature RMSE scores and lower positive temperature biases; the improvement is most noticeable on the no-FDDA Grid 3. The fact that the RMSE improvement through the use of the RRTMG is greater for the near total darkness episode than for the

partial sunlight episode was not unexpected, because previous examination of the partial sunlight episode revealed that the reduced positive temperature bias with RRTMG was due to the longwave component while the shortwave component of RRTMG partially counteracted this effect (not shown).

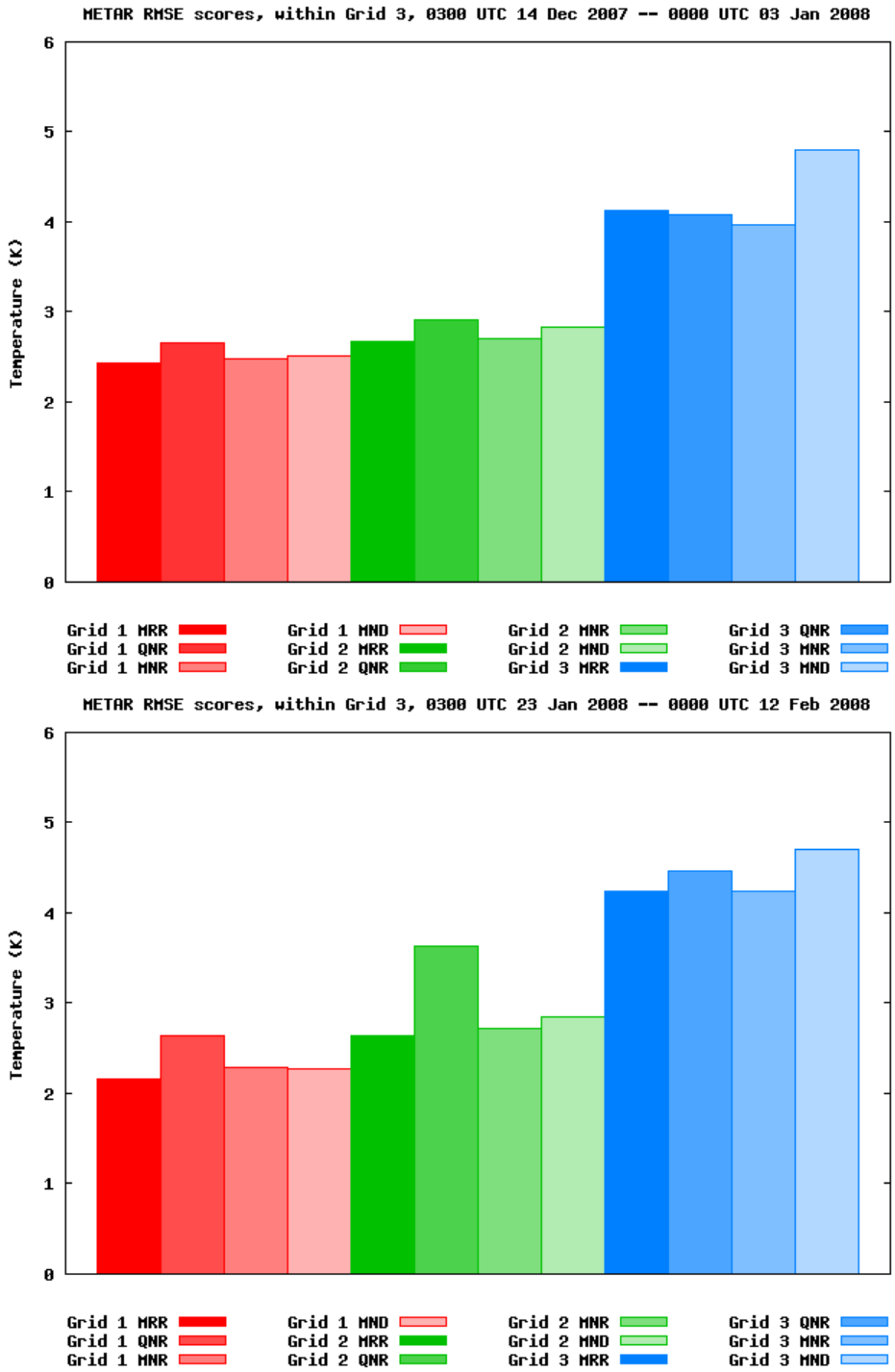


Fig. 10: Surface METAR RMSE scores for temperature for entire near total darkness episode (top) and partial sunlight episode (bottom). Labels for degree of shading refer to experiment names in Table 3. Verification statistics were computed every 3 hours during each episode as described in text.

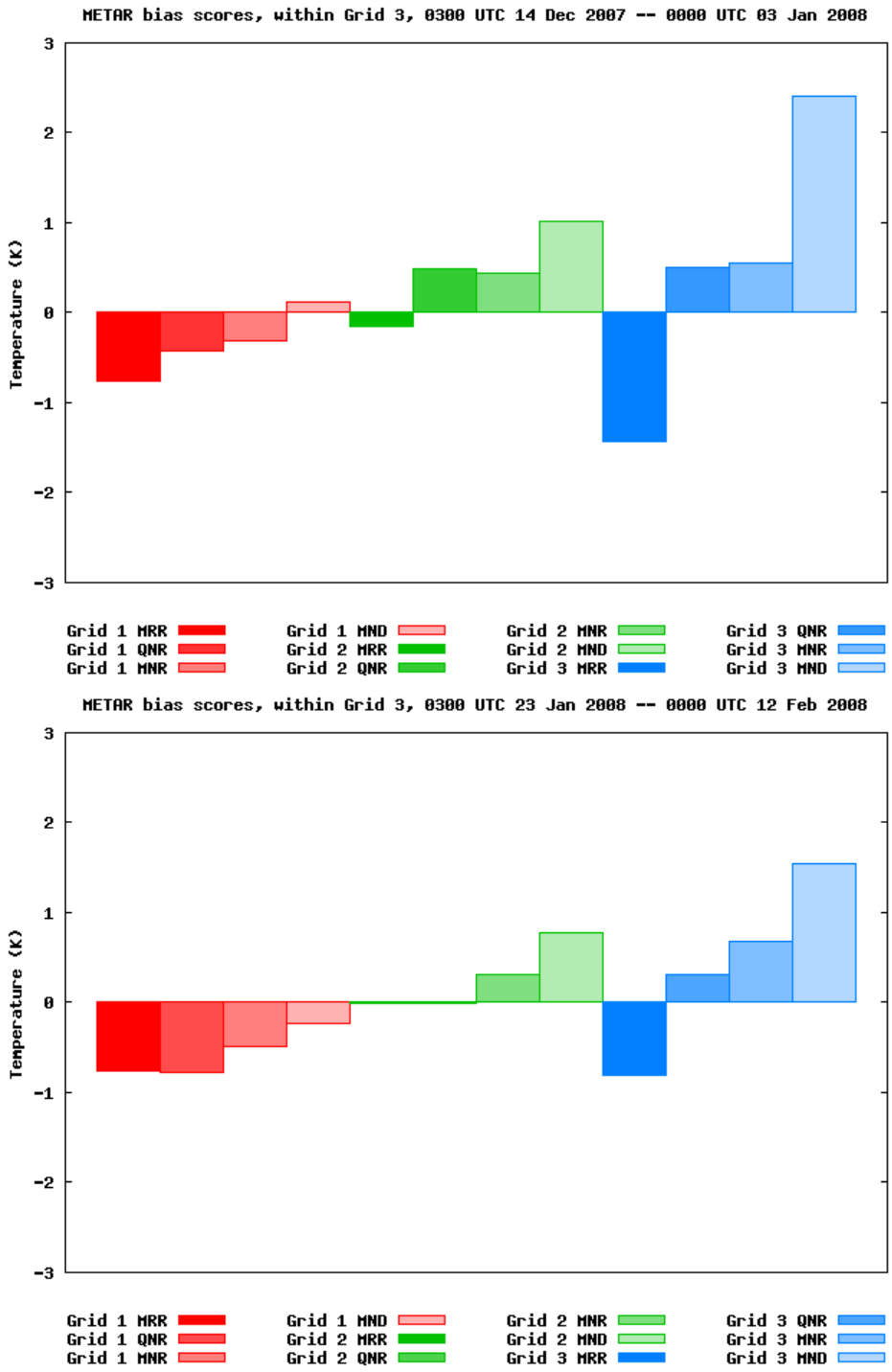


Fig. 11: Same as Fig. 10, but for surface METAR bias scores for temperature.

Switching from the MYJ to the QNSE PBL scheme (compare MNR to QNR) further reduced and improved the magnitude of positive METAR temperature bias (for Grid 3 and the Grid 2 partial sunlight episode). However, the temperature RMSE scores for QNR are consistently greater than those for MNR; so this improved bias is not reflected in more skillful forecasts. The results of the QNSE PBL scheme are encouraging and should be analyzed in greater depth in a future project. We decided that the sensitivity test introducing the RUC LSM should use the MYJ scheme due to our greater experience with MYJ in WRF.

The effect of switching from Noah to RUC (compare MNR to MRR) produces the coldest surface temperatures of any of the experiments. While this leads to the best magnitude METAR temperature biases for Grid 2, the MRR Grid 3 temperature bias is considerably more negative, especially for the near total darkness episode. The MRR temperature RMSE scores for the METARs are the best, or tied for the best, of the four physics experiments for Grid 2 and the Grid 3 partial sunlight episode, but slightly worse than MNR and QNR for the Grid 3 near total darkness episode.

In terms of surface METAR wind speed RMSE and bias errors (Figs. 12 and 13) we see that there is less variability among the different physics schemes. For virtually all variables, grids, and episodes, however, the scores for experiment MNR are slightly better than the others. The wind speed RMSE scores tend to be slightly worse on Grid 3 without FDDA than on Grid 2 with obs nudging, but better than those on Grid 1 that uses analysis nudging but with a much coarser horizontal resolution.

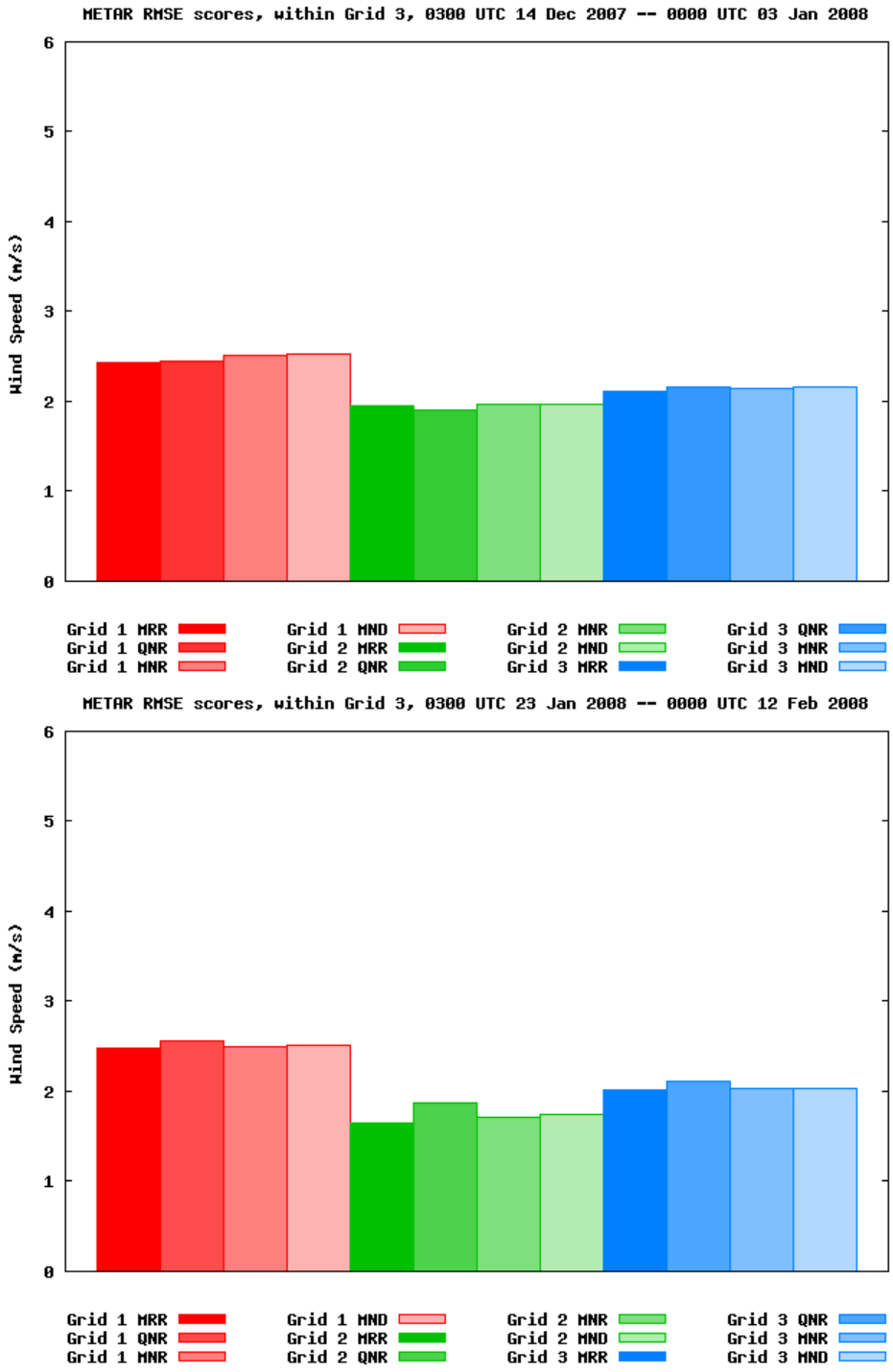


Fig. 12: Same as Fig. 10, but for surface METAR RMSE scores for wind speed.

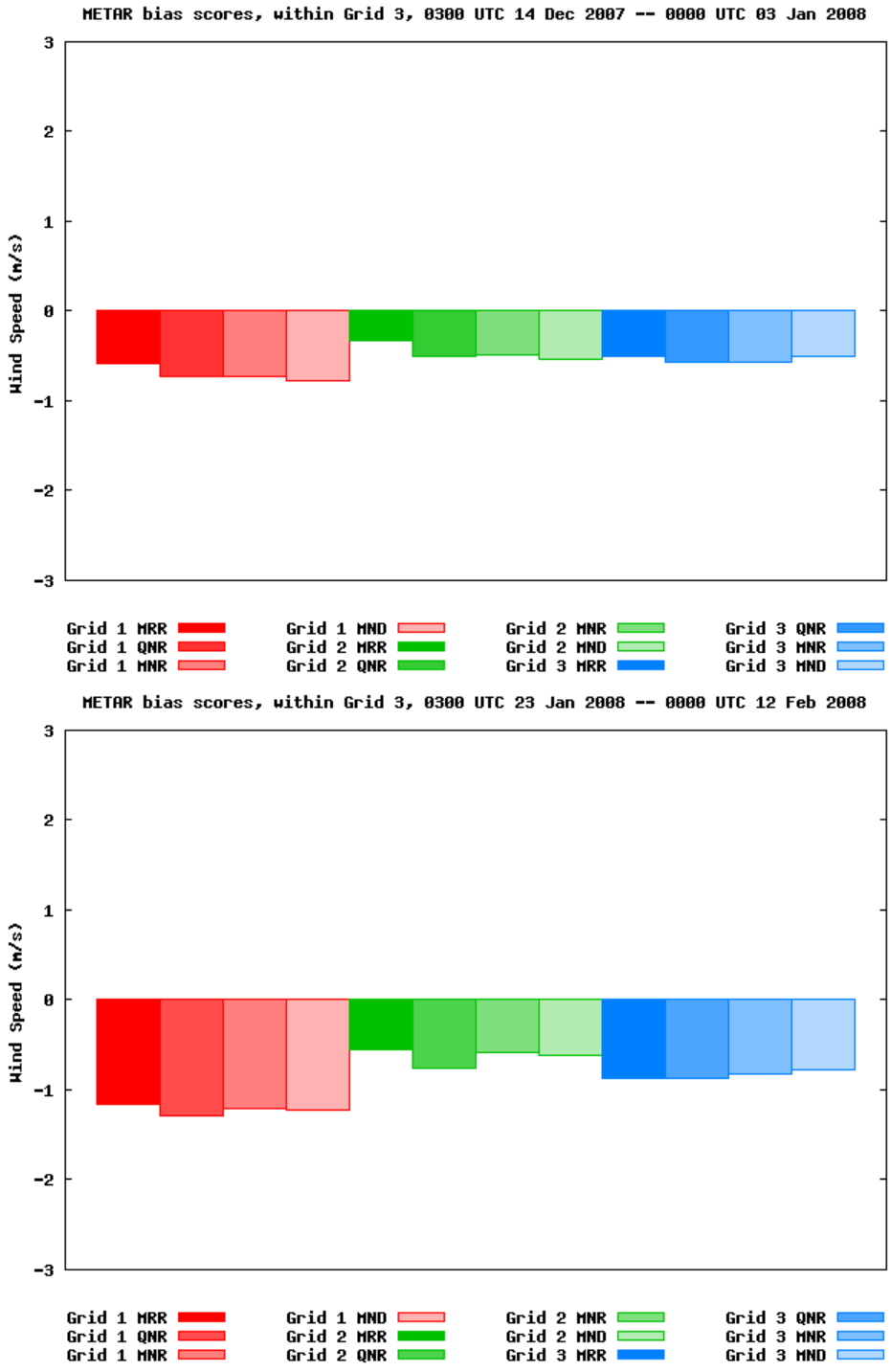


Fig. 13: Same as Fig. 10, but for surface METAR bias scores for wind speed.

In order to learn more about the nature of these biases, statistics for each episode can be compiled for each of the four 5-day (or 5.5-day or 6-day) simulation segments. One instructive comparison is between 14-20 Dec 2007 and 20-25 Dec 2007 (Fig. 14). The temperature difference between different physics configurations remains quite consistent between the two periods, but in the 14-20 Dec period the model temperature bias tends to be more negative than for the 20-25 Dec period. It can be shown that the large negative temperature biases of MRR are predominantly from the 14-20 Dec period. It should be noted that the highest exceedances / lowest temperatures for the near total darkness episode occur around 21 Dec. In general, Grid 3 tends to magnify the temperature biases of Grid 2, except for the MRR model for 20-25 Dec, where the Grid 3 temperature bias is reduced to almost zero.

A time series of the averaged observed, MNR, and MRR temperatures at the locations of the Grid 3 METARs is shown in Fig. 15. Note that the strongest MRR negative temperature biases in each episode tend to occur during times when the temperature is decreasing toward the coldest temperatures near 21 Dec in the near total darkness episode and about 05-09 Feb 2008 for the partial sunlight episode. At these times the MNR temperature bias also tends to be negative, but not by as much. However, immediately after the coldest temperatures are reached, the model biases become positive, and then the MRR configuration is preferred because temperature biases are smaller in magnitude. In particular, during the cold 5-9 Feb period MRR lacks the strong positive spikes in temperature bias that occur in the MNR simulation during the afternoons.

Verifying model features above the surface was made difficult by the scarcity of such observations in the region; the only rawinsonde sounding stations within Grid 2 are at Anchorage, McGrath, and Fairbanks, and of these only Fairbanks is located within Grid 3. No other reliable set of above-surface observations within Grid 3 was available for the episodes. A time-averaged composite of the vertical temperature structure of the Fairbanks sounding, compared to that from the different model physics configurations, is shown in Fig. 16. Since the quality-controlled observations used in the verification are located at the background GFS pressure levels, which have 25 hPa spacing near the ground, this is the effective maximum vertical resolution of the figure. The figure shows the zone from 700 hPa down to 975 hPa, which is the lowest pressure bin located entirely above the surface at Fairbanks. Note that the chosen variations in physics packages have virtually no effect above approximately 850 hPa, and all the modeled temperature profiles are extremely close to the observed profile, presumably due to the impact of Grid 2 obs nudging along the boundaries of Grid 3. From about 850 hPa to 925 hPa, the models begin to diverge from the observations for the near total darkness episode; the MND configuration is about one degree C too warm, but the models with the RRTMG radiation package reduce the positive temperature bias by about a factor of two. For the partial sunlight episode all models track the observations closely down to about 900 hPa. Below 950 hPa the MRR configuration becomes the coldest of the models, and the closest to the observed profile, especially for the near total darkness episode. At these lowest levels the RRTMG sensitivity remains much greater for the near total darkness episode than for the partial sunlight episode. The MNR and QNR configurations are always virtually indistinguishable, suggesting that choice of PBL scheme has little impact on the vertical temperature structure at 975 hPa and higher elevations.

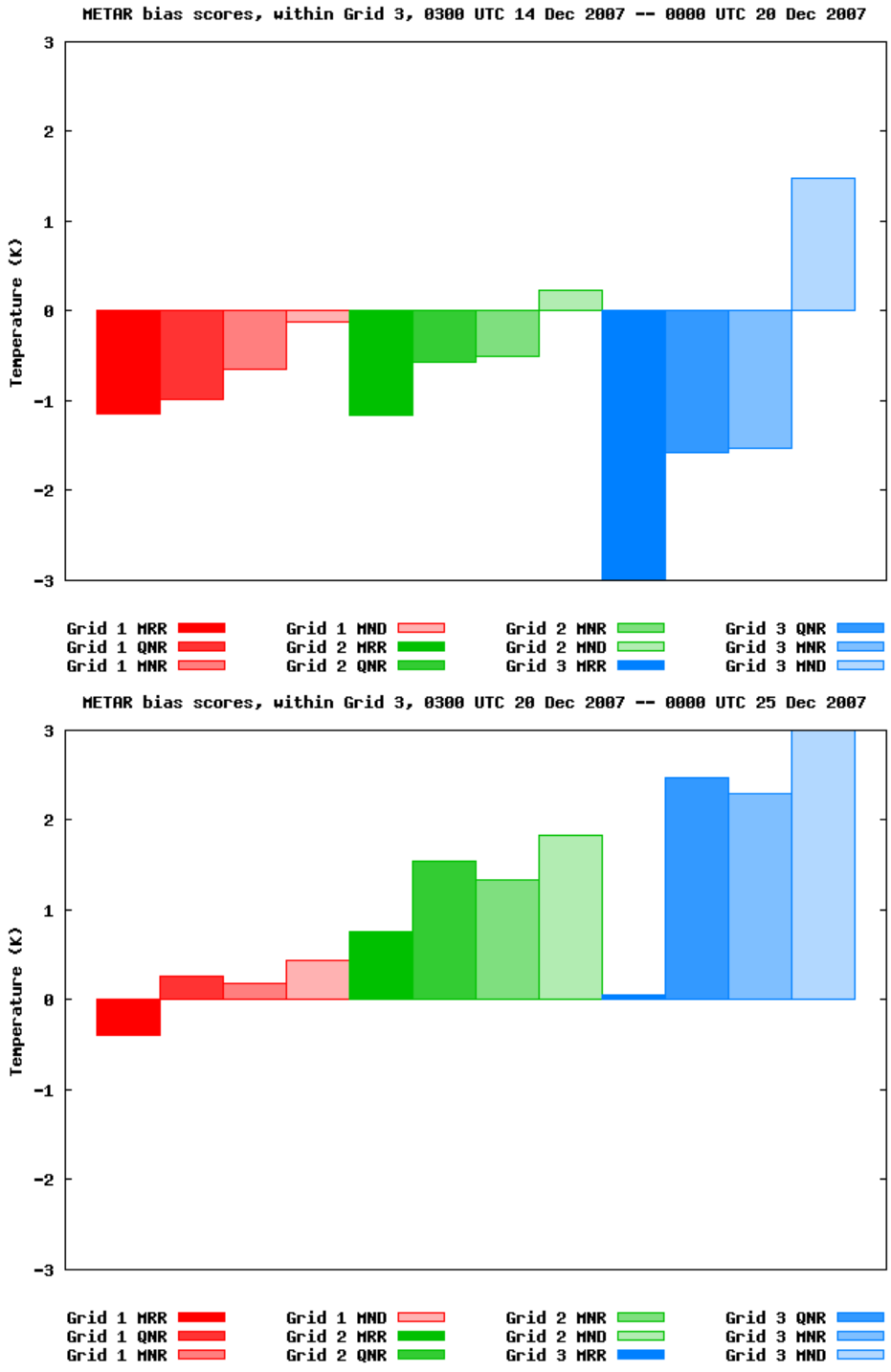


Fig. 14: Surface METAR bias scores for temperature during the near total darkness episode within the 14-20 Dec period (top) and 20-25 Dec period (bottom). Otherwise, same as Fig. 11.

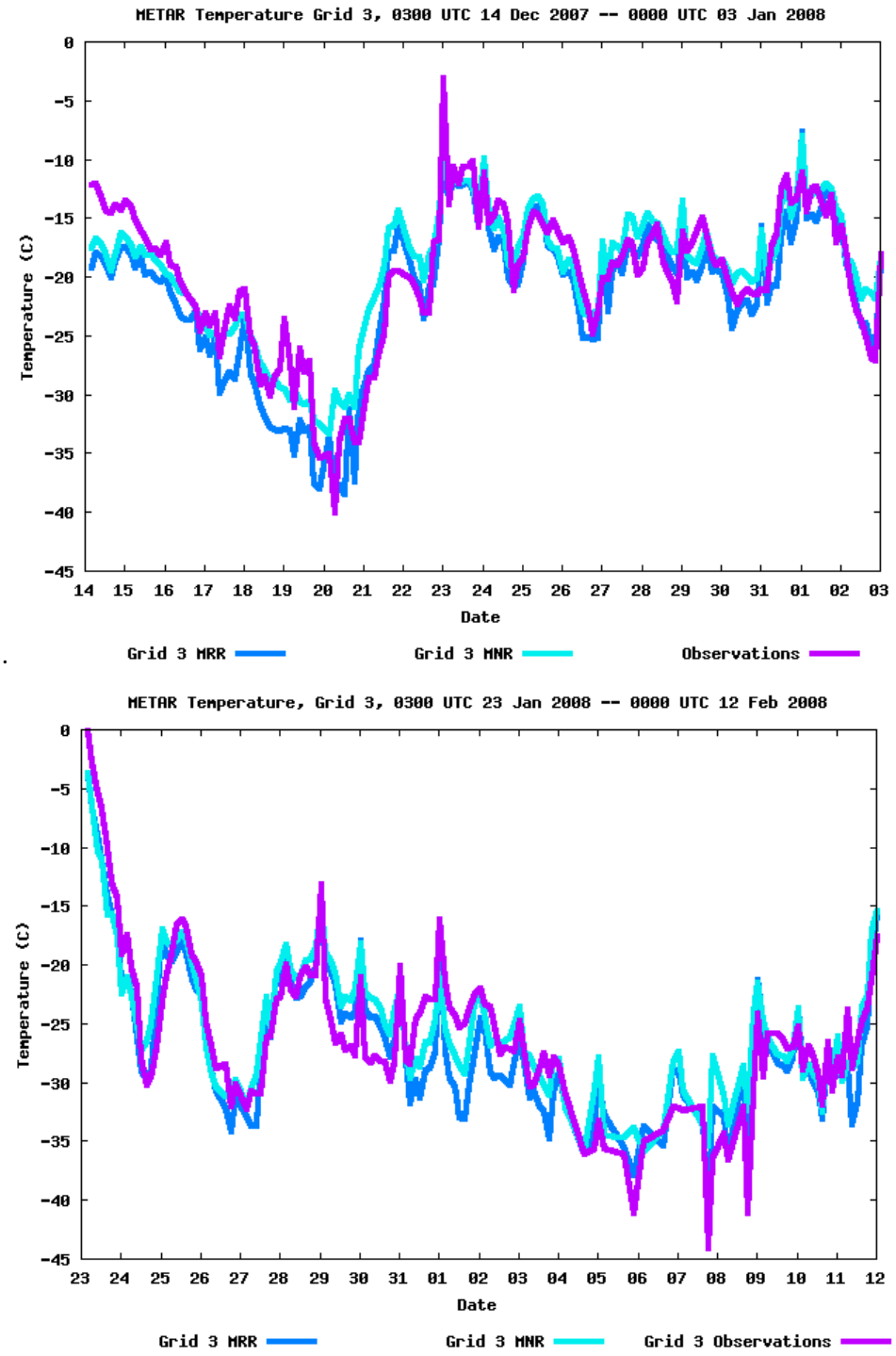


Fig. 15: Time series of temperature for near total darkness episode (top) and partial sunlight episode (bottom), averaged over the sites of all the surface METAR stations within Grid 3. Dark blue indicates value within Grid 3 from experiment MRR; light blue indicates value within Grid 3 from experiment MNR; purple indicates observed METAR value.

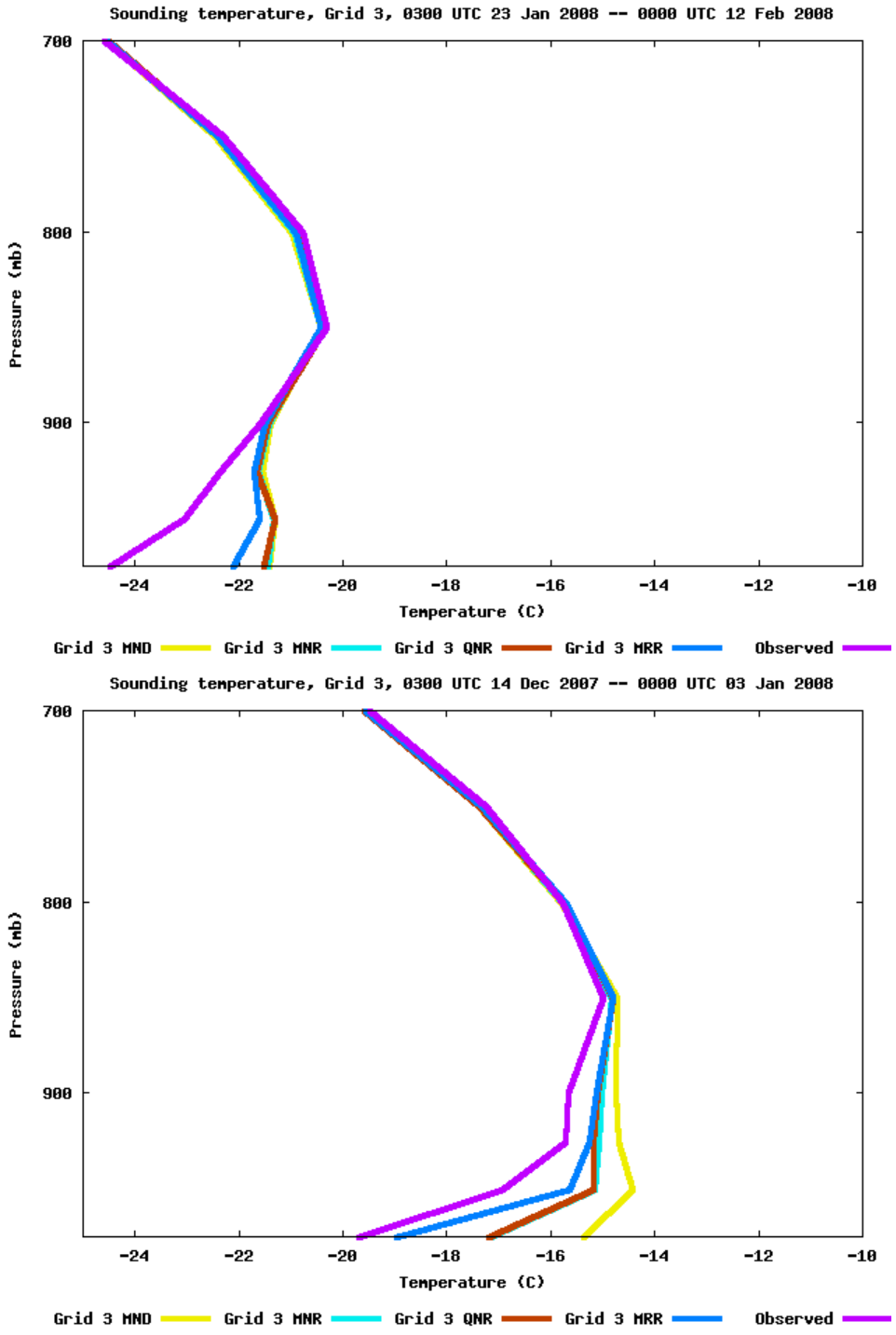


Fig. 16: Time-averaged vertical profile of Fairbanks sounding (PAFA) temperatures for near total darkness episode (top) and partial sunlight episode (bottom). Dark blue indicates value from experiment MRR; brown indicates value from experiment QNR; light blue indicates value from experiment MNR; yellow indicates value from experiment MND; purple indicates observed sounding value.

In order to learn more about the behavior of the different models, we examined the time series of the reported surface-level temperature of the raw Fairbanks sounding in comparison to the lowest-level model values at that location. When we compare the time series for the period surrounding the coldest temperatures of each episode (Fig. 17), an obvious diurnal trend appears in the partial sunlight episode observations during the coldest period from about Day 12 to Day 19 (4 – 11 Feb 2008). Little diurnal trend appears in the observations earlier in the episode; by contrast, the models all have a significant diurnal trend in surface temperature throughout the partial sunlight episode. The model diurnal amplitude during the 4-11 Feb 2008 period for the experiments other than MRR is approximately consistent with the observed amplitude, but the temperature values are consistently about 7°C too warm during this period. The MRR diurnal amplitude is somewhat larger than the others, such that it is similar to the other models for the warmer 0000 UTC times, but is much closer to the observations for the colder 1200 UTC times. For the period of rapidly falling temperatures immediately prior to 4-11 Feb the MRR experiment remains colder than the other models at the 1200 UTC times. In this case, the model 0000 UTC soundings are close to the observations, so the presence of a diurnal tendency in the model but not the observations during this time causes the 1200 UTC model soundings to be too cold, and the MRR sounding to be very cold.

During the near total darkness episode there is little diurnal variation in either the model or the observations. However, we again see the feature that when the temperatures are rapidly decreasing below -30°C, the MRR configuration has a substantial cold bias; once the coldest temperatures are achieved, however, the MRR configuration is better able to capture the low temperatures than the other models.

Finally, in order to gain as much insight as possible into the model-predicted PBL structure near the surface during the coldest episodes, we performed an alternate verification procedure using the raw Fairbanks sounding for the last ten days of the partial sunlight episode (2 – 12 Feb 2008). Instead of interpolating the model sounding to 25 hPa increments of the observed sounding, we interpolated the raw sounding to each WRF model level using some basic assumptions. (The WRF model levels are specified in terms of $(p - p_T)/(p_s - p_T)$ where p_T is the specified model top pressure, p_s is the surface pressure, and all pressures are the dry hydrostatic components; here we converted each WRF level to a pressure in the Fairbanks sounding using the observed surface pressure and the assumption that the actual pressure is approximately the dry hydrostatic pressure; the temperature at the resultant pressure was found by log-pressure interpolation. Finally, the physical height for each WRF level in the base state over ocean was used to determine the abscissa coordinate in Fig. 18.) This procedure gives us increased vertical resolution near the surface, where the model levels are much closer than 25 hPa (i.e., roughly 250 m in physical distance) apart. A plot of the temperature structure (Fig. 18) shows the same general trends as in the 25-hPa plot of Fig. 16. The two simulations using the Noah scheme (QNR and MNR) are similar, while the simulation using the RUC LSM (MRR) is consistently colder in the lowest 500 m. However, all simulations have a warm bias in the lowest 700 m. Though in the lowest 100 m the models have average vertical temperature gradients as large as, or even larger than, those in the observations, the vertical temperature gradients comprising the inversions in the observations extend to a much

greater altitude, consistent with the significantly greater temperature differences between the surface and the 1-km level found in the observations.

In summary, it appears that during periods of near total darkness and the cold, dry, calm conditions characteristic of high fine particulate concentrations, all models possess a low-level warm bias, but the bias is minimized and the statistics are generally the best in the MRR (MYJ PBL / RUC LSM / RRTMG radiation) experiment. The reason for the improved statistics in MRR for the extremely cold episodes is not precisely known at present, but it is probably related to some combination of its potentially multi-level snow model (which can serve to reduce the heat flux from the ground to the atmosphere) and the presence of a ground surface 'skin' layer in the RUC LSM (which has no thermal inertia itself and could decrease the time needed for the ground and the adjacent atmosphere to respond to a negative heat budget). A few caveats are in order, however. During the period of decreasing temperatures immediately preceding temperatures below approximately -35°C, the MRR configuration is still colder than the other models, but for these periods MRR tends to exacerbate an already cold model bias instead of improve a warm model bias. Since the observations for these falling temperature periods tend to show fairly continuous frozen precipitation (in contrast to the coldest temperature periods which tend to have ice fog and no precipitation), it is possible that all the model configurations have difficulties with modeling the microphysics/radiation interaction. For example, if the radiation scheme is not taking into account the presence of ice crystals when they exist in the actual atmosphere, the absence of their radiative heating effect on the surface during these extremely cold conditions could be significant. Another caveat is that when partial sunlight is present, MRR tends to warm more rapidly than the other models, and all models tend to have substantial warm biases in these conditions.

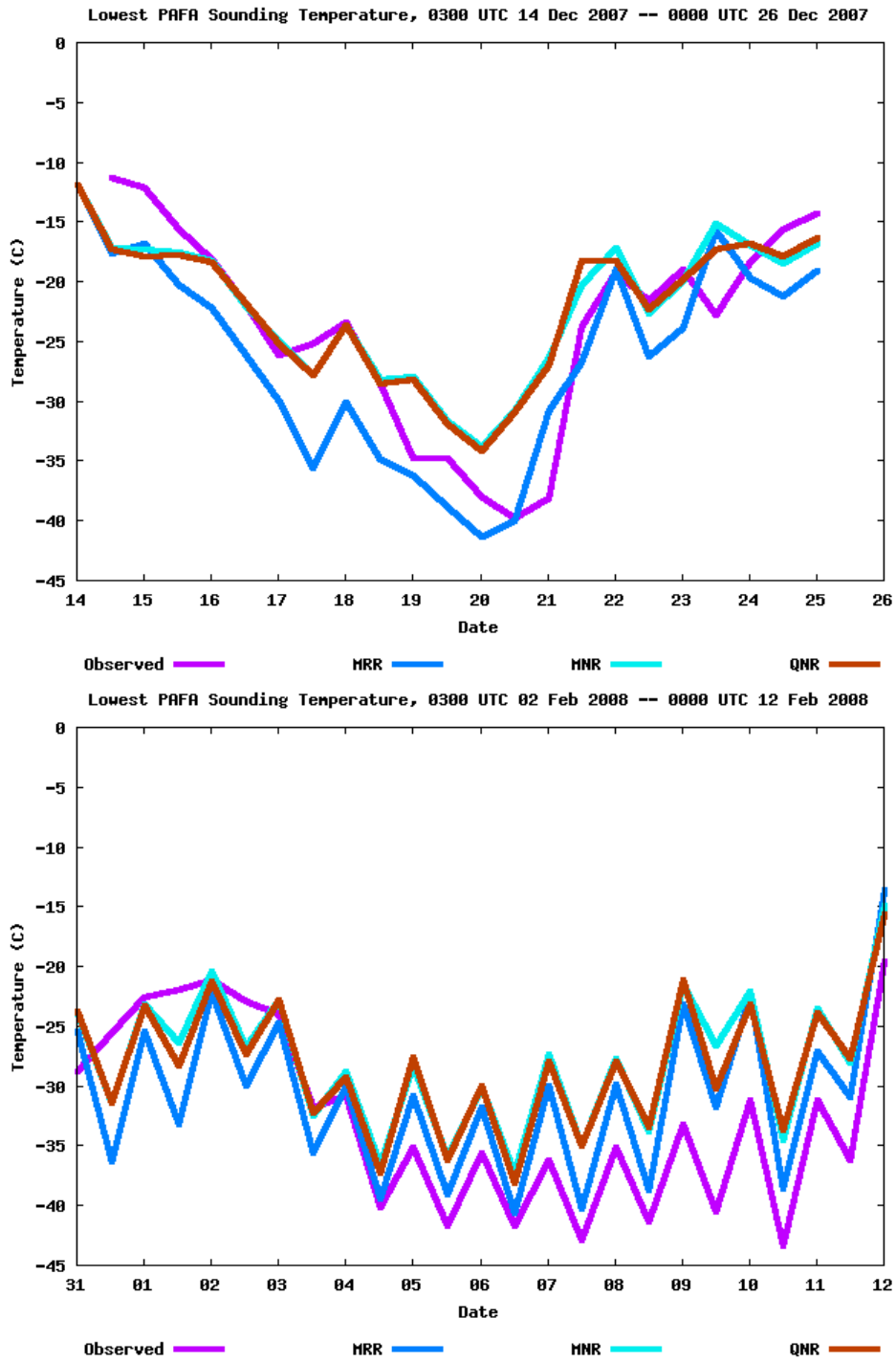


Fig. 17: Time series of raw Fairbanks surface-level reported sounding temperatures (PAFA) for 14-26 Dec 2007 period of near total darkness episode (top), and 02-12 Feb 2008 period of partial sunlight episode (bottom). Colors are same as in Fig. 16.

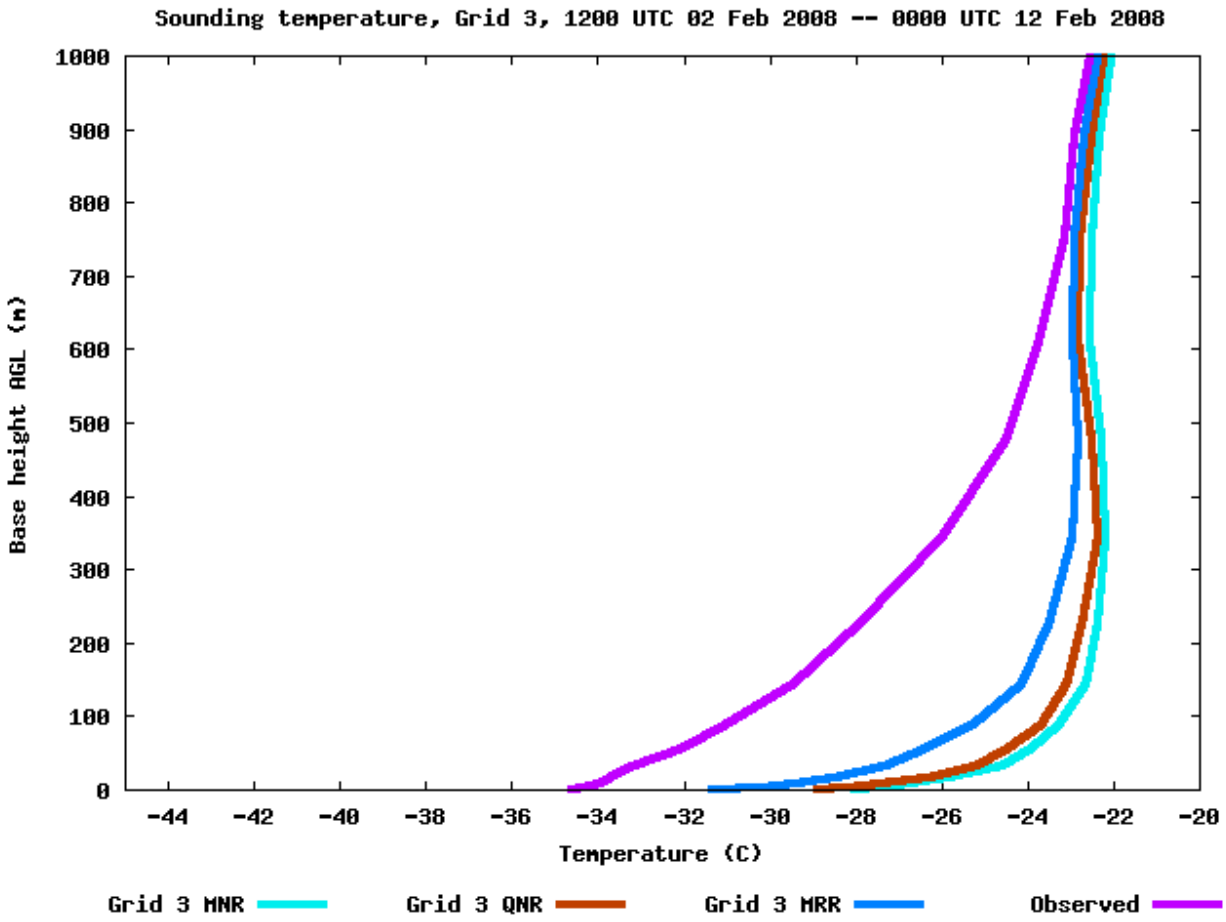


Fig. 18: Time-averaged vertical profile of Fairbanks sounding (PAFA) temperatures for 02-12 Feb 2008 period during partial sunlight episode, where observations are interpolated to WRF vertical levels as described in text. Dark blue indicates value from experiment MRR; brown indicates value from experiment QNR; light blue indicates value from experiment MNR; purple indicates observed sounding value.

5. SELECTION OF PREFERRED PHYSICS CONFIGURATION AND FINAL DYNAMIC-ANALYSIS SIMULATION

Based on the results of the physics sensitivity test, we concluded that the physics suite contained in experiment MRR (MYJ PBL, RUC LSM, and RRTMG radiation) was the best one to be used to simulate the two episodes. The high exceedance events that are of importance occur during the coldest temperature periods when the RUC LSM appeared to perform the best. However, the tendency of the MRR suite to produce significant negative temperature biases during the falling temperature periods must be noted.

We thus concluded that we should perform an additional dynamic-analysis simulation with the MRR physics package but with Grid 3 obs nudging in order to reduce the noted temperature biases and generate the best atmospheric analysis. Because the MRR Grid 2 statistics, in the presence of obs

nudging, were almost always quite good, we were optimistic that any systematic biases present in the MRR simulation on Grid 3 would be greatly alleviated through obs nudging. As noted above, however, we did not nudge the wind fields from surface data on Grid 3, whose influence is below ~150 m (see Fig. 8), because of concerns that the local topographic drainage flows generated by the model in the topography around Fairbanks may be smoothed out by the FDDA procedure. However, we did retain nudging of wind fields on Grid 3 for observations above the surface (i.e., from the Fairbanks sounding).

The initial specifications of the parameters used for the Grid 3 obs nudging simulation are listed within the parentheses of Table 2. They closely correspond to values on the other grids. However, the value of RINXY (a horizontal radius of influence) was decreased on Grid 3 from a value of 100 km to 75 km. This value was determined by performing a temporal correlation of the Grid 3 temperature innovations within the MRR no-FDDA simulation at the location of the METAR stations, and estimating the characteristic horizontal distance at which the Grid 3 METAR observational-based surface innovations were correlated for (see Fig. 19). The surface pressure difference parameter used in the horizontal weighting function in complex terrain (henceforth Δp_d) was also reduced from 75 hPa to 37.5 hPa based on the results of the correlation analysis (e.g., note the relationship between correlation value and the elevation difference labels in Fig. 19). This parameter controls how far the influence of a surface observation may spread along topography as the surface pressure varies from that at the obs site; our results suggested that some station pairs close in horizontal distance but with different vertical elevations were much less correlated than similar stations with little terrain difference.

An additional complication derives from the fact that the WRF method of reducing the weight of surface observations based on Δp_d is different from the MM5 method defined in Stauffer and Seaman (1994). In default WRF, if there is a difference between the model surface pressure at the location of a surface observation, p_b, and the model surface pressure at a grid point in question, p, the weight of the surface observation is reduced by a factor w given by:

$$w = \max\left[0.0,\ 1.0 - \frac{|p - p_b|}{\Delta p_d}\right]\left[\frac{r_0^2 - r^2}{r_0^2 + r^2}\right], \quad (1)$$

where r is the horizontal distance between the grid point and the observation, and r_0 is the surface radius of influence parameter (RINXY in Table 2). In MM5, on the other hand, the surface pressure difference is used to artificially increase the horizontal radius of influence parameter, according to:

$$w = \frac{r_0^2 - \left[r + r_0 \frac{|p - p_b|}{\Delta p_d} \right]^2}{r_0^2 + \left[r + r_0 \frac{|p - p_b|}{\Delta p_d} \right]^2}. \quad (2)$$

Though the two functions are often similar, the WRF function tends to be more horizontally isotropic and less sensitive to terrain features, as well as generally nonzero over greater horizontal differences. (The WRF method will give nonzero weights to surface observations unless either $|p\text{-}p_b|$ exceeds Δp_d or r exceeds r_0, whereas the MM5 method can give a zero weight even if neither criterion is met because the terrain difference increases the effective distance from observation to grid point.) In the final Grid 3 FDDA simulations used here, the MM5 method for surface pressure difference weighting was used.

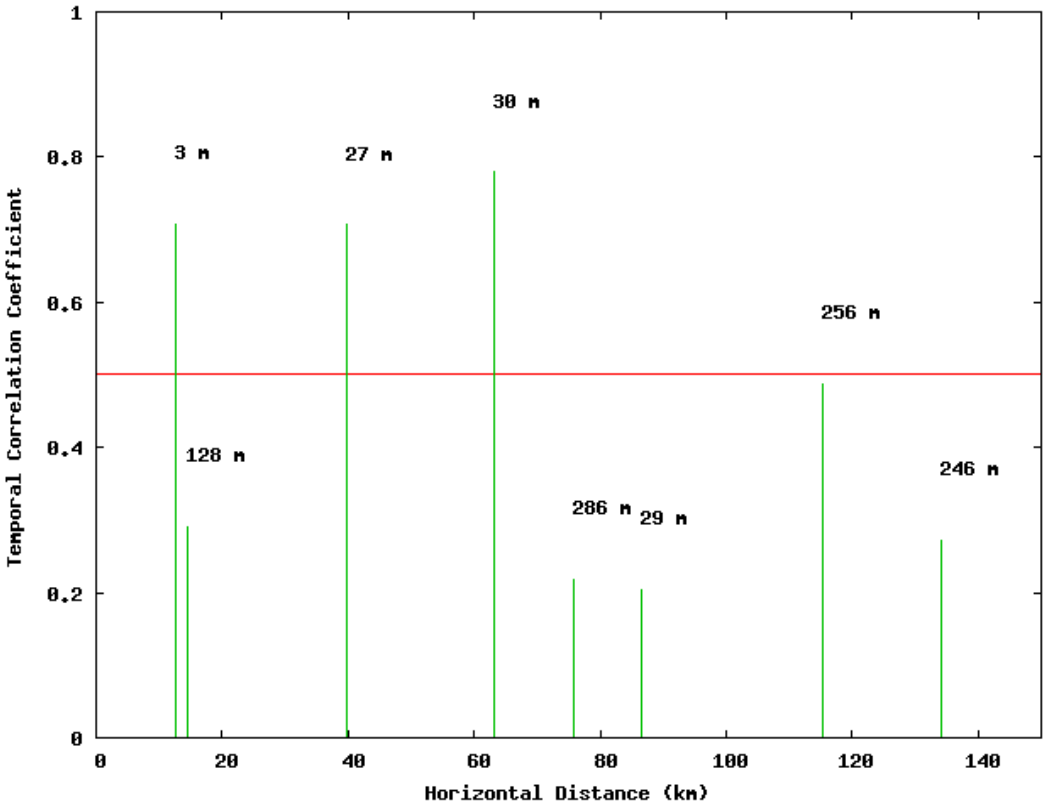


Fig. 19: Temporal correlation coefficients vs. horizontal separation distance between various pairs of surface METAR stations located within Grid 3 (green). Red line indicates a temporal correlation coefficient of 0.5. Numerical labels indicate elevation distance between stations in meters.

The value of TWINDO (Table 2), the obs nudging time window half-period defining the temporal influence of an innovation (Stauffer and Seaman 1994), should also be considered. Ideally this parameter would be a function of height and decrease in value towards the surface, to take into account the shorter temporal correlation time scales for surface data reflecting surface processes. Although this capability will be present in WRF version 3.2, in the version 3.1 that we used for this study, it is simply a constant (though it may vary with grid). Our experience suggests that the value chosen, 2.0 hours, is generally best for the assimilation of sounding data, but may be somewhat too large for the surface (Schroeder et al. 2006). For the final version of the Grid 3 FDDA simulations, we manually encoded the Penn State MM5 method used in WRF version 3.2 so that the effective value of TWINDO was 2.0 hours above the surface, but 1.0 hours at the surface.

Finally, two additional modifications were made to the default WRF version 3.1 FDDA procedure. In the default procedure the surface level observation of a sounding is treated differently than a surface observation. Specifically, a surface observation is assumed to be applicable to the lowest model level at the horizontal location of the observation, whereas all sounding observations including one at the surface level are assumed to be applicable at the vertical model location with the same pressure as the pressure of the observation. So a sounding surface level observation will not necessarily be placed at the lowest model level if the model surface pressure is not the same as the observed surface pressure. Also, the surface pressure difference is used to reduce the weight of a surface observation at remote horizontal grid points , but not the weight of a surface-level sounding observation. This inconsistent treatment becomes more of an issue in station-poor regions such as that of the Grid 3 used in this study, where the relative influence of the Fairbanks sounding to all Grid 3 METAR stations may be quite significant. In the final Grid 3 FDDA simulations, the code was modified to remove the surface-level observation from the rest of the sounding and treat it as a separate surface observation. Furthermore, to reflect the Penn State MM5 method, the Δp_d weighting function was applied to soundings as a unit, in addition to surface observations.

Figures 20-22 show the vertical profiles of RMSEs verified against the Fairbanks sounding for a series of trial simulations of the first six days of the near total darkness episode (14-20 Dec. 2007) using the MRR physics suite but different variations of the Grid 3 obs nudging procedure. First, the benefit of Grid 3 obs nudging is immediately apparent, and Fig. 21 shows in particular that the simulations with retained Grid 3 wind obs nudging above the near-surface layer have substantially reduced wind speed RMSE scores in comparison with the two simulations that don't. This helps justify our proposed procedure of retaining Grid 3 wind obs nudging above the near-surface layer but turning it off within the near-surface layer to allow the model to generate its own topographic flows. Second, for the non-wind fields shown in Fig. 20 and Fig. 22 we see that the TWINDO = 2.0 hours statistics tend to be somewhat better than the TWINDO = 0.45 hours statistics, in agreement with our past experience. The proposed Grid 3 obs nudging procedure, including, among other modifications, using TWINDO = 2.0 hours above the surface but TWINDO = 1.0 hours at the surface, produces results quite similar to the TWINDO = 2.0 hours simulation.

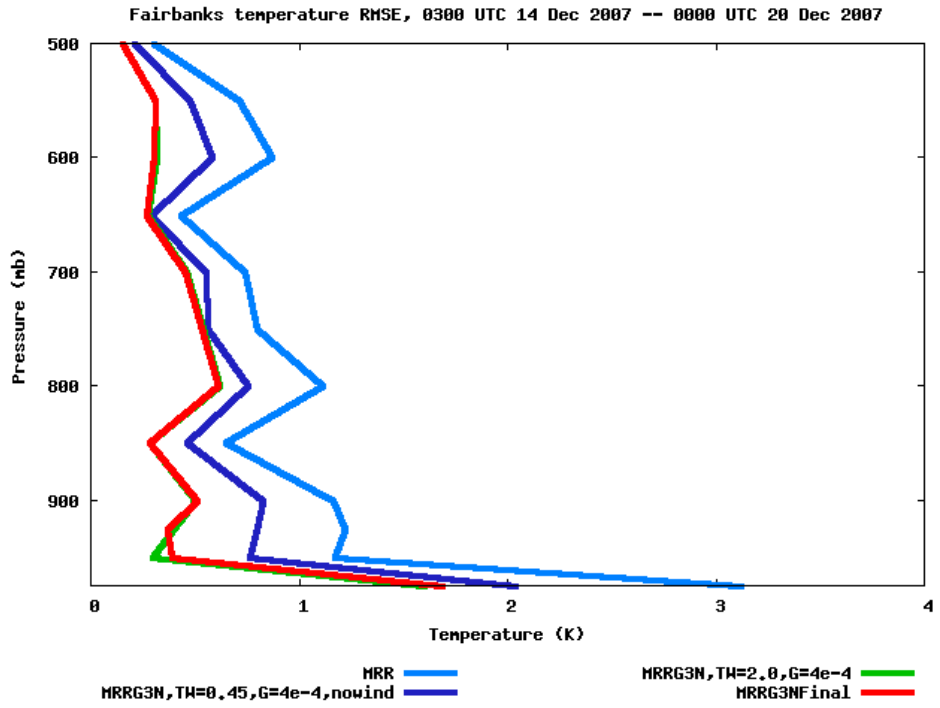


Fig. 20: Time-averaged vertical profile of Fairbanks sounding (PAFA) temperature RMSE scores for 14-20 Dec 2007 period of near total darkness episode. Blue indicates the value from experiment MRR; violet indicates the value from MRR experiment using default Grid 3 obs nudging with TWINDO = 0.45 hours and no wind nudging; green indicates the value from MRR experiment using default Grid 3 obs nudging with TWINDO = 2.0 hours and nudging of wind above the near-surface layer only; red indicates the value from MRR experiment using the final version of Grid 3 obs nudging with the modifications as described in the text.

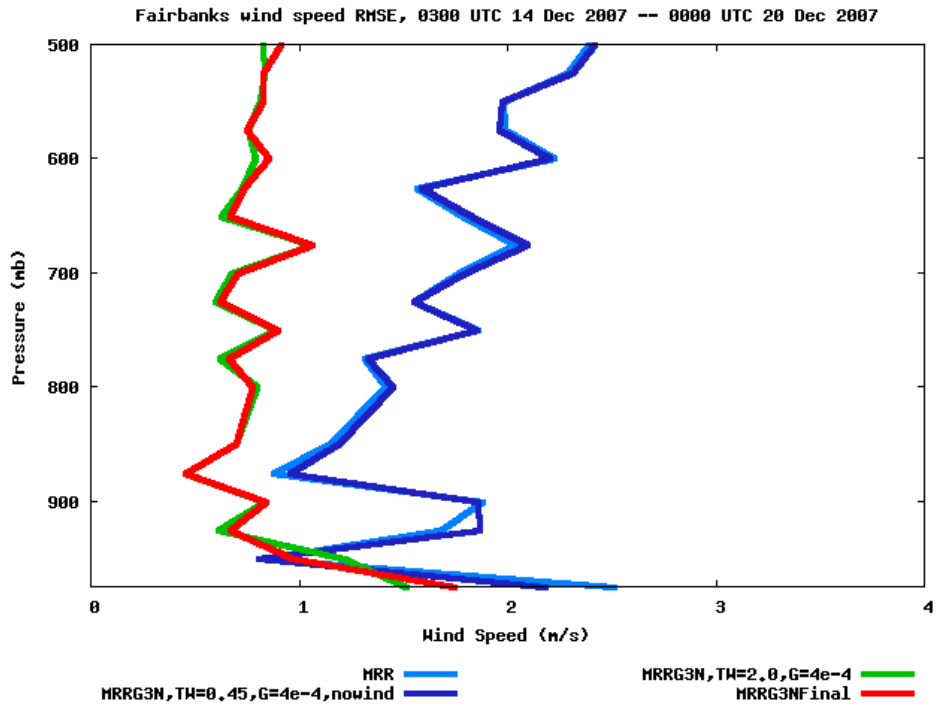


Fig. 21: Same as Fig.20, but for wind speed RMSEs.

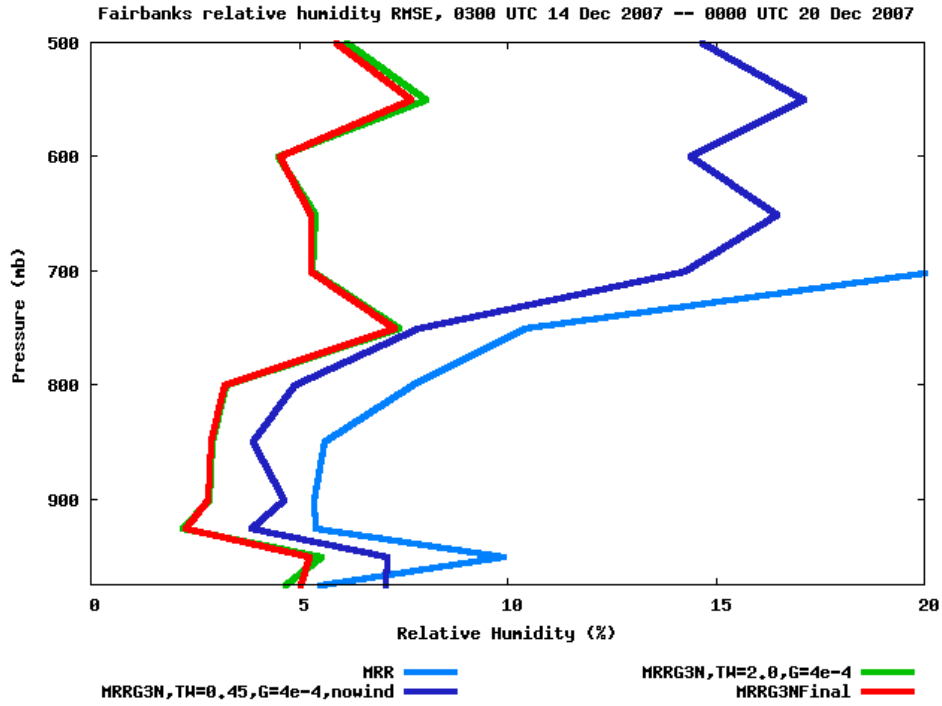


Fig. 22: Same as Fig. 20, but for relative humidity RMSEs.

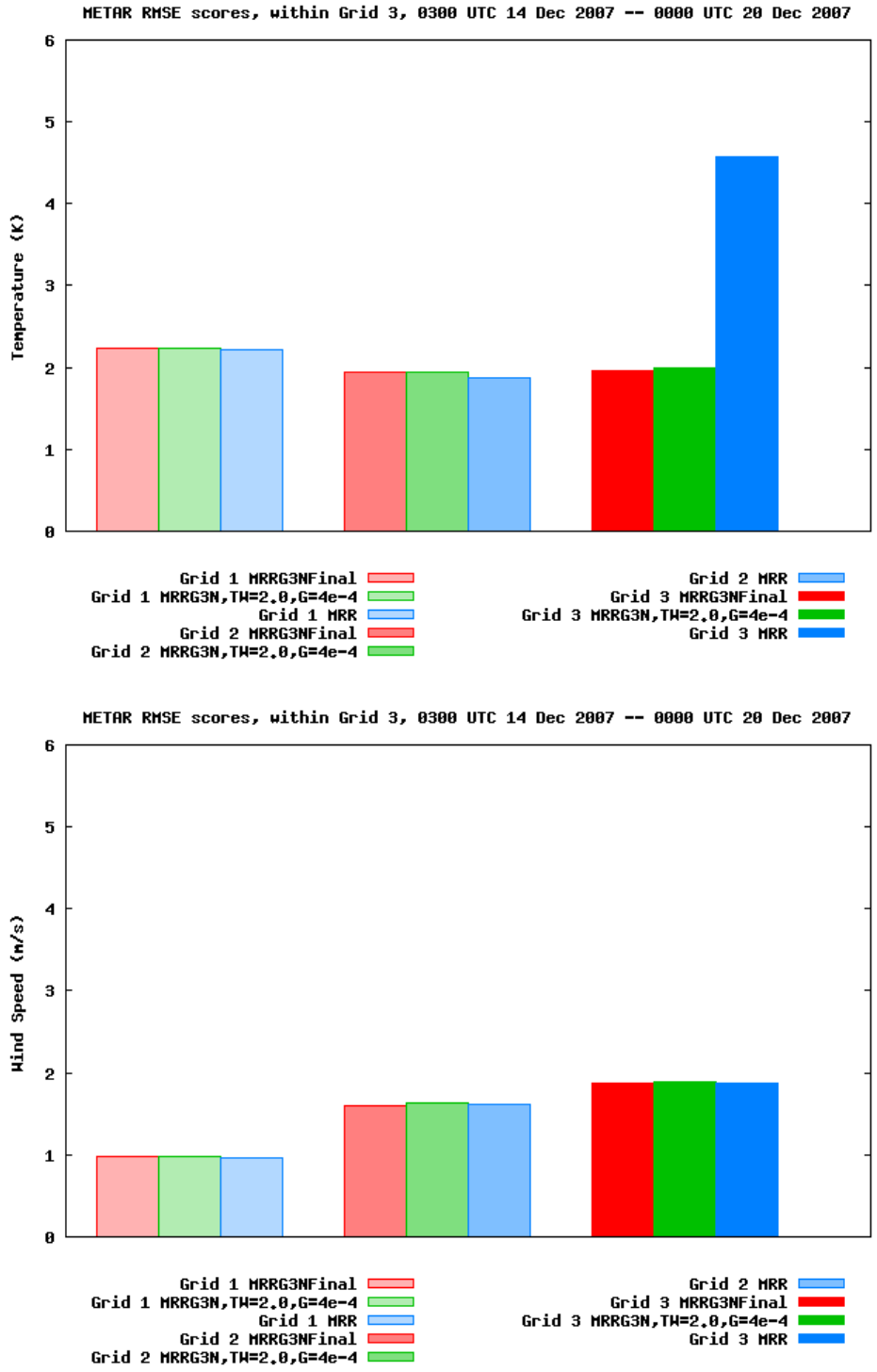


Fig. 23: Surface METAR RMSE scores for during 14-20 Dec 2007 period of near total darkness for temperature (top) and wind speed (bottom). Blue indicates value from experiment MRR; green indicates value from experiment MRR using default Grid 3 obs nudging with TWINDO = 2.0 hours and nudging of wind above the near-surface layer only (i.e., MRRG3N,TW=2.0,G=4e-4); red indicates the value from MRR experiment using the final version of Grid 3 obs nudging with the modifications as described in the text (i.e., MRRG3NFinal).

Fig. 23 shows RMSE statistics for the sample period for the surface METAR stations within Grid 3. The lightest, medium, and darkest shades in the histogram plot correspond to the dark blue, brown, and yellow curves in the vertical profile plots. In all cases the improvement of the MRR temperature RMSE scores from the Grid 3 obs nudging is quite dramatic, and shows the utility of our dynamic analysis approach. The fact that some of our modified obs nudging procedures carried over to all grids caused the Grid 1 and Grid 2 results to change from those of the MRR experiment, but the magnitudes of the changes are small. Wind speed statistics for the surface METARs show little sensitivity to the presence of either Grid 3 obs nudging of temperature and humidity, or Grid 3 obs nudging of winds above the near-surface layer. The proposed Grid 3 obs nudging procedure produces only slight differences from those of the more standardized Grid 3 obs nudging procedure shown, but to the extent there are differences they are generally slight improvements.

In summary, the use of our proposed modified Grid 3 obs nudging procedure, at least for this six-day test period, produces the desired effect of greatly improving the surface temperature statistics without significantly degrading the other statistics, and is also consistent with our past experience as to the preferred specification of obs nudging parameters. Therefore, we proceded to perform the final dynamic-analysis simulations in their entirety using the proposed Grid 3 obs nudging procedure.

Figures 24-26 show the overall statistics for the final dynamic-analysis Grid 3 obs nudging simulation for the entire near-total darkness episode in comparison to those of the non-Grid 3 obs nudging simulation MRR. The final temperature biases in comparison to the surface METARs are below 0.5°C in magnitude, with RMSE errors 2-3°C. The temperature RMSE errors decrease below 1°C above 900 hPa. Wind speed biases are under 1 m s^{-1} at the surface, while RMSE errors are on the order of 2 m s^{-1} throughout the lower troposphere. Qualitatively, the statistics for the final partial sunlight episode (Figs. 27-29) show very similar tendencies.

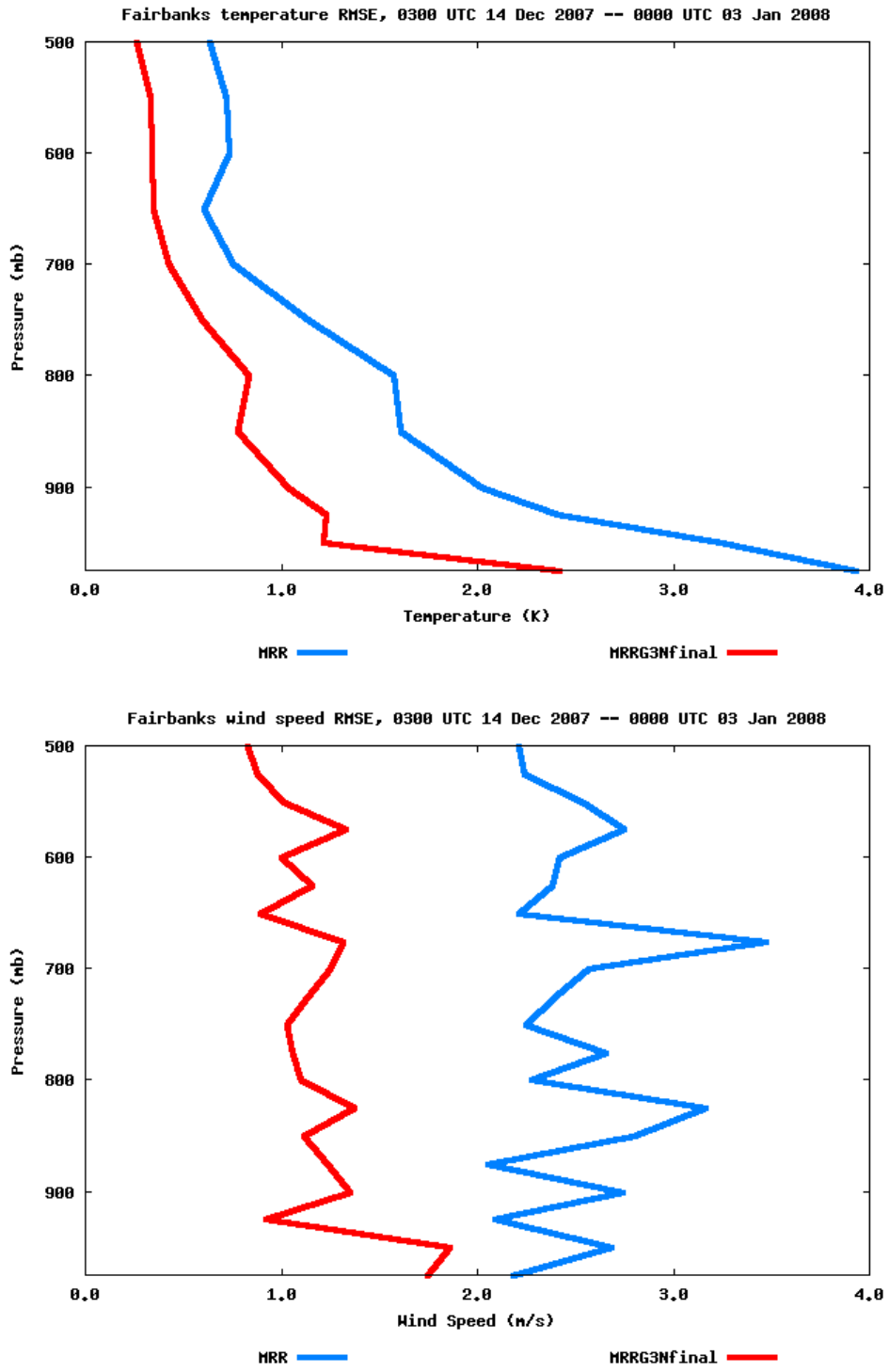


Fig. 24: Time-averaged vertical profile of Fairbanks sounding (PAFA) on Grid 3 for temperature (top) and wind speed (bottom) for 14 Dec 2007—03 Jan 2008 near total darkness episode. Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.

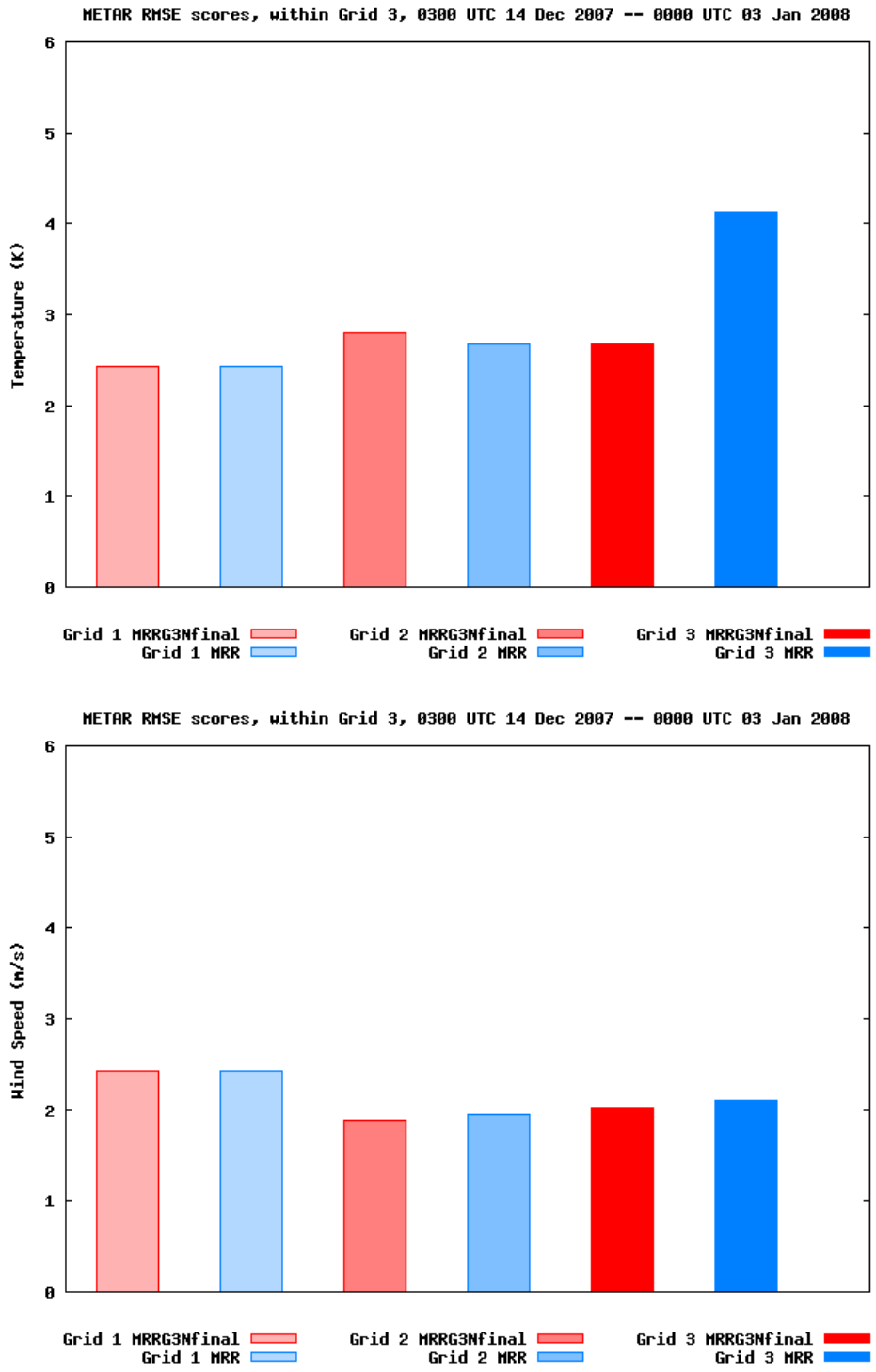


Fig. 25: Surface METAR RMSE scores during 14 Dec 2007—03 Jan 2008 near total darkness episode for temperature (top) and wind speed (bottom). Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.

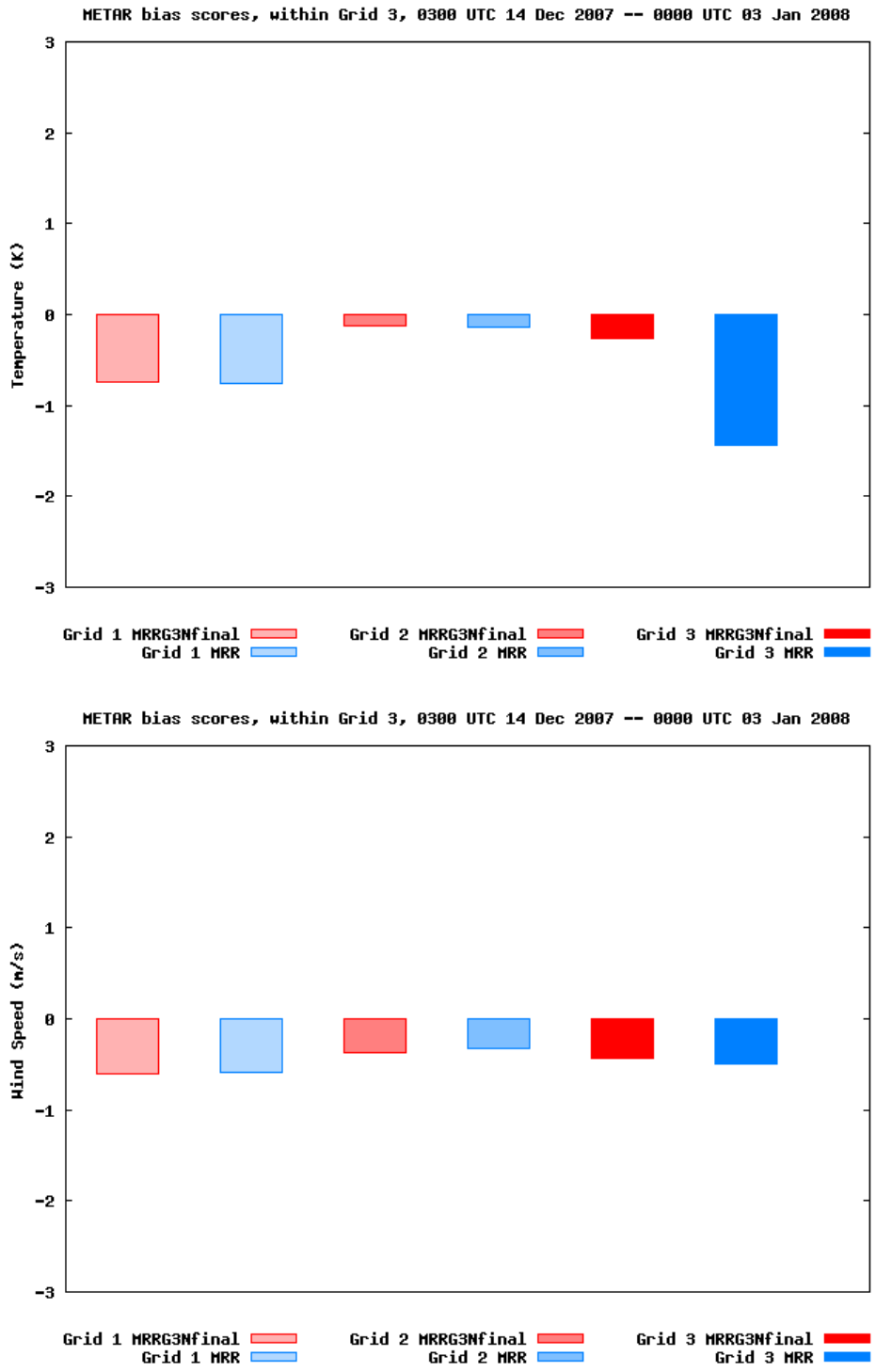


Fig. 26: Same as Fig. 25, but for bias errors.

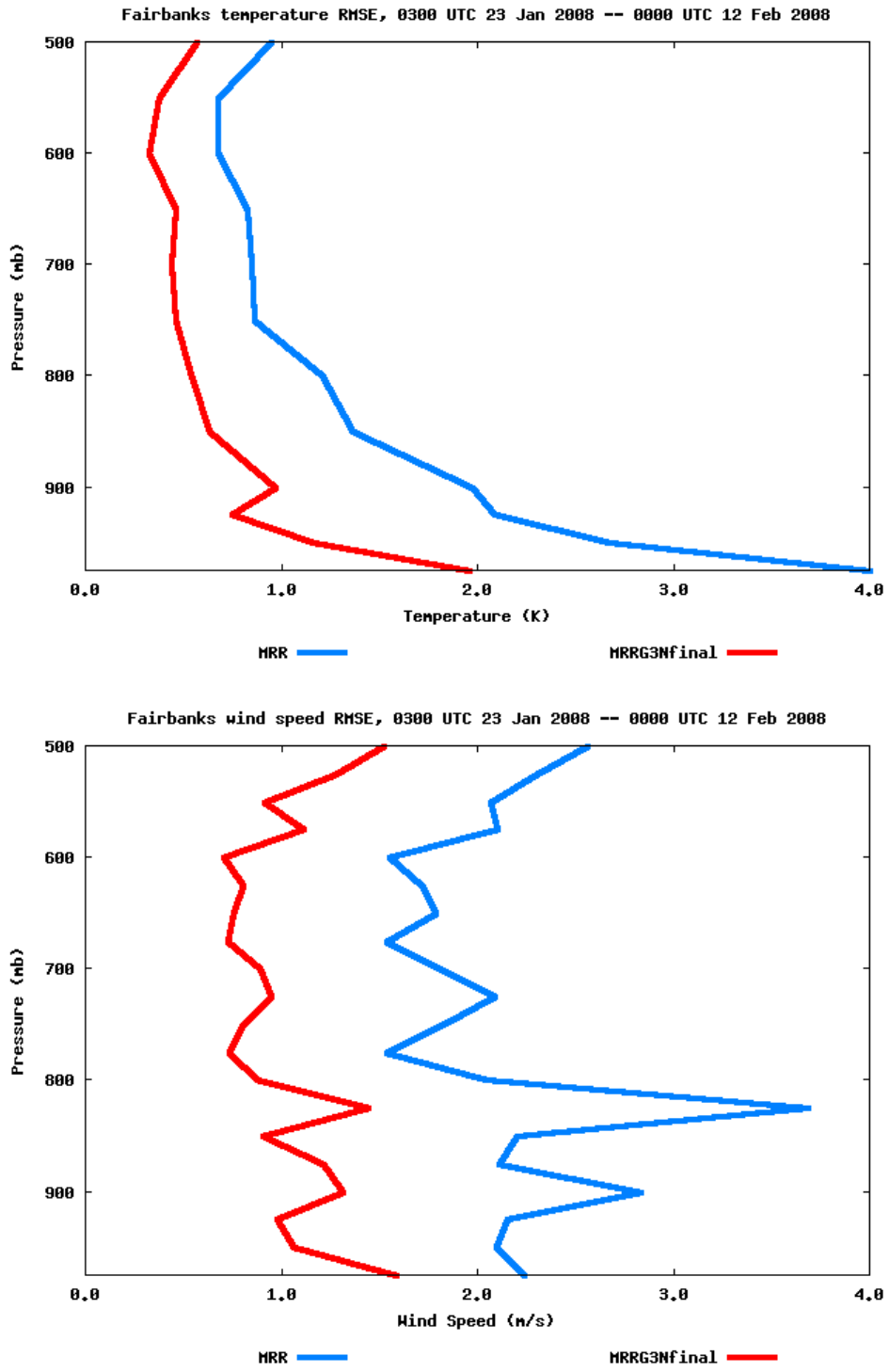


Fig. 27: Time-averaged vertical profile of Fairbanks sounding (PAFA) on Grid 3 for temperature (top) and wind speed (bottom) for 23 Jan 2008—12 Feb 2008 partial sunlight episode. Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.

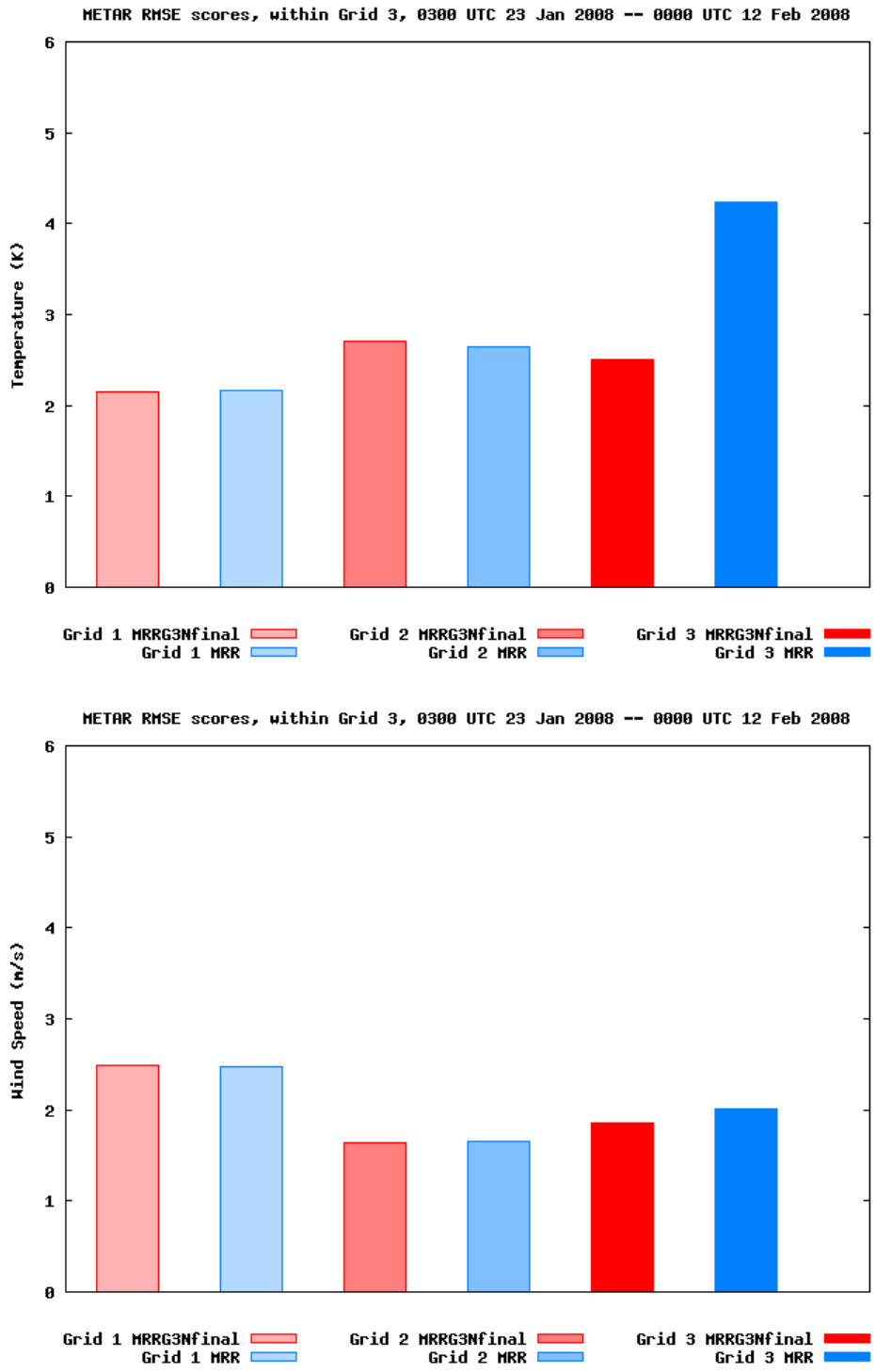
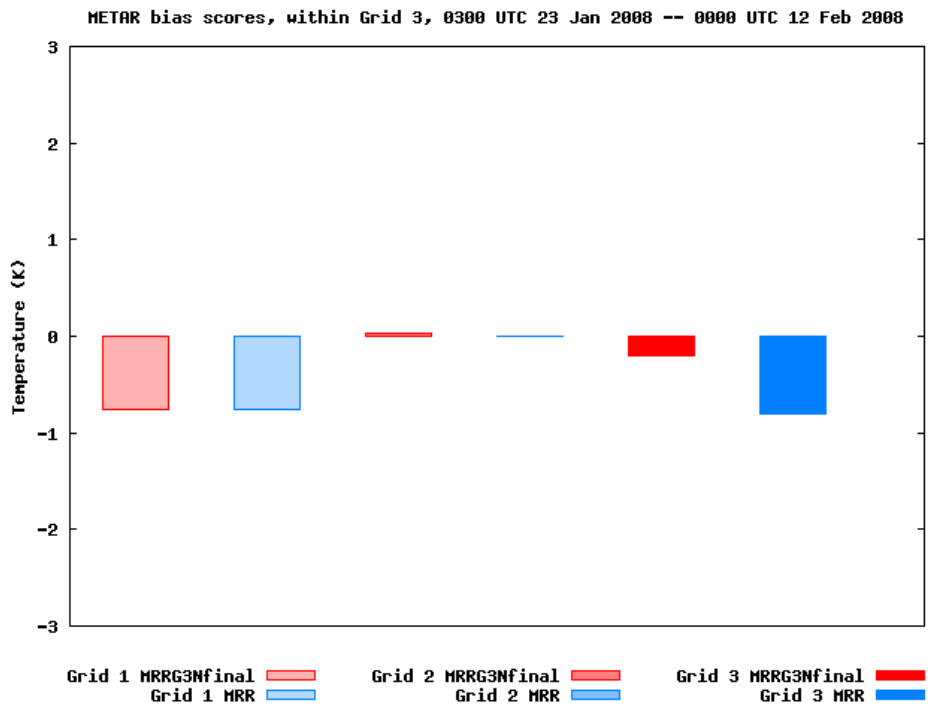


Fig. 28: Surface METAR RMSE scores during 23 Jan 2008—12 Feb 2008 partial sunlight episode for temperature (top) and wind speed (bottom). Blue indicates value from experiment MRR; red indicates value from final dynamic-analysis MRR simulation using Grid 3 obs nudging.



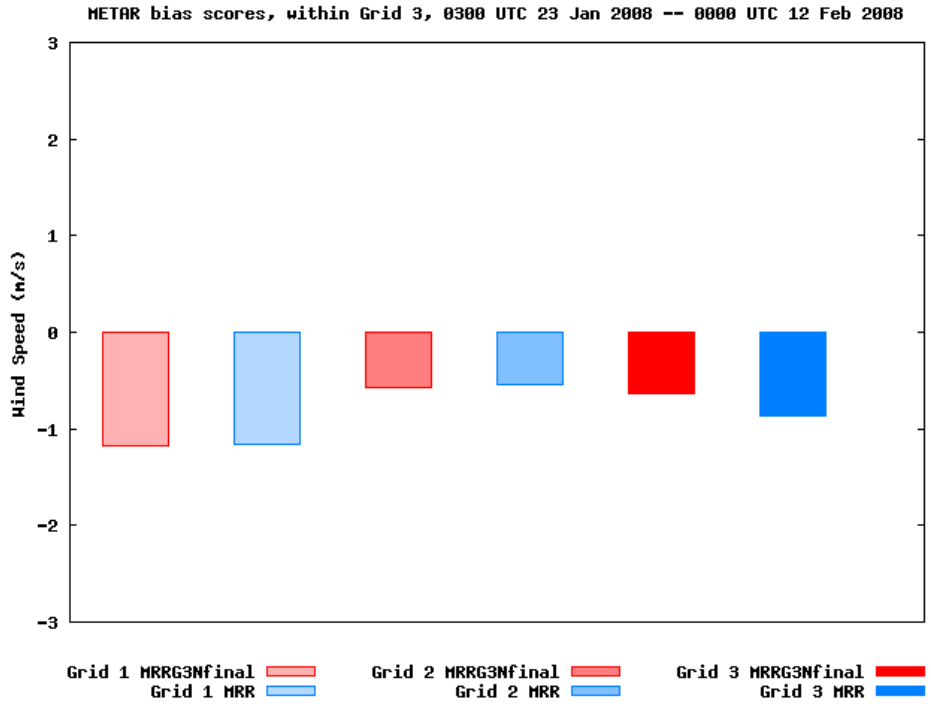


Fig. 29: Same as Fig. 28, but for bias errors.

6. CONCLUSIONS

6.1 Summary

The purpose of the project was to develop, adapt, and test a methodology for stable boundary layer representation (initial onset, space/time evolution, dissipation) in three-dimensional numerical models, with a specific focus on the dark, extremely cold environments such as those in the winter in the Fairbanks, AK region. A particular concern is the frequent occurrence of very high fine particular matter (PM2.5) concentrations within the stable boundary layers that form in these conditions.

Ten tasks were defined in the Statement of Work (SOW) for this project. A summary of these tasks and a brief overview of the work completed can be found in the Appendix to this report. Two twenty-day episodes were selected from the 2007-2008 winter season to study periods of extremely cold temperatures and high PM2.5 concentrations and to evaluate model performance: one in near total darkness (14 Dec 2007 – 03 Jan 2008), and the other in partial sunlight (23 Jan 2008 – 12 Feb 2008). One baseline physics configuration and three physics sensitivity experiments were performed for each episode. The physics sensitivity experiments were used to assess the impact of different planetary boundary layer (PBL) parameterizations, land surface models, and atmospheric radiation schemes on the simulations. Each simulation used three nested grids: Grid 1 (12-km horizontal grid spacing) and Grid 2 (4-km) utilized the multiscale multigrid data assimilation strategy of Stauffer and Seaman (1994) in order to ensure the model and observations remained close over the extended duration of the simulations. Grid 3 (1.3-km), centered over the Fairbanks region, did not use any direct data assimilation, and so was best-suited for quantifying the physics sensitivity; it also possesses sufficient horizontal resolution to be used by the EPA as meteorological input to chemical and air transport and dispersion models. From the different physics packages one was to be recommended to the EPA for further mesoscale modeling of the region.

The use of the three-grid configuration with a multiscale, multigrid four-dimensional data assimilation (FDDA) strategy on the outer two grids and no direct FDDA on Grid 3 consistently produced qualitatively plausible atmospheric fields throughout the variety of meteorological conditions found in the episodes, despite the relatively sparse data density. Quantitatively, the multiscale, multigrid FDDA strategy led to improved root-mean-square-error (RMSE) scores for both wind and temperature on all grids. The FDDA on the outer domains had the desired effect of improving the simulations of Grid 3 without FDDA and used for physics sensitivity tests, by providing improved lateral boundary conditions.

The best RMSE scores for the combination of both surface and sounding data required modification of the default FDDA procedure. These modifications included applying surface wind observational data to the third model vertical level instead of the lowest model level, because wind observations are normally taken at a height of 10 m which is the height of the third level in the high vertical resolution configuration used here. The influence of surface observations was also restricted to approximately the lowest 100 m, instead of to the top of the PBL, because the model-predicted PBL height in these simulations, based on the turbulent kinetic energy profile, was often found to be 1 km or higher. This

correction applied the surface innovation (observation minus model value) in these predominantly stable boundary layers over a much shallower layer than in the default FDDA procedure and produced improved statistical results in the lower troposphere.

All model physics combinations tended to have a positive temperature bias on Grid 3, especially during the most extremely cold periods. All of the physics sensitivity tests tended to reduce the warm bias in comparison with the selected baseline physics package. Switching from the RRTM longwave / Dudhia shortwave radiation package to the RRTMG longwave and shortwave radiation package led to significantly reduced warm biases and better RMSE statistics. RRTMG was then used in all future physics sensitivity tests. The reduced warm bias seemed to be due to the longwave component, both because of direct examination of surface fluxes in the partial sunlight case, and due to the fact that the difference was more pronounced in the near total darkness episode.

Though none of the four physics suites tested in the study was unambiguously superior to all of the others in terms of RMSE statistics, the simulation with the Rapid Update Cycle (RUC) land surface model, the Mellor-Yamada-Janjić (MYJ) PBL model, and the RRTMG radiation package was selected as the one to be recommended to EPA for modeling extremely cold SBLs and as the basis for producing the final atmospheric analysis. For both the near-total-darkness and partial sunlight episodes, the MYJ/RUC/RRTMG (henceforth MRR) physics suite had the lowest surface wind speed RMSE scores. For the partial sunlight episode the MRR configuration was one of two physics suites with the lowest surface temperature RMSE scores, and was among the lowest for the near-total-darkness episode. Of all the physics suites, the MRR package had the lowest warm bias during the most extremely cold periods, both when compared to the surface METAR stations and the Fairbanks sounding. The reason is not known for sure but is probably due to some combination of the effects of its snow model and top-level 'skin' layer. Since the extremely cold conditions are those with the potential for the highest PM2.5 concentrations, we took this as an additional reason to recommend the MRR physics suite for use by EPA.

However, there were periods in each episode, generally when the temperature was steadily decreasing in advance of an extremely cold period, during which all the physics configurations would tend to have a cold bias. During these periods the MRR configuration would still have colder temperatures than the other physics suites, and thus have worse magnitude temperature biases and RMSE scores. The relatively poorer performance of the MRR suite during a such a period accounts for the relatively poorer surface temperature statistics of the MRR suite compared to the MNR suite for the entire near-total-darkness episode. The reason for this behavior is not definitely known, but it is thought to be related to the interaction of radiation with the ice condensate that tends to occur during these periods. Also, the temperature biases of the MRR physics suite during the extremely cold period near the end of the partial sunlight episode were not quite as improved during daylight hours as during nighttime hours as compared to the other physics suites. Therefore, while overall we recommended the MRR configuration to EPA for these episodes, we also strongly recommended that the final fine-scale atmospheric data analysis (i.e., from Grid 3) to be provided to EPA should come from an additional simulation in which FDDA is performed directly on Grid 3, in order to reduce some of this error.

Use of obs nudging for temperature and humidity (and not surface wind) on Grid 3 produced large improvements in the mass fields as expected, and also improvements in the wind fields above the surface. Results were very encouraging and suggested that a smaller (larger) time window should be used for the surface (above-surface) data assimilation. This capability present in the Penn State MM5 FDDA system has been added to the new-release version of WRF.

In addition to this final report, deliverables to the EPA will include the full three-dimensional output at relatively fine temporal resolution (every 1 hour for Grid 1; every 12 minutes for Grids 2 and 3) for the final Grid 3 nudging simulation as well as all the baseline and physics sensitivity simulations. Model namelists, initialization files, and modifications to the model source code will also be provided.

The development and refinement of WRF FDDA capabilities and supporting software, including the surface analysis nudging, observation nudging and the OBSGRID objective analysis and obs-nudging pre-processing code, occurred concurrently with this project. This separate development effort led by PI Dave Stauffer and funded by the Defense Threat Reduction Agency (DTRA) allowed us rapid access to the most recent and robust versions of the WRF FDDA code, which greatly benefited this project.

The results of the default FDDA procedures not performing well here in this high vertical resolution modeling study of stable boundary layer environments motivated an additional FDDA code development effort to make the vertical influence functions of surface observations within the FDDA be a function of stability regime type, as well as to provide the user with greater flexibility in specifying the vertical influence functions. These modifications were not finalized in time to be used for this project but are scheduled to appear in the next official release of the WRF model.

An extended abstract and oral presentation were made at the 13th Conference on Mesoscale Processes (Gaudet et al. 2009), and a manuscript based on the project is in preparation.

6.2 Limitations of the Study and Recommendations for Future Work

Sensitivity to the microphysics parameterization was not performed here, but may be important to investigate further. In particular, results from this study suggested that both the occurrence of large negative RUC temperature biases and large differences between the RRTM and RRTMG longwave radiation schemes tended to occur when low-level ice condensate was present. Therefore, the microphysics / radiation interaction should probably be investigated further.

A fourth grid with 0.44-km horizontal grid spacing centered over Fairbanks was set up and initialized with topography, but it was not used in the sensitivity experiments here. Although this is finer horizontal resolution than the resolution requested by EPA, some of Penn State's past studies of SBLs (Stauffer et al. 2009) have suggested that the weak wind flows in these conditions may be sensitive to topographic features on these smaller scales, and it might be important to know if finer resolution is also required to resolve the topographic flows of the Fairbanks region.

The latest version of the WRF FDDA code has been designed to have more flexibility in how the temporal and spatial weighting functions are specified. Future simulations that use these new WRF FDDA options that were not yet available for this study should produce a further reduction of model error.

The availability of more meteorological observations from the immediate Fairbanks North Star Borough region, and in particular observations immediately above the surface, would allow one to make a more rigorous assessment of the accuracy of the different physics schemes (in particular, the PBL parameterizations).

More testing and analysis of the model physical parameterizations should be performed to determine the cause of the strong model biases often observed in the simulations, such as the generally persistent warm bias, and the cold RUC land surface model bias during falling temperature conditions.

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APPENDIX – SUMMARY OF TASKS

Ten tasks were included in the Statement of Work (SOW) for this project. An overview of the tasks and a summary of the work completed on each of these tasks are provided below:

- Task 1 – Participate in kick-off teleconference in accordance with the SOW.

This took place on 11 Sep 2008. The EPA was provided with the specifications of the nested grid configuration that we proposed in the SOW, and we received in turn particular information about the period and region of study from the EPA.

- Task 2 – Prepare workplan and QA/QC plan in accordance with the SOW.

This was submitted to the EPA during Nov. 2008, along with an updated timetable of deliverables provided during the next monthly teleconference. Included was a description of our proposed simulation plan, choice of baseline physics and grid configuration, and method of simulation.

- Task 3 – Participate in monthly project teleconferences.

We held hour-long teleconferences with the project manager and other scientists at Research Triangle Park and EPA Region 10 (which includes Alaska in its jurisdiction) near the beginning of every month between the kick-off meeting and Jan. 2010. These teleconferences were indispensible for coordinating the needs of EPA with our capabilities and adapting to unforeseen developments as they arose.

- Task 4 – Prepare brief monthly progress reports.

These reports provided to the EPA at the end of every month from Oct. 2008 – Dec. 2009, contained in total most of the information and task completion history found in this report.

- Task 5 – Set up meteorological model and conduct initial baseline testing.

After some minor modifications were made to the proposed model grid configuration to maximize the utility of available data, the final specifications of Grids 1, 2, and 3 were confirmed with the EPA in Feb. 2009; more precise coordination of these grids with a parallel emissions modeling project were completed in May 2009. The data assimilation procedures required for the multiscale multigrid procedure to be used for the project were still being developed for the WRF meteorological model, led by PI Dave Stauffer also working on this contract, which helped expedite the testing and validation of these procedures. Furthermore, the testing results had to be confirmed with the version 3.1 of WRF used for most of this study, released in Apr 2009. By Jun 2009 we determined that the model components were ready to begin physics sensitivity testing.

- Task 6 – Develop and/or adapt one or more stable boundary layer and land-surface models in accordance with the SOW.

For the choice of stable boundary model in the WRF baseline physics package, we used the Mellor-Yamada-Janjić (MYJ) parameterization that we had used for our previous studies of the stable boundary layer in Alaska, with a few modifications. For the land surface model, however, we decided that we should make use of the Noah model available in version 3.1 of WRF, since it included a number of adaptations to snow-covered terrain that would be critical in this study. Using the particular Noah adaptations in version 3.1 of WRF was one reason for using that model when it became available. After we confirmed that using the Noah land surface model initialized with Global Forecast System (GFS) model data produced reasonable results, we discovered that the default WRF data assimilation procedure needed to be modified to interact properly with the stable boundary layers generated by the high-resolution model. By Jul 2009 we had decided on the baseline physics package to be used for the main simulations.

- Task 7 – Conduct up to five sensitivity tests for the selected modeling periods and evaluate results in accordance with the SOW.

Two twenty-day episodes from the 2007-2008 winter season, both with periods of extremely cold temperatures and high PM2.5 concentrations, were selected for evaluation of model performance: one in near total darkness (14 Dec 2007 – 03 Jan 2008), and the other in partial sunlight (23 Jan 2008 – 12 Feb 2008). In addition to the baseline physics configuration that included the MYJ planetary boundary layer (PBL) scheme, the Noah land surface model, and the RRTM longwave / Dudhia shortwave radiation package, three other physics sensitivity tests were performed for the entirety of each twenty-day episode, which involved using the RRTMG radiation package (longwave and shortwave), the Quasi-Normal Scale Elimination (QNSE) PBL scheme, and the Rapid Update Cycle (RUC) land surface model. After some discussion, the specific combinations used, in addition to the baseline, were MYJ / Noah / RRTMG, QNSE/ Noah / RRTMG, and MYJ / RUC / RRTMG. After statistical comparison with available observations, there was no clearly superior model physics combination; however, the MYJ / RUC / RRTMG option seemed to do the best job at reproducing the extremely cold temperatures characteristic of the high exceedance episodes. However, all model configurations tended to have substantial warm surface temperature biases in these conditions on the innermost 1.3-km Grid 3 when no data assimilation was performed on it. (Data assimilation was performed on the outer Grids 1 and 2 for the physics sensitivity experiments to improve the lateral boundary conditions on Grid 3.) In Jan 2009 it was decided that the MYJ / RUC / RRTMG combination was to be recommended, but that final dynamic analyses using this physics package along with Grid 3 data assimilation should be performed for each episode in order to reduce the atmospheric model errors and biases before they are used in air transport and chemistry models.

- Task 8 – Participate in 1.5-day meeting with Project Officer and scientific staff at EPA/RTP in accordance with the SOW.

This meeting occurred 19-20 Nov 2009 at Research Triangle Park (RTP), NC, between one of the co-PI's (Brian Gaudet) and the Project Officer and other scientific staff at RTP. During this meeting scientific discussion of the results occurred, and a preliminary agreement that the MYJ/RUC/RRTMG combination was the most promising was reached. The main results of the project to date were presented, and plans for bringing the project to completion were made.

- Task 9 – Prepare final report and electronic data and computer code files in accordance with the SOW.

- Task 10 – Revise draft final report and data files.

This report serves to help complete Tasks 9 and 10. A pair of 2-Terabyte external hard drives were obtained from EPA for use for transferring the data, whose cumulative size is approximately 600 Gigabytes per episode simulation. The files to be transferred consist of a full three-dimensional set of model output files, generated every hour for the 12-km Grid 1, and every 12 minutes for the 4-km Grid 2 and 1.3-km Grid 3. The output for each episode from the final dynamic initialization (i.e., with data assimilation on Grid 3) using the best choice physics package will be transferred first; later, the output from the baseline and physics sensitivity studies without Grid 3 data assimilation will be transferred to EPA. In addition, the namelist specifications for each simulation, the WRF version 3.1 code as modified for the project, and the initial, boundary condition, and four-dimensional data assimilation (FDDA) files required for each WRF simulation will be included.

Investigation of means for $PM_{2.5}$ mitigation through atmospheric modeling

Final report Phase I
12/1/08 – 12/31/10

Prepared for the Fairbanks North Star Borough

By

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Summary

The Alaska adapted Weather Research and Forecasting model incline coupled with a chemistry package is used to assess the situation of $PM_{2.5}$ concentrations in the Fairbanks $PM_{2.5}$-nonattainment area in the winter months, to explore two mitigation scenarios and to assess the role of point-source emissions for the $PM_{2.5}$ concentrations at breathing level. The evaluation of the model results by the few data available suggests overall acceptable performance of WRF/Chem. WRF/Chem was chosen, as this research model was an air-quality model that was already adapted and tested for Alaska conditions.

Simulations were performed with WRF/Chem with and without consideration of point-source emissions for November 2005 to February 2006. The results suggest that point-source emissions contribute to the $PM_{2.5}$-nonattainment problem, but are not the main cause.

Two mitigations scenarios were performed for October 2008 to March 2009. The first mitigation scenario was a direct one as it assumed reduction of $PM_{2.5}$-emissions by replacing non-certified wood-burning devices with certified wood-burning devices while keeping emissions from all non-wood burning sectors the same. Comparison of the reference simulation that assumes business-as-usual, with the various simulations assuming replacement of non-certified wood-burning devices indicates that such replacements reduce the $PM_{2.5}$-concentrations at breathing level. However, a small replacement program that leads to only 6% reduction of $PM_{2.5}$-emissions on average is insufficient to achieve attainment. According to sensitivity studies, the magnitude of $PM_{2.5}$-concentration reductions at breathing level depends strongly on the number and kind of devices replaced, and the assumed partitioning of heating among devices in households with more than one heating device. Further uncertainty results from the unknown location of wood-burning devices.

Since $PM_{2.5}$ is not only emitted, but also can form by physio-chemical processes (gas-to-particle conversion) in the atmosphere from precursor gases, the second mitigation scenario addressed an indirect strategy to achieve mitigation of the $PM_{2.5}$ problem by reducing an important precursor of $PM_{2.5}$ namely sulfur. This emission-reduction scenario assumed the introduction of low sulfur fuel for domestic heating and use in all oil-burning facilities (e.g. oil-burning power plants) if they did not already use low sulfur fuel. This simulation was also performed for October 2008 to March 2009. Comparison of the results of the simulations suggest that on average over the entire winter and nonattainment area, a slightly higher reduction of $PM_{2.5}$-concentrations can be achieved when introducing low sulfur fuel than for the small wood-burning device replacement program assumed in the other emission reduction scenario. However, the results also suggest that locally and temporally $PM_{2.5}$-concentrations may increase after introduction of low sulfur fuel due to shifts in the equilibria of precursor concentrations. The increase is due to a shift towards more formation of nitrate that has a higher mass than sulfate. Note that introduction of low sulfur fuel not only changes the emissions of SO_2, but also the emissions of other species released during the combustion of oil and hence causes a shift in the distribution of precursors. The effect of such shifts in precursors on the equilibria depends on temperature, light and moisture conditions. The aforementioned meteorological conditions all affect gas-to-particle conversion and hence the production of $PM_{2.5}$ in the atmosphere. Since introduction of low sulfur fuel may, under certain conditions, lead to increased, instead of decreased $PM_{2.5}$-concentrations, a woodstove replacement program seems to be the safer way to achieve mitigation than a measure that tries to achieve mitigation indirectly.

Calculation of the relative response factors and new design values suggests that none of the scenarios assumed in this study may alone lead to attainment. Therefore, combined measures and/or other measures like enhancement of the use of gas should be examined in the future.

1. Brief description of Fairbanks' nonattainment problem

In 2006, the Environmental Protection Agency (EPA) tightened the previous 24h National Ambient Air Quality Standard (NAAQS) for particulate matter (PM)[1] with diameter <2.5µm ($PM_{2.5}$) from 65µg/m^3 to 35µg/m^3. The annual $PM_{2.5}$ standard of 15µg/m^3 remained. Data collected by the Fairbanks North Star Borough (FNSB) and faculty at the Geophysical Institute (GI) indicate that in the past years 24h-average $PM_{2.5}$ concentrations[2] exceeded the new standard frequently (cf. Fig. 1). Since in previous years, the measurements at the official PM measurement site of the FNSB at the State Building exceeded the new NAAQS for $PM_{2.5}$ repeatedly, a $PM_{2.5}$ nonattainment area was assigned.

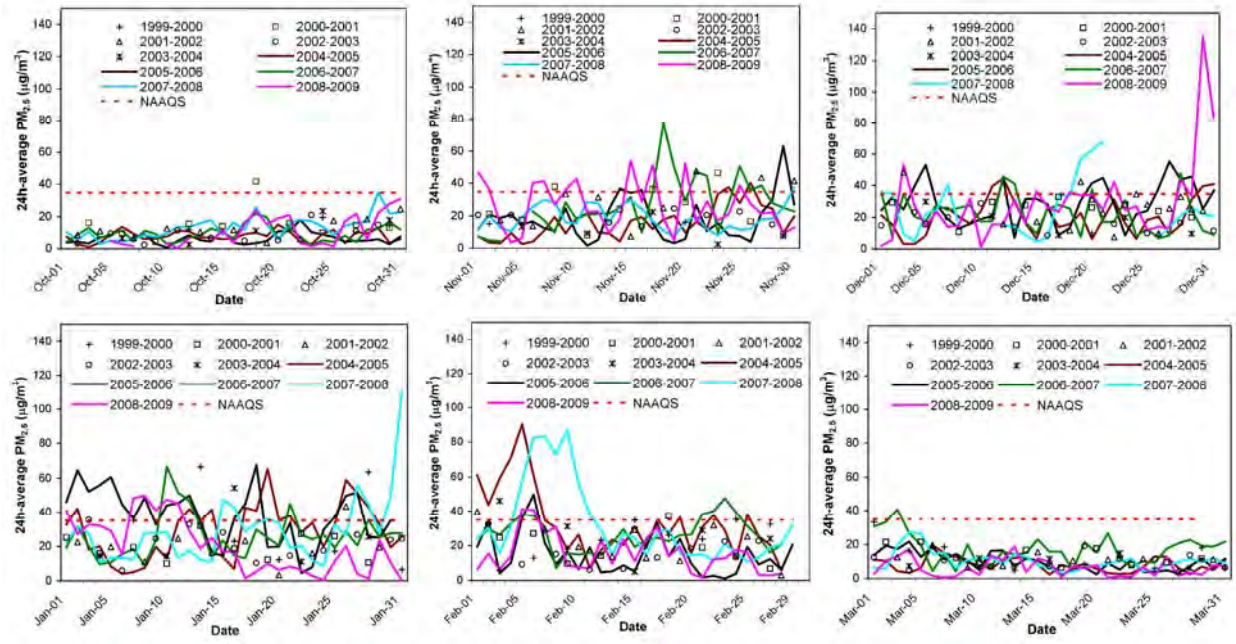

Fig. 1. $PM_{2.5}$ concentrations measured in downtown Fairbanks from October 1 to March 31 in various years from 1999 to 2009. Modified after *Tran and Mölders* [2011]

In Fairbanks, exceedances typically occur during the cold season (October to March) hereafter referred to as winter, and the fire season (summer) [*Tran and Mölders*, 2011]. In Alaska summer, fire events frequently create $PM_{2.5}$ concentrations well in excess of levels deemed "unhealthy". However, these events may be excluded from being considered as an exceedance if it can be proven that the exceedance was due to a particular event [*EPA*, 2007]. While exceedances due to fires may be considered as "natural events" under the aforementioned circumstances, the exceedances in winter are due to anthropogenic activity.

Analysis of available data showed that there are various factors contributing to the $PM_{2.5}$ exceedances in winter: topography, weather, and emissions[3] [*Tran and Mölders*, 2011].

[1] Particulate matter is often also called particulates. Here PM are tiny subdivisions of solid matter suspended in the atmosphere.
[2] Concentration refers to the amount of a substance per defined volume. Typically, concentration is expressed in terms of mass per unit volume (e.g. µg/m^3).
[3] Emission refers to the release of gases and/or particulate matter into the atmosphere, i.e. a flow. Typically, emissions are expressed in terms of mass per unit area per time (e.g. kg/(m^{2}s)).

Fairbanks' being located at the edge of an air-mass source region[4] yields low wind-speeds, and cold air that remains in place over long time [*Tran and Mölders*, 2011]. In addition, wintertime radiative cooling leads to inversions, i.e. a temperature increase with height[5]. Fairbanks experiences strong semi-permanent inversions with temperature differences of 5-10K from the basis close to the earth's surface to the top of the inversion during the period from November to February [*Bourne et al.*, 2010]. Such inversions hinder the vertical exchange of air. Consequently, if an inversion is present, $PM_{2.5}$ and other pollutants will accumulate in the air underneath the inversion, and will potentially lead to $PM_{2.5}$ exceedances [*Tran and Mölders*, 2011]. The fact that Fairbanks is surrounded by hills further contributes to the low exchange of polluted and clean air masses. Other meteorological factors affecting concentrations are mixing height, atmospheric stability, longevity and strength of inversions [*Mölders and Kramm,* 2010].

Heat and energy production as well as traffic are the main sources for $PM_{2.5}$ emissions. In winter, roughly 30% of the $PM_{2.5}$ in downtown Fairbanks may stem from traffic [*Johnson et al.*, 2009]. Pervious studies [*Davies et al.*, 2009] indicate that non-certified woodstoves and wood-boilers strongly contribute to the $PM_{2.5}$ emissions from the heating sector. Another source for $PM_{2.5}$ is gas-to-particle conversion a process that occurs naturally in the atmosphere [e.g. *Kumar et al.*, 2010].

Trace gases that are emitted are referred to as primary pollutants. Pollutants resulting from reaction of primary pollutants and other naturally available gases are called secondary pollutants. Particulate matter that is emitted is called primary PM. Secondary PM forms already in the plumes, but also elsewhere in the atmosphere, from gas-to particle conversion. Any $PM_{2.5}$ that results from gas-to-particle-conversion is called secondary $PM_{2.5}$ hereafter.

The term aerosol refers to solid and liquid particles suspended in the atmosphere. Aerosols can exist in the nucleation, accumulation and coarse mode. Aerosols in the coarse mode typically stem from mineral dust and ash fly from biomass burning. The terms *nucleation mode* and *accumulation* mode denote the mechanical and chemical processes that produce aerosol particles in these two size ranges.

In the nucleation mode, the aerosols are the smallest. They are produced by *gas-to-particle conversion*. Gas-to-particle conversion produces particles when trace gases react with other gases or particles that exist in the atmosphere or when trace gases absorb solar radiation that leads to photochemical reactions. In the nucleation mode, most aerosol particles consist of sulfuric compounds, and stem from the oxidation of sulfur containing precursor gases (like SO_2, H_2S, CS_2, COS, CH_3SCH_3, and CH_3SSCH_3) to sulfate (SO_4^{2-}), and subsequent condensation into particle form. This process is called homogenous gas-to-particle conversion. These tiny highly mobile sulfate aerosol particles can coagulate. Much of the sulfate aerosol from gas-to-particle conversion finally ends up in the 0.1-1.0µm size range. Sulfur dioxide (SO_2), for instance, can yield the formation of various sulfates in the presence of ammonia (NH_3) and water vapor via gas-to-particle conversion. Sources for SO_2 in the atmosphere are volcanic emissions, and emissions from fires, traffic, power-production and combustion for heating. Important anthropogenic sources for ammonia are domesticated animals and fertilizer.

[4] An air-mass source region is a region over which air remains frequently for a long enough time that the surface affects the air mass' temperature and moisture properties substantially.

[5] Under normal conditions, temperature decreases with height in the troposphere. Temperature inversion means that temperature increases with height. Inversion layer refers to the atmospheric layer within that such an increase exists.

Gas-to-particle-conversion forms ammonium (NH_4^+) $PM_{2.5}$ by the reaction of ammonia in the gas-phase with sulfur, nitrogen, and other acidic species forming ammonium nitrate and ammonium-sulfate particulate matter. $PM_{2.5}$ ammonium nitrate, for instance, forms from the NO_x-reaction by-product nitric acid and ammonia.

Nitrate (NO_3^-) containing aerosols typically exceed 1µm in diameter, i.e. they do not form by homogenous, but heterogeneous gas-to-particle conversion processes. They also may stem from evaporation of droplets, among other things.

In the accumulation mode (0.1-2.5µm in diameter), *coagulation* of smaller particles and/or *heterogeneous condensation* of gases onto existing particles produce particles. The largest mass and amount of particles occur in the accumulation mode due to the lack of efficient removal mechanisms for these particles.

The term secondary aerosol refers to particles that are produced by precursor gases, condensation and other processes in the atmosphere. This means that $PM_{2.5}$ can be released in the atmosphere from emissions, or be produced in the plume of stacks or in the atmosphere by gas-to-particle conversion. Primary aerosol refers to particles directly emitted into the atmosphere as particles. Primary aerosols produced by combustion span all three size ranges.

Measurements by the FNSB show a large spatial and temporal variability in $PM_{2.5}$ concentrations (e.g. Figs. 2, 3). The reasons for the observed spatial variability in $PM_{2.5}$ concentrations are manifold. In business districts dominated by central heating, traffic usually contributes more than in low-traffic residential areas dominated by heating with coal, wood or oil. $PM_{2.5}$ emissions from traffic, power plants and home heating with oil also depend on sulfur content [e.g. *Johnson et al.*, 2009]. $PM_{2.5}$ concentrations at breathing level depend on the emissions and meteorological factors like temperature, mixing height, atmospheric stability, longevity and strength of inversions [*Dawson et al.*, 2007; *Mölders and Kramm*, 2010; *Tran and Mölders*, 2011].

Fig. 2. $PM_{2.5}$ concentrations as measured in Fairbanks by the mobile platforms (lines of dots) on 12-29-2008 during the drive starting at 1523 AST (Alaska Standard Time). Measurements have been also made in the hills and the North Pole area (not shown here). Single dots are the $PM_{2.5}$ concentrations as measured at the stationary sites. Color code: deep green 0-35 $\mu g/m^3$, olive 35-105 $\mu g/m^3$, orange 105-210 $\mu g/m^3$, red 210-350 $\mu g/m^3$, and >350 $\mu g/m^3$ grey. Courtesy to *F. di Genova* [2009]

Due to the temperature dependency of chemical reaction [e.g. *Seinfeld and Pandis*, 1997] secondary pollutants, gas-to-particle-conversion and the emissions from energy and heat production differ for warm and cold atmospheric conditions. For $PM_{2.5}$ ammonium nitrate formation not only the NO_x reaction by-product nitric acid and ammonia have to be available, but also temperatures must be low and relative humidity must be high [*Wexler and Seinfeld*, 1992]. This means that the local change rate $\partial[C]/\partial X$ in concentration [C] with changes in the meteorological quantity X can differ in winter from those in summer or in other words is different for Fairbanks' winter conditions as compared to winter conditions in a warmer climate.

As previously indicated, $PM_{2.5}$ is a complex mixture of components − nitrate, sulfate, organic carbon, elemental carbon (EC) other primary particulate matter, ammonium and water − that show strong seasonal variations (Fig. 3) due to differences in sources, temperature and humidity. Analysis of previous measurements suggests that the burning sector and especially wood-burning strongly contribute to the high $PM_{2.5}$ concentrations in the FNSB (e.g. Fig. 3).

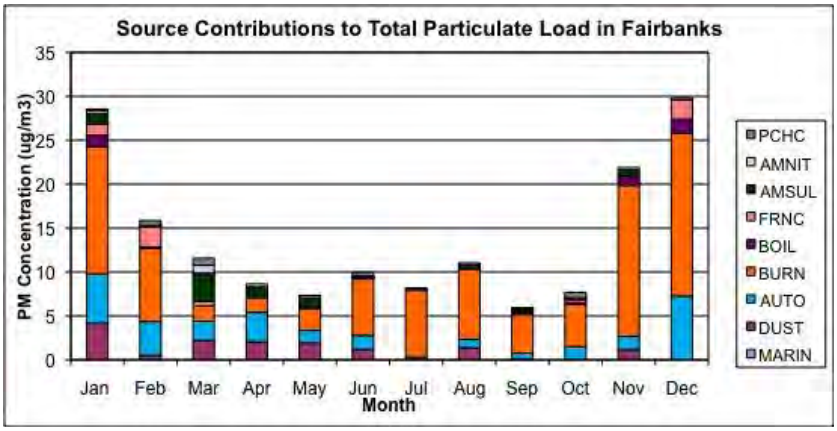

Fig. 3. $PM_{2.5}$ composition in Fairbanks. PCHC, AMNIT, AMSUL, FRNC, BOIL, BURN, AUTO, DUST and MARINE stand for coal-fired power plant, ammonium nitrate, ammonium sulfate, furnace, industrial boilers, biomass burning, automobiles, soils, and marine $PM_{2.5}$. Courtesy to *C.F. Cahill and A.N. Wallace* [2010]

If no action is taken to reduce the $PM_{2.5}$ concentrations in Fairbanks, Fairbanks will likely exceed the $PM_{2.5}$ standard in winters in the future. Such non-compliance is expected to have significant social, health and/or economic impacts on Fairbanks, the FNSB and their citizens.

The EPA, FNSB, Alaska Department of Environmental Conservation (DEC), Alaska Health & Social Services and scientists are concerned about the $PM_{2.5}$ concentrations in Fairbanks as $PM_{2.5}$ has various known health adverse effects. For instance, exposure to airborne $PM_{2.5}$ is associated with cardiovascular events and mortality in elderly and cardiac patients [*Riediker et al.*, 2004]. Various studies indicate that people − especially children − living in close proximity to roadways show more respiratory symptoms, decreased lung function, more respiratory hospitalizations and increased incidence of asthma than their peer groups in other environmental conditions [e.g. *McCreanor et al.*, 2007]. Climate-geographical location plays no role and a pre-existing family history of asthma is not required, i.e. living close to heavy traffic or heavily industrialized areas is the important factor [*Gordian* 2010; pers. communication]. Investigations on healthy young men who were exposed to $PM_{2.5}$ from road traffic suggest that these men experienced pathophysiological changes that involve inflammation, coagulation and cardiac rhythm [*Riediker et al.*, 2004].

2. Selection of the air quality model

Obviously, no exposure to any pollutants would avoid adverse health impacts from air pollution, but this is impossible to realize. The current NAAQS were set according to the best scientific knowledge to protect human health. These values are re-evaluated from time to time to adjust to newest scientific findings if required. Often tightening the NAAQS requires emission regulations. Such emission regulations may have enormous socio-economic impacts for both public and private stakeholders. Therefore, it is helpful to assess the effectiveness of a potential regulation and/or the contribution of an emission source sector being under suspicion to strongly contribute to the exceedance of the new NAAQS.

Photo-chemical models of various complexity have been used for a long time to examine (1) the relation between meteorological conditions and air quality, (2) the formation and distribution of acid rain, (3) air-quality issues, and (4) the role of long-range transport of pollutants for air quality [e.g. *Chang et al.*, 1989; *Mölders et al.*, 1994; *Grell et al.*, 2000, 2005; *Tetzlaff et al.*, 2002; *Otte et al.*, 2005; *Yu et al.*, 2008; *Eder et al.*, 2009; *Mölders et al.*, 2010]. The use of such air-quality models for emissions permits and/or for regulatory purposes has a long tradition not only at EPA [*EPA*, 2009]. Recently, ambient air-quality modeling has been used successfully to estimate individual and population exposure for human health research in mid-latitudes [e.g. *Bell* 2006].

The great advantage of photo-chemical models is that they permit easily to change emissions in the model world. The model then provides the atmospheric response, i.e. the concentrations that result in response to the altered emissions. This means photo-chemical models permit us to answer "What …if" questions like

- "What will happen to the $PM_{2.5}$ concentrations at breathing level if we replace a certain amount of non-certified wood-burning devices by EPA certified wood-burning devices?"
- "What will happen if we reduce the sulfur content in fuel used for domestic heating and power productions?"

They also permit us to assess the contribution of an emission source of interest to the $PM_{2.5}$ concentrations at breathing level, and answer questions like

- "What do the power plants contribute to the $PM_{2.5}$ concentrations at breathing level?"

Modeling is a useful tool to access in which direction emission-reduction efforts will go, how the altered emissions in combinations with the various chemical and meteorological processes affect the concentrations, and what the impact of emissions sources are. To answer such questions it is necessary to perform at least two simulations. One simulation considers the emissions as they are currently (business-as-usual). This simulation is the reference simulation and provides the baseline. The second simulation that is applied for the same meteorological condition as the first one, considers the emissions of the altered emission scenario (e.g. the change in emissions in response to a "woodstove exchange program"). Comparison of the results of the simulations permits us to assess how much the concentrations change in response to the altered emissions.

The goal of this study was to conduct photo-chemical model simulations with a complex state-of-the-art research model to quantify numerically the potential impacts of various emission reduction scenarios on the $PM_{2.5}$ concentrations at breathing level in Fairbanks, the Fairbanks nonattainment area and its adjacent land. These modeling studies in combination with various

other investigations related to Fairbanks' nonattainment problem [e.g. *Davies et al.*, 2009; *Carlson et al.*, 2010], ongoing studies and measurements are to help policy makers in the decision making process on which measures to apply to decrease the $PM_{2.5}$ levels in the future and to inform the public.

The Weather Research and Forecasting model inline coupled with a chemistry model commonly known as WRF/Chem [*Grell et al.*, 2005] is a state-of-the-art photo-chemical research model[6] based on the newest scientific knowledge. It simulates the meteorology and the trace-gas and aerosol cycles from emission, through a variety of chemical reactions, to transport, and finally removal from the atmosphere by wet or dry deposition. WRF/Chem can consider feedbacks between chemistry and meteorology.

WRF/Chem was chosen as it was the only photo-chemical model that was already adapted for application in Alaska [*Mölders et al.*, 2010, 2011]. These modifications, among other things, ensure Alaska-typical values of the vertical profiles of initial background concentrations (e.g., acetylene, CH_3CHO, CH_3OOH, CO, ethane, HCHO, HNO_3, H_2O_2, isoprene, NO_x, O_3, propene, propane, SO_2) and boundary conditions. The modifications also ensure that Fairbanks and other settlements are included in the land-use data and that winter typical vegetation parameters are used from Mid-October to Mid-April. In addition, modifications concerning the stomatal behavior of Alaska vegetation and dry deposition of trace gases on snow were included [*Mölders et al.*, 2010, 2011]. Furthermore, first evaluations studies of the Alaska adapted WRF/Chem already existed that showed accepatble performance for Alaska [*Mölders et al.*, 2010, 2011]. Such studies did not exist for other photo-chemical models yet.

We used the following model setup that was capable of capturing Alaska winter conditions well in previous studies [*Mölders*, 2008; *Mölders and Kramm*, 2010; *Mölders et al.*, 2010; *Yarker et al.*, 2010]. The WRF-Single-Moment six-class scheme that allows the coexistence of super-cooled water droplets and ice-crystals and processes among the solid and liquid phase cloud and precipitation components, served to simulate resolvable cloud- and precipitation-formation processes [*Hong and Lim*, 2006; *Hong et al.*, 2006]. It is able to simulate falling snow crystals and ice fog, which are of relevance for Fairbanks in winter. To consider the impact of the cumulus convection even though it rarely occurs in Fairbanks winters, we used the cumulus-ensemble scheme [*Grell and Dévényi*, 2002] as it is well suitable for the grid-resolution at which WRF/Chem was run for this study. The Goddard two-stream multi-band scheme was used to calculate shortwave radiation processes. It considers, among other things, the impacts of clouds and ice fog on shortwave radiation. This is important as the shortwave radiation affects photolysis rates. Long-wave radiation was calculated with the **R**apid **R**adiative **T**ransfer **M**odel [*Mlawer et al.*, 1997] that takes into account multiple spectral bands, trace gases, and cloud microphysical species (cloud-droplets, rain drops, ice-crystals, etc.), among other things. It allows considering the effects that pollution, ice fog and clouds have on long-wave radiation. The 1D-prognostic scheme by Janjić [2002] was applied to determine turbulent processes[7] in the atmospheric boundary layer[8] (ABL), i.e. the first 1000m or so above ground level (AGL). For the

[6] Note that WRF/Chem is a complex state-of-the-art research model, not a regulatory model.
[7] Turbulence refers to rapid fluctuations.
[8] The ABL is the lowest part of the atmosphere that is directly influenced by its contact with the surface. In the ABL, turbulence and vertical mixing can be strong.

atmospheric surface layer[9], i.e. the first 100m or so, Monin-Obukhov similarity hypotheses were used to describe the turbulent processes; the so-called Zilitinkevich thermal roughness-length concept was considered for the underlying viscous sublayer [*Janjić*, 1994]. Previous studies showed that out of various parameterizations available in WRF/Chem these parameterizations of ABL and surface layer processes provide the best results most of the time for Interior Alaska [e.g. *Mölders and Kramm*, 2010]. Simulating the ABL processes adequately is required to capture inversions and their strength and hence the accumulation of pollutants underneath. *Smirnova et al.*'s [2000] land-surface model (LSM) was used to determine the exchange of heat and moisture at the land-atmosphere interface. This LSM calculates, among other things, the soil-temperature and moisture states including frozen soil, snow conditions at various depths in the snow-pack, and vegetation impacts on the atmosphere. The LSM was chosen as it considers permafrost and snow processes. Simulating these processes adequately is important to capture the strength of inversions.

The chemical mechanism by *Stockwell et al.* [1990] served to calculate gas-phase chemistry, i.e. reactions among trace gases. This mechanism considers the chemical reactions that occur in the polluted and non-polluted atmosphere at day and night. Inorganic reactions and constants involve 14 stable inorganic compounds, four inorganic short-lived intermediates and three abundant stable species (oxygen, nitrogen, water). The organic chemistry scheme considers 26 groups of stable organic compounds and 16 groups of organic short-lived intermediates (peroxy radicals). Photolysis frequencies were calculated in accord with *Madronich* [1987] as even at winter solstice Fairbanks still experiences 3.7h of sunlight. These frequencies were used in the calculation of photochemical processes. Photolysis calculation considered 21 photo-chemical reactions. In mid latitudes, the chemical processes during daylight (daytime chemistry) differ from those at night (nighttime chemistry). In Fairbanks, however, the fraction of the day with daylight strongly differs over the winter. In Fairbanks, the sun is only a few hours above the horizon in January and December, while it is appreciably longer above the horizon to provide energy for photochemical processes in October, November, February and March. Thus, the importance of photochemical processes and their contribution to chemical transformations differs strongly over the winter due to the large differences in available shortwave radiation (see Fig. 11c). Thus, "daytime" and "nighttime" chemistry play a different role in January and December than the other winter months. Therefore, it was considered necessary to simulate several months rather than a short episode in the coldest month.

Various processes (transport, turbulence, evapotranspiration, sorption, desorption, biogenic activity, emission, settling, chemical reactions) are involved in the dry deposition process, i.e. the removal of trace gases from the atmosphere. Thus, dry deposition not only depends on the physical and chemical states of the atmosphere, but also on the surface on which the trace gases and particles deposit. The formulation of dry deposition [*Wesely*, 1989] with the modifications introduced by *Mölders et al.* [2011] considers these processes. The modifications serve to treat dry deposition of trace gases more realistically under low temperature conditions and consider dry deposition on snow. Since the stomata of Alaska vegetation often are still open at $-5^{o}\mathrm{C}$, the threshold for total stomata closure was lowered accordingly in the LSM and deposition module.

[9] In the atmosphere, surface layer refers to the layer where the turbulent air is most affected by interaction with the surface. The characteristics of the turbulence depend on the distance from the surface. The surface layer is characterized, among other things, by large concentration gradients of any substances transported to or from the surface.

Aerosol chemistry and physics was treated based on a modified version of the Regional Particulate Model [*Binkowski and Shankar*, 1995], where the vertical transfer of particulate matter is treated in accord with *Kramm et al.* [1992]. Among other things, the aerosol module considers aerosol chemistry and physics, and aerosol formation by gas-to-particle conversion, and Secondary Organic Aerosol (SOA) formation processes [*Schell et al.*, 2001] and the removal of particulate matter from the atmosphere by wet and dry deposition of aerosols. These aerosol chemistry modules have been well tested for mid latitudes. A through evaluation for Alaska is still missing due to lack of observational data. First evaluations with the limited data available [*Mölders et al.*, 2010, 2011] suggest acceptable performance most of the time.

3. Model domain, initial and boundary conditions

The Alaska Emission allocation Model (AkEM) [*Mölders* 2009, 2010] and WRF/Chem were set up for a domain covering most of Interior Alaska with a horizontal grid increment of $4\text{km} \times 4\text{km}$. Since Alaska available land-use data did not consider any urban areas, we introduced Fairbanks, North Pole, Eielson and the villages into the WRF/Chem land-use data file (Fig. 4) based on satellite data using Google Earth. Relevant WRF/Chem-simulated concentrations and meteorological quantities were written out hourly as a function of time and space for the domain of interest. The domain of interest for the analysis encompasses 89,600km^2 centered around Fairbanks up to 100hPa (Fig. 4).

WRF/Chem used logarithmically increasing vertical grid increments with the smallest increment being located above the ground and the largest increment reaching to the top of the model located at 100hPa. In total, there are 28 layers. In the lower troposphere, the tops of the layers were at 8, 16, 64, 113, 219, 343, 478, 632, and 824m AGL. The lowest atmospheric model layer represents the "breathing level". This vertical and horizontal grid is a compromise to ensure still sufficient vertical and horizontal resolution, and allow for several months long simulations in a reasonable amount of time.

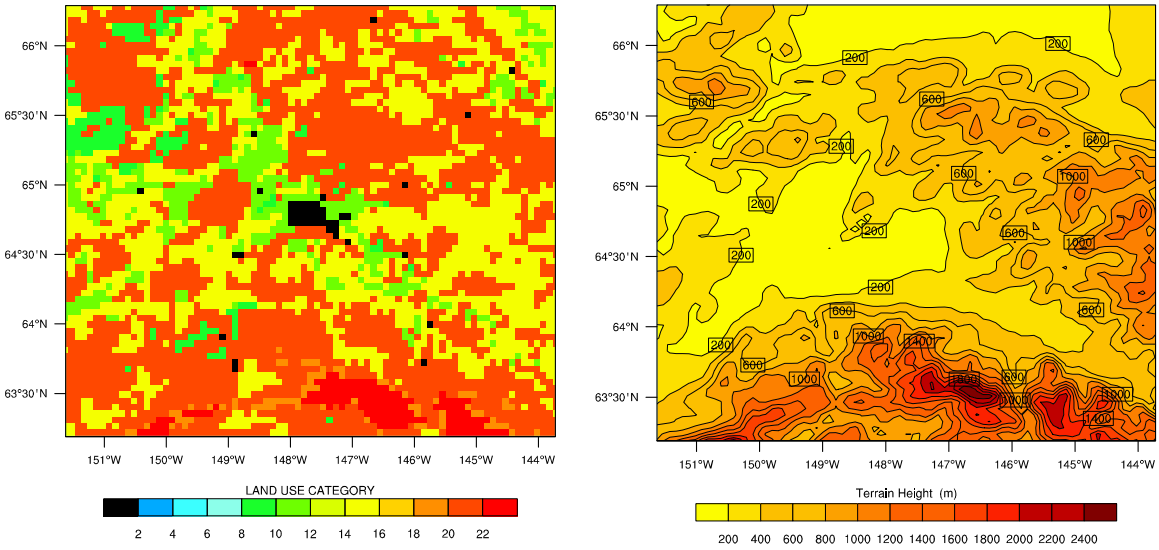

Fig. 4. Land-use (left) and topography (right) in the domain of interest for the analysis of this study. The land-use category code is 1 urban and built-up land, 2 dryland cropland and pasture, 3 irrigated cropland and pasture,4 mixed dryland/irrigated cropland and pasture, 5 cropland/grassland mosaic, 6 cropland/woodland mosaic, 7 grassland, 8 shrubland, 9 mixed shrubland/grassland, 10 savanna, 11 deciduous broadleaf forest, 12 deciduous needleleaf forest, 13 evergreen broadleaf, 14 evergreen needleleaf, 15 mixed forest, 16 water bodies, 17 herbaceous wetland, 18 wooden wetland, 19 barren or sparsely vegetated, 20 herbaceous tundra, 21 wooded tundra, 22 mixed tundra, 23 bare ground tundra, 24 snow or ice.

The meteorological fields were initialized every five days using data downscaled from the $1^o \times 1^o$, 6h-resolution National Centers for Environmental Prediction global final analyses (FNL). At the beginning of the simulations, WRF/Chem was initialized with idealized vertical profiles of Alaska background concentrations for each chemical specie (e.g., acetylene, CH_3CHO, CH_3OOH, CO, ethane, HCHO, HNO_3, H_2O_2, isoprene, NO_x, O_3, propene, propane, SO_2). For all further days, the simulated chemical fields of the previous day served as initial conditions to simulate the next day.

Since Fairbanks is far remote from any emission sources, Alaska background concentrations were used for the chemical lateral boundary conditions. The meteorological boundary conditions were downscaled and interpolated from the FNL-data.

WRF/Chem was run in forecast mode, i.e. no nudging or data assimilation was applied. The reference simulation and the simulation that was to assess the contribution of point sources to the $PM_{2.5}$ concentrations at breathing level, start with the same meteorological and chemical initial conditions on November 1, 2005 0000 UTC (see Table 1). In the mitigation investigations, the reference simulation and all mitigation scenarios start with the same meteorological and chemical initial conditions on October 1, 2008 0000 UTC (see Table 1). This procedure ensures that differences in simulated concentrations only result in response to the changes in assumed emissions.

Emissions were considered as a function of time (month, weekday, and hour) and space (latitude, longitude and height). Various types of emission sources are considered. Point sources are fixed (immobile) facilities that emit gaseous or particulate atmospheric pollutants (e.g. smokestacks, power plants, industrial plants, steel mills). A line source is one-dimensional emission source (e.g., vehicle traffic on a highway). An area source is a two-dimensional source of diffuse emissions (e.g. the emissions from domestic heating, landfills, fires). For more details, see e.g. *http://en.wikipedia.org/wiki/Air_pollution_dispersion_terminology* [2011].

In the case of point sources, emissions are released into the model levels that are calculated depending on stack parameters (stack height, stack diameter, flow temperature, flow velocity, etc.). WRF/Chem, among other things, also includes plume rise [*Peckham et al.*, 2009]. In the case of area and line sources, the model level in which the emissions are released depends on the kind of emission source. For instance, emissions from city or highway traffic are released into the first model layer above ground (Fig. 5).

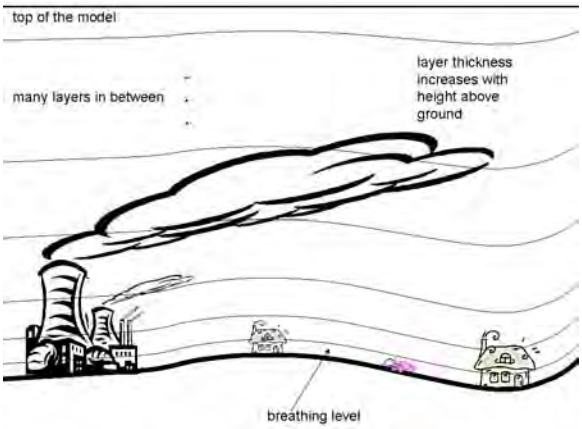

Fig. 5. Schematic view of the vertical grid structure and consideration of various emission sources. The spacing of vertical model layers increases logarithmically with height. Note that not all model layers and potential emission sources considered by WRF/Chem are pictured here.

Some Alaska plant species remain photosynthetically active up to temperatures as low as -5°C (23°F). Thus, we considered biogenic emissions of isoprenes, monoterpenes, and volatile organic compounds (VOC) by plants, and nitrogen emissions by soil as calculated by the **M**odel of **E**missions of **G**ases and **A**erosols from **N**ature [*Guenther et al.*, 1994; *Simpson et al.*, 1995] if the ground is not covered by snow.

4. Meteorological episodes simulated

At the start of the project in 2008, the most recent emission data available for the FNSB were the National Emission Inventory (NEI[10]) data of 2005. In December 2008, the FNSB expected that a gridded emission-data inventory with 400m spatial and hourly resolution representing the winter 2007/08 would be available for Fairbanks and its vicinity in April 2009 [*Conner* pers. communication, 2008]. Therefore, it was planned to switch to a more recent episode for the simulations on the impact of introduction of low sulfur fuel and a "woodstove replacement program" despite doing so would require producing an additional reference (baseline) simulation (Table 1).

4.1 Emissions

All NEI data were annual values for the various species and emission sectors in the FNSB. These emission data were allocated for use in WRF/Chem using the AkEM [*Mölders*, 2009; 2010]. Input data to AkEM are the EPA NEI data, stack parameters, data for the split of $PM_{2.5}$ and VOC, allocation data of annual, daily, hourly emission percentages for area, line, and point sources, population density data, land-use and street network data as well as meteorological data. The split of $PM_{2.5}$ emissions into ammonium (NH_4), carbon, nitrate (NO_3), potassium, sodium, and sulfate (SO_4) was made based on observations provided by the FNSB [*Conner,* 2009]. Due to the lack of observational data, we split the total anthropogenic VOC emissions into the various species like ethane, butane, formaldehyde, pentane, hexane, ethylene, propylene, acetylene, benzene, toluene, xylene, tri-methylbenzene, and other aromatics depending on emission-source types in accord with *Mölders et al.* [2011].

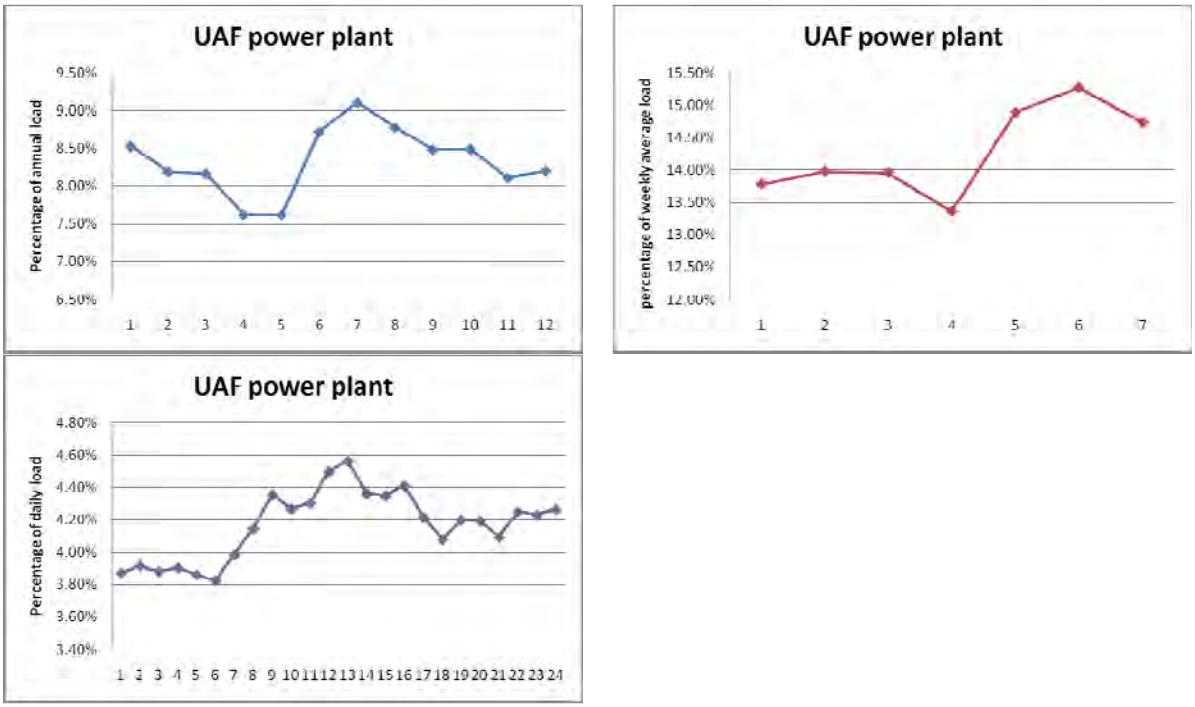

Fig. 6. Activity allocation as derived for the UAF power plant for (from upper left to lower left) monthly, weekday and hourly activity. Data courtesy by *Waard* [2008]

[10] Typically the National Emission Inventory is abbreviated as NEI and the year is added, e.g. NEI1999 would be the NEI for 1999.

AkEM calculates hourly emission rates for each grid-cell from the annual emission E_{total} given by the NEI. In doing so, AkEM uses the spatial and temporal activity allocation functions for the various emission sources that have been recommended by EPA for Alaska with the modifications that have been derived in collaboration with local partners. Figure 6 exemplarily shows the emission-allocation functions as derived from data for the UAF power plant. Area emissions from the burning sector, for instance, are distributed spatially depending on specie, activity, population, and/or land-use, and time. The model level and grid cell into which point sources emit, depends on stack parameters, latitude, and longitude and plume raise that is calculated using Biggs formula [*Peckham et al.*, 2009].

4.1.1 Emission data for 2005/06

We performed a quality assessment and quality control (QA/QC) on the NEI2005 data for the FNSB. The QA/QC showed that for some point sources stack parameters were missing and/or the coordinates were incorrect or vice versa. We worked with the respective facility operators and EPA to fill in and/or replace the data with the correct data.

We worked with Golden Valley Electricity Association and UAF's power plant employees to obtain Alaska specific annually, daily and hourly emission profiles for 2005 (e.g. Fig. 6) and implemented them into the AkEM. We used the population-density data provided by the FNSB from the Census 2000 [data provided by *Duncan*, 2009] and projected them onto the model domain. AkEM requires these data for determining/distributing the area emissions.

For the winter 2005/06 simulations AkEM [*Mölders*, 2009] used allocations functions depending on space and time. Allocation differed with time of the day, day of the week and month. For 2006, an increase in annual emissions of 1.5% was assumed across the board.

4.1.2 Emission data for 2008/09

In December 2008, the FNSB expected that gridded spatially high resolved hourly emission data for winter 2007/08 would be available in April 2009 from SRL. The FNSB wanted to have the option to switch to a more recent episode (probably 2008/09) than 2005/06 for the "woodstove replacement" and "low sulfur emission" simulations. The reasons for this request were manifold. More observational data for model evaluation are available for this more recent winter. Moreover, since 2007, the number of woodstoves has increased notably and 2008 was discussed as a potential design year.

Early in 2010, the anticipated SRL-emission inventory for winter 2007/08 was still not available[11] due to unforeseen delays and difficulties in collecting the data that were beyond the control of SRL and/or the FNSB. Moreover, the QA/QC had still to be performed by EPA. Early, in 2010, the FNSB decided that we should perform the "woodstove replacement" and "low sulfur scenarios" for winter 2008/09. Meanwhile, namely, the NEI2008 became available except for point-source emissions. The NEI2008 more closely represents the current emission situation in the FNSB, as it considers emission changes between 2005 and 2008 and hence is more recent than the NEI2005. Therefore, we did a new reference simulation and the mitigation scenarios for winter 2008/09 (Table 1).

Note that the main difference between the emission data that we used for this study and those of the anticipated SRL-inventory is that the NEI2008 in combination with AkEM treat emission

[11] As of January 2011, we have no access to the SRL-compiled 2007/08 emission data.

data for the FNSB in a top-down approach, while the SRL-inventory treats emissions in a bottom-up approach. A top-down approach assesses emission rates based on aggregated-statistical methodologies, while the bottom-up approach compiles a site-specific emission inventory based on the detailed information for each area [e.g. *Kim et al.*, 2010]. Inter-comparison analysis suggests that standard emissions data from a top-down approach are appropriate for atmospheric model simulations [e.g. *Kannari et al.*, 2008]. The differences, advantages and disadvantages between these two types of approaches have been widely discussed in the literature [e.g. *Kannari et al.*, 2008; *Kim et al.*, 2010] and are therefore not repeated here.

Emissions of mobile and several nonpoint-emission sectors were available from the NEI2008. The NEI2008 considered aircraft emission as point sources. Other point-source sectors were not yet available in the NEI2008 and were not expected to be available before 2011. Therefore, we updated the point-source emission inventory (EI) by personal communications with the facilities holders in the FNSB whom we contacted with this request. Note that not all facilities contacted did respond. For those facilities without reported emission data, we used estimates on point-source emissions based on the previous inventory assuming a 1.5% increase per year.

The mobile emissions in the NEI2008 are less than what they were in the NEI2005, which is consistent with the lower traffic activity in 2008 as compared to 2005 [*DOT*, 2009]. Some nonpoint-emission sectors were required to be updated with the latest borough employment data. We performed these updates using the respective data from the Alaska Department of Labor and Workforce Development [*http://laborstats.alaska.gov/cgi/dataanalysis/?PAGEID=94*].

However, there were some nonpoint-emission sectors that EPA was not planning to estimate unless additional resources became available. Those sectors included industrial/commercial/ institutional fuel combustion and the residential wood combustion. The latter make up a large portion of the emission in the FNSB according to the NEI2005. Therefore, the emissions from these sectors were included in the emission database used for our simulations of winter 2008/09 to obtain realistic emission conditions. For industrial/commercial/institutional fuel combustion, we assumed the 2008 emissions to be the same as in NEI2005 because they were expected to have just marginally changed over 2005-2008. Emissions from residential wood combustions were taken from *Davies et al.* [2009] as was requested by the FNSB. The outcome showed much higher emissions from residential wood combustion in 2008 as compared to that category in the NEI2005. This increase in woodstove emissions, however, is expected given the situation in the FNSB in winter 2008/09. Note that in the NEI2005, EPA estimated emissions from residential wood combustions based on the small partition of wood-burning devices as obtained from the Census 2000. Meanwhile, in response to the increasing oil prices, many residents had added wood-burning devices to reduce heating costs. The wood-cutting permits have increased threefold in 2009 as compared to 2007 [*Conner* 2010, pers. communication]. To derive the annual emissions for 2009 from those of 2008, an increase in annual emissions of 1.5% was assumed across the board.

For allocation of the winter 2008/09 emissions a modified version of AkEM [*Mölders*, 2010] was used that applied allocations functions depending on space, time and temperature. Allocation differs with time of the day, day of the week; month and deviation of the daily mean temperature from the 30-year monthly average mean temperature. This modification (calibration) of the emission model was introduced to improve the allocation functions based on our experience with the simulations for winter 2005/06 and several sensitivity studies paid from other sources. This

modification of the emission allocation permits to better consider the temperature dependency of cold start enhanced emissions (CSEE) and the increase in energy consumption for heating for temperatures below 18°C (64.4°F) using a modified equation of *Hart and de Dear* [2004]. The temperature dependency for production of electrical power was determined assuming that freezers, refrigerators and hot water production consume equal amounts of energy. The same allocation functions and temperature correction as for power plants is assumed for emissions from fuel combustion for electricity production by nonpoint sources, but these emissions are considered dependent on population density [*Mölders*, 2010]. AkEM assumed that the non-temperature corrected allocation function is valid for the mean temperature of the month [*Mölders*, 2010]. Thus, the inclusion of temperature dependency increases (decreases) the emission factors for temperatures below (above) the monthly mean temperature. The temperatures used in these corrections are the 2m-temperatures read in from the WRF/Chem initialization data. Figure 7 exemplarily shows the impact of temperature-dependent emissions for March 3, 2005 where the domain average temperature was -22.1°C (-7.8°F).

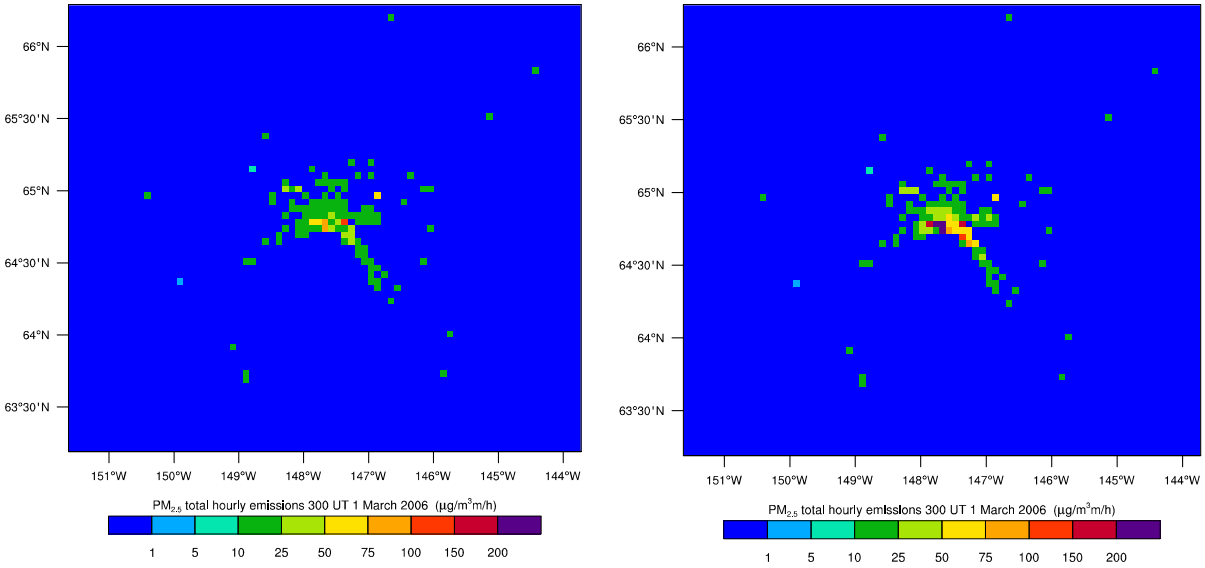

Fig. 7. Emissions of $PM_{2.5}$ without (left) and with consideration of temperature correction. This day is colder – the daily average temperature is 22.1°C (-7.8°F) - than the climatological average March temperature of -11.7°C (10.9°F) for which the original allocation functions were valid. As expected, emissions increase in response to the low temperatures. *Davies et al.*'s [2009] emission data were used.

4.2 Emission scenarios

This section describes the emission scenarios used in the mitigation simulations. Table 1 summarized the simulations performed for this study. Throughout this report, the simulations as their results are referred to as REF and NPE, or REF, WSR and LSF, respectively.

4.2.1 Emission scenario for investigation of point source contribution

The 2005/2006 winter was chosen because at the start of the project in 2008, the most recent available emission-data inventory was the NEI2005. Since the concentrations resulting from point-source (PS) emissions alone were so low that $PM_{2.5}$ concentrations were governed mainly by background chemistry, we performed simulations with emissions from all sectors as the reference simulation (REF). In a further simulation, we considered emissions from all sectors

except point-source emissions (NPE). This means emissions of all species emitted by point-sources were set to zero in the NPE scenario. Simulations with consideration of point-source emissions were performed for October 1, 2005 to February 28, 2006. The first 15 days performed for October 2005 served for calibration. The rest of October 2005 served to spin-up the chemical fields. Simulations without consideration of point sources were performed from November 1, 2005 to February 28, 2006. The simulations with and without consideration of point-source emissions start with the same initial conditions of the meteorological fields and chemical components on November 1, 2005 as obtained from the spin-up. Comparison of the concentrations obtained by the REF and NPE simulations for November 1, 2005 to February 28, 2006 served to quantify the contribution of the point sources (e.g. power plants) to the $PM_{2.5}$ concentrations at breathing level.

Table 1. List and names of simulations performed with WRF/Chem for this study. Note that LSF and WSR have the same reference simulation.

Simulation name	Description	episode simulated
REF	Reference simulation with all emissions using the NEI2005	October 1, 2005 to February 28, 2006
NPE	Simulation using the NEI2005, but excluding emissions of all species from all point sources	November 1, 2005 to February 28, 2006
REF	Reference simulation with all emissions using the NEI2008 with the updates as described in the emission section	October 1, 2008 to March 31, 2009
WSS1	"Woodstove replacement" sensitivity study that assumes non-certified wood-burning devices are replaced by modern EPA-certified woodstoves using *Davies et al.*'s [2009] numbers of wood-burning devices, while keeping emissions from all other emission sectors the same as in the respective reference simulation	October, 1 2008 to October 15, 2008
WSS2	as WSS1, but using the numbers wood-burning devices from SRL's draft report	October, 1 2008 to October 17, 2008
WSR	as WSS2, but using the numbers of *Carlson et al.*'s [2010] final report	October 1, 2008 to March 31, 2009
LSF	"Introduction of low sulfur fuel for heating and power generation", while keeping emissions from all other emission sectors the same as in the respective reference simulation	October 1, 2008 to March 31, 2009

4.2.2 Emissions for the "woodstove replacement" scenarios

A set of simulations addressed the influence of a "woodstove-replacement action" on the $PM_{2.5}$ concentrations at breathing level. The reference simulation (REF) considered emissions from all sectors available in the NEI2008 and the additional information described before. The simulation assuming "woodstove replacements" considered the same emissions as in REF minus the emissions from non-certified wood-burning devices that were assumed to be replaced plus the emissions that stem from the certified wood-burning devices that replaced the non-certified wood-burning devices. The reference and "woodstove replacement" simulations started with the same initial conditions of the meteorological fields and the same Alaska-typical chemical background concentrations for October 1, 2008.

To compile the emission data for the "woodstove-replacement" simulations, we analyzed *Davies et al.*'s [2009] results. We searched the literature and collected data on other species than $PM_{2.5}$ emitted by EPA-certified woodstoves and other wood-burning devices. These data were required as not only the $PM_{2.5}$ emissions from wood-burning devices, but also the emissions of the other species emitted by these devices will change if non-certified wood-burning devices are replaced by EPA-certified wood-burning devices. This means all species emitted by wood-burning were changed in the "woodstove-replacement scenarios". The consideration of changes for all species emitted by wood-burning devices is required because some $PM_{2.5}$ can form from gas-to-particle conversions once the species are in the atmosphere as explained before.

Davies et al.'s [2009] data only provide the total number of certified woodstoves (6912), but not the split between certified woodstoves with catalytic and non-catalytic equipment. The same is true for masonry heaters and pellet stoves. We assumed the same emission rates for wood-burning devices with catalytic and non-catalytic equipment.

Table 2. Number of households in Fairbanks. Data courtesy of *T. Duncan* [2010]

Year	Pre-2005	2005	2006	2007	2008	2009
Number of households	33970	34946	35910	36952	37550	38292

The number of households changed over the years (Table 2). As obvious from the sum of the devices listed in *Davies et al*. [2009] report, some households have at least two heating devices. We assumed that in the case of households with more than one heating device, woodstoves co-exist with oil furnaces. For fire-safety reasons it is unlikely that a woodstove exists in a household with gas. It is unlikely that woodstoves co-exist with hydronic or masonry heaters or pellet stoves as well. The category "others" is most likely central heating which also has a low likelihood to co-exist with woodstoves. Coal and woodstoves are unlikely to co-exist as typically people who burn coal also burn wood in the same stove. To avoid double counting of households in their emission contribution, we determined the number of households with at least two heating devices

$$N_{two} = N_{devices} - N_{households} \quad (1)$$

Where $N_{devices}$ and $N_{households}$ are the number of heating devices and households in that particular year. After studying *Davies et al.*'s [2009] data, it seemed reasonable to assume that households with two devices use the woodstove to other device in a ratio 33.5:66.5 of the time. Sensitivity studies indicated that the total emission reduction is very sensitive to how households split their heating among their available devices. Thus, we recommend collecting data on the "split" behavior to reduce uncertainty in future modeling studies.

We determined the actual number of devices contributing at a time to wood-burning emission as

$$N_x^{'} = N_x\left(1 - 0.665\frac{N_{two}}{N_1 + N_2 + N_3}\right) \quad (2)$$

Where the x stands 1, 2 and 3, with 1 to 3 representing non-certified woodstoves, EPA-certified woodstoves with catalytic equipment, and EPA-certified woodstoves without catalytic equipment, respectively. Analogously, the number of devices contributing at a time to emissions from oil furnaces is determined as

$$N_7^{'} = N_7\left(1 - 0.335\frac{N_{two}}{N_7}\right) \quad (3)$$

Where the index 7 denotes oil furnaces. After this procedure, the sum $\sum_{k=1}^{11} N_k^{'}$ equals the number of households.

Davies et al.'s [2009] data for Fairbanks' wood-burning emissions differ from those assumed in the compilation of the NEI2008. We used *Davies et al.*'s [2009] data for all wood-burning devices and oil furnaces as requested by the FNSB. We used EPA's data for the other categories, as data for these devices were not included in *Davies et al.*'s [2009] report.

The total annual emission rate of the i^{th} specie from heating after "woodstove replacement" is given by

$$E_{NEIyyyy,WSR} = E_{NEI,yyyy} + N_{exchange}E_2 - \sum_j N_j E_j \quad (4)$$

Where $N_{exchange}$ and E_2 are the number of wood-burning devices replaced and emission rates per certified wood-burning device, E_j are N_j the emission rates and numbers of noncertified wood-burning devices, and the index j stands for noncertified wood-burning devices, respectively.

In all "woodstove replacement" emission scenarios, we assumed emissions from all sectors to remain the same as in the reference simulation except for the heating sector. For the heating sector, we assumed the emissions from all heating devices but wood-burning devices to remain the same as in the reference simulation too. This means that in all "woodstove replacement" simulations, we only altered the emissions from the wood-burning sector.

In a first sensitivity study on "woodstove replacement", we determined the emissions remaining from wood-burning after the replacement of non-certified devices by assuming the number of residential wood-burning devices as reported in *Davies et al.* [2009]. We calculated the emissions from residential wood combustion, subtracted the contribution from non-certified devices (assumed to be replaced) and added the contribution that the certified device (that replaced the non-certified devices) would have. The simulation with this emission scenario is referred to as WSS1 hereafter. In total, 15 days (10-1-2008 to 10-15-2008) were simulated assuming this scenario.

In a second sensitivity study on "woodstove replacement", we determined the emissions remaining from wood-burning after the replacement of non-certified devices by assuming the number of wood-burning devices that became available from a draft by the Sierra Research Laboratories (SRL) group. This data based on a survey of 300 households in the nonattainment area carried out by SRL. The number of wood-burning devices reported in the draft and in the final report by *Carlson et al.* [2010] is lower than the estimates used in *Davies et al.*'s [2009] report. Note that there is high uncertainty in the actual number of wood-burning devices that exist in the nonattainment area [*Conner* 2011; pers. communication]. The draft SRL report did not include pellet stoves. *Carlson et al.*'s [2010] data only provide the total of certified woodstoves, but not the split between certified woodstoves with catalytic and non-catalytic equipment. We assumed the same emission rates for both. Again, we calculated the emissions from residential wood combustion, subtracted the contribution from non-certified devices

(assumed to be replaced) and added the contribution that the certified device (that replaced the non-certified devices) would have. The simulation performed using the emission scenario obtained this way is called WSS2 hereafter. We run this set of "woodstove-replacement" simulation from 10-01-2008 to 10-17-2008.

The final SRL report by *Carlson et al.* [2010] included pellet stoves as a separate category in the wood-burning sector. For the third "woodstove replacement" simulation, we determined the emissions remaining from wood-burning after the replacement of non-certified devices by assuming the number of wood-burning devices that were given in *Carlson et al.*'s [2010] final report. Using these numbers, we calculated the emissions from residential wood combustion, subtracted the contribution from non-certified devices (assumed to be replaced) and added the contribution that the certified device (that replaced the non-certified devices) would have. *Carlson et al.*'s [2010] data only provide the total of certified woodstoves, but not the split between certified woodstoves with catalytic and non-catalytic equipment. We assumed the same emission rates for both. A full winter simulation was performed assuming this emission scenario. This simulation is called WSR hereafter (Table 1).

Figure 8 exemplarily shows the hourly emission rates from all heating sectors for the Fairbanks area prior to and after the assumed three different "woodstove-replacement scenarios". In all "woodstove-replacement scenarios", we considered the impact on emissions of all species, not only $PM_{2.5}$.

The policy options recommended by *Davies et al.* [2009] estimated to reduce $PM_{2.5}$ emissions from residential heating from 874 tons/year to 422 tons/year, or 52% for their base year. The "woodstove replacement" scenario assuming *Davies et al.* [2009] numbers of wood-burning devices reduces the emissions for 2008 to 40%, while those with the SRL draft and *Carlson et al.*'s [2010] numbers reduce the emissions much less (Fig. 8). Note that changing out non-certified wood-burning devices to certified ones would reduce theoretically both primary and secondary $PM_{2.5}$ emission at the same order. In *Davies et al.* [2009], $PM_{2.5}$ accounts for both primary and secondary aerosol that forms after the emissions. WRF/Chem considers primary $PM_{2.5}$ from emissions and calculates the secondary $PM_{2.5}$ that builds in stacks and in air [*Peckham et al.*, 2009].

Note that if primary $PM_{2.5}$ emission were reduced greatly by changing noncertified wood-burning devices to oil furnaces, the secondary $PM_{2.5}$ emission might increase. Oil furnaces namely have higher emission rates of SO_x and NO_x than wood-burning devices. SO_x and NO_x are the main precursors of secondary $PM_{2.5}$ that forms through gas-to-particle conversion. Therefore, exchanging noncertified wood-burning devices to oil furnaces with current fuel sulfur content will be less effective in reducing $PM_{2.5}$ emission than exchanging them with certified wood-burning devices.

Obviously there is uncertainty in our study due to the unknown number of woodstoves that exist and that can be replaced. Unfortunately, no data were available, where what wood-burning devices are operated and when they were operated and how they were operated and how often. We simply assumed the distribution of wood-burning devices to be proportional to the distribution of population density. This assumption holds uncertainty in the spatial distribution that may affect local maximum concentrations as well as 24h-averages of $PM_{2.5}$ concentrations. *Fortun and Mölders* [2009] showed that uncertainty in the diurnal course of emission marginally affects the 24h-average $PM_{2.5}$ concentrations. However, uncertainty in the spatial distribution can

provide notable differences in the 24h-average $PM_{2.5}$ concentrations. Sensitivity studies on the emissions indicate that uncertainty in emission rates also results from the unknown partitioning of the use of wood-burning and other heating devices in households having more than one heating option. Note that the simulations on "woodstove replacement" do not consider that additional wood-burning devices have been added since 2008.

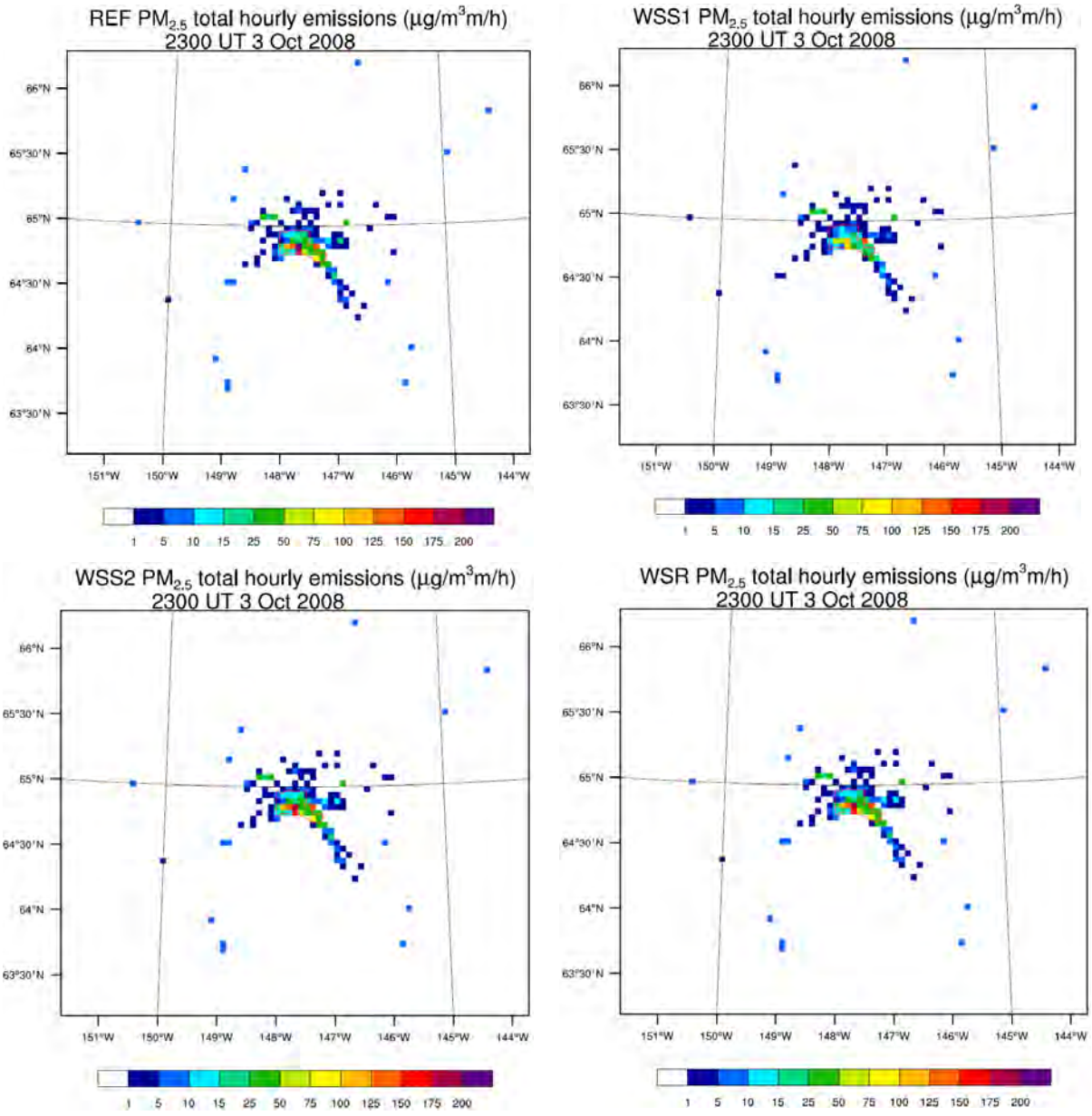

Fig. 8. Emissions of $PM_{2.5}$ as obtained with AkEM (upper left to lower right) before (REF) and after the assumed "woodstove replacement" assuming *Davies et al.*'s [2009] (WSS1), SRL's draft report (WSS2), and *Carlson et al.*'s [2010] (WSR) data on the numbers of heating devices. All "woodstove-replacement scenarios" result in reduced emissions over the nonattainment area. The nonattainment area is schematically superimposed in red.

As pointed out above, there is uncertainty in any emission data. This uncertainty is related to the approaches used and assumptions made. *Davies et al.* [2009] developed the emission rates for wood-burning devices using the operation-emission limits of the device (grams/hour) issued by EPA multiplied with the total hours of heating per year per household. Doing so, provided a

$PM_{2.5}$-emission rate of 60lb/yr.hh for noncertified and of 17lb/yr.hh for certified woodstoves. *Carlson et al.* [2010] list the amount of wood used annually as 3.95 cords wood/yr.hh. If one takes the EPA AP-42 emission factors of noncertified and certified woodstoves (30.6 and 14.6lb/short tons of dry wood, respectively), one obtains for the emission rates of noncertified and certified woodstoves 145lb/yr.hh and 69lb/yr.hh, respectively. *Davies et al.*'s [2009] study is based on heating hours and emission limits, while *Carlson et al.*'s [2010] study is based on fuel used. This means *Davies et al.*'s [2009] and *Carlson et al.*'s [2010] studies use different approaches. We used the AP-42 emission factors to compare their data. Depending on the approach, one will for each replaced woodstove reduce the emissions by (60-17) lb/yr.hh = 43lb/yr.hh and (145-69) lb/yr.hh = 76lb/yr.hh, respectively.

We used *Davies et al.*'s [2009] emission-rate data for all wood devices and oil furnaces as requested by the FNSB, but used *Carlson et al.*'s [2010] data for number of devices. Note that using this data seemed to be "safer" because the amount of reduction in response to a "woodstove replacement" program is smaller than using *Carlson et al.*'s [2010] emission rates. This means that the relative response factors that we obtained from our "woodstove replacement" simulations may underestimate the actual reduction that a woodstove replacement program can provide. In the sensitivity study WSS1, we used EPA's data for the "others" category, as data for these devices were not included in *Davies et al.*'s [2009] report. In the sensitivity study WSS2, we used *Carlson et al*.'s [2010] number of devices without consideration of pellet-stoves.

4.2.3 Emission scenario for introduction of low sulfur fuel for heating oil and power generation and other oil-burning point sources

The third scenario (LSF) represents a measure that aims at mitigation of $PM_{2.5}$ concentrations indirectly by reduction of precursors. As pointed out above sulfur can contribute to $PM_{2.5}$ formation in the atmosphere. Thus, the third emission scenario performed for winter 2008/09 assessed the impact of the introduction of low sulfur fuel for use as heating oil and in oil-burning power plants and other point-sources on the $PM_{2.5}$ concentrations at breathing level. The target emission categories that we considered in the "low sulfur fuel" scenario are heating oil, point source facilities and power plants that burn oil. The emissions from domestic and industrial combustion (including power plants) used in the reference simulation (REF) represent the emissions from relatively sulfur-rich fuel.

In the LSF simulation, the emissions from all sectors were kept the same as in the reference simulation except for emissions from domestic heating with heating oil, and oil-burning point sources and power plants with sulfur-rich fuel. The emissions from these sectors were replaced by emissions one would obtain with low sulfur content fuel for the same combustion amount.

To determine the amount of emission reduction due to a change from high to low sulfur-content fuels we reviewed the literature. Since the fuel-sulfur content may affect other emissions than just $PM_{2.5}$, we adjusted the emissions of these other species as well. Doing so is required as particles and hence $PM_{2.5}$ may form due to gas-to-particle conversion from various species as explained earlier.

NESCAUM [2005] reported the emission reduction due to reducing the sulfur content of No. 2 distilled heating oil from 2,000-3,000ppm to 500ppm for SO_2, PM and NO_x as 75%, 80% and 10% respectively. In our study, we assumed the same transition of sulfur content in heating fuel in Fairbanks, and applied the same reduction found by *NESCAUM* [2005]. Since no reduction

benefits were reported for VOC and CO, we assumed that lowering of sulfur content in heating oil does not affect the VOC and CO emissions.

From personal communication with several power-plant operators in the FNSB, we learned that almost all power plants in the FNSB are burning No. 2 fuel oil having sulfur content about 4,000ppm. This fuel is similar to the fuel used for household heating. For the LSF simulations, we modified the point-source emissions with respect to low sulfur-fuel emissions for those oil-burning facilities that did not yet use low sulfur fuel already.

To our best knowledge, no report exists on the effects of low sulfur-fuel usage on the emissions of power plants. Therefore, we assumed a similar transition of sulfur content in heating fuel in the FNSB as reported in *NESCAUM* [2005] and applied the reduction given for power plants. Note that the actual reduction would be higher than the assumed reduction since the emission control devices in power plants become more effective as the sulfur content decreases.

In the low sulfur fuel (LSF) scenario, the emission reductions due to low sulfur fuel are only applied to those power plants and point sources that burn No. 2 fuel oil. For these facilities, a reduction rate of 75%, 80% and 10% was applied to the SO_x, PM and NO_x emissions, respectively. For power plants burning both fuel oil and coal, only emissions from burning oil were subject to the emission reduction. We only got the break-down of the fuel-type consumption for the UAF power plant. Since the UAF power plant works on economic principles as the other power-plant operators do, we assumed a similar break-down of fuel types used for those facilities that burn different fuel types. No changes in emissions were made for power plants burning only coal.

4.3 Analysis methods

We compared the results of the simulations performed with modified emissions with the results of their respective reference simulation to assess the impact of the various emission mitigation measures or the contribution of point-source emissions on the $PM_{2.5}$ concentrations in the nonattainment area and in the grid-cell holding the FNSB official measurement site. This site is located on top of the State Building.

We used the Student t-test [*von Stroch and Zwiers*, 1999] to test the $PM_{2.5}$-concentration differences between REF and NPE for winter 2005/06, and REF and WSR or LSF for winter 2008/09 for their statistical significance at the 95% confidence level. The null hypothesis was that concentrations in REF and NPE, or REF and WSR or REF and LSF do not differ. In the following, we only use the word significant when data fail to pass this test.

Note that from a scientific point of view, it is important whether an emission source causes significant differences in the $PM_{2.5}$-concentrations. However, from a regulation point of view it is not of relevance whether or not, an emission source contributes significantly (in a statistical sense) to the concentrations of $PM_{2.5}$. Instead, it is important whether the emission-sources' contributions are the main contributor, i.e. dominate the concentration values, and whether reducing the emissions of these sources may lead to compliance.

If a certain kind of emission sources is the dominating one, regulation on the emission may help solve the exceedance problem. Here again distinctions have to be made. An emission source far away from the nonattainment area and/or far away from any settlements will typically dominate the concentrations in its surroundings, as it is most likely the only emission source out there. Thus, the large percentage contribution of such an emission source will not be worrisome as long

as the concentrations do not exceed the NAAQS. If an emission source is located in an unpopulated area close to populated areas, its contribution also may percentagewise be the main contributor. Then one has to consider how large the impact is on the adjacent populated areas and whether this impact leads to exceedances of the NAAQS. These facts have to be kept in mind in the following discussion.

For all scenarios, we determined the relative response factors and new design values.

4.3.1 Analysis of point source contribution

Differences between the highest 24h average $PM_{2.5}$-concentration obtained by REF and NPE were investigated to assess the impact of PS-emissions on the $PM_{2.5}$-concentrations at breathing level. The number, frequency and locations of grid-cells with 24h-average $PM_{2.5}$ exceedances were determined for both simulations to assess the contribution of PSs to exceedances. In addition, we examined the radius of impact of the point sources on the $PM_{2.5}$ concentrations at breathing level. Grid-cells affected by PS-emission will have non-zero $PM_{2.5}$-concentration difference between REF and NPE. Therefore, the influence of PS-emissions on the $PM_{2.5}$-concentration at breathing level was investigated by analyzing the correlation between the PS-emissions at each emitting level with the $PM_{2.5}$-concentration-difference. In the domain of interest, 27 PSs emit into the second (8-16m) to the seventh model layer (343-478m) due to plume raise.

The impact of each individual PS on the perturbation of $PM_{2.5}$-concentration is difficult to identify unambiguously because in WRF/Chem, like other photochemical models, all PSs located within the same grid cell are lumped but emit into the levels into which the individual PSs would emit. After lumping, there are nine grid columns holding PSs. Due to the lumping we cannot investigate individual PS impacts on $PM_{2.5}$-concentration at breathing level, but the cumulative impact of all PSs within a grid-column on the downwind $PM_{2.5}$ concentrations of that column. We examined the impact for each grid column holding PSs and denote these PS1 to PS9, hereafter. See Figure 14 for locations.

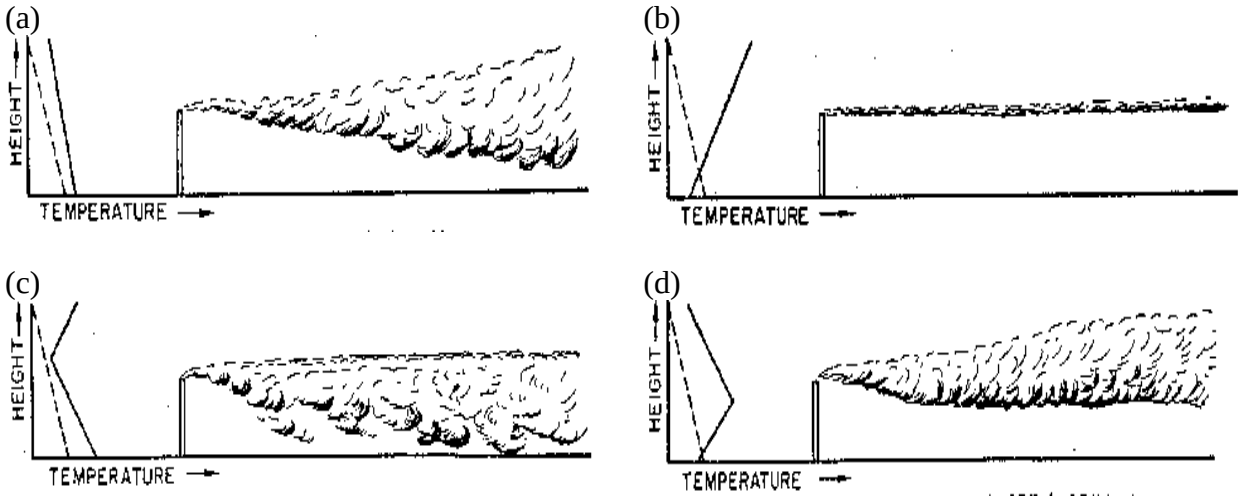

Fig. 10. Schematic view of temperature profiles and plume behavior for emissions in the case of (a) no inversion layer, (b) into an inversion layer, (c) below an inversion layer, and (d) above an inversion layer. From: *http://www.iitap.iastate.edu/gcp/acid/images/plume.gif.*

We only considered the $PM_{2.5}$-concentration-difference distribution at grid cells located downwind of a grid-cell with PSs. At each PS1 to PS9, we used the wind direction from the first level above ground to the uppermost emitting level to identify the downwind grid cells of each level in each simulation hour. This treatment ensured that not all grid cells around the PSs, but only the grid cells impacted by the PS are considered. These $PM_{2.5}$-concentration-difference values were used to calculate the correlation with the PS-emissions for November to February (NTF). All correlations were tested for their statistical significance at the 95% or higher confidence level using a Student-t test.

PSs in the downwind sectors of a PS-holding column may affect the $PM_{2.5}$-concentrations in its downwind. Therefore, the correlation behavior of each PS1 to PS9 was investigated under consideration of potential impacts by other PS holding grid-columns. As atmospheric temperature inversion and wind speed affects the dispersion of the PS emissions, we investigated separately the correlation between PS-emissions and $PM_{2.5}$-concentration-difference for different wind-speed classes at the emitting level and under conditions when PSs emitted below, above and into inversion layer (Fig. 10). We applied different time lags in determining the correlations to account for the lag in time between the actual emission and the time when the $PM_{2.5}$ reaches the downwind grid-cells at breathing level.

4.3.2 Analysis of the "woodstove replacement" scenario

We used the Student t-test to examine the $PM_{2.5}$-concentration differences (REF-WSR) for their significance at the 95% level of confidence. To verify that the differences are really due to replacing "woodstoves", we adopted a False Ensemble Analysis method (FEA) which was developed and applied successfully in climate model data analysis [*Carpenter et al.*, 1989; *Werth and Avissar*, 2002]. We performed the analysis for each month of the REF and WSR simulations. First, the true difference of 24h-average $PM_{2.5}$-concentration between REF and WSR was determined for each month. Secondly, a set of false "REF" and "WSR" ensembles was created by randomly replacing results of simulation days of REF (WSR) with the results of the corresponding simulation days of WSR (REF). Because the emission strengths are allocated depending on the hour of the day, day of the week and month of the year, and daily mean temperature [*Mölders,* 2010], each randomly selected REF-day had to be replaced by the corresponding WSR-day. In this way, emissions only differ with respect to the emission changes in response to the wood-burning devices exchanged. A random generator was used to create an index array, which days of the month were to be chosen to create the false ensemble, and REF (WSR) files were replaced accordingly. The replacement was completed as the number of WSR (REF) simulation days makes up 50% of the total days of the false "REF" ("WSR") ensemble by which the false "REF" and "WSR" can be considered as having no net difference in the mean emission.

Theoretically, $n!/[(n/2)!]\times 2$ numbers of false ensembles can be generated from n simulation days in the way described above. However, considering the time constrains and computational limitation, we generated 400 false "REF-WSR" ensembles randomly for each month. For each set of false "REF" and "WSR" ensemble the difference of 24h-average $PM_{2.5}$-concentration was determined as was done for the true difference REF-WSR. Finally, the true and 400 false concentration differences were ranked. The above procedure was applied for each grid cell. If at a grid cell, the true difference falls in the top 5% of all values, we can conclude that the true $PM_{2.5}$-concentration difference is real, i.e. the "woodstove replacement" actually reduced the $PM_{2.5}$-concentration in the grid cell of interest.

4.3.2 Analysis of the “low sulfur” scenario

Emissions of $PM_{2.5}$, PM_{10}, SO_2, NO and VOC from the current sulfur content fuel (REF) and the use of low sulfur fuel (LSF) were analyzed and compared on a monthly and daily basis. Note that these pollutants were selected as they are primary particular matter and precursors for secondary aerosols, i.e. they can affect the $PM_{2.5}$-concentrations at breathing level. Since the emissions were considered temperature-dependent, the mean temperatures and their deviation from the long-term mean temperature were analyzed and used to elucidate the variations in emission reductions.

Concentrations of $PM_{2.5}$ and other pollutants (PM_{10}, sulfate, nitrate, VOC) in the nonattainment area obtained by REF and LSF were compared. The monthly, daily, and hourly variations of $PM_{2.5}$-concentration reductions after introduction of low sulfur fuel were quantified and analyzed. The variations in the aerosol composition were also identified. Furthermore, mean meteorological quantities (temperature, dewpoint temperature, relative humidity, wind-speed, shortwave radiation fluxes, atmospheric boundary layer height, precipitation and cloudiness) were used in the analysis of $PM_{2.5}$-concentration reductions as there were feedbacks of aerosols on the meteorology.

Furthermore, we also applied the FEA to the REF and LSF data.

5. Evaluation

As pointed out above, we used the results of the WRF/Chem simulations of the first 15 days October 2005 for calibration. Within the framework of another project, WRF/Chem was evaluated by data from a Doppler SOund Detection And Ranging (SODAR) device, twice-daily radiosondes, 33 surface meteorological and four aerosol sites [*Mölders et al.* 2011].

The evaluation used the following performance skill-scores (root-mean-square error [RMSE], bias, standard deviation of error [SDE], correlation coefficient [R]) following *von Storch and Zwiers* [1999] for the meteorological quantities, and the fractional bias ($FB = \left(\overline{C_s} - \overline{C_o}\right) \Big/ \left[0.5\left(\overline{C_s} + \overline{C_o}\right)\right]$), normalized mean-square error ($NMSE = \left(\overline{C_s} - \overline{C_o}\right)^2 \Big/ \left(\overline{C_s} \cdot \overline{C_o}\right)$), geometric mean bias ($MG = \exp\left(\overline{\ln C_s} - \overline{\ln C_o}\right)$), and the fraction of simulated concentrations C_s being within a factor of two of the observed concentrations C_o (FAC2) following *Chang and Hanna* [2004] for the chemical quantities. These are standard measures typically used in the evaluation of photochemical models and hence allow us to assess how good the Alaska adapted WRF/Chem performs for Alaska winter relative to models applied for cases in mid latitudes.

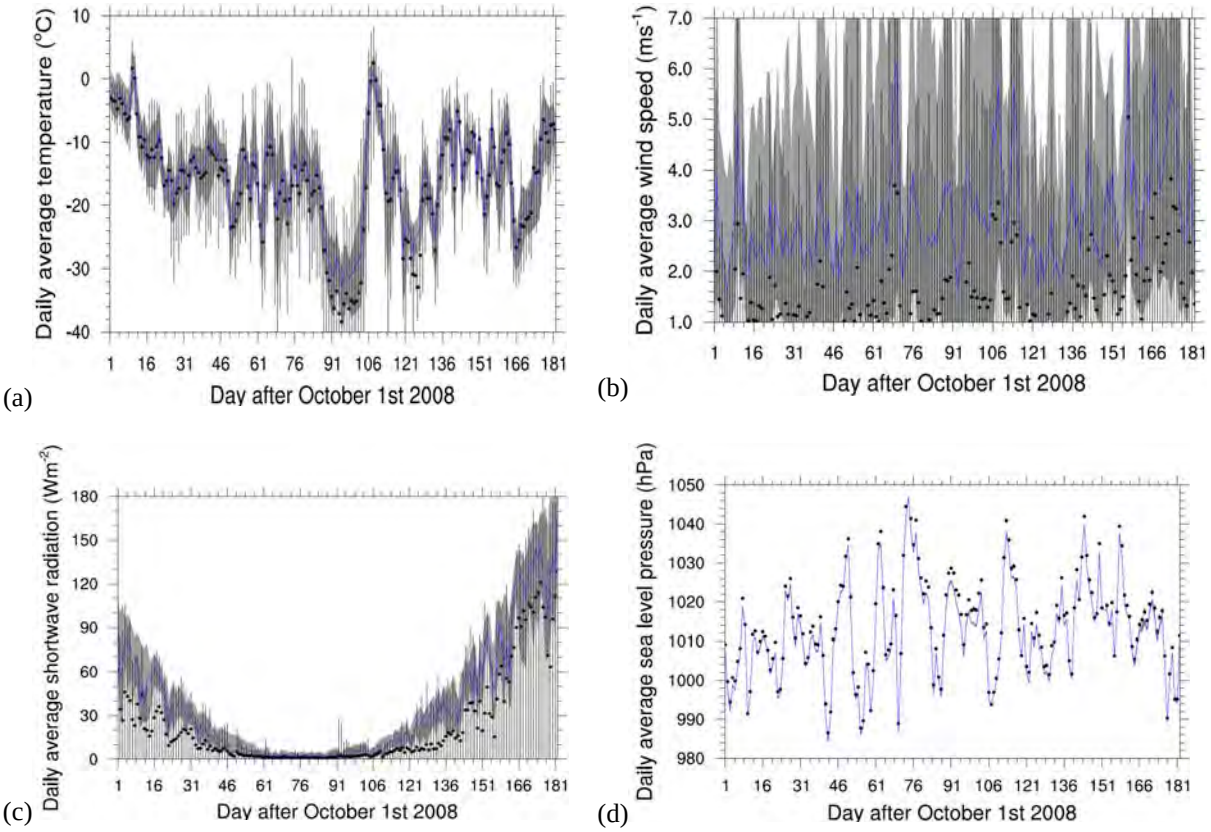

Fig.11. Temporal evolution of daily averaged of (a) air-temperature, (b) wind-speed, (c) downward shortwave radiation, and (d) pressure averaged over all sites for which data were available as simulated (blue line) and observed (dots). Plots for dewpoint (not shown) and air-temperatures look similar. Grey-shading and vertical bars indicate variance of simulated and observed quantities, respectively. Note that there were only two sites with pressure data Fairbanks International Airport and Eielson Air Force Base. Due to their relative close location, there is not much spatial variance. Therefore, no bars on the spatial variance of pressure are plotted.

All our simulations were run in"forecast" mode, i.e. no nudging or data assimilation was applied. *Mölders et al.* [2011] found that biases determined based on all available data from the 33 sites over NTF are 1.6K, 1.8K, 1.85m/s, -5^{o}, and 1.2hPa for temperature, dewpoint temperature, wind-speed, wind-direction, and sea-level pressure, respectively, in NTF 2005/06. Figure 11 shows the average temporal evolution of simulated and observed meteorological quantities as obtained for October 2008 to March 2009 (OTM) on average over all 23 sites within the domain of interest for which data were available for that time. Note that there were less meteorological sites operating in the area covered by the domain of interest for analysis in winter 2008/09 than 2005/06. Over OTM 2008/09, the overall biases over all sites are 1.3K, 2.1K, 1.55m/s, -4^{o}, and -1.9hPa for temperature, dewpoint temperature, wind-speed, wind-direction, and sea-level pressure, respectively. The 2005/06 temperature bias is only marginally higher than that reported by *Gaudet and Staufer* [2010] for their WRF short-term study with a 4km grid increment performed for Fairbanks using data assimilation. The wind-speed RMSE is slightly higher than the RMSE reported for their short study. Note that it is relatively easy to optimize a model for a short period of several days, while it is rather difficult to achieve a generally acceptable performance over an episode as long as four or six months like in our study.

The evaluation by means of SODAR-data revealed that WRF/Chem slightly over(under)estimates wind-speed in the lower (upper) ABL. WRF/Chem captures the frequency of low-level jets well, but overestimates the strength of moderate low-level jets [*Mölders et al.* 2011].

As aforementioned there are hardly any chemical data available for winter 2005/06. While $PM_{2.5}$ concentration data exist only at two sites (Fairbanks State Building, Denali Park) for winter 2005/06, measurements exist at 12 sites in Fairbanks for winter 2008/09. Based on the limited data available WRF/Chem simulated the maximum $PM_{2.5}$-concentration about 6% too low for winter 2005/06. Data from four aerosol sites suggest large underestimation of PM_{10}, and NO_3 at the remote sites outside of the nonattainment area and underestimation of $PM_{2.5}$ at the State Building in winter 2005/06 [*Mölders et al.* 2011].

Averaged over the two $PM_{2.5}$- and SO_4-sites, 41% and 50% of the simulated values, respectively, fell within ±50% of the observed concentration value for winter 2005/06. The low data density – for 2005/06 only one $PM_{2.5}$ observational site exists in the nonattainment area – may falsely indicate errors due to local effects [*Mölders et al.* 2011].

The hourly $PM_{2.5}$ evaluation of winter 2008/09 shows that 29%, and 36% of the simulated and observed concentrations agree within ±50% for the fixed sites FNSB (site at the State Building), and Peger Road, respectively. The performance for the 24h-average $PM_{2.5}$ is better – 46% of the fixed sites agree within ±50%. At the FNSB State Building, Peger Road, North Pole, Sadler and Denali site 35%, 58%, 38%, 39% and 58% of the simulated 24-average $PM_{2.5}$ concentrations are within ±50% of the observations, respectively. The scientific community considers photo-chemical models with fractional biases within ±30%, random scatter being within a factor of two or three of the mean, and 50% of the predictions falling within a factor of two of the observations to perform well [e.g. *Chang and Hanna* 2004]. Thus, our WRF/Chem simulations for 2005/06 fall in the lower end of acceptable performance, while those for 2008/09 are slightly better. The better performance for 2008/09 than 2005/06 may be due to the introduction of a temperature-dependency of traffic, power generation and domestic heating emissions in AkEM in response to the evaluation for 2005/06.

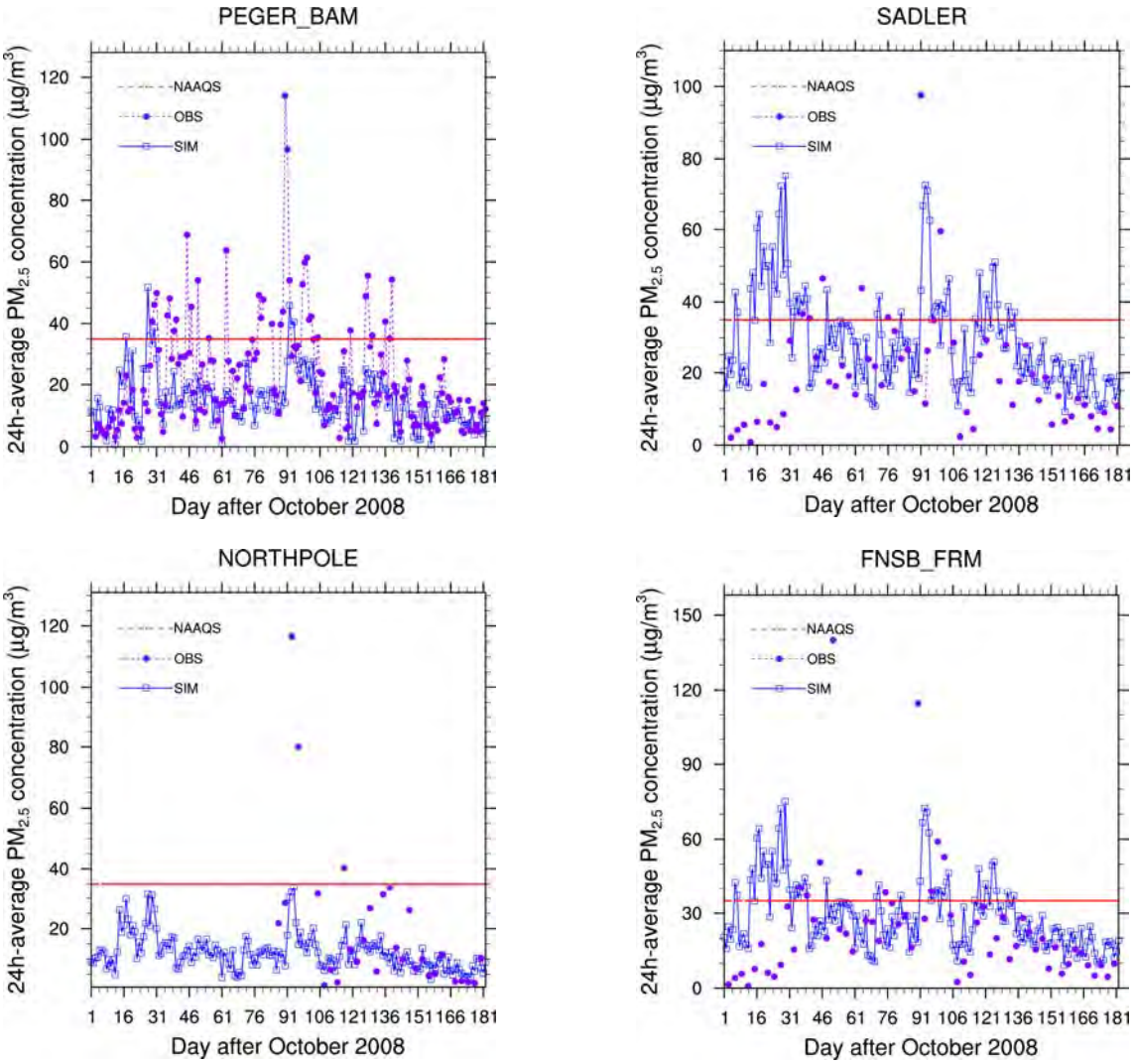

Fig. 12. Comparison of simulated and observed concentrations as obtained for winter 2008/09 for various sites. FNSB is the site at the State Building.

The evaluation of both winters indicates that WRF/Chem captures the temporal evolution of $PM_{2.5}$ concentrations well except during sudden temperature changes, underestimation of inversion-strengths and timing of frontal passages (e.g. Fig. 12). In October, WRF/Chem underestimates the $PM_{2.5}$ concentrations appreciably at all sites for which data are available. This behavior suggests that the assumed emissions for October 2008 are too low. Note that there are hardly any Alaska specific emission allocation functions. We used the allocation functions recommended by EPA for Alaska, which we modified to avoid obviously unreasonable emissions (e.g. emissions from lawn mowing in October), when no Alaska specific allocation functions could be obtained.

Errors in $PM_{2.5}$-concentrations relate strongly to temperature errors, i.e. to WRF rather than its chemical package [see also *Mölders et al.* 2011]. In October 2008, WRF/Chem underestimates the concentrations strongly at some sites (e.g. Sadler). It should be examined whether emissions are underestimated in October. On the contrary, in other months simulated and observed concentrations agree better in magnitude. The discrepancies found may also result from

channeling effects in streets or slight offsets of dispersion plumes. The occasional much higher observed than simulated concentrations are most likely due to contamination of the measurements by mobile sources at the site (e.g. busses idling at the Peger site upwind of the sampler). All these discrepancies are common in and known to occur for all photochemical models of the scale deployed here [e.g. *Chang and Hanna,* 2004].

The evaluation of winter 2005/06 suggested that simulated $PM_{2.5}$-concentrations may be slightly too low on average over the polluted and unpolluted site. However, averaging of polluted and non-polluted sites may be misleading due to the strong concentration differences of polluted and non-polluted sites. In both winters, WRF/Chem seems to overestimate the concentration slightly at the polluted sites. In winter 2005/06 and 2008/09, the mean biases over all available sites are 4.2 and 4.0$\mu g/m^3$, respectively. However, this bias affects the reference as well as the simulations with the emission scenarios. Since we are examining concentration differences in this study, the impact of the aforementioned errors can be considered as small.

6. Results

We examined the meteorological conditions on days with $PM_{2.5}$ exceedances. We found three distinct local circulation patterns at breathing level and five different circulation patterns higher above ground between 100 and 200 m that lead to exceedances of the NAAQS at breathing level (Fig. 13). If at breathing level, wind is very calm (<1m/s) and comes from various directions and the air remains in town, local exceedances will occur within the nonattainment area. The same will be true if slight drainage of the Fairbanks air occurs towards southwest, down the Tanana Valley or if air moves into town from southeast under calm wind conditions in Fairbanks. Obviously, in this case, advection of polluted air from the Salcha air shed and North Pole can contribute to causing the exceedances.

Exceedances are also related to what happens at heights between 100 and 200m or so. If at these levels, air moves out of town slowly down the Tanana Valley, air slowly travels through Fairbanks down the Tanana Valley, air moves towards North Pole and Eielson Air Force Base up the Tanana Valley, or air drains to both sides of the Tanana Valley (Fig. 13), exceedances will occur at some places in the nonattainment area at breathing level. This behavior is especially true when at the same time, winds are relatively calm over Fairbanks or the air circulates slowly over the town.

In the following, $PM_{2.5}$-concentrations at breathing level are discussed if not mentioned otherwise.

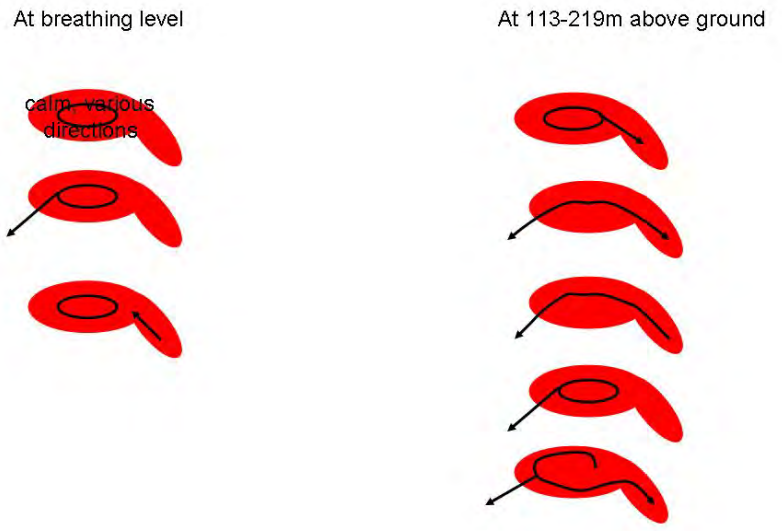

Fig. 13. Circulation pattern associated with violations at breathing level. The red area schematically illustrates Fairbanks, North Pole and Salcha air sheds. Wind-speeds must be very low.

Note that winter 2008/09 except for February and in particular October 2008 were colder than the 30-year average (Table 3).

Table 4 compares the results of the WSR, LSF and REF simulations. The results suggest that in October 2008, January, February and March 2009 the assumed “woodstove replacement” yields a stronger reduction of the $PM_{2.5}$-concentrations at breathing level than the introduction of low sulfur fuel. In November and December 2008, introduction of low sulfur fuel, on average,

provides the higher mitigation of the $PM_{2.5}$-concentrations. The results suggest that "woodstove replacement" provides a temporally more constant percentage reduction of around 6% averaged over the nonattainment area than does the introduction of low sulfur fuel (Table 4).

Table 3. Monthly mean temperatures at Fairbanks International Airport in Fahrenheit. Courtesy to *H. Angelhoff* [2011]. The 30-average for 1971-2000 is taken from *Shulski and Wendler* [2007]. Values for the episode simulated in this study are high-lighted.

	Oct	Nov	Dec	Jan	Feb	Mar	Oct-Mar
2007	21.2	11.5	-3.4	-6.6	-6.7	-6.5	1.6
2008	15.1	-1.4	-7.8	-9.2	-5.9	15.4	1.0
2009	30.7	-1.2	-2.8	-12	-1.5	5.6	3.1
2010	27.5	11.9	-17.9	-13.7	2.9	10.8	3.6
2007-2009	22.3	3.0	-4.7	-9.3	-4.7	4.8	1.9
2008-2010	24.4	3.1	-9.5	-11.6	-1.5	10.6	2.6
1971-2000	24	2	-6	-10	-4	11	2.8

Table 4. Monthly average $PM_{2.5}$-concentration as obtained for the grid-cell holding the State Building and averaged over the nonattainment area for October 2008 to March 2009. The percentage reduction is given in brackets.

	$PM_{2.5}$ ($\mu g/m^3$)					
	State Building			Nonattainment area		
	REF	WSR	LSF	REF	WSR	LSF
OCT	40.2	38.5 (4.2%)	39.2 (2.5%)	12.9	12.2 (5.4%)	12.5 (3.1%)
NOV	30.3	28.8 (5.0%)	28.5 (5.6%)	11.0	10.3 (6.3%)	10.0 (9.0%)
DEC	25.8	24.5 (5.0%)	24.4 (5.4%)	9.2	8.6 (6.5%)	8.5 (7.6%)
JAN	33.9	32.2 (5.0%)	32.7 (3.5%)	11.0	10.3 (6.4%)	10.4 (5.5%)
FEB	27.1	25.5 (5.9%)	26.0 (4.1%)	9.8	9.2 (6.1%)	9.3 (5.1%)
MAR	17.1	16.1 (5.8%)	16.2 (5.3%)	5.7	5.3 (6.4%)	5.3 (7.0%)

6.1 Impact of point-source emissions

This section discusses findings from the simulations performed for winter 2005/06. See Table 1 for details on the simulations.

The influence of emissions from elevated point sources on the $PM_{2.5}$ concentration at breathing level was investigated by analyzing the correlation between the PSs' emissions at each level with the $PM_{2.5}$-concentration at the breathing level. The highest effective level reached by the plume from point-source emissions is the model layer representing the conditions between 343 and 478m. Note that the buoyancy, depending on temperature of the plume, velocity at release etc. and the environmental conditions, determine which levels the emissions from PSs can reach.

Table 5. Monthly average of $PM_{2.5}$-concentration at the State Building and averaged over the nonattainment area as obtained from the simulations for winter 2005/06. The percentage reduction is given in brackets.

	$PM_{2.5}$ ($\mu g/m^3$)			
	State Building		Nonattainment area	
	REF	NPE	REF	NPE
NOV	30.5	29.2 (4.2%)	14.4	13.4 (6.9%)
DEC	26.4	25.4 (3.8%)	12.5	12.0 (4%)
JAN	40.9	39.7 (2.9%)	15.9	14.9 (6.3%)
FEB	21.6	20.9 (3.2%)	9.6	9.2 (4.2%)

Since no emissions from PSs are considered in NPE, the monthly total emission strength does not differ between REF and NPE from November 2005 to February 2006 except at the locations of the PSs. Since most of the PS and the strongest PSs are located in the highly populated

Fairbanks area, here the largest differences between REF and NPE in emissions as well as concentrations occur. Emission and concentration differences are larger in December and January as during these months emissions from PSs are higher than in November and February. The majority of the PSs are facilities that emit more in December and January to cover the higher heating and/or energy demands during the darker, colder December and January than the relatively warmer and less dark November and February.

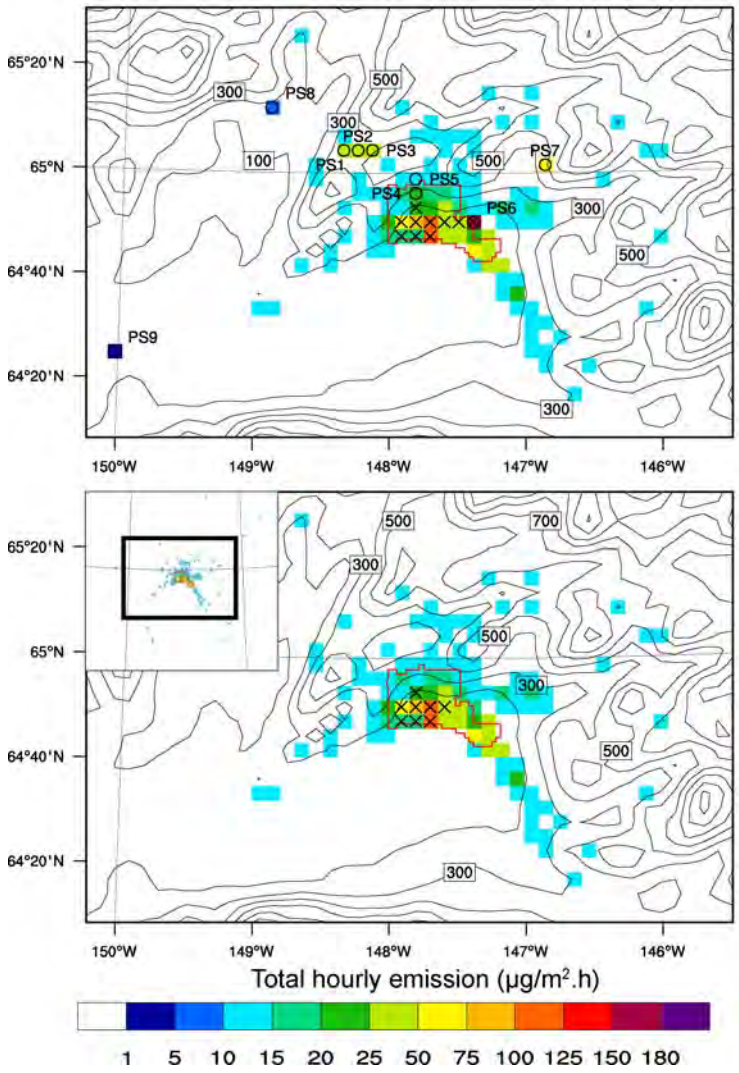

Fig. 14. Zoom-in on the spatial distribution of areas experiencing $PM_{2.5}$-concentration exceeding the NAAQS (grid cells with crosses) in REF (top) and NPE (bottom) exemplarily superimposed on the map of total hourly emission on 0200 UTC December 1, 2005. The black box indicates the location of the zoom-in area. PS1 to PS9 indicate locations of grid columns with point sources.

$PM_{2.5}$-concentration obtained by REF and NPE differ hardly with respect of the number of NAAQS exceedances. Within the domain of interest, the NAAQS is exceeded 10 (7), 6 (5), 22 (21) and 1(1) times in REF (NPE) in November, December, January, and February, respectively. The locations of exceedances within the nonattainment area are identical in both REF and NPE except at PS6 and the adjacent grid cell to its west (Fig. 14). Except for two events in November

2005 in REF, the grid-cell holding the State Building monitoring station experienced exceedances on all exceedance events in REF and NPE.

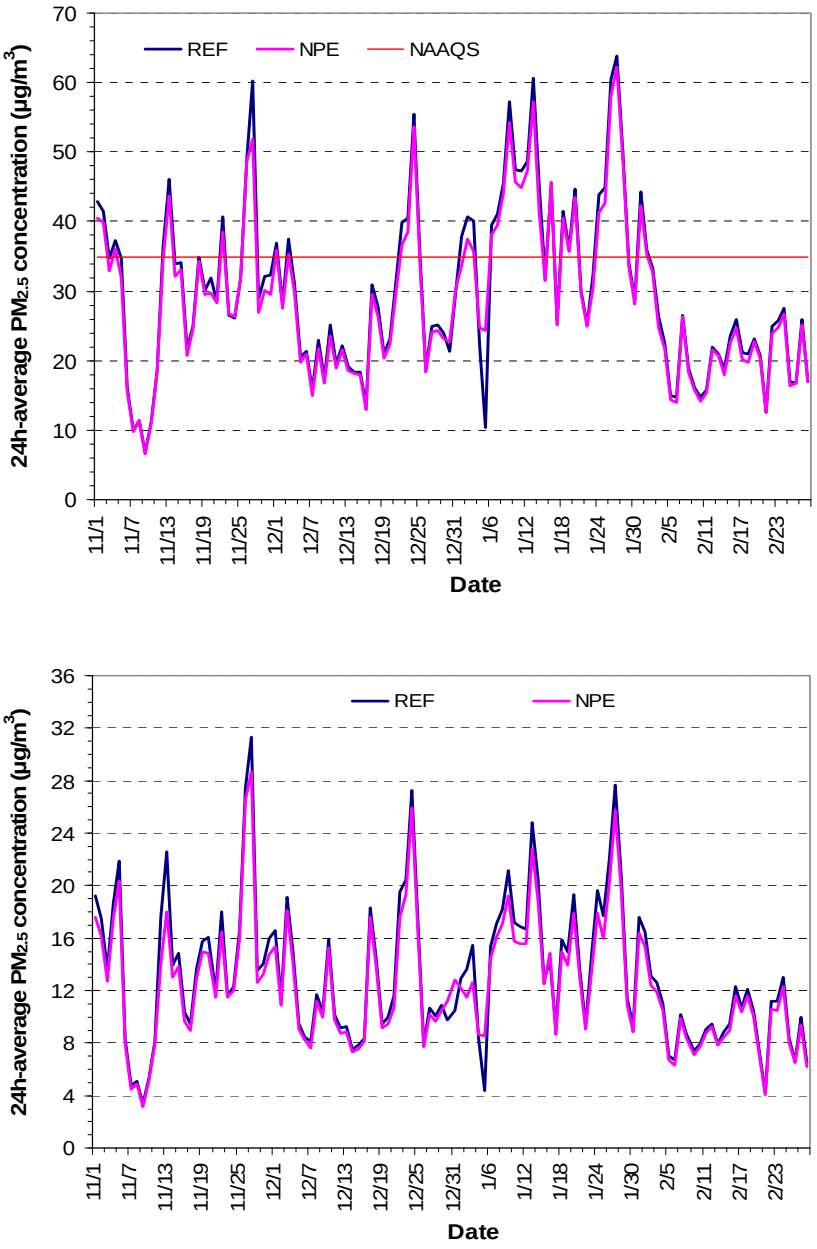

Fig. 15. Temporal evolution of 24h $PM_{2.5}$-concentrations as obtained for the grid-cell that holds the State Building (top) and the 24h $PM_{2.5}$-concentration averaged over the nonattainment area (bottom) for the simulations with (REF) and without (NPE) inclusion of point sources. NAAQS is the National Ambient Air Quality Standard of 35µg/m^3.

Despite the number of exceedances in REF exceeds that in NPE occasionally, the days with exceedances in REF, but not in NPE show almost the same magnitude of $PM_{2.5}$-concentration (Fig. 15). Over the entire simulation period, the average differences of between REF and NPE 24h-average $PM_{2.5}$-concentration are 0.04µg/m^3, 0.8µg/m^3 and 1.0µg/m^3 over the entire analysis domain, the nonattainment area and at the State Building, respectively. The average difference of

highest concentrations between REF and NPE were as low as 1.3µg/m^3 and barely exceeded 3µg/m^3. The most notable differences occurred at locations close to the PS-holding columns. The highest concentration differences occurred for PS6 and on 47% of 120 simulation days and amounted 7µg/m^3 on average. Note that PS6 has the strongest $PM_{2.5}$ emissions among the PS-holding columns.

These findings suggest that PS-emissions do not strongly increase the $PM_{2.5}$-concentration within the nonattainment area except for the grid-cell PS6. In the nonattainment area, on days and at the locations of exceedances, emission from PSs accounted for 4% of the 24h-average $PM_{2.5}$-concentration on average and barely exceeded 10%. These findings mean that emissions from area sources induced high $PM_{2.5}$-concentration in the nonattainment area and the emissions from the PSs just added the small amount needed to exceed the NAAQS. This also means that emissions from PSs play a minor role for the $PM_{2.5}$ exceedances in the nonattainment area.

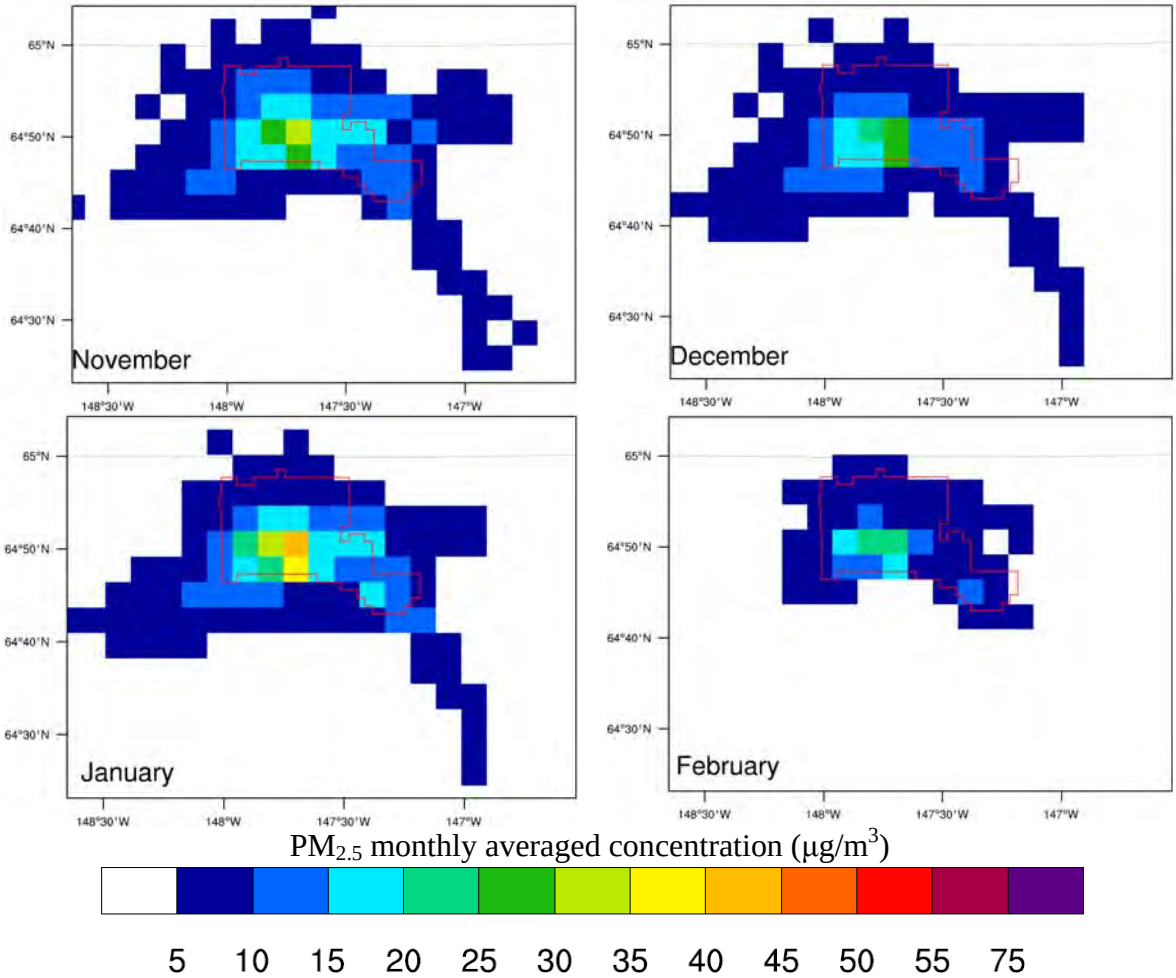

Fig. 16. Zoom-in on monthly mean 24h-average $PM_{2.5}$ concentration in NTF as obtained by REF for winter 2005/06.

Figure 16 shows a zoom on the spatial distribution monthly mean 24h-average $PM_{2.5}$-concentrations at breathing level. The hot spots remain the same over all four months, but with different magnitude. The hot spots remain the same in the simulation without consideration of point source emissions (Fig. 17). The concentrations are only slightly lower in the simulation without consideration of point source emissions. These facts indicate that area and line sources

(e.g. domestic combustion, traffic) are the main cause emission wise for the high $PM_{2.5}$ concentrations.

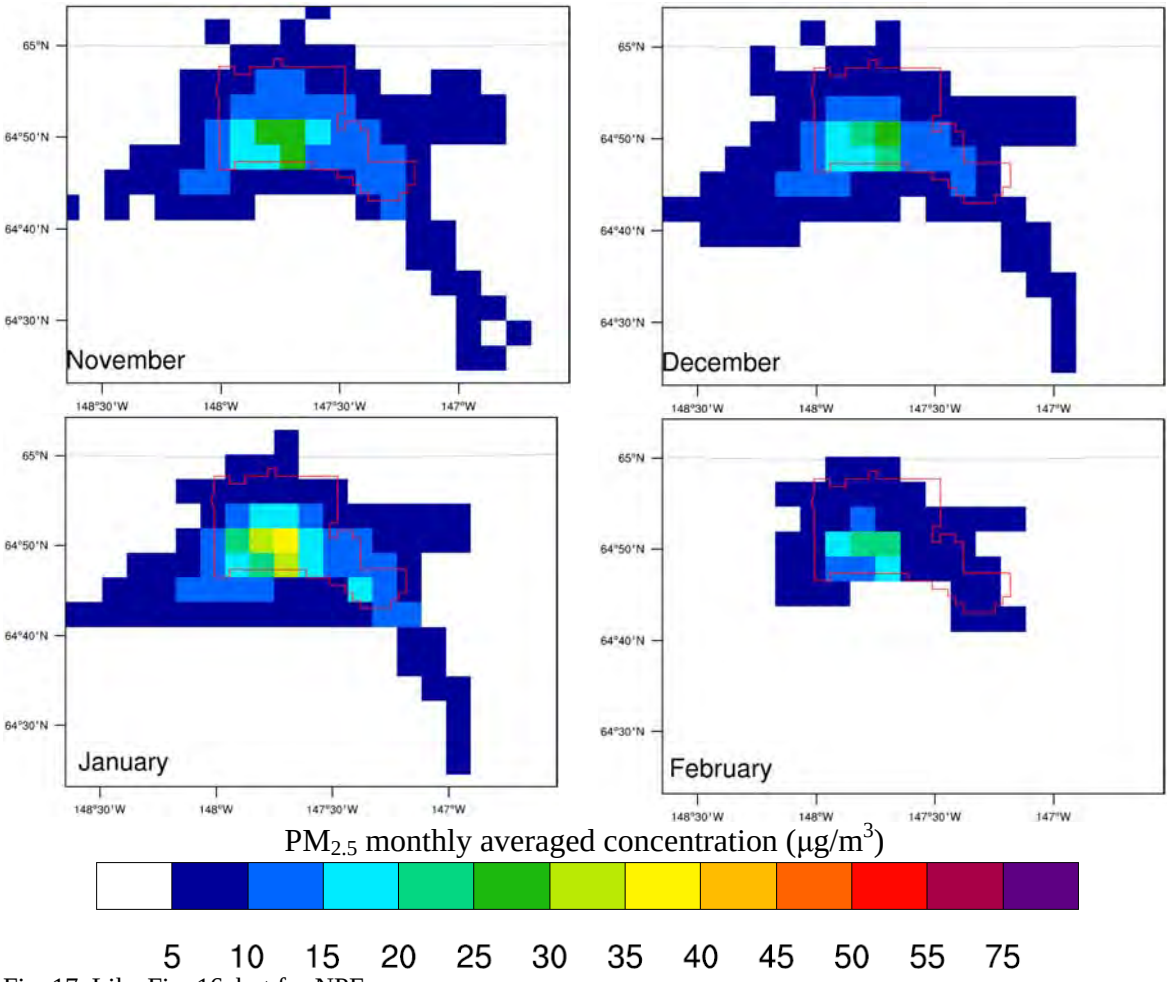

Fig. 17. Like Fig. 16, but for NPE.

Theoretically, higher $PM_{2.5}$-concentration at breathing level are expected with higher PS-emission rates, and under normal atmospheric conditions (no inversion), the location having the highest concentration at breathing level will be farther away from the PS as the effective emission level increases. Our analysis showed statistically significant correlations between emissions and $PM_{2.5}$-concentrations, but the correlation values are low and vary highly among PS-holding columns due to PS characteristics, location and co-location effects. In the downwind of PSs, the impact of point-source emissions on the $PM_{2.5}$-concentration decreases rapidly with increasing distance from the PS.

Investigations show that the total emissions within a grid-column and the simulated $PM_{2.5}$-concentrations at breathing level correlate highly in populated areas. This finding is true for both REF and NPE. The correlation between the total emissions within a grid-column and the simulated $PM_{2.5}$-concentrations at breathing level will only marginally differ if no point-source emissions are considered in the calculation of the $PM_{2.5}$ concentrations. This finding suggests that PS emissions are not the main causes for high $PM_{2.5}$ concentrations.

We evaluated the impact-radius of PS-emissions on the $PM_{2.5}$ concentrations at breathing level. Correlation values between PS-emissions and $PM_{2.5}$-concentration-differences at downwind grid-cells differ generally with wind-speed. Overall, under low wind-speed (<2ms^{-1}) conditions, the highest correlation values at breathing level occur within 2km from the PS; correlations under stronger wind-speed decrease, but are highest farther downwind (e.g. Fig. 18). The occurrence of highest correlation also shifts farther downwind when the emission-level height increases. Nevertheless, regardless of emission level and wind-speed, the highest correlations occurred within 10km from the PS. Beyond 10km from the PS, correlations are small and non-significant and small for low wind-speeds, but significant for moderate wind-speeds (≥5m/s). The strongest correlations are obtained typically with time lags of 0 or 1h.

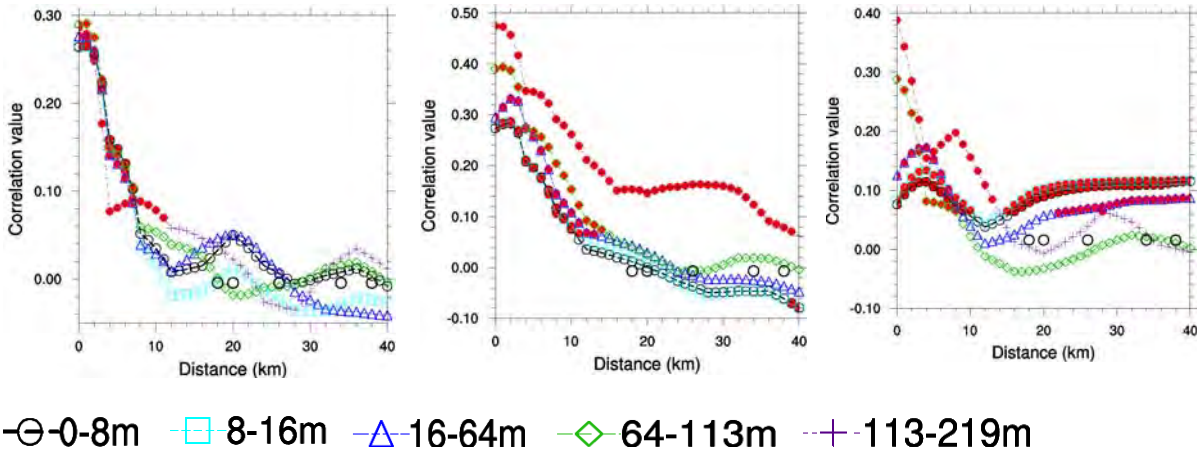

Fig. 18. Correlation of emissions at PS6 with the $PM_{2.5}$-concentration-difference (REF-NPE) at downwind grid-cells in subsequently lower levels from the emitting level (113-219m) to the breathing level (0-8m) under wind-speeds <2m/s (left), 2-5m/s (middle) and ≥5m/s (right). The emitting level is the highest level displayed in the figure. Open black circles indicate the relative position of grid columns holding other PSs near the PS-holding grid-column of interest. Closed red circles represent statistically significant (at the 95% confidence level) correlations.

Atmospheric temperature inversions influence the dispersion of PS-emissions (Fig. 10). As can be easily derived from Figure 10, theoretically, PS-emissions emitting into levels above, in-between and below inversion layers would have their impact on the breathing level from the lowest to highest magnitude, respectively. In the following, we talk about "no-inversion conditions" when the bottom of any inversion layer aloft is 200m above the emitting-level. "Below-inversion" refers to when the bottom of any inversion aloft is less than 50m above the highest emitting-level. On average, WRF/Chem predicted in-between-inversion, above-inversion, below-inversion and no-inversion conditions for PS-emissions in 64%, 18%, 10% and 8% of the time, respectively. Note that WRF/Chem for 2005/06 predicted the frequency of inversions acceptably [*Mölders et al*., 2011].

In general, WRF/Chem reproduced successfully the emission-inversion relationship at all PSs. Here we only show the correlation at PS6 as an example. The strongest and significant correlations between PS-emissions and $PM_{2.5}$-concentration-difference at breathing level occurred under "below-inversion" conditions and the highest correlation values typically occurred at 8-10km downwind depending on emission level and wind speed (e.g. Fig. 19). The second strongest (significant) correlations occurred under "in-between-inversion" conditions. Then the highest correlation values occurred within 0-12km downwind depending on wind-speed, emission level and inversion strength. The location of highest correlation typically shifts

farther downwind as the inversion strength increases and vice versa. Under both "no-inversion" and "above-inversion" conditions, PS-emissions correlate marginally and insignificantly with the breathing level $PM_{2.5}$-concentration. Based on these finding we conclude that PSs have their highest impact on the $PM_{2.5}$-concentration at breathing level within 10km of their location.

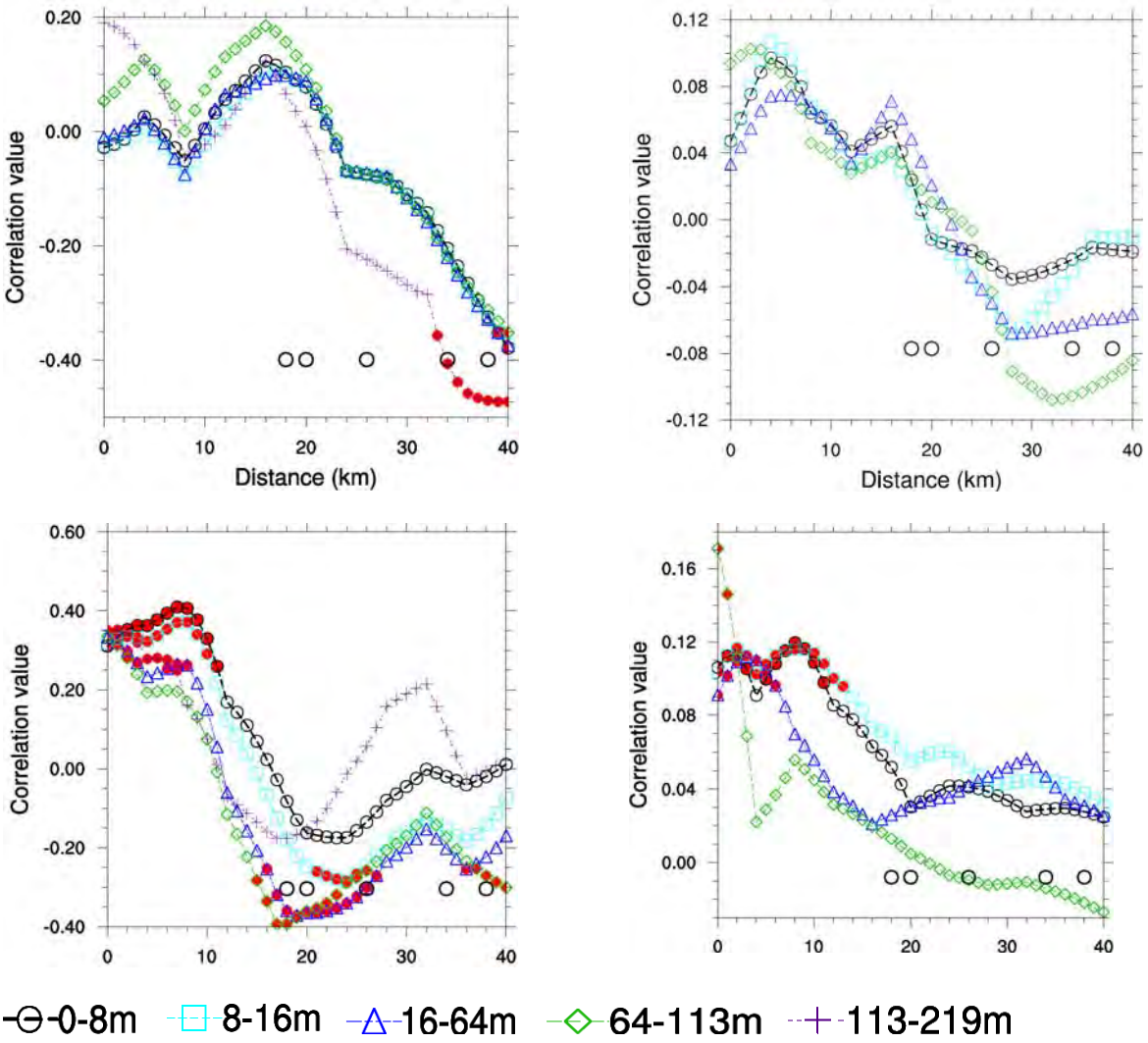

Fig. 19. Correlation of $PM_{2.5}$ emissions at PS6 with $PM_{2.5}$-concentration-difference at downwind grid-cells in subsequently lower levels from the emitting-level to the breathing level (0-8m) under conditions when there was "no inversion", emission into levels above, just below and in between inversion layers (top-left to bottom-right, respectively). The emitting-level is the highest level displayed in the figure. Open black circles indicate the relative position of grid columns holding other PSs in the vicinity of the PS-holding grid-column of interest. Closed red circles represent statistically significant (at the 95% confidence level) correlations.

6.2 Potential impact of "woodstove replacement" programs

As pointed out above, WSR is a very moderate "woodstove replacement" scenario in comparison with the sensitivity simulation that assumed a replacement of all non-certified wood burning devices based on the number of devices given in *Davies et al.*'s [2009] report (WSS1). The emission reduction in WSR was much lower than in WSS1 (cf. section 4). Within the nonattainment area, the emission strength in WSR was 6$\mu gm^{-2}h^{-1}$ (6%) less than in REF on

average whereas in WSS1 the emission strength was 40% lower than in REF. Because of the comparably small emission difference between REF and WSR, simulated $PM_{2.5}$-concentration of REF and WSR differ typically only slightly (Figs. 20, 21).

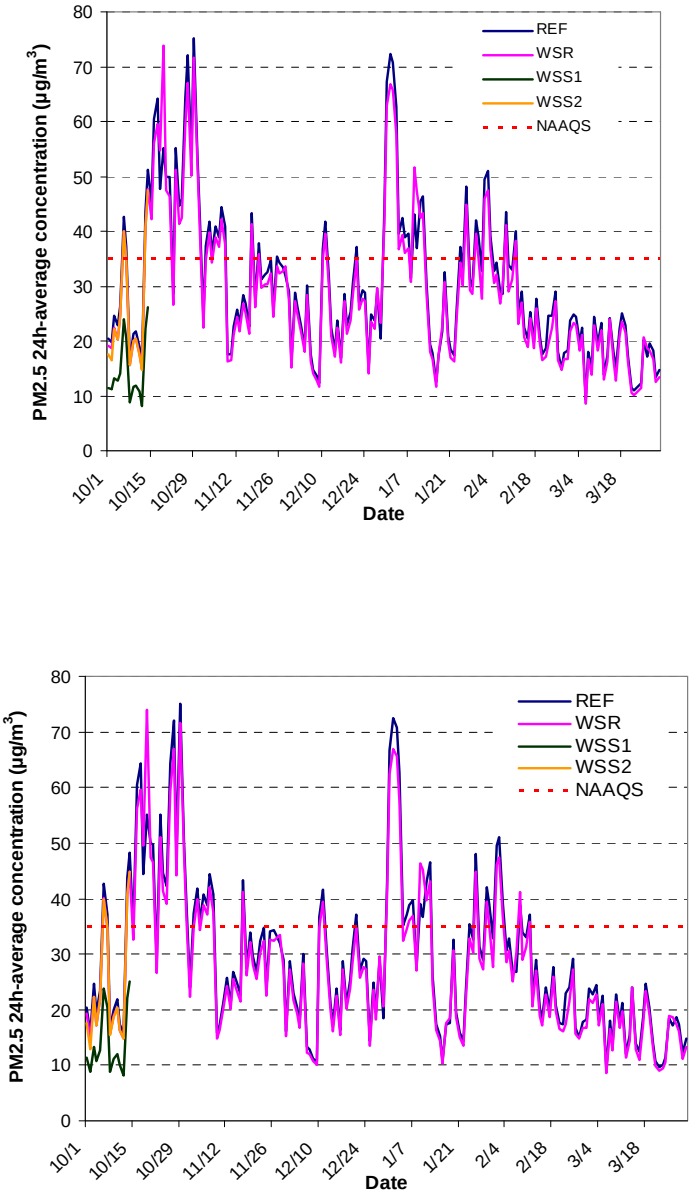

Fig. 20. Highest 24h-average $PM_{2.5}$ concentration as obtained anywhere in the model domain (top) and the 24h-average concentration at the grid-cell holding the State Building (bottom) in REF, WSR, WSS1, and WSS2. Note that the highest concentrations within the model domain occurred in the nonattainment area.

In comparison with the emissions in REF, the average $PM_{2.5}$-emission reductions in the nonattainment area are 6%, 36%, and 7% in WSR, WSS1, WSS2, respectively. The highest 24h-average $PM_{2.5}$-concentration difference anywhere in the domain amounts 5.7µgm^{-3} on February 22, 2009 (Fig. 20). Averaged over the nonattainment area, the highest (2.1µg/m^3) and the second highest (2.0µg/m^3) difference in 24h-averaged $PM_{2.5}$-concentrations were simulated for October 27, 2008 and January 1, 2009, respectively, and the average difference over time and the nonattainment area amounts 0.6µg/m^3. About 45% and 33% of the concentration differences fall

between 0.5-1µg/m^3 and 0-0.5 µg/m^3, respectively (Fig. 22). All grid-cells with the highest concentrations are located in the nonattainment area.

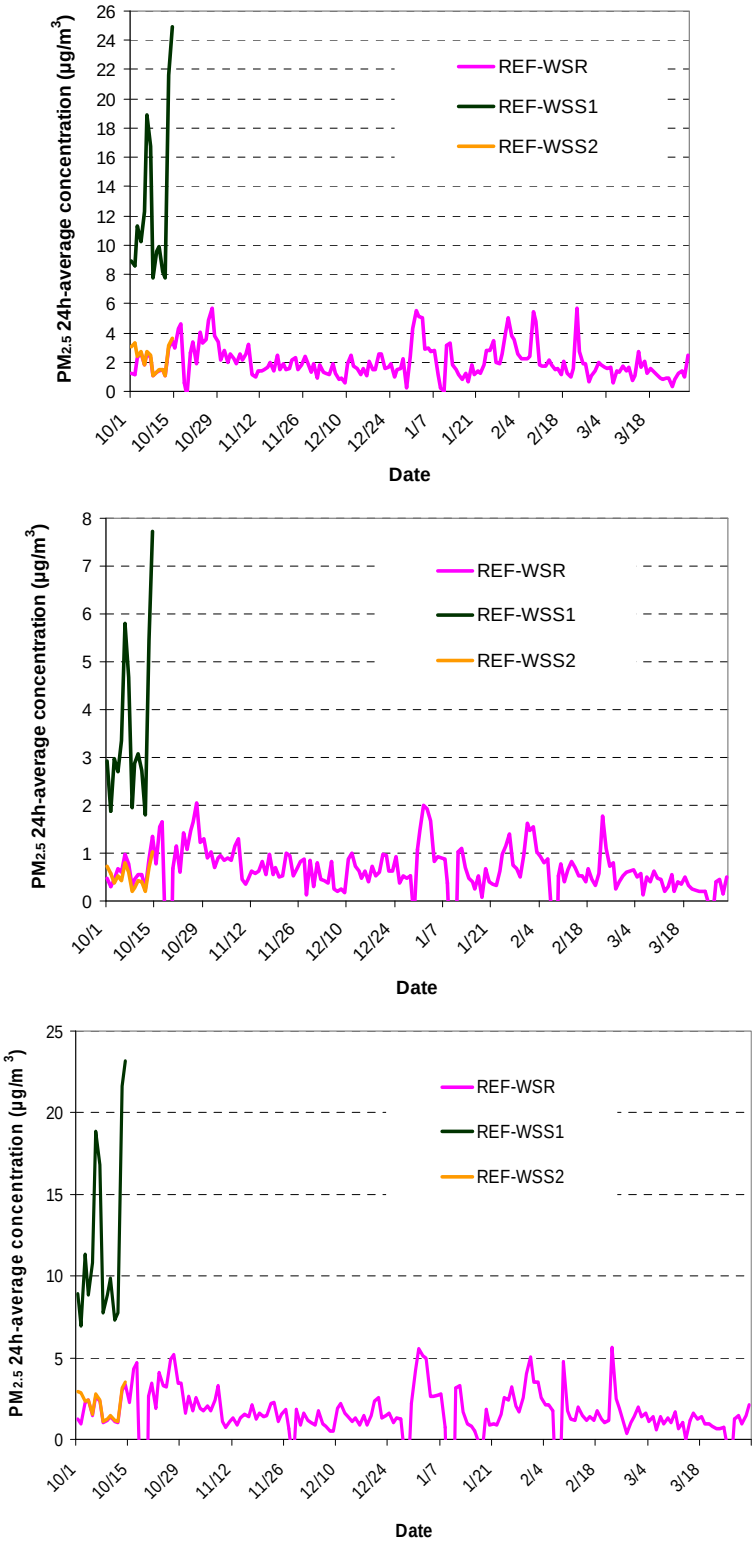

Fig. 21. Highest 24h-average $PM_{2.5}$-concentration difference from REF for WSR, WSS1, WSS2 as obtained in the domain (top), on average over the nonattainment area (middle) and the grid-cell with the State Building (bottom).

In the nonattainment area, the monthly average $PM_{2.5}$-concentration differences amount to $0.7\mu g/m^3$, $0.7\mu g/m^3$, $0.6\mu g/m^3$, $0.7\mu g/m^3$, $0.6\mu g/m^3$ and $0.3\mu g/m^3$ in October, November, December, January, February and March, respectively. We calculated the 24h-averaged $PM_{2.5}$-concentration difference for each day of the 182 simulation days and sorted them from high to low differences. We picked the 20% highest and 20% lowest concentration differences from this list. Note that 20% corresponds to 36 days in our study. The investigation showed that 14 and 13 of the top 20% highest and lowest concentration differences occurred in October and January, respectively. Off the 20% lowest, nine days occurred in March. This means the highest differences typically occurred in October and January whereas the lowest differences occurred in March. This finding means that the highest mitigation of $PM_{2.5}$-concentrations can be achieved in the months that are coldest.

The Student t-test showed statistically significant $PM_{2.5}$-concentration differences only within the nonattainment area and some adjacent grid-cells (Fig. 23). Outside the nonattainment area, the $PM_{2.5}$-concentration differences are very low and non-significant. Although the Student t-test shows that the concentration differences are significant, there is still a possibility that the $PM_{2.5}$-concentration difference at a given grid-cell is not due to the reduced emission, but rather due to some variable random effects between the two simulations (e.g. truncation errors, model sensitiveness). This is especially true for very small differences in $PM_{2.5}$-concentration. We adopted the FEA analysis [*Carpenter et al.*, 1989; *Werth and Avissar*, 2002] to verify that the differences are really due to the "woodstove replacement".

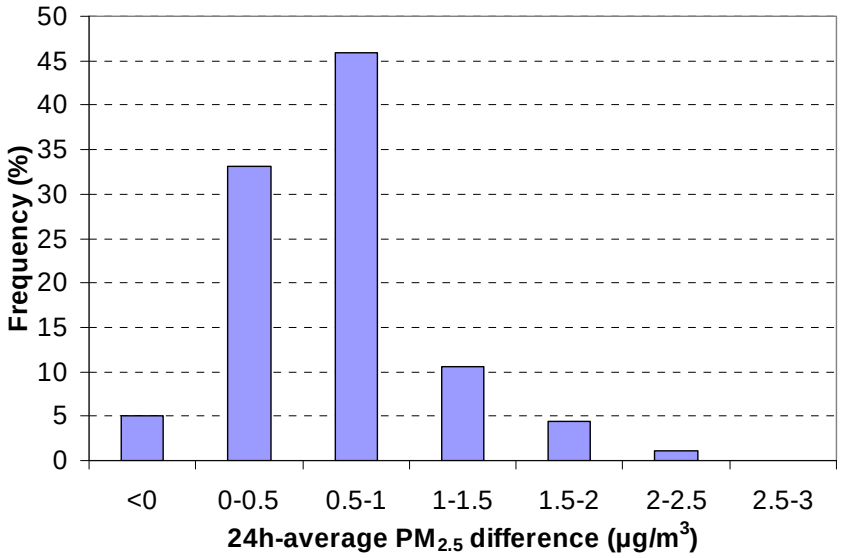

Fig. 22. Frequency distribution of 24h-average $PM_{2.5}$-concentration difference as obtained for WSR.

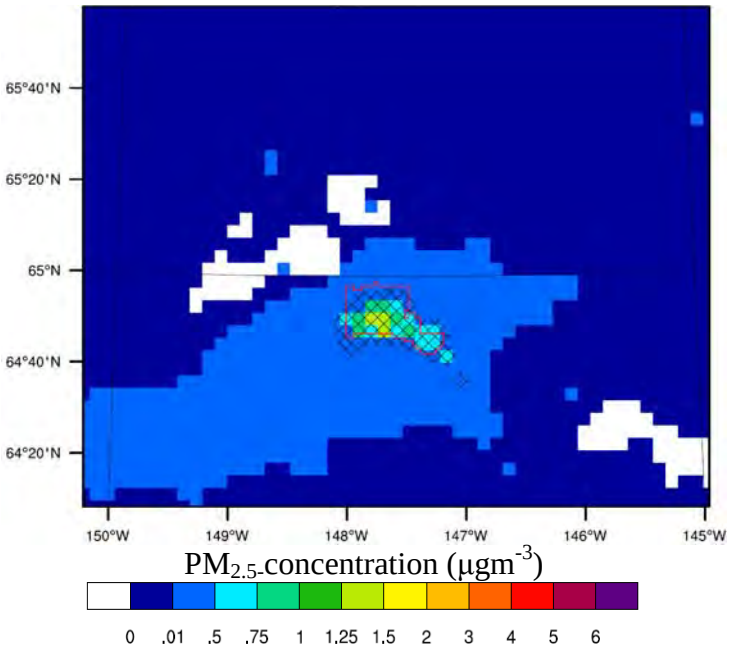

Fig. 23. Zoom-in showing the average difference of $PM_{2.5}$-concentration between REF and WSR for October 1, 2008 to March 31, 2009. The hashed shading indicates grid cells where the difference is statistically significant at 95% or higher level of confidence

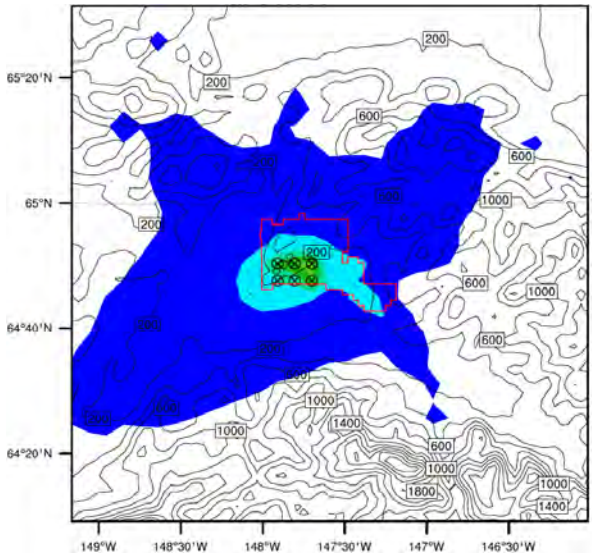

Fig. 24. Zoom-in map of grid-cells for which exceedances were simulated during October 1, 2008 to February 28, 2009 in REF. The 24h-average $PM_{2.5}$ concentration on October 1, 2008 is superimposed. The crossed circles indicate grid cells for which exceedance were simulated during OTM; the red polygon indicates schematically the nonattainment area. Grid-cells for which exceedances were simulated in WSR are identical to those for which exceedances occurred in REF (therefore not shown).

In February 2009, several grid-cells exist in the northwest of the nonattainment area that have ranks lower than the top 5%. Some of them have non-significant concentration-differences according to the Student-t test (Fig. 24). For November and December 2008, the ranks of true

concentration differences are relatively uniform anywhere in the whole model domain whereas they vary strongly in other months. This behavior coincides with the temporal evolution of the 24h-average $PM_{2.5}$-concentration difference (Fig. 21) that indicates low variation of the difference in November and December 2008, but strong variation in the other months.

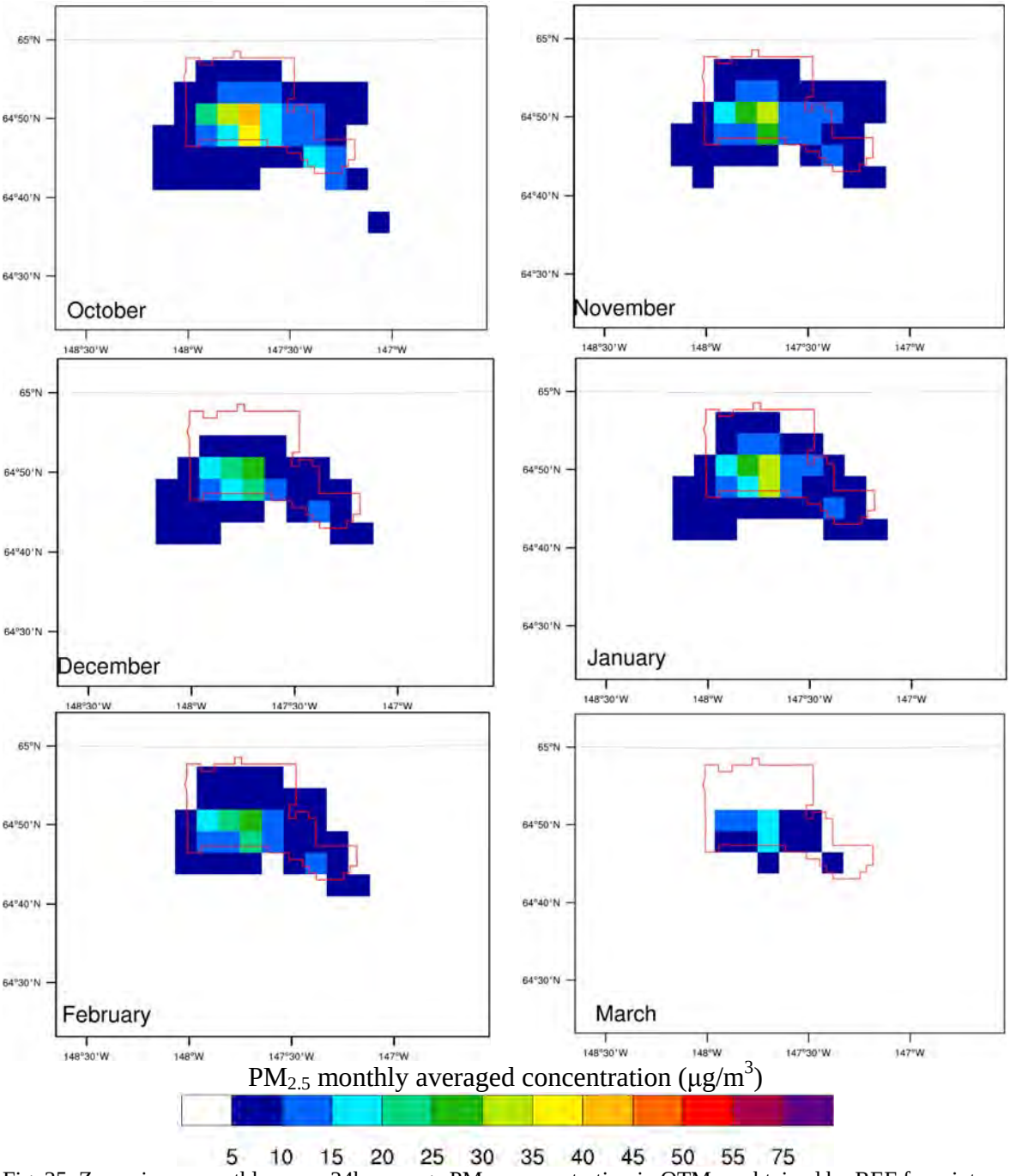

Fig. 25. Zoom-in on monthly mean 24h-average $PM_{2.5}$ concentration in OTM as obtained by REF for winter 2008/09.

According to the FEA, exchanging the noncertified wood-burning devices helped to reduce the number of exceedance days during OTM. The number of exceedance days anywhere in the nonattainment area are 20 (19), 10 (7), 5 (3), 15 (14), and 5 (5) in REF (WSR) for October,

November, December, January, February respectively. All exceedance events of OTM occurred at grid-cells in the nonattainment area. At the grid-cell holding the State Building monitoring site, exceedances were simulated for 52 (44) days in REF (WSR). At grid-cells other than that holding the official site, exceedances were simulated for 40 (34) days by REF (WSR). Despite the different number of exceedance days, locations (grid-cells) that experienced exceedances are identical in REF and WSR during OTM (Fig. 25). Days and grid-cells having the highest $PM_{2.5}$-concentrations during simulated exceedance events during OTM are also identical. This fact indicates that there are no offsets in the temporal and spatial distribution of exceedance events between REF and WSR.

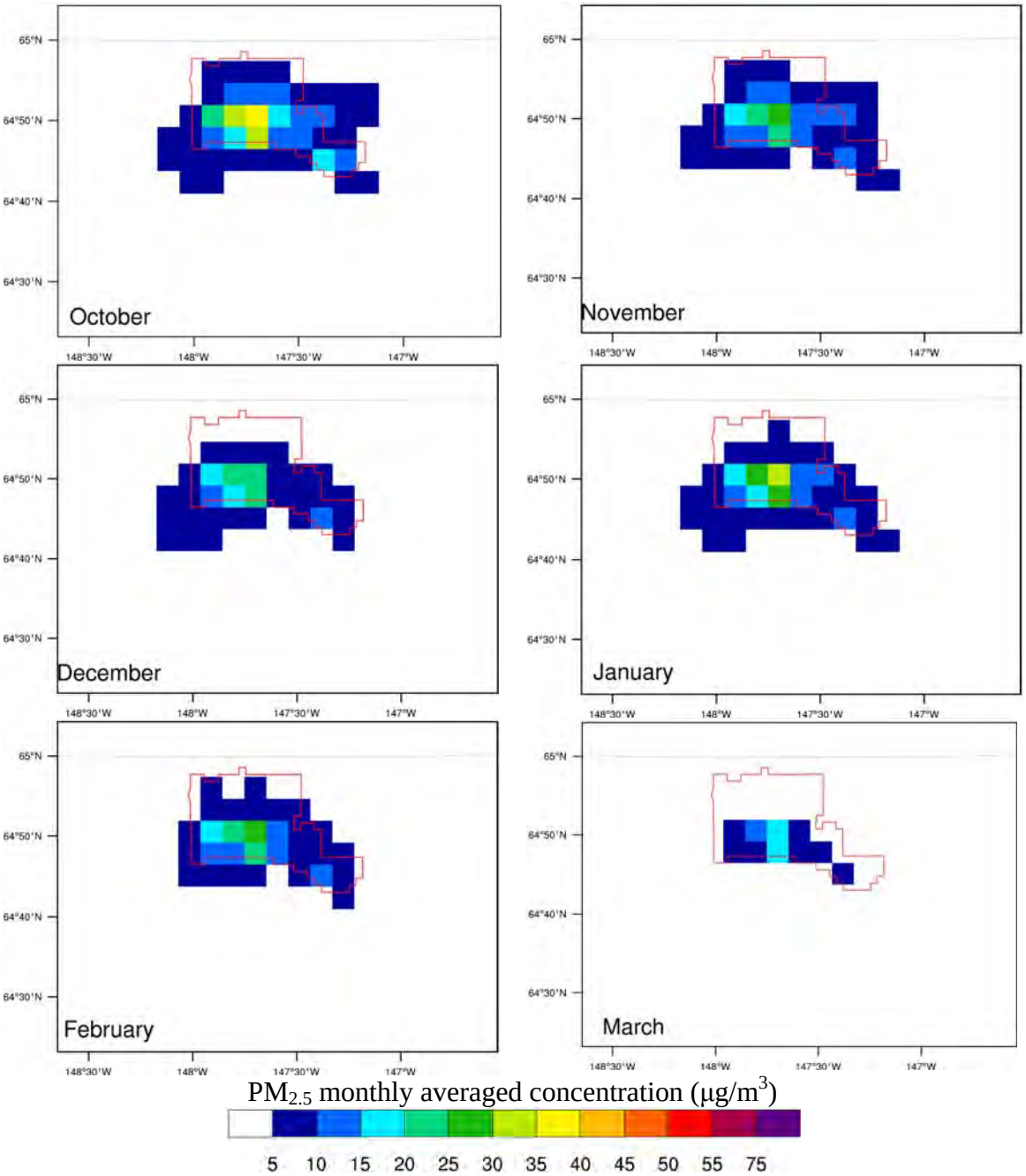

Fig. 26. Like Fig. 25, but for WSR.

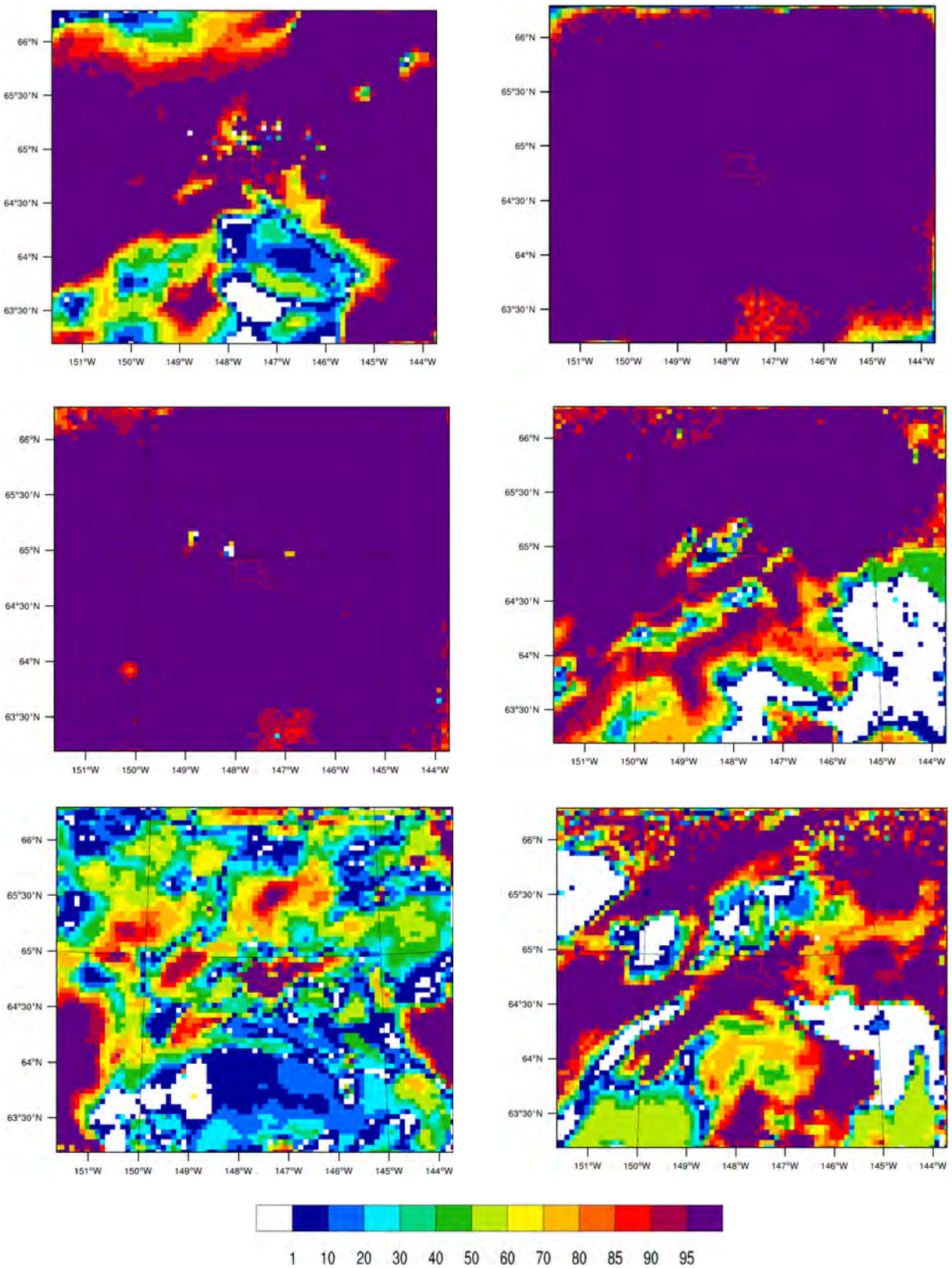

Fig. 27. Monthly rank of "true" differences over "false" differences of $PM_{2.5}$-concentration for October 2008 to March 2009 (from top left to bottom right). At grid-cells ranking higher than the 95% percentile, the "woodstove replacement" can be considered as the factor that actually reduced the $PM_{2.5}$ concentrations at breathing level.

Comparison of the monthly mean 24h-average $PM_{2.5}$ concentrations obtained with REF and WSR (Figs. 25, 26) indicates that the hot spots remain the same, but with slightly lower concentrations.

The FEA was applied for every month from October 2008 to March 2009. The ranks of the true-difference concentrations varied highly at all grid-cells throughout OTM except for those in the nonattainment area (Fig. 27). The ranks of true concentration difference at grid-cells in the nonattainment area lay consistently in the top 5% of the false ensembles. This means that exchanging the non-certified wood-burning devices does really help to reduce the $PM_{2.5}$-concentrations in the nonattainment area.

The results of the Student-t test and FEA (Fig. 27) indicate that exchanging the noncertified wood-burning devices does really help to reduce the $PM_{2.5}$-concentration in the nonattainment area. This outcome results from the fact that wood-burning devices emit into low levels of the atmosphere. Therefore, the emitted species are not transported far away from their sources. This behavior is especially true for conditions with low wind-speeds, as they frequently exist during winter in Fairbanks [cf. *Tran and Mölders*, 2010]. Thus, the impact of emissions from wood-burning on the $PM_{2.5}$-concentrations at breathing level remains local compared to the impacts of elevated point sources.

6.2.1 Sensitivity studies on "woodstove replacements"

We compared the emission reductions that related only to the different numbers of heating devices in WSS1, WSS2 and WSR with each other as well as with the reference simulation. Recall that the reference simulation, and the simulations assuming the "woodstove replacement" using *Davies et al.*'s number of devices, and the "woodstove replacement" using the SRL draft report and *Carlson et al.*'s number of devices were denoted as REF, WSS1, WSS2, and WSR, respectively (Table 1). Due to the tremendous CPU time required for a half-year long simulation the WSS1 and WSS2 simulations were carried out only for a limited time. While WSS1 reduces the $PM_{2.5}$ concentrations in the nonattainment area greatly, WSS1 is much less doing so (Figs. 20, 21). Within the 15 days of simulation, WSS2 reduces the 24h-average $PM_{2.5}$ concentrations by 3.6μg/m^3 to the highest, while WSS1 reduces them by as much as 25μg/m^3. WSS1's reduction helped efficiently to avoid four exceedances encountered locally in REF. On the contrary, the reduction in WSS2 was not sufficient to do so. The locations of exceedances do not differ between REF, WSS1 and WSS2 and they all occur in the nonattainment area. The reduction benefit of WSS1 was higher when local exceedances existed, while the reduction obtained in WSS2 differed marginally with time.

The sensitivity studies suggested large uncertainty in the magnitude of the efficiency of a "woodstove replacement" program. This uncertainty mainly results from (1) the unknown number of wood-burning devices that exist in the nonattainment area and could be replaced, (2) the unknown partitioning of the use of wood-burning and other heating devices in households with more than one heating option, (3) the unknown temporal use of wood-burning devices, and (4) the unknown spatial distribution of wood-burning devices.

6.3 Potential impact of usage of low sulfur fuel for heating oil, power generation and in oil-burning facilities

Introducing low sulfur fuel decreased the total monthly $PM_{2.5}$-emissions in the nonattainment area from October to March by 15.666, 17.448, 15.407, 15.447, 14.294, and 13.381 kg/km^2,

respectively from 140.130, 94.184, 94.118, 101.265, and 98.398 kg/km^2, respectively. The percentage total daily $PM_{2.5}$-emission reductions from October to March were 11.1%, 18.5%, 16.4%, 13.0, 14.1, and 13.6%, respectively. The decreases in monthly emissions of SO_2, NO and VOC were approximately 23%, 1% and 0%, respectively.

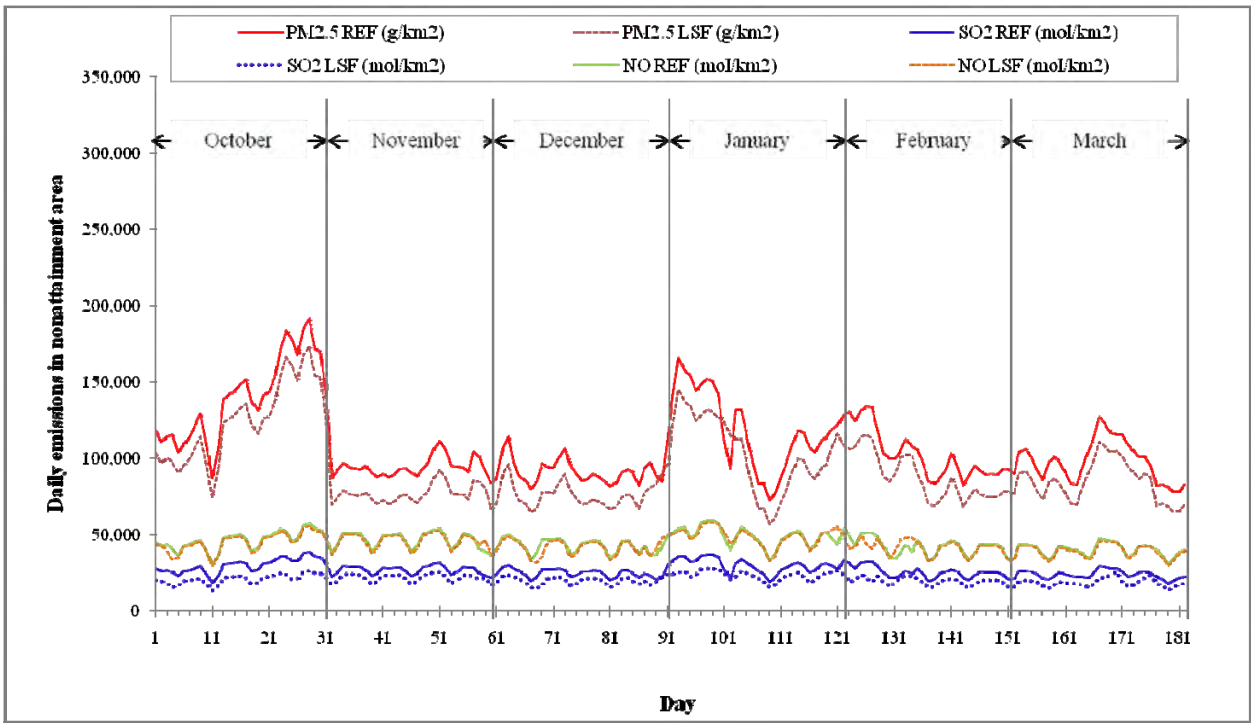

Fig. 28. Temporal evolution of daily emissions averaged over the nonattainment area for October 2008 to March 2009 as assumed in REF and LSF. The day refers to the day since start of the simulation (1 October 2008).

The daily mean temperatures are a main factor that affects the efficiency of utilizing low sulfur fuel. Low temperatures cause incomplete combustion and support the gas-to-particle conversion. During OTM, October 2008 had the highest frequency of days with daily near-surface temperatures below the 1971-2000 30-year monthly mean temperature (Table 3). Consequently, October 2008 had high emissions of particulate matter. Daily emissions in the nonattainment area with the current fuel sulfur content and after introduction of low sulfur fuel are compared in Figure 28.

In the nonattainment area, the monthly average $PM_{2.5}$-concentration amounted to 13.0, 11.6, 9.2, 11.0, 9.8 and 5.7μg/m^3, respectively, and 9.9μg/m^3 on average over OTM. The monthly average $PM_{2.5}$-concentration difference (REF-LSF) amounts to 0.4, 1.0, 0.7, 0.6, 0.5 and 0.4μg/m^3 in October, November, December, January, February and March, respectively, and 0.6μg/m^3 on average over the entire winter. The percentage reductions varied from 3% to 9% (Table 4). November had the highest assumed emission reduction and simulated concentration reductions. The daily reduction in emissions does not yield to a linearly corresponding reduction in the daily average $PM_{2.5}$ concentrations at breathing level in the nonattainment area (cf. Figs. 28, 29).

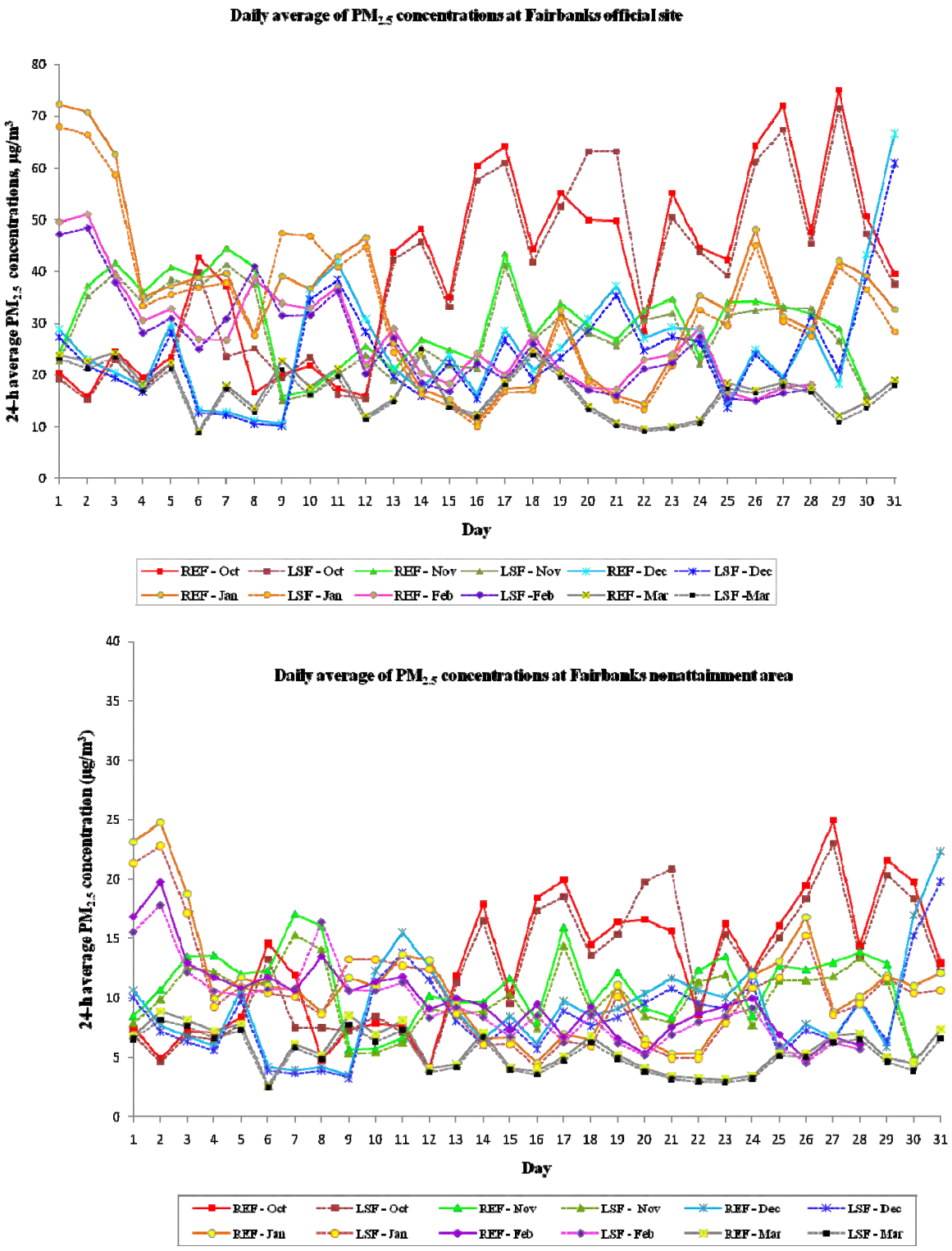

Fig. 29. Temporal evolution of simulated 24h-average $PM_{2.5}$ concentrations as obtained for the grid-cell that holds the State Building (top) and the 24h-average $PM_{2.5}$ concentrations averaged over the nonattainment area (bottom) in the various months of winter 2008/09. REF and LSF refer to the reference simulation and the simulation assuming the introduction of low sulfur fuel for heating oil, power generation and facilities burning oil (see Table 1).

On average, the simulated reduction of 24h-average $PM_{2.5}$ concentrations during OTM was 0.6µg/m^3. The maximum 24h-average $PM_{2.5}$-concentrations reduction of 4.4µg/m^3 occurred in October (Fig. 29). Focusing on the values simulated for the grid-cell holding the official $PM_{2.5}$-monitoring site in the nonattainment area at the State Building, the average daily concentrations reduction was 1.2µg/m^3 for OTM. The maximum 24h-average $PM_{2.5}$-concentration reduction at the State Building site was 13.6µg/m^3 and was simulated for October 2008. In comparison with the $PM_{2.5}$-concentrations obtained for other grid-cells in the nonattainment area, this site had the highest frequency of exceedance days (19, 8, 5, 15, 5, and 0 exceedance days for October to March, respectively), and most of them had the highest $PM_{2.5}$-concentrations, when compared to other grid-cells in the nonattainment area on the same day.

We calculated the 24h-averaged $PM_{2.5}$-concentration difference between REF and LSF for each day of the total 182 simulation days and sorted them from high to low differences. We picked the 20% highest and 20% lowest concentration differences from this list. Note that 20% corresponds to 36 days in this case. Investigation of the top 20% showed that 14 of the highest concentration differences occurred in November. Off the 20% lowest, most days (14) occurred in March. This means the highest differences typically occurred in November whereas the lowest differences occurred in March. The highest differences were mainly due to the concentration values. In this scenario, high monthly average concentrations mostly translated into high monthly average reductions. Table 4 shows that high $PM_{2.5}$ concentrations occurred in October, January, and November from the first to the third rank, respectively. In October and January, the concentrations were high, but there were some days for which $PM_{2.5}$ concentrations increased after introduction of low sulfur fuel. Therefore, in October and January, the $PM_{2.5}$-concentration reduction was not as high as in November. The lowest difference for $PM_{2.5}$-concentrations occurred for March as this month had the lowest $PM_{2.5}$-concentrations.

The daily reductions in $PM_{2.5}$-concentrations vary strongly with the meteorological conditions and over the months (Fig. 29). By reducing the fuel sulfur content of oil, the number of simulated exceedance days in October 2008 to March 2009, which amounted to 20, 10, 5, 15, 5 and 0 in REF were reduced to 19, 8, 4, 14, 5 and 0 in LSF, respectively. The simulations suggested that in total, five exceedance days could have been avoided by introduction of low sulfur fuel.

Remarkably, on several days, the 24h-average $PM_{2.5}$-concentrations increased in the nonattainment area after introduction of low sulfur fuel. Note that similar was found also in another sulfur reduction study carried out over the North Pacific for January with another configuration of WRF/Chem [*T.T. Tran*, 2011; pers. communication]. In our study, on some simulated days, the increase of $PM_{2.5}$-concentrations stemmed from the increase of $PM_{2.5}$ emissions, for example at the end of December and in mid-January (Fig. 28). The emissions increased due to the non-linear temperature dependency of emissions from power generation and domestic combustion considered in AkEM.

However, the increase of $PM_{2.5}$ concentrations on October 8, 10, 20-22, and February 7-9 and March 14 did not coincide with increased $PM_{2.5}$ emissions. These increases despite of decreased $PM_{2.5}$ emissions are due to gas-to-particle conversion. Recall that the usage of low sulfur fuel leads to a different emission spectrum for various other species. Increases of $PM_{2.5}$ concentrations occurred both inside and outside the nonattainment area (e.g. Fig. 30). The increases were related to the atmospheric chemistry of NO_x that affected the thermodynamic equilibria of sulfate-nitrate-ammonia-water in aerosols.

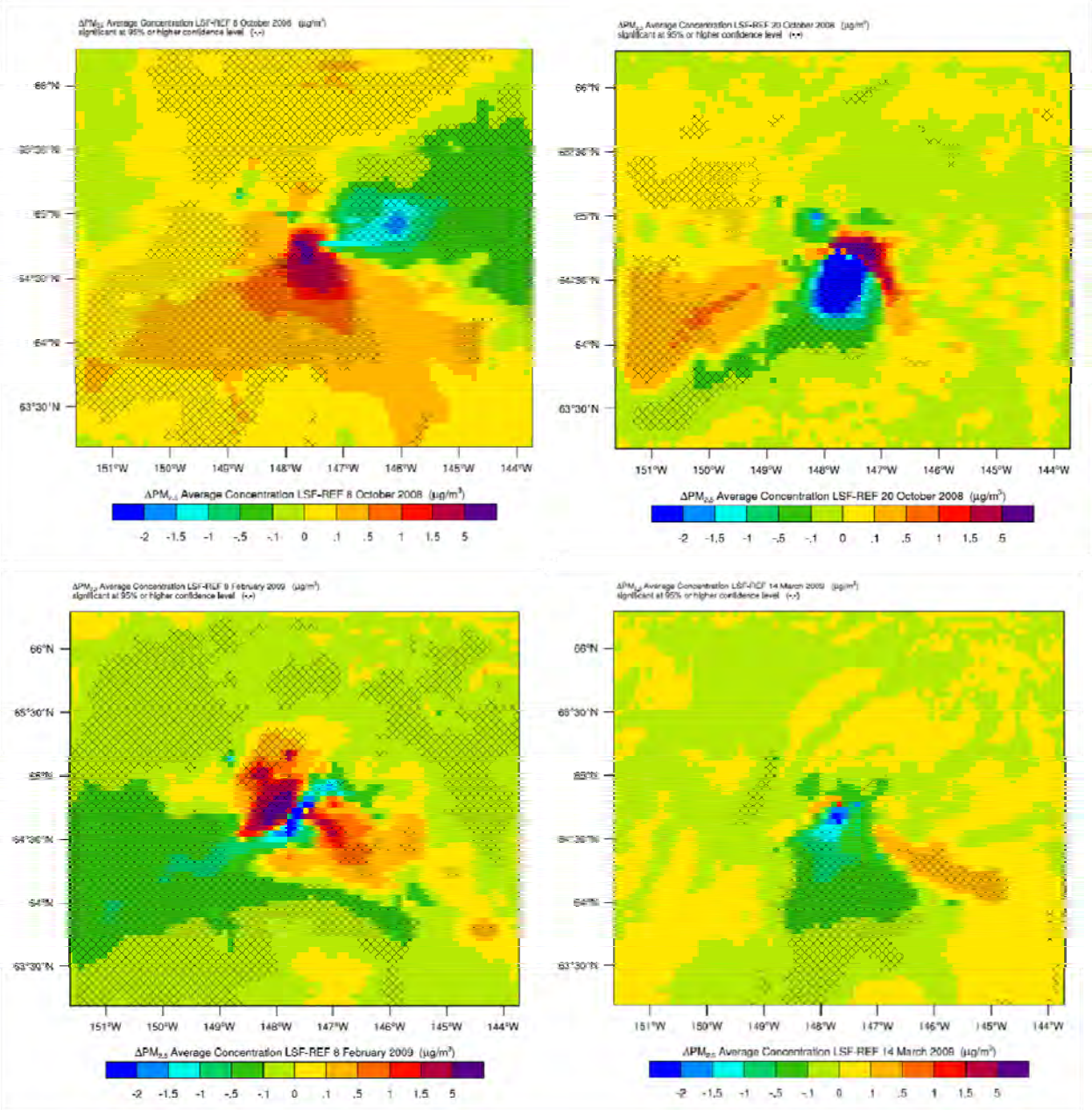

Fig. 30. Examples of $PM_{2.5}$-concentration difference distributions on days with days with locally increased $PM_{2.5}$ concentrations after introduction of low sulfur fuel. The hashed shading indicates grid cells wherein the difference (REF-LSF) is statistically significant at 95% or higher level of confidence.

The large number of days (12 days in the nonattainment area, 13 days for the grid-cell holding the State Building) with increased $PM_{2.5}$-concentrations and the emission-concentration relationship (Figs. 28, 29) suggest that the locally increased $PM_{2.5}$-concentrations after introduction of low sulfur fuel are most likely not a model artifact, but real. The reduction of SO_2 emissions and lower SO_2-concentrations in LSF reduced the sulfate-aerosol concentrations. This circumstance further resulted in partial replacement of the reduced aerosol mass by available nitric acid. The percent fraction of nitrate increased, but sulfate decreased on days with increased $PM_{2.5}$ concentrations (Fig. 31). Note that nitrate has more mass than sulfate.

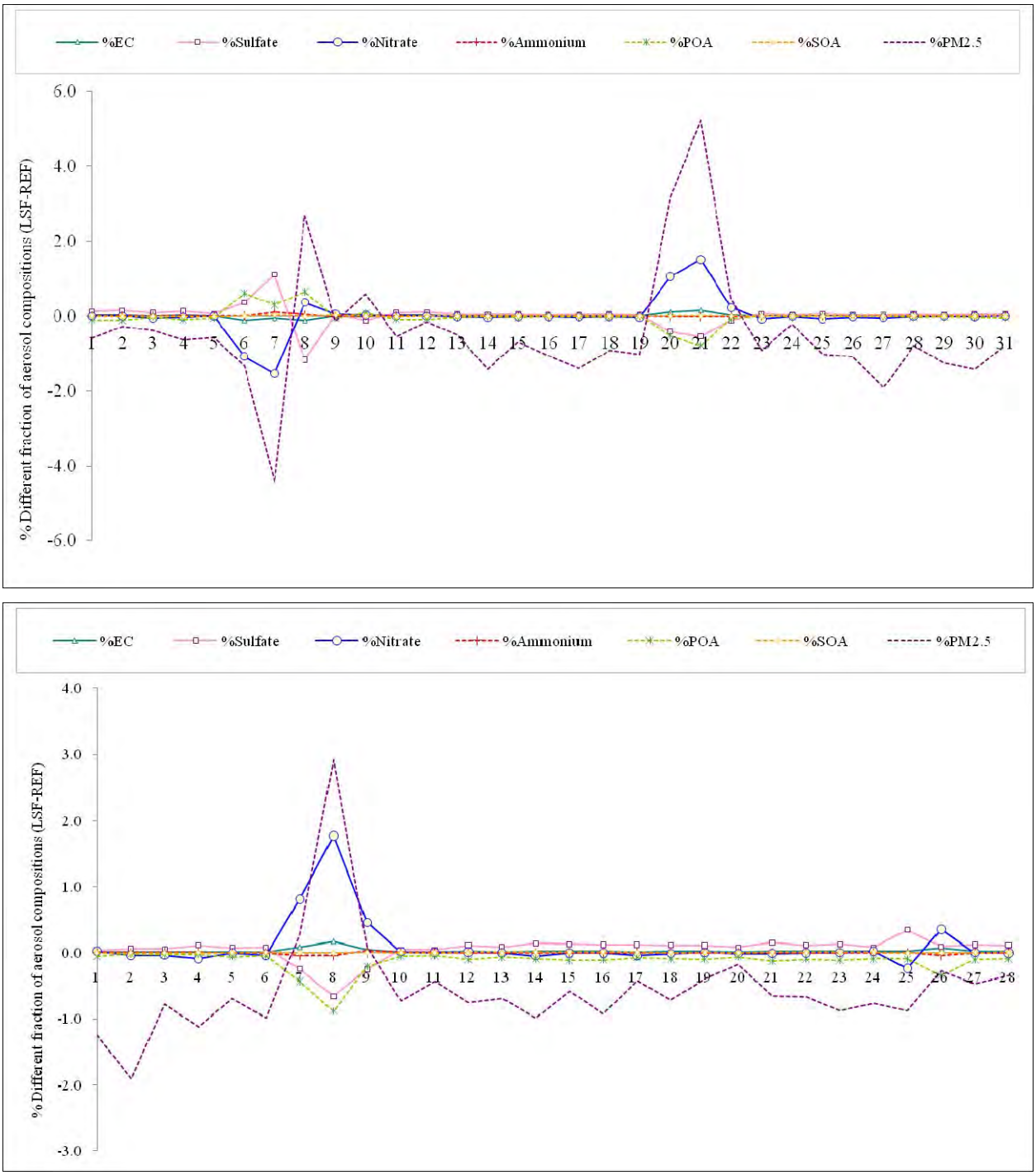

Fig. 31. Temporal evolution of daily average percentage difference of aerosol composition in the nonattainment area as obtained for October (top) and February (bottom).

The investigation of the reasons is beyond the scope of this study. However, preliminary analysis within the framework of a PhD thesis suggests that less transformation and removal of NO_x after introduction of low sulfur fuel during months with still relatively high solar radiation led to an increase of the nitrate concentrations, and increased the particulate matter concentrations accordingly (Fig. 31). The replacement of nitrate brought about a shift of the NH_4NO_3 equilibrium toward the gas-phase. Consequently, the NO_3-concentrations increased in the

atmosphere after introducing low sulfur fuel. The fact that no such increase occurs during the months with lowest insolation (e.g. December, January) suggests that chemical processes initiated by photolysis play an important role. As explained earlier, during October, February, and March, photolysis plays a stronger role as photolysis rates are higher than in December or January. Consequently, NO, NO_2 and NO_3 concentrations increase during October, February, and March, and $PM_{2.5}$ concentrations increased accordingly. The high aerosol concentrations fed back to meteorology. The simulated atmosphere became more stable and air quality became worse in the Fairbanks nonattainment area. The increase of nitrate, which means an increase of aerosols in the atmosphere, and the effect of chemistry on meteorology, should be analyzed for full understanding, but both tasks are beyond the scope of this study.

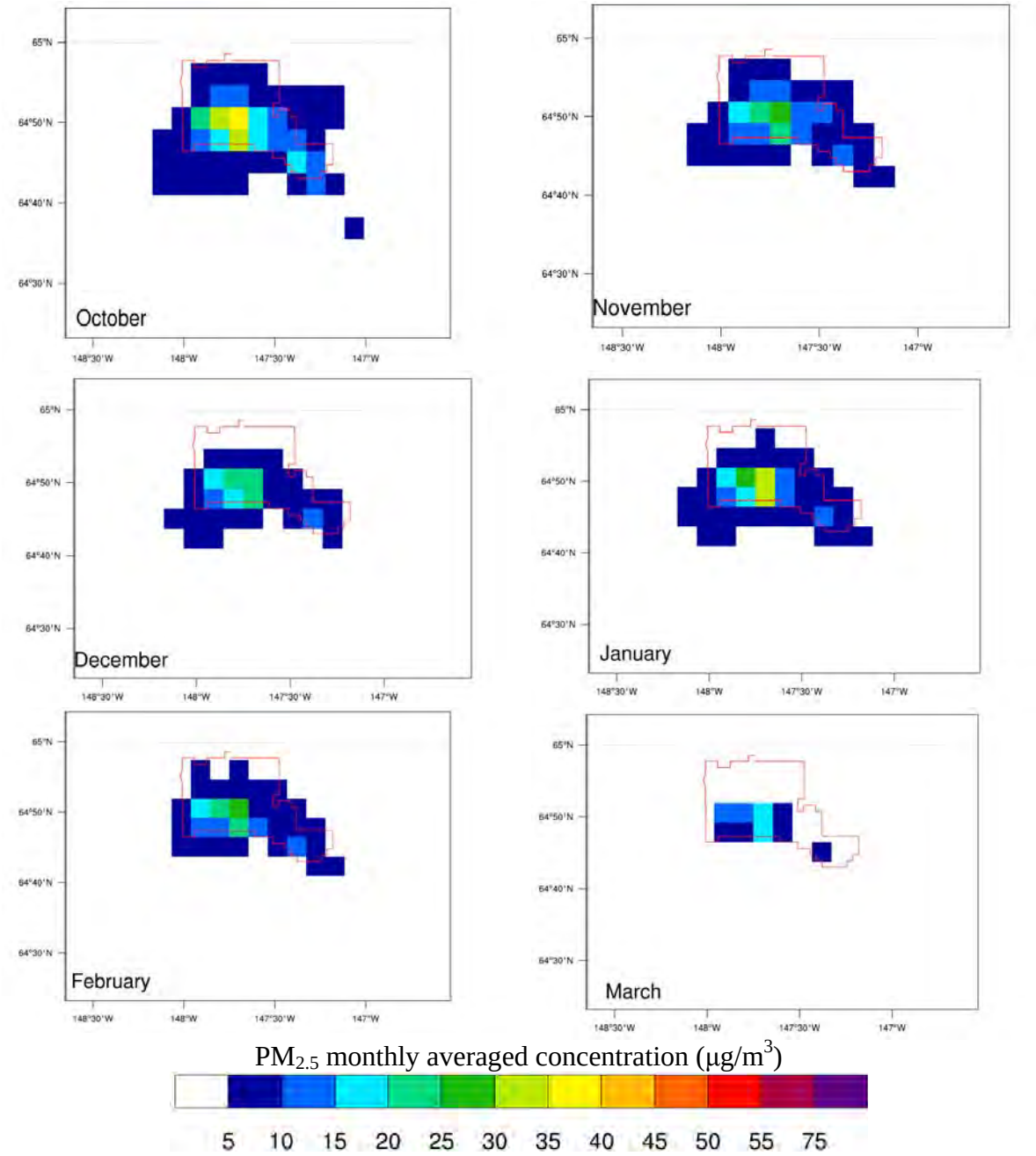

Fig. 32. Like Fig. 25 but for LSF.

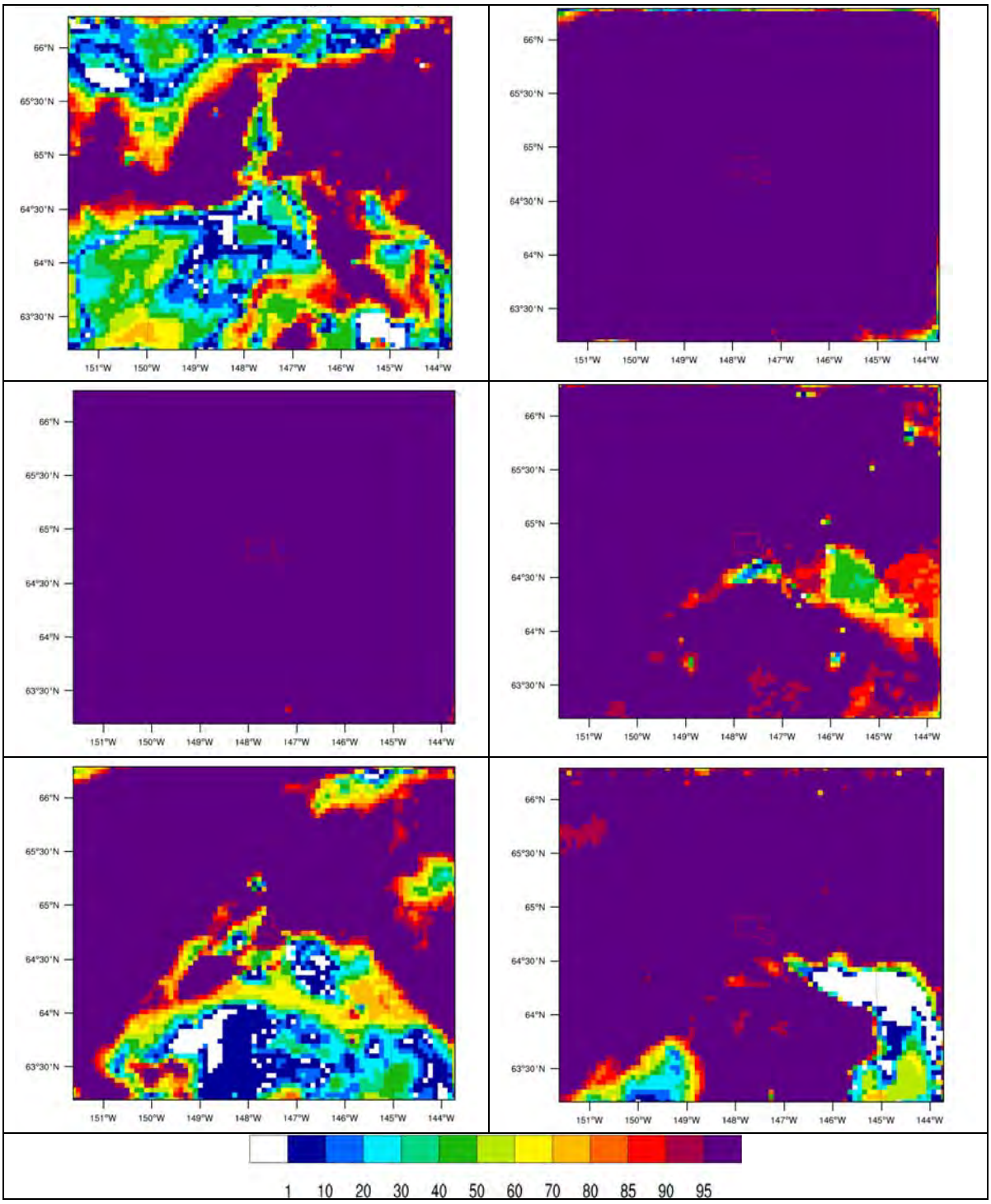

Fig. 33. Monthly rank of "true" differences over "false" differences of $PM_{2.5}$-concentration for October 2008 to March 2009 (from top left to bottom). At grid-cells ranking higher than the 95% percentile, the low sulfur fuel scenario has high efficiency in reducing concentrations in nonattainment area only in November, December, January and March.

Comparison of the monthly mean 24h-average $PM_{2.5}$ concentrations (Figs. 25, 32) shows the same hot spots in October, January, February and March than for REF, but these hotspots have

lower values in LSF. The local reduction is smaller in February and March than in the relatively cold October. The distribution-patterns of $PM_{2.5}$ concentrations change notably for November and December. These spatial changes suggest that gas-to-particle conversion to changes in the concentrations. Note that these processes depend on the concentrations of precursor gases, photolysis rates, temperature and humidity in non-linear ways. Thus, small changes in the concentrations of precursors may lead to much higher or lower gas-to-particle conversion rates.

Like for NPE and WSR we applied the FEA method to the data of LSF and REF. The FEA results indicate that the concentration differences (REF-LSF) in November, December, January, February and March are due to the introduction of low sulfur fuel (Fig. 33). In October, obviously random effects may play a role.

6.3 Comparison of the mitigation measures relative to each other

EPA's Office of Air Quality Planning and Standards in conjunction with the EPA Regional Offices compute design values based on observations in previous years, and review and publish them annually [*EPA*, 2011]. Design values are expressed as a concentration instead of an exceedance. These design values describe the air-quality status of a given area relative to the NAAQS. Consequently, design values can be used to classify nonattainment areas, develop control strategies, and assess progress towards meeting the NAAQS [*EPA*, 2011]. The design value for the baseline year 2008 for the Fairbanks nonattainment area is 44.5μg/m^3 [*Huff,* 2011; pers. communication]. The design values of 2005-2007, 2006-2008, and 2007-2009 were 39, 41, and 57, respectively [*EPA*, 2011]. These values partly reflect the decreasing air quality in response to the increase in wood burning.

Emissions are temperature dependent – more heating is required when it is colder than warmer outside. The winter episode 2007-2009 was about 0.7^{o}F colder than that of 2008-2010 (Table 3). This fact explains why the 2008-2010 design value is smaller than the 2007-2009 design value. The average temperature OTM for winter 2008/09 was 0.3^{o}F, i.e. much colder than winter 2007/08 (4.9^{o}F) or winter 2009/10 (4.5^{o}F).

An easy way to compare the impacts of the altered emissions on the $PM_{2.5}$ concentrations and their composition at breathing level is to determine the relative response factors (RRF). The RRF for each simulated particulate matter component j at site i is given by [*EPA*, 2007]

$$RRF_{ij} = \frac{\lfloor C_{j,projected} \rfloor}{\lceil C_{j,current} \rceil} \quad (5)$$

Where in our study $\lfloor C_{j,projected} \rfloor$ is the mean concentration obtained from the various simulations with altered emissions (e.g. WSR or LSF), and $\lfloor C_{j,current} \rfloor$ is the respective mean concentration obtained from the reference simulation for the episode simulated. Note that the lower the RRF value is the higher is the response to the measure (e.g. “woodstove replacement”, “introduction of low sulfur fuel”).

Table 6 summarizes the RRFs for the grid-cell holding the State Building, i.e. the official monitoring site. The RRFs suggest that point sources contribute slightly to the $PM_{2.5}$ concentration and its composition at the State Building. This finding is not surprising because several point sources are in the immediate vicinity of this site. However, as discussed above, on average over the non-attainment area, the contribution of point sources to the total $PM_{2.5}$ concentration is relatively low. The very low RRF for NH_4 obtained for January results from the

very low NH_4 concentrations in both REF and NPE as compared to the other months. Speciation data did not become available before the end of this project. Therefore, no through analysis and interpretation of simulated vs. observed speciation is included in this report. A first screen of this data, however, supports that simulated NH_4 concentrations are too low (Fig. 34). A detailed analysis of simulated speciation was beyond the scope of our study, but should be done in the future to improve forecasts. Future studies should investigate the role of NH_4 and the emission sources of NH_3 that seem to be missing in the NEI2008 for Fairbanks.

Table 6. Relative response factors for $PM_{2.5}$ and the particulate matter composition as obtained for the scenarios without point source emissions (NPE), with woodstove replacement (WSR) and low sulfur fuel (LSF) at the grid-cell holding the official $PM_{2.5}$ site at the State Building for various periods. EC, ORG and PBW stand for elemental carbon, organic compounds, and particle bound water, respectively. Note that for the NPE scenario investigations were only to be carried out for November through February (cf. Table 1). Note that the baseline (reference) for the response factors of NPE (winter 2005/06) differs from that of WSR and LSF. WSR and LSF both use the same baseline of winter 2008/09.

	$PM_{2.5}$	SO_4	NO_3	NH_4	EC	ORG	PBW
			NPE				
Nov	0.957	0.961	0.858	0.976	0.961	0.961	0.949
Dec	0.964	0.963	0.954	1.019	0.962	0.962	0.971
Jan	0.973	0.978	0.849	0.247	0.977	0.977	0.959
Feb	0.970	0.971	0.954	0.810	0.970	0.970	0.971
Nov-Dec	0.960	0.962	0.901	0.996	0.961	0.961	0.960
Jan-Feb	0.972	0.976	0.865	0.254	0.975	0.975	0.963
Winter 05/06	0.966	0.969	0.892	0.965	0.969	0.969	0.961
			WSR				
Oct	0.958	0.959	0.865	1.003	0.959	0.959	0.954
Nov	0.950	0.952	0.898	1.005	0.951	0.951	0.948
Dec	0.950	0.952	1.001	1.001	0.950	0.951	0.949
Jan	0.953	0.952	0.887	1.075	0.952	0.952	0.951
Feb	0.944	0.940	1.041	0.891	0.939	0.939	0.944
Mar	0.941	0.943	0.855	1.005	0.941	0.941	0.941
Oct-Dec	0.954	0.955	0.880	1.004	0.954	0.954	0.951
Jan-Mar	0.946	0.947	0.935	0.976	0.945	0.945	0.946
Winter 08/09	0.950	0.951	0.897	0.991	0.950	0.950	0.949
			LSF				
Oct	0.975	0.974	1.023	1.016	0.973	0.973	0.976
Nov	0.943	0.944	0.937	0.998	0.943	0.943	0.944
Dec	0.945	0.946	0.925	0.999	0.944	0.944	0.945
Jan	0.966	0.966	0.947	1.074	0.965	0.965	0.965
Feb	0.957	0.955	1.129	0.887	0.955	0.955	0.961
Mar	0.953	0.954	0.926	1.002	0.952	0.952	0.953
Oct-Dec	0.957	0.957	0.970	1.004	0.956	0.956	0.958
Jan-Mar	0.960	0.959	1.006	0.973	0.959	0.959	0.961
Winter 08/09	0.958	0.958	0.981	0.990	0.957	0.957	0.959

The RRFs also indicate that there is not much wiggle room related to point-source emission. Recall that in the real world, point sources cannot be “switched off”. Power plants, for instance, ensure the supply of energy. Thus, if “switching them off” in the model world does not reduce the concentration much – as indicated by the RRFs – introduction of filters to reduce the point-source emissions will not solve the problem either as the point sources still will emit even though at a lower rate.

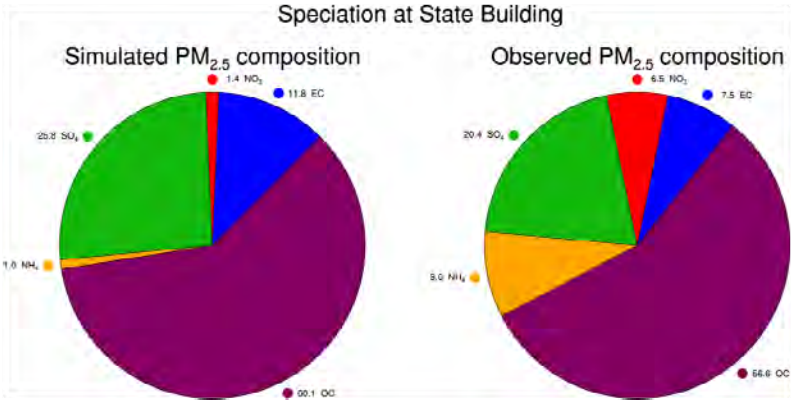

Fig. 34. Comparison of simulated and observed $PM_{2.5}$ components for winter 2005/06. Observed data courtesy of *D. Huff* [2011].

The RRFs for the "low sulfur fuel" and "woodstove replacement" scenarios are of similar magnitude, but on average over the entire winter slightly favor a "woodstove replacement" program. The RRFs to the introduction of low sulfur fuel show a higher variability among months than to the woodstove replacement. This means that for individual months "introduction of low sulfur fuel" may yield a stronger mitigation than "woodstove replacement". However, the latter seems to be the more temporally reliable measure as it more stably provides similar RRFs.

The RRFs of the various compounds of $PM_{2.5}$ indicate shifts in the composition in response to the altered emissions (Table 6). This means that both measures ("woodstove replacement", "introduction of low sulfur fuel" for heating and use in oil burning facilities) strongly affect the atmospheric chemistry and secondary aerosol formation via gas-to-particle conversion. The composition changes differ for the two measures. The "woodstove replacement" yields a shift towards more NH_4 and less NO_3 aerosols in most months. The composition shifts in response to "introduction of low sulfur fuel" vary more strongly among months than in response to "woodstove replacement".

To calculate the future design values we multiplied the observed design value with the RRFs obtained for the various measures tested. The resulting new design values are listed in Table 7.

Table 7. Calculated $PM_{2.5}$ "design values" ($\mu g/m^3$) in response to the tested measures for the grid-cell holding the State Building for various periods. Here "winter" refers to November 2005 to February 2006 for the NPE scenario and October 2008 to March 2009 for the "woodstove replacement" and "low sulfur fuel" scenarios.

	No point source emissions	small woodstove replacement program	introduction of low sulfur fuel
Oct	-.-	42.6	43.4
Nov	42.6	42.3	42.0
Dec	42.9	42.3	42.1
Jan	43.3	42.4	43.0
Feb	43.2	42.0	42.6
Mar	-.-	41.9	42.4
Oct-Dec	-.-	42.5	42.6
Jan-Mar	-.-	42.1	42.7
Nov-Dec	42.7	-.-	42.6
Jan-Feb	43.3	-.-	43.4
Winter	43.0	42.3	42.0

The introduction of low sulfur fuel results in a slightly lower new design value than the small "woodstove replacement program" assumed in WSR. The results also showed that such a small "woodstove replacement program" reduces the design value already by 2.2μg/m^3. The sensitivity studies performed on "woodstove replacement" suggested that a more rigorous replacement (WSS1) than assumed in WSR may yield much higher mitigation. Since the introduction of low sulfur fuel is very expensive, since a further reduction of sulfur content costs even more, and since the RRF and resulting new design values vary strongly among months when introducing low sulfur fuel, it seems that a rigorous replacement of non-certified wood-burning devices is the more promising way to achieve compliance.

Comparison of Figs. 25, 26, and 32 suggests that both "woodstove replacement" as well as "introduction of low sulfur fuel" reduce the concentrations in the nonattainment area. However, while hot spots remain in the same areas in the case of a "woodstove replacement" for all months, this is not the case when introducing low sulfur fuel.

7. Conclusions

We performed simulations for November 2005 to February 2006 with and without consideration of point-source emissions (Table 1) using the Alaska-adapted WRF/Chem[12] to assess the contribution of point-source emissions on the $PM_{2.5}$-concentrations at breathing level. The emission data for the reference simulation (business-as-usual) based on the NEI2005. The simulation without consideration of point-source emissions was run with the same meteorological input data and same emission data except that all point-source emissions were set to zero (NPE). Based on the comparison of the results of these simulations, we conclude that point sources are not the major cause for Fairbanks' wintertime $PM_{2.5}$-pollution problem. This conclusion is also supported by the results of the other mitigation scenarios. Eliminating the point-source emissions – as it is practically done in the NPE simulation – only led to marginal decreases in $PM_{2.5}$ concentrations at breathing level and only five avoidances of exceedances at locations in the nonattainment area. The highest $PM_{2.5}$-concentrations obtained in REF and NPE only differ 1.3μg/m^3 on average. The locations where simulated $PM_{2.5}$ exceeds the NAAQS occur in the nonattainment area. According to the results of REF and NPE, PS6[13] is the point source that often contributes to exceedances in the nonattainment area. However, in these cases concentrations without that point source were already high. Note that this point source has the highest emission rate. Emissions from point sources located in the nonattainment area may influence the $PM_{2.5}$-concentration at breathing level within 10km or so from the point-source-holding air column. This phenomenon is a combined effect of extreme atmospheric stable condition, weak circulation, and for some point sources the low-level in which they emit. These meteorological conditions altogether inhibit transport of the pollutants out of the area. It would be worth examining how increases in stack height and emission temperature (which also would lead to emissions into higher levels) would affect the point-sources' radius of impact and the $PM_{2.5}$ concentrations at breathing level.

Based on or simulations with and without consideration of point-source emissions we conclude that when "switching off" of the point sources does not solve the problem, reducing point-source emissions by new techniques will not solve the problem either as the point sources still emit even though at a lower rate. For days that are close to the NAAQS, just a marginal increase in area emission would lead to an exceedance.

Some of the $PM_{2.5}$ in the air is formed in the air from gases that transform to particles via physico-chemical processes called gas-to-particle conversion. Since gas-to-particle conversion non-linearly depends on temperature and vapor pressure of species and introducing measures to further clean the exhausts of point sources alters the composition of the point-source emission plumes, it may be worth examining whether in combination with other measures such additional filtering may nevertheless be beneficial.

In addition to the investigation on the impact of point sources on $PM_{2.5}$-concentrations in the nonattainment area, we performed a suit of simulations for October 2008 to March 2009 with the Alaska optimized WRF/Chem (Table 1). This suit of simulations assumed the same meteorological initial input data and boundary conditions. The reference simulation (REF) used the NEI2008 updated with point-source emissions (for details see section on emissions). Two scenarios were run. One scenario assumed a replacement program for non-certified wood-

[12] Note that WRF/Chem is a complex state-of-the-art research model, not a regulatory model.
[13] Privacy law forbids naming facilities.

burning devices. With the assumptions made on how households with several heating devices partition heating among devices and the burning behavior and number of non-certified burning devices replaced, the $PM_{2.5}$ emissions from heating were reduced by 4% on average over the nonattainment area over the six months (WSR). Two sensitivity studies were performed assuming different numbers of non-certified wood-burning devices that could be replaced (WSS1, WSS2). In addition, sensitivity analysis was made how emissions change with the assumptions on the burning behavior (partitioning among devices, time of burning). The second scenario mitigation for winter 2008/09 assumed the use of low sulfur fuel for domestic combustion, oil-burning point-source facilities and that part of power generation that used oil-fuel in accord with the 2008 allowances for fuel-sulfur content (LSF).

The LSF and WSR mitigation studies (like the study on the contribution of point-source emissions on the $PM_{2.5}$-concentrations at breathing level) suggest that emissions from area sources (e.g. domestic heating) and/or traffic are the main contributors to the $PM_{2.5}$ NAAQS exceedances occurring in the nonattainment area.

The "woodstove replacement" simulations indicate that a program for replacement of wood-burning devices can reduce the $PM_{2.5}$-concentrations at breathing level in the Fairbanks $PM_{2.5}$-nonattainment area. The study suggests that the highest mitigation of $PM_{2.5}$-concentrations with a "woodstove replacement" can be achieved in the months that are coldest. The sensitivity studies suggest that the reduction effectiveness depends on the number of wood-burning devices exchanged and on what kinds of devices are replaced (see results of WSR, WSS1, WSS2). The average emission reduction in the heating sector calculated for October 1 to October 15, 2008 amounts 40%, 7% and 6% on average over the nonattainment area under the assumption made for the "woodstove replacement" in WSS1, WSS2, and WSR, respectively. Note that we are here talking about the emission reduction of primary $PM_{2.5}$, not the emission reductions for other species (e.g. SO_2, NO_x, VOC) that go along with a "woodstove replacement".

Unfortunately, no data are available, where and what wood-burning devices are operated and when and how intensively. In our study, we simply assumed the distribution of wood-burning devices as being proportional to the population density. This assumption holds uncertainty in the spatial distribution that may affect local maximum concentrations as well as 24h-averages of $PM_{2.5}$-concentrations according to sensitivity studies. Further uncertainty is due to the unknown number of wood-burning devices that exist and that can be replaced. Sensitivity studies on the emissions indicated that uncertainty results from the unknown partitioning of the use of wood-burning and other heating devices in households with more than one heating option. Despite these uncertainties, all simulation studies on "woodstove replacement" show in common a mitigation of $PM_{2.5}$-concentrations on average at breathing level. Note that the simulations on "woodstove replacement" do not consider that additional wood-burning devices may have been added since 2008 or might be added in the future.

Based on the studies performed on the replacement of wood-burning devices we can conclude that exchanging noncertified wood-burning devices can help to reduce the number of exceedance days during October to March. The full benefit of exceedance reduction due to the "woodstove replacement" may be underestimated by WSR because the number of woodstoves exchanged may be on the lower end of the number of woodstoves that actually could/will be exchanged. Nevertheless, the concentration offsets between the baseline simulation REF and the "future" simulation WSR (Table 6, Figs. 25, 26) imply that replacement of non-certified wood-burning devices alone when only preformed in low numbers will not be sufficient to avoid all $PM_{2.5}$

exceedances. If emissions of area and point sources only slightly increase due to increasing of traffic, population, etc. the benefit due to the "woodstove replacement" will be set off quickly. This means a high number of non-certified wood-burning devices has to be replaced.

We further conclude that there is an urgent need to collect data on the location and kind of wood-burning devices used in the nonattainment area and to obtain additional information on how households with wood-burning devices and another heating device partition their heating among these heat sources. Information is also needed on the diurnal burning behavior on weekdays, weekends and holidays. Since emissions also depend on the dryness of the wood, data on the fraction of seasoned and non-seasoned wood typically burned will be helpful in better assessing the contribution from wood-burning devices to the $PM_{2.5}$-concentrations at breathing level. Furthermore, it would be good to know how accurate data from surveys may be if people fear, their information could later lead to measures that may be of disadvantage to them. This means it has to be examined whether we do obtain the correct information in surveys.

Our study suggests that the introduction of low sulfur fuel can reduce the number of exceedance days. The simulations suggest that introduction of low sulfur fuel as assumed in LSF leads occasionally to higher reductions than achieved by the "woodstove replacement" (WSR) assumed in this study. However, the results also suggest that up to 20% of the days in months with relatively long daylight hours (October, February, March) may experience increases in $PM_{2.5}$-concentrations at breathing level in response to introduction of low sulfur fuel due to gas-to-particle conversion. This increase is related to shifts in the thermodynamic equilibrium of sulfate-nitrate-ammonia-water in aerosol during months with still or already again enough daylight. The highest temporal and local differences in simulated $PM_{2.5}$ concentrations in response to introducing low sulfur fuel typically occurred in November whereas the lowest differences occurred in March. The reason is that October had high and February, March small increases in $PM_{2.5}$-concentrations after introducing low sulfur, while there were no increases in November.

The results of the simulation on the introduction of low sulfur fuel also suggest that in the case of measures aiming at mitigation indirectly by reduction of precursors it is important to simulate an entire winter emission season. Otherwise one could by accident just be lucky to have chosen a period where reduction occurs and oversee that there may be cases where despite reduced emissions of precursors the concentrations go up. Moreover, only in the case of the statistics over the entire winter it is possible to judge whether, on average, mitigation can be reached. Our study also suggests that care has to be taken in the judgment of the representativeness of the winter examined.

The simulation results showed that "introduction of low sulfur fuel" (LSF) results in a slightly lower new design value than the small "woodstove replacement program" assumed in WSR. The results also showed that a small "woodstove replacement program" such as assumed in WSR already reduces the design value by $2.2 \mu g/m^3$. The sensitivity studies performed on "woodstove replacement" (WSS1, WSS2) suggested that a more rigorous replacement of wood-burning devices (WSS1) may yield much higher mitigation than the small exchange program assumed in WSR. Since the introduction of low sulfur fuel is very expensive and further reduction costs even more, and since the relative response factors and new design values vary strongly among months when introducing low sulfur fuel, it seems that a rigorous replacement of non-certified wood-burning devices is much more promising to achieve compliance.

The results of all the simulations performed for this study suggest that a single pollution-control policy may not be sufficient to help comply with the 24h-average $PM_{2.5}$ NAAQS. Due to the high nonlinearity of chemical processes, we cannot assume that a combined "woodstove replacement" and "low sulfur fuel" program will lead to the goal. An additional study considering both measures would be required because precursors for gas-to-particle conversion are changed by both measures and interaction among the impacts of the two measures may yield to diminution or enhancement of wanted or even unwanted effects. Since changes in emissions of precursors lead to changes in gas-to-particle conversion, combinations of different control methods (i.e. "woodstove replacement" and concurrent "low sulfur fuel" programs) and other mitigation strategies (i.e. replacement of oil furnaces by gas, replacement of oil furnaces and wood-burning devices by gas) should be investigated. Future studies should also examine the impact of introducing other energy sources and/or expansion the use of gas for heating and energy generation.

The results of our study also show a stronger percentage mitigation of $PM_{2.5}$-concentrations on average over the entire nonattainment area than at the grid cell holding the State Building. In the future, it should be examined whether observations also show differences in changes of air quality at various sites in the nonattainment area. If so, local sources may play a role and they should be identified.

Unfortunately, the speciation data did not become available during the time of the project. Thus, an evaluation of the simulated composition of $PM_{2.5}$ is still pending, but planned for the future. Such an evaluation of simulated speciation is an urgent need to assess the role of ammonia. Based on speciation data of prior years and a first screen of the data that became available after the end of the project (Fig. 34), various scientists are concerned that the NEI2008 may underestimate the NH_4 emissions in the FNSB.

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Fairbanks North Star Borough $PM_{2.5}$ Non-Attainment Area CMAQ Modeling

Final Report Phase II

Reporting Period: January 1, 2012 – December 31, 2012

Project: 398831 CMAQ-DEC 2012

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1. Background

The Community Multiscale Air Quality (CMAQ) model version 4.7.1 was adapted to simulate the $PM_{2.5}$-concentrations in Fairbanks, Interior Alaska in phase I [*Mölders and Leelasakultum*, 2011]. The adapted CMAQ was applied to a two-week episode in January/February, 2008 and November, 2008 each for investigations on and understanding of the $PM_{2.5}$-situation in the Fairbanks nonattainment area.

According to the final report of phase I [*Mölders and Leelasakultum*, 2011], the CMAQ model was configured to use the global mass-conserving Yamartino advection scheme, the eddy vertical diffusion module, the Carbon Bond Five (CB05) lumped gas phase chemistry mechanism, which uses the Euler Backward Iterative (EBI) as solver, the AERO5 aerosol mechanism, the photolysis inline module, and the Asymmetric Convective Method (ACM) cloud processor to compute convective mixing (cloud_acm_ae5). As described in the final report of phase I, we had made several changes to the CMAQ code to improve the prediction of $PM_{2.5}$-concentrations and to represent the conditions in the Fairbanks domain. Those changes were the development of Alaska specific initial and boundary conditions, modification of the dry deposition code, reducing of the minimum mixing height, replacing the minimal stomata resistances, decreasing the lowest and highest eddy diffusivity coefficients by half and scaling them according to the fraction of land-use, and reducing the wind-speed by half in valleys within the domain. The latter step has been abandoned in the further studies. This step was only done only for investigation of the magnitude of the impact of the overestimated wind-speeds obtained from the Alaska adapted WRF (see *Gaudet and Stauf*er [2012] for details on this WRF version). This means all results reported in the current report use the original simulated wind-speed as obtained from WRF.

Based on the CMAQ's output in phase I, Sierra Research Inc. had improved the emission input data generated by using the Sparse Matrix Operator Kernel Emission (SMOKE). Penn State [*Gaudet and Stauf*er, 2012] had updated the meteorological input data generated for the Alaska adapted CMAQ model (called adapted CMAQ hereafter) by using the Weather Research and Forecasting (WRF; *Skamarock et al*. [2009]) in its version adapted for Fairbanks by *Gaudet and Stauf*er [2011]. Hereafter, we refer to the January/February episode data before and after the update as January v1 and January v2, respectively. Without the reducing wind-speed in the valleys by half, the new version of the emission inventory data and the meteorological input data brought an increase in the simulated $PM_{2.5}$-concentrations at the grid-cell holding the State Office Building site. Here CMAQ underestimated the $PM_{2.5}$-concentrations previously. Therefore, the reduction of the wind-speeds in the valleys by half is not required for the January v2 and November episode.

2. Activities

Building upon the Alaska adapted CMAQ described in the final report of phase I and the results of phase I, we incorporated the final Penn State WRF output files and the first complete emissions inventory from SMOKE which accounts for Fairbanks specific temporal and spatial variations that we obtained from Sierra Research Inc.. We prepared an assessment of the CMAQ performance, which includes using metrics established by *Boylan and Russell* [2006] and running CMAQ Process Analysis (PA). In the following sections, we describe and assess the results of these activities.

2.1 Configuration of CMAQ for the November 2008 Episode

The November episode covers November 2 to November 16, 2008. The emissions developed for the November episode were updated by Sierra Research Inc. for the emissions from mobile sources. They also included the emissions from airports. The temporal evolutions of 24h-average of simulated $PM_{2.5}$-concentrations show that the model overestimates the 24h-average $PM_{2.5}$-concentrations at the State Office Building site at the beginning of the episode (November 2-4); the adapted model failed to capture the peaks on November 6, 9 and 16, and shows a nonexistent temporal minimum on November 7 (Fig. 1).

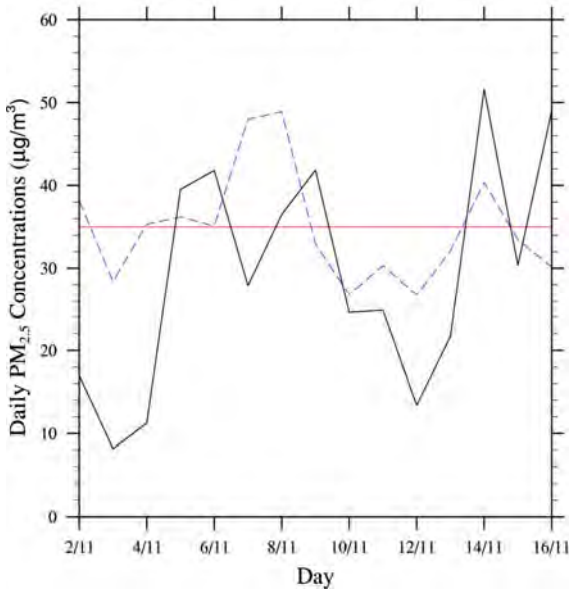


Fig. 1 Time series of simulated (blue dashed line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations as obtained with the adapted CMAQ simulation that used the revised WRF and SMOKE input for the November episode at the State Office Building site.

The 24h-average $PM_{2.5}$-concentrations obtained from the adapted CMAQ simulations with the observations have a correlation coefficient of 0.31. The scatter between simulated and observed 24h-average $PM_{2.5}$-concentrations is shown in Figure 2. We also found that allowing for a time lag of one between the simulation results and the observations increases the correlation

coefficient from 0.31 to 0.37. According to the observations, there are nine days in the November episode that have $PM_{2.5}$-concentrations below the National Ambient Air Quality Standard (NAAQS) of 35 µg/m^3, and there are six days with $PM_{2.5}$-concentrations above the NAAQS. For most of the days of the episode, the simulated and observed 24h-average $PM_{2.5}$-concentrations agree well; there are two days with false alarm, two days of missed events and three pairs of data outside the factor of two agreement (Fig. 2).

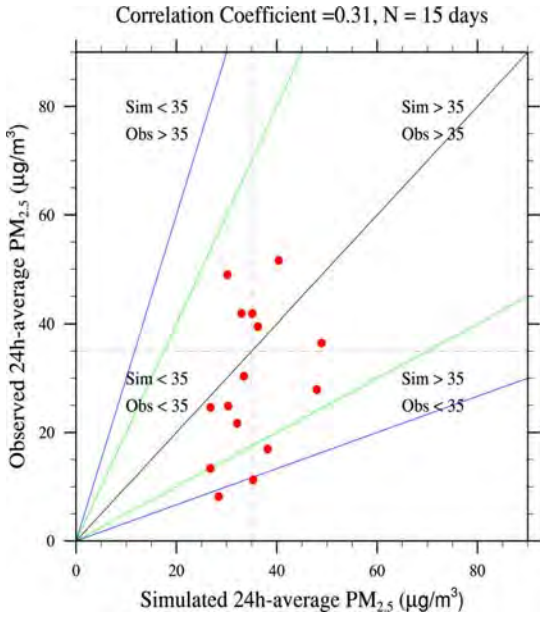
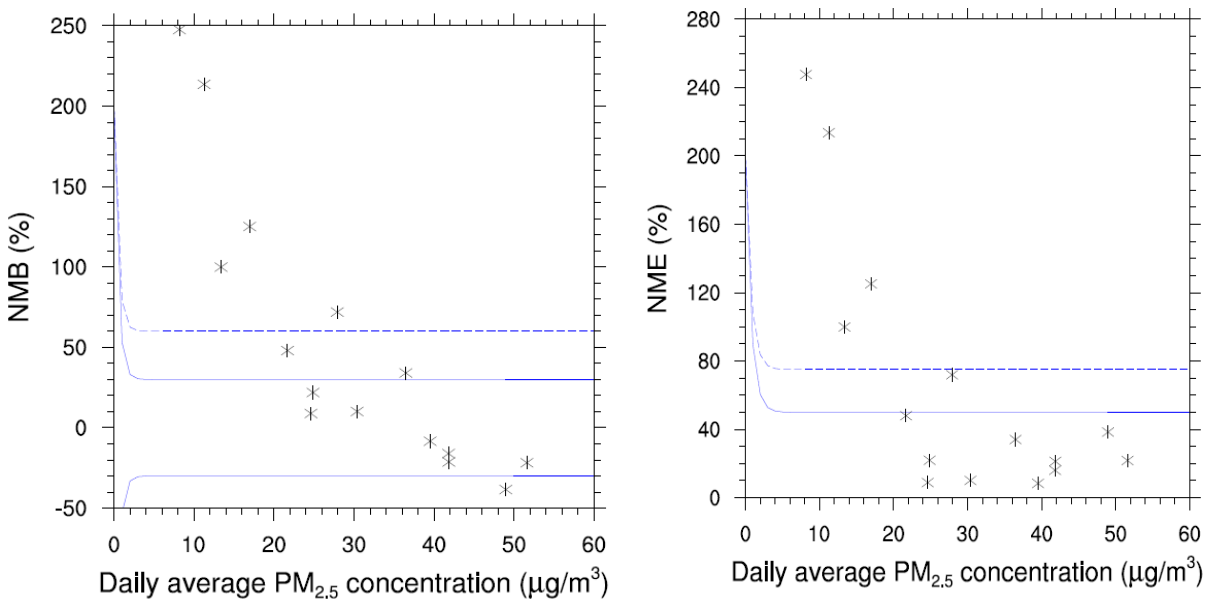


Fig.2 Scatter plot of 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulation that used the revised WRF and SMOKE input for the November episode and the observations at the State Office Building site. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

The bugle plots and soccer plots show that the adapted CMAQ simulation has five days outside the performance criteria (Fig. 3, a-c). Three of five days are the days in the beginning of the episode, which are probably due to spin-up effects in the CMAQ model itself. Moreover, all of those five days have very low (below NAAQS) 24h-average $PM_{2.5}$-concentrations.

(a) (b)



(c)

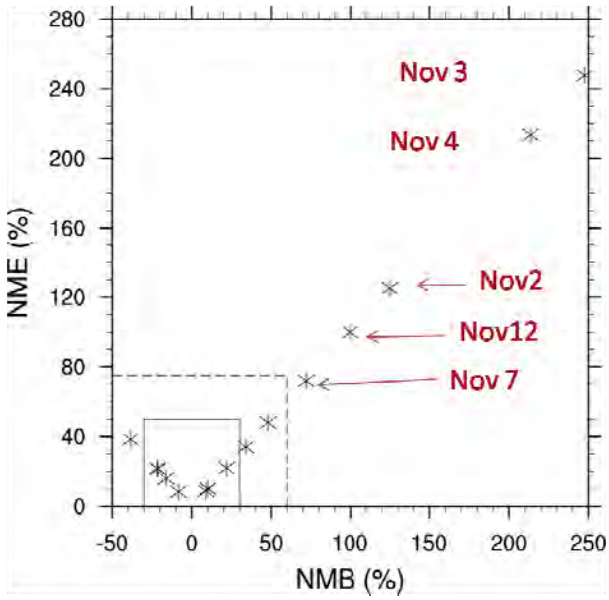


Fig. 3 Bugle plots of (a) normalized mean biases, (b) normalized mean errors, and soccer plots of (c) normalized mean errors and biases of simulated 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulations that used the revised WRF and SMOKE input for the November episode at the State Office Building site.

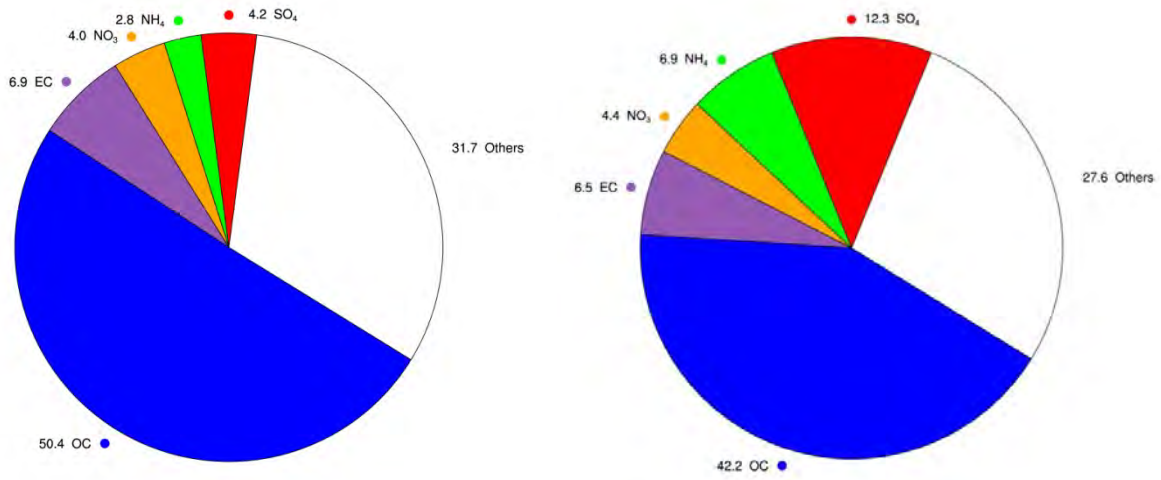


Fig. 4 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by the CMAQ with modifications on average over the November episode (left), and as observed on average over the 3 days, for which data was available during that episode, at the State Office Building site. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j), Na and Cl.

Comparing the simulated and observed composition of 24h-average $PM_{2.5}$ aerosol showed that the adapted CMAQ overestimated the percentage of organic carbon, but underestimated the percentage of sulfate and ammonium (Fig. 4).

Data of observed $PM_{2.5}$-composition data are available on a 1-in-3 day basis. The 24h-average $PM_{2.5}$-composition as simulated by the Alaska adapted CMAQ for the November episode were compared for each day that had observations (Fig. 5). On November 8 and 14 (with respect to Alaska Standard Time; AST), which have observed $PM_{2.5}$-composition data, there are small contributions from transport from outside the domain into the area [*Mölders and Leelasakultum*, 2012]. Note that typically advection from outside Alaska does not increase $PM_{2.5}$-concentrations by more than 2 $\mu g/m^3$ [e.g. *Cahill*, 2003; *Tran* et al., 2011; *Mölders* et al., 2012]. For details, see discussion later in this report. The simulations are not able to capture the peak on November 14 well.

Simulated sulfate and ammonium are underestimated on all three days (Fig. 5). Sodium and chloride are both underestimated. A possible reason for the underestimation of sodium (Na) and chloride (Cl) is that no sea-salt is emitted into the domain as there is no ocean and that some sodium and chlorine might be advected during the episode. However, this shortcoming has no big impact on the concentrations of total $PM_{2.5}$ as Na and Cl make up only a small amount of $PM_{2.5}$-composition (<1%). Simulated organic, nitrate and elemental carbon are almost in the same order of magnitude as observed.

We also conducted a process analysis. Process analysis is a technique that provides information about the impacts of individual processes on the change in a species' concentration. In the following, we refer to horizontal transport as the sum of horizontal advection and diffusion, and to vertical transport as the sum of vertical advection and diffusion. In our discussion, the term aerosol processes represents the net effects of aerosol thermodynamics, new particle formation, condensation of sulfuric acid and organic carbon on preexisting particles, and the coagulation within and between the Aitken and accumulation modes of particulate matter. Cloud processes represent the net effects of cloud attenuation of photolytic rates, aqueous-phase chemistry, below-and in-cloud mixing with chemical species, cloud scavenging and wet deposition [*Liu et al.*, 2010].

According to the process analysis, emissions were the dominant contributor to the $PM_{2.5}$ and SO_4 concentrations, and the horizontal transport contributed to and removed $PM_{2.5}$ and SO_4 at the grid-cell holding the State Office Building site (Fig. 6a-b). The aerosol processes played a small role here. This means $PM_{2.5}$ is mainly composed of primary PM and SO_4 at this site. $PM_{2.5}$ and SO_4 were mainly vented out through vertical transport. Dry deposition played a small role in the removal of $PM_{2.5}$ and cloud process did not play any role here. Note that cloud processes are irrelevant when there are not clouds as these processes then do not occur.

Different from the findings for sulfate, the aerosol processes played the main role for nitrate formation. At the grid-cell holding the State Office Building site, horizontal transport contributed strongly to nitrate. Note that the nitrate concentrations also show an offset like found for $PM_{2.5}$ (see discussion above). The major removal process was vertical transport, i.e. vertical mixing. Note that various studies performed with WRF for Alaska indicated that WRF has difficulties to simulate the strength of inversions with temperature gradients greater than 8K/100m and that WRF tends to overestimate vertical mixing [e.g. *Mölders et al.,* 2011, 2012, *Tran*, 2012]. An overestimation of the vertical transport of pollutants may lead to diluted concentrations and underestimation of the concentrations as particles are too quickly removed from the breathing level. The process analysis also revealed that dry deposition caused a small loss to nitrate. Cloud processes neither produced nor removed nitrate in this grid-cell (Fig. 6c).

For ammonium, the aerosol processes are the dominant contributor at the grid-cell of the State Office Building site. Horizontal transport contributed to ammonium on some days. The major removal process was vertical transport, and dry deposition caused only a small loss to ammonium. Cloud processes did not play a role here similar to what was found for both sulfate and nitrate (Fig. 6d).

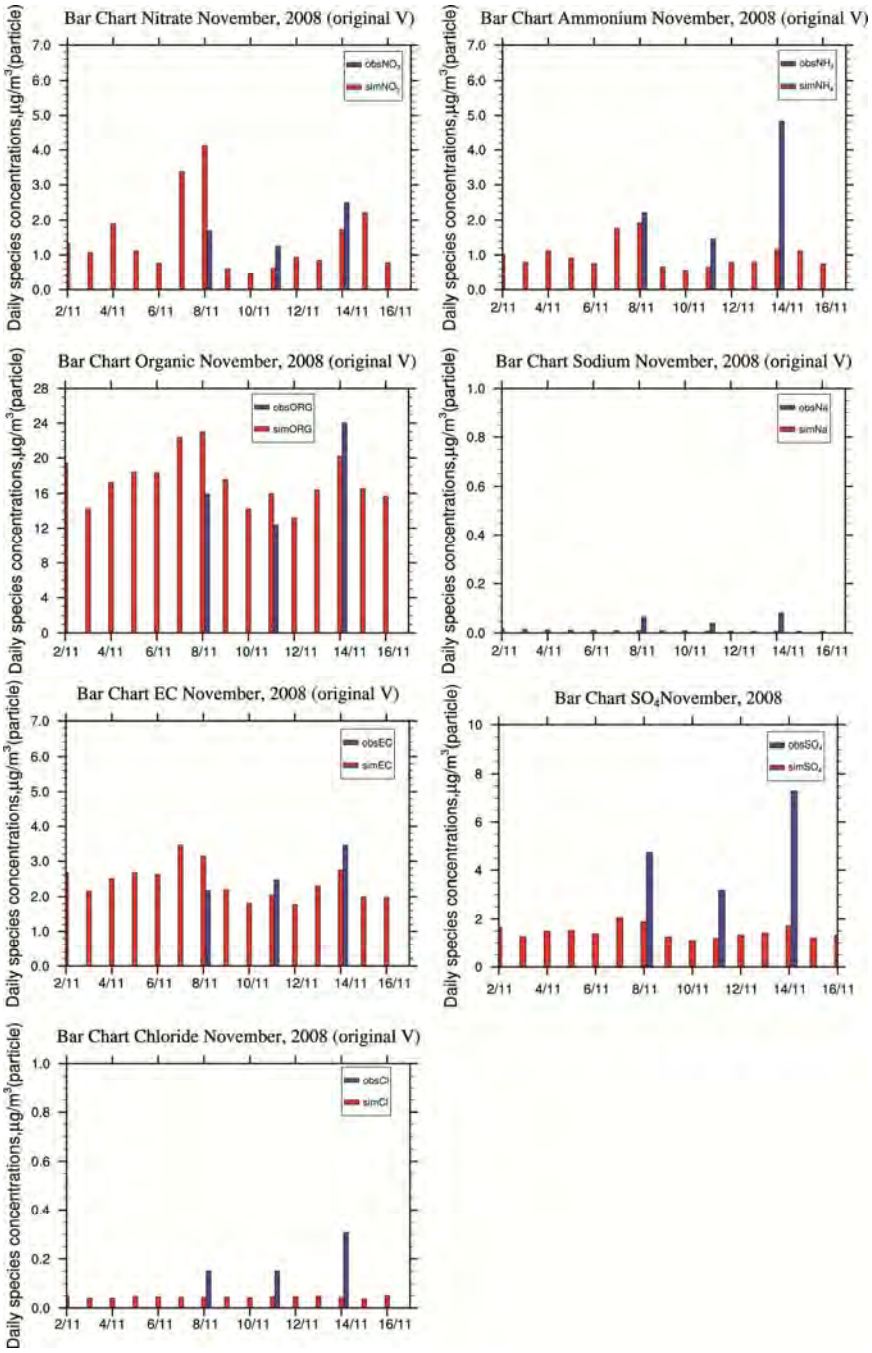


Fig. 5 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained for the November episode at the State Office Building site.

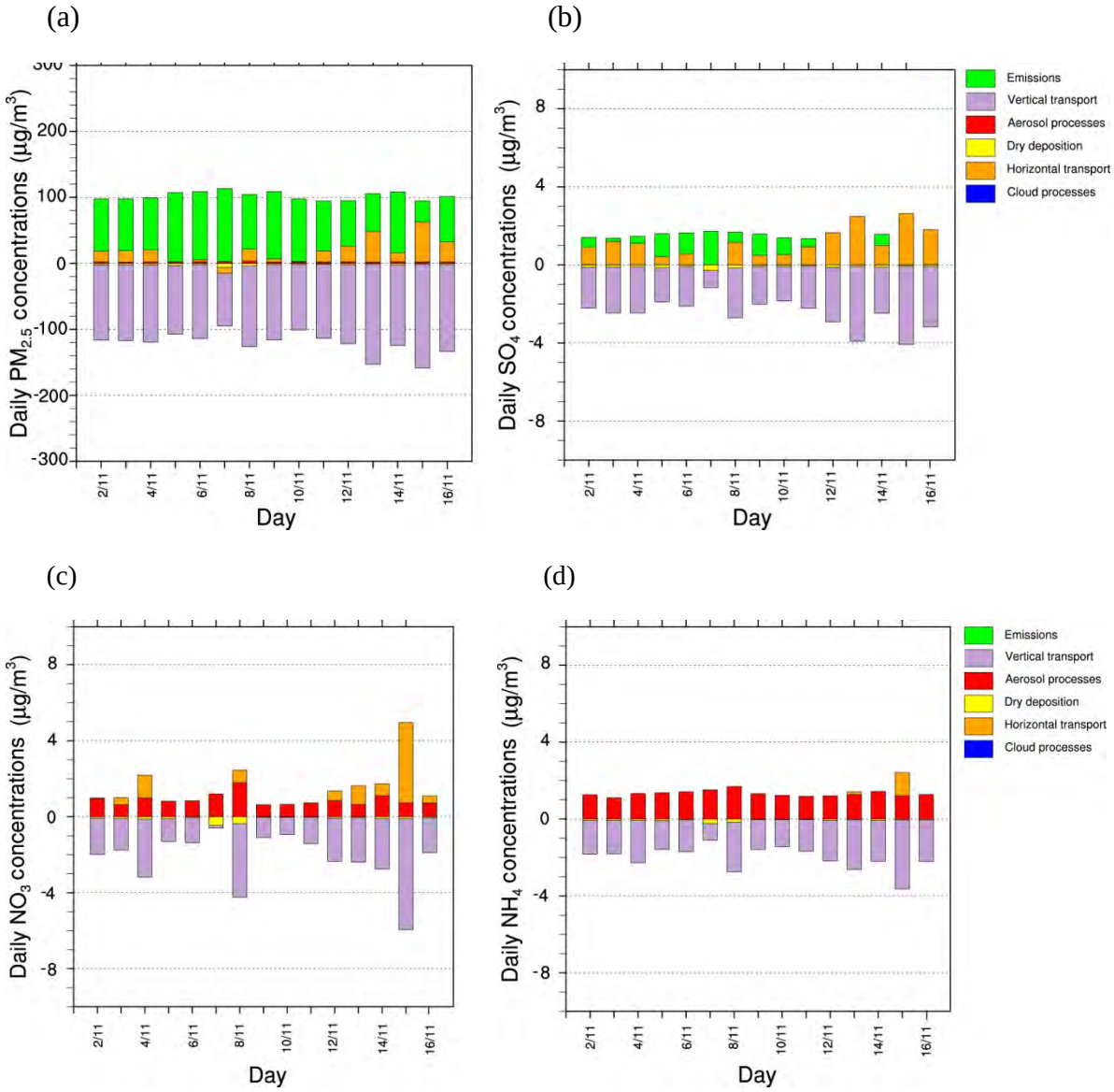


Fig. 6 Daily mean hourly contributions of individual processes to the (a) $PM_{2.5}$-concentrations, (b) SO_4-concentrations, (c) NO_3-concentrations and (d) NH_4-concentrations as obtained from the process analysis at the State Office Building site for the November episode. Simulations were performed using the revised WRF and SMOKE input.

2.2 Configuration of CMAQ for the January/February 2008 Episode (January v2)

The January episode covers January 23 to February 9, 2008. The temporal evolutions of 24h-average simulated $PM_{2.5}$-concentrations show that the model mostly overestimates the 24h-average $PM_{2.5}$-concentrations at the State Office Building site; the model fails to capture the peak on February 8 (Fig. 7). The model predicts a non-existing temporal minimum on February 2 (Fig. 7). The CMAQ model seems to be ahead in predicting 24h-average $PM_{2.5}$-concentrations by about 24 hours.

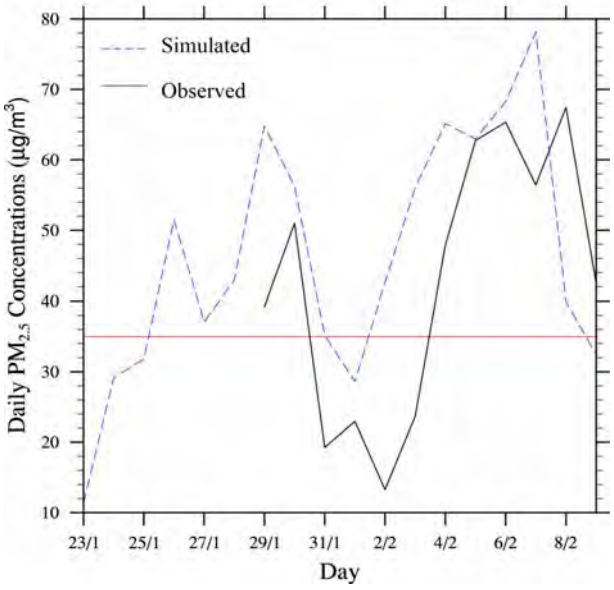


Fig. 7 Timeseries of simulated (blue dashed line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations at the State Office Building site as obtained from the adapted CMAQ simulation that used the revised WRF and SMOKE input for the January episode.

The 24h-average $PM_{2.5}$-concentrations obtained from the adapted CMAQ simulations correlate with the observations with a correlation coefficient of 0.52. Figure 7 shows the scatter of the simulated and observed values. To examine the reasons for the relatively low correlation we examined the timeseries. The temporal evolutions of simulated and observed hourly and 24h-average $PM_{2.5}$-concentrations suggested an offset. To quantify the offset we calculated the correlation with various time lags. We found that allowing for a time lag for one day increases the correlation coefficient from 0.52 to 0.84 [*Mölders and Leelasakultum*, 2012]. Allowing a 24h-time lag can increase the correlation coefficients of the hourly average $PM_{2.5}$-concentrations at the State Office Building site from 0.23 to 0.50, and the correlation increases even more to 0.59 when we allow a time lag of 26 hours. This means that some of the low correlation is caused by a temporal offset between simulated and observed 24h-average $PM_{2.5}$-concentrations.

It also means that if this shift in timing would not exist, the adapted CMAQ would perform better.

According to the observations, there are four days in the January episode that have $PM_{2.5}$-concentrations below the NAAQS, and there are eight days with $PM_{2.5}$-concentrations above this standard. On most of the days of the January episode, the simulated and the observed 24h-average $PM_{2.5}$-concentrations agree well; there are two days with false alarm, one day of a missed event, and two pairs of data outside the factor of two agreement (Fig. 8).

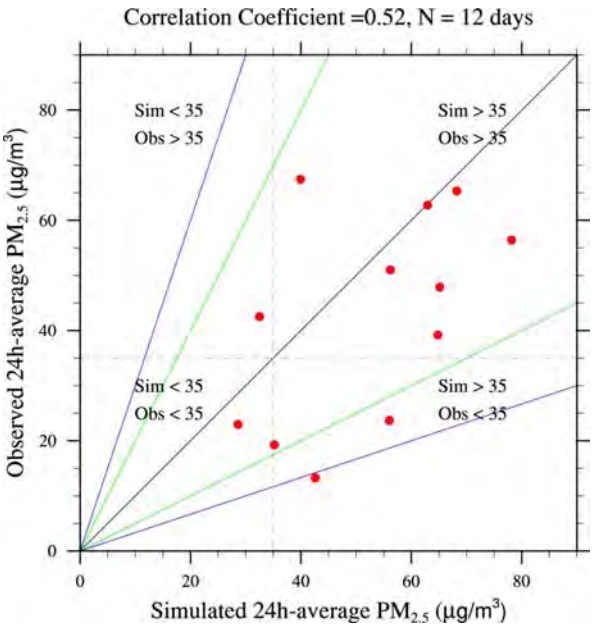
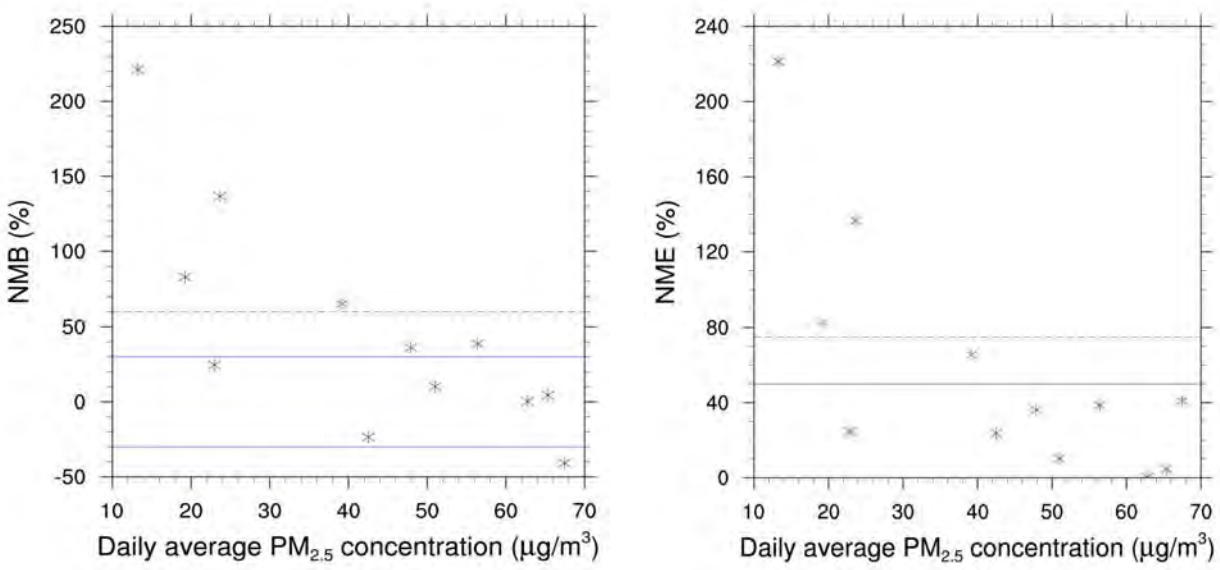


Fig.8 Scatter plots of 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulation that used the revised WRF and SMOKE input during the January episode at the State Office Building site. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

(a) (b)



(c)

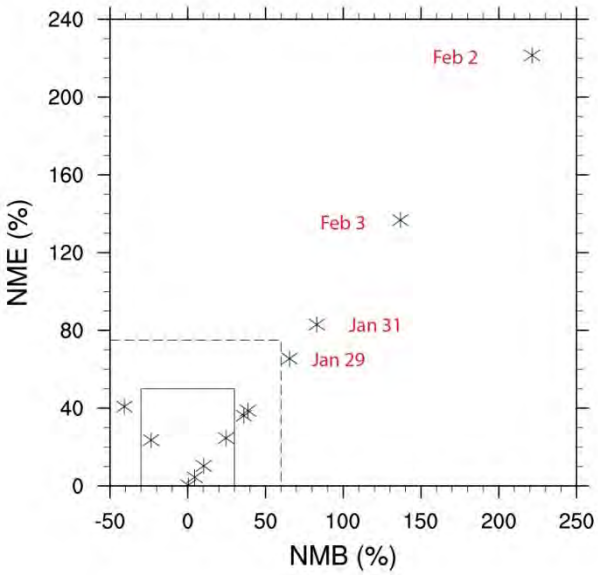


Fig. 9 Bugle plots of (a) normalized mean biases (NMB), and (b) normalized mean errors (NME) and soccer plot of normalized mean errors and biases of 24h-average $PM_{2.5}$-concentrations at the State Office Building site as obtained from the adapted CMAQ simulations that used the revised WRF and SMOKE input for the January episode.

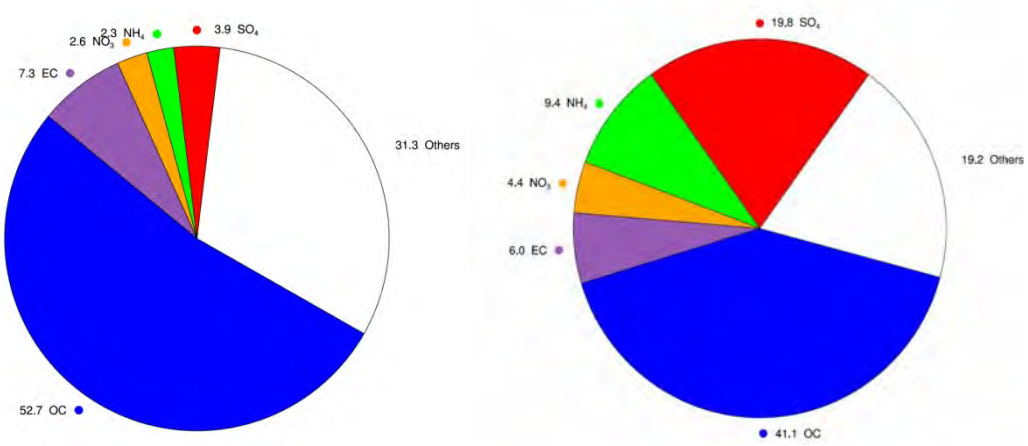


Fig. 10 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by CMAQ with the modifications on average over the January episode (left), and as observed on average over the six days, for which data was available at the State Office Building site. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j), Na and Cl.

The bugle plots and soccer plots show that on four days the adapted CMAQ simulation provides results outside the performance criteria (Fig. 3, a-c). Three of these four days are days, on which the 24h-average $PM_{2.5}$-concentrations are below the NAAQS. Therefore, we conclude that the adapted CMAQ model has difficulties to capture extremely low $PM_{2.5}$-concentrations well. Note that it is harder to predict very low than high concentrations correctly. Thus, this behavior is typical in air-quality modeling [e.g. *Boylan and Russell*, 2006].

Comparison of the simulated and observed composition of 24h-average $PM_{2.5}$ aerosol showed that the adapted CMAQ overestimated the percentage of organic carbon, but underestimated the percentage of sulfate, ammonium, nitrate and elemental carbon at the State Office Building site for the January episode (Fig. 10).

The 24h-average $PM_{2.5}$-composition as simulated by the Alaska adapted CMAQ for the January episode was compared for each day that had observed data (Fig. 11). During February 5-10, there was higher sulfur content, and on February 6 and 9 (AST), there were small contributions from long-range transport [*Mölders and Leelasakultum*, 2012]. Simulated sulfate (SO_4) and Ammonium (NH_4) are underestimated on all six days (Fig. 11). Sodium and chloride are both underestimated (see earlier discussion for reasons). Simulated organic, nitrate (NO_3) and elemental carbon (EC) concentrations are almost of the same order of magnitude as the observations and well follow the temporal evolution of the observations.

Similar to the findings of the November episode, in the January episode, emissions were the dominant contributor to the $PM_{2.5}$- and SO_4-concentrations at the grid-cell holding the State

Office Building (Fig. 12a-b). Horizontal transport contributed to and removed $PM_{2.5}$ and SO_4 at this site. The aerosol processes played a small role here. This fact indicates that $PM_{2.5}$ is composed mainly of primary PM and SO_4 at this site. $PM_{2.5}$ and SO_4 were mainly vented out through vertical transport. Dry deposition played a small role in the removal of $PM_{2.5}$ and cloud process did not play any role here. Note that if there are no clouds cloud processes cannot contribute to/affect the concentrations.

Like for the November episode, the findings obtained for nitrate differed from those for sulfate. The aerosol processes played the main role for nitrate formation. High contributions of nitrate also came from horizontal transport, i.e. neighbored grid-cells, but could not capture the conditions on February 9. The major removal process was vertical transport, and dry deposition caused a small loss to nitrate. Cloud processes neither produced nor removed nitrate in this grid-cell (Fig. 12c).

For ammonium, the aerosol processes are the dominant contributor at this site. Horizontal transport form neighbored grid-cells contributed to the ammonium concentrations on some days. The major removal process was vertical transport, and dry deposition caused only a small loss to ammonium. Cloud processes did not play a role here similar to what was found for both sulfate and nitrate (Fig. 12d).

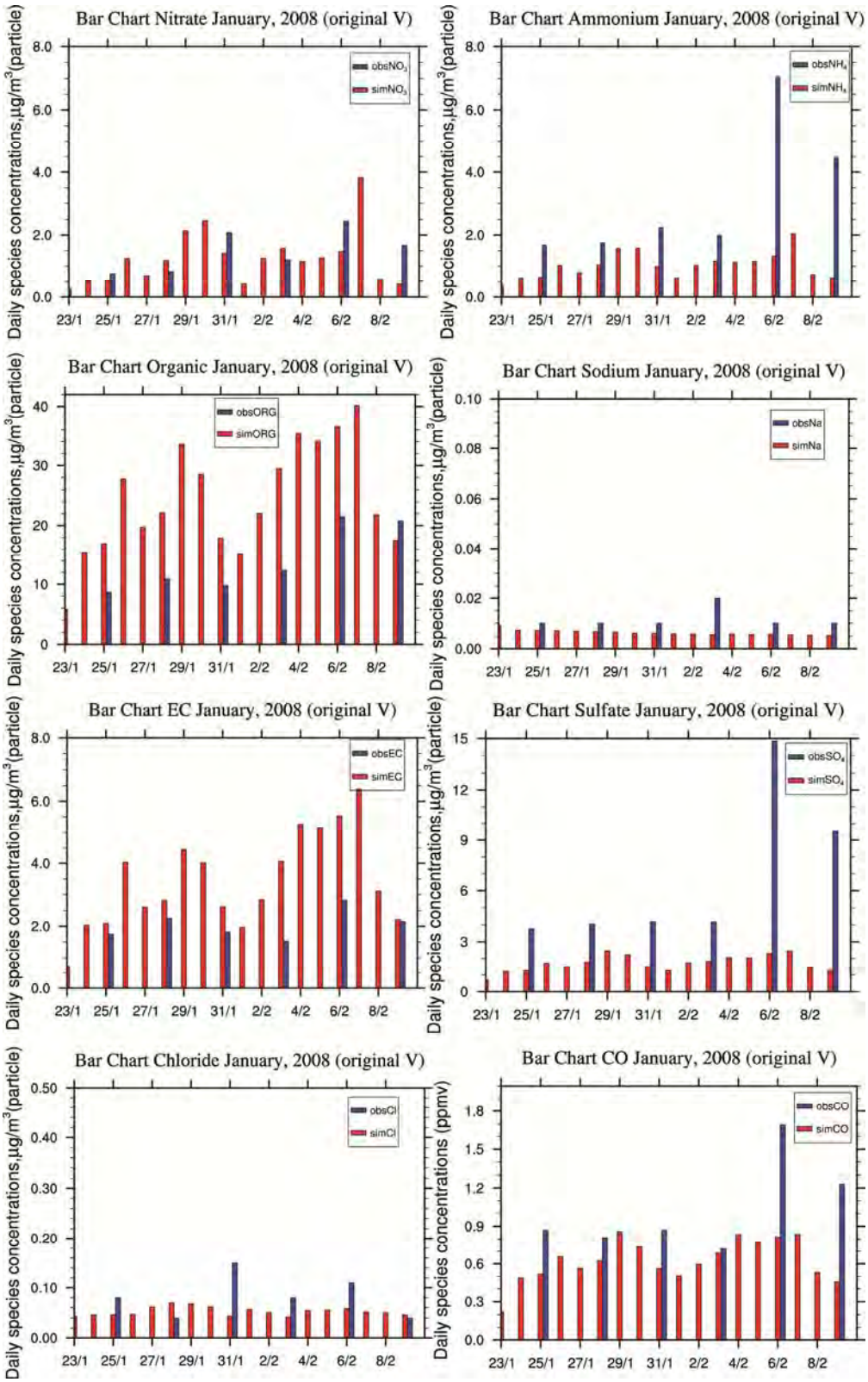


Fig. 11 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained at the State Office Building for the January episode.

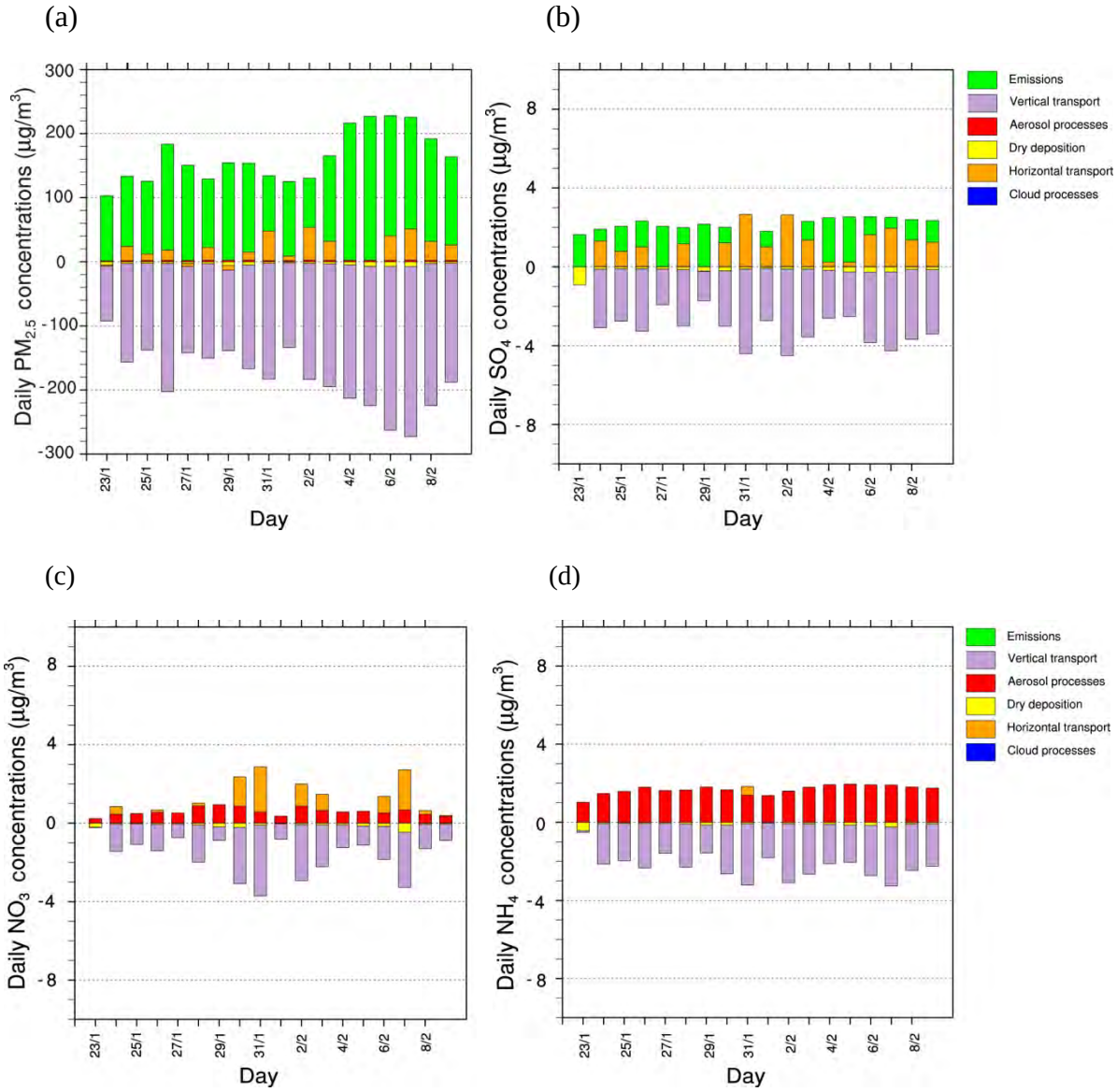


Fig. 12 Daily mean hourly contributions of individual processes to the (a) $PM_{2.5}$-concentrations, (b) SO_4-concentrations, (c) NO_3-concentrations, and (d) NH_4-concentrations as obtained at the State Office Building site from the adapted CMAQ simulation that used the revised WRF and SMOKE input for the January episode.

2.3 Documentation of Changes in CMAQ and Performance Improvements Made during Phase II

The simulations of the Alaska adapted CMAQ model underestimated sulfate (SO_4). Sulfate is the second major component in the composition of $PM_{2.5}$ in the Fairbanks nonattainment area. The simulations of the Alaska adapted CMAQ model also showed a time lag of ~24 hours in comparison with the observations at the State Office Building site for both the January and November episodes.

2.3.1 Improvements Implemented to Reduce the Sulfate-Underestimation

The performance of CMAQ in predicting fine particulate matter ($PM_{2.5}$) and its species has been evaluated in many studies [e.g. *Appel et al.*, 2008; *Eder and Yu*, 2006; *Mathur et al.*, 2008]. Obviously, according to these studies, CMAQ's performance tends to be lower in winter than summer for $PM_{2.5}$ and most species. CMAQ is also likely to underpredict sulfate during winter [*Appel et al.*, 2008; *Eder and Yu*, 2006; *Mathur et al.*, 2008].

The statistical performance skills for sulfate are poorer for the Fairbanks domain than for other US states (Table 1). Slightly lower performance skills were also found for Alaska than the Lower 48 for WRF/Chem simulations [*Mölders et al.*, 2012]. Thus, based on the literature, we may conclude that air-quality models may generally have difficulty with relatively lower temperature conditions. Thus, the extremely low temperature during the winter in Fairbanks might be a reason of the sulfate underestimation. This conclusion is backed by the evaluation studies for the Lower 48 that report weaker performance for $PM_{2.5}$-prediction winter than summer episodes [e.g. *Appel et al.*, 2008]. Therefore, we made several changes to the code of CMAQv4.7.1 to improve the sulfate simulation.

We performed various studies to examine the reasons for and to reduce the underestimation of sulfate and $PM_{2.5}$. In the following, first, the changes are described and later their impact will be discussed.

1) Increase of the Default Values for Fe and Mn in AQ_PAEAMS.EXT

In aerosol and aqueous chemistry, iron and manganese can play important roles for sulfate formation. Therefore, we updated the background values of Fe (III) and Mn (II) from $0.010\mu g/m^3$ to $0.040\mu g/m^3$ and decreased Mn (II) from $0.005\mu g/m^3$ to $0.001\mu g/m^3$following the measurement made in Fairbanks during winter 2011-2012 by *Peltier* [2012].

2) Increase of Sulfate and SO_2-concentrations for the Initial and Background concentrations (IC/BC)

The concentrations of sulfate and SO_2 of the previous initial and background concentrations were suspected to be too low. We now use the concentrations from the Clean Air Status and Trends Network (CASTNet) at the Denali site of winter 2008/09 (October–February). Thus, at the near-surface level the new SO_2-concentration is now 3.50×10^{-4} ppm. This value is closer to the default values that are used in the Eastern US. Modifying the near-surface concentration lead to ~1.7 increased near-surface SO_4-concentrations as compared to the total SO_4-concentrations obtained with the old values. The vertical profiles of SO_2 and sulfate are still based on *Jaeschke et al.* [1999] as no other vertical profile data is available to our best knowledge.

3) Change the dry deposition code back to the CMAQ v.4.7.1 original code

The modifications introduced for the dry deposition of SO_2 in phase I (deposition onto tundra, which was switched off in the original CMAQ, revised vegetation parameters for Alaska, formulations for dry deposition onto snow; see *Mölders and Leelasakultum* [2012]) led to increased removal of sulfate as compared to the original CMAQ. Therefore, we changed the parameterization of the SO_2 dry deposition processes back to their original version as it was in CMAQv.4.7.1 except that we kept the dry deposition on tundra. Note that if we would change this back to the original code it would mean that no deposition would be considered over most of the domain. Note that tundra covers most of the domain. In the original version of CMAQ, the code run over all vegetation types except for tundra to save computational time. This procedure is justifiable and makes sense for regions without tundra vegetation. However, in regions where tundra occurs, it would mean that no deposition is calculated over these tundra areas.

We want to point out that the changes that we originally made in phase I, are valid from a scientific point of view. The dry deposition over snow is quite different than over snow-free surfaces and should be dealt with similar as described in *Zhang et al.* [2003], i.e. likea we introduced it into CMAQ during phase I. The change back to the original formulation was only made to come closer to the observations and because of the philosophy to stay with the original code when changes do not lead to improvement for Alaska.

4) Reduction of the liquid-water threshold for resolvable scale clouds

Mueller et al. [2006] found that CMAQ underestimated sulfate because of a problem in the diagnosis of cloud cover. They found that reducing the liquid-water threshold values by 50% can decrease the cloud bias and lead to better results for sulfate predictions. Therefore, we decreased these threshold values by 50% in “rescld.F” of CMAQ model. The response will be discussed later.

5) Improved parameterization for the sulfuric acid – water nucleation rates

In CMAQ, the parameterization of the homogeneous nucleation rate of sulfuric acid and water is based on *Kulmala et al.* [1998]. *Vehkamaki et al.* [2002] published an extension of the formulation by *Kulmala et al.* [1998] to lower temperatures and a wider relative humidity range. CMAQ model v4.7.1 had not yet been updated to include this extension. Its formulas hold for temperatures between -43^{o}C and 32^{o}C, relative humidity between 0.01% and 100%, nucleation rates between 10^{-7} and $10^{10}cm^{-3}s^{-1}$, and sulfuric acid concentrations of 10^{4} to $10^{11}cm^{3}$. We coded and implemented this extended parameterization for the calculation of the nucleation rates based on *Vehkamaki et al.* [2002] and presented the results in the secondary quaterly report phase II. Later on, we updated the calculation based on personal communication with *Vehkamak* [2012]. This updated calculation is basically similar to what we have done, but the numbers include more digits. Furthermore, there are more conditions considered [*Vehkamaki,* 2012; pers. comm.]. The fortran code can be found at

http://www.atm.helsinki.fi/~hvehkama/publica/vehkamaki_hi_t_binapara.f90.

2.3.2 Response to the Improvements Made to Reduce the Sulfate-Underestimation

The introduction of the above improvements led to an increase in the percentage sulfate concentrations of total $PM_{2.5}$ at the grid-cell of the State Office Building site. The percentage of sulfate increased from 4.2 to 5.3% and from 3.9 to 5.0% for the November and January episode, respectively (Fig. 13). The increase in the percentage of SO_4 affected the partitioning of other species. This means concurrently the percentage of NH_4 increased, while the percentage of NO_3 and organic compounds decreased. These shifts in percentage may be explained as follows. The enhancement of sulfur dioxide and sulfate affected the thermodynamic equilibrium of the aerosol system. The sulfate-related aerosol acidity may be further neutralized by NH_3 to form ammonium sulfate aerosol ($(NH_4)_2SO_4$) [*Lovejoy*, 1996; *Seinfeld*, 2006]. The rest of ammonia can also neutralize nitric acid (HNO_3), and forms ammonium nitrate aerosol (NH_4NO_3).

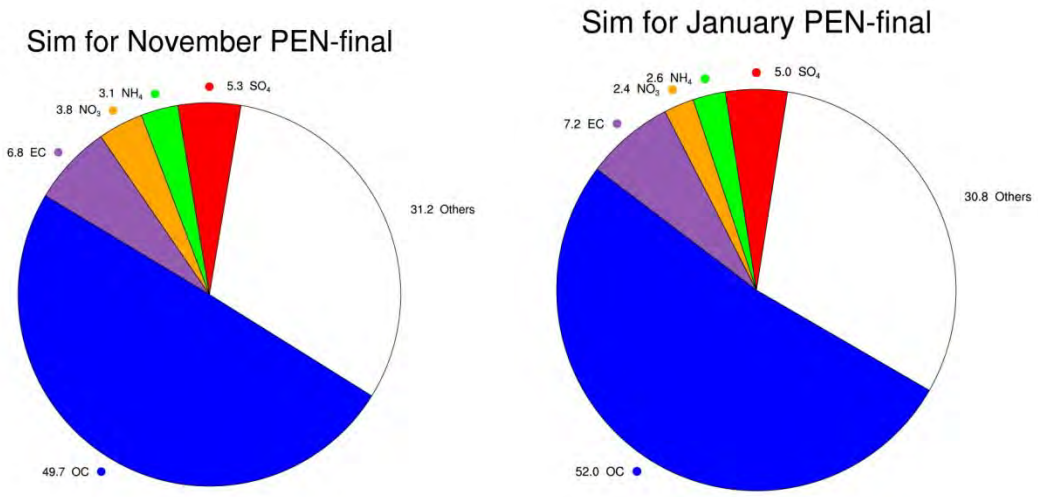


Fig. 13 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by the CMAQ simulations with the final modifications and using the PennState provided meteorology (PEN-final) on average over the November episode (left), and the January episode (right) at the grid-cell of the State Office Building site. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j), Na and Cl. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn.

The comparison of the absolute differences between the simulations before and after the improvements shows increases in sulfate, and ammonium and decreases in nitrate on every simulated day for both episodes (Figs. 14, 15). On average, the absolute increase of sulfate is 0.4 $\mu g/m^3$ or 28-29% for both episodes. The improvements did not bring a change in the organic concentrations (Figs. 14, 15); the decreased percentage of organic compounds is due to the increase of the percentage of SO_4 and NH_4. Note that the final modifications did not change the

temporal evolutions of sulfate and $PM_{2.5}$-concentrations, and the final version of Alaska adapted CMAQ still underpredicts sulfate aerosol.

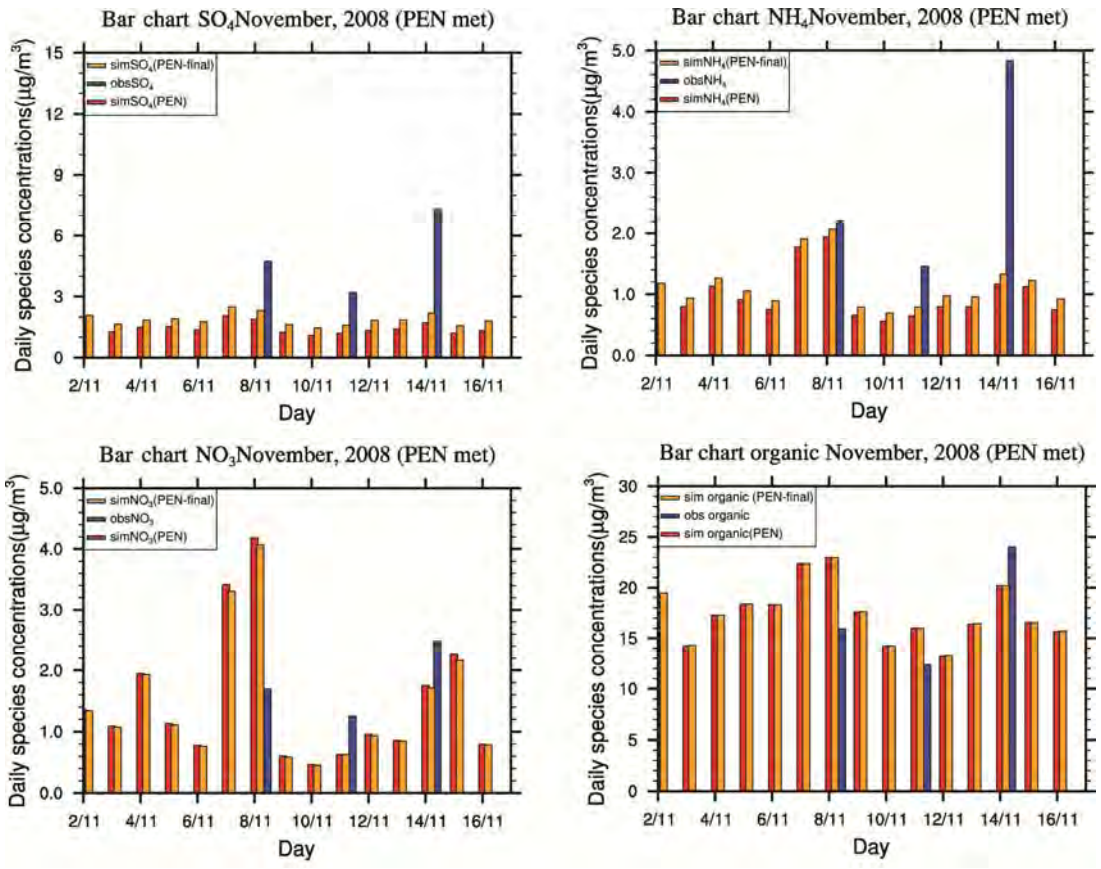


Fig. 14 Bar charts of simulated species as obtained from the previous CMAQ modification described in the final report of phase I (red), and as obtained from the final CMAQ modification described above (orange) and observed species (blue) of the 24h-average $PM_{2.5}$-composition for SO_4, NH_4, NO_3, and organic carbon for the November episode.

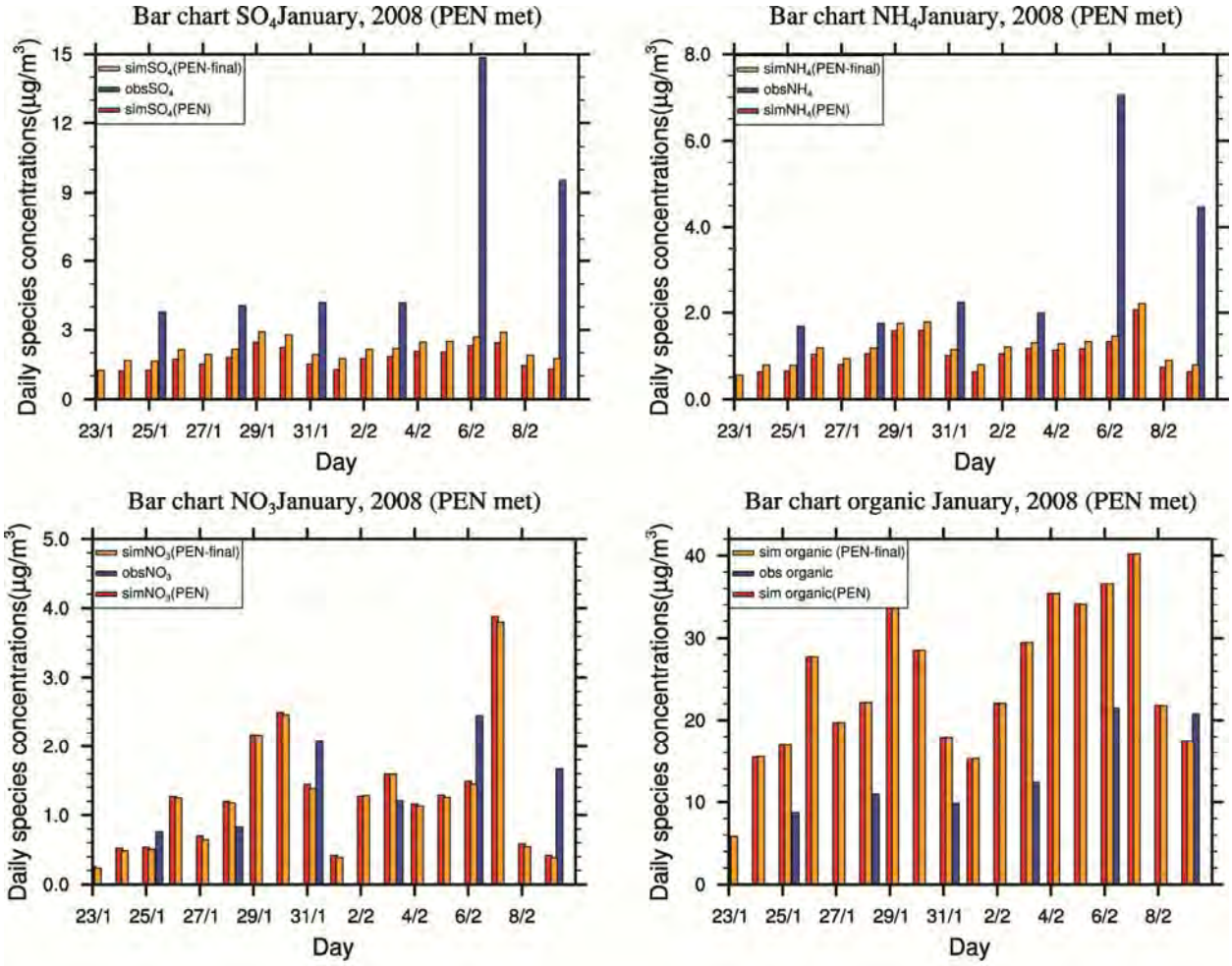


Fig. 15 Bar charts of simulated species as obtained from the previous CMAQ modification described in the final report of phase I (red), and as obtained from the final CMAQ modification described above (orange) and observed species (blue) of the 24h-average $PM_{2.5}$-composition for SO_4, NH_4, NO_3, and organic carbon for the January episode.

The process analysis of sulfate concentrations at the grid-cell of the State Office Building site shows that the final modifications caused changes in the horizontal and vertical transport (Fig. 16). This means that the modifications led to changes in neighbored grid-cells. These changes then led to advection of slightly modified (composition wise) air. On average in the November episode, the final CMAQ modification increased the contribution of sulfate from horizontal transport, cloud and aerosol processes by 0.39, 8.4×10^{-7} and 4.8×10^{-4}µg/m^3, respectively. The contributions to sulfate from removal by dry deposition and vertical transport decreased by -0.02 and 0.28µg/m^3. There was no change in the emissions as we used the same emission inventory.

On average over the January episode, the final CMAQ modification led to increased contributions of sulfate from horizontal transport, cloud and aerosol processes by 0.30, 1.1×10^{-6} and 5.6×10^{-4} µg/m^3, respectively. In the runs with the modifications, the removal of sulfate by

dry deposition and by vertical transport decreased by -0.02 and 0.37μg/m^3, respectively, as compared to the run without the modifications.

Table 1. Performance statistics for sulfate species simulated by the CMAQ model that did not employ the revised WRF and SMOKE input (January v1 episode), the CMAQ model with the previous modification (January v2 episode, PEN-WRF) described in the final report of phase I, and with the CMAQ model version with the final modification (PEN-WRFfinal) for the January and November episode on the days. Statistics are based on the observed sulfate data was available at the Fairbanks State Office Building site. The statistics of the annual simulations of sulfate in other states in US as reported by *Eder and Yu* [2006] are included for comparison. Here "No." stands for the number of days with observations. Furthermore, r, MB, RMSE, NMB and NME are the correlation skill score, mean bias, root-mean-square error, normalized mean bias, and normalized mean error.

Sulfate	**No.**	**Mean model**	**Mean observed**	**r**	**MB**	**RMSE**	**NMB (%)**	**NME (%)**
	January v1 episode							
PEN-WRF	6	1.3	6.8	0.36	-5.4	6.8	-80.3	80.3
	January v2 episode							
PEN-WRF	6	1.7	6.8	0.56	-5.1	6.4	-75.4	75.4
PEN-WRFfinal	6	2.1	6.8	0.61	-4.7	6.1	-69.6	69.6
	November episode							
PEN-WRF	3	1.6	5.1	0.61	-3.5	3.8	-68.5	68.5
PEN-WRFfinal	3	2.0	5.1	0.66	-3.1	3.4	-60.0	60.0
Eder and Yu, 2006	6970	3.33	3.40	0. 77	-0.77	2.25	-2.0	42.0

The statistical performance of the Alaska adapted CMAQ version that did not employ the revised WRF and SMOKE input (January v1), the CMAQ with the modifications that employs the revised WRF and SMOKE (January v2), and from the final CMAQ modification in simulating sulfate are compared in Table 1. Introducing the changes in the parameterizations increased the mean sulfate concentrations on the days, which had observed sulfate concentrations at the State Office Building site, in the range of 1.7 to 2.1μg/m^3 and 1.6 to 2.2μg/m^3 for the January and November episode, respectively. The mean biases (MB) were -4.7 and -3.1 μg/m^3 for the latest changes in the parameterization for the January and November episode, respectively. The

normalized mean bias (NMB) and normalized mean error (NME) from all simulations are high (exceed 50%) in comparison with the annual NMBs in the study by *Eder and Yu* [2006]. The examination the NMB and NME for the two episodes reveals better performance in simulating sulfate with the latest modifications. Our analysis of the performance also revealed that the correlation coefficients between the observed and simulated sulfate data increase as the concentrations of sulfate increase (Table 1).

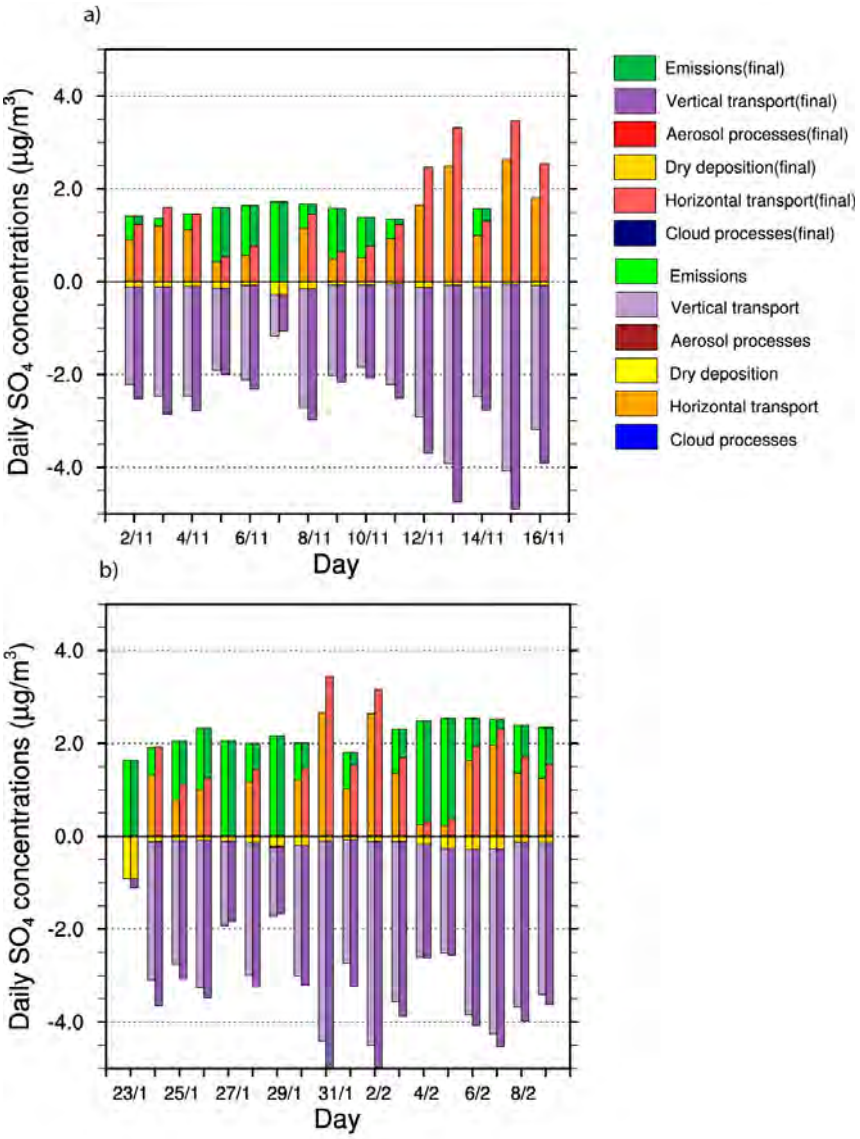


Fig. 16 Comparison of the daily contributions of individual processes to the SO_4-concentrations as obtained by CMAQ with the previous modifications and with CMAQ with the modifications described in this report at the grid-cell of the State Office Building site for the (a) November and (b) January episode.

Table 2. Performance statistics for the 24h-average $PM_{2.5}$-concentrations as obtained from the Alaska adapted CMAQ with the previous modifications and the CMAQ with the final modifications at the grid-cell of the State Office Building site for the January v1, January v2 and November episodes. The small differences as compared to the 1st quarterly report of phase II are due to the use of the SMVGEAR solver instead of the EBI solver that is needed for the process analysis.

24h-average $PM_{2.5}$-concentrations	**January v1**	**January v2**	**November**	**Final modifications**	
				January	**November**
Number of pairs used in the calculation of the statistics	12	12	15	12	15
Mean simulated($\mu g/m^3$)	35.0	52.6	34.9	53.1	35.5
Mean observed ($\mu g/m^3$)	42.6	42.6	29.3	42.6	29.3
Mean bias ($\mu g/m^3$)	-3.0	6.6	5.6	7.0	6.2
Mean fractional bias (%)	-1	17	26	18	31
Mean error ($\mu g/m^3$)	9.2	10.8	12.1	11.0	15.7
Mean fractional error (%)	24	26	42	27	54
Average difference (sim-obs)	-4.5	9.9	5.6	10.5	6.2
Simulated min| max ($\mu g/m^3$)	26.6 | 49.7	28.6 | 78.2	26.8 | 49.0	29.3 | 78.8	27.3 |49.4
Observed min|max ($\mu g/m^3$)	13.3 | 67.4	13.3 | 67.4	8.2 | 51.6	13.3 | 67.4	8.2 | 51.6
Number of simulated exceedance days	7	10	7	10	7
Number of observed exceedance days	8	8	6	8	6
STDEV of simulation ($\mu g/m^3$)	7.3	16.2	6.8	16.2	6.7
STDEV of observation ($\mu g/m^3$)	19.0	19.0	13.7	19.0	13.7
Variance of simulation$(\mu g/m^3)^2$	52.8	262.2	46.0	262.0	45.5
Variance of observation$(\mu g/m^3)^2$	362.8	362.8	188.3	362.8	188.3
Correlation coefficient	0.38	0.52	0.31	0.52	0.31

The Alaska adapted CMAQ with the final modifications given in this report is still not able to simulate sulfate concentrations as high as the observations suggest. As the process analysis indicated that the emission process is the main source of sulfate at the grid-cell of the State

Office Building site, we performed simulations with the same CMAQ configuration, but used an earlier version of the emission inventory. The comparison showed that the model showed better performance in simulating sulfate at the State Office Building site with the earlier version of the emission inventory. Therefore, we compared the emission inventories to examine what changes in the emissions led to these differences in model performance. Our investigations showed that in the latest version of the emission inventory there was a decrease of sulfate from 7% to 2-3% in the partitioning of the $PM_{2.5}$-emissions in comparison with the earlier version of the emission inventory (see also discussion in *Mölders and Leelasakultum* [2012]). Therefore, the decrease of sulfate in the partitioning of the $PM_{2.5}$-emissions is probably the main cause of underestimation of sulfate concentrations. The main differences we see in these WRF-CMAQ runs that only differ by the emission inventory used, show us the sensitivity of the model to the emissions and their partitioning. However, the latest version of the emission inventory reflects the latest inventory accuracy with new woodstove changeout, census and mobile numbers. Therefore, the latest emission inventory has to be considered superior over the earlier versions from a from a research standpoint.

Finally, we compared the performance statistics of the 24h-average $PM_{2.5}$-concentrations from Alaska adapted CMAQ version that did not employ the revised WRF and SMOKE input, the CMAQ modification that employed the revised WRF and SMOKE, and the CMAQ with the final modifications (Table 2). The final modifications did not increase the correlation coefficient or change the temporal evolution. The results of soccer plot and bugle plot are similar as prior to introducing the latest changes. As the differences are not statistically relevant, they are not shown here.

2.3.3 Investigation of the Causes for the Temporal Offset

As discussed above, the time-lag effect caused the model to fail to capture the temporal evolution of $PM_{2.5}$-concentrations well. Consequently, the correlation coefficients between the simulated and observed $PM_{2.5}$-concentrations for both episodes are lower than they should be. We run a hierarchy of simulations to test the causes for the temporal offset found at the grid-cell of the State Office Building site.

In the earlier simulations, the time-steps for the operator splitting were set as follows: maximum sync time-step = 12 min, minimum sync time-step=1.5 minute, and up to sigma = 0.9. We hypothesized that the CMAQ model might be too slow in updating the chemistry, which consequently could lead to the temporal offset at the grid-cell of the State Office Building site. Therefore, we reduced the time step for the operator splitting to be as follows: maximum sync time-step = 6 min, minimum sync time-step=1minute, and up to sigma =0.7. The temporal evolution of $PM_{2.5}$-concentrations for the longer time-step (PEN-WRF) and the shorter time-step (PEN-WRFfinal) were compared. The comparison showed no difference in the temporal evolutions for both the January and November episode (Figs. 17, 18). The differences in concentrations might be due to the improvement of parameterizations in the PEN-final version.

Additionally, we also run the simulations by using the emission of the next day (PEN-Eshift), i.e. we shifted the emissions by one day. The temporal evolutions of simulated $PM_{2.5}$-concentrations showed only marginal differences from those simulations that used the emissions in sync with the meteorological data (Fig. 17).

Another reason for the temporal offset between simulated and observed $PM_{2.5}$-concentrations was hypothesized to be an offset in the simulated meteorology. Therefore, we ran WRF for the two episodes in a different configuration than the PennSate WRF. In the following, we refer to these simulations as "UAF-WRF". Our WRF-simulations differ in the model configuration from the WRF-simulations performed and provided by PennState. Note that the simulations provided by PennState are called "PEN-WRF", hereafter. The new WRF simulations served to examine whether an offset in meteorology is the cause for the time lag in the $PM_{2.5}$-concentrations.

The domains for the simulations with the UAF-WRF are based on the domains used in the PEN-WRF for easy comparison. Our model configuration like theirs used three one-way nested horizontal grids with horizontal grid spacing of 12km, 4km and 1.3km, respectively. Domain 3 that has a 1.3km grid increment was used to provide the meteorological input data to simulate the chemical transport and transformation of species with the CMAQ model. For the UAF-WRF simulations, the initial meteorological conditions were downscaled from the $1^o \times 1^o$, 6h-resolution National Centers for Environmental Prediction global final analyses. The simulations were performed in forecast mode (turning off nudging) for January 23, 2008 0000UTC to February 12, 2008 0000UTC and November 02, 2008 0000UTC to November 18, 2008 0000UTC. The selection of options in the first simulations of the UAF-WRF (UAF-WRFv1) bases on long-year experience of the PI and her research group with meteorological simulations for Alaska [e.g. *Mölders and Olson*, 2004; *Mölders and Walsh*, 2004; *Mölders and Kramm*, 2007; 2010; *Chigullapalli and Mölders*, 2008; *Yarker et al.*, 2010; *Mölders et al.*, 2011; 2012]. The selection of options in the second set of simulations with the UAF-WRF (UAF-WRFv2) for domain 3 is the same as those in the PEN-WRF except that we turned off the OBS nudging. The meteorological fields were initialized every day. The model configurations for both the PEN-WRF and UAF-WRFv1 and UAF-WRFv2 are compared in Table 3.

Nudging to observations (OBS nudging) is a technique that adds artificial forcing functions to a model's prognostic equations to nudge the solutions toward the observations. Those individual observations are spread in space and time. In domain 3, there is a limited number of radiosonde sounding sites [*Mölders et al.*, 2011]. Thus, OBS nudging might cause a temporal offset, as obviously the WRF model was unable to capture the temperature inversion at the right time and place. Therefore, we turned off the OBS nudging for a sensitivity study for both UAF-WRFv1 and UAF-WRFv2. Note that in Fairbanks, many inversions are locally forced when the right synoptic conditions exist [*Mayfield*, 2012].

The comparison of the temporal evolutions of the $PM_{2.5}$-concentrations as obtained by CMAQ with the UAF-WRFv1 and UAF-WRFv2 with those obtained with the PEN-WRF indicates that

the meteorological input data led to changes in the temporal evolutions of $PM_{2.5}$-concentrations. However, none of the obtained changes in $PM_{2.5}$-concentrations led a perfect fit with the observed $PM_{2.5}$-concentrations (Figs.17, 18). The UAF-WRFv1 simulations with the *Lin et al.*'s [1983] microphysics scheme seem to provide the highest $PM_{2.5}$-concentration peaks in the beginning of the November episode and the lowest dip in the $PM_{2.5}$-concentrations on November 11 as compared with the other simulations (Fig. 17). For the January episode, the simulation with the *Lin et al.* [1983] microphysics scheme showed the smallest temporal shift as compared to the PEN-WRF, but still showed the offset (Fig. 18). The simulations with the Morrison 2-moment [*Morrison et al.*, 2005] scheme tend to smooth the peak and dip. As a result, the simulations with the UAF-WRFv2 clearly brought the 24h-average $PM_{2.5}$-concentrations down.

Table 3. WRF-model configurations of the PennState University (PEN-WRF) and University of Alaska Fairbanks simulations for domain 3 version 1 (UAF-WRFv1) and version 2 (UAF-WRFv2). The main differences of model configurations are indicated in bold letters.

Model Configurations	PEN-WRF	UAF-WRFv1	**UAF-WRFv2**
Cumulus Parameterization	None	Grell G3	None
Microphysics	Morrison 2-moment	Lin et al.	Morrison 2-moment
Longwave radiation	RRTMG	RRTM	RRTMG
Shortwave radiation	RRTMG	Goddard	RRTMG
PBL scheme	Mellor-Yamada-Janjic (Eta)	Mellor-Yamada-Janjic (Eta)	Mellor-Yamada-Janjic (Eta)
Surface Layer scheme	Monin-Obukhov (Janjic Eta)	Monin-Obukhov (Janjic Eta)	Monin-Obukhov (Janjic Eta)
Land-surface scheme	RUC Land-Surface Model	RUC Land-Surface Model	RUC Land-Surface Model
Urban model	No urban physics	No urban physics	No urban physics
Land use classification	USGS	USGS	USGS
3D analysis nudging	OFF	OFF	OFF
SFC analysis nudging	OFF	OFF	OFF
OBS nudging	**ON**	**OFF**	**ON**

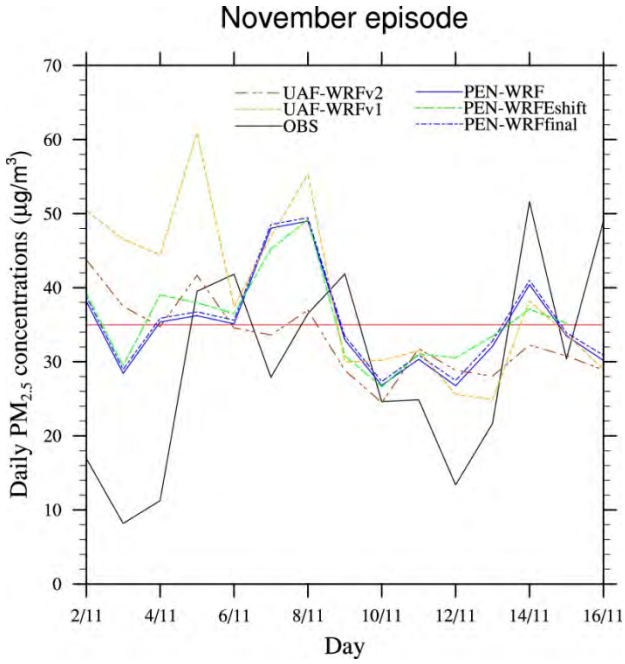


Fig. 17 Temporal evolutions of 24h-average $PM_{2.5}$-concentrations as simulated at the grid-cell of the State Office Building site by the Alaska adapted CMAQ that uses a longer time-step (PEN-WRF) and the shorter time-step (PEN-final), emission on the next day, with the UAF-WRF version 1 (UAF-WRFv1) and version 2 (UAF-WRFv2) and as observed (OBS) at the State Office Building for the November episode.

The correlation coefficients between the simulated $PM_{2.5}$-concentrations obtained with CMAQ using the PEN-WRF, PEN-WRFEshift, PEN-WRFfinal, UAF-WRFv1 and UAF-WRFv2 and the observations are 0.31, 0.26, 0.31, -0.01 and -0.12, respectively for the November episode. For the January episode, the correlation coefficients were all 0.52 no matter whether CMAQ used the PEN-WRF, PEN-WRFfinal and UAF-WRFv1 meteorology. It can be clearly seen that the PEN-WRF is providing the best correlation coefficient of simulated and observed $PM_{2.5}$-concentrations. However, the temporal offset of the model still exists even when we run the WRF with the OBS nudging turned off, but otherwise with the same options as used by PennState. Therefore, we recommend to do more tests and find a WRF-setup that better represents the temporal evolution of 24h-average $PM_{2.5}$-concentrations at the State Office Building site.

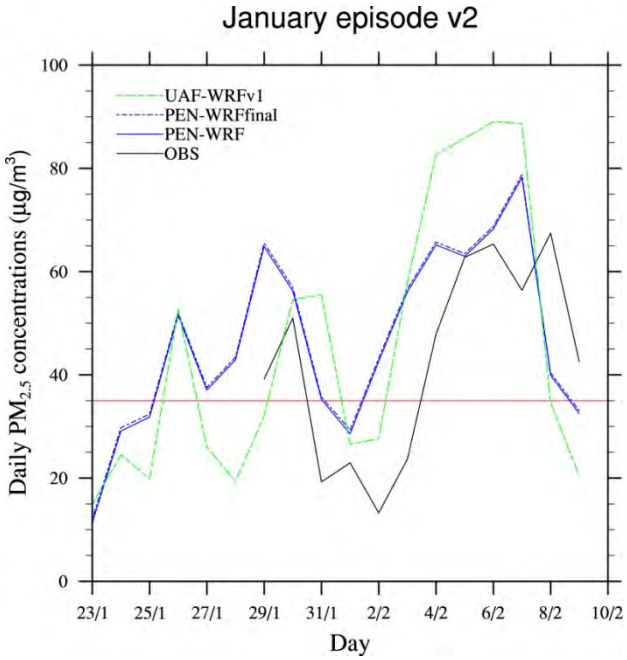


Fig. 18 Temporal evolutions of 24h-average $PM_{2.5}$-concentrations as simulated by the Alaska adapted CMAQ that uses a longer time-step (PEN), a shorter time-step (PEN-final), emission of the next day, with the UAF-WRF version 1 (UAF-WRFv1) and version 2 (UAF-WRFv2) and observed at the State Office Building site (OBS) for the January episode.

2.4 Investigation on the Boundary and Initial Conditions

To create the boundary conditions (BC) for domain 3, we would have had to run CMAQ on domain 2 at least. However, emission data for domain 1 and 2 were never created as various studies with WRF/Chem [*Tran et al.*, 2011; *Mölders et al.*, 2012] and observational analysis [*Cahill*, 2003] showed that the contribution by transport of $PM_{2.5}$ towards Alaska are more than an order of magnitude smaller than the concentration of the NAAQS. This means that there were no issues related to the BC. Consequently, the Alaska Department of Environmental Conservation did not request Sierra Research Inc. to create an emission inventory for Alaska and did not ask us to perform CMAQ simulations on domain 2. Note that typically, the chemical fields predicted on domain 2 at the boundaries of domain 3 would serve as the BC for domain 3. For these reasons, we could not investigate the impact of the BC on the concentrations in domain 3 directly. Nevertheless, we performed a work intensive series of tests to investigate the impact of the BC on the concentrations simulated in domain 3 indirectly. These tests as their results are discussed in the following.

In the final report of phase I [*Mölders and Leelasakultum*, 2012], we already reported on potential impacts of BC when comparing the results at the boundaries of the smaller 66×66 domain with concentrations at these places in simulations on a 199×199 domain. The interested reader is referred to this document for further reading on BC impacts.

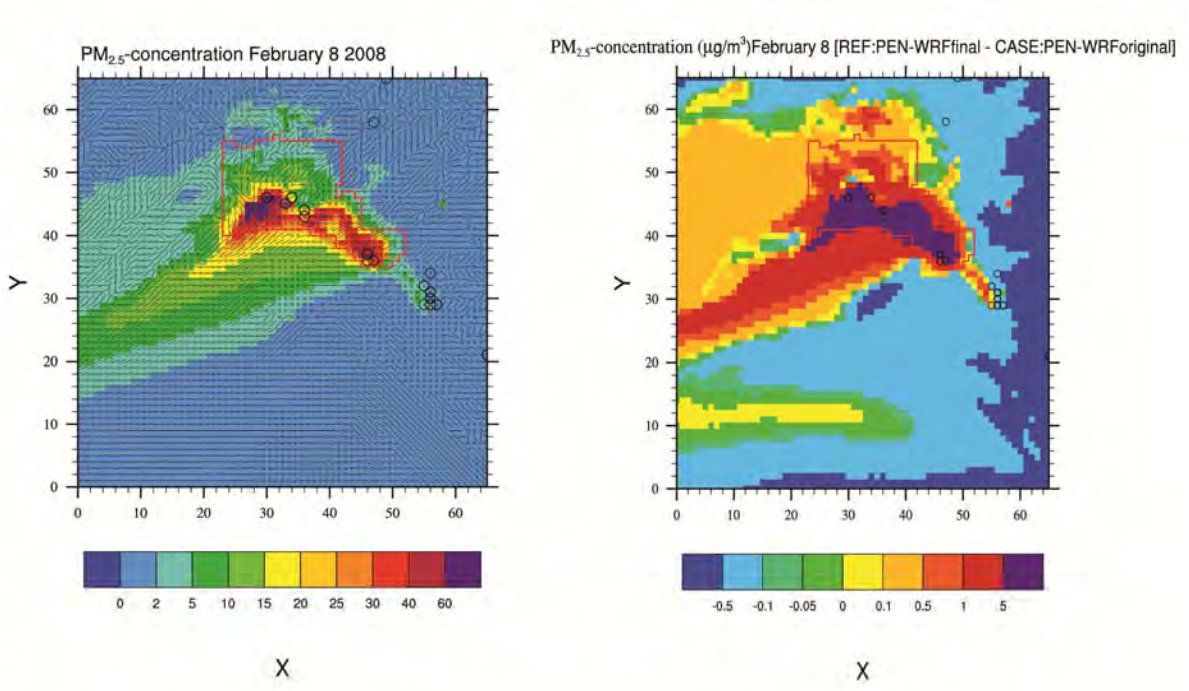


Fig. 19 Exemplary plot of (a) 24h-average $PM_{2.5}$-concentrations as simulated by CMAQ with the PEN-WRF meteorology (PEN-WRFfinal) with the wind barbs and (b) 24h-average $PM_{2.5}$-concentration differences at breathing level between the simulations with the final CMAQ and the PEN-WRF meteorology that uses the cleaner IC/BC conditions (see text for details) and the original CMAQ with that uses the default initial and boundary condition and PEN-WRF meteorology (PEN-WRForiginal). Differences are PEN-WRFfinal-PEN-WRForiginal.

To determine the impact of the initial conditions (IC) and BC, we compared the results from the final Alaska adapted CMAQ simulation that was generated with the PennState meteorological data (PEN-WRFfinal) with the results from the original CMAQ version with the default initial and boundary conditions that represent the background concentrations in the eastern United States. We assumed that the initial and boundary conditions developed for Alaska are "clean" background conditions. The boundary-condition impacts on the 24h-average $PM_{2.5}$-concentrations make a difference of less than 0.5µg/m^3 outside the nonattainment area (Fig. 19). For the January episode, the maximum difference due to the boundary conditions amounts 1.4 µg/m^3. However, on some days, effects of the boundary conditions can be found inside the nonattainment area in the range of 0.1 to 0.5µg/m^3. The magnitude of the BC impacts depends on wind-speed and direction.

For example on February 8, the northeast wind blows the $PM_{2.5}$ to the southwest. This consequently results in an impact of the boundary condition on the concentrations inside the nonattainment area (Fig. 19). The difference between the clean background condition and the default BC also shows in a difference in the 24h-average $PM_{2.5}$-concentrations about 0.1-0.5

$\mu g/m^3$. The results for the impact of recirculation pattern on the $PM_{2.5}$-concentrations in the domain are shown in the Appendix.

Using IMPROVE network observations of winter 2008/09 combined with HYSPLIT [*Draxler et al.*, 2009] backward meteorological trajectories simulations at 0000 UTC on days with high $PM_{2.5}$-concentrations ($>2\mu g/m^3$) at the Denali IMPROVE site and heights of 1000m to 8500m in steps of 500m above ground showed transport of particles from Asia to Denali Park at several levels. However, at the Denali IMPROVE site the $PM_{2.5}$-concentrations are still far away from the NAAQS and typically below $3\mu g/m^3$. This means long-range transport may contribute to the $PM_{2.5}$-concentrations in the nonattainment area by a couple of $\mu g/m^3$, but is not the reason for the exceedances. In winter, the advected amount of $PM_{2.5}$ is too small to cause an exceedance unless the $PM_{2.5}$-concentrations are already close to the NAAQS.

Photochemical modeling with WRF/Chem, for which various emission datasets were available, showed that the region receives only minor amounts of pollution from long-range transport [*Tran et al.*, 2011; *Mölders et al.*, 2012]. The major sources of primary particulate matter are within the nonattainment area. Typically, $PM_{2.5}$-exceedances occur during strong temperature-inversions on calm-wind days when the inversion traps local emissions from heating and vehicles near the surface [*Tran and Mölders*, 2011; *Mölders et al.*, 2012]. On these days, wind-speeds are low and advection from outside the nonattainment area is marginal.

2.5 Assessment of CMAQ Sensitivity to Secondary Chemistry

We investigated the sensitivity of the Alaska adapted CMAQ model version to chemistry before the final improvements were made for the January v1 and November episode. In the nonattainment area, the overall and average concentrations of sulfate, nitrate and organic for turning on and turning off chemistry were compared (Table 4).

The comparison of the sulfate, nitrate and organic concentrations of the two episodes shows that the concentrations of all three species are higher in the January than November episode. Turning off the chemistry decreases the sulfate concentrations by 9% and 3% for the January and November episode, respectively. Doing so, decreases the organic compound concentrations by 1% and less than 1%, and decreases the nitrate concentrations by 90% and 95% for the January and November episode, respectively (Table 4). The nitrate-aerosol production is related to the neutralization of HNO_3 vapor, which is a by-product of photochemical reactions. In the November episode, there is more sunlight than January episode. Thus, gas-phase and aerosol chemistry of nitrate play a greater role than in the January episode. For sulfate and organic compounds, the lower temperatures and dry conditions of the January episode support more gas-to-particle conversion than in the November episode. Consequently, those aqueous vapors tend to convert into particles and increase the mass of sulfate and organic particulate matter.

Table 4. Overall mass and average mass of sulfate, nitrate and organic compounds in the nonattainment area for the case of turning off the chemistry (chem_noop and aero_noop in CMAQ), turning off the gas chemistry (chem_noop), turning off the aerosol chemistry (aero_noop), and turning on the chemistry.

Nonattainment area	**Sulfate (μg/m^3)**	**Nitrate(μg/m^3)**	**Organic(μg/m^3)**
Overall mass			
January			
Turn on chemistry	152,490	103,508	713,109
Turn off gas-chemistry	148,521 (-3%)	40,787(-61%)	712,325(N)
Turn off aero-chemistry	139,856(-8%)	10,764(-90%)	708,086(-1%)
Turn off chem.	139,317(-9%)	10,161(-90%)	707,934(-1%)
November			
Turn on	125,201	189,067	1,354,795
Turn off gas-chemistry	125,413(N)	30,136(-84%)	1,354,053(N)
Turn off aero-chemistry	121,161(-3%)	10,489(-94%)	1,351,743(N)
Turn off chemistry	122,050(-3%)	10,069(-95%)	1,351,745(N)
Average mass			
January			
Turn on	0.85	0.57	3.96
Turn off gas-chemistry	0.82(-3%)	0.23(-61%)	3.95(N)
Turn off aero-chemistry	0.78(-8%)	0.06(-90%)	3.93(-1%)
Turn off chemistry	0.77(-9%)	0.06(-90%)	3.93(-1%)
November			
Turn on	0.88	1.33	9.53
Turn off gas-chemistry	0.88(N)	0.21(-84%)	9.52(N)
Turn off aero-chemistry	0.85(-3%)	0.07(-94%)	9.51(N)
Turn off chemistry	0.86(-3%)	0.07(-95%)	9.51(N)

At the grid-cell of the State Office Building site, the ratios of simulated to observed sulfate, nitrate and organic carbon and of precursors to concentrations were also investigated. On average over the January episode, the ratios of modeled SO_2/modeled aerosol sulfate are 189.0 and 154.1 for the Alaska adapted CMAQ model before and after the improvements, respectively. For the November episode, the average ratios of modeled SO_2/modeled aerosol sulfate are 184.8 and 147.5 for the Alaska adapted CMAQ model before and after the improvements, respectively. These findings mean that introducing the improvements led to more conversion of SO_2 to sulfate at the grid-cell of the State Office Building site. The ratios of emitted SO_2/emitted sulfate are 248.6 and 227.8 for the January episode v2 and for the November episode, respectively. The ratios of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate are 0.62 and 0.65 for the final improvements of CMAQ for the January v2 and November episode, respectively. Note that there is no observed SO_2 data for the two episodes.

Furthermore, for the simulations that did not employ the revised WRF and SMOKE inputs, the ratio of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate are very close (0.63 and 0.62). However, the ratio of emitted SO_2/emitted sulfate for the January v1 is 380.1, which is higher than for the January v2 case. The ratio of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate is close to one. This finding indicates that the concentrations of SO_2 and sulfate at the grid-cell of the State Office Building site are mainly from emissions.

For organic carbon, the averaged ratios of modeled VOC/modeled organic carbon are 0.20 for both the Alaska adapted CMAQ model before and after the improvements for the January v2 episode. For the November episode, the average ratio of modeled VOC/modeled organic carbon is 0.18 for the Alaska adapted CMAQ model both before and after the improvements, i.e. it stayed the same. The introduction of the improvements does not lead to a difference in the organic carbon concentrations at the gri-d-cell of the State Office Building site. The ratios of emitted VOC/emitted organic carbon are 72.2 and 94.4 for the January episode v2 and for the November episode, respectively. The ratios of modeled VOC/modeled organic carbon divided by emitted VOC/emitted organic carbon are 0.19 and 0.18 for the final improvements of CMAQ for the January v2 and November episode, respectively. The simulations that did not employ the revised WRF and SMOKE inputs, have a ratio of modeled VOC/modeled organic carbon divided by emitted VOC/emitted organic carbon of 0.66. For the January v1 episode, the ratio of emitted VOC/emitted organic carbon is 30.1, which is lower than for the January v2 case. The low ratio of modeled VOC/modeled organic carbon divided by emitted VOC/emitted organic carbon indicates that there is higher gas-to-particle conversion of VOC to organic carbon than sulfate at the grid-cell of the State Office Building site.

For nitrate, the averaged ratios of modeled NO_2/modeled aerosol sulfate are 175.4 and 179.2 for the January v2 episode before and after implementation of the improved parameterizations. For the November episode, the averaged ratios are 137.8 and 140.7 before and after implementation of the improved parameterizations. The increase of sulfate concentrations after the improvement

brought about a decrease of the modeled nitrate aerosol concentrations. The averaged ratios of modeled NO_2/modeled aerosol sulfate for the January v1 episode is 180.7.

The temporal evolutions the ratios of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate agree with the temporal evolutions of the meteorological variables such as 2m-temperatures and 2m-water mixing ratios clearly in both episodes (Fig. 20). Lower temperature and lower water mixing ratio conditions lead to more gas-to-particle conversion. We found that on the first day of the simulations, the ratios are very low. These low ratios might be the effect of the spin-up of the chemistry in CMAQ.

a)

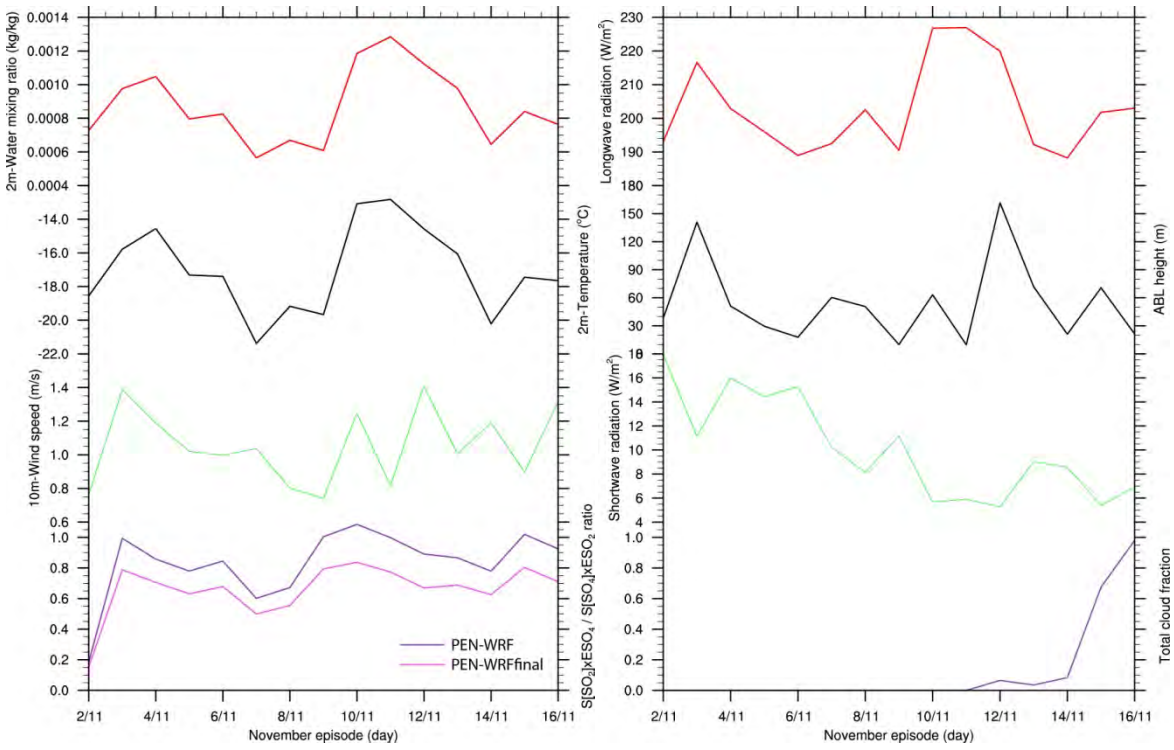


Fig. 20 continued

b)

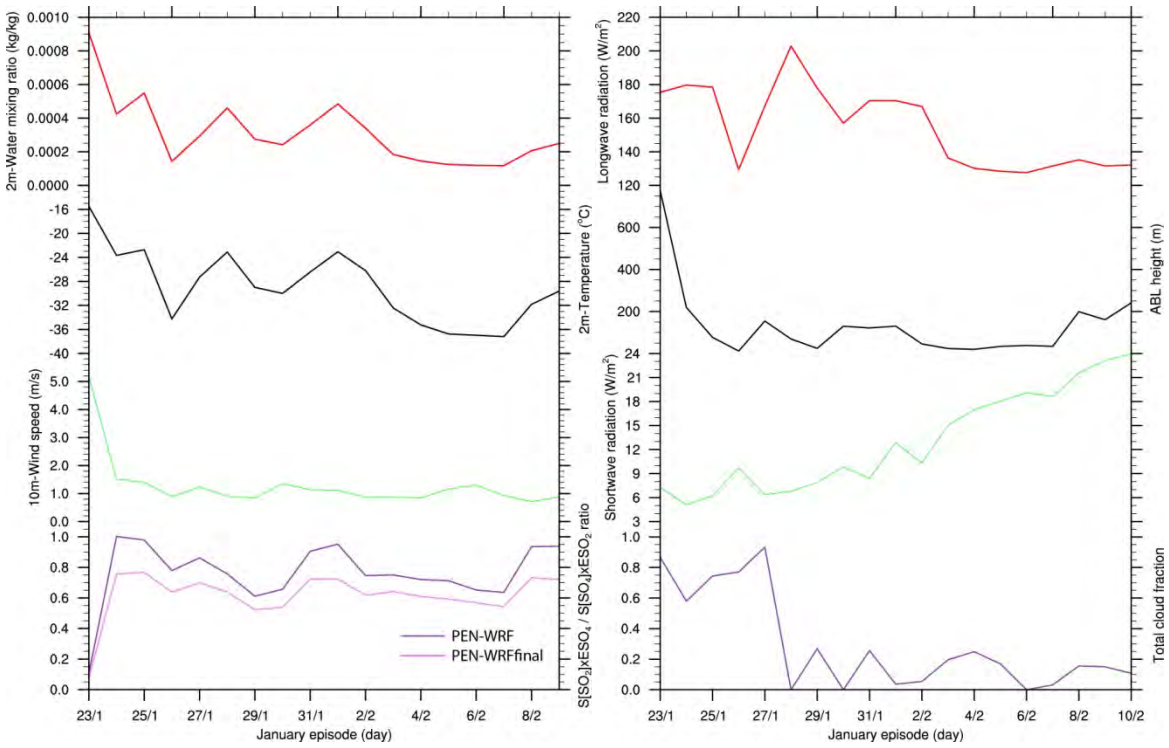


Fig. 20 Temporal evolutions of ratios of modeled SO_2/modeled aerosol sulfate divided by emitted SO_2/emitted sulfate as obtained from the CMAQ simulations prior to the improvements (PEN-WRF) and after the CMAQ improvements (PEN-WRFfinal) described in this report and the temporal evolutions of the meteorological variables generated by MCIP for the CMAQ model, which include 2m-water mixing ratio, 2m-temperature, 10m-windspeed, long-wave radiation, atmospheric boundary layer (ABL) height, shortwave radiation and total cloud fraction as obtained at the grid-cell of the State Office Building site for the (a) January and (b) November episode.

3. Conclusions and Recommendations

With the final improvements of the parameterizations and parameters made within the framework of this contract, the Alaska adapted CMAQ model showed an increase in the simulated sulfate concentrations at the grid-cell of the State Office Building site. Despite this success, the adapted CMAQ model still underpredicts the sulfate concentrations at the grid-cell of the State Office Building site. The normalized mean errors are 60% and 70% for the November and January episode, respectively.

We made various sensitivity simulations and tests to examine the reasons for the underestimation. These investigations and the process analysis provide strong evidence that most likely the partitioning of the emitted $PM_{2.5}$ is part of the reason for the underestimation of sulfate at the grid-cell of the State Office Building site. However, we have to use the emissions as they

partitioned in the newest version of the emission inventory as it is based on the most current insights on the emission situation in Fairbanks. Therefore, we strongly recommend further assessing and/or improving the percent partitioning of total particulate matter emissions into sulfate and other species.

Our results support the findings from other authors [e.g. *Appel et al.,* 2008] for winter cases in the Lower 48 that CMAQ underpredicts sulfate compared to observations. At UAF, currently further research is performed within the framework of a dissertation why CMAQ underestimates sulfate at low temperatures. Thus, it has to be expected that possible changes to CMAQ will become available in the future to better capture the sulfate concentrations for subarctic conditions.

Another reason for the underestimation that we cannot exclude is that in the subarctic there may be physical/chemical processes in the sulfate chemistry that are of relevance at low temperatures, low water vapor mixing ratios or both. These conditions rarely exist in the Lower 48. Thus, if such processes exit in the subarctic they may have been overlooked in studies for mid-latitudes. It is obvious that when a relevant process has not yet been found/identified, it, of course, is not considered in the code. Thus, the model cannot simulate the process and its impact on sulfate concentrations. The detection of missing processes would require long laboratory studies. Eventually, it would require long test series to derive parameterizations of the processes from the data and to implement and test the parameterizations in the model.

Our investigations and sensitivity studies also showed that the input meteorology and temporal offsets therein strongly determine the temporal evolutions of simulated 24h-average $PM_{2.5}$-concentrations. Therefore, we recommend further tests for the best options in the WRF setup for producing meteorological data with less temporal offset.

Our investigations suggest that the CMAQ for these episodes needs about three days to spin up the chemical fields. Therefore, we recommend to discard the first three days of simulations as spin up time and to not consider them in any assessment for the State Implementation Plan development. We further recommend that the simulation results of the first three days should be discarded from any evaluation as the chemical fields still spin-up.

We recommend that the final Alaska adapted CMAQ version presented here is tested for other episodes that have more observational data that the January and November episodes. The low data density does not permit assessment whether the occasional weak performance is related to model, emission and/or observational errors. Furthermore, with data available at just one site it is impossible to assess whether CMAQ captures the spatial distribution right. Some of the discrepancies might be just spatial offsets due to the overestimation of wind-speed. Low data availability always bears the risk to adapt a model in the wrong direction, as one can be easily right for the wrong reason at one place. This risk decreases when the amount of data increases.

A revised version of the emission inventory just became available [*Hixson*, 2012; pers. comm.]. It has to be examined how much the updated emissions will impact the simulated $PM_{2.5}$-concentrations and affect the simulated sulfate concentrations.

Acknowledgements

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Appendix 1

The following pages show an hourly sequence of plots illustrating how polluted Fairbanks air that left the nonattainment area enters the nonattainment area as aged polluted air. The wind barbs indicate wind direction. Circles mean zero wind speed and hence no wind direction. The color gives the $PM_{2.5}$-concentrations as indicated in the legend.

Fairbanks $PM_{2.5}$ Source Apportion Estimates Winter 2008/2009

The University of Montana is under contract to ADEC to conduct a multi-year study of $PM_{2.5}$ monitoring data collected in Fairbanks. The initial analysis focused on monitoring data collected during the 2008/2009 winter to determine the percent distribution of emission sources impacting each monitoring site. This information is critical to the Borough's efforts to identify which sources need to be controlled in order to reduce wintertime $PM_{2.5}$ concentrations in Fairbanks. It is also needed to determine if the emission source contributions are consistent throughout the Borough or vary by location.

Up until the winter of 2008/2009, chemical speciation $PM_{2.5}$ monitoring data were collected only at the State Office Building in downtown Fairbanks. To expand coverage of the Borough, three additional sites were added that winter: (1) North Pole; (2) Peger Road at the Borough Transportation Center; and (3) a field located to the northwest of the intersection between Geist Road and the Parks Highway, known as the Reindeer site. Because of delays in getting the monitors installed and operating, data collection did not begin until January 25, 2009. Thus, measurements collected at these sites did not capture the elevated concentrations recorded earlier in the winter. The State Office Building, however, collected data all winter (November 8, 2008, through April 7, 2009). A map of the location of each of the sites within the Borough is displayed in Figure 1.

The University of Montana employed several methods to analyze the data collected at each monitoring site. They first used a statistical analysis procedure, which is approved by EPA, called Chemical Mass Balance or CMB to assess relationships in the chemical compounds collected at each site to chemical compounds emitted from each emission source (e.g., automobiles, wood smoke, etc.). The second approach used was Carbon-14, which looks at the age distribution of carbon molecules found at each site. The newer carbon is generally, but not completely, associated with wood burning, while the older carbon is associated with petrochemicals or fossil fuels. The third method used was to measure an organic chemical compound known as levoglucosan, which is a unique byproduct of wood burning. Since there is some uncertainty with each method, this approach provides a broader range of insight into emission source contributions and greater comfort that the findings are correct and defensible.

The CMB analysis results for each site are displayed in Figure 2. It shows that wood smoke is estimated to be the dominant emissions source at each site, with a contribution uniformly exceeding 60% of the measured $PM_{2.5}$ mass. The contributions of other emission sources are more variable; the second largest contributor was found to be sulfate (a compound that includes particles directly emitted during combustion and secondary particles formed in the atmosphere) and the third largest contributor to be ammonium nitrate (also a secondary particle). Generally speaking, sulfate is a function of the sulfur content of the fuels burned in the community. Recent regulations have all but eliminated sulfur from gasoline and Diesel fuel in Alaska. Therefore, the fuels contributing sulfur to the atmosphere include distillate fuel oil used in space heating and coal. Similarly,

Figure 1
Location of $PM_{2.5}$ Monitors in Fairbanks

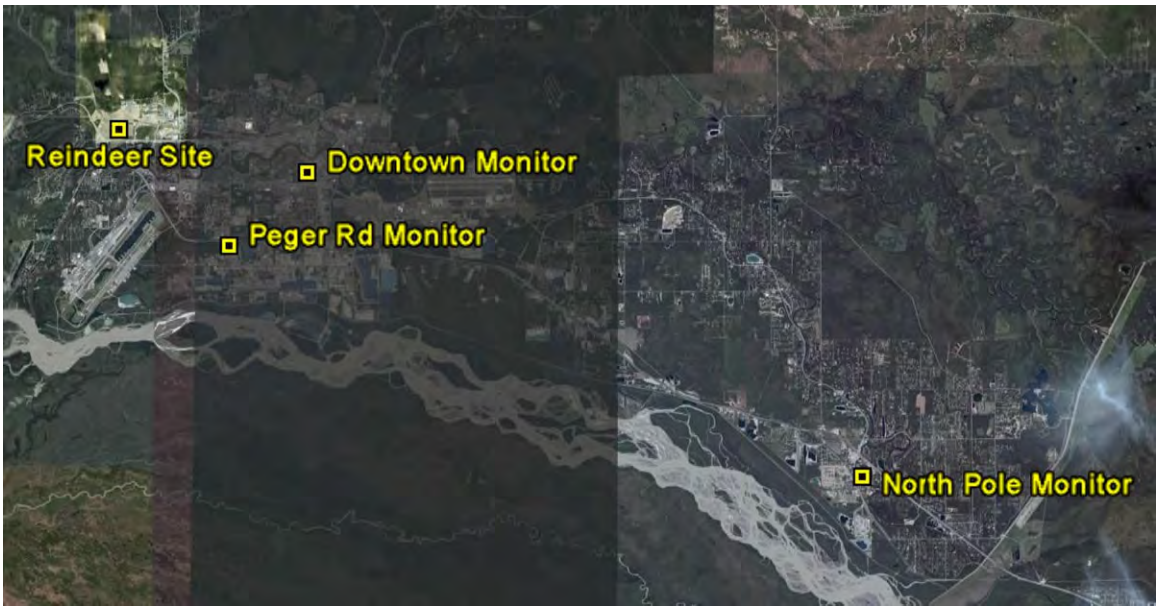
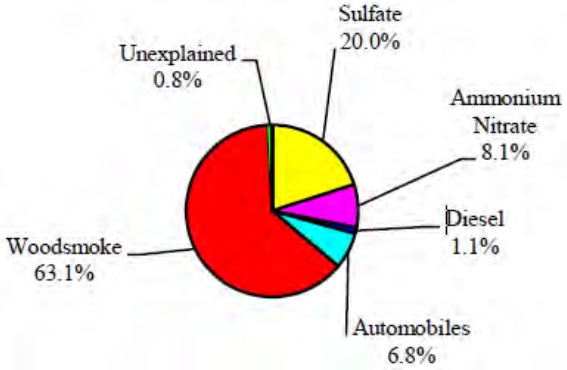
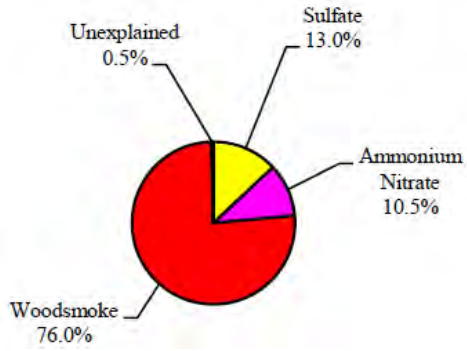


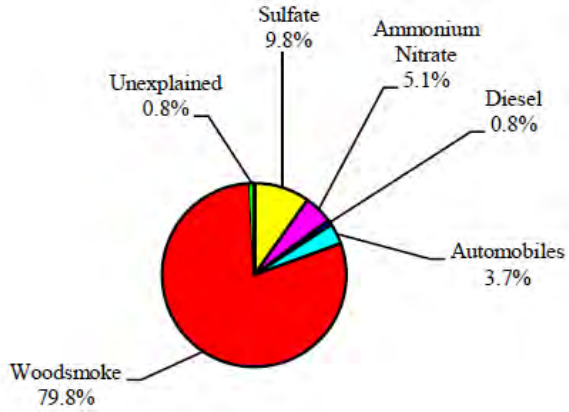
Figure 2
Emission Source Contribution Estimated from CMB Analysis



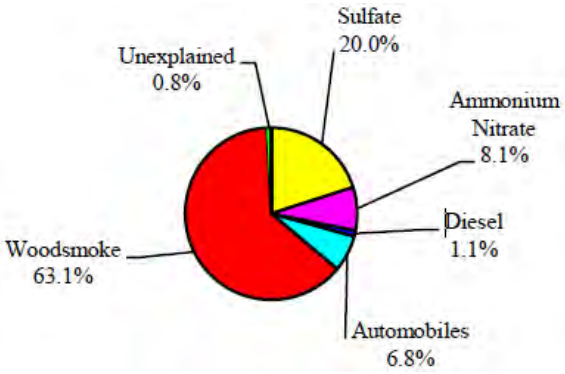
State Building



RAMS



North Pole



Peger Road

ammonium nitrate comes from ammonia and nitrogen oxide (NOx) emissions. Sources of ammonia include waste treatment and motor vehicles. NOx emissions come from all combustion sources.

The Carbon-14 analysis was performed on a limited sample of measurements at the three new sites and more extensively for the State Office Building. The results, which are expressed as a range, found that wood smoke values stretch from a low of 34–62% at Peger Road to high of 50–60% at North Pole. While these estimates of the wood smoke contribution are lower and more variable than the CMB results, they also support the finding that wood smoke is a major source of the $PM_{2.5}$ mass measured at each of the monitoring sites in Fairbanks.

Levoglucosan was found to comprise 3% of the $PM_{2.5}$ mass measured at the State Office Building, 2% at Peger Road, and 6% at the North Pole and the Reindeer sites. These values are consistent with and generally higher than those measured in other urban areas in the northwest of the U.S., including Seattle and Spokane, WA and Missoula and Libby MT. CMB analyses for the latter communities estimated the wood smoke contribution to $PM_{2.5}$ to range from 56–82% of the wintertime $PM_{2.5}$ mass.

In summary, the contribution of wood smoke to $PM_{2.5}$ mass varies depending on the method used to prepare the estimate and the location. Nevertheless, three separate chemical analysis methods consistently estimate wood smoke to be a very significant source of $PM_{2.5}$ in all areas of Fairbanks and to be potentially the largest single contributor.

Measurements of $PM_{2.5}$ collected at monitors in Fairbanks during the entire 2009/2010 winter are currently being analyzed (i.e., chemically speciated). The results will be forwarded to the University of Montana for source apportionment analysis shortly; findings from that effort are expected to be available in October. For additional information on the results presented above, please contact Dr. James Conner at the Borough.

###

Reconciling Trends in Carbon Measurements for Fairbanks 2006-2010

Summary

A February 2009 change from the Met One SASS sampler using a NIOSH analysis methodology to the URG3000N sampler using an IMPROVE analysis methodology has resulted in an inconsistency in the particulate carbon measurement history for Fairbanks, Alaska. In order to develop a consistent history of speciated particulate matter for the region, these two carbon data sets must be reconciled. A number of journal articles and presentations have attempted to address this issue across a number of regions (Cheng 2011a, Chow 2010, Frank 2010, Schichtel 2010). Reconciliation of the total carbon (TC) and organic carbon (OC) across measurement techniques and analysis techniques proves difficult due to sampling artifacts and analysis methodology differences (McDow 1990). The elemental carbon (EC) discrepancies only occur due to the latter (McDow 1990). The design period for Fairbanks spans the years 2006 through 2010. Due to the long history of measurements with the Met One SASS sampler using a NIOSH analysis protocol, the continued usage of the Met One SASS sampler at other sites in the region, and given that the modeling episodes both occur in 2008, the best practice would be to correct the newer URG3000N IMPROVE measurements of EC/OC to reflect NIOSH-like values.

Sampler Differences

A comparison of the two samplers used in Fairbanks has shown that the higher face velocity and smaller filter area of the URG3000N reduce a positive artifact present in the SASS sampler from adsorbed OC. The positive artifact reduction reduces the overall total carbon. However, the higher face velocity of the URG3000N also results in a negative artifact due to evaporative losses of semi-volatile materials (McDow 1990). The overall difference in carbon is therefore a reduction of a positive artifact from SASS and introduction of a negative artifact from URG3000N. The magnitude of these changes is difficult to assess even with collocated samples (Chow 2010). There are multiple sites in and around Fairbanks that continue to use the Met One SASS sampler. At this time, however, there is no quantitative comparison of the magnitude of these sampling artifacts for Fairbanks, so direct comparisons cannot be made between the samplers at different sites. A value judgment of which sampler is best suited for conditions in Fairbanks is not possible as the URG3000N is not collocated with any of the Met One SASS samplers.

Analysis Differences

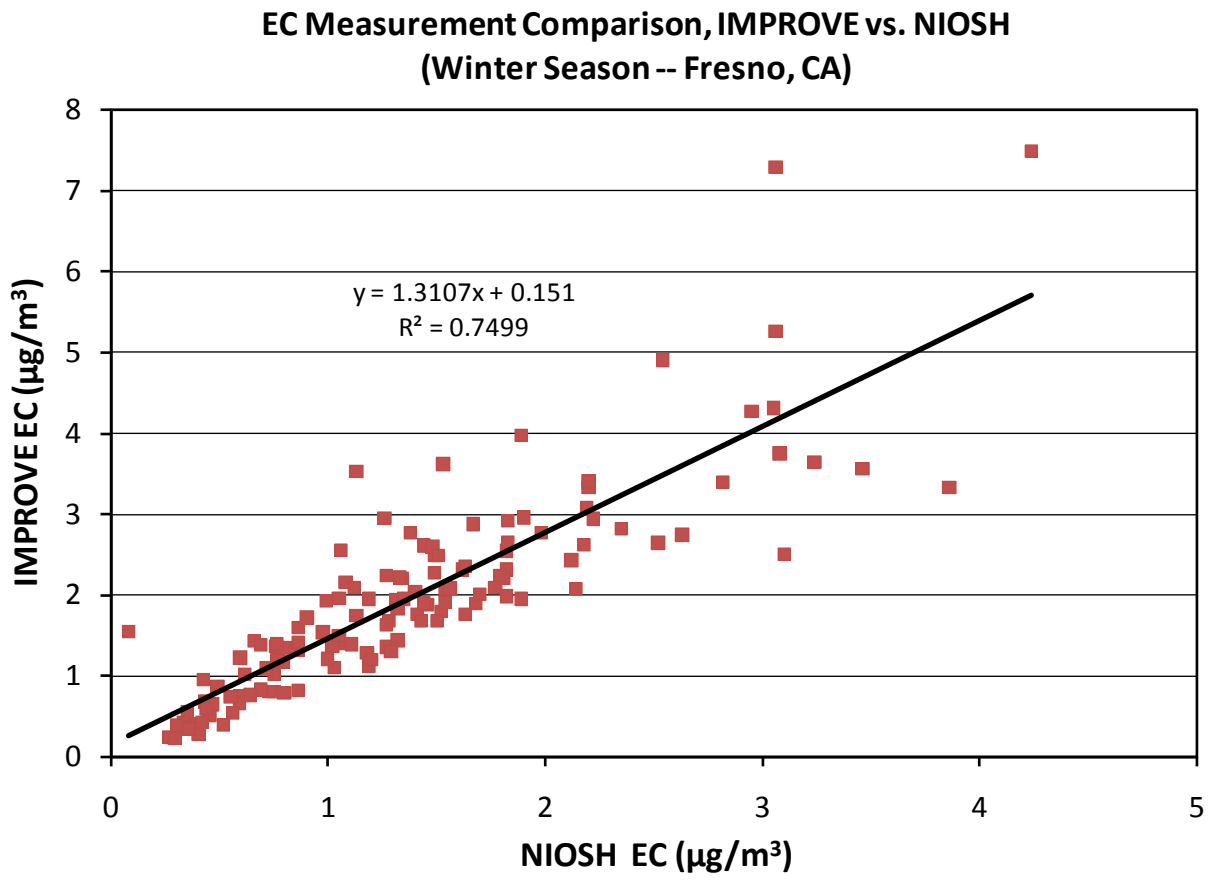
A further complication is the ongoing debate about the merits of the NIOSH and IMPROVE protocols for representing EC and OC. While the OC can be influenced by the sampler itself due to adsorption and evaporation, the EC should remain relatively the same between two samplers (McDow 1990). However, the EC (as well as OC) will vary depending on the analysis technique employed (IMPROVE, NIOSH, TOT, TOR). The literature suggests that the EC shift seen when comparing NIOSH and IMPROVE techniques is largely driven by the products of wood

combustion (Schauer 2003, Chow 2001). The choice of TOR versus TOT can also have a significant impact on the measurement of EC (Chow 2004, Cheng 2011b).

Proposed Changes

Using collocated IMPROVE and CSN sampler data from Fresno, CA from the years 2004 through 2009 an IMPROVE to NIOSH correction factor for EC has been developed. Figure 1 shows the EC concentrations as measured for the winters in Fresno, CA. The emissions source mix for Fresno, CA in the winter seems the most comparable to Fairbanks as it does include a significant amount of wood smoke as compared to other sites with collocated samplers. The conversion for IMPROVE EC to NIOSH EC would follow the equation y=1.3107x + 0.151, where y is the IMPROVE EC and x represents NIOSH EC. In this context, IMPROVE implies the use of the URG3000N sampler and NIOSH implies the Met One SASS. Corrected EC values would then be used to derive the corrected OC.

Figure 1
EC Correlation between the Collocated IMPROVE and CSN Samplers



Conclusion

Considering the unsettled nature of these debates, it seems the best course of action is to rely on the weight of the historical measurement data which used the Met One SASS sampler and NIOSH protocol to correct the newer IMPROVE data. This sampler and analysis technique were employed for the bulk of the design period 2006 through early 2009 and also cover the episodes in 2008 for which CMAQ simulations are already underway. An additional concern is the ability to compare the carbon measurements at the downtown site with the other monitor sites in and around Fairbanks. At present, there are no other sites using the URG3000N with IMPROVE analysis in the region. Adjusting the IMPROVE carbon measurements represents a more efficient means of comparing data gathered at multiple sites in Fairbanks. Considering that EC should differ only from the change in analysis protocol, not the change in samplers, an EC correction factor should be devised based on collocated sampler data from a region with comparable sources and meteorology to Fairbanks. Thus far the best data set appears to be from a site in Fresno, CA. The corrected EC can then be used to derive a corrected OC concentration for the period of 2009 through 2010. Going forward, the Fairbanks North-Star Borough will maintain a collocated Met One SASS sampler at the downtown site. Filters from the collocated sampler will be analyzed using the NIOSH protocol to provide a basis for comparing against the URG3000N IMPROVE sampler as well as other monitor sites in Fairbanks.

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Fairbanks North Star Borough $PM_{2.5}$ Non-Attainment Area CMAQ Modeling

First "Quarterly" Report Phase II

Reporting Period: January 1, 2012 – April 30, 2012

Project: 398831 CMAQ-DEC 2012

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1. Background

Due to deadlines that the Alaska Department of Environmental Conservation (DEC) had to meet with respect to the development of the Fairbanks State Implementation Plan (SIP), DEC had postponed the due date for the Quarterly Report. They wanted to provide time to UAF to perform investigations on questions DEC personnel needed to answer at their deadlines. Various phone conferences were held where UAF reported on the progress and the results of the investigations performed to answer DEC's urgent questions. Due to this DEC approved and requested later submission of the Quarterly Report, this report covers a longer period than three month.

The Community Multiscale Air Quality (CMAQ) model version 4.7.1 was adapted to simulate the $PM_{2.5}$-concentrations in Fairbanks, the interior of Alaska in phase I (Mölders and Leelasakultum 2011). In the time covered by the current report, we applied the adapted CMAQ to a two-week episode in January/February, 2008 and November, 2008 each for further improvement and investigations and understanding of the $PM_{2.5}$-situation in the Fairbanks nonattainment area.

The episode January, 2008 was first used to evaluate the performance of the CMAQ model. According to the final report of phase I (Mölders and Leelasakultum 2011), the model was configured to use the global mass-conserving Yamartino advection scheme, the eddy vertical diffusion module, the Carbon Bond Five (CB05) lumped gas phase chemistry mechanism which using the Euler Backward Iterative (EBI) as solver, the AERO5 aerosol mechanism, the photolysis inline module and the Asymmetric Convective Method (ACM) cloud processor to compute convective mixing (cloud_acm_ae5).

Several changes were made to the CMAQ code with the purpose of improving the prediction of $PM_{2.5}$-concentrations and for representing the Fairbanks domain conditions:

1. The default initial condition and boundary conditions were replaced with the developed Alaska specific initial and boundary condition.
2. The dry deposition code were modified to made the dry deposition occurred in the tundra-typed land-use, which is the major type of land-use in Fairbanks domain. Some other changes related to the dry deposition include the adjustment for the resistance to snow of SO_2, the soil resistance, the canopy cuticle resistance to be functioning with the low temperature, reducing of wet canopy resistance (see Mölders et al. 2011), reducing and scaling the area-to-volume ratio for buildings according to the urban fraction of Fairbanks, and increasing the pH value for snow/rain/wet surfaces to the average values found in Alaska.
3. The code in Meteorology-Chemistry Interface Processor (MCIP) version 3.6 for the minimum mixing height constant was reduced in accord with the observations in Fairbanks, and the minimal stomata resistances were also replaced.

4. The lowest and highest eddy diffusivity coefficients, which play an important role for the vertical distribution of concentrations, were decreased by half, and scaled according to the fraction of land-use.
5. The wind-speed in the valley of domain was reduced by half for calibrating the over-estimation of the simulated wind-speed by WRF.

The evaluations of the performance of the Alaska adapted CMAQ from phase I considered the January/February episode. It showed that the mean average of 24h-average $PM_{2.5}$-concentrations at the grid-cell that holds the official monitoring site is 38.07μg/m^3, whereas the mean average of observed data is 41.7μg/m^3. The ratio of means (sim/obs) is 1.13. The mean bias, mean fractional bias, mean error and mean fractional error are -3.76μg/m^3, -0.32%, 13.13μg/m^3, 34.51%, respectively. The CMAQ model overestimated during January 31 to February 2, and underestimated during February 5 to February 9. The correlation coefficient between the observed and simulated 24h-average $PM_{2.5}$-concentrations is 0.39 for 13 pairs of data. Bugle plots and soccer plots indicate weak performance on February 2 and February 8, 2008 (AKT). The Alaska adapted CMAQ model simulated the speciation of total dry $PM_{2.5}$ as 48% organic carbon (OC), 6% elemental carbon (EC), 4% nitrate, 3% ammonia, 2% sulfate and 36% others. The observed speciation of total dry $PM_{2.5}$ was 41% OC, 6% EC, 5% nitrate, 9% ammonia, 20% sulfate, and 19% others. The model obviously underestimated the sulfate compositions and ammonium, slightly overestimated OC and had very good performance for nitrate and EC.

Based on the CMAQ's output in phase I, Sierra Research Inc. had improved the emission input data, and Penn State had improved the meteorological input data for the CMAQ. Hereafter, we referred to the January/February episode data before the improvements as January v1 and we referred to the January/February episode data after the improvements as January v2. This first quarterly of Phase II will cover:

1. The simulations of the adapted CMAQ for the January v1 episode including the Relocatable Air Monitoring System (RAMS) data, $PM_{2.5}$ speciation and the sensitivity tests we performed
2. The comparison of simulations and the model performance for the November episode performed with and without reduction of the wind-speed in the valleys, including the simulations for $PM_{2.5}$ speciation and various sensitivity tests
3. The comparison of simulations and the model performance for the January v2 episode with and without CMAQ modifications
4. The statistical performance of the November and January v2 episodes with the CMAQ modifications and the performance evaluation for the $PM_{2.5}$-speciations in the January v2 episode
5. The process analysis results for the November episode and January v2 episode

2. Activities

2.1 Evaluations of the Alaska adapted CMAQ for the January v1 episode with RAMS data, $PM_{2.5}$ speciation and the sensitivity tests

The significance tests in the final report of phase I showed that the simulated and observed 24h-average $PM_{2.5}$-concentrations had statistical differences due to the low sample number. Therefore, the Relocatable Air Monitoring System (RAMS) data of the $PM_{2.5}$-concentrations were also included for evaluating the adapted CMAQ performance. The locations of the RAMS (Fig. 1) were Julie Shelton's house (N 64.88º W147.68º) for January 18 to January 24, David Leone's house (N 64.80º W147.45º) for January 24 to January 31, Anne Ruggle's house (N 64.88º W147.82º) for January 31 to February 7, Alaska Rubber (N 64.80º W147.70º) for February 7 to February 14 (see Fig. 1).

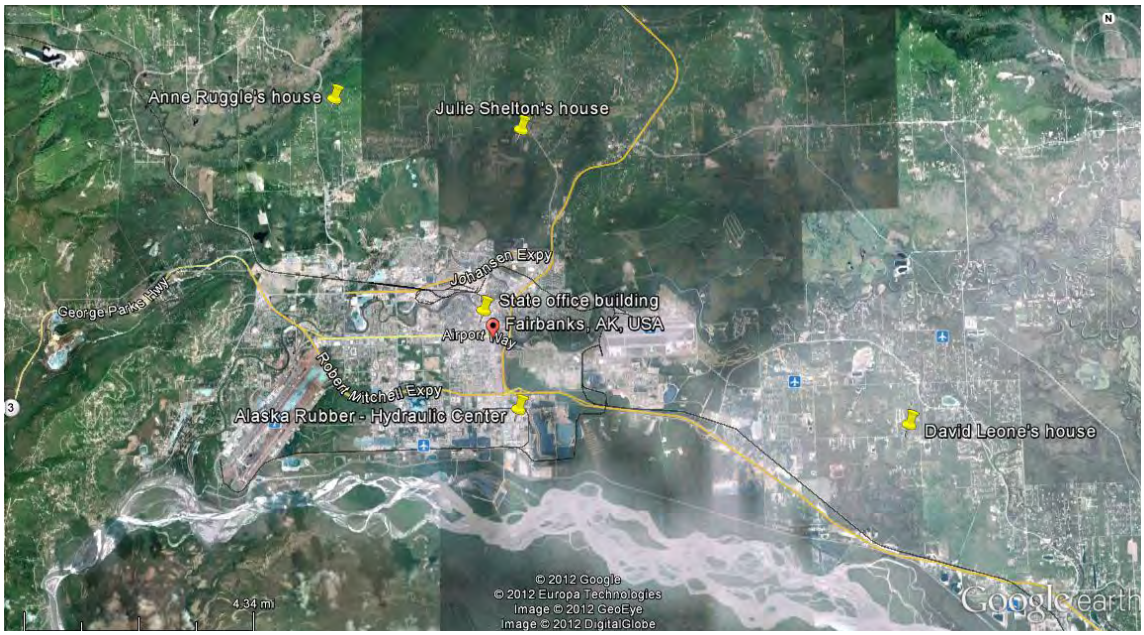


Fig. 1 Locations of the Relocatable Air Monitoring System (RAMS) and the State Building site.

The temporal evolution of the observed RAMS $PM_{2.5}$-concentrations were compared with the simulated $PM_{2.5}$-concentrations (Fig.2). The RAMS data suggested some spatial and temporal offsets during the local extremes, for instance, the adapted CMAQ model underestimated during January 26-January 28, and during February 8-10 (Fig. 2).

Combining the simulated and observed data of 24h-average $PM_{2.5}$-concentrations from both State Building and RAMS sites led to the increase of correlation coefficient to 0.51 for 29 pairs of data. There is no statistically significant difference at the 95% confidence level for both hourly and daily data. The scatter plot between the simulated and observed 24h-average $PM_{2.5}$-concentrations show the agreement of majority within the factor of two (Fig.3). For those pairs of data, that have agreement less than a factor of three, are the RAMS on January 27, February 2,

8, 9, which are sites above the inversion. Possibly, this is due to sub-grid scale effects, which are not resolved by the model.

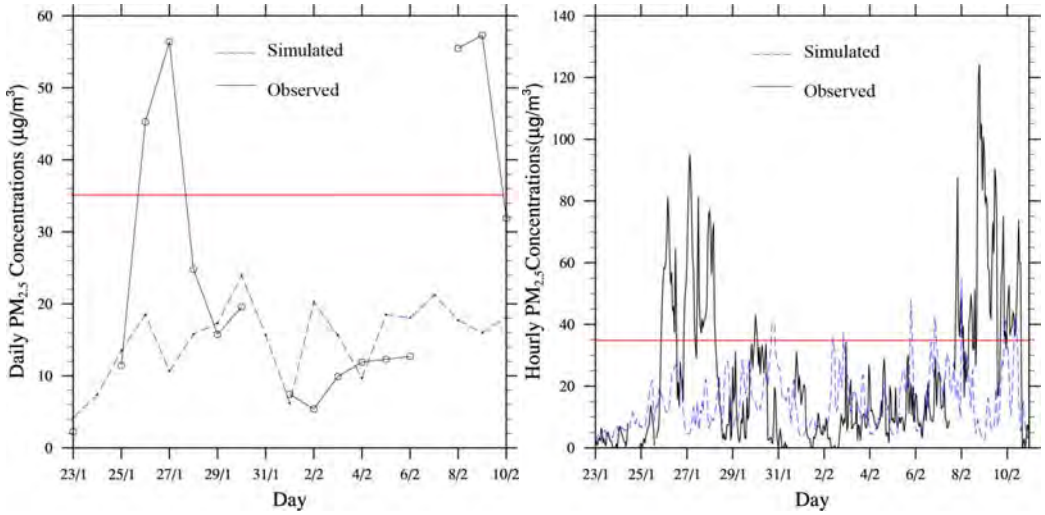


Fig. 2 Time series of the adapted CMAQ simulated (blue dashed line) and RAMS observed data (black solid line) for (a) 24h-average $PM_{2.5}$-concentrations and (b) hourly $PM_{2.5}$-concentrations (right) for January v1

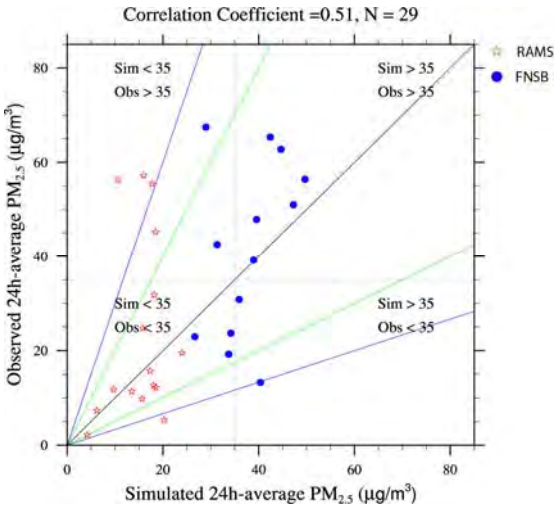


Fig. 3 Scatter plots of 24h-average $PM_{2.5}$-concentrations for January v1. The blue dots and red stars represent the data for the State Building and RAMS sites, respectively. The green line indicates the factor of two and the blue line indicates the factor of three agreement between simulated and observed values. Note that 30% of agreement within a factor of two is considered good performance (Chang and Hanna 2004).

The bugle plots and soccer plots show the similar results as the scatter plots i.e. that most pairs of data outside the performance criteria (see Boylan and Russell 2006 for a definition of the criteria) are from the RAM sites located above the inversion (Fig. 4). Note that it is common

knowledge that models like WRF have difficulties capturing inversions in very complex terrain as they use the mean terrain height within a grid-cell as the representative height, while the measurements capture the actual terrain impacts (Mölders and Kramm 2010). At the State Building site, there are two pairs outside the performance criteria. They occurred on January 31 and February 2, when the model overestimated the $PM_{2.5}$-concentrations and the observed data were extremely low.

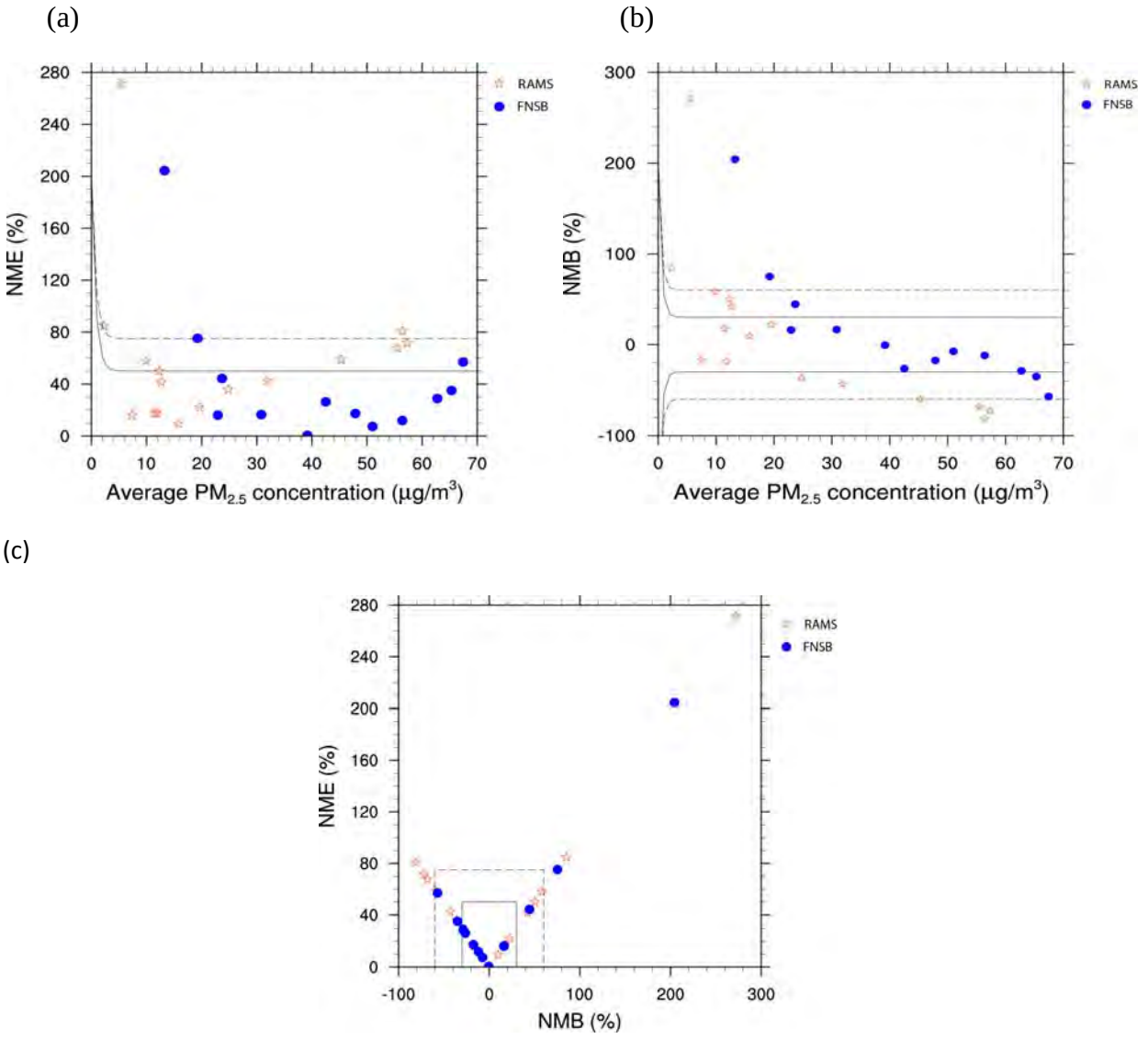


Fig. 4 Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-concentrations and (c) soccer plot of normalized mean errors and biases all determine with respect to the observations at the State Building site (blue dots) and RAMS sites (red stars) for January v1. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

The observed temperatures during January 31 to February 2 were the period when temperature rebounded slightly (PennState final report, 2011). WRF estimated too low surface temperatures on these days, for example, the WRF-simulated hourly surface temperature at 15 UTC on January 31 is about -30ºC (Fig. 5) in the Fairbanks nonattainment area, whereas the observed temperature at the Fairbanks International Airport at that time was about -24ºC. The too low temperatures would lead to enhanced gas-to-particle conversion than actually would occur with the correct temperature and lead to further over-prediction of the $PM_{2.5}$-concentrations at the State Building site.

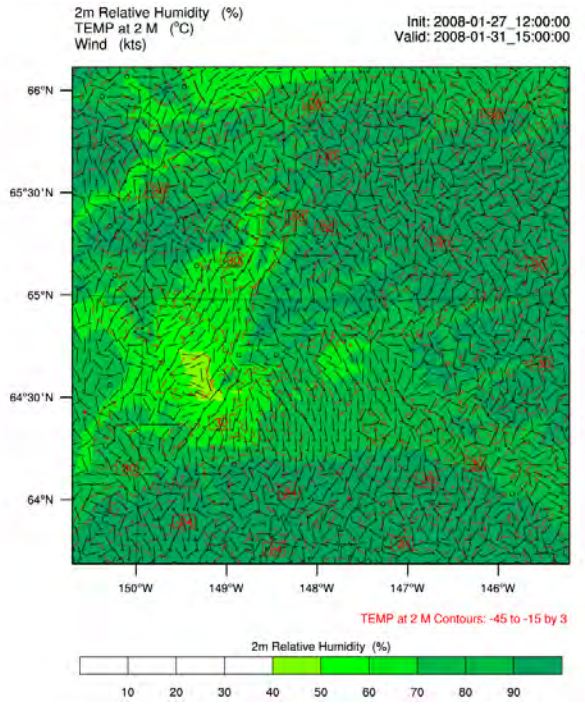


Fig. 5 Example of WRF simulated 2m temperatures (color), 2m relative humidity (contours) and 10m wind-speeds (barbs) in the Fairbanks domain on January 31 at 1500UTC.

The performance of the adapted CMAQ in simulating the $PM_{2.5}$-compositions was evaluated. The six days with pairs of observed and simulated $PM_{2.5}$-compositions were compared in bar charts and scatter plots (Figs. 6, 7). The adapted CMAQ model predicted best for OC and EC, which have high concentrations and make up large fractions of total $PM_{2.5}$. Simulated and observed sulfate and ammonium fail to agree within a factor of three. The bugle plots and soccer plots show similar results as the scatter plots, i.e., that most pairs of species data that fall outside the performance criteria are sulfate, ammonium and chloride (Cl) (Fig. 8). The Cl outlier occurred in the November episode as well (see later discussion), therefore we increased the initial and background Cl-concentrations at the lowest level according to the IMPROVE data in our simulations of January v2 and the November episode. The improved Cl-profiles are given in Appendix A. The NH_4-outlier may be due to underestimation of the NH_3 emissions (for a discussion on potential reasons for the NH3-emission underestimation see Mölders et al. (2012).

The adapted CMAQ underestimated SO_4 by five times the observed value, which requires improvement and further investigations. Some first results of these investigations are discussed later in this report, while other investigations are ongoing.

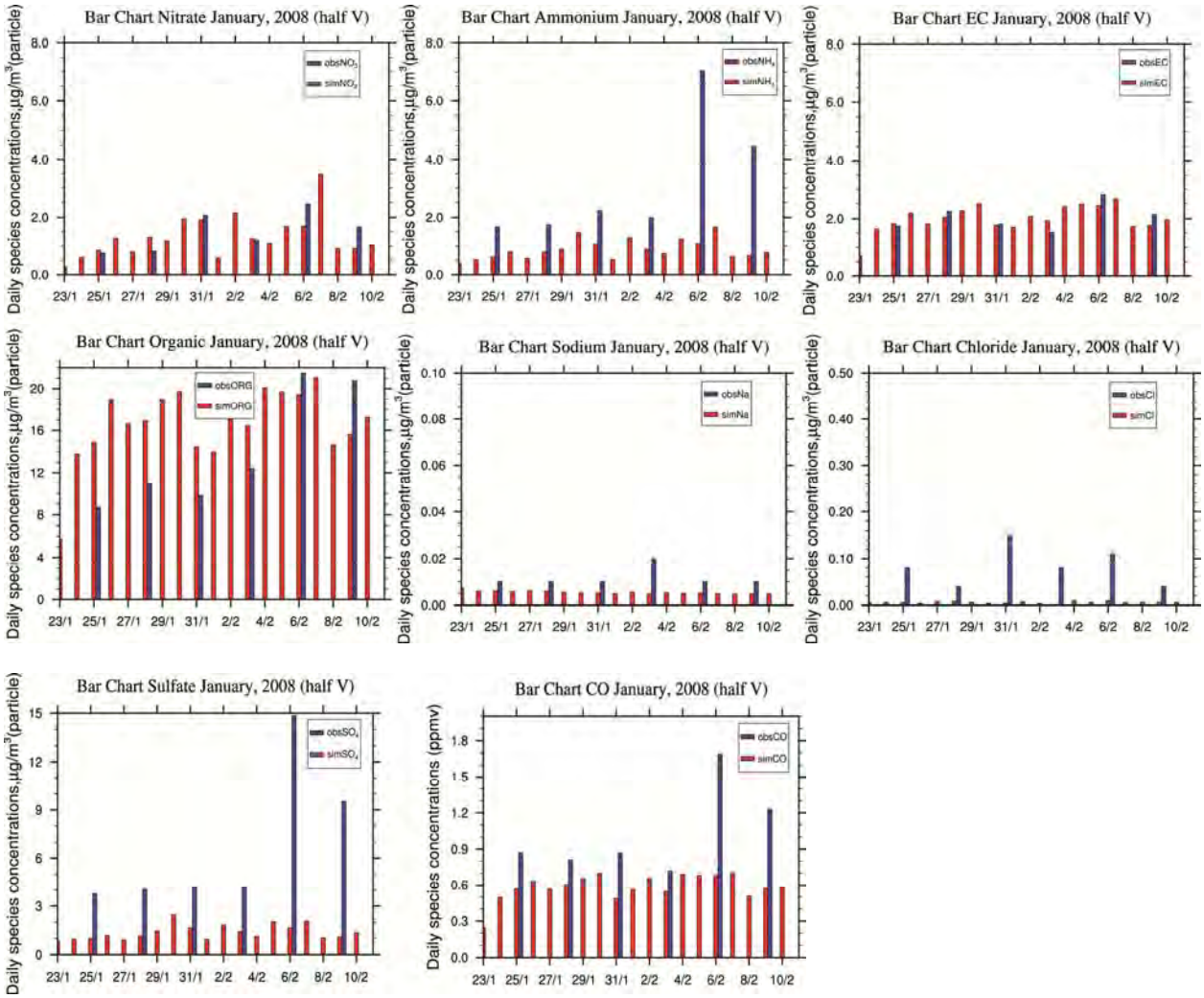


Fig. 6 Bar charts of observed (blue) and simulated (red) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4, CO for January v1. Note that this episode was run with 50% reduction of the near-surface wind speeds in the valleys (see Mölders and Leelasakultum 2011 for details on the simulation setup)

The 24h-average $PM_{2.5}$-concentrations at the State Building site were simulated for the case of without point source emissions, gas chemistry, aerosol chemistry, chemistry and compared with the observation data and the simulations, which include everything (reference/normal adapted CMAQ simulation), Fig. 9. It can clearly be seen that chemistry played a lesser role for the $PM_{2.5}$-concentrations than the emissions from point sources. The simulations wherein the point source emissions were turned off led to a decrease in $PM_{2.5}$-concentrations at State Building site of on average 3.9µg/m^3 (11%), whereas the simulation with turned off chemistry, aerosol

chemistry and gas chemistry led to decreased $PM_{2.5}$ concentrations by on average 2.0 (6%), 2.0 (6%) and 1.2µg/m^3 (4%), respectively. Note that in the adapted CMAQ model, turning off the aerosol chemistry resulted in the same results as turning off all chemistry. This behavior may be a hint that a process is missing in aerosol chemistry and/or aerosol chemistry is not taking place as too much water is in the ice phase.

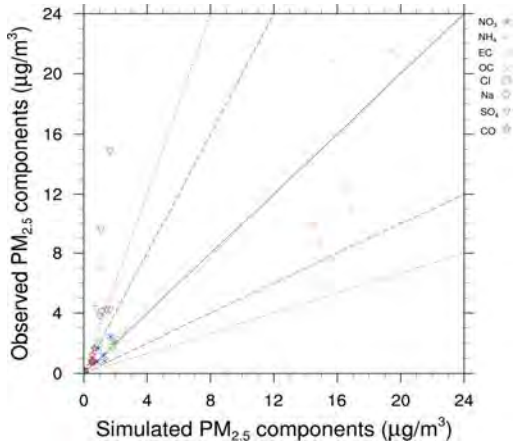


Fig. 7 Scatter plot of simulated and observed 24h-average $PM_{2.5}$-composition for January v1. See Mölders and Leelasakultum (2011) for details on the simulation setup

On the day which simulated the highest concentrations (49.7µg/m^3 on February 7), the chemistry process had the maximum contribution to the 24h-average $PM_{2.5}$ concentrations 4.9µg/m^3(10%) at the State Building. In this 4.9µg/m^3, the aerosol chemistry process contributed 3.9µg/m^3 (8%) to the total aerosol production of chemistry process.

(a) (b)

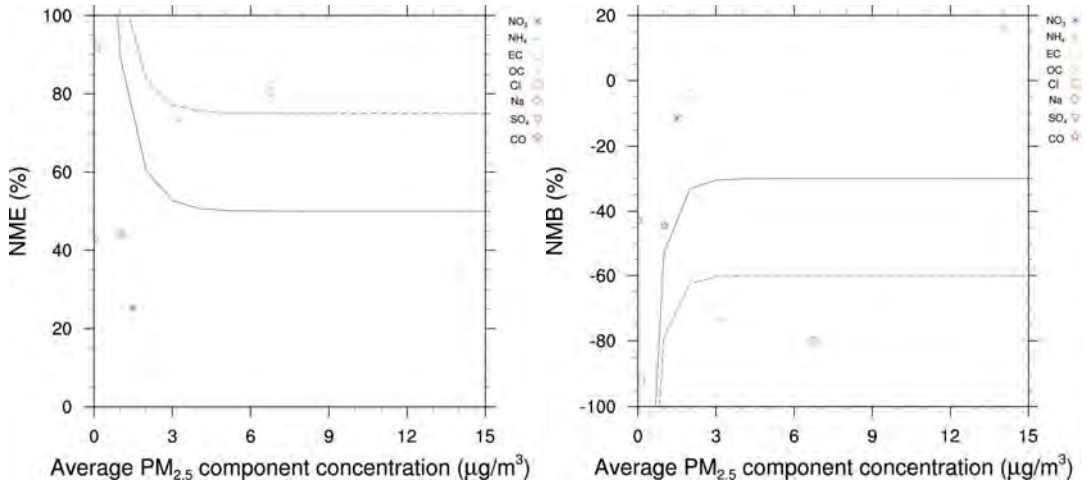


Fig. 8 continued on next page

(c)

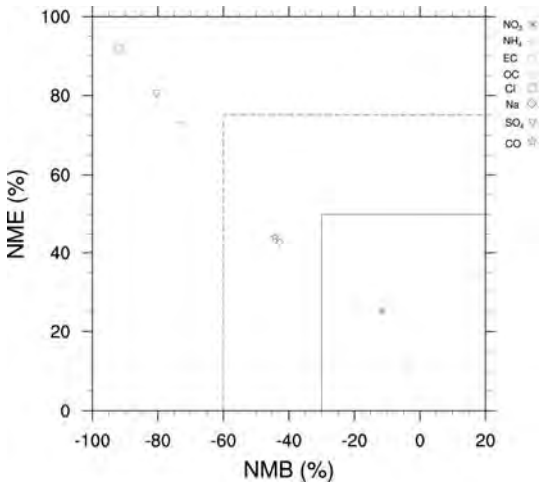


Fig. 8 Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-composition and (c) soccer plot of normalized mean errors and biases all determined with respect to the observations at the State Building site for January v1. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

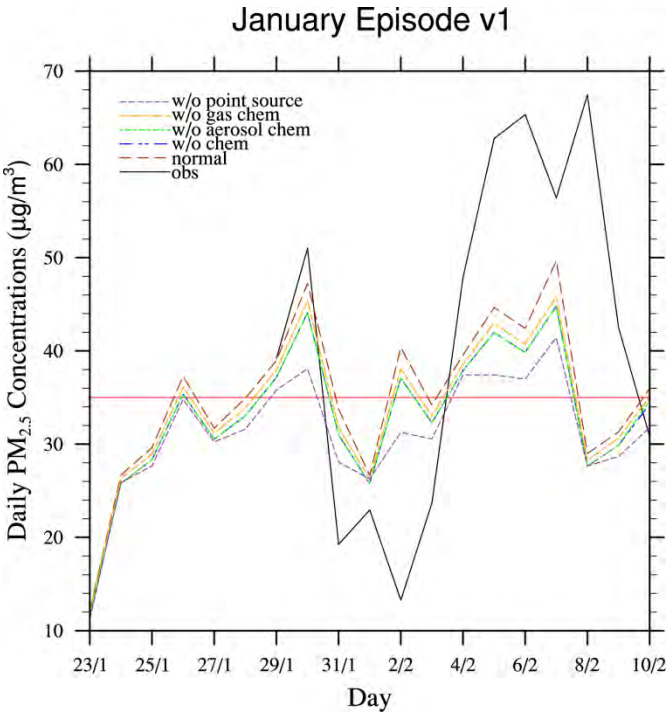


Fig. 9 Time series of observed (black solid line) and adapted CMAQ simulated data as obtained by various sensitivity tests that where performed without consideration of point sources, without consideration of gas chemistry, without consideration of aerosol chemistry, without consideration of chemistry and with consideration of all processes and emissions (reference/normal) for the 24h-average $PM_{2.5}$-concentrations at the State Building for January v1. The red solid line indicates the National Ambient Air Quality Standard of 35µg/m^3.

The highest and the second highest contribution from point source emission of 9.2 and 9.1µg/m^3 was simulated on January 30 and February 2. The percent contributions from point source emissions on these two days are 19% and 22%, respectively.

2.2 Comparison of simulations and their performance for the November episode with and without reduction of wind-speeds in the valleys

The November episode covers November 2 to November 16, 2008. The emissions developed for the November episode were updated by Sierra Research Inc. for the emissions from mobile sources, and include the emissions from airports. The comparison of the spatial distribution of emissions in the January v1 and November episode showed that the magnitudes of $PM_{2.5}$-emissions in the November episode are higher for the area north of the Fairbanks nonattainment area (Fig.10).

(a) (b)

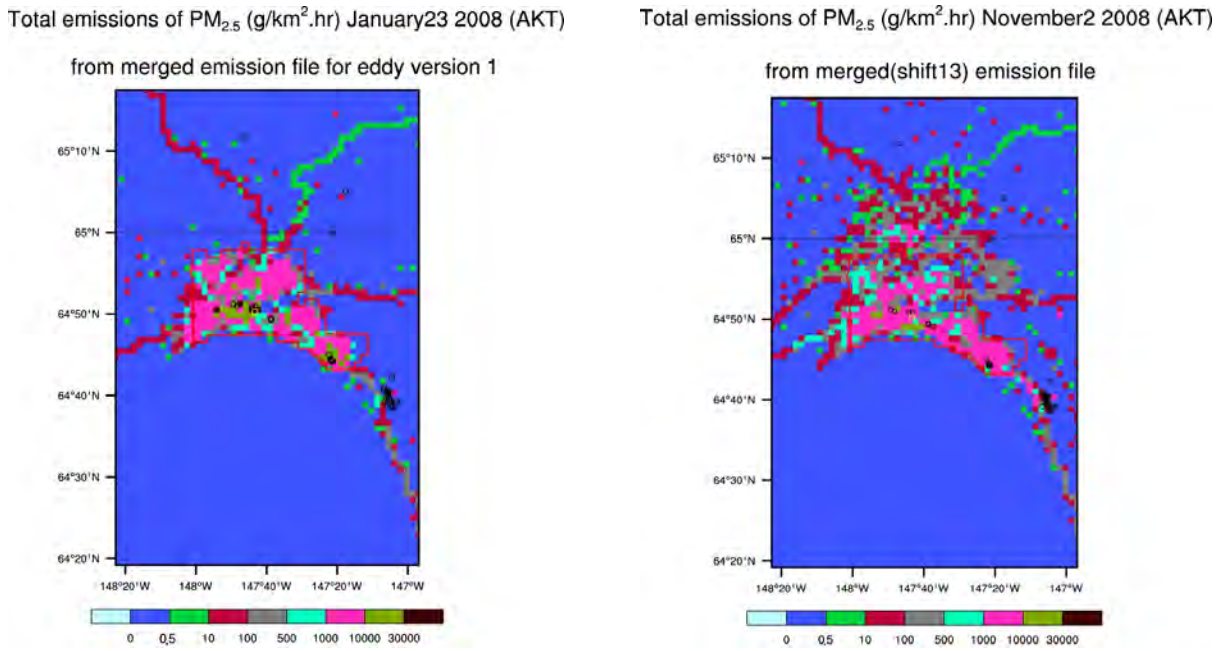


Fig. 10 Example of zoom in on the emissions as obtained from the Sierra Research Inc. emission inventory for Fairbanks for the (a) January v1 and (b) November episode. The red polygon indicates the Fairbanks nonattainment area.

In the January v1 episode, the wind-speeds in the valleys were reduced by half in order to increase the simulated $PM_{2.5}$-concentrations at the State Building site. As discussed by Mölders and Leelasakultum (2011) this reduction violates the continuity equation and was only a test to examine whether the strong overestimation of wind-speed is a potential cause for underestimation of $PM_{2.5}$-concentrations. Note that overestimation of near-surface wind-speeds

is a well known problem common to all meteorological models for simulations in areas with stagnant air conditions like in the Fairbanks area (see (Zhao et al., 2011), Mölders et al. 2012 for a discussion).

Our investigations showed that reducing the wind-speed by half is not required for the November episode as the emissions for November episode had been updated and increased by Sierra Research Inc. We therefore compare here the simulation results of the case study with reduction of wind-speed by half and the case study that used the original WRF-simulated wind-speeds.

The temporal evolutions of 24h-average $PM_{2.5}$-concentrations show that the case with reduction of wind-speed by half provides higher $PM_{2.5}$-concentrations at State Building site by on average 9.8µg/m^3 than the adapted CMAQ simulation with the original wind-speed. The impacts of the wind-speed reduction on the $PM_{2.5}$-concentrations varied with time. The highest difference in $PM_{2.5}$-concentrations was 14.1µg/m^3 on November 15, 2008 and the lowest differences in $PM_{2.5}$-concentrations were 6-7µg/m^3 during November 5 to 6 and 9 to 11 (Fig. 11). The simulated hourly $PM_{2.5}$-concentrations in the adapted CMAQ simulation with reduction of wind-speeds showed the higher concentrations as well (Fig. 12). The reduction of wind-speed during the relatively calm wind-periods probably resulted in the little differences.

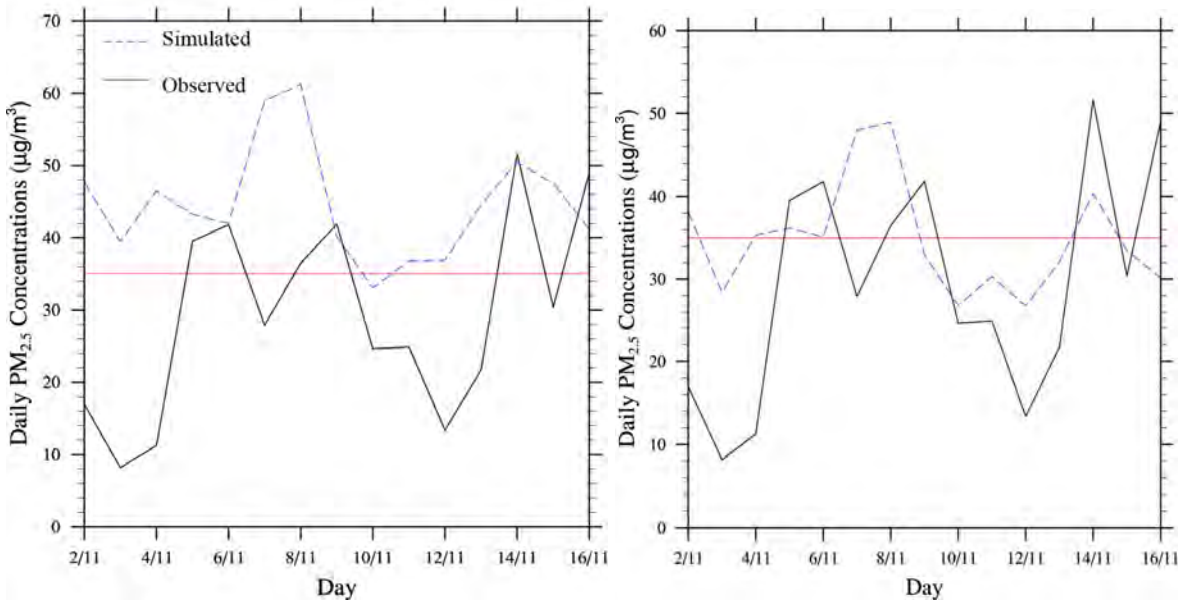


Fig. 11 Time series of simulated (blue dashed line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations as obtained with the adapted CMAQ simulation that used reduced wind-speeds in the valleys (left) and the adapted CMAQ simulation that used the original wind-speed from WRF (right) during the November episode at the State Building site.

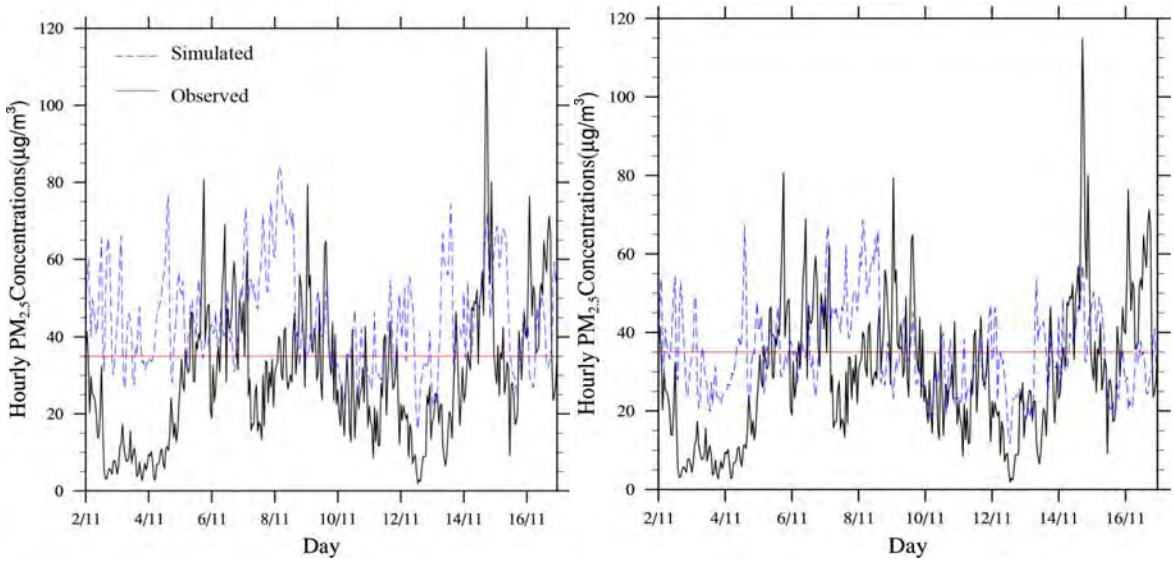


Fig. 12 Like Fig. 11, but for hourly $PM_{2.5}$-concentrations.

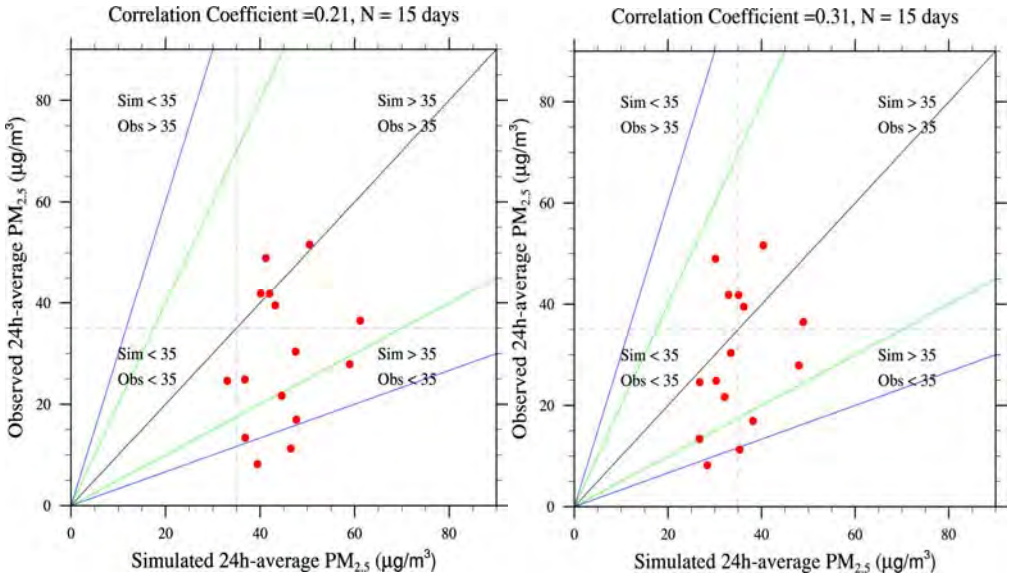


Fig.13 Scatter plots of 24h-average $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulation with reduction of wind speed (left) and the adapted CMAQ simulation with the original WRF simulated wind-speeds (right) for the November episode. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

The scatter plots of 24h-average and hourly $PM_{2.5}$-concentrations obtained from the adapted CMAQ simulations with reduction of wind-speed and the adapted CMAQ simulation using the original WRF simulated wind-speeds have the correlation coefficients of 0.21and 0.31, respectively (Fig. 13). The reduction of the wind-speed in the valleys resulted in six pairs of data outside the factor of two agreement. For the adapted CMAQ simulations with the original WRF-

simulated wind-speed, there were four pairs of data outside of the factor of two agreement. The scatter plot of the hourly $PM_{2.5}$-concentrations obtained by from the adapted CMAQ simulation with the original WRF wind-speeds also shows a better correlation coefficient (0.2) for the 360 hours of data (Fig. 14).

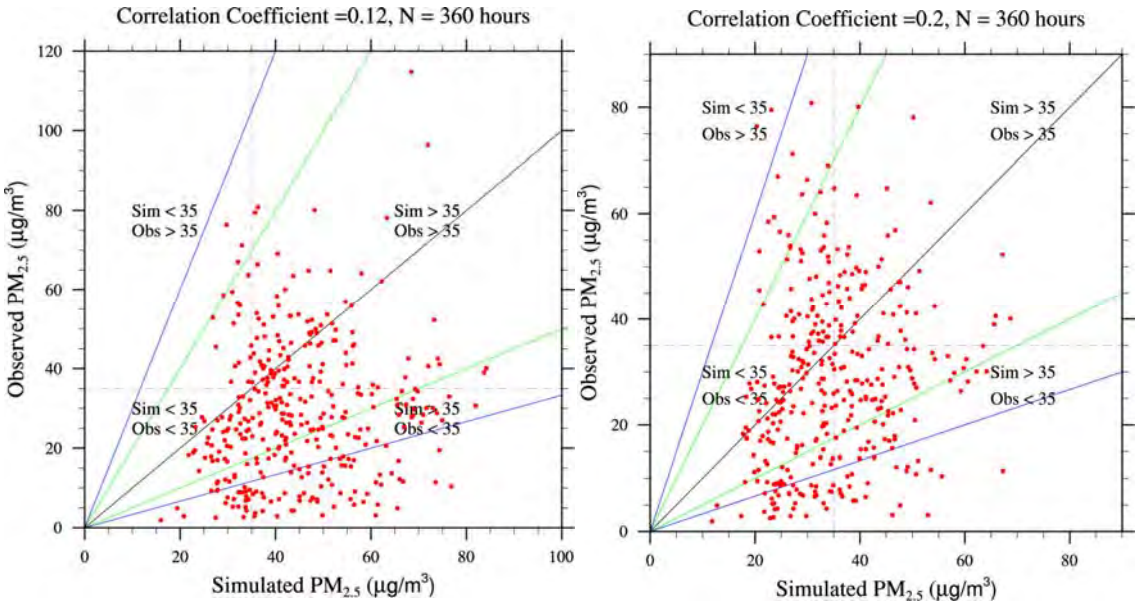


Fig.14 Scatter plots of hourly $PM_{2.5}$-concentrations as obtained from the adapted CMAQ simulations with reduction of wind-speeds in the valleys (left) and the adapted CMAQ simulation with the original WRF simulated wind-speed (right) for the November episode. The green line indicates the factor of two and the blue line indicates the factor of three agreement.

The bugle plots and soccer plots show that the adapted CMAQ simulation with the reduction of wind-speed has seven days outside the criteria, while the adapted CMAQ simulation with the original WRF-simulated wind-speeds has five days outside the criteria (Fig. 15-17).

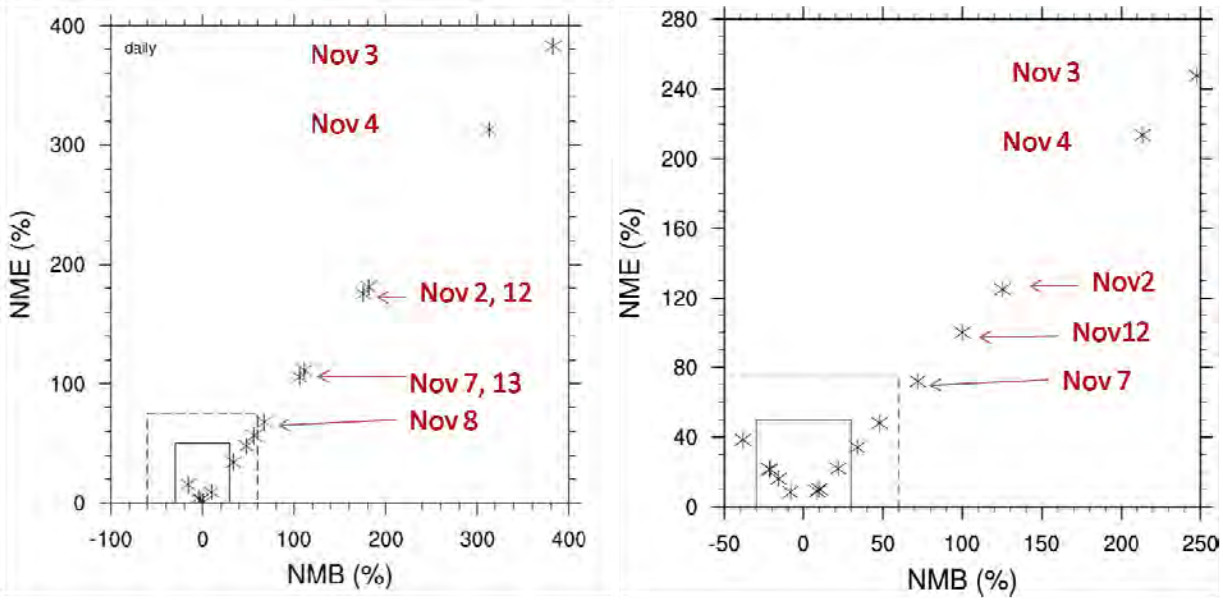


Fig. 15 Soccer plots of normalized mean errors and biases all determined with respect to the observations at the State Building site as obtained from the adapted CMAQ simulations with reduction of wind speed (left) and the adapted CMAQ simulations with the original WRF-simulated wind-speeds (right) for the November episode.

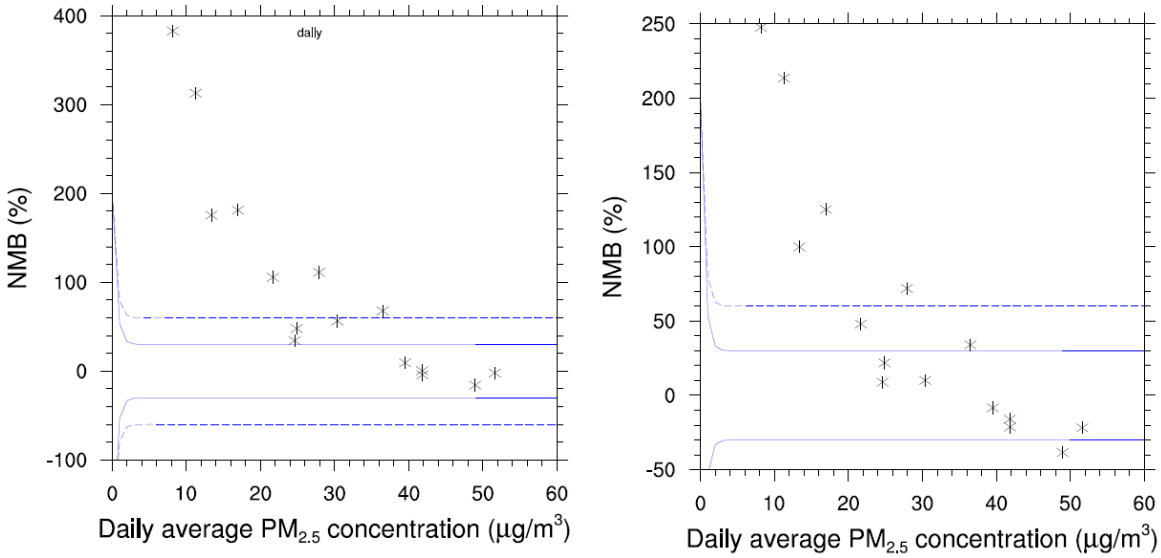


Fig. 16 Bugle plots of normalized mean biases of simulated 24h-average $PM_{2.5}$-concentrations at the State Building site as obtained from the adapted CMAQ simulations with reduction of wind-speed (left) and the adapted CMAQ simulation with the original WRF-simulated wind-speeds (right) for the November episode.

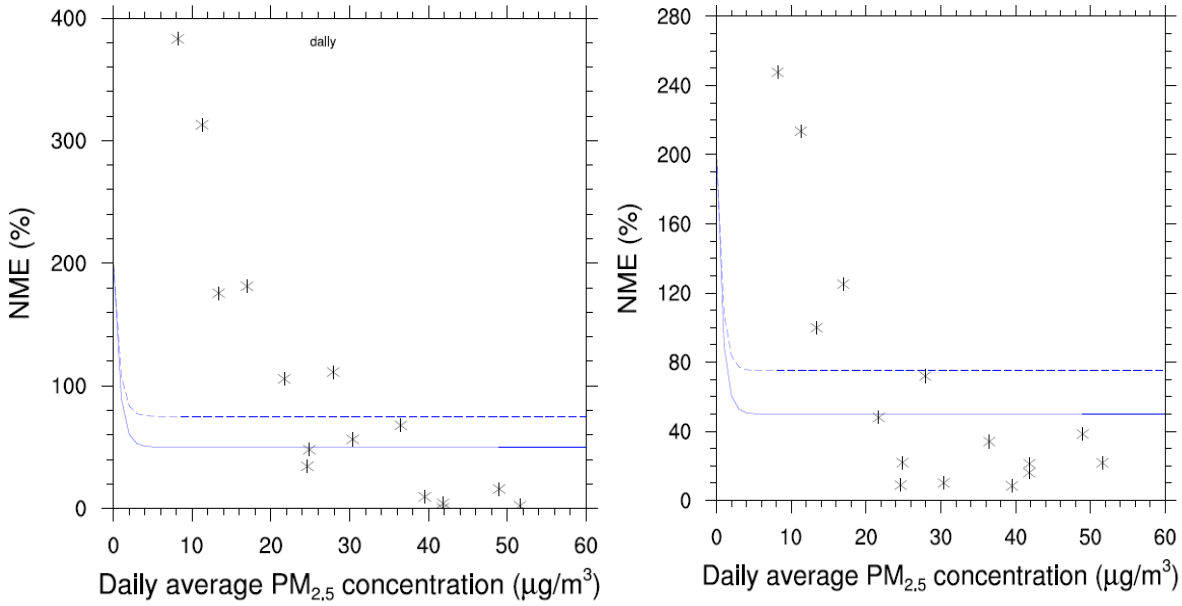


Fig. 17 Bugle plots of normalized mean errors of simulated 24h-average $PM_{2.5}$-concentrations at the State Building site as obtained from the adapted CMAQ simulation with reduction of wind-speed (left) and the adapted CMAQ simulation with the original WRF-simulated wind-speed (right) for the November episode.

The performance of adapted CMAQ in simulating the $PM_{2.5}$-composition during November was evaluated for both cases. The observed and simulated $PM_{2.5}$-compositions were compared in scatter plots (Fig. 18). The simulation, which used the original WRF-simulated wind-speeds, shows that sulfate and ammonium are outside of the factor of two agreement. The adapted CMAQ model predicted best for OC and EC, which have high concentrations and make up a large fraction of the total $PM_{2.5}$. The soccer plots for the adapted CMAQ simulation with wind-speed reduction show that sodium and chloride are outside the performance criteria. For the adapted CMAQ simulation with the original WRF-simulated wind-speeds show that sodium, chloride and sulfate are outside the performance criteria (Fig. 19). However, the increase of the Cl-concentrations for the initial/boundary conditions (IC/BC) for the adapted CMAQ simulation with the original WRF-simulated wind-speeds led to decreased NME and NMB for the Cl-species (Fig. 19) The new profile of Cl is included in the Appendix. The buggle plot of normalized mean bias for the adapted CMAQ simulations with the original WRF-simulated wind-speeds shows that sulfate is outside the criteria (Figs. 20, 21).

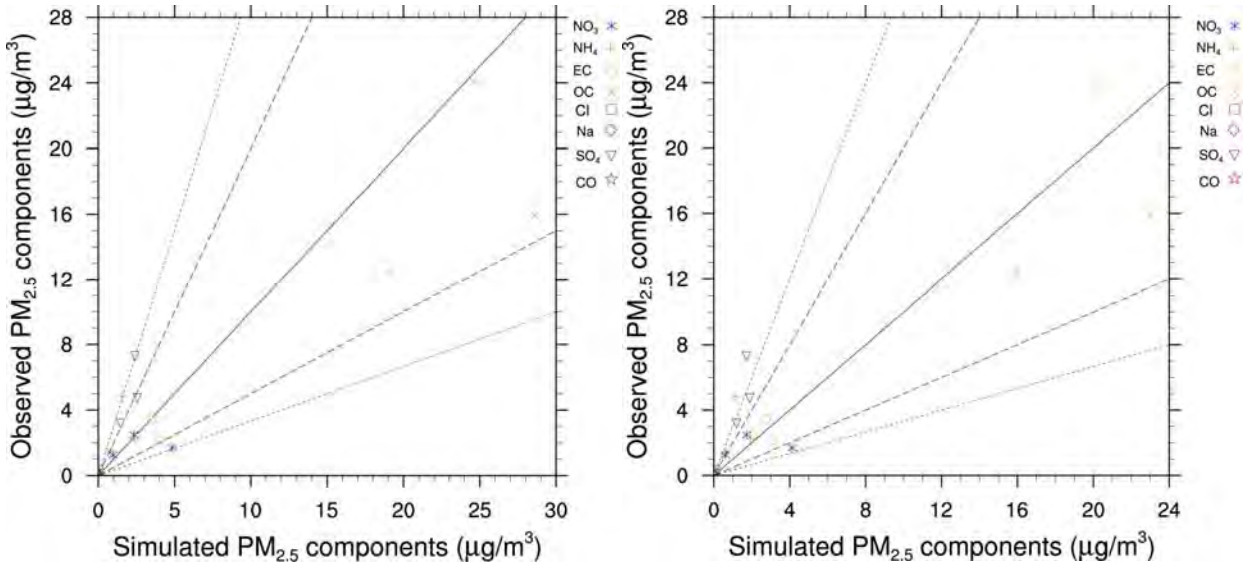


Fig.18 Scatter plot between simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode.

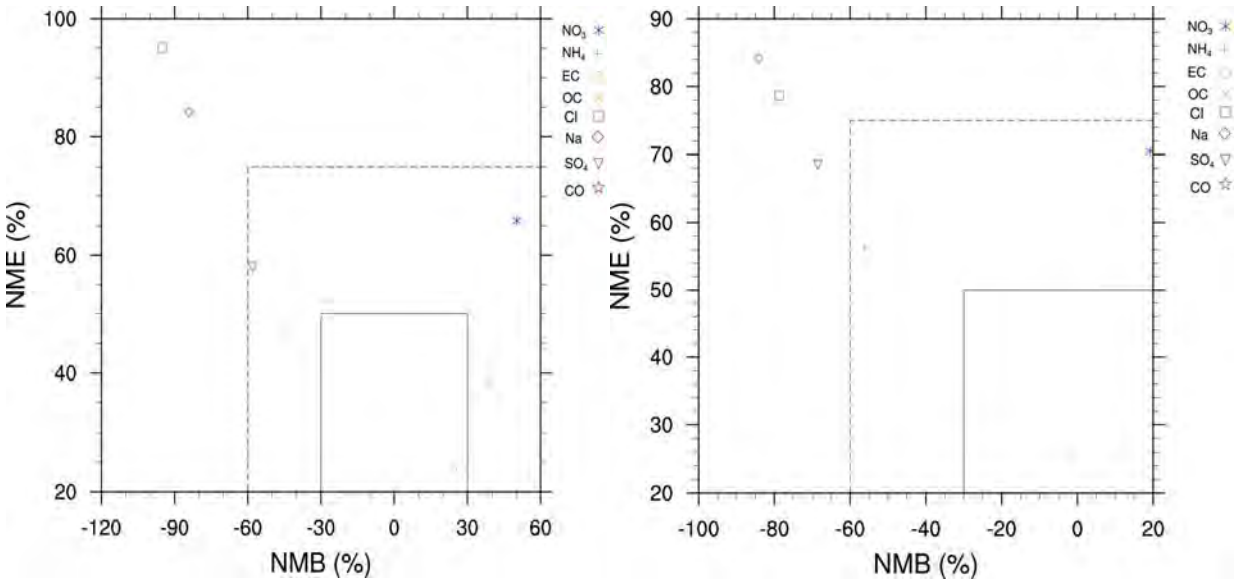


Fig. 19. Soccer plots of normalized mean errors and biases of simulated 24h-average $PM_{2.5}$-composition simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

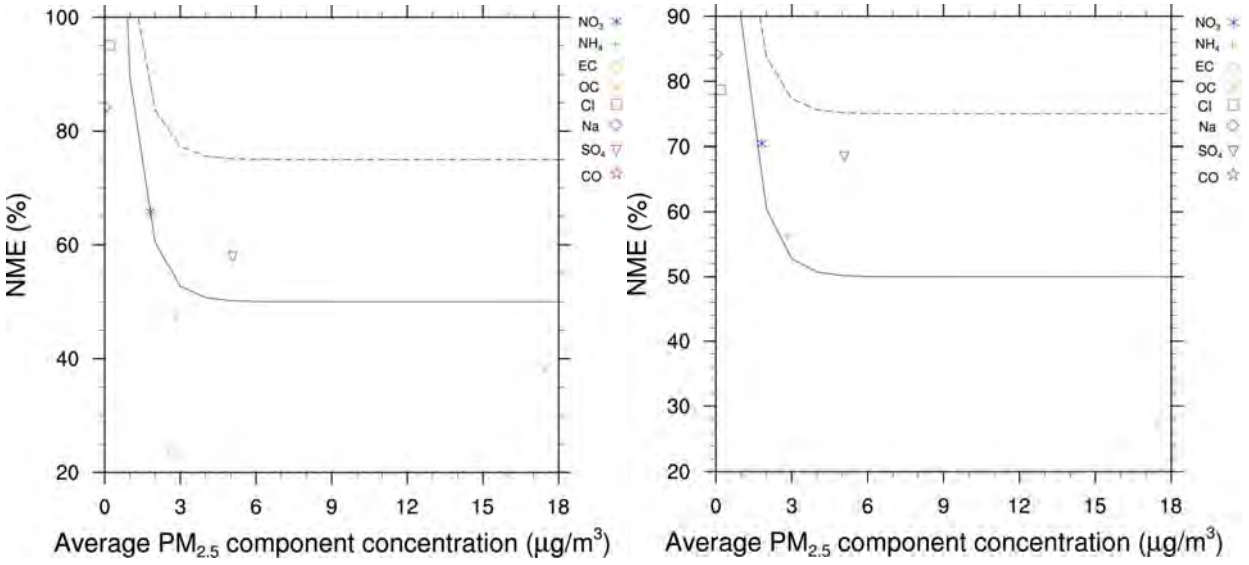


Fig. 20 Bugle plots of normalized mean errors of simulated 24h-average $PM_{2.5}$-composition simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

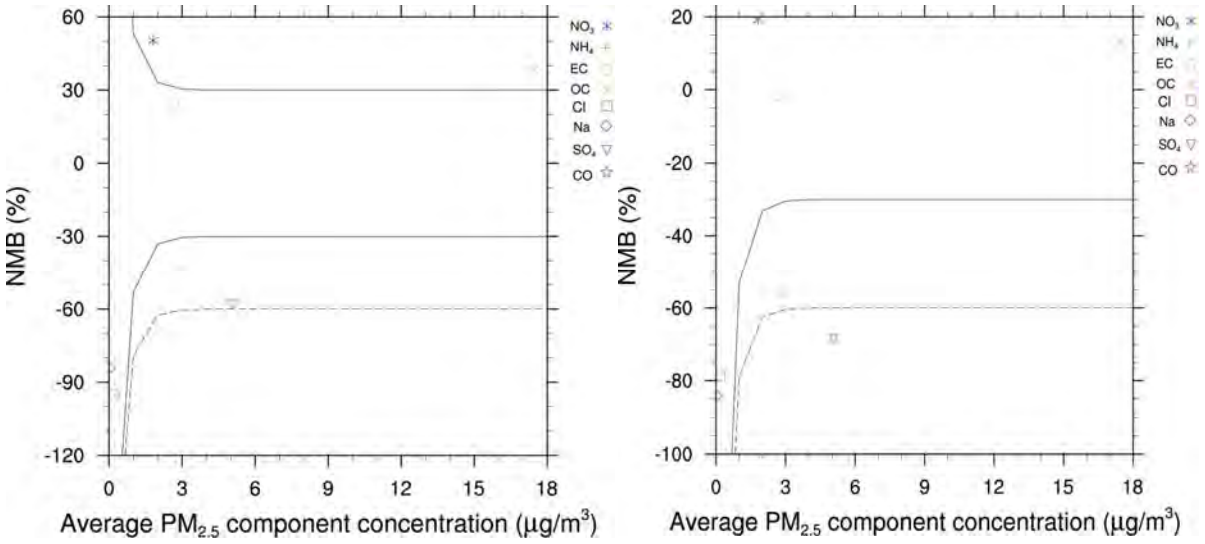
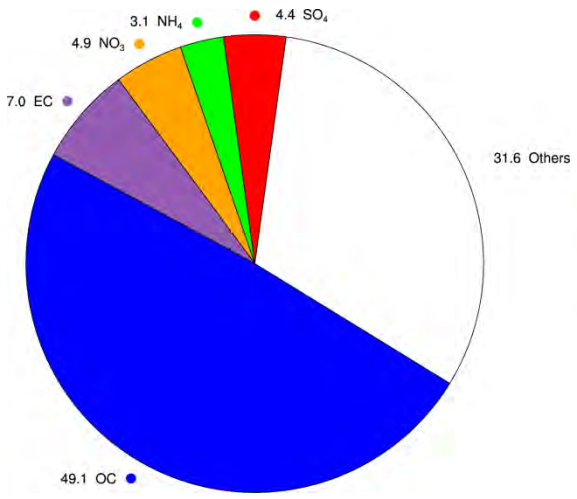
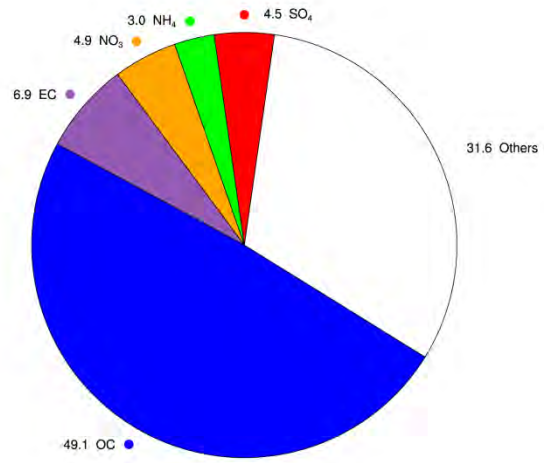


Fig. 21 Bugle plots of normalized mean biases of simulated 24h-average $PM_{2.5}$-composition simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site as obtained for the adapted CMAQ simulation with reduction wind-speeds in the valley (left) and the adapted CMAQ simulations using the original WRF-simulated wind-speeds (right) for the November episode. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

(a)



(b)



(c)

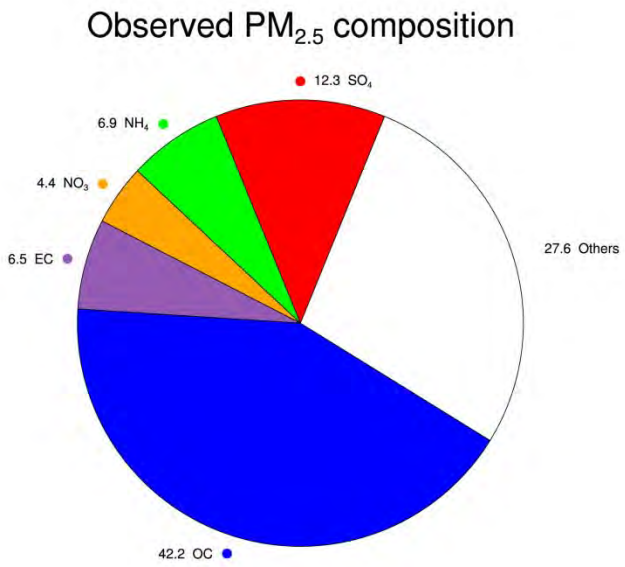


Fig. 22 The $PM_{2.5}$-composition at State Building site as obtained by (a) the adapted CMAQ simulation with reduction of wind-speeds in the valleys by half and (b) the adapted CMAQ simulations with modifications using the original WRF-simulated wind-speeds, and (c) observations of 24h-average $PM_{2.5}$-composition averaged over the 3 days with data available in the November episode. In the observations the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the adapted CMAQ simulation results, the category "others" refers to unspecified anthropogenic mass (A25i+A25j).

In both case studies, in the simulated $PM_{2.5}$-composition, the percentage of organic carbon was overestimated, but the percentage of sulfate, and ammonium was underestimated (Fig. 32). The adapted CMAQ model predicted elemental carbon and nitrate well. Note that there were only 3 days, which had the available observed $PM_{2.5}$-composition data during the November episode.

Besides the normal case (reference simulations) with the adapted CMAQ, we performed adapted CMAQ simulations for the November episode without consideration of gas chemistry, without consideration of aerosol chemistry, and without consideration of chemistry. We compared the results of these sensitivity studies with the observed data (Fig. 23). We did not perform a sensitivity study without consideration of point-source emissions as the way Sierra Research Inc. provided the November emission data did not allow us this option. The emission file for November episode were in a merged file, not separately for area and point source emissions like the emission data provided for the January v1 episode. The interested reader is referred to Frost et al. (2006) and Tran and Mölders (2012) for a detailed discussion on point-source emission impacts.

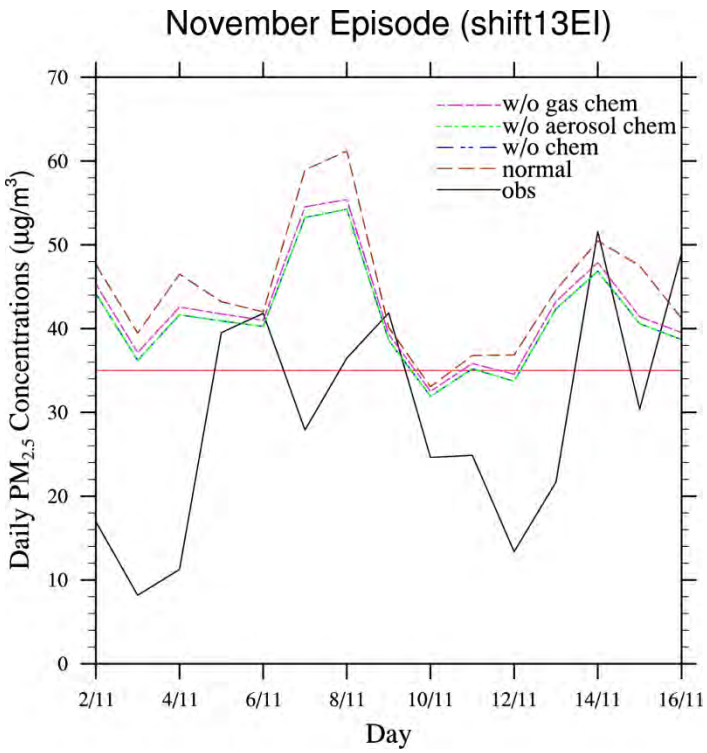


Fig. 23 Time series of observed (black solid line) and adapted CMAQ simulated 24h-average $PM_{2.5}$-concentrations at State Building site as obtained by the various sensitivity studies without consideration of gas chemistry, without consideration of aerosol chemistry, without consideration of chemistry, and with consideration of everything (reference/normal) for the November episode. The red solid line indicates the National Ambient Air Quality Standard of 35µg/m^3.

Similar to the January v1 episode, chemistry played a small role for the $PM_{2.5}$-formation. The simulations with turned off chemistry, turned off aerosol chemistry and turned off gas chemistry led to decreases in $PM_{2.5}$-concentrations of on average 2.2 (6%), 2.2 (6%) and 1.5µg/m^3 (4%), respectively. Turning off the gas chemistry led to the same results as turning off all chemistry.

On the day, for which the highest concentrations were simulated (48.9/m^3 on November 8), the chemistry processes had the maximum contribution to the 24h-average $PM_{2.5}$-concentrations 5.8µg/m^3 (12%) at the State Building site. In this 5.8µg/m^3, the aerosol chemistry processes contributed 4.9µg/m^3 (10%) to the total aerosol production by chemistry processes.

Since the times series of simulated and observed PM2.5-concentrations indicated a temporal offset, we correlated the simulated 24h-average $PM_{2.5}$-concentrations at State Building site with the observed data by allowing various time lags. We found that allowing a time lag of one day for the simulation results obtained with reduced wind-speed can increase the correlation coefficient from 0.21 to 0.46. For the reference simulation that uses the original WRF-simulated wind-speeds, allowing a time lag of one day increased the correlation coefficient from 0.31 to 0.37 (Fig. 24). This increasing of the correlation indicates that the adapted CMAQ model has a 24h delay in capturing the $PM_{2.5}$-concentrations at the State Building site for November episode.

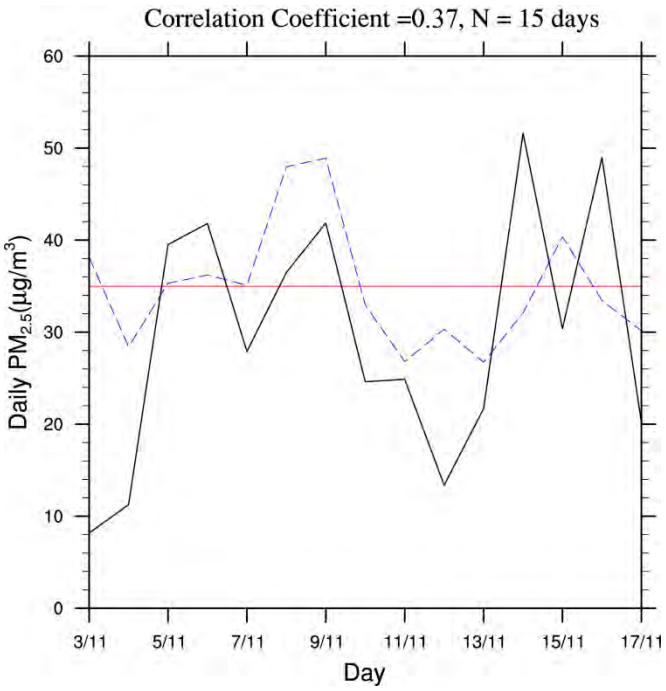


Fig. 24 Time series of simulated (blue dash line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations that allow a one day time lag for the adapted CMAQ simulation using the original WRF-simulated wind-speed for the November episode at the State Building site.

The reduction of the wind-speed by half might demolish the continuity equation (see discussion in Mölders and Leelasakultum 2011), but it led to a clear increase of $PM_{2.5}$-concentrations and better performance in simulating the sulfate compositions at the State Building site (Figs. 19-21). Although, the comparison with the observed data had lower correlation coefficients than 0.5 for both cases, allowing a time lag of one day increased the correlation coefficients in both cases.

2.3 Comparison of simulations and their performance for January v2 with and without CMAQ modifications

Like January v1, January v2 covers January 23 to February 9, 2008. The emissions used for the January episode v2 were developed by Sierra Research Inc. who updated the emission inventory for emissions from mobile sources, and included the emissions from airports like in the November episode (see their reports for details and the reasoning). The comparison of the spatial distribution of emissions as used for January v1 and January v2 shows that there is the increase in emissions from the mobile sectors for the January v2, mostly outside of the nonattainment area (Fig. 25). There are both increases and decreases in emissions inside the nonattainment area for the new version of emission inventory; the increase of the emissions is mostly south of the nonattainment area (Fig. 26).

Furthermore, January v1 and January v2 also differ by the meteorological data used (Fig. 27). January v2 uses WRF simulations provided by PennState that they created with an updated data assimilation procedure (see their final report for details). On the days, for which CMAQ overestimated the 24h-average $PM_{2.5}$-concentrations at the State Building site, the meteorological data in January v2 tend to have lower of relative humidity in the Fairbanks nonattainment area (64°40'N- 65°N, 147°W-148°W), and the area with low temperatures covers a larger area of the domain. These changes in the meteorology in the January v2 simulations results in an increase of $PM_{2.5}$-concentrations as it supports the gas-to-particle conversion process. For a discussion on the impact of errors in simulated meteorological quantities on simulated $PM_{2.5}$-concentrations see reader is referred to Mölders et al. (2011, 2012).

With the improvements in the emission inventory and the WRF meteorological data for January v2, the adapted CMAQ 24h-average $PM_{2.5}$-concentrations at the State Building site increased noticeably without the need for a wind-speed reduction (cf. Figs. 9, 28). The temporal evolution of $PM_{2.5}$-concentrations for January v2 with CMAQ modifications shows similar trends with that obtained without modifications. Note that CMAQ without modification would not consider deposition on snow or tundra-type land as well as would have unrealistic (for Alaska) pH-value thresholds, IC/BC and other important parameters. January v2 with modifications shows that most of the times both the 24h-average and hourly $PM_{2.5}$-concentrations at the State Building site are overestimated (Figs. 27, 28). Note that for SIP development this behavior is preferred over underestimation.

(a) (b)

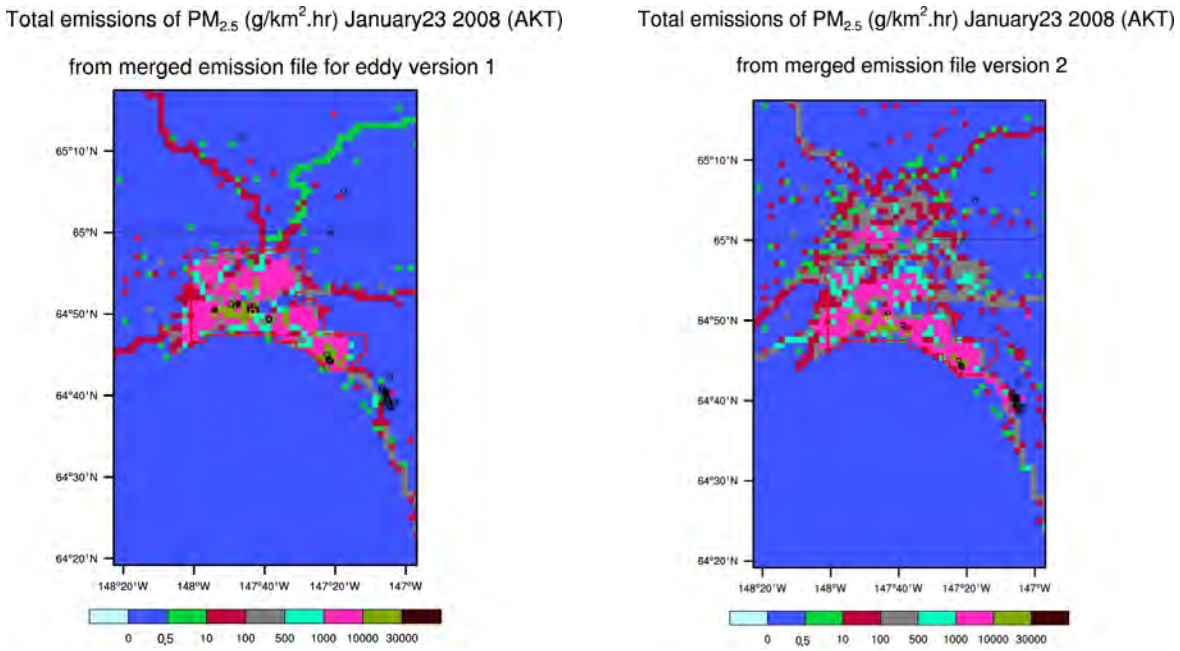


Fig. 25 Example of the emissions as obtained from the Sierra Research Inc. emission inventory for (a) January v1 and (b) January v2. The red polygon indicates the Fairbanks nonattainment area. The circles indicate point-source locations.

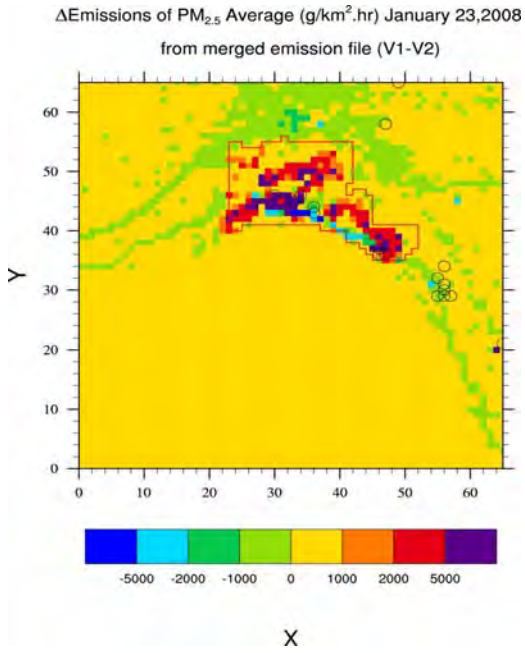
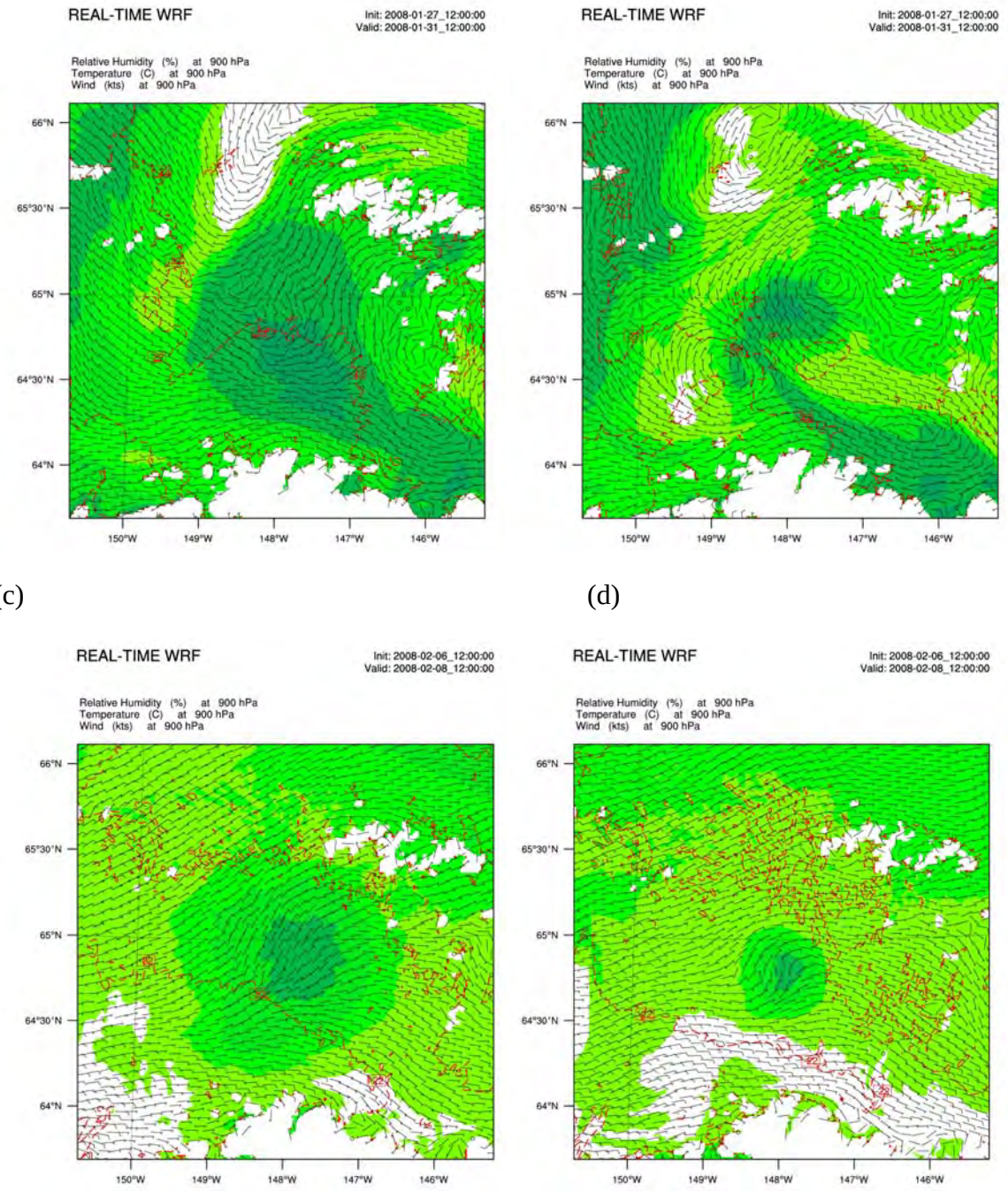


Fig. 26 Like Fig. 25, but for $PM_{2.5}$-emissions difference (January v1 minus January v2) at breathing level on January 23, 2008 as obtained from Sierra Research Inc. emission inventory.

(a) (b)



(c) (d)

Fig. 27 Example of temperature (red contours), relative humidity (color), wind-speed and direction (barbs) at 900 hPa on January 31, 2008 1200UTC for (a) January v1 and (b) January v2, and on February 8, 2008 1200UTC for (c) January v1 and (d) January v2 as obtained from the PennState group.

The modifications of CMAQ resulted in a correlation coefficient of 0.52 for the 24h-average $PM_{2.5}$-concentrations, which is better than the correlation obtained for the simulation with the

CMAQ without modifications (Fig. 30). For the 12 pairs of data of the results from CMAQ with and without modifications, 83% of values lie within the factor of the two agreement (Fig. 30). However, the two points outside the factor of the two agreement for the CMAQ simulations without modifications are a "missed event" (Simulated<35μg/m^3 and Observed>35μg/m^3), and one value (simulated<35μg/m^3 and observed>35μg/m^3). Whereas, those two points in the CMAQ simulation with modifications are "false alarms" (simulated>35μg/m^3 and observed<35μg/m^3) (Fig. 30). The simulated hourly $PM_{2.5}$-concentrations of the CMAQ with modifications also yield a higher correlation coefficient with the observed data than those obtained without CMAQ modifications (Fig. 31).

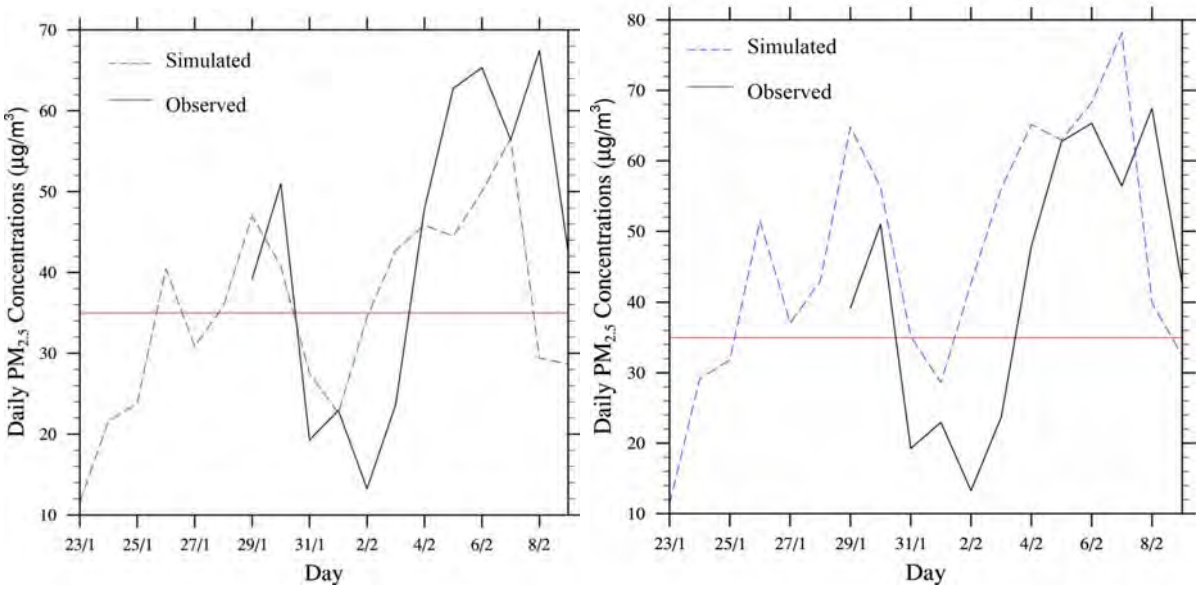


Fig. 28 Time series of simulated (blue dash line) and observed 24h-average $PM_{2.5}$-concentrations at the State Building site (black solid line) as obtained for January v2 without modifications (left) and January v2 with modifications (right).

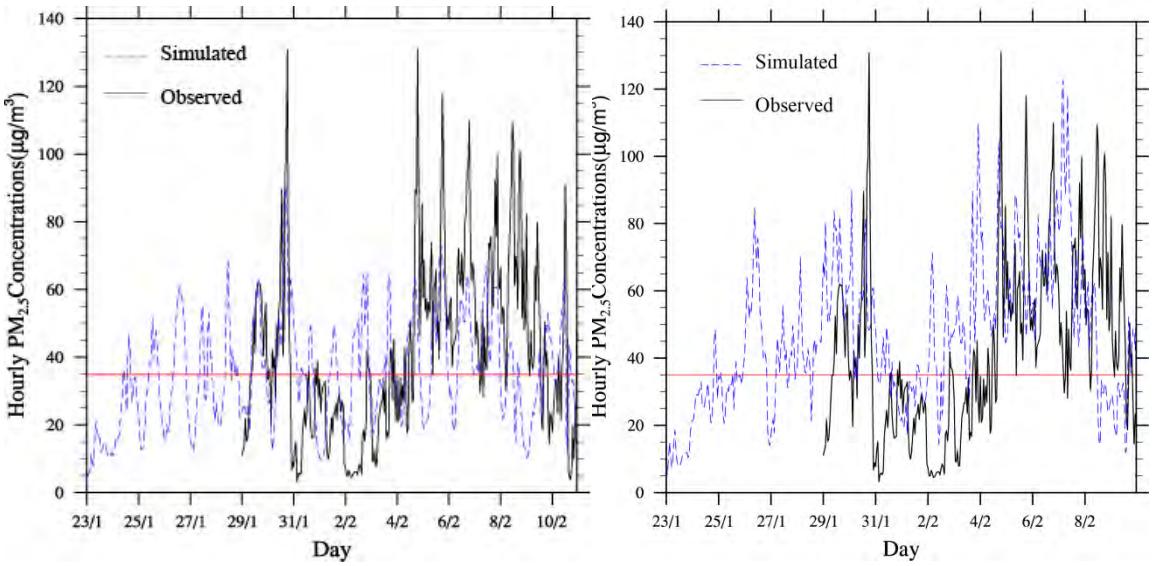


Fig. 29 Time series of simulated (blue dash line) and observed hourly $PM_{2.5}$-concentrations at the State Building site (black solid line) as obtained for January v2 without modifications (left) and January v2 with modifications (right).

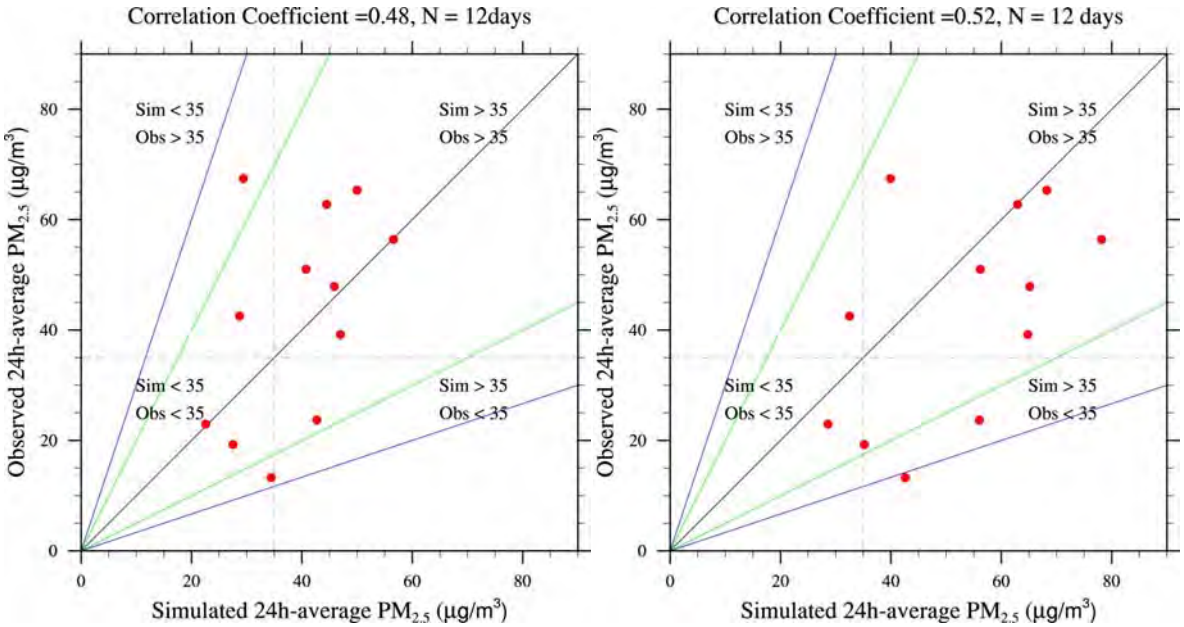


Fig. 30 Scatter plots of 24h-average $PM_{2.5}$-concentrations as obtained for January v2 without modifications (left) and January v2 with modifications (right). The green line indicates the factor of two agreement, and the blue line indicates the factor of three agreement.

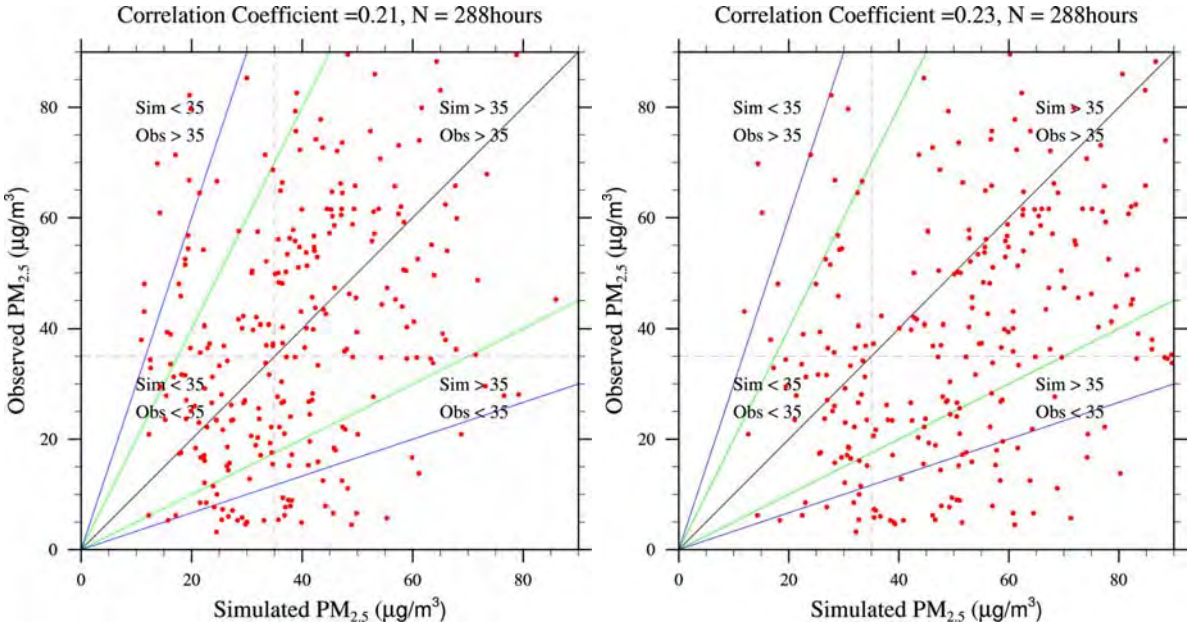


Fig. 31 Scatter plots of hourly average $PM_{2.5}$-concentrations as obtained by January v2 without modifications (left) and January v2 with modifications (right). The green line indicates the factor of two agreement, and the blue line indicates the factor of three agreement.

Furthermore, we run the CMAQ with modifications, but without the reduction of the lowest and the highest eddy diffusivity. The hypothesis of this test is that reductions of default eddy diffusivities by half caused the over-prediction and false alarms.

The temporal evolution of simulation with all modifications except the eddy diffusivity reduction shows similar result as the case of without these modifications (Figs. 28, 29, 31). The correlation coefficient between the simulated and observed 24h-average $PM_{2.5}$-concentrations obtained by the CMAQ with modifications, but without the reduction of the eddy diffusivity is 0.46. There are two values outside the factor of two agreement, which is similar to the CMAQ simulation of without these modifications (Fig. 31).

This means that the reduction of the default eddy diffusivities by half is the modification that led to the increase of $PM_{2.5}$-concentrations at the State Building site. It caused the over-prediction, and false alarms, however, setting the eddy diffusivities to the default does not lead to the improvement of the correlation between simulated and observed data. The CMAQ with the modifications and the reduction of the eddy diffusivities by half shows the best correlation coefficient (0.52). Thus, we recommend this setup.

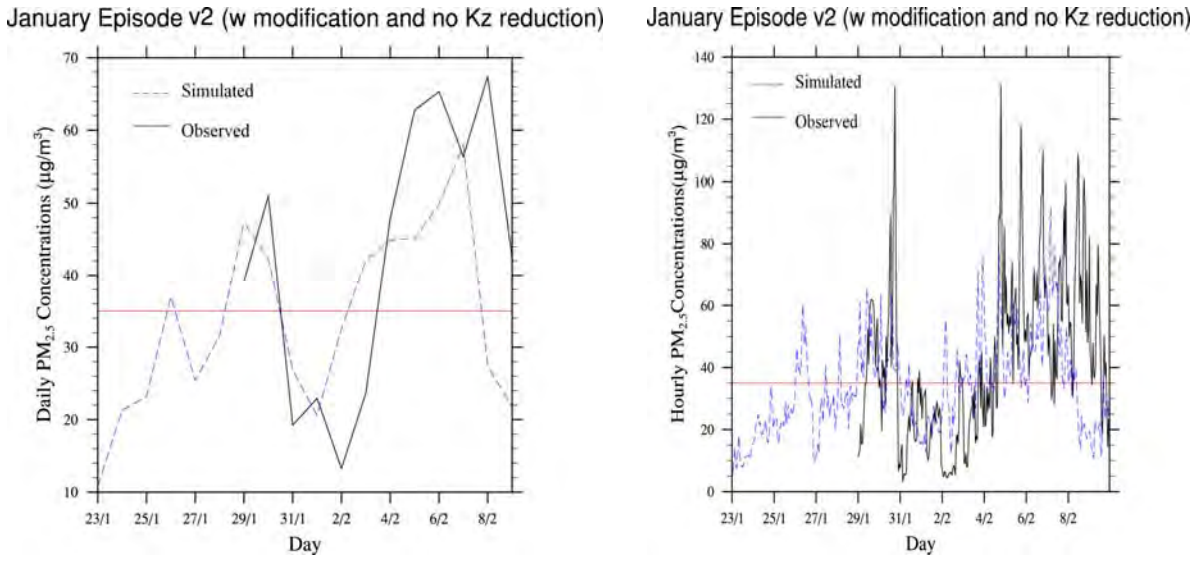


Fig. 32 Time series of simulated (blue dash line) and observed 24h-average $PM_{2.5}$-concentrations (left) and with modifications for hourly $PM_{2.5}$-concentrations (right) at the State Building site (black solid line) as obtained for January v2 with all modifications except the eddy diffusivity reduction.

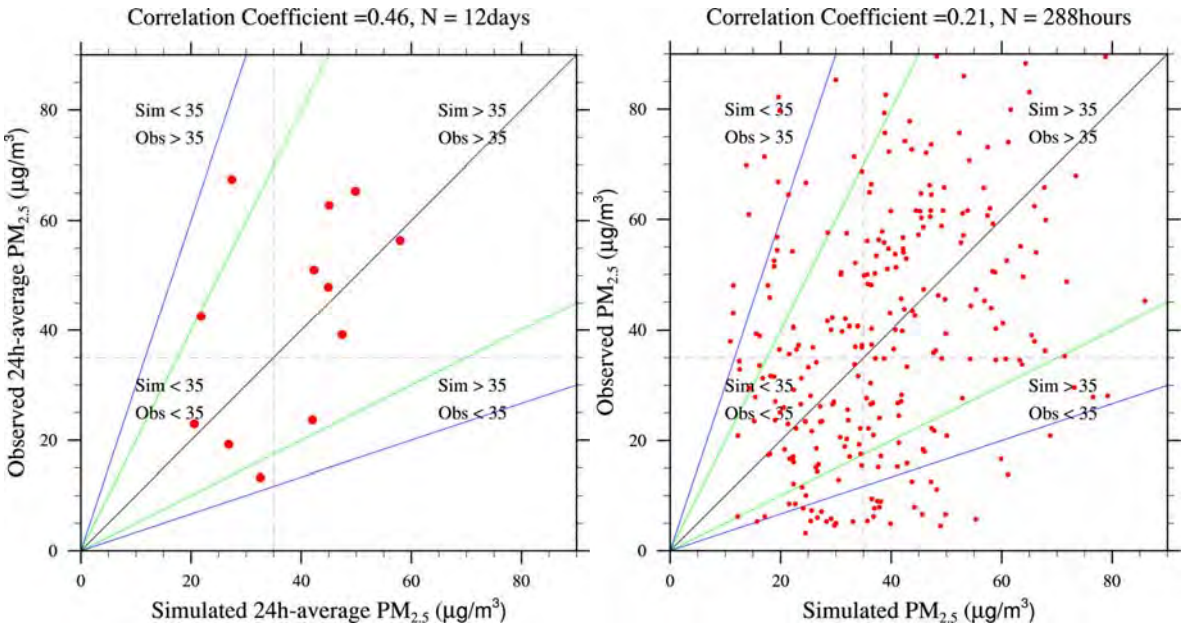


Fig. 33 Scatter plots of 24-h average $PM_{2.5}$-concentrations (left) and hourly average $PM_{2.5}$-concentrations (right) as obtained by January v2 with modifications, but without reduction of the eddy diffusivity. The green line indicates the factor of two agreement and the blue line indicates the factor of three agreement.

We also preformed simulations for January v2 without consideration of gas chemistry, without consideration of aerosol chemistry, and without consideration of chemistry. We compared the

results of these simulations to each other, the results of the simulation that considers all processes and with the observations (Fig. 34). Similar to the January v1episode, chemistry played a small role for the $PM_{2.5}$-formation. The simulations with turned off chemistry, turned off aerosol chemistry and turned off gas chemistry led to decreases in $PM_{2.5}$-concentrations of on average 2.0 (4%), 2.0 (4%) and 1.2µg/m^3 (3%), respectively. Note that in the CMAQ model turning off the gas chemistry resulted in the same result with turning off all chemistry.

On the day, for which the highest concentration was simulated (78.2/m^3 on February 7), the chemistry processes had the maximum contribution to the 24h-average $PM_{2.5}$-concentrations 5.6µg/m^3(7%) at the State Building. In this 5.6µg/m^3, the aerosol chemistry process contributed 4.4µg/m^3 (6%) to the total aerosol production of chemistry process.

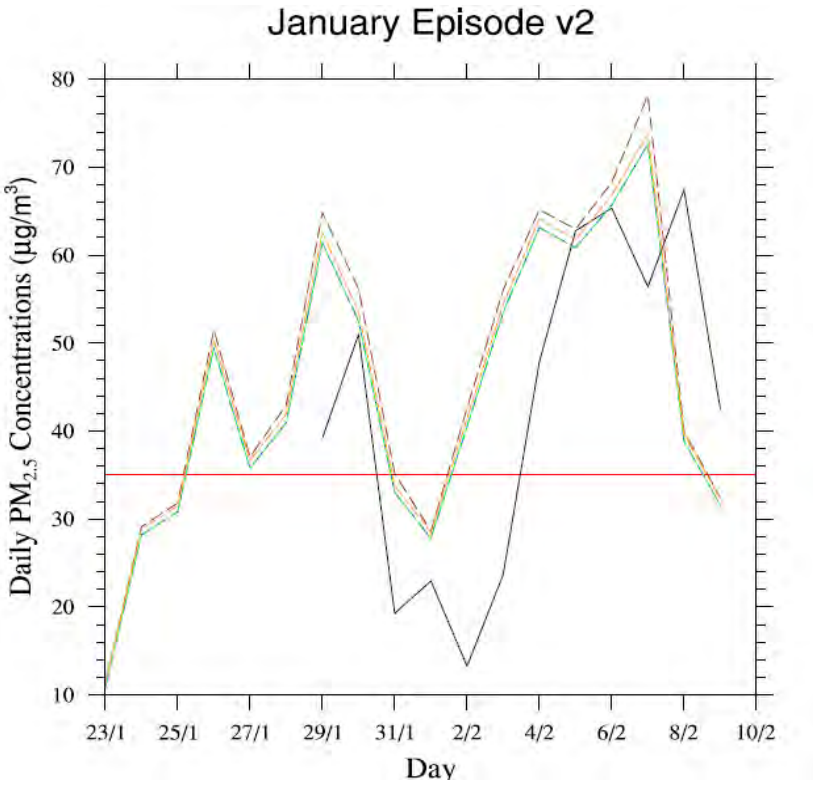
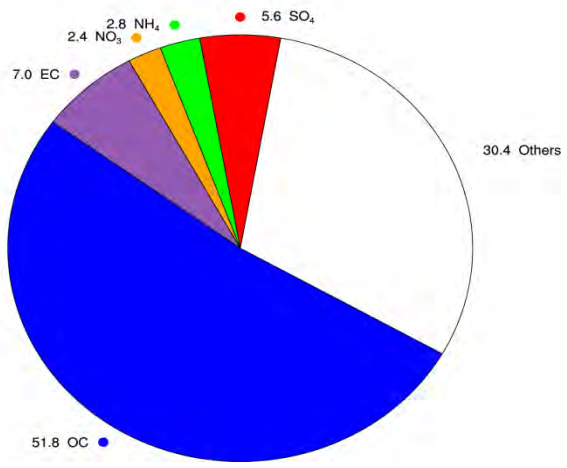


Fig. 34 Time series of CMAQ simulated and observed 24h-average $PM_{2.5}$-concentrations at State Building for the January episode v2 (black solid line). The sensitivity studies include simulations without consideration of gas chemistry, without consideration of aerosol chemistry, without consideration of chemistry and the simulation with consideration of everything (reference/normal). The red solid line indicates the National Ambient Air Quality Standard of 35µg/m^3.

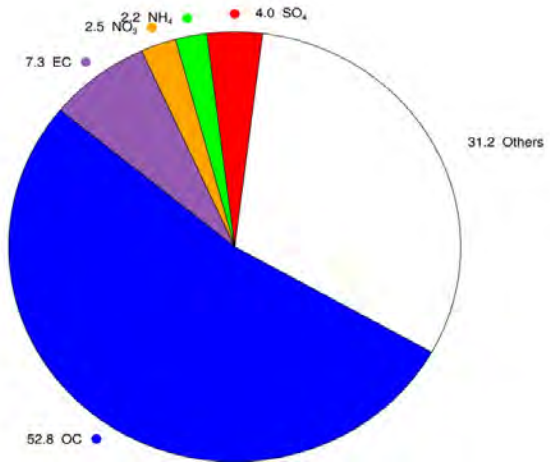
Comparing between the observed and the simulated composition of 24h -average $PM_{2.5}$ aerosol, showed that simulated $PM_{2.5}$ composition with the modifications and without the modifications

reveals that the adapted CMAQ overestimated the percentage of organic carbon, but underestimated the percentage of sulfate, ammonium, nitrate and elemental carbon (Fig. 35). Note that there were only 6 days, which had the observed $PM_{2.5}$-composition data during the study period.

(a)



(b)



(c)

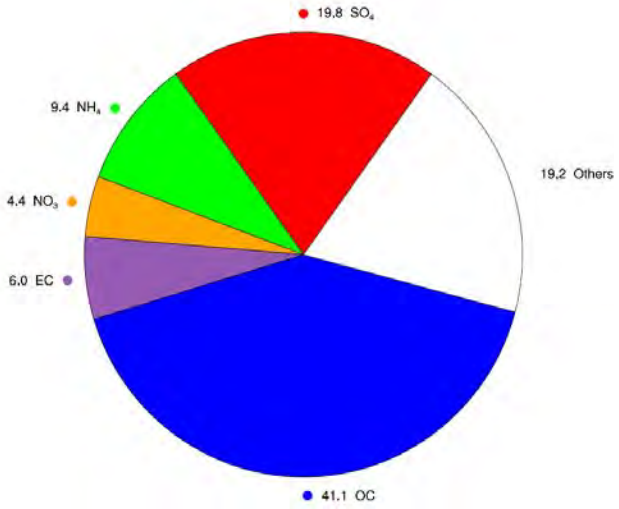


Fig. 35 Composition of simulated 24h-average total $PM_{2.5}$ as obtained by (a) CMAQ without modifications, (b) CMAQ with modifications, and (c) as observed on average over the 6 days for which data was available at the State Building site. In the observations, the category "others" includes Al, Br, Ca, Na, Cl, Cu, Fe, Pb, Ni, K, Se, Si, S, Sn, Ti, V, Zn. In the simulations, the category "others" refers to unspecified anthropogenic mass (A25i+A25j).

For the January v2 episode, we also correlated the simulated 24h-average $PM_{2.5}$-concentrations obtained by the Alaska adapted CMAQ model with the observed data by allowing a time lag. We found that allowing a time lag for one day increases the correlation coefficient from 0.52 to 0.84 (Fig. 36). Allowing a 24h time lag can increase the correlation coefficients of the hourly average $PM_{2.5}$-concentrations at State Building site from 0.23 to 0.50, and the correlation increases even more to 0.59 when we allow a time lag for 26 hours. These findings clearly indicate that the discrepancies between simulated and observed $PM_{2.5}$-concentrations are partly due to errors in simulated meteorology.

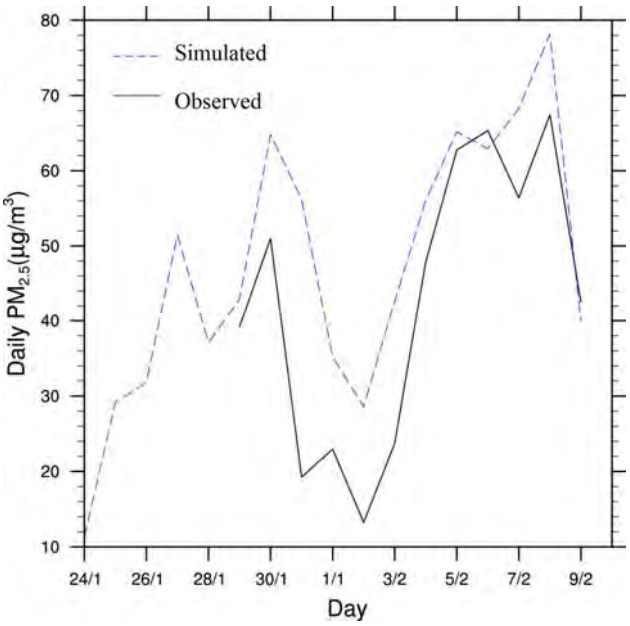


Fig. 36 Time series of simulated (blue dash line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations with a one day time lag for the January v2 episode at the State Building site.

2.4 Statistical performance for the November episode and January episode v2 with CMAQ modification

The statistical performance of the Alaska adapted CMAQ (Mölders and Leelasakultum 2011) for the November episode and January episode v2 was determined and is shown in Tables 1 and 2, respectively.

Table 1. Performance statistics for the Alaska adapted CMAQ at the State Building site for November episode. StDev is the standard deviation.

Fairbanks official monitoring Site	# of observ-ations	Mean CMAQ simulated (µg/m^3)	Mean observed (µg/m^3)	Ratio of Means (sim/obs)	Mean bias (µg/m^3)	Mean Fractional Bias (%)	Mean error (µg/m^3)	Mean Fractional Error (%)	Correlation coefficient
Hourly	360	34.9	29.3	1.92	5.56	30	15.51	53	0.21
24h-average	15	34.9	29.3	1.52	5.56	26	12.09	43	0.31
Fairbanks Official monitoring site	Average difference sim-obs (µg/m3)	Simulated exceedance days	Observed exceedance days	Simulated min|max (µg/m^3)	Observed min|max (µg/m^3)	STDEV of simulation (µg/m^3)	STDEV of observation (µg/m^3)	Variance of simulation (µg/m^3)^2	Variance of observation (µg/m^3)^2
24h-average	5.6	7	6	26.7 |48.9	8.17 |51.6	6.8	13.7	45.8	188.3

Table 2. Performance statistics for the Alaska adapted CMAQ at the State Building for the January v2 episode. Note that the statistics for the January v1 episode can be found in Mölders and Leelasakultum (2011).

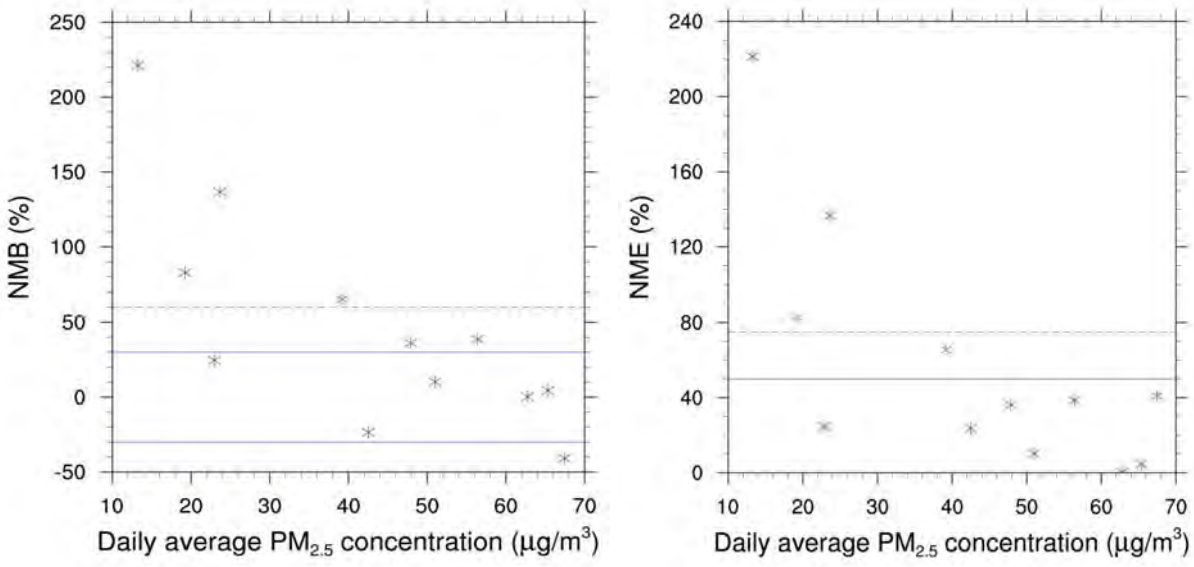
Fairbanks Official monitoring site	#of Observ-ations	Mean CMAQ simuled (µg/m^3)	Mean observed (µg/m^3)	Ratio of means (sim/obs)	Mean bias (µg/m^3)	Mean Fractional Bias (%)	Mean error (µg/m^3)	Mean Fractional Error (%)	Correlation coefficient
Hourly	288	46.3	42.6	1.34	6.59	20.23	16.33	38.39	0.23
24h-average	12	46.3	42.6	0.98	6.59	17.51	10.76	26.18	0.52
Fairbanks official monitoring site	Average difference sim-obs (µg/m3)	Simulated Exceedance days	Observed Exceedance days	Simulated min|max (µg/m3)	Observed min|max (µg/m3)	STDEV of simulation (µg/m3)	STDEV of observation (µg/m3)	Variance of simulation (µg/m^3)^2	Variance of observation (µg/m^3)^2
24h-average	9.9	10	8	28.6 |78.2	13.3 | 67.4	16.18	19.05	261.88	362.82

The Alaska adapted CMAQ model shows a better performance for the January episode v2 than the November episode. The mean simulated of 24h-average $PM_{2.5}$-concentration for the November episode is 34.9µg/m^3 and the mean observed 24h-average $PM_{2.5}$-concentration was 29.3µg/m^3. The higher means of simulated 24h-average $PM_{2.5}$-concentrations were for the January episode v2, which has lower temperatures and lower insolation. Although the average difference between the simulated and observed $PM_{2.5}$-concentrations in January v2 is as high as 9.9µg/m^3, the correlation coefficient, mean fractional bias, and mean fractional error indicate a better performance of the adapted CMAQ for the January v2 than November episode.

The performance metrics of Boyland and Rusell (2006) overlain in the soccer plot and bugle plots of the CMAQ performance for January v2 shows that four days are outside of the criteria (Fig. 37). Those four days are January 29, 31, and February 2, 3, which had 24h-average $PM_{2.5}$-

concentrations of 39.2, 19.2, 13.3, and 23.7µg/m^3, respectively. This means the adapted CMAQ captured well the air quality on those days that had high $PM_{2.5}$-concentrations, but not on those days with low concentrations. Similar was found for WRF/Chem (Mölders et al. 2012).

(a) (b)



(c)

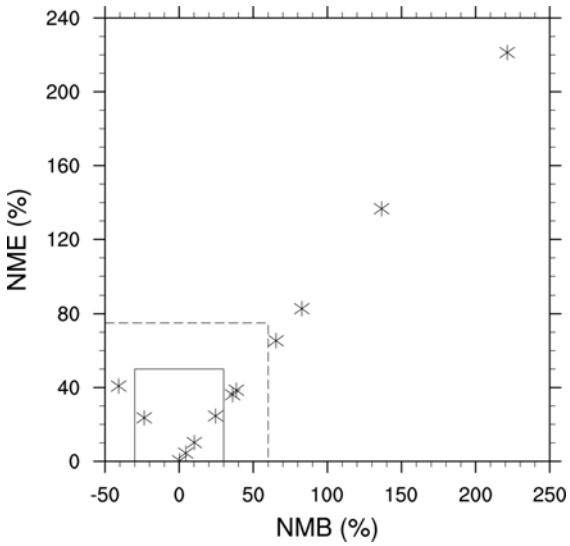


Fig. 37. Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-concentrations, and (c) soccer plot of normalized mean errors and biases all determined with respect to the observations at the State Building site for January v2 as obtained with the CMAQ with modifications. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

The RAMS data of the $PM_{2.5}$-concentrations were also included in the evaluation of the adapted CMAQ for January v2. The temporal evolutions of the RAMS-observed $PM_{2.5}$-concentrations were compared with the simulated $PM_{2.5}$-concentrations (Fig. 38). The RAMS data suggested some temporal offsets at times of local extremes, for instance, the adapted CMAQ model shows a drop on January 27, where the observed 24h-average $PM_{2.5}$-concentrations peaks (Fig. 38).

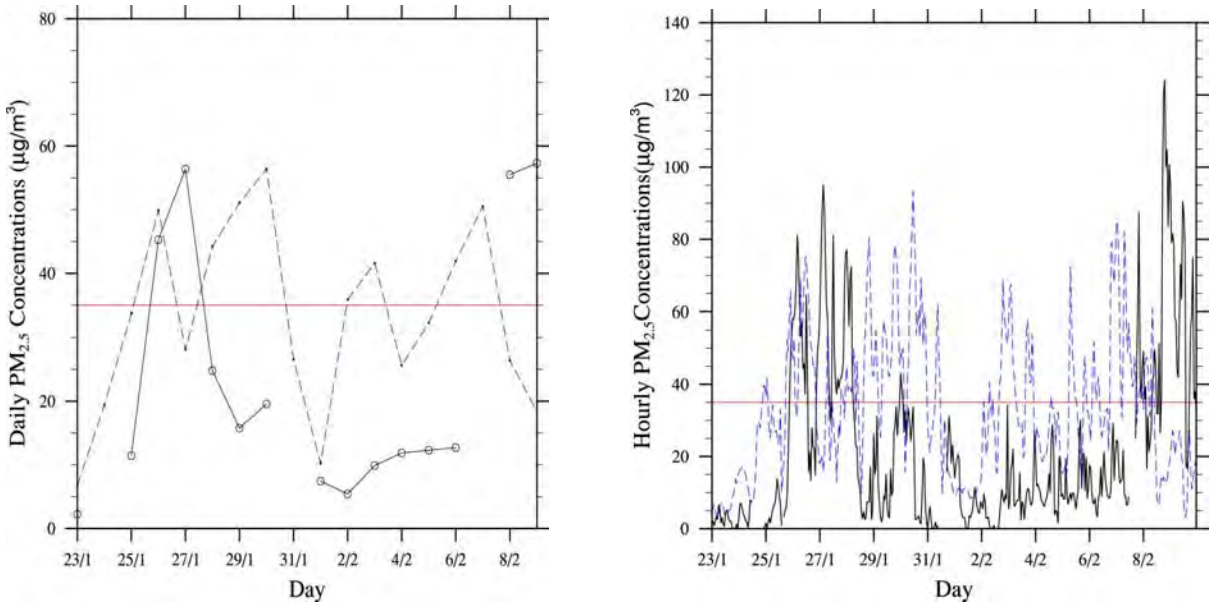


Fig. 38 Time series of simulated with the CMAQ with all modifications (blue dash line) and observed (black solid line) 24h-average $PM_{2.5}$-concentrations (left) and hourly $PM_{2.5}$-concentrations (right) at the State Building site as obtained for January v2.

The performance of CMAQ in simulating the $PM_{2.5}$-compositions for January v2 was evaluated. The scatter plot of simulated and observed $PM_{2.5}$-composition shows that one value for sulfate and one value for ammonium are not in the factor of three agreement (Fig. 39). The soccer plot and bugle plots indicate that the increased Cl-concentrations for the IC/BC led to the better performance for chloride. However, sulfate and ammonium are still outside of the criteria similar as it was found for the November episode (Fig. 40). Additionally, there was one value of OC and EC each that was outside the criteria.

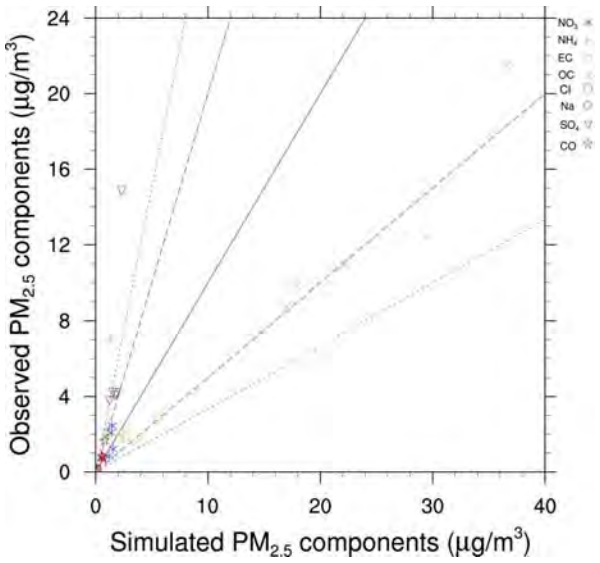


Fig.39 Scatter plot of simulated and observed 24h-average $PM_{2.5}$-composition at the State Building site for the January v2 episode.

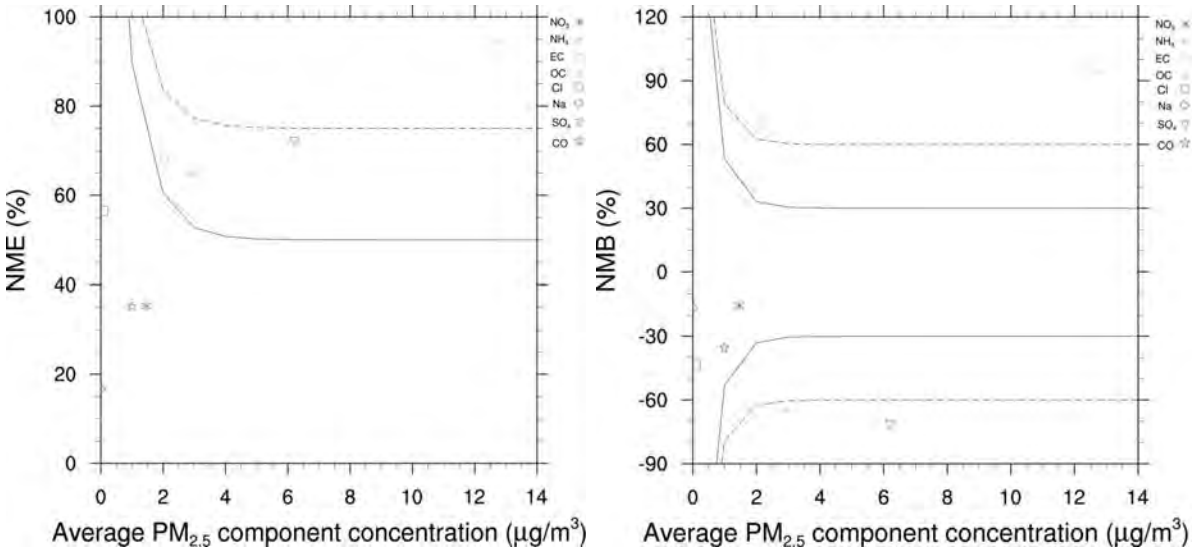


Fig. 40. Bugle plots of normalized mean (a) errors and (b) biases of simulated 24h-average $PM_{2.5}$-composition and (c) soccer plot of normalized mean errors and biases all determined with respect to the observations at the State Building site for January v2. The dashed and solid lines indicate the performance criteria and performance goals in accord with Boylan and Russell (2006).

2.5 Process analysis for the November and January v2 episodes and investigation on boundary conditions

The 24h-average $PM_{2.5}$-composition as simulated by the Alaska adapted CMAQ for the November episode and January v2 episode were compared for each day that had observed data (Figs. 41, 42). In the November episode, there were only three days, which had observed 24-haverage $PM_{2.5}$-composition data. Note that there was no observed CO data on these days. Overall, the Alaska adapted CMAQ model overestimated OC and EC, but underestimated SO_4, NH_4, Na and Cl. The adapted CMAQ model overestimated NO_3 on one day and underestimated NO_3 on two days.

In the January episode, there were six days with observed $PM_{2.5}$-composition data. The adapted CMAQ model shows similar results as for the November episode, i.e. it overestimated OC and EC, but underestimated SO_4, NH_4, Na, Cl and CO. The adapted CMAQ model overestimated NO_3 on two days and underestimated NO_3 on four days, but the trend of simulated NO_3-concentrations seemed to follow the observed data.

Ten-day backward trajectories (http://ready.arl.noaa.gov/HYSPLIT_traj.php) were run for the days, which had observed 24h-average $PM_{2.5}$-concentration data. The trajectories were determined starting at 00UTC and at 20m, 200m, 1000m above ground level over the Fairbanks meteorological station. The backward trajectories indicate that on the days, which had low observed 24h-average $PM_{2.5}$-composition concentrations, i.e. November 12 and February 4, the aerosols at the low levels (20m) were from the local sources (Fig. 43). Long-range transport contributed to the peak on the days, which had high observed 24h-average $PM_{2.5}$-composition concentrations, which CMAQ model seemed to be not able to capture. However, again the long-range is not the cause for the $PM_{2.5}$-problem. Note that a half year study with WRF/Chem for winter 2008/09 showed only a few days that had advection from outside Alaska (Mölders et al. 2012). Investigations by Cahill (2003) based on about a decade of observations also showed that the advection of $PM_{2.5}$ by long-range transport is not the reason for the $PM_{2.5}$-problem in Fairbanks. Investigations by Tran et al. (2011) performed for January 2000 also suggested only marginal advection of $PM_{2.5}$ from Asia to the Interior of Alaska and confirmed the results found here and by the afore cited authors.

The underestimations of SO_4 and NH_4 on every day of both episodes indicate errors, which need to be investigated and corrected. Some first steps in this direction are reported on later in this report.

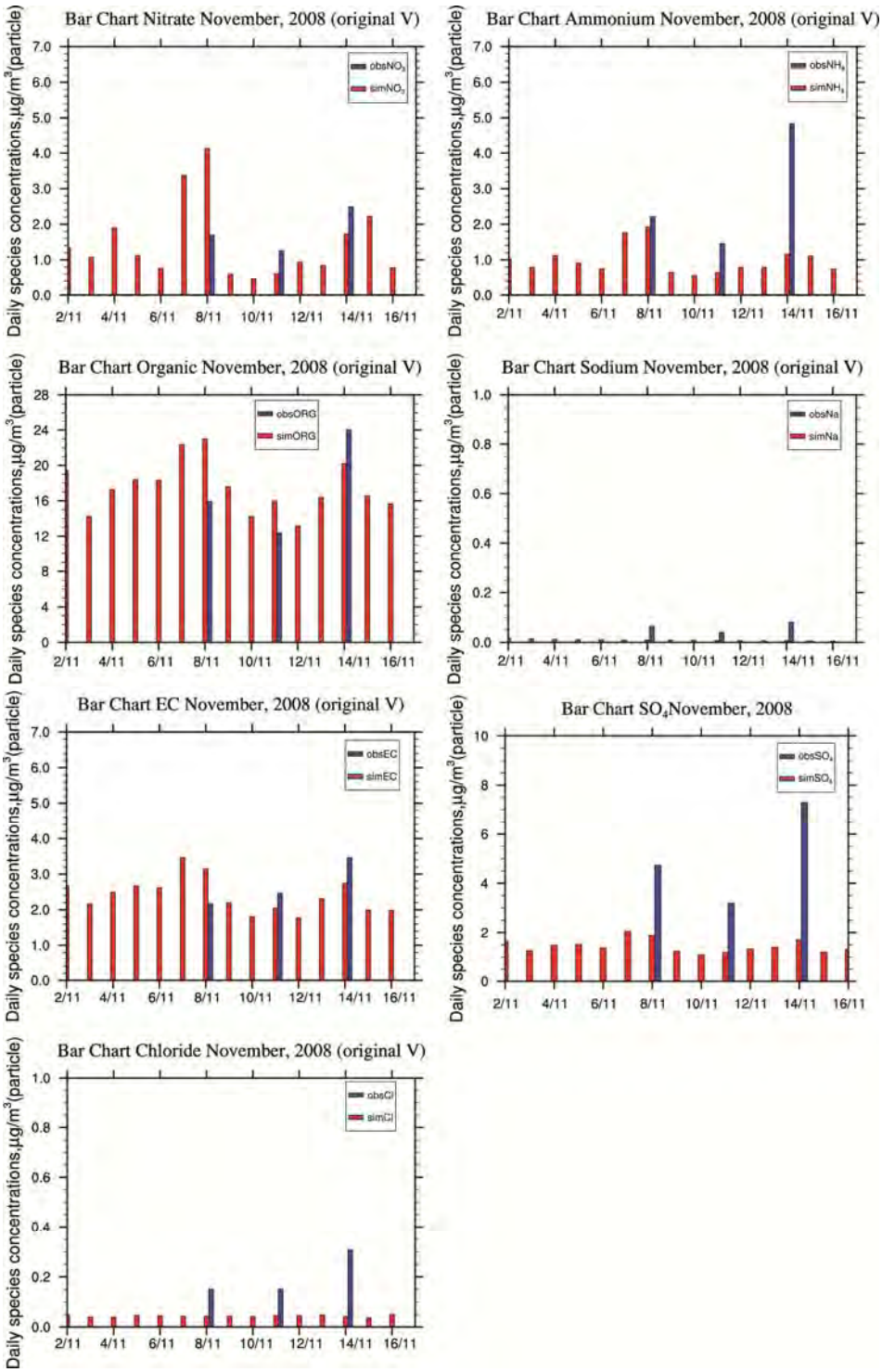


Fig. 41 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained for the November episode.

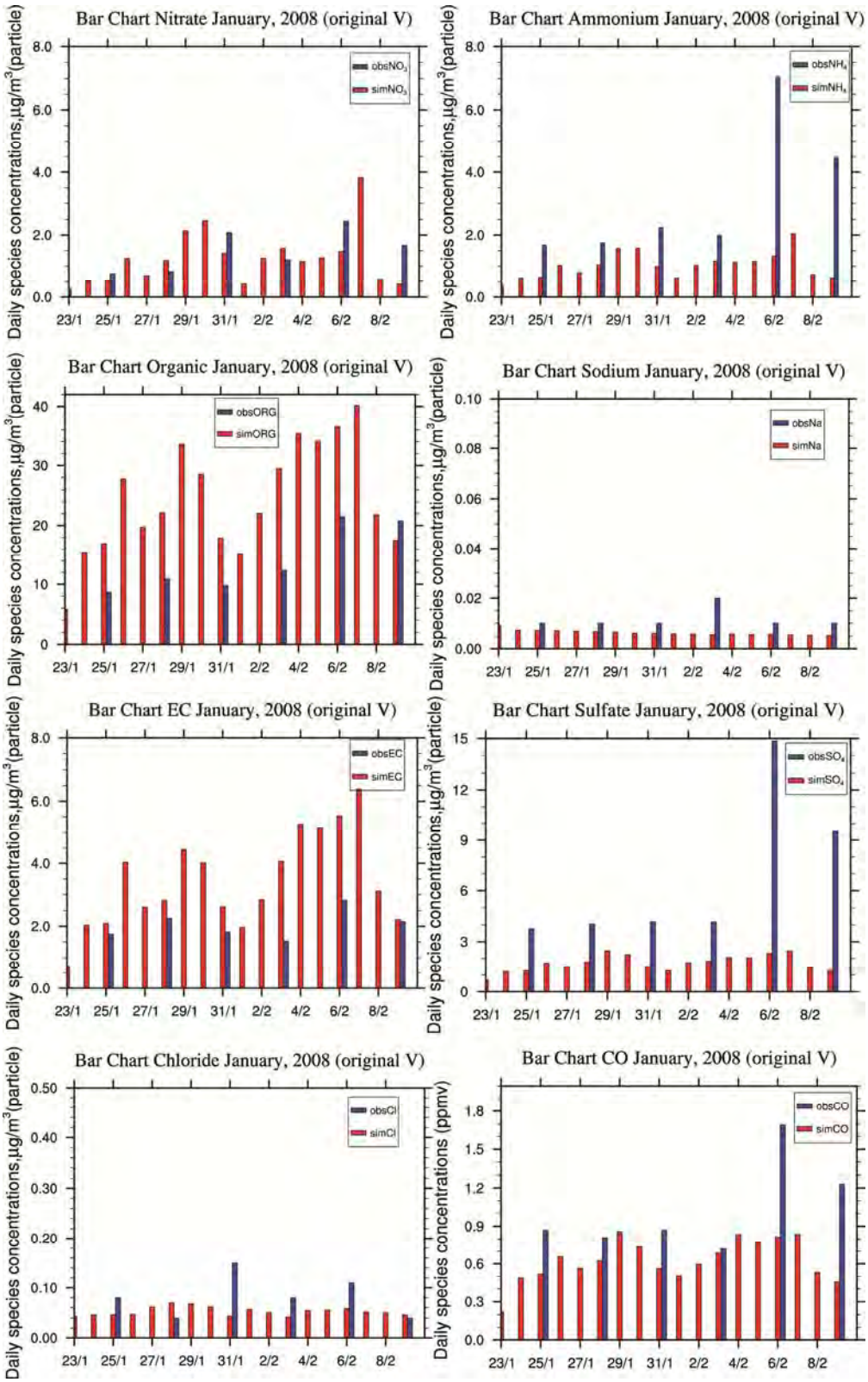


Fig. 42 Bar charts of simulated (red) and observed (blue) 24h-average $PM_{2.5}$-composition for NO_3, NH_4, EC, OC, Na, Cl, SO_4 as obtained for the January v2 episode.

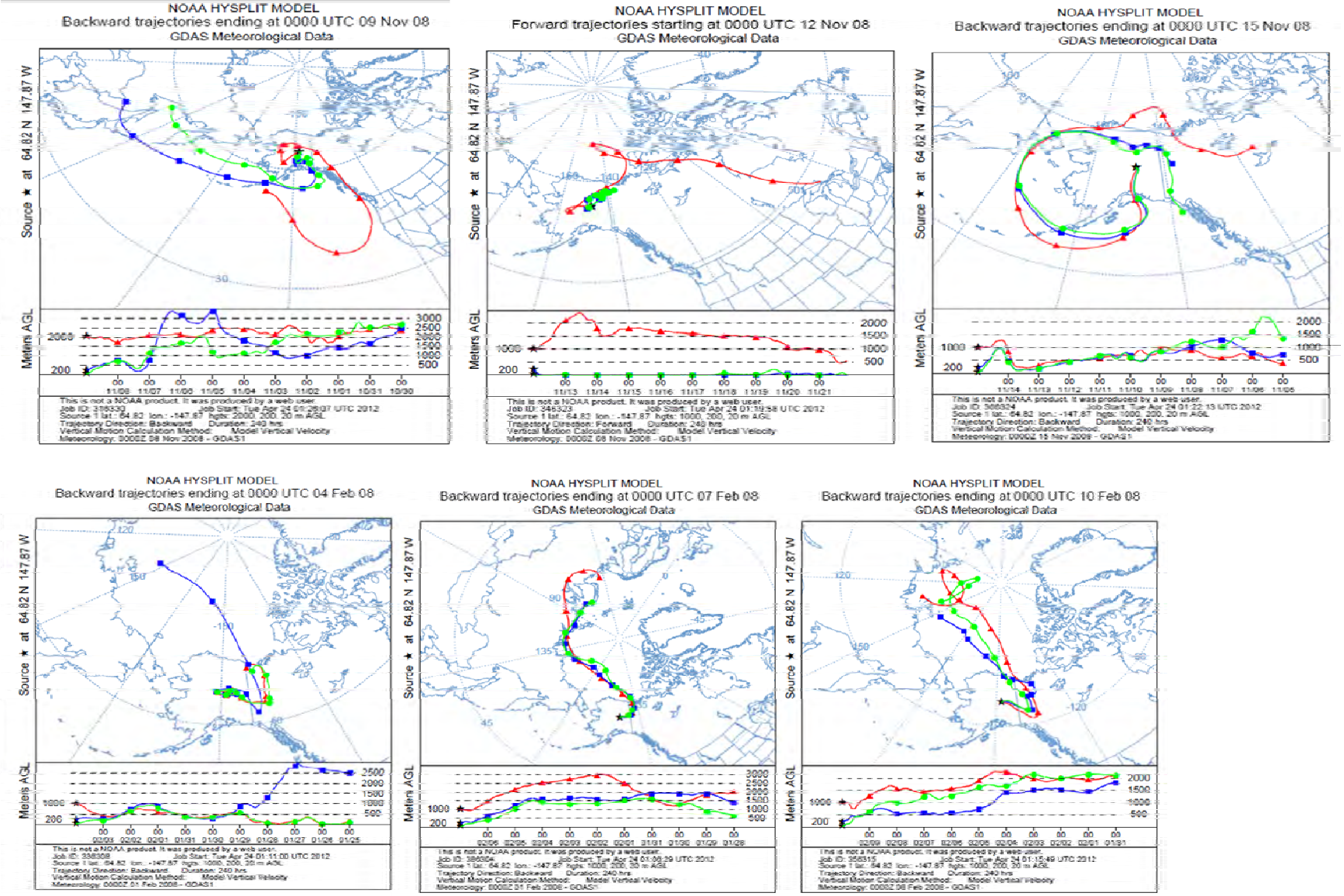


Fig. 43 Ten-day backward trajectories as calculated for November 9, 12, and 15, 2008, and February 4, 7, and 10, 2008 at 00 UTC.

To investigate the under-prediction of SO_4 at the State Building site, we conducted a process analysis. Process analysis is a technique that provides information about the impacts of individual processes on the change in a species' concentration. In the following, we refer to horizontal transport as the sum of horizontal advection and diffusion, and to vertical transport as the sum of vertical advection and diffusion. Aerosol processes represent the net effects of aerosol thermodynamics, new particle formation, condensation of sulfuric acid and organic carbon on preexisting particles, and the coagulation within and between Aitken and accumulation modes of particulate matter (PM). Cloud processes represent the net effects of cloud attenuation of photolytic rates, aqueous-phase chemistry, below-and in-cloud mixing with chemical species, cloud scavenging and wet deposition (Liu et al., 2010).

The hourly process analysis results for $PM_{2.5}$-concentrations and other species were analyzed for the domain. In the following, the results for the grid-cell holding the State Building site are discussed. Figure 44 shows the contributions of individual processes to the 24h-average $PM_{2.5}$-concentration in the first model layer (0-4m) at the grid-cell holding the State Building site. According to the process analysis, emissions were the dominant contributor to the $PM_{2.5}$-concentrations, and the horizontal transport contributed and removed $PM_{2.5}$ at this grid-cell. The aerosol processes played a small role here, which indicates that $PM_{2.5}$ is composed mainly of primary PM at this site. $PM_{2.5}$ was mainly vented out through vertical transport. Dry deposition played a small role in the removal of $PM_{2.5}$ and cloud process did not play any role here.

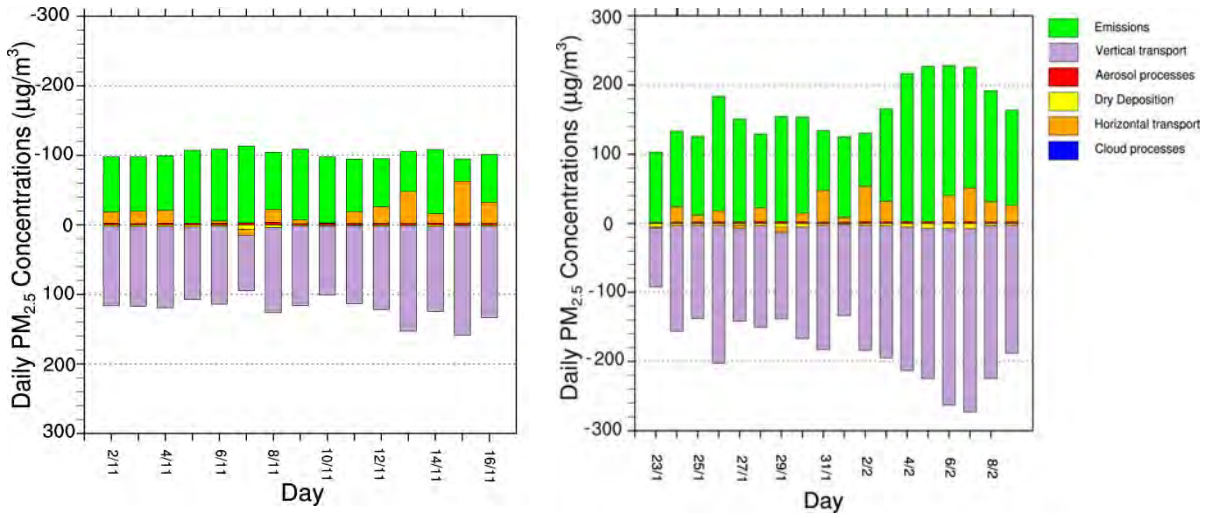


Fig. 44 Daily mean hourly contributions of individual processes to the $PM_{2.5}$-concentrations at the State Building site as obtained for the November episode (left) and January v2 episode (right).

For the sulfate species, the major contributors were emissions and horizontal transport. Comparing the observed sulfate bar chart (Fig. 42) with the process analysis plot (Fig. 45), it

could be verified that there was some offsets for the horizontal transport. For example, on November 14 or February 6, when the observed sulfate concentrations were highest, the horizontal transport in the process analysis (Fig. 45) dropped and peaked on the following day. Similar to $PM_{2.5}$, the major removal process for sulfate at the grid holding the State Building site was vertical transport. The dry deposition processes played a small role here, and aerosol processes and cloud processes did not play a role in sulfate formation. The latter may be a hint at overlooked sulfate forming processes or too low aqueous phase processes.

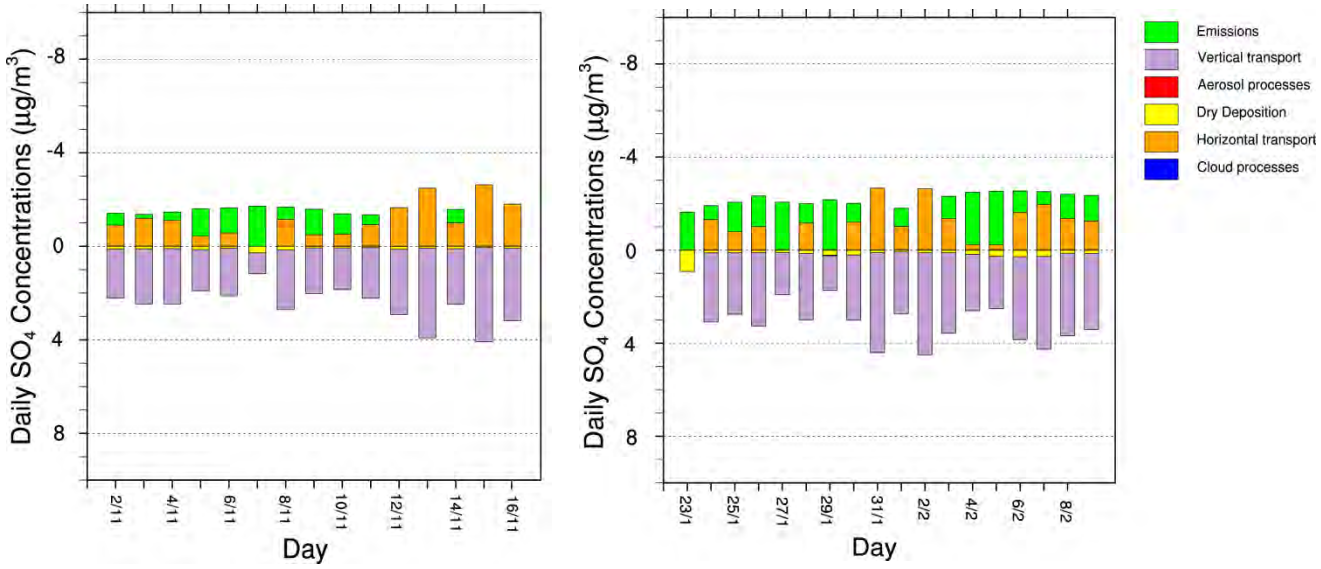


Fig. 45 Daily mean hourly contributions of individual processes to the SO_4-concentrations at the State Building site for the November episode (left) and January v2 episode (right).

Different from sulfate, the aerosol processes played the main role for nitrate formation. High production of nitrate also came from horizontal transport, which also shows an offset. The major removal process was vertical transport, and dry deposition caused a small loss to nitrate. Cloud processes neither produced nor removed nitrate in this grid-cell (Fig. 46).

For ammonium, the aerosol processes are the dominant contributor at this site. Horizontal transport contributed to ammonium on some days. The major removal process was vertical transport, and dry deposition caused only a small loss to ammonium. Cloud processes did not play a role here similar to what was found for both sulfate and nitrate (Fig. 47).

According to the process analysis results, cloud processes did not play a role for the formation or removal of aerosols at this grid cell. In general, the aqueous-phase oxidation of SO_2 in clouds is able to increase the SO_4-formation. Therefore, the average amount of water and ice mixing ratios simulated by WRF for both episodes were compared in vertical model column over the State Building site. Figure 48 shows that the cloud phase at this site is in the solid (ice) phase, which might affect the aqueous reactions and may be a cause for the low formation of SO_4-aerosol. The

water phase represents the integral sum of cloud water mixing ratios and rain-water mixing ratios, and the ice phase represents the integral sum of snow, ice and graupel mixing ratios. Note that the comparison of 120 WRF-simulations over Alaska showed that the Morrison-code used in the WRF-simulations tends to produce relatively higher ice phase than liquid phase (Chigullapalli and Mölders 2008).

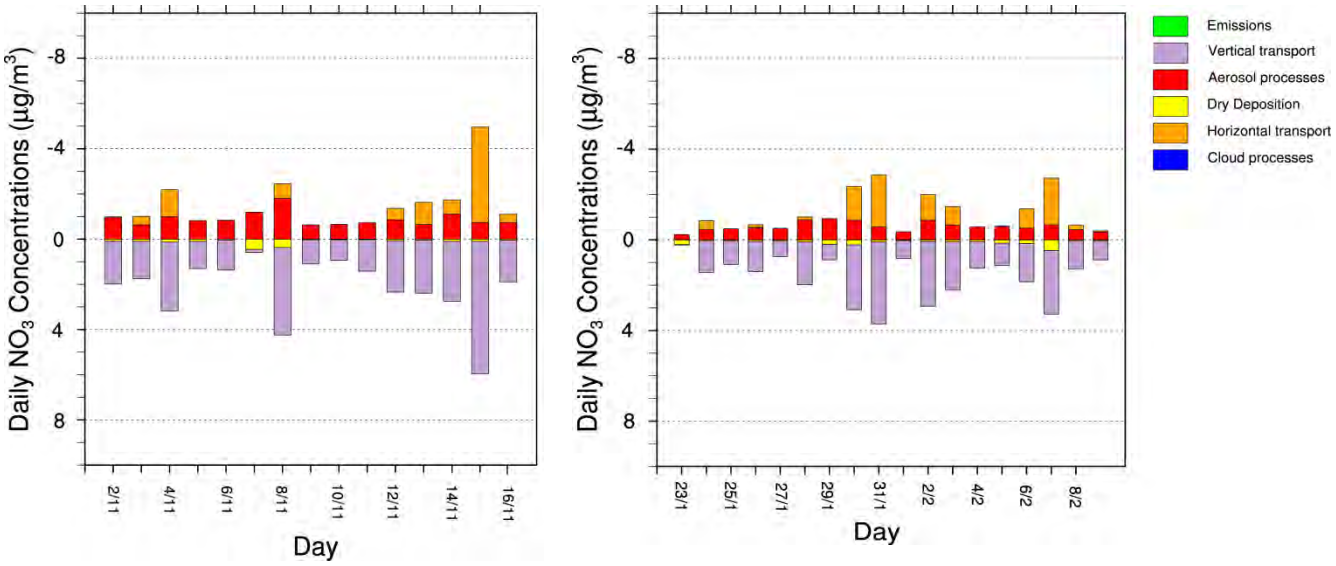


Fig. 46 Daily mean hourly contributions of individual processes to the NO_3-concentrations at State Building site as obtained for the November episode (left) and January v2 episode (right).

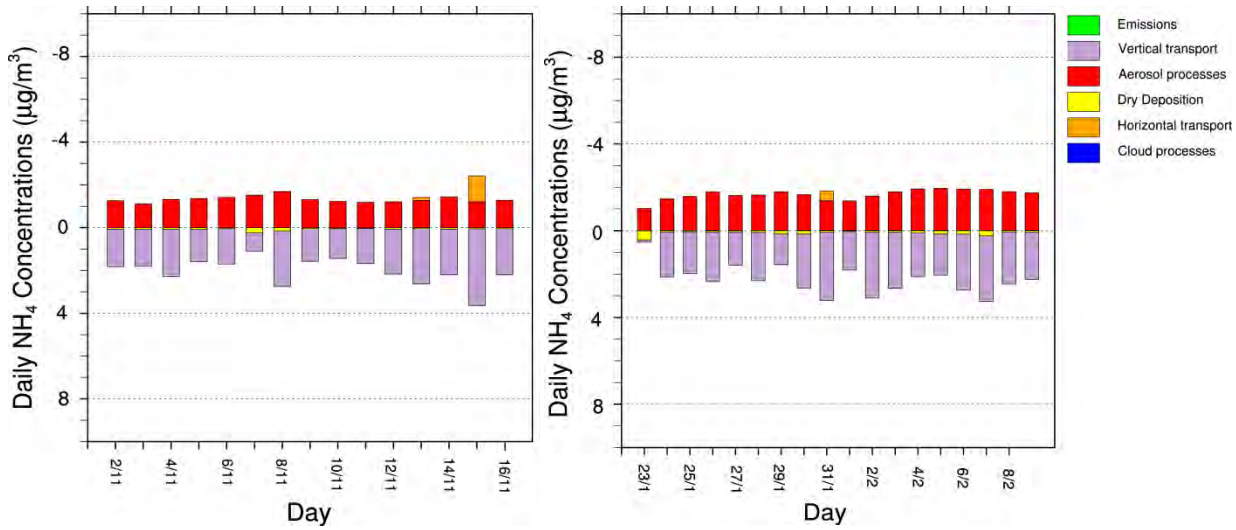
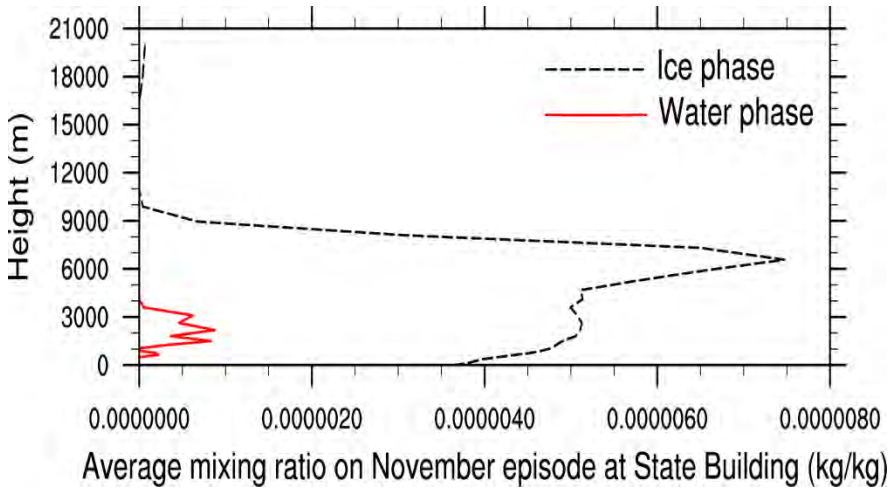


Fig. 47 Daily mean hourly contributions of individual processes to the NH_4-concentrations at the State Building site as obtained for the November episode (left) and January v2 episode (right).

(a)



(b)

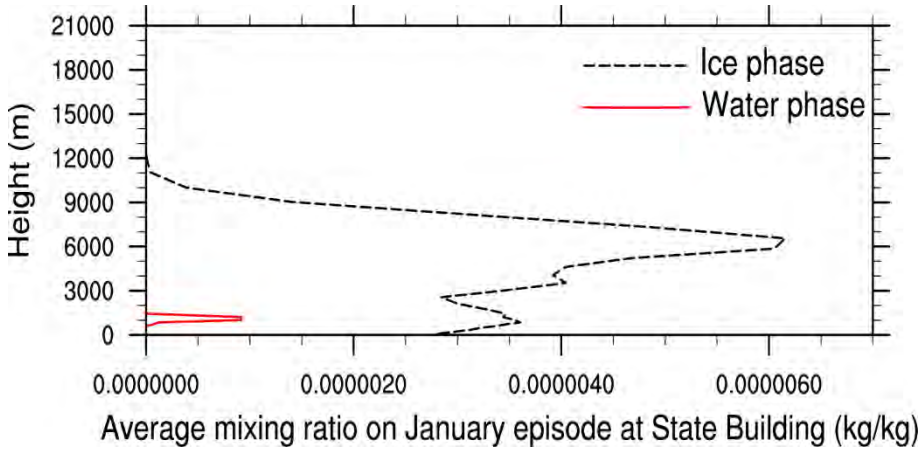


Fig. 47 Average ice phase and water phase mixing ratios at the State Building site as obtained for the (a) November episode and (b) January v2 episode.

Besides the effects from cloud processes, the underestimation of sulfate might come from too low SO_2-emissions. To test this hypothesis, we performed adapted CMAQ simulations wherein we doubled the SO_2-emissions that were given in the Sierra Research Inc. emission inventory. The results of this sensitivity study show that doubling the SO_2-emissions would increase the sulfate species concentrations, but not increase them (proportionally) two times (Fig. 48).

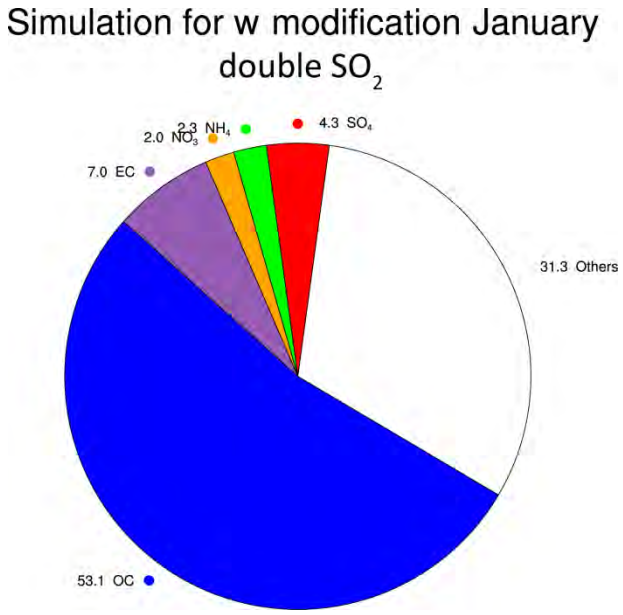


Fig. 48 Composition of total $PM_{2.5}$ averaged for the three days with observations as obtained by the adapted CMAQ for the January v2 episode and the sensitivity study with adapted CMAQ assuming doubled SO_2 emissions.

In a nutshell, the chemical processes have the dominant role in the formation of nitrate and ammonium, but not in the sulfate formation at the grid-cell holding the State Building site. Emissions are the main contributor to sulfate and $PM_{2.5}$-concentrations, and horizontal transport is another main contributor. The offset of the simulated meteorology led to the delay in prediction the $PM_{2.5}$ and its species of about 24 hours. The underestimation the sulfate composition is probably from the low amount of water in the liquid/water phase, i.e. low water content available to react with SO_2. Consequently, the cloud processes did not play a role for the aerosol formation. We recommend testing this hypothesis by adapted CMAQ simulations that use WRF simulations with a different cloud module. Studies on the impact of the parameterizations namely show that the partitioning between the solid and liquid phase in clouds differs strongly among parameterizations of cloud microphysical schemes (Mölders et al. 1995, 1997, Mölders 1999, Mölders and Kramm 2010) with consequences for the aqueous phase reactions (Mölders et al. 1994, Mölders and Laube 1994).

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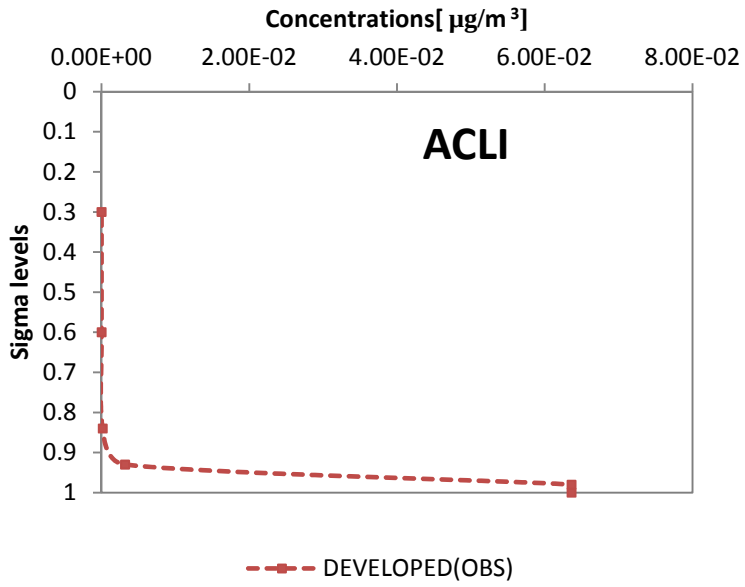
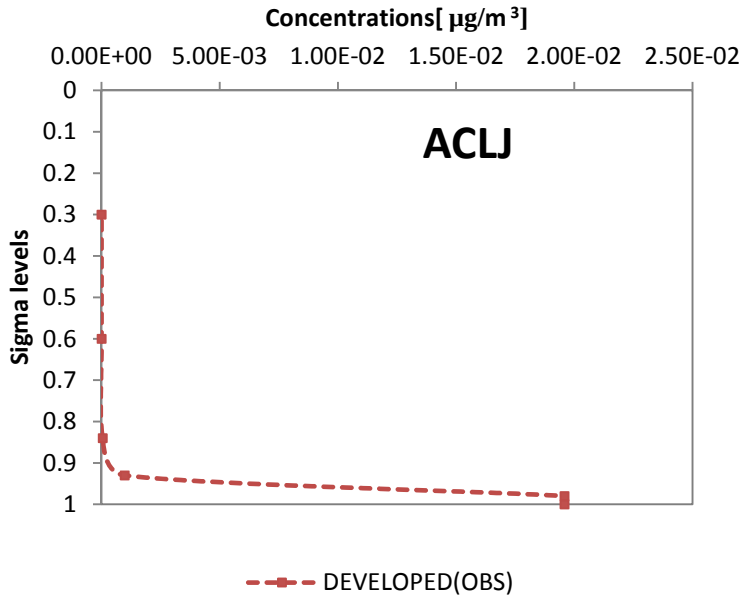
Appendix

The Cl-concentrations in the lowest level of the adapted CMAQ are now based on the average Cl-concentrations for January and November of 2003-2004 as observed at the Denali site (IMPROVE website). The vertical distribution assumed a reduction by 5% of the lower eta-level for every level between eta=0.93 and eta=0.30 (see panels below).





The Fairbanks, Alaska $PM_{2.5}$ Source Apportionment Research Study Winters 2005/2006-2012/2013, and Summer 2012

Final Report

Amendments 6 and 7

December 23, 2013

by

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1.0. Executive Summary

Fairbanks, Alaska has some of the highest measured ambient $PM_{2.5}$ (particulate matter less than or equal to 2.5 microns in diameter) concentrations in the United States, with wintertime levels often exceeding the 24-hour $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) of 35 $\mu g/m^3$. In an effort to understand the sources of $PM_{2.5}$ in the Fairbanks airshed, source apportionment using Chemical Mass Balance (CMB) modeling was conducted at multiple locations throughout Fairbanks each winter between 2005/2006 and 2012/2013. $PM_{2.5}$ source apportionment was also conducted at the NCORE and State Building sites during the summer of 2012 for comparison. Modeling for each of the sites/years was conducted using source profiles from both the Environmental Protection Agency (EPA) as well as Fairbanks-specific profiles developed by OMNI Environmental Services (OMNI).

Throughout the program, wintertime $PM_{2.5}$ average concentrations ranged from 8.2 $\mu g/m^3$ (RAMS, winter 2008/2009) up to 46.9 $\mu g/m^3$ (NPF3, winter 2012/2013), with many of the sites having frequent exceedances of the 24-hour NAAQS on the scheduled sample days. The results of the CMB modeling using source profiles developed by the EPA revealed that wood smoke (likely residential wood combustion) was the major source of $PM_{2.5}$ throughout the winter months in Fairbanks, contributing between ~60% to over 80% of the measured $PM_{2.5}$ depending on site and winter / year. The other sources of $PM_{2.5}$ identified by the CMB model were secondary sulfate (~7-21%), ammonium nitrate (3-11%), diesel exhaust (not detected-11%), and automobiles (not detected-7%). Approximately 1-2% of the ambient $PM_{2.5}$ was unexplained.

When conducting CMB modeling with Fairbanks-specific space heater source profiles developed by OMNI, final results were somewhat similar to the sources identified using EPA profiles. Consistent with the EPA modeling, wood smoke was identified as being a large source of $PM_{2.5}$ at the majority of the sampling sites, contributing from 30% to 77% to the ambient wintertime $PM_{2.5}$. In addition, the OMNI profile for No. 2 fuel oil combustion was frequently identified during the winter months, contributing anywhere from 10% to 47% to the ambient $PM_{2.5}$ throughout the winter months at each of the sites. Combustion of No. 2 fuel oil (and contribution to ambient $PM_{2.5}$) was determined to be especially high at the State Building and Peger Road sites.

Summer source apportionment revealed that ambient levels of $PM_{2.5}$ were very low at both the State Building and NCORE sites (~5.5 $\mu g/m^3$). CMB modeling using both the EPA and OMNI profiles identified wood smoke as the predominant source during the summer months, likely from residential outdoor biomass waste burning and regional controlled/wildfires. In summary, CMB modeling results using both the EPA and OMNI profiles support that residential home heating (residential wood stoves and heating with No. 2 fuel oil) are the major contributors to the ambient $PM_{2.5}$ in the Fairbanks airshed during the winter months. Wood smoke was also consistently identified during the summer months, albeit at much lower concentrations compared to winter concentrations.

2.0. Overview

The primary objective of this research study was to identify the major sources of ambient $PM_{2.5}$ in Fairbanks, Alaska using both EPA and OMNI (Fairbanks-specific) source profiles in a CMB model. Specifically, source apportionment was conducted for the following time periods/locations:

Winter 2005/2006: State Building.
Winter 2006/2007: State Building.
Winter 2007/2008: State Building.
Winter 2008/2009: State Building, North Pole, RAMS, Peger Road.
Winter 2009/2010: State Building, North Pole, RAMS, Peger Road.
Winter 2010/2011: State Building, North Pole, Peger Road.
Winter 2011/2012: State Building, NCORE, RAMS, North Pole, NPF3.
Summer 2012: State Building, NCORE.
Winter 2012/2013: State Building, NCORE, NPF3, NPE.

Within this report, the sampling, analytical, and computer modeling methodologies are described in Sections 3.0 through 5.0, respectively. Sections 6.0 and 7.0 present the results of the $PM_{2.5}$ sampling and CMB modeling program (using both EPA and OMNI source profiles), respectively, while Section 8.0 provides a discussion of all of the CMB modeling findings. Section 9.0 presents the results of the Quality Assurance / Quality Control (QA/QC) program. In Appendix A, the eight source profiles developed from the OMNI emissions testing are displayed, while Appendix B contains a listing of sample days excluded from CMB modeling. Finally, Appendix C presents the CMB results for each sample day (per site and season) using both EPA and OMNI profiles.

3.0. $PM_{2.5}$ Sampling Program

3.1. Sampling Program Experimental Method

For each of the winter sampling programs (November-March), $PM_{2.5}$ sampling was typically conducted every three days following the EPA"s fixed monitoring schedule. For the winters of 2005/2006, 2006/2007, and 2007/2008, sampling was conducted at the State Building site. $PM_{2.5}$ sampling was conducted at the State Building, North Pole, and Peger Road (also known as the Transit Yard) sites during the winters of 2008/2009, 2009/2010, and 2010/2011, respectively. A Relocatable Air Monitoring System (RAMS) collected $PM_{2.5}$ samples only during the winters of 2008/2009, 2009/2010, and 2011/2012. From January 14-March 19, 2009, the mobile RAMS was located at the Reindeer Site (i.e. University of Alaska Fairbanks Experimental Farm property between the Parks Highway and Geist Rd). From March 19 through the end of the program, the mobile RAMS was located at Woodriver Elementary School (Palo Verde Ave/ Univ. West). In this report, results for the Reindeer and Elementary School sites are presented as one location (i.e. the "RAMS Site").

In addition to the RAMS site, samples were also collected every three days at four additional sites (State Building, NCORE, North Pole, and NPF3) during the winter 2011/2012. For the winter of 2012/2013, the RAMS and North Pole sites were discontinued while the NPE site was added. Finally, $PM_{2.5}$ samples were collected at two locations during the summer of 2012 (State Building and NCORE) for a site comparison, as well as providing a comparison for summer results with winter results.

At each of the sites, 24-hour $PM_{2.5}$ sampling was conducted using a MetOne (Grants Pass, OR) Spiral Ambient Speciation Sampler (SASS). During each 24-hour sampling event at each of the sites, the SASS collected ~9.7 m^3 of air through Teflon, nylon, and quartz filter media, respectively (flow rate of 6.7 liters per minute (LPM)). Starting in the winter of 2009/2010, a URG 3000N Sequential Particulate

Speciation System was used to collect sample on a quartz filter at the State Building site for organics analyses. During each 24-hour event the URG collected air sample at a flow rate of 22.0 LPM.

3.2. Sampling Program Quality Assurance / Quality Control (QA/QC)

A stringent Quality Assurance / Quality Control (QA/QC) program was employed throughout this study. Prior to sampling, clean filters (Teflon, nylon, and quartz) were provided by Research Triangle Institute (RTI, Research Triangle Park, NC). Following the sampling events, exposed Teflon and nylon filters were sent back to RTI for laboratory analyses, while the exposed quartz filters were sent to Desert Research Institute (Reno, NV). During shipment of both clean and exposed filter sample media, all $PM_{2.5}$ filters remained in their protective containers and were FedEx overnighted in a cooler containing cold packs during transport.

Throughout the sampling program, the air samplers were maintained by Fairbanks North Star Borough (FNSB) Air Quality staff, with support from Alaska Department of Environmental Conservation (ADEC) staff. During each sampling event (24-hour period), the filters were subjected to temperatures that did not exceed the ambient temperature by more than five °C for more than 30 minutes continuously. Fairbanks site personnel removed the exposed filters from the samplers within 48 hours after the episode ended, and refrigerated the exposed filters immediately upon collection. The air samplers were also audited with an independent transfer standard during the program to verify the accurate measurement of air flow rates, ambient/filter temperatures, and barometric pressures. In addition, $PM_{2.5}$ filter field blanks were collected periodically throughout the program in an effort to determine any artifact contamination.

4.0. Analytical Program

4.1. $PM_{2.5}$ Speciation Data

The Met One Super SASS located at each of the sites collected ambient $PM_{2.5}$ on Teflon, nylon, and quartz filter media, respectively. The majority of the exposed SASS filter samples were analyzed by RTI. From the Teflon filter, a gravimetric analysis (RTI, 2008) was initially performed followed by an elemental analysis (RTI, 2009a) using energy-dispersive X-ray fluorescence (EDXRF) where 31 elements were quantified. From the nylon filter, ions (including ammonium, potassium, sodium, nitrate, and sulfate) were measured by ion chromatography (IC) (RTI, 2009b; RTI, 2009c). Depending on the site and year, quartz filters were either analyzed by RTI for Elemental Carbon and Organic Carbon (EC/OC) concentrations using Thermal Optical Transmittance (RTI, 2009d), or by Desert Research Institute using the IMPROVE_A method (Chow et al., 2007). Following the analyses, sample results (including analyte concentrations and uncertainties) were provided to the University of Montana for use in the CMB source apportionment model.

4.2. Analytical Program QA/QC

RTI and the Desert Research Institute were responsible for QA/QC activities within their laboratories.

5.0. Computer Modeling Program

In this project, the most recent version of the Chemical Mass Balance (CMB) computer model (Version 8.2) was utilized to apportion the sources of $PM_{2.5}$ in Fairbanks. The CMB receptor model (Friedlander, 1973; Cooper and Watson, 1980; Gordon, 1980, 1988; Watson, 1984; Watson et al., 1984; 1990; Hidy and Venkataraman, 1996) is based on an effective-variance least squares method, and consists of a solution to linear equations that expresses each receptor chemical concentration as a linear sum of products of source fingerprint abundances and contributions.

For each sample day (from the multiple sites), the CMB modeling process began by selecting from a combination of 91 sources (**see Table 1**) and 43 chemical species (36 elements, 5 ions, OC and EC, **Table 5**) in an effort to reconstruct the measured Fairbanks ambient $PM_{2.5}$ mass and chemical composition. As part of the CMB modeling procedure, multiple combinations would be tried for each sample run in an effort to select the best combination of sources and species, with an evaluation of the diagnostic performance measures conducted each time until an optimal fit could be obtained. The resulting output file contained the source contribution estimate (SCE) of each identified source, along with the associated standard errors (STD ERR). Unexplained concentrations were also calculated by taking the difference between the actual measured mass and the CMB predicted mass for each sample run.

5.1. CMB Model EPA Source Profiles

Discussions were held with Sierra Research, FNSB, and ADEC in an effort to identify all of the potential sources of $PM_{2.5}$ in Fairbanks prior to setting up the CMB model. Following these discussions, a comprehensive list of sources that could potentially contribute $PM_{2.5}$ to the Fairbanks airshed was developed. For each identified source, an attempt was made to locate a source profile. Source profiles are the fractional mass abundances of measured chemical species relative to primary $PM_{2.5}$ mass in source emissions, and are part of the input data loaded into the CMB model. Source profiles represent a general source category rather than any local, individual, $PM_{2.5}$ emission source.

The source profiles listed in **Table 1** (known throughout this report as "EPA Source Profiles") were either taken directly from the most recent version of SPECIATE 4.0 (USEPA, 2006) or from previous Missoula Valley (Montana) CMB applications (Carlson, 1990; Schmidt, 1996; Ward and Smith, 2005). SPECIATE 4.0 is EPA's repository of Total Organic Compound (TOC) and Particulate Matter (PM) speciated source profiles for use in source apportionment studies. For each source found in the database, both the compound fraction and uncertainty for the source-specific compounds are presented. The profiles in **Table 1** are listed together as source groups, and can be broken down into profiles for street sand and road dust (Profiles 1- 6), pure secondary source emissions (Profiles 7-9), gasoline and diesel exhaust emissions (Profiles 10 – 40), tire and brake wear (Profiles 41 - 48), meat cooking (Profiles 49 - 53), residential wood combustion (Profiles 54 – 78), and other local sources / industry in Fairbanks (Profiles 79-91). Multiple source profiles for each source were used because source compositions can vary substantially among sources, even within a single source over an extended period of time.

Since Missoula and Fairbanks have similar topographies (i.e. valley locations impacted by temperature inversions, cold winter temperatures, etc.) and many of the same sources of $PM_{2.5}$, several of the CMB source profiles developed in past Missoula CMB applications were included in the Fairbanks $PM_{2.5}$ source apportionment program. These include profiles for street sand (Profiles 1), secondary sulfate (Profile 7), secondary ammonium sulfate (Profile 8), secondary ammonium nitrate (Profile 9), diesel train (Profile 39) and diesel truck exhaust (Profile 40), and residential wood combustion (Profile 56). All SPECIATE and Missoula CMB profiles used in the Fairbanks CMB were reviewed before being loaded into the CMB model. For those chemical species known to be absent from specific source types, default values of zero for the mass fraction and uncertainty of 0.0001 were used.

One assumption of the CMB model is that compositions of source emissions are constant over the period of ambient and source sampling, and that chemical species do not react with each other. CMB is well suited for apportioning sources of primary aerosols (those emitted directly as particles). However, it is difficult to attribute secondary aerosols formed through gas-to-particle transformation in the atmosphere to specific sources. Sulfate, nitrate, and ammonium abundances in directly emitted particles are not sufficient to account for the concentrations of these species measured in the atmosphere. Therefore, to

account for secondary aerosol contributions to $PM_{2.5}$ mass, sulfate (Profile 7), ammonium sulfate (Profile 8), and ammonium nitrate (Profile 9) were expressed as "pure" secondary source profiles, and represented by their chemical form.

Table 1: $PM_{2.5}$ Source Profiles ("EPA Profiles") Used in the Fairbanks CMB.

Profile	Description
1	CITY STREET SANDING PILE, STREET SAND
2	SPECIATE 411302.5, PAVED ROAD DUST – COMPOSITE
3	SPECIATE 412202.5, UNPAVED ROAD DUST – COMPOSITE
4	SPECIATE 92053, PAVED ROAD DUST – SIMPLIFIED
5	SPECIATE 92088, UNPAVED ROAD DUST – SIMPLIFIED
6	SPECIATE 92073, SAND & GRAVEL – SIMPLIFIED
7	SULFATE (SO4 IS ONLY SPECIE, THEREFORE IS ONLY NONZERO CONCENTRATION)
8	AMMONIUM SULFATE (INCLUDES NH4)
9	AMMONIUM NITRATE (INCLUDES NH4)
10	SPECIATE 311052.5 LIGHT DUTY VEHICLE-LEADED COMPOSITE
11	SPECIATE 312022.5 LIGHT DUTY VEHICLE-UNLEADED
12	SPECIATE 321022.5 LIGHT DUTY VEHICLE-DIESEL
13	SPECIATE 321032.5 LIGHT DUTY VEHICLE-DIESEL (2ND PROFILE OF THIS TYPE)
14	SPECIATE 322032.5, HEAVY DUTY VEHICLE-DIESEL
15	SPECIATE 311082.5, LIGHT DUTY VEHICLE - NON CATALYST
16	SPECIATE 311072.5, LIGHT DUTY VEHICLE - WITH CATALYST
17	SPECIATE 322022.5, HEAVY DUTY DIESEL
18	SPECIATE 322082.5, HEAVY DUTY DIESEL TRUCKS
19	SPECIATE 312012.5, LIGHT DUTY VEHICLE – UNLEADED
20	SPECIATE 312032.5, LIGHT DUTY VEHICLE – UNLEADED
21	SPECIATE 3875, GASOLINE EXHAUST - WINTER, SMOKER
22	SPECIATE 3884, GASOLINE EXHAUST - WINTER, LOW EMITTER PROFILE 1
23	SPECIATE 3888, GASOLINE EXHAUST - WINTER, LOW EMITTER PROFILE 2
24	SPECIATE 3892, GASOLINE EXHAUST - WINTER, HIGH EMITTER PROFILE 1
25	SPECIATE 3896, GASOLINE EXHAUST - WINTER, HIGH EMITTER PROFILE 2
26	SPECIATE 3900, GASOLINE EXHAUST - WINTER, NON-SMOKER
27	SPECIATE 3904, GASOLINE EXHAUST - WINTER, SMOKER PROFILE 1
28	SPECIATE 3908, GASOLINE EXHAUST - WINTER, SMOKER PROFILE 2
29	SPECIATE 3878, DIESEL EXHAUST PROFILE 1
30	SPECIATE 3879, DIESEL EXHAUST PROFILE 2
31	SPECIATE 3880, DIESEL EXHAUST PROFILE 3
32	SPECIATE 3912, DIESEL EXHAUST PROFILE 4
33	SPECIATE 3913, DIESEL EXHAUST PROFILE 5
34	SPECIATE 3914, DIESEL EXHAUST PROFILE 6
35	SPECIATE 92035, HDDV EXHAUST – SIMPLIFIED
36	SPECIATE 92042, LDDV EXHAUST – SIMPLIFIED
37	SPECIATE 92049, NON-CATALYST GASOLINE EXHAUST – SIMPLIFIED
38	SPECIATE 92050, ONROAD GASOLINE EXHAUST – SIMPLIFIED
39	DIESEL TRAIN (SENT FROM MISSOULA)
40	DIESEL TRUCK (SENT FROM MISSOULA)
41	SPECIATE 340022.5, TIRE WEAR PROFILE 1
42	SPECIATE 340032.5, TIRE WEAR PROFILE 2
43	SPECIATE 340082.5, TIRE WEAR PROFILE 3
44	SPECIATE 3156, TIRE WEAR PROFILE 4

45	SPECIATE 92087, TIRE DUST – SIMPLIFIED
46	SPECIATE 340042.5, BRAKE LINING – ASBESTOS
47	SPECIATE 3157, BRAKE WEAR
48	SPECIATE 92009, BRAKE LINING DUST – SIMPLIFIED
49	SPECIATE 160002.5, MEAT COOKING – CHARBROILING
50	SPECIATE 160012.5, MEAT COOKING – FRYING
51	SPECIATE 4383, COOKING
52	SPECIATE 91005, COOKING - CHARBROILING COMPOSITE
53	SPECIATE 92015, CHARBROILING – SIMPLIFIED
54	SPECIATE 421042.5 RESIDENTIAL WOOD SMOKE FROM MEDFORD, OR
55	SPECIATE 421052.5 RESIDENTIAL WOOD SMOKE FROM POCATELLO, ID
56	RESIDENTIAL WOOD COMBUSTION (SUPPLIED BY MISSOULA)
57	SPECIATE 423182.5, RESIDENTIAL WOOD COMBUSTION
58	SPECIATE 423032.5, RESIDENTIAL WOOD COMBUSTION, COMPOSITE
59	SPECIATE 423302.5, COMPOSITE OF RESIDENTIAL WOODBURNING SOURCES
60	SPECIATE 421022.5, WOOD STOVES - AVERAGE ALL FUELS
61	SPECIATE 421012.5, WOOD STOVES - PINE FUELS
62	SPECIATE 3235, RESIDENTIAL WOOD BURNING PROFILE 1
63	SPECIATE 3236, RESIDENTIAL WOOD BURNING PROFILE 2
64	SPECIATE 3238, RESIDENTIAL WOOD BURNING PROFILE 3
65	SPECIATE 3239, RESIDENTIAL WOOD BURNING PROFILE 4
66	SPECIATE 3240, RESIDENTIAL WOOD BURNING PROFILE 5
67	SPECIATE 3769, RESIDENTIAL WOOD BURNING PROFILE 6
68	SPECIATE 3770, RESIDENTIAL WOOD BURNING PROFILE 7
69	SPECIATE 423192.5, RESIDENTIAL WOOD COMBUSTION COMPOSITE
70	SPECIATE 423312.5, RESIDENTIAL WOODSTOVE COMPOSITE
71	SPECIATE 91031, RESIDENTIAL WOOD COMBUSTION: HARDSOFT – COMPOSITE
72	SPECIATE 91032, RESIDENTIAL WOOD COMBUSTION: HARDSOFTN/A – COMPOSITE
73	SPECIATE 91033, RESIDENTIAL WOOD COMBUSTION: SOFT – COMPOSITE
74	SPECIATE 92067, RESIDENTIAL WOOD COMBUSTION: HARD – SIMPLIFIED
75	SPECIATE 92068, RESIDENTIAL WOOD COMBUSTION: HARDSOFT – SIMPLIFIED
76	SPECIATE 92069, RESIDENTIAL WOOD COMBUSTION: HARDSOFT N/A – SIMPLIFIED
77	SPECIATE 92071, RESIDENTIAL WOOD COMBUSTION: SYNTHETIC – SIMPLIFIED
78	SPECIATE 92090, WILDFIRES – SIMPLIFIED
79	SPECIATE 92006, ASPHALT ROOFING – SIMPLIFIED
80	SPECIATE 92025, DISTILLATE OIL COMBUSTION – SIMPLIFIED
81	SPECIATE 92048, NATURAL GAS COMBUSTION – SIMPLIFIED
82	SPECIATE 92052, OVERALL AVERAGE / DEFAULT (WASTE DISPOSAL, MISC) – SIMPLIFIED
83	SPECIATE 92060, PROCESS GAS COMBUSTION – SIMPLIFIED
84	SPECIATE 92063, RESIDENTIAL NATURAL GAS COMBUSTION – SIMPLIFIED
85	SPECIATE 92072, RESIDUAL OIL COMBUSTION – SIMPLIFIED
86	SPECIATE 92075, SEA SALT – SIMPLIFIED
87	SPECIATE 92079, SINTERING FURNACE-SIMPLIFIED (ZINC PROD, FLUE DUST HANDLING)
88	SPECIATE 92082, SOLID WASTE COMBUSTION – SIMPLIFIED
89	SPECIATE 92084, SUBBITUMINOUS COMBUSTION – SIMPLIFIED
90	SPECIATE 92085, SURFACE COATING – SIMPLIFIED
91	SPECIATE 92086, TIRE BURNING – SIMPLIFIED

5.2. CMB Modeling Using Fairbanks-Specific ("OMNI") Profiles

One limitation of using the EPA SPECIATE source profiles for CMB modeling (as described above) is that the profiles are not representative of Fairbanks-specific home heating fuel types. In other words, the

profiles were not developed using Fairbanks specific fuels or generated under Fairbanks-specific operating and meteorological conditions. To address this concern, emission testing was conducted by OMNI Environmental Services (Portland, OR) for a variety of home heating fuels and home heating devices commonly used in Fairbanks. These emissions results were provided to the University of Montana for development of Fairbanks-specific source profiles, with these profiles then used in CMB source apportionment modeling.

Prior to emissions testing, the FNSB provided OMNI with Fairbanks specific fuel types to be used in a variety of home heating devices. The goal of the OMNI testing was to generate emission profiles for the following types of heating appliances and fuel types: pellet stoves, EPA wood stoves (birch, spruce), conventional wood stoves (birch, spruce), EPA hydroponic heaters (birch, spruce), non qualified outdoor hydroponic heaters (spruce, birch, wet stoker coal), oil burners (No. 1 fuel oil, No. 2 fuel oil), waste oil burning, coal stoves (dry stoker coal, wet stoker coal, wet lump coal, dry lump coal), and coal hydroponic heaters (wet stoker coal and coal-typical moisture).

During each of the 41 trials, emission samples were collected on Teflon and quartz filter samples, respectively. From the Teflon filter, $PM_{2.5}$ mass, ions (potassium, sodium, ammonium, nitrate, and sulfate), and elements (33 in total) were quantified. From the quartz filter, levels of Organic Carbon and Elemental Carbon were measured. The Research Triangle Institute (RTI, Research Triangle Park, NC) conducted all of the analyses, and reported results in µg of analyte/filter. Following the completion of OMNI emissions testing, results from the trials were sent to FNSB, ADEC, and Sierra Research for a comprehensive review of methodology (sampling and analytical) and completeness. From the 41 emissions trials that were conducted by OMNI, University of Montana was instructed to focus on only eight of the trials. University of Montana then took the raw emissions data from these eight source types and transformed them into source profiles that were used in the CMB model.

The Fairbanks-specific source profiles that were developed from the OMNI emissions testing are presented in **Table 2.** In developing the profiles, the raw data from OMNI had to be put into a format recognized by the CMB model. First, the raw mass, elemental, OC/EC, and ion data (in µg/filter) measured by the Teflon and quartz filters were corrected for volume ($dsft^3$). This volume was the amount of air collected (for each filter) during each emissions testing trial. For the Teflon filters, the collected volumes varied from 1.12 up to 22.63 $dsft^3$, while for the quartz filter volumes ranged from 1.74 to 21.27 $dsft^3$. These values (µg/ $dsft^3$) were then normalized to the overall mass (units in µg/ $dsft^3$) to give the mass fraction of each species. For uncertainty, a default value of 0.0001 was utilized, with a value of "-99" utilized for missing species.

Table 2: OMNI Source Profiles ("OMNI Profiles") Used in the Fairbanks CMB.

Profile	Description
100	OMNI Profile, EPA Wood Stove, Birch, Low
101	OMNI Profile, EPA OWHH, Birch, Low
102	OMNI Profile, Conventional Wood Stove, Birch, Low
103	OMNI Profile, Oil Burner, No. 2 Fuel Oil
104	OMNI Profile, Coal Stove, Wet Stoker Coal, Low
105	OMNI Profile, Coal HH, Wet Stoker Coal, Single
106	OMNI Profile, WasteOil Brnr, Waste Oil, Single
107	OMNI Profile, EPA Wood Stove, spruce, low
108	OMNI Profile, Coal Stove Dry Lump Coal, low

The eight source profiles developed from the OMNI emissions testing are presented in **Appendix A**.

5.3. CMB Modeling Program QA/QC

A comprehensive QA/QC plan was applied throughout the CMB modeling program to ensure accurate results, including the use of the CMB validation protocol (Watson et al., 2004). The QA/QC protocol:

1) determines model applicability;
2) selects a variety of profiles to represent identified contributors;
3) evaluates model outputs and performance measures;
4) identifies and evaluates deviations from model assumptions;
5) identifies and corrects model input deficiencies;
6) verifies consistency and stability of source contribution estimates; and
7) evaluates CMB results with respect to other data analysis and source assessment methods.

For each model run, evaluations of several different combinations of source profiles were used, with the number of chemical species always exceeding the number of source types. As described in **Table 3**, statistical parameters used to evaluate the validity of source contribution estimates included TSTAT, R^2, Chi^2, DF, and R/U ratios. The results of these fitting parameters (for each modeling run) have to be within the EPA target ranges for the modeling results to be considered valid. It should also be noted that concentrations of species found on field/trip blanks were not subtracted (or blank-corrected) from the ambient sample concentrations before the modeling was conducted.

Table 3: Statistical Criteria for the CMB Model.

Output / Statistic	Abbreviation	EPA Target	Explanation
Std. Error	STD ERR	⩽SCE	The standard error of the SCE.
T-statistic	TSTAT	> 2.0	The ratio of the value of the SCE to the uncertainty in the SCE. A T-STAT greater than 2 means that the SCE has a relative uncertainty of less than 50%.
R-square	R-SQUARE (R^2)	0.8 to 1.0	A measure of the variance of the ambient concentration explained by the calculated concentration.
Chi-square	CHI-SQUARE (Chi^2)	0.0 to 4.0	A term that compares the difference between the calculated and measured ambient concentrations to the uncertainty of the difference. A perfect fit has a chi-square of 0.0, and a chi-square less than 2 usually indicates a good fit.
Percent Mass Explained	% MASS	100% ± 20%	The ratio of the total calculated to measured mass.
Degrees of Freedom	DF	> 5	The difference between the number of fitting species and the number of fitting sources.
Ratio of Calculated to Measured	RATIO C/M	0.5 to 2.0	The ratio of the calculated to measured concentration of an ambient species. Ideally, this value should be 1.0.
Ratio of Residual to Uncertainty	RATIO R/U	–2.0 to 2.0	The ratio of the residual (calculated minus measured) to the uncertainty of the residual (square root of the sum of squares of the uncertainties).

6.0. $PM_{2.5}$ Sampling Results

In presenting the final $PM_{2.5}$ results (in units of microgram of analyte per cubic meter volume of air collected, $\mu g/m^3$), there were several sample days throughout the program that were excluded from the overall average calculations due to sampler malfunctions or collection errors. Sample days where a

good statistical fit was not achieved using the CMB model were also excluded from the average calculations. A complete listing of these sample days along with a description of why the data points were excluded are presented in **Appendix B**.

6.1. $PM_{2.5}$ Mass Results

Table 4 presents the average $PM_{2.5}$ mass that was measured from Teflon filters collected at each of the sites throughout the program. Overall, wintertime $PM_{2.5}$ average concentrations ranged from 8.2 $\mu g/m^3$ (RAMS, winter 2008/2009) up to 46.9 $\mu g/m^3$ (NPF3, winter 2012/2013), with many of the sites having frequent exceedances of the 24-hour NAAQS on the scheduled sample days. Results from the summer 2012 show that $PM_{2.5}$ mass averages were very low, averaging less than 6.0 $\mu g/m^3$ at both the State Building and NCORE sites. Note that in **Table 4** there are two $PM_{2.5}$ masses listed for the winter 2008/2009 State Building and RAMS sites. The first $PM_{2.5}$ mass values are the average $PM_{2.5}$ concentrations originally presented in the Final Report submitted to ADEC (dated July 23, 2012). For consistency with the CMB modeling results presented in this report, updated CMB modeling was conducted on the 2008/2009 datasets using OMNI profiles in addition to automobile and diesel source profiles (note that auto / diesel exhaust were not identified in the initial OMNI modeling). The second $PM_{2.5}$ mass values presented for 2008/2009 (State Building and RAMS) are the average $PM_{2.5}$ concentrations for those sample days in which updated CMB modeling was conducted. Please note that when using the OMNI profiles, there were times when a statistical fit could not be obtained for a specific sampling day, thus explaining the smaller "n" and therefore different average $PM_{2.5}$ mass (compared to the EPA modeling runs) for specific winters/sites. For the remainder of the winters (2009/2010 through 2012/2013), a single asterisk "*" indicates the average concentrations for the days in which modeling was conducted using only the EPA profiles, while "**" indicates the average $PM_{2.5}$ concentrations for those days in which only OMNI profiles were used for modeling. No asterisk indicates that the number of modeling runs was identical between the EPA and OMNI modeling activities (therefore $PM_{2.5}$ averages were the same).

6.2. $PM_{2.5}$ Chemical Speciation Results

Tables 5 through **11** present the average concentrations (in $\mu g/m^3$) of elements, ions, and OC/EC, respectively, measured throughout the sampling programs at each of the sites/years. The minimum detection limits (MDL) in $\mu g/m^3$ for each compound are also presented, with the bolded values (within the tables) indicating analyte concentrations measured at or above the MDL. All MDLs were provided by RTI. Also please note that **Table 6** contains the revised average speciated data for the winter 2008/2009 where CMB modeling was updated using the OMNI profiles (along with the automobile and diesel exhaust profiles). For the remainder of the speciated data results in **Tables 7-11**, a single asterisk "*" indicates the average speciated data concentrations for the days in which modeling was conducted using only the EPA profiles, while "**" indicates the average concentrations for those days in which only OMNI profiles were used for modeling. No asterisk indicates that the number of modeling runs was identical between the EPA and OMNI modeling activities (therefore speciated analyte averages were the same).

Out of the 36 elements quantified, only about 13 were consistently measured at or above their reported MDLs. Sulfur typically had the highest concentration of the measured elements (especially at the State Building and Peger Road sites), followed by chlorine and potassium. Regarding the ions that were measured, sulfate had the highest concentration at each of the sites, followed by ammonium and nitrate. Total Carbon (TC) measurements were always heavily influenced by the OC fractions at each of the sites. Results from the field and trip blanks for the species listed in **Tables 5-11** were minimal throughout the sampling/analytical program, therefore data were not blank corrected prior to using in the CMB model.

Table 4: Average $PM_{2.5}$ Mass Concentrations ($\mu g/m^3$).

Winter, Site	$PM_{2.5}$ mass	Sampling Dates	n
2005/2006, State Building	18.9	11/3/05 – 3/30/06	36
2006/2007, State Building	19.9	11/1/06 – 3/31/07	39
2007/2008, State Building	18.7	11/2/07 – 3/31/08	40
Winter 2008/2009			
State Building	25.3, 24.4	11/8/08 – 4/7/09	47, 46
North Pole	18.9	1/25/09 – 4/7/09	21
RAMS	8.2, 8.3	1/25/09 – 4/7/09	23, 22
Peger Road	16.8	1/25/09 – 4/7/09	26
Winter 2009/2010			
State Building	28.8*, 24.5**	11/3/09 – 3/15/10	40*, 31**
North Pole	33.7	11/3/09 – 3/15/10	35
RAMS	36.7	11/15/09 – 3/15/10	29
Peger Road	29.0*, 29.5**	11/3/09 – 3/15/10	38*, 37**
Winter 2010/2011			
State Building	20.2	11/1/10 – 2/8/11	15
North Pole	26.8	1/9/11 – 2/5/11	10
Peger Road	28.6	1/9/11 – 2/5/11	10
Winter 2011/2012			
State Building	20.0*, 19.5**	11/2/11 – 3/31/12	38*, 36**
North Pole	24.2*, 23.0**	11/2/11 – 3/25/12	35*, 34**
RAMS	22.1*, 22.7**	12/20/11 – 2/27/12	16*, 15**
NCORE	19.5*, 19.3**	11/2/11 – 3/31/12	44*, 42**
NPF3	18.3	3/1/12 – 3/31/12	7
Summer 2012			
State Building	5.7	6/2/12-8/31/12	20
NCORE	5.1	6/14/12-8/31/12	17
Winter 2012/2013			
State Building	21.8	11/2/12 – 3/29/13	29
NPE	28.1*, 27.8**	11/2/12 – 3/29/13	41*, 40**
NCORE	25.5*, 25.1**	11/2/12 – 3/29/13	38*, 39**
NPF3	46.9	11/2/13 – 3/29/13	42

Note: The minimum detection limit (MDL) for the State Building site was 0.740 $\mu g/m^3$, and ~0.745 $\mu g/m^3$ for all of the other sites. *EPA profiles used. ** OMNI profiles used.

Table 5: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations ($\mu g/m^3$) – State Building, Winters of 2005/2006, 2006/2007, and 2007/2008.

	State Building 11/3/05 – 3/30/06 n= 36	State Building 11/1/06 – 3/31/07 n=39	State Building 11/2/07 – 3/31/08 n=40	MDL
Magnesium	0.009	0.008	0.006	0.011
Aluminum	**0.020**	**0.031**	0.009	0.013
Silicon	**0.063**	**0.042**	**0.048**	0.011
Phosphorus	0.000	0.002	0.001	0.010
Sulfur	**1.339**	**1.249**	**1.153**	0.007
Chlorine	**0.017**	**0.068**	**0.073**	0.005
Potassium	**0.083**	**0.081**	**0.102**	0.004
Calcium	**0.056**	**0.029**	**0.029**	0.005
Titanium	**0.005**	0.000	0.001	0.004
Vanadium	0.001	0.001	0.000	0.003
Chromium	**0.002**	**0.012**	**0.002**	0.002
Manganese	**0.002**	**0.002**	0.001	0.002
Iron	**0.069**	**0.084**	**0.052**	0.001
Nickel	**0.001**	**0.004**	**0.001**	0.001
Copper	**0.004**	**0.006**	**0.004**	0.001
Zinc	**0.043**	**0.040**	**0.039**	0.003
Gallium	0.001	0.000	0.000	0.002
Arsenic	**0.001**	**0.001**	**0.001**	0.001
Selenium	0.001	0.000	0.000	0.002
Bromine	**0.005**	**0.004**	**0.003**	0.002
Rubidium	0.001	0.000	0.000	0.002
Strontium	**0.006**	**0.006**	**0.002**	0.002
Yttrium	0.001	0.000	0.000	0.003
Zirconium	0.001	0.001	0.000	0.004
Molybdenum	0.000	0.000	0.000	0.006
Silver	0.003	0.002	0.001	0.013
Cadmium	0.003	0.001	0.001	0.017
Indium	0.003	0.001	0.000	0.018
Tin	0.005	0.003	0.002	0.025
Antimony	0.004	0.001	0.001	0.038
Barium	**0.016**	0.002	0.002	0.010
Lanthanum	0.006	0.000	0.000	0.008
Mercury	0.002	0.001	0.000	0.007
Lead	**0.007**	**0.004**	**0.004**	0.004
Sodium	**0.045**	**0.041**	0.028	0.037
Cobalt	0.000	0.000	0.000	0.001
Sulfate	**3.816**	**3.479**	**3.215**	0.010
Nitrate	**1.102**	**1.054**	**0.954**	0.007
Ammonium	**1.648**	**1.573**	**1.446**	0.017
Potassium	**0.072**	**0.064**	**0.095**	0.014
Sodium (ion)	**0.066**	**0.072**	**0.076**	0.027
Total Carbon	**10.4**	**10.9**	**11.1**	0.24
Organic Carbon	**8.7**	**9.3**	**9.2**	0.24
Elemental Carbon	**1.7**	**1.6**	**1.8**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.

Table 6: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2008/2009.

	State Building 11/8/08 – 4/7/09 n= 47*, 46**	North Pole 1/25/09 – 4/7/09 n=21	RAMS 1/25/09 – 4/7/09 n=23*, 22**	Peger Road 1/25/09 – 4/7/09 n=26	MDL
Magnesium	0.011	**0.012**	**0.016, 0.014**	**0.018**	0.013, 0.011
Aluminum	**0.021**	0.005	0.011	**0.016**	0.014, 0.013
Silicon	**0.049, 0.048**	**0.024**	**0.031, 0.032**	**0.062**	0.011
Phosphorus	0.005	0.001	0.000	**0.010**	0.012, 0.010
Sulfur	**1.730, 1.558**	**0.637**	**0.367, 0.369**	**0.968**	0.008, 0.007
Chlorine	**0.125, 0.123**	**0.103**	**0.100, 0.076**	**0.151**	0.007, 0.005
Potassium	**0.136, 0.131**	**0.113**	**0.041, 0.042**	**0.069**	0.006, 0.004
Calcium	**0.047, 0.046**	**0.014**	**0.015**	**0.045**	0.006, 0.005
Titanium	0.001	0.000	0.000	0.001	0.005, 0.004
Vanadium	0.000	0.000	0.000	0.000	0.003
Chromium	**0.003**	**0.004**	0.000	0.000	0.002
Manganese	0.001	0.001	0.000	0.001	0.002
Iron	**0.058, 0.054**	**0.027**	**0.017**	**0.053**	0.002, 0.001
Nickel	**0.001**	**0.001**	0.000	0.000	0.001
Copper	**0.004**	**0.001**	**0.001**	**0.004**	0.002, 0.001
Zinc	**0.065, 0.062**	**0.015**	**0.008**	**0.058**	0.003, 0.004
Gallium	0.000	0.000	0.000	0.000	0.002
Arsenic	0.000	0.000	**0.001**	0.001	0.001, 0.002
Selenium	0.000	0.000	0.000	0.000	0.002
Bromine	**0.005**	**0.003**	**0.005**	**0.007**	0.002
Rubidium	0.000	0.000	0.000	0.000	0.002
Strontium	**0.004**	0.001	0.001	**0.002**	0.002
Yttrium	0.000	0.000	0.000	0.000	0.003
Zirconium	0.000	0.000	0.000	0.000	0.004, 0.005
Molybdenum	0.000	0.000	0.000	0.000	0.006, 0.009
Silver	0.001	0.002	0.001	0.002	0.013, 0.015
Cadmium	0.002	0.000	0.000	0.000	0.017, 0.019
Indium	0.001	0.002	0.002	0.003	0.018, 0.022
Tin	0.005	0.002	0.002	0.003	0.025, 0.032
Antimony	0.001	0.002	0.002, 0.001	0.001	0.038, 0.042
Barium	0.001	0.000	0.000	0.000	0.015, 0.010
Lanthanum	0.000	0.001	0.000	0.000	0.014, 0.008
Mercury	0.001	0.001	0.001	0.001	0.007, 0.009
Lead	0.003	0.002	0.003	**0.005**	0.004, 0.005
Sodium	**0.113, 0.111**	**0.107**	**0.108, 0.092**	**0.141**	0.037, 0.040
Cobalt	0.000	0.000	0.000	**0.001**	0.001
Sulfate	**4.585, 4.194**	**1.739**	**1.052, 1.056**	**2.541**	0.010
Nitrate	**1.282, 1.268**	**0.709**	**0.615, 0.623**	**1.127**	0.007
Ammonium	**2.160, 1.974**	**0.683**	**0.430, 0.439**	**1.235**	0.018, 0.017
Potassium	**0.137, 0.134**	**0.135**	**0.058, 0.057**	**0.096**	0.015, 0.014
Sodium (ion)	**0.126, 0.126**	**0.155**	**0.148, 0.132**	**0.162**	0.027, 0.030
Total Carbon	**14.5, 13.7**	**12.6**	**5.1, 5.2**	**10.0**	0.24
Organic Carbon	**12.9, 12.2**	**11.7**	**4.7, 4.8**	**8.7**	0.24
Elemental Carbon	**1.6, 1.5**	**0.9**	**0.5**	**1.3**	0.24

Note: MDL–minimum detection limit. MDLs include those from both the State building, and other three sites. Bolded values indicate concentrations measured at or above the MDL. *Average concentrations originally presented in the Final Report submitted to ADEC (dated July 23, 2012). **Average concentrations for those sample days in which updated CMB modeling (with OMNI profiles as well as auto/diesel profiles) was conducted.

Table 7: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2009/2010.

	State Building 11/3/09–3/15/10 n=40*, 31**	North Pole 11/3/09–3/15/10 n=35	RAMS 11/15/09–3/15/10 n=29	Peger Road 11/3/09–3/15/10 n=38*, 37**	MDL
Magnesium	0.009	0.004	0.003	0.007, 0.008	0.013, 0.011
Aluminum	**0.020, 0.014**	0.004	0.008	0.007	0.014, 0.013
Silicon	**0.054, 0.050**	**0.031**	**0.057**	**0.073, 0.074**	0.011
Phosphorus	0.008, 0.004	0.000	0.000	**0.025, 0.026**	0.012, 0.010
Sulfur	**1.760, 1.404**	**0.915**	**1.388**	**1.618, 1.654**	0.008, 0.007
Chlorine	**0.151, 0.116**	**0.151**	**0.154**	**0.290, 0.297**	0.007, 0.005
Potassium	**0.130, 0.114**	**0.202**	**0.185**	**0.132, 0.134**	0.006, 0.004
Calcium	**0.042, 0.039**	**0.014**	**0.028**	**0.058, 0.059**	0.006, 0.005
Titanium	0.001, 0.002	0.001	0.002	0.003	0.005, 0.004
Vanadium	0.000	0.000	0.000	0.000	0.003
Chromium	**0.002**	0.000	**0.004**	0.001	0.002
Manganese	**0.002**	0.001	**0.006**	**0.004**	0.002
Iron	**0.061, 0.055**	**0.024**	**0.080**	**0.109, 0.111**	0.002, 0.001
Nickel	**0.001**	0.000	**0.004**	0.000	0.001
Copper	**0.006, 0.004**	**0.006**	**0.004**	**0.008**	0.002, 0.001
Zinc	**0.072, 0.061**	**0.031**	**0.045**	**0.121, 0.123**	0.003, 0.004
Gallium	0.000	0.000	0.000	0.000	0.002
Arsenic	**0.001,** 0.000	0.000	**0.001**	**0.001**	0.001, 0.002
Selenium	0.000	0.000	0.000	0.000	0.002
Bromine	**0.004, 0.003**	**0.004**	**0.011**	**0.011**	0.002
Rubidium	0.001	0.000	0.000	0.000	0.002
Strontium	**0.002**	0.000	0.001	0.001	0.002
Yttrium	0.000	0.000	0.000	0.000	0.003
Zirconium	0.001	0.000	0.000	0.000	0.004, 0.005
Molybdenum	0.000	0.000	0.000	0.000	0.006, 0.009
Silver	0.002	0.002	0.001	0.002	0.013, 0.015
Cadmium	0.003	0.001	0.001	0.003	0.017, 0.019
Indium	0.003	0.001	0.003	0.001	0.018, 0.022
Tin	0.004, 0.003	0.004	0.004	0.001	0.025, 0.032
Antimony	0.007, 0.008	0.008	0.008	0.006, 0.005	0.038, 0.042
Barium	0.005	0.000	0.000	0.000	0.015, 0.010
Lanthanum	0.000	0.000	0.000	0.000	0.014, 0.008
Mercury	0.000	0.000	0.000	0.000	0.007, 0.009
Lead	**0.005**, 0.004	**0.004**	**0.014**	**0.017**	0.004, 0.005
Sodium	**0.084, 0.077**	**0.076**	**0.086**	**0.140, 0.142**	0.037, 0.040
Cobalt	0.000	0.000	0.000	0.000	0.001
Sulfate	**4.633, 3.911**	**2.452**	**3.890**	**4.173, 4.256**	0.010
Nitrate	**1.505, 1.417**	**0.888**	**1.029**	**1.706, 1.725**	0.007
Ammonium	**2.433, 1.894**	**1.232**	**1.822**	**2.420, 2.460**	0.018, 0.017
Potassium	**0.141, 0.129**	**0.184**	**0.170**	**0.123, 0.125**	0.015, 0.014
Sodium (ion)	**0.080, 0.079**	**0.117**	**0.135**	**0.134, 0.131**	0.027, 0.030
Total Carbon	**13.2, 11.4**	**22.3**	**24.1**	**16.2, 16.5**	0.24
Organic Carbon	**11.5, 10.0**	**19.8**	**21.5**	**13.4, 13.7**	0.24
Elemental Carbon	**1.7, 1.4**	**2.5**	**2.6**	**2.8**	0.24

Note: MDL–minimum detection limit. MDLs include those from both the State building, and other three sites. Bolded values indicate concentrations measured at or above the MDL. *EPA runs only. **OMNI runs only.

Table 8: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2010/2011.

Analyte	State Building 11/1/10–2/8/11 n=15	North Pole 1/9/11–2/5/11 n=10	Peger Road 1/9/11–2/5/11 n=10	MDL
Magnesium	0.001	0.000	0.000	0.013, 0.011
Aluminum	0.008	**0.015**	**0.033**	0.014, 0.013
Silicon	**0.027**	0.009	**0.032**	0.011
Phosphorus	0.002	0.000	**0.014**	0.012, 0.010
Sulfur	**1.188**	**0.757**	**1.608**	0.008, 0.007
Chlorine	**0.089**	**0.112**	**0.280**	0.007, 0.005
Potassium	**0.089**	**0.184**	**0.142**	0.006, 0.004
Calcium	**0.027**	**0.016**	**0.046**	0.006, 0.005
Titanium	0.001	0.000	0.001	0.005, 0.004
Vanadium	0.000	0.000	0.000	0.003
Chromium	**0.002**	0.000	0.000	0.002
Manganese	0.001	0.000	**0.004**	0.002
Iron	**0.040**	**0.019**	**0.076**	0.002, 0.001
Nickel	**0.001**	0.000	0.000	0.001
Copper	**0.002**	**0.002**	**0.007**	0.002, 0.001
Zinc	**0.051**	**0.029**	**0.107**	0.003, 0.004
Gallium	0.000	0.000	0.000	0.002
Arsenic	0.000	**0.001**	**0.001**	0.001, 0.002
Selenium	0.000	0.000	0.000	0.002
Bromine	**0.004**	**0.002**	**0.010**	0.002
Rubidium	0.000	0.000	0.000	0.002
Strontium	0.001	0.000	**0.007**	0.002
Yttrium	0.000	0.000	0.000	0.003
Zirconium	0.000	0.001	0.001	0.004, 0.005
Molybdenum	0.000	0.000	0.000	0.006, 0.009
Silver	0.001	0.000	0.000	0.013, 0.015
Cadmium	0.001	0.003	0.004	0.017, 0.019
Indium	0.002	0.005	0.001	0.018, 0.022
Tin	0.001	0.000	0.000	0.025, 0.032
Antimony	0.006	0.012	0.002	0.038, 0.042
Barium	0.000	0.000	0.000	0.015, 0.010
Lanthanum	0.000	0.000	0.000	0.014, 0.008
Mercury	0.000	0.000	0.000	0.007, 0.009
Lead	0.003	0.001	**0.014**	0.004, 0.005
Sodium	**0.044**	0.003	**0.060**	0.037, 0.040
Cobalt	0.000	0.000	**0.001**	0.001
Sulfate	**3.352**	**2.393**	**5.047**	0.010
Nitrate	**1.158**	**0.755**	**1.790**	0.007
Ammonium	**1.565**	**0.885**	**2.396**	0.018, 0.017
Potassium	**0.084**	**0.165**	**0.147**	0.015, 0.014
Sodium (ion)	**0.030**	**0.062**	**0.081**	0.027, 0.030
Total Carbon	**8.5**	**16.7**	**15.3**	0.24
Organic Carbon	**7.5**	**14.6**	**12.6**	0.24
Elemental Carbon	**1.0**	**2.1**	**2.7**	0.24

Note: MDL–minimum detection limit. MDLs include those from both the state building, and other two sites. Bolded values indicate concentrations measured at or above the MDL.

Table 9: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Winter 2011/2012.

	State Building 11/2/11 – 3/31/12 n=38*, 36**	North Pole 11/2/11 – 3/25/12 n=35*, 34**	RAMS 12/20/11 – 2/27/12 n=16*, 15**	NCORE 11/2/11 – 3/31/12 n=44*, 42**	NPF3 3/1/12 – 3/31/12 n=7	MDL
Magnesium	**0.011**, 0.009	**0.019, 0.017**	**0.015, 0.016**	**0.017, 0.018**	**0.023**	0.011
Aluminum	0.009, 0.008	0.001	0.009	0.007, 0.008	0.010	0.013
Silicon	**0.042, 0.043**	**0.017**	**0.037, 0.036**	**0.033, 0.032**	**0.031**	0.011
Phosphorus	0.000	0.000	0.000	0.000	0.000	0.010
Sulfur	**1.203, 1.153**	**0.655, 0.627**	**0.971, 0.998**	**1.049**	**0.584**	0.007
Chlorine	**0.080**	**0.150, 0.145**	**0.113, 0.118**	**0.112**	**0.164**	0.005
Potassium	**0.114, 0.111**	**0.264, 0.258**	**0.200, 0.209**	**0.132**	**0.164**	0.004
Calcium	**0.028, 0.027**	**0.017, 0.016**	**0.032, 0.033**	**0.026**	**0.014**	0.005
Titanium	0.003	0.001, 0.000	0.001	0.001	0.000	0.004
Vanadium	0.000	0.000	0.000	0.000	0.000	0.003
Chromium	**0.002**, 0.001	0.001	0.001	0.001	0.000	0.002
Manganese	0.001	0.001	**0.002, 0.003**	**0.002, 0.001**	0.001	0.002
Iron	**0.042, 0.041**	**0.020**	**0.062, 0.064**	**0.039, 0.037**	**0.015**	0.001
Nickel	0.000	0.000	**0.001**	0.000	0.000	0.001
Copper	**0.003**	**0.004**	**0.006**	**0.004**	**0.001**	0.001
Zinc	**0.041**	**0.023, 0.022**	**0.039, 0.041**	**0.037, 0.036**	**0.012**	0.003
Gallium	0.000	0.000	0.000	0.000	0.000	0.002
Arsenic	0.000	0.000	0.000	**0.001**	0.000	0.001
Selenium	0.000	0.000	0.000	0.000	0.000	0.002
Bromine	**0.005**	**0.004, 0.003**	**0.003**	**0.005**	**0.008**	0.002
Rubidium	0.000	0.000	0.000	0.000	0.000	0.002
Strontium	**0.003**	**0.002**	**0.006**	**0.003**	0.000	0.002
Yttrium	0.000	0.000	0.000	0.000	0.000	0.003
Zirconium	0.001	0.001	0.002	0.001	0.000	0.004
Molybdenum	0.000	0.000	0.000	0.000	0.000	0.006
Silver	0.001	0.000	0.000	0.000	0.002	0.013
Cadmium	0.003	0.001	0.000	0.001	0.000	0.017
Indium	0.002	0.002	0.001	0.002	0.001	0.018
Tin	0.004	0.001, 0.002	0.005	0.002	0.000	0.025
Antimony	0.007, 0.006	0.008	0.005	0.008, 0.009	0.005	0.038
Barium	0.000	0.004	**0.023, 0.022**	**0.010**	0.000	0.010
Lanthanum	0.000	0.000	0.000	0.000	0.000	0.008
Mercury	0.000	0.000	0.000	0.000	0.000	0.007
Lead	0.001, 0.002	0.001	0.002	0.002	0.000	0.004
Sodium	**0.097, 0.092**	**0.098, 0.095**	**0.076, 0.078**	**0.107, 0.109**	**0.148**	0.037
Cobalt	0.000	0.000	**0.001**	**0.001**	0.000	0.001
Sulfate	**3.283, 3.135**	**1.817, 1.733**	**2.883, 2.764**	**2.900, 2.901**	**1.576**	0.010
Nitrate	**0.924, 0.915**	**0.502, 0.493**	**0.949, 0.936**	**0.827, 0.815**	**0.462**	0.007
Ammonium	**1.228, 1.176**	**0.491, 0.462**	**0.969, 0.923**	**0.991, 0.992**	**0.432**	0.017
Potassium	**0.095, 0.093**	**0.237, 0.231**	**0.157, 0.159**	**0.105**	**0.114**	0.014
Sodium (ion)	**0.104, 0.101**	**0.101, 0.098**	**0.071, 0.072**	**0.094, 0.095**	**0.143**	0.027
Total Carbon	**8.5, 8.6**	**13.7, 13.4**	**12.4, 12.2**	**10.6, 10.9**	**12.5**	0.24
Organic Carbon	**7.3, 7.4**	**12.5, 12.3**	**10.6, 10.4**	**9.0, 9.2**	**11.3**	0.24
Elemental Carbon	**1.2, 1.3**	**1.2, 1.1**	**1.8**	**1.6**	**1.2**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.
*EPA runs only. **OMNI runs only.

Table 10: Average $PM_{2.5}$ Elemental, Ion, and OC/EC Concentrations (µg/m^3) – Summer 2012.

	State Building 6/2/12 – 8/31/12 n=20	NCORE 6/14/12 – 8/31/12 n=17	MDL
Magnesium	0.001	0.000	0.011
Aluminum	**0.021**	**0.021**	0.013
Silicon	**0.080**	**0.098**	0.011
Phosphorus	0.000	0.000	0.010
Sulfur	**0.143**	**0.146**	0.007
Chlorine	**0.005**	0.002	0.005
Potassium	**0.025**	**0.023**	0.004
Calcium	**0.018**	**0.020**	0.005
Titanium	0.003	0.002	0.004
Vanadium	0.000	0.000	0.003
Chromium	**0.002**	0.000	0.002
Manganese	0.001	0.001	0.002
Iron	**0.040**	**0.042**	0.001
Nickel	0.000	0.000	0.001
Copper	**0.001**	**0.001**	0.001
Zinc	0.002	**0.003**	0.003
Gallium	0.000	0.000	0.002
Arsenic	0.000	0.000	0.001
Selenium	0.000	0.000	0.002
Bromine	0.001	0.001	0.002
Rubidium	0.000	0.000	0.002
Strontium	0.001	0.000	0.002
Yttrium	0.000	0.000	0.003
Zirconium	0.000	0.001	0.004
Molybdenum	0.000	0.000	0.006
Silver	0.001	0.000	0.013
Cadmium	0.002	0.000	0.017
Indium	0.002	0.000	0.018
Tin	0.005	0.001	0.025
Antimony	0.012	0.011	0.038
Barium	0.000	0.000	0.010
Lanthanum	0.000	0.000	0.008
Mercury	0.000	0.000	0.007
Lead	0.000	0.000	0.004
Sodium	0.007	0.011	0.037
Cobalt	0.000	0.000	0.001
Sulfate	**0.358**	**0.311**	0.010
Nitrate	**0.181**	**0.207**	0.007
Ammonium	**0.051**	**0.025**	0.017
Potassium	**0.010**	**0.020**	0.014
Sodium (ion)	**0.017**	**0.059**	0.027
Total Carbon	**2.0**	**4.6**	0.24
Organic Carbon	**1.8**	**4.2**	0.24
Elemental Carbon	**0.22**	**0.4**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.

Table 11: Average $PM_{2.5}$ Elemental Concentrations ($\mu g/m^3$) – Winter 2012/2013.

	State Building 11/2/12 – 3/29/13 n=29	NPE 11/2/12 – 3/29/13 n=41*, 40**	NCORE 11/2/12 – 3/29/13 n=38*, 39**	NPF3 11/2/13 – 3/29/13 n=42	MDL
Magnesium	0.007	0.010	0.006	0.010	0.011
Aluminum	0.008	0.003	0.008	0.001	0.013
Silicon	**0.043**	**0.021**	**0.045, 0.044**	**0.029**	0.011
Phosphorus	0.005	0.001	0.008	0.001	0.010
Sulfur	**1.370**	**0.891, 0.892**	**1.602, 1.573**	**1.239**	0.007
Chlorine	**0.078**	**0.096, 0.097**	**0.081, 0.080**	**0.131**	0.005
Potassium	**0.154**	**0.310, 0.309**	**0.192, 0.189**	**0.438**	0.004
Calcium	**0.036**	**0.018**	**0.038**	**0.014**	0.005
Titanium	0.001	0.000	0.001	0.001	0.004
Vanadium	0.000	0.000	0.000	0.000	0.003
Chromium	**0.002**	**0.002**	**0.003**	0.001	0.002
Manganese	0.001	0.001	0.001	0.001	0.002
Iron	**0.051**	**0.031, 0.030**	**0.054, 0.053**	**0.028**	0.001
Nickel	**0.001**	0.000	**0.001,** 0.000	0.000	0.001
Copper	**0.003**	**0.002**	**0.003**	**0.002**	0.001
Zinc	**0.053**	**0.030**	**0.055**	**0.037**	0.003
Gallium	0.000	0.000	0.000	0.000	0.002
Arsenic	0.000	0.000	0.000	**0.001**	0.001
Selenium	0.000	0.000	0.000	0.000	0.002
Bromine	**0.004**	**0.004**	**0.004**	**0.003**	0.002
Rubidium	0.000	0.000	0.000	0.001	0.002
Strontium	**0.003**	0.001	**0.003**	**0.002**	0.002
Yttrium	0.000	0.000	0.000	0.000	0.003
Zirconium	0.001	0.001	0.000	0.001	0.004
Molybdenum	0.000	0.000	0.000	0.000	0.006
Silver	0.000	0.001	0.001	0.001	0.013
Cadmium	0.001	0.001	0.000	0.000	0.017
Indium	0.001	0.003	0.003, 0.002	0.003	0.018
Tin	0.003	0.003	0.002	0.003	0.025
Antimony	0.007	0.001	0.001	0.002	0.038
Barium	0.002	0.001	0.004	0.001	0.010
Lanthanum	0.000	0.000	0.000	0.000	0.008
Mercury	0.000	0.000	0.000	0.000	0.007
Lead	0.002	0.001	0.002	0.002	0.004
Sodium	**0.068**	**0.064, 0.066**	**0.062**	**0.066**	0.037
Cobalt	0.000	0.000	0.000	0.000	0.001
Sulfate	**3.496**	**2.476, 2.287**	**3.970, 4.088**	**3.004**	0.010
Nitrate	**1.074**	**0.686, 0.655**	**1.250**	**0.805**	0.007
Ammonium	**1.409**	**0.878, 0.783**	**1.636, 1.672**	**1.099**	0.017
Potassium	**0.118**	**0.288**	**0.177, 0.180**	**0.374**	0.014
Sodium (ion)	**0.047**	**0.181, 0.184**	**0.157, 0.155**	**0.130**	0.027
Total Carbon	**9.2**	**18.6, 18.3**	**14.3, 14.5**	**33.3**	0.24
Organic Carbon	**7.5**	**16.3, 16.0**	**12.1, 12.3**	**29.8**	0.24
Elemental Carbon	**1.6**	**2.4, 2.3**	**2.2, 2.2**	**3.6**	0.24

Note: MDL–minimum detection limit. Bolded values indicate concentrations measured at or above the MDL.
*EPA runs only. **OMNI runs only.

7.0. Chemical Mass Balance Results

Tables 12 and 13 present the $PM_{2.5}$ sources identified by the CMB model for each of the sites when using the EPA source profiles, including source contribution estimates (± standard errors) and % of total $PM_{2.5}$. **Tables 14 and 15** present the CMB results when using the OMNI profiles. In addition, **Figures 1-6** present the sources identified (over time) for each of the sites using the EPA source profiles, while **Figures 7-12** present the source trends for each of the sites using the OMNI profiles. Finally, CMB results are summarized as pie charts in **Figures 13-64** for both EPA and OMNI profiles for each winter/site, followed by a table comparing the results generated when using both the EPA and OMNI source profiles (**Tables 16-40**).

When using the EPA profiles, five source profile types were identified by the CMB model as contributors to the ambient $PM_{2.5}$ throughout the winter months. Wood smoke (likely residential wood combustion) was the major source of $PM_{2.5}$ identified, contributing between ~60% to over 80% of the measured $PM_{2.5}$ at the monitoring sites. The other sources of $PM_{2.5}$ identified by the CMB model were secondary sulfate (~7-21%), ammonium nitrate (3-11%), diesel exhaust (not detected-11%), and automobiles (not detected-7%). Approximately 1-2% of the $PM_{2.5}$ was unexplained by the CMB model.

When utilizing the OMNI profiles in the CMB, the results are somewhat different. In addition to the five profiles identified using the EPA profiles, the OMNI source profile representing No. 2 fuel oil was also identified in nearly every CMB run. Wood smoke was still identified as the largest source of wintertime $PM_{2.5}$ at the North Pole, RAMS, NCORE, NPF3, and NPE sites. However, at the State Building and Peger Road sites, No. 2 fuel oil combustion was found to be the largest source, contributing from 30-50% of the ambient wintertime $PM_{2.5}$.

It should be noted that the results of CMB modeling using OMNI profiles for the winter of 2008/2009 were originally presented to ADEC in a previous report (July 23, 2012). In carrying out the updated modeling using the OMNI profiles in other years (in addition to the winter of 2008/2009), it was discovered that automobiles and diesel exhaust contributed a small amount to ambient $PM_{2.5}$ when using the OMNI profiles. To be consistent with results from the other winters, the 2008/2009 data sets were re-analyzed for the State Building, RAMS, North Pole, and Peger Road sites, with these results presented in **Table 14**. Results for the North Pole and RAMS sites remained unchanged to the previous modeling. However, for the State Building and Peger Road sites, automobiles and diesel exhaust which were not detected in the initial CMB modeling were now detected at low contributions (autos: 0.3-1.7%; diesel: 0.1-0.5%). Using this new profile combination also lowered the wood smoke contribution from 56.0% to 36.1% at the State Building, while No. 2 fuel oil contributions increased from 14.2% to 47.4%. At the Peger Road site, wood smoke was revised to 42.0% while No. 2 fuel oil was elevated from 27.2% to 38.7%. These new findings as well as those from the other winters illustrate that No. 2 fuel oil combustion is a significant source of ambient $PM_{2.5}$ (when using the OMNI profiles) – especially at the State Building and Peger Road sites.

For the first time, CMB source apportionment modeling was conducted during the summer months in Fairbanks. Overall, ambient $PM_{2.5}$ concentrations were very low at both sites during the summer of 2012 (5.7 $\mu g/m^3$ at the State Building, and 5.1 $\mu g/m^3$ at the NCORE site). Contributions of sulfate, ammonium nitrate, and street sand/road dust were very similar between the State Building and NCORE sites. More vehicle emissions were detected at the NCORE site compared to the State Building site when using both EPA and OMNI profiles. As expected, No. 2 fuel oil was not detected at either site. However, wood smoke was still determined to be the largest source at both sites (56-74%), likely due to residential outdoor biomass waste burning and influences from regional wildland fire events.

Table 12: Source Contribution Estimates ± Standard Errors (µg/m^3) – EPA profiles.
Note that percentages in parentheses are percent contributions to overall ambient $PM_{2.5}$ mass.

	Sulfate	Ammonium Nitrate	Diesel	Autos	Wood Smoke	Unexplained	$PM_{2.5}$ Mass	n	Sampling Dates
State Building 2005/2006	4.0±0.5 (21.0 %)	1.8 ±0.5 (9.6 %)	1.3±0.4 (7.1 %)	0.4±0.2 (2.3 %)	11.3±1.7 (59.8 %)	0.1 (0.3 %)	18.9	36	11/3/05-3/30/06
State Building 2006/2007	3.7±0.5 (18.7 %)	1.7 ±0.5 (8.4 %)	1.5±0.5 (7.6 %)	1.1±0.4 (5.8 %)	11.5±2.0 (57.9 %)	0.3 (1.6 %)	19.9	39	11/1/06-3/31/07
State Building 2007/2008	3.4±0.4 (18.2 %)	1.5±0.5 (8.1 %)	1.7±0.5 (9.0 %)	1.2±0.4 (6.2 %)	10.9±1.6 (58.5 %)	0.02 (0.1 %)	18.7	40	11/2/07-3/31/08
2008/2009	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	5.1±0.6 (20.0 %)	2.1 ±0.7 (8.1 %)	0.3±0.1 (1.1 %)	1.7±0.7 (6.8 %)	16.0±2.3 (63.1 %)	0.2 (0.8 %)	25.3	47	11/8/08-4/7/09
North Pole	1.9±0.2 (9.8 %)	1.0±0.2 (5.1 %)	0.2±0.05 (0.8 %)	0.7±0.3 (3.7 %)	15.0±2.0 (79.8 %)	0.2 (0.8 %)	18.9	21	1/25/09-4/7/09
RAMS	1.1±0.1 (13.0 %)	0.9±0.1 (10.5 %)	ND	ND	6.3±0.8 (76.0 %)	0.04 (0.5 %)	8.2	23	1/25/09-4/7/09
Peger Road	2.8±0.3 (16.7 %)	1.5±0.4 (8.9 %)	1.2±0.5 (7.3 %)	0.7±0.2 (3.9 %)	10.6±1.6 (62.7 %)	0.1 (0.5 %)	16.8	26	1/25/09-4/7/09
2009/2010	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	5.2±0.6 (18.1 %)	2.5±0.7 (8.9 %)	0.6±0.3 (2.2 %)	0.7±0.3 (2.5 %)	19.5±1.9 (67.8 %)	0.2 (0.6 %)	28.8	40	11/3/09-3/15/10
North Pole	2.6±0.3 (7.8 %)	1.2±0.3 (3.6 %)	0.8±0.2 (2.5 %)	1.3±0.4 (3.8 %)	27.1±3.7 (81.2 %)	0.3 (1.0 %)	33.7	35	11/3/09-3/15/10
RAMS	4.0±0.5 (10.9 %)	0.9±0.2 (2.5 %)	2.5±0.6 (6.8 %)	2.3±0.7 (6.2 %)	26.9±4.1 (73.5 %)	0.04 (0.1 %)	36.7	29	11/15/09-3/15/10
Peger Road	4.8±0.5 (16.5 %)	2.1±0.6 (7.4 %)	2.8±0.7 (9.6 %)	0.4±0.1 (1.3 %)	18.6±3.0 (64.4 %)	0.3 (0.9 %)	29.0	38	11/3/09-3/15/10
2010/2011	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	3.5±0.4	1.7±0.5	ND	0.4±0.1	14.6±1.1	0.004	20.2	15	11/1/10-

	(17.3 %)	(8.4 %)		(1.9 %)	(72.4 %)	(0.02 %)			2/8/11
North Pole	2.1±0.3 (8.0 %)	0.9±0.2 (3.5 %)	0.9±0.3 (3.4 %)	1.4±0.5 (5.1 %)	21.3±3.2 (79.4 %)	0.2 (0.6 %)	26.8	10	1/9/11-2/5/11
Peger Road	4.8±0.5 (16.6 %)	2.0±0.5 (7.1 %)	0.8±0.2 (2.9 %)	0.7±0.3 (2.5 %)	20.2±3.9 (70.6 %)	0.1 (0.3 %)	28.6	10	1/9/11-2/5/11
2011/2012	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	3.5±0.4 (17.8 %)	1.5±0.5 (7.5 %)	0.2±0.04 (1.2 %)	0.4±0.1 (2.1 %)	14.0±1.4 (70.4 %)	0.2 (1.0 %)	20.0	38	11/2/11-3/31/12
North Pole	1.8±0.2 (7.8 %)	0.7±0.2 (3.1 %)	0.1±0.04 (0.6 %)	0.3±0.1 (1.2 %)	20.4±2.3 (85.5 %)	0.4 (1.9 %)	24.2	35	11/2/11-3/25/12
RAMS	2.9±0.3 (13.2 %)	1.4±0.4 (6.4 %)	1.2±0.3 (5.7 %)	0.9±0.4 (4.0 %)	14.9±1.8 (69.0 %)	0.4 (1.8 %)	22.1	16	12/20/11-2/27/12
NCORE	3.0±0.3 (15.8 %)	1.3±0.4 (6.8 %)	1.4±0.5 (7.5 %)	0.8±0.3 (4.2 %)	12.4±1.6 (64.4 %)	0.2 (1.3 %)	19.5	44	11/2/11-3/31/12
NPF3	1.7±0.2 (9.2 %)	0.7±0.2 (3.8 %)	0.9±0.4 (4.9 %)	0.8±0.4 (4.2 %)	14.2±2.0 (77.0 %)	0.2 (1.0 %)	18.3	7	3/1/12-3/31/12
2012/2013	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	3.9±0.5 (17.9 %)	1.7±0.5 (8.0 %)	1.2±0.4 (5.5 %)	0.1±0.04 (0.5 %)	14.7±1.5 (67.7 %)	0.1 (0.6 %)	21.8	29	11/2/12-3/29/13
NPE	2.5±0.3 (9.0 %)	1.1±0.3 (3.8 %)	3.0±0.6 (10.9 %)	0.7±0.2 (2.6 %)	20.3±2.5 (72.8 %)	0.2 (0.8 %)	28.1	41	11/2/12-3/29/13
NCORE	4.7±0.5 (18.4 %)	2.0±0.6 (7.9 %)	2.4±0.7 (9.6 %)	1.1±0.5 (4.4 %)	15.1±2.0 (59.3 %)	0.1 (0.3 %)	25.5	38	11/2/12-3/29/13
NPF3	3.4±0.4 (7.4 %)	1.3±0.4 (2.8 %)	4.5±0.9 (9.8 %)	0.6±0.2 (1.4 %)	35.9±4.2 (77.6 %)	0.5 (1.0 %)	46.9	42	11/2/12-3/29/13

ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011.

Table 13: Source Contribution Estimates ± Standard Errors (µg/m^3) – Summer 2012 EPA Profiles.

Summer 2012	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Street Sand**	**Wood Smoke**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	0.4±0.1 (7.1 %)	0.2±0.1 (3.9 %)	0.01±0.003 (0.1 %)	0.2±0.1 (3.9 %)	0.3±0.1 (4.4 %)	4.2±0.2 (73.7 %)	0.4 (6.9 %)	5.7	20	6/2/12-8/31/12
NCORE	0.4±0.1 (6.8 %)	0.2±0.1 (3.8 %)	0.3±0.1 (4.9 %)	1.0±0.2 (17.2%)	0.3±0.1 (4.6 %)	3.3±0.4 (56.0 %)	0.4 (6.7 %)	5.1	17	6/14/12-8/31/12

Figure 1: State Building Source Contribution Estimates (µg/m^3) – EPA profiles.

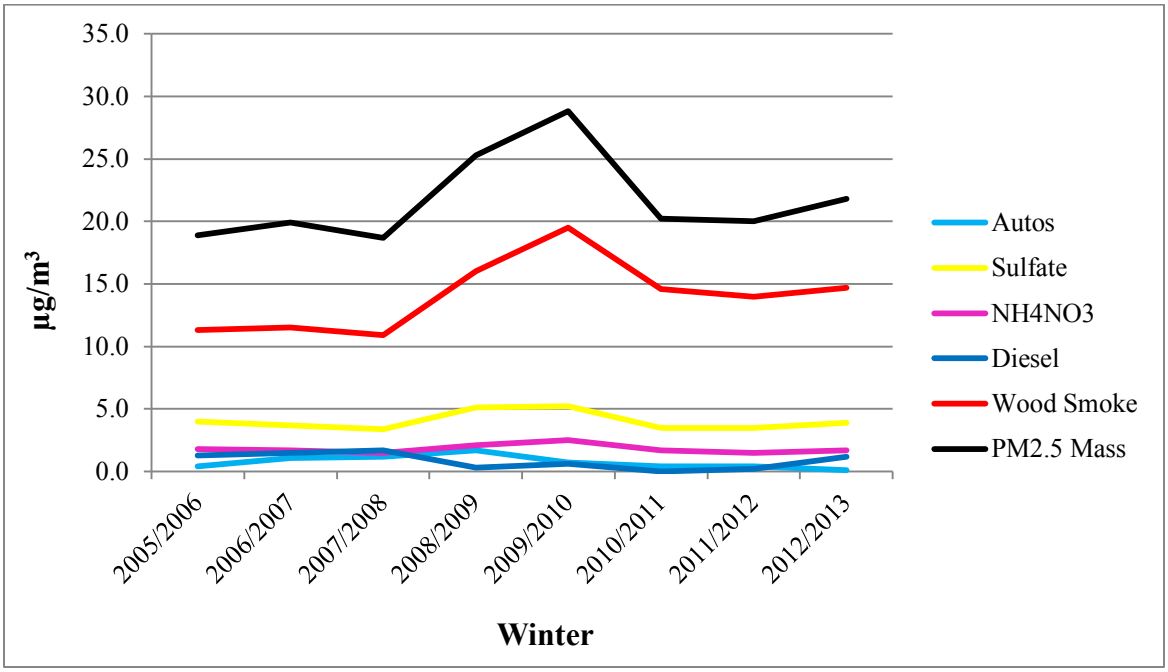

Figure 2: North Pole Source Contribution Estimates (µg/m^3) – EPA profiles.

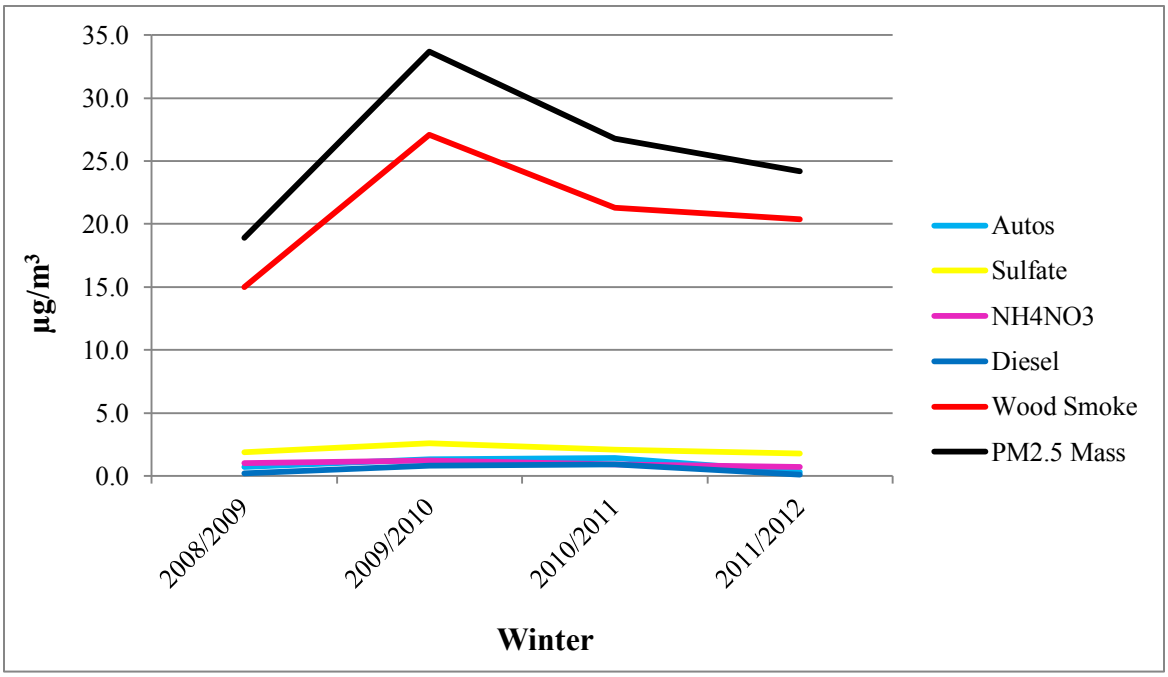

Figure 3: RAMS Source Contribution Estimates (µg/m^3) – EPA profiles.

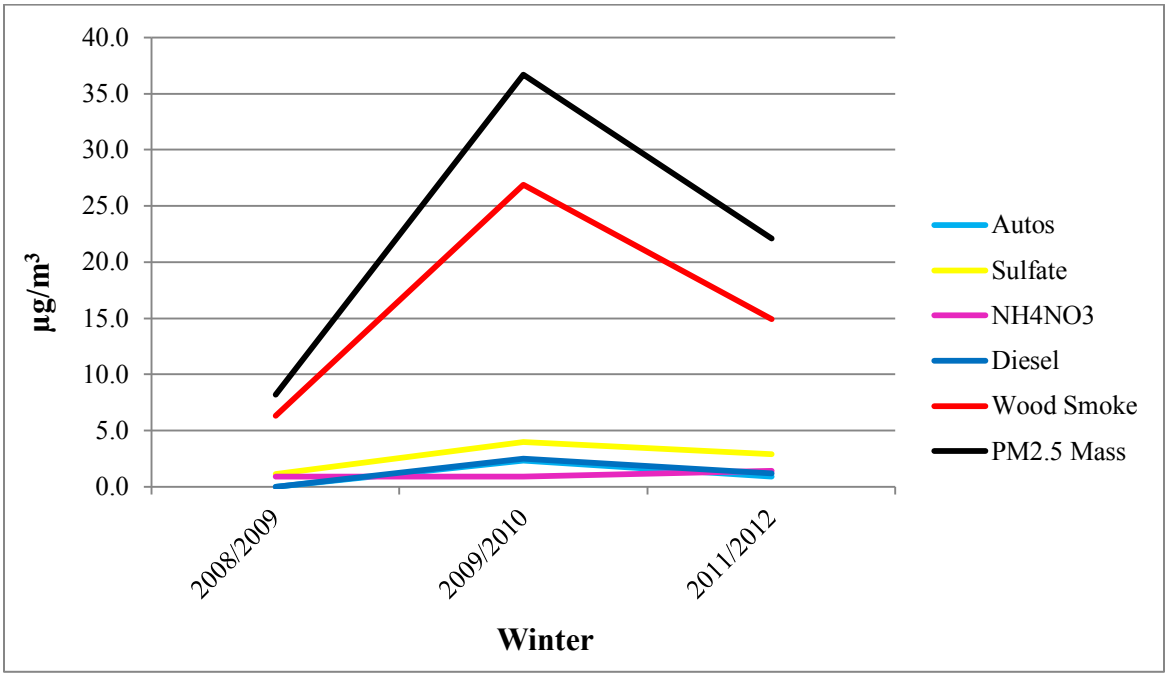

Figure 4: Peger Road Source Contribution Estimates (µg/m^3) – EPA profiles.

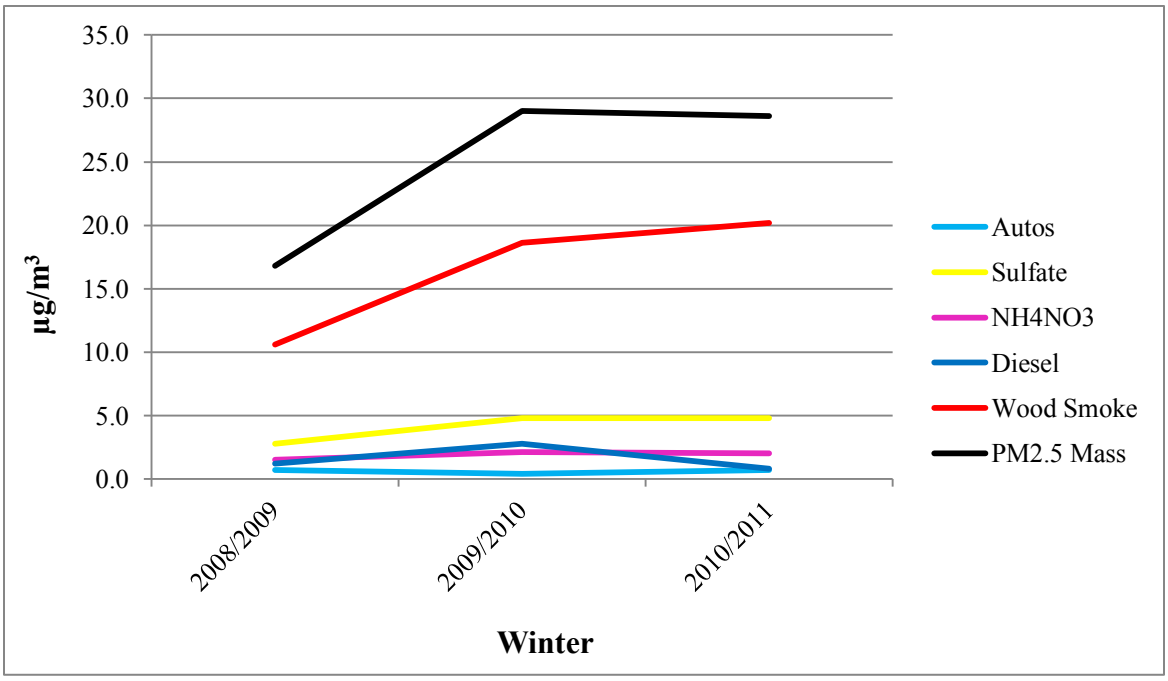

Figure 5: NCORE Source Contribution Estimates (µg/m^3) – EPA profiles.

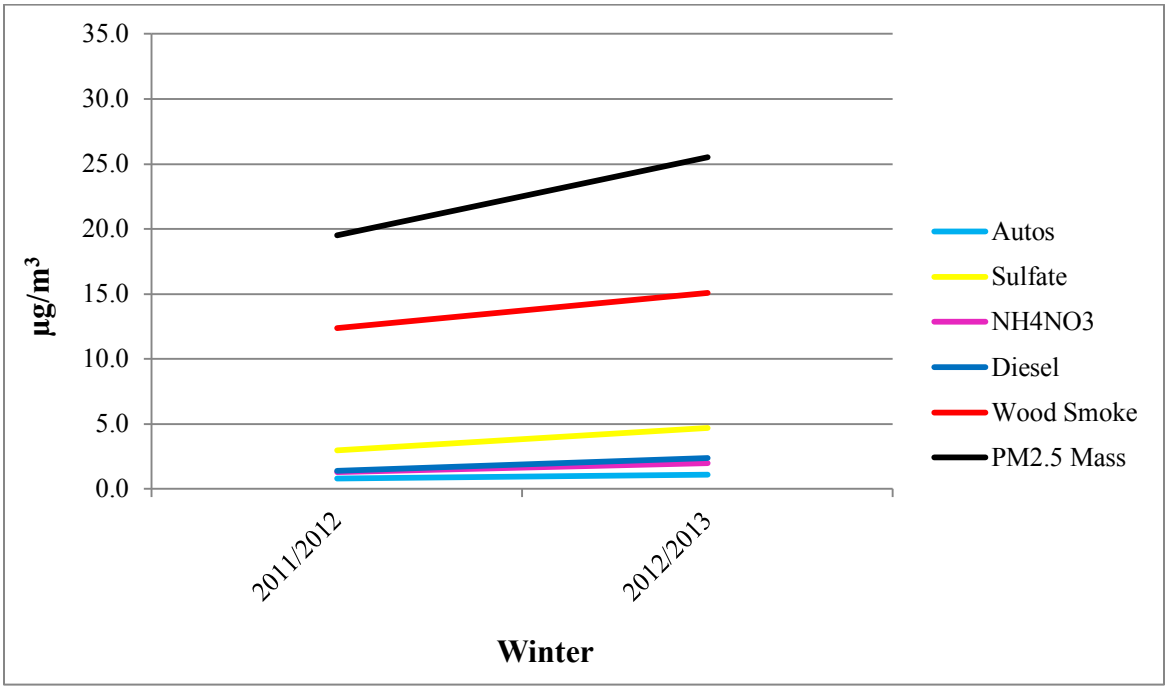

Figure 6: NPF3 Source Contribution Estimates (µg/m^3) – EPA profiles.

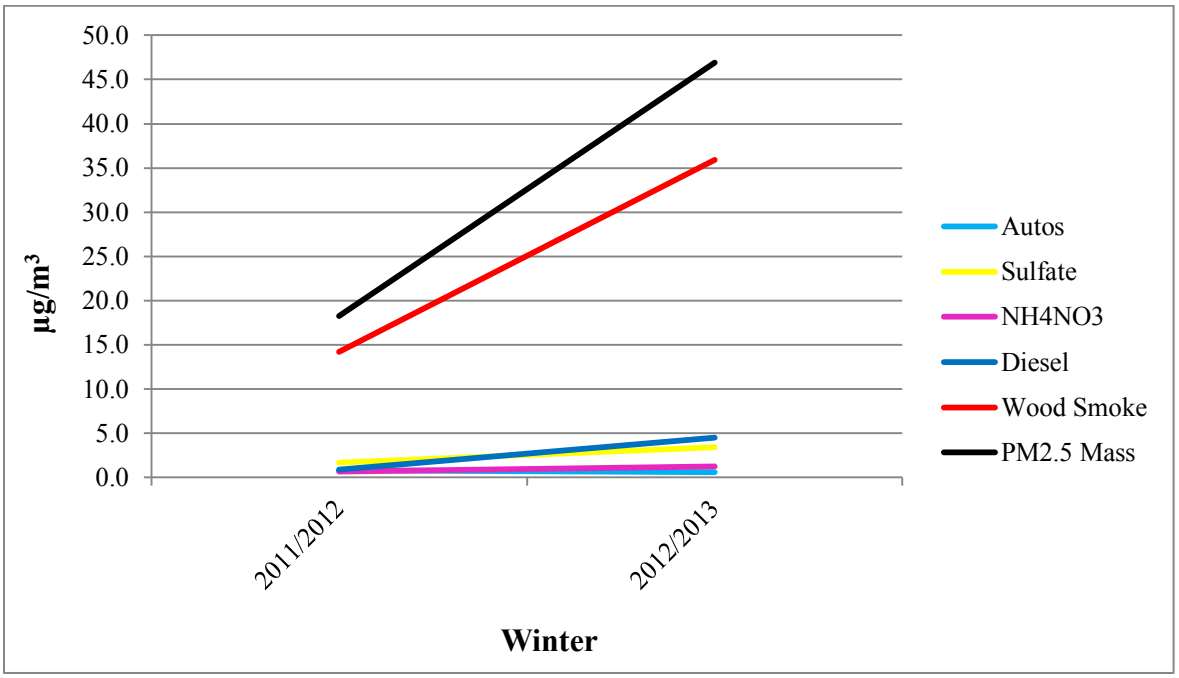

Table 14: Source Contribution Estimates ± Standard Errors (µg/m^3) – OMNI Profiles.
Note that percentages in parentheses are percent contributions to overall ambient $PM_{2.5}$ mass.

	Sulfate	Ammonium Nitrate	Diesel	Autos	Wood Smoke	No. 2 Fuel Oil	Unexplained	$PM_{2.5}$ Mass	n	Sampling Dates
State Building 2005/2006	2.4±0.5 (12.8 %)	1.3 ±0.3 (6.7 %)	0.4±0.2 (2.3 %)	Not Detected	5.9±1.6 (31.7 %)	8.4±1.6 (44.7 %)	0.4 (1.9 %)	18.9	36	11/3/05-3/30/06
State Building 2006/2007	2.0±0.4 (10.1 %)	1.1 ±0.3 (5.7 %)	0.2±0.1 (0.9 %)	0.3±0.1 (1.5 %)	7.3±1.9 (36.6 %)	9.0±1.7 (45.0 %)	0.03 (0.1 %)	19.9	39	11/1/06-3/31/07
State Building 2007/2008	1.9±0.4 (10.0 %)	1.0 ±0.3 (5.5 %)	1.0±0.4 (5.5 %)	0.3±0.1 (1.6 %)	5.9±1.5 (31.9 %)	8.4±1.5 (45.4 %)	0.01 (0.1 %)	18.7	40	11/2/07-3/31/08
2008/2009	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
*State Building	4.4±0.6 (17.9 %)	1.9 ±0.6 (7.9 %)	Not Detected	Not Detected	13.8±1.7 (56.0 %)	3.5±0.7 (14.2 %)	1.0 (4.0 %)	25.3	47	11/8/08-4/7/09
**State Building	2.5±0.5 (10.4 %)	1.2 ±0.3 (5.2 %)	0.04 ±0.02 (0.1 %)	0.06 ±0.03 (0.3 %)	8.7±1.9 (36.1 %)	11.4±1.8 (47.4 %)	0.1 (0.5 %)	24.4	46	11/8/08-4/7/09
North Pole	1.4±0.2 (7.6 %)	0.9 ±0.2 (4.7 %)	Not Detected	Not Detected	13.6±1.2 (73.4 %)	2.1±0.5 (11.1 %)	0.6 (3.3 %)	18.9	21	1/25/09-4/7/09
RAMS	0.8±0.1 (9.2 %)	0.8 ±0.1 (9.2 %)	Not Detected	Not Detected	5.4±0.8 (63.9 %)	1.4±0.4 (16.8 %)	0.1 (0.9 %)	8.3	22	1/25/09-4/7/09
*Peger Road	2.0±0.3 (11.7 %)	1.4 ±0.3 (8.4 %)	Not Detected	Not Detected	8.6±1.2 (51.0 %)	4.6±0.9 (27.2 %)	0.3 (1.6 %)	16.8	26	1/25/09-4/7/09
**Peger Road	1.6±0.3 (9.6 %)	1.2 ±0.2 (7.3 %)	0.1±0.04 (0.5 %)	0.3±0.1 (1.7 %)	7.1±1.4 (42.0 %)	6.6±1.3 (38.7 %)	0.04 (0.3 %)	16.8	26	1/25/09-4/7/09
2009/2010	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.2±0.5 (9.3 %)	1.6 ±0.3 (6.5 %)	0.4±0.1 (1.8 %)	0.4±0.1 (1.4 %)	8.7±2.0 (36.0 %)	10.0±1.8 (41.1 %)	1.0 (3.9 %)	24.5	31	11/3/09-3/15/10
North Pole	1.1±0.2 (3.2 %)	0.9 ±0.2 (2.6 %)	1.5±0.4 (4.3 %)	1.0±0.4 (2.9 %)	22.4±2.1 (65.1 %)	7.3±0.9 (21.3 %)	0.2 (0.6 %)	33.7	35	11/3/09-3/15/10
RAMS	1.8±0.4 (4.9 %)	0.9 ±0.2 (2.5 %)	0.8±0.3 (2.3 %)	0.9±0.4 (2.5 %)	21.0±2.2 (57.2 %)	11.2±1.4 (30.5 %)	0.1 (0.1 %)	36.7	29	11/15/09-3/15/10
Peger Road	2.3±0.5 (7.8 %)	1.9 ±0.4 (6.4 %)	1.7±0.5 (5.7 %)	0.4±0.2 (1.4 %)	9.2±2.5 (31.2 %)	13.7±2.1 (46.3 %)	0.3 (1.2 %)	29.5	37	11/3/09-3/15/10

2010/2011	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.0±0.4 (9.8 %)	1.3 ±0.3 (6.6 %)	0.2±0.04 (0.9 %)	0.2±0.1 (1.1 %)	6.5±1.7 (32.7 %)	8.3±1.5 (41.5 %)	1.5 (7.5 %)	20.2	15	11/1/10-2/8/11
North Pole	1.0±0.2 (3.9 %)	0.7 ±0.1 (2.7 %)	0.9±0.3 (3.3 %)	1.9±0.5 (7.1 %)	16.6±1.9 (62.5 %)	5.3±0.8 (20.0 %)	0.2 (0.6 %)	26.8	10	1/9/11-2/5/11
Peger Road	2.1±0.5 (7.3 %)	2.0 ±0.4 (6.7 %)	1.0±0.3 (3.3 %)	0.6±0.2 (2.2 %)	9.5±2.6 (32.7 %)	13.5±2.1 (46.4 %)	0.4 (1.3 %)	28.6	10	1/9/11-2/5/11
2011/2012	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.2±0.4 (11.0 %)	1.0 ±0.3 (5.1 %)	0.5±0.1 (2.3 %)	0.8±0.2 (4.3 %)	7.6±1.6 (38.5 %)	6.4±1.5 (32.2 %)	1.3 (6.6 %)	19.5	36	11/2/11-3/31/12
North Pole	1.2±0.2 (5.3 %)	0.5 ±0.1 (2.1 %)	None Detected	0.6±0.2 (2.4 %)	17.3±1.6 (75.4 %)	2.4±0.7 (10.3 %)	1.0 (4.5 %)	23.0	34	11/2/11-3/25/12
RAMS	1.9±0.4 (8.4 %)	1.0 ±0.3 (4.7 %)	0.3±0.1 (1.3 %)	0.9±0.4 (4.0 %)	11.5±1.9 (51.4 %)	4.9±1.5 (21.8 %)	1.9 (8.5 %)	22.7	15	12/20/11-2/27/12
NCORE	2.0±0.4 (10.5 %)	0.9 ±0.3 (4.6 %)	0.2±0.1 (1.1 %)	0.4±0.2 (2.1 %)	10.1±1.7 (53.0 %)	5.4±1.4 (28.2 %)	0.1 (0.5 %)	19.3	42	11/2/11-3/31/12
NPF3	1.2±0.2 (6.4 %)	0.5 ±0.2 (2.7 %)	None Detected	None Detected	14.1±1.3 (76.6 %)	2.2±0.7 (12.1 %)	0.4 (2.2 %)	18.3	7	3/1/12-3/31/12
2012/2013	**Sulfate**	**Ammonium Nitrate**	**Diesel**	**Autos**	**Wood Smoke**	**No. 2 Fuel Oil**	**Unexplained**	**$PM_{2.5}$ Mass**	**n**	**Sampling Dates**
State Building	2.9±0.5 (13.3 %)	1.3 ±0.4 (6.1 %)	0.2±0.1 (0.9 %)	0.4±0.2 (2.0 %)	8.7±1.8 (40.1 %)	6.0±1.5 (27.6 %)	2.1 (9.9 %)	21.8	29	11/2/12-3/29/13
NPE	1.5±0.3 (5.4 %)	0.6 ±0.1 (2.0 %)	0.8±0.2 (2.8 %)	0.8±0.2 (2.9 %)	18.8±1.8 (66.6 %)	4.9±1.1 (17.1 %)	0.9 (3.1 %)	27.8	40	11/2/12-3/29/13
NCORE	3.0±0.5 (12.1 %)	1.3 ±0.3 (5.2 %)	0.4±0.1 (1.5 %)	0.7±0.2 (2.6 %)	11.0±2.0 (44.2 %)	8.5±1.8 (34.1 %)	0.1 (0.2 %)	25.1	39	11/2/12-3/29/13
NPF3	2.2±0.4 (4.8 %)	0.6 ±0.1 (1.3 %)	0.4±0.1 (1.0 %)	0.1±0.03 (0.2 %)	34.7±2.3 (75.2 %)	6.4±1.3 (13.8 %)	1.8 (3.8 %)	46.9	42	11/2/12-3/29/13

ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011. *CMB results originally presented in the Final Report submitted to ADEC (dated July 23, 2012). **Updated CMB modeling was conducted.

Table 15: Source Contribution Estimates ± Standard Errors (µg/m^3) – Summer 2012 OMNI Profiles.

Summer 2012	Sulfate	Ammonium Nitrate	Diesel	Autos	Street Sand	Wood Smoke	Unexplained	$PM_{2.5}$ Mass	n	Sampling Dates
State Building	0.4±0.05 (6.5 %)	0.2±0.05 (3.9 %)	0.02±0.01 (0.4 %)	0.3±0.1 (4.5 %)	0.3±0.1 (4.6 %)	3.6±0.1 (64.3 %)	0.9 (15.8 %)	5.7	20	6/2/12-8/31/12
NCORE	0.4±0.05 (6.0 %)	0.2±0.05 (3.8 %)	0.2±0.03 (2.7 %)	0.3±0.1 (5.7 %)	0.2±0.1 (3.7 %)	4.2±0.4 (70.5 %)	0.5 (7.7 %)	5.1	17	6/14/12-8/31/12

Figure 7: State Building Source Contribution Estimates (µg/m^3) – OMNI profiles.

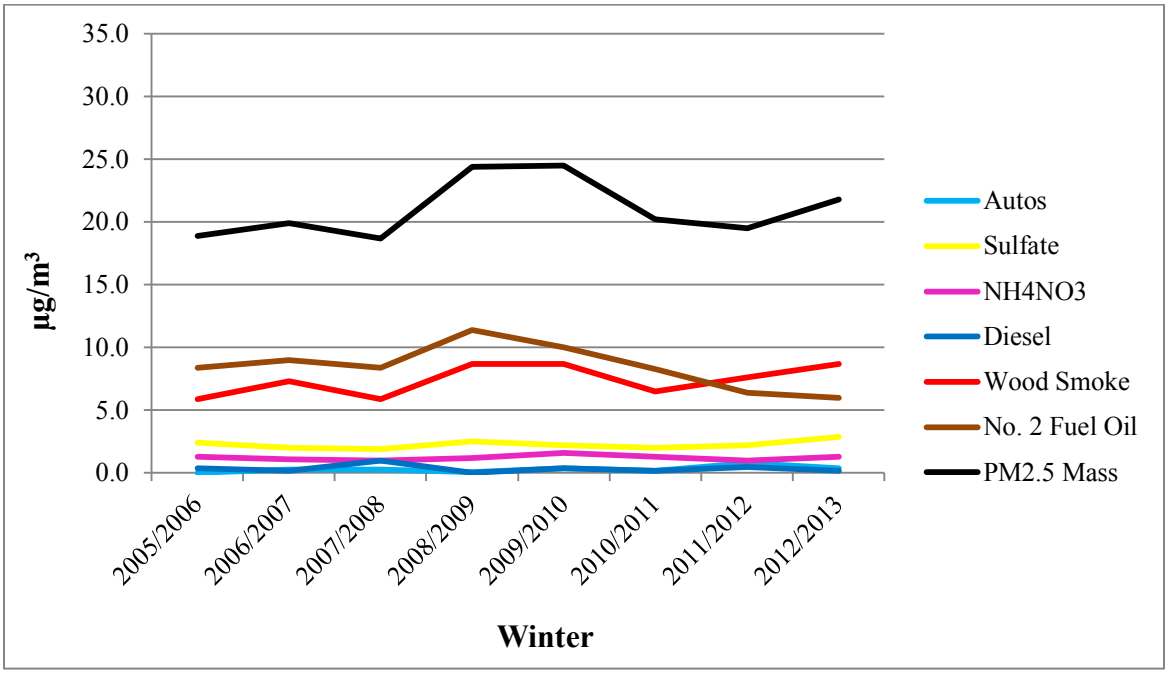

Figure 8: North Pole Source Contribution Estimates (µg/m^3) – OMNI profiles.

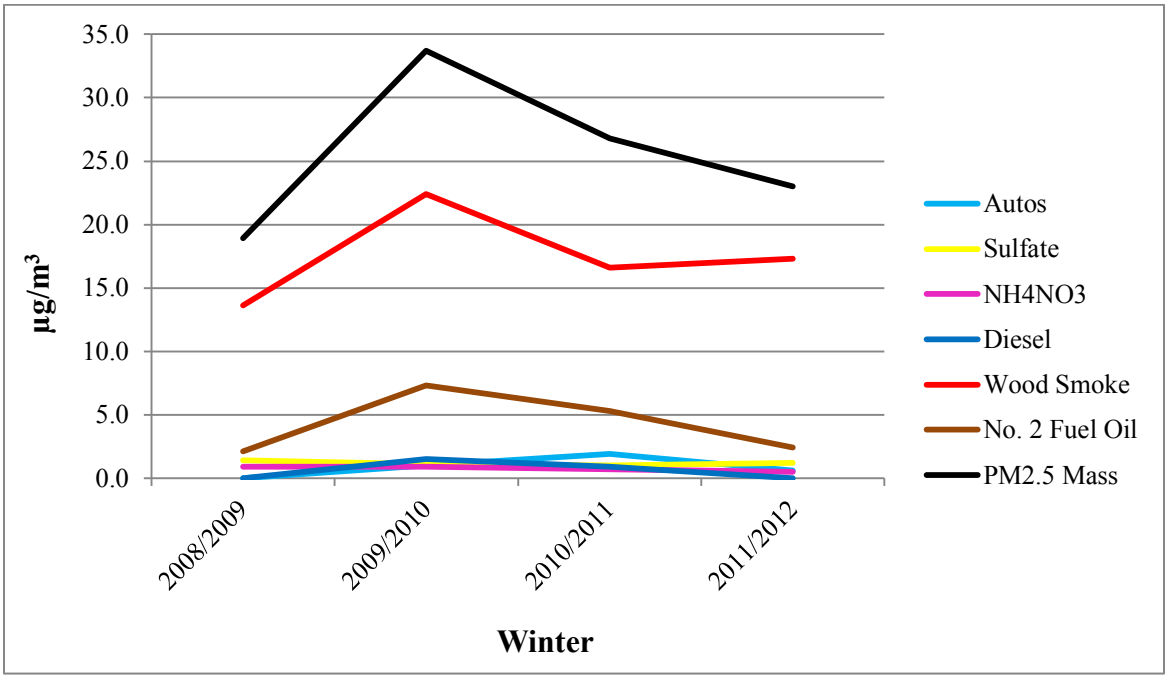

Figure 9: RAMS Source Contribution Estimates (µg/m^3) – OMNI profiles.

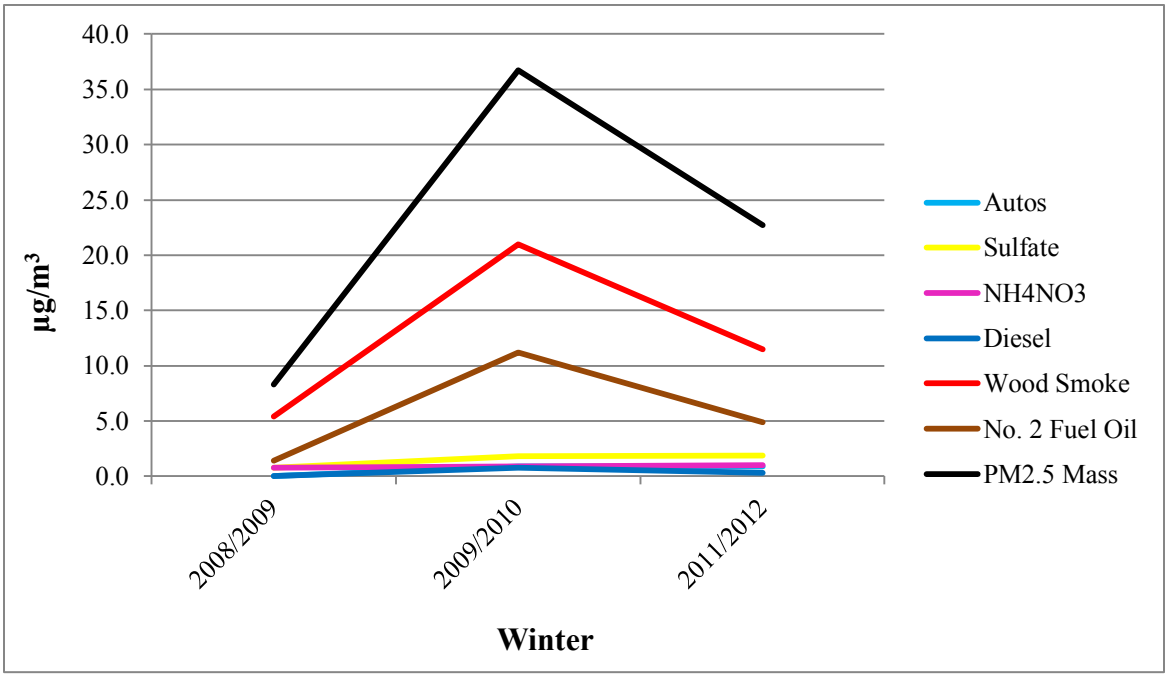

Figure 10: Peger Road Source Contribution Estimates (µg/m^3) – OMNI profiles.

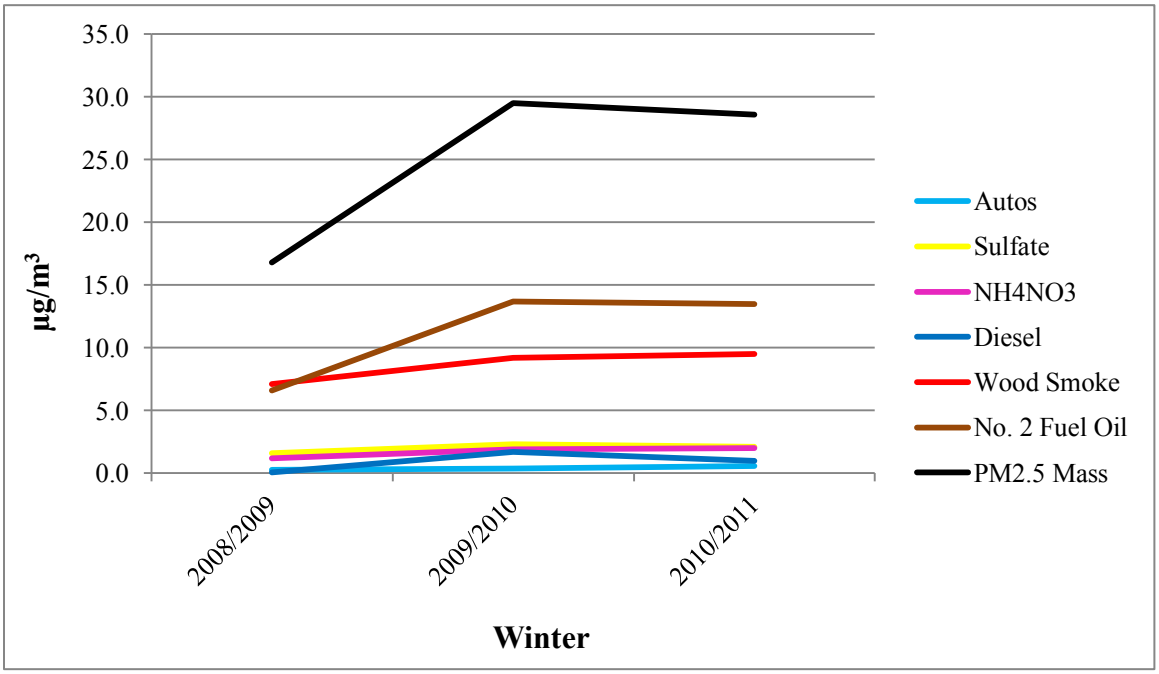

Figure 11: NCORE Source Contribution Estimates (µg/m^3) – OMNI profiles.

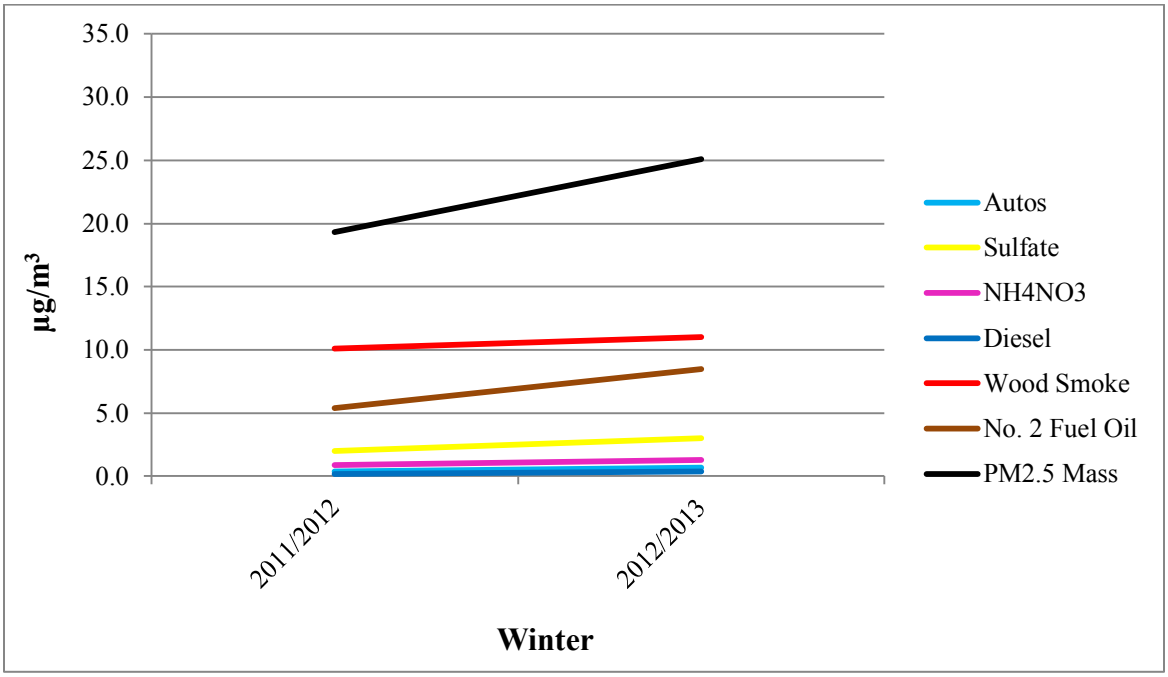

Figure 12: NPF3 Source Contribution Estimates (µg/m^3) – OMNI profiles.

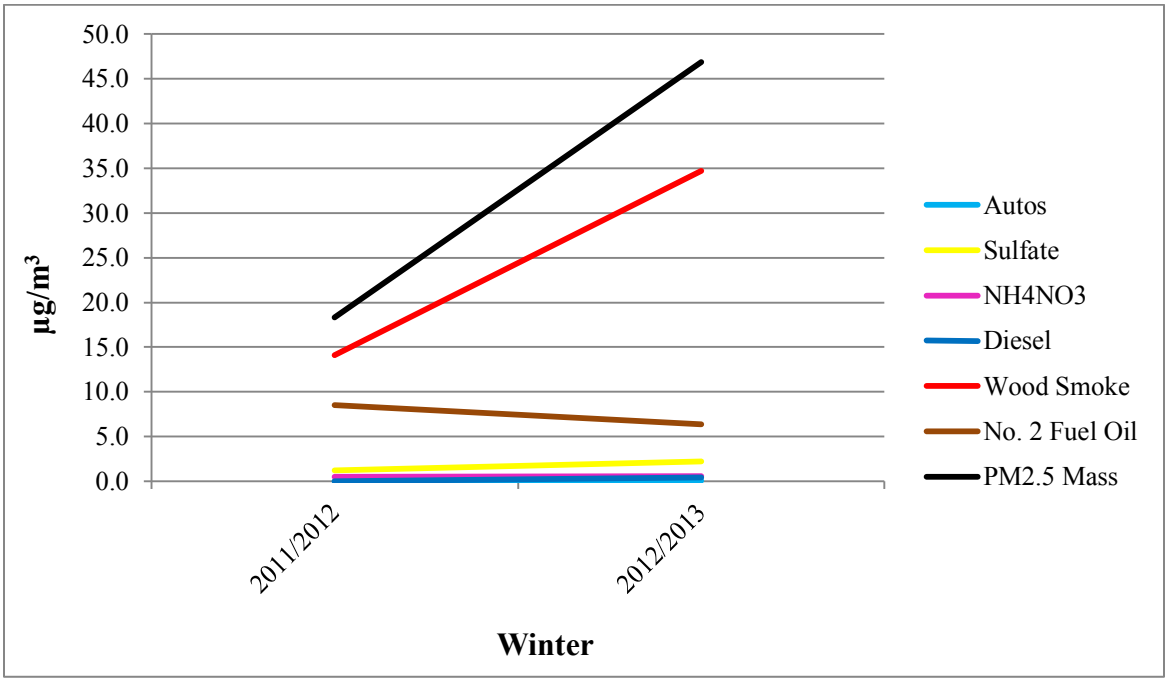

Figure 13: Winter 2005/2006, State Building.
CMB Results with EPA Source Profiles, November 3, 2005 – March 30, 2006.

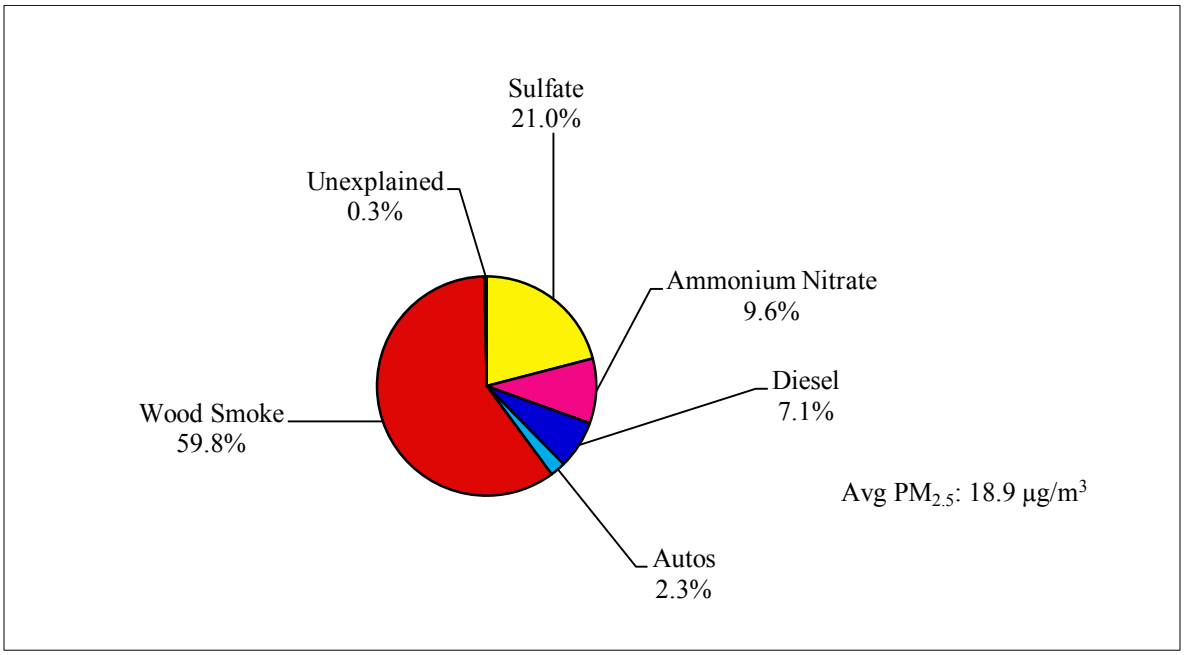

Figure 14: Winter 2005/2006, State Building.
CMB Results with OMNI Source Profiles, November 3, 2005 – March 30, 2006.

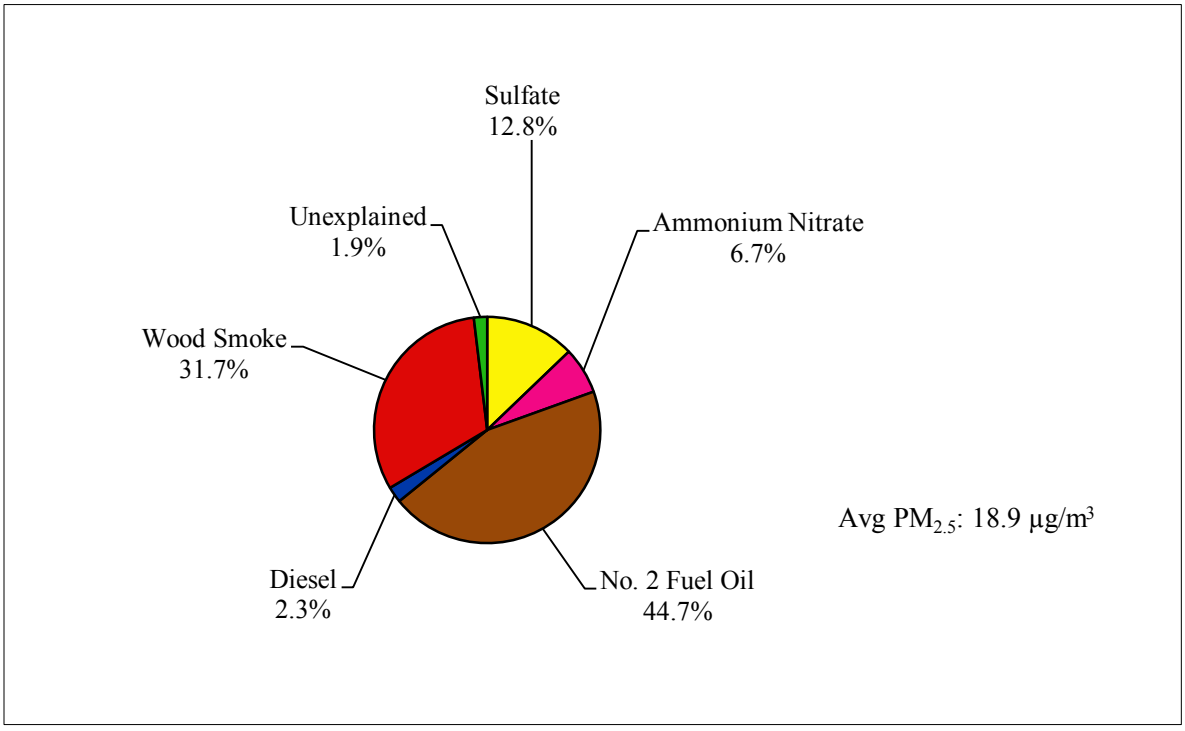

Table 16: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2005/2006.

Season:	Winter 2005/2006 (EPA)	Winter 2005/2006 (OMNI)
Dates:	11/3/05-3/30/06	11/3/05-3/30/06
n:	36	36
$PM_{2.5}$ Mass ($\mu g/m^3$):	18.9	18.9
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	4.0 (21.0 %)	2.4 (12.8 %)
Ammonium Nitrate:	1.8 (9.6 %)	1.3 (6.7%)
Diesel:	1.3 (7.1 %)	0.4 (2.3%)
Automobiles:	0.4 (2.3 %)	Not Identified
Wood Smoke:	11.3 (59.8 %)	5.9 (31.7 %)
No. 2 Fuel Oil:	Not Identified	8.4 (44.7 %)
Unexplained:	0.1 (0.3 %)	0.4 (1.9 %)

Figure 15: Winter 2006/2007, State Building.
CMB Results with EPA Source Profiles, November 1, 2006 – March 31, 2007.

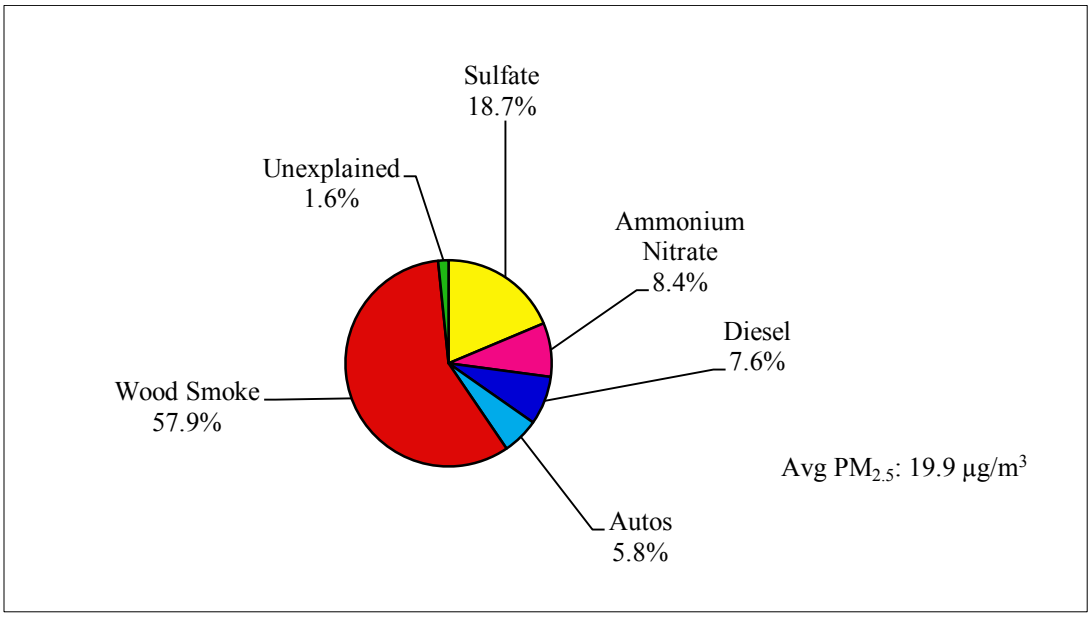

Figure 16: Winter 2006/2007, State Building.
CMB Results with OMNI Source Profiles, November 1, 2006 – March 31, 2007.

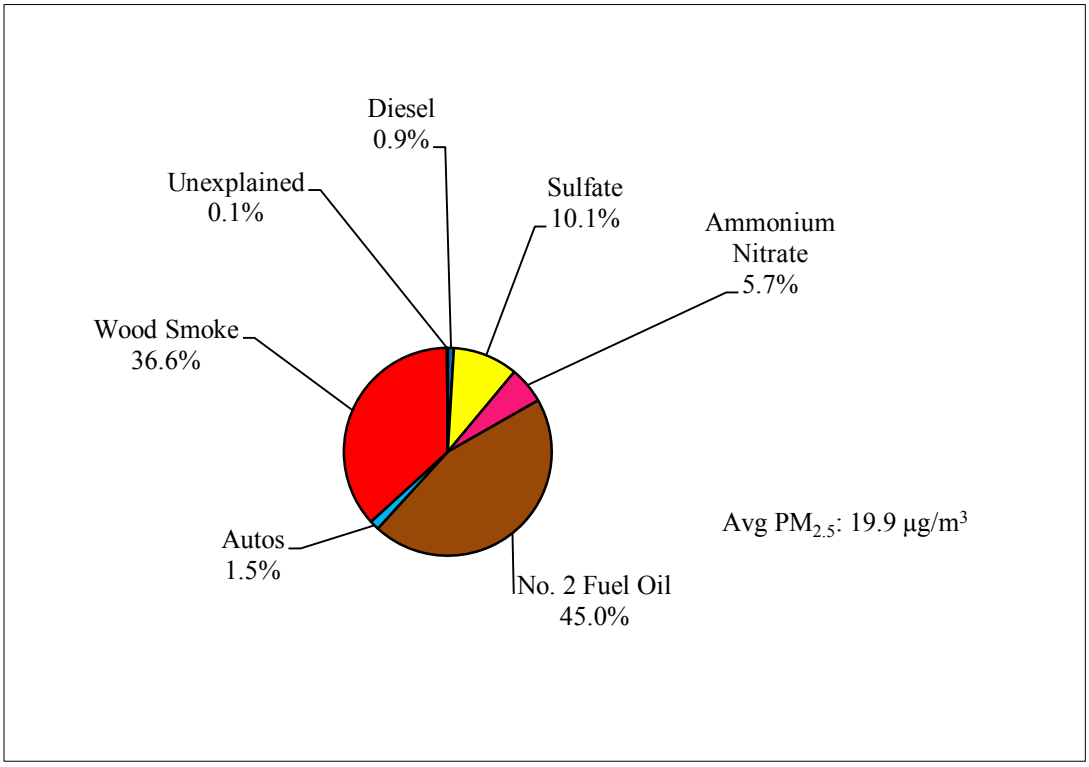

Table 17: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2006/2007.

Season:	Winter 2006/2007 (EPA)	Winter 2006/2007 (OMNI)
Dates:	11/1/06-3/31/07	11/1/06-3/31/07
n:	39	39
$PM_{2.5}$ Mass ($\mu g/m^3$):	19.9	19.9
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.7 (18.7 %)	2.0 (10.1 %)
Ammonium Nitrate:	1.7 (8.4 %)	1.1 (5.7 %)
Diesel:	1.5 (7.6 %)	0.2 (0.9 %)
Automobiles:	1.1 (5.8 %)	0.3 (1.5 %)
Wood Smoke:	11.5 (57.9 %)	7.3 (36.6 %)
No. 2 Fuel Oil:	Not Identified	9.0 (45.0 %)
Unexplained:	0.3 (1.6 %)	0.03 (0.1 %)

Figure 17: Winter 2007/2008, State Building.
CMB Results with EPA Source Profiles, November 2, 2007 – March 31, 2008.

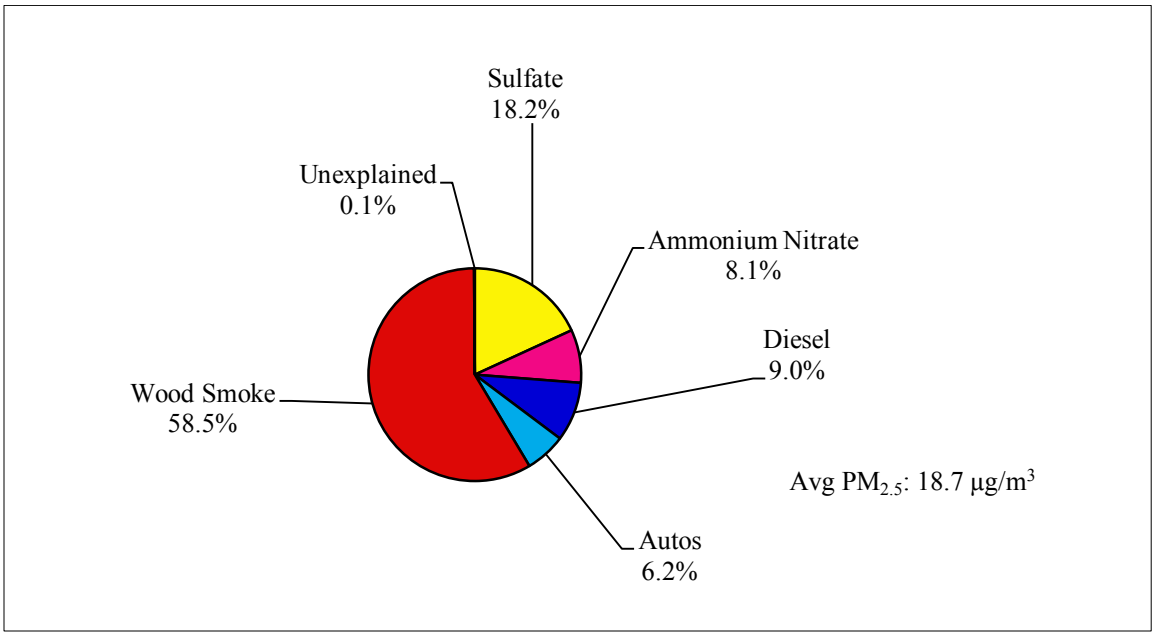

Figure 18: Winter 2007/2008, State Building.
CMB Results with OMNI Source Profiles, November 2, 2007 – March 31, 2008.

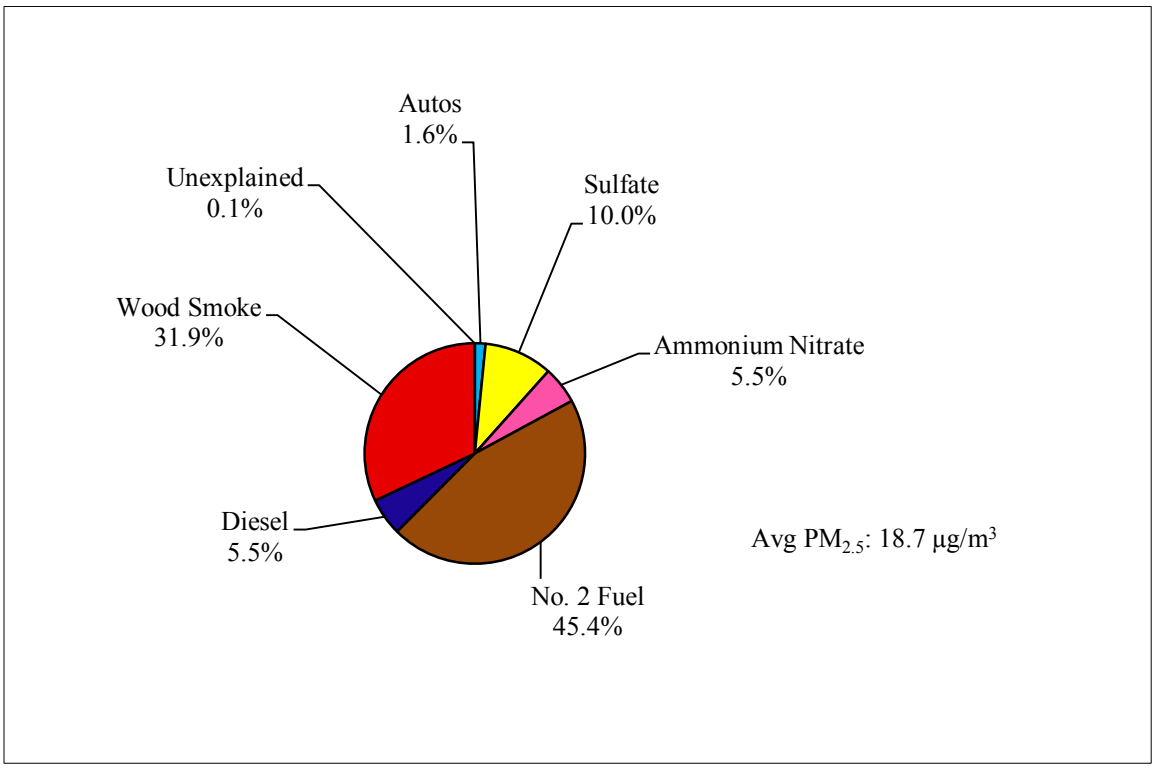

Table 18: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2007/2008.

Season:	Winter 2007/2008 (EPA)	Winter 2007/2008 (OMNI)
Dates:	11/2/07-3/31/08	11/2/07-3/31/08
n:	40	40
$PM_{2.5}$ Mass ($\mu g/m^3$):	18.7	18.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.4 (18.2 %)	1.9 (10.0 %)
Ammonium Nitrate:	1.5 (8.1 %)	1.0 (5.5 %)
Diesel:	1.7 (9.0 %)	1.0 (5.5 %)
Automobiles:	1.2 (6.2 %)	0.3 (1.6%)
Wood Smoke:	10.9 (58.5 %)	5.9 (31.9 %)
No. 2 Fuel Oil:	Not Identified	8.4 (45.4 %)
Unexplained:	0.02 (0.1 %)	0.01 (0.1 %)

Figure 19: Winter 2008/2009, State Building.
CMB Results with EPA Source Profiles, November 8, 2008 – April 7, 2009.

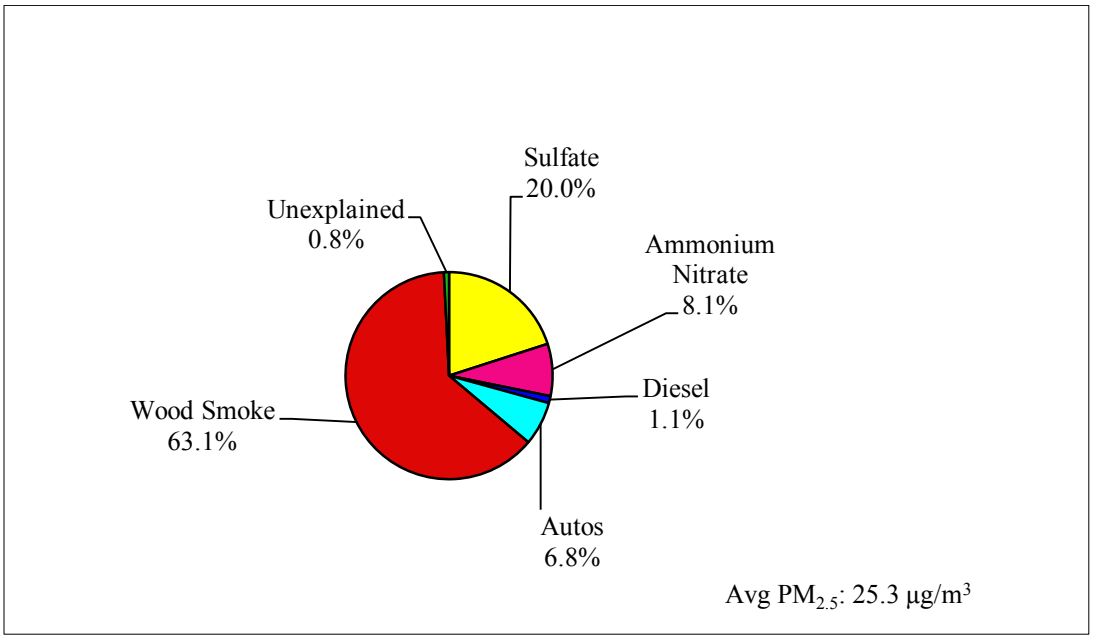

Figure 20: Winter 2008/2009, State Building.
CMB Results with OMNI Source Profiles, November 8, 2008 – April 7, 2009.
(Submitted originally to ADEC in July 23, 2012 final report).

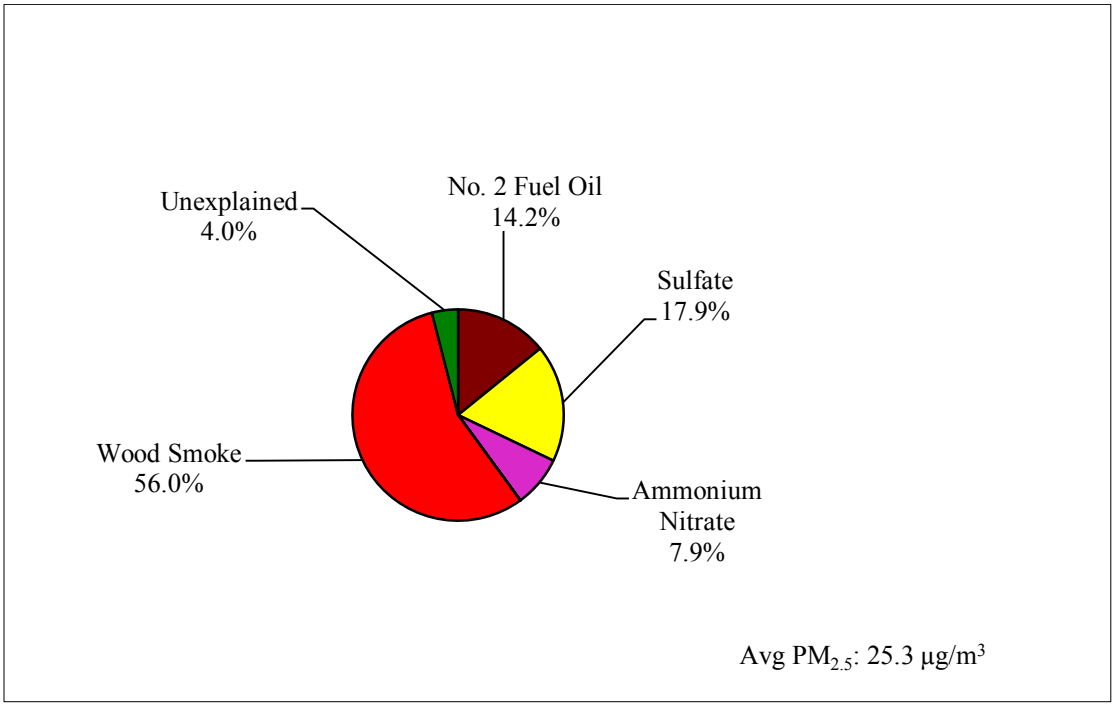

Figure 21: Winter 2008/2009, State Building.
CMB Results with OMNI Source Profiles, November 8, 2008 – April 7, 2009.
(Updated CMB modeling using OMNI profiles and auto / diesel profiles).

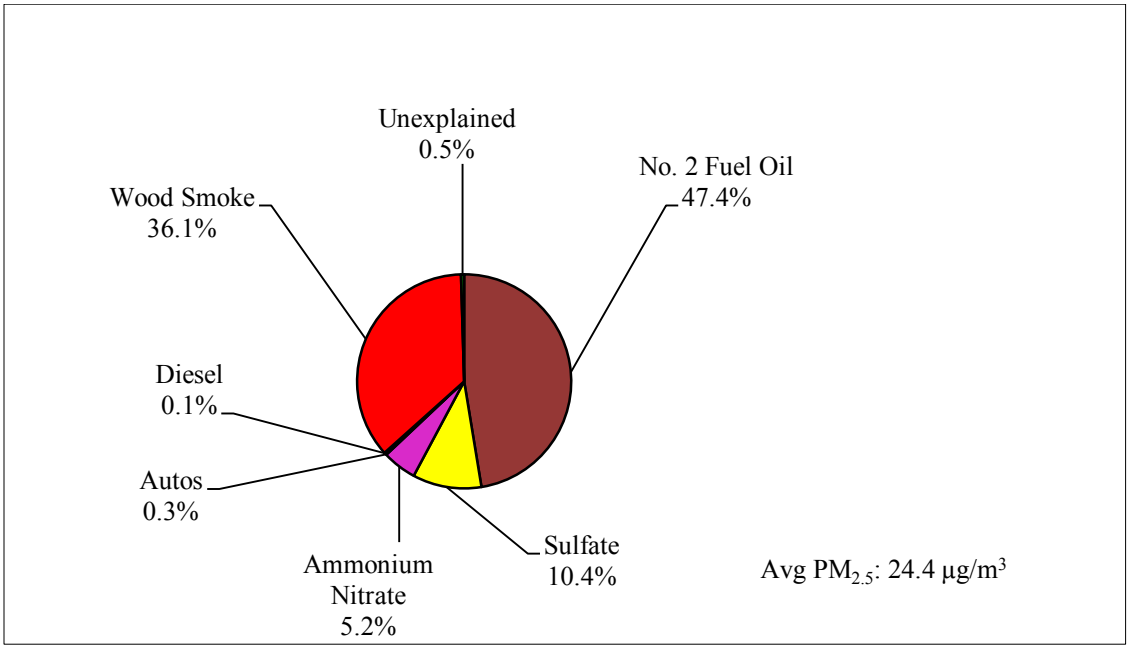

Table 19: Comparison of CMB Results - EPA and OMNI Source Profiles.
State Building, Winter 2008/2009.

Season:	**Winter 2008/2009 (EPA)**	**Winter 2008/2009 (OMNI)***	**Winter 2008/2009 (OMNI)****
Dates:	11/8/08-4/7/09	11/8/08-4/7/09	11/8/08-4/7/09
n:	47	47	46
$PM_{2.5}$ Mass (µg/m^3):	25.3	25.3	24.4
CMB Source Estimates (µg/m^3 and %)			
Sulfate:	5.1 (20.0 %)	4.4 (17.9 %)	2.5 (10.4 %)
Ammonium Nitrate:	2.1 (8.1 %)	1.9 (7.9%)	1.2 (5.2%)
Diesel:	0.3 (1.1 %)	Not Identified	0.04 (0.1 %)
Automobiles:	1.7 (6.8 %)	Not Identified	0.06 (0.3 %)
Wood Smoke:	16.0 (63.1 %)	13.8 (56.0 %)	8.7 (36.1 %)
No. 2 Fuel Oil:	Not Identified	3.5 (14.2 %)	11.4 (47.4 %)
Unexplained:	0.2 (0.8 %)	1.0 (4.0 %)	0.1 (0.5 %)

***Original OMNI CMB modeling (July 23, 2012 report). **Updated OMNI CMB modeling with autos and diesel profiles.**

Figure 22: Winter 2008/2009, North Pole.
CMB Results with EPA Source Profiles, January 25, 2009 – April 7, 2009.

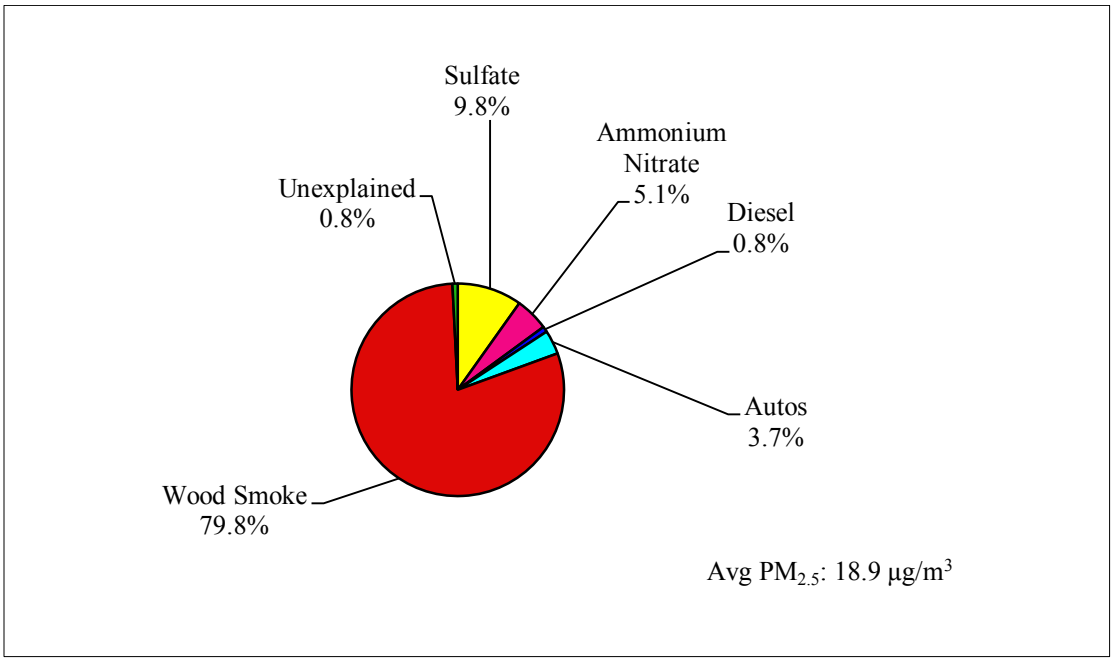

Figure 23: Winter 2008/2009, North Pole.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.

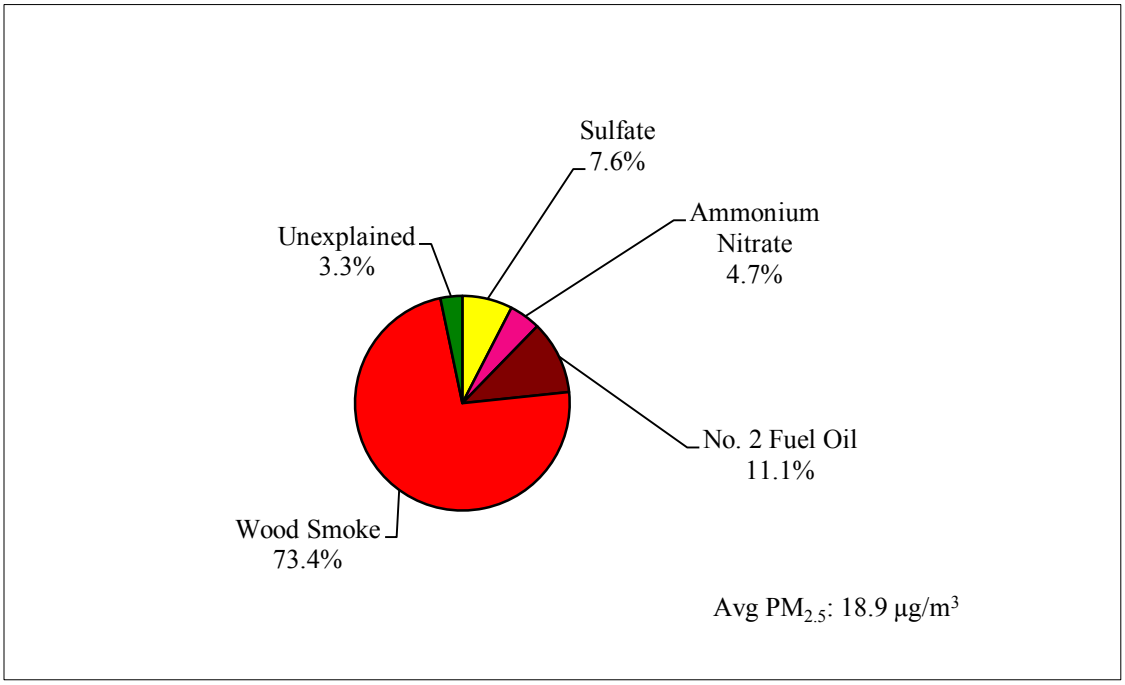

Table 20: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2008/2009.

Season:	Winter 2008/2009 (EPA)	Winter 2008/2009 (OMNI)
Dates:	1/25/09-4/7/09	1/25/09-4/7/09
n:	21	21
$PM_{2.5}$ Mass ($\mu g/m^3$):	18.9	18.9
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	1.9 (9.8 %)	1.4 (7.6 %)
Ammonium Nitrate:	1.0 (5.1 %)	0.9 (4.7 %)
Diesel:	0.2 (0.8 %)	Not Identified
Automobiles:	0.7 (3.7 %)	Not Identified
Wood Smoke:	15.0 (79.8 %)	13.6 (73.4 %)
No. 2 Fuel Oil:	Not Identified	2.1 (11.1 %)
Unexplained:	0.2 (0.8 %)	0.6 (3.3 %)

Figure 24: Winter 2008/2009, RAMS.
CMB Results with EPA Source Profiles, January 25, 2009 – April 7, 2009.

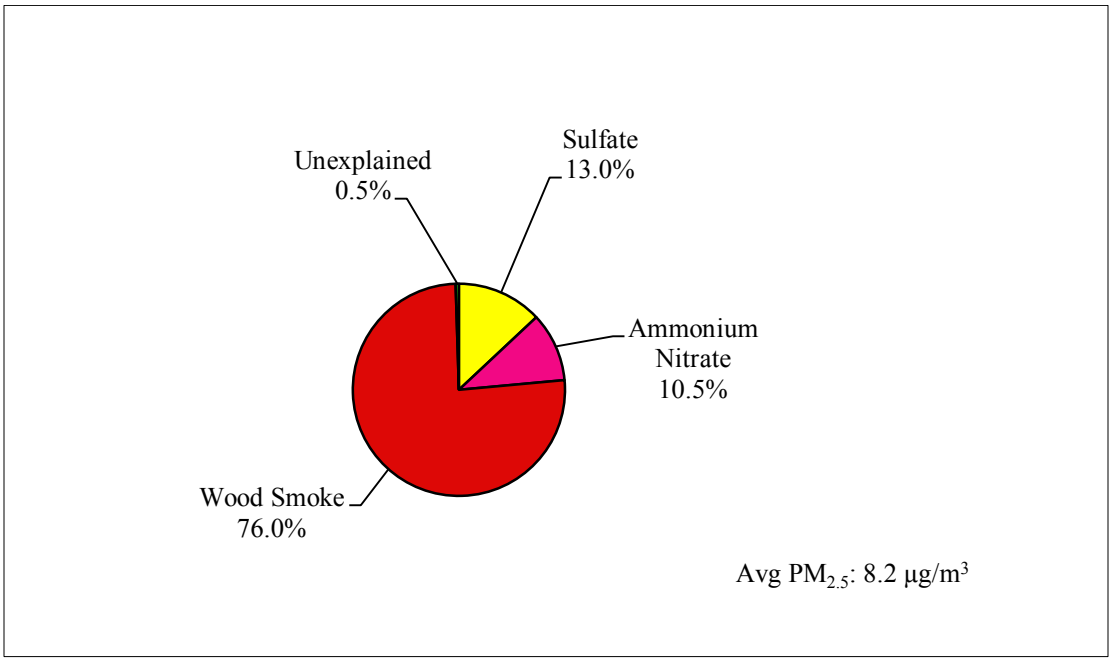

Figure 25: Winter 2008/2009, RAMS.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.

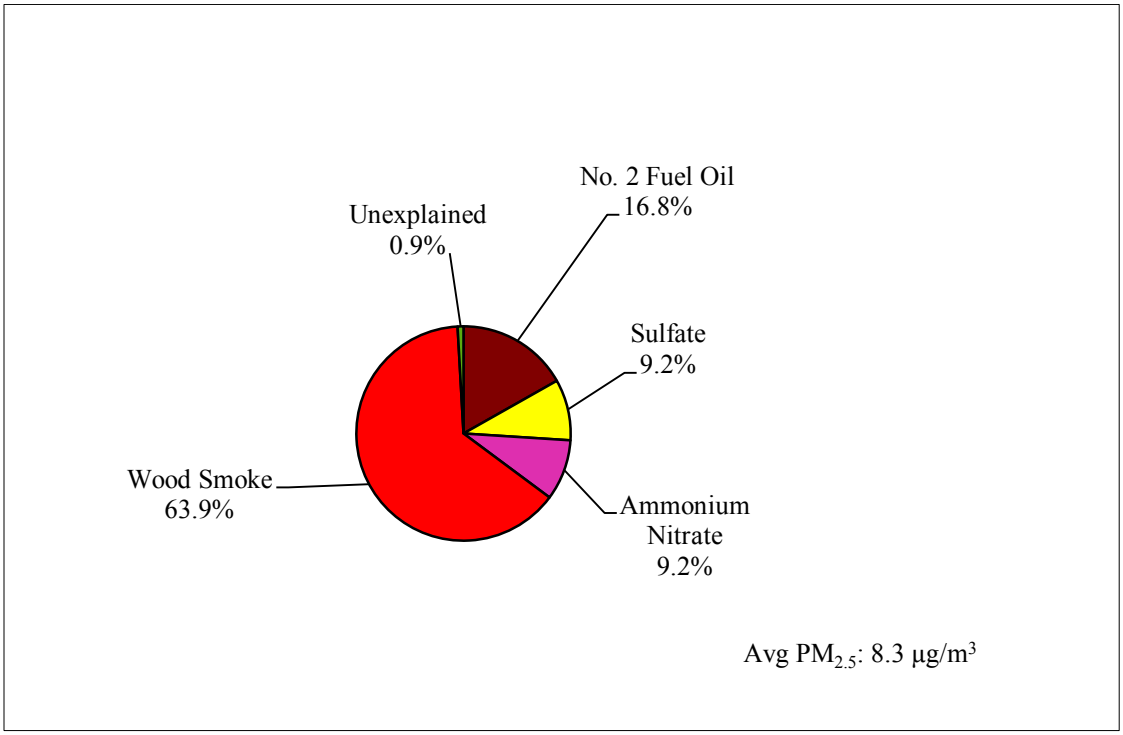

Table 21: Comparison of CMB Results - EPA and OMNI Source Profiles. RAMS, Winter 2008/2009.

Season:	Winter 2008/2009 (EPA)	Winter 2008/2009 (OMNI)
Dates:	1/25/09-4/7/09	1/25/09-4/7/09
n:	23	22
$PM_{2.5}$ Mass ($\mu g/m^3$):	8.2	8.3
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	1.1 (13.0 %)	0.8 (9.2 %)
Ammonium Nitrate:	0.9 (10.5 %)	0.8 (9.2 %)
Diesel:	Not Identified	Not Identified
Automobiles:	Not Identified	Not Identified
Wood Smoke:	6.3 (76.0 %)	5.4 (63.9 %)
No. 2 Fuel Oil:	Not Identified	1.4 (16.8 %)
Unexplained:	0.04 (0.5 %)	0.1 (0.9%)

Figure 26: Winter 2008/2009, Peger Road.
CMB Results with EPA Source Profiles, January 25, 2009 – April 7, 2009.

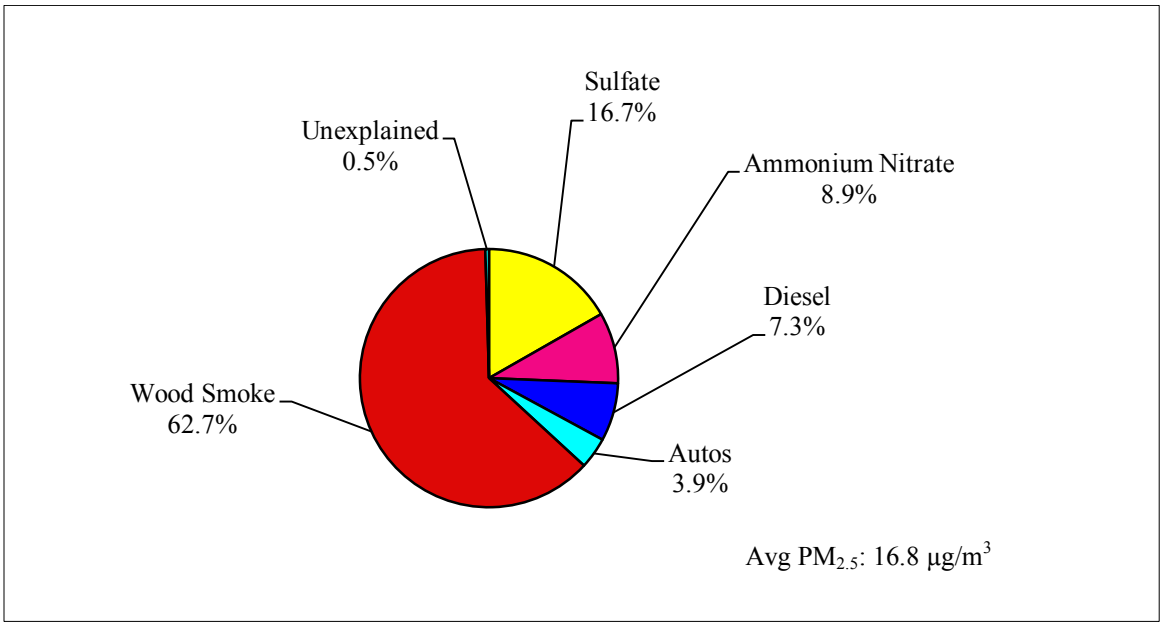

Figure 27: Winter 2008/2009, Peger Road.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.
(Submitted originally to ADEC in July 23, 2012 final report).

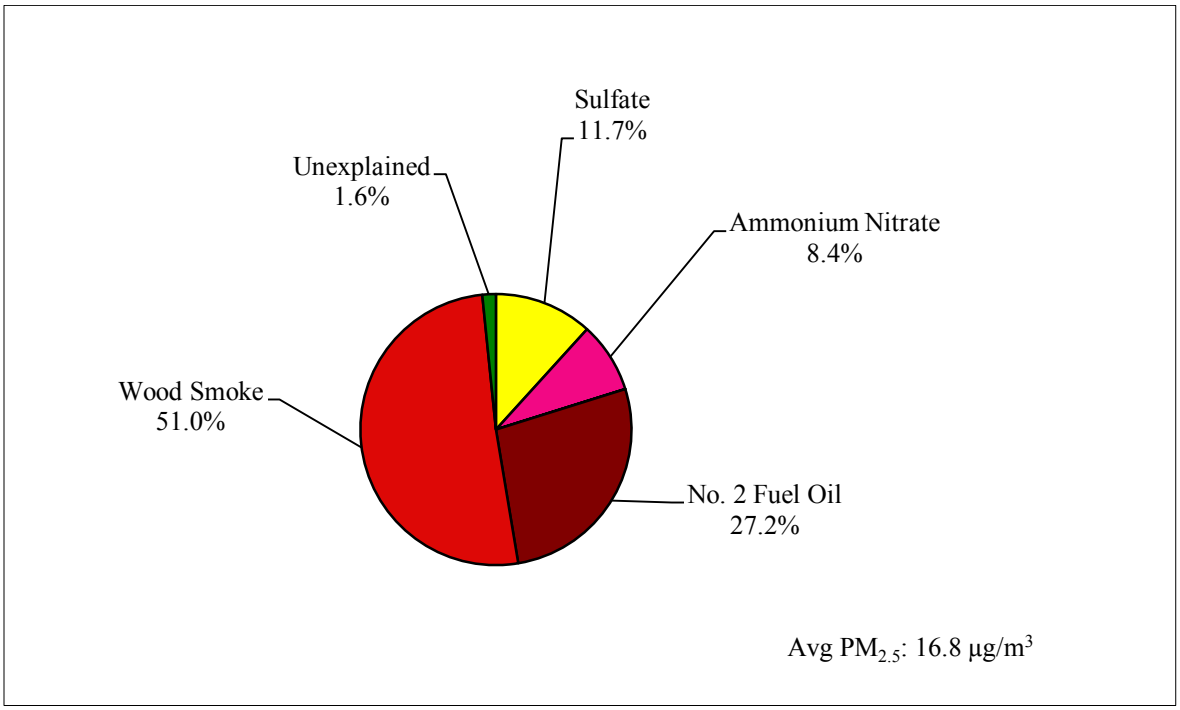

Figure 28: Winter 2008/2009, Peger Road.
CMB Results with OMNI Source Profiles, January 25, 2009 – April 7, 2009.
(Updated CMB modeling using OMNI profiles and auto / diesel profiles).

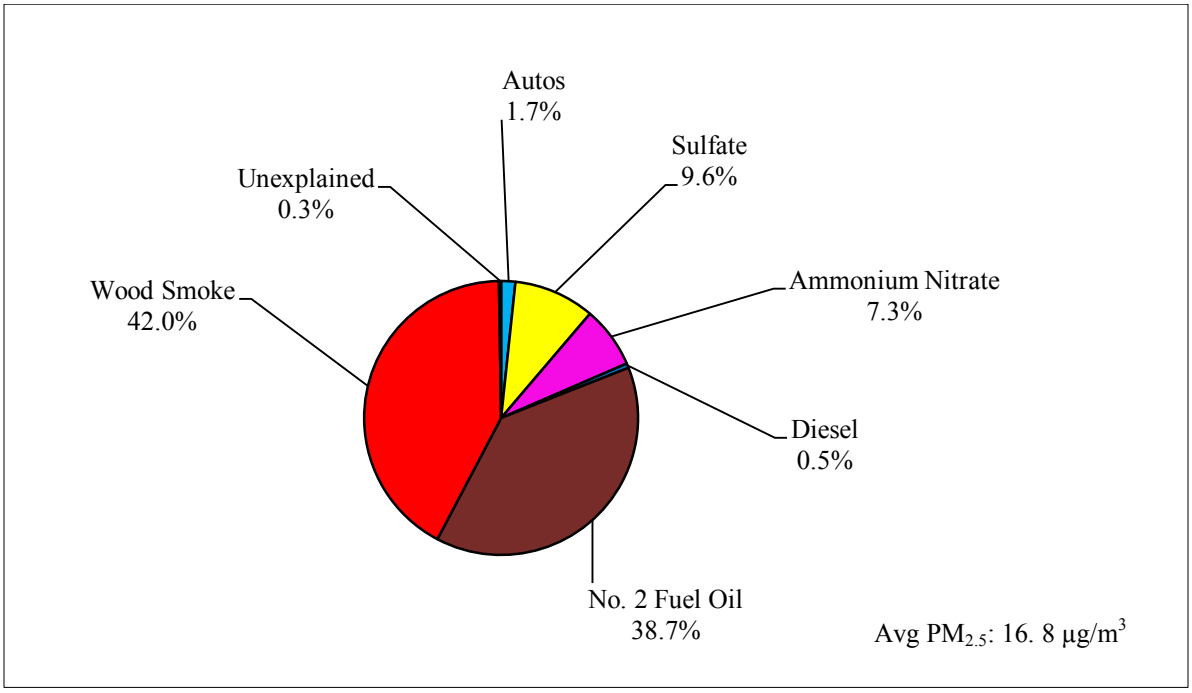

Table 22: Comparison of CMB Results - EPA and OMNI Source Profiles.
Peger Road, Winter 2008/2009.

Season:	Winter 2008/2009 (EPA)	Winter 2008/2009 (OMNI)*	Winter 2008/2009 (OMNI)**
Dates:	1/25/09-4/7/09	1/25/09-4/7/09	1/25/09-4/7/09
n:	26	26	26
$PM_{2.5}$ Mass (µg/m^3):	16.8	16.8	16.8
CMB Source Estimates (µg/m^3 and %)			
Sulfate:	2.8 (16.7 %)	2.0 (11.7 %)	1.6 (9.6 %)
Ammonium Nitrate:	1.5 (8.9 %)	1.4 (8.4 %)	1.2 (7.3 %)
Diesel:	1.2 (7.3 %)	Not Identified	0.1 (0.5 %)
Automobiles:	0.7 (3.9 %)	Not Identified	0.3 (1.7 %)
Wood Smoke:	10.6 (62.7 %)	8.6 (51.0 %)	7.1 (42.0 %)
No. 2 Fuel Oil:	Not Identified	4.6 (27.2 %)	6.6 (38.7 %)
Unexplained:	0.1 (0.5 %)	0.3 (1.6 %)	0.04 (0.3 %)

***Original OMNI CMB modeling (July 23, 2012 report). **Updated OMNI CMB modeling with autos and diesel profiles.**

Figure 29: Winter 2009/2010, State Building.
CMB Results with EPA Source Profiles, November 3, 2009–March 15, 2010.

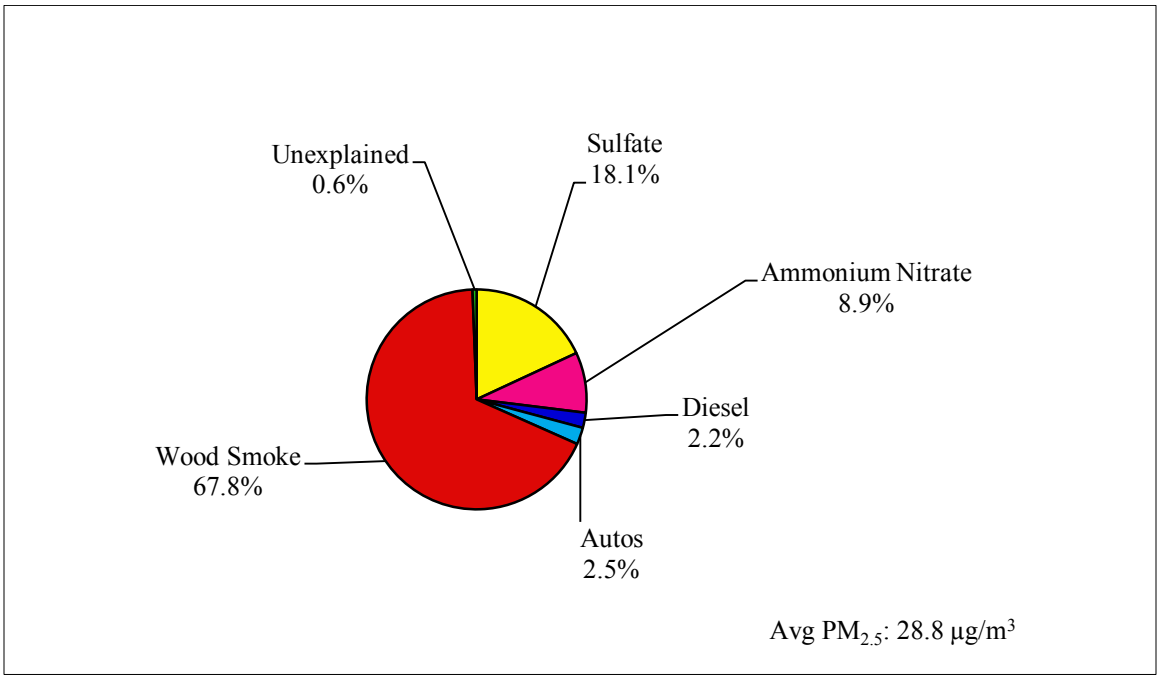

Figure 30: Winter 2009/2010, State Building.
CMB Results with OMNI Source Profiles, November 3, 2009–March 15, 2010.

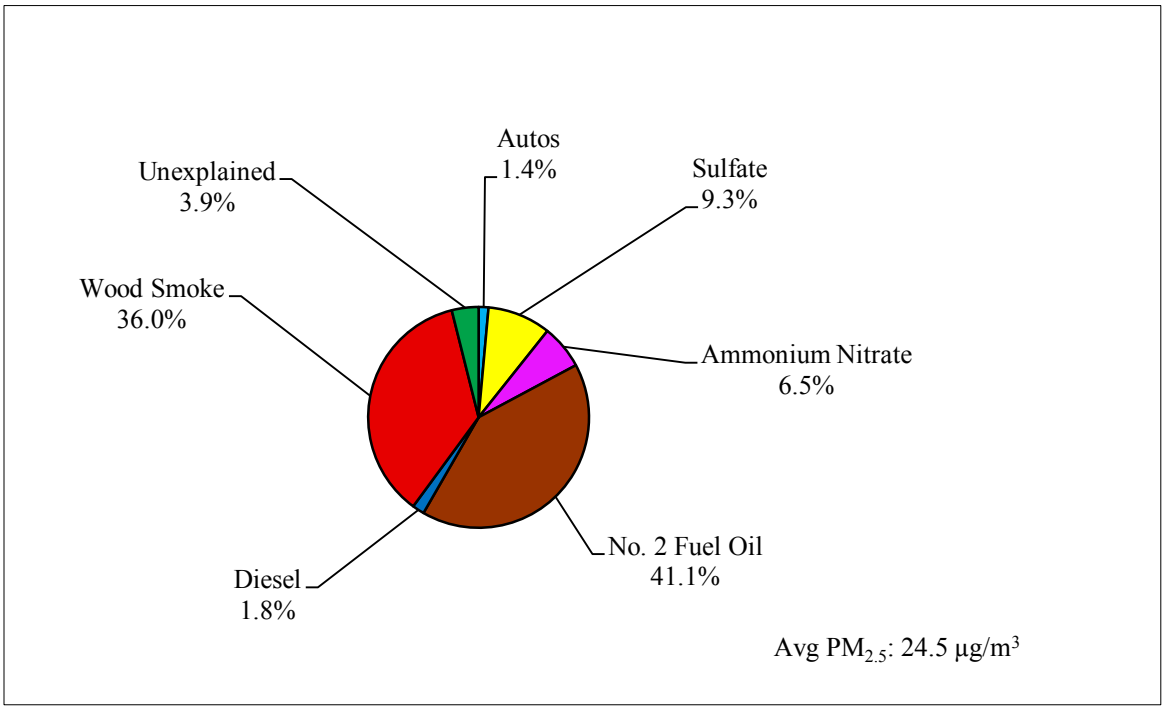

Table 23: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/3/09-3/15/10	11/3/09-3/15/10
n:	40	31
$PM_{2.5}$ Mass ($\mu g/m^3$):	28.8	24.5
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	5.2 (18.1 %)	2.2 (9.3 %)
Ammonium Nitrate:	2.5 (8.9 %)	1.6 (6.5 %)
Diesel:	0.6 (2.2 %)	0.4 (1.8 %)
Automobiles:	0.7 (2.5 %)	0.4 (1.4 %)
Wood Smoke:	19.5 (67.8 %)	8.7 (36.0 %)
No. 2 Fuel Oil:	Not Identified	10.0 (41.1 %)
Unexplained:	0.2 (0.6 %)	1.0 (3.9 %)

Figure 31: Winter 2009/2010, North Pole.
CMB Results with EPA Source Profiles, November 3, 2009 – March 15, 2010.

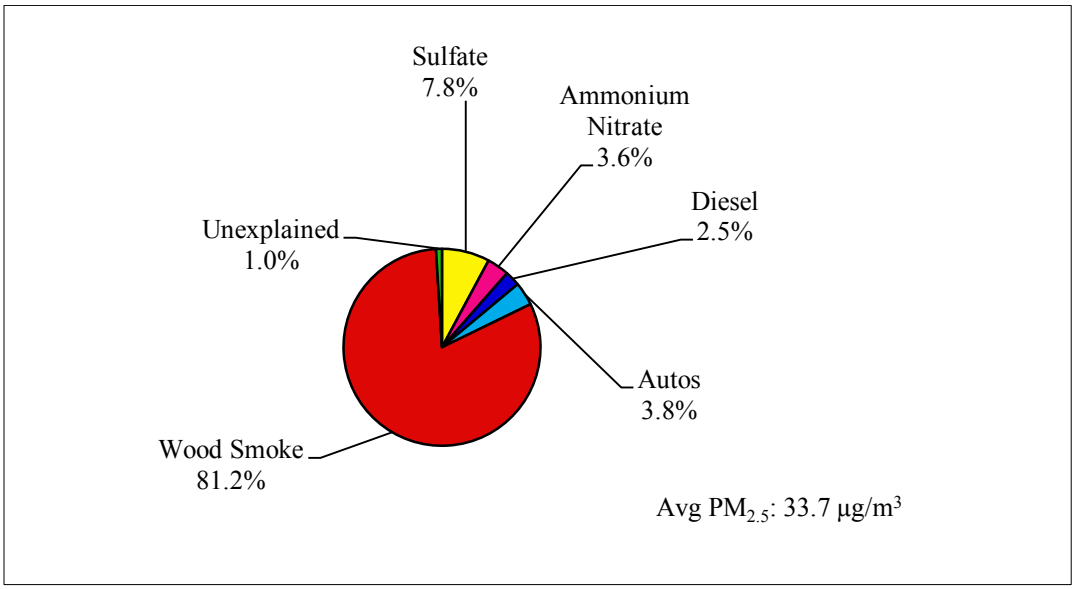

Figure 32: Winter 2009/2010, North Pole.
CMB Results with OMNI Source Profiles, November 3, 2009–March 15, 2010.

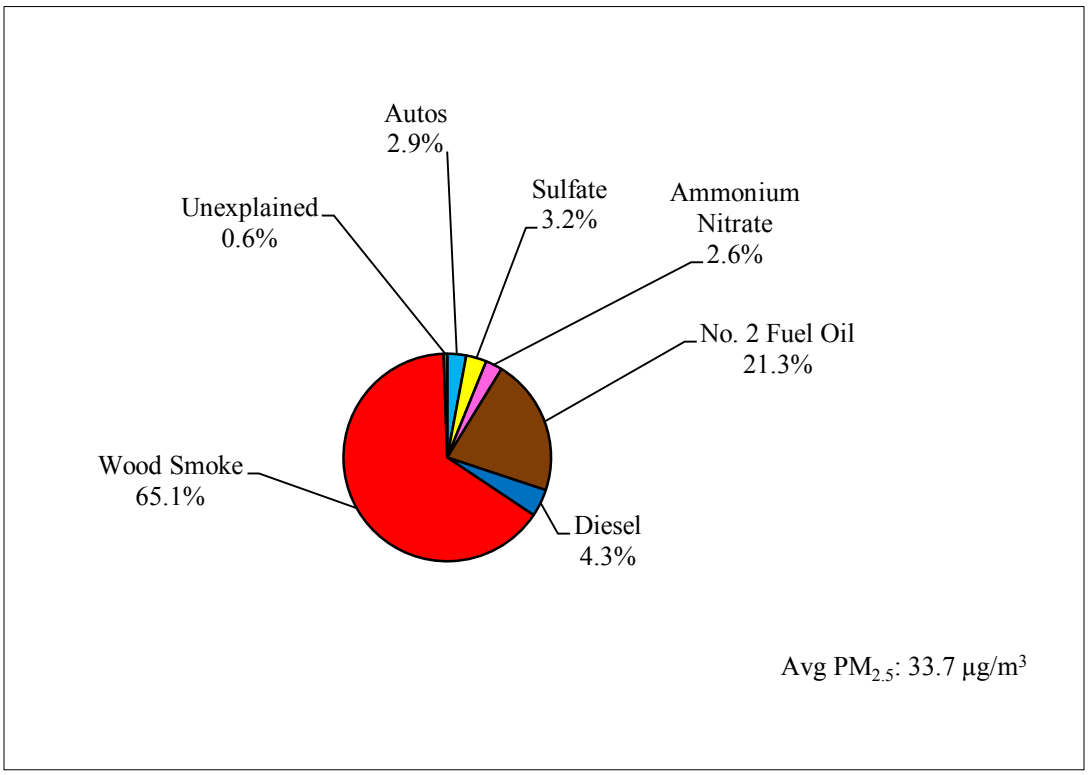

Table 24: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/3/09-3/15/10	11/3/09-3/15/10
n:	35	35
$PM_{2.5}$ Mass ($\mu g/m^3$):	33.7	33.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	2.6 (7.8 %)	1.1 (3.2 %)
Ammonium Nitrate:	1.2 (3.6 %)	0.9 (2.6 %)
Diesel:	0.8 (2.5 %)	1.5 (4.3 %)
Automobiles:	1.3 (3.8 %)	1.0 (2.9 %)
Wood Smoke:	27.1 (81.2 %)	22.4 (65.1 %)
No. 2 Fuel Oil:	Not Identified	7.3 (21.3 %)
Unexplained:	0.3 (1.0 %)	0.2 (0.6 %)

Figure 33: Winter 2009/2010, RAMS.
CMB Results with EPA Source Profiles, November 15, 2009 – March 15, 2010.

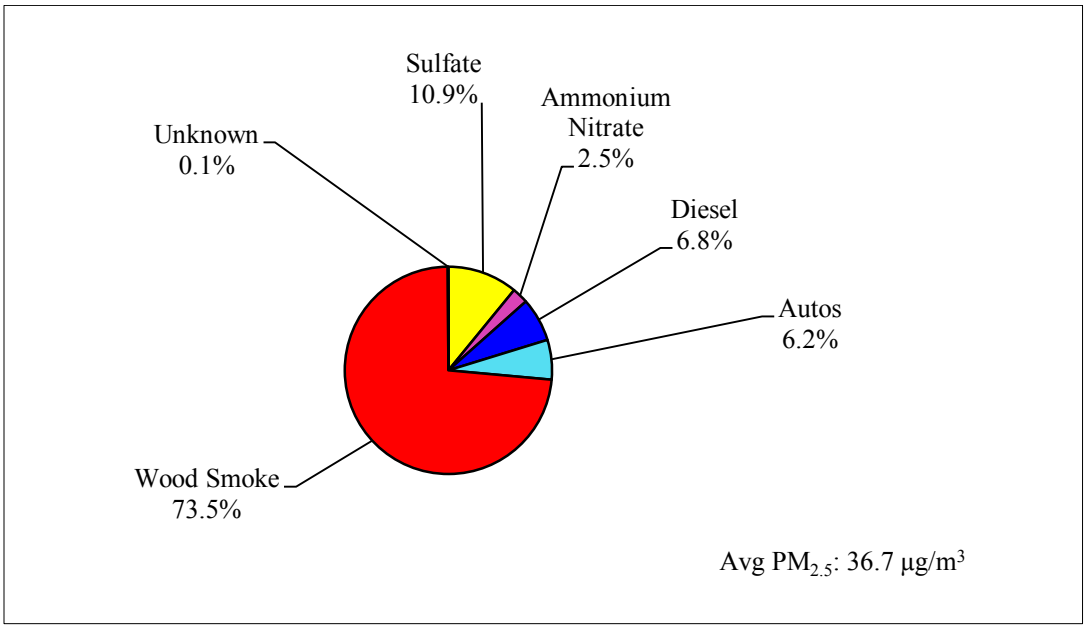

Figure 34: Winter 2009/2010, RAMS.
CMB Results with OMNI Source Profiles, November 15, 2009 – March 15, 2010.

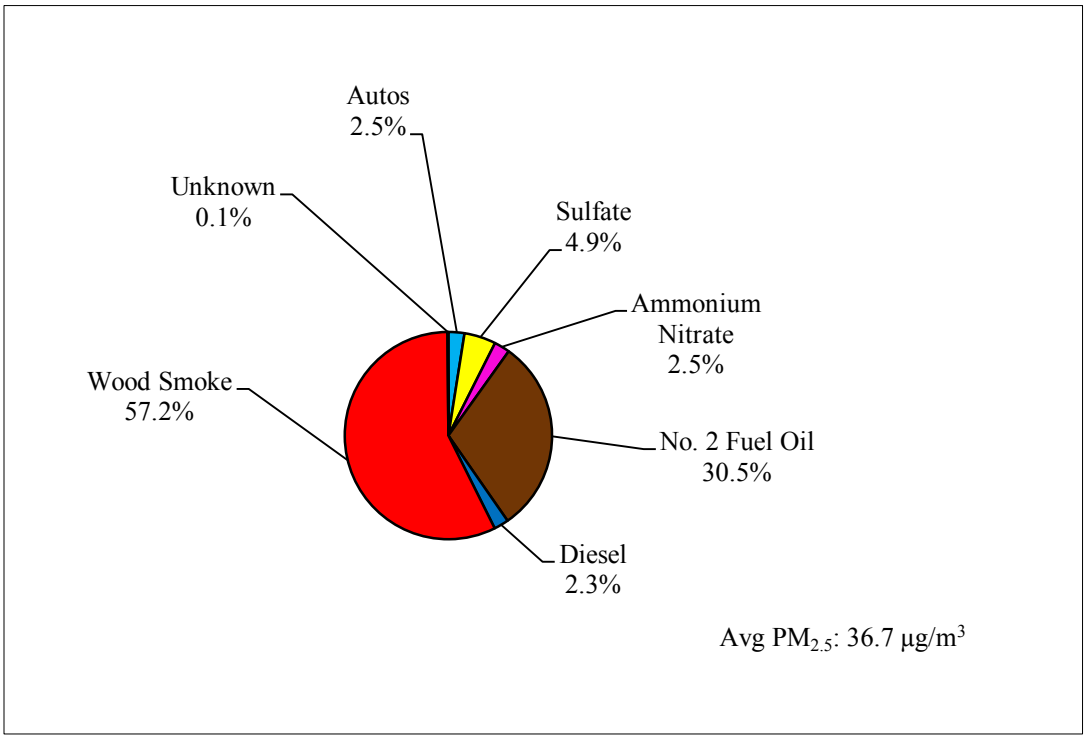

Table 25: Comparison of CMB Results - EPA and OMNI Source Profiles. RAMS, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/15/09-3/15/10	11/15/09-3/15/10
n:	29	29
$PM_{2.5}$ Mass ($\mu g/m^3$):	36.7	36.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	4.0 (10.9 %)	1.8 (4.9 %)
Ammonium Nitrate:	0.9 (2.5 %)	0.9 (2.5 %)
Diesel:	2.5 (6.8 %)	0.8 (2.3 %)
Automobiles:	2.3 (6.2 %)	0.9 (2.5 %)
Wood Smoke:	26.9 (73.5 %)	21.0 (57.2 %)
No. 2 Fuel Oil:	Not Identified	11.2 (30.5 %)
Unexplained:	0.04 (0.1 %)	0.1 (0.1 %)

Figure 35: Winter 2009/2010, Peger Road.
CMB Results with EPA Source Profiles, November 3, 2009 – March 15, 2010.

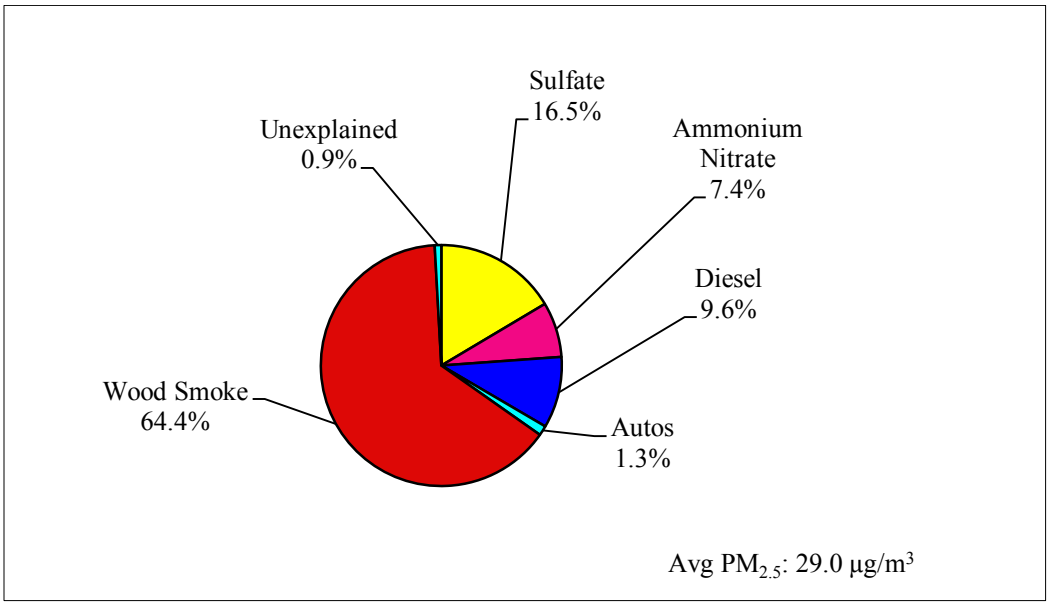

Figure 36: Winter 2009/2010, Peger Road.
CMB Results with OMNI Source Profiles, November 3, 2009 – March 15, 2010.

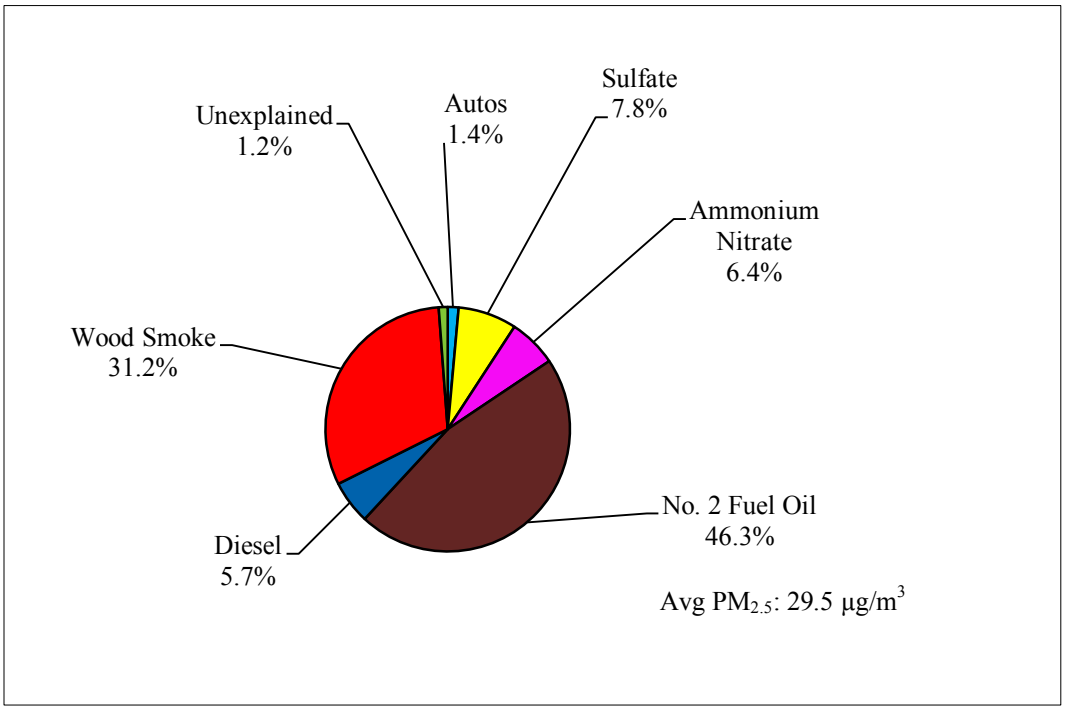

Table 26: Comparison of CMB Results - EPA and OMNI Source Profiles. Peger Road, Winter 2009/2010.

Season:	Winter 2009/2010 (EPA)	Winter 2009/2010 (OMNI)
Dates:	11/3/09-3/15/10	11/3/09-3/15/10
n:	38	37
$PM_{2.5}$ Mass ($\mu g/m^3$):	29.0	29.5
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	4.8 (16.5 %)	2.3 (7.8 %)
Ammonium Nitrate:	2.1 (7.4 %)	1.9 (6.4 %)
Diesel:	2.8 (9.6 %)	1.7 (5.7 %)
Automobiles:	0.4 (1.3 %)	0.4 (1.4 %)
Wood Smoke:	18.6 (64.4 %)	9.2 (31.2 %)
No. 2 Fuel Oil:	Not Identified	13.7 (46.3 %)
Unexplained:	0.3 (0.9 %)	0.3 (1.2 %)

Figure 37: Winter 2010/2011, State Building.
CMB Results with EPA Source Profiles, November 1, 2010 – February 8, 2011.

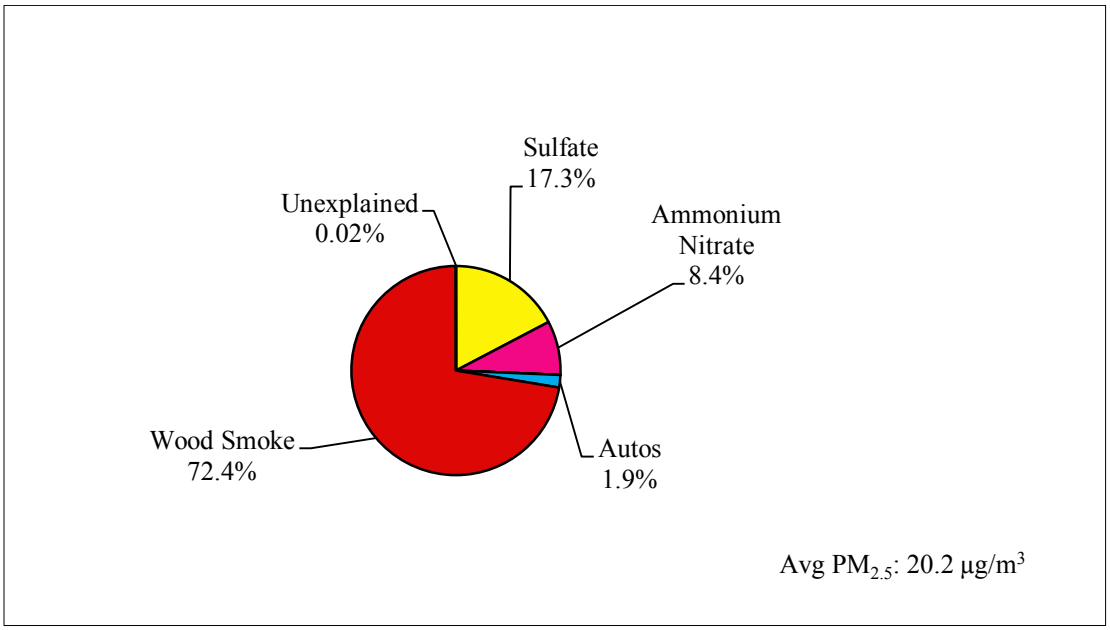

Figure 38: Winter 2010/2011, State Building.
CMB Results with OMNI Source Profiles, November 1, 2010 – February 8, 2011.

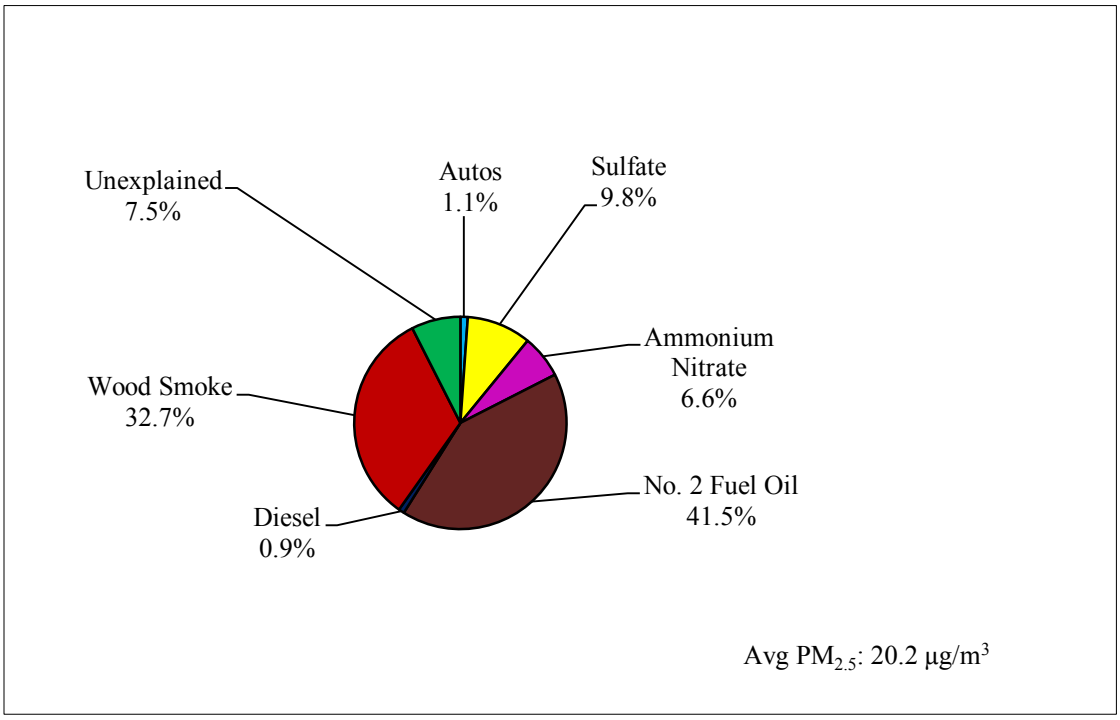

Table 27: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2010/2011.

Season:	Winter 2010/2011 (EPA)	Winter 2010/2011 (OMNI)
Dates:	11/1/10-2/8/11	11/1/10-2/8/11
n:	15	15
$PM_{2.5}$ Mass ($\mu g/m^3$)	20.2	20.2
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.5 (17.3 %)	2.0 (9.8 %)
Ammonium Nitrate:	1.7 (8.4 %)	1.3 (6.6 %)
Diesel:	Not Identified	0.2 (0.9 %)
Automobiles:	0.4 (1.9 %)	0.2 (1.1 %)
Wood Smoke:	14.6 (72.4 %)	6.5 (32.7 %)
No. 2 Fuel Oil:	Not Identified	8.3 (41.5 %)
Unexplained:	0.004 (0.02 %)	1.5 (7.5 %)

Figure 39: Winter 2010/2011, North Pole.
CMB Results with EPA Source Profiles, January 9, 2011 – February 5, 2011.

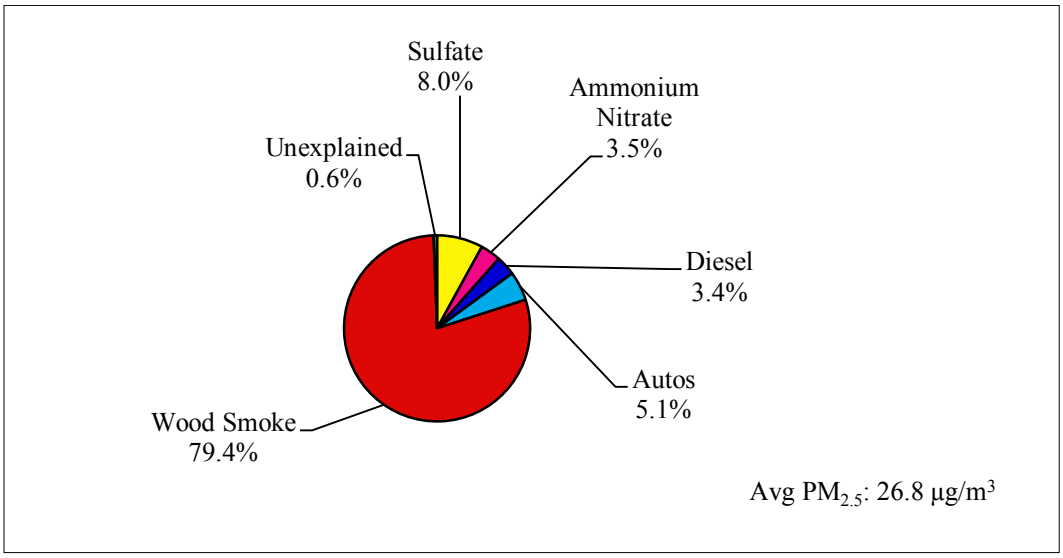

Figure 40: Winter 2010/2011, North Pole.
CMB Results with OMNI Source Profiles, January 9, 2011 – February 5, 2011.

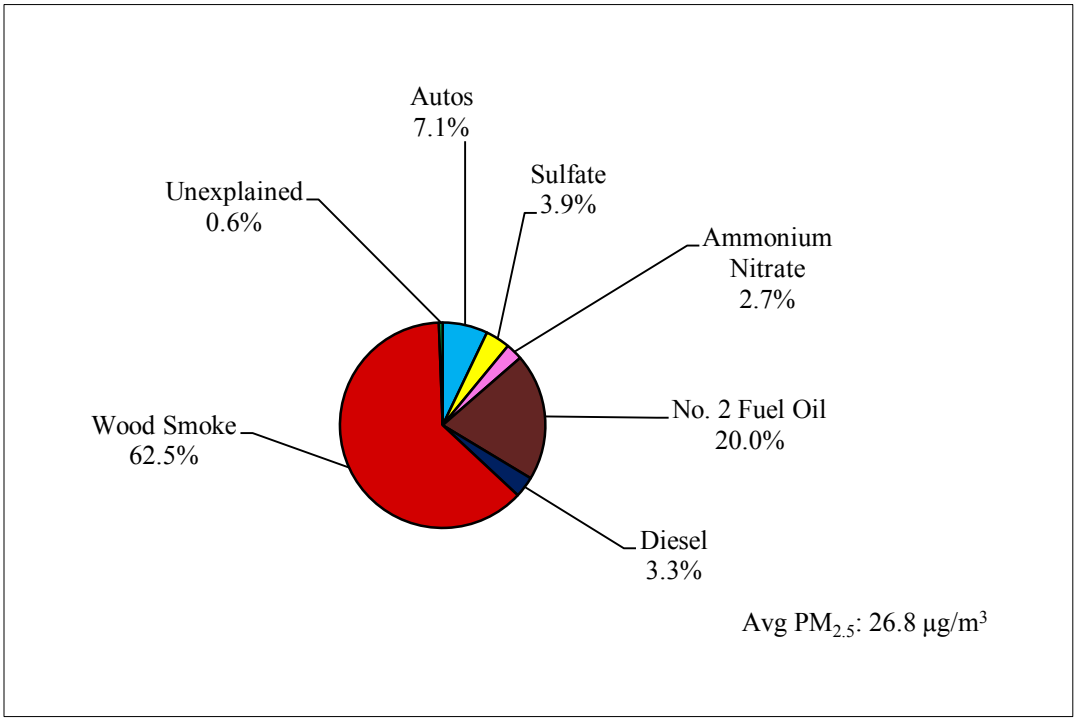

Table 28: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2010/2011.

Season:	Winter 2010/2011 (EPA)	Winter 2010/2011 (OMNI)
Dates:	1/9/11-2/5/11	1/9/11-2/5/11
n:	10	10
$PM_{2.5}$ Mass ($\mu g/m^3$):	26.8	26.8
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	2.1 (8.0 %)	1.0 (3.9 %)
Ammonium Nitrate:	0.9 (3.5 %)	0.7 (2.7 %)
Diesel:	0.9 (3.4 %)	0.9 (3.3 %)
Automobiles:	1.4 (5.1 %)	1.9 (7.1 %)
Wood Smoke:	21.3 (79.4 %)	16.6 (62.5 %)
No. 2 Fuel Oil:	Not Identified	5.3 (20.0 %)
Unexplained:	0.2 (0.6 %)	0.2 (0.6 %)

Figure 41: Winter 2010/2011, Peger Road.
CMB Results with EPA Source Profiles, January 9, 2011 – February 5, 2011.

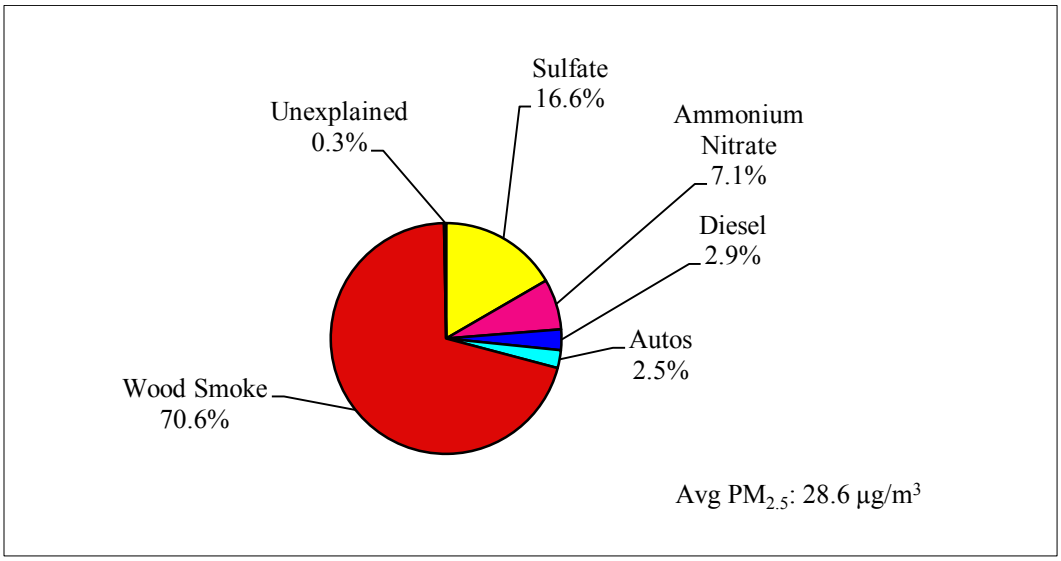

Figure 42: Winter 2010/2011, Peger Road.
CMB Results with OMNI Source Profiles, January 9, 2011 – February 5, 2011.

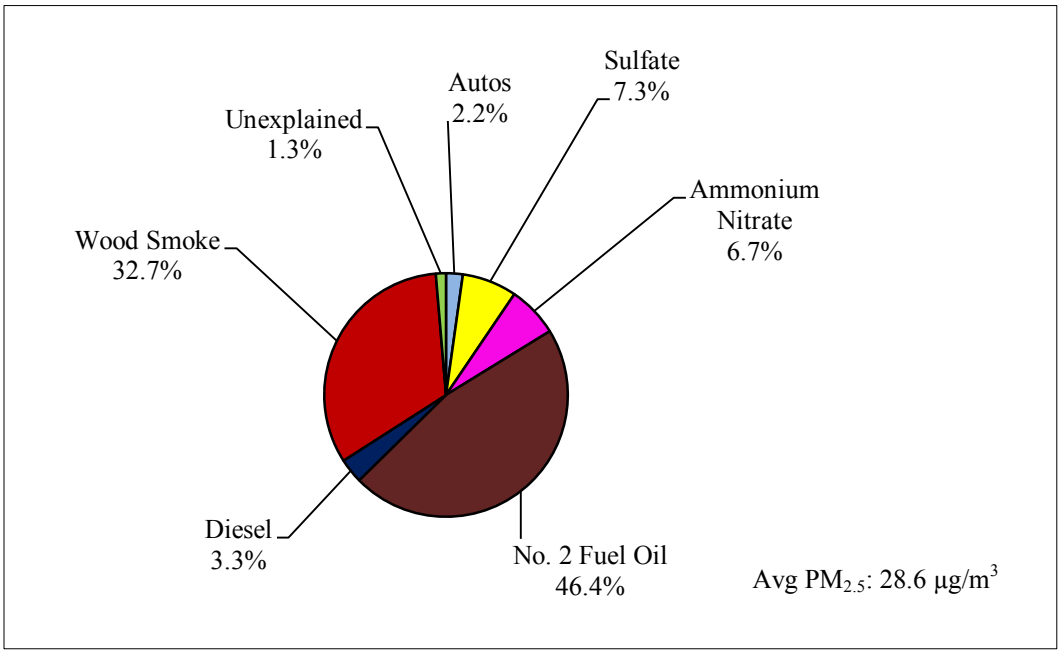

Table 29: Comparison of CMB Results - EPA and OMNI Source Profiles. Peger Road, Winter 2010/2011.

Season:	Winter 2010/2011 (EPA)	Winter 2010/2011 (OMNI)
Dates:	1/9/11-2/5/11	1/9/11-2/5/11
n:	10	10
$PM_{2.5}$ Mass (µg/m^3):	28.6	28.6
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	4.8 (16.6 %)	2.1 (7.3 %)
Ammonium Nitrate:	2.0 (7.1 %)	2.0 (6.7 %)
Diesel:	0.8 (2.9 %)	1.0 (3.3 %)
Automobiles:	0.7 (2.5 %)	0.6 (2.2 %)
Wood Smoke:	20.2 (70.6 %)	9.5 (32.7 %)
No. 2 Fuel Oil:	Not Identified	13.5 (46.4 %)
Unexplained:	0.1 (0.3 %)	0.4 (1.3 %)

Figure 43: Winter 2011/2012, State Building.
CMB Results with EPA Source Profiles, November 2, 2011 – March 31, 2012.

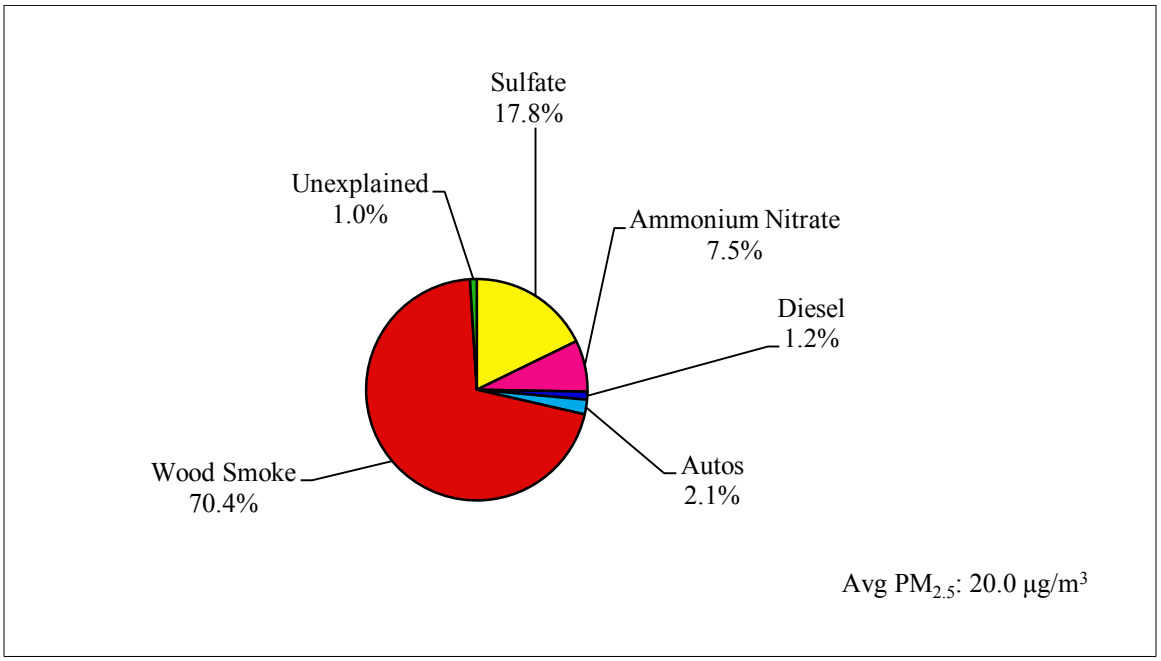

Figure 44: Winter 2011/2012, State Building.
CMB Results with OMNI Source Profiles, November 2, 2011 – March 31, 2012.

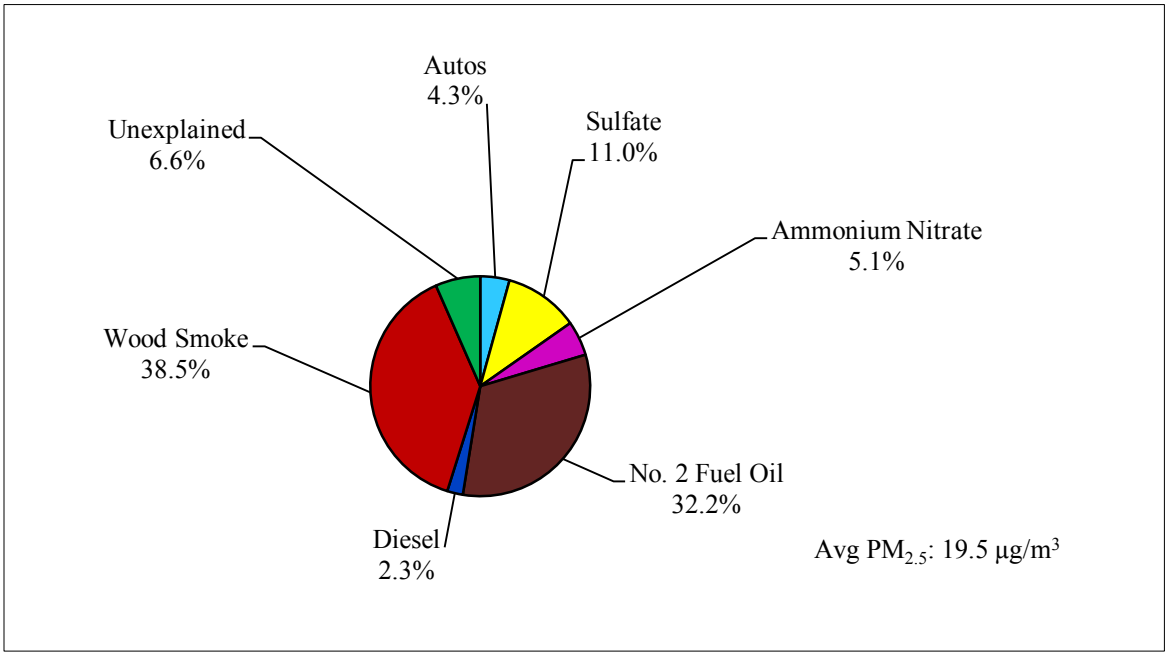

Table 30: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	11/2/11-3/31/12	11/2/11-3/31/12
n:	38	36
$PM_{2.5}$ Mass ($\mu g/m^3$):	20.0	19.5
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.5 (17.8 %)	2.2 (11.0 %)
Ammonium Nitrate:	1.5 (7.5 %)	1.0 (5.1 %)
Diesel:	0.2 (1.2 %)	0.5 (2.3 %)
Automobiles:	0.4 (2.1 %)	0.8 (4.3 %)
Wood Smoke:	14.0 (70.4 %)	7.6 (38.5 %)
No. 2 Fuel Oil:	Not Identified	6.4 (32.2 %)
Unexplained:	0.2 (1.0 %)	1.3 (6.6 %)

Figure 45: Winter 2011/2012, North Pole.
CMB Results with EPA Source Profiles, November 2, 2011 – March 25, 2012.

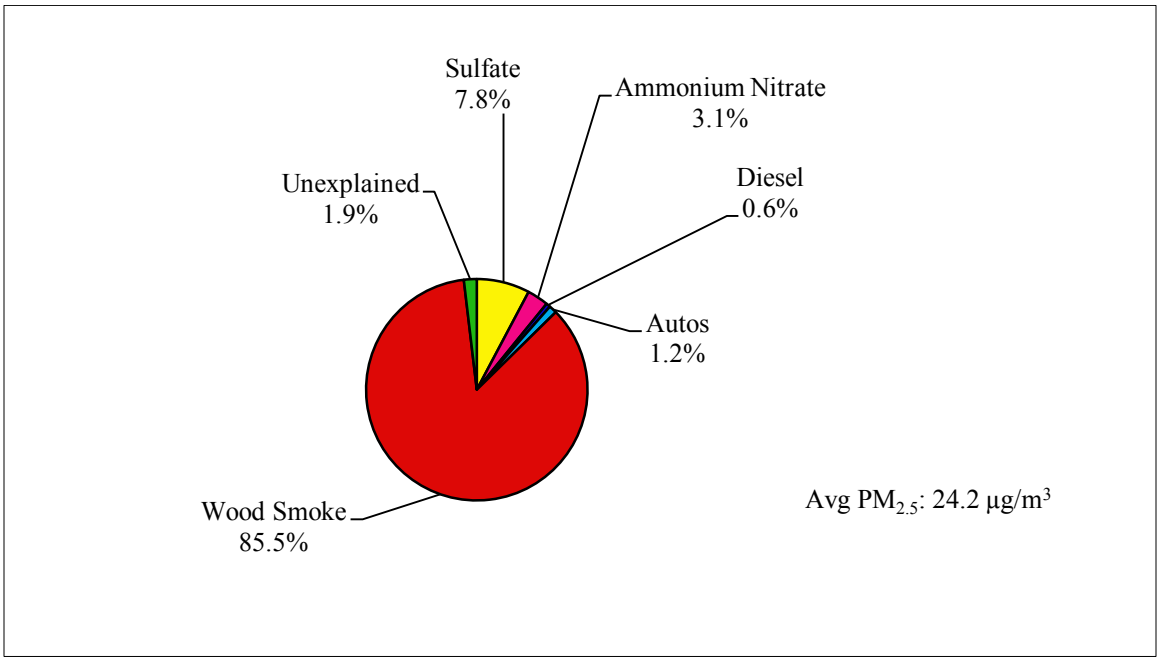

Figure 46: Winter 2011/2012, North Pole.
CMB Results with OMNI Source Profiles, November 2, 2011 – March 25, 2012.

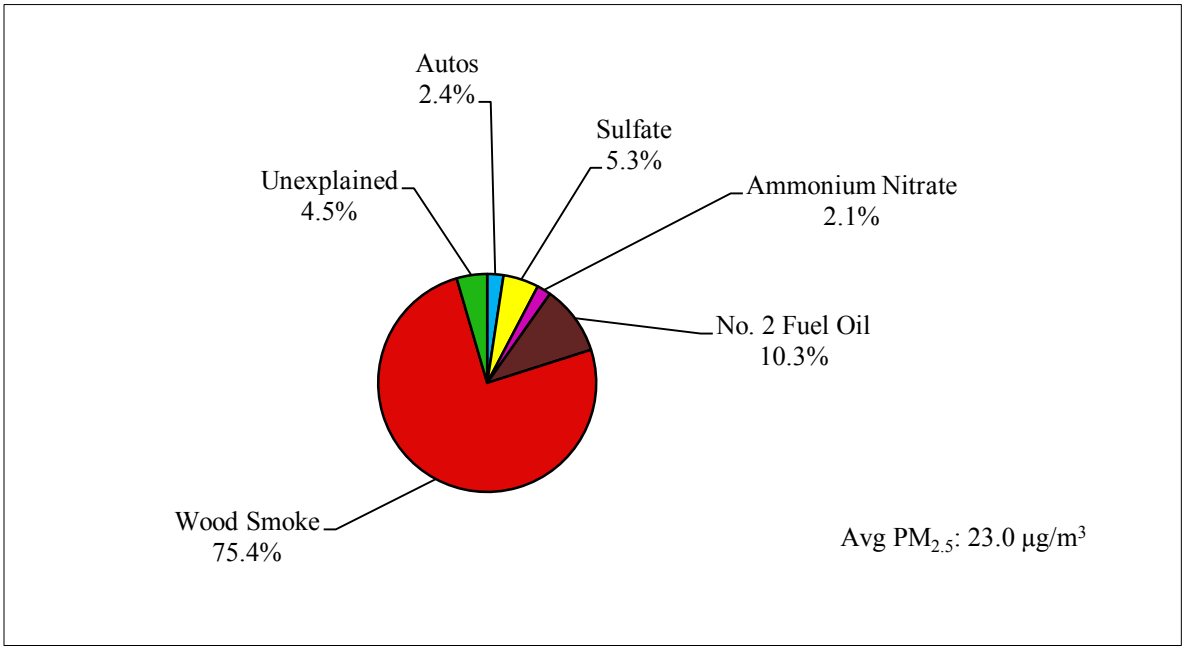

Table 31: Comparison of CMB Results - EPA and OMNI Source Profiles. North Pole, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	11/2/11-3/25/12	11/2/11-3/25/12
n:	36	35
$PM_{2.5}$ Mass (µg/m^3):	24.2	23.0
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	1.8 (7.8 %)	1.2 (5.3 %)
Ammonium Nitrate:	0.7 (3.1 %)	0.5 (2.1 %)
Diesel:	0.1 (0.6 %)	Not Identified
Automobiles:	0.3 (1.2 %)	0.6 (2.4 %)
Wood Smoke:	20.4 (85.5 %)	17.3 (75.4 %)
No. 2 Fuel Oil:	Not Identified	2.4 (10.3 %)
Unexplained:	0.4 (1.9 %)	1.0 (4.5 %)

Figure 47: Winter 2011/2012, RAMS.
CMB Results with EPA Source Profiles, December 20, 2011 – February 27, 2012.

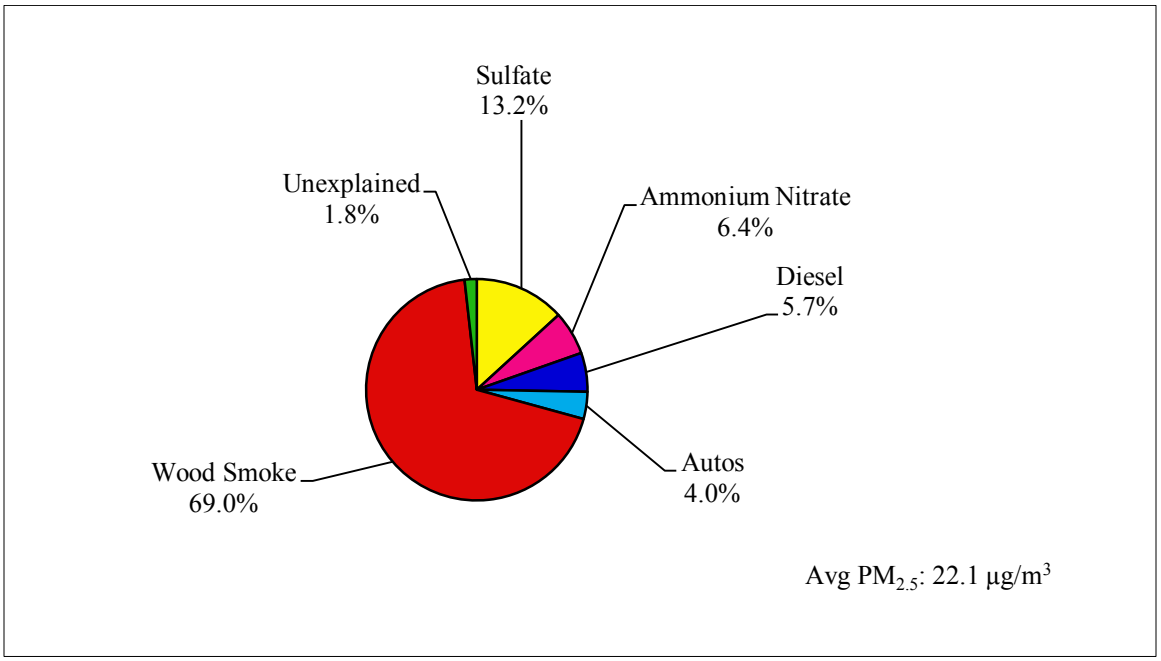

Figure 48: Winter 2011/2012, RAMS.
CMB Results with OMNI Source Profiles, December 20, 2011 – February 27, 2012.

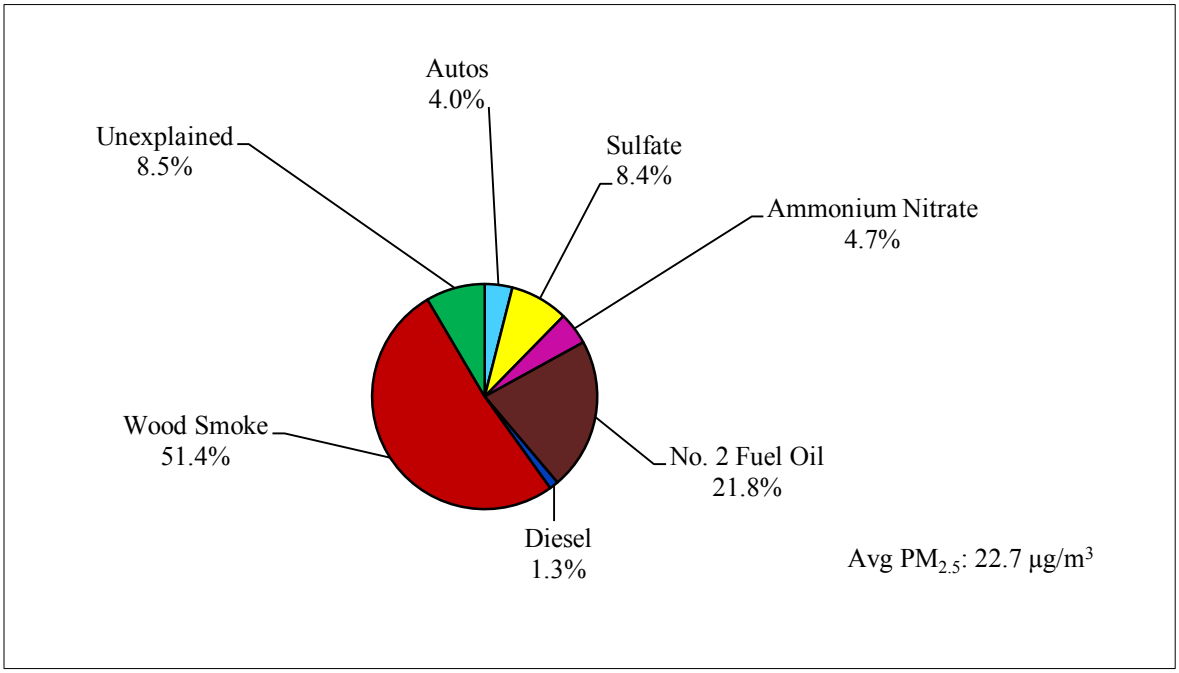

Table 32: Comparison of CMB Results - EPA and OMNI Source Profiles. RAMS, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	12/20/11-2/27/12	12/20/11-2/27/12
n:	16	15
$PM_{2.5}$ Mass (µg/m^3):	22.1	22.7
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	2.9 (13.2 %)	1.9 (8.4 %)
Ammonium Nitrate:	1.4 (6.4 %)	1.0 (4.7 %)
Diesel:	1.2 (5.7 %)	0.3 (1.3 %)
Automobiles:	0.9 (4.0 %)	0.9 (4.0 %)
Wood Smoke:	14.9 (69.0 %)	11.5 (51.4 %)
No. 2 Fuel Oil:	Not Identified	4.9 (21.8 %)
Unexplained:	0.4 (1.8 %)	1.9 (8.5 %)

Figure 49: Winter 2011/2012, NCORE.
CMB Results with EPA Source Profiles, November 2, 2011 – March 31, 2012.

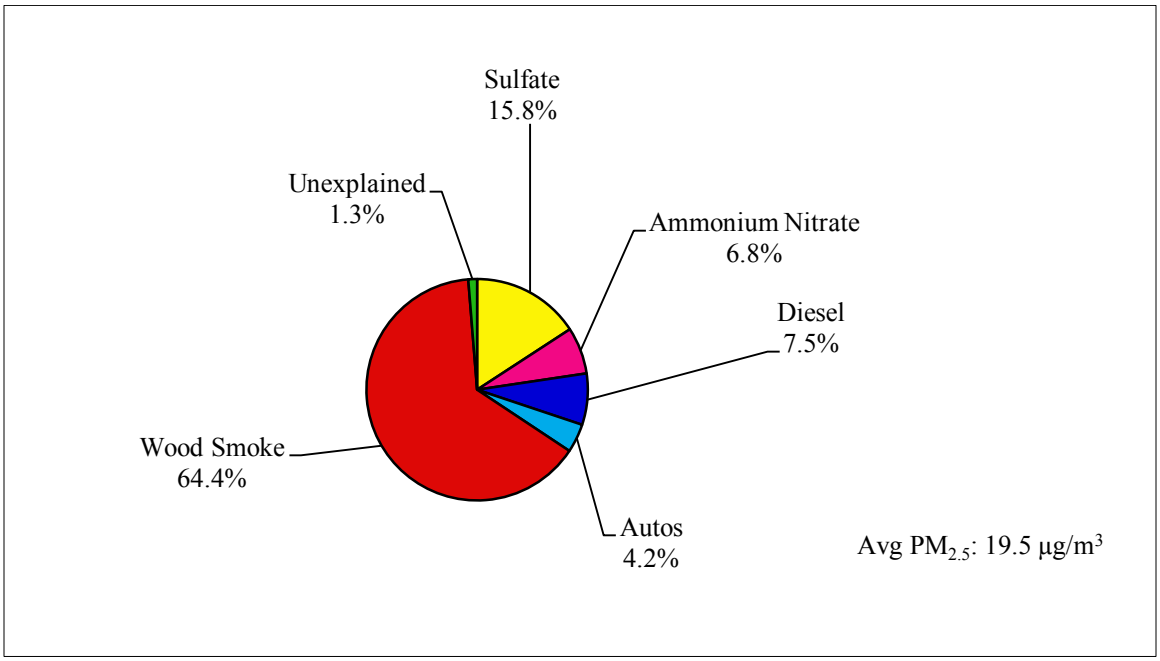

Figure 50: Winter 2011/2012, NCORE.
CMB Results with OMNI Source Profiles, November 2, 2011 – March 31, 2012.

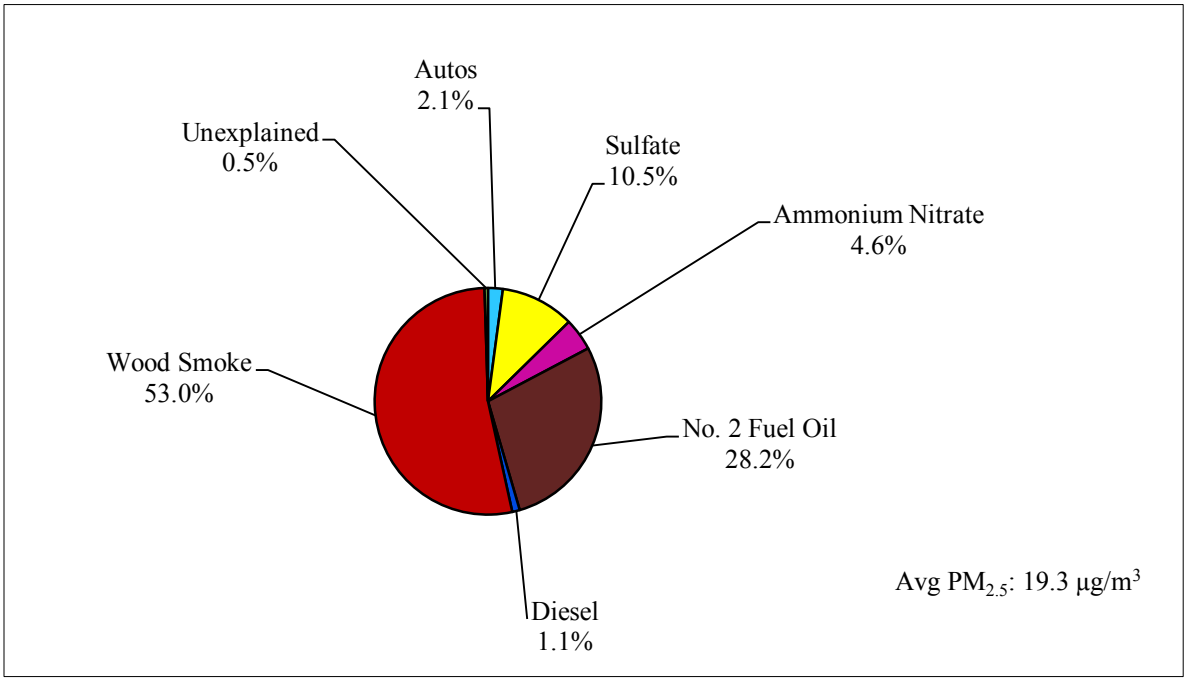

Table 33: Comparison of CMB Results - EPA and OMNI Source Profiles. NCORE, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	11/2/11-3/31/12	11/2/11-3/31/12
n:	44	42
$PM_{2.5}$ Mass ($\mu g/m^3$):	19.5	19.3
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.0 (15.8 %)	2.0 (10.5 %)
Ammonium Nitrate:	1.3 (6.8 %)	0.9 (4.6 %)
Diesel:	1.4 (7.5 %)	0.2 (1.1 %)
Automobiles:	0.8 (4.2 %)	0.4 (2.1 %)
Wood Smoke:	12.4 (64.4 %)	10.1 (53.0 %)
No. 2 Fuel Oil:	Not Identified	5.4 (28.2 %)
Unexplained:	0.2 (1.3 %)	0.1 (0.5 %)

Figure 51: Winter 2011/2012, NPF3.
CMB Results with EPA Source Profiles, March 1, 2011 – March 31, 2012.

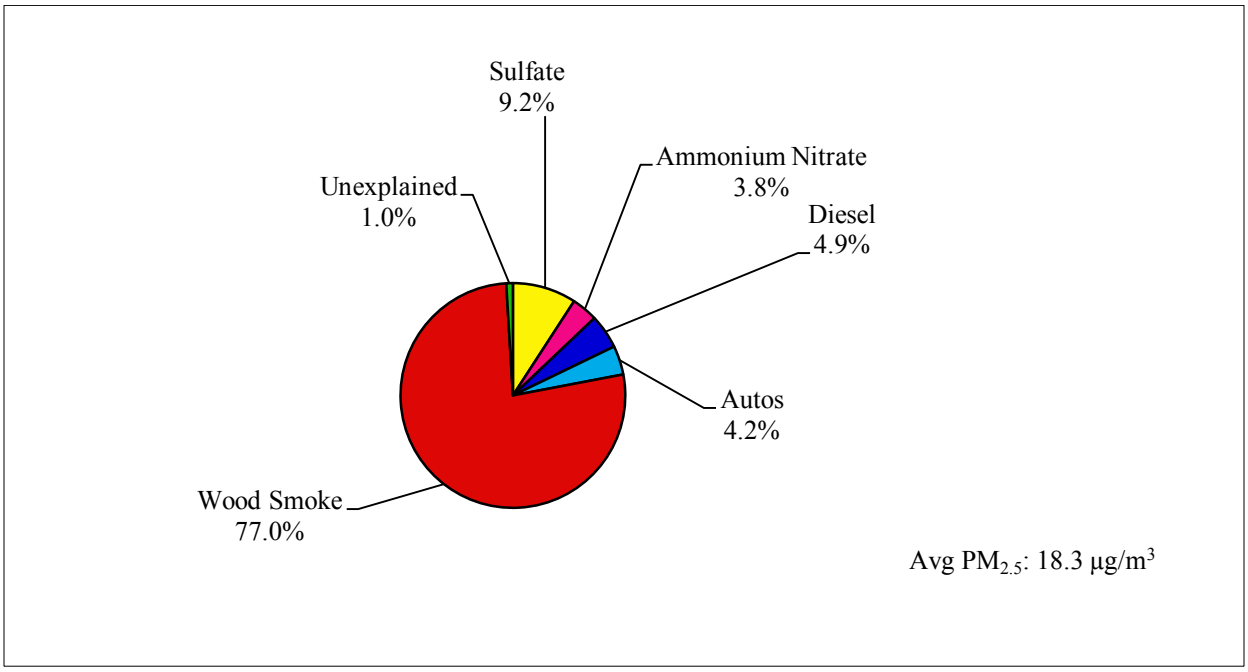

Figure 52: Winter 2011/2012, NPF3.
CMB Results with OMNI Source Profiles, March 1, 2011 – March 31, 2012.

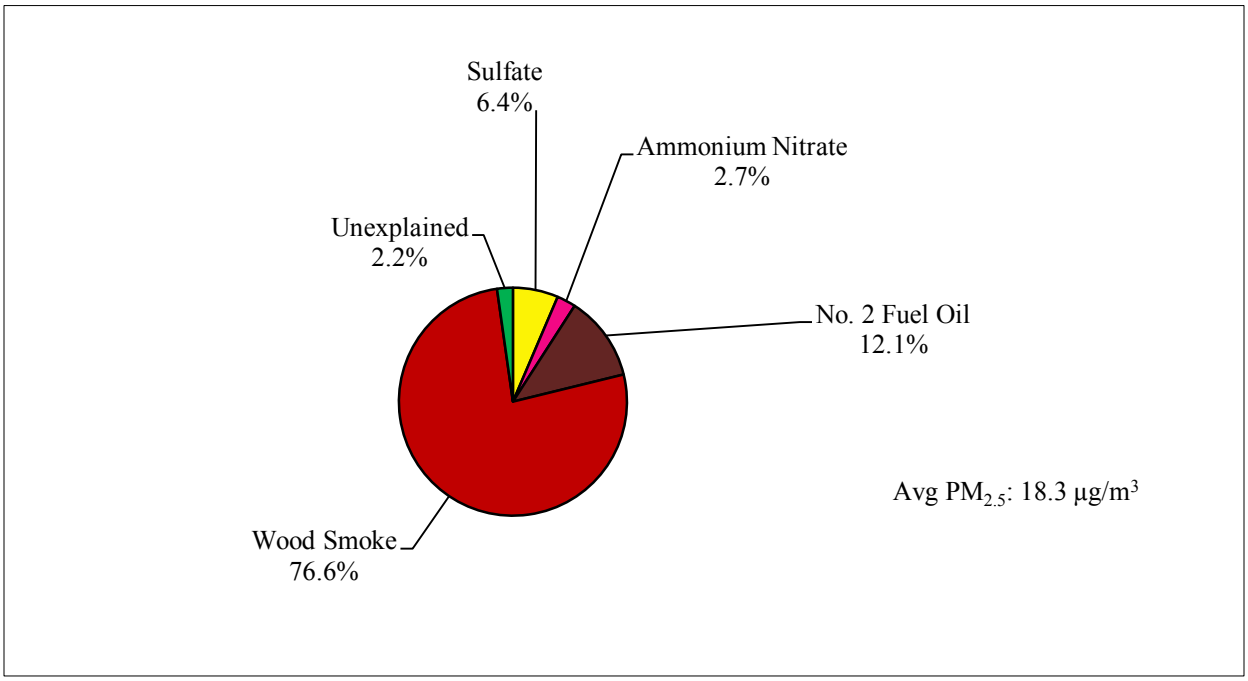

Table 34: Comparison of CMB Results - EPA and OMNI Source Profiles. NPF3, Winter 2011/2012.

Season:	Winter 2011/2012 (EPA)	Winter 2011/2012 (OMNI)
Dates:	3/1/12-3/31/12	3/1/12-3/31/12
n:	7	7
$PM_{2.5}$ Mass (µg/m^3):	18.3	18.3
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	1.7 (9.2 %)	1.2 (6.4 %)
Ammonium Nitrate:	0.7 (3.8 %)	0.5 (2.7 %)
Diesel:	0.9 (4.9 %)	Not Identified
Automobiles:	0.8 (4.2 %)	Not Identified
Wood Smoke:	14.2 (77.0 %)	14.1 (76.6 %)
No. 2 Fuel Oil:	Not Identified	2.2 (12.1 %)
Unexplained:	0.2 (1.0 %)	0.4 (2.2 %)

Figure 53: Summer 2012, State Building.
CMB Results with EPA Source Profiles, June 2, 2012 – August 31, 2012.

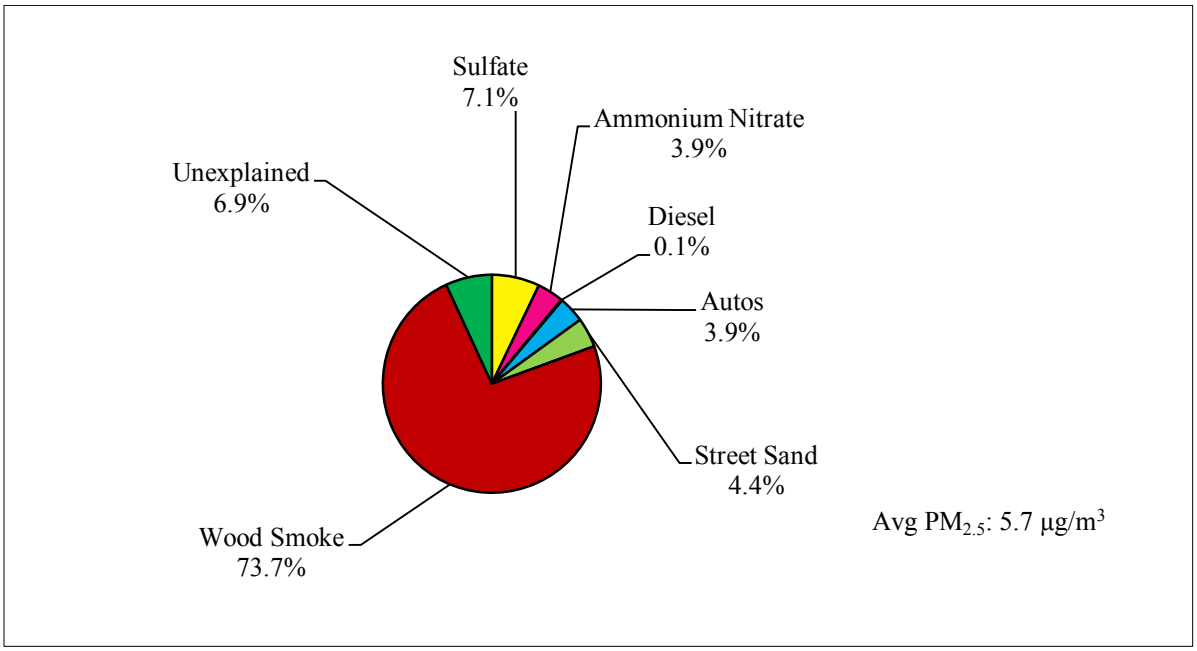

Figure 54: Summer 2012, State Building.
CMB Results with OMNI Source Profiles, June 2, 2012 – August 31, 2012.

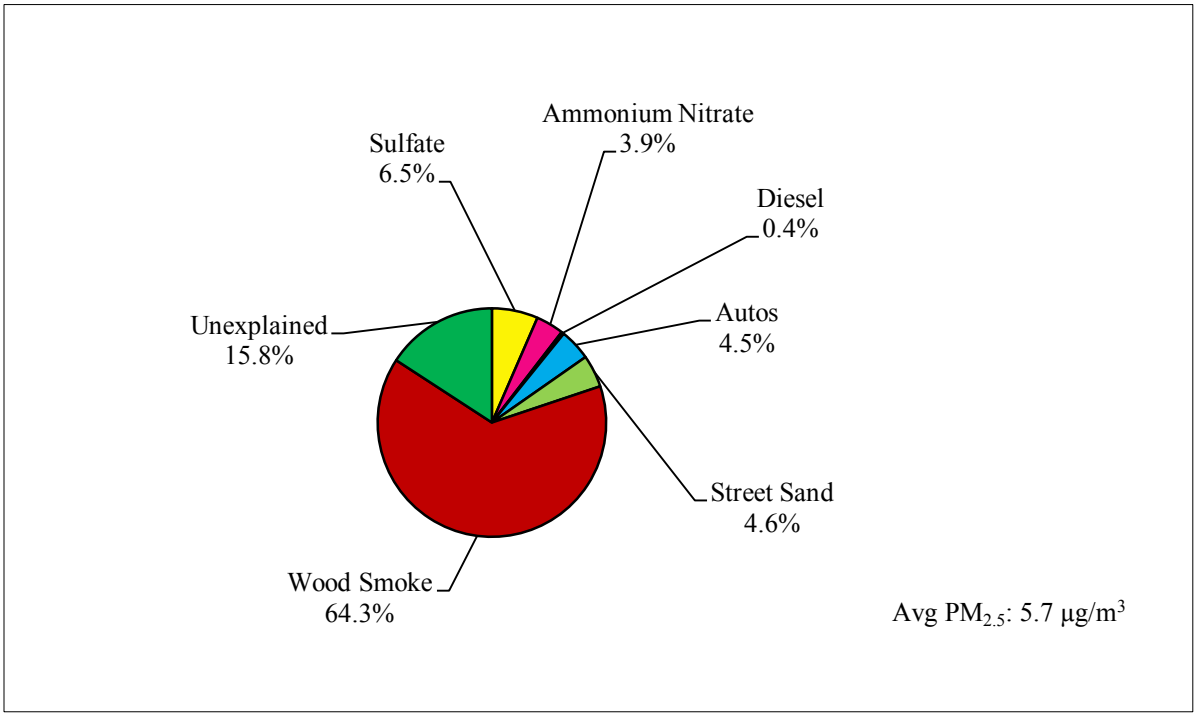

Table 35: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Summer 2012.

Season:	Summer 2012 (EPA)	Summer 2012 (OMNI)
Dates:	6/2/12-8/31/12	6/2/12-8/31/12
n:	20	20
$PM_{2.5}$ Mass ($\mu g/m^3$):	5.7	5.7
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	0.4 (7.1 %)	0.4 (6.5 %)
Ammonium Nitrate:	0.2 (3.9 %)	0.2 (3.9 %)
Diesel:	0.01 (0.1 %)	0.02 (0.4 %)
Automobiles:	0.2 (3.9 %)	0.3 (4.5 %)
Wood Smoke:	4.2 (73.7 %)	3.6 (64.3 %)
No. 2 Fuel Oil:	Not Identified	Not Identified
Street Sand:	0.3 (4.4 %)	0.3 (4.6 %)
Unexplained:	0.3 (6.9 %)	0.9 (15.8 %)

Figure 55: Summer 2012, NCORE.
CMB Results with EPA Source Profiles, June 14, 2012 – August 31, 2012.

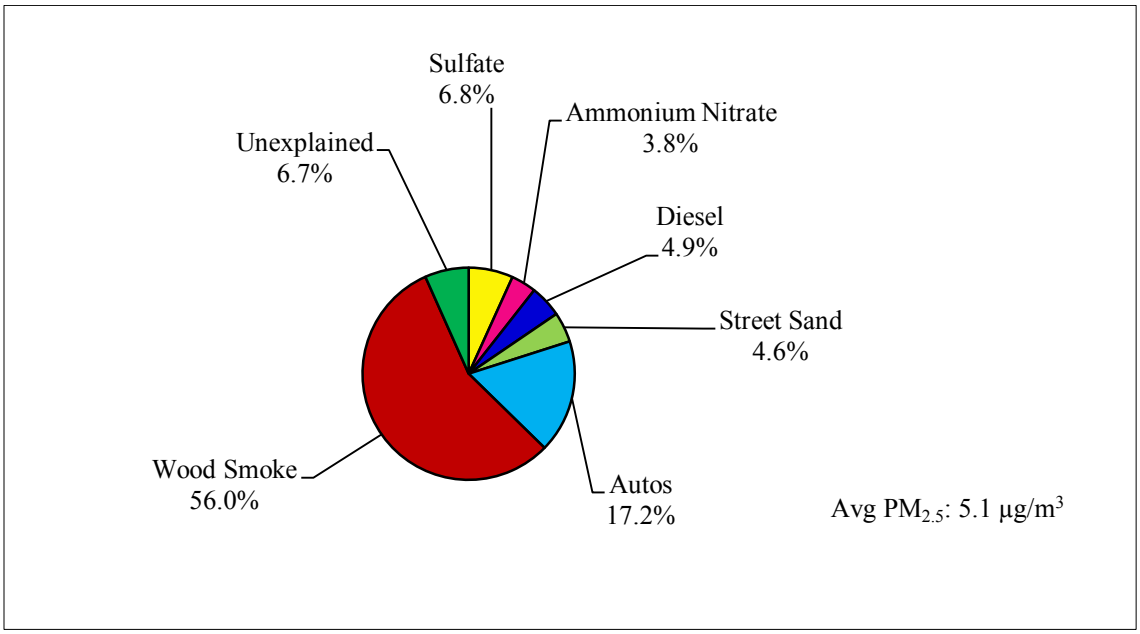

Figure 56: Summer 2012, NCORE.
CMB Results with OMNI Source Profiles, June 14, 2012 – August 31, 2012.

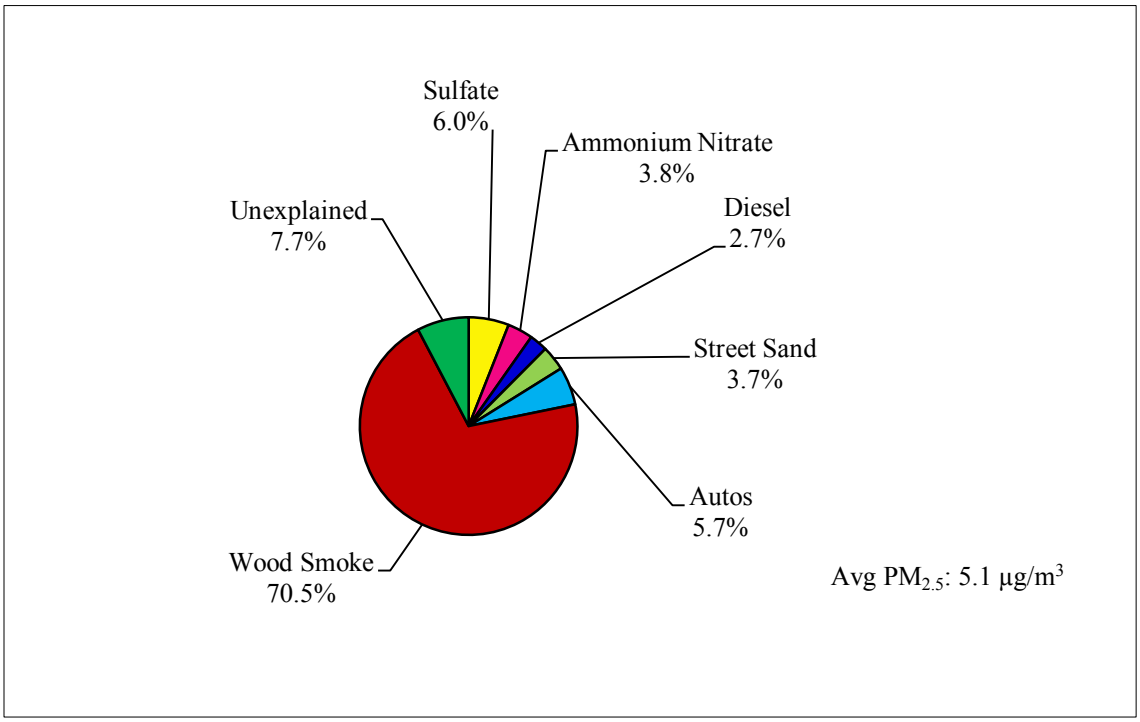

Table 36: Comparison of CMB Results - EPA and OMNI Source Profiles. NCORE, Summer 2012.

Season:	Summer 2012 (EPA)	Summer 2012 (OMNI)
Dates:	6/14/12-8/31/12	6/14/12-8/31/12
n:	17	17
$PM_{2.5}$ Mass ($\mu g/m^3$):	5.1	5.1
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	0.4 (6.8 %)	0.4 (6.0 %)
Ammonium Nitrate:	0.2 (3.8 %)	0.2 (3.8 %)
Diesel:	0.3 (4.9 %)	0.2 (2.7 %)
Automobiles:	1.0 (17.2 %)	0.3 (5.7 %)
Wood Smoke:	3.3 (56.0 %)	4.2 (70.5 %)
No. 2 Fuel Oil:	Not Identified	Not Identified
Street Sand:	0.3 (4.6 %)	0.2 (3.7 %)
Unexplained:	0.4 (6.7 %)	0.5 (7.7 %)

Figure 57: Winter 2012/2013, State Building.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

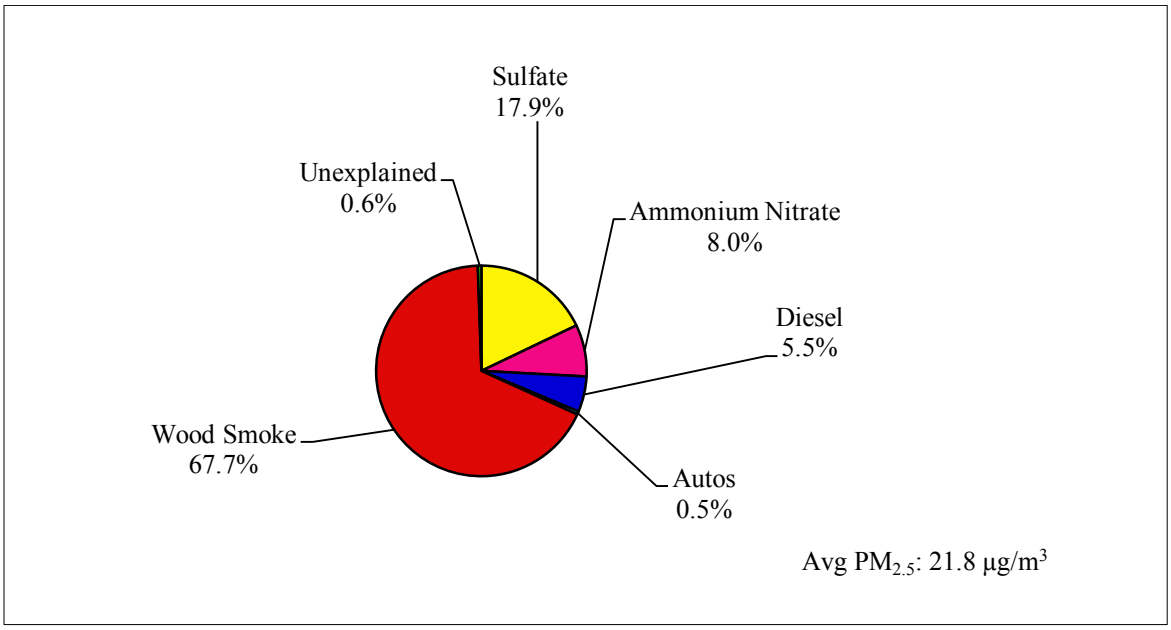

Figure 58: Winter 2012/2013, State Building.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

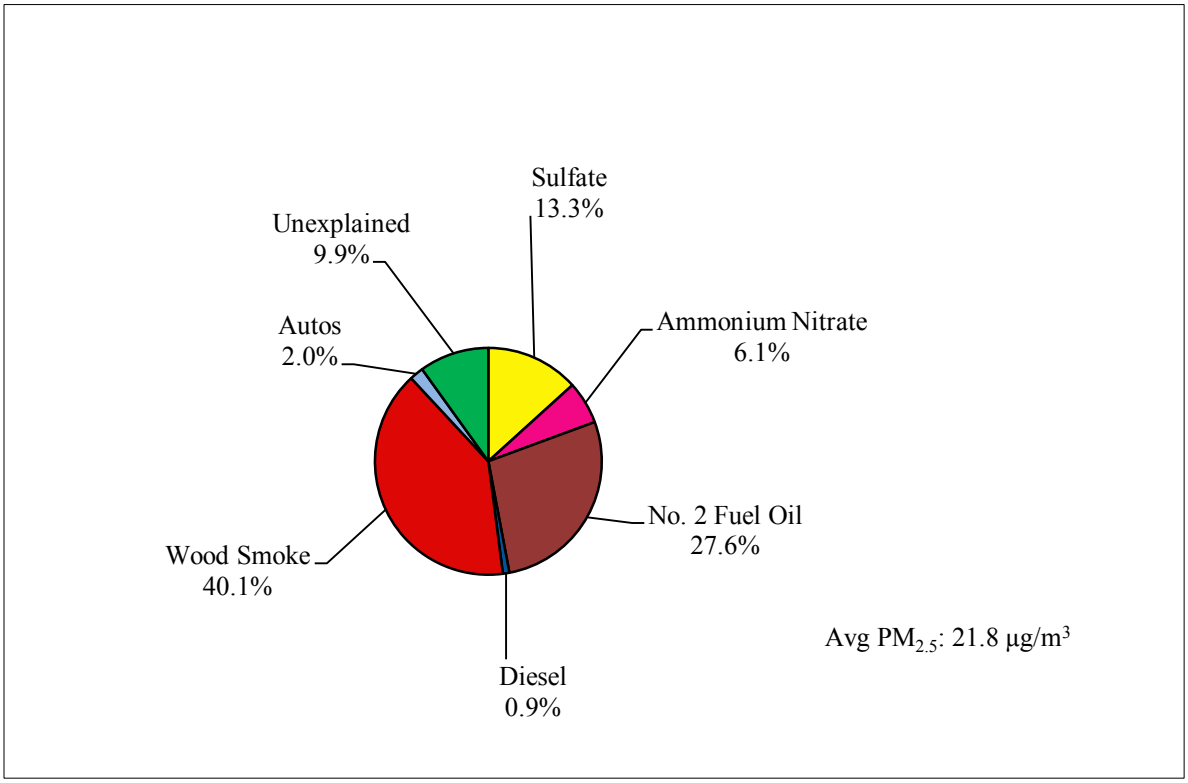

Table 37: Comparison of CMB Results - EPA and OMNI Source Profiles. State Building, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	29	29
$PM_{2.5}$ Mass ($\mu g/m^3$):	21.8	21.8
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.9 (17.9 %)	2.9 (13.3 %)
Ammonium Nitrate:	1.7 (8.0 %)	1.3 (6.1 %)
Diesel:	1.2 (5.5 %)	0.2 (0.9 %)
Automobiles:	0.1 (0.5 %)	0.4 (2.0 %)
Wood Smoke:	14.7 (67.7 %)	8.7 (40.1 %)
No. 2 Fuel Oil:	Not Identified	6.0 (27.6 %)
Unexplained:	0.1 (0.6 %)	2.1 (9.9 %)

Figure 59: Winter 2012/2013, NPE.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

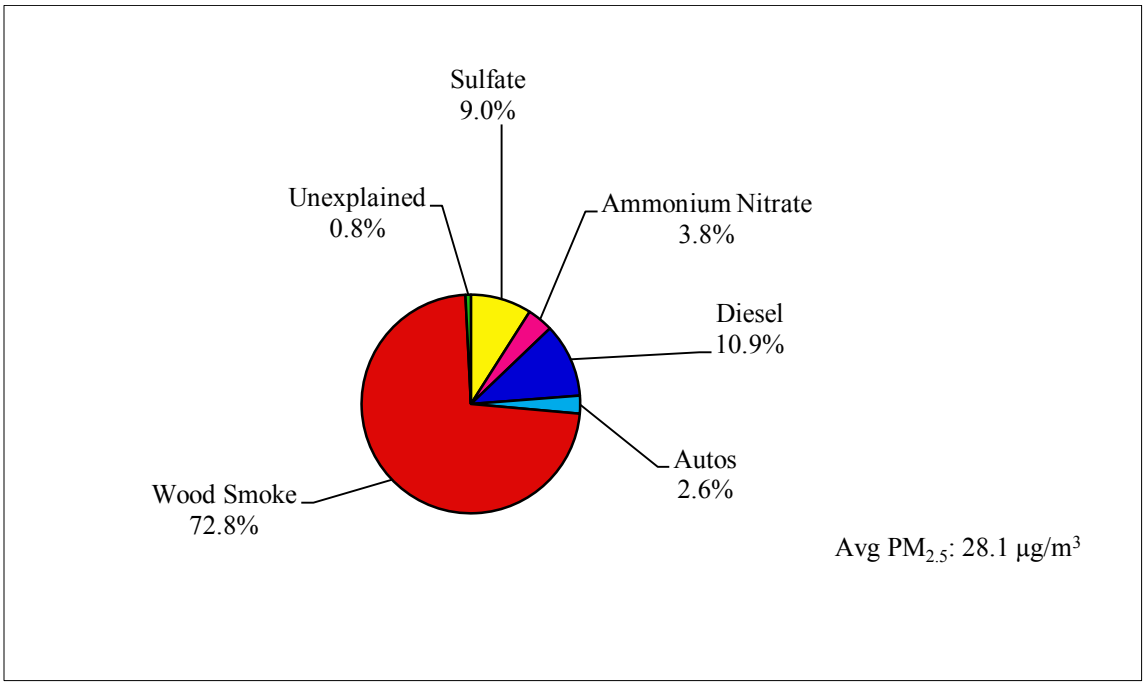

Figure 60: Winter 2012/2013, NPE.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

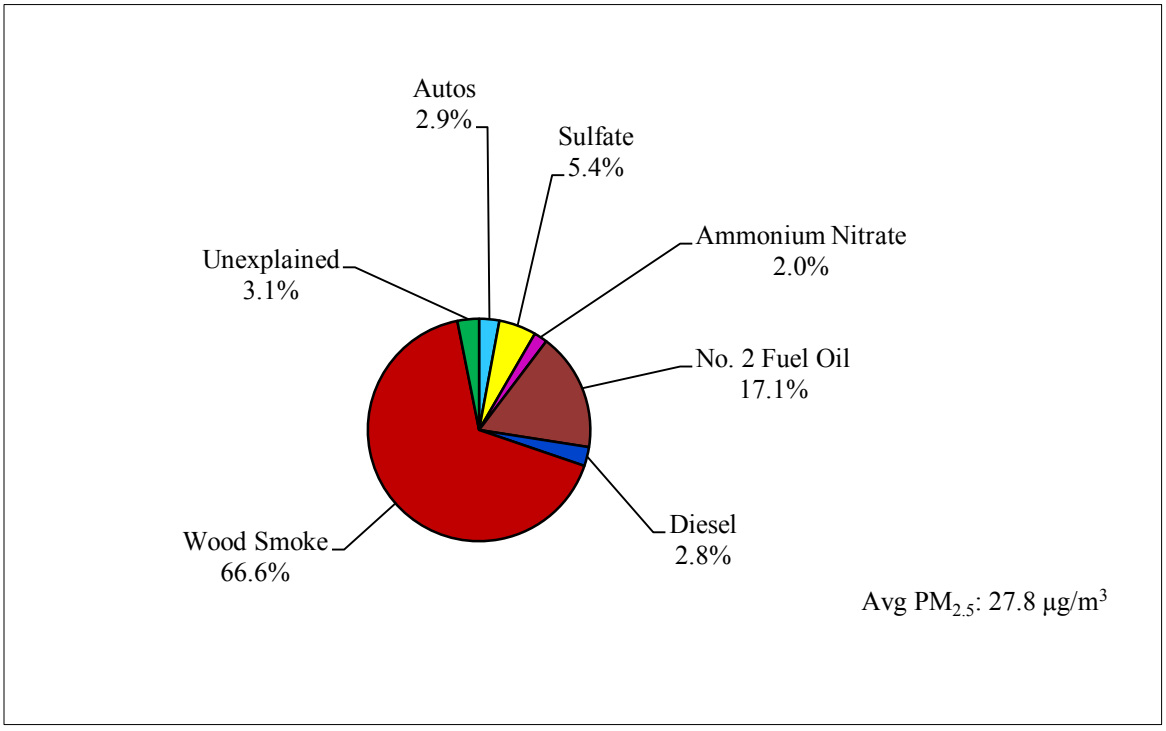

Table 38: Comparison of CMB Results - EPA and OMNI Source Profiles. NPE, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	41	40
$PM_{2.5}$ Mass (µg/m^3):	28.1	27.8
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	2.5 (9.0 %)	1.5 (5.4 %)
Ammonium Nitrate:	1.1 (3.8 %)	0.6 (2.0 %)
Diesel:	3.0 (10.9 %)	0.8 (2.8 %)
Automobiles:	0.7 (2.6 %)	0.8 (2.9 %)
Wood Smoke:	20.3 (72.8 %)	18.8 (66.6 %)
No. 2 Fuel Oil:	Not Identified	4.9 (17.1 %)
Unexplained:	0.2 (0.8 %)	0.9 (3.1 %)

Figure 61: Winter 2012/2013, NCORE.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

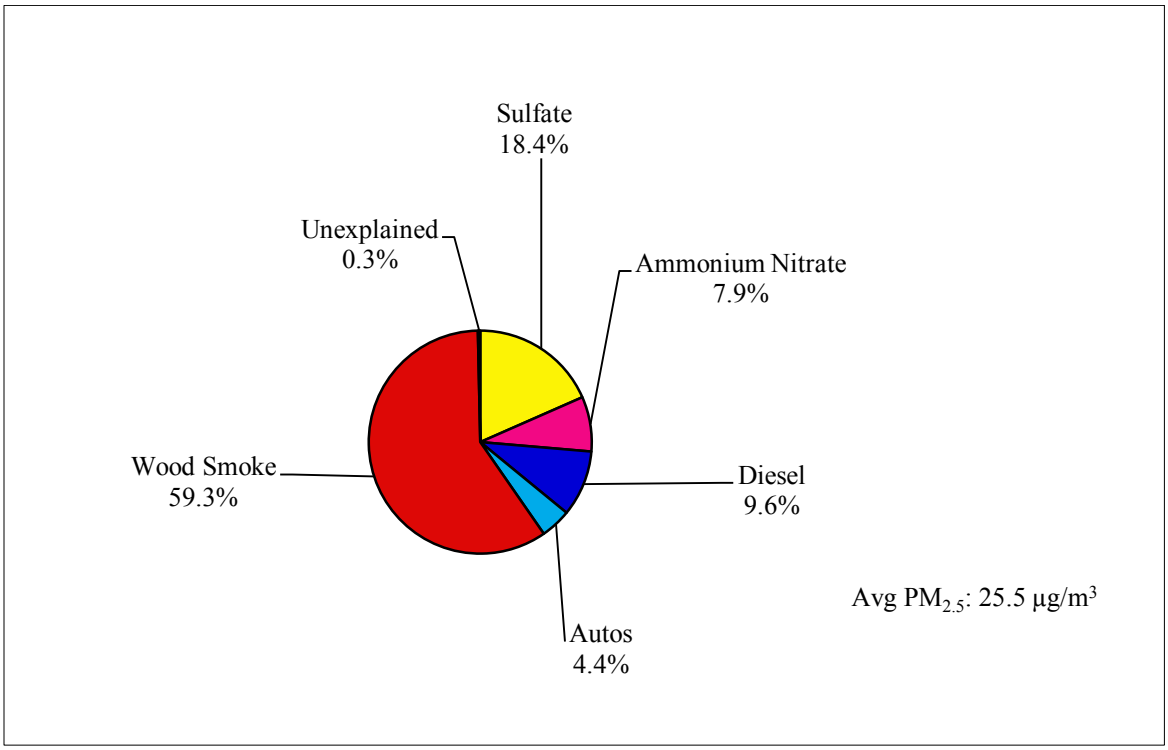

Figure 62: Winter 2012/2013, NCORE.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

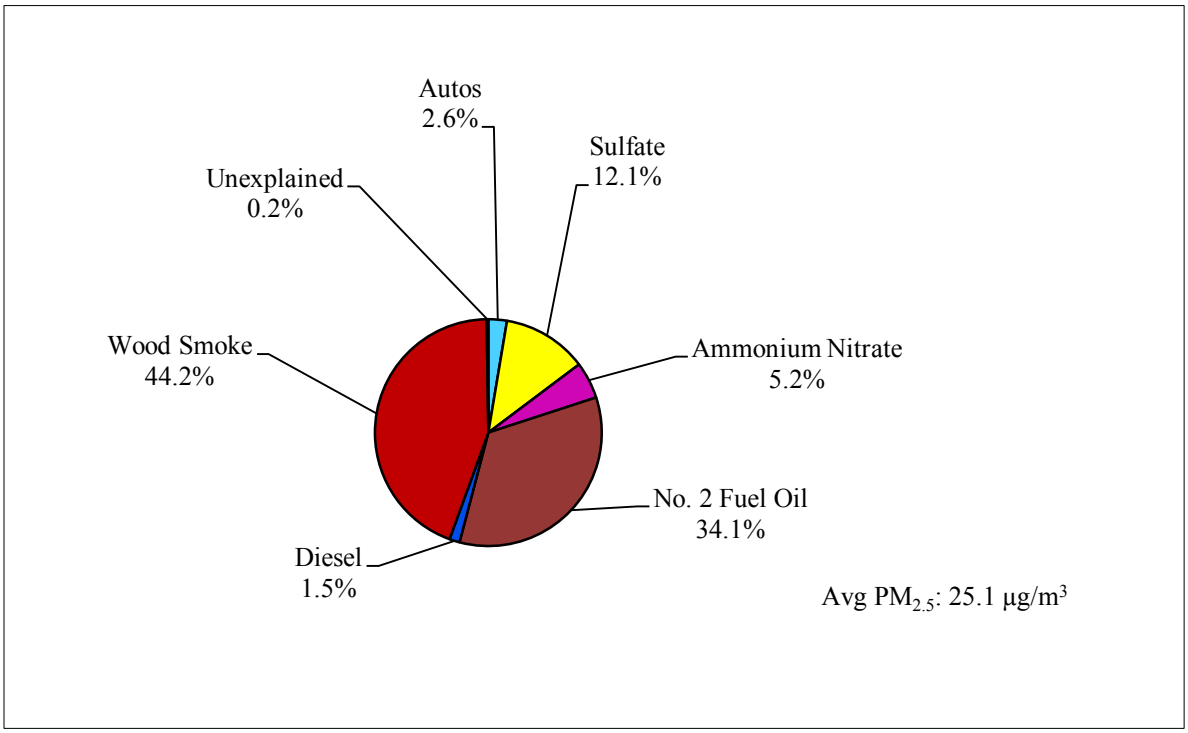

Table 39: Comparison of CMB Results - EPA and OMNI Source Profiles. NCORE, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	38	39
$PM_{2.5}$ Mass (µg/m^3):	25.5	25.1
CMB Source Estimates (µg/m^3 and %)		
Sulfate:	4.7 (18.4 %)	3.0 (12.1 %)
Ammonium Nitrate:	2.0 (7.9 %)	1.3 (5.2 %)
Diesel:	2.4 (9.6 %)	0.4 (1.5 %)
Automobiles:	1.1 (4.4 %)	0.7 (2.6 %)
Wood Smoke:	15.1 (59.3 %)	11.0 (44.2 %)
No. 2 Fuel Oil:	Not Identified	8.5 (34.1 %)
Unexplained:	0.1 (0.3 %)	0.1 (0.2 %)

Figure 63: Winter 2012/2013, NPF3.
CMB Results with EPA Source Profiles, November 2, 2012 – March 29, 2013.

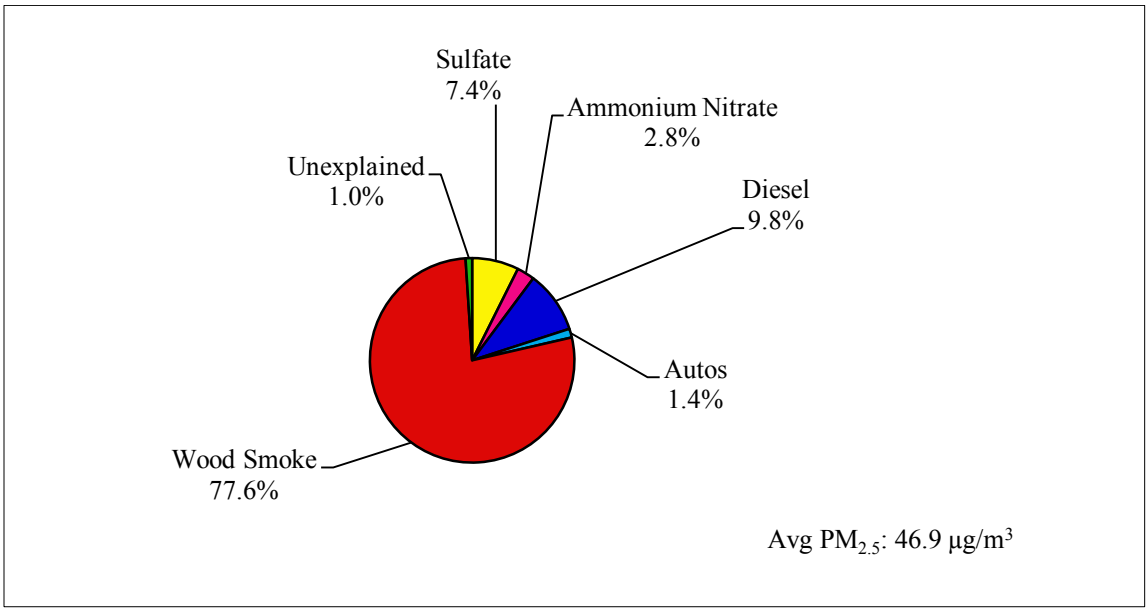

Figure 64: Winter 2012/2013, NPF3.
CMB Results with OMNI Source Profiles, November 2, 2012 – March 29, 2013.

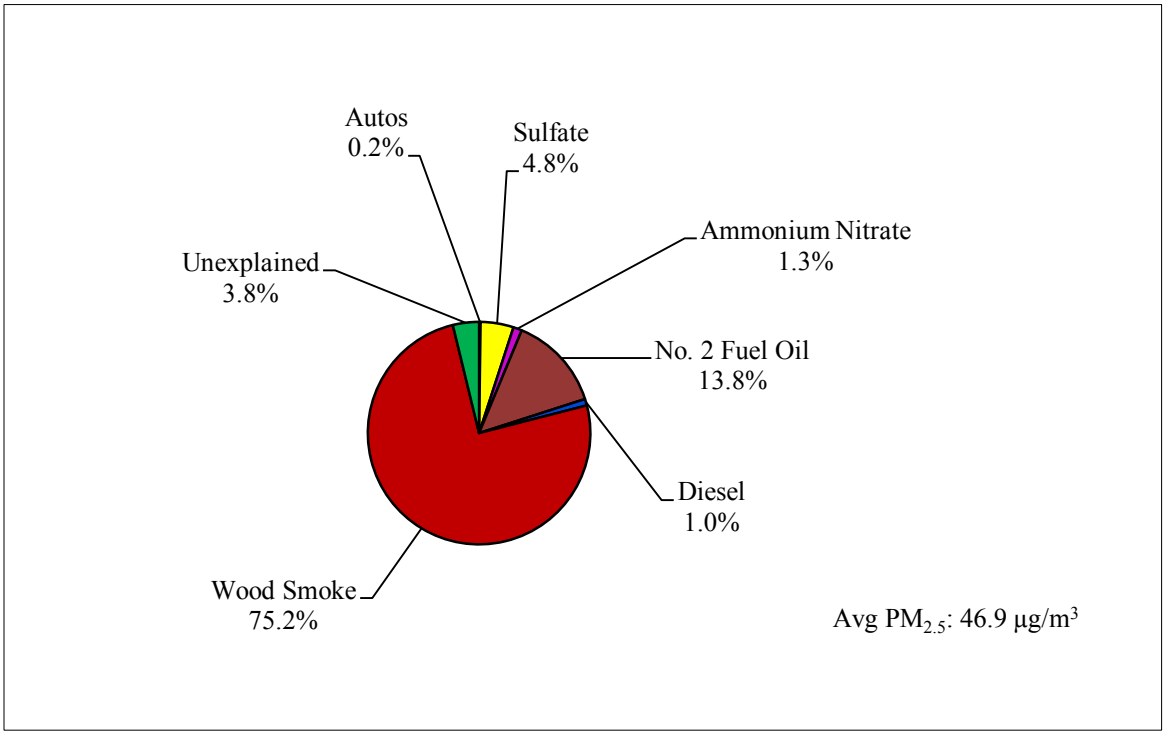

Table 40: Comparison of CMB Results - EPA and OMNI Source Profiles. NPF3, Winter 2012/2013.

Season:	Winter 2012/2013 (EPA)	Winter 2012/2013 (OMNI)
Dates:	11/2/12-3/29/13	11/2/12-3/29/13
n:	42	42
$PM_{2.5}$ Mass ($\mu g/m^3$):	46.9	46.9
CMB Source Estimates ($\mu g/m^3$ and %)		
Sulfate:	3.4 (7.4 %)	2.2 (4.8 %)
Ammonium Nitrate:	1.3 (2.8 %)	0.6 (1.3 %)
Diesel:	4.5 (9.8 %)	0.4 (1.0 %)
Automobiles:	0.6 (1.4 %)	0.1 (0.2 %)
Wood Smoke:	35.9 (77.6 %)	34.7 (75.2 %)
No. 2 Fuel Oil:	Not Identified	6.4 (13.8 %)
Unexplained:	0.5 (1.0 %)	1.8 (3.8 %)

8.0. Discussion - CMB Modeling

The Tables in **Appendix C** present the $PM_{2.5}$ sources identified by the CMB model (including source contribution estimates and standard errors) for each sample day throughout the program using both EPA and OMNI profiles. The standard error is a single standard deviation. When a standard error value is multiplied by two or three times, the result may be taken as a measure of the upper and lower limit of an individual source"s contribution. There is about a 66% probability that the true source contribution is within one standard error and about a 95% probability that the true contribution is within two standard errors of the source contribution estimate. Below is a more complete discussion of the individual source types identified by the CMB modeling.

8.1. Wood Smoke

The wood smoke source identified by the CMB model during the winter months should be viewed as a general source predominantly composed of wood stove emissions. In addition to residential wood stoves, other biomass combustion emission sources could have contributed to the wood smoke results in Fairbanks, including smoke from outdoor boilers, residential open burning of biomass waste, and small industrial sources. A source profile (Profile 56 in **Table 1**) developed in Missoula, Montana in the late 1980s served as a good statistically fitting wood smoke profile when using the non-OMNI profiles for each of the winters/sites when conducting the Fairbanks CMB analyses. It should also be noted that many other residential wood combustion source profiles from the EPA SPECIATE database gave good statistical fits throughout the computer modeling process for each of the sites, including the following wood smoke profiles listed in **Table 1**: 61, 62, 65, and 66. When compared to profiles of other sources, these wood smoke profiles typically had higher levels of elemental potassium, potassium ion, and OC. Generally, both elemental potassium and the potassium ion gave good fits when modeling, with the elemental form usually providing the better statistical fit.

When focusing on the OMNI profiles in the CMB model, FBK107 (EPA Wood Stove, spruce, low) gave the best statistical fit. However, other OMNI profiles for wood smoke combustion were statistically significant as well, and were used in the CMB modeling: FBK101 (EPA OWHH, Birch, Low), FBK102 (Conventional Wood Stove, Birch, Low), and FBK100 (EPA Wood Stove, Birch, Low). Given that all of these wood smoke profiles (both EPA and OMNI) provided strong statistical fits (i.e. gave the best results), this supports that wood smoke (likely from residential wood combustion) is a major source of $PM_{2.5}$ in the Fairbanks airshed throughout the winter months. It should also be noted that wood smoke was determined to be the largest source of $PM_{2.5}$ at both the State Building and NCORE sites (56-72%) during the summer of 2012, likely due to residential outdoor biomass waste burning and influences from regional wildland forest fire events.

8.2. Secondary Pollutants

"Pure secondary" aerosols such as ammonium nitrate and sulfate are actually formed through gas-to-particle transformations in the atmosphere, and are represented by their chemical form in the model. As noted earlier, one assumption of the CMB model is that compositions of source emissions are constant over the period of ambient and source sampling, and that chemical species do not react with each other. CMB is well suited for apportioning sources of primary aerosols (those emitted directly as particles). However, it is difficult to attribute secondary aerosols formed through gas-to-particle transformation in the atmosphere to specific sources. Using the secondary sulfate and the ammonium nitrate profiles allows us to account for the secondary aerosol contributions to $PM_{2.5}$ mass.

Sulfate is a large source contributor to ambient $PM_{2.5}$, representative of particles directly emitted during combustion and secondary particles formed in the atmosphere. Sulfate is a function of the sulfur content of the fuels burned in the Fairbanks community. Recent regulations have all but eliminated sulfur from

gasoline and diesel fuel in Alaska. Therefore, the fuels contributing sulfur (and sulfate) to the Fairbanks airshed likely include distillate fuel oil used in space heating and coal combustion. Ammonium nitrate (NH_4NO_3) is a secondary pollutant that was also identified frequently by the CMB model at each of the sites. Identified source contributions were very similar when using the EPA and OMNI profiles, with slightly less sulfate and ammonium nitrate identified when using the OMNI profiles. It should be noted that even though ammonium sulfate was not detected by the CMB model as a $PM_{2.5}$ source (secondary) when both sulfate and ammonium nitrate were used as fitting species, it is likely a significant contributor to the measured $PM_{2.5}$ levels. When using the secondary sulfate source profile in the model, sulfur was used as the fitting species in each model run to apportion sulfate contributions.

Ammonia (NH_3) and oxides of nitrogen (NOx) are the precursors for ammonium nitrate particles, with just under half all NOx emissions in the United States estimated to come from the transportation sector (Seinfeld and Pandis, 1998; Dreher and Harley, 1998). $PM_{2.5}$ has been found to correlate with gaseous emissions of NOx from vehicles, with heavy duty vehicles contributing significantly greater amounts of NOx and particulate matter on a per vehicle basis than light duty vehicles (Gillies et al., 2001). Between 40 and 45% of all NOx emissions in the United States are estimated to come from transportation, with about half of this coming from light-duty gasoline trucks and cars and approximately one-quarter from heavy-duty gasoline and diesel vehicles (Seinfeld and Pandis, 1998; Dreher and Harley, 1998). Other sources of NOx in Fairbanks might include industry, natural gas furnaces, and residential wood combustion. In other parts of the lower 48, ammonia emissions to the atmosphere can arise from many sources including the decay of livestock waste, use of chemical fertilizers, emissions from sewage waste treatment plants, and biological processes in soils (Fraser and Cass, 1998). In Fairbanks, combustion processes such as motor vehicles likely are a significant source of ammonia.

8.3. Mobile Sources

Profiles for this source group typically had higher levels of EC when compared to the wood smoke profiles. When using the EPA profiles, the CMB model determined that vehicles were a measurable source of $PM_{2.5}$ at each of the sites throughout the winter months. Automobile exhaust (gasoline-powered) contributions to $PM_{2.5}$ were detected at the sites up to 7%. Diesel exhaust was also measured at each of the sites, contributing up to 11%. When using the OMNI wood smoke and fuel oil profiles in the CMB model, mobile sources were identified as being smaller contributors to the ambient $PM_{2.5}$. For the majority of the CMB runs using OMNI profiles, both automobiles and diesel exhaust were found to typically contribute less than 6% to the overall ambient $PM_{2.5}$.

8.4. Other Sources

When conducting CMB modeling using the EPA source profiles, there were other sources identified by the CMB model as contributors to the ambient $PM_{2.5}$. However, these sources were not identified as statistically significant contributors (i.e. evaluated based on CMB model statistical criteria). These sources include the following: street sand, distillate oil combustion, natural gas combustion, residual oil combustion, and sub bituminous coal combustion. Street sand was detected by the CMB model from filters collected during the early spring, but never in concentrations that were considered statistically significant (TSTAT >2). In addition, the source profile for natural gas combustion was identified on several occasions, but never in amounts that were statistically significant.

Regarding the combustion sources such as distillate oil, residual oil, and sub bituminous coal, primary $PM_{2.5}$ emissions were not identified as being statistically significant from these individual sources. To investigate this further, the CMB model was run with both the EPA SPECIATE distillate oil and coal profile in the model, and in the absence of the secondary sulfate profile (using both the sulfur and sulfate fitting species). In both instances, the model provided very poor statistical fits. Using the secondary

sulfate profile (as a potential surrogate for these sources) provided excellent statistical fits on nearly every sample run.

When using the OMNI profiles in the CMB modeling, the No. 2 fuel oil profile (FBK103) was consistently identified as a source of $PM_{2.5}$ at each of the sites during all winters. The other OMNI profiles for coal, including FBK104 (Coal Stove, Wet Stoker Coal, Low), FBK105 (Coal HH, Wet Stoker Coal, Single), and 108 (Coal Stove Dry Lump Coal, low) were not identified in the CMB model. Similarly, the OMNI profile for waste oil (FBK106, WasteOil Brnr, Waste Oil, Single) was not identified by the CMB model to be a source of $PM_{2.5}$ at any of the other sites (for each year).

9.0. Quality Assurance / Quality Control Results

9.1. Sampling Program QA/QC

For the Fairbanks sampling program, Alaska DEC and FNSB personnel maintained and audited the $PM_{2.5}$ samplers at each of the sites. There were several days throughout the program where samples were not collected (and therefore CMB analyses were not conducted) due to sampler malfunctions. These sample days are identified in **Appendix B**. In addition, CMB source apportionment was not conducted on additional sample days during the winter months due to low $PM_{2.5}$ mass. If the measured $PM_{2.5}$ concentration is less than 7 $\mu g/m^3$, the percent mass may be outside of the acceptable ranges because the uncertainty in the mass measurement is approximately 1 to 2 $\mu g/m^3$. These days are also identified in **Appendix B**. These low mass days were primarily excluded for the winter days when the ambient $PM_{2.5}$ concentrations were much higher. During the summer 2012 sample days, CMB modeling runs were conducted on all days (regardless of ambient $PM_{2.5}$ mass concentrations) in an effort to identify the sources during these low-mass days.

9.2. Analytical Program QA/QC

RTI (speciation analyses) and Desert Research Institute were responsible for QA/QC activities within their respective laboratories. To monitor for artifact contamination in the field and in the laboratory, Teflon, nylon, and quartz filter field blanks were collected throughout the sampling programs. The results of the $PM_{2.5}$ speciation field blank analyses show that the Teflon and quartz filters collected throughout the program did not measure significant artifacts for mass, elements, or Total Carbon. Several ions measured from the nylon filter blanks had levels above the MDLs, including sulfate, nitrate, ammonium, and sodium. Care was taken when utilizing these ions as fitting species to avoid inaccurate source apportionment to the fine PM.

9.3. CMB Program QA/QC

EPA‟s validation protocol (Watson et al., 2004) was followed throughout this CMB modeling program to ensure accurate results. For each model run, several different combinations of source profiles were evaluated, and the number of chemical species always exceeded the number of source types. The source contribution estimates and the statistics and diagnostic information were reviewed for each model run to determine the validity of the initial model results. The analysis was repeated by eliminating source profiles that gave negative source contribution estimates or standard errors that exceeded the source contribution estimates. When conducting the CMB model runs, only sources with TSTATs >2 were reported. If a TSTAT was <2, then the source was not considered a significant contributor for that sample day.

The majority of the CMB fitting parameters used to evaluate the validity of source contribution estimates were well within EPA target ranges. **Tables 41** (CMB with EPA profiles) **and 42** (CMB with OMNI profiles) present the program average key „goodness-of-fit‟ statistics commonly evaluated for CMB models, the results for the Fairbanks CMB runs, and the EPA target ranges for each parameter.

The values for R^2, Chi^2, DF, and % mass explained for each CMB model run were generally well within the EPA target ranges. For the most part, the R/U ratios were all less than 2, and source collinearity (similarities between identified sources) was not a problem throughout this modeling application.

Table 41: Average Goodness-Of-Fit Parameter - EPA Profiles.

	R^2	Chi^2	Degrees of Freedom	% Mass Explained	TSTAT
EPA Target	**0.8 - 1.00**	**0.00 – 4.0**	**> 5**	**80 – 120%**	**>2**
State Building, 2005/2006	0.94	0.35	27	99.7	>2
State Building, 2006/2007	0.95	0.27	26	98.4	>2
State Building, 2007/2008	0.96	0.21	32	100.1	>2
2008/2009	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.95	0.25	28	99.3	>2
North Pole	0.98	0.11	37	99.2	>2
RAMS	0.96	0.19	37	100.5	>2
Peger Road	0.98	0.09	36	99.5	>2
2009/2010	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.96	0.34	37	99.4	>2
North Pole	0.97	0.17	36	99.0	>2
RAMS	0.98	0.07	36	99.9	>2
Peger Road	0.98	0.13	36	99.2	>2
2010/2011	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.98	0.19	38	100.0	>2
North Pole	0.97	0.15	35	99.4	>2
Peger Road	0.98	0.10	36	99.7	>2
2011/2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.96	0.25	37	99.0	>2
North Pole	0.97	0.18	38	98.1	>2
RAMS	0.98	0.13	37	98.3	>2
NCORE	0.97	0.18	37	98.8	>2
NPF3	0.98	0.10	36	101.0	>2
Summer 2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.98	0.39	38	93.1	>2
NCORE	0.89	0.56	38	107.7	>2

2012/2013	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	0.96	0.27	38	99.4	>2
NPE	0.97	0.17	35	99.2	>2
NCORE	0.96	0.22	36	99.7	>2
NPF3	0.97	0.21	35	99.0	>2

Note: ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011.

Table 42: Average Goodness-Of-Fit Parameters - OMNI Profiles.

	R^2	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
EPA Target	**0.8 - 1.00**	**0.00 – 4.0**	**> 5**	**80 – 120%**	**>2**
State Building, 2005/2006	0.98	0.17	22	98.1	>2
State Building, 2006/2007	0.99	0.15	19	100.1	>2
State Building, 2007/2008	0.99	0.13	25	100.1	>2
2008/2009	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
*State Building	0.96	0.40	19	96.1	>2
**State Building	0.99	0.18	20	99.5	>2
North Pole	0.97	0.36	29	96.8	>2
RAMS	0.97	0.27	28	100.9	>2
*Peger Road	0.98	0.19	28	98.4	>2
**Peger Road	0.99	0.12	28	99.7	>2
2009/2010	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.13	28	96.1	>2
North Pole	0.97	0.67	27	100.6	>2
RAMS	0.98	0.49	28	100.1	>2
Peger Road	0.99	0.15	28	98.9	>2
2010/2011	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.10	29	92.6	>2
North Pole	0.97	0.65	28	99.4	>2
Peger Road	0.99	0.21	28	101.4	>2
2011/2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.16	27	93.3	>2
North Pole	0.97	0.37	29	95.5	>2
RAMS	0.98	0.17	29	91.6	>2

NCORE	0.99	0.13	29	99.5	>2
NPF3	0.98	0.24	29	97.8	>2
Summer 2012	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.38	30	84.4	>2
NCORE	0.90	0.62	35	108.3	>2
2012/2013	**R^2**	**Chi^2**	**Degrees of Freedom**	**% Mass Explained**	**TSTAT**
State Building	1.0	0.11	29	90.2	>2
NPE	0.98	0.35	27	96.8	>2
NCORE	0.99	0.10	27	100.2	>2
NPF3	0.98	0.39	27	96.3	>2

Note: ND: not detected by the CMB model. Sampling was not conducted at the RAMS site during the winter of 2010/2011. *Averages originally presented in the Final Report submitted to ADEC (dated July 23, 2012). **Averages for those sample days in which updated CMB modeling (with OMNI profiles as well as auto/diesel profiles) was conducted.

It is believed that all of the $PM_{2.5}$ emission sources (or at least the source types) were identified during this CMB modeling program. Missing source types are identified by a low percent mass explained (<80%) and/or a RATIO R/U <<-2.0 for chemical species which are in the missing source. In addition, a "high negative" residual for one or more species and a large Chi^2 can be indicative of missing sources. The good agreement between the calculated source contributions and the measured ambient concentrations indicate that all of the major source types are included in the calculations, and that ambient and source profile measurements are reasonably accurate. CMB is intended to complement rather than replace other data analysis and modeling methods. For this project, the sensitivity of the CMB model's results to the errors in the source profiles were evaluated by using different chemical abundances of a source type and by changing the fitting species used in the source type. The results of the sensitivity tests for each run showed that the CMB calculations carried out in this study were acceptable. Although there were a few cases where the fitting parameters were outside the EPA target range, none of these cases were considered invalid, and all of the fits were quite strong. Therefore, the source contribution estimates identified in this project can be considered valid.

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Appendix A. OMNI Source Profiles

	FBK100	FBK101	FBK102	FBK103	FBK104	FBK105	FBK106	FBK107	FBK108
	OMNI_5_WS	OMNI_9_OW	OMNI_15_W	OMNI_17_O	OMNI_23_C	OMNI_29_C	OMNI_18_W	OMNI_6_WS	OMNI_38_C
	FINE	FINE	FINE	FINE	FINE	FINE	FINE	FINE	FINE
Magnesium	0.000128902	0.000179751	6.69E-05	0	0	0.003971831	0.002287551	0	0
aluminum	8.06E-05	0	0	0.003478261	6.87E-05	0.007352113	0.000792668	0.0002849	0.000276817
silicon	0	0	0	0.001014493	0	0.01343662	0.000284456	0	0.000138408
phosphorus	0	0	0	0	0	0.00056338	0.083318258	0	0
sulfur	0.004114804	0.005342382	0.006735058	0.060289855	0.002835052	0.131014085	0.022316115	0.002393162	0.004273356
chlorine	0.002239678	0.003898264	0.002305977	0.00115942	0.000790378	0.000676056	0.213184956	0.002336182	0.00032872
potassium	0.018032226	0.026834189	0.021868867	0.001449275	0.000137457	0.03828169	0.044103785	0.008091168	0.000207612
calcium	0.00023565	0.000577158	7.14E-05	0.002753623	0.000120275	0.030732394	0.021598429	0.001168091	0.000155709
titanium	0	1.22E-06	0	0	3.44E-05	0.000450704	0	0	0
vanadium	8.06E-06	0	0	0	1.72E-05	0.000140845	0	0	0
chromium	2.62E-05	1.10E-05	0	0	0	0.000591549	0	2.85E-05	1.73E-05
manganese	3.42E-05	2.57E-05	2.68E-05	0	0	0.000507042	0	5.70E-05	0
iron	0.00012286	3.79E-05	1.78E-06	0.001449275	0.000171821	0.022	0.005232088	8.55E-05	8.65E-05
nickel	1.01E-05	1.22E-06	4.46E-06	0.000144928	1.72E-05	0.000422535	0	0.00017094	0
copper	1.61E-05	1.71E-05	0	0.000144928	0	0.003267606	0	0	0
zinc	0.003689829	0.003307655	0.003407672	2.90E-05	0.000120275	0.006704225	0.160667698	0.000826211	0.000155709
gallium	-99	-99	-99	-99	-99	-99	-99	-99	-99
germanium	-99	-99	-99	-99	-99	-99	-99	-99	-99
arsenic	0	0	4.46E-06	0	1.72E-05	0.000647887	0	0	0
selenium	0	0	0	0	0	0.000112676	0	0	0
bromine	1.81E-05	1.96E-05	2.23E-05	0	0	0.000309859	0.000217805	2.85E-05	3.46E-05
rubidium	3.02E-05	2.93E-05	2.23E-05	0	0	0.000253521	0	0	0
strontium	6.04E-06	6.11E-06	0	0	0	0.000309859	0	2.85E-05	0
yttrium	-99	-99	-99	-99	-99	-99	-99	-99	-99
zirconium	0	2.45E-06	0	0	8.59E-05	0.000422535	0	0	0
molybdenum	-99	-99	-99	-99	-99	-99	-99	-99	-99
palladium	-99	-99	-99	-99	-99	-99	-99	-99	-99

silver	-99	-99	-99	-99	-99	-99	-99	-99	-99
cadmium	0	0	0	0	0.000120275	0	0	0	0
indium	4.63E-05	0	0	0.002173913	0.000137457	0	0	0	0
tin	1.61E-05	0	0	0	0	0	0	0	0
antimony	0	0	0	0	0	0.000535211	0	0	0
barium	2.42E-05	9.78E-06	0	0	0	0.001183099	0	2.85E-05	0
lanthanum	-99	-99	-99	-99	-99	-99	-99	-99	-99
mercury	-99	-99	-99	-99	-99	-99	-99	-99	-99
lead	0.000002	0.000013	0.000009	0	0.000017	0.005352	0.001751	0.000028	0.000104
TC	-99	-99	-99	-99	-99	-99	-99	-99	-99
OC	2.115074382	0.481054286	0.687010777	0.518922229	0.649153878	0.08233928	0.009590277	0.777831363	0.666746667
EC	0.190318936	0.043286298	0.158647144	0.079583588	0.045820433	0.018000626	0.002592587	0.100578934	0.02072309
Sulfate	0.007468278	0.009576914	0.006347012	0.422985507	0.005257732	0.39943662	0.054980957	0.004928775	0.007958478
Nitrate	0.000968781	0.001228907	0.000677966	0.017057971	0.006185567	0.005380282	0.066209236	0.004245014	0.001608997
Ammonium	0.000104733	0.000132062	0	0.149318841	0.00128866	0.026225352	0	0.00017094	0.001799308
Chloride	-99	-99	-99	-99	-99	-99	-99	-99	-99
Potassium	0.015750252	0.022772071	0.016271186	0	0	0.036591549	0.040194001	0.007407407	0.000363322
Fluoride	-99	-99	-99	-99	-99	-99	-99	-99	-99
Sodium	0.000219537	0.000242113	0.000133809	0.003942029	0.000395189	0.041971831	0.06715782	0.000598291	0.000276817
Calcium	-99	-99	-99	-99	-99	-99	-99	-99	-99
Magnesium	-99	-99	-99	-99	-99	-99	-99	-99	-99
Sodium	0.0018429	0.001823184	0.00206512	0	0	0.046957746	0	0	0
Cobalt	6.04E-06	4.89E-06	4.46E-06	0	1.72E-05	0.000140845	0	1.14E-05	0

Appendix B. Days On Which CMB Modeling Was Not Conducted.

State Building Winter 2005/2006	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	State Building Winter 2006/2007	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	State Building Winter 2007/2008	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/9/05	*	11/1/06	5.7**	11/14/07	*
11/18/05	4.3**	11/13/06	*	12/2/07	5.4**
11/24/05	*	11/16/06	*	12/14/07	4.0**
12/3/05	*	12/16/06	*	12/20/07	*
12/13/05	*	12/19/06	*	2/24/08	*
12/27/05	*	12/25/06	*	3/1/08	5.2**
1/2/05	*	1/9/07	*	3/7/08	5.8**
1/5/06	*	1/18/07	*	3/10/08	*
1/11/06	*	2/2/07	*	3/16/08	*
1/17/06	*	2/20/07	*	3/25/08	5.7**
2/4/06	*	3/1/07	*	3/31/08	5.7**
2/13/06	5.9**	3/7/07	*		
2/19/06	4.4**				
3/24/06	4.8**				

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.

State Building Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
12/8/08	*	2/18/09	*
1/16/09	2.3**	3/5/09	4.7**
2/6/09	*	3/17/09	3.8**
3/5/09	5.7**	3/20/09	4.6**
3/20/09	*	3/23/09	4.5**
3/26/09	*	3/26/09	3.0**

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
Note that 12/29/08 did not give a good fit for OMNI rerun for State Building site.

RAMS Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	Peger Road Winter 2008/2009	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
3/17/09	4.4**	2/6/09	*
3/20/09	*		
3/23/09	4.7**		
3/26/09	3.8**		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
Note that 2/21/09 had a low mass (6.2 $\mu g/m^3$) and poor fit for OMNI RAMS CMB.

State Building Winter 2009/2010 EPA Runs	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	State Building Winter 2009/2010 OMNI Runs	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2009/2010	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/9/09	*	11/9/09	*	11/19/09	*
11/12/09	4.0**	11/12/09	4.0**	1/14/10	4.5**
11/18/09	4.9**	11/18/09	4.9**	1/29/10	3.3**
12/3/09	*	12/3/09	*	2/1/10	*
12/6/09	0.4**	12/6/09	0.4**	2/19/10	*
12/15/09	4.1**	12/9/09	*	2/25/10	3.8**
12/18/09	3.6**	12/12/09	*	3/6/10	*
2/25/10	3.1**	12/15/09	4.1**	3/9/10	4.1**
3/6/10	3.8**	12/18/09	3.6**		
3/9/10	3.4**	12/30/2009	*		
		1/2/2010	*		
		1/5/2010	*		
		1/20/10	*		
		1/26/10	*		
		2/4/10	*		
		2/25/10	3.1**		
		3/6/10	3.8**		
		3/9/10	3.4**		
		3/12/10	*		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.

RAMS Winter 2009/2010	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	Peger Road Winter 2009/2010	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/17/09	*	11/18/09	*
11/18/09	*	11/19/09	*
11/19/09	*	2/25/10	*
1/26/10	*	3/9/10	3.6**
1/29/10	*		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
Note that 2/22/10 gave a poor fit for OMNI Peger Road CMB.

State Building Winter 2010/2011	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2010/2011
11/4/10	3.3**	None.
11/25/10	*	
12/16/10	*	
12/19/10	*	
12/22/10	*	
12/25/10	*	
12/28/10	*	
12/31/10	*	
1/3/11	*	
1/6/11	*	
1/9/11	*	
1/12/11	*	
1/15/11	*	
1/18/11	*	
1/21/11	*	
1/24/11	*	
1/27/11	*	
1/30/11	*	
2/2/11	*	

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.

Peger Road Winter 2010/2011
None.

State Building Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	North Pole Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/5/11	*	11/2/11	***
11/20/11	*	12/5/11	2.5**
12/5/11	*	12/23/11	5.6**
12/11/11	*	1/22/12	***
12/23/11	6.3**	1/25/12	***
1/1/12	*	2/3/12	***
1/22/12	*	2/9/12	***
2/3/12	6.5**	2/12/12	***
2/24/12	5.0**	2/24/12	3.5**
2/27/12	4.3**	2/27/12	2.1**
3/4/12	*	3/1/12	5.1**
3/7/12	*	3/7/12	4.1**
3/31/12	5.4**	3/13/12	4.3**
		3/16/12	5.5**

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.
Note that 1/28/12 and 1/31/12 (State Building) provided poor statistical fits for the OMNI CMB.
Note that 1/28/12 and 1/31/12 (State Building) provided poor statistical fits for the OMNI CMB, while the 1/28/12 date also provided a poor fit for the 1/28/12 North Pole CMB run.

RAMS Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NCORE Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NPF3 Winter 2011/2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
1/13/12	***	12/5/11	5.1**	3/1/12	4.5**
1/19/12	3.1**	12/23/11	5.6**	3/13/12	5.1**
1/22/12	0.8**	1/22/12	3.3**	3/28/12	5.2**
1/25/12	0.7**	2/24/12	5.7**	3/31/12	4.8**
1/28/12	2.8**	2/27/12	3.6**		
2/3/12	5.6**	3/25/12	***		
2/24/12	5.9**	3/31/12	5.6**		
2/27/12	3.5**				

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.
Note that 1/16/12 (RAMS) and 2/6/12 and 2/9/12 (NCORE) provided poor statistical fits for the OMNI CMB.

State Building Summer 2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NCORE Sumer 2012	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
6/2/12	***	6/26/12	***
7/2/12	***	7/5/12	***
7/8/12	***	7/8/12	***
7/14/12	***	7/11/12	***
7/17/12	*	7/14/12	***
7/23/12	***	7/17/12	***
8/4/12	***	7/23/12	***
8/16/12	***	8/25/12	*
8/22/12	***	8/28/12	***
8/28/12	***	8/31/12	***
8/31/12	***		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.

State Building Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NPE Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/17/12	3.3**	11/23/12	5.3**
11/29/12	*	12/11/12	5.5**
12/5/12	***	1/19/13	5.8**
12/11/12	5.8**	1/22/13	4.4**
12/17/12	***	2/21/13	3.4**
12/20/12	***	3/5/13	*
12/23/12	***	3/14/13	2.6**
12/26/12	***	3/20/13	1.0**
1/10/13	***	3/23/13	4.6**
1/13/13	***		
1/16/13	*		
1/25/13	***		
1/31/13	***		
2/9/13	*		
2/15/13	***		
2/21/13	3.8**		
3/5/13	*		
3/14/13	*		
3/20/13	*		
3/23/13	*		
3/26/13	4.8**		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.
Note that 12/26/12 (NPE) provided poor statistical fits for the OMNI CMB.

NCORE Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)	NPF3 Winter 2012/2013	Low $PM_{2.5}$ Mass ($\mu g/m^3$)
11/2/12	*	11/2/12	*
11/5/12	*	12/5/12	*
11/17/12	3.7**	12/8/12	*
11/26/12	*	1/22/13	4.2**
12/11/12	5.8**	2/15/13	*
1/7/13	*	2/18/13	*
1/31/13	***	2/21/13	4.0**
2/15/13	3.8**	3/14/13	3.2**
2/21/13	*		
3/14/13	3.5**		
3/23/13	5.0**		
3/26/13	5.0**		

*No, incomplete, or invalid CMB data set.
**Mass was too small to conduct a CMB analysis.
***Could not get a good statistical fit for CMB analysis.

Appendix C. CMB Results for Each Sample Day.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors ($\mu g/m^3$) – EPA Profiles. State Building – Winter 2005/2006.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/05	17.8	3.9	0.4	1.6	0.5	0.0	0.0	0.0	0.0	13.2	1.4
11/6/05	12.8	2.2	0.2	1.7	0.3	0.0	0.0	0.0	0.0	8.9	1.1
11/9/05	*	*	*	*	*	*	*	*	*	*	*
11/12/05	20.8	3.8	0.6	1.3	0.5	6.6	2.5	0.0	0.0	7.7	2.2
11/15/05	30.5	6.4	1.0	2.6	0.8	0.0	0.0	5.0	1.9	15.4	2.5
11/18/05	4.3**	**	**	**	**	**	**	**	**	**	**
11/21/05	9.1	1.9	0.2	1.3	0.3	0.0	0.0	0.0	0.0	6.3	0.8
11/24/05	*	*	*	*	*	*	*	*	*	*	*
11/27/05	26.4	4.8	0.8	2.1	0.7	0.0	0.0	3.2	1.2	14.5	2.2
11/30/05	21.7	3.7	0.6	4.6	0.7	0.0	0.0	2.4	1.0	9.9	1.6
12/3/05	*	*	*	*	*	*	*	*	*	*	*
12/6/05	17.1	2.9	0.3	2.0	0.6	0.0	0.0	3.4	1.0	9.2	1.5
12/9/05	16.1	2.7	0.3	0.0	0.0	0.0	0.0	4.4	1.0	8.4	1.5
12/13/05	*	*	*	*	*	*	*	*	*	*	*
12/15/05	25.1	5.0	0.6	1.9	0.9	0.0	0.0	4.9	1.4	12.9	2.1
12/18/05	25.8	5.2	0.8	2.2	0.8	0.0	0.0	3.6	1.3	13.8	2.2
12/21/05	25.9	4.8	0.5	1.6	0.6	0.0	0.0	6.4	1.6	12.7	2.1
12/24/05	24.4	4.2	0.5	2.2	0.5	0.0	0.0	4.4	1.4	13.2	2.0
12/27/05	*	*	*	*	*	*	*	*	*	*	*
12/30/05	34.2	7.3	0.8	3.0	0.9	0.0	0.0	0.0	0.0	25.2	3.0
1/2/06	*	*	*	*	*	*	*	*	*	*	*
1/5/06	*	*	*	*	*	*	*	*	*	*	*
1/8/06	31.4	6.1	0.7	2.7	0.8	0.0	0.0	0.0	0.0	23.8	2.2
1/11/06	*	*	*	*	*	*	*	*	*	*	*
1/14/06	18.2	3.3	0.4	1.6	0.4	0.0	0.0	0.0	0.0	12.7	1.5
1/17/06	*	*	*	*	*	*	*	*	*	*	*
1/20/06	31.1	6.5	1.0	2.3	0.8	0.0	0.0	0.0	0.0	23.9	3.1
1/23/06	26.5	5.7	0.9	1.7	0.7	9.0	4.0	0.0	0.0	12.0	2.2
1/26/06	42	12.1	1.3	2.9	1.5	0.0	0.0	0.0	0.0	27.1	3.3
1/29/06	30.7	7.5	0.8	3.6	1.0	0.0	0.0	0.0	0.0	20.0	2.4
2/1/06	7.0	1.3	0.1	1.1	0.2	0.0	0.0	0.0	0.0	5.6	0.9
2/4/06	*	*	*	*	*	*	*	*	*	*	*
2/7/06	15.3	2.9	0.5	2.0	0.6	0.0	0.0	3.3	0.9	7.1	1.3
2/10/06	7.4	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	5.8	0.7
2/13/06	5.9**	**	**	**	**	**	**	**	**	**	**
2/16/06	12.9	2.2	0.3	1.6	0.4	0.0	0.0	2.0	0.7	7.5	1.2
2/19/06	4.4**	**	**	**	**	**	**	**	**	**	**
2/22/06	7.1	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	4.4	0.7
2/25/06	15.1	3.9	0.4	1.6	0.5	0.0	0.0	0.0	0.0	9.9	2.8
2/28/06	20.1	3.4	0.4	1.4	0.4	0.0	0.0	0.0	0.0	14.2	1.7
3/3/06	23.2	5.0	0.6	3.9	0.7	0.0	0.0	5.3	1.6	8.9	1.7

3/6/06	15.1	3.6	0.4	1.7	0.5	0.0	0.0	0.0	0.0	9.6	1.2
3/9/06	7.9	2.6	0.3	0.7	0.3	0.0	0.0	0.0	0.0	4.2	0.8
3/12/06	9.4	2.8	0.3	0.7	0.4	0.0	0.0	0.0	0.0	5.5	0.9
3/15/06	8.5	2.7	0.4	1.0	0.3	0.0	0.0	0.0	0.0	4.7	0.7
3/18/06	11.3	2.5	0.4	1.1	0.3	0.0	0.0	0.0	0.0	7.0	1.0
3/21/06	9.4	2.2	0.4	1.3	0.3	0.0	0.0	0.0	0.0	5.8	0.9
3/24/06	4.8**	**	**	**	**	**	**	**	**	**	**
3/27/06	10.6	2.1	0.3	1.4	0.3	0.0	0.0	0.0	0.0	7.1	1.9
3/30/06	13.7	2.8	0.3	1.6	0.4	0.0	0.0	0.0	0.0	9.6	2.6
Average	**18.9**	**4.0**	**0.5**	**1.8**	**0.5**	**0.4**	**0.2**	**1.3**	**0.4**	**11.3**	**1.7**

Notes: *No or incomplete CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. State Building – Winter 2005/2006.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/05	17.8	3.9	0.4	1.5	0.5	0.0	0.0	0.0	0.0	13.8	1.3
11/6/05	12.8	1.2	0.2	1.3	0.2	5.2	1.0	0.0	0.0	5.0	1.1
11/9/05	*	*	*	*	*	*	*	*	*	*	*
11/12/05	20.8	2.2	0.6	0.9	0.3	8.5	1.7	0.0	0.0	7.6	1.7
11/15/05	30.5	3.3	1.0	1.5	0.5	16.6	2.6	0.0	0.0	7.7	2.3
11/18/05	4.3**	**	**	**	**	**	**	**	**	**	**
11/21/05	9.1	1.8	0.2	1.2	0.2	0.0	0.0	0.0	0.0	6.5	0.7
11/24/05	*	*	*	*	*	*	*	*	*	*	*
11/27/05	26.4	2.4	0.7	1.2	0.3	12.9	2.0	0.0	0.0	8.8	1.9
11/30/05	21.7	2.1	0.6	3.9	0.5	8.7	2.0	0.0	0.0	6.4	1.7
12/3/05	*	*	*	*	*	*	*	*	*	*	*
12/6/05	17.1	1.9	0.4	1.5	0.4	5.3	1.9	1.5	0.8	6.8	1.7
12/9/05	16.1	1.5	0.4	0.0	0.0	6.6	2.2	2.9	1.0	5.1	1.9
12/13/05	*	*	*	*	*	*	*	*	*	*	*
12/15/05	25.1	2.8	0.6	1.1	0.4	10.9	2.2	2.5	1.0	7.7	2.1
12/18/05	25.8	2.8	0.8	1.3	0.4	13.3	2.2	0.0	0.0	8.0	2.1
12/21/05	25.9	2.8	0.5	0.8	0.4	11.0	2.2	3.5	1.5	7.1	2.2
12/24/05	24.4	2.4	0.5	1.5	0.4	9.5	1.9	0.0	0.0	10.0	1.8
12/27/05	*	*	*	*	*	*	*	*	*	*	*
12/30/05	34.2	4.3	0.8	2.0	0.6	15.5	3.4	2.7	1.2	5.7	2.8
1/2/06	*	*	*	*	*	*	*	*	*	*	*
1/5/06	*	*	*	*	*	*	*	*	*	*	*
1/8/06	31.4	3.3	0.6	1.6	0.5	15.2	2.7	0.0	0.0	6.8	2.3
1/11/06	*	*	*	*	*	*	*	*	*	*	*
1/14/06	18.2	1.8	0.4	1.0	0.3	8.1	1.5	0.0	0.0	6.6	1.5
1/17/06	*	*	*	*	*	*	*	*	*	*	*
1/20/06	31.1	3.0	1.0	1.1	0.4	18.6	2.5	0.0	0.0	9.1	2.4
1/23/06	26.5	2.4	0.8	1.3	0.4	17.9	2.2	0.0	0.0	3.4	2.0
1/26/06	42	7.9	1.4	1.2	1.1	22.9	5.9	0.0	0.0	9.1	4.5
1/29/06	30.7	4.4	0.8	2.5	0.6	16.6	3.4	0.0	0.0	7.5	2.9
2/1/06	7.0	0.8	0.2	0.9	0.1	2.7	0.6	0.0	0.0	3.9	0.8
2/4/06	*	*	*	*	*	*	*	*	*	*	*
2/7/06	15.3	1.9	0.6	1.5	0.4	6.0	2.2	2.3	0.8	4.0	1.8
2/10/06	7.4	0.8	0.2	0.3	0.1	2.7	0.6	0.0	0.0	4.2	0.8
2/13/06	5.9**	**	**	**	**	**	**	**	**	**	**
2/16/06	12.9	1.5	0.3	1.3	0.2	4.5	1.2	0.0	0.0	6.2	1.2
2/19/06	4.4**	**	**	**	**	**	**	**	**	**	**
2/22/06	7.1	1.0	0.2	0.4	0.1	3.0	0.8	0.0	0.0	2.1	0.8
2/25/06	15.1	2.3	0.4	1.0	0.3	8.4	1.8	0.0	0.0	2.6	1.6
2/28/06	20.1	3.3	0.4	1.4	0.4	0.0	0.0	0.0	0.0	13.8	1.5
3/3/06	23.2	2.9	0.6	3.0	0.5	11.7	2.4	0.0	0.0	5.0	2.1
3/6/06	15.1	3.5	0.4	1.7	0.5	0.0	0.0	0.0	0.0	10.4	1.3
3/9/06	7.9	1.6	0.2	0.4	0.2	5.6	0.7	0.0	0.0	0.0	0.0
3/12/06	9.4	1.6	0.3	0.3	0.2	7.0	0.7	0.0	0.0	0.0	0.0

3/15/06	8.5	1.4	0.4	0.5	0.2	7.1	0.7	0.0	0.0	0.0	0.0
3/18/06	11.3	1.0	0.3	0.5	0.1	8.3	0.7	0.0	0.0	0.0	0.0
3/21/06	9.4	2.2	0.4	1.3	0.3	0.0	0.0	0.0	0.0	6.3	1.0
3/24/06	4.8**	**	**	**	**	**	**	**	**	**	**
3/27/06	10.6	1.3	0.3	1.1	0.2	4.0	1.0	0.0	0.0	3.3	1.0
3/30/06	13.7	1.5	0.3	1.1	0.2	7.1	1.2	0.0	0.0	3.1	1.2
Average	**18.9**	**2.4**	**0.5**	**1.3**	**0.3**	**8.4**	**1.6**	**0.4**	**0.2**	**5.9**	**1.6**

Notes: *No or incomplete CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. State Building – Winter 2006/2007.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/06	5.7**	**	**	**	**	**	**	**	**	**	**
11/4/06	27.9	4.5	0.6	2.3	0.6	0.0	0.0	0.0	0.0	22.4	2.6
11/7/06	13.5	1.8	0.2	1.2	0.2	3.6	1.7	0.0	0.0	6.1	1.5
11/10/06	21.3	3.1	0.4	1.6	0.4	0.0	0.0	3.3	1.2	12.1	1.9
11/13/06	*	*	*	*	*	*	*	*	*	*	*
11/16/06	*	*	*	*	*	*	*	*	*	*	*
11/19/06	25.8	6.2	0.8	1.9	0.8	0.0	0.0	0.0	0.0	16.1	2.0
11/22/06	12.7	1.8	0.2	1.5	0.3	0.0	0.0	1.4	0.6	8.5	1.3
11/25/06	32.1	6.2	0.8	2.0	0.8	0.0	0.0	0.0	0.0	23.0	5.9
11/28/06	25.7	5.2	0.6	2.2	0.8	0.0	0.0	3.5	1.3	13.5	2.1
12/1/06	8.0	1.7	0.2	0.9	0.2	0.0	0.0	0.0	0.0	5.8	0.8
12/4/06	15.5	2.3	0.3	2.5	0.5	0.0	0.0	2.5	0.8	8.3	1.4
12/7/06	35.1	3.9	0.5	1.7	0.5	15.2	3.4	0.0	0.0	10.2	2.0
12/10/06	16.3	2.7	0.3	1.3	0.5	0.0	0.0	2.8	0.9	9.5	1.5
12/13/06	15.1	2.6	0.3	1.3	0.3	4.8	2.0	0.0	0.0	5.4	1.7
12/16/06	*	*	*	*	*	*	*	*	*	*	*
12/19/06	*	*	*	*	*	*	*	*	*	*	*
12/22/06	26.0	6.9	0.9	2.1	1.0	0.0	0.0	3.4	1.6	13.4	2.2
12/25/06	*	*	*	*	*	*	*	*	*	*	*
12/28/06	23.8	3.8	0.5	1.5	0.7	0.0	0.0	3.6	1.1	13.5	2.0
12/31/06	16.9	4.1	0.5	1.4	0.6	0.0	0.0	2.0	0.9	10.7	1.7
1/3/07	11.0	2.1	0.3	1.3	0.3	0.0	0.0	0.0	0.0	7.1	1.0
1/6/07	19.8	3.5	0.4	1.2	0.5	5.8	2.8	0.0	0.0	10.0	1.8
1/9/07	*	*	*	*	*	*	*	*	*	*	*
1/12/07	30.4	5.3	0.7	3.1	0.7	0.0	0.0	5.2	1.7	15.7	2.4
1/15/07	16.3	2.2	0.3	0.9	0.3	0.0	0.0	0.0	0.0	13.1	2.8
1/18/07	*	*	*	*	*	*	*	*	*	*	*
1/21/07	23.8	4.4	0.5	2.2	0.6	0.0	0.0	3.7	1.5	12.1	1.9
1/24/07	17.4	3.7	0.5	1.8	0.5	0.0	0.0	2.8	1.3	8.5	1.5
1/27/07	31.6	5.9	0.7	2.8	0.8	6.9	3.4	0.0	0.0	14.5	3.3
1/30/07	25.0	3.9	0.5	2.0	0.5	0.0	0.0	7.7	1.5	10.2	1.8
2/2/07	*	*	*	*	*	*	*	*	*	*	*
2/5/07	34.6	5.3	0.7	3.3	0.7	8.4	3.8	0.0	0.0	18.3	2.9
2/8/07	14.8	3.0	0.4	0.8	0.4	0.0	0.0	0.0	0.0	11.1	1.3
2/11/07	14.6	2.0	0.2	1.1	0.3	0.0	0.0	0.0	0.0	10.2	1.4
2/14/07	18.0	3.3	0.4	1.7	0.6	0.0	0.0	3.4	1.0	10.0	1.5
2/17/07	21.5	4.1	0.5	1.6	0.5	0.0	0.0	2.1	1.0	13.7	2.0
2/20/07	*	*	*	*	*	*	*	*	*	*	*
2/23/07	38.7	8.4	1.0	3.2	1.1	0.0	0.0	0.0	0.0	27.0	5.9
2/26/07	15.1	3.3	0.4	1.1	0.4	0.0	0.0	0.0	0.0	10.5	2.9
3/1/07	*	*	*	*	*	*	*	*	*	*	*
3/4/07	18.8	4.1	0.5	2.0	0.6	0.0	0.0	0.0	0.0	12.8	1.5
3/7/07	*	*	*	*	*	*	*	*	*	*	*
3/10/07	10.6	2.4	0.3	0.7	0.3	0.0	0.0	0.0	0.0	7.8	1.1
3/13/07	14.6	3.7	0.4	1.0	0.5	0.0	0.0	0.0	0.0	9.5	2.6

3/16/07	13.7	3.0	0.4	0.9	0.4	0.0	0.0	0.0	0.0	10.3	2.7
3/19/07	14.3	2.9	0.4	1.5	0.5	0.0	0.0	2.9	0.9	7.2	1.3
3/22/07	7.2	1.3	0.2	0.4	0.2	0.0	0.0	0.0	0.0	5.4	0.9
3/25/07	15.8	3.4	0.4	1.5	0.4	0.0	0.0	2.7	1.2	7.4	1.3
3/28/07	18.2	3.6	0.4	2.3	0.5	0.0	0.0	3.4	1.3	8.0	1.4
3/31/07	14.0	2.6	0.3	1.6	0.3	0.0	0.0	2.4	1.0	7.6	1.3
Average	**19.9**	**3.7**	**0.5**	**1.7**	**0.5**	**1.1**	**0.4**	**1.5**	**0.5**	**11.5**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2006/2007.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/06	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
11/4/06	27.9	2.5	0.5	1.6	0.4	**0.0**	**0.0**	10.0	1.9	**0.0**	**0.0**	14.3	3.0
11/7/06	13.5	0.9	0.2	0.9	0.1	**0.0**	**0.0**	4.5	0.7	**0.0**	**0.0**	8.0	1.4
11/10/06	21.3	1.9	0.4	1.1	0.3	**0.0**	**0.0**	6.7	1.5	**0.0**	**0.0**	9.8	1.6
11/13/06	*	*	*	*	*	*	*	*	*	*	*	*	*
11/16/06	*	*	*	*	*	*	*	*	*	*	*	*	*
11/19/06	25.8	3.3	0.7	0.9	0.5	**0.0**	**0.0**	15.1	2.6	**0.0**	**0.0**	7.3	3.5
11/22/06	12.7	1.0	0.2	1.4	0.2	**0.0**	**0.0**	4.3	0.9	**0.0**	**0.0**	6.8	1.1
11/25/06	32.1	3.1	0.7	0.9	0.4	**0.0**	**0.0**	16.3	2.5	**0.0**	**0.0**	14.1	3.7
11/28/06	25.7	3.1	0.6	1.4	0.4	**0.0**	**0.0**	11.4	2.4	**0.0**	**0.0**	9.2	2.1
12/1/06	8.0	1.0	0.2	0.6	0.1	**0.0**	**0.0**	3.5	0.8	**0.0**	**0.0**	3.8	0.9
12/4/06	15.5	1.2	0.3	2.1	0.2	**0.0**	**0.0**	5.8	1.2	1.5	0.7	5.7	1.3
12/7/06	35.1	2.2	0.5	1.1	0.3	11.6	3.0	8.8	1.7	**0.0**	**0.0**	8.6	3.0
12/10/06	16.3	1.5	0.3	0.8	0.2	**0.0**	**0.0**	6.1	1.2	**0.0**	**0.0**	7.9	1.3
12/13/06	15.1	1.4	0.3	1.0	0.2	**0.0**	**0.0**	6.5	1.1	**0.0**	**0.0**	7.0	1.7
12/16/06	*	*	*	*	*	*	*	*	*	*	*	*	*
12/19/06	*	*	*	*	*	*	*	*	*	*	*	*	*
12/22/06	26.0	3.9	0.8	0.9	0.5	**0.0**	**0.0**	16.8	3.0	**0.0**	**0.0**	5.0	2.5
12/25/06	*	*	*	*	*	*	*	*	*	*	*	*	*
12/28/06	23.8	2.1	0.4	0.9	0.3	**0.0**	**0.0**	9.0	1.7	**0.0**	**0.0**	10.5	1.7
12/31/06	16.9	2.7	0.5	0.8	0.4	**0.0**	**0.0**	7.9	2.0	**0.0**	**0.0**	7.2	1.8
1/3/07	11.0	1.3	0.3	1.0	0.2	**0.0**	**0.0**	4.2	1.0	**0.0**	**0.0**	4.0	1.1
1/6/07	19.8	1.8	0.4	1.0	0.3	**0.0**	**0.0**	9.1	1.4	**0.0**	**0.0**	9.3	2.3
1/9/07	*	*	*	*	*	*	*	*	*	*	*	*	*
1/12/07	30.4	3.0	0.6	2.2	0.5	**0.0**	**0.0**	12.1	2.4	**0.0**	**0.0**	11.7	2.2
1/15/07	16.3	1.1	0.2	0.7	0.2	**0.0**	**0.0**	5.9	0.9	**0.0**	**0.0**	9.1	1.6
1/18/07	*	*	*	*	*	*	*	*	*	*	*	*	*
1/21/07	23.8	2.4	0.5	1.4	0.3	**0.0**	**0.0**	10.7	1.9	**0.0**	**0.0**	8.1	1.8
1/24/07	17.4	2.1	0.4	1.3	0.3	**0.0**	**0.0**	8.3	1.7	**0.0**	**0.0**	5.1	1.6
1/27/07	31.6	3.2	0.7	1.9	0.5	**0.0**	**0.0**	14.9	2.7	**0.0**	**0.0**	9.6	2.4
1/30/07	25.0	2.0	0.6	1.3	0.6	**0.0**	**0.0**	9.3	2.6	3.6	1.1	10.0	3.1
2/2/07	*	*	*	*	*	*	*	*	*	*	*	*	*
2/5/07	34.6	2.2	0.6	2.8	0.4	**0.0**	**0.0**	16.5	2.1	**0.0**	**0.0**	15.2	3.3
2/8/07	14.8	1.5	0.4	0.6	0.2	**0.0**	**0.0**	7.6	1.2	**0.0**	**0.0**	5.2	1.3
2/11/07	14.6	1.0	0.2	0.7	0.1	**0.0**	**0.0**	5.7	0.9	**0.0**	**0.0**	6.1	1.1
2/14/07	18.0	1.9	0.5	1.1	0.4	**0.0**	**0.0**	7.6	2.3	2.3	0.8	5.1	1.9
2/17/07	21.5	2.6	0.5	0.9	0.4	**0.0**	**0.0**	9.6	2.0	**0.0**	**0.0**	8.4	1.9
2/20/07	*	*	*	*	*	*	*	*	*	*	*	*	*
2/23/07	38.7	4.6	0.9	1.8	0.6	**0.0**	**0.0**	20.9	3.4	**0.0**	**0.0**	11.5	4.4
2/26/07	15.1	1.7	0.4	0.9	0.2	**0.0**	**0.0**	8.5	1.4	**0.0**	**0.0**	4.1	1.9
3/1/07	*	*	*	*	*	*	*	*	*	*	*	*	*
3/4/07	18.8	2.5	0.5	1.8	0.4	**0.0**	**0.0**	8.7	2.0	**0.0**	**0.0**	6.1	1.7
3/7/07	*	*	*	*	*	*	*	*	*	*	*	*	*

3/10/07	10.6	1.5	0.3	0.3	0.2	**0.0**	**0.0**	4.9	1.1	**0.0**	**0.0**	3.5	1.6
3/13/07	14.6	1.8	0.4	0.8	0.2	**0.0**	**0.0**	10.5	0.9	**0.0**	**0.0**	**0.0**	**0.0**
3/16/07	13.7	1.7	0.4	0.8	0.2	**0.0**	**0.0**	6.9	1.4	**0.0**	**0.0**	4.0	1.3
3/19/07	14.3	1.6	0.3	0.9	0.2	**0.0**	**0.0**	7.4	1.3	**0.0**	**0.0**	4.4	1.2
3/22/07	7.2	0.7	0.2	0.3	0.1	**0.0**	**0.0**	2.8	0.6	**0.0**	**0.0**	2.9	1.0
3/25/07	15.8	1.9	0.4	0.9	0.3	**0.0**	**0.0**	8.0	1.5	**0.0**	**0.0**	5.8	2.1
3/28/07	18.2	1.6	0.4	1.6	0.3	**0.0**	**0.0**	10.4	1.5	**0.0**	**0.0**	4.9	2.1
3/31/07	14.0	1.4	0.3	1.1	0.2	**0.0**	**0.0**	6.5	1.2	**0.0**	**0.0**	5.0	1.2
Average	**19.9**	**2.0**	**0.4**	**1.1**	**0.3**	**0.3**	**0.1**	**9.0**	**1.7**	**0.2**	**0.1**	**7.3**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. State Building – Winter 2007/2008.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/07	11.0	1.5	0.2	0.8	0.2	0.0	0.0	0.0	0.0	9.4	1.0
11/5/07	23.5	3.2	0.4	1.3	0.4	0.0	0.0	0.0	0.0	19.4	1.8
11/8/07	13.1	1.9	0.2	0.6	0.3	0.0	0.0	4.4	1.0	6.0	1.1
11/11/07	23.8	3.8	0.5	2.2	0.5	0.0	0.0	5.5	1.4	11.7	1.9
11/14/07	*	*	*	*	*	*	*	*	*	*	*
11/17/07	9.1	0.7	0.2	1.5	0.3	1.7	0.8	0.0	0.0	5.2	1.1
11/20/07	18.4	2.4	0.3	0.6	0.3	0.0	0.0	3.8	0.9	11.8	1.7
11/23/07	11.7	1.3	0.2	0.6	0.2	0.0	0.0	2.3	0.7	7.4	1.1
11/26/07	12.7	1.8	0.2	0.6	0.2	0.0	0.0	3.9	1.0	6.0	1.1
11/29/07	29.3	5.0	0.6	2.0	0.6	11.6	3.1	0.0	0.0	9.7	2.8
12/2/07	5.4**	**	**	**	**	**	**	**	**	**	**
12/5/07	24.2	3.1	0.4	1.3	0.4	9.7	2.8	0.0	0.0	10.1	1.8
12/8/07	17.7	2.9	0.4	1.7	0.6	0.0	0.0	3.3	1.0	9.3	1.5
12/11/07	11.8	1.7	0.2	1.0	0.4	0.0	0.0	2.2	0.7	6.8	1.1
12/14/07	4.0**	**	**	**	**	**	**	**	**	**	**
12/17/07	25.6	4.5	0.6	1.8	0.7	0.0	0.0	2.9	1.2	16.5	2.4
12/20/07	*	*	*	*	*	*	*	*	*	*	*
12/23/07	32.5	6.3	0.8	2.4	1.2	0.0	0.0	6.7	1.6	18.0	2.8
12/26/07	13.0	3.0	0.4	1.5	0.4	0.0	0.0	1.5	0.7	7.0	1.2
12/29/07	16.4	2.7	0.3	1.8	0.6	0.0	0.0	4.1	0.9	7.9	1.4
1/1/08	24.4	5.0	0.6	1.3	0.7	7.3	3.6	0.0	0.0	10.2	1.9
1/4/08	10.2	1.4	0.2	1.3	0.3	0.0	0.0	1.2	0.6	6.9	1.1
1/7/08	20.8	4.2	0.5	1.7	0.7	0.0	0.0	3.4	1.1	11.2	1.7
1/10/08	7.3	1.5	0.2	0.6	0.2	0.0	0.0	0.0	0.0	5.2	0.7
1/13/08	8.4	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	6.3	0.8
1/16/08	25.1	3.9	0.5	1.9	0.5	7.5	3.1	0.0	0.0	12.4	2.1
1/19/08	26.4	4.4	0.5	2.6	0.6	0.0	0.0	5.6	1.5	13.2	2.1
1/22/08	7.8	1.4	0.2	0.5	0.3	0.0	0.0	1.6	0.6	4.6	0.8
1/25/08	18.2	4.4	0.5	1.5	0.7	0.0	0.0	2.8	1.1	9.5	1.6
1/28/08	24.4	4.3	0.5	1.4	0.5	8.3	2.7	0.0	0.0	8.5	2.4
1/31/08	26.2	4.6	0.6	2.6	0.6	0.0	0.0	0.0	0.0	19.0	1.8
2/3/08	24.2	4.6	0.6	2.1	0.6	0.0	0.0	0.0	0.0	16.5	1.9
2/6/08	68.0	17.1	2.1	5.0	2.2	0.0	0.0	0.0	0.0	48.3	6.0
2/9/08	43.7	11.1	1.4	3.5	1.4	0.0	0.0	0.0	0.0	27.4	3.7
2/12/08	9.5	2.1	0.3	0.8	0.3	0.0	0.0	0.0	0.0	7.3	1.1
2/15/08	8.7	1.8	0.2	0.6	0.2	0.0	0.0	0.0	0.0	6.1	0.9
2/18/08	14.9	2.0	0.3	1.2	0.5	0.0	0.0	3.6	0.9	8.3	1.4
2/21/08	7.5	1.1	0.1	0.8	0.2	0.0	0.0	0.0	0.0	6.2	0.8
2/24/08	*	*	*	*	*	*	*	*	*	*	*
2/27/08	17.2	3.1	0.4	1.2	0.5	0.0	0.0	2.2	0.8	11.3	1.7
3/1/08	5.2**	**	**	**	**	**	**	**	**	**	**
3/4/08	24.7	3.1	0.4	2.7	0.4	0.0	0.0	6.3	1.3	12.4	1.9
3/7/08	5.8**	**	**	**	**	**	**	**	**	**	**
3/10/08	*	*	*	*	*	*	*	*	*	*	*

3/13/08	11.0	2.1	0.3	2.0	0.3	0.0	0.0	0.0	0.0	7.1	0.9
3/16/08	*	*	*	*	*	*	*	*	*	*	*
3/19/08	6.6	1.3	0.2	0.6	0.2	0.0	0.0	0.0	0.0	4.5	0.7
3/22/08	10.1	2.3	0.3	1.0	0.3	0.0	0.0	0.0	0.0	6.4	0.9
3/25/08	5.7**	**	**	**	**	**	**	**	**	**	**
3/28/08	8.5	1.4	0.2	1.2	0.2	0.0	0.0	0.0	0.0	6.0	0.8
3/31/08	5.7**	**	**	**	**	**	**	**	**	**	**
Average	**18.7**	**3.4**	**0.4**	**1.5**	**0.5**	**1.2**	**0.4**	**1.7**	**0.5**	**10.9**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. State Building – Winter 2007/2008.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/07	11.0	0.8	0.2	0.8	0.1	0.0	0.0	3.2	0.7	0.0	0.0	7.8	1.0
11/5/07	23.5	1.2	0.4	1.1	0.3	0.0	0.0	9.8	1.8	2.1	1.0	10.6	2.3
11/8/07	13.1	1.0	0.2	0.5	0.1	0.0	0.0	4.5	0.8	2.4	1.2	4.3	1.3
11/11/07	23.8	2.2	0.5	1.6	0.3	0.0	0.0	8.9	1.8	2.9	1.3	7.4	1.9
11/14/07	*	*	*	*	*	*	*	*	*	*	*	*	*
11/17/07	9.1	0.4	0.1	1.3	0.1	0.0	0.0	2.2	0.4	1.1	0.5	4.5	0.9
11/20/07	18.4	1.3	0.3	0.4	0.2	0.0	0.0	6.7	1.1	2.0	0.8	8.3	1.4
11/23/07	11.7	0.9	0.2	0.5	0.1	5.2	2.2	3.2	0.7	0.0	0.0	1.8	0.4
11/26/07	12.7	0.9	0.2	0.5	0.1	0.0	0.0	4.6	0.8	2.6	1.0	3.7	1.1
11/29/07	29.3	2.6	0.6	1.3	0.4	0.0	0.0	12.9	2.2	3.1	1.4	7.7	2.3
12/2/07	5.4**	**	**	**	**	**	**	**	**	**	**	**	**
12/5/07	24.2	1.6	0.4	1.0	0.2	0.0	0.0	7.9	1.3	2.6	1.1	10.0	2.4
12/8/07	17.7	1.8	0.4	1.2	0.3	6.3	2.6	6.7	1.4	0.0	0.0	1.8	0.6
12/11/07	11.8	1.0	0.2	0.7	0.1	0.0	0.0	3.5	0.8	0.0	0.0	6.4	1.0
12/14/07	4.0**	**	**	**	**	**	**	**	**	**	**	**	**
12/17/07	25.6	2.2	0.5	0.9	0.3	0.0	0.0	11.9	1.8	0.0	0.0	10.3	1.9
12/20/07	*	*	*	*	*	*	*	*	*	*	*	*	*
12/23/07	32.5	3.2	0.8	1.1	0.4	0.0	0.0	18.2	2.7	7.0	1.7	2.7	1.0
12/26/07	13.0	1.9	0.4	1.0	0.3	0.0	0.0	6.3	1.5	0.0	0.0	4.1	1.3
12/29/07	16.4	1.5	0.4	1.3	0.4	0.0	0.0	6.7	2.1	2.4	0.9	5.3	2.1
1/1/08	24.4	3.8	0.7	1.2	0.5	0.0	0.0	5.6	2.6	0.0	0.0	14.9	3.3
1/4/08	10.2	0.8	0.2	1.0	0.1	0.0	0.0	3.0	0.7	0.0	0.0	6.0	0.9
1/7/08	20.8	2.4	0.6	0.9	0.4	0.0	0.0	10.3	2.3	1.9	0.9	5.3	2.0
1/10/08	7.3	0.9	0.2	0.5	0.1	0.0	0.0	3.6	0.7	0.0	0.0	2.9	0.8
1/13/08	8.4	0.9	0.2	0.5	0.1	0.0	0.0	3.1	0.7	0.0	0.0	4.6	0.9
1/16/08	25.1	1.9	0.4	1.6	0.3	0.0	0.0	10.4	1.6	0.0	0.0	12.4	2.5
1/19/08	26.4	2.1	0.5	1.8	0.3	0.0	0.0	11.5	1.9	0.0	0.0	9.9	1.9
1/22/08	7.8	1.0	0.2	0.3	0.1	0.0	0.0	2.6	0.7	0.0	0.0	3.8	0.8
1/25/08	18.2	2.6	0.6	0.7	0.4	0.0	0.0	10.3	2.1	0.0	0.0	4.7	1.7
1/28/08	24.4	2.2	0.5	0.8	0.4	0.0	0.0	11.2	2.0	1.7	0.8	8.5	2.8
1/31/08	26.2	2.3	0.5	2.4	0.4	0.0	0.0	12.3	2.0	0.0	0.0	7.3	2.7
2/3/08	24.2	2.5	0.6	1.3	0.4	0.0	0.0	11.3	2.1	0.0	0.0	8.2	2.0
2/6/08	68.0	8.5	1.6	1.9	1.1	0.0	0.0	48.1	3.5	0.0	0.0	0.0	0.0
2/9/08	43.7	6.3	1.3	1.5	0.9	0.0	0.0	27.1	5.0	0.0	0.0	9.1	4.0
2/12/08	9.5	1.1	0.3	0.4	0.2	0.0	0.0	5.0	0.9	1.3	0.6	1.3	0.4
2/15/08	8.7	1.0	0.2	0.3	0.1	0.0	0.0	4.0	0.8	0.0	0.0	3.0	0.9
2/18/08	14.9	1.1	0.3	0.8	0.3	0.0	0.0	5.2	1.6	1.9	0.7	5.8	1.6
2/21/08	7.5	0.7	0.2	0.6	0.1	0.0	0.0	2.2	0.6	2.2	0.9	1.3	0.3
2/24/08	*	*	*	*	*	*	*	*	*	*	*	*	*
2/27/08	17.2	1.8	0.4	1.0	0.3	0.0	0.0	7.6	1.4	0.0	0.0	8.2	1.5
3/1/08	5.2**	**	**	**	**	**	**	**	**	**	**	**	**
3/4/08	24.7	1.7	0.4	2.1	0.3	0.0	0.0	7.8	1.5	3.6	1.3	8.8	1.8
3/7/08	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
3/10/08	*	*	*	*	*	*	*	*	*	*	*	*	*

3/13/08	11.0	1.3	0.3	1.7	0.2	0.0	0.0	3.9	1.1	0.0	0.0	4.9	1.1
3/16/08	*	*	*	*	*	*	*	*	*	*	*	*	*
3/19/08	6.6	0.8	0.2	0.3	0.1	0.0	0.0	3.0	0.6	0.0	0.0	2.5	0.7
3/22/08	10.1	1.3	0.3	0.6	0.2	0.0	0.0	5.3	1.0	0.0	0.0	2.3	1.0
3/25/08	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
3/28/08	8.5	0.8	0.2	1.0	0.1	0.0	0.0	2.9	0.7	0.0	0.0	3.6	0.8
3/31/08	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**18.7**	**1.9**	**0.4**	**1.0**	**0.3**	**0.3**	**0.1**	**8.4**	**1.5**	**1.0**	**0.4**	**5.9**	**1.5**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. State Building – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/8/08	40.0	4.7	0.6	2.8	0.6	0.0	0.0	2.3	1.1	27.0	3.6
11/11/08	31.9	3.6	0.4	2.0	0.5	10.7	3.2	0.0	0.0	17.2	2.6
11/14/08	52.1	8.8	1.1	4.5	1.1	14.6	5.9	0.0	0.0	26.2	4.2
11/17/08	20.7	2.7	0.3	2.0	0.4	0.0	0.0	0.0	0.0	15.4	2.0
11/20/08	16.8	3.0	0.4	1.2	0.5	2.7	1.3	0.0	0.0	11.7	2.0
11/23/08	23.4	3.6	0.4	2.1	0.6	0.0	0.0	2.8	1.0	14.6	2.2
11/26/08	22.0	3.0	0.5	1.5	0.6	4.0	1.5	0.0	0.0	13.5	2.3
11/29/08	16.4	2.3	0.3	1.6	0.3	0.0	0.0	0.0	0.0	12.0	1.6
12/2/08	47.0	10.5	1.3	3.2	1.3	0.0	0.0	0.0	0.0	28.1	3.8
12/5/08	31.0	4.1	0.5	2.2	0.5	11.1	3.4	0.0	0.0	15.5	2.5
12/8/08	*	*	*	*	*	*	*	*	*	*	*
12/11/08	18.9	2.9	0.4	1.5	0.5	2.6	1.3	0.0	0.0	12.5	2.1
12/14/08	39.0	7.0	0.9	3.0	0.9	0.0	0.0	0.0	0.0	24.2	3.1
12/17/08	34.9	7.3	0.9	2.3	0.9	0.0	0.0	3.1	1.5	21.4	3.0
12/20/08	26.1	4.3	0.5	2.6	0.6	0.0	0.0	0.0	0.0	18.0	2.4
12/23/08	47.5	5.5	0.7	2.8	0.7	0.0	0.0	0.0	0.0	38.5	3.3
12/26/08	15.9	2.6	0.4	1.1	0.6	3.6	1.4	0.0	0.0	9.0	1.8
12/29/08	66.0	28.8	3.5	2.4	3.7	0.0	0.0	0.0	0.0	55.2	6.5
1/1/09	28.2	5.2	0.6	2.2	0.7	0.0	0.0	0.0	0.0	18.2	2.4
1/4/09	37.3	6.8	0.8	1.9	0.8	10.2	4.7	0.0	0.0	20.1	3.2
1/7/09	63.7	17.6	2.2	4.0	2.2	0.0	0.0	0.0	0.0	35.2	5.0
1/10/09	56.7	16.1	2.0	3.7	2.0	0.0	0.0	0.0	0.0	33.5	4.7
1/13/09	31.4	5.9	0.8	3.3	1.0	5.4	2.3	0.0	0.0	17.6	3.1
1/16/09	2.3**	**	**	**	**	**	**	**	**	**	**
1/19/09	8.2	1.7	0.2	1.4	0.2	0.0	0.0	0.0	0.0	3.9	0.7
1/22/09	6.4	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	5.1	0.8
1/25/09	26.7	4.3	0.5	3.7	0.6	0.0	0.0	0.0	0.0	18.2	2.4
1/28/09	31.5	8.3	1.0	2.5	1.0	0.0	0.0	0.0	0.0	20.1	2.8
1/31/09	13.4	3.0	0.4	1.3	0.4	0.0	0.0	0.0	0.0	9.1	1.3
2/3/09	18.7	4.4	0.5	1.7	0.6	0.0	0.0	0.0	0.0	13.4	1.8
2/5/09	43.1	7.2	0.8	4.6	0.9	0.0	0.0	0.0	0.0	26.9	3.2
2/6/09	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.6	6.2	0.7	3.4	0.8	0.0	0.0	0.0	0.0	22.7	2.8
2/9/09	12.3	2.0	0.2	1.3	0.3	0.0	0.0	0.0	0.0	8.5	1.2
2/12/09	18.6	2.7	0.3	2.4	0.4	0.0	0.0	1.5	0.8	12.5	1.8
2/15/09	29.6	5.3	0.7	3.4	0.7	7.6	3.8	0.0	0.0	14.6	2.4
2/18/09	23.3	4.8	0.6	1.7	0.6	0.0	0.0	0.0	0.0	16.5	4.3
2/21/09	15.6	3.0	0.4	1.2	0.4	0.0	0.0	0.0	0.0	11.7	1.6
2/24/09	19.6	3.2	0.4	2.3	0.5	4.5	2.2	0.0	0.0	9.1	2.1
2/27/09	6.9	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	4.7	1.4
3/2/09	15.7	2.9	0.4	1.3	0.4	4.5	2.0	0.0	0.0	6.7	1.8
3/5/09	5.7**	**	**	**	**	**	**	**	**	**	**
3/8/09	10.2	2.5	0.3	0.7	0.3	0.0	0.0	0.0	0.0	6.5	0.9
3/11/09	16.1	2.1	0.3	2.4	0.4	0.0	0.0	1.8	0.7	9.8	1.4

3/14/09	14.9	3.1	0.4	1.0	0.4	0.0	0.0	0.0	0.0	10.2	1.3
3/17/09	10.0	2.6	0.3	0.8	0.3	0.0	0.0	0.0	0.0	6.4	1.0
3/20/09	*	*	*	*	*	*	*	*	*	*	*
3/23/09	9.6	2.3	0.3	1.0	0.3	0.0	0.0	0.0	0.0	6.0	0.9
3/26/09	*	*	*	*	*	*	*	*	*	*	*
3/29/09	10.0	2.1	0.3	1.0	0.3	0.0	0.0	1.5	0.7	5.4	0.9
4/1/09	9.6	1.8	0.2	1.1	0.3	0.0	0.0	0.0	0.0	6.6	1.0
4/4/09	7.8	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	5.7	0.9
4/7/09	10.4	2.3	0.3	1.3	0.3	0.0	0.0	0.0	0.0	6.8	0.9
Average	**25.3**	**5.1**	**0.6**	**2.1**	**0.7**	**1.7**	**0.7**	**0.3**	**0.1**	**16.0**	**2.3**

Notes: *No or incomplete CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. State Building – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/8/08	40.0	2.8	0.6	1.8	0.4	11.9	2.3	19.0	2.6
11/11/08	31.9	1.7	0.4	1.3	0.3	8.9	1.4	22.2	2.8
11/14/08	52.1	8.7	1.1	4.4	1.1	0.0	0.0	31.4	2.6
11/17/08	20.7	1.6	0.4	1.5	0.3	5.9	1.3	11.1	1.5
11/20/08	16.8	3.2	0.4	1.1	0.4	0.0	0.0	13.9	1.2
11/23/08	23.4	2.1	0.5	1.5	0.3	8.2	1.7	11.2	1.8
11/26/08	22.0	1.9	0.4	0.9	0.3	7.8	1.5	11.7	1.7
11/29/08	16.4	1.4	0.3	1.2	0.2	4.8	1.1	8.5	1.3
12/2/08	47.0	10.5	1.3	3.1	1.3	0.0	0.0	28.3	2.6
12/5/08	31.0	2.3	0.5	1.5	0.3	9.7	1.9	13.2	1.9
12/8/08	*	*	*	*	*	*	*	*	*
12/11/08	18.9	3.1	0.4	1.5	0.4	0.0	0.0	14.6	1.3
12/14/08	39.0	7.0	0.9	2.8	0.9	0.0	0.0	24.3	2.1
12/17/08	34.9	7.5	0.9	2.2	0.9	0.0	0.0	23.2	2.1
12/20/08	26.1	2.6	0.5	1.9	0.4	9.6	2.1	11.0	2.0
12/23/08	47.5	5.2	0.6	2.7	0.7	0.0	0.0	30.8	2.6
12/26/08	15.9	2.9	0.4	1.1	0.4	0.0	0.0	11.9	1.1
12/29/08	66.0	28.6	3.5	5.8	3.6	0.0	0.0	21.7	2.1
1/1/09	28.2	3.6	0.7	1.4	0.5	9.0	2.7	12.1	2.4
1/4/09	37.3	4.0	0.8	0.7	0.5	15.0	3.1	13.5	2.8
1/7/09	63.7	17.5	2.1	3.8	2.2	0.0	0.0	36.0	3.5
1/10/09	56.7	16.0	2.0	3.5	2.0	0.0	0.0	34.0	3.3
1/13/09	31.4	6.4	0.8	3.2	0.8	0.0	0.0	22.0	1.9
1/16/09	2.3**	**	**	**	**	**	**	**	**
1/19/09	8.2	1.2	0.2	1.2	0.2	2.5	1.0	2.6	0.9
1/22/09	6.4	1.4	0.2	0.4	0.2	0.0	0.0	5.2	0.6
1/25/09	26.7	2.4	0.5	2.9	0.4	10.7	2.2	10.3	2.1
1/28/09	31.5	8.2	1.0	2.4	1.0	0.0	0.0	20.5	1.9
1/31/09	13.4	3.0	0.4	1.2	0.4	0.0	0.0	9.2	1.0
2/3/09	18.7	4.3	0.5	1.6	0.6	0.0	0.0	13.5	1.3
2/5/09	43.1	7.1	0.8	4.5	0.9	0.0	0.0	26.9	1.9
2/6/09	*	*	*	*	*	*	*	*	*
2/7/09	32.6	3.6	0.7	2.3	0.5	14.3	2.8	13.1	2.4
2/9/09	12.3	1.3	0.3	1.1	0.2	4.1	1.0	5.8	1.1
2/12/09	18.6	2.8	0.3	2.7	0.4	0.0	0.0	13.3	1.2
2/15/09	29.6	4.9	0.6	4.1	0.7	0.0	0.0	18.1	1.6
2/18/09	23.3	4.7	0.6	2.2	0.6	0.0	0.0	13.9	1.3
2/21/09	15.6	2.9	0.4	1.6	0.4	0.0	0.0	11.6	1.1
2/24/09	19.6	1.8	0.4	2.2	0.3	7.9	1.6	7.0	1.5
2/27/09	6.9	1.0	0.2	0.5	0.1	2.9	0.8	2.0	0.8
3/2/09	15.7	1.6	0.3	1.3	0.3	6.6	1.3	5.9	1.3
3/5/09	5.7**	**	**	**	**	**	**	**	**
3/8/09	10.2	2.4	0.3	0.9	0.3	0.0	0.0	6.3	0.8
3/11/09	16.1	1.3	0.3	2.3	0.3	4.1	1.2	8.5	1.3

3/14/09	14.9	1.6	0.4	0.8	0.2	7.9	1.3	4.3	1.3
3/17/09	10.0	2.6	0.3	1.1	0.3	0.0	0.0	6.6	0.8
3/20/09	*	*	*	*	*	*	*	*	*
3/23/09	9.6	2.3	0.3	1.2	0.3	0.0	0.0	6.2	0.7
3/26/09	*	*	*	*	*	*	*	*	*
3/29/09	10.0	2.1	0.3	1.2	0.3	0.0	0.0	6.7	0.8
4/1/09	9.6	1.1	0.2	1.1	0.2	3.7	0.9	3.4	1.3
4/4/09	7.8	0.9	0.2	0.5	0.1	3.9	0.7	1.4	0.7
4/7/09	10.4	1.4	0.3	1.2	0.2	5.0	1.1	2.8	1.0
Average	**25.3**	**4.4**	**0.6**	**1.9**	**0.6**	**3.5**	**0.7**	**13.8**	**1.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – Revised OMNI Profiles (with auto / diesel). State Building – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/8/08	40.0	2.8	0.6	1.8	0.4	11.9	2.3	**0.0**	**0.0**	**0.0**	**0.0**	19.0	2.6
11/11/08	31.9	1.7	0.4	1.3	0.3	8.9	1.8	**0.0**	**0.0**	1.6	0.8	19.6	3.1
11/14/08	52.1	3.2	0.9	2.5	0.5	29.7	3.2	**0.0**	**0.0**	**0.0**	**0.0**	18.1	4.9
11/17/08	20.7	1.6	0.4	1.5	0.3	5.9	1.3	**0.0**	**0.0**	**0.0**	**0.0**	11.1	1.5
11/20/08	16.8	1.8	0.4	0.6	0.3	7.8	1.4	**0.0**	**0.0**	**0.0**	**0.0**	8.7	1.5
11/23/08	23.4	2.1	0.5	1.5	0.3	8.2	1.7	**0.0**	**0.0**	**0.0**	**0.0**	11.2	1.8
11/26/08	22.0	1.9	0.4	0.9	0.3	7.8	1.5	**0.0**	**0.0**	**0.0**	**0.0**	11.7	1.7
11/29/08	16.4	1.4	0.3	1.2	0.2	4.8	1.1	**0.0**	**0.0**	**0.0**	**0.0**	8.5	1.3
12/2/08	47.0	5.4	1.2	**0.0**	**0.0**	28.5	4.1	**0.0**	**0.0**	**0.0**	**0.0**	8.3	3.6
12/5/08	31.0	1.6	0.5	1.4	0.5	11.3	2.4	2.9	1.4	**0.0**	**0.0**	13.8	3.4
12/8/08	*	*	*	*	*	*	*	*	*	*	*	*	*
12/11/08	18.9	1.5	0.3	0.9	0.2	8.6	1.3	**0.0**	**0.0**	**0.0**	**0.0**	8.3	1.5
12/14/08	39.0	3.0	0.7	1.5	0.4	21.4	2.7	**0.0**	**0.0**	**0.0**	**0.0**	15.4	4.1
12/17/08	34.9	3.8	0.8	**0.0**	**0.0**	21.0	2.9	**0.0**	**0.0**	**0.0**	**0.0**	9.0	2.7
12/20/08	26.1	2.6	0.5	1.9	0.4	9.6	2.1	0.0	0.0	0.0	0.0	11.0	2.0
12/23/08	47.5	5.2	0.6	2.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	30.8	2.6
12/26/08	15.9	1.7	0.4	0.6	0.2	7.0	1.4	**0.0**	**0.0**	**0.0**	**0.0**	7.3	1.4
12/29/08	*	*	*	*	*	*	*	*	*	*	*	*	*
1/1/09	28.2	3.6	0.7	1.4	0.5	9.0	2.7	0.0	0.0	0.0	0.0	12.1	2.4
1/4/09	37.3	3.4	0.7	**0.0**	**0.0**	17.4	2.4	**0.0**	**0.0**	**0.0**	**0.0**	19.1	4.0
1/7/09	63.7	8.6	1.7	**0.0**	**0.0**	50.5	3.6	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1/10/09	56.7	7.8	1.5	**0.0**	**0.0**	46.9	3.3	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1/13/09	31.4	3.8	0.8	2.2	0.6	14.6	3.0	**0.0**	0.0	**0.0**	**0.0**	12.4	2.7
1/16/09	2.3**	**	**	**	**	**	**	**	**	**	**	**	**
1/19/09	8.2	1.2	0.2	1.2	0.2	2.5	1.0	**0.0**	**0.0**	**0.0**	**0.0**	2.6	0.9
1/22/09	6.4	0.9	0.2	0.3	0.1	2.6	0.7	**0.0**	**0.0**	**0.0**	**0.0**	3.4	0.8
1/25/09	26.7	2.4	0.5	2.9	0.4	10.7	2.2	0.0	0.0	0.0	0.0	10.3	2.1
1/28/09	31.5	4.2	0.9	**0.0**	**0.0**	22.3	3.0	**0.0**	**0.0**	**0.0**	**0.0**	8.8	4.3
1/31/09	13.4	1.8	0.4	0.8	0.3	6.5	1.4	**0.0**	**0.0**	**0.0**	**0.0**	4.8	1.3
2/3/09	18.7	2.9	0.6	1.1	0.4	8.4	2.2	**0.0**	**0.0**	**0.0**	**0.0**	7.8	1.9
2/5/09	43.1	3.7	0.7	3.1	0.6	19.3	3.0	**0.0**	**0.0**	**0.0**	**0.0**	13.5	2.6
2/6/09	*	*	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.6	3.6	0.7	2.3	0.5	14.3	2.8	**0.0**	**0.0**	**0.0**	**0.0**	13.1	2.4
2/9/09	12.3	1.3	0.3	1.1	0.2	4.1	1.0	**0.0**	**0.0**	**0.0**	**0.0**	5.8	1.1
2/12/09	18.6	1.7	0.4	2.2	0.3	5.9	1.4	**0.0**	**0.0**	**0.0**	**0.0**	9.1	1.5
2/15/09	29.6	2.9	0.7	3.1	0.5	12.8	2.6	**0.0**	**0.0**	**0.0**	**0.0**	8.6	2.2
2/18/09	23.3	2.9	0.6	1.5	0.4	10.0	2.3	**0.0**	**0.0**	**0.0**	**0.0**	7.2	2.0
2/21/09	15.6	1.3	0.3	1.0	0.2	9.5	1.3	**0.0**	**0.0**	**0.0**	**0.0**	5.0	1.3
2/24/09	19.6	1.8	0.4	2.2	0.3	7.9	1.6	**0.0**	**0.0**	**0.0**	**0.0**	7.0	1.5
2/27/09	6.9	1.0	0.2	0.5	0.1	2.9	0.8	**0.0**	**0.0**	**0.0**	**0.0**	2.0	0.8
3/2/09	15.7	1.6	0.3	1.3	0.3	6.6	1.3	**0.0**	**0.0**	**0.0**	**0.0**	5.9	1.3
3/5/09	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
3/8/09	10.2	1.5	0.3	0.5	0.2	5.7	1.1	**0.0**	**0.0**	**0.0**	**0.0**	3.3	1.6
3/11/09	16.1	1.3	0.3	2.3	0.3	4.1	1.2	**0.0**	**0.0**	**0.0**	**0.0**	8.5	1.3

3/14/09	14.9	1.6	0.4	0.8	0.2	7.9	1.3	**0.0**	**0.0**	**0.0**	**0.0**	4.3	1.3
3/17/09	10.0	1.1	0.3	0.6	0.2	8.4	0.7	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
3/20/09	*	*	*	*	*	*	*	*	*	*	*	*	*
3/23/09	9.6	1.4	0.3	0.9	0.2	5.0	1.1	**0.0**	**0.0**	**0.0**	**0.0**	2.9	1.0
3/26/09	*	*	*	*	*	*	*	*	*	*	*	*	*
3/29/09	10.0	1.4	0.3	0.8	0.2	4.6	1.1	**0.0**	**0.0**	**0.0**	**0.0**	3.0	1.0
4/1/09	9.6	1.1	0.2	1.1	0.2	3.7	0.9	**0.0**	**0.0**	**0.0**	**0.0**	3.4	1.3
4/4/09	7.8	0.8	0.2	0.5	0.1	4.0	0.7	**0.0**	**0.0**	**0.0**	**0.0**	2.1	1.1
4/7/09	10.4	1.4	0.3	1.2	0.2	5.0	1.1	**0.0**	**0.0**	**0.0**	**0.0**	2.8	1.0
Average	**25.3**	**2.5**	**0.5**	**1.2**	**0.3**	**11.4**	**1.8**	**0.06**	**0.03**	**0.04**	**0.02**	**8.7**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
North Pole – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	39.8	2.6	0.3	1.7	0.3	0.0	0.0	0.0	0.0	29.9	3.3
1/28/09	13.8	2.0	0.2	0.9	0.2	0.0	0.0	0.0	0.0	10.7	1.4
1/31/09	9.7	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	7.4	0.9
2/3/09	15.0	1.7	0.2	0.8	0.2	0.0	0.0	0.0	0.0	14.0	1.7
2/5/09	32.1	2.9	0.3	2.4	0.6	3.4	1.0	0.0	0.0	23.8	3.0
2/6/09	26.0	1.9	0.2	1.4	0.3	0.0	0.0	5.0	2.3	18.3	2.4
2/7/09	61.7	5.4	0.6	2.7	0.7	0.0	0.0	0.0	0.0	53.5	5.8
2/9/09	6.0	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	5.3	0.7
2/12/09	32.0	2.1	0.2	1.3	0.3	0.0	0.0	4.8	2.4	24.5	3.1
2/15/09	34.3	2.3	0.3	1.5	0.3	0.0	0.0	0.0	0.0	28.4	3.2
2/18/09	*	*	*	*	*	*	*	*	*	*	*
2/21/09	10.3	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	8.1	1.1
2/24/09	26.1	1.9	0.2	1.1	0.3	0.0	0.0	4.6	2.2	18.3	2.4
2/27/09	6.7	1.4	0.2	0.7	0.2	0.0	0.0	0.0	0.0	4.4	0.7
3/2/09	10.4	1.3	0.1	0.7	0.2	0.0	0.0	0.0	0.0	7.7	1.0
3/5/09	**4.7****	**	**	**	**	**	**	**	**	**	**
3/8/09	6.1	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.6	0.7
3/11/09	12.5	1.0	0.1	0.8	0.1	0.0	0.0	0.0	0.0	11.3	2.4
3/14/09	14.1	2.0	0.2	0.6	0.3	0.0	0.0	0.0	0.0	12.1	1.5
3/17/09	**3.8****	**	**	**	**	**	**	**	**	**	**
3/20/09	**4.6****	**	**	**	**	**	**	**	**	**	**
3/23/09	**4.5****	**	**	**	**	**	**	**	**	**	**
3/26/09	**3.0****	**	**	**	**	**	**	**	**	**	**
3/29/09	11.8	1.8	0.2	0.7	0.2	0.0	0.0	0.0	0.0	9.8	2.1
4/1/09	10.6	1.3	0.1	0.5	0.2	0.0	0.0	0.0	0.0	8.2	1.7
4/4/09	7.5	1.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.6	1.3
4/7/09	11.4	1.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9.2	1.2
Average	**18.9**	**1.9**	**0.2**	**1.0**	**0.2**	**0.2**	**0.0**	**0.7**	**0.3**	**15.0**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
North Pole – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	39.8	1.2	0.2	1.2	0.2	6.3	0.9	30.0	2.4
1/28/09	13.8	1.4	0.2	0.7	0.2	3.1	1.0	8.5	1.1
1/31/09	9.7	0.8	0.1	0.4	0.1	2.2	0.6	5.6	0.8
2/3/09	15.0	1.6	0.2	0.9	0.2	0.0	0.0	13.6	1.0
2/5/09	32.1	1.7	0.3	1.8	0.3	6.5	1.4	21.7	1.8
2/6/09	26.0	0.8	0.2	1.2	0.1	4.9	0.7	20.1	1.8
2/7/09	61.7	5.3	0.6	2.5	0.7	0.0	0.0	48.4	2.7
2/9/09	6.0	1.0	0.1	0.8	0.1	0.0	0.0	5.7	0.6
2/12/09	32.0	1.3	0.2	0.9	0.2	4.0	1.0	22.2	1.6
2/15/09	34.3	1.5	0.3	1.3	0.2	4.6	1.1	22.6	1.7
2/18/09	*	*	*	*	*	*	*	*	*
2/21/09	10.3	1.0	0.2	0.5	0.1	1.6	0.7	7.0	0.9
2/24/09	26.1	1.1	0.2	0.9	0.2	3.7	0.9	16.9	1.4
2/27/09	6.7	1.3	0.1	0.8	0.2	0.0	0.0	4.3	0.6
3/2/09	10.4	1.0	0.2	0.6	0.1	1.7	0.7	6.5	0.8
3/5/09	4.7**	**	**	**	**	**	**	**	**
3/8/09	6.1	1.0	0.1	0.4	0.1	0.0	0.0	4.4	0.6
3/11/09	12.5	0.7	0.1	0.7	0.1	1.4	0.6	8.3	0.9
3/14/09	14.1	1.9	0.2	0.7	0.2	0.0	0.0	12.0	0.9
3/17/09	3.8**	**	**	**	**	**	**	**	**
3/20/09	4.6**	**	**	**	**	**	**	**	**
3/23/09	4.5**	**	**	**	**	**	**	**	**
3/26/09	3.0**	**	**	**	**	**	**	**	**
3/29/09	11.8	1.2	0.2	0.6	0.2	3.2	0.9	5.7	0.9
4/1/09	10.6	1.2	0.1	0.6	0.2	0.0	0.0	8.0	0.9
4/4/09	7.5	1.2	0.1	0.4	0.2	0.0	0.0	5.8	0.8
4/7/09	11.4	1.5	0.2	0.5	0.2	0.0	0.0	9.1	0.8
Average	**18.9**	**1.4**	**0.2**	**0.9**	**0.2**	**2.1**	**0.5**	**13.6**	**1.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. RAMS – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	12.5	1.4	0.2	1.5	0.2	8.8	1.2
1/28/09	7.8	0.9	0.1	0.6	0.1	6.3	0.9
1/31/09	7.2	0.9	0.1	0.6	0.1	6.1	0.9
2/3/09	10.5	1.4	0.2	1.1	0.2	8.4	1.1
2/5/09	8.8	0.7	0.1	0.8	0.1	7.4	0.8
2/6/09	8.5	0.6	0.1	0.9	0.1	7.1	1.0
2/7/09	11.3	1.1	0.1	1.3	0.2	8.8	0.9
2/9/09	5.3	0.7	0.1	0.9	0.1	4.2	0.6
2/12/09	11.8	1.5	0.2	1.6	0.2	8.8	0.9
2/15/09	9.6	0.9	0.1	1.3	0.1	7.4	1.0
2/18/09	6.5	0.7	0.1	0.8	0.1	5.0	0.7
2/21/09	6.2	1.0	0.1	0.6	0.1	4.7	0.7
2/24/09	10.7	1.1	0.1	1.5	0.2	7.6	1.0
2/27/09	6.3	1.0	0.1	0.6	0.1	4.7	0.7
3/2/09	7.4	1.2	0.1	0.7	0.2	5.4	0.7
3/5/09	6.0	1.0	0.1	0.8	0.1	4.4	0.6
3/8/09	6.0	0.9	0.1	0.5	0.1	4.2	0.7
3/11/09	6.3	0.8	0.1	0.8	0.1	5.1	1.2
3/14/09	6.3	1.1	0.1	0.8	0.1	4.4	0.6
3/17/09	4.4**	**	**	**	**	**	**
3/20/09	*	*	*	*	*	*	*
3/23/09	4.7**	**	**	**	**	**	**
3/26/09	3.8**	**	**	**	**	**	**
3/29/09	7.7	1.4	0.2	0.4	0.2	5.6	0.7
4/1/09	9.3	1.7	0.2	1.1	0.2	6.8	1.0
4/4/09	8.3	1.3	0.2	0.4	0.2	6.3	0.8
4/7/09	9.2	1.6	0.2	0.6	0.2	7.6	0.9
Average	**8.2**	**1.1**	**0.1**	**0.9**	**0.1**	**6.3**	**0.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. RAMS – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	12.5	0.9	0.2	1.2	0.2	2.5	0.7	7.2	0.9
1/28/09	7.8	0.5	0.1	0.4	0.1	1.7	0.4	5.1	0.7
1/31/09	7.2	0.8	0.1	0.6	0.1	0.0	0.0	6.2	0.6
2/3/09	10.5	0.8	0.1	0.8	0.1	3.3	0.6	6.1	0.9
2/5/09	8.8	0.4	0.1	0.7	0.1	1.0	0.3	6.8	0.7
2/6/09	8.5	0.6	0.1	0.9	0.1	0.0	0.0	7.1	0.7
2/7/09	11.3	0.6	0.1	1.1	0.1	2.0	0.5	8.2	0.9
2/9/09	5.3	0.6	0.1	0.9	0.1	0.0	0.0	4.4	0.5
2/12/09	11.8	1.4	0.2	1.5	0.2	0.0	0.0	9.9	0.8
2/15/09	9.6	0.7	0.1	1.2	0.1	1.2	0.6	6.6	0.8
2/18/09	6.5	0.6	0.1	0.8	0.1	0.0	0.0	5.9	0.8
2/21/09	6.2**	**	**	**	**	**	**	**	**
2/24/09	10.7	0.8	0.2	1.3	0.1	1.6	0.7	6.6	0.8
2/27/09	6.3	1.0	0.1	0.6	0.1	0.0	0.0	5.1	0.8
3/2/09	7.4	0.4	0.1	0.6	0.1	4.2	0.4	2.2	0.6
3/5/09	6.0	0.7	0.1	0.7	0.1	1.2	0.5	2.7	0.7
3/8/09	6.0	0.7	0.1	0.4	0.1	1.2	0.5	3.5	0.6
3/11/09	6.3	0.8	0.1	0.8	0.1	0.0	0.0	3.9	0.5
3/14/09	6.3	1.1	0.1	0.8	0.1	0.0	0.0	4.9	0.6
3/17/09	4.4**	**	**	**	**	**	**	**	**
3/20/09	*	*	*	*	*	*	*	*	*
3/23/09	4.7**	**	**	**	**	**	**	**	**
3/26/09	3.8**	**	**	**	**	**	**	**	**
3/29/09	7.7	0.9	0.2	0.3	0.1	2.4	0.6	4.4	0.8
4/1/09	9.3	1.2	0.2	0.9	0.2	2.5	0.9	4.9	1.3
4/4/09	8.3	0.8	0.1	0.2	0.1	2.9	0.6	3.6	1.0
4/7/09	9.2	0.9	0.2	0.3	0.1	3.7	0.7	4.1	1.1
Average	**8.3**	**0.8**	**0.1**	**0.8**	**0.1**	**1.4**	**0.4**	**5.4**	**0.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
Peger Road – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	28.6	4.1	0.5	3.5	0.5	0.0	0.0	3.8	1.4	16.5	2.2
1/28/09	31.3	7.7	0.9	2.5	1.0	0.0	0.0	0.0	0.0	20.6	2.6
1/31/09	13.5	2.4	0.3	0.9	0.3	0.0	0.0	0.0	0.0	10.0	2.7
2/3/09	17.8	3.2	0.4	1.1	0.4	0.0	0.0	0.0	0.0	13.2	1.7
2/5/09	48.0	7.6	0.8	3.8	1.0	17.3	5.2	0.0	0.0	23.9	3.5
2/6/09	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.7	4.8	0.6	2.5	0.6	0.0	0.0	3.1	1.1	22.4	2.8
2/9/09	9.2	1.2	0.1	1.1	0.2	0.0	0.0	1.4	0.6	6.2	1.0
2/12/09	22.8	3.0	0.3	2.2	0.5	0.0	0.0	2.7	0.8	14.9	2.0
2/15/09	32.1	4.7	0.5	4.2	0.8	0.0	0.0	3.5	1.2	19.6	2.6
2/18/09	17.5	3.3	0.4	1.6	0.5	0.0	0.0	1.7	0.8	11.1	1.6
2/21/09	14.6	2.6	0.3	1.0	0.3	0.0	0.0	2.1	1.0	8.3	1.3
2/24/09	20.1	2.9	0.3	2.5	0.5	0.0	0.0	1.8	0.7	13.1	1.8
2/27/09	8.0	1.7	0.2	0.8	0.2	0.0	0.0	0.0	0.0	5.3	0.8
3/2/09	17.5	3.5	0.4	1.5	0.5	0.0	0.0	2.1	0.8	10.9	1.6
3/5/09	5.7	1.0	0.1	0.7	0.2	0.0	0.0	1.0	0.5	2.6	0.6
3/8/09	8.0	1.9	0.2	0.6	0.2	0.0	0.0	0.0	0.0	5.2	1.5
3/11/09	16.6	2.0	0.2	2.2	0.3	0.0	0.0	4.1	1.0	8.2	1.3
3/14/09	11.9	2.6	0.3	0.8	0.4	0.0	0.0	1.6	0.8	6.8	1.1
3/17/09	10.2	2.0	0.2	0.6	0.3	0.0	0.0	0.0	0.0	7.2	0.9
3/20/09	7.4	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	5.0	0.7
3/23/09	11.5	2.2	0.3	0.7	0.3	0.0	0.0	1.7	0.7	6.9	1.0
3/26/09	6.7	0.9	0.1	0.3	0.1	0.0	0.0	0.0	0.0	5.5	0.8
3/29/09	10.9	1.8	0.2	0.9	0.2	0.0	0.0	1.4	0.6	6.8	1.0
4/1/09	13.0	1.9	0.2	1.1	0.3	0.0	0.0	0.0	0.0	9.8	1.2
4/4/09	7.9	1.2	0.1	0.4	0.2	0.0	0.0	0.0	0.0	6.8	1.6
4/7/09	13.3	2.2	0.2	1.3	0.3	0.0	0.0	0.0	0.0	9.4	2.5
Average	**16.8**	**2.8**	**0.3**	**1.5**	**0.4**	**0.7**	**0.2**	**1.2**	**0.5**	**10.6**	**1.6**

Notes: *No, incomplete, or invalid CMB data set.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. Peger Road – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	28.6	2.2	0.4	2.7	0.4	9.9	1.8	12.2	1.7
1/28/09	31.3	7.7	0.9	2.3	1.0	0.0	0.0	21.0	1.6
1/31/09	13.5	1.3	0.2	0.7	0.2	5.8	1.0	5.0	1.1
2/3/09	17.8	3.1	0.4	1.4	0.4	0.0	0.0	13.3	1.0
2/5/09	48.0	3.7	0.7	3.3	0.6	19.9	3.0	17.3	2.7
2/6/09	*	*	*	*	*	*	*	*	*
2/7/09	32.7	2.4	0.5	2.2	0.4	13.9	1.9	14.2	1.9
2/9/09	9.2	0.9	0.2	1.0	0.1	1.9	0.7	6.1	0.8
2/12/09	22.8	1.7	0.3	2.0	0.3	7.3	1.4	12.5	1.5
2/15/09	32.1	2.3	0.5	3.8	0.4	12.2	2.0	13.9	1.9
2/18/09	17.5	3.3	0.4	1.9	0.4	0.0	0.0	12.6	1.0
2/21/09	14.6	1.6	0.3	0.8	0.2	5.3	1.2	6.4	1.2
2/24/09	20.1	2.8	0.3	2.7	0.4	0.0	0.0	14.7	1.1
2/27/09	8.0	1.2	0.2	0.7	0.2	2.8	0.9	3.1	0.9
3/2/09	17.5	3.5	0.4	1.8	0.5	0.0	0.0	12.7	1.0
3/5/09	5.7	0.7	0.1	0.6	0.1	1.5	0.6	2.6	0.7
3/8/09	8.0	1.2	0.2	0.5	0.2	3.5	0.9	2.0	0.9
3/11/09	16.6	1.2	0.2	2.1	0.2	3.7	1.0	8.9	1.1
3/14/09	11.9	1.6	0.3	0.7	0.2	5.7	1.2	4.2	1.1
3/17/09	10.2	1.1	0.2	0.5	0.2	4.1	0.9	4.0	0.9
3/20/09	7.4	0.8	0.1	0.5	0.1	2.8	0.6	2.8	0.7
3/23/09	11.5	1.4	0.3	0.6	0.2	5.3	1.0	4.2	1.0
3/26/09	6.7	0.6	0.1	0.3	0.1	1.6	0.4	4.0	0.9
3/29/09	10.9	1.7	0.2	1.1	0.2	0.0	0.0	8.1	0.8
4/1/09	13.0	1.2	0.2	1.1	0.2	3.4	0.9	7.3	1.4
4/4/09	7.9	0.7	0.1	0.3	0.1	2.7	0.5	4.7	1.0
4/7/09	13.3	1.2	0.2	1.2	0.2	5.0	1.0	4.7	1.0
Average	**16.8**	**2.0**	**0.3**	**1.4**	**0.3**	**4.6**	**0.9**	**8.6**	**1.2**

Notes: *No, incomplete, or invalid CMB data set.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – Revised OMNI Profiles (with auto / diesel). Peger Road – Winter 2008/2009.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/25/09	28.6	2.2	0.4	2.7	0.4	0.0	0.0	0.0	0.0	9.9	1.8	12.2	1.7
1/28/09	31.3	3.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	21.3	2.8	6.7	2.4
1/31/09	13.5	1.3	0.2	0.7	0.2	0.0	0.0	0.0	0.0	5.8	1.0	5.0	1.1
2/3/09	17.8	1.9	0.4	0.9	0.3	0.0	0.0	0.0	0.0	7.2	1.4	8.4	1.4
2/5/09	48.0	3.8	0.7	3.1	0.6	7.4	3.1	0.0	0.0	19.9	3.0	17.8	5.3
2/6/09	*	*	*	*	*	*	*	*	*	*	*	*	*
2/7/09	32.7	2.4	0.5	2.2	0.4	0.0	0.0	0.0	0.0	13.9	1.9	14.2	1.9
2/9/09	9.2	0.9	0.2	1.0	0.1	0.0	0.0	0.0	0.0	1.9	0.7	6.1	0.8
2/12/09	22.8	1.7	0.3	2.0	0.3	0.0	0.0	0.0	0.0	7.3	1.4	12.5	1.5
2/15/09	32.1	2.3	0.5	3.8	0.4	0.0	0.0	0.0	0.0	12.2	2.0	13.9	1.9
2/18/09	17.5	2.1	0.4	1.4	0.3	0.0	0.0	0.0	0.0	6.3	1.6	8.4	1.4
2/21/09	14.6	1.6	0.3	0.8	0.2	0.0	0.0	0.0	0.0	5.3	1.2	6.4	1.2
2/24/09	20.1	1.8	0.3	2.3	0.3	0.0	0.0	0.0	0.0	6.1	1.4	10.6	1.4
2/27/09	8.0	1.2	0.2	0.7	0.2	0.0	0.0	0.0	0.0	2.8	0.9	3.1	0.9
3/2/09	17.5	2.2	0.4	1.2	0.3	0.0	0.0	0.0	0.0	7.3	1.7	7.8	1.5
3/5/09	5.7	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	1.5	0.6	2.6	0.7
3/8/09	8.0	1.2	0.2	0.5	0.2	0.0	0.0	0.0	0.0	3.5	0.9	2.0	0.9
3/11/09	16.6	1.3	0.3	2.1	0.2	0.0	0.0	2.4	1.0	3.6	1.1	6.8	1.2
3/14/09	11.9	1.6	0.3	0.7	0.2	0.0	0.0	0.0	0.0	5.7	1.2	4.2	1.1
3/17/09	10.2	1.1	0.2	0.5	0.2	0.0	0.0	0.0	0.0	4.1	0.9	4.0	0.9
3/20/09	7.4	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.8	0.6	2.8	0.7
3/23/09	11.5	1.4	0.3	0.6	0.2	0.0	0.0	0.0	0.0	5.3	1.0	4.2	1.0
3/26/09	6.7	0.6	0.1	0.3	0.1	0.0	0.0	0.0	0.0	1.6	0.4	4.0	0.9
3/29/09	10.9	1.1	0.2	0.8	0.2	0.0	0.0	0.0	0.0	4.0	0.8	5.1	0.9
4/1/09	13.0	1.2	0.2	1.1	0.2	0.0	0.0	0.0	0.0	3.4	0.9	7.3	1.4
4/4/09	7.9	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	2.7	0.5	4.7	1.0
4/7/09	13.3	1.2	0.2	1.2	0.2	0.0	0.0	0.0	0.0	5.0	1.0	4.7	1.0
Average	**16.8**	**1.6**	**0.3**	**1.2**	**0.2**	**0.3**	**0.1**	**0.1**	**0.04**	**6.6**	**1.3**	**7.1**	**1.4**

Notes: *No, incomplete, or invalid CMB data set.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. State Building – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.8	2.1	0.3	1.1	0.3	3.5	1.3	0.0	0.0	6.4	0.8
11/6/09	5.2	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	4.1	0.2
11/9/09	*	*	*	*	*	*	*	*	*	*	*
11/12/09	4.0**	**	**	**	**	**	**	**	**	**	**
11/15/09	15.7	2.2	0.3	1.4	0.3	0.0	0.0	0.0	0.0	13.0	1.0
11/17/09	21.8	3.3	0.4	2.0	0.4	0.0	0.0	6.1	1.3	9.8	1.5
11/18/09	4.9**	**	**	**	**	**	**	**	**	**	**
11/19/09	10.5	1.5	0.2	1.2	0.2	0.0	0.0	0.0	0.0	7.7	0.8
11/21/09	24.9	3.9	0.5	1.6	0.5	0.0	0.0	0.0	0.0	19.0	1.5
11/24/09	34.2	6.2	0.8	2.7	0.8	0.0	0.0	3.6	1.7	21.1	1.6
11/27/09	20.9	3.1	0.4	1.1	0.4	4.5	1.8	0.0	0.0	12.2	1.8
11/30/09	14	2.7	0.3	1.3	0.3	3.3	1.6	0.0	0.0	6.3	0.9
12/3/09	*	*	*	*	*	*	*	*	*	*	*
12/6/09	0.4**	**	**	**	**	**	**	**	**	**	**
12/9/09	49	9.5	1.2	3.9	1.2	0.0	0.0	9.4	4.5	27.0	5.2
12/10/09	54.4	8.8	1.0	2.2	1.1	0.0	0.0	0.0	0.0	43.9	8.9
12/11/09	43.7	7.4	0.8	4.8	1.0	0.0	0.0	0.0	0.0	29.5	3.5
12/12/09	38.1	6.9	0.8	1.9	0.9	0.0	0.0	0.0	0.0	29.8	2.5
12/13/09	44.4	7.2	0.8	3.8	0.9	12.6	4.0	0.0	0.0	19.1	3.8
12/15/09	4.1**	**	**	**	**	**	**	**	**	**	**
12/18/09	3.6**	**	**	**	**	**	**	**	**	**	**
12/21/09	40.2	6.8	0.8	2.7	0.9	0.0	0.0	0.0	0.0	30.9	2.5
12/24/09	29.8	4.8	0.6	2.3	0.6	0.0	0.0	0.0	0.0	22.5	0.9
12/27/09	24.1	4.5	0.6	1.5	0.6	0.0	0.0	0.0	0.0	19.5	1.6
12/30/09	42.2	8.1	1.0	2.7	1.0	0.0	0.0	0.0	0.0	33.2	2.8
1/2/10	48.6	11.2	1.4	3.4	1.4	0.0	0.0	0.0	0.0	28.3	3.1
1/5/10	52.3	8.8	1.1	3.7	1.1	0.0	0.0	0.0	0.0	42.8	3.5
1/8/10	46.2	9.5	1.2	3.5	1.2	0.0	0.0	0.0	0.0	28.6	1.8
1/11/10	38.5	8.6	1.1	2.4	1.1	0.0	0.0	0.0	0.0	27.3	1.6
1/14/10	11.8	2.4	0.3	1.0	0.3	0.0	0.0	0.0	0.0	8.5	0.7
1/17/10	15.8	2.7	0.3	1.3	0.4	0.0	0.0	0.0	0.0	12.0	1.0
1/20/10	41.0	6.8	0.8	3.1	0.9	0.0	0.0	0.0	0.0	29.1	2.1
1/23/10	30.7	5.5	0.7	2.6	0.7	0.0	0.0	0.0	0.0	23.2	1.0
1/26/10	80.2	18.9	2.3	8.0	2.4	0.0	0.0	0.0	0.0	53.6	3.6
1/29/10	26.4	5.5	0.7	2.2	0.7	0.0	0.0	0.0	0.0	18.4	1.0
2/1/10	24.1	4.0	0.5	5.0	0.6	0.0	0.0	0.0	0.0	15.2	3.0
2/4/10	32.4	7.9	1.0	3.6	1.0	0.0	0.0	0.0	0.0	20.4	1.5
2/7/10	14.6	2.8	0.3	1.7	0.4	0.0	0.0	0.0	0.0	9.7	0.5
2/10/10	22.1	3.2	0.4	3.1	0.5	0.0	0.0	0.0	0.0	15.7	0.6
2/13/10	30.6	4.9	0.6	3.9	0.7	0.0	0.0	0.0	0.0	23.5	1.9
2/16/10	26.3	4.1	0.5	4.0	0.6	0.0	0.0	4.6	2.1	13.8	2.4
2/19/10	22.8	2.6	0.3	3.8	0.4	4.5	1.5	0.0	0.0	12.0	1.5
2/22/10	12.2	2.2	0.3	1.5	0.3	0.0	0.0	0.0	0.0	8.8	0.8
2/25/10	3.1**	**	**	**	**	**	**	**	**	**	**

2/28/10	10.1	1.2	0.1	2.0	0.2	0.0	0.0	0.0	0.0	7.2	0.4
3/3/10	21.3	2.8	0.3	1.8	0.4	0.0	0.0	1.8	0.8	13.9	0.8
3/6/10	3.8**	**	**	**	**	**	**	**	**	**	**
3/9/10	3.4**	**	**	**	**	**	**	**	**	**	**
3/12/10	9.1	1.3	0.2	0.7	0.2	0.0	0.0	0.0	0.0	6.7	0.4
3/15/10	6.9	1.1	0.1	1.1	0.2	0.0	0.0	0.0	0.0	4.8	1.2
Average	**28.8**	**5.2**	**0.6**	**2.5**	**0.7**	**0.7**	**0.3**	**0.6**	**0.3**	**19.5**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.8	1.1	0.2	0.7	0.2	**0.0**	**0.0**	**0.0**	**0.0**	5.3	0.8	6.5	0.9
11/6/09	5.2	0.5	0.1	0.2	0.1	**0.0**	**0.0**	0.4	0.1	1.7	0.4	2.2	0.4
11/9/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/12/09	4.0**	**	**	**	**	**	**	**	**	**	**	**	**
11/15/09	15.7	1.2	0.2	1.1	0.2	**0.0**	**0.0**	**0.0**	**0.0**	4.5	0.9	10.5	1.0
11/17/09	21.8	1.1	0.5	1.3	0.6	4.2	1.4	**0.0**	**0.0**	9.4	2.7	5.9	2.9
11/18/09	4.9**	**	**	**	**	**	**	**	**	**	**	**	**
11/19/09	10.5	0.8	0.2	1.0	0.1	**0.0**	**0.0**	**0.0**	**0.0**	3.2	0.7	6.3	0.9
11/21/09	24.9	1.8	0.4	1.0	0.3	**0.0**	**0.0**	**0.0**	**0.0**	10.5	1.5	10.8	1.7
11/24/09	34.2	3.3	0.7	1.7	0.5	**0.0**	**0.0**	2.7	0.9	15.9	2.7	6.7	2.9
11/27/09	20.9	1.8	0.4	0.8	0.2	**0.0**	**0.0**	2.0	0.5	7.0	1.4	9.1	1.5
11/30/09	14	1.6	0.3	0.9	0.2	**0.0**	**0.0**	**0.0**	**0.0**	5.8	1.2	5.9	1.3
12/3/09	*	*	*	*	*	*	*	*	*	*	*	*	*
12/6/09	0.4**	**	**	**	**	**	**	**	**	**	**	**	**
12/9/09	*	*	*	*	*	*	*	*	*	*	*	*	*
12/10/09	54.4	5.5	0.9	**0.0**	**0.0**	**0.0**	**0.0**	5.6	2.0	17.4	3.7	26.0	5.1
12/11/09	43.7	2.3	0.6	2.8	0.4	**0.0**	**0.0**	**0.0**	**0.0**	28.4	2.4	8.8	2.4
12/12/09	*	*	*	*	*	*	*	*	*	*	*	*	*
12/13/09	44.4	2.8	0.6	2.4	0.4	**0.0**	**0.0**	**0.0**	**0.0**	23.2	2.4	13.3	2.3
12/15/09	4.1**	**	**	**	**	**	**	**	**	**	**	**	**
12/18/09	3.6**	**	**	**	**	**	**	**	**	**	**	**	**
12/21/09	40.2	3.6	0.8	1.6	0.5	**0.0**	**0.0**	**0.0**	**0.0**	16.1	2.8	18.1	3.1
12/24/09	29.8	2.6	0.5	1.5	0.4	**0.0**	**0.0**	**0.0**	**0.0**	12.1	2.0	11.7	2.2
12/27/09	24.1	2.6	0.5	0.9	0.4	**0.0**	**0.0**	**0.0**	**0.0**	9.8	1.9	12.1	2.2
12/30/09	*	*	*	*	*	*	*	*	*	*	*	*	*
1/2/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/5/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/8/10	46.2	6.4	1.2	2.4	0.9	**0.0**	**0.0**	**0.0**	**0.0**	16.8	4.3	13.7	4.7
1/11/10	38.5	5.0	1.0	1.0	0.7	**0.0**	**0.0**	**0.0**	**0.0**	20.4	3.8	7.9	4.2
1/14/10	11.8	1.6	0.3	0.7	0.2	**0.0**	**0.0**	**0.0**	**0.0**	4.8	1.2	2.7	1.3
1/17/10	15.8	1.7	0.3	1.0	0.2	**0.0**	**0.0**	**0.0**	**0.0**	4.9	1.3	8.6	1.4
1/20/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/23/10	30.7	3.1	0.6	1.7	0.4	**0.0**	**0.0**	**0.0**	**0.0**	12.9	2.4	11.6	2.7
1/26/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/29/10	26.4	3.2	0.6	1.4	0.4	**0.0**	**0.0**	**0.0**	**0.0**	13.2	2.4	5.9	2.7
2/1/10	24.1	2.1	0.5	4.2	0.5	**0.0**	**0.0**	**0.0**	**0.0**	9.9	2.0	8.5	2.2
2/4/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/7/10	14.6	1.7	0.3	1.2	0.3	**0.0**	**0.0**	**0.0**	**0.0**	6.2	1.3	3.9	1.5
2/10/10	22.1	1.5	0.4	2.5	0.3	**0.0**	**0.0**	**0.0**	**0.0**	9.2	1.4	7.2	1.5
2/13/10	30.6	2.6	0.6	3.1	0.5	**0.0**	**0.0**	**0.0**	**0.0**	11.7	2.2	14.5	2.4
2/16/10	26.3	2.5	0.5	3.3	0.4	**0.0**	**0.0**	**0.0**	**0.0**	9.2	2.1	4.8	2.3
2/19/10	22.8	1.1	0.3	3.3	0.3	**0.0**	**0.0**	1.9	0.3	7.5	1.3	8.5	1.4
2/22/10	12.2	1.3	0.3	1.1	0.2	**0.0**	**0.0**	0.8	0.4	4.6	1.0	4.3	1.1
2/25/10	3.1**	**	**	**	**	**	**	**	**	**	**	**	**

2/28/10	10.1	0.9	0.2	1.8	0.2	**0.0**	**0.0**	**0.0**	**0.0**	1.7	0.7	4.8	0.8
3/3/10	21.3	1.6	0.3	1.3	0.2	6.7	1.0	**0.0**	**0.0**	6.6	1.3	6.1	1.4
3/6/10	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
3/9/10	3.4**	**	**	**	**	**	**	**	**	**	**	**	**
3/12/10	*	*	*	*	*	*	*	*	*	*	*	*	*
3/15/10	6.9	1.0	0.1	1.1	0.2	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	4.3	0.1
Average	**28.8**	**2.2**	**0.5**	**1.6**	**0.3**	**0.4**	**0.1**	**0.4**	**0.1**	**10.0**	**1.8**	**8.7**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. North Pole – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	6.1	0.4	0.0	0.1	0.1	0.0	0.0	0.0	0.0	5.7	0.7
11/9/09	12.9	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	11.0	1.0
11/15/09	16.7	0.9	0.1	0.8	0.1	0.0	0.0	0.0	0.0	13.1	1.3
11/17/09	13.3	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	10.9	1.1
11/18/09	6.5	0.9	0.1	0.9	0.1	0.0	0.0	0.0	0.0	4.6	0.6
11/19/09	*	*	*	*	*	*	*	*	*	*	*
11/21/09	18.5	1.9	0.2	1.0	0.2	0.0	0.0	0.0	0.0	15.0	1.3
11/27/09	27.8	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	25.4	5.0
12/3/09	15.3	1.1	0.1	0.6	0.1	0.0	0.0	0.0	0.0	12.1	1.2
12/9/09	83.5	5.1	0.7	1.3	0.7	0.0	0.0	0.0	0.0	81.0	15.7
12/10/09	80.5	5.9	0.7	1.4	0.8	0.0	0.0	0.0	0.0	73.3	14.3
12/11/09	58.4	4.5	0.5	1.7	0.6	0.0	0.0	0.0	0.0	48.8	5.3
12/12/09	37.9	2.7	0.3	1.8	0.4	0.0	0.0	0.0	0.0	32.6	3.6
12/13/09	54.8	4.2	0.5	1.7	0.6	0.0	0.0	0.0	0.0	46.2	5.0
12/15/09	6.2	0.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0	6.0	0.7
12/21/09	45.0	4.0	0.4	1.8	0.5	0.0	0.0	0.0	0.0	36.1	2.9
12/24/09	25.2	1.5	0.2	0.9	0.2	0.0	0.0	0.0	0.0	20.0	1.7
12/27/09	17.0	1.5	0.2	0.5	0.2	0.0	0.0	0.0	0.0	13.1	1.3
12/30/09	115.4	9.9	1.1	3.1	1.2	0.0	0.0	14.0	3.2	79.0	9.6
1/2/10	53.1	5.0	0.6	1.3	0.6	0.0	0.0	0.0	0.0	44.9	5.0
1/8/10	36.6	2.9	0.3	2.2	0.4	0.0	0.0	0.0	0.0	33.2	5.8
1/11/10	17.6	1.8	0.2	0.5	0.2	5.5	2.1	0.0	0.0	10.6	1.6
1/14/10	4.5**	**	**	**	**	**	**	**	**	**	**
1/17/10	20.0	1.7	0.2	0.9	0.2	4.2	2.1	0.0	0.0	14.0	1.9
1/20/10	53.5	4.3	0.5	1.4	0.6	14.8	3.7	0.0	0.0	32.7	4.2
1/23/10	42.0	2.8	0.3	1.4	0.4	0.0	0.0	0.0	0.0	35.9	6.0
1/26/10	90.9	7.3	0.8	2.4	1.0	0.0	0.0	0.0	0.0	79.1	6.7
1/29/10	3.3**	**	**	**	**	**	**	**	**	**	**
2/1/10	*	*	*	*	*	*	*	*	*	*	*
2/4/10	31.4	3.0	0.3	1.2	0.4	0.0	0.0	7.0	1.3	18.8	2.5
2/7/10	10.3	1.3	0.1	1.1	0.2	0.0	0.0	0.0	0.0	8.2	0.9
2/10/10	32.9	2.8	0.3	1.4	0.4	0.0	0.0	8.0	1.4	18.8	2.5
2/13/10	54.6	3.3	0.4	2.0	0.4	0.0	0.0	0.0	0.0	53.6	10.4
2/16/10	39.6	2.3	0.3	1.7	0.3	12.7	2.8	0.0	0.0	25.0	3.3
2/19/10	*	*	*	*	*	*	*	*	*	*	*
2/22/10	7.0	0.8	0.1	0.8	0.1	0.0	0.0	0.0	0.0	7.0	0.8
2/25/10	3.8**	**	**	**	**	**	**	**	**	**	**
2/28/10	8.2	0.9	0.1	1.2	0.1	0.0	0.0	0.0	0.0	5.7	0.7
3/3/10	28.2	1.5	0.2	0.9	0.2	7.7	2.3	0.0	0.0	16.8	2.3
3/6/10	*	*	*	*	*	*	*	*	*	*	*
3/9/10	4.1**	**	**	**	**	**	**	**	**	**	**
3/12/10	5.6	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	4.3	0.6
3/15/10	7.5	0.9	0.1	0.6	0.1	0.0	0.0	0.0	0.0	6.3	1.4
Average	**33.7**	**2.6**	**0.3**	**1.2**	**0.3**	**1.3**	**0.4**	**0.8**	**0.2**	**27.1**	**3.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. North Pole – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	6.1	0.2	0.0	0.1	0.0	0.0	0.0	2.0	0.8	0.8	0.1	2.8	0.6
11/9/09	12.9	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.7	0.3	8.2	1.0
11/15/09	16.7	0.4	0.1	0.6	0.1	0.0	0.0	0.0	0.0	2.1	0.4	11.2	0.9
11/17/09	13.3	0.6	0.1	1.2	0.1	0.0	0.0	0.0	0.0	3.1	0.5	9.8	1.0
11/18/09	6.5	0.6	0.1	0.7	0.1	0.0	0.0	0.0	0.0	1.6	0.5	3.7	0.6
11/19/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/21/09	18.5	0.8	0.2	0.6	0.1	0.0	0.0	0.0	0.0	4.8	0.6	13.0	1.1
11/27/09	27.8	0.6	0.1	0.6	0.1	0.0	0.0	1.7	0.7	1.7	0.5	27.2	2.1
12/3/09	15.3	0.3	0.1	0.5	0.1	0.0	0.0	2.8	0.8	3.5	0.3	7.3	1.0
12/9/09	83.5	1.7	0.4	0.8	0.3	0.0	0.0	11.9	1.7	16.4	1.5	48.5	4.4
12/10/09	80.5	2.4	0.5	1.0	0.3	0.0	0.0	0.0	0.0	15.5	1.9	62.7	4.8
12/11/09	58.4	1.8	0.4	0.8	0.3	0.0	0.0	0.0	0.0	11.9	1.4	47.2	3.7
12/12/09	37.9	1.5	0.3	1.2	0.2	0.0	0.0	0.0	0.0	6.6	1.2	24.1	1.9
12/13/09	54.8	1.7	0.4	1.3	0.2	0.0	0.0	4.9	1.3	11.5	1.4	39.7	3.6
12/15/09	6.2	0.1	0.0	0.5	0.0	0.0	0.0	1.8	0.6	1.9	0.2	2.2	0.5
12/21/09	45.0	2.3	0.4	1.1	0.3	9.8	3.8	0.0	0.0	8.8	1.7	24.4	2.7
12/24/09	25.2	0.5	0.1	0.7	0.1	0.0	0.0	0.0	0.0	5.6	0.5	15.6	1.2
12/27/09	17.0	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.0	0.4	13.5	1.3
12/30/09	115.4	4.0	0.8	1.1	0.5	0.0	0.0	6.2	2.2	26.6	3.1	91.0	7.7
1/2/10	53.1	2.0	0.4	0.9	0.3	0.0	0.0	0.0	0.0	13.7	1.6	43.2	3.7
1/8/10	36.6	1.2	0.3	1.8	0.2	0.0	0.0	4.4	1.1	9.9	1.1	21.5	2.5
1/11/10	17.6	0.8	0.2	0.4	0.1	0.0	0.0	0.0	0.0	4.6	0.6	13.2	1.4
1/14/10	4.5**	**	**	**	**	**	**	**	**	**	**	**	**
1/17/10	20.0	1.0	0.2	0.8	0.1	0.0	0.0	0.0	0.0	3.9	0.8	12.7	1.2
1/20/10	53.5	1.4	0.4	1.0	0.3	0.0	0.0	1.9	0.8	13.4	1.8	35.4	3.3
1/23/10	42.0	1.4	0.3	1.1	0.2	0.0	0.0	9.1	1.4	8.6	1.1	24.1	2.8
1/26/10	90.9	2.6	0.6	2.1	0.4	0.0	0.0	0.0	0.0	22.0	2.2	59.2	5.0
1/29/10	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
2/1/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/4/10	31.4	1.7	0.3	1.0	0.2	7.2	3.1	0.0	0.0	7.3	1.3	15.7	2.1
2/7/10	10.3	0.2	0.1	1.0	0.1	0.0	0.0	0.0	0.0	5.6	0.4	4.1	0.6
2/10/10	32.9	1.3	0.3	1.2	0.2	9.6	3.1	0.0	0.0	8.1	1.1	15.0	2.0
2/13/10	54.6	1.4	0.3	1.6	0.2	8.8	3.8	0.0	0.0	10.4	1.3	29.5	2.9
2/16/10	39.6	1.0	0.2	1.4	0.2	0.0	0.0	4.7	1.1	5.6	0.9	26.5	2.5
2/19/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/22/10	7.0	0.0	0.0	0.7	0.1	0.0	0.0	0.0	0.0	4.3	0.2	1.7	0.1
2/25/10	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
2/28/10	8.2	0.5	0.1	1.2	0.1	0.0	0.0	0.0	0.0	1.8	0.4	4.7	0.7
3/3/10	28.2	0.5	0.1	0.7	0.1	0.0	0.0	0.0	0.0	5.6	0.5	15.8	1.2
3/6/10	*	*	*	*	*	*	*	*	*	*	*	*	*
3/9/10	4.1**	**	**	**	**	**	**	**	**	**	**	**	**
3/12/10	5.6	0.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0	1.4	0.4	3.5	0.6
3/15/10	7.5	0.4	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.5	0.3	4.6	0.9
Average	**33.7**	**1.1**	**0.2**	**0.9**	**0.2**	**1.0**	**0.4**	**1.5**	**0.4**	**7.3**	**0.9**	**22.4**	**2.1**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
RAMS – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/15/09	34.6	3.0	0.3	1.3	0.4	6.2	2.8	0.0	0.0	24.7	3.2
11/17/09	*	*	*	*	*	*	*	*	*	*	*
11/18/09	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*
11/21/09	50.2	4.6	0.5	0.0	0.0	11.3	3.8	0.0	0.0	34.9	4.5
11/27/09	33.7	2.4	0.3	0.8	0.3	0.0	0.0	0.0	0.0	30.1	6.0
12/3/09	22.5	2.3	0.3	0.0	0.0	5.8	2.4	0.0	0.0	14.8	2.1
12/9/09	55.4	6.4	0.7	0.0	0.0	0.0	0.0	8.3	2.1	36.0	4.5
12/10/09	72.2	7.4	0.8	0.0	0.0	0.0	0.0	4.9	2.3	56.8	6.9
12/11/09	57.6	6.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	53.2	10.5
12/12/09	59.3	7.0	0.8	2.1	0.9	0.0	0.0	0.0	0.0	49.9	5.6
12/13/09	68.7	6.7	0.8	0.0	0.0	24.1	5.2	0.0	0.0	42.0	5.5
12/21/09	52.0	5.1	0.6	0.0	0.0	0.0	0.0	7.6	1.8	35.9	4.5
12/24/09	32.2	3.0	0.3	0.9	0.4	0.0	0.0	5.1	1.3	21.6	2.8
12/27/09	6.6	0.5	0.1	0.3	0.1	0.0	0.0	2.4	0.8	3.4	0.7
12/30/09	68.8	8.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	60.9	12.1
1/2/10	64.9	8.6	1.0	0.0	0.0	18.3	5.9	0.0	0.0	41.7	5.5
1/8/10	39.0	3.9	0.5	1.1	0.5	0.0	0.0	7.7	1.2	25.2	3.1
1/11/10	52.5	8.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	45.2	9.1
1/14/10	12.5	1.4	0.2	0.8	0.2	0.0	0.0	1.2	0.6	9.2	1.2
1/17/10	24.4	1.9	0.2	0.9	0.3	0.0	0.0	2.2	0.7	20.2	2.5
1/20/10	56.7	5.5	0.7	2.1	0.7	0.0	0.0	0.0	0.0	51.2	10.1
1/23/10	55.4	5.9	0.7	1.8	0.8	0.0	0.0	11.1	2.1	33.6	4.3
1/26/10	*	*	*	*	*	*	*	*	*	*	*
1/29/10	*	*	*	*	*	*	*	*	*	*	*
2/19/10	35.9	4.5	0.5	4.9	0.7	0.0	0.0	8.1	1.6	16.6	2.3
2/22/10	21.4	2.9	0.3	2.0	0.4	0.0	0.0	2.7	0.8	13.6	1.8
2/25/10	7.2	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	5.8	1.1
2/28/10	17.1	1.5	0.2	2.3	0.3	0.0	0.0	0.0	0.0	13.1	2.5
3/3/10	28.4	3.6	0.4	2.1	0.5	0.0	0.0	4.8	1.3	17.2	2.3
3/6/10	5.2	0.7	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.8	0.6
3/9/10	5.3	0.6	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.1	0.6
3/12/10	12.0	1.5	0.2	0.7	0.2	0.0	0.0	3.9	0.9	5.6	1.0
3/15/10	12.0	1.2	0.1	1.3	0.2	0.0	0.0	2.3	0.6	7.9	1.1
Average	**36.7**	**4.0**	**0.5**	**0.9**	**0.2**	**2.3**	**0.7**	**2.5**	**0.6**	**26.9**	**4.1**

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$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
RAMS – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/15/09	34.6	1.6	0.3	1.1	0.2	0.0	0.0	0.0	0.0	7.7	1.3	20.6	1.8
11/17/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/18/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/21/09	50.2	1.5	0.4	0.6	0.2	0.0	0.0	0.0	0.0	14.9	1.3	35.9	2.8
11/27/09	33.7	0.7	0.2	0.6	0.1	7.8	2.1	0.0	0.0	8.8	0.7	15.4	2.0
12/3/09	22.5	1.3	0.2	0.4	0.2	0.0	0.0	0.0	0.0	5.5	1.0	13.0	1.3
12/9/09	55.4	3.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	17.0	2.3	29.9	2.7
12/10/09	72.2	3.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	19.8	2.7	41.5	3.5
12/11/09	57.6	2.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	18.5	1.8	42.0	3.5
12/12/09	59.3	3.8	0.7	1.6	0.5	0.0	0.0	0.0	0.0	17.9	2.9	32.8	3.2
12/13/09	68.7	2.2	0.5	1.0	0.3	0.0	0.0	4.4	1.1	20.4	1.8	41.8	3.7
12/21/09	52.0	1.7	0.4	0.5	0.2	0.0	0.0	3.0	0.9	15.2	1.4	34.5	3.1
12/24/09	32.2	1.0	0.2	0.6	0.1	0.0	0.0	3.6	1.0	10.2	0.9	18.5	2.1
12/27/09	6.6	0.1	0.0	0.3	0.0	0.0	0.0	1.6	0.8	2.2	0.2	2.4	0.6
12/30/09	68.8	3.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	23.3	2.5	49.9	4.3
1/2/10	64.9	2.6	1.2	0.9	0.4	9.3	4.8	0.0	0.0	23.1	2.2	28.2	5.3
1/8/10	39.0	2.3	0.5	0.8	0.3	0.0	0.0	5.7	1.6	12.3	1.8	17.7	2.3
1/11/10	52.5	4.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	20.1	3.2	21.7	3.0
1/14/10	12.5	0.9	0.2	0.7	0.1	0.0	0.0	0.0	0.0	3.3	0.7	7.7	0.9
1/17/10	24.4	1.1	0.2	0.7	0.2	0.0	0.0	0.0	0.0	5.2	0.9	17.6	1.4
1/20/10	56.7	2.2	0.5	1.7	0.3	0.0	0.0	0.0	0.0	16.1	1.8	42.1	3.8
1/23/10	55.4	3.1	0.6	1.4	0.4	9.4	4.3	0.0	0.0	14.8	2.4	27.2	3.3
1/26/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/29/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/19/10	35.9	2.2	0.5	4.6	0.5	0.0	0.0	0.0	0.0	11.4	2.0	15.4	2.0
2/22/10	21.4	1.1	0.3	1.7	0.2	0.0	0.0	0.0	0.0	10.3	1.1	8.6	1.2
2/25/10	7.2	0.3	0.1	0.3	0.1	0.0	0.0	1.4	0.7	2.3	0.3	1.9	0.8
2/28/10	17.1	0.8	0.2	2.2	0.2	0.0	0.0	3.3	0.9	3.8	0.8	7.1	1.5
3/3/10	28.4	1.9	0.4	1.8	0.3	0.0	0.0	0.0	0.0	9.2	1.6	14.2	1.6
3/6/10	5.2	0.3	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.5	0.3	3.9	0.6
3/9/10	5.3	0.3	0.1	0.3	0.0	0.0	0.0	1.4	0.7	1.7	0.2	2.0	0.7
3/12/10	12.0	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	3.5	0.6	8.0	1.2
3/15/10	12.0	0.7	0.2	1.2	0.1	0.0	0.0	0.0	0.0	3.5	0.6	6.8	0.8
Average	**36.7**	**1.8**	**0.4**	**0.9**	**0.2**	**0.9**	**0.4**	**0.8**	**0.3**	**11.2**	**1.4**	**21.0**	**2.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. Peger Road – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.7	1.7	0.2	1.0	0.4	0.0	0.0	2.4	0.8	8.2	1.2
11/9/09	12.0	1.5	0.2	1.0	0.2	0.0	0.0	2.3	0.9	6.1	1.0
11/15/09	16.2	1.7	0.2	1.2	0.2	0.0	0.0	2.2	0.9	10.4	1.5
11/17/09	13.7	1.7	0.2	1.2	0.4	0.0	0.0	2.0	0.7	8.9	1.2
11/18/09	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*
11/21/09	19.1	3.6	0.4	1.1	0.5	0.0	0.0	1.8	0.8	13.0	1.8
11/27/09	16.5	2.7	0.3	1.4	0.4	0.0	0.0	0.0	0.0	15.7	1.4
12/3/09	12.9	1.5	0.2	1.0	0.3	0.0	0.0	2.2	0.6	8.1	1.2
12/9/09	66.6	12.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0	56.3	5.6
12/10/09	64.0	12.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	54.0	5.4
12/11/09	58.8	10.3	1.2	2.7	1.3	0.0	0.0	4.4	2.1	38.4	4.7
12/12/09	36.8	6.3	0.7	2.6	0.8	0.0	0.0	0.0	0.0	29.0	6.0
12/13/09	40.7	6.6	0.7	2.6	0.9	0.0	0.0	0.0	0.0	30.8	7.7
12/21/09	41.7	6.5	0.7	2.1	0.9	0.0	0.0	9.2	2.1	22.1	3.1
12/24/09	28.6	4.8	0.5	2.2	0.6	11.2	3.0	0.0	0.0	10.8	2.6
12/27/09	17.8	2.8	0.3	1.3	0.4	0.0	0.0	5.7	1.2	7.1	1.2
12/30/09	49.9	9.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	41.9	3.0
1/2/10	45.6	9.5	1.1	3.7	1.2	0.0	0.0	0.0	0.0	29.9	3.7
1/8/10	39.7	7.7	0.9	2.7	1.0	0.0	0.0	0.0	0.0	28.2	7.3
1/11/10	47.1	12.1	1.3	3.1	1.5	0.0	0.0	0.0	0.0	30.3	7.8
1/14/10	9.2	1.0	0.1	0.6	0.1	3.4	1.4	0.0	0.0	3.7	1.2
1/17/10	17.6	2.3	0.3	1.4	0.3	0.0	0.0	3.5	1.0	10.0	1.5
1/20/10	29.6	5.2	0.6	2.6	0.7	0.0	0.0	7.8	1.7	12.7	2.0
1/23/10	32.2	5.0	0.6	2.3	0.7	0.0	0.0	0.0	0.0	24.4	6.2
1/26/10	64.1	11.0	1.2	4.0	1.5	0.0	0.0	0.0	0.0	49.7	4.9
1/29/10	33.9	5.7	0.6	2.2	0.8	0.0	0.0	12.6	2.0	11.5	2.0
2/1/10	23.5	3.5	0.4	3.5	0.5	0.0	0.0	0.0	0.0	16.5	4.6
2/4/10	33.9	7.4	0.8	3.1	1.0	0.0	0.0	0.0	0.0	23.3	6.1
2/7/10	11.1	1.6	0.2	1.2	0.2	0.0	0.0	1.7	0.6	6.5	1.0
2/10/10	33.5	3.8	0.4	4.2	0.6	0.0	0.0	8.5	1.5	15.5	2.2
2/13/10	32.6	4.9	0.5	5.7	1.1	0.0	0.0	6.4	1.7	15.4	2.2
2/16/10	35.9	4.6	0.5	6.2	1.2	0.0	0.0	7.8	1.9	16.8	2.3
2/19/10	33.2	2.9	0.3	6.5	0.5	0.0	0.0	9.4	1.4	14.1	2.0
2/22/10	8.9	0.8	0.1	1.3	0.3	0.0	0.0	2.2	0.7	4.7	0.8
2/25/10	*	*	*	*	*	*	*	*	*	*	*
2/28/10	9.4	0.8	0.1	1.7	0.1	0.0	0.0	0.0	0.0	7.2	1.5
3/3/10	25.8	3.1	0.3	2.1	0.4	0.0	0.0	10.7	1.5	9.4	1.6
3/6/10	6.5	0.6	0.1	0.4	0.1	0.0	0.0	0.0	0.0	5.6	0.8
3/9/10	3.6**	**	**	**	**	**	**	**	**	**	**
3/12/10	7.8	1.0	0.1	0.8	0.1	0.0	0.0	2.5	0.8	3.5	0.7
3/15/10	10.8	0.9	0.1	1.1	0.1	0.0	0.0	0.0	0.0	8.9	1.9
Average	**29.0**	**4.8**	**0.5**	**2.1**	**0.6**	**0.4**	**0.1**	**2.8**	**0.7**	**18.6**	**3.0**

Notes: **Incomplete filter collection, so no model run conducted.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. Peger Road – Winter 2009/2010.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/3/09	13.7	0.8	0.2	0.7	0.1	0.0	0.0	0.0	0.0	4.4	0.6	7.3	0.9
11/9/09	12.0	0.6	0.3	0.8	0.3	1.9	0.8	0.0	0.0	3.9	1.3	4.9	1.5
11/15/09	16.2	0.9	0.2	1.0	0.1	0.0	0.0	0.0	0.0	4.1	0.8	9.0	1.0
11/17/09	13.7	1.0	0.2	1.1	0.2	0.0	0.0	0.0	0.0	4.2	0.8	7.4	1.0
11/18/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/19/09	*	*	*	*	*	*	*	*	*	*	*	*	*
11/21/09	19.1	1.9	0.4	0.8	0.3	0.0	0.0	0.0	0.0	9.6	1.5	8.1	1.4
11/27/09	16.5	1.0	0.4	1.2	0.4	0.0	0.0	3.0	0.8	8.8	2.3	2.7	0.7
12/3/09	12.9	0.7	0.1	0.7	0.1	0.0	0.0	0.0	0.0	4.0	0.6	7.6	0.9
12/9/09	66.6	6.0	1.1	2.1	0.8	0.0	0.0	0.0	0.0	33.8	4.5	27.5	6.2
12/10/09	64.0	5.9	1.1	2.1	0.8	0.0	0.0	0.0	0.0	32.0	4.4	27.0	6.1
12/11/09	58.8	5.2	1.0	2.0	0.7	0.0	0.0	0.0	0.0	30.4	4.1	19.9	3.6
12/12/09	36.8	3.4	0.7	2.2	0.5	0.0	0.0	0.0	0.0	16.1	2.7	11.8	2.4
12/13/09	40.7	3.0	0.6	2.1	0.4	6.2	2.7	0.0	0.0	19.0	2.4	12.2	4.5
12/21/09	41.7	3.4	0.7	1.6	0.5	0.0	0.0	4.3	1.7	17.5	2.6	13.4	2.6
12/24/09	28.6	1.9	0.4	2.1	0.3	0.0	0.0	0.0	0.0	15.1	1.7	9.6	1.7
12/27/09	17.8	1.2	0.2	0.8	0.2	0.0	0.0	3.1	0.7	6.8	1.0	6.9	1.6
12/30/09	49.9	4.2	0.8	1.8	0.6	0.0	0.0	5.6	1.3	27.6	3.3	11.4	4.5
1/2/10	45.6	5.2	1.0	1.9	0.7	0.0	0.0	0.0	0.0	24.0	4.0	13.0	3.3
1/8/10	39.7	3.4	0.7	2.3	0.5	0.0	0.0	3.2	1.1	22.0	2.7	7.4	3.6
1/11/10	47.1	6.2	1.1	0.9	0.8	0.0	0.0	0.0	0.0	32.2	4.6	5.3	5.7
1/14/10	9.2	0.5	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.3	0.4	6.4	1.0
1/17/10	17.6	1.1	0.2	0.9	0.2	0.0	0.0	0.0	0.0	6.2	0.9	8.4	1.1
1/20/10	29.6	2.5	0.6	1.6	0.6	0.0	0.0	3.4	1.0	13.8	3.0	8.5	3.6
1/23/10	32.2	1.9	0.6	2.0	0.5	3.2	1.4	0.0	0.0	14.9	2.7	10.8	3.5
1/26/10	64.1	5.1	1.0	3.5	0.7	0.0	0.0	4.9	2.0	31.9	4.1	16.2	5.5
1/29/10	33.9	1.9	0.4	1.8	0.3	0.0	0.0	6.8	1.0	17.9	1.7	5.6	2.6
2/1/10	23.5	1.5	0.3	3.2	0.3	0.0	0.0	0.0	0.0	11.0	1.4	4.2	1.9
2/4/10	33.9	4.0	0.7	2.7	0.6	0.0	0.0	0.0	0.0	18.6	3.1	5.0	2.6
2/7/10	11.1	0.9	0.2	1.1	0.2	0.0	0.0	0.0	0.0	4.2	0.8	5.0	0.9
2/10/10	33.5	1.7	0.4	3.9	0.4	0.0	0.0	5.1	1.4	11.5	1.7	9.9	1.9
2/13/10	32.6	2.2	0.7	4.5	0.7	0.0	0.0	4.3	1.2	15.1	3.7	6.6	2.8
2/16/10	35.9	2.0	0.7	5.2	0.8	0.0	0.0	4.5	1.4	14.0	3.7	10.2	3.2
2/19/10	33.2	1.0	0.3	5.5	0.4	0.0	0.0	4.7	1.5	9.6	1.5	10.9	2.0
2/22/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/25/10	*	*	*	*	*	*	*	*	*	*	*	*	*
2/28/10	9.4	0.6	0.1	1.4	0.1	2.6	1.2	0.0	0.0	1.9	0.5	3.1	1.5
3/3/10	25.8	0.7	0.2	1.9	0.2	0.0	0.0	6.3	0.9	9.9	0.9	8.1	1.6
3/6/10	6.5	0.3	0.1	0.3	0.0	1.8	0.8	0.0	0.0	2.0	0.2	1.7	0.8
3/9/10	3.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/12/10	7.8	0.5	0.2	0.7	0.2	0.0	0.0	1.3	0.5	2.5	0.9	3.1	1.2
3/15/10	10.8	0.5	0.1	1.0	0.1	0.0	0.0	2.2	0.8	2.6	0.4	4.2	1.0
Average	**29.0**	**2.3**	**0.5**	**1.9**	**0.4**	**0.4**	**0.2**	**1.7**	**0.5**	**13.7**	**2.1**	**9.2**	**2.5**

Notes: **Incomplete filter collection, so no model run conducted.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/10	14.5	2.0	0.2	0.9	0.3	0.0	0.0	0.0	0.0	11.5	0.4
11/4/10	3.3**	**	**	**	**	**	**	**	**	**	**
11/7/10	9.6	1.9	0.2	1.2	0.3	0.0	0.0	0.0	0.0	6.5	1.0
11/10/10	8.6	1.2	0.1	0.8	0.2	0.0	0.0	0.0	0.0	6.5	0.2
11/13/10	8.1	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	6.5	0.2
11/16/10	22.0	3.1	0.4	1.4	0.4	0.0	0.0	0.0	0.0	18.2	1.1
11/19/10	17.6	2.4	0.3	1.5	0.3	0.0	0.0	0.0	0.0	13.9	0.5
11/22/10	11.5	2.0	0.2	0.8	0.3	5.9	1.2	0.0	0.0	2.9	0.5
11/25/10	*	*	*	*	*	*	*	*	*	*	*
11/28/10	14.4	2.4	0.3	1.2	0.3	0.0	0.0	0.0	0.0	10.4	0.5
12/1/10	43.1	8.9	1.1	3.1	1.1	0.0	0.0	0.0	0.0	31.0	1.7
12/4/10	7.0	1.3	0.2	0.7	0.2	0.0	0.0	0.0	0.0	5.0	0.7
12/7/10	36.5	7.6	0.9	1.9	1.0	0.0	0.0	0.0	0.0	26.6	3.9
12/10/10	26.1	4.5	0.6	2.2	0.6	0.0	0.0	0.0	0.0	19.1	2.8
12/13/10	15.2	2.4	0.3	1.3	0.3	0.0	0.0	0.0	0.0	11.4	1.6
12/16/10	*	*	*	*	*	*	*	*	*	*	*
12/19/10	*	*	*	*	*	*	*	*	*	*	*
12/22/10	*	*	*	*	*	*	*	*	*	*	*
12/25/10	*	*	*	*	*	*	*	*	*	*	*
12/28/10	*	*	*	*	*	*	*	*	*	*	*
12/31/10	*	*	*	*	*	*	*	*	*	*	*
1/3/11	*	*	*	*	*	*	*	*	*	*	*
1/6/11	*	*	*	*	*	*	*	*	*	*	*
1/9/11	*	*	*	*	*	*	*	*	*	*	*
1/12/11	*	*	*	*	*	*	*	*	*	*	*
1/15/11	*	*	*	*	*	*	*	*	*	*	*
1/18/11	*	*	*	*	*	*	*	*	*	*	*
1/21/11	*	*	*	*	*	*	*	*	*	*	*
1/24/11	*	*	*	*	*	*	*	*	*	*	*
1/27/11	*	*	*	*	*	*	*	*	*	*	*
1/30/11	*	*	*	*	*	*	*	*	*	*	*
2/2/11	*	*	*	*	*	*	*	*	*	*	*
2/5/11	34.9	6.8	0.8	4.4	0.9	0.0	0.0	0.0	0.0	23.3	1.3
2/8/11	33.5	5.0	0.6	3.1	0.7	0.0	0.0	0.0	0.0	26.3	1.0
Average	**20.2**	**3.5**	**0.4**	**1.7**	**0.5**	**0.4**	**0.1**	**0.0**	**0.0**	**14.6**	**1.1**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. State Building – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/1/10	14.5	1.0	0.2	0.5	0.1	0.0	0.0	1.0	0.2	4.5	0.8	7.0	0.9
11/4/10	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
11/7/10	9.6	1.2	0.2	1.0	0.2	0.0	0.0	0.0	0.0	3.2	0.9	3.3	1.0
11/10/10	8.6	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	2.7	0.5	4.1	0.6
11/13/10	8.1	0.7	0.1	0.6	0.1	0.8	0.4	0.0	0.0	1.6	0.5	4.5	0.6
11/16/10	22.0	1.8	0.4	1.3	0.3	2.6	1.2	0.0	0.0	7.2	1.5	7.6	1.6
11/19/10	17.6	1.4	0.3	1.3	0.2	0.0	0.0	0.0	0.0	5.6	1.1	9.2	1.2
11/22/10	11.5	1.8	0.2	0.8	0.2	0.0	0.0	1.5	0.3	0.0	0.0	6.8	0.4
11/25/10	*	*	*	*	*	*	*	*	*	*	*	*	*
11/28/10	14.4	1.4	0.3	0.9	0.2	0.0	0.0	0.0	0.0	5.1	1.1	5.9	1.2
12/1/10	43.1	5.0	1.0	1.7	0.7	0.0	0.0	0.0	0.0	21.4	3.9	10.7	4.3
12/4/10	7.0	0.9	0.2	0.5	0.1	0.0	0.0	0.0	0.0	2.1	0.6	2.7	0.7
12/7/10	36.5	3.8	0.8	1.6	0.5	0.0	0.0	0.0	0.0	20.9	3.1	4.5	3.4
12/10/10	26.1	2.6	0.5	2.1	0.4	0.0	0.0	0.0	0.0	10.2	2.0	8.6	2.2
12/13/10	15.2	1.4	0.3	0.9	0.2	0.0	0.0	0.0	0.0	5.5	1.0	5.7	1.2
12/16/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/19/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/22/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/25/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/28/10	*	*	*	*	*	*	*	*	*	*	*	*	*
12/31/10	*	*	*	*	*	*	*	*	*	*	*	*	*
1/3/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/6/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/9/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/12/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/15/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/18/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/21/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/24/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/27/11	*	*	*	*	*	*	*	*	*	*	*	*	*
1/30/11	*	*	*	*	*	*	*	*	*	*	*	*	*
2/2/11	*	*	*	*	*	*	*	*	*	*	*	*	*
2/5/11	34.9	3.2	0.7	3.0	0.5	0.0	0.0	0.0	0.0	20.4	2.8	3.3	3.1
2/8/11	33.5	2.5	0.6	2.9	0.4	0.0	0.0	0.0	0.0	13.6	2.1	14.0	2.4
Average	**20.2**	**2.0**	**0.4**	**1.3**	**0.3**	**0.2**	**0.1**	**0.2**	**0.04**	**8.3**	**1.5**	**6.5**	**1.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. North Pole – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	23.4	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	20.8	1.5
1/12/11	11.7	1.0	0.1	0.5	0.1	0.0	0.0	2.2	0.6	8.1	1.1
1/15/11	33.8	2.6	0.3	0.8	0.3	9.8	2.7	0.0	0.0	21.9	2.9
1/18/11	26.8	2.3	0.3	1.1	0.3	0.0	0.0	3.0	1.1	18.7	2.4
1/21/11	40.8	5.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	37.0	7.4
1/24/11	6.5	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	5.5	0.8
1/27/11	14.0	1.1	0.1	0.7	0.1	3.8	1.9	0.0	0.0	7.8	1.2
1/30/11	58.5	3.3	0.4	1.6	0.4	0.0	0.0	0.0	0.0	54.3	10.6
2/2/11	23.3	2.0	0.2	1.5	0.3	0.0	0.0	0.0	0.0	19.4	1.4
2/5/11	28.8	2.2	0.2	1.5	0.3	0.0	0.0	4.0	1.1	19.7	2.5
Average	**26.8**	**2.1**	**0.3**	**0.9**	**0.2**	**1.4**	**0.5**	**0.9**	**0.3**	**21.3**	**3.2**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. North Pole – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	23.4	0.7	0.1	1.1	0.1	5.3	1.9	0.0	0.0	2.9	0.6	13.0	1.6
1/12/11	11.7	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	1.8	0.5	8.5	0.8
1/15/11	33.8	0.8	0.2	0.6	0.1	0.0	0.0	1.8	0.7	7.3	0.7	22.8	2.1
1/18/11	26.8	0.8	0.2	0.6	0.2	0.0	0.0	1.2	0.6	6.9	1.1	17.8	1.9
1/21/11	40.8	2.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	13.4	1.9	19.6	2.1
1/24/11	6.5	0.4	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.6	0.3	4.6	0.6
1/27/11	14.0	0.6	0.1	0.5	0.1	0.0	0.0	0.0	0.0	2.1	0.5	11.4	1.1
1/30/11	58.5	1.4	0.3	1.1	0.2	13.5	2.6	0.0	0.0	8.8	1.2	35.1	4.9
2/2/11	23.3	1.4	0.2	1.3	0.2	0.0	0.0	3.8	1.0	2.5	1.1	14.0	1.9
2/5/11	28.8	0.8	0.2	1.1	0.1	0.0	0.0	1.9	0.7	5.9	0.7	19.0	1.8
Average	**26.8**	**1.0**	**0.2**	**0.7**	**0.1**	**1.9**	**0.5**	**0.9**	**0.3**	**5.3**	**0.8**	**16.6**	**1.9**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. Peger Road – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	22.7	3.0	0.3	2.6	0.4	0.0	0.0	0.0	0.0	17.2	4.4
1/12/11	48.4	10.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	37.3	4.0
1/15/11	24.6	3.8	0.4	1.1	0.5	7.2	3.0	0.0	0.0	12.9	2.0
1/18/11	44.9	9.1	1.0	2.7	1.2	0.0	0.0	0.0	0.0	34.7	7.2
1/21/11	23.3	4.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	18.2	4.6
1/24/11	12.4	1.7	0.2	1.1	0.3	0.0	0.0	1.5	0.6	8.2	1.2
1/27/11	14.6	2.0	0.2	1.6	0.5	0.0	0.0	3.0	0.7	8.3	1.3
1/30/11	35.4	4.9	0.5	2.8	0.7	0.0	0.0	0.0	0.0	26.5	6.6
2/2/11	25.1	2.6	0.3	4.3	0.4	0.0	0.0	3.8	1.1	13.4	1.8
2/5/11	34.0	5.6	0.6	4.0	0.8	0.0	0.0	0.0	0.0	25.0	6.3
Average	**28.6**	**4.8**	**0.5**	**2.0**	**0.5**	**0.7**	**0.3**	**0.8**	**0.2**	**20.2**	**3.9**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. Peger Road – Winter 2010/2011.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
1/9/11	22.7	1.1	0.5	2.5	0.6	4.1	1.4	0.0	0.0	7.5	2.6	7.4	2.8
1/12/11	48.4	5.1	1.0	1.8	0.7	0.0	0.0	3.2	1.3	29.4	4.0	7.5	5.0
1/15/11	24.6	1.6	0.3	0.8	0.2	0.0	0.0	0.0	0.0	11.8	1.3	11.7	2.1
1/18/11	44.9	4.2	0.8	2.1	0.6	0.0	0.0	0.0	0.0	26.9	3.2	11.0	4.3
1/21/11	23.3	2.0	0.4	0.8	0.3	0.0	0.0	0.0	0.0	11.4	1.6	11.0	2.3
1/24/11	12.4	1.0	0.2	0.8	0.1	0.0	0.0	0.0	0.0	3.7	0.8	7.0	0.9
1/27/11	14.6	1.1	0.2	1.2	0.2	0.0	0.0	0.0	0.0	5.1	0.9	7.4	1.0
1/30/11	35.4	2.0	0.5	2.5	0.5	0.0	0.0	2.5	0.9	14.6	2.4	13.7	3.2
2/2/11	25.1	0.7	0.4	3.5	0.4	2.4	1.0	0.0	0.0	8.5	1.8	11.7	2.0
2/5/11	34.0	2.2	0.5	3.7	0.4	0.0	0.0	3.9	0.9	16.3	2.0	6.8	2.8
Average	**28.6**	**2.1**	**0.5**	**2.0**	**0.4**	**0.6**	**0.2**	**1.0**	**0.3**	**13.5**	**2.1**	**9.5**	**2.6**

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. State Building – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	11.0	2.2	0.3	0.8	0.3	0.0	0.0	0.0	0.0	8.2	0.7
11/5/11	*	*	*	*	*	*	*	*	*	*	*
11/8/11	10.3	1.6	0.2	0.5	0.2	0.0	0.0	0.0	0.0	8.4	1.2
11/11/11	8.9	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	7.2	0.2
11/14/11	24.6	3.6	0.4	1.2	0.5	0.0	0.0	0.0	0.0	19.8	1.6
11/17/11	32.8	6.2	0.8	2.1	0.8	0.0	0.0	0.0	0.0	23.4	5.7
11/20/11	*	*	*	*	*	*	*	*	*	*	*
11/23/11	14.8	2.1	0.3	0.9	0.3	0.0	0.0	0.0	0.0	11.5	0.7
11/26/11	24.7	4.4	0.5	1.6	0.6	0.0	0.0	0.0	0.0	18.3	1.5
11/29/11	27.2	4.6	0.6	1.5	0.6	0.0	0.0	0.0	0.0	20.2	1.7
12/2/11	14.7	1.9	0.2	1.0	0.2	0.0	0.0	0.0	0.0	11.5	2.1
12/5/11	*	*	*	*	*	*	*	*	*	*	*
12/8/11	27.2	4.4	0.5	1.9	0.6	0.0	0.0	0.0	0.0	21.1	1.7
12/11/11	*	*	*	*	*	*	*	*	*	*	*
12/14/11	24.7	4.0	0.5	1.6	0.5	8.2	2.3	0.0	0.0	9.9	1.3
12/17/11	37.3	5.9	0.7	1.5	0.7	0.0	0.0	0.0	0.0	31.6	5.8
12/20/11	13.8	1.5	0.2	0.8	0.2	0.0	0.0	0.0	0.0	12.1	0.4
12/23/11	6.3**	**	**	**	**	**	**	**	**	**	**
12/26/11	23.1	4.0	0.5	1.6	0.5	8.0	2.4	0.0	0.0	10.9	1.4
12/29/11	31.8	5.7	0.7	1.6	0.7	0.0	0.0	0.0	0.0	25.5	2.1
1/1/12	*	*	*	*	*	*	*	*	*	*	*
1/4/12	14.3	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	11.2	0.9
1/7/12	15.6	3.2	0.4	1.1	0.4	0.0	0.0	0.0	0.0	11.0	1.0
1/10/12	24.4	4.0	0.5	1.2	0.5	0.0	0.0	0.0	0.0	18.0	2.6
1/13/12	23.2	4.8	0.6	1.2	0.6	0.0	0.0	0.0	0.0	17.9	0.9
1/16/12	29.1	6.1	0.8	2.4	0.8	0.0	0.0	8.8	1.6	12.1	1.6
1/19/12	40.5	8.1	1.0	4.0	1.0	0.0	0.0	0.0	0.0	27.3	1.5
1/22/12	*	*	*	*	*	*	*	*	*	*	*
1/25/12	9.8	1.8	0.2	0.8	0.2	0.0	0.0	0.0	0.0	6.9	0.5
1/28/12	36.8	7.6	0.9	2.2	1.0	0.0	0.0	0.0	0.0	18.3	2.0
1/31/12	18.7	4.9	0.6	1.8	0.6	0.0	0.0	0.0	0.0	11.4	1.2
2/3/12	6.5**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	3.9	0.5	2.1	0.5	0.0	0.0	0.0	0.0	18.4	1.2
2/9/12	18.1	2.3	0.3	1.2	0.3	0.0	0.0	0.0	0.0	13.8	0.8
2/12/12	18.3	2.1	0.3	1.9	0.3	0.0	0.0	0.0	0.0	14.8	0.8
2/15/12	27.0	4.5	0.6	2.2	0.6	0.0	0.0	0.0	0.0	20.2	2.9
2/18/12	25.6	3.9	0.5	3.2	0.5	0.0	0.0	0.0	0.0	17.5	1.2
2/21/12	13.7	2.9	0.4	1.7	0.4	0.0	0.0	0.0	0.0	9.8	0.9
2/24/12	5.0**	**	**	**	**	**	**	**	**	**	**
2/27/12	4.3**	**	**	**	**	**	**	**	**	**	**
3/1/12	9.0	2.2	0.3	0.8	0.3	0.0	0.0	0.0	0.0	5.8	0.4
3/4/12	*	*	*	*	*	*	*	*	*	*	*
3/7/12	*	*	*	*	*	*	*	*	*	*	*
3/10/12	9.5	2.2	0.3	1.3	0.3	0.0	0.0	0.0	0.0	5.9	0.4
3/13/12	13.9	2.7	0.3	1.4	0.4	0.0	0.0	0.0	0.0	9.7	0.8

3/16/12	16.3	3.4	0.4	1.3	0.4	0.0	0.0	0.0	0.0	11.5	0.9
3/19/12	10.6	2.6	0.3	1.2	0.3	0.0	0.0	0.0	0.0	6.9	1.1
3/22/12	13.3	3.0	0.4	1.4	0.4	0.0	0.0	0.0	0.0	9.2	0.8
3/25/12	11.0	1.7	0.2	1.2	0.2	0.0	0.0	0.0	0.0	7.9	0.5
3/28/12	8.6	1.4	0.2	1.0	0.2	0.0	0.0	0.0	0.0	6.3	0.4
3/31/12	5.4**	**	**	**	**	**	**	**	**	**	**
Average	**20.0**	**3.5**	**0.4**	**1.5**	**0.5**	**0.4**	**0.1**	**0.2**	**0.04**	**14.0**	**1.4**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. State Building – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	11.0	1.6	0.3	0.6	0.2	0.0	0.0	0.0	0.0	2.4	1.1	6.8	1.3
11/5/11	*	*	*	*	*	*	*	*	*	*	*	*	*
11/8/11	10.3	1.1	0.2	0.3	0.2	0.0	0.0	0.0	0.0	2.2	0.8	6.1	0.9
11/11/11	8.9	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.4	0.5	6.3	0.6
11/14/11	24.6	2.3	0.4	0.9	0.3	0.0	0.0	0.0	0.0	5.9	1.7	16.4	1.9
11/17/11	32.8	3.8	0.8	1.2	0.5	0.0	0.0	0.0	0.0	12.9	3.0	12.4	2.0
11/20/11	*	*	*	*	*	*	*	*	*	*	*	*	*
11/23/11	14.8	1.4	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.7	1.0	6.4	1.2
11/26/11	24.7	2.7	0.5	1.1	0.4	0.0	0.0	0.0	0.0	8.2	2.0	12.5	2.2
11/29/11	27.2	2.8	0.5	0.9	0.4	0.0	0.0	0.0	0.0	8.8	2.1	13.5	2.3
12/2/11	14.7	1.4	0.3	0.9	0.2	0.0	0.0	1.0	0.3	2.2	1.1	8.5	1.2
12/5/11	*	*	*	*	*	*	*	*	*	*	*	*	*
12/8/11	27.2	2.5	0.5	1.2	0.4	0.0	0.0	0.0	0.0	9.8	1.9	13.2	2.1
12/11/11	*	*	*	*	*	*	*	*	*	*	*	*	*
12/14/11	24.7	2.5	0.5	1.1	0.3	4.2	1.6	0.0	0.0	7.5	1.9	10.3	2.1
12/17/11	37.3	3.7	0.7	0.0	0.0	7.9	2.4	0.0	0.0	13.6	2.6	12.2	2.9
12/20/11	13.8	1.4	0.2	0.8	0.2	3.1	0.9	0.0	0.0	0.0	0.0	8.2	0.5
12/23/11	6.3**	**	**	**	**	**	**	**	**	**	**	**	**
12/26/11	23.1	2.2	0.5	1.0	0.4	1.7	0.8	0.0	0.0	8.3	2.1	11.2	2.2
12/29/11	31.8	3.8	0.7	1.1	0.5	0.0	0.0	0.0	0.0	9.0	2.6	20.0	2.9
1/1/12	*	*	*	*	*	*	*	*	*	*	*	*	*
1/4/12	14.3	1.4	0.3	0.8	0.2	0.0	0.0	0.0	0.0	2.9	1.0	9.6	1.1
1/7/12	15.6	2.1	0.4	0.7	0.3	0.0	0.0	0.0	0.0	5.6	1.5	6.4	1.6
1/10/12	24.4	2.7	0.5	0.8	0.4	0.0	0.0	0.0	0.0	6.7	1.9	11.3	2.1
1/13/12	23.2	3.0	0.6	0.6	0.4	0.0	0.0	0.0	0.0	10.1	2.2	8.7	2.4
1/16/12	29.1	3.7	0.8	1.4	0.5	0.0	0.0	5.9	1.0	13.6	2.9	4.8	2.0
1/19/12	40.5	5.2	1.0	2.9	0.7	0.0	0.0	0.0	0.0	15.4	3.6	13.4	4.0
1/22/12	*	*	*	*	*	*	*	*	*	*	*	*	*
1/25/12	9.8	1.2	0.2	0.6	0.2	0.0	0.0	0.8	0.2	2.9	0.9	2.0	1.0
1/28/12	*	*	*	*	*	*	*	*	*	*	*	*	*
1/31/12	*	*	*	*	*	*	*	*	*	*	*	*	*
2/3/12	6.5**	**	**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	2.2	0.5	1.6	0.3	0.0	0.0	4.9	0.4	7.7	1.7	4.7	1.9
2/9/12	18.1	1.6	0.3	0.9	0.2	5.4	1.1	0.0	0.0	4.2	1.2	5.2	1.4
2/12/12	18.3	1.4	0.3	1.6	0.2	4.5	0.9	0.0	0.0	4.2	1.1	6.6	1.2
2/15/12	27.0	2.4	0.5	1.5	0.4	0.0	0.0	3.0	0.5	10.4	1.9	6.7	2.1
2/18/12	25.6	2.6	0.5	2.6	0.4	0.0	0.0	0.0	0.0	7.7	2.0	7.7	2.2
2/21/12	13.7	1.9	0.4	1.3	0.3	0.0	0.0	0.9	0.4	5.2	1.6	4.3	1.7
2/24/12	5.0**	**	**	**	**	**	**	**	**	**	**	**	**
2/27/12	4.3**	**	**	**	**	**	**	**	**	**	**	**	**
3/1/12	9.0	1.2	0.2	0.4	0.2	0.0	0.0	0.0	0.0	5.8	0.2	0.0	0.0
3/4/12*	*	*	*	*	*	*	*	*	*	*	*	*	*
3/7/12*	*	*	*	*	*	*	*	*	*	*	*	*	*
3/10/12	9.5	1.6	0.3	1.1	0.2	0.0	0.0	0.0	0.0	2.7	1.2	3.5	1.3

3/13/12	13.9	1.8	0.3	1.0	0.3	0.0	0.0	0.0	0.0	5.6	1.3	2.7	1.4
3/16/12	16.3	2.1	0.3	0.7	0.3	3.8	1.3	0.0	0.0	7.8	0.7	0.0	0.0
3/19/12	10.6	1.7	0.3	0.9	0.2	0.0	0.0	0.0	0.0	4.5	1.3	2.2	1.4
3/22/12	13.3	2.0	0.4	1.0	0.3	0.0	0.0	0.0	0.0	5.6	1.5	2.4	1.6
3/25/12	11.0	1.3	0.2	1.0	0.2	0.0	0.0	0.0	0.0	2.1	1.0	4.8	1.1
3/28/12	8.6	1.0	0.2	0.8	0.2	0.0	0.0	0.0	0.0	2.3	0.8	3.1	0.9
3/31/12	5.4**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**20.0**	**2.2**	**0.4**	**1.0**	**0.3**	**0.8**	**0.2**	**0.5**	**0.1**	**6.4**	**1.5**	**7.6**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. North Pole – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	***	***	***	***	***	***	***	***	***	***	***
11/5/11	8.8	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	7.7	1.3
11/8/11	9.2	0.6	0.1	0.3	0.1	0.0	0.0	0.0	0.0	7.7	0.9
11/11/11	12.3	0.5	0.1	0.3	0.1	0.0	0.0	0.0	0.0	12.4	1.2
11/14/11	30.5	1.4	0.2	0.6	0.2	0.0	0.0	0.0	0.0	27.5	4.1
11/17/11	23.2	1.8	0.2	0.7	0.2	0.0	0.0	0.0	0.0	21.7	2.5
11/20/11	82.6	7.7	0.9	2.0	1.0	0.0	0.0	0.0	0.0	63.9	7.1
11/23/11	12.6	0.6	0.1	0.4	0.1	0.0	0.0	0.0	0.0	10.4	1.0
11/26/11	22.4	1.5	0.2	0.7	0.2	0.0	0.0	0.0	0.0	19.2	2.2
11/29/11	30.4	2.6	0.3	0.9	0.3	0.0	0.0	0.0	0.0	28.5	5.7
12/2/11	10.5	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.6	1.1
12/5/11	2.5**	**	**	**	**	**	**	**	**	**	**
12/8/11	42.0	2.8	0.3	1.0	0.4	0.0	0.0	0.0	0.0	38.1	3.3
12/11/11	7.9	0.4	0.0	0.1	0.1	0.0	0.0	0.0	0.0	7.0	1.3
12/14/11	16.1	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	14.6	3.0
12/17/11	36.4	2.8	0.3	0.8	0.3	0.0	0.0	0.0	0.0	32.2	2.1
12/20/11	12.5	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	11.6	1.3
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**
12/26/11	38.3	1.9	0.2	1.0	0.2	0.0	0.0	0.0	0.0	33.3	2.3
12/29/11	34.1	2.6	0.3	1.0	0.3	0.0	0.0	0.0	0.0	31.8	2.9
1/1/12	33.5	2.8	0.4	0.8	0.4	0.0	0.0	0.0	0.0	31.5	2.3
1/4/12	11.6	0.9	0.1	0.7	0.1	0.0	0.0	0.0	0.0	9.5	1.0
1/7/12	10.0	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.2	0.9
1/10/12	16.5	1.3	0.2	0.5	0.2	0.0	0.0	0.0	0.0	14.7	3.0
1/13/12	17.8	2.1	0.2	0.6	0.3	4.5	2.2	0.0	0.0	11.2	1.7
1/16/12	43.0	2.6	0.3	1.2	0.4	0.0	0.0	0.0	0.0	39.8	5.9
1/19/12	39.5	3.0	0.3	1.8	0.4	0.0	0.0	5.2	1.3	28.2	3.5
1/22/12	***	***	***	***	***	***	***	***	***	***	***
1/25/12	***	***	***	***	***	***	***	***	***	***	***
1/28/12	64.9	4.7	0.5	1.5	0.6	0.0	0.0	0.0	0.0	48.5	3.1
1/31/12	14.5	2.1	0.2	1.0	0.3	0.0	0.0	0.0	0.0	12.3	1.2
2/3/12	***	***	***	***	***	***	***	***	***	***	***
2/6/12	42.8	3.0	0.3	1.6	0.4	0.0	0.0	0.0	0.0	32.9	2.3
2/9/12	***	***	***	***	***	***	***	***	***	***	***
2/12/12	***	***	***	***	***	***	***	***	***	***	***
2/15/12	9.0	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	8.3	1.1
2/18/12	29.2	2.1	0.2	1.1	0.3	0.0	0.0	0.0	0.0	25.4	3.8
2/21/12	13.2	0.6	0.1	0.3	0.1	0.0	0.0	0.0	0.0	12.5	2.0
2/24/12	3.5**	**	**	**	**	**	**	**	**	**	**
2/27/12	2.1**	**	**	**	**	**	**	**	**	**	**
3/1/12	5.1**	**	**	**	**	**	**	**	**	**	**
3/4/12	26.0	2.1	0.2	0.8	0.3	5.2	2.3	0.0	0.0	18.8	2.5
3/7/12	4.1**	**	**	**	**	**	**	**	**	**	**
3/10/12	11.1	1.4	0.2	0.6	0.2	0.0	0.0	0.0	0.0	8.6	1.1

3/13/12	4.3**	**	**	**	**	**	**	**	**	**	**
3/16/12	5.5**	**	**	**	**	**	**	**	**	**	**
3/19/12	18.3	1.9	0.2	0.8	0.2	0.0	0.0	0.0	0.0	14.7	1.8
3/22/12	8.3	1.4	0.2	0.5	0.2	0.0	0.0	0.0	0.0	6.8	0.9
3/25/12	6.5	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.9	0.7
Average	**24.2**	**1.8**	**0.2**	**0.7**	**0.2**	**0.3**	**0.1**	**0.1**	**0.04**	**20.4**	**2.3**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn‟t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. North Pole – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	***	***	***	***	***	***	***	***	***	***	***
11/5/11	8.8	0.4	0.1	0.2	0.1	2.2	0.9	0.0	0.0	4.4	1.1
11/8/11	9.2	0.4	0.1	0.2	0.1	0.0	0.0	0.6	0.3	8.1	0.9
11/11/11	12.3	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	10.5	1.0
11/14/11	30.5	0.7	0.1	0.5	0.1	0.0	0.0	2.0	0.5	26.3	1.9
11/17/11	23.2	1.4	0.2	0.4	0.2	0.0	0.0	2.4	1.0	18.0	1.5
11/20/11	82.6	3.9	0.7	0.0	0.0	0.0	0.0	16.0	2.7	69.5	5.8
11/23/11	12.6	0.4	0.1	0.3	0.1	0.0	0.0	0.8	0.3	7.8	0.9
11/26/11	22.4	1.1	0.2	0.5	0.2	0.0	0.0	2.3	0.8	16.6	1.3
11/29/11	30.4	1.9	0.3	0.5	0.3	0.0	0.0	4.0	1.4	19.6	1.7
12/2/11	10.5	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.6	0.7
12/5/11	2.5**	**	**	**	**	**	**	**	**	**	**
12/8/11	42.0	1.5	0.3	0.8	0.2	0.0	0.0	4.5	1.1	36.6	2.7
12/11/11	7.9	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	7.2	0.9
12/14/11	16.1	0.7	0.1	0.3	0.1	0.0	0.0	1.4	0.5	14.0	1.3
12/17/11	36.4	1.8	0.3	0.5	0.2	0.0	0.0	4.0	1.3	28.9	2.5
12/20/11	12.5	0.7	0.1	0.3	0.1	2.7	1.2	0.0	0.0	8.8	1.6
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**
12/26/11	38.3	1.1	0.2	0.8	0.2	0.0	0.0	2.5	0.9	24.7	2.1
12/29/11	34.1	1.2	0.2	0.6	0.2	3.7	1.7	5.7	0.9	22.8	2.9
1/1/12	33.5	4.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	25.4	1.9
1/4/12	11.6	0.7	0.1	0.7	0.1	0.0	0.0	0.0	0.0	10.6	0.9
1/7/12	10.0	0.5	0.1	0.3	0.1	0.0	0.0	1.1	0.4	8.1	0.8
1/10/12	16.5	1.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	17.8	1.3
1/13/12	17.8	1.5	0.3	0.0	0.0	0.0	0.0	3.5	1.0	10.5	1.2
1/16/12	43.0	1.4	0.3	0.9	0.2	0.0	0.0	4.1	1.0	37.0	2.7
1/19/12	39.5	2.0	0.4	1.3	0.3	0.0	0.0	5.2	1.5	27.6	2.0
1/22/12	***	***	***	***	***	***	***	***	***	***	***
1/25/12	***	***	***	***	***	***	***	***	***	***	***
1/28/12	***	***	***	***	***	***	***	***	***	***	***
1/31/12	14.5	1.5	0.3	0.8	0.2	0.0	0.0	3.2	1.1	11.1	1.2
2/3/12	***	***	***	***	***	***	***	***	***	***	***
2/6/12	42.8	2.1	0.4	1.3	0.3	10.2	2.8	3.7	1.5	17.0	2.5
2/9/12	***	***	***	***	***	***	***	***	***	***	***
2/12/12	***	***	***	***	***	***	***	***	***	***	***
2/15/12	9.0	0.5	0.1	0.3	0.1	0.0	0.0	0.0	0.0	8.3	0.7
2/18/12	29.2	1.4	0.2	1.0	0.2	0.0	0.0	2.4	1.0	22.2	1.9
2/21/12	13.2	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	12.6	1.1
2/24/12	3.5**	**	**	**	**	**	**	**	**	**	**
2/27/12	2.1**	**	**	**	**	**	**	**	**	**	**
3/1/12	5.1**	**	**	**	**	**	**	**	**	**	**
3/4/12	26.0	1.6	0.3	0.5	0.2	0.0	0.0	2.9	1.1	18.2	1.5
3/7/12	4.1**	**	**	**	**	**	**	**	**	**	**
3/10/12	11.1	0.9	0.2	0.5	0.1	0.0	0.0	2.0	0.7	7.4	0.9
3/13/12	4.3**	**	**	**	**	**	**	**	**	**	**

3/16/12	5.5**	**	**	**	**	**	**	**	**	**	**
3/19/12	18.3	1.3	0.2	0.5	0.2	0.0	0.0	3.5	0.9	12.0	1.2
3/22/12	8.3	0.8	0.1	0.4	0.1	0.0	0.0	2.5	0.6	5.0	1.1
3/25/12	6.5	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	4.7	0.6
Average	**23.0**	**1.2**	**0.2**	**0.5**	**0.1**	**0.6**	**0.2**	**2.4**	**0.7**	**17.3**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. RAMS – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
12/20/11	21.8	1.5	0.2	0.9	0.2	0.0	0.0	0.0	0.0	15.6	1.4
12/23/11	13.7	1.0	0.1	0.4	0.1	0.0	0.0	0.0	0.0	8.8	1.1
12/26/11	45.0	4.0	0.4	1.6	0.5	0.0	0.0	0.0	0.0	29.4	2.3
12/29/11	24.6	3.9	0.4	1.4	0.5	0.0	0.0	0.0	0.0	18.9	2.3
1/1/12	21.3	3.5	0.4	1.4	0.4	6.7	2.8	0.0	0.0	11.1	1.8
1/4/12	15.1	2.0	0.2	1.0	0.3	0.0	0.0	1.9	0.9	9.9	1.4
1/7/12	23.4	2.7	0.3	1.0	0.3	0.0	0.0	0.0	0.0	18.1	1.7
1/10/12	16.2	2.8	0.3	0.8	0.4	0.0	0.0	0.0	0.0	15.6	1.4
1/13/12	***	***	***	***	***	***	***	***	***	***	***
1/16/12	13.5	1.7	0.2	1.5	0.2	0.0	0.0	0.0	0.0	16.1	1.4
1/19/12	3.1**	**	**	**	**	**	**	**	**	**	**
1/22/12	0.8**	**	**	**	**	**	**	**	**	**	**
1/25/12	0.7**	**	**	**	**	**	**	**	**	**	**
1/28/12	2.8**	**	**	**	**	**	**	**	**	**	**
1/31/12	23.5	3.6	0.4	1.2	0.5	0.0	0.0	0.0	0.0	19.8	1.7
2/3/12	5.6**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	4.1	0.5	1.9	0.5	0.0	0.0	0.0	0.0	18.0	4.6
2/9/12	19.4	2.3	0.3	1.2	0.3	0.0	0.0	4.3	1.1	11.0	1.6
2/12/12	18.1	2.1	0.2	1.7	0.3	0.0	0.0	3.7	1.0	9.3	1.4
2/15/12	30.8	4.4	0.5	2.1	0.6	0.0	0.0	6.9	1.5	14.5	2.1
2/18/12	25.9	3.8	0.4	2.9	0.5	7.0	3.0	0.0	0.0	13.3	2.0
2/21/12	17.0	2.4	0.3	1.2	0.3	0.0	0.0	2.9	1.0	9.6	1.4
2/24/12	5.9**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.5*	**	**	**	**	**	**	**	**	**	**
Average	**22.1**	**2.9**	**0.3**	**1.4**	**0.4**	**0.9**	**0.4**	**1.2**	**0.3**	**14.9**	**1.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
RAMS – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
12/20/11	21.8	1.3	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	12.1	1.1
12/23/11	13.7	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.8
12/26/11	45.0	2.3	0.4	0.9	0.3	0.0	0.0	0.0	0.0	8.5	1.7	14.3	2.4
12/29/11	24.6	2.5	0.5	0.8	0.3	0.0	0.0	0.0	0.0	7.7	1.9	13.3	1.8
1/1/12	21.3	2.5	0.4	1.1	0.3	0.0	0.0	0.0	0.0	4.3	1.8	11.5	1.7
1/4/12	15.1	1.3	0.2	0.8	0.2	0.0	0.0	0.0	0.0	3.5	1.0	8.9	1.1
1/7/12	23.4	1.7	0.3	0.6	0.2	0.0	0.0	0.0	0.0	5.5	1.2	11.8	1.9
1/10/12	16.2	1.8	0.3	0.7	0.2	0.0	0.0	4.4	1.2	5.7	1.3	3.5	0.6
1/13/12	***	***	***	***	***	***	***	***	***	***	***	***	***
1/16/12	***	***	***	***	***	***	***	***	***	***	***	***	***
1/19/12	3.1**	**	**	**	**	**	**	**	**	**	**	**	**
1/22/12	0.8**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/12	0.7**	**	**	**	**	**	**	**	**	**	**	**	**
1/28/12	2.8**	**	**	**	**	**	**	**	**	**	**	**	**
1/31/12	23.5	2.3	0.4	1.0	0.3	0.0	0.0	0.0	0.0	6.9	1.7	17.0	1.8
2/3/12	5.6**	**	**	**	**	**	**	**	**	**	**	**	**
2/6/12	24.8	2.8	0.5	1.4	0.4	5.2	2.4	0.0	0.0	6.2	2.1	10.4	3.6
2/9/12	19.4	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.0	2.8	1.2	12.6	1.3
2/12/12	18.1	0.9	0.4	1.4	0.4	3.0	1.1	0.0	0.0	4.4	2.0	9.3	2.3
2/15/12	30.8	2.3	0.7	1.5	0.8	5.2	1.8	0.0	0.0	7.8	3.8	14.9	4.4
2/18/12	25.9	2.3	0.4	2.3	0.4	0.0	0.0	0.0	0.0	7.2	1.6	16.9	2.4
2/21/12	17.0	1.7	0.3	1.0	0.2	0.0	0.0	0.0	0.0	3.1	1.2	10.0	1.2
2/24/12	5.9**	**	**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.5**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**22.1**	**1.9**	**0.4**	**1.0**	**0.3**	**0.9**	**0.4**	**0.3**	**0.1**	**4.9**	**1.5**	**11.5**	**1.9**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. NCORE – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	12.8	2.2	0.2	0.8	0.3	0.0	0.0	0.0	0.0	9.5	1.0
11/5/11	7.5	1.0	0.1	0.4	0.1	0.0	0.0	0.0	0.0	6.4	1.5
11/8/11	12.7	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	10.3	1.0
11/11/11	14.0	1.2	0.1	0.6	0.2	0.0	0.0	0.0	0.0	13.6	1.3
11/14/11	17.8	2.7	0.3	1.1	0.3	0.0	0.0	3.2	1.1	11.0	1.6
11/17/11	38.1	5.2	0.6	1.9	0.7	0.0	0.0	0.0	0.0	30.8	2.2
11/20/11	30.4	5.8	0.6	1.7	0.7	0.0	0.0	4.0	1.8	18.4	2.5
11/23/11	12.6	2.3	0.3	0.9	0.3	0.0	0.0	0.0	0.0	9.7	1.0
11/26/11	31.9	3.7	0.4	1.5	0.5	0.0	0.0	0.0	0.0	25.6	1.8
11/29/11	22.3	3.9	0.4	1.4	0.5	0.0	0.0	1.8	0.9	15.4	2.0
12/2/11	12.8	1.7	0.2	0.9	0.2	0.0	0.0	1.5	0.6	8.9	1.2
12/5/11	5.1**	**	**	**	**	**	**	**	**	**	**
12/8/11	27.4	3.6	0.4	1.5	0.5	9.9	3.0	0.0	0.0	12.6	1.9
12/11/11	9.0	1.2	0.1	0.5	0.3	0.0	0.0	1.8	0.6	5.8	0.9
12/14/11	28.3	4.1	0.5	1.6	0.5	9.7	3.2	0.0	0.0	12.9	2.0
12/17/11	29.7	5.4	0.6	1.4	0.7	0.0	0.0	6.5	1.7	15.9	2.3
12/20/11	10.8	1.5	0.2	0.9	0.2	0.0	0.0	2.0	0.9	6.2	1.0
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**
12/26/11	24.9	4.0	0.4	1.6	0.5	9.5	3.1	0.0	0.0	12.0	1.9
12/29/11	23.6	4.1	0.5	1.5	0.6	0.0	0.0	1.9	0.9	16.4	2.2
1/1/12	28.0	3.3	0.4	1.4	0.4	0.0	0.0	0.0	0.0	23.5	2.1
1/4/12	33.6	0.8	0.2	1.1	0.1	0.0	0.0	0.0	0.0	24.0	1.8
1/7/12	14.6	2.8	0.3	1.0	0.4	0.0	0.0	0.0	0.0	11.0	1.1
1/10/12	19.6	3.8	0.4	1.1	0.5	0.0	0.0	0.0	0.0	15.3	1.4
1/13/12	19.0	4.3	0.5	1.1	0.5	0.0	0.0	0.0	0.0	13.2	1.5
1/16/12	26.4	4.9	0.6	2.0	0.6	0.0	0.0	4.9	1.6	14.4	2.1
1/19/12	38.0	6.5	0.7	3.6	0.8	0.0	0.0	6.7	2.0	19.2	2.7
1/22/12	3.3**	**	**	**	**	**	**	**	**	**	**
1/25/12	9.0	1.6	0.2	0.6	0.2	0.0	0.0	0.0	0.0	7.1	1.6
1/28/12	28.1	5.7	0.6	1.5	0.7	0.0	0.0	0.0	0.0	20.2	3.3
1/31/12	20.1	3.8	0.4	1.7	0.7	0.0	0.0	3.5	1.1	11.1	1.6
2/3/12	6.7	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	5.0	1.2
2/6/12	24.7	3.9	0.4	2.0	0.5	0.0	0.0	0.0	0.0	9.0	1.5
2/9/12	24.0	2.4	0.3	1.3	0.3	0.0	0.0	0.0	0.0	14.4	1.4
2/12/12	17.0	2.2	0.3	1.7	0.5	0.0	0.0	2.8	0.8	10.9	1.6
2/15/12	30.7	4.5	0.5	2.2	0.6	0.0	0.0	9.4	1.6	12.7	2.0
2/18/12	26.9	3.9	0.4	3.0	0.5	6.5	3.0	0.0	0.0	13.3	2.0
2/21/12	16.2	2.4	0.3	1.3	0.3	0.0	0.0	1.9	0.7	10.8	1.4
2/24/12	5.7**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.6**	**	**	**	**	**	**	**	**	**	**
3/1/12	13.9	2.5	0.3	0.9	0.3	0.0	0.0	1.9	0.7	8.5	1.2
3/4/12	13.1	2.4	0.3	0.9	0.3	0.0	0.0	2.2	0.7	7.1	1.1
3/7/12	6.4	1.0	0.1	0.8	0.1	0.0	0.0	1.3	0.6	3.3	0.6
3/10/12	9.8	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	6.8	0.9

3/13/12	15.8	3.0	0.3	1.3	0.4	0.0	0.0	0.0	0.0	13.1	1.7
3/16/12	17.1	3.2	0.4	1.3	0.4	0.0	0.0	3.9	1.2	8.2	1.3
3/19/12	12.1	2.4	0.3	1.2	0.3	0.0	0.0	0.0	0.0	8.2	1.0
3/22/12	13.3	2.8	0.3	1.3	0.4	0.0	0.0	2.3	1.0	6.5	1.1
3/25/12	***	***	***	***	***	***	***	***	***	***	***
3/28/12	9.2	1.5	0.2	1.2	0.2	0.0	0.0	0.0	0.0	8.0	1.1
3/31/12	5.6**	**	**	**	**	**	**	**	**	**	**
Average	**19.5**	**3.0**	**0.3**	**1.3**	**0.4**	**0.8**	**0.3**	**1.4**	**0.5**	**12.4**	**1.6**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn˝t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. NCORE – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/11	12.8	1.5	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.0	1.1	7.6	1.5
11/5/11	7.5	0.9	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.8
11/8/11	12.7	1.1	0.2	0.4	0.1	0.0	0.0	0.0	0.0	2.4	0.8	8.3	1.3
11/11/11	14.0	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	11.1	1.1
11/14/11	17.8	1.8	0.3	0.7	0.2	0.0	0.0	0.0	0.0	4.5	1.3	10.4	1.3
11/17/11	38.1	2.9	0.5	1.1	0.4	0.0	0.0	0.0	0.0	11.9	2.1	21.0	3.2
11/20/11	30.4	3.1	0.6	0.8	0.4	0.0	0.0	0.0	0.0	13.8	2.4	11.7	2.1
11/23/11	12.6	1.6	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.8	1.2	7.6	1.1
11/26/11	31.9	2.1	0.4	0.9	0.3	0.0	0.0	0.0	0.0	8.0	1.5	18.9	2.3
11/29/11	22.3	2.7	0.5	0.8	0.4	0.0	0.0	0.0	0.0	7.5	2.0	11.4	1.8
12/2/11	12.8	1.7	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	10.3	0.9
12/5/11	5.1**	**	**	**	**	**	**	**	**	**	**	**	**
12/8/11	27.4	2.3	0.4	1.0	0.3	5.3	2.2	0.0	0.0	6.1	1.7	12.9	3.4
12/11/11	9.0	1.1	0.1	0.5	0.1	0.0	0.0	1.3	0.6	0.0	0.0	6.2	0.7
12/14/11	28.3	2.7	0.5	1.0	0.4	4.8	2.4	0.0	0.0	6.8	2.0	13.4	3.7
12/17/11	29.7	3.5	0.6	0.0	0.0	6.8	3.3	0.0	0.0	10.5	2.4	7.9	3.1
12/20/11	10.8	1.4	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	7.9	0.7
12/23/11	5.6**	**	**	**	**	**	**	**	**	**	**	**	**
12/26/11	24.9	2.2	0.4	0.9	0.3	0.0	0.0	0.0	0.0	9.2	1.6	14.5	2.4
12/29/11	23.6	2.3	0.4	0.9	0.3	0.0	0.0	0.0	0.0	9.2	1.7	11.8	1.7
1/1/12	28.0	2.6	0.4	1.1	0.4	0.0	0.0	0.0	0.0	3.9	1.8	19.5	2.6
1/4/12	33.6	1.2	0.2	0.8	0.2	0.0	0.0	0.0	0.0	3.3	0.9	15.3	1.8
1/7/12	14.6	1.8	0.3	0.6	0.2	0.0	0.0	0.0	0.0	5.5	1.4	7.9	1.3
1/10/12	19.6	2.4	0.4	0.7	0.3	0.0	0.0	2.5	0.9	6.2	1.8	9.9	1.6
1/13/12	19.0	2.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	8.7	1.8	6.5	1.6
1/16/12	26.4	3.0	0.5	1.3	0.4	0.0	0.0	0.0	0.0	9.7	2.2	11.7	2.0
1/19/12	38.0	3.7	0.7	2.6	0.5	0.0	0.0	0.0	0.0	14.7	2.8	14.4	2.5
1/22/12	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/12	9.0	1.2	0.2	0.5	0.2	0.0	0.0	0.0	0.0	1.9	0.9	6.1	1.3
1/28/12	28.1	3.6	0.6	0.8	0.5	0.0	0.0	0.0	0.0	11.0	2.6	8.4	3.2
1/31/12	20.1	2.4	0.4	1.1	0.3	0.0	0.0	0.0	0.0	7.4	1.8	9.4	1.6
2/3/12	6.7	1.0	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.8
2/6/12	***	***	***	***	***	***	***	***	***	***	***	***	***
2/9/12	***	***	***	***	***	***	***	***	***	***	***	***	***
2/12/12	17.0	1.6	0.3	1.5	0.2	0.0	0.0	0.0	0.0	2.6	1.2	12.4	1.3
2/15/12	30.7	2.8	0.7	1.6	0.7	0.0	0.0	4.8	1.1	7.7	3.8	14.8	4.3
2/18/12	26.9	2.4	0.4	2.4	0.4	0.0	0.0	0.0	0.0	7.0	1.8	17.5	2.6
2/21/12	16.2	1.7	0.3	1.1	0.2	0.0	0.0	0.0	0.0	3.5	1.3	10.0	1.3
2/24/12	5.7**	**	**	**	**	**	**	**	**	**	**	**	**
2/27/12	3.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/1/12	13.9	1.6	0.3	0.5	0.2	0.0	0.0	0.0	0.0	5.2	1.2	6.5	1.2
3/4/12	13.1	1.8	0.3	0.7	0.3	0.0	0.0	0.0	0.0	3.5	1.3	6.5	1.2
3/7/12	6.4	1.1	0.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.6
3/10/12	9.8	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	3.2	1.0	4.3	1.0

3/13/12	15.8	2.0	0.4	0.9	0.3	0.0	0.0	0.0	0.0	5.8	1.5	9.5	1.5
3/16/12	17.1	2.0	0.4	0.8	0.3	0.0	0.0	0.0	0.0	6.0	1.5	7.3	1.4
3/19/12	12.1	1.5	0.3	0.9	0.2	0.0	0.0	0.0	0.0	4.4	1.1	4.8	1.1
3/22/12	13.3	1.7	0.3	0.9	0.2	0.0	0.0	0.0	0.0	5.4	1.3	4.6	1.2
3/25/12	***	***	***	***	***	***	***	***	***	***	***	***	***
3/28/12	9.2	1.1	0.2	1.0	0.2	0.0	0.0	0.0	0.0	2.1	0.9	6.5	0.9
3/31/12	5.6**	**	**	**	**	**	**	**	**	**	**	**	**
Average	**19.3**	**2.0**	**0.4**	**0.9**	**0.3**	**0.4**	**0.2**	**0.2**	**0.1**	**5.4**	**1.4**	**10.1**	**1.7**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn˝t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. NPF3 – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
3/1/12	4.5**	**	**	**	**	**	**	**	**	**	**
3/4/12	37.4	2.7	0.3	1.1	0.3	0.0	0.0	3.3	1.2	29.7	3.7
3/7/12	6.1	0.7	0.1	0.3	0.1	0.0	0.0	1.8	0.7	3.5	0.7
3/10/12	20.5	1.9	0.2	0.8	0.2	0.0	0.0	0.0	0.0	16.9	2.0
3/13/12	5.1**	**	**	**	**	**	**	**	**	**	**
3/16/12	7.5	1.1	0.1	0.5	0.1	0.0	0.0	0.0	0.0	5.9	0.9
3/19/12	27.8	2.5	0.3	0.9	0.3	5.4	2.5	0.0	0.0	18.3	2.4
3/22/12	15.2	1.9	0.2	0.7	0.3	0.0	0.0	1.3	0.6	12.5	1.7
3/25/12	13.6	1.1	0.1	0.6	0.1	0.0	0.0	0.0	0.0	12.7	2.6
3/28/12	5.2**	**	**	**	**	**	**	**	**	**	**
3/31/12	4.8**	**	**	**	**	**	**	**	**	**	**
Average	**18.3**	**1.7**	**0.2**	**0.7**	**0.2**	**0.8**	**0.4**	**0.9**	**0.4**	**14.2**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. NPF3 – Winter 2011/2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
3/1/12	4.5**	**	**	**	**	**	**	**	**
3/4/12	37.4	2.0	0.3	0.6	0.3	3.9	1.4	27.8	2.0
3/7/12	6.1	0.6	0.1	0.3	0.1	0.0	0.0	4.8	0.6
3/10/12	20.5	1.5	0.3	0.5	0.2	2.2	1.1	14.8	1.3
3/13/12	5.1**	**	**	**	**	**	**	**	**
3/16/12	7.5	0.8	0.1	0.4	0.1	1.5	0.6	4.9	1.0
3/19/12	27.8	1.4	0.2	0.6	0.2	4.3	1.0	25.4	2.2
3/22/12	15.2	1.1	0.2	0.5	0.2	3.5	0.8	11.0	1.1
3/25/12	13.6	1.1	0.1	0.6	0.1	0.0	0.0	10.0	0.8
3/28/12	5.2**	**	**	**	**	**	**	**	**
3/31/12	4.8**	**	**	**	**	**	**	**	**
Average	**18.3**	**1.2**	**0.2**	**0.5**	**0.2**	**2.2**	**0.7**	**14.1**	**1.3**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/5/12	4.8	0.5	0.1	0.4	0.1	1.5	0.3	0.0	0.0	0.5	0.2	1.6	0.2
6/8/12	6.0	0.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.4	0.3
6/11/12	5.9	0.5	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	4.5	0.1
6/14/12	4.6	0.4	0.0	0.2	0.0	0.5	0.2	0.0	0.0	0.0	0.0	2.5	0.2
6/17/12	3.8	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1	2.8	0.1
6/20/12	8.6	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.9	0.2	6.0	0.1
6/23/12	6.4	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	5.1	0.3
6/26/12	3.2	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.1
6/29/12	3.7	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1
7/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/5/12	4.3	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.1
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	3.7	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.1
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	*	*	*	*	*	*	*	*	*	*	*	*	*
7/20/12	3.6	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.2
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	8.1	0.8	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.2
7/29/12	3.9	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.2
8/1/12	3.6	0.2	0.0	0.1	0.0	0.7	0.1	0.0	0.0	1.1	0.1	1.4	0.2
8/4/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/7/12	4.2	0.4	0.0	0.2	0.0	1.3	0.2	0.0	0.0	0.0	0.0	2.3	0.2
8/10/12	4.6	0.3	0.0	0.2	0.0	0.5	0.2	0.0	0.0	0.3	0.1	3.7	0.3
8/13/12	7.7	0.6	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.7	0.3	5.9	0.1
8/16/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/19/12	20.2	0.5	0.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	18.6	0.1
8/22/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/25/12	3.2	0.3	0.0	0.2	0.0	0.0	0.0	0.2	0.1	0.0	0.0	2.6	0.1
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.7**	**0.4**	**0.1**	**0.2**	**0.1**	**0.2**	**0.1**	**0.1**	**0.003**	**0.3**	**0.1**	**4.2**	**0.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
State Building – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/5/12	4.8	0.4	0.1	0.4	0.1	0.0	0.0	0.3	0.1	0.5	0.2	3.2	0.1
6/8/12	6.0	0.4	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.1
6/11/12	5.9	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	3.6	0.1
6/14/12	4.6	0.3	0.0	0.2	0.0	0.7	0.2	0.0	0.0	0.0	0.0	1.9	0.1
6/17/12	3.8	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1	2.2	0.0
6/20/12	8.6	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.9	0.2	4.8	0.1
6/23/12	6.4	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0.2	4.7	0.1
6/26/12	3.2	0.2	0.0	0.1	0.0	0.4	0.1	0.0	0.0	0.0	0.0	2.2	0.1
6/29/12	3.7	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.1
7/2/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/5/12	4.3	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.1
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	3.7	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.1
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	*	*	*	*	*	*	*	*	*	*	*	*	*
7/20/12	3.6	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.1
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	8.1	0.7	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.2
7/29/12	3.9	0.4	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.1
8/1/12	3.6	0.2	0.0	0.1	0.0	0.0	0.0	0.2	0.0	1.2	0.2	2.0	0.1
8/4/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/7/12	4.2	0.4	0.0	0.1	0.0	1.5	0.2	0.0	0.0	0.0	0.0	1.8	0.1
8/10/12	4.6	0.3	0.0	0.2	0.0	0.8	0.2	0.0	0.0	0.3	0.1	3.1	0.1
8/13/12	7.7	0.5	0.1	0.2	0.1	0.9	0.3	0.0	0.0	0.7	0.2	4.3	0.2
8/16/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/19/12	20.2	0.4	0.1	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.1
8/22/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/25/12	3.2	0.2	0.0	0.2	0.0	0.8	0.2	0.0	0.0	0.0	0.0	1.9	0.1
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.7**	**0.4**	**0.05**	**0.2**	**0.05**	**0.3**	**0.1**	**0.02**	**0.01**	**0.3**	**0.1**	**3.6**	**0.1**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
NCORE – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/14/12	2.9	0.2	0.0	0.1	0.3	0.0	0.0	2.2	0.5	0.2	0.1	0.0	0.0
6/17/12	4.3	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.1	3.7	0.4
6/20/12	5.9	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.4	0.1	5.1	0.5
6/23/12	6.6	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.8	0.1	5.9	1.0
6/26/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/29/12	3.1	0.3	0.0	0.0	0.0	0.0	0.0	2.8	0.5	0.0	0.0	0.0	0.0
7/2/12	4.3	0.3	0.0	0.3	0.1	4.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0
7/5/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/20/12	3.4	0.6	0.1	0.3	0.1	2.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	5.9	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.5
7/29/12	4.2	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.6
8/1/12	4.0	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	1.3	0.2	3.4	0.4
8/4/12	3.2	0.3	0.1	0.2	0.0	3.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0
8/7/12	4.5	0.4	0.0	0.2	0.1	3.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0
8/10/12	4.3	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.1	4.2	0.6
8/13/12	6.5	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.4	0.1	5.1	0.5
8/16/12	4.2	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.6
8/19/12	15.6	0.5	0.1	0.7	0.1	0.0	0.0	0.0	0.0	0.3	0.1	15.3	1.8
8/22/12	4.3	0.2	0.1	0.2	0.0	3.5	0.7	0.0	0.0	0.6	0.1	0.0	0.0
8/25/12	*	*	*	*	*	*	*	*	*	*	*	*	*
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.1**	**0.4**	**0.1**	**0.2**	**0.1**	**1.0**	**0.2**	**0.3**	**0.1**	**0.3**	**0.1**	**3.3**	**0.4**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
NCORE – Summer 2012.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Street Sand	Street Sand STD ERR	Wood Smoke	Wood Smoke STD ERR
6/14/12	2.9	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	2.8	0.4
6/17/12	4.3	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.1	4.2	0.4
6/20/12	5.9	0.4	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.1	5.7	0.5
6/23/12	6.6	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.8	0.1	6.6	0.7
6/26/12	***	***	***	***	***	***	***	***	***	***	***	***	***
6/29/12	3.1	0.3	0.0	0.0	0.0	0.0	0.0	2.8	0.5	0.0	0.0	0.0	0.0
7/2/12	4.3	0.3	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.4
7/5/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/8/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/11/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/14/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/17/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/20/12	3.4	0.6	0.1	0.3	0.1	2.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0
7/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
7/26/12	5.9	0.8	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.4
7/29/12	4.2	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.6
8/1/12	4.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.7	0.1	3.2	0.3
8/4/12	3.2	0.3	0.1	0.2	0.0	3.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0
8/7/12	4.5	0.4	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.5
8/10/12	4.3	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.1	3.9	0.5
8/13/12	6.5	0.4	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.5	0.2	5.6	0.4
8/16/12	4.2	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.5
8/19/12	15.6	0.5	0.1	0.6	0.1	0.0	0.0	0.0	0.0	0.4	0.1	14.3	1.0
8/22/12	4.3	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.1	3.5	0.5
8/25/12	*	*	*	*	*	*	*	*	*	*	*	*	*
8/28/12	***	***	***	***	***	***	***	***	***	***	***	***	***
8/31/12	***	***	***	***	***	***	***	***	***	***	***	***	***
Average	**5.1**	**0.4**	**0.05**	**0.2**	**0.05**	**0.3**	**0.1**	**0.2**	**0.03**	**0.2**	**0.1**	**4.2**	**0.4**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles.
State Building – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	14.9	2.2	0.3	1.0	0.3	0.0	0.0	0.0	0.0	10.8	0.4
11/5/12	19.7	3.6	0.4	1.7	0.5	0.0	0.0	0.0	0.0	14.6	1.2
11/8/12	34.9	6.3	0.8	2.6	0.8	0.0	0.0	0.0	0.0	26.1	1.2
11/11/12	13.8	1.9	0.2	0.8	0.2	0.0	0.0	0.0	0.0	10.5	0.7
11/14/12	22.2	3.4	0.4	1.6	0.4	0.0	0.0	0.0	0.0	16.7	0.6
11/17/12	3.3**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.4	5.7	0.7	1.9	0.7	0.0	0.0	0.0	0.0	19.9	1.8
11/23/12	19.3	3.7	0.5	1.4	0.5	0.0	0.0	1.6	0.7	12.8	0.8
11/26/12	52.0	10.6	1.3	3.4	1.3	0.0	0.0	12.0	4.8	24.5	6.0
11/29/12	*	*	*	*	*	*	*	*	*	*	*
12/2/12	31.0	5.1	0.6	2.3	0.7	0.0	0.0	0.0	0.0	24.0	4.7
12/5/12	***	***	***	***	***	***	***	***	***	***	***
12/8/12	22.6	4.7	0.6	1.2	0.6	0.0	0.0	0.0	0.0	17.7	3.5
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**
12/14/12	10.6	1.9	0.2	0.8	0.2	0.0	0.0	1.7	0.5	7.1	0.8
12/17/12	***	***	***	***	***	***	***	***	***	***	***
12/20/12	***	***	***	***	***	***	***	***	***	***	***
12/23/12	***	***	***	***	***	***	***	***	***	***	***
12/26/12	***	***	***	***	***	***	***	***	***	***	***
12/29/12	26.9	4.1	0.5	2.3	0.5	0.0	0.0	5.4	0.8	14.6	1.2
1/1/13	7.0	0.9	0.1	0.8	0.1	0.0	0.0	0.0	0.0	5.4	1.0
1/4/13	24.4	3.3	0.4	1.4	0.4	0.0	0.0	5.9	0.6	13.4	0.7
1/7/13	29.1	5.4	0.7	1.7	0.7	0.0	0.0	2.7	1.0	20.0	1.1
1/10/13	***	***	***	***	***	***	***	***	***	***	***
1/13/13	***	***	***	***	***	***	***	***	***	***	***
1/16/13	*	*	*	*	*	*	*	*	*	*	*
1/19/13	21.5	4.7	0.6	1.7	0.6	0.0	0.0	0.0	0.0	14.3	2.2
1/22/13	22.2	4.3	0.5	1.6	0.6	0.0	0.0	0.0	0.0	15.9	2.3
1/25/13	***	***	***	***	***	***	***	***	***	***	***
1/28/13	41.4	9.1	1.1	2.7	1.1	0.0	0.0	0.0	0.0	28.3	2.3
1/31/13	***	***	***	***	***	***	***	***	***	***	***
2/3/13	23.1	3.6	0.5	1.9	0.5	0.0	0.0	0.0	0.0	17.8	1.0
2/6/13	18.0	3.3	0.4	2.4	0.4	0.0	0.0	0.0	0.0	13.0	0.9
2/9/13	*	*	*	*	*	*	*	*	*	*	*
2/12/13	27.0	4.7	0.6	2.5	0.6	0.0	0.0	3.9	1.7	14.4	2.6
2/15/13	***	***	***	***	***	***	***	***	***	***	***
2/18/13	17.8	4.0	0.5	1.8	0.5	0.0	0.0	0.0	0.0	12.2	0.8
2/21/13	3.8**	**	**	**	**	**	**	**	**	**	**
2/24/13	16.1	2.2	0.3	1.3	0.3	0.0	0.0	0.0	0.0	13.1	0.6
2/27/13	18.2	2.8	0.4	1.5	0.4	0.0	0.0	1.2	0.5	11.9	0.6
3/2/13	17.1	2.6	0.3	2.0	0.4	0.0	0.0	0.0	0.0	11.7	1.7
3/5/13	*	*	*	*	*	*	*	*	*	*	*
3/8/13	14.6	1.9	0.2	1.3	0.3	0.0	0.0	0.0	0.0	11.4	0.7
3/11/13	16.6	3.2	0.4	1.9	0.4	0.0	0.0	0.0	0.0	11.2	2.2

3/14/13	*	*	*	*	*	*	*	*	*	*	*
3/17/13	10.7	2.1	0.3	1.2	0.3	3.0	1.2	0.0	0.0	4.3	0.6
3/20/13	*	*	*	*	*	*	*	*	*	*	*
3/23/13	*	*	*	*	*	*	*	*	*	*	*
3/26/13	4.8**	**	**	**	**	**	**	**	**	**	**
3/29/13	12.2	1.4	0.2	1.3	0.2	0.0	0.0	0.0	0.0	9.5	0.4
Average	**21.8**	**3.9**	**0.5**	**1.7**	**0.5**	**0.1**	**0.04**	**1.2**	**0.4**	**14.7**	**1.5**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. State Building – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	14.9	1.6	0.3	0.8	0.2	0.0	0.0	0.8	0.3	2.8	1.1	8.4	1.3
11/5/12	19.7	2.2	0.4	1.2	0.3	0.0	0.0	0.0	0.0	7.1	1.6	8.8	1.8
11/8/12	34.9	3.7	0.7	1.7	0.5	0.0	0.0	0.0	0.0	13.9	2.8	13.3	3.1
11/11/12	13.8	1.4	0.3	0.6	0.2	0.0	0.0	0.0	0.0	2.7	1.0	6.7	1.1
11/14/12	22.2	2.1	0.4	1.2	0.3	0.0	0.0	0.0	0.0	6.9	1.5	10.7	1.7
11/17/12	3.3**	**	**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.4	3.3	0.7	1.0	0.5	0.0	0.0	0.0	0.0	12.8	2.5	8.8	2.8
11/23/12	19.3	2.4	0.5	0.9	0.3	0.0	0.0	1.3	0.5	7.1	1.8	6.5	2.0
11/26/12	52.0	10.2	1.3	3.5	1.3	0.0	0.0	0.0	0.0	0.0	0.0	32.0	2.1
11/29/12	*	*	*	*	*	*	*	*	*	*	*	*	*
12/2/12	31.0	2.8	0.6	1.4	0.4	0.0	0.0	0.0	0.0	11.8	2.2	17.7	2.4
12/5/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/8/12	22.6	2.8	0.6	0.5	0.4	0.0	0.0	0.0	0.0	9.9	2.1	7.4	1.6
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
12/14/12	10.6	1.3	0.2	0.6	0.2	2.3	1.1	0.0	0.0	2.7	1.0	3.6	0.9
12/17/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/20/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/23/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/26/12	***	***	***	***	***	***	***	***	***	***	***	***	***
12/29/12	26.9	3.1	0.6	1.7	0.4	0.0	0.0	0.0	0.0	8.2	2.3	5.3	2.6
1/1/13	7.0	0.9	0.1	0.7	0.1	1.8	0.6	0.0	0.0	0.0	0.0	3.9	0.3
1/4/13	24.4	2.6	0.5	1.0	0.4	0.0	0.0	0.0	0.0	6.5	1.8	10.3	2.0
1/7/13	29.1	3.3	0.7	0.9	0.4	0.0	0.0	2.3	0.6	12.0	2.5	9.1	2.7
1/10/13	***	***	***	***	***	***	***	***	***	***	***	***	***
1/13/13	***	***	***	***	***	***	***	***	***	***	***	***	***
1/16/13	*	*	*	*	*	*	*	*	*	*	*	*	*
1/19/13	21.5	3.0	0.6	1.1	0.4	0.0	0.0	0.0	0.0	9.1	2.2	4.7	2.5
1/22/13	22.2	2.8	0.5	1.1	0.4	0.0	0.0	0.0	0.0	8.1	2.0	7.3	2.3
1/25/13	***	***	***	***	***	***	***	***	***	***	***	***	***
1/28/13	41.4	8.9	1.1	2.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	22.8	1.8
1/31/13	***	***	***	***	***	***	***	***	***	***	***	***	***
2/3/13	23.1	3.2	0.6	1.4	0.4	0.0	0.0	0.0	0.0	7.4	2.3	6.0	2.6
2/6/13	18.0	3.7	0.5	2.3	0.5	0.0	0.0	1.4	0.7	0.0	0.0	9.4	0.9
2/9/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/12/13	27.0	3.5	0.7	2.0	0.5	0.0	0.0	0.0	0.0	8.4	2.6	6.7	2.9
2/15/13	***	***	***	***	***	***	***	***	***	***	***	***	***
2/18/13	17.8	2.6	0.5	1.3	0.4	0.0	0.0	0.0	0.0	7.9	1.9	4.8	2.1
2/21/13	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
2/24/13	16.1	2.0	0.4	1.0	0.3	0.0	0.0	0.0	0.0	4.2	1.5	5.8	1.6
2/27/13	18.2	2.1	0.4	1.3	0.3	3.9	1.4	0.0	0.0	4.0	1.6	7.5	1.7
3/2/13	17.1	1.9	0.4	1.8	0.3	2.6	1.3	0.0	0.0	3.3	1.5	6.8	1.6
3/5/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/8/13	14.6	1.3	0.3	1.1	0.2	0.0	0.0	0.0	0.0	3.0	1.0	6.7	1.1
3/11/13	16.6	2.2	0.4	1.5	0.3	0.0	0.0	0.0	0.0	5.7	1.6	4.4	1.8

3/14/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/17/13	10.7	1.2	0.2	0.9	0.2	0.0	0.0	0.0	0.0	4.5	1.0	3.7	1.1
3/20/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/23/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/26/13	4.8**	**	**	**	**	**	**	**	**	**	**	**	**
3/29/13	12.2	1.2	0.2	1.0	0.2	1.9	0.8	0.0	0.0	3.4	1.0	2.8	1.0
Average	**21.8**	**2.9**	**0.5**	**1.3**	**0.4**	**0.4**	**0.2**	**0.2**	**0.1**	**6.0**	**1.5**	**8.7**	**1.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. NPE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	30.0	2.6	0.3	0.8	0.3	0.0	0.0	7.2	1.0	16.8	2.2
11/5/12	23.9	1.6	0.2	0.9	0.2	8.2	1.7	0.0	0.0	15.1	2.0
11/8/12	51.2	3.2	0.4	1.0	0.4	0.0	0.0	4.0	1.0	45.1	2.8
11/11/12	17.4	1.4	0.2	0.6	0.2	5.9	1.4	0.0	0.0	10.5	1.4
11/14/12	14.9	0.9	0.1	0.5	0.1	0.0	0.0	0.0	0.0	13.5	2.0
11/17/12	7.3	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	5.1	0.6
11/20/12	21.8	3.0	0.3	0.8	0.4	0.0	0.0	4.9	1.0	12.3	1.6
11/23/12	5.3**	**	**	**	**	**	**	**	**	**	**
11/26/12	75.2	6.3	0.7	1.8	0.8	0.0	0.0	12.4	2.1	46.9	5.7
11/29/12	68.1	6.2	0.7	1.9	0.8	0.0	0.0	11.6	2.0	44.3	5.4
12/2/12	51.7	4.0	0.4	1.2	0.5	0.0	0.0	10.7	1.5	30.1	3.7
12/5/12	32.7	2.8	0.3	1.7	0.4	0.0	0.0	9.0	1.2	20.6	2.6
12/8/12	56.8	6.9	0.8	1.8	0.9	0.0	0.0	6.9	1.5	37.4	4.5
12/11/12	5.5**	**	**	**	**	**	**	**	**	**	**
12/14/12	7.0	0.6	0.1	0.5	0.1	0.0	0.0	0.7	0.3	5.5	0.7
12/17/12	37.3	3.5	0.4	1.0	0.4	0.0	0.0	6.1	0.9	29.0	3.4
12/20/12	47.3	4.2	0.5	1.1	0.5	0.0	0.0	5.9	1.1	35.9	4.2
12/23/12	62.4	5.8	0.7	1.8	0.7	0.0	0.0	7.3	1.4	46.7	5.5
12/26/12	40.2	2.0	0.2	2.5	0.3	0.0	0.0	5.3	0.8	31.8	3.7
12/29/12	31.5	2.6	0.3	1.0	0.3	0.0	0.0	6.0	1.0	21.4	2.7
1/1/13	10.0	0.8	0.1	0.4	0.1	0.0	0.0	0.0	0.0	9.4	1.0
1/4/13	47.7	3.1	0.3	1.2	0.4	0.0	0.0	8.3	1.2	28.9	3.5
1/7/13	38.3	3.4	0.4	1.3	0.4	0.0	0.0	4.3	1.1	25.9	3.2
1/10/13	17.8	1.9	0.2	0.9	0.2	5.3	1.6	0.0	0.0	10.1	1.4
1/13/13	14.9	1.1	0.1	0.6	0.1	4.6	1.2	0.0	0.0	8.2	1.1
1/16/13	19.8	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	17.7	3.6
1/19/13	5.8**	**	**	**	**	**	**	**	**	**	**
1/22/13	4.4**	**	**	**	**	**	**	**	**	**	**
1/25/13	26.8	4.2	0.5	1.4	0.5	0.0	0.0	2.7	0.9	18.8	2.3
1/28/13	39.9	4.8	0.5	1.5	0.6	0.0	0.0	6.1	1.5	26.6	3.3
1/31/13	22.3	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	19.8	1.8
2/3/13	11.0	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	8.7	1.1
2/6/13	15.2	2.3	0.3	1.4	0.3	0.0	0.0	0.0	0.0	11.4	2.9
2/9/13	23.6	1.9	0.2	0.7	0.2	0.0	0.0	0.0	0.0	22.6	1.8
2/12/13	41.6	2.9	0.3	1.8	0.4	6.1	2.8	0.0	0.0	31.0	3.9
2/15/13	11.1	0.8	0.1	0.6	0.1	0.0	0.0	0.0	0.0	6.5	1.0
2/18/13	16.0	2.0	0.2	0.9	0.3	0.0	0.0	0.0	0.0	13.4	1.6
2/21/13	3.4**	**	**	**	**	**	**	**	**	**	**
2/24/13	13.9	1.6	0.2	0.7	0.2	0.0	0.0	0.0	0.0	11.2	1.0
2/27/13	20.3	1.4	0.2	1.0	0.2	0.0	0.0	2.0	0.9	15.7	2.0
3/2/13	23.6	1.8	0.2	1.5	0.2	0.0	0.0	1.1	0.5	25.6	3.0
3/5/13	*	*	*	*	*	*	*	*	*	*	*
3/8/13	12.4	0.9	0.1	0.7	0.2	0.0	0.0	1.2	0.4	9.8	1.2

3/11/13	14.4	1.6	0.2	1.0	0.2	0.0	0.0	0.0	0.0	13.0	1.6
3/14/13	2.6**	**	**	**	**	**	**	**	**	**	**
3/17/13	15.5	1.3	0.1	0.8	0.2	0.0	0.0	1.0	0.4	13.0	1.6
3/20/13	1.0**	**	**	**	**	**	**	**	**	**	**
3/23/13	4.6**	**	**	**	**	**	**	**	**	**	**
3/26/13	6.2	0.8	0.1	0.3	0.1	0.0	0.0	0.0	0.0	4.4	0.9
3/29/13	11.8	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	10.8	1.4
Average	**28.1**	**2.5**	**0.3**	**1.1**	**0.3**	**0.7**	**0.2**	**3.0**	**0.6**	**20.3**	**2.5**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn˝t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles.
NPE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	30.0	0.9	0.4	0.0	0.0	3.4	0.7	0.0	0.0	7.9	2.0	19.1	2.2
11/5/12	23.9	0.6	0.1	0.6	0.1	0.0	0.0	1.7	0.4	3.0	0.5	19.2	1.5
11/8/12	51.2	1.9	0.4	0.5	0.3	0.0	0.0	7.9	1.2	6.9	1.4	35.0	3.1
11/11/12	17.4	0.7	0.2	0.4	0.2	0.0	0.0	1.0	0.4	2.9	0.9	14.3	1.4
11/14/12	14.9	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	1.5	0.4	10.9	0.9
11/17/12	7.3	0.3	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.7	0.3	3.1	0.5
11/20/12	21.8	2.0	0.3	0.0	0.0	5.3	2.2	0.0	0.0	5.5	1.4	9.8	1.5
11/23/12	5.3**	**	**	**	**	**	**	**	**	**	**	**	**
11/26/12	75.2	2.3	0.7	0.0	0.0	0.0	0.0	4.7	1.1	17.8	3.3	55.4	5.1
11/29/12	68.1	1.6	0.7	0.0	0.0	0.0	0.0	5.2	1.1	22.5	3.4	43.1	4.3
12/2/12	51.7	2.0	0.4	0.0	0.0	13.4	2.4	0.0	0.0	8.9	1.4	34.0	4.7
12/5/12	32.7	1.8	0.3	1.2	0.3	0.0	0.0	4.7	1.1	5.3	1.4	19.7	1.9
12/8/12	56.8	4.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	15.9	3.1	31.2	3.0
12/11/12	5.5**	**	**	**	**	**	**	**	**	**	**	**	**
12/14/12	7.0	0.6	0.1	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.4
12/17/12	37.3	2.3	0.5	0.0	0.0	0.0	0.0	1.7	0.8	8.4	2.0	25.2	2.4
12/20/12	47.3	2.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	10.0	1.9	33.0	2.3
12/23/12	62.4	3.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	14.7	2.5	41.4	3.0
12/26/12	40.2	**	**	**	**	**	**	**	**	**	**	**	**
12/29/12	31.5	1.8	0.3	0.9	0.3	0.0	0.0	0.0	0.0	3.5	1.4	23.4	1.6
1/1/13	10.0	0.7	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.8
1/4/13	47.7	1.3	0.3	0.8	0.2	0.0	0.0	4.2	0.7	5.4	1.0	37.2	2.5
1/7/13	38.3	2.3	0.4	0.7	0.3	0.0	0.0	0.0	0.0	5.8	1.7	24.2	1.8
1/10/13	17.8	1.0	0.2	0.6	0.2	1.4	0.7	0.0	0.0	3.4	1.2	12.9	1.7
1/13/13	14.9	0.8	0.1	0.6	0.2	1.6	0.6	0.0	0.0	0.0	0.0	12.9	1.2
1/16/13	19.8	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	2.7	1.0	11.8	1.2
1/19/13	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
1/22/13	4.4**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/13	26.8	2.7	0.5	0.7	0.4	0.0	0.0	0.0	0.0	8.6	2.0	14.3	1.8
1/28/13	39.9	2.4	0.5	0.7	0.3	0.0	0.0	0.0	0.0	11.8	1.8	21.2	1.9
1/31/13	22.3	1.2	0.2	0.8	0.2	2.9	1.2	0.0	0.0	3.1	0.9	15.3	2.1
2/3/13	11.0	1.3	0.1	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	8.7	0.7
2/6/13	15.2	1.4	0.3	1.2	0.2	0.0	0.0	0.0	0.0	4.1	1.1	7.1	1.1
2/9/13	23.6	1.7	0.2	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	18.1	1.4
2/12/13	41.6	2.0	0.4	1.3	0.3	0.0	0.0	0.0	0.0	4.7	1.5	28.0	2.1
2/15/13	11.1	0.8	0.1	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.7
2/18/13	16.0	1.5	0.3	0.6	0.2	0.0	0.0	0.0	0.0	3.0	1.1	11.1	1.2
2/21/13	3.4**	**	**	**	**	**	**	**	**	**	**	**	**
2/24/13	13.9	1.1	0.2	0.3	0.2	5.2	1.5	0.0	0.0	2.8	0.8	4.0	1.4
2/27/13	20.3	1.3	0.2	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	16.7	1.1
3/2/13	23.6	1.8	0.2	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	23.9	1.3
3/5/13	*	*	*	*	*	*	*	*	*	*	*	*	*
3/8/13	12.4	0.9	0.1	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	10.9	0.7
3/11/13	14.4	1.4	0.2	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	12.5	1.0

3/14/13	2.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/17/13	15.5	1.0	0.2	0.6	0.1	0.0	0.0	0.0	0.0	2.0	0.7	11.8	0.9
3/20/13	1.0**	**	**	**	**	**	**	**	**	**	**	**	**
3/23/13	4.6**	**	**	**	**	**	**	**	**	**	**	**	**
3/26/13	6.2	0.7	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.7
3/29/13	11.8	0.6	0.1	0.6	0.1	0.0	0.0	0.0	0.0	1.3	0.5	9.4	0.9
Average	**27.8**	**1.5**	**0.3**	**0.6**	**0.1**	**0.8**	**0.2**	**0.8**	**0.2**	**4.9**	**1.1**	**18.8**	**1.8**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. NCORE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*
11/5/12	*	*	*	*	*	*	*	*	*	*	*
11/8/12	29.9	5.9	0.7	2.4	0.8	0.0	0.0	0.0	0.0	22.3	1.9
11/11/12	16.3	1.8	0.2	0.8	0.2	0.0	0.0	0.0	0.0	13.7	0.9
11/14/12	23.0	3.2	0.4	1.7	0.4	0.0	0.0	2.9	0.7	15.8	1.9
11/17/12	3.7**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.2	5.1	0.6	2.2	0.6	0.0	0.0	5.0	1.1	15.4	2.0
11/23/12	29.2	4.7	0.5	1.6	0.6	0.0	0.0	0.0	0.0	23.2	5.8
11/26/12	*	*	*	*	*	*	*	*	*	*	*
11/29/12	57.4	11.2	1.3	1.0	1.4	0.0	0.0	0.0	0.0	45.4	3.2
12/2/12	35.5	6.4	0.7	2.6	0.8	0.0	0.0	8.6	1.8	15.5	2.2
12/5/12	32.2	6.5	0.7	2.9	0.8	0.0	0.0	3.7	1.8	17.0	2.4
12/8/12	25.1	4.5	0.5	1.5	0.6	0.0	0.0	3.4	1.0	13.8	1.8
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**
12/14/12	11.4	1.9	0.2	0.9	0.4	0.0	0.0	2.9	0.6	7.2	1.0
12/17/12	49.2	10.9	1.2	3.1	1.4	0.0	0.0	5.8	2.1	34.6	4.3
12/20/12	46.4	12.2	1.4	2.9	1.5	12.4	7.4	0.0	0.0	21.1	3.6
12/23/12	41.2	9.8	1.1	2.8	1.2	13.4	6.0	0.0	0.0	16.9	3.0
12/26/12	27.8	5.9	0.7	1.9	0.7	0.0	0.0	4.9	1.6	14.8	2.1
12/29/12	28.2	4.4	0.5	2.3	0.6	0.0	0.0	5.1	1.3	14.8	2.0
1/1/13	7.9	1.0	0.1	0.7	0.1	0.0	0.0	0.0	0.0	6.7	0.6
1/4/13	23.4	3.4	0.4	1.6	0.4	0.0	0.0	5.1	1.1	13.0	1.8
1/7/13	*	*	*	*	*	*	*	*	*	*	*
1/10/13	21.6	3.3	0.4	2.5	0.4	0.0	0.0	3.6	0.8	12.8	1.6
1/13/13	14.9	2.2	0.3	1.1	0.3	0.0	0.0	2.0	0.7	10.0	1.4
1/16/13	26.7	4.9	0.5	2.9	0.6	0.0	0.0	4.9	1.4	13.9	1.9
1/19/13	22.4	4.6	0.5	2.0	0.6	0.0	0.0	0.0	0.0	16.1	2.0
1/22/13	27.9	4.8	0.5	2.1	0.7	0.0	0.0	3.5	1.0	17.7	2.3
1/25/13	28.6	6.3	0.7	2.4	0.8	8.0	3.9	0.0	0.0	13.3	2.1
1/28/13	40.3	8.7	1.0	2.2	1.1	0.0	0.0	0.0	0.0	27.0	2.8
1/31/13	***	***	***	***	***	***	***	***	***	***	***
2/3/13	22.5	3.7	0.4	1.3	0.5	0.0	0.0	0.0	0.0	14.8	1.4
2/6/13	19.6	3.6	0.4	2.5	0.5	0.0	0.0	4.2	1.3	8.2	1.4
2/9/13	21.4	3.3	0.4	1.7	0.4	0.0	0.0	4.6	1.0	9.6	1.4
2/12/13	25.5	5.1	0.6	2.8	0.7	0.0	0.0	5.2	1.5	12.7	1.8
2/15/13	3.8**	**	**	**	**	**	**	**	**	**	**
2/18/13	18.4	4.1	0.5	1.9	0.5	0.0	0.0	0.0	0.0	12.2	3.1
2/21/13	*	*	*	*	*	*	*	*	*	*	*
2/24/13	15.5	2.5	0.3	1.4	0.3	0.0	0.0	0.0	0.0	12.3	1.5
2/27/13	21.4	3.4	0.4	1.9	0.4	0.0	0.0	3.6	0.9	12.9	1.7
3/2/13	24.4	2.8	0.3	2.5	0.4	9.1	2.1	0.0	0.0	9.6	1.4
3/5/13	35.4	4.9	0.6	5.2	0.7	0.0	0.0	5.7	1.6	17.8	2.5
3/8/13	17.4	2.1	0.2	1.7	0.3	0.0	0.0	4.4	0.8	7.9	1.1
3/11/13	17.5	3.1	0.3	1.9	0.4	0.0	0.0	3.3	0.9	8.8	1.3

3/14/13	3.5**	**	**	**	**	**	**	**	**	**	**
3/17/13	13.0	2.2	0.2	1.4	0.3	0.0	0.0	0.0	0.0	9.0	1.2
3/20/13	11.4	2.0	0.2	1.3	0.3	0.0	0.0	0.0	0.0	8.1	1.1
3/23/13	5.0**	**	**	**	**	**	**	**	**	**	**
3/26/13	5.0**	**	**	**	**	**	**	**	**	**	**
3/29/13	10.8	1.8	0.2	1.4	0.2	0.0	0.0	0.0	0.0	8.0	1.1
Average	**25.5**	**4.7**	**0.5**	**2.0**	**0.6**	**1.1**	**0.5**	**2.4**	**0.7**	**15.1**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. NCORE – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/5/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/8/12	29.9	3.2	0.6	2.1	0.5	5.6	2.8	0.0	0.0	14.8	2.6	4.5	0.9
11/11/12	16.3	1.0	0.2	0.6	0.1	0.0	0.0	0.0	0.0	3.4	0.8	10.9	1.2
11/14/12	23.0	2.2	0.4	1.2	0.3	0.0	0.0	0.0	0.0	6.6	1.7	13.1	1.5
11/17/12	3.7**	**	**	**	**	**	**	**	**	**	**	**	**
11/20/12	27.2	3.1	0.7	1.2	0.5	0.0	0.0	2.4	0.8	12.9	2.9	7.5	2.3
11/23/12	29.2	2.3	0.5	0.0	0.0	2.2	0.7	0.0	0.0	12.3	2.2	12.4	2.8
11/26/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/29/12	57.4	10.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.8	3.5
12/2/12	35.5	3.6	0.8	1.6	0.7	0.0	0.0	3.7	1.0	13.7	3.7	13.7	4.3
12/5/12	32.2	3.5	0.7	1.7	0.5	0.0	0.0	0.0	0.0	16.2	2.6	8.5	2.2
12/8/12	25.1	2.8	0.5	0.8	0.4	0.0	0.0	0.0	0.0	10.2	2.1	9.6	1.8
12/11/12	5.8**	**	**	**	**	**	**	**	**	**	**	**	**
12/14/12	11.4	1.4	0.3	0.6	0.2	0.0	0.0	3.5	0.7	3.1	1.0	2.1	0.4
12/17/12	49.2	6.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	28.7	4.3	18.7	3.6
12/20/12	46.4	6.9	1.2	0.0	0.0	0.0	0.0	0.0	0.0	28.6	4.6	10.3	5.7
12/23/12	41.2	5.3	1.0	1.1	0.7	0.0	0.0	0.0	0.0	24.7	3.9	8.2	4.8
12/26/12	27.8	3.5	0.6	1.0	0.5	0.0	0.0	0.0	0.0	12.6	2.6	10.0	2.1
12/29/12	28.2	2.6	0.5	1.7	0.4	0.0	0.0	0.0	0.0	8.6	1.9	13.2	1.7
1/1/13	7.9	0.9	0.1	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.0	0.6
1/4/13	23.4	2.1	0.4	1.0	0.3	4.6	2.0	0.0	0.0	7.3	1.6	7.9	2.1
1/7/13	*	*	*	*	*	*	*	*	*	*	*	*	*
1/10/13	21.6	2.2	0.5	1.9	0.4	0.0	0.0	1.5	0.6	7.7	2.0	8.4	1.7
1/13/13	14.9	2.2	0.2	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.9
1/16/13	26.7	2.8	0.5	2.2	0.4	0.0	0.0	0.0	0.0	10.5	2.1	10.6	1.8
1/19/13	22.4	2.7	0.5	1.2	0.4	0.0	0.0	0.0	0.0	10.5	2.0	9.1	1.8
1/22/13	27.9	2.8	0.5	1.2	0.4	0.0	0.0	0.0	0.0	11.5	2.1	13.3	1.8
1/25/13	28.6	3.5	0.6	1.4	0.5	0.0	0.0	0.0	0.0	14.9	2.6	9.9	3.2
1/28/13	40.3	8.4	0.9	2.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	21.7	2.2
1/31/13	***	1.4	0.2	1.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	9.2	0.5
2/3/13	22.5	3.5	0.4	1.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	12.1	1.1
2/6/13	19.6	2.2	0.4	2.0	0.4	0.0	0.0	1.8	0.7	7.2	2.1	7.1	2.6
2/9/13	21.4	2.3	0.4	1.2	0.3	6.3	1.8	0.0	0.0	5.2	1.6	7.1	2.8
2/12/13	25.5	3.3	0.6	2.1	0.5	0.0	0.0	0.0	0.0	9.3	2.4	10.5	2.0
2/15/13	3.8**	**	**	**	**	**	**	**	**	**	**	**	**
2/18/13	18.4	2.4	0.4	1.3	0.3	0.0	0.0	0.0	0.0	8.9	1.8	6.4	2.2
2/21/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/24/13	15.5	1.5	0.3	1.0	0.2	0.0	0.0	0.0	0.0	5.8	1.2	8.6	1.2
2/27/13	21.4	2.4	0.4	1.4	0.3	0.0	0.0	0.0	0.0	6.8	1.8	10.3	1.6
3/2/13	24.4	1.9	0.4	2.2	0.4	0.0	0.0	1.5	0.6	3.7	1.8	15.1	2.3
3/5/13	35.4	2.6	0.5	4.3	0.5	0.0	0.0	0.0	0.0	12.0	2.2	14.1	2.0
3/8/13	17.4	2.1	0.2	1.6	0.3	6.8	2.1	0.0	0.0	0.0	0.0	8.3	1.0
3/11/13	17.5	2.2	0.4	1.6	0.3	0.0	0.0	0.0	0.0	4.1	1.6	8.8	1.3

3/14/13	3.5**	**	**	**	**	**	**	**	**	**	**	**	**
3/17/13	13.0	1.5	0.3	1.1	0.2	0.0	0.0	0.0	0.0	3.5	1.1	7.2	1.1
3/20/13	11.4	1.4	0.3	1.0	0.2	0.0	0.0	0.0	0.0	3.1	1.1	6.1	1.0
3/23/13	5.0**	**	**	**	**	**	**	**	**	**	**	**	**
3/26/13	5.0**	**	**	**	**	**	**	**	**	**	**	**	**
3/29/13	10.8	1.2	0.2	1.1	0.2	0.0	0.0	0.0	0.0	3.1	0.9	6.1	1.0
Average	**25.1**	**3.0**	**0.5**	**1.3**	**0.3**	**0.7**	**0.2**	**0.4**	**0.1**	**8.5**	**1.8**	**11.0**	**2.0**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – EPA Profiles. NPF3 – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*
11/5/12	34.9	2.5	0.3	1.1	0.3	0.0	0.0	5.5	1.0	23.1	2.8
11/8/12	106.4	7.5	0.8	1.9	0.9	0.0	0.0	17.3	2.6	69.1	8.3
11/11/12	31.5	2.3	0.3	0.8	0.3	0.0	0.0	4.8	0.9	21.1	2.6
11/14/12	25.5	1.9	0.2	1.0	0.2	0.0	0.0	2.0	0.7	19.5	2.4
11/17/12	7.3	0.8	0.1	0.2	0.1	0.0	0.0	0.0	0.0	6.1	0.5
11/20/12	44.0	3.3	0.4	0.9	0.4	0.0	0.0	3.6	1.5	38.9	2.9
11/23/12	8.5	0.8	0.1	0.3	0.1	0.0	0.0	0.7	0.3	7.0	0.9
11/26/12	138.1	9.3	1.0	2.4	1.2	0.0	0.0	22.0	3.3	98.1	11.7
11/29/12	154.6	11.2	1.3	3.0	1.4	0.0	0.0	25.2	3.8	108.4	13.0
12/2/12	124.7	7.2	0.8	2.1	0.9	0.0	0.0	14.2	2.0	91.8	10.6
12/5/12	*	*	*	*	*	*	*	*	*	*	*
12/8/12	*	*	*	*	*	*	*	*	*	*	*
12/11/12	6.4	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.6
12/14/12	9.8	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.7
12/17/12	83.6	6.0	0.7	1.6	0.8	0.0	0.0	7.0	1.5	62.6	7.2
12/20/12	111.4	8.7	1.0	2.0	1.1	0.0	0.0	13.6	2.2	98.5	11.4
12/23/12	98.2	8.0	0.9	2.3	1.0	0.0	0.0	12.2	2.0	76.0	8.8
12/26/12	106.5	6.5	0.8	2.4	0.8	0.0	0.0	9.1	1.7	85.3	9.8
12/29/12	55.9	3.4	0.4	0.6	0.4	0.0	0.0	6.9	1.0	42.5	4.9
1/1/13	24.4	1.4	0.2	0.9	0.2	0.0	0.0	0.0	0.0	22.3	2.6
1/4/13	84.3	6.6	0.7	2.1	0.8	0.0	0.0	12.2	2.2	55.2	6.7
1/7/13	95.6	6.6	0.7	2.0	0.8	0.0	0.0	8.6	2.4	73.8	8.8
1/10/13	23.9	2.0	0.2	1.0	0.3	0.0	0.0	0.0	0.0	21.2	2.4
1/13/13	23.6	1.2	0.1	0.7	0.2	0.0	0.0	2.8	0.7	18.6	2.3
1/16/13	36.8	2.9	0.4	1.4	0.4	0.0	0.0	0.0	0.0	33.3	6.5
1/19/13	10.3	1.1	0.1	0.7	0.2	0.0	0.0	0.7	0.3	8.3	1.1
1/22/13	4.2**	**	**	**	**	**	**	**	**	**	**
1/25/13	58.1	5.7	0.7	2.2	0.7	0.0	0.0	4.2	1.3	45.5	5.3
1/28/13	66.2	5.9	0.7	1.6	0.7	0.0	0.0	4.4	1.5	57.1	6.7
1/31/13	36.1	2.8	0.3	1.6	0.4	0.0	0.0	3.6	1.2	26.6	3.3
2/3/13	24.0	1.5	0.2	1.5	0.2	0.0	0.0	0.0	0.0	21.1	2.4
2/6/13	26.0	3.1	0.3	1.9	0.4	0.0	0.0	2.8	1.0	16.9	2.1
2/9/13	30.1	1.7	0.2	0.9	0.2	6.1	1.7	0.0	0.0	21.3	2.7
2/12/13	26.6	2.5	0.3	1.4	0.3	7.0	2.5	0.0	0.0	17.5	2.4
2/15/13	*	*	*	*	*	*	*	*	*	*	*
2/18/13	*	*	*	*	*	*	*	*	*	*	*
2/21/13	4.0**	**	**	**	**	**	**	**	**	**	**
2/24/13	24.6	2.1	0.2	1.0	0.3	4.7	1.8	0.0	0.0	17.4	2.2
2/27/13	37.6	3.0	0.3	1.5	0.4	4.7	2.3	0.0	0.0	28.2	3.5
3/2/13	32.2	1.8	0.2	1.3	0.2	0.0	0.0	0.0	0.0	28.3	2.1
3/5/13	32.2	1.8	0.2	1.3	0.2	0.0	0.0	2.9	1.0	25.1	3.1
3/8/13	25.7	1.4	0.2	1.3	0.2	0.0	0.0	1.1	0.5	22.7	2.6
3/11/13	31.4	2.5	0.3	1.5	0.3	4.5	2.0	0.0	0.0	23.0	2.9

3/14/13	3.2**	**	**	**	**	**	**	**	**	**	**
3/17/13	25.3	1.7	0.2	1.1	0.3	0.0	0.0	1.5	0.5	21.2	2.5
3/20/13	9.8	1.0	0.1	0.8	0.1	0.0	0.0	0.0	0.0	8.0	0.9
3/23/13	6.6	0.8	0.1	0.5	0.1	0.0	0.0	0.0	0.0	5.8	0.7
3/26/13	6.3	0.7	0.1	0.4	0.1	0.0	0.0	0.0	0.0	5.4	0.7
3/29/13	23.5	1.2	0.1	1.2	0.2	0.0	0.0	1.6	0.5	19.9	2.3
Average	**46.9**	**3.4**	**0.4**	**1.3**	**0.4**	**0.6**	**0.2**	**4.5**	**0.9**	**35.9**	**4.2**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

$PM_{2.5}$ Source Contribution Estimates and Standard Errors (µg/m^3) – OMNI Profiles. NPF3 – Winter 2012/2013.

Date	$PM_{2.5}$ Mass	Sulfate	Sulfate STD ERR	Ammonium Nitrate	Ammonium Nitrate STD ERR	Autos	Autos STD ERR	Diesel	Diesel STD ERR	No. 2 Fuel Oil	No. 2 Fuel Oil STD ERR	Wood Smoke	Wood Smoke STD ERR
11/2/12	*	*	*	*	*	*	*	*	*	*	*	*	*
11/5/12	34.9	1.7	0.3	0.7	0.2	0.0	0.0	0.0	0.0	3.6	1.3	24.5	1.6
11/8/12	106.4	2.5	0.6	0.0	0.0	0.0	0.0	8.0	1.3	18.7	1.8	80.0	5.7
11/11/12	31.5	1.7	0.3	0.5	0.2	0.0	0.0	0.0	0.0	3.2	1.2	22.2	1.5
11/14/12	25.5	1.5	0.3	0.7	0.2	0.0	0.0	0.0	0.0	2.3	1.1	18.1	1.3
11/17/12	7.3	0.5	0.1	0.2	0.1	0.0	0.0	0.0	0.0	1.1	0.4	5.3	0.7
11/20/12	44.0	1.3	0.3	0.5	0.2	0.0	0.0	5.6	0.8	6.8	1.0	30.7	2.4
11/23/12	8.5	0.6	0.1	0.2	0.1	0.0	0.0	0.0	0.0	1.0	0.4	6.9	0.6
11/26/12	138.1	5.3	1.0	0.0	0.0	0.0	0.0	0.0	0.0	20.2	3.7	100.1	5.5
11/29/12	154.6	5.9	1.1	0.0	0.0	0.0	0.0	0.0	0.0	27.6	4.1	108.2	6.1
12/2/12	124.7	4.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0	18.6	3.3	88.5	4.9
12/5/12	*	*	*	*	*	*	*	*	*	*	*	*	*
12/8/12	*	*	*	*	*	*	*	*	*	*	*	*	*
12/11/12	6.4	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.8	0.5
12/14/12	9.8	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	0.6
12/17/12	83.6	4.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	13.6	2.8	55.2	3.6
12/20/12	111.4	5.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	4.0	91.5	5.4
12/23/12	98.2	5.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	20.8	3.5	70.0	4.5
12/26/12	106.5	4.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	16.3	2.9	75.2	4.4
12/29/12	55.9	3.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.8	2.3
1/1/13	24.4	1.4	0.2	0.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	20.9	1.3
1/4/13	84.3	2.7	0.6	1.1	0.4	0.0	0.0	4.8	1.1	14.0	2.1	71.4	5.1
1/7/13	95.6	4.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	13.0	2.8	65.1	4.1
1/10/13	23.9	1.5	0.3	0.7	0.2	0.0	0.0	0.0	0.0	2.6	1.1	18.2	1.5
1/13/13	23.6	1.2	0.1	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	19.9	1.1
1/16/13	36.8	1.6	0.3	1.0	0.2	0.0	0.0	0.0	0.0	5.2	1.2	34.4	2.5
1/19/13	10.3	0.7	0.1	0.6	0.1	0.0	0.0	0.0	0.0	1.4	0.5	7.5	0.7
1/22/13	4.2**	**	**	**	**	**	**	**	**	**	**	**	**
1/25/13	58.1	3.7	0.7	1.1	0.5	0.0	0.0	0.0	0.0	12.5	2.8	37.4	3.0
1/28/13	66.2	3.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	12.9	2.6	47.4	3.5
1/31/13	36.1	1.8	0.3	1.1	0.3	0.0	0.0	0.0	0.0	4.9	1.4	24.8	1.9
2/3/13	24.0	1.4	0.2	1.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	19.6	1.3
2/6/13	26.0	2.1	0.4	1.4	0.3	0.0	0.0	0.0	0.0	5.6	1.6	14.6	1.5
2/9/13	30.1	0.9	0.2	0.6	0.1	4.1	1.1	0.0	0.0	2.6	0.7	22.4	2.2
2/12/13	26.6	1.8	0.3	1.1	0.3	0.0	0.0	0.0	0.0	3.7	1.3	17.4	1.5
2/15/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/18/13	*	*	*	*	*	*	*	*	*	*	*	*	*
2/21/13	4.0**	**	**	**	**	**	**	**	**	**	**	**	**
2/24/13	24.6	1.6	0.3	0.7	0.2	0.0	0.0	0.0	0.0	2.8	1.1	16.5	1.3
2/27/13	37.6	2.2	0.4	1.1	0.3	0.0	0.0	0.0	0.0	4.0	1.6	24.6	1.8
3/2/13	32.2	1.3	0.2	1.1	0.2	0.0	0.0	0.0	0.0	2.1	0.9	26.6	1.9
3/5/13	32.2	1.8	0.2	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	25.9	1.5
3/8/13	25.7	1.4	0.2	1.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	21.1	1.2
3/11/13	31.4	2.4	0.3	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	23.4	1.3

3/14/13	3.2**	**	**	**	**	**	**	**	**	**	**	**	**
3/17/13	25.3	1.2	0.2	0.8	0.2	0.0	0.0	0.0	0.0	2.8	0.9	19.5	1.3
3/20/13	9.8	0.6	0.1	0.7	0.1	0.0	0.0	0.0	0.0	1.0	0.5	8.4	0.8
3/23/13	6.6	0.5	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.8	0.4	5.9	0.7
3/26/13	6.3	0.4	0.1	0.3	0.1	0.0	0.0	0.0	0.0	0.8	0.3	5.2	0.6
3/29/13	23.5	1.2	0.1	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	19.7	1.1
Average	**46.9**	**2.2**	**0.4**	**0.6**	**0.1**	**0.1**	**0.03**	**0.4**	**0.1**	**6.4**	**1.3**	**34.7**	**2.3**

Notes: *No, incomplete, or invalid CMB data set. **Mass was too small to conduct a CMB analysis. ***Couldn"t get a good statistical fit during CMB modeling.

Characterization of $PM_{2.5}$ from Fairbanks, AK: Organics Analysis for Residential Oil Burner Emissions

Interim Report: 6/2011

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1. Executive Summary

Fairbanks, AK experiences very high levels of ambient $PM_{2.5}$ during the winter months. Studies are currently under way to determine the sources of the $PM_{2.5}$ so that the issue might be addressed. Possible sources of the $PM_{2.5}$ include residential heating (wood, fuel oil, and/or natural gas combustion), transportation (diesel and gasoline engines), and coal combustion.

The current project is to provide a more complete characterization of the organic chemical composition of $PM_{2.5}$ from Fairbanks with the goal of identifying and quantifying chemical species that can be used to indicate and monitor $PM_{2.5}$ emissions from fossil fuel combustion.

A comprehensive chemical analysis for hopanes, steranes and PAHs has been performed on eight PM samples from Fairbanks, selected to represent typical or high $PM_{2.5}$ days. The results of these analyses have been examined with special attention to compounds reported by previous authors as emissions from fossil fuel sources. Emphasis has been placed on sulfur-containing compounds (dibenzothiophene and benzo naphtho thiophene) which are known emissions of diesel vehicles and residential oil burners and a polynuclear aromatic hydrocarbon (picene) which has been reported as a unique marker for coal combustion.

The results indicate that the levels of selected hopanes, steranes, picene and thiophenes, measured either as a concentration in air or as a fraction of $PM_{2.5}$, are very high. These concentrations are significantly higher than those reported in previous studies for coal, diesel or residential oil burner PM emissions or for airsheds in the United States and in Europe. Given that picene is a specific marker of coal emissions, the results indicate that coal combustion emissions are likely a significant contributor to Fairbanks $PM_{2.5,,}$ specifically the sulfate/sulfur fraction. Overall, the results indicate that fossil fuel combustion, particularly of emissions from coal and residential fuel oil combustion, is a significant contributor to Fairbanks $PM_{2.5}$.

2. Methods

2.1 Samples selected for analysis.

Eight Fairbanks $PM_{2.5}$ samples from the winter of 2009-2010 were selected in consultation with Alaska DEC and submitted to Desert Research Institute for comprehensive analysis of 83 PAHs (including substituted PAHs, dibenzothiophene and benzonaphthothiophene) and 23 hopanes and steranes. The samples, listed in Table 1, were all from the downtown sampling site and had a range of $PM_{2.5}$ levels from 15.7 to 54.4 ug/m^3. A laboratory blank filter was also sent for analysis, and the reported levels of all compounds are blank corrected.

Desert Research Institute (DRI) returned two spreadsheets with the analytical results for hopanes and steranes and for PAHs. The amount and estimated uncertainty of each compound found on the filter is reported in ng. These spreadsheets of the raw analytical results are included with this report.

2.2 Analysis of the Raw Results

The DRI results provide a great deal of information about the samples. However, these raw results are difficult to interpret or utilize without some context. Based on a review of relevant published studies, several specific chemical compounds were selected for further analysis. These compounds are listed in Tables 2 and 3 and are those reported as significant components of particulate matter from combustion of specific fossil fuels: residential heating oil, diesel vehicles, gasoline vehicles, and coal. Unfortunately, many of the published reports only provide levels for a subset of the compounds selected. It is not clear if those that are not reported were included in the original analysis but were not detected or if they were not subject to analysis. Blank cells indicate that no level was reported for those compounds in the cited publication, while "nd" indicates that those compounds were reported as not detected.

Table 1: Date, identity and $PM_{2.5}$ level of the filters selected for analysis.

Date	Cassette Number	$PM_{2.5}$ Level ug/m^3
11/15/2009	510	15.7
11/27/2009	773	20.9
12/10/2009	772	54.4
12/13/2009	215	44.4
12/27/2009	721	24.1
1/11/2010	615	38.5
1/17/2010	753	15.8
2/10/2010	735	22.1

The sampled volume and $PM_{2.5}$ levels for each Fairbanks sample were used to determine the concentrations of the selected compounds in the ambient air (ng/m^3) and as a fraction of the $PM_{2.5}$ (ppm). These results are also reported in Tables 2 and 3 as the median and maximum for those samples for which the compounds were detected. In most cases, the compounds were detected on all or nearly all samples. The exception is 20S-5α(H),14α(H),17α(H)-ergostane, which was detected on only two samples (510 and 735).

3. Results and Discussion

The results from literature review and calculated analytical results for fourteen selected compounds are presented in Tables 2^{1-6} and 3^{7-9}. These compounds are classified into hopanes and steranes, thiophenes, and PAHs.

3.1 Hopanes and Steranes

The hopanes and steranes are typically found and reported in distillate fossil fuel emissions, but have also been reported in coal emissions. The highest levels reported are for diesel auto emissions, and the lowest are for coal emissions. The second column of coal results, presented as mg/kg of fuel, indicate that these compounds are present in coal emissions but do not allow direct comparison with the other values reported. The hopanes and steranes are not present in emissions from biomass

Table 2: Levels of selected marker compounds as a fraction of particulate matter (ppm).

	Compound	Residential Oil Burner[3]	Diesel Vehicles[1,4]	Gasoline Vehicles[5]	Bituminite Coal[6]	Bituminite Coal[2,b]	Fairbanks Median (Maximum)
Hopanes/Steranes (petroleum products)	17α(H)-22,29,30-Trisnorhopane		5.3		0.4	67	16.6 (90.6)
	17α(H),21ß(H)-29-Norhopane	2.22	14.8	2.5		85	41.3 (152)
	17α(H),21ß(H)-Hopane	3.53	61.6	4.4	1.4	45	26.0 (79.8)
	22S-17α(H),21ß(H)-30-Homohopane	1.02		nd	1.1	10	17.7 (55.9)
	22R-17α(H),21ß(H)-30-Homohopane	0.64		nd	0.2	17	23.5 (129)
	22S-17α(H),21ß(H)-30,31-Bishomohopane	0.58		nd	nd	11	8.5 (34.5)
	22R-17α(H),21ß(H)-30,31-Bishomohopane	0.40		nd	nd	16	15.9 (39.5)
	20R-5α(H),14ß(H),17ß(H)-cholestane	2.03	4.2				39.2 (45.7)
	20S-5α(H),14α(H),17α(H)-ergostane	4.53	17.0				4.43 (4.97)
	20R-5α(H),14ß(H),17ß(H)-stigmastane	1.87	20.6				4.89 (6.36)
Thio-phenes	Dibenzothiophene		12.6 10.7[a]	43[a]			49.0 (65.8)
	2,3-Benzo[b]naphtha[1,2-d]thiophene		23.8				15.8 (29.7)
PAH	Picene				nd	94	36.2 (69.3)
	Retene				4.6	nd	44.2 (68.0)

[a]Found in the gas phase only. [b]Emission factors in mg/kg of fuel.

Table 3: Levels of selected marker compounds found in ambient air (ng/m^3)

	Compound	Ambient Air, Europe[8]	Mingo Junction, OH[7]	Zheng Southeastern USA[9]	Fairbanks Median (Maximum)
Hopanes/Steranes (petroleum products)	17α(H)-22,29,30-Trisnorhopane			0.06	0.53 (2.18)
	17α(H),21ß(H)-29-Norhopane		0.1-0.6	0.36	1.26 (3.67)
	17α(H),21ß(H)-Hopane		0.05-0.3	0.38	0.72 (1.92)
	22S-17α(H),21ß(H)-30-Homohopane			0.20	0.47 (1.17)
	22R-17α(H),21ß(H)-30-Homohopane			0.18	0.61 (3.11)
	22S-17α(H),21ß(H)-30,31-Bishomohopane			0.11	0.38 (0.72)
	22R-17α(H),21ß(H)-30,31-Bishomohopane			0.08	0.45 (0.95)
	20R-5α(H),14ß(H),17ß(H)-cholestane				0.88 (2.49)
	20S-5α(H),14α(H),17α(H)-ergostane				0.082 (0.086)
	20R-5α(H),14ß(H),17ß(H)-stigmastane				0.12 (0.24)
Thio-phenes	Dibenzothiophene	0.029 (0.095)			0.93 (2.92)
	2,3-Benzo[b]naphtho[1,2-d]thiophene	0.012 (0.082)			0.45 (0.72)
PAH	Picene		<0.0006 - 0.2		0.76 (1.67)
	Retene				1.08 (2.58)

combustion, and thus provide a general indication of the extent to which an air shed is affected by fossil fuel emissions. Unfortunately, however, none of the compounds provide a specific marker of any particular fossil fuel source.

The results for the Fairbanks samples show very high levels of the selected hopanes and steranes. This is clear from inspection of Table 2, which shows that the hopanes and steranes typically represent a much higher fraction of $PM_{2.5}$ than any of the reported fossil fuel sources. There are exceptions in which the Fairbanks levels are about the same as or lower than diesel emissions. These results are striking, however, since $PM_{2.5}$ in Fairbanks is expected to be a mixture of PM from various sources including non-fossil fuel sources.

The ambient air levels of hopanes and steranes in Fairbanks also far exceed those reported for other airsheds (Table 3). Since these airsheds are impacted by automobiles and Mingo Junction Ohio is also affected by coal emissions, the very high levels in Fairbanks are notable. Clearly, fossil fuel emissions have a substantial impact on Fairbanks $PM_{2.5}$.

An alternative approach for the analysis of hopane results is to calculate the ratio of 17α (H) 21β (H) hopane to 22R-17α (H), 21β (H) homohopane.[2, 6, 10] This value has been reported to be 3.7 for gasoline emissions and 2.5 for diesel emissions.[10] Unfortunately, conflicting results have been reported for coal combustion emissions, with Oros *et al.*[2] reporting values of 0.1-2.6 and Zhang *et al.*[6] reporting values of 4.28-9.19. The average value observed for Fairbanks is 1.2 ± 0.4. This relatively low value places the result for Fairbanks within the range reported by Oros *et al.*, which implies that coal emissions may have a significant impact on Fairbanks $PM_{2.5}$.

The hopane and sterane results indicate that fossil fuel emissions have a substantial effect on air quality in Fairbanks. However, the results are not very helpful in more clearly identifying the specific fossil fuel source. For this reason, regular further analysis of hopanes and steranes is not recommended unless it is conducted as part of a more in-depth comprehensive source apportionment based on organic compounds.

3.2 Thiophenes

Dibenzothiophene, napthobenzothiophenes and alkylated derivatives of these compounds are reported to be representative of diesel fuel vehicle emissions.[1, 4] These compounds make up a significant fraction of the sulfur content of diesel fuel (Table 4). Low sulfur diesel fuel has lower concentrations of these compounds, and vehicles utilizing low sulfur diesel fuel emit reduced quantities of these compounds. The values reported in Table 2 for diesel emissions are from vehicles utilizing low sulfur diesel fuel.[1, 4] Rogge *et al.*[3] did not report thiophenes in the emissions from residential fuel oil combustion, but Huffman *et al.* did report that typically 25-35% of the sulfur in residential fuel oil particulate is thiophenic sulfur.[11] Given the similar composition of # 2 fuel oil and diesel fuel, and the fact that the sulfur content of # 2 fuel oil is not regulated with respect to sulfur content, it stands to reason that these compounds may be found in the $PM_{2.5}$ emissions from #2 fuel oil as well. In fact, #2 fuel oil obtained from Fairbanks was found to have a level of dibenzothiophene much higher than that reported previously for high sulfur diesel fuel (Table 4). Waste oil fuel and and #1 fuel oil from Fairbanks were found to have dibenzothiophene levels between that of low and high sulfur diesel fuels. Dibenzothiophene has also been reported in the emissions from gasoline vehicles. In this and one report on diesel emissions, dibenzothiophene was found primarily in the gas phase. Given the ambient

Table 4: Dibenzothiophene levels in three fuel oils from Fairbanks and in diesel fuels.

Fuel	Dibenzothiophene (ppm)
Fuel #1	34.3
Fuel #2	461
Waste Fuel	21.7
LSDF[3]	15.2
HSDF[3]	84.0

temperatures in Fairbanks, it seems likely that the compound would be found in the particulate phase. These sulfur compounds are not present in wood smoke, and were not reported in coal studies. It is not clear, however, whether or not they are present in PM from coal combustion.

The results in Table 2 indicate that the Fairbanks PM has high levels of thiophenes in comparison to PM emitted from vehicles burning low sulfur diesel fuel. As with the hopane and sterane results discussed in section 3.1, these results are striking given that Fairbanks $PM_{2.5}$ is expected to be a mixture of PM from various sources and not only diesel fuel or residential fuel oil burners. The observed dibenzo- and benzonaphtho- thiophene levels do not, however, explain the relatively high levels of non-sulfate sulfur observed in Faribanks $PM_{2.5}$. These compounds represent only 7.7 and 2.5 ppm S in the $PM_{2.5}$ respectively.

The results in Table 3 show that the ambient levels of these thiophenes in Fairbanks are much higher than those reported for several European cities. The average $PM_{2.5}$ levels in those cities varied from 11 to 30 ug/m^3, and median concentration of dibenzo- and benzonaphtho- thiophenes as a fraction of the $PM_{2.5}$ was 1.3 and 0.48 ppm respectively. The very high levels observed in Fairbanks, considered either as ambient concentration or as a fraction of $PM_{2.5}$, are remarkable given that diesel powered automobiles and trucks are typically much more prevalent in European cities.

The thiophene results presented here point rather strongly to residential fuel oil burners utilizing #2 fuel oil obtained from Fairbanks (and/or possibly coal combustion) as a source of $PM_{2.5}$ in Fairbanks. Analysis of the $PM_{2.5}$ obtained from residential oil burner studies utilizing Fuel #2 will be especially useful in confirming this result. Fuel #2 from Fairbanks has exceptionally high levels of dibenzothiophene, suggesting that this and other thiophenes will be very useful markers of emissions from combustion of that oil. Further, combustion of this fuel in Fairbanks may explain some of the high levels of sulfur observed in the $PM_{2.5}$.

3.3 PAHs

Picene is a 5-ring PAH that has been reported as being representative of emissions from coal combustion.[2, 6, 7] Zhang *et al.* reported picene as being "unique to the organic carbon emissions from coal combustion," although picene was not detected in all coal particulate and was notably absent from bituminous coal emissions from industrial boilers.[6] Zhang *et al.* did report picene in brown and mixed coal emissions from residential boilers (3.7 and 2.0 ppm respectively) as well as much higher levels in the emissions from residential oil burners (72-284 ppm).[6] Oros et al. reported picene and methyl picenes as bituminous coal smoke markers , and C_2 substituted picenes as more general coal-specific markers.[2] As a large PAH, picene can be expected to be found primarily in the particulate phase.

Results for picene as a fraction of Fairbanks $PM_{2.5}$ (Table 2) are relatively difficult to interpret given the scarcity of relevant information in comparable units found in the literature. By comparison to the results of Zhang *et al.*[6], the levels in Fairbanks are much higher (by a factor of 10 or more) than would be expected from commercial boilers. The levels observed in Fairbanks are not as high as those reported by Zhang *et al.* for residential coal burners in China, but are of a similar magnitude for combustion of some types of coal in Chinese residential coal burners.

Results for ambient picene levels are also surprising. Fairbanks has much higher levels of picene than Mingo Junction, OH, which was specifically studied because of a significant impact of coal emissions. Source apportionment in Mingo Junction using organic marker profiles concluded that coal soot makes up 3 to 10% of the organic carbon in the $PM_{2.5}$, depending on season.[7]

Relatively high levels of picene are observed in Fairbanks when considered either as a fraction of $PM_{2.5}$ or as ambient concentration. This is a very strong indication that coal combustion, and very likely coal combustion in a poorly designed or operated boiler, is a significant contributor to Fairbanks $PM_{2.5}$.

Retene is an alkyl substituted 3-ring PAH that has commonly been associated with combustion of soft woods.[12] This compound is included in this report, however, because it has also been reported as a component of coal combustion emissions.[6] Levels in Fairbanks are relatively high compared with those reported by Zhang et al. for bituminous coal emissions from industrial boilers, similar to the level reported by these authors for brown coal emissions from industrial boilers (60 ppm) and much lower than those reported for residential coal burners (364-5000 ppm).[6] Ambient levels in Fairbanks are similar to or lower than those reported for southeastern US cities.[7] It is not clear whether the retene observed in Faribanks $PM_{2.5}$ is indicative of coal combustion, wood combustion, or both.

Table 5: Ratio of indeno[123-cd]pyrene to sum of indeno[123-cd]pyrene and benzo[ghi]perylene for various sources.

Source	IP/(IP+BghiP)
Gasoline autos	0.18
Diesel autos	0.37
Coal combustion	0.56
Wood combustion[12]	0.54
Fairbanks $PM_{2.5}$	0.39 ± 0.02

Another commonly used measure for sourcing PAH emissions is the ratio of indeno[123-cd]pyrene to the sum of indeno[123-cd]pyrene and benzo[ghi]perylene (IP/(IP+BghiP)).[6, 12, 13] Typical values for this ratio from various fossil fuel sources, woodsmoke and for Fairbanks are reported in Table 5. No value is available for residential oil combustion $PM_{2.5}$. The ratio for Fairbanks is quite consistent between samples, and is most similar to that reported for diesel fuel emissions.

4 Conclusions

The results of this preliminary study are very informative, but are not conclusive. It is not possible to draw unqualified or quantitative conclusions concerning the sources of Fairbanks $PM_{2.5}$ with the limited number of samples and compounds analyzed. However, the results do show that Fairbanks $PM_{2.5}$ is more complex chemically than was previously realized, and strongly suggest that fossil fuel combustion represents a measurable contribution to $PM_{2.5}$ in Fairbanks. The levels of hopanes and steranes, thiophenes, and picene are all high relative to previous reports whether considered as a fraction of PM or as ambient concentrations. These compounds are all representative of fossil fuel combustion sources.

The hopanes and steranes are not representative of any particular fossil fuel source, but do indicate the overall contribution of fossil fuels. Analysis of the ratio of 17α (H) 21β (H) hopane to 22R-17α (H), 21β (H) homohopane might suggest that coal combustion is a significant source of $PM_{2.5}$ in Fairbanks, but inconsistent literature values for this ratio cause significant uncertainty in this conclusion.

The relatively high levels of thiophenes observed in Fairbanks $PM_{2.5}$ are a strong indication of significant transportation diesel fuel or residential oil burner contributions. Again, the levels of these compounds are higher than those previously reported for diesel PM or in cities with many more diesel vehicles than Fairbanks. The #2 fuel oil used in residential oil burners in Fairbanks also contains a very high concentration of dibenzothiophene, implying that this is a likely source. The low sulfur diesel fuel used in Fairbanks should significantly limit the contribution of diesel transportation to the thiophene concentrations. Coal combustion emissions can not be ruled out as a source of some of the thiophenes, but few if any quantitative data exist concerning the presence or absence of thiophenes in coal combustion emissions. Although the concentrations of thiophenes are relatively high, their concentrations are not sufficient to explain the sulfur content of Fairbanks $PM_{2.5}$.

Picene is also observed at remarkably high levels whether considered relative to the $PM_{2.5}$ mass or as ambient concentration. This compound is considered to be a good and selective marker of coal combustion, so this result is strong evidence that coal combustion is a source of $PM_{2.5}$ in Fairbanks. Based on literature values, however, the concentrations of picene in Fairbanks can not be explained by

industrial boiler emissions alone. This begs the question of whether the boilers operating in the Fairbanks area are being operated under suboptimal conditions, or if there are other coal combustion sources contributing to Fairbanks $PM_{2.5}$.

The ratio of IP/(IP+BghiP) for Fairbanks $PM_{2.5}$ is lower than that reported previously for coal or wood combustion, and is indicative of diesel vehicle emissions. This may indicate either a significant contribution from diesel transportation, a significant contribution from residential heating oil, or a combination of wood/coal with diesel/residential heating oil and gasoline auto PM.

Further study of Fairbanks $PM_{2.5}$ needs to be conducted before any more quantitative or conclusive source apportionment using organic tracers can be conducted. This approach would be much more informative once analyses have been performed on $PM_{2.5}$ obtained from representative sources under controlled conditions. A comprehensive organic speciation of many more samples than were analyzed in the current study, combined with a source apportionment procedure using organic compounds as tracers ,[9, 14, 15] could lead to a more complete picture of the Fairbanks $PM_{2.5}$ problem.

Alternatively, analysis of Fairbanks $PM_{2.5}$ for a limited number of selected analytes could be informative. This is especially true if these analyses were used to evaluate the effects and efficacy of remediation efforts and/or in combination with local or regional mapping of concentrations. If this limited and less costly approach is to be pursued, the current study suggests that the most likely marker candidates for analysis are levoglucosan (wood smoke), picene (coal) and thiophenes (residential oil and/or diesel). Initial and preliminary studies in our laboratory indicate that these three compounds can be determined at relevant concentrations using a single extraction followed by two separate gas chromatographic separations.

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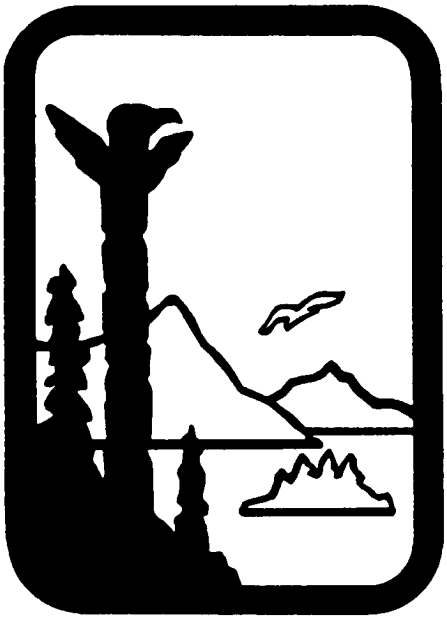

Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.09

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

No Appendix- Placeholder

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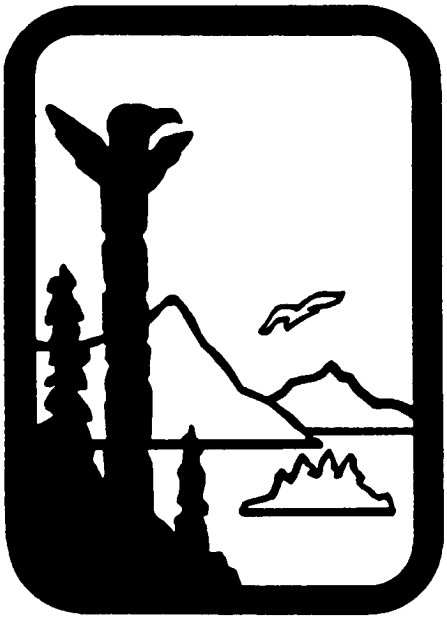

Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.10

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

Public Review Draft

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Appendix III.D.5.10

Preliminary Summary of Fairbanks Firewood & Pellet Log Emission Measurements.

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sierra research

Preliminary Summary of Fairbanks Firewood & Pellet Log Emission Measurements

prepared for:

Alaska Department of Environmental Conservation

September 28, 2014

prepared by:

Sierra Research
1801 J Street
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(916) 444-6666

and

Dirigo Laboratories
Clackamas, OR

Preliminary Summary of Fairbanks Firewood & Pellet Log Emission Measurements

- The Borough and State commissioned Dirigo Laboratories to measure PM emission benefits of burning locally produced pellet logs in Fairbanks.
- Fairbanks commissioned tests of (1) dry Fairbanks birch cordwood (20% moisture content), (2) pellet logs (7.5% moisture content), and (3) a 50/50 mix of cordwood and pellet logs in both a U.S. EPA certified stove and an uncertified stove.
- Dirigo followed EPA test procedures and measured PM emissions at both low-medium and high burn rates. Test results at low-medium burn rates (typical in Fairbanks and used to quantify emissions in the SIP inventory) showed the following:
    - Reductions in PM emissions for both the pellet logs and the mix relative to dry cordwood, ranged from 18% - 54%; and
    - 50/50 mix reductions were roughly twice those found for pellet logs, ranging from 40% - 54%.
- DEC commissioned tests of (1) wet Fairbanks birch cordwood (~40% moisture content) and (2) a 50/50 mix of wet cordwood and pellet logs. Test results at low-medium burn rates showed the 50/50 mix produced the following:
    - 64% reduction in PM emissions for both uncertified and certified stoves relative to wet cordwood.
- Because the tests showed variability in the low burn emission rates, additional tests are needed to confirm the results and assess benefits relative to spruce and other sources of cord wood (wet and dry) burned in Fairbanks.
- While the test results are based on limited samples, they indicate substantial emission reduction potential when the pellet logs are burned in combination with cord wood (wet or dry).
- The test results cannot be generalized to other “energy logs” because they are sensitive to the wood composition and moisture content of the product.
- A preliminary estimate of emission reductions that could be achieved through pellet log use was developed based on existing annual production capacity of 3,000 tons that could be expanded to 15,000 tons by 2019.
- A program targeting pellet log/cordwood mix use on unhealthy days (defined as days forecasted above 35 ug/m^3), which averaged 24 days/winter 2010 – 2013 at the State Office Building, was considered based on current and forecasted pellet log production capacity.
- Assuming a 60% compliance rate with such a targeted program by 2019, a 50/50 mix program would produce an additional 21.8% reduction in space heating PM emissions using 3,700 tons per/year, which is well below potential production capacity in 2019.

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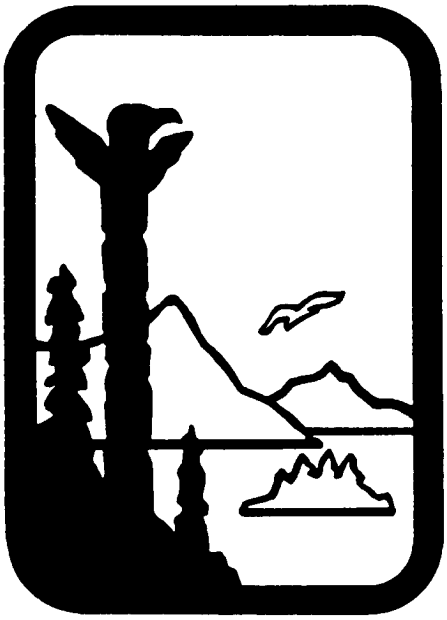

Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.11

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

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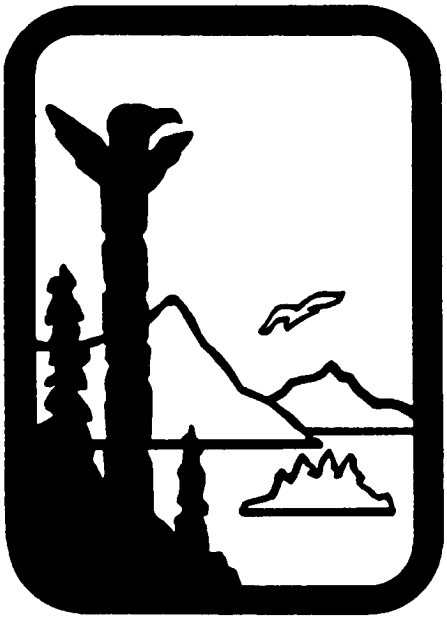

Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.12

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

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Appendix III.D.5.12

FNSB Air Quality Ordinances.

ADEC & FNSB MOU January 2010.

MOA for the Selection & Funding of Projects Funded by CMAQ within the FNSB PM2.5 Nonattainment Area.

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Title 8
HEALTH AND SAFETY

Chapters:

8.01 Emergency Medical Service
8.02 Health and Social Services
8.03 Emergency Communication Services
8.04 *Repealed*
8.05 Carbon Monoxide Emergency Episode Prevention Plan
8.06 Oxygenated Fuel
8.07 Curfew for Minors
8.08 Fireworks
8.10 Solid Waste Collection District
8.12 Garbage and Solid Waste
8.14 Abandoned Vehicles
8.16 *Repealed*
8.18 *Repealed*
8.20 Vehicle Plug-In Program
8.21 $PM_{2.5}$ Air Quality Control Program

Chapter 8.01
EMERGENCY MEDICAL SERVICE

Sections:

8.01.010 Creation of powers.
8.01.020 Emergency medical service – Intent.
8.01.030 Emergency medical services (EMS) boards.
8.01.040 *Repealed.*
8.01.050 Functions and duties.
8.01.060 Organization.
8.01.070 Definitions.

8.01.010 Creation of powers.

There is established a nonareawide service within the borough designated “Fairbanks North Star Borough Emergency Medical and Facilities Service” within the area outside of the cities of Fairbanks and North Pole, as shown on the corresponding map in the clerk’s office. The Fairbanks North Star Borough Emergency Medical Service area shall have emergency medical services and facilities, including ambulance powers. (Ord. 83-154 § 2, 1983)

8.01.020 Emergency medical service – Intent.

The borough shall exercise the power to provide emergency medical service as approved by the electorate to promote efficiency and performance of emergency medical services throughout the borough. (Ord. 83-154 § 2, 1983)

8.01.030 Emergency medical services (EMS) boards.

A. EMS Advisory Board. There is created an emergency medical services board, which shall consist of members appointed by the mayor with assembly concurrence. The composition of the board shall be as follows:

1. Three citizens-at-large;

2. Three service unit representatives (nominations to be elected by all EMS service units collectively);

3. One medical board representative;

4. One Fairbanks Memorial Hospital representative;

5. One regional EMS planning agency representative;

6. One Fairbanks North Star Borough EMS coordinator (ex officio, nonvoting);

7. One Fairbanks North Star Borough assembly member (ex officio, nonvoting).

The EMS advisory board shall contain no more than nine voting members.

B. Medical Board. There is created a medical board which shall consist of members appointed by the mayor with assembly concurrence. The composition of the medical board shall be as follows:

1. Seven physicians, to include at least one emergency room physician and one physician-at-large (non-EMS related);

2. One ambulance service unit representative (to be selected by provider groups);

3. One nonambulance EMS service unit representative (to be selected by provider groups);

4. One Fairbanks North Star Borough EMS coordinator (ex officio, nonvoting).

The medical board shall contain no more than nine voting members. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

8.01.040 Board compensation.

Repealed by Ord. 87-034. (Ord. 83-154 § 2, 1983)

8.01.050 Functions and duties.

A. The EMS advisory board shall act as an emergency medical service advisory board for the area outside of the cities of Fairbanks and North Pole to the mayor, including making studies, holding public hearings, and making recommendations to the mayor in conjunction with medical board recommendations, on areas which may include, but are not limited to, the following:

1. Levels of EMS service;

2. Capital improvement projects;

3. The annual operational budget of service units;

4. Emergency medical service policies and procedures;

5. Emergency medical services training units;

6. Appropriate equipment for service units;

7. Service unit personnel qualifications;

8. Service unit backup equipment;

9. New emergency medical service unit areas and locations;

10. Fees to be charged for ambulance service;

11. Mutual aid and support agreements with ambulance services of other jurisdictions and with private ambulance services;

12. The EMS policy manual;

13. *Repealed by Ord. 87-034;*

14. The proposed annual budget for emergency medical services within the Fairbanks North Star Borough;

15. Capital improvement needs for each service unit;

16. Ordinances and actions to be taken by the mayor;

17. Consultations with other advisory bodies, such as the planning commission, medical board, and any other medical, health, or public safety organizations.

Each service unit shall coordinate directly with the EMS advisory board in regard to its budget and all other matters for which the board is responsible.

B. The medical board shall perform the following functions and duties:

1. Create and supervise standing orders;

2. Establish medical communication protocols;

3. Establish medical criteria for new and current levels of service, to include:

a. Desirable response times;

b. Personnel qualifications and levels of training;

c. Medical equipment needs for designated levels of service;

d. Response area boundaries, medical facilities, and changes to existing service areas;

4. Approve all medical equipment and training requests that require borough funding. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

8.01.060 Organization.

All matters of administration shall be the responsibility of the emergency medical services (EMS) coordinator. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

8.01.070 Definitions.

As used herein, “service unit” means a geographically defined area to which a certain emergency medical service group is assigned. (Ord. 87-034 § 2, 1987; Ord. 83-154 § 2, 1983)

Chapter 8.02
HEALTH AND SOCIAL SERVICES

Sections:

8.02.010 Definitions.

8.02.010 Definitions.

“Health and social services” means programs that are essential to the maintenance of life or focus primarily on prevention such as health screening, preventive services and referral. (Ord. 93-039 § 3, 1993)

Chapter 8.03
EMERGENCY COMMUNICATION SERVICES

Sections:

8.03.010 Enhanced 911 emergency reporting system.
8.03.020 Definitions.
8.03.030 Enhanced emergency reporting systems.
8.03.040 *Repealed.*

8.03.010 Enhanced 911 emergency reporting system.

A. Pursuant to AS 29.35, any *local exchange telephone company* providing service within the *borough* shall cooperate in the establishment of an enhanced 911 emergency reporting system.

B. The area served by the *enhanced 911 system* shall be the entire Fairbanks North Star Borough, excluding Eielson Air Force Base. (Ord. 2014-29 § 3, 2014; Ord. 2013-64 § 3, 2013; Ord. 93-057 § 2, 1993)

8.03.020 Definitions.

In this chapter and Chapter 3.60 FNSBC, the following definitions apply:

"*911 PSAP selective router demarcation point*" is the physical point at which the public network of a telecommunications company ends and the private network of the *borough*'s 911 system begins.

"*911 service area*" or "*enhanced 911 service area*" means the area within the *borough* that has been designated to receive enhanced 911 service; the area designated to receive an *enhanced 911 system* is not a "service area" under Article X, Section 5 of the Alaska Constitution.

"*Borough*" means the Fairbanks North Star Borough.

"*Enhanced 911 equipment*" means any equipment dedicated to the operation of, or use in, the establishment, operation or maintenance of an *enhanced 911 system*, including customer premises equipment, automatic number identification or automatic location identification controllers and display units, printers, recorders, software and other essential communication equipment.

"*Enhanced 911 system*" or "*system*" means a telephone system consisting of network, database and *enhanced 911 equipment* that uses the single three-digit number, 911, for

reporting a medical, fire, police, or other emergency situation, and which enables the users of a public telephone system to reach a *public safety answering point* and includes the personnel required to acquire, install, operate and maintain the system.

"*Local exchange access line*" means a telephone line that connects a *local exchange service* customer to the *local exchange telephone company* switching office and has the capability of reaching local public safety agencies, but does not include a line used by a carrier to provide interexchange services.

"*Local exchange service*" means the transmission of two-way interactive switched voice communications furnished by a *local exchange telephone company* within the Fairbanks North Star Borough, including access to *enhanced 911 systems*.

"*Local exchange telephone company*" means a telephone utility certified by the Alaska Public Utilities Commission to provide *local exchange service* in the Fairbanks North Star Borough.

"*Public safety answering point*" means a 24-hour local communications facility that receives 911 service calls and directly dispatches emergency response services or that relays calls to the appropriate public or private safety agency. (Ord. 2013-64 § 4, 2013; Ord. 2010-59 § 3, 2011; Ord. 93-057 § 2, 1993)

8.03.030 Enhanced emergency reporting systems.

A. The *borough* may purchase, lease or contract for any *enhanced 911 equipment* or services required to establish or maintain an *enhanced 911 system* at *public safety answering points* from a *local exchange telephone company* or other qualified vendor of an *enhanced 911 system*.

B. If the *enhanced 911 system* is to be provided for an area that is included in more than one telephone company service area, the *borough* may enter into such agreements as are necessary to establish and operate the *system*.

C. The *borough* hereby designates both 911 Cushman Street and 800 William C Leary Lane in Fairbanks as the two *911 PSAP selective router demarcation points* solely for the purposes of 911 call delivery by telecommunications carriers. (Ord. 2013-64 § 5, 2013; Ord. 93-057 § 2, 1993)

8.03.040 Enhanced 911 advisory committee.

Repealed by Ord. 2014-13. (Ord. 2010-59 § 4, 2011; Ord. 94-010 § 2, 1993)

Chapter 8.04
AIR POLLUTION

(Repealed by Ord. 2013-07)

Chapter 8.05
CARBON MONOXIDE EMERGENCY EPISODE PREVENTION PLAN

Sections:

8.05.010 Purpose.
8.05.020 Episode criteria.

8.05.010 Purpose.

The Fairbanks area emergency episode prevention plan is designed to prevent carbon monoxide concentrations within the borough from reaching levels which endanger the public health. Primary responsibility for implementation of this plan rests with the borough's air quality division of the department of transportation. (Amended during 1993 republication; Ord. 85-065 § 2, 1985)

8.05.020 Episode criteria.

A. During the winter months of November through February the borough shall review daily carbon monoxide data. When the CO concentration reaches the onset level for an episode and is expected to remain at that level for 12 hours, an alert will be declared.

B. The following definitions are adopted:

"Alert" means when the FNSB air quality division determines, using available data, that a violation of the nine parts per million for an eight-hour average will likely occur.

"Episode" means when conditions reach alert status.

"Forecast" means a description of the current dispersion conditions described as good, fair or poor and including the expected CO concentrations expressed in parts per million for an eight-hour average.

"Maintenance area" means:

1. The Fairbanks/Fort Wainwright subarea, including Township 1 South, Range 1 West, Sections 2 through 23, the portion of Section 1 west of the Fort Wainwright military reservation boundary, and the portions of Section 24 north of the Old Richardson Highway and west of the military reservation boundary;

2. Township 1 South, Range 2 West, Sections 13 and 24, the portion of Section 12 southwest of Chena Pump Road, and the portions of Sections 14 and 23 southeast of the Chena River;

3. Township 1 South, Range 1 East, Sections 7, 8 and 18, and the portions of Section 19 north of the Richardson Highway; and

4. The North Pole subarea, including Township 2 South, Range 2 East, and the portions of Section 9 and 10 southwest of the Richardson Highway.

C. Carbon Monoxide Control Measures. FNSB air quality division will notify local media to ensure the declared alert is broadcast. Information within the notification will contain the CO forecast and procedures to reduce sources of CO, e.g., use of public transportation, use of engine preheating, elimination of unnecessary use of motor vehicles. (Ord. 2013-07 § 3, 2013; Ord. 2004-61 § 2, 2004; Ord. 2003-71 § 2, 2003; amended during 1993 republication; Ord. 91-044 § 2, 1991; Ord. 85-065 § 2, 1985)

Chapter 8.06
OXYGENATED FUEL

Sections:

8.06.010 Purpose.
8.06.020 Definitions.
8.06.030 Unlawful acts.
8.06.040 Penalty for violations.

8.06.010 Purpose.

The purpose of this chapter is the protection of health and safety of the residents of the Fairbanks North Star Borough from problems caused by the use of oxygenated fuel.

It establishes a zero tolerance local ambient air quality standard as provided for by 42 USC 7545(M)(3). (Ord. 94-018 § 2, 1994)

8.06.020 Definitions.

“Borough” means the Fairbanks North Star Borough.

“Mandate” includes, but is not limited to, cases where sanctions of any kind are proposed for failure to adopt an oxygenated fuel program.

“Oxygenated fuel” means a fuel that:

1. Contains an average of 2.7 percent oxygen by weight for the control period; and

2. Contains at least 2.0 percent oxygen by weight. (Ord. 94-018 § 2, 1994)

8.06.030 Unlawful acts.

A. No public official or government entity may cause or enforce mandatory sales and use of oxygenated fuel within the borough.

B. This chapter shall remain in effect until such time that the federal, state and borough governments certify, in conjunction with independent peer-reviewed scholarly confirmation, that the oxygenated fuel to be used in the Fairbanks North Star Borough is not harmful to the health and safety of borough residents and their environment. (Ord. 94-018 § 2, 1994)

8.06.040 Penalty for violations.

A. Nothing in this chapter shall prohibit the Fairbanks North Star Borough from taking civil action for violations of any provisions of this chapter.

B. Nothing in this chapter shall prohibit individuals from taking civil action for violations of their rights or for the compromising of their health and safety. (Ord. 94-018 § 2, 1994)

Chapter 8.07
CURFEW FOR MINORS

Sections:

8.07.010 Definitions.
8.07.020 Offenses.
8.07.030 Exceptions.
8.07.040 *Repealed.*

8.07.010 Definitions.

In this chapter:

“Curfew hours” means:

1. September through May:

   a. 11:00 p.m. on any Sunday, Monday, Tuesday, Wednesday, or Thursday until 5:00 a.m. of the following day; and

   b. 1:00 a.m. on any Saturday and Sunday until 5:00 a.m. of the same day.

2. June through August: 1:00 a.m. on any day until 5:00 a.m. of the same day.

“Emergency” means an unforeseen combination of circumstances or the resulting state that calls for immediate action. The term includes, but is not limited to, a fire, natural disaster, automobile accident, or any situation requiring immediate action to prevent physical injury or loss of life.

“Establishment” means any privately owned place of business operated for a profit to which the public is invited, including but not limited to any place of amusement or entertainment.

“Guardian” means:

1. A person who, under court order, is the guardian of the minor; or

2. Public or private agency with whom a minor has been placed by a court.

“Knowingly” means, with respect to conduct or to a circumstance described by a provision of law defining an offense, that a person is aware that his or her conduct is of that nature or that the circumstance exists; when knowledge of the existence of a particular fact is an element of an offense, that knowledge is established if a person is aware of a substantial probability of its existence, unless the person actually believes it does not exist.

"Minor" means any person under the age of 18 years.

"Operator" means any individual, firm, association, partnership, or corporation operating, managing, or conducting any establishment. The term includes the members or partners of an association or partnership and the officers of a corporation.

"Parent" means a person who is:

1. A natural parent, adoptive parent, or stepparent of another person; or

2. At least 18 years of age and authorized by a parent or guardian to have the care and custody of a minor.

"Physical injury" means a physical pain or an impairment of physical condition.

"Public place" means any place to which the public or a substantial group of the public has access, and includes but is not limited to streets, highways, sidewalks, bridges, alleys, plazas, parks, driveways, parking lots, and the common areas of schools, hospitals, apartment houses, office buildings, transport facilities, and shops.

"Remain" means to:

1. Linger or stay; or

2. Fail to leave the premises when requested to do so by a police officer or the owner, operator, or other person in control of the premises. (Ord. 98-043 § 2, 1998)

8.07.020 Offenses.

A. A minor commits an offense if he or she remains in any public place or on the premises of any establishment within the Fairbanks North Star Borough during curfew hours.

B. A parent or guardian of a minor commits an offense if he or she knowingly permits, or by insufficient control allows, the minor to remain in any public place or on the premises of any establishment within the Fairbanks North Star Borough during curfew hours in violation of this chapter. Indifference as to the activities or whereabouts of the minor shall be prima facie evidence of insufficient control.

C. The owner, operator, or any employee of an establishment commits an offense if he or she knowingly allows a minor to remain upon the premises of the establishment during curfew hours. (Ord. 98-043 § 2, 1998)

8.07.030 Exceptions.

A. It is an exception to prosecution under FNSBC 8.07.020(A) and (B) if the minor was:

1. Accompanied by his or her parent or guardian;

2. On an errand at the written direction of his or her parent or guardian, without any detour or stop (written direction must be signed, timed, and dated by the parent or guardian and must indicate the specific errand);

3. Involved in an emergency;

4. Engaged in an employment activity, or going to or returning from an employment activity, without detour or stop;

5. On the public right-of-way immediately abutting the minor's residence or immediately abutting the residence of a next door neighbor, if the neighbor did not complain to the police department about the minor's presence;

6. Attending, or going to or returning home from, without any detour or stop, an official school, religious, or other recreational activity supervised by adults and sponsored by the Fairbanks North Star Borough, Fairbanks North Star Borough School District, a civic organization, or another similar entity that takes responsibility for the minor;

7. Exercising First Amendment rights protected by the United States Constitution, such as the free exercise of religion, freedom of speech, and the right of assembly; or

8. Married or had disabilities of minority removed in accordance with AS 9.55.

B. It is an exception to prosecution under FNSBC 8.07.020(C) that the owner, operator, or employee of an establishment promptly notified the police department that a minor was present on the premises of the establishment during curfew hours and refused to leave. (Ord. 98-043 § 2, 1998)

8.07.040 Penalties.

Repealed by Ord. 2013-26. (Ord. 2012-66 § 4, 2013; Ord. 98-043 § 2, 1998)

Chapter 8.08
FIREWORKS[1]

Sections:

8.08.010 Defined.
8.08.020 Sale prohibited.
8.08.030 Use restricted.
8.08.040 Displays – Permit required.
8.08.050 Authorized sale and use.
8.08.060 Penalty for violations.

8.08.010 Defined.

"*Fireworks*" means and includes any combustible or explosive composition, or any substance or combination of substances, or article prepared for the purpose of producing a visible or an audible effect by combustion, explosion, deflagration or detonation, and shall include toy pistols, toy cannons, toy canes or toy guns in which explosives are used, the type of nonmanned balloons which require fire underneath to propel the same, firecrackers, torpedoes, skyrockets, Roman candles, daygo bombs, or other devices of like construction and any devices containing any explosive or flammable compound, or any tablets or other devices containing any explosive substance, except that the term "*fireworks*" shall not include auto flares, ammunition, paper caps, containing not in excess of an average of 0.25 of a grain of explosive content per cap manufactured in accordance with the Interstate Commerce Commission regulations for packing and shipping as provided therein, and toy pistols, toy canes, toy guns, or other devices for use of such caps, and sale and use of which shall be permitted at all times. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.010)

8.08.020 Sale prohibited.

The sale of *fireworks* is prohibited. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.020)

8.08.030 Use restricted.

Except as provided in FNSBC 8.08.040 and 8.08.050, no person shall, except on real property owned by him, under his control or with permission granted by the owner, use or explode *fireworks*. The mayor may, in times of extreme fire danger, prohibit all use or explosion of *fireworks* in the Fairbanks North Star Borough within the areas outside the cities of Fairbanks and North Pole. (Ord. 2014-16 § 2, 2014; Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.030)

8.08.040 Displays – Permit required.

A. *Fireworks* may be used for public displays by municipalities, fair associations, amusement parks and other organizations or groups of individuals, under the following conditions:

1. A permit is obtained from the borough mayor or his authorized representative after approval of the local fire authorities;

2. In determining whether to issue or deny a permit for the use of *fireworks* at a public display, the borough mayor or his designee shall consider the following:

a. The location of the proposed display and the surrounding property;

b. The type of *fireworks* and the length of the proposed display;

c. The danger of the proposed display to persons and property; and

d. The experience and the competency in handling *fireworks* of the person in charge of the proposed display;

3. A bond is filed with the borough, in the amount of at least $1,000 to ensure payment of all damages to persons or property caused by the display. The bond requirement will not be operative if the holder of the permit has in effect an insurance policy which accomplished the same purpose as the bond.

B. No permit is transferable.

C. Any *fireworks* that remain unfired after the display is concluded shall be immediately disposed of in a way safe for the particular type of *fireworks* remaining. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.040)

8.08.050 Authorized sale and use.

Nothing in this chapter shall be construed to prohibit any resident wholesaler, dealer or jobber to sell at wholesale such *fireworks* as are not herein prohibited; or the sale of any kind of *fireworks* provided the same are to be shipped directly out of the borough, in accordance with the Interstate Commerce Commission regulations covering the transportation of explosives and other dangerous articles by motor, rail, and water; or the use of *fireworks* by railroads or other transportation agencies for signal purposes or illumination, or the sale or use of blank cartridges for a show or theater, or for signal or ceremonial purposes in athletics or sports, or for use by military organizations. This chapter does not pertain to those explosives or devices

used in construction, logging or mining and would not prohibit the use of these explosives or devices in such activities. (Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.050)

8.08.060 Penalty for violations.

Every person, firm, corporation, club, association or organization violating any of the provisions of this chapter is guilty of a violation punishable by a $1,000 fine. (Ord. 2013-65 § 17, 2013; Ord. 72-27, 1972; Ord. 72-5, 1972; Ord. 69-1, 1969; prior code § 32.05.060)

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[1] For statutory provisions authorizing municipalities to regulate the offering for sale, exposure for sale, sale, use or explosion of fireworks, see AS 29.35.

Chapter 8.10
SOLID WASTE COLLECTION DISTRICT

Sections:

8.10.010 Solid waste collection district.

8.10.010 Solid waste collection district.

A. There is hereby established the Fairbanks North Star Borough solid waste collection district. The district is not a service area. The district shall consist of the area lying within the boundaries of the city of North Pole and the area outside all the cities in the borough.

B. The assembly may levy taxes, charges, or assessments in the district to finance the collection of solid waste in the district. (Recodified during 2004 republication; Ord. 91-008 § 3, 1991. Formerly 1.02.160.)

Chapter 8.12
GARBAGE AND SOLID WASTE[1]

Sections:

8.12.011 Chapter purpose.
8.12.021 Definitions.
8.12.031 Solid waste disposal facilities.
8.12.033 Recycling of materials.
8.12.034 *Recodified.*
8.12.035 Approved recyclers.
8.12.036 *Repealed.*
8.12.041 General prohibition.
8.12.046 Landfill tipping fees.
8.12.051 Use of borough waste facilities.
8.12.055 Waiver of tipping fees.
8.12.061 Collection and transportation of solid waste.
8.12.071 Penalty for violations.

8.12.011 Chapter purpose.

The declared purpose of this chapter is the protection of the public health, safety and welfare of the people of the Fairbanks North Star Borough. The chapter and any regulations promulgated pursuant thereto are intended to:

A. Control dumping and disposal of solid waste at such place and in such manner that it will not be a detriment to the health, safety and welfare of the citizens of the borough;

B. Provide facilities for the proper disposal of solid waste at minimum cost;

C. Reduce litter and littering;

D. Promote resource recovery, recycling and reuse of solid waste;

E. Preserve and enhance the beauty and quality of our environment;

F. Promote responsible agricultural practices and encourage economic activity.

No section of this chapter should be interpreted as prohibiting residents from reusing articles from the waste stream discarded at a borough transfer site. (Ord. 2009-39 § 2, 2009; Ord. 84-29 § 2, 1984)

8.12.021 Definitions.

In this chapter unless the context requires otherwise:

“Avoided costs” means the savings realized by the solid waste collection district or solid waste disposal funds of the borough if recyclables are diverted from the landfill or separated from the waste stream prior to being deposited in the landfill or a transfer station. Avoided costs shall not include hauling costs avoided by the city of Fairbanks. Avoided hauling costs of the borough shall include avoided costs of hauling recyclables from outside the city of Fairbanks, tipping fees avoided by the taxpayers of the solid waste collection district, and calculated savings to the solid waste operation that result from a lower amount of refuse being handled at the landfill including avoided closure and post-closure costs. To determine avoided hauling costs and tipping fees, an approved recycler must have a method of weighing the recycled goods approved as accurate and verifiable by the Fairbanks North Star Borough. To determine avoided landfill costs, the methodology used will be the methodology used by the MacTech study, or other comparable study as selected at the sole discretion of the mayor, to calculate landfill costs, adjusted for the projected reduction in tonnage.

“Biomass” means a given quantity of organic material.

“Bulky wastes” are large items of refuse including but not limited to appliances, vehicles, furniture, large auto parts, tires, trees and branches, stumps and flotage.

“Commingled recyclables” means a mixture of several recyclable materials into one container.

“Curbside collection” means programs where recyclable materials are collected at the curb from special containers, to be brought to various processing facilities.

“Director” means the public works director, or his/her designee.

“Diversion rate” means a measure of the amount of recyclables diverted for recycling compared with the total amount that was previously landfilled.

“Documentation” means written proof that a quantity of recyclables has been recycled and will not be landfilled.

“Drop-off center” means a method of collecting recyclable or compostable materials in which individuals take materials to collection sites and deposit them into designated containers.

“Garbage” means any putrescible solid and semisolid animal or vegetable wastes resulting from the production, handling, preparation, cooking, serving or consumption of food or food materials.

“Hazardous waste” means a waste or combination of wastes that because of quantity, concentration or physical, chemical or infectious, pathological or radiological characteristics might cause, or significantly contribute to:

1. An increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or

2. A substantial present or potential hazard to human health or to the environment if improperly managed, treated, stored, transported or disposed of or otherwise managed.

“Industrial solid waste” means any waste substance or a combination thereof resulting from the operation of or from any process of industry, manufacturing, trade or business, or from the development of any agricultural or natural resources.

“Inert solid wastes” means wastes including but not limited to wood, glass, crockery, brick, plastics, rubber or other materials which have minimum potential for environmental degradation and leachate production.

“Infectious waste” means certain laboratory, surgical and hospital waste; surgical specimens including pathological specimens, tissues, blood elements, excreta and secretions obtained from patients; disposable materials that have been in contact with persons who have a suspected or diagnosed communicable disease; a substance that might harbor or transmit pathogenic organisms; disposable materials from outpatient areas, emergency rooms and rooms of patients with a suspected or diagnosed communicable disease that requires isolation; and certain equipment, including instruments, syringes and needles.

“Junk” means used materials which will not be further utilized unless collected and processed for reuse or recycling.

“Litter” means any discarded, used or unconsumed substance or waste material which has not been deposited in a suitable litter receptacle.

“Manual separation” means the separation of recyclable or compostable materials from waste by hand sorting.

“Materials recovery” means extraction of materials from the waste stream for reuse or recycling, including source separation, front-end recovery, in-plant recycling, post-combustion recovery, leaf composting, etc.

“Mechanical separation” means the separation of waste into various components using mechanical means, such as cyclones, trommels and screens.

“Putrescible waste” means material that can decompose and cause obnoxious odors.

“Recyclable metals” means copper, brass, bronze, aluminum, lead, zinc, and ferrous metals, but does not include steel cans and those metals that are bonded or fused to other materials and cannot be readily separated.

“Recyclables” means materials that have useful physical or chemical properties after serving their original purpose and that can, therefore, be reused or remanufactured into additional products, including refuse derived fuel (RDF).

“Recycling” means the process by which a material that would otherwise be placed in the landfill is collected, reprocessed, or remanufactured, and then reused, or used for energy.

“Refuse” means any putrescible or nonputrescible solid waste, except human excreta.

“Resource recovery” means the processing of solid wastes in such a way as to produce materials or energy which may be used in manufacturing, agriculture, or other processes.

“Rubbish” means any solid waste except ashes and putrescible waste.

“Secured” means tied down or otherwise not subject to release.

“Sewage sludge” means the organic sludge generated by municipal or other wastewater collection and treatment activities, and may include primary, secondary and digested sludges, grit and screenings.

“Sludge” means any solid, semisolid or liquid waste which contains at least five percent solids by weight generated at a municipal, commercial or industrial wastewater treatment plant, septic tank, water supply treatment plant or air pollution control facility; “sludge” includes any similar material accumulated in and removed from a storage tank or surface impoundment containing oil, industrial liquid waste, acid, chemicals or other similar substances.

“Solid waste” means drilling wastes, garbage, refuse, sludge and other discarded material, including solid, liquid, semi-solid or contained gaseous material resulting from industrial, commercial and agricultural operations, and from community activities. For the purposes of this chapter “solid waste” does not include:

1. Spoil and overburden from road construction, land clearing or mining operations;

2. Mining waste regulated by the Federal Surface Mining Control and Reclamation Act of 1977, as amended, and by the Alaska Surface Mining Control and Reclamation Act of

1982 (AS 27.21);

3. Domestic sewage and other wastes that are discharged into the pass through a sewer system to a publicly owned treatment works;

4. Industrial or mining wastes that are being collected, stored or treated in:

a. A wastewater treatment plant before discharge or removal, or

b. An industrial processing facility for continual reuse;

5. Industrial discharges that are point sources subject to permits under Section 402 of the Federal Water Pollution Control Act, as amended;

6. Source, special nuclear, or byproduct material as defined by the Nuclear Waste Policy of 1982, as amended January 7, 1983, at Public Law 97-425.

“Source separation” means the segregation of specific materials at the point of generation for separate collection. Recyclables are source separated at residences as part of a recycling program.

“Special solid waste” means hazardous wastes, infectious wastes, radioactive wastes, industrial wastes or sludges and sewage residues. (Ord. 2012-49 § 2, 2012; Ord. 2009-39 § 3, 2009; Ord. 2003-43 § 2, 2003; Ord. 94-045 §§ 2, 3, 1994; amended during 1993 republication; Ord. 89-038 § 2, 1989; Ord. 84-29 § 2, 1984)

8.12.031 Solid waste disposal facilities.

A. The borough may require any person dumping solid waste at the following areas to dump where specified, and may reject or impound any waste which is judged to be unacceptable. Impoundment implies that the waste and its container, but not the vehicle used to transport the waste, may be impounded. The following facilities are designated for the disposal of all types of solid waste, with the exception of special solid waste:

1. South Cushman baler and landfill;

2. Other borough-owned or borough-operated landfills.

B. Collection and transfer sites provided as part of the borough’s solid waste collection district are designated solely for the disposal of residential solid waste by residents of the borough residing outside the city of Fairbanks.

C. The following facilities are for the disposal of solid waste as approved by the owners of

such facilities. Only persons with the prior approval of the owners may dump solid waste at these facilities:

1. Military landfills;

2. Other containers which will be dumped at the South Cushman baler and landfill, including private dumpsters located at apartment complexes, mobile home parks and other locations. For the purposes of this paragraph, in the case of leased private dumpsters, the lessee shall be considered the owner;

3. Other locations, as approved and permitted by the state, subject to the conditions of such permits.

D. Any administrative decisions of the director or the solid waste superintendent pursuant to this chapter may be appealed to the pollution control commission. In all actions under the provisions of this chapter, the name of the complainant will be a matter of public information. (Ord. 94-056 § 2, 1994; amended during 1993 republication; Ord. 89-038 § 3, 1989; Ord. 84-29 § 2, 1984)

8.12.033 Recycling of materials.

A. The borough shall ensure that, at all borough-owned or operated landfills and primary collection and transfer sites, separate locations or containers are provided to receive and hold recyclable materials. These may include but are not limited to:

1. Glass;

2. Aluminum cans;

3. Corrugated cardboard, flattened;

4. Computer paper;

5. Office paper;

6. Scrap metal:

a. Aluminum,

b. Copper,

c. Iron,

d. Brass,

e. Stainless steel;

7. Car radiators;

8. Plastic;

9. Biomass material;

10. Other materials selected by the borough.

B. The borough may provide for this separation by either:

1. Ensuring that borough-provided locations or containers are available; or

2. Contracting with a private firm to furnish and service such locations or containers.

C. If the borough provides for the deposit of such materials directly, periodically the borough shall sell to recycling firms the materials collected in these locations or containers.

D. Deposit of materials other than the appropriate, designated materials in any of the thus-established locations or containers, or the removal of any such materials, except by prior written permission of the borough, is prohibited.

E. The borough shall waive in whole or in part the tipping fee to persons, businesses and entities which separate recyclable materials into lots designated by the borough which may include aluminum, glass, plastic, cardboard, mixed paper, newspaper, electronics or wood products in loads delivered to the landfill. A waiver may be granted for other materials, if recommended by the commission and approved by the mayor with notification to the assembly. The waiver shall be no greater than 100 percent of the tipping fee. Nonseparated loads of recyclables shall not receive a waiver. The mayor is authorized to establish a rate schedule for such waivers.

F. It is the policy of the Fairbanks North Star Borough to encourage reduction, reuse and recycling of solid wastes generated in the borough. These efforts may include payment of a portion of actual avoided costs of hauling and land filling to approved recyclers/reusers not to exceed $175,000. Subject to appropriation, avoided costs, less a 25 percent reduction, may be paid to approved recyclers when documentation is provided to show that materials separated as recyclables have been removed from the waste stream by recycling within the current fiscal year. Twenty-five percent of avoided costs may be paid to a fund established to maintain the efforts of the commission.

G. The borough may implement a program of designated burial of source separated recyclable materials that are not removed from the waste stream. (Ord. 2009-39 §§ 4, 5, 2009; Ord. 94-045 § 4, 1994; amended by voter approval 10/5/93; Ord. 91-035 § 2, 1991; Ord. 89-060 § 2, 1990)

8.12.034 Recycling commission.

Recodified as Chapter 2.110 FNSBC by Ord. 2011-30. (Ord. 2009-39 § 7, 2009; Ord. 94-045 § 5, 1994)

8.12.035 Approved recyclers.

A. The recycling commission shall recommend to the administration those recyclers authorized to remove recyclables for the purpose of reuse or remanufacture who will be eligible to receive payment for tonnage of materials that will not be placed in the landfill. The commission shall evaluate proposals from recyclers. The evaluation criteria will include the following:

1. Valid Alaska business license and city license if applicable;

2. Proof of financial resources in proportion to the business purpose;

3. Authorized site approval documentation by DEC and FNSB, if necessary;

4. Submission and approval of a business plan to show:

    a. Type(s) of materials to be recycled or shipped;

    b. Location of approved material sites including appropriate site zoning;

    c. Estimated number of tons to be recycled each month;

    d. Program start date for waste generated after specified date; and

    e. Consistency with the borough's overall recycling plan.

5. The overall impact on the goal of recycling and reduction of solid wastes generated in the borough.

B. Notwithstanding FNSBC 16.30.010 through 16.30.080, the mayor or his designee may enter into a contract with any or all recyclers recommended by the recycling commission and who demonstrate an ability to make a significant positive impact on the borough's recycling plan goals sufficient to justify the cost of the contract. No funds shall be paid pursuant to

FNSBC 8.12.033(F) to a recycler until a contract has been agreed to and signed by the borough and recycler. The contract shall not exceed a term of 10 years. The contract must include a provision authorizing termination at will by the mayor. (Ord. 2009-39 § 8, 2009; Ord. 94-045 § 6, 1994)

8.12.036 Recycling promotion special revenue fund.

Repealed by Ord. 2009-39. (Ord. 94-045 § 7, 1994)

8.12.041 General prohibition.

A. No person shall dispose of solid wastes, special solid wastes or sludge in any place except those listed in FNSBC 8.12.031.

B. No person shall dump, throw, drop or deposit any special solid waste in the Fairbanks North Star Borough except approved haulers at approved facilities.

C. No person shall allow the accumulation of garbage, solid waste, animal feces, etc., on property where he resides or which he owns or controls to impose a threat to public health. Nothing in this section shall be construed to restrict normal agricultural practices in the rural and agricultural or general use zones.

D. No person shall discard any litter into or on any water or land within the borough, except that nothing in this section shall be construed to affect the authorized collection and discarding of such litter in or on areas or receptacles provided for such purpose.

E. No person shall dump solid waste in the borough's public dumpsters collected from any location other than individual residences located in the borough outside the city of Fairbanks.

F. No solid waste shall be dropped, deposited, discarded or otherwise disposed at a public dumpster unless it remains within the public dumpster. Any disposal outside the container is a violation of subsection (D) of this section.

G. No person shall dump at the borough's public dumpsters bulky wastes, dead animals, infectious wastes, demolition debris or special solid wastes. (Ord. 2013-07 § 4, 2013; Ord. 94-056 § 3, 1994; Ord. 89-038 § 4, 1989; Ord. 84-29 § 2, 1984)

8.12.046 Landfill tipping fees.

A. Except as otherwise provided in this chapter, any person disposing of solid waste at the borough landfill shall pay a tipping fee established in accordance with FNSBC 3.50.010.

B. The borough mayor may permit a commercial hauler regulated by the state of Alaska to

dispose of residential solid waste collected solely from individual residences located in the solid waste collection district and delivered directly to the borough landfill without direct payment of a tipping fee. Such tipping fees shall be paid to the landfill by the solid waste collection district. (Ord. 2001-34 § 2, 2001)

8.12.051 Use of borough waste facilities.

A. Any person wishing to dispose of solid waste generated or collected from a location outside of the borough shall be charged a fee that reflects the actual costs of providing such services, including but not limited to current operational costs, probable operational and monitoring costs for the life of the landfill, and landfill closure and replacement costs.

B. Disposal of solid waste generated or collected from a location outside of the borough shall not be permitted unless the solid waste meets the conditions of the borough's ADEC solid waste permit.

C. Disposal of more than 25 tons of solid waste per month from a source outside of the borough shall not be permitted unless the mayor determines that:

1. The solid waste can be safely and efficiently disposed of at the borough landfill;

2. The solid waste will not significantly impact the capacity of the borough landfill; and

3. There will be no harm to the borough or the borough landfill.

D. Disposal of solid waste from a source outside the borough for longer than 60 days shall also require concurrence of the borough assembly. (Ord. 97-036 § 2 1997; Ord. 84-29 § 2, 1984)

8.12.055 Waiver of tipping fees.

A. The borough will waive the tipping fee to residents of the borough who bring minor loads of nonhazardous solid waste to the landfill. For the purpose of this subsection, loads of nonhazardous waste brought to the landfill from a residence in a passenger vehicle, a pick-up truck, or a trailer with two wheels and a single axle will be considered minor loads if the vehicle is not registered in the name of a company or business or used for commercial purposes.

B. Any Internal Revenue Code Section 501(c)(3) or 501(d) nonprofit organization which accepts clothing, furniture or other items of personal property, on a year-round basis, and sells those items of personal property to raise funds for the organization's services, or distributes those items of personal property to persons in need, shall be exempt from paying tipping fees on that personal property which is in such disrepair that it cannot be resold and must be

transported to and disposed of in the landfill.

C. The borough mayor may waive tipping fees for materials to the landfill for borough recycling or hazardous waste disposal programs and for community cleanup activities. The mayor may waive tipping fees for debris from private residences in the borough damaged by fire if there is no reimbursement for such waived fees from any other source. The mayor, when there is a direct and primary benefit to the public, may waive tipping fees for materials removed from deteriorated property, as defined in FNSBC 3.11.070, during the course of rehabilitation, repair, construction, reconstruction, renovation, demolition, removal or replacement of any structure on such property.[2]

D. All other loads will be considered commercial and will be charged the usual tipping fee on the entire load. (Ord. 2005-26 § 4, 2005; Ord. 99-006 § 2, 1999; Ord. 94-085 § 2, 1994; Ord. 94-074 §§ 2, 3, 1994; Ord. 93-002 § 3, 1993; Ord. 91-056 § 2, 1991)

8.12.061 Collection and transportation of solid waste.

A. The owner or occupant of any premises, business establishment, industrial establishment, or refuse collection service shall be responsible for the collection and transportation of all solid waste accumulated at a premises, business establishment or industrial establishment to an approved solid waste disposal facility in accordance with this chapter.

B. Garbage and similar putrescible wastes, or refuse containing such materials, shall be collected and transported in containers which are covered and leakproof.

C. Vehicles or containers used for the collection and transportation of any solid waste shall be loaded and moved in such a manner that the contents will not fall, leak or spill therefrom. Where spillage does occur, it is the responsibility of the collector or transporter to pick up the material, return it to the vehicle or container, and properly clean the area. Any person collecting or transporting solid waste who permits the waste to fall, leak or spill from the vehicle or who fails to clean up waste which has fallen, leaked or spilled from his vehicle shall be subject to a civil penalty not to exceed $1,000 in addition to the cost of cleanup incurred by the borough or other public agency.

D. Any person who arrives at any borough-operated solid waste disposal facility, including the South Cushman balefill/landfill and any borough solid waste transfer station, with a vehicle or container which is not covered or with a load which is not secured is in violation of this section. (Ord. 2003-43 § 3, 2003; Ord. 84-29 § 2, 1984)

8.12.071 Penalty for violations.

This chapter does not affect the private right of any person to bring an action for damages or other relief because of injury caused by garbage or solid waste. (Ord. 2013-26 § 7, 2013; Ord. 2003-43 §§ 4, 5, 6, 2003; Ord. 89-038 § 5, 1989; Ord. 84-29 § 2, 1984)

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[1] For statutory provisions authorizing municipalities to regulate garbage and solid waste collection and disposal, see AS 29.35.

[2] Code reviser's note: Ordinance 2005-26, amending subsection (C) of this section, may be repealed by voters through referendum.

Chapter 8.14
ABANDONED VEHICLES

Sections:

8.14.010 Definitions.
8.14.015 Unlawful acts.
8.14.020 Removal of abandoned vehicles.
8.14.030 Notice of impoundment.
8.14.040 Disposition – Destruction.
8.14.050 Disposition – Sale.
8.14.060 Waiver of claims for damages.

8.14.010 Definitions.

“Abandoned vehicle” means a vehicle that is:

1. Registered or titled as required under AS 28.10 that has been left unattended, standing, parked upon or within 10 feet of the traveled portion of a highway or vehicular way or area in excess of 48 hours;

2. Registered or titled as required under AS 28.10 that reasonably appears to have been left standing or parked on private property in excess of 24 hours or upon other public property for more than 30 days, without the consent of the owner or person in charge of the property;

3. A wrecked or junked vehicle that reasonably appears to have been left unattended, standing, parked upon or within 10 feet of the traveled portion of a highway or vehicular way or area in excess of 24 hours; or

4. A wrecked or junk vehicle that reasonably appears to have been left standing or parked on private property or other public property in excess of 24 hours and without the consent of the owner or person in charge of the property.

“Director” means the director of community planning, or his designee.

“Junk vehicle” means a vehicle that:

1. Is not currently registered, except for a vehicle used exclusively for competitive racing;

2. Is stripped, wrecked, or otherwise inoperable due to mechanical failure;

3. Has not been repaired because of mechanical difficulties or because the cost of

repairs required to make it operable exceeds the fair market value of the vehicle; or

4. Is in a condition that exhibits more than one of the following: broken glass, missing wheels or tires, missing body panels or parts, or missing drive train parts.

"Wrecked vehicle" means a vehicle that is disabled and cannot be used as a vehicle without substantial repair or reconstruction.

These definitions are for the purpose of this chapter only and shall not be used as definitions for language used in other chapters. (Ord. 2001-71 § 2, 2001; Ord. 86-017 § 42, 1986; Ord. 82-41 § 2, 1982)

8.14.015 Unlawful acts.

A. A person may not abandon a vehicle upon a highway or vehicular way or area.

B. A person may not abandon a vehicle upon public property or upon private property without the consent of the owner or person in lawful possession or control of the property. (Ord. 2001-71 § 8, 2001)

8.14.020 Removal of abandoned vehicles.

A. An abandoned vehicle may be impounded by the director or his designee in accord with this chapter.

B. Notwithstanding subsection (A) of this section, no vehicle may be removed from private property without the written request or consent of the property owner or occupant. (Ord. 2001-71 § 3, 2001; Ord. 82-41 § 2, 1982)

8.14.030 Notice of impoundment.

A. Within 30 days of impoundment, notice shall be given to the registered owner of record (and lienholder of record, if any) of the abandoned vehicle. When the persons involved are known, adequate notice shall be by either certified mail or personal service. The giving of notice by mail is considered complete upon the return of the receipt or upon return of the notice as undeliverable, refused or unclaimed. If such persons are not known or cannot be located the vehicle shall be impounded and notice shall be by publication in the manner prescribed in the rules of court for service of process by publication. The director shall attempt to ascertain ownership from the Department of Public Safety.

B. Notice under this section shall contain:

1. The description of the vehicle;

2. The date, time, grounds and place of removal;

3. An itemized statement of amounts due the borough for towing and storage and stating that such fees must be paid prior to redemption of the vehicle;

4. A statement that the vehicle will be disposed of 15 days from the date notice was mailed or published unless the vehicle is redeemed and costs paid; and

5. A statement that the owner of the vehicle may, at any time within the 15-day period, request a hearing before the director concerning whether the vehicle was left for the period specified in FNSBC 8.14.010 or concerning the amount due. (Ord. 2001-71 § 4, 2001; Ord. 82-41 § 2, 1982)

8.14.040 Disposition – Destruction.

If the director determines that an abandoned vehicle impounded pursuant to this chapter has been scrapped, dismantled or destroyed beyond repair, or if he determines that because of the age and condition of the vehicle it is no longer of significant value, he may dispose of it by crushing or other means of destruction upon the expiration of the 15-day period required by FNSBC 8.14.030.

The borough may also dispose of junk vehicles at the written request of the registered owner of the vehicle or person in lawful possession or control of the vehicle. This written request shall be on a form prescribed by the borough. (Ord. 2001-71 § 5, 2001; Ord. 82-41 § 2, 1982)

8.14.050 Disposition – Sale.

A. The director may sell abandoned vehicles impounded in accord with this chapter at a public auction.

B. The public auction shall be preceded by at least 20 days' notice of public auction posted in a newspaper of general circulation in the borough.

C. The notice of public auction shall state the description of the vehicle, date, time and place of auction, the name of the owner if known and a statement that, subject to the provisions of subsection (E) of this section, the vehicle shall be sold to the highest spot cash bidder.

D. The owner of the vehicle, upon presenting satisfactory proof of ownership, may redeem an abandoned vehicle prior to the time of sale after paying the borough towing and storage costs and a pro rata share of the cost of the notice and other costs of impoundment and sale.

E. A certificate of sale shall be issued for all vehicles sold at the auction. The certificate shall

stipulate that the vehicle must be titled with the Department of Public Safety before the vehicle is released to the purchaser. Upon a showing that certificate of title has been obtained the vehicle will be released to the purchaser. If no such showing has been made within a 20-day period the purchase price will be returned and the vehicle may be disposed of pursuant to this section. (Ord. 2001-71 § 6, 2001; Ord. 82-41 § 2, 1982)

8.14.060 Waiver of claims for damages.

A. An owner of an abandoned vehicle, by the act of abandonment, waives any claims he may have for damage to or loss of his vehicle which may result from actions taken pursuant to this chapter. Such damage or loss includes but is not limited to accidental damage or destruction occasioned by removal transport and storage, and acts of third parties.

B. Should a vehicle purchased at auction pursuant to FNSBC 8.14.050 be damaged or destroyed prior to release, the purchaser's remedy is limited to a return of the purchase price. (Ord. 2001-71 § 7, 2001; Ord. 82-41 § 2, 1983)

Chapter 8.16
JUNKYARDS

(Repealed by Ord. 2005-29)

Chapter 8.18
VEHICLE INSPECTION AND MAINTENANCE PROGRAM

(Repealed by Ord. 2009-36)

Chapter 8.20
VEHICLE PLUG-IN PROGRAM

Sections:

8.20.010 Vehicle plug-in program.

8.20.010 Vehicle plug-in program.

A. Parking Lot Owner Responsibilities. Between November 1st of each year and March 31st of the subsequent year, each employer or business with a total of 275 or more parking spaces with outlets within the borough maintenance area shall supply electricity to outlets located in its parking lots for use by motorists in plugging in vehicles equipped with engine heaters. Electricity shall be supplied on days when temperatures fall below 21 degrees Fahrenheit, as measured by the National Weather Service at the Fairbanks International Airport.

1. Power Cycling. Power to parking lots may be cycled on and off every other hour during days when temperatures fall below the 21 degrees Fahrenheit threshold to conserve electricity use.

2. Record Keeping. Each employer or business subject to subsection (A) of this section shall maintain a logbook that documents the days on which power is supplied to electrical outlets located in its parking lots. Notations of special circumstances that prevent the supply of electricity to outlets shall be included. The logbooks shall be maintained for a five-year period and be available for inspection upon borough request.

3. New Parking Lots.

a. Employers and businesses subject to subsection (A) of this section shall provide outlets for any new parking spaces intended for use by a motorist for longer than two hours.

b. Notwithstanding subsection (A) of this section, an employer or business shall provide outlets for new parking spaces when such spaces increase its number of spaces intended for use by a motorist for longer than two hours to 275 or more. The employer or business shall supply electricity to such outlets on days when temperatures fall below 21 degrees Fahrenheit, as measured by the National Weather Service at the Fairbanks International Airport in accordance with this chapter.

4. Maintenance of Outlets. Each employer or business subject to subsection (A) of this section shall maintain the electrical outlets in operable condition. No employer or

business subject to subsection (A) of this section shall decrease the number of parking spaces with outlets without prior approval of the I/M program administrator.

B. Implementing Policies and Procedures. Within six months of the effective date of the ordinance codified in this chapter, the borough shall develop administrative policies and procedures for implementing and enforcing this program.

C. Penalties for Violation.

1. The borough may institute a civil action against an employer or business that violates a provision of this chapter. In addition to injunctive and compensatory relief, the borough may obtain a civil penalty not to exceed $1,000 for each violation. The borough may bring an action to enjoin a violation or to recover a civil penalty notwithstanding the availability of any other remedy.

2. Each day that a violation of this chapter continues constitutes a separate violation.

D. Definitions.

“Employer” or “business” means all private and public sector entities, including state, local and federal agencies, departments, offices, boards, commissions, corporations and political subdivisions or other organizational units, including the University of Alaska and school district. The total number of parking spaces includes all agencies, divisions, subsidiaries and locations of the employer or business within the borough maintenance area.

“Maintenance area” means the area located within the borough that is set out and described by federal law (40 CFR 81.302) but excluding the city of North Pole. (Ord. 2004-61 § 3, 2004; Ord. 2001-17 § 3, 2001)

Chapter 8.21
PM2.5 AIR QUALITY CONTROL PROGRAM

Sections:

8.21.010 Definitions.
8.21.020 Borough listed appliances.
8.21.025 Prohibited acts.
8.21.030 *Repealed.*
8.21.035 Enhanced voluntary removal, replacement and repair program.
8.21.040 Forecasting exceedances and voluntary restrictions in the nonattainment area during an alert.
8.21.045 Voluntary burn cessation program.
8.21.050 *Repealed.*
8.21.060 *Repealed.*

8.21.010 Definitions.

In this chapter, the following definitions apply:

"*Air quality alert*" means an advisory, *alert* or *episode* concerning air quality whether issued by the Fairbanks North Star Borough or the state of Alaska.

"*Alert*" means a notice issued by the FNSB air quality division when the *division* determines, using available data, that a violation of the 35 micrograms per cubic meter will likely occur.

"*Appliance*" means a device or apparatus that is manufactured and designed to utilize energy and which does not require a stationary source air quality permit from the state of Alaska under 18 AAC 50.

"*Cook stove*" means a wood burning *appliance* that is designed primarily for cooking food and that has the following characteristics:

1. An oven, with a volume of 0.028 cubic meters (one cubic foot) or greater, and an oven rack;

2. A device for measuring oven temperatures;

3. A flame path that is routed around the oven;

4. A shaker grate;

5. An ash pan;

6. An ash clean-out door below the oven; and

7. The absence of a fan or heat channels to dissipate heat from the device.

"*Division*" means the Fairbanks North Star Borough air quality division.

"*Episode*" means when conditions reach *alert* status.

"*Fireplace*" means an assembly consisting of a hearth and open fire chamber of noncombustible factory-built or masonry materials and provided with a chimney, for use with solid fuels, which cannot be operated with an air to fuel ratio of less than 35 to one.

"*Fireplace insert*" means a *solid fuel burning appliance* similar in function and performance to a freestanding wood burning stove, which is made from cast iron or steel designed to be installed in an existing masonry or prefabricated *fireplace*.

"*Forecast*" means a description of the current dispersion conditions described as good, fair, or poor and including the expected $PM_{2.5}$ concentrations expressed in micrograms per cubic meter.

"*Heating appliances*" means, but is not limited to: oil furnaces, gas furnaces, wood stoves, coal stoves, wood-fired *hydronic heaters*, wood-fired furnaces, coal-fired *hydronic heaters*, coal-fired furnaces, *masonry heaters*, *pellet stoves*, *cook stoves*, and *fireplaces.*

"*Hydronic*" means having to do with a system moving heat from one location to another by means of the circulation of a heat transfer liquid through piping or tubing.

"*Hydronic heater*" means a fuel burning *appliance* designed to (1) burn wood or other solid fuels and (2) heat building space and/or domestic hot water via the distribution, typically through pipes, of a fluid heated in the *appliance*.

"*Masonry heater*" means a wood burning *appliance* that complies with the guidelines of ASTM E1602-08, Standard Guide for Construction of *Masonry Heaters*, and:

1. Is designed and intended for operation only in a closed combustion chamber configuration; and

2. Has enough thermal storage capacity to maintain no less than 50.0 percent of the maximum masonry-mass temperature for at least four hours after the maximum masonry-mass temperature has been reached; and

3. The *masonry heater* design and installation has been confirmed and documented by a qualified person or entity approved by the borough.

"*Nonattainment area*" is the area depicted on the map attached to the ordinance codified in this chapter and is further defined as follows:

Township Range Delineated Boundary for the Fairbanks *Nonattainment Area*

MTRS F001N001 – All Sections, MTRS F001N001E – Sections 2-11, 14-23, 26-34, MTRS F001N002 – Sections 1-5, 8-17, 20-29, 32-36, MTRS F001S001E – Sections 1, 3-30, 32-36, MTRS F001S001W – Sections 1-30, MTRS F001S002E – Sections 6-8, 17-20, 29-36, MTRS F001S002W – Sections 1-5, 8-17, 20-29, 32-33, MTRS F001S003E – Sections 31-32, MTRS F002N001E – Sections 31-35, MTRS F002N001 – Sections 28, 31-36, MTRS F002N002 – Sections 32-33, 36, MTRS F002S001E – Sections 1-2, MTRS F002S002E – Sections 1-17, 21-24, MTRS F002S003E – Sections 5-8, 18.

"*Particulate matter*" or "*PM*" means total particulate matter including PM_{10} and $PM_{2.5}$ (condensable and noncondensable fraction) and is a complex airborne mixture of extremely small particles and liquid droplets that are made up of a number of components, including acids, organic chemicals, metals, soil, or dust.

"*Pellet fuel burning appliance*" or "*pellet stove*" means a closed combustion, vented pellet burning *appliance* with automatic components creating an active air flow system, sold with the hopper and auger combination as integral parts, and designed, warranted, safety listed, and advertised by the manufacturer specifically to be fueled by pellets of sawdust, wood products and other biomass materials while prohibiting the use of cordwood.

"$PM_{2.5}$" means *particulate matter* comprised of particles that have diameters of two and one-half microns or less.

"*Sale*" means the transfer of ownership or control.

"*Solid fuel burning appliance*" means any *appliance*, unless specifically excluded from this definition, designed to produce heat by burning nongaseous and nonliquid fuels. This definition includes, but is not limited to:

1. Wood stoves;

2. Coal stoves;

3. Wood-fired *hydronic heaters*;

4. Wood-fired furnaces;

5. Coal-fired *hydronic heaters*;

6. Coal-fired furnaces; and

7. *Fireplace inserts*.

The following *appliances* are specifically excluded from this definition:

1. *Masonry heaters*;

2. *Pellet fuel burning appliances*;

3. *Cook stoves*; and

4. *Fireplaces*. (Ord. 2013-35 § 3, 2013; Ord. 2013-06 § 2, 2013; Ord. 2011-32 § 2, 2011; Ord. 2011-12 § 2, 2011; Ord. 2011-03 § 2, 2011; amended by citizen initiative 10/28/10; Ord. 2010-28 § 2, 2010)

8.21.020 Borough listed appliances.

An *appliance* shall be listed by the borough if:

A. The *appliance* is certified by the U.S. Environmental Protection Agency as meeting the federal emissions limit standard appropriate for that *appliance* or in the case of *hydronic heaters* is at least phase II qualified. For purposes of this section, “certified” means that the solid fuel *appliance* meets emission performance standards when tested by an accredited independent laboratory and labeled according to procedures specified by the EPA in 40 CFR 60 Subpart AAA; or

B. The *appliance* is tested by an accredited independent laboratory, or other qualified person or entity approved by the borough, establishing that it meets the EPA emissions limit standard appropriate for that *appliance* or an emissions limit standard equivalent to that of a listed *appliance* in a similar category. (Ord. 2012-61 § 2, 2012)

8.21.025 Prohibited acts.

The borough shall not, in any way, regulate, prohibit, curtail, nor issue fines or fees associated with the *sale*, distribution, or operation of *heating appliances* or any type of combustible fuel. (Ord. 2013-06 § 3, 2013)

8.21.030 Voluntary replacement and repair program.

Repealed by Ord. 2014-10. (Ord. 2012-61 § 3, 2012; Ord. 2011-32 §§ 3 – 9, 2011; Ord. 2010-37 §§ 2 – 5, 2010; Ord. 2010-28 § 2, 2010)

8.21.035 Enhanced voluntary removal, replacement and repair program.

The Fairbanks North Star Borough shall, to the extent funds are available and appropriated by the assembly, offer an enhanced removal, replacement and repair program to help offset the costs of removing, replacing or repairing a *solid fuel burning appliance* (SFBA) or *fireplace*. This program shall be subject to the following eligibility requirements, conditions, and criteria:

A. General Requirements.

1. Application. An application approved by the *division* and signed by all property owner(s) must be submitted along with any documentation required by the *division*. Applicants must fully comply with the *division*'s inspection process which shall verify the existence of a qualifying SFBA or *fireplace*.

2. Priority Ranking. Applications may be prioritized and may be limited by the *division* in its discretion based on geographical location, the overall air quality benefit and the type of SFBA or *fireplace* being removed, replaced or repaired.

3. Eligibility[1]. The program is limited to properties within the borough's $PM_{2.5}$ *nonattainment area* boundary in which a qualifying SFBA or *fireplace* is installed. If an application is approved for the program, the applicant will be given up to 90 days to meet all of the requirements. Applicants must have no delinquent property tax or penalty or interest owing at the time of application and at completion of the program requirements.

4. Additional Requirements. In addition to the general requirements set forth in this section, applicants must also meet the following requirements:

a. Fully comply with the inspection process required by the *division* that shall ensure that the existence of the qualifying *appliance* to be removed, replaced or repaired is properly documented.

b. Removal of *appliance*.

c. Delivery of *appliance* to an authorized decommission station.

d. Certificate of destruction delivered to the *division*, if applicable.

e. Final installation of a qualified *appliance* visually verified.

f. All aspects of this section may be performed by borough-approved personnel or a borough-approved vendor.

5. Payments. Applicants will be eligible for reimbursements or, at the option of the applicant, payment may be made directly to a borough-approved vendor. Reimbursements and payments shall be available as follows:

a. Replacement of an outdoor *hydronic heater*: With either an EPA certified SFBA with an emission rate less than or equal to 2.5 grams/hour, an EPA Phase II qualified pellet burning *hydronic heater* with an emission rate equal to or less than 0.2 pounds/million BTUs, or an *appliance* designed to use pellets, home heating oil (excluding waste oil), natural gas, propane, hot water district heat, electricity or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the appliance for proper installation).

Appliance + Fuel Payment
Up to $10,000 for purchase and installation of the *appliance* plus fuel payment, if applicable.

b. Replacement of a non-EPA certified SFBA, *fireplace*, or an EPA certified SFBA that has an emission rate greater than 2.5 grams/hour: With either an EPA certified SFBA with an emission rate equal to or less than 2.5 grams/hour and an emission rate 50 percent or less than the replaced heater, or an *appliance* designed to use pellets, home heating oil (excluding waste oil), natural gas, propane, hot water district heat, electricity or a *masonry heater* (including parts, labor and any costs associated with upgrading the chimney to the extent required by the manufacturer of the appliance for proper installation).

Appliance + Fuel Payment
Up to $4,000 for purchase and installation of the *appliance* plus fuel payment, if applicable.

c. Removal of a SFBA (limited to a one-time participation in this program per

property).

Cash Payment
$2,000 – if removing outdoor *hydronic heater*
$1,000 – if removing other SFBAs

d. Fuel Payment. If a *pellet fuel burning appliance* or a *pellet stove* is purchased and installed under this program, the applicant is eligible to receive an additional $300.00 payment for the purchase of pellets manufactured in the Fairbanks North Star Borough. If a wood burning *appliance* is purchased and installed under this program, the applicant is eligible to receive an additional $300.00 payment for borough-approved pressed wood energy logs manufactured in the Fairbanks North Star Borough.

e. Repair Program.

i. The repair program will pay for the:

(A) Replacement of a wood stove's catalytic converter that has exceeded its life span through the one-time payment of up to $750.00.

(B) Replacement of any emissions-reducing component of an EPA-certified wood stove up to the maximum amount of $750.00.

ii. In addition to the general requirements set forth in this section, applicants must fully comply with any inspection process required by the *division*, which may be performed by a borough-approved vendor. (Ord. 2014-10 § 3, 2014)

8.21.040 Forecasting exceedances and voluntary restrictions in the nonattainment area during an alert.

A. During the winter months of October through March, the borough shall issue a daily *PM forecast* at 4:30 p.m. Monday through Friday. When the *PM* concentration reaches the onset level for an *episode* and is expected to remain at that level for 12 hours, an *alert* will be declared. Once an *alert* is declared, *PM* control measures set forth in this section shall be implemented and continued until the *alert* is cancelled.

B. Voluntary Restrictions in the *Nonattainment Area* During an *Alert*.

1. Residents shall be requested to voluntarily stop operation of *solid fuel burning*

appliances, *pellet stoves*, and *masonry heaters* in the *nonattainment area*.

2. The *division* will notify local media to ensure the declared *alert* is broadcast. Information within the notification will contain the *PM forecast* and procedures to reduce sources of *PM*. (Ord. 2010-28 § 2, 2010)

8.21.045 Voluntary burn cessation program.

The Fairbanks North Star Borough will, to the extent funds are available and appropriated by the assembly, establish a program to encourage, incentivize, and facilitate the voluntary cessation of the use of wood burning *appliances* (i.e., wood stoves, wood-fired *hydronic heaters*, wood-fired furnaces, *fireplaces*, *fireplace inserts*, *masonry heaters* or *pellet fuel burning appliances*) in the *nonattainment area* during *air quality alerts*. It is recognized that it will be difficult or impossible for some households to participate in this program (e.g., those that heat solely with wood or for which wood is a necessary supplement during periods of cold weather). Therefore, this program is intended for households that are able to use space heating alternatives with significantly lower $PM_{2.5}$ emissions, including those fueled by gas, oil, electricity, propane or district heat, but not wood or *pellet stoves* or other wood burning *appliances*. This program will at a minimum consist of the following components:

A. The borough may contract with an agency that will provide services to promote the program. This agency must have the standing, experience, and capability to carry out a campaign to advertise, reach out, and attract a large number of participants in the *nonattainment area* who are willing to cease the use of a wood burning *appliance* during *air quality alerts*.

B. Incentives will be provided to households that participate in the program. These incentives may include the provision of (1) a sign-up bonus such as cash, a voucher, or goods and services useful to a household that heats with wood; (2) a thank-you letter, window or yard sign; or, (3) other form of public acknowledgment. The cost of this incentive to the borough shall not exceed $25.00 per household. These incentives may be provided or augmented by private contributions.

C. Facilitation of this program by the borough will include, but not be limited to, the provision of notice of *air quality alerts* to individual households by methods such as electronic mail messages, text messages, automated phone calls, notices to radio and television stations, and information posted on electronic reader or display boards located throughout the borough in locations best suited to notify residents of *air quality alerts*.

D. Private contributions, including goods and/or services, will be sought for all appropriate

elements of the program. In general this will focus on the provision of materials, equipment, and certain one-time services, but not to fund borough staff positions. (Ord. 2014-11 § 2, 2014)

8.21.050 Voluntary emissions standard and educational program.

Repealed by Ord. 2012-09. (Ord. 2011-03 § 9, 2011)

8.21.060 Enhanced SFBA change out program.

Repealed by Ord. 2014-10. (Ord. 2013-35 § 2, 2013)

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[1] Code reviser's note: Section 4 of Ordinance 2014-10 provides: "This ordinance shall be effective at 5:00 p.m. of the first Borough business day following its adoption except that the amendment expanding the program outside the borough's $PM_{2.5}$ nonattainment area by deleting the geographically limiting eligibility language in FNSB 8.21.035 (3) is effective January 1, 2015."

MEMORANDUM OF UNDERSTANDING
BETWEEN
ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION
AND
FAIRBANKS NORTH STAR BOROUGH
FOR
AIR POLLUTION CONTROL

I. Purpose

The purpose of this memorandum of understanding is to clarify the joint responsibilities for air pollution control and monitoring within the Fairbanks North Star Borough with respect to $PM_{2.5}$ and for the maintaining and monitoring of carbon monoxide within the Fairbanks North Star Borough. The Alaska Department of Environmental Conservation (DEC) and the Fairbanks North Star Borough (Borough) have joint responsibility for air pollution control in the Fairbanks North Star Borough. The parties to this Memorandum of Understanding recognize that clear lines of responsibility must be established and maintained to maximize the efficient utilization of available resources and to provide the greatest protection to the public's health and safety. It is with this recognition that these two parties hereby enter into this agreement.

II. Major Stationary Sources

DEC will retain responsibility for permitting, inspection, surveillance, and enforcement of all currently permitted facilities under DEC authority, and for any new sources that require DEC permit approval under AS 46.14.

DEC will:

notify the Borough upon receipt of any permit applications or renewals for State Air Quality Permits for stationary sources located within the Borough, to allow sufficient time for Borough comment on such permitting activities;

respond to Borough requests during the Department permit review, for additional information from a permit applicant pursuant to 18 AAC 50 or the State Implementation Plan for Air Quality Control; and

provide information in a reasonable time period to the Borough in response to requests for information on permitted facilities.

The Borough will:

register with DEC's online system for public notice announcements when it becomes available; and

notify DEC when it desires information on a permitted facility, permit application or renewal.

III. Open Burning

DEC will be responsible for issuing approvals for open burning of materials from land clearing operations of 40 acres or greater, and for the open burning of petroleum-based materials or other materials in a way that gives off black smoke.

DEC will:

provide the Borough with copies of all open burning approvals issued by DEC for sites within the Borough; and

notify applicants to contact the Borough regarding the Borough Codes pertaining to open burning.

The Borough will:

provide DEC and the Division of Forestry with copies of a handout, designed for distribution to burn permit applicants, which outlines the Borough open burning regulations;

advise DEC and the Division of Forestry of any changes to the Borough's open burning regulations and permit procedures; and

conduct an advertising campaign designed to educate the public regarding any significant changes in the Borough's open burning regulations and permit procedures.

IV. Area Source Control Programs

The Borough and DEC recognize that many small stationary pollution emission sources have the potential to collectively impact air quality. These small sources are categorized as area sources by EPA and DEC and may be regulated by local, state, or federal rules, but are not typically permitted by the DEC Air Permit program. They include, but are not limited to, the following types of sources: solid fuel-fired heating devices, commercial and residential space heating, small sources that fall below permitting thresholds, and fugitive dust sources.

The Borough will:

take the lead in developing and implementing local control programs to address pollution from area sources and will notify and consult with DEC regarding local control programs being considered for implementation to

insure coordination with any existing state programs or regulations .

DEC will:

notify and consult with the Borough regarding any proposed state area source programs or regulations that could impact a local control program or activities within the Borough; and

provide technical assistance related to state and federal requirements that could impact development and implementation of a local control program.

The Borough and DEC will:

look for opportunities to share data related to area sources that can further technical efforts in assessing air quality impacts;

jointly determine whether, and when, the two agencies will need to coordinate on implementation of an area source program;

jointly determine the roles and responsibilities for each agency in implementing any coordinated area source program;

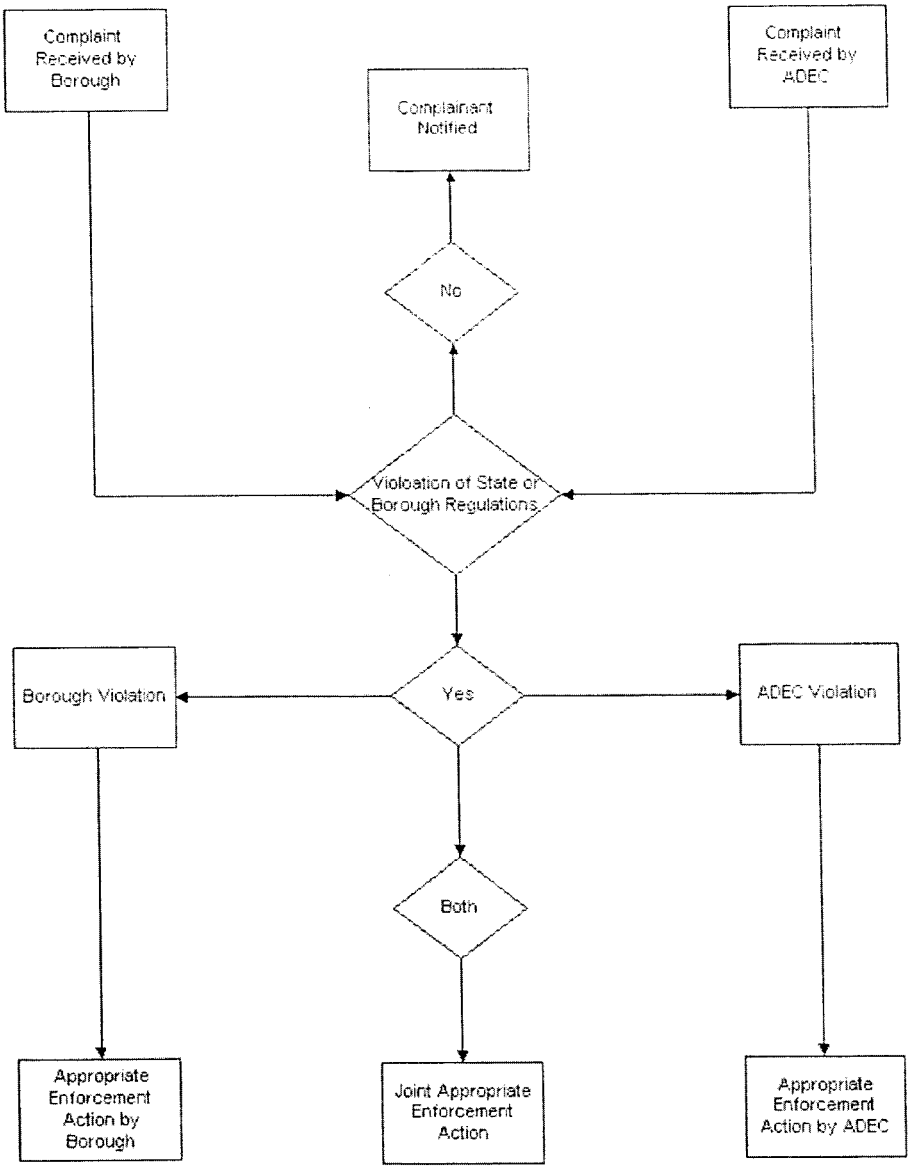
upon agreement by both agencies as to the roles, responsibilities, funding, and any other essential details of a coordinated area source program, work cooperatively to implement the program; and

amend this agreement, as soon as practical, to incorporate the relevant details related to an approved area source program so that clear lines of responsibility are delineated.

V. Complaint Response

DEC and the Borough will continue to respond jointly to public complaints regarding air pollution within the Borough. The flow chart delineates the course of action to be used in assessing the need for appropriate enforcement actions.

Air Pollution Control MOU-DEC/FNSB



As indicated above, both DEC and the Borough will be responsible for assessing whether or not an air quality complaint received by their respective agency is a violation of either Borough or State regulations. This will necessitate close communication between the agencies regarding each other's regulations. Once it is determined whether or not either, or both, State or Borough regulations are being, or have been violated, the appropriate agency will take the lead role in enforcement action.

Complaints received by DEC related to permitted stationary sources will be handled by DEC. If the Borough is interested in any complaints regarding permitted facilities, the Borough will contact DEC and DEC will provide the information.

VI. Ambient Air Monitoring/Air Quality Forecasting

The Borough will maintain and operate the network of carbon monoxide (CO) and fine particulate ($PM_{2.5}$) ambient air monitors to identify and describe existing air quality conditions within the Borough. The Borough will review monitoring needs with DEC and EPA in consideration of resources available for the purpose of assigning monitoring priorities. The Borough will continue to provide recorded daily ambient air quality forecasts during the period of October 1 through March 31 each winter. DEC will provide technical support and quality assurance related to the ambient air monitoring network.

Close communication and cooperation between the agencies is necessary to share information on ambient air conditions to determine the need for issuing an air quality advisory, or declaring an air episode due to anthropogenic or natural events.

DEC will:

continue to provide technical assistance to the Borough in the areas of ambient air monitoring science, instrument operation, and quality assurance;

send to the Borough copies of correspondence and applicable materials associated with air quality monitoring work performed by DEC within the Borough and air monitoring information received from EPA or other sources which may be of interest to the Borough;

notify the Borough as to reporting requirements, due dates, etc.;

review and approve in writing monitoring site locations as required;

provide, or facilitate in-state, technical assistance and training as time and funding allows;

perform quarterly audit tests on the Borough's air quality monitoring network;

assist Borough staff with field monitoring during periods of Borough staffing problems as time and funding allows;

provide filter weighing operations for the analysis of particulate filters;

loan air monitoring equipment, shelters and supplies for use in FNSB seasonal monitoring studies, based on availability;

replace air monitoring equipment (e.g. CO, PM, meteorological monitors,

data loggers) in future years, based on state amortization priorities and available funding;

work cooperatively with the Borough to select the State's NCORE site, to be located in Fairbanks;

provide assistance for major repairs to air monitoring equipment to insure minimum down time for instrumentation during catastrophic failures; and

conduct an annual monitoring network assessment and develop recommendations for any changes which may be necessary in coordination with the Borough and EPA.

The Borough will:

operate and maintain the CO and $PM_{2.5}$ ambient air and meteorological monitoring network as required in accordance with state and federal regulations, guidelines, and the yearly DEC/EPA and Borough Air Programs work plan;

operate and maintain the PM2.5 speciation monitor in accordance with state and federal regulations, guidelines, and the yearly DEC/EPA and Borough Air Programs work plan;

conduct special air monitoring studies of criteria pollutants to identify/better define air quality problem areas, as funding and staff allow;

maintain instruments and equipment in good working order subject to available funding. In the event that funding is reduced DEC/FNSB will discuss and mutually agree before deferring maintenance;

submit to DEC in writing for approval any desired/required changes in the monitoring network;

maintain trained staff capable of operating and maintaining monitoring equipment and coordinate training needs with DEC to identify potential local and in-state training opportunities;

participate in the State's air quality data quality assurance program, and submit required data to DEC and/or EPA;

submit annual/quarterly air quality monitoring data to DEC within 30 days after the end of a quarter, to include but not be limited to CO and $PM_{2.5}$;

work cooperatively with DEC to select the State's NCORE site, to be located in Fairbanks;

continue to implement, as needed, the Borough's emergency episode

prevention and response plan for CO;

provide a recorded daily CO forecast during periods of poor air quality, when CO concentrations are of concern. The daily CO forecast will also be provided on the Borough web page and phone system for media and the general public; and

provide a recorded weekly $PM_{2.5}$ forecast to address potential impacts during the summer wildfire season and the winter $PM_{2.5}$ season. A daily forecast will be provided during periods of poor air quality. The $PM_{2.5}$ forecast will also be provided on the Borough web page and phone system for media and the general public. As part of that forecast, provide a description of the air dispersion (poor, fair, or good) forecast for each day, with weekend and holiday projections made the previous Friday.

VII. Air Quality Planning

The Borough will continue its efforts to maintain the national ambient air quality standard for carbon monoxide and work towards meeting attainment for fine particulate matter ($PM_{2.5}$). This will include the study and possible implementation of reasonable, cost-effective strategies designed to reduce ambient air pollutant concentrations which will allow the Borough to maintain the carbon monoxide standard and attain the $PM_{2.5}$ standard.

DEC will:

provide technical and administrative assistance to the Borough;

- in the area of maintenance of the national ambient air quality standard for carbon monoxide; and
- In the area of development of the attainment plan for $PM_{2.5}$

work with the Borough to develop additional programs that will;

- aid the Borough in maintaining the health based standard for carbon monoxide in the Fairbanks area, subject to available funding;
- aid the Borough in attaining the health based standard for $PM_{2.5}$ in the Fairbanks area, subject to available funding; and
- assist the Borough in its dealings with EPA, particularly in the development of additional strategies to reduce ambient air pollutant levels in the Fairbanks area.

The Borough will:

continue its efforts to maintain the national ambient air quality standard for carbon monoxide;

update the CO maintenance plan per the Clean Air Act requirements or as

needed to address local objectives;

continue its efforts to attain the national ambient air quality standard for $PM_{2.5}$.;

implement $PM_{2.5}$ strategies to attain the standard that are shown to be reasonable and cost effective;

assist DEC to study $PM_{2.5}$ concentrations at cold temperatures, and the resultant impact of $PM_{2.5}$ on the prospects for attaining and maintaining the $PM_{2.5}$ standard in Fairbanks, including potential use of new and innovative programs;

develop emission inventories as needed to support or implement $PM_{2.5}$ SIPs; and

take the lead in collaboratively developing with DEC a $PM_{2.5}$ attainment plan to bring Fairbanks into attainment with the national ambient air quality standard.

VIII. Mobile Source Control Programs

The Borough and DEC recognize that air pollution emissions from motor vehicles and other mobile sources have the potential to collectively impact air quality. Mobile sources are typically regulated by federal and state rules, but local programs can be beneficial in reducing emissions.

The Borough will:

take the lead in developing and implementing local control programs to address pollution from mobile sources and will notify and consult with DEC regarding local control programs being considered for implementation to insure coordination with any existing state programs or regulations;

DEC will:

maintain state regulations that allow a vehicle inspection & maintenance program to remain as a CO contingency measure in the Fairbanks CO maintenance plan as required by EPA;

notify and consult with the Borough regarding any proposed state mobile source programs or regulations that could impact a local control program or activities within the Borough; and

provide technical assistance related to state and federal requirements that could impact development and implementation of a local control program.

The Borough and DEC will:

look for opportunities to share data related to mobile sources that can further technical efforts in assessing air quality impacts;

jointly determine whether, and when, the two agencies will need to coordinate on implementation of an mobile source program;

jointly determine the roles and responsibilities for each agency in implementing any coordinated mobile source program;

upon agreement by both agencies as to the roles, responsibilities, funding, and any other essential details of a coordinated mobile source program, work cooperatively to implement the program; and

amend this agreement, as soon as practical, to incorporate the relevant details related to any approved mobile source program so that clear lines of responsibility are delineated.

IX. Dynamometer Testing System and Congestion Mitigation & Air Quality Projects

The Borough will:

use the test van, dynamometer, analytical equipment and support equipment for vehicle and cold weather testing projects as needed;

share data collected from all studies utilizing the dynamometer testing system;

with adequate notice, provide DEC access to the dynamometer testing system for special projects; and

provide DEC the opportunity to reclaim the dynamometer testing system.

DEC will:

notify the Borough 90-days prior to the department's need to use the dynamometer testing facility for special projects; and

share data collected from all studies utilizing the dynamometer testing system.

DEC and the Borough will:

coordinate requests for CMAQ projects; and

jointly determine roles and responsibilities for implementing CMAQ projects

at the time that the projects are submitted to the metropolitan planning organization or Department of Transportation for funding.

X. Notice/Project Contacts

For purposes of this agreement each agency will identify a project manager who will have overall responsibility for management of the agreement. The project managers may designate and identify in writing to the other agency, other staff with responsibility for implementing specific activities under the agreement.

For purposes of this agreement DEC's project manager is,

Alice Edwards, Acting Director, Division of Air Quality

For purposes of this agreement, the Borough's project manager is,

Glenn Miller, Director, Department of Transportation

All project work plans and approvals shall be submitted through the project managers designated in this section.

Parties agree to notify each other in writing of changes in project manager or activity managers within 10 days of change.

XI. Budgetary

DEC and the Borough shall negotiate annually funding agreements for the coming year. These annual funding agreements will be negotiated between the DEC Air Quality Director and the FNSB Director of Transportation. Future year appropriations shall be discussed and operational costs agreed upon no later than January 31st of each year to assist with annual budget development. The annual funding agreements shall be documented in writing and make specific reference to this Memorandum of Understanding.

DEC shall:

provide each year that the conditions of this Memorandum of Understanding are met, a total of $54,000 per year for the work described in the approved annual work plan and up to $18,500 per year for operation and maintenance of the PM2.5 speciation sampler (to be negotiated annually); and

make, upon receipt of a request for reimbursement which shows at least 50 percent of the local match funds have been expended, an initial payment of $40,000. The balance will be provided upon completion of the work identified in the approved annual work plan, for each fiscal year, and the

submission of a final Financial Status Report which identifies the total program expenditures.

The Borough shall:

adhere to applicable sections of 40 CFR 30, 31, 32, 33, and 35, Subpart A. The principal "parts" of 40 CFR, Chapter 1, Subchapter B, and Part 32 "Debarment and Suspension Under EPA Assistance Programs"; Part 31 "Uniform Administrative Requirements for Grants and Cooperative Agreements to State and Local Governments"; and Part 32 "Debarment and Suspension Under EPA Assistance Programs";

comply with the requirements of the Single Audit Act (OMB Circular A128);

file a preliminary financial status report on or before August 20 each-year;

file a final financial status report on or before September 20 each year;

inventory and track all equipment purchased. Disposal shall be in accordance with current federal requirements. Purchase of equipment exceeding $3,000 for a complete unit must be approved by DEC in advance of purchase;

when issuing statements, press releases, requests for proposals, bid solicitations, and other documents describing projects or programs funded in whole or in part with grant money, clearly state (a) the percentage of the total cost of the program or project which will be funded with grant money, and b) the dollar amount of grant funds for the project or program;

make a good-faith effort to maintain a drug-free work place by publishing a statement notifying employees that manufacturing, distributing, dispensing, possessing, or using a controlled substance in the work place is prohibited;

when issuing contracts, ensure all contractors and subcontractors have a valid Alaska business license;

provide for DEC representation on committees reviewing RFPs and contract awards using DEC pass through or DEC grant and Borough funds;

submit copies of signed subcontracts and purchase orders between FNSB and minority/women construction and supply firms on a quarterly bases;

ensure that no portion of this award may be used for lobbying or propaganda purposes as prohibited by 18 U.S.C. Section 1913 or Section 607(a) of Public Law 96-74;

ensure that the cost principles of OMB Circular A-87 are applicable to this award. When indirect costs are included within the assistance budget, the

recipient must be in compliance with A-87 and EPA regulations regarding allowable project costs. Actual indirect costs charged to this agreement may not exceed the final approved rates as negotiated annually between the State and the appropriate cognizant federal agency;

in accordance with the Clean Air Act, Section 105 b(3) and EPA regulations, provide matching funds to support the programs which are at least equal to the local matching funds spent in the prior year; and

spend local matching funds on at least a pro rata share with the understanding that local funds spent for the year must equal or exceed the amount spent in the previous year. Should the amount of local funds not equal or exceed the previous year's grant expenditures, the grant may be revoked. Unexpended grant funds shall revert to DEC to be reprogrammed (if prior to June 30 of each year) or returned to EPA according to federal law.

XII. It is mutually agreed:

1. that the Borough and DEC shall employ and maintain staff to carry out the activities necessary to administer the air quality programs outlined in this agreement;

2. that payments under this agreement require funds from future appropriations and are subject to future appropriations by the Borough Assembly and the state legislature;

3. that nothing in this agreement shall be construed as obligating DEC or the Borough to the expenditure of funds, or for the future payment of funds, in excess of that authorized by this agreement.

4. that the Borough may provide funding to DEC for performing special projects negotiated under this agreement.

5. that future year awards will be authorized only upon receipt of federal funds and upon an approved annual work plan, which must include lawfully appropriate detailed budget information, project period, and signature blocks for both parties.

6. that an interim financial status report will be filed on or before March 31 each year. The purpose is to determine if all grant funds will be expended by the end of the fiscal year (June 30). If grant funds will not be fully expended, DEC may restrict the amount of grant funds and reprogram the unexpended funds in accordance with EPA regulations.

7. that specific full-time equivalents listed for each task in the annual work plan are both parties' best estimate and only approximate; and

8. that amendments to this agreement may be proposed by either party and shall become effective upon approval of both parties.

XIII. Execution/Modification and Duration of Agreement

This amendment will be in effect upon signature by both parties until amended or revoked. The agreement may be terminated upon 90 days' written notice by either party. FNSB shall return all unexpended funds to DEC. In addition, all notes, data collected, equipment and any draft reports shall be submitted to DEC within 30 days of termination of this agreement by either party.

Alaska Department of
Environmental Conservation

By: _____
Larry Hartig
Commissioner

Date: 1/26/10

By: _____
Joanna McDowell
DEC Finance Officer

Date: 1/22/10

Fairbanks North Star Borough

By: _____
Luke Hopkins
Mayor

Date: 1/20/10

Reviewed by Legal Department
Date: 1/20/10
By: _____

FINAL

MEMORANDUM OF AGREEMENT FOR THE SELECTION AND FUNDING OF PROJECTS FUNDED BY CMAQ WITHIN THE FAIRBANKS NONATTAINMENT AREA FOR PM 2.5

Among the Alaska Department of Transportation and Public Facilities (ADOT&PF), the Fairbanks Metropolitan Area Transportation System (FMATS), the Fairbanks North Star Borough (FNSB) and the Alaska Department of Environmental Conservation (ADEC)

I. PURPOSE

A. This Memorandum of Agreement (MOA) is a written agreement among the Fairbanks area MPO (FMATS), state agencies (ADEC, ADOT&PF), and the designated air quality planning agency (Fairbanks North Star Borough, FNSB) describing their respective roles and responsibilities including project selection and CMAQ fund management necessary for air quality related transportation planning.

II. BACKGROUND

A. The U.S. Environmental Protection Agency (EPA) has designated the following townships and ranges of the Fairbanks North Star Borough as a non-attainment area for PM 2.5: -MTRS F001N001 – All sections; -MTRS F001N001E – Sections 2 – 11, 14 – 23, 26 – 34; -MTRS F001N002 – Sections 1 – 5, 8 – 17, 20 – 29, 32 – 36; -MTRS F001S001E – Sections 1, 3 – 30, 32 – 36; -MTRS F001S001W – Sections 1 – 30; -MTRS F001S002E – Sections 6 – 8, 17 – 20, 29 – 36; -MTRS F001S002W – Sections 1 – 5, 8 – 17, 20 – 29, 32 - 33; -MTRS F001S003E-Sections 31 - 32; -MTRS F002N001E- Sections 31 – 35; -MTRS F002N001-Sections 28, 31 – 36; -MTRS F002N002-Sections 32 - 33, 36; -MTRS F002S001E - Sections 1 - 2; -MTRS F002S002E - Sections 1 - 17, 21 – 24; -MTRS F002S003E - Sections 5 - 8, 18. A map of the non-attainment area is attached as Appendix A.

B. This PM 2.5 nonattainment designation became effective on December 14, 2009.

C. The above non-attainment area is larger than the FMATS Metropolitan Planning Area (MPA) illustrated in Appendix A as the MPO boundary.

D. 23 CFR 450.314(b) states that if the metropolitan planning area does not include the entire nonattainment or maintenance area, there shall be an agreement among the state department of transportation, state air quality agency, affected local agencies and the metropolitan planning organizations describing the process for cooperative planning and analysis of all projects outside the metropolitan planning area but within the nonattainment or maintenance area.

E. Further, 23 CFR 450.314(c) states that in the nonattainment area or maintenance areas, if the MPO is not the designated agency for air quality planning under section 174 of the Clean Air Act (42 USC 7504), there shall be a written agreement between the MPO and the designated air quality planning agency describing their respective roles and responsibilities for air quality related transportation planning.

III. AGENCY ROLES & RESPONSIBILITIES

A. ADEC

1. ADEC and the FNSB have joint responsibility for air pollution control in the FNSB.

2. ADEC will provide technical assistance in the development of the Fairbanks PM2.5 nonattainment area CMAQ transportation project listing.

3. ADEC will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

B. ADOT&PF Northern Region (NR)

1. NR will provide technical assistance in the development of the Fairbanks CMAQ transportation project listing.

2. NR will prepare and submit the PDAs to fund the selected projects, administer project funds to the appropriate implementing agency, and will assist in the development of the environmental documentation, design, right-of-way, utility and construction of selected projects as required.

3. NR will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

4. NR will issue an annual thirty-day Call for Nominations prior to January 31.

C. ADOT&PF Division of Program Development (HQ)

1. HQ will make Federal CMAQ funding available for eligible air quality projects in Fairbanks.

2. HQ will provide CMAQ funding for the purposes of travel demand modeling and conformity determination for the updates of the plans and programs and to include projects outside of the MPA in the nonattainment area. No local match is currently required. Should local match be required in the future, agreements will be developed through interagency consultation.

3. HQ will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

4. HQ will (subject to available CMAQ funding) include in the STIP all projects agreed to by the Fairbanks CMAQ Project Evaluation Board and submitted by the FNSB.

D. FMATS

1. FMATS will work with local agencies in developing and submitting projects to the Fairbanks CMAQ Project Evaluation Board.

2. FMATS will include all projects approved by the Fairbanks CMAQ Project Evaluation Board and submitted by the FNSB in the informational section of the TIP.

3. FMATS will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

E. FNSB

1. FNSB and the ADEC have joint responsibility for air pollution control in the FNSB.

2. FNSB is the lead air quality agency for the Fairbanks area and will determine the priorities for the CMAQ funding provided to the PM2.5 nonattainment area.

3. FNSB will provide to the NR a list of PM 2.5 CMAQ transportation projects for the PM2.5 nonattainment area for inclusion in the STIP.

4. FNSB will participate and be a member on the Fairbanks CMAQ Project Evaluation Board.

IV. CMAQ PROJECT EVALUATION BOARD

A. Board membership

1. The Fairbanks CMAQ Project Evaluation Board (hereinafter Board) will have 7 members representing the following entities: ADEC, FMATS, City of Fairbanks, City of North Pole, FNSB, ADOT&PF (NR) and ADOT&PF (HQ). The Board may select a chair to facilitate evaluation discussions.

B. Project Evaluation Criteria

1. The Board will develop criteria to use in evaluating projects submitted to the Board.

2. The developed criteria will take into account eligible uses of CMAQ funding and consider the projects efficacy in addressing PM2.5 attainment.

3. Evaluation criteria will be provided to agencies for use in developing CMAQ project proposals for submittal to the Board.

C. Project Submission

1. Any member of the Board may submit a project for evaluation and possible inclusion in the STIP.

2. Board Members will notify their respective agencies of the time window for the Call for Nominations.

D. Project Evaluation

1. The Board will use the developed evaluation criteria to score the projects.

2. Projects evaluated will be ranked by their total score.

3. Based upon the project ranking and scheduling, projects will be submitted to the FNSB mayor for approval and then to NR for inclusion in the STIP subject to CMAQ funding available to the Fairbanks PM2.5 nonattainment area.

4. In compiling the proposed list for inclusion in the STIP, if the next ranked project is too costly to be included due to fiscal constraint, the next project below it may be included instead.

5. The Board will meet as necessary to allow FNSB to submit its slate of proposed projects in time for inclusion in a draft STIP or draft STIP amendment. It is anticipated that the Board will meet at a minimum once per year, preferably no later than March 31, to solicit, rank, and recommend projects.

E. Conflict Resolution Process

1. Conflicts regarding the submission of a project listing to NR, including the inclusion or absence of a project, will be resolved according to the following process:

a) The conflict resolution process is initiated in writing, via email, from any signatory who has a conflict or grievance to all other signatories in the MOA who are affected by the conflict or grievance.

b) Within fifteen (15) working days after receipt of such notice, each affected party, along with its director or designee, will meet and determine reasonable measures to resolve the conflict.

c) If the conflict has not been resolved at the expiration of sixty (60) days after receipt of the initial notice, the conflict shall be referred to the Office of the Governor for final resolution.

2. All parties understand and agree that the timeline above, while ambitious, may not suffice in getting the matter resolved in time for inclusion in the draft STIP or draft STIP amendment.

V. AGREEMENT TERMS

A. This agreement shall be effective upon signature of all parties and binding until amended or revoked. The anticipated duration of the agreement is tied to the PM 2.5 non-attainment designation and is required until the area has achieved attainment status and maintained such status for a period of at least twenty years. The undersigned agencies may revise or replace this MOA via unanimous written agreement. The agreement may be terminated by a signing agency upon 90 days' written notice to all the signatory parties.

B. An interagency consultation process shall be used for revision of the MOA as necessary.

VI. SIGNATORIES

The undersigned hereby agree to comply with the provisions and terms of this MOA as described above.

Steve Titus

Steve Titus, P.E., Chair, FMATS — Date 9/15/10

Larry Hartig

Larry Hartig, Commissioner, ADEC — Date 10/4/10

Mayor Luke Hopkins

Mayor Luke Hopkins, Fairbanks North Star Borough — Date 9/15/10

Leo von Scheben

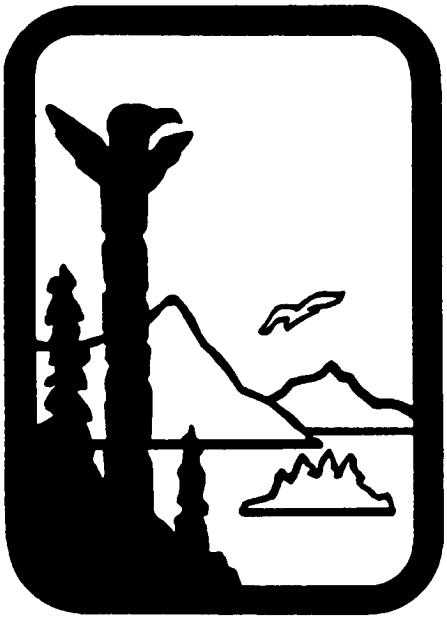
Leo von Scheben, P.E., L.S., M.B.A., Commissioner, ADOT&PF — Date 9/29/10

Reviewed by Legal Department
Date: 9/15/10
By:

Abbreviations Guide

ADOT & PF – Alaska Department of Transportation and Public Facilities
ADEC – Alaska Department of Environmental Conservation
CMAQ – Congestion Mitigation/Air Quality Program
EPA – United States Environmental Protection Agency
FHWA – Federal Highway Administration
FMATS – Fairbanks Metropolitan Area Transportation System
FNSB – Fairbanks North Star Borough
FTA – Federal Transit Administration
HQ - Alaska Department of Transportation and Public Facilities, Headquarters
PDA – Project Development Authorization
PM2.5 – Fine Particulate Matter Less Than 2.5 Micrometers
MOA – Memorandum of Agreement
MPA – Metropolitan Planning Area
MPO – Metropolitan Planning Organization
MTP – Metropolitan Transportation Plan
NR - Alaska Department of Transportation and Public Facilities, Northern Region
RLRTP – Regional Long Range Transportation Plan
SIP – State Implementation Plan
STIP – Statewide Transportation Improvement Program
TIP – Transportation Improvement Program
USDOT – United States Department of Transportation

Alaska Department of Environmental Conservation



Amendments to:
State Air Quality Control Plan

Vol. III: Appendix III.D.5.13

{Appendix to Volume II. Analysis of Problems, Control Actions; Section III. Area-wide Pollutant Control Program; D. Particulate Matter; 5. Fairbanks North Star Borough PM2.5 Control Plan}

No Appendix- Placeholder

November 14, 2014

Sean Parnell
Governor

Larry Hartig
Commissioner

(This page serves as a placeholder for two-sided copying)