CHEMICAL MASS BALANCE SOURCE APPORTIONEMENT OF $PM_{2.5}$ AEROSOL IN THE COLUMBIA RIVER GORGE

Draft

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EXECUTIVE SUMMARY

$PM_{2.5}$ (particles with aerodynamic diameters less than 2.5 µm) samples of 24-hour duration were taken on Wednesdays and Saturdays from 9/1/1996 through 8/31/1998 at the eastern (Wishram) and western (Mt. Zion) ends of the Columbia River Gorge to determine the spatial and temporal distribution of particle concentrations and to quantify the possible contributions to $PM_{2.5}$ concentrations and to fine particle haze. Major findings of the study are:

- Data were of good quality and sufficient to determine the major components responsible for $PM_{2.5}$ light extinction and potential source contributors. Internal consistency tests showed good agreement with the exception of fine chloride as measured by IC and chlorine measured by PIXE.
- The two year average $PM_{2.5}$ at the Mt. Zion site on the western end of the Gorge was 5.5 $\mu g/m^3$ and was 5.8 $\mu g/m^3$ at the Wishram site on the east end of the Gorge. The highest concentrations of $PM_{2.5}$ occurred on 04/29/1998 at both sites with 23.5 $\mu g/m^3$ at Mt. Zion and 26.4 $\mu g/m^3$ at Wishram. This event coincided with satellite observations of an Asian dust storm originating in the Gobi Desert impacting the states of Washington and Oregon in the US. Chemical concentrations were generally consistent at both ends of the Gorge. Organic carbon was the largest $PM_{2.5}$ component at each site (26% to 29%), followed by sulfate (18%).
- Primary motor vehicle exhaust, secondary ammonium sulfate, primary vegetative burning, and soil were the major contributors to $PM_{2.5}$ at both sites. On average, 50% of the $PM_{2.5}$ mass was attributed to carbonaceous aerosol (motor vehicle and vegetative burning) and ~24% to ammonium sulfate at both the Mt. Zion and Wishram sites. The aerosol at Wishram contained 50% more soil than at Mt. Zion (9% and 6% of $PM_{2.5}$, respectively). The combination of ammonium nitrate and aged marine aerosol (sodium nitrate) accounted for ~12% of the aerosol mass at both locations. Fresh marine aerosol (sodium chloride) accounted for 3% of the $PM_{2.5}$ at Mt. Zion and 1% at Wishram. The aluminum smelter source contribution estimate (SCE) accounted for 7% of the fine aerosol mass at Wishram but only 2% at Mt. Zion. Contributions from paper mill and coal power plants were indistinguishable from primary soil and secondary sulfate SCEs.
- During summer months, most of the marine aerosol is neutralized to sodium nitrate by nitric acid generated by photochemical conversion of oxides of nitrogen emissions. Elevated geological material contributions were found during spring and late summer. These contributions were smaller during winter when seasonal precipitation suppresses emissions and limits access to these remote sites.
- Coarse mass was measured at the Wishram site only. On average, coarse mass extinction accounts for 12%, fine aerosol light extinction accounts for 65%, and Rayleigh scattering accounts for 23% of the total reconstructed light extinction.
- The CMB model outputs estimates of the source contributions for each of the source profiles used to fit the ambient data. On average days, sources of Source Contribution Estimates (SCE's) of carbonaceous aerosol were responsible for 47% and 51% of the $PM_{2.5}$ light extinction at the Mt. Zion and Wishram sites, respectively. Ammonium sulfate SCEs were responsible for 32% of the haze at Mt. Zion and 26% at Wishram.

Aluminum smelting SCEs accounted for 4% of the fine aerosol light extinction at Wishram, but only 1% at Mt. Zion. Fresh and aged marine aerosol SCEs caused 13% of the haze at Mt. Zion, but only 9% at Wishram. Fine geologic material SCE was responsible for less than 2% of the light extinction at both sites. The contributions of primary emissions from paper mills and coal fired power plants SCEs were not distinguishable from the impacts caused by fine geologic material. Ammonium nitrate SCE was responsible for 6% of the fine particle haze at Mt. Zion and 8% at Wishram.

- On the 25% worst visibility days during the period, the relative distribution of the SCEs indicate that carbonaceous aerosol sources (mobile sources and vegetative burning) account for 44% of the light extinction at Mt. Zion and 42% of the $PM_{2.5}$ light extinction at Wishram. Ammonium sulfate SCE accounts for 40% of the $PM_{2.5}$ light extinction at Mt. Zion and 30% at Wishram. Coal fired power plant are the dominant emitters of SO_2 that is a precursor to ammonium sulfate aerosol. Ammonium nitrate SCE and aged sea salt SCE each account for 7% of the fine aerosol haze at Mt. Zion. At Wishram, 13% of the haze is due to ammonium nitrate SCE and 8% is due to aged marine aerosol SCE. Fresh marine aerosol SCE is responsible for less than 1% of the $PM_{2.5}$ light extinction on poor visibility days.

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1. INTRODUCTION

The Columbia River Gorge Chemical Mass Balance (CRGCMB) Study intends to attribute the sources of visibility impairing particulate matter (PM) in the Columbia River Gorge (CRG) for the period September 1996 to August 1998. This study is part of a larger effort sponsored by the Oregon Department of Environmental Quality and the Washington State Department of Ecology involving meteorological and chemical modeling to track the sources of haze in the CRG.

1.1 Study Objectives

The CRGCMB study objectives are:

- To identify pollutant sources that may cause visibility impairment within the CRG using existing emissions inventories.
- To identify the strengths and limitations of the CMB receptor model in its application to identifying sources of haze in the Columbia River Gorge.
- To provide source contribution estimates (SCEs) to $PM_{2.5}$ at the Mt. Zion (COGO1) and Wishram (CORI1) IMPROVE sites located in the CRG on the 25% best, 25% worst, and average visibility days.
- To provide an SCE related to the visible light extinction in the CRG on the 25% best, 25% worst, and average visibility days.

1.2 Technical Approach

A receptor-oriented source apportionment approach was taken in this study. In such an approach, chemical properties of principal sources are used to develop a fingerprint of each major emissions source type. These "source profiles" are then used in receptor models to calculate the amount which each source type contributes to $PM_{2.5}$ concentrations measured at receptors. The well-established CMB8 receptor model (Watson et al., 1998a) is applied in this study to attribute ambient concentrations to pollution sources. The Windows-based CMB8 has recently been adopted by U.S. EPA for regulatory use.

Air Quality measurements used in this study include $PM_{2.5}$ (i.e., particles with aerodynamic diameters less than 2.5 microns) mass and coarse mass from two IMPROVE sites taken from 9/01/96 through 08/31/98. Source profiles were assembled from samples collected in a variety of other studies.

SCEs of $PM_{2.5}$ were converted to SCEs of light extinction using default formulations based on chemical species concentrations used in the IMPROVE network.

1.3 Guide to Report

This section states the background and objectives of the CRGCMB Study. Section 2 documents the ambient visibility monitoring network in the CRG. Emissions sources in the vicinity of the monitoring sites and throughout Oregon, Washington, and Western Canada are described in Section 3. Emission profiles representing the major sources in the vicinity of the measurement locations are summarized in Section 4. Section 5 examines the temporal and spatial variations of $PM_{2.5}$ concentrations. Quantitative source contributions to $PM_{2.5}$ concentrations and light estinction at the measurement sites are also reported in Section 5. Study results, conclusions, and recommendations are contained in Section 6. The bibliography and references are assembled in Section 7. Details about the emissions inventory, source contribution estimates, and source profiles are included in Appendices.

2. AMBIENT PM$_{2.5}$ DATA

Optical and speciated PM2.5 measurements have been made routinely at two locations within the Columbia River Gorge Scenic Area: Mt. Zion, WA (symbol COGO1) and Wishram, WA (symbol CORI1).

2.1 Mt. Zion (COGO1) (45.5694 °N, -122.2114 °E, 225 m asl)

The Mt. Zion sites is located on the Washington State side of the Columbia River Gorge approximately 30 km east of downtown Portland, OR. During summer months, westerly winds bring air from Portland and the coast through the CRG. Sources to the west of the Gorge should impact the Mt. Zion site with higher concentrations when compared to sites further down wind.

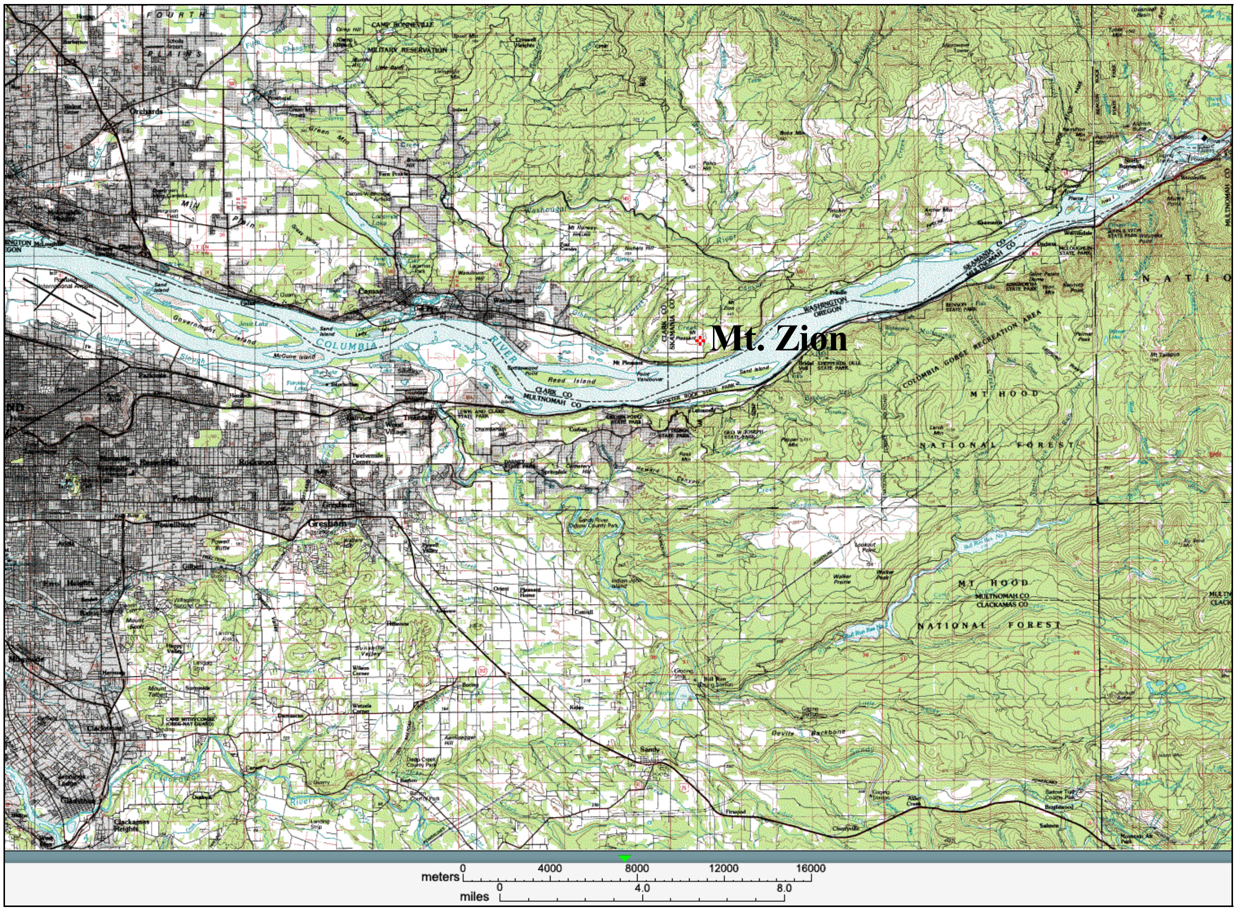

Figure 2-1. Topographic map of Mt. Zion Site location with respect to Portland, OR on the western edge of map.

2.2 Wishram (CORI1) – (45.6677 °N, -121.0233 °E, 201 m asl)

The Wishram site is also located on the Washington State side of the Columbia River Gorge approximately 8 km East of The Dalles, OR. This site is considered to be representative of the Eastern edge of the Gorge. This site should be most impacted by sources on the east end of the Gorge during the winter months when winds are easterly.

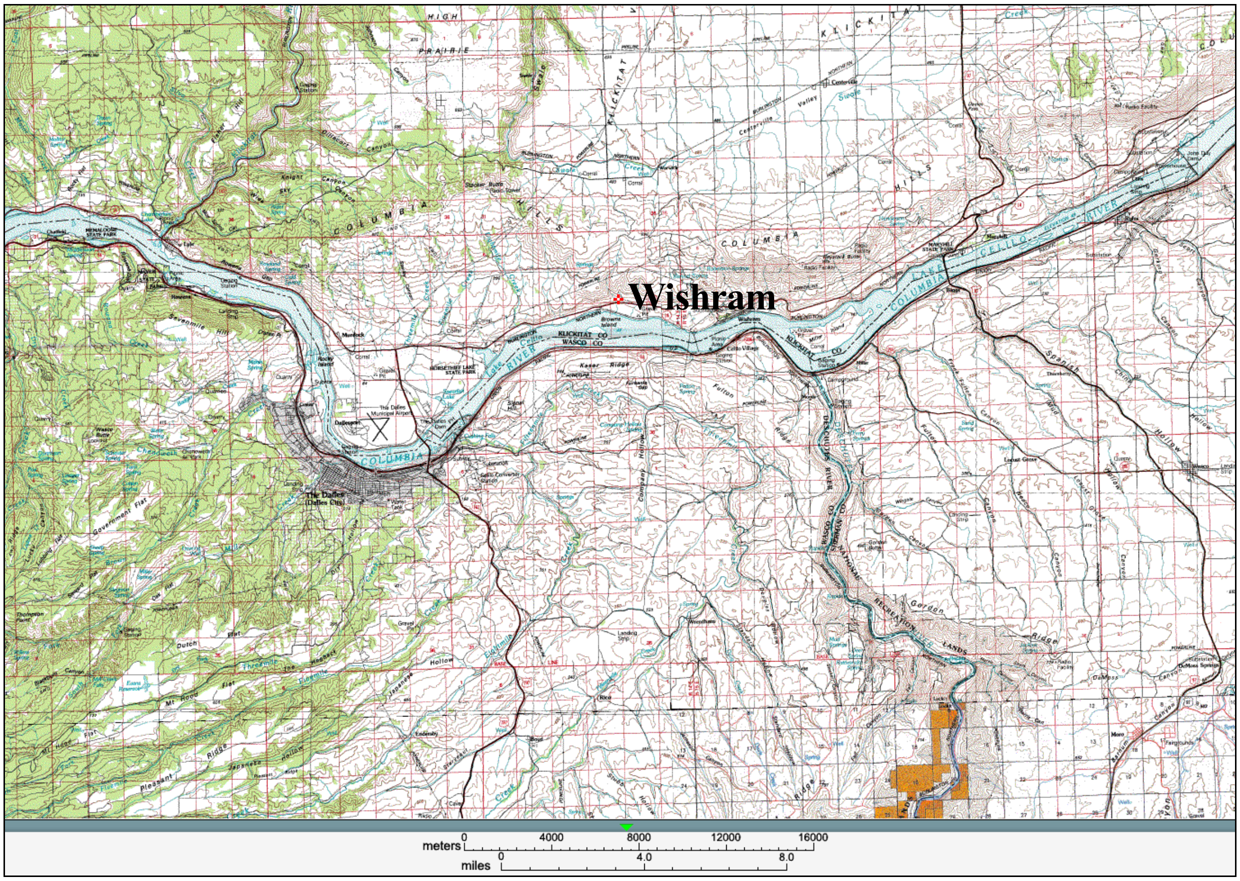

Figure 2-2. Topographic map of Wishram Site showing proximity to The Dalles, OR.

2.3 $PM_{2.5}$ Measurement Methods

The Interagency Monitoring of Protected Visual Environments (IMPROVE) site at Wishram has been operating since 1993. Measurements at Mt. Zion were made from September 1996 through September 1998 and then suspended. Measurements began again at Mt Zion in December 1999.

The IMPROVE monitor has the capacity to sample aerosols simultaneously on 4 individual channels. Channels A-C have a 2.5 µm diameter aerodynamic size cut while channel D has a 10 µm aerodynamic cut size (Table 2-1). UC Davis analyzes the Teflon filters from module A for fine mass and its elemental constituents. The Research Triangle Institute analyzes the nylon filters from module B of the IMPROVE sampler for ions using ion chromatography (IC). The Desert Research Institute analyses the quartz filters from module C of the IMPROVE sampler for organic and elemental carbon using the DRI thermal/optical reflectance carbon analyzer. UC Davis also analyzes the PM_{10} mass from the Teflon filter in module D. Details of the analyses applied to each filter are shown in Table 2-2. The Wishram site operated between September 1996 and September 1998 with all 4 IMPROVE channels. The Mt. Zion site was operated with only channels A-C during that period.

Table 2-1. IMPROVE Sampler Methods

Module	*Filter*	*d_{ae} range*	*Major Variables*
A	Teflon	0 - 2.5 µm	mass, S, organics by H, soil and trace elements, b_{abs}
B	nylon	0 - 2.5 µm	nitrate, sulfate, (preceded by carbonate denuder)
C	quartz	0 - 2.5 µm	organic and elemental carbon
D	Teflon	0 - 10 µm	PM_{10} mass

Table 2-2. IMPROVE Analytical Methods

Filter	Lab	Method	Code	Variable	Reference
Teflon A	UCD	gravimetric analysis		Mass	Feeney et al., 1984
		integrating plate method	LIPM	coefficient of absorption	Campbell et al., 1995
		proton elastic scattering analysis	PESA	H	Cahill , 1987
		particle induced X-ray emission	PIXE	Na to Mn, Mo	Cahill , 1987
		X-ray fluorescence	XRF	Fe to Zr, Pb	Cahill, 1987
nylon B	RTI	ion chromatography	IC	nitrate, sulfate, chloride	Chow and Watson, 1998b
quartz C	DRI	thermal optical reflectance (carbon)	TOR	organic and elemental carbon	Chow et al., 1993
Teflon D	UCD	gravimetric analysis		Mass	Feeney et al., 1984

2.4 $PM_{2.5}$ Data Evaluation

Several self-consistent comparisons can be made to evaluate the IMPROVE $PM_{2.5}$ data. Reconstructed mass results from a weighted sum of chemical components that accounts for unmeasured ammonium, oxides formed from elements, and hydrogen and carbon components in organic material. Figure 2-3 compares reconstructed to measured $PM_{2.5}$ mass for valid measurements from the Mt. Zion site in the upper panel and the Wishram site in the lower panel. Most of these points show equivalent concentrations within the limits of analytical uncertainty. This implies that the sum of CMB source contributions should be within one or two propagated uncertainty intervals of the measured mass.

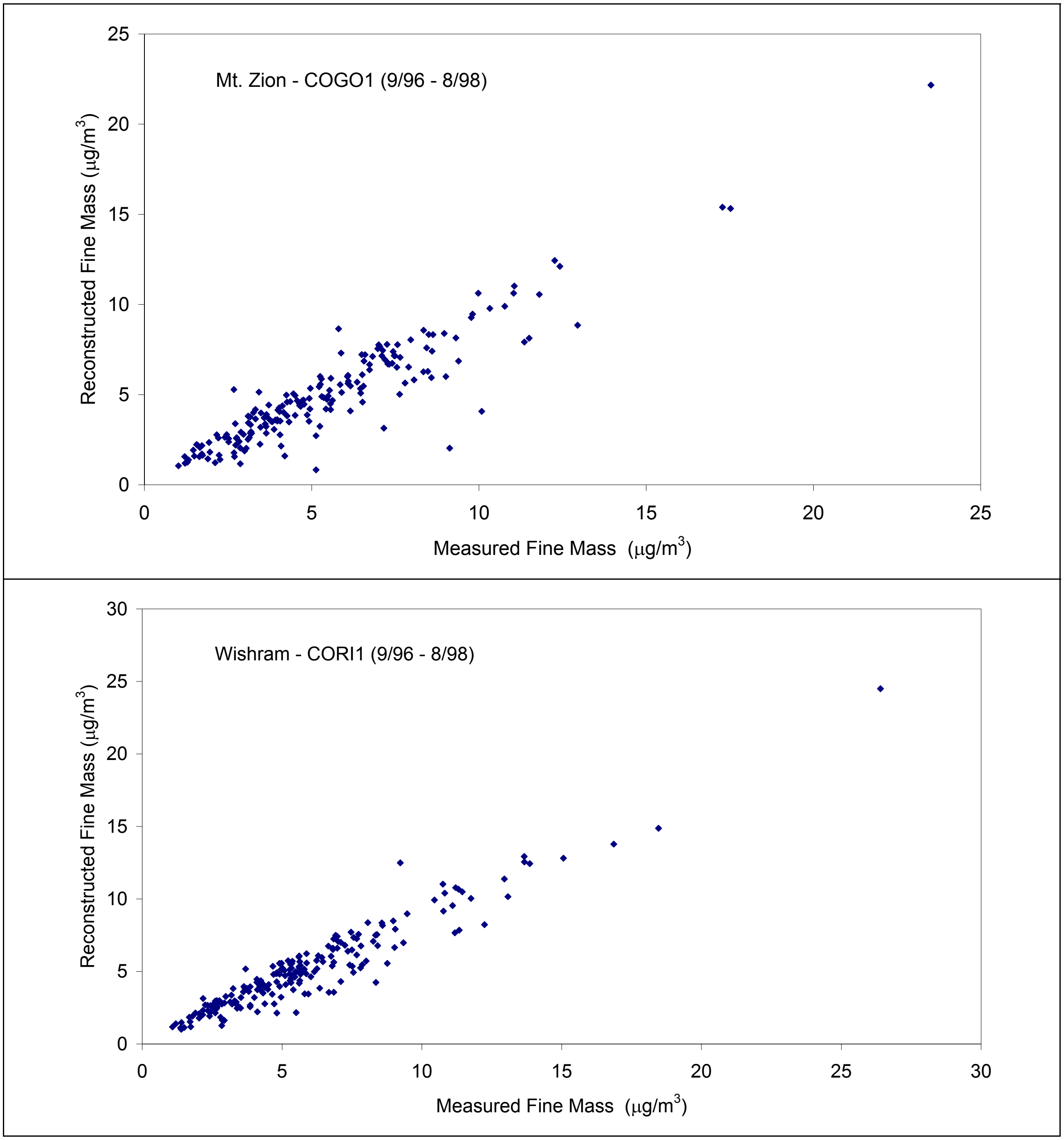

Figure 2-3. Comparison of measured fine mass with reconstructed fine mass at Mt. Zion and Wishram IMPROVE sites in the Columbia River Gorge.

Figure 2-4 shows a high correspondence between sulfate measured by ion chromatography on the nylon filter and total sulfur measured by PIXE on the Teflon filter. A sulfate to sulfur ratio of three in this data set indicates that all of the sulfur is in a soluble form of sulfate. This comparison also demonstrates that IMPROVE modules A and B sampled the same aerosol, that flow rates were equivalent, and that the two separate laboratories performing analyses were precise and traceable. Major deviations in any of these variables would not permit such a good comparison.

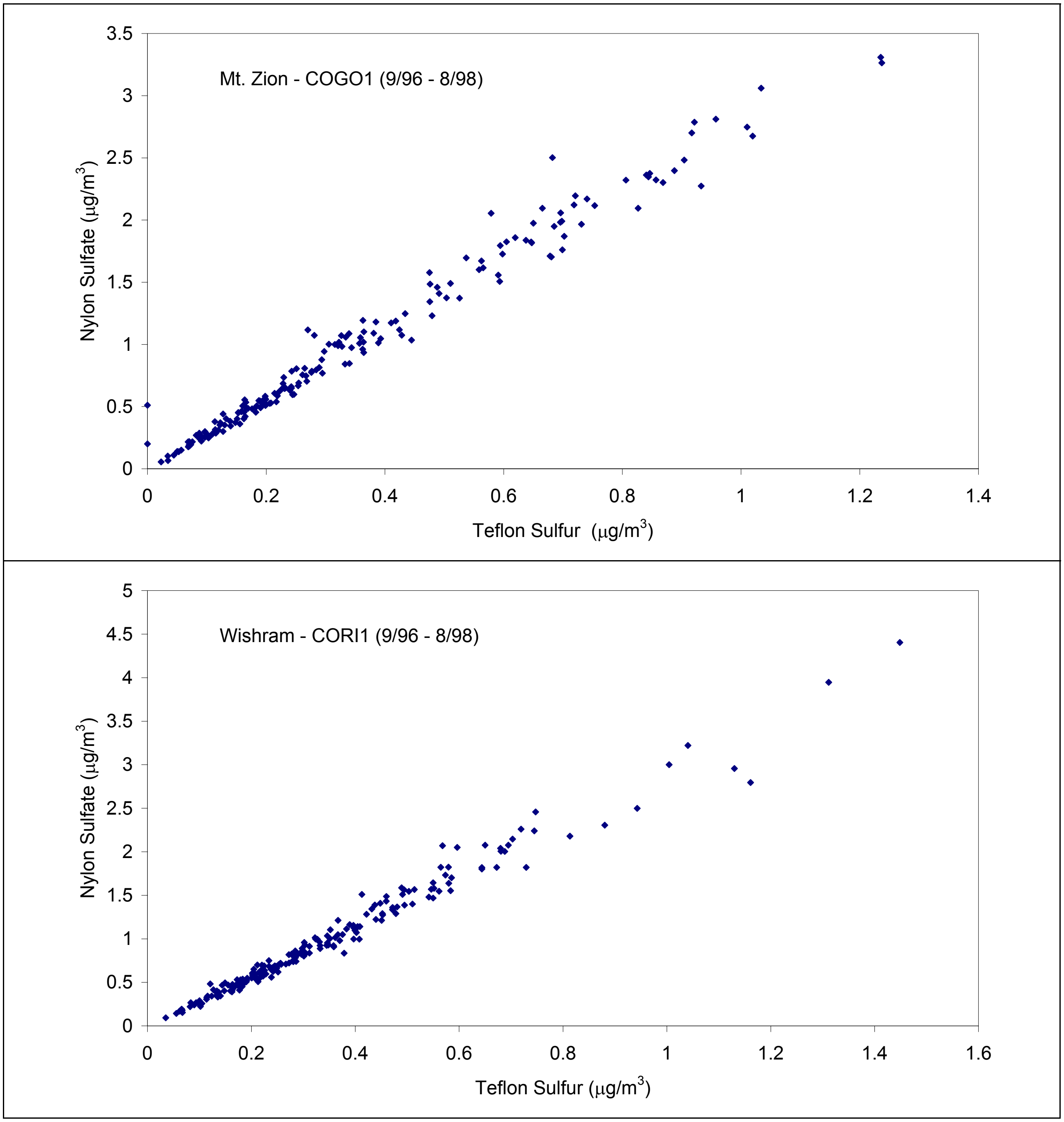

Figure 2-4. Comparison of sulfur measured on Teflon filters (Channel A) with sulfate measured on nylon filters (Channel B) at Mt. Zion and Wishram IMPROVE sites in the Columbia River Gorge.

PM_{10} mass, but not chemical composition, was quantified at the Wishram site; PM_{10} was not measured at the Mt. Zion site. By definition, $PM_{2.5}$ must be less than or equal to PM_{10} mass concentrations, and Figure 2-5 shows this comparison for the available data. This is the case, within stated precision intervals, for all of the measurements. Figure 2-5 also shows that the fraction of PM_{10} that is $PM_{2.5}$ can range from 10% to 90% at Wishram.

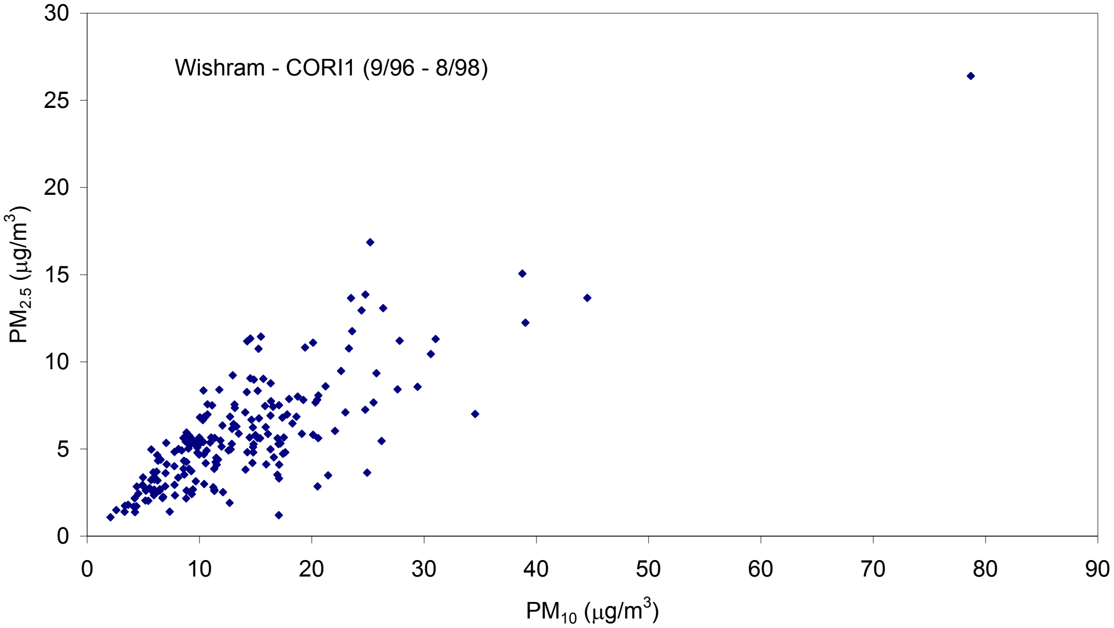

Figure 2-5. Comparison of PM2.5 with PM_{10} mass concentration at the Wishram site.

2.5 Species Concentrations

Table 2-3 summarizes the $PM_{2.5}$ mass and chemical concentrations obtained for all valid sample days from 9/1/96 through 8/31/98 at the two monitoring sites. The two year annual average $PM_{2.5}$ was 5.5 µg/m^3 at the Mt. Zion site and was 5.9 µg/m^3 at the Wishram site. The 24-hour maximum $PM_{2.5}$ of 23.5 µg/m^3 at Mt. Zion and 26.4 µg/m^3 at Wishram were both observed on 4/29/1998.

The average PM_{10} concentrations at the Wishram site was 13.7 µg/m^3. $PM_{2.5}$ and PM_{10} concentrations at these sites were typical of the annual concentrations measured at other sites in the region (Eldred et al.., 1994, 1997, Eldred, 1997; Malm, 1992; Malm et al., 1994). In the northwestern U.S., these concentrations decrease with distance from the Pacific Coast into eastern Washington, eastern Oregon, Idaho, and northern Nevada.

The most abundant $PM_{2.5}$ chemical components in Columbia River Gorge were organic carbon and sulfate. Average concentrations of these components differed by less than 10% from the east to the west side of the Gorge. This spatial consistency indicates that these pollutants are uniformly distributed throughout the Gorge owing most likely to regional sources.

Organic carbon consists of hundreds, possibly thousands, of separate compounds. The mass concentration of organic carbon can be accurately measured, as can carbonate carbon, but only about 10% of specific organic compounds that it contains have been measured. Vehicle exhaust (Rogge et al., 1993b), residential and agricultural burning (Rogge et al., 1998), meat cooking (Rogge et al., 1991), fuel combustion (Rogge et al., 1997), road dust (Rogge et al., 1993c), and particle formation from heavy hydrocarbon (C_8 to C_{20}) gases (Pandis et al., 1992) are the major sources of $PM_{2.5}$ organic carbon. Because of this lack of molecular specificity, and owing to the semi-volatile nature of many carbon compounds, particulate "organic carbon" is operationally defined by the sampling and analysis method (Chow et al., 1993; Shah et al., 1984, 1986). Elemental carbon is black, often called "soot." Elemental carbon contains pure, graphitic carbon, but it also contains high molecular weight, dark-colored, non-volatile organic materials such as tar, biogenics, and coke. Elemental carbon usually accompanies organic carbon in combustion emissions with diesel exhaust (Watson et al., 1994b) being the largest contributor.

On average, organic carbon constituted 26% to 29% of $PM_{2.5}$ and was the largest fraction of $PM_{2.5}$ at each site. Elemental carbon constituted 6% to 7% of the average $PM_{2.5}$ at the two sites. The highest organic carbon (OC) concentration was 7.2 $\mu g/m^3$ on 9/24/97 at Mt. Zion when $PM_{2.5}$ was 17.5 $\mu g/m^3$ and the highest elemental carbon concentration was 1.5 $\mu g/m^3$ on 10/22/97 when $PM_{2.5}$ was 17.3 $\mu g/m^3$ at the Mt. Zion site. The OC concentration was 6.0 $\mu g/m^3$ on 11/22/97, close to its maximum concentration. Organic to elemental carbon ratios were 3.3 at the Wishram site and 4.6 at the Mt. Zion site. Ratios much higher than three are indicative of secondary organic aerosol that forms from heavy hydrocarbons (Turpin et al., 1991). These ratios indicate that most of organic carbon at the Wishram site is of primary origin, but that a moderate fraction of organic carbon at the Mt. Zion site may form from heavy hydrocarbon gases. Secondary organic particles can often form in forested areas where biogenic monoterpene emissions are often abundant precursors (Hoffman et al., 1997). These elevated ratios can also result from adsorption of organic gases on the quartz fiber filter. An adjustment for this artifact is made with IMPROVE samples by subtracting the carbon measured on the field blank, which are similar to levels on a backup filter.

Ammonium sulfate $(NH_4)_2SO_4)$, ammonium bisulfate (NH_4HSO_4), and sulfuric acid (H_2SO_4) are the most common forms of sulfate found in atmospheric particles, resulting from conversion of gases to particles. These compounds are water-soluble and reside almost exclusively in the $PM_{2.5}$ size fraction. Sodium sulfate (Na_2SO_4) may be found in coastal areas such as the CRG where sulfuric acid has been neutralized by sodium chloride (NaCl) in sea salt. Although gypsum (Ca_2SO_4) and some other geological compounds contain sulfate, these are not easily dissolved in water for chemical analysis and are more abundant in the coarse fraction than in $PM_{2.5}$; these compounds are usually classified in the geological fraction.

The highest sulfate concentration of 4.4 $\mu g/m^3$ was measured at the Wishram site on 05/06/98 when $PM_{2.5}$ was 13.7 $\mu g/m^3$. Since ammonium was not measured, a cation/anion balance is not possible for these measurements. Ammonium sulfate is the most probable form of the measured sulfate, but there may also be some abundance of sodium sulfate and ammonium bisulfate in the CRG where ammonia concentrations might be small.

Ammonium nitrate (NH_4NO_3) is often found to be the most abundant nitrate compound, resulting from a reversible gas/particle equilibrium of ammonia gas (NH_3), nitric acid gas (HNO_3), and particulate ammonium nitrate. Because this equilibrium is reversible, ammonium nitrate particles can easily evaporate in the atmosphere, or after they have been collected on a filter, owing to changes in temperature and relative humidity (Watson et al., 1994a). Sodium nitrate $(NaNO_3)$ is found in the $PM_{2.5}$ and coarse fractions near sea coasts and salt playas (e.g., Watson et al., 1994c) where nitric acid vapor irreversibly reacts with sea salt (NaCl).

Salt is found in suspended particles near sea coasts, open playas, and after road de-icing materials are applied. Bulk sea water contains 57±7% chloride, 32±4% sodium, 8±1% sulfate, 1.1±.1% soluble potassium, and 1.2±0.2% calcium (Pytkowicz and Kester, 1971). In its raw form (e.g., deicing sand), salt is usually in the coarse particle fraction and classified as a geological material (Chow et al., 1996). The presence of marine aerosol is a certainty in the

CRG. It is also possible that de-icing material affects the non-urban sites during winter because nearby roadways must be cleared of snow. After evaporating from a suspended water droplet (as in sea salt or when resuspended from melting snow), it is abundant in the $PM_{2.5}$ fraction. Sodium chloride is often neutralized by nitric or sulfuric acid in urban air where it is often encountered as sodium nitrate or sodium sulfate (Pilinis et al., 1987).

The highest nitrate concentration of 3.4 $\mu g/m^3$ was measured at the Wishram site on 01/29/97 corresponding to a 16.9 $\mu g/m^3$ $PM_{2.5}$ concentration. The highest sodium concentration of 2.4 $\mu g/m^3$ was found at the Mt. Zion site on 09/27/97 corresponding to a $PM_{2.5}$ level of 10.1 $\mu g/m^3$. Annual average nitrate at the Wishram site was ~10% higher than the Mt. Zion site. Conversely, annual average sodium concentrations at the Mt. Zion site was ~20% higher than the average at the Wishram site. The IMPROVE denuder/nylon configuration measures higher nitrate than would be expected from an FRM on which some of the ammonium nitrate might volatilize during sampling.

Suspended dust consists mainly of oxides of aluminum, silicon, calcium, titanium, iron, and other metal oxides (Chow and Watson, 1994). The precise combination of these minerals depends on the geology of the area and industrial processes such as steel-making, smelting, mining, and cement production. Geological material is mostly in the coarse particle fraction (Houck et al., 1990), and typically constitutes ~50% of PM_{10} while only contributing 5 to 15% of $PM_{2.5}$ (Chow et al., 1992a; Watson et al., 1994c). This is consistent with the low aluminum, silicon, iron, calcium, and titanium concentrations at all sites.

Although their concentrations are low, trace metal concentrations are often indicative of source contributions. Average lead and bromine concentrations were less than 5 ng/m^3 at the Mt. Zion site, but ~50% higher than levels measured at the Wishram site on the east end of the Gorge. Similarly, average vanadium and nickel concentrations were also quite low in the CRG (< 2 ng/m3). The maximum potassium concentration of 0.54 $\mu g/m^3$ at Wishram and 0.49 $\mu g/m^3$ at Mt. Zion was measured on 04/29/98. Potassium is usually associated with vegetative burning, similar to that from prescribed burns and forest fires. On 4/29/98 however, the potassium maximum is coincident with very high dust loading that appear to have origins in Chinese deserts.

A high degree of consistency was observed for average annual aerosol component concentrations at the two IMPROVE sites in the Gorge (Table 2-4). Some seasonal differences were observed however. Seasonal average nitrate concentrations only ranged from 0.38 $\mu g/m^3$ to 0.41 $\mu g/m^3$ throughout the year at the Mt. Zion site but spanned 0.22 $\mu g/m^3$ in summer to 0.78 $\mu g/m^3$ in winter at the Wishram site. In contrast, ammonium sulfate concentrations showed a larger seasonal trend at the Mt. Zion site than at the Wishram site. Sulfate concentrations in the Gorge were highest in the summer and lowest in the winter at Mt. Zion. Soil concentrations were highest in the summer at both sites, but were nearly 2 times higher at the eastern Wishram site than at the Mt. Zion site. Chloride and Chlorine concentrations were highest in the winter at the Mt. Zion site but were highest in the fall at the Wishram site. Seasonal average sodium concentrations were ~60% higher on the east side of the Gorge in fall and winter than in spring and summer, but varied by less than 15% on the Pacific side of the Gorge.

Table 2-3. Minimum, Maximum, and Average of species concentrations at Mt. Zion and Wishram IMPROVE sites in the Columbia River Gorge.

			Wishram (CORI1) 9/1/96 – 8/31/98			Mt. Zion (COGO1) 9/1/96 – 8/31/98		
Species Code	Species	UNITS	Min	Avg	Max	Min	Avg	Max
ALf	Aluminum: Fine	ug/m3	0.000	0.083	1.914	0.000	0.042	1.766
ASf	Arsenic: Fine	ug/m3	0.000	0.000	0.002	0.000	0.000	0.002
BRf	Bromine: Fine	ug/m3	0.000	0.001	0.004	0.000	0.002	0.004
CAf	Calcium: Fine	ug/m3	0.000	0.031	0.794	0.000	0.027	0.746
CHLf	Chloride: Fine	ug/m3	-0.064	0.066	2.019	-0.076	0.130	2.629
CLf	Chlorine: Fine	ug/m3	0.000	0.042	1.980	0.000	0.107	2.474
CRf	Chromium: Fine	ug/m3	0.000	0.000	0.004	0.000	0.000	0.004
CUf	Copper: Fine	ug/m3	0.000	0.000	0.005	0.000	0.001	0.006
ECf	Carbon: Fine total elemental	ug/m3	0.052	0.396	1.458	0.065	0.354	1.456
EC1f	Carbon: Fine elemental (EC1)	ug/m3	0.057	0.423	2.159	0.081	0.395	1.847
EC2f	Carbon: Fine elemental (EC2)	ug/m3	-0.013	0.071	0.185	-0.037	0.059	0.177
EC3f	Carbon: Fine elemental (EC3)	ug/m3	-0.011	0.014	0.058	-0.011	0.012	0.061
FEf	Iron: Fine	ug/m3	0.005	0.056	1.057	0.002	0.035	0.865
Hf	Hydrogen: Fine	ug/m3	0.058	0.235	0.661	0.047	0.227	0.742
Kf	Potassium: Fine	ug/m3	0.014	0.052	0.536	0.008	0.055	0.499
MF	PM$_{2.5}$: mass	ug/m3	1.083	5.758	26.402	1.019	5.499	23.512
MGf	Magnesium: Fine	ug/m3	0.000	0.002	0.164	0.000	0.007	0.186
MNf	Manganese: Fine	ug/m3	0.000	0.001	0.008	0.000	0.001	0.006
MT	PM$_{10}$: mass	ug/m3	2.070	13.751	78.689			
N2f	Nitrite: Fine	ug/m3	-0.088	-0.017	0.025	-0.080	-0.018	0.023
NAf	Sodium: Fine	ug/m3	0.000	0.175	1.835	0.000	0.216	2.377
NIf	Nickel: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.001
NO3f	Nitrate: Fine	ug/m3	0.029	0.438	3.389	0.033	0.398	1.710
OCf	Carbon: Fine total organic	ug/m3	0.240	1.461	6.689	0.383	1.594	7.244
OC1f	Carbon: Fine organic (OC1)	ug/m3	-0.037	0.160	0.861	-0.068	0.217	0.951
OC2f	Carbon: Fine organic (OC2)	ug/m3	0.037	0.295	1.380	0.064	0.332	1.756
OC3f	Carbon: Fine organic (OC3)	ug/m3	0.058	0.535	2.337	0.062	0.560	2.716
OC4f	Carbon: Fine organic (OC4)	ug/m3	0.056	0.358	1.514	0.065	0.374	1.904
OPf	Carbon: Fine organic (OP)	ug/m3	0.000	0.112	0.827	-0.008	0.112	0.799
Pf	Phosphorus: Fine	ug/m3	0.000	0.000	0.004	0.000	0.000	0.007
PBf	Lead: Fine	ug/m3	0.000	0.002	0.015	0.000	0.003	0.058
RBf	Rubidium: Fine	ug/m3	0.000	0.000	0.003	0.000	0.000	0.002
Sf	Sulfur: Fine	ug/m3	0.035	0.348	1.449	0.000	0.360	1.237
SEf	Selenium: Fine	ug/m3	0.000	0.000	0.001	0.000	0.000	0.001
SIf	Silicon: Fine	ug/m3	0.000	0.108	3.441	0.000	0.074	3.082
SO4f	Sulfate: Fine	ug/m3	0.093	0.998	4.404	0.056	1.025	3.308
SRf	Strontium: Fine	ug/m3	0.000	0.000	0.006	0.000	0.000	0.006
TIf	Titanium: Fine	ug/m3	0.000	0.005	0.094	0.000	0.004	0.078
Vf	Vanadium: Fine	ug/m3	0.000	0.001	0.007	0.000	0.001	0.006
ZNf	Zinc: Fine	ug/m3	0.000	0.004	0.011	0.001	0.004	0.032
ZRf	Zirconium: Fine	ug/m3	0.000	0.000	0.001	0.000	0.000	0.001
ammSO4f	Ammonium sulfate: Fine	ug/m3	0.145	1.436	5.976	0.000	1.486	5.103
ammNO3f	Ammonium Nitrate: Fine	ug/m3	0.037	0.565	4.372	0.043	0.514	2.205
ECf	Carbon: Fine total elemental	ug/m3	0.052	0.396	1.458	0.065	0.354	1.456
OMCf	Carbon: Fine organic mass	ug/m3	0.337	2.046	9.365	0.536	2.231	10.142
SOILf	Soil: Fine	ug/m3	0.083	0.649	16.813	0.021	0.415	15.019
RCFM	Reconstructed Fine Mass	ug/m3	1.017	5.092	24.504	0.828	4.999	22.165
CM	PM2.5-10: mass	ug/m3	0.743	7.993	52.287			
ammSO4f_bext	Ammonium sulfate extinction: Fine	Mm-1	1.640	15.119	61.505	0.000	15.641	58.086
ammNO3f_bext	Ammonium nitrate extinction: Fine	Mm-1	0.317	6.544	56.141	0.483	5.738	29.839
OMCf_bext	Organic carbon extinction: Fine	Mm-1	1.346	8.182	37.460	2.145	8.924	40.566
ECf_bext	Elemental carbon extinction: Fine	Mm-1	0.519	3.961	14.583	0.654	3.539	14.562
SOILf_bext	Soil extinction: Fine	Mm-1	0.083	0.649	16.813	0.021	0.415	15.019
CM_bext	Coarse mass extinction	Mm-1	0.446	4.796	31.372			
aerosol_bext	Aerosol extinction	Mm-1	7.855	39.252	144.269			
dv	deciview	dv	5.797	15.080	27.361			

Table 2-4. Seasonal variations of species concentrations at Mt. Zion and Wishram IMPROVE sites in the Columbia River Gorge.

Species Code	Species	UNITS	Wishram (CORI1) 9/1/96 – 8/31/98 Winter (dec-feb)	Wishram (CORI1) 9/1/96 – 8/31/98 Spring (mar-may)	Wishram (CORI1) 9/1/96 – 8/31/98 Summer (jun-aug)	Wishram (CORI1) 9/1/96 – 8/31/98 Fall (sep-oct)	Mt. Zion (COGO1) 9/1/96 – 8/31/98 Winter (dec-feb)	Mt. Zion (COGO1) 9/1/96 – 8/31/98 Spring (mar-may)	Mt. Zion (COGO1) 9/1/96 – 8/31/98 Summer (jun-aug)	Mt. Zion (COGO1) 9/1/96 – 8/31/98 Fall (sep-oct)
ALf	Aluminum: Fine	ug/m3	0.084	0.100	0.061	0.090	0.016	0.059	0.063	0.034
ASf	Arsenic: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BRf	Bromine: Fine	ug/m3	0.001	0.002	0.001	0.002	0.001	0.002	0.002	0.002
CAf	Calcium: Fine	ug/m3	0.019	0.044	0.031	0.031	0.016	0.035	0.030	0.028
CHLf	Chloride: Fine	ug/m3	0.086	0.046	0.016	0.120	0.207	0.086	0.015	0.186
CLf	Chlorine: Fine	ug/m3	0.065	0.015	0.005	0.087	0.187	0.055	0.011	0.155
CRf	Chromium: Fine	ug/m3	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.001
CUf	Copper: Fine	ug/m3	0.000	0.001	0.001	0.000	0.000	0.001	0.002	0.001
ECf	Carbon: Fine total elemental	ug/m3	0.437	0.375	0.320	0.455	0.304	0.334	0.372	0.412
EC1f	Carbon: Fine elemental (EC1)	ug/m3	0.434	0.407	0.417	0.433	0.327	0.355	0.429	0.480
EC2f	Carbon: Fine elemental (EC2)	ug/m3	0.062	0.075	0.077	0.071	0.056	0.059	0.059	0.063
EC3f	Carbon: Fine elemental (EC3)	ug/m3	0.009	0.015	0.015	0.017	0.010	0.012	0.012	0.013
FEf	Iron: Fine	ug/m3	0.034	0.076	0.061	0.054	0.015	0.044	0.053	0.029
Hf	Hydrogen: Fine	ug/m3	0.213	0.207	0.263	0.259	0.136	0.222	0.282	0.289
Kf	Potassium: Fine	ug/m3	0.039	0.057	0.053	0.060	0.033	0.058	0.063	0.068
MF	PM$_{2.5}$: mass	ug/m3	5.569	5.335	6.084	6.115	3.898	5.255	6.612	6.604
MGf	Magnesium: Fine	ug/m3	0.000	0.002	0.001	0.003	0.006	0.008	0.004	0.008
MNf	Manganese: Fine	ug/m3	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001
MT	PM$_{10}$: mass	ug/m3	11.38	13.97	15.74	14.07				
N2f	Nitrite: Fine	ug/m3	-0.031	-0.013	-0.002	-0.021	-0.035	-0.007	-0.002	-0.024
NAf	Sodium: Fine	ug/m3	0.209	0.135	0.130	0.230	0.208	0.193	0.238	0.232
NIf	Nickel: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NO3f	Nitrate: Fine	ug/m3	0.783	0.330	0.217	0.414	0.408	0.380	0.386	0.414
OCf	Carbon: Fine total organic	ug/m3	1.424	1.223	1.391	1.837	1.215	1.416	1.680	2.128
OC1f	Carbon: Fine organic (OC1)	ug/m3	0.189	0.146	0.119	0.190	0.193	0.173	0.206	0.299
OC2f	Carbon: Fine organic (OC2)	ug/m3	0.305	0.245	0.298	0.336	0.247	0.310	0.359	0.425
OC3f	Carbon: Fine organic (OC3)	ug/m3	0.516	0.399	0.461	0.785	0.395	0.500	0.587	0.780
OC4f	Carbon: Fine organic (OC4)	ug/m3	0.345	0.311	0.324	0.460	0.290	0.340	0.400	0.481
OPf	Carbon: Fine organic (OP)	ug/m3	0.068	0.123	0.190	0.066	0.089	0.093	0.128	0.144
Pf	Phosphorus: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PBf	Lead: Fine	ug/m3	0.002	0.002	0.001	0.002	0.003	0.002	0.002	0.005
RBf	Rubidium: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sf	Sulfur: Fine	ug/m3	0.306	0.331	0.434	0.320	0.201	0.370	0.586	0.340
SEf	Selenium: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SIf	Silicon: Fine	ug/m3	0.032	0.167	0.139	0.092	0.022	0.111	0.106	0.063
SO4f	Sulfate: Fine	ug/m3	0.858	0.963	1.281	0.884	0.612	1.052	1.644	0.950
SRf	Strontium: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TIf	Titanium: Fine	ug/m3	0.002	0.006	0.006	0.005	0.001	0.005	0.009	0.004
Vf	Vanadium: Fine	ug/m3	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001
ZNf	Zinc: Fine	ug/m3	0.004	0.004	0.003	0.004	0.004	0.004	0.004	0.005
ZRf	Zirconium: Fine	ug/m3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ammSO4f	Ammonium sulfate: Fine	ug/m3	1.261	1.366	1.790	1.320	0.830	1.526	2.418	1.402
ammNO3f	Ammonium Nitrate: Fine	ug/m3	1.010	0.426	0.280	0.533	0.527	0.491	0.498	0.534
ECf	Carbon: Fine total elemental	ug/m3	0.437	0.375	0.320	0.455	0.304	0.334	0.372	0.412
OMCf	Carbon: Fine organic mass	ug/m3	1.993	1.712	1.947	2.572	1.700	1.983	2.352	2.979
SOILf	Soil: Fine	ug/m3	0.382	0.903	0.694	0.618	0.159	0.584	0.597	0.358
RCFM	Reconstructed Fine Mass	ug/m3	5.084	4.781	5.031	5.499	3.520	4.918	6.238	5.685
CM	PM2.5-10: mass	ug/m3	5.807	8.637	9.656	7.964				
ammSO4f_bext	Ammonium sulfate extinction: Fine	Mm-1	16.370	14.019	15.610	14.434	10.280	15.502	21.715	16.699
ammNO3f_bext	Ammonium nitrate extinction: Fine	Mm-1	13.098	4.395	2.462	6.132	6.659	4.984	4.495	6.531
OMCf_bext	Organic carbon extinction: Fine	Mm-1	7.972	6.849	7.789	10.287	6.802	7.931	9.409	11.916
ECf_bext	Elemental carbon extinction: Fine	Mm-1	4.372	3.745	3.197	4.548	3.038	3.335	3.721	4.122
SOILf_bext	Soil extinction: Fine	Mm-1	0.382	0.903	0.694	0.618	0.159	0.584	0.597	0.358
CM_bext	Coarse mass extinction	Mm-1	3.484	5.182	5.794	4.779				
aerosol_bext	Aerosol extinction	Mm-1	45.678	35.093	35.545	40.798				
dv	deciview		16.053	14.282	14.552	15.441				

2.6 Aerosol Composition on Best, Worst and Average Visibility Day

The IMPROVE network routinely reduces their speciated aerosol concentration measurements into five principle component: soil, ammonium sulfate, ammonium nitrate, organic carbon, and elemental carbon (IMPROVE, 2002). These components permit a more in-depth understanding of the aerosol speciation without adding the complexity of tracking 35 or more chemicical species. The principal aerosol components are calculated from the major measured aerosol species.

The geologic material component is estimated by summing the elements predominantly associated with soil plus oxygen for the normal oxides (Al_2O_3, SiO_2, CaO, FeO, Fe_2O_3, and TiO_2) plus a correction for other compounds such as MgO, Na_2O, water, and carbonate. The final equation for the geologic component of aerosol mass is:

$$[\text{Soil}] = 2.20\,[\text{Al}] + 2.49\,[\text{Si}] + 1.63\,[\text{Ca}] + 2.42\,[\text{Fe}] + 1.94\,[\text{Ti}]$$

where elemental concentrations measured by X-ray fluorescence (XRF) have units of $\mu g/m^3$. The components of these factors were confirmed in a comparison of local resuspended soils, and ambient aerosols in the western United States (Cahill et al., 1981; Pitchford et al., 1981). Based on the assumption that aerosol organic mass is 70% carbon (Watson et al., 1989), the organic mass component can be calculated from the measured organic carbon as:

$$[\text{OMC}] = 1.4\,[\text{OC}]$$

where [OC] = organic carbon concentration measured by thermal optical reflectance (TOR) in $\mu g/m^3$. The elemental carbon component [EC] of the aerosol mass is assumed to exist as pure elemental carbon as measured by TOR. In the rural areas in the Western United States, particulate sulfate and particulate nitrate are usually neutralized with ammonium. Based on this assumption, the equations for the ammonium sulfate and ammonium nitrate components of the aerosol are:

$$[\text{Ammonium Sulfate}] = 1.375\,[\text{SO}_4]$$

where $[SO_4]$ = IC sulfate concentration in $\mu g/m^3$.

$$[\text{Ammonium Nitrate}] = 1.29\,[\text{NO}_3]$$

where $[NO_3]$ = IC nitrate concentration in $\mu g/m^3$.

The combination of the 5 individual components is referred to here as the calculated aerosol mass that often accounts for the measured mass within the propagated uncertainties. Minimum, maximum, average, and seasonal average concentrations of these 5 primary components are shown in Table 2-3 and Table 2-4.

The relative size of these components along with the unexplained mass (i.e. the measured $PM_{2.5}$ minus the sum of the 5 aerosol components) is shown in Figure 2-6. For all cases, the largest component of the aerosol mass in the organic material that accounts for 39% of the fine aerosol mass at Mt. Zion and 38% of the fine aerosol mass at Wishram on the worst visibility days. The next largest component is ammonium sulfate that accounts for 30% and 24% of the aerosol mass on the worst days at Mt. Zion and Wishram, respectively. Ammonium nitrate and soil account for nearly equal amounts of the worst days aerosol mass at both sites: 9% to 10% each at Mt. Zion and 12% each at Wishram. Elemental carbon accounts for the least amount of fine mass on the 20% worst visibility days: 6% at Mt. Zion and 7% at Wishram.

On average days, the relative amounts of species to total fine mass is quite similar to the 20% worst visibility days. One difference is that the fraction of unexplained mass increases as average PM concentrations decrease. This may be due to analytical uncertainties in the gravimetric and chemical measurements that play a larger role when the quantity of material analyzed decreases. On the 20% best visibility days, the unexplained mass accounts for 22% and 20% of the measured fine mass at Mt. Zion and Wishram, respectively. The relative ranking of the major components is consistant with the average and worst visibility days in that organic material and sulfate account for the largest fraction of the fine mass. Soil, nitrate, and elemental carbon have nearly equivalent contributions to best visibility days at Mt. Zion. At Wishram, the relative contribution of soil to total mass is nearly two times that of nitrate and elemental carbon.

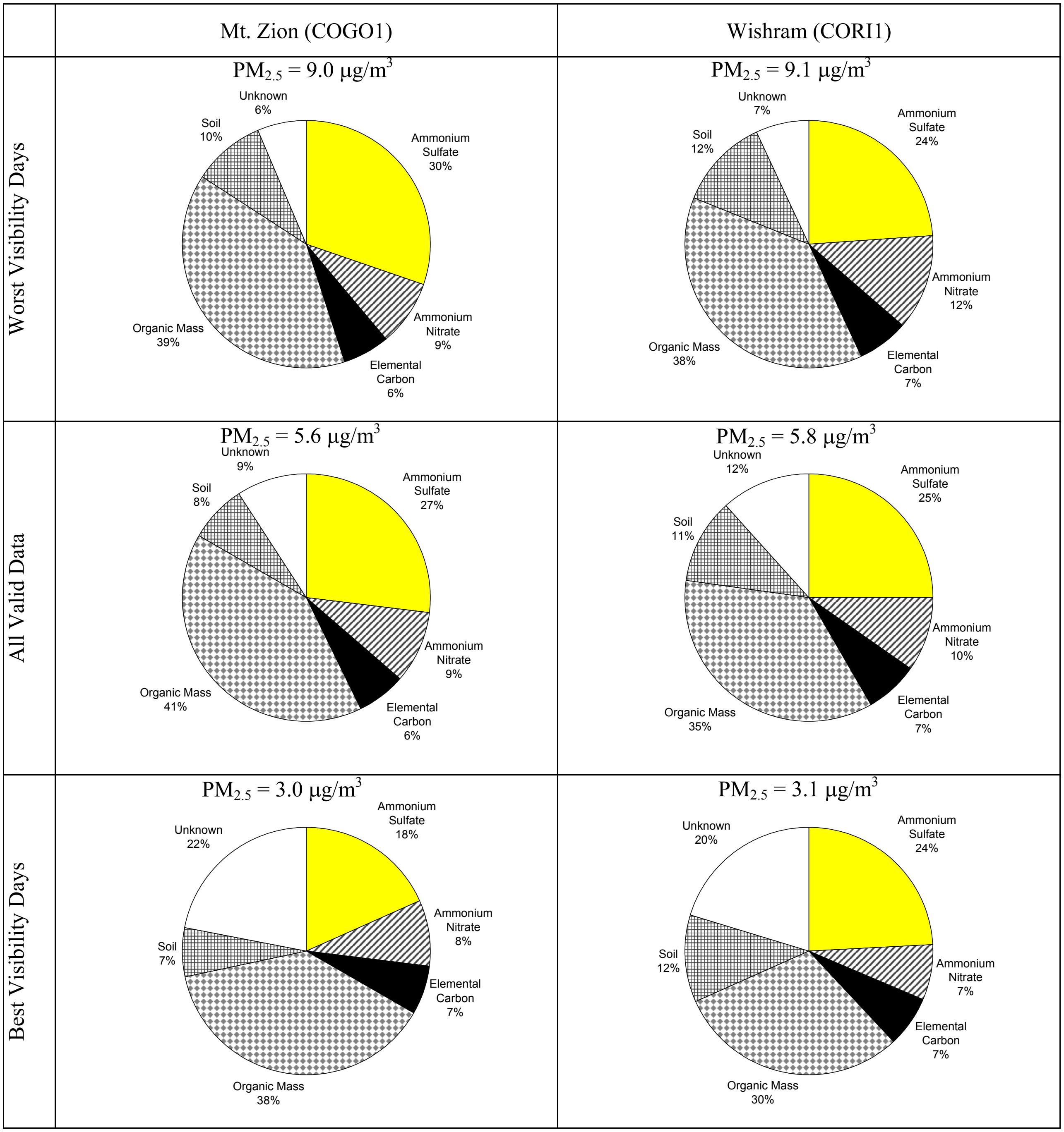

Figure 2-6. Relative amount of principle fine aerosol components for 20% worst, average, and 20% best visibility days at the Mt. Zion and Wishram sites in the CRG.

2.7 Comparison of Modeling Period with Temperature and Precipitation of 30 Year Climatology.

Many emissions sources are linked to weather. For example, climate control systems in buildings require more power and consequently cause higher emissions when temperatures are colder than usual in winter or when they are higher than normal in summer. Lower than normal precipitation in summer can increase the windblown emission potential of soils and make forests more prone to fire. Windfields are critical parameters for understanding how emission sources impact receptors. Weather can also have indirect effects on ambient pollution levels; snowcover can increase the earth's albedo and prevent the dissipation of an inversion layer. The analysis in this report examines the chemical speciation of aerosol in the CRG over a two year period (9/1/96 to 9/1/98). This section compares temperature and precipitation records for this period with the 30 year climatological records to determine if this period was substantially different from historical averages.

Monthly data from surface meteorological stations near the IMPROVE monitors were downloaded from the National Climatic Data Center (NCDC) for the modeling period. The two years of data were averaged by month. The Troutdale Airport and the Dallesport Airport meteorological stations were selected to represent the surface conditions at the Mt. Zion and Wishram sites, respectively. Summaries of the 30 year (1961 – 1990 for Troutdale and 1971 – 2000 for Dallesport) monthly mean temperature, min and max monthly mean temperature, monthly mean precipitiation (including rain and snow), and min and max monthly mean precipitation were downloaded from the NCDC website for comparison with the data from the modeling period.

The comparison of the monthly mean temperatures and precipitation is shown in Figure 2-7 and Figure 2-8. Monthly average temperatures during the modeling period were similar to the 30 year average temperatures. The figures show that annual temperatures at Troutdale are slightly more temperate (cooler in the summer and warmer in the winter) than at Dallesport. At Troutdale the monthly mean temperatures during the modeling period were between 2 and 5 degrees F higher than the 30 year average temperatures during May, July, and August. The August At the Dallesport site, February and August temperatures were approximately 2 to 3 degrees F higher than the mean. For the remainder of the year, temperatures were within 2 degrees F of the 30 year monthly average. No month in the modeling period set the 30 year monthly mean minimum or maximum temperature record are either site.

Figure 2-8 shows the monthly mean precipitation records at the two stations for the modeling period. Precipitation was generally above average for both sites for all months except February and July through September. Precipitation during the summer months was very close (within 0.1 inches) of the mean precipitation. The higher than average precipitation for the majority of the year may have reduced soil emissions and attenuated emissions from forest fires. At the Dallesport site, the lowest precipitation of the 30 year average occurred in Auguest 1998 (no measurable precip) and the most precipitation was observed for May in 1998 (2.3 inches) and for December in 1996 (7.2 inches). No rain fell at the Troutdale site in August 1998 however February 1996 at 4.4 inches has the most precipitation compared to the 30 year average.

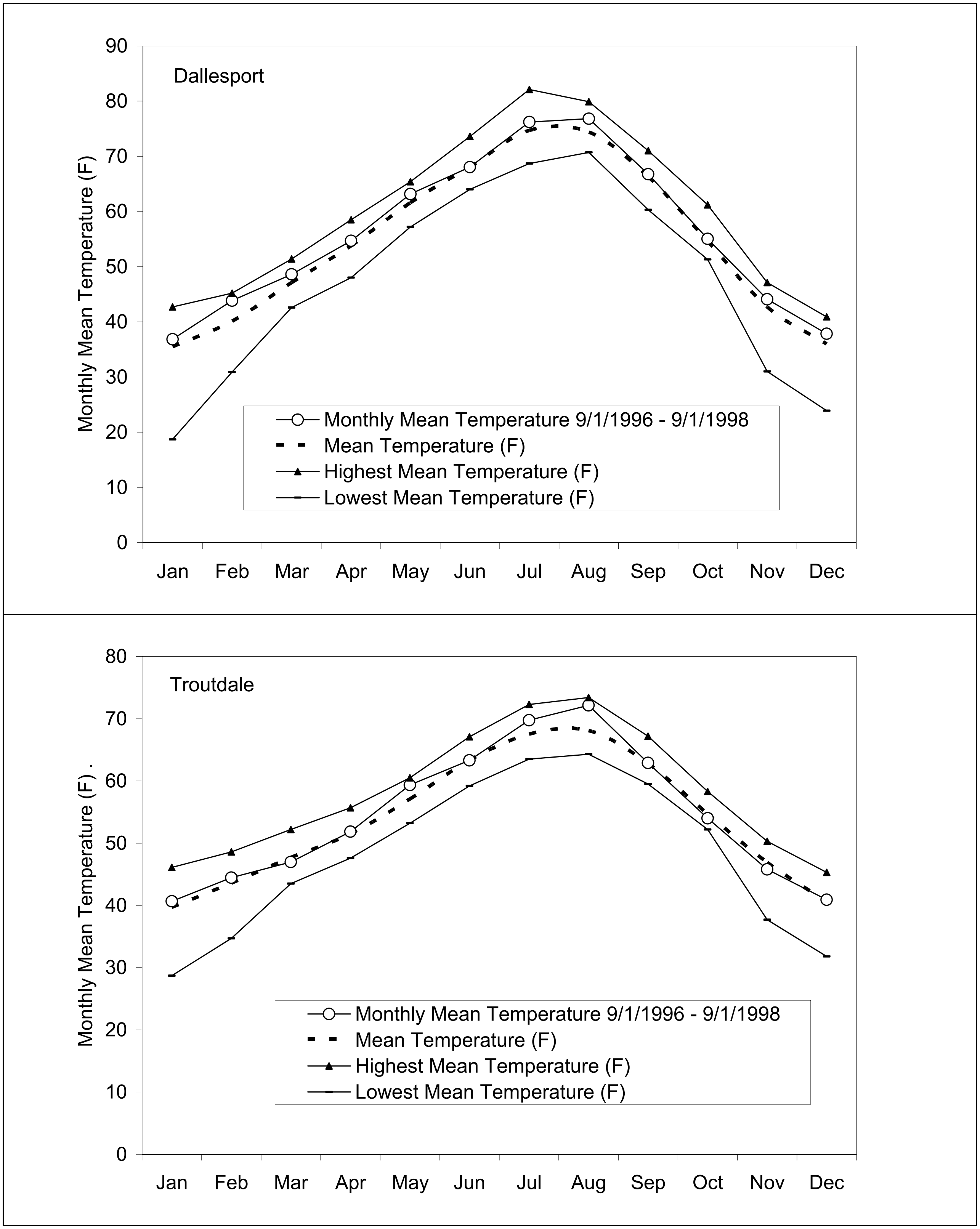

Figure 2-7. Comparison of monthly average temperature during modeling period (9/1/96 to 9/1/98) with 30 climatological average data at the Dallesport monitoring station near the Wishram IMPROVE site and at the Troutdale monitoring station near the Mt. Zion site.

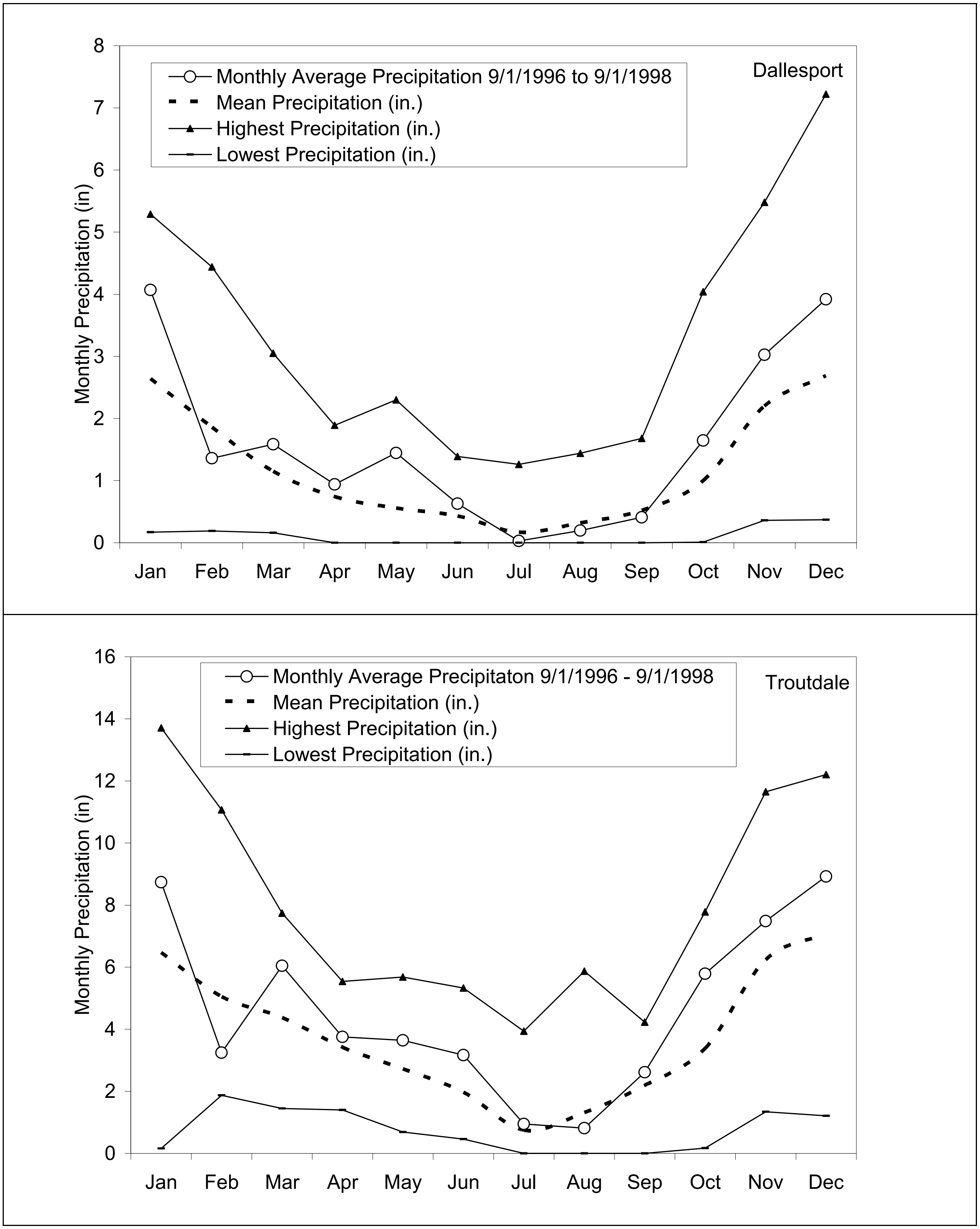

Figure 2-8. Comparison of monthly average precipitation during modeling period (9/1/96 to 9/1/98) with 30 climatological average data at the Dallesport monitoring station near the Wishram IMPROVE site and at the Troutdale monitoring station near the Mt. Zion site.

3. EMISSIONS INVENTORY AND SELECTION OF SOURCE PROFILES

3.1 County Level National Emissions Inventory

CMB apportions ambient PM mass to a selection of source profiles based on how well the chemical signatures of the source profiles can be fit to the observed ambient chemical species. The accuracy of the resultant apportionment is dependent on the selection of the source profiles used to fit the data. An emissions inventory documenting the location and magnitude of all sources surrounding the receptor of interest permits the identification of major source types that are likely to have the largest impact on the air quality.

The National Emissions Inventory (NEI) is assembled by the U.S. EPA to document emissions of criteria pollutants and precursors (i.e. NO_x, SO_2, PM, VOC, NH_3, CO) as well as toxic chemicals. The inventory is resolved at the county level and is based on a combination of locally produced data from state, tribal, and local governments and federally produced data. Comprehensive inventories area assembled every 3 years with the latest version having a base year of 1999. Emissions inventories for interim years are produced by growing the comprehensive inventories using economic and demographic databases.

Maps showing the pollutant density of the 1999 base year NEI (NEI99) are included in Appendix A. These maps are drawn using the color same scale as the Canadian Emissions Inventory maps also included in Appendix A. With respect to the receptor sites on the Columbia River Gorge, the major source areas for PM include the greater Portland area immediately to the west and the Seattle/Tacoma area to the north west. The Vancouver, British Columbia area may also be significant, however, emissions from this urban area a not likely to differ significantly from the Portland or Seattle metropolitan areas.

Tables of the major sources of criteria pollutants and precursors are presented in Appendix B. Data is assembled from the NEI99 for all counties in Oregon and Washington. Emissions of PM are designated by size and by sampling method used to produce the emissions factor. PM_{10} and $PM_{2.5}$ refer to particulate matter with sizes less than 10 um and 2.5 um respectively. PM Filterable and PM Primary refer to different operational methods used to estimate the emissions factor. By definition, PM Primary is the sum of the filterable material (PM-Filterable) emitted from a source and the condensable material (PM-Condensable) that forms when hot exhaust gases cool to ambient temperatures. Estimates of both Filterable and Primary PM are presented in the NEI99 because different techniques were used to estimate emissions from different sources.

The states of Oregon and Washington produced prescribed and wild fire emissions inventories independently of the NEI inventory for the base year 1999. The fire emissions are shown in the tables for PM, NO_x, and VOC in Appendix B. The state produced fire emissions were not resolved for filterable and condensable fractions. Comparison of the state produced fire emissions and the NEI indicate that the state emissions estimates of PM, NOx, and VOC are ¼ or less of the size of the NEI estimates. The source of this discrepancy warrants further attention because resolving forest fire from mobile source $PM_{2.5}$ contributions is an important objective for visual air quality management. This is particularly true in the CRG where organic and elemental carbon (major components of mobile and biomass burning sources) account for ~50% of the ambient $PM_{2.5}$.

Combining emissions of filterable and primary PM, the major sources of directly emitted $PM_{2.5}$ in the Oregon and Washington NEI inventory fall into two categories: (1) biomass burning (i.e. prescribed and wild forest fires, residential wood combustion, and agricultural burning); (2) fugitive dust (i.e. unpaved road dust, crop tilling, and paved road dust—note: windblown dust is not estimated in the NEI99). Particulate matter from diesel vehicles is a much smaller fraction (< 5%) of the $PM_{2.5}$ inventory. Biomass burning and fugitive dust source types have very distinct chemical signatures. Biomass emissions are largely composed of unburned carbonaceous material and are measured as organic carbon and elemental carbon on both source dominated and ambient samples. Fugitive dust emissions are largely composed of elemental species such as iron, aluminum, silicon, and calcium. Due to the markedly different compositions of these two source types, the CMB model can resolve attributions from these two sources with high confidence.

Ambient aerosol is composed of primary particles that are emitted directly from sources (i.e. soot and dust) as well as secondary particles that form from precursor species emitted as gases that react to form PM. Common secondary PM include sulfuric acid, ammonium sulfate, ammonium bisulfate, ammonium nitrate, and organic species. Precursors to these particles are represented in the emissions inventory as NO_x, VOC, SO_2, and NH_3. Major sources of NOx include diesel and gasoline vehicles. Major sources of VOC include gasoline vehicles and engines and biomass burning. Major sources of SO_2 include coal combustion and residual oil combustion. Major sources of NH_3 include livestock waste and fertilizer application.

3.2 Nearby and Very Large Point Sources

Large point sources such as coal fired power plants or paper mills may directly impact one or both of the receptor sites in the CRG. Figure 3-1 shows the location of the largest sources of SO_2 and $PM_{2.5}$ in the region. Major source in the CRG include the following source types.

3.2.1 Aluminum Manufacturers

At least 4 primary aluminum manufacturers were operating in the CRG in 1999: Reynolds Metals Longview, Vanalco, Northwest Aluminum, and Goldendale Aluminum.

The Reynolds Metals facility in Longview WA emited 509 tpy of $PM_{2.5}$ and 57 tpy of SO_2 in 1999. Reynolds Metals is currently inoperative. The Vanalco plant in Vancouver WA is a center worked prebake plant that has operated on purchased electricity. As of Nov 2002, the VANALCO was shut down, but has been purchased by a Swiss company and will reopen as soon as market conditions allow. In 1999, the Vanalco plant emitted 294 tpy of PM2.5 and 1937 tpy of SO_2.

The Goldendale smelter is a vertical stud Soderburg process. Electricity has been purchased from BPA when the plant is running. The Goldendale smelter emitted 377 tpy of $PM_{2.5}$ and 505 tpy of SO_2 in 1999. The Northwest Aluminum plant is being converted into a secondary aluminum plant. Emissions in 1999 were 319 tpy $PM_{2.5}$ and 537 tpy SO_2.

3.2.2 Coal Fired Power Plants

Based on the 1999 NEI, the Pacificorp Power Plant in Centralia, WA emitted 88 ktpy of SO_2 and 1096 tpy of $PM_{2.5}$ accounting for 48% of a SO_2 point source emission in EPA Region 10. Since 1999, the Centralia power plant has been equipped with low NO_x burners (limited to about 0.33 lb/mmBtu), 2 Eletrostatic Precipitators (ESPs) in series (to meet a 0.02 grain/dscf limit), and a wet limestone scrubber to meet a 10,000 ton per year limitation for the plant. The next largest SO_2 source in Region 10 is the Portland General Electric facility in Morrow County, OR ~200 km east of the CRG.

3.2.3 Forestry Products and Processing

Numerous Kraft pulp mills operate in and around the CRG. One of the worlds largest pulp and paper complexes exists in Longview Wa. Based on the emission inventory, these sources emit less PM2.5 and SO2 than the aluminum and coal fired power industry, but may contribute primary particles with a unique signature that can be identified by the CMB.

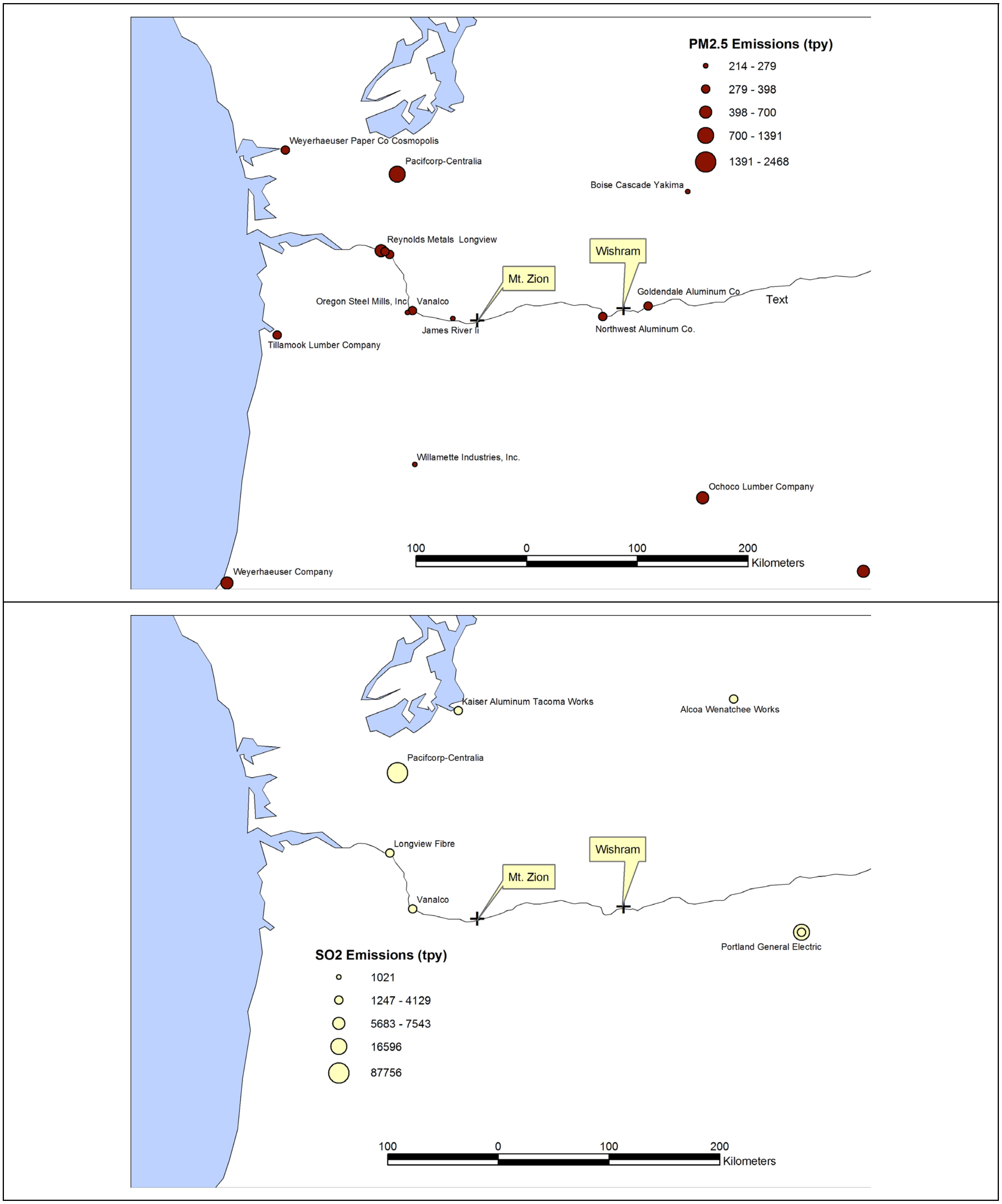

Figure 3-1. Map of major $PM_{2.5}$ (top panel) and SO_2 (lower panel) points sources near the Columbia River Gorge Scenic Area. Only sources emitting more than 200 TPY of $PM_{2.5}$ or 1000 TPY of VOC are drawn on the maps.

3.2.4 Other sources

Additional point sources in the area include the Portland International Airport (PDX) which emits carbonaceous particulate matter associated with aircraft operation, ground support equiment, and backup power supplies. To the south east of PDX there is a glass recycling facility that has visible oil fired boiler emissions. In White Salmon, WA (across the Columbia River from Hood River, OR) a hog fuel (dried tree bark) boiler emits ~100 tpy of $PM_{2.5}$. Particulate controls have been installed between 1999 and 2002 reducing emissions from their levels in 1996 – 1998.

The fuel burned in the processes associated with these smaller point sources is chemically identical to the major sources of gasoline, diesel, and vegetative material combustion. Thus, emissions from these processes are likely to be collinear (i.e. chemically indistinguishable) with emission from mobile sources and vegetative burning. This limitation of the CMB should be considered when interpreting the source attribution results.

3.3 Selection of Source Profile Types

Based on the major sources of primary and precursor emissions, the following source types have been identified for use in the CMB modeling:

- Biomass burning smoke
- Soil dust
- Motor vehicle exhaust
- Coal combustion

Other sources that may contribute to particles observed in the Columbia River Gorge include:

- Sea salt aerosol (both fresh NaCl and aged $NaNO_3$)
- Paper mills
- Aluminium smelters

Additional source profile for the following secondary species will also be used in the CMB modeling

- Ammonium sulfate
- Ammonium nitrate

4. SOURCE PROFILES

4.1 Chemical Composition of Primary Emissions

Table 4-1 summarizes the chemicals often found in different source emissions according to their chemical abundances. Given the source types identified by the emissions inventory, it is to be expected that aluminum from smelting operation in the CRG will be elevated over their abundances in crustal material. Uninventoried metal processing industries, such as galvanizing and plating, sometimes contribute trace amounts of zinc, copper, lead, and possibly some rare metals such as molybdenum, zirconium, and cadmium. Substantial amounts of aluminum, silicon, calcium, and titanium are expected from suspended dust, and organic and elemental carbon are anticipated from vehicle exhaust, residential wood burning, prescribed burning, wildfires, and cooking.

Specific source profiles used for CMB source apportionment and the studies in which they were measured are described in the following subsections. These are a subset of the profiles included in DRI's master source profile data base. These profiles were selected for the following reasons:

- **Compatibility with ambient measurements:** These profiles report fractional abundances for the same elemental, ion, and carbon variables that are in the ambient data base. In particular, the organic and elemental carbon measurements are derived from the same Thermal/Optical Reflectance method (Chow et al., 1993).
- **Similarity to the study area and monitoring period:** Mobile source exhaust profiles are from recent years and use similar fuels and have vehicle mixes similar to those of Seattle. The geological profiles are specific to Pacific Northwest Region.
- **Representative of source types in the inventory:** Suspended dust, vegetative burning, and mobile source exhaust are common to all urban areas. Marine aerosol is expected owing to the proximity of the monitoring sites to the Pacific Ocean. Coal-fired power stations, paper manufacturing, and aluminum manufacturing have been identified as potentially important contributors by the emissions inventory. These profiles represent specific source-types, and not specific emitters. It is not possible to make a one-to-one association between the specific facilities listed in Section 3.2 and these profiles.

Table 4-1. Chemicals from Particles in Different Emissions Sources

Source Type	Dominant Particle Size	Chemical Abundances in Percent Mass $\leq 0.1\%$	 0.1 to 1%	 1 to 10%	 $\geq 10\%$
Paved Road Dust	Coarse	Cr, Sr, Pb, Zr	$SO_4^=$, Na^+, K^+, P, S, Cl, Mn, Zn, Ba, Ti	Elemental Carbon (EC), Al, K, Ca, Fe	Organic Carbon (OC), Si
Unpaved Road Dust	Coarse	NO_3^-. NH_4^+, P, Zn, Sr, Ba	$SO_4^=$, Na^+, K^+, P, S, Cl, Mn, Ba, Ti	OC, Al, K, Ca, Fe	Si
Construction	Coarse	Cr, Mn, Zn, Sr, Ba	$SO_4^=$, K^+, S, Ti,	OC, Al, K, Ca, Fe	Si
Agricultural Soil	Coarse	NO_3^-. NH_4^+, Cr, Zn, Sr	$SO_4^=$, Na^+, K^+, S, Cl, Mn, Ba, Ti	OC, Al, K, Ca, Fe	Si
Natural Soil	Coarse	Cr, Mn, Sr, Zn, Ba	Cl^-, Na^+, EC, P, S, Cl, Ti	OC, Al, Mg, K, Ca, Fe	Si
Lake Bed	Coarse	Mn, Sr, Ba	K^+, Ti	$SO_4^=$, Na^+, OC, Al, S, Cl, K, Ca, Fe	Si
Mobile source	Fine	Cr, Ni, Y	NH_4^+, Si, Cl, Al, Si, P, Ca, Mn, Fe, Zn, Br, Pb	Cl^-, NO_3^-. $SO_4^=$, NH_4^+, S	OC, EC
Vegetative Burning	Fine	Ca, Mn, Fe, Zn, Br, Rb, Pb	NO^- ,$SO_4^=$, NH_4^+, Na^+, S	Cl^-, K^+, Cl, K	OC, EC
Residual Oil Combustion	Fine	K^+, OC, Cl, Ti, Cr, Co, Ga, Se	NH_4^+, Na^+, Zn, Fe, Si	V, OC, EC, Ni	S, $SO_4^=$
Incinerator	Fine	V, Mn, Cu, Ag, Sn	K^+, Al, Ti, Zn, Hg	NO_3^-. Na^+, EC, Si, S, Ca, Fe, Br, La, Pb	$SO_4^=$, NH_4^+, OC, Cl
Coal-Fired Boiler	Fine	Cl, Cr, Mn, Ga, As, Se, Br, Rb, Zr	NH_4^+, P, K, Ti, V, Ni, Zn, Sr, Ba, Pb	$SO_4^=$, OC, EC, Al, S, Ca, Fe	Si
Oil-Fired Power Plant	Fine	V, Ni, Se, As, Br, Ba	Al, Si, P, K, Zn	NH_4^+, OC, EC, Na, Ca, Pb	S, $SO_4^=$
Steel Blast Furnace	Fine	V, Se	K, Cu, Ni, Ti, Pb	$SO_4^=$, Na, Si, Cl, S, Ca, Cr, Zn	Fe, Mn
Smelter Fire	Fine	V, Mn, Sb, Cr, Ti	Cd, Zn, Mg, Na, Ca, K, Se	Fe, Cu, As, Pb	S
Antimony Roaster	Fine	V, Cl, Ni, Mn	$SO_4^=$, Sb, Pb	S	None reported
Paper Mill	Fine	Mn, Cu, Zn, Pb	EC, Mg, Al, Si, Ni, Cr, Br	OC, Cl, K, Fe	S, $SO_4^=$, Na
Ferro Manganese	Fine	Ti, Cr, Cu, Pb	Al, Si, Cl, Zn, Br	NO_3^-, $SO_4^=$, OC, EC, Na, Ca, Fe	K, Mn
Aluminum Reduction Potline	Fine	As, Br, Cu, Pb, Rh	Ca, Cl, Fe, K, Si,	EC, S	Al, OC, SO_4^{2-}
Marine	Fine and Coarse	Ti, V, Ni, Sr, Zr, Pd, Ag, Sn, Sb, Pb	Al, Si, K, Ca, Fe, Cu, Zn, Ba, La	NO_3^-. $SO_4^=$, S, OC, EC	Cl^-, Na^+, Na, Cl

The following subsections describe the origins of the source profiles used in the CMB modeling in this study.

4.2 BRAVO Source Profiles

The Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study investigated the sources of haze at Big Bend National Park in southwest Texas. As part of the study, source profiles were collected from mobile sources, coal fired power plants, soil dust, vegetative burning, oil refineries and other sources throughout Texas.

4.2.1 Mobile Source

The ground-based source-dominated method obtained mobile source exhaust samples at seven locations in San Antonio and Laredo, Texas (Figure 1). A portable, ground-based sampling system was located on a median, sidewalk or shoulder within 2 m of the nearest high density traffic lane, with the sampling inlet placed at 1.5 m above ground level. The sampler consisted of a Bendix/ Sensidyne 240 cyclone followed by parallel 47-mm Teflon-membrane and quartz-fiber filter channels. The flow rate through each channel was 70 L/min, resulting in a d_{50} cut point of 2.25 µm. Thirty-four samples of approximately two-hour sampling durations were obtained between 09/24/99 and 12/11/99 during morning (0630-0830 CST), noon (1000-1400 CST), late afternoon (1600-1800 CST), and evening (1800-2400 CST) rush hours. Most vehicles passing the sampling trane (~90%) were light-duty, gasoline-powered vehicles, although the cross-border diesel truck volume was larger in Laredo than in other parts of Texas.

Though dominated by mobile source emissions, roadside mobile source samples also contain suspended road dust and particles from other "background" sources. The Chemical Mass Balance (CMB) model (Watson et al., 1990) was used to adjust the mobile source samples for background source contributions using the technique described by Watson et al. (1994). Each roadside source sample was submitted to CMB with the following sources: paved road dust, secondary ammonium sulfate and ammonium nitrate, and vegetative (grass) burning. Only chemical species assumed to come from the background but not the mobile source sources (i.e., Al, Si, K, Ca, Ti, Rb, and Sr from paved road dust, NH_4^+, SO_4^{2+}, and NO_3^- from secondary ammonium sulfate and ammonium nitrate, and water-soluble K^+ from vegetative burning) were used as CMB fitting species. The contributions of the background sources to mass and all chemical species were subtracted from the mobile source profile concentrations and the differences were used to calculate the adjusted mobile source source profiles with appropriate error propagation. All adjusted mobile source profiles were composited to produce a profile representing a mix of mobile sources emissions with ~93% light duty gasoline vehicles and ~7% heavy duty diesel vehicles.

4.2.2 Vegetative Burning

Vegetative burning profiles were obtained by ground-based source-dominated sampling in the plumes of small controlled burns of wood debris at Big Bend National Park. Most of the vegetative cuttings were collected as part of a habitat restoration project that removed non-native trees and shrubs from a high-elevation section of the park that had been used for grazing cattle. These areas were often subject to wildfires. Fuels included three abundant species from the area (mesquite, tamarisk, and huisache), and native dry grass. The wood was dried for several months prior to burning. Approximately 5 to 10 kg of fuel was lit using a torch and allowed to burn for 10 minutes prior to sampling. The sampling system inlet was inserted into the plume ~5 m downwind of the fires where the temperature was slightly above ambient. The profiles were composited to create a single profile (BURN3-7) representative of a variety of biomass burning emissions. Some error may be introduced into the source attribution because the plant species burned as part of the BRAVO study may not be representative of the fauna in the Pacific Northwest. The advantage of using The BRAVO source profiles were used for the CMB in this study because they are some of only a few vegetative burning profiles that include the thermal carbon fractions from the TOR analysis. This additional resolution is needed to better separate mobile source emissions from biomass burning.

4.2.3 Coal Fired Power Plant

Dilution stack sampling (Hildemann et al., 1989) (Hildemann et al., 1989) was applied to four coal-fired power plant boilers, a petroleum refinery catalytic cracker, and two cement kilns burning coal, coke, scrap tires, woodchips, and used oil filters. Emissions were withdrawn from the stack or duct through an isokinetic button hook nozzle, then through a heated copper line to a 12.5 cm diameter × 2.7 m length u-tube where the exhaust was mixed with clean dilution air at ambient temperature under turbulent flow conditions. Dilution ratios ranged from 9 to 60, with a typical ratio of 30 parts of clean air to each part of exhaust. The diluted air was aged for ~80 seconds to allow for condensation, coagulation, and rapid reactions to occur prior to being drawn through three Bendix/Sensidyne cyclones (2.5 μm cutpoint at 113 L/min) to a multi-port sampling manifold that accommodated different collection substrates.

Twenty-six coal-fired boiler samples were acquired from three electrical generating stations that supplied power for domestic use and from one station that supplied power to an aluminum processing facility. Exhaust emission controls included a baghouse at one plant, a baghouse backed up by a wet limestone scrubber at another plant, an electrostatic precipitator followed by a baghouse at a third plant, and a dry limestone scrubber to remove acidity and fluorine from added potliner material at the aluminum facility. Bottom fly ash samples were acquired from three of the power plants. The source profiles from these sources were composited (BVCFPP) to represent coal fired power plants with a variety of control technologies.

4.2.4 Coal Fly Ash

Geological source locations representing various soil types and land uses were chosen from U.S. Department of Agriculture Soil Conservation Service maps. Site surveys around BRAVO sampling sites and in major Texas cities identified additional sampling locations. Samples included paved road dust from busy traffic intersections, unpaved roads, and soil. Three fly ash samples from the electrostatic precipitator residue of a coal-fired power station were collected by grab sampling. Samples were air-dried in the laboratory under a low-relative-humidity (approximately 20% to 30%) atmosphere, sieved through a Tyler 400-mesh screen (< 38 μm geometric diameter), resuspended in a laboratory chamber, and collected on filters through $PM_{2.5}$ and PM_{10} impactor inlets at a flow rate of 10 L/min.24 (Chow et al., 1994). The composited source profiles (BVCLFA) may represent emissions from coal fired power plants without particulate controls.

4.3 Puget Sound Source Profiles

4.3.1 Soil Profiles

Few geologic source profiles exist for soils in the Pacific Northwest. Main et al. (1994) collected and analyzed soil samples from Kent, Seattle, and Tacoma, WA as for a PM_{10} source attribution study. The source profiles from these samples were composited to obtain a profile

(KTSSOIL) representative of a range of soils in the area. Only total organic and total elemental carbon were reported for these soil samples. In order to utilize, the 8 fraction carbon measurements available with the mobile source and vegetative burning profiles, the distribution of thermal fractions of organic and elemental carbon (OC1 – OC4, OCP, and EC1 – EC3 from the TOR analysis) was inferred from a composite of soil samples collected as part of the BRAVO study in organically rich soils in east Texas.

4.4 Secondary Aerosol Source Profiles

Because species such as sulfate and nitrate and can be formed through gas-to-particle transformation in the atmosphere, they cannot be entirely accounted for by primary emissions profiles. Secondary source profiles are also included in Appendix D which consist of "pure" ammonium nitrate (AMNIT) and ammonium sulfate (AMSUL). Given that particle nitrate is measured in most samples, there is likely to be sufficient ammonia for this neutralization (Watson et al., 1994b).

4.5 Marine Source Profiles

The bulk seawater compositions of Pytkowicz and Kester (1971) represents a pure marine aerosol (MAR100). However, marine aerosol has been observed to react rapidly with available nitric acid (Pilinis and Seinfeld, 1987). The nitric acid liberates chloride from the predominantly sodium chloride aerosol forming as sodium nitrate salt and emitting hydrogen chloride gas. As the marine aerosol ages a larger fraction of the chloride is liberated until the remaining aerosol is composed of sodium nitrate along with other minor sea salt species. An aged marine aerosol (MAR0) represents seasalt with a complete substitution of the chloride with nitrate. Both the fresh and the aged marine profiles are used in the CMB modeling to empirically determine the extent to which the fresh marine aerosol has converted to sodium nitrate.

4.6 Other Profiles

This Aluminum Reduction Potline (ARPL) profile corresponds to Aluminum reduction potline and was obtained from EPA's source profile library #29102. The South Africa Paper and Pulp Industries (SAPPILK1) profile was assembled from stack samples collected from the rotary lime kiln at the Kraft paper mill Ngodwana, South Africa. The sample was collected in June of 1993 and the particulate emissions are composed primarily of calcium and sulfate (Englebrecht et al., 1994). Since secondary sulfate is represented with its own profile, and calcium is a major component of crustal material, the CMB apportionment to the paper mill source will depend largely on the accuracy of the geologic profile (KTSSOIL) to represent the geologic emissions in at the receptor site. Since on most days there is an abundance of sulfate aerosol, any excess calcium not explained by the geologic profile will be associated with the paper mill source. The eight fraction carbon profiles were not available for these two sources. Abundances for these fractions were created by equally distributing OC across the 4 fractions OC1 to OC4 and EC across the three fractions EC1 to EC3.

4.7 Source Profile Summary

This a priori examination of source profiles for the study cannot determine which profiles will be distinguishable by CMB modeling. Current modeling software contains diagnostic tests to allow the degree of "collinearity" (or similarity among profiles) to be evaluated for each combination of source and receptor data. Geological profiles are too similar to permit distinction of geological sub-types in a single CMB analysis. However, different geological profiles may better account for ambient concentrations in different ambient samples. It is unlikely that CMB receptor modeling by itself, and without measurement of additional unique species, will distinguish different geological source profiles from each other. The same is true for mobile source exhaust from gasoline- and diesel-fueled vehicles. A composite mobile source exhaust profile from a recent study is used. Sulfate and nitrate are present in the primary emissions from many of these sources, though the majority of the sulfate and nitrate measured in ambient samples in the study area will be of secondary origin.

Contributions from miscellaneous sources including residential wood combustion, coal- and oil-fired boilers, steel production, and other industrial processes may be present, although primary contributions from such sources are expected to be small based on overall emissions levels.

4.8 Distinguishing Carbonaceous Emissions Sources

Resolving source contributions from major carbonaceous aerosol sources is desirable for developing control strategies that will reduce concentrations of one of the major components of haze in the Columbia River Gorge. Sources of these carbonaceous aerosol are listed in Appendix B and include highway vehicle emissions, ships, trains, airplanes, residential wood combustion, wild and prescribed fires, and fuel oil boilers.

In addition, some potential contributors to ambient particulate concentrations are commonly omitted from area-source inventories. Hildemann et al. (1991) and Rogge et al. (1993) have identified charbroiling and frying of meat in both restaurants and homes as a potential source of organic particulate matter that has been neglected in previous PM_{10} inventories. Their studies show that almost all of these emissions are in the $PM_{2.5}$ size fraction. Emissions rates measured for regular and extra-lean hamburger meat which was charbroiled or fried on a restaurant-style grill (with commonly used grease traps) showed emissions rates of 40 g/kg charbroiled regular meat, 7.1 g/kg charbroiled extra-lean meat, 1.1 g/kg fried regular meat, and 1.4 g/kg fried extra-lean meat. As a conservative estimate, if there are 5,000,000 meat-eaters in the Oregon/Washington area who each cook 20 kg of meat per year, with 5 g of particles emitted for each kg of meat cooked, then ~500 metric tons of fine particle emissions would enter the region's atmosphere each year. This is a relatively small source compared to prescribed fires for example which accounts for more than 90,000 tpy of $PM_{2.5}$ emissions in the two states during 1999.

The eight carbon fractions resolved with the Thermal Optical Reflectance analytical technique may permit a more source specific attribution when used with the CMB. These additional fractions were found to identify independently varying factors in the ambient aerosol at the Beacon Hill IMPROVE site in Seattle (Maycut, 2001; Larson, 2002). The Positive Matrix Factorization (PMF) program was used to identify the factors that were then compared with OC/EC ratios in existing source profiles to assign the appropriate source to each factor.

Only a limited number of source profiles exist with measured abundances of the 8 TOR carbon fractions. The BRAVO source profiles (Chow et al., 2002) were collected and analyzed using consistent procedures to permit the inter-comparison of the relative abundances of these components in mobile sources, vegetative burning, and meat cooking.

Figure 4-1 shows the relative abundance of the 8 carbon fractions in the vegetative burning source profiles. The OC1 component ranges in abundance from 12% in Mesquite 1 to over 40% in Tamerisk 1. Despite this broad range in abundances, all vegetative burning profiles (with the exception of the creosote treated fenceposts) show a lack of abundance in EC2 and EC3 (i.e. < 1%). In contrast, the roadside vehicle exhaust profiles (Figure 4-2) on average are composed of ~20% EC2 and ~2% EC3. If these differences are consistent with the source emissions in the CRG, using the additional 8 carbon fractions as species in the CMB source attiribution should more accurately resolve the mobile source emissions from the vegetative burning emissions.

Figure 4-3 shows the relative carbon fraction abundances of the cooking source profiles. With the exception of smoked chicken (that may be a combination of meat cooking and vegetative burning), these profiles contain less than 15% EC and are composed predominantly (~62%) of a combination of OC2 and OC3.

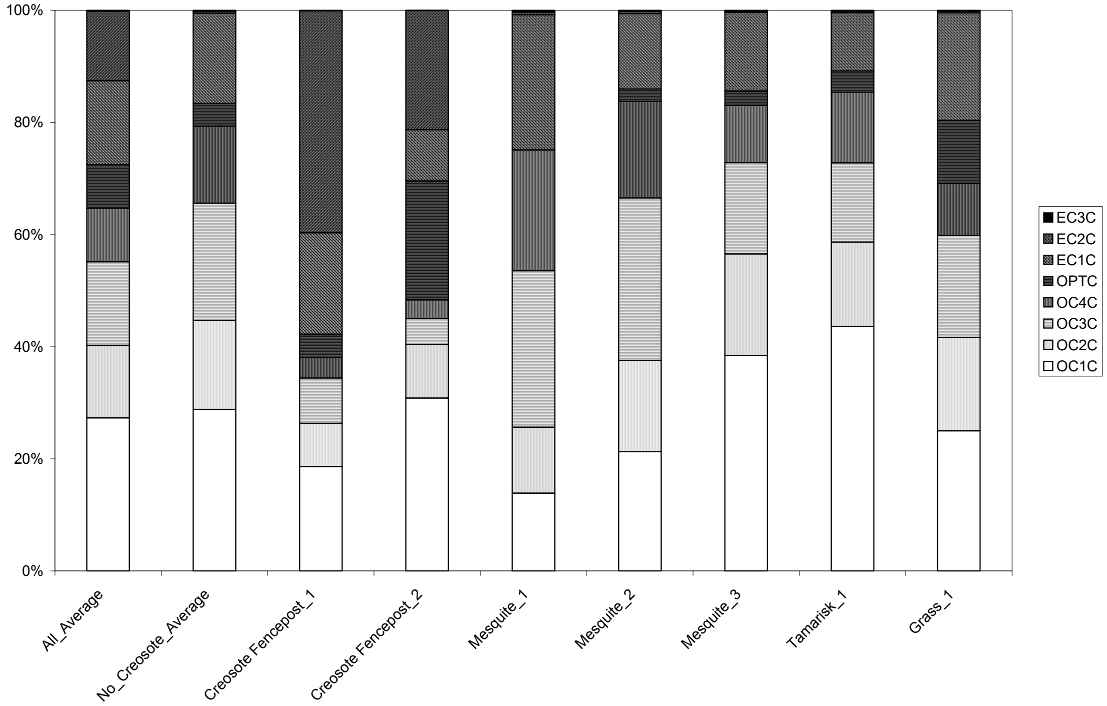

Figure 4-1. Relative distribution of 8 carbon fractions from TOR analysis for biomass/open burning source profiles. Note the creosote treated fenceposts have elevated levels of EC2. These two profiles are not representative of typical prescribed and wild fires.

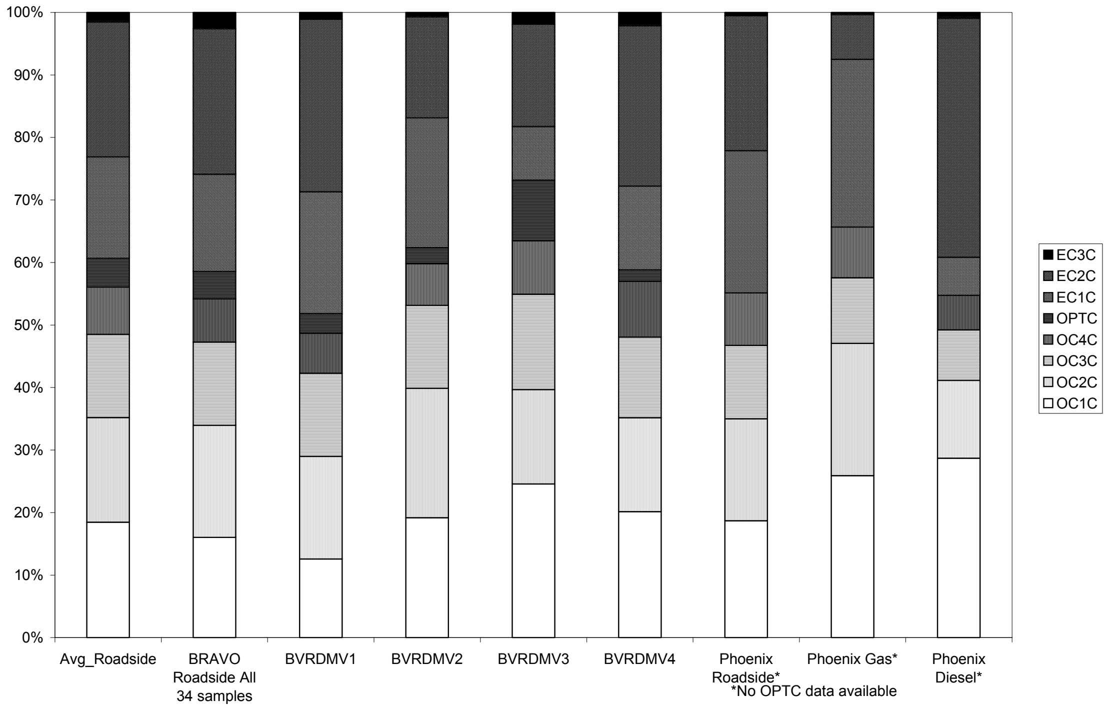

Figure 4-2. Relative distribution of 8 carbon fractions from TOR analysis for mobile source profiles. The seven profiles on the left side of the figure represent a combination of gasoline and diesel emissions. All profiles have substantial quantities of EC2. The Phoenix Gasoline profile has substantially more OC1 than OC2 while the Phoenix Diesel profile has more OC2 than OC1.

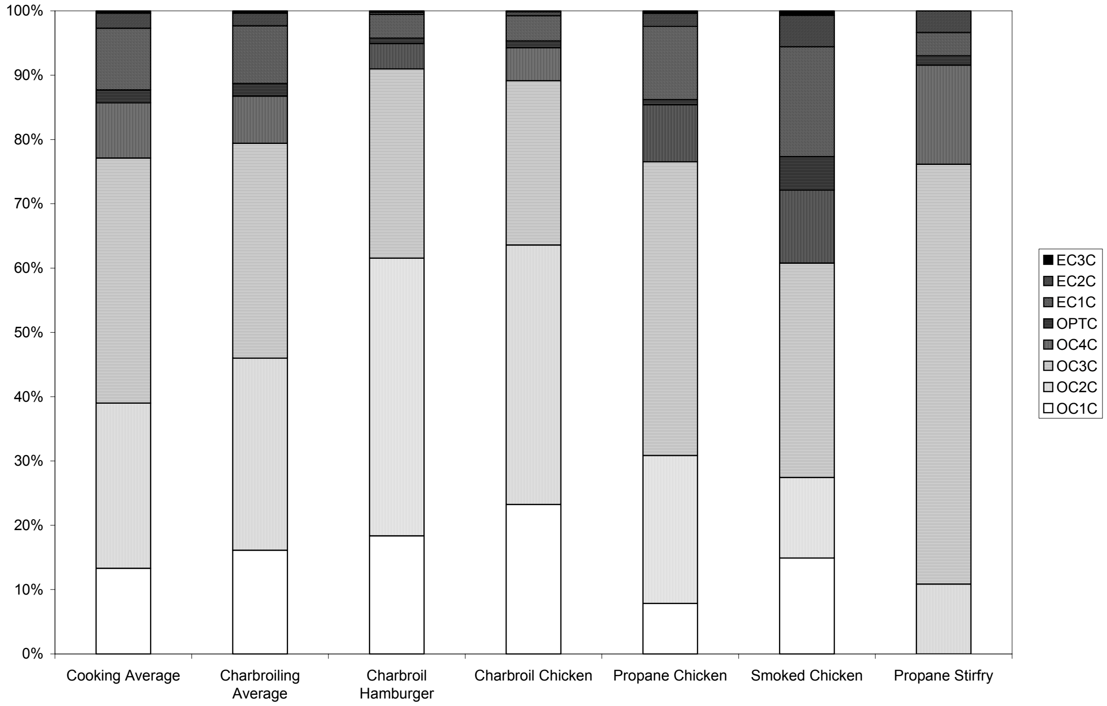

Figure 4-3. Relative distribution of 8 carbon fractions from TOR analysis for food cooking profiles. All profiles have substantially more OC than EC. Emissions are largely composed of OC2 and OC3.

5. SOURCE/RECEPTOR MODELING

5.1 Chemical Mass Balance Receptor Modeling

The CMB receptor model was applied to chemical concentrations measured at the two sites in the CRG to estimate source contributions from potential PM sources that may impair visibility in this scenic area.

The CMB model expresses each receptor concentration of a chemical species as a linear sum of products of source profile abundances and source contributions. The model calculates values for contributions from each source and the uncertainties of those values. The source profile abundances (the fractional amount of the species in the emissions from each source type) and the receptor concentrations, each with realistic uncertainty estimates, serve as input data to the CMB model. The output consists of the contribution from each source type to the total ambient aerosol mass as well as to individual chemical species concentrations. Input data uncertainties are used both to weight the relative importance of the input data to the model solution and to estimate uncertainties of the source contributions.

Current CMB software (Watson et al., 1997b, 1998a) applies the effective variance solution developed and tested by Watson et al. (1984) because: 1) it calculates realistic uncertainties of source contributions from both the source and receptor uncertainties; and 2) chemical species measured more precisely in both source and receptor samples are given greater influence in the solution than are less precisely-measured species.

Watson (1979) observed that individual sources with similar source profiles, such as different soils and road dusts, would yield unreliable source contribution estimates if used in the same CMB. Henry (1982; 1992) proposed a quantitative method of identifying this interference among similar source compositions, which is known as “collinearity.” Henry’s “singular value decomposition” defines an “estimable space in which resolvable sources should lie” (Henry, 1982; 1992). The source types that do not fall into this estimable space are collinear, or too similar to be resolved from a combination of one or more of the source types that lie within the estimable space. Henry (1982; 1992) further proposed that linear combinations of collinear source profiles would better estimate the summed contributions from these sources. Analytical measures of collinearity are available in the U.S. EPA/DRI Version 8.0 of the CMB model.

The CMB modeling procedure requires: 1) identification of the contributing source types; 2) selection of chemical species to be included; 3) estimation of the fractions of each chemical species contained in each source type (i.e., the source profiles); 4) estimation of the uncertainties in both ambient concentrations and source compositions; and 5) solution of the CMB equations.

These procedures are described in a CMB applications and validation protocol (Watson et al., 1991, 1998a). The protocol provides a regimen that makes the results from CRG CMB study source apportionment comparable to apportionments in other studies.

The CMB applications and validation protocol consists of seven steps: 1) determination of model applicability; 2) estimation of initial source contribution; 3) examination of model outputs and performance measures; 4) identification of deviations from model assumptions; 5) identification and correction of model input errors; 6) verification of the consistency and stability of source contribution estimates; and 7) evaluation of the results of the CMB analysis with respect to other source assessment methods. The activities carried out for each of these steps are described in this section.

5.1.1 CMB Model Applicability

The requirements for CMB model applicability are as follows: 1) a sufficient number of receptor samples are taken with an accepted method to evaluate visibility levels; 2) samples are analyzed for chemical species that are also present in source emissions; 3) potential source contributors have been identified and chemically characterized; and 4) the number of non-collinear source types is less than the number of measured species. All of these criteria have been attained for the CRG CMB study. $PM_{2.5}$ samples were taken with well-characterized IMPROVE samplers. Samples collected 2 times per week were analyzed for mass, carbon, ion, and elemental concentrations. As described in Chapter 4, profiles to represent primary particle emissions from major potential sources in the study area were compiled from other studies.

Chemical abundances in DRI's source profile database and species concentrations from the IMPROVE ambient records were paired as indictated in Table 5-1. Each database contains some fields that are not found in the other. The unmatched species can not be used in the CMB analysis. It should also be noted that the methods used to analyze certain species are not consistant across the databases. For example, sodium in the DRI source profile database is analyzed by XRF and is prone to larger relative analytical uncertainties than the IMPROVE sodium that is analyzed by PIXE. These discrepancies may introduce some additional uncertainties associated with source attributions since each method has a unique precision, accuracy, and detection limit.

Table 5-1. Species map between DRI's source profile library and IMPROVE ambient species.

Method	Species	Source Library Code		IMPROVE Code	IMPROVE Species	Method
XRF	Silver	AGXC				
XRF	Aluminum	ALXC	↔	ALf	Aluminum: Fine	PIXE
XRF	Arsenic	ASXC	↔	ASf	Arsenic: Fine	XRF
XRF	Gold	AUXC				
XRF	Barium	BAXC				
XRF	Bromine	BRXC	↔	BRf	Bromine: Fine	XRF
XRF	Calcium	CAXC	↔	CAf	Calcium: Fine	PIXE
XRF	Cadmium	CDXC				
IC	Chloride	CLIC	↔	CHLf	Chloride: Fine	IC
XRF	Chlorine	CLXC	↔	CLf	Chlorine: Fine	PIXE
Unspecified	Cabonate	CO3C				
XRF	Cobalt	COXC				
XRF	Chromium	CRXC	↔	CRf	Chromium: Fine	PIXE
XRF	Copper	CUXC	↔	CUf	Copper: Fine	XRF
TOR	Elemental Carbon	ECTC	↔	ECf	Carbon: Fine total elemental	TOR
TOR	Elemental Carbon 1	EC1C	↔	EC1f	Carbon: Fine elemental (EC1)	TOR
TOR	Elemental Carbon 2	EC2C	↔	EC2f	Carbon: Fine elemental (EC2)	TOR
TOR	Elemental Carbon 3	EC3C	↔	EC3f	Carbon: Fine elemental (EC3)	TOR
XRF	Iron	FEXC	↔	FEf	Iron: Fine	XRF
				Hf	Hydrogen: Fine	PESA
XRF	Gallium	GAXC				
Unspecified	Hydrogen Sulfide	H2SC				
XRF	Mercury	HGXC				
XRF	Indium	INXC				
AA	Potassium	KPAC				
XRF	Potassium	KPXC	↔	Kf	Potassium: Fine	PIXE
XRF	Lanthanum	LAXC				
				MF	PM2.5: mass	Gravimetry
				MT	PM10: mass	Gravimetry
XRF	Magnesium	MGXC	↔	MGf	Magnesium: Fine	PIXE
XRF	Manganese	MNXC	↔	MNf	Manganese: Fine	PIXE
XRF	Molybdenum	MOXC	↔	MOf	Molybdenum: Fine	PIXE
				N2f	Nitrite: Fine	IC
AA	Sodium	NAAC				
XRF	Sodium	NAXC	↔	NAf	Sodium: Fine	PIXE
AC	Ammonia	NH3C				
AC	Ammonium	N4CC	↔	NH4f	Ammonium ion: Fine	AC
XRF	Nickel	NIXC	↔	NIf	Nickel: Fine	XRF
IC	Nitrate	N3IC	↔	NO3f	Nitrate: Fine	IC
TOR	Organic Carbon	OCTC	↔	OCf	Carbon: Fine total organic	TOR
TOR	Organic Carbon 1	OC1C	↔	OC1f	Carbon: Fine organic (OC1)	TOR
TOR	Organic Carbon 2	OC2C	↔	OC2f	Carbon: Fine organic (OC2)	TOR
TOR	Organic Carbon 3	OC3C	↔	OC3f	Carbon: Fine organic (OC3)	TOR
TOR	Organic Carbon 4	OC4C	↔	OC4f	Carbon: Fine organic (OC4)	TOR
TOR	Organic Carbon Pyrolysis Fraction	OPTC	↔	OPf	Carbon: Fine organic (OP)	TOR
XRF	Phosphorus	PHXC	↔	Pf	Phosphorus: Fine	PIXE
IC	Phosphate	P4IC				
XRF	Lead	PBXC	↔	PBf	Lead: Fine	XRF
XRF	Palladium	PDXC				
XRF	Rubidium	RBXC	↔	RBf	Rubidium: Fine	XRF
XRF	Sulfur	SUXC	↔	Sf	Sulfur: Fine	PIXE
XRF	Antimony	SBXC				
XRF	Selenium	SEXC	↔	SEf	Selenium: Fine	XRF
XRF	Silicon	SIXC	↔	SIf	Silicon: Fine	PIXE
XRF	Tin	SNXC				
Unspecified	Sulfur Dioxide	SO2C				
IC	Sulfate	S4IC	↔	SO4f	Sulfate: Fine	IC
XRF	Strontium	SRXC	↔	SRf	Strontium: Fine	XRF
XRF	Titanium	TIXC	↔	TIf	Titanium: Fine	PIXE
XRF	Uranium	URXC				
XRF	Vanadium	VAXC	↔	Vf	Vanadium: Fine	PIXE
XRF	Yttrium	YTXC				
XRF	Zinc	ZNXC	↔	ZNf	Zinc: Fine	XRF
XRF	Zrconium	ZRXC	↔	ZRf	Zirconium: Fine	XRF

The number of non-collinear source profiles used for apportionment is less than the number of measured species. Examination of the chemical profiles shows significant differences among profiles for major source types such as primary geological material, primary mobile source exhaust, primary vegetative burning, marine, and secondary ammonium sulfate and ammonium nitrate.

Several industrial source profiles, specifically coal-fired boilers, aluminum smelter, and pulp and paper industries that were identified by emissions inventories as SO_2 and $PM_{2.5}$ emitters, are also included.

5.1.2 Initial Source Contributions

An initial material balance on the average concentrations of major chemical components for all sites provides an initial understanding of the source types needed in the CMB. On average between 9/1/1996 and 8/31/1998, $PM_{2.5}$ in the Columbia River Gorge consisted of 10% geological material, 43% carbonaceous aerosol (i.e., the sum of organic material (1.4*OCT) and elemental carbon), 29% ammonium sulfate, and 10% ammonium nitrate (Green et al., 2001). The major challenges for CMB source apportionment at CRG monitors are: 1) to resolve carbon sources, the major ones being mobile source exhaust and vegetative burning or cooking; and 2) to account for industrial contributions via their trace element abundances.

5.1.3 CMB Model Outputs and Performance Measures

The CMB does not determine which sources are contributors and which ones are not. These are selected by the modeler based on a survey of potential contributors (Chapters 3 and 4). The CMB does provide substantial information on which combinations of profiles are likely to provide contributions by means of statistical performance measures (Watson et al., 1991). The most important of these measures, that are evaluated for every sample, are: 1) the source contributions estimates (SCEs) and their uncertainties; 2) “CHI-SQUARE,” the weighted sum of the squares of the differences between calculated and measured species concentrations (values between one and two indicate acceptable fits while values less than one indicate good fits to the data); 3) “R-SQUARE,” the fraction of the variance in the measured concentrations accounted for by the variance in the calculated species concentrations (values of “R-SQUARE” greater than 0.9 indicate a good fit to the measured data); and 4) ”PERCENT MASS,” or the percent of total mass accounted for by the source contribution estimates (values between 80% and 120% are considered to be good).

The CMB output also contains the ratios of calculated to measured concentration (C/M) and the ratio of the difference between calculated and measured concentration divided by the uncertainty of this difference (R/U) for each chemical species. These indices allow the user to examine fits of individual species. For example, aluminum (Al), silicon (Si), and calcium (Ca) are important markers that distinguish geological contributions from those of other sources. Organic and elemental carbon are in nearly all particles formed by incomplete combustion, and water-soluble potassium (K^+) is useful as a marker that separates vegetative burning from mobile source exhaust contributions.

Sometimes, the "C/M ratio" differs from unity, but the "R/U ratio" is small (between –2 and +2 is acceptable). This occurs when ambient or source profile uncertainties are a large fraction of the chemical abundance. Under these conditions, a poor agreement between calculated and measured concentrations for a particular species does not significantly affect the source contribution estimates because the large uncertainty gives that species a low influence in the source apportionment calculation.

Collinearity or similarity between source profiles is identified by the "Eligible Space Dimension and Maximum Uncertainty" clusters. These replace the U/S CLUSTERS and SUM OF CLUSTER SOURCES in CMB7. This treatment (Henry, 1992) uses two parameters, maximum source uncertainty and minimum source projection on the eligible space. These are set to default values of 1.0 and 0.95, respectively, in CMB8. The maximum source uncertainty determines the eligible space to be spanned by the eigenvectors whose inverse singular values are less than or equal to the maximum source uncertainty. The "Number of Estimable Sources" are the source contributions that are estimable given their source contributions and propagated uncertainties. This changes with the acceptable uncertainty specified in the model options menu.

Collinearity may result, in part, from small source contribution estimates with relatively large uncertainties. The appearance of profiles in the eligible space clusters does not invalidate the source contribution estimates. These clusters offer guidance that the relative uncertainties of the source contribution estimates might be reduced by eliminating one or more of the profiles or by linearly combining the profiles into a new profile that represents the combined contribution from both source types.

Initial tests with different combinations of source profiles were performed on Mt. Zion chemical measurements to determine which profiles best explain the measured concentrations. The CMB performance measures were examined to determine how well the ambient concentrations were explained by the source contribution estimates. The sensitivity of these estimates to changes in the mix of profiles was also studied. These analyses found that the CMB8 model would fail to converge on a set SCE's for many cases with high sodium. These instances tended to occur in summer and fall months when winds typically blow from the coast. Colinearities in the source attribution were occurring between ammonium nitrate (AMNIT), fresh marine (MAR100), and aged marine (MAR0) source profiles. This collection of sources is largely dependent on three measured species: sodium, nitrate, and chloride. That is, there are 3 species – 3 profiles = 0 degrees of freedom for this source combination. Large uncertainties in the resolution of sodium and chloride in either the source or ambient samples, can lead to conditions where the sources will not fit the data via a positive combination of profiles. When the model failed to converge, either the MAR100 or the MAR0 source was removed from the list of potential source profiles based on the selection that resulted in the best fit.

5.1.4 Compliance with Model Assumptions

The CMB model assumptions are: 1) compositions of source emissions are constant over the period of ambient and source sampling; 2) chemical species do not react with one another (i.e., they add linearly); 3) all sources that may significantly contribute to the receptor have been identified and their emissions characterized; 4) the number of source categories is less than or equal to the number of chemical species; 5) the source profiles are linearly independent (i.e., they are statistically different); and 6) measurement uncertainties are random, uncorrelated, and normally distributed.

The degree to which these assumptions are met in practice depends to a large extent on the types and quality of chemical measurements made at the sources and receptors. The CMB model has been subjected to a number of tests to determine its ability to tolerate deviations from the model assumptions. There is substantial variability among individual profiles, and even among profiles from different source types, so Assumption 1 is never completely met.

With respect to Assumption 2, all of the source types are treated as non-reactive. This is the case for primary emissions from geological material, mobile source exhaust, and woodburning in which little change is expected between source and receptor. Coal-fired power station emissions are accompanied by large amounts of sulfur dioxide that convert to sulfate during transport. Some of the $PM_{2.5}$ apportioned to secondary sulfate is surely due to these sources, but this is not quantified by profile measurements of fresh emissions at the source. Although the CMB can estimate the contributions from different secondary aerosol compounds such as ammonium nitrate, ammonium sulfate, ammonium bisulfate, sulfuric acid, and sodium nitrate, it cannot attribute these compounds to emitters by itself.

With respect to Assumption 3, some source profiles may be missing or not well suited to represent emissions from the related sources. Unique point sources such as pulp mills, hog fuel boilers, and aluminum producers may have chemical signatures that are unique to a particular facility. The appropriateness of using source profiles from other sources may results in inaccuracies in the source contribution. There are very few of source profiles that were obtained from sources in the vicinity of CRG. Despite this shortcoming, the analysis of the emissions inventory indicated that the major source types are included in the collection of source profiles.

When the CMB model is applied, the source contribution estimates were often outside of the 80% to 120% target range at both sites. However, calculated mass concentrations were most of the time within propagated uncertainties of source contribution estimates. This is often observed in samples with a large soluble fraction (e.g., ammonium sulfate) and could be due to liquid water that did not evaporate prior to filter weighing. In addition, total mass on many samples was less than 2 $\mu g/m^3$. The relative uncertainties associated with these ambient measurements are higher and are propagated into the SCE's.

With respect to Assumption 4, nearly all of the chemical species and up to twelve profiles were used in each calculation. The number of chemical species always exceeded the number of source types.

Assumption 5 could be met for profiles in different categories, but not for profiles within the same category (e.g., diesel- and gasoline-fueled vehicles). The pulp and paper profile (SAPPILK1) was often collinear with the geologic source profile (KTSSOIL). This occurs when a large contributor, such as road dust, is included with a small contributor, such as the WTE profile. The smaller contributions to each chemical species get confused with the variability of the larger source contribution. Greater detail in chemical speciation of both source and ambient data is needed to separate the contributions from different sub-categories.

The effects of deviations from Assumption 6 have not been studied to a great extent. Non-randomness and correlation among measurement errors would result in biases in the calculated concentrations with respect to measured concentrations. For this study, all of the CMB assumptions are met to the extent that the source contribution estimates can be considered valid.

A summary of the performance measures for the 194 CMB runs from Mt. Zion (COGO1) and the 206 runs at Wishram (CORI1) are shown in Table 5-2. The average and standard deviation of the quality of the fits for both sites were approximately equal. The average CHI-SQUARE value at Mt. Zion was only slightly lower than at Wishram indicating a better fit.

Two samples in particular (04/29/1998 at both Mt. Zion and Wishram) had CHI-SQUARE values larger than 20. In these cases, $PM_{2.5}$ aerosol mass was greater than 23 $\mu g/m^3$ and samples were heavily enriched with silicon and iron but lacked much of the calcium usually found in the KTSSOIL geologic profile. This event was coincident with a large scale Asian dust storm originating from the Gobi Desert in China on April 18-19, 1998. Satellite images indicate that parts of this dust plume reached the western United States as early as 25-26 April (following a week of transport across the Pacific). Air Stagnation Advisories were issued for eastern Washington State on 30 April as light winds allowed the dust layer and low-level pollutants to reduce air quality over that region (CIMSS, 2002). The extent and frequency of these global dust transport issues requires additional investigation that is beyond the scope of the current study.

Despite discrepancies in some specific cases, the distributions of high R-SQUARE and low CHI-SQUARE values imply that the combination of the selected source profiles and chemical species adequately explained the ambient measurements.

Table 5-2. Summary of CMB Model Performance Measures

Site	Statistic	R-SQUARE	CHI-SQUARE	% Mass
Mt. Zion (COGO1)	Average ± Standard Deviation	0.89 ± 0.05	1.5 ± 1.6	94 ± 17
Mt. Zion (COGO1)	Minimum	0.53	0.41	18
Mt. Zion (COGO1)	Median	0.90	1.2	96
Mt. Zion (COGO1)	Maximum	0.96	20	193
Wishram (CORI1)	Average ± Standard Deviation	0.88 ± 0.05	1.7 ± 1.6	93 ± 18
Wishram (CORI1)	Minimum	0.50	0.54	46
Wishram (CORI1)	Median	0.89	1.4	92
Wishram (CORI1)	Maximum	0.96	22	159
Both	Average ± Standard Deviation	0.88 ± 0.05	1.6 ± 1.6	94 ± 18
Both	Minimum	0.49	0.41	18
Both	Median	0.89	1.3	94
Both	Maximum	0.96	22	193

5.1.5 Identification and Correction of Model Input Errors

Ambient air quality data from the Mt. Zion (COGO1) and Wishram (CORI1) sites were downloaded from the IMPROVE web site (http://vista.cira.colostate.edu/improve). Data were imported into a MS Excel spreadsheet for processing. The following verification and gap filling steps were followed to create the CMB input file.

- Select only sample days with "Normal" fine aerosol component (i.e. Ammonium Sulfate, Ammonium Nitrate, Soil, Organic Carbon, and Elemental Carbon) data flags. This ensures that all gravimetric and chemical analysis data needed for CMB are valid (Level 1) and present in the CMB input table.
- Replace all zero valued analytical uncertainties with the average uncertainty of all other measurements of a particular species.
- Delete fields not related to fine aerosol mass or composition (i.e. derived light extinction fields).
- Replace negative concentrations with 0 and update the uncertainty to be the square root of the sum of squares of the negative value and the for that species concentration.

5.1.6 Consistency and Stability of Source Contribution Estimates

Several CMB calculations were made for each sample. These evaluated the stability of the solution by adding or deleting source profiles and fitting species and examining changes in the source contribution estimates. In all but a few cases, changes in source contribution estimates due to addition or removal of fitting species were less than the calculated uncertainties for the source contribution estimate. In those cases where the presence or absence of a single species made a large difference in the source contribution estimates, the species was left in the fit. Examples of these key species include EC2 for mobile source profile BVRDMV and potassium and chloride for vegetative burning BURN3-7.

On 09/24/1997, the 2 year maximum levels of organic (> 6 $\mu g/m^3$) and elemental carbon (> 3 $\mu g/m^3$) were observed at both the Mt. Zion and Wishram sites. The seasonal timing and spatial consistency of the grossly elevated carbon levels are characteristic of a regional scale forest fire. The SCE for the Mt. Zion site supported this hypothesis by attributing 11 ± 2 $\mu g/m^3$ to burning and 4 ± 1 $\mu g/m^3$ to mobile source emissions. For the same sample day, the CMB fit at the Wishram site apportioned 10 ± 2 $\mu g/m^3$ to mobile sources emissions and 1.0 ± 0.4 $\mu g/m^3$ to burning. An MPIN analysis of this attribution indicated that chloride (in the absence of sodium) was controlling the attribution of the burning profile for both fits. On this day, the ambient concentrations were < 0.02 $\mu g/m^3$ for both IC chloride and PIXE chlorine at the Wishram site and 2.6 ± 0.1 $\mu g/m^3$ for IC chloride and < 0.02 $\mu g/m^3$ for chlorine at the Mt. Zion site. As a result, inconsistencies in the measured chloride have a significant effect on the ability of the CMB to resolve mobile source emissions from biomass burning. Removing chloride, potassium, and bromine from the fitting species on this day failed to attribute more than 50% of the $PM_{2.5}$ to vegetative burning. The results suggest that the presence of EC2 and EC3 in the mobile source source profile and their absence in the vegetative burning profile are insufficient to resolve the SCE's of these two sources on this day.

5.1.7 Consistency with Other Information

Geological contributions are higher on non-winter samples when drier conditions and the absence of frozen surfaces allow for more dust suspension. Ammonium sulfate contributions are highest during the summer months when photochemical conversion is most prevalent. Ammonium nitrate contributions are highest during the winter when lower temperatures favor particle equilibrium. The aluminum reduction potline source is highest at the Wishram site especially in the winter. The proximity of this site to the Goldendale and Northwest aluminum companies supports the accuracy of this source attribution. Marine impacts are consistently higher at the Mt. Zion site closer to the coast.

5.2 Spatial and Seasonal Patterns of Source Attributions

Individual SCE's for each valid sample day were calculated and are summarized in Appendix C. The following subsections explore validity of the model results with respect to the seasonal and spatial patterns of the source attributions.

5.2.1 Marine and Nitrate

Figure 5-1 shows the monthly average SCE's for the fresh marine, aged marine, and ammonium nitrate sources at the two CRG sites. The error bars represent the root mean square

(RMS) error based on the stardard error of the SCE's. Although ammonium aerosol was not measured at the IMPROVE sites, the ammonium nitrate SCE is consistently higher at the Wishram sites east of the Gorge. Both sites show ammonium nitrate peaking in the cooler winter months.

Source attribution of fresh and aged marine aerosol and ammonium nitrate depends on a few key species. Sodium is a conservative (non-volatile) species that is the major cation in seawater. Chloride is the major anion in seawater and it is volatile as hydrochloric acid. Nitrate typically replaces chloride in the aerosol form as the sea salt aerosol ages to produce sodium nitrate. Nitrate forms salts with other cations including calcium and maganesium, but the predominant form of nitrate as an aerosol is ammonium nitrate.

The IMPROVE samples collected in the CRG are analyzed for only three of the four key species in the marine-nitrate system: chloride, nitrate, and sodium but not ammonium. With just three species and three source profiles to fit to these species, there are no remaining degrees of freedom in the CMB fit. If all three species are measured accurately, the source contribution estimates of marine, aged marine, and ammonium nitrate should be robust. Sodium and chloride are difficult species to measure by X-Ray Fluorescence because they have low atomic numbers and tend to be more transparent to X-Rays than heavier elements such as lead. Chloride is measured by ion chromatography on the filter samples and these measurements are incorporated in the CMB analysis. The ability of the CMB to resolve fresh and aged sea salt from ammonium nitrate is limited with the current set of measurements used on the IMPROVE sampler. Measurement of aerosol ammonium and soluble sodium by atomic absorption spectrometry would reduce the uncertainty of the source attribution.

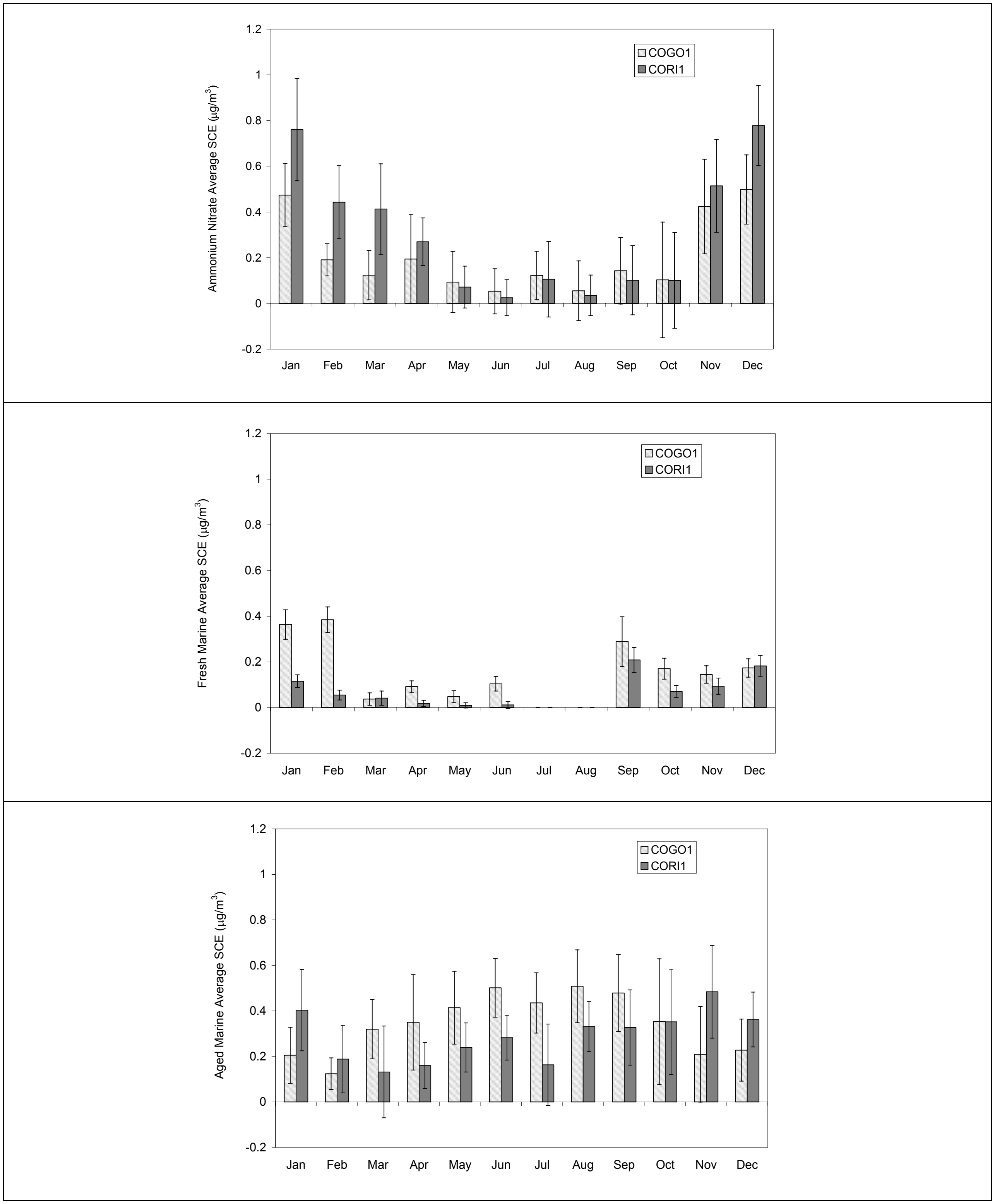

Figure 5-1. Annual cycles of marine aerosol and ammonium nitrate $PM_{2.5}$ SCE's in the CRG between 9/1/1996 and 8/31/1998 at the Mt. Zion (COGO1) and the Wishram (CORI1) IMPROVE sites.

Aged marine aerosol (predominantly $NaNO_3$) has generally higher concentrations than the fresh marine aerosol (NaCl). One exception to this occurs at the Mt. Zion site in the winter months when storms may deliver the fresh marine aerosol directly to the western receptor site before nitrate substitution can occur.

Sea spray is predominantly composed of coarse particles. The marine aerosol apportioned by the CMB is likely to represents the fine tail of the sources size distribution. Fine marine aerosol are likely to be larger (D_p = 1 to 2 μm) than aerosol generated by combustion processes (D_p = 0.2 μm). The deposition velocities of these larger particles are greater resulting in shorter atmospheric lifetimes. The higher concentrations of aged marine aerosol observed on the eastern end of the Gorge (Wishram) is consistent with a marine airmass that comes onshore and scavenges nitric acid vapor downwind of urban areas.

5.2.2 Sulfate and Coal

Chapter 3 indicated that the largest sources of SO_2 in the region are the Centralia power plant to the northeast and the Boardman unit (Portland Gas and Electric) to the southeast of the CRG. These facilities also may also emit primary ash particles. The two source profiles Coal Fired Power Plant and Coal Fly Ash may represent primary emissions from these facilities. The annual trends of sulfate and the primary coal SCE's are shown in Figure 5-2. Sulfate peaks at both sites in the summer months when it is at its annual maximum. At this time, the sulfate concentrations are highest at western end of the Gorge. In winter, sulfate SCE's are slightly higher at Wishram. The conversion of SO_2 to sulfate is dependent on ambient levels of moisture and oxidants, but typically occurs on time scales of days to weeks. In this time, plumes from point sources disperse over large regions resulting in a spatially uniform blanket of sulfate aerosol. The nearly equivalent levels of sulfate at either end of the Gorge is consistent with this conceptual model.

None of the monthly average attributions to the primary emissions from the coal sources are greater than the RMS errors. The trace elements present in these ash profiles are also present in the soil profile that accounts for a larger fraction of the $PM_{2.5}$ mass. Attributions to the coal fired power plant source profile were most dependent on ambient selenium concentrations.

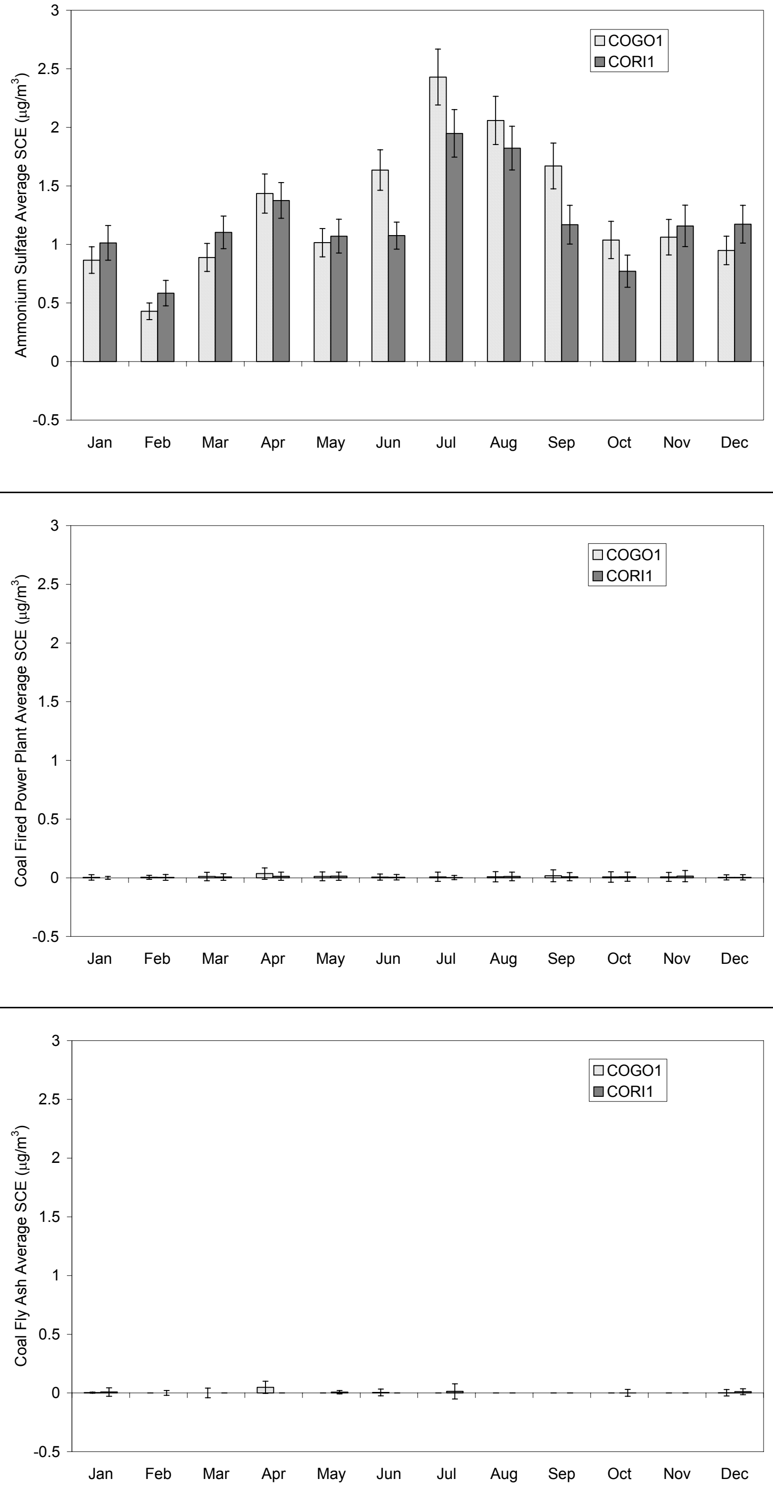

Figure 5-2. Annual cycles of sulfate and primary coal fired power plant $PM_{2.5}$ SCE's in the CRG between 9/1/1996 and 8/31/1998 at the Mt. Zion (COGO1) and the Wishram (CORI1) IMPROVE sites.

5.2.3 Geologic Material

The SCE's of the KTSSOIL geologic source profile show strong seasonal cycles with individual peaks in the spring and summer (Figure 5-3). As described above, a single Asian dust storm event on 4/29/1998 is largely responsible for the elevated soil levels observed in the month of April. The remainder of the annual cycle of soil concentrations are inversely related to rainfall near each site. Portland receives approximately 3 times more annual precipitation than The Dalles with peak intensity in November through February. Rainfall reaches a minimum at both sites in July and August as soil concentrations peak. Soil emissions are mostly composed of coarse particles with mass median diameters ~ 5 µm or larger. Because of their higher deposition velocities, the atmospheric lifetimes of soil particles are shorter. Unlike sulfate particles, high soil concentrations are frequently associated with nearby sources such as unpaved road, construction activity, dry lake beds, or storage piles.

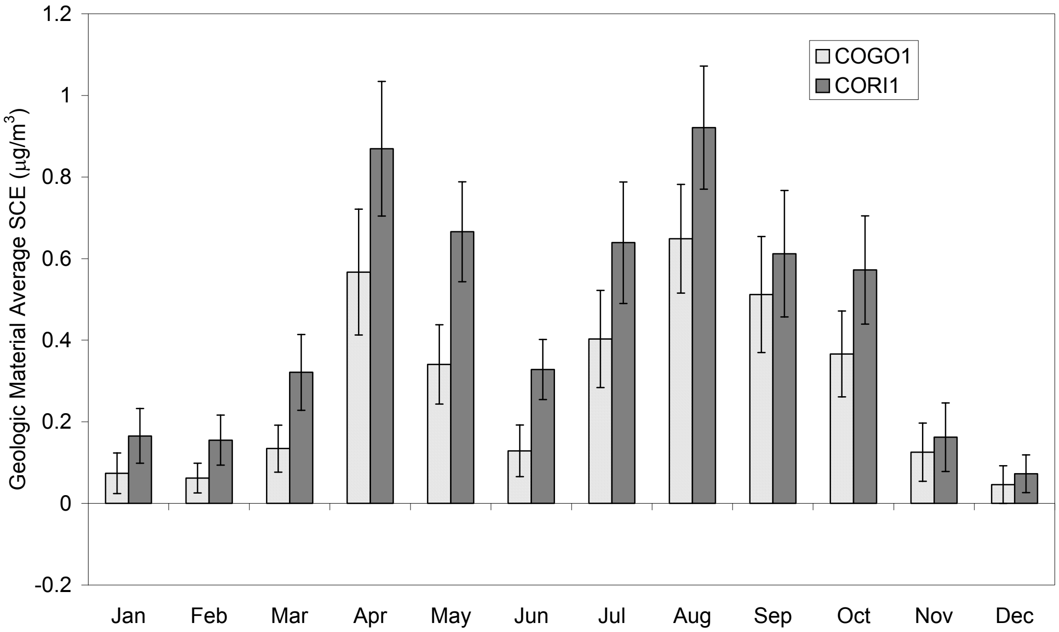

Figure 5-3. Annual cycle of geologic material $PM_{2.5}$ SCE's in the CRG between 9/1/1996 and 8/31/1998 at the Mt. Zion (COGO1) and the Wishram (CORI1) IMPROVE sites.

5.2.4 Carbonaceous Aerosol

The mobile source SCE exhibits a stronger seasonal cycle than does the vegetative burning SCE (Figure 5-4). The $PM_{2.5}$ attribution to mobile sources is ~ 50% higher between July through November than during the remainder of the year. Emissions from vehicles should remain relatively constant throughout the year, however seasonal variations in the atmospheric mixing depths and source regions may be more important factors affecting the observed carbonaceous aerosol concentrations in the Gorge. During the summer months winds from the west deliver urban air from Portland to the CRG. At the same time, stonger solar intensity and deeper mixing depths dilute the emissions resulting in lower concentrations. In winter, the opposite effect occurs; emissions from the less populated eastern Gorge are trapped closer to the ground resulting in concentrations that are not substantially different than summertime.

Forest fires and agricultural burning are most likely to occur during the warm dry season, however residential wood combustion accounts for a large fraction of particle emissions during the winter months. The emissions inventory for the area suggests that vegetative burning should dominate the emissions of carbonaceous aerosol. Despite the large difference in estimated emissions (appendix B), the CMB SCE's for the mobile source profile are on average 5 to 10 times higher than vegetative burning at both sites.

Each one of these competing factors makes verification and interpretation of the carbonaceous aerosol SCE's more difficult. Given the strong dependence of the vegetative burning attribution on chloride (rather than one of the eight carbon fractions), and the highly variable conditions of fire emissions, these two source types may not be distinguishable from each other using the current set of source profiles. The source attribution results of these two sources should be evaluated as the sum of mobile source emissions and vegetative burning.

5.2.5 Point Sources

SCE's of the aluminum smelting operations on the east side of the CRG were evident at the Wishram site during winter months (Figure 5-5). Large spatial differences in the SCEs between the two sites suggests that a source near the Wishram location is impacting the air quality at that site. Winter airflow from the east would implicate the Goldendale Aluminum Company. Aluminum was the key species responsible for the aluminum smelting attribution.

SCE's from the pulp and paper mill profile were not significant at either site throughout the year. Calcium and possibly sulfate emissions from this source would be explained with the ammonium sulfate and soil profiles. These results suggest that any contributions due to pulp and paper manufacturing are incorporated into the geologic SCE's.

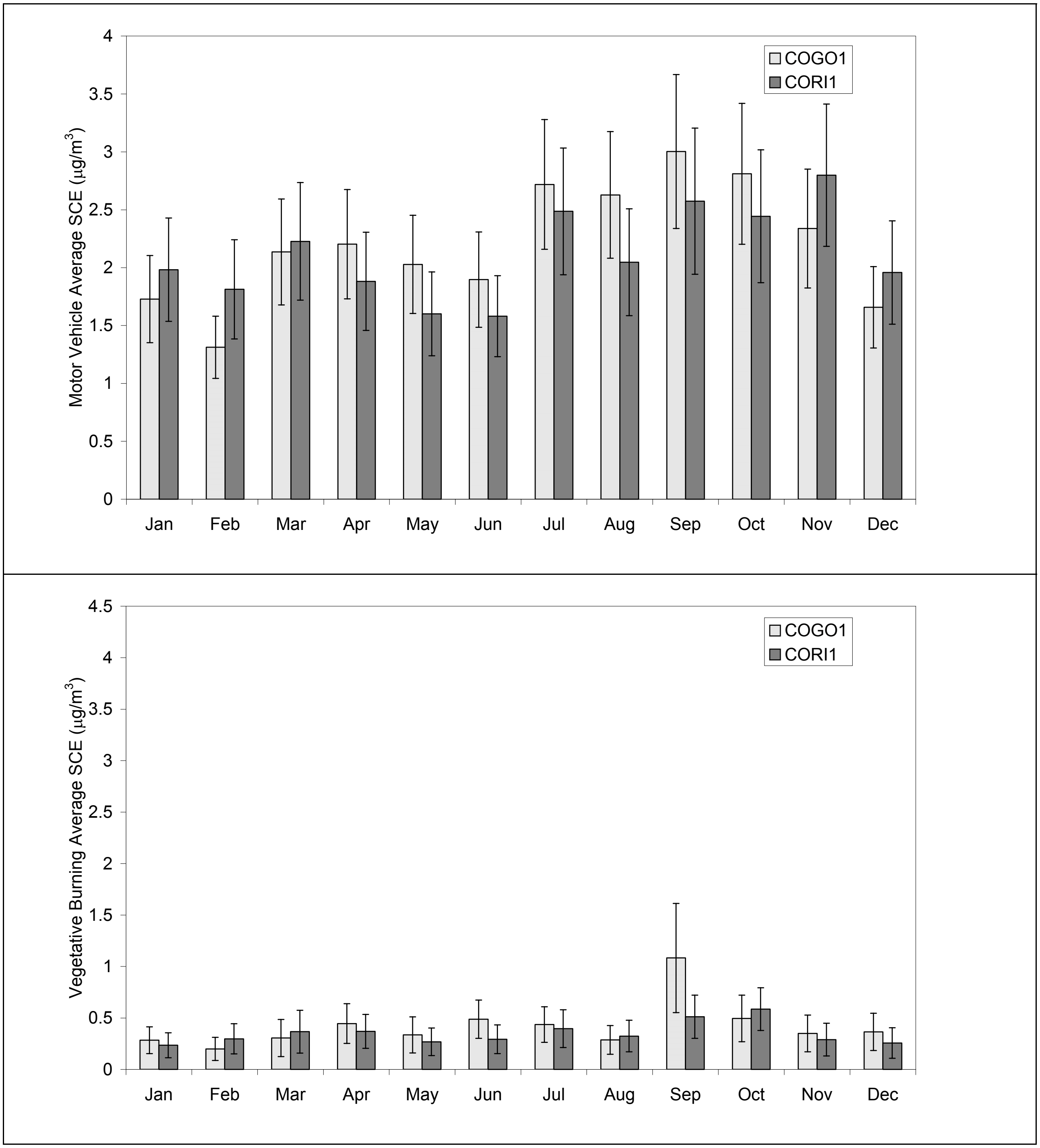

Figure 5-4. Annual cycles of carbonacious $PM_{2.5}$ SCE's in the CRG between 9/1/1996 and 8/31/1998 at the Mt. Zion (COGO1) and the Wishram (CORI1) IMPROVE sites.

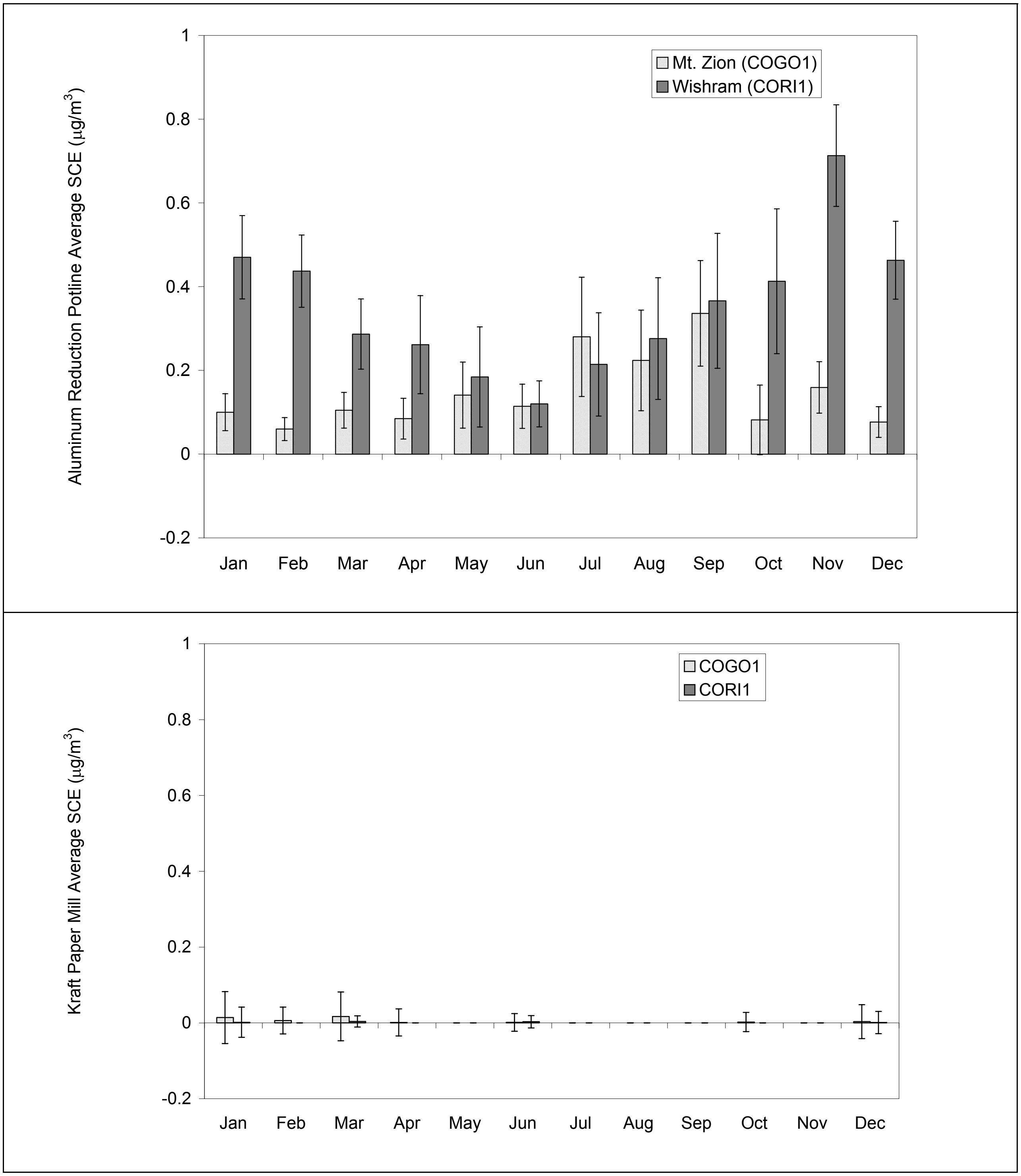

Figure 5-5. Annual cycles of unique point source SCE's in the CRG between 9/1/1996 and 8/31/1998 at the Mt. Zion (COGO1) and the Wishram (CORI1) IMPROVE sites.

5.2.6 Pure Species Profiles

Pure species profiles are used in the CMB analysis to account for unknown or poorly matched sources that are influencing concentrations at the receptor sites. Seasonal cycles in the SCEs may provide insight to the origins of these species. The lead SCE shows a very strong seasonal and spatial pattern unlike any of the other source profiles (Figure 5-6). Lead is higher from February to October at the Mt. Zion site near Portland, OR than at the Wishram site. Excess lead SCEs are roughly equivalent at both sites during November through January. Unlike soil concentrations however, excess lead shows two distinct peaks in February and October. This seasonal trend may be due to a nearby point source that only operates in February through October.

In contrast to lead, more excess bromine is observed at the Wishram site than at the Mt. Zion site. Bromine peaks between March and August at both sites. The sources responsible for the unexplained lead and bromine in the CRG are unknown. These results indicate that emissions from sources with unique tracers are measurable above background in the CRG.

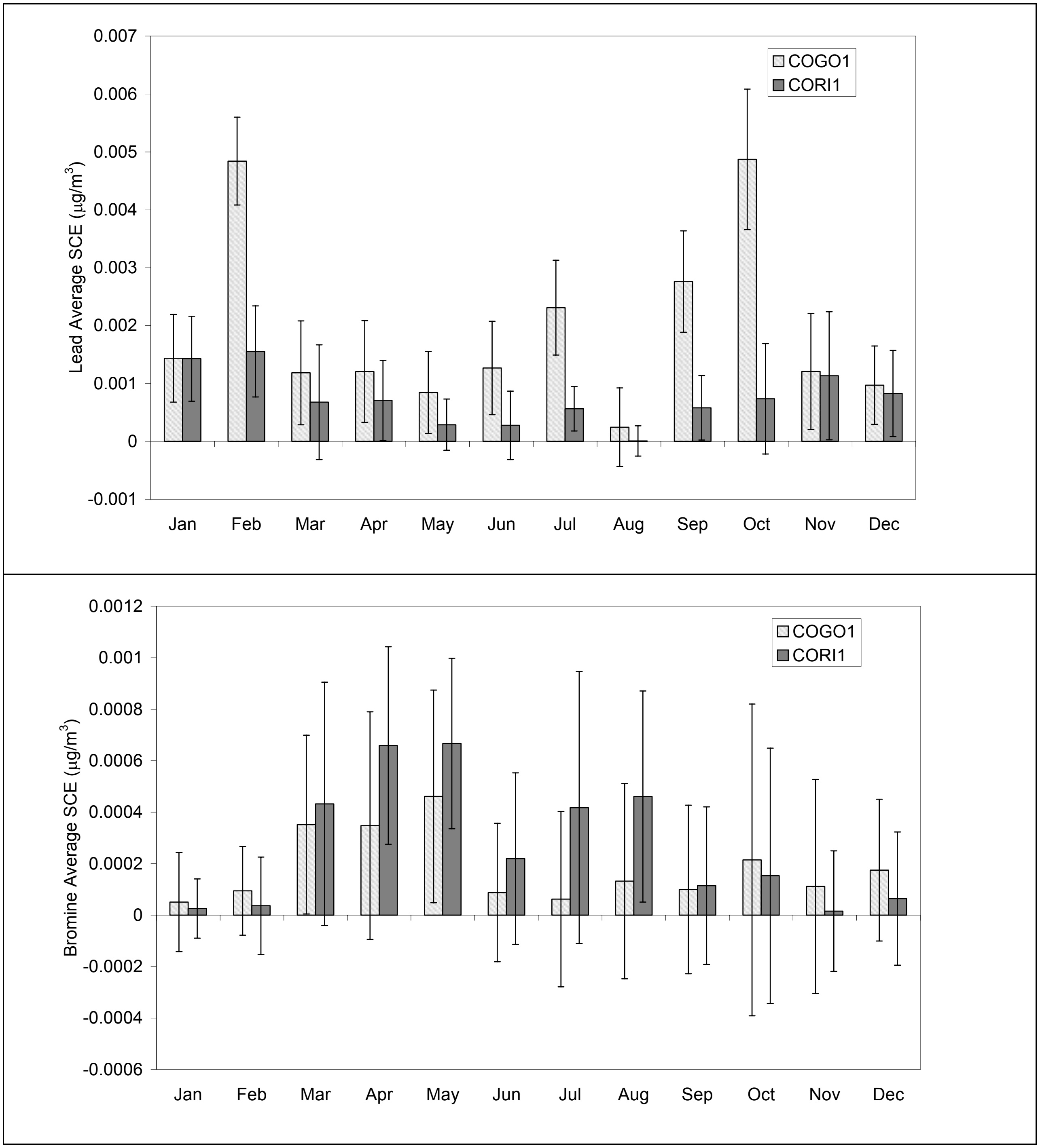

Figure 5-6. Annual cycles of pure species SCE's in the CRG between 9/1/1996 and 8/31/1998 at the Mt. Zion (COGO1) and the Wishram (CORI1) IMPROVE sites.

5.3 Relationship between Source Contribution Estimates and Daily Resultant Winds

Daily resultant wind direction and average wind speed data was obtained from meteorological stations located near the IMPROVE monitors. Resultant wind direction (RWD) is the direction of the vector sum of all valid hourly winds recorded over a 24 hour period. While an airmass may not travel in a consistant direction over the coarse of a day, the resultant wind direction is intended to represent the net transport of air over that period. When associated with source contribution estimates, the resultant wind direction is expected to be related to the direction of the sources contributing to the measured aerosol. Average wind speed is another useful parameter for assessing source locations. When the average wind speed is low, conditions are favorable for a buildup of pollutants from local sources.

Hourly measurements of wind speed, wind direction, and temperature are made at the Wishram IMPROVE site and at the Troutdale Airport (~15 km west of the Mt. Zion site). Hourly data were matched with the CMB SCE's at each site. Overall, data recovery from these sites were very good. The average number of valid hourly measurements at Troutdale matched to each SCE at Mt. Zion was 22.1 hours with a minimum of 14 hours. At Wishram, the average number of hourly measurements for each SCE was 23.9 hours with a minimum of 15 hours.

The topographic map on Figure 2-2 shows that Wishram site on the north side of the Columbia at the base of a ridge running East-West. Consequently, measured resultant winds at the Wishram site were never greater than 5 mph and northerly on any of the IMPROVE sampling days. In contrast, 10 out of 167 days at the Troutdale airport have met these criteria since the monitoring location is in an area where the Gorge is wider and surface winds are more representative regional scale air flow. These results indicate that surface winds may not always be indicative of regional flows especially when monitors are located in valleys surrounded by complex terrain.

The surface winds at the Troutdale and Wishram sites were classified for each day between 9/96 and 9/98 when the IMPROVE monitors were operational. If daily average wind speeds were less than 5 mph, the conditions were classified as clam. If winds were greater the 5 mph, the conditions were classified as northerly (RWD ≤ 45° or RWD > 315°), easterly (45° < RWD ≤ 135°), southerly (135° < RWD ≤ 225°), or westerly (225° < RWD ≤ 315°). Ambient PM concentrations, light extinction, aerosol growth factor f(RH), and source contribution estimates are averaged based on the five meteorological classifications (i.e. calm, northerly, easterly, southerly, and westerly) and are shown in Table 5-3. These data are shown graphically in Figure 5-7 through Figure 5-11. The areas of the bubbles in the figures are proportional to the values shown in Table 5-3. Data from Mt. Zion are shown on the left (western) side of the figures with black bubbles and Wishram data are shown on the right side with grey bubbles.

5.3.1 Meteorological Trends with Aerosol Concentrations, Light Extinction, and f(RH).

The highest $PM_{2.5}$ mass concentrations at Mt. Zion occur when winds are less than 5 mph or northerly. Under calm conditions, average $PM_{2.5}$ at Wishram is only 5% less than avegage $PM_{2.5}$ at Mt. Zion. These data suggest that major $PM_{2.5}$ sources are in the proximity of the monitoring sites and accumulate under calm winds and/or that secondary aerosols form from precursor gases (i.e. SO_2, NO_x, NH_3, VOC) after they have been transported from other areas and stagnate in the vicinity of the monitors.

Although the ocean is west of Mt. Zion, the f(RH) aerosol growth term is greatest when winds are clam or from the south and east. The southeasterly origin of the f(RH) is likely due to the prevailing wind during the colder winter season. Under cooler temperatures, air becomes more saturated with water (i.e. RH increases) even when the mixing ratio of water is held constant. Since winds blow from the south and east at Mt. Zion predominantly in the cooler months, the RH is higher and the f(RH) term is higher as well. The consequence of this behavior is that secondary sulfate and nitrate that are hygroscopic more efficiently scatter light during the cooler months than in summer. At both locations fine aerosol light extinction is greatest when winds are calm due to both high aerosol mass and f(RH).

Only coarse mass ($PM_{10} - PM_{2.5}$) was measured at the Wishram site between 9/96 and 9/98. Average coarse mass concentrations are highest when winds are blowing from areas to the south and west of Wishram. Aerosols have a with aerodynamic diameter greater than 2.5 have a higher gravitational settling velocity than smaller accumulation mode aerosols. As a result, the atmospheric lifetime of coarse aerosols is shorter than that of $PM_{2.5}$. Because of this attribute, coarse aerosols are less likely to travel far from their source prior to deposition. Elevated coarse aerosol concentrations at Wishram with southerly and westerly winds suggests that sources in or near the city of The Dalles are contributing to some of the coarse mass observed at the Wishram site. This coarse mass contribution is only a small fraction (~10%) of the total light extinction budget at Wishram. The increase in light extinction from calm and easterly winds more than offsets the increased contribution to light extinction from the southerly and westerly coarse particle sources.

5.3.2 Meteorological Trends with Source Contribution Estimates

The relationship between wind classification and SCE's are shown in the lower section of Table 5-3 and Figure 5-8 through Figure 5-11. The upper panel of Figure 5-8 shows the directional dependence of the ammonium nitrate SCE. Ammonium nitrate concentrations under easterly winds are more than twice the concentration during calm conditions and more than 3 times larger than during any other wind conditions. This example demonstrates the need for caution when interpreting the wind stratified results. Ammonium nitrate has a very low vapor pressure and readily volatilizes during the warmer months. Its formation is more stable during wintertime conditions. In the CRG, wintertime winds are predominantly from the west. Consequently, the seasonality of the wind direction is partly the reason why ammonium nitrate is elevated when winds are easterly. Easterly ammonium nitrate concentrations are more than 2 times larger than those at the Wishram site. The difference between the aveage SCE's at the two sites implies that the source causing elevated levels of ammonium nitrate is located east of the Wishram site.

The average marine SCE (i.e. the sum of the fresh and aged marine SCE) is largest when surface winds are blowing from the north and west at Mt. Zion and when they are blowing from the south and west at Wishram. This result is consistent with the location of the Pacific Ocean to the west of the CRG.

At the Wishram site, ammonium sulfate is largest with winds are from the east in the direction of the Portland General Electric Power Station. At Mt. Zion ammonium sulfate is elevated when winds blow from the north and west where the Pacificorp-Centrailia Coal Fired Power Plant is located.

The wind classification dependence of the SCE's of Coal Fly Ash, Primary Coal Emissions, and Aluminum Reduction Potlines are shown in Figure 5-9. Both Coal Fly Ash and Primary Coal Emissions are largest at Mt. Zion when conditions are calm. For primary emissions, this suggests that the sources associated with these profiles are in the vicinity of the Mt. Zion monitor. At the Wisram site, the primary coal profiles are largest when winds are southerly and to a lesser extent easterly. There are no large coal fired power plants in the vicinity of Mt. Zion or to the south and east of Wishram. The attributions primary $PM_{2.5}$ (i.e. non-sulfate) to these sources is quite small

Table 5-3. Summary of meteorological stratification of ambient data and CMB source attributions.

		Mt. Zion					*Wishram*			
Category	**Description**	**Calm**	**Northerly**	**Easterly**	**Southerly**	**Westerly**	**Calm**	**Easterly**	**Southerly**	**Westerly**
Number	Number of Samples in Average	26	10	23	73	35	11	27	41	115
Coarse Mass	PM_{10} - $PM_{2.5}$ (μg/m$^{3)}$						5.46	6.79	8.59	8.06
Fine Mass	$PM_{2.5}$ (μg/m$^{3)}$	7.96	7.89	4.69	4.48	5.96	7.70	6.66	6.29	5.19
f(rh)	Unitless Aerosol Growth Term	4.56	2.03	4.08	4.19	3.22	5.46	3.49	2.94	2.22
Total bext	Light Extinction (Mm^{-1})						70.7	60.2	46.8	36.7
Fine bext Mm-1	Light Extinction (Mm^{-1})	62.8	47.1	42.2	35.8	47.1	67.4	56.1	41.6	31.8
MAR0	Aged Marine (μg/m^3)	0.38	0.70	0.17	0.23	0.52	0.29	0.23	0.39	0.25
MAR100	Fresh Marine (μg/m^3)	0.06	0.00	0.05	0.31	0.09	0.00	0.00	0.12	0.07
Total Marine	Aged + Fresh Marine (μg/m^3)	0.45	0.70	0.21	0.53	0.62	0.29	0.23	0.51	0.33
AMNIT	Ammonium Nitrate (μg/m^3)	0.24	0.07	0.58	0.18	0.10	0.48	1.24	0.26	0.09
AMSUL	Ammonium Sulfate (μg/m^3)	1.79	2.62	1.11	0.77	1.71	1.03	1.49	1.07	1.19
ARPL	Aluminum Reduction Potline (μg/m^3)	0.16	0.30	0.11	0.10	0.16	0.80	0.41	0.53	0.22
BVCFPP	Primary Coal Fired Power Plant (μg/m^3)	0.025	0.012	0.004	0.007	0.011	0.009	0.003	0.012	0.008
BVCLFA	Primary Coal Fly Ash (μg/m^3)	0.030	0.000	0.001	0.001	0.001	0.000	0.002	0.007	0.003
SAPPILK1	Pulp and Paper Mill (μg/m^3)	0.001	0.000	0.013	0.003	0.001	0.000	0.001	0.000	0.001
KTSSOIL	Soil (μg/m^3)	0.49	0.52	0.09	0.21	0.33	0.34	0.17	0.52	0.47
BVRDMV	Mobile Source (μg/m^3)	2.92	2.95	2.00	1.74	2.44	3.21	2.30	2.15	1.91
BURN3-7	Vegetative Burning (μg/m^3)	0.46	0.47	0.37	0.47	0.44	0.37	0.22	0.30	0.36

(<0.05 μg/m^3) and may be associated with other source that emit similar species to primary coal emissions and fly ash.

Average aluminum reduction potline SCE's are largest when winds are northerly at the Mt. Zion site and are lesser but equivalent when winds are stagnant or easterly. Aluminum companies exist directly to the west of Mt. Zion (Vanalco) and to the northwest (Reynolds Metals). The largest aluminum reduction potline SCE's occur during calm conditions at Wishram. This is consistent with the location of aluminum companies to the east and west of the monitoring site.

Mobile source and biomass burning SCE's are the least dependent of all sources on wind classification. Based on the large population density of the Portland area, one would expect that mobile source SCE's should be largest when winds are westerly at Mt. Zion. Rather, the SCEs are greatest when winds are calm or from the north. In addition to delivering pollutants from distant sources, high winds also have the effect of diluting emissions and decreasing their overall impact on receptors. At the Wishram site, mobile source SCE's are greatest when winds are clam. The vegetative burning SCEs are largest at Mt. Zion when winds are from calm or from any direction other than east. At Wishram, average vegetative burning SCE's are also smallest when winds are from the east.

Geologic material or soil SCE's are highest when winds are from the north or calm at Mt. Zion and from the west or south at Wishram (Figure 5-11). Soil emissions are very seasonal and are greatest during warmer and drier months. During the summer months, winds are more prone to blow from west to east in the CRG. Consequently, some of the geologic SCE dependence on direction may be due to the coincidence of drier conditions and westerly winds in the CRG.

The pulp and paper mill SCE shows a very strong directional dependence at Mt. Zion, but is negligible in size at the Wishram site. At Mt. Zion, the pulp and paper SCE is ~4 times larger under easterly conditions than at any other time. Since no similar trend is seen at the Wishram site, it is reasonable to conclude that the source responsible for the pulp and paper SCE is located east of Mt. Zion, but not in the proximity of Wishram. The emissions inventory shows that the James River plant is the closest point source (~15 km west) to Mt. Zion, but its relative position makes this an unlikely source of the elevated pulp and paper product. The Dee Forest Products Inc (64 tpy $PM_{2.5}$) and the Hanel Lumber Co. Inc (11 tpy $PM_{2.5}$) are located directly east (40 km to 50 km) of Mt. Zion near Hood River, OR on the south side of the Columbia River and may have emissions with similar speciation to the pulp and paper profile.

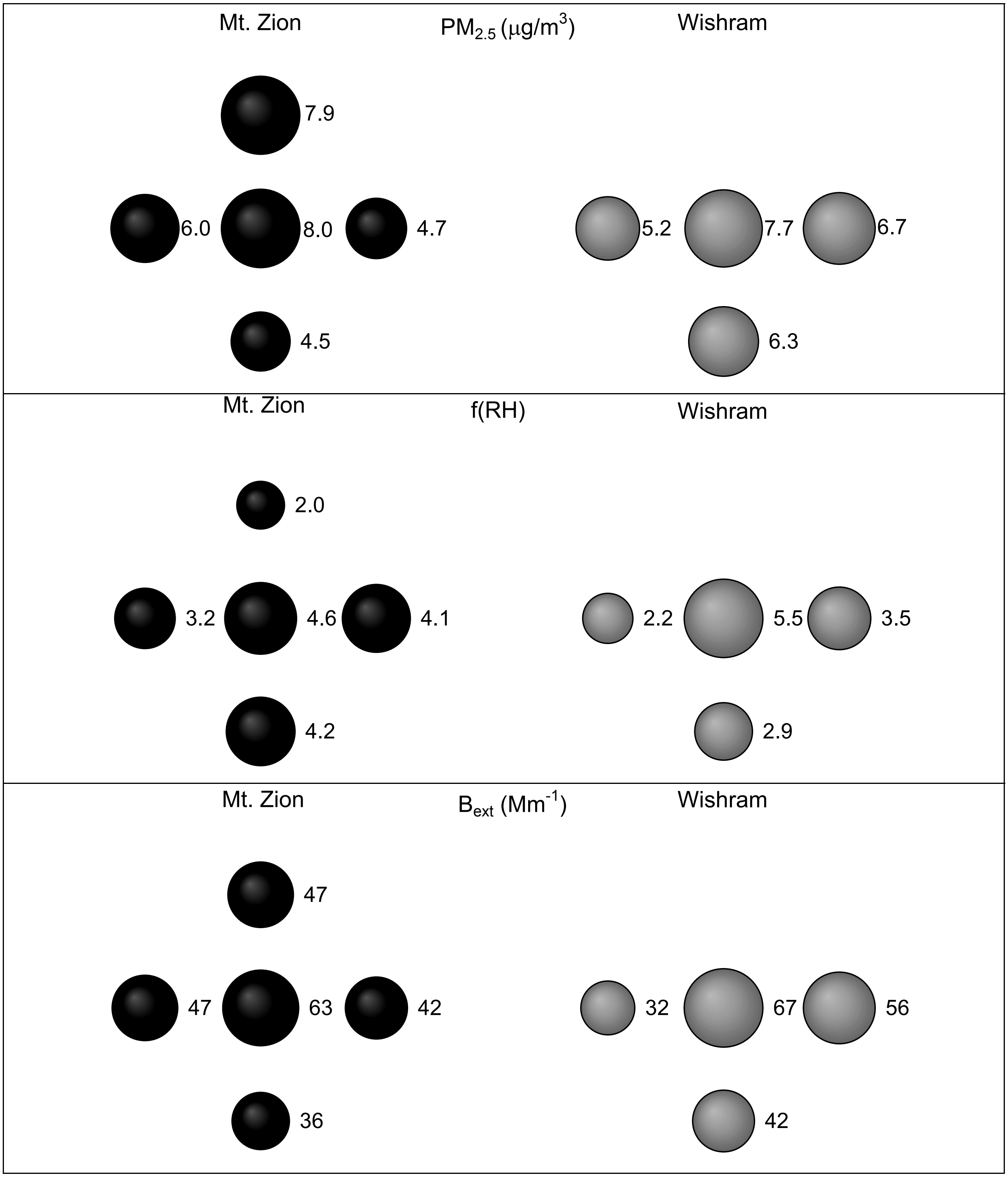

Figure 5-7. Surface wind classification grouping of average PM$_{2.5}$, f(RH), and B$_{ext}$. Black markers correspond to the Mt. Zion site and grey markers correspond to the Wishram site. The middle marker of each set represents the average attribute during calm conditions (daily average wind speed < 5 mph). The top, right, bottom, and left markers correspond to average attribute when winds are from the north, east, south, and west, respectively.

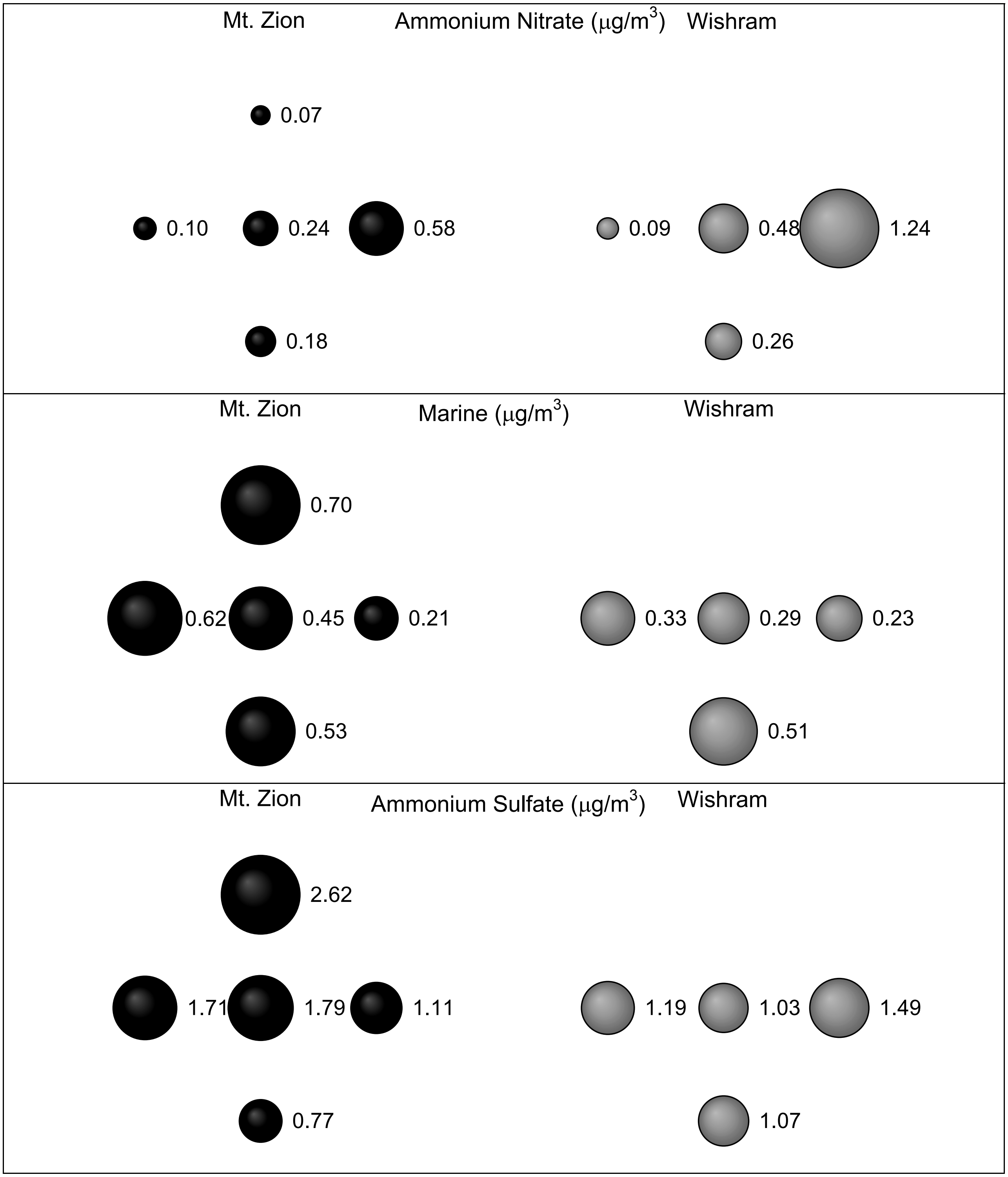

Figure 5-8. Surface wind classification grouping of average SCE's of Ammonium Nitrate, Marine (fresh plus aged), and Ammonium Sulfate. Black markers correspond to the Mt. Zion site and grey markers correspond to the Wishram site. The middle marker of each set represents the average attribute during calm conditions (daily average wind speed < 5 mph). The top, right, bottom, and left markers correspond to average attribute when winds are from the north, east, south, and west, respectively.

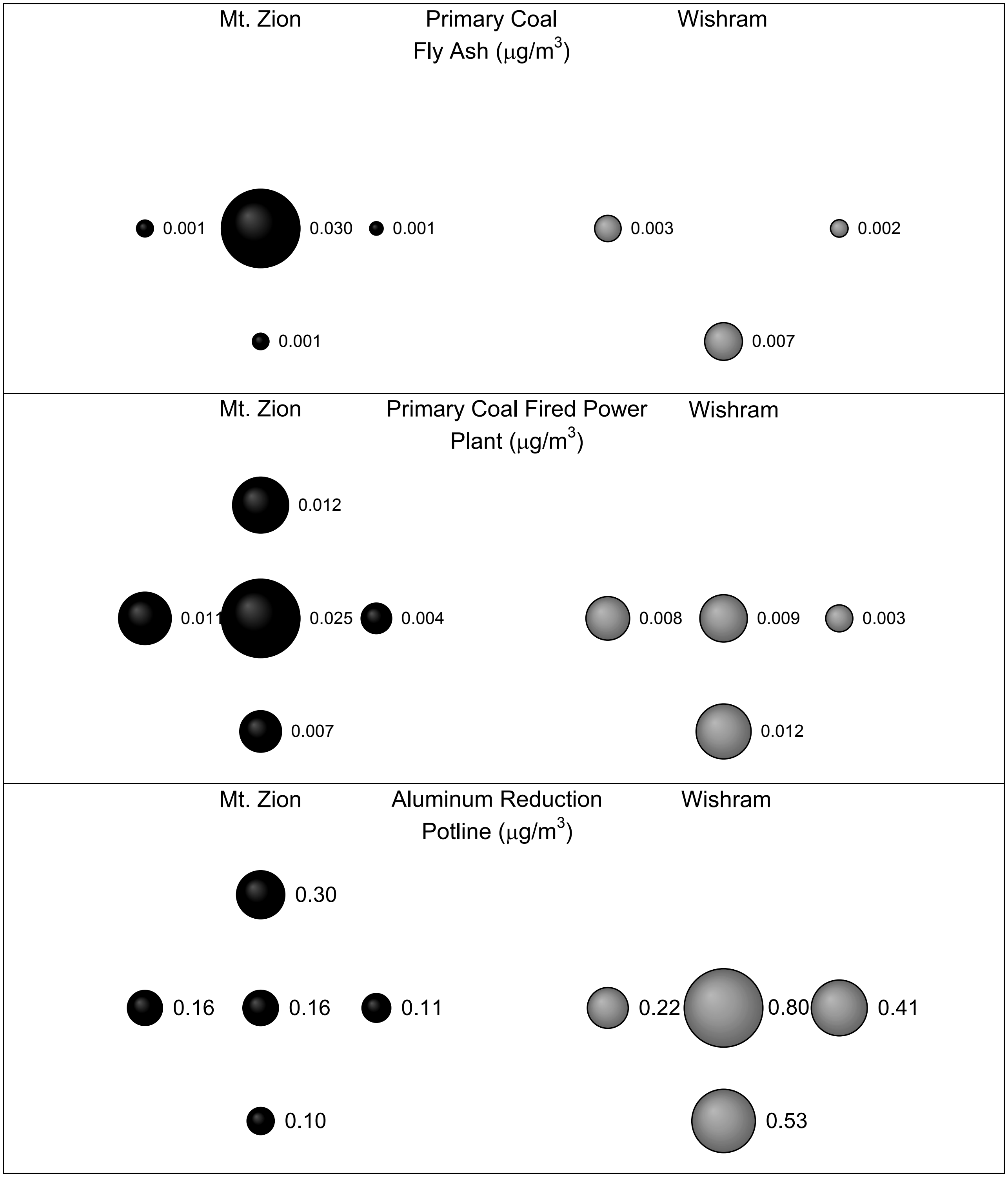

Figure 5-9. Surface wind classification grouping of average SCE's of Primary Coal Fly Ash, Primary Coal Emissions, and Aluminum Reduction Potline . Black markers correspond to the Mt. Zion site and grey markers correspond to the Wishram site. The middle marker of each set represents the average attribute during calm conditions (daily average wind speed < 5 mph). The top, right, bottom, and left markers correspond to average attribute when winds are from the north, east, south, and west, respectively.

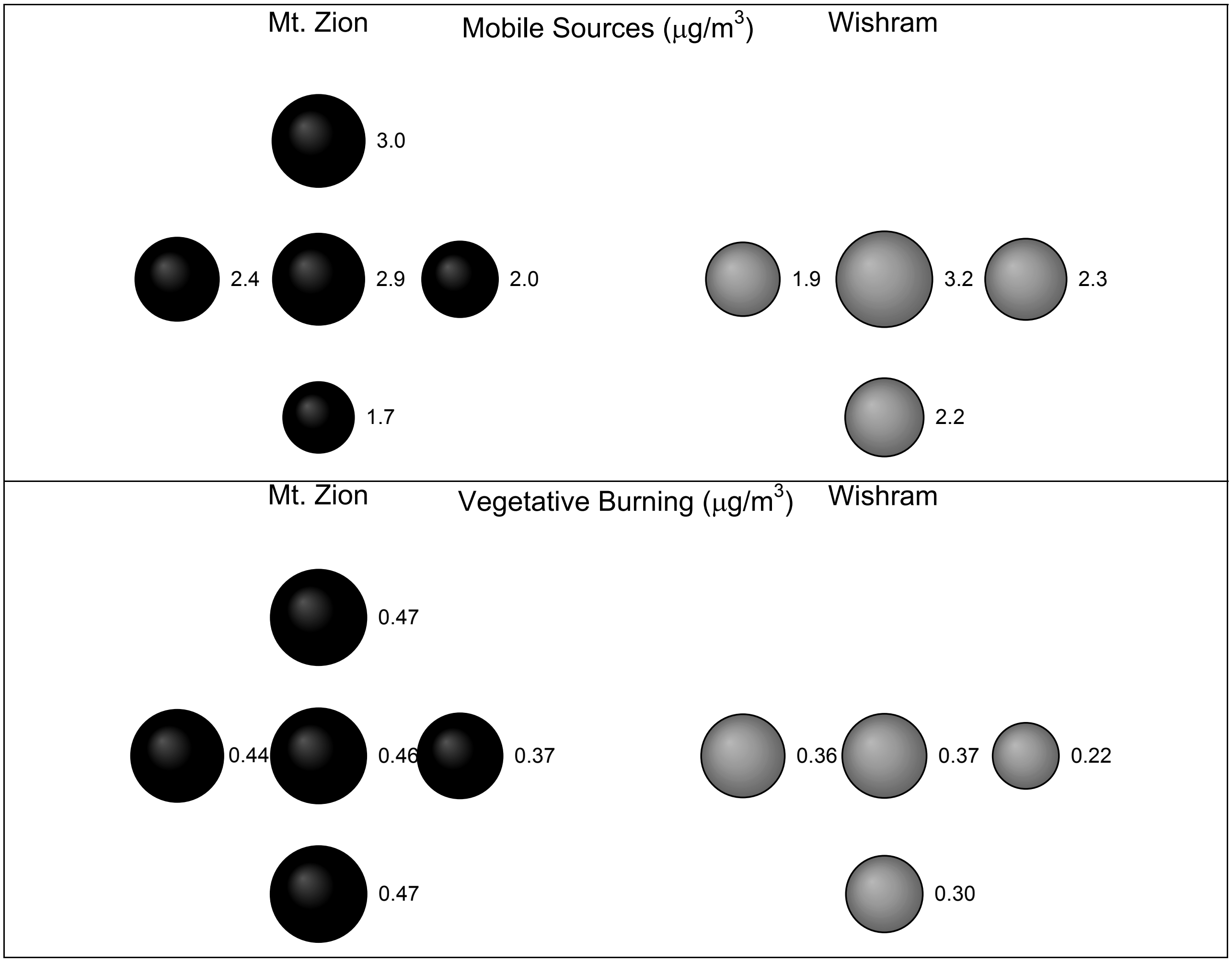

Figure 5-10. Surface wind classification grouping of average SCE's of mobile sources and vegetative burning. Black markers correspond to the Mt. Zion site and grey markers correspond to the Wishram site. The middle marker of each set represents the average attribute during calm conditions (daily average wind speed < 5 mph). The top, right, bottom, and left markers correspond to average attribute when winds are from the north, east, south, and west, respectively.

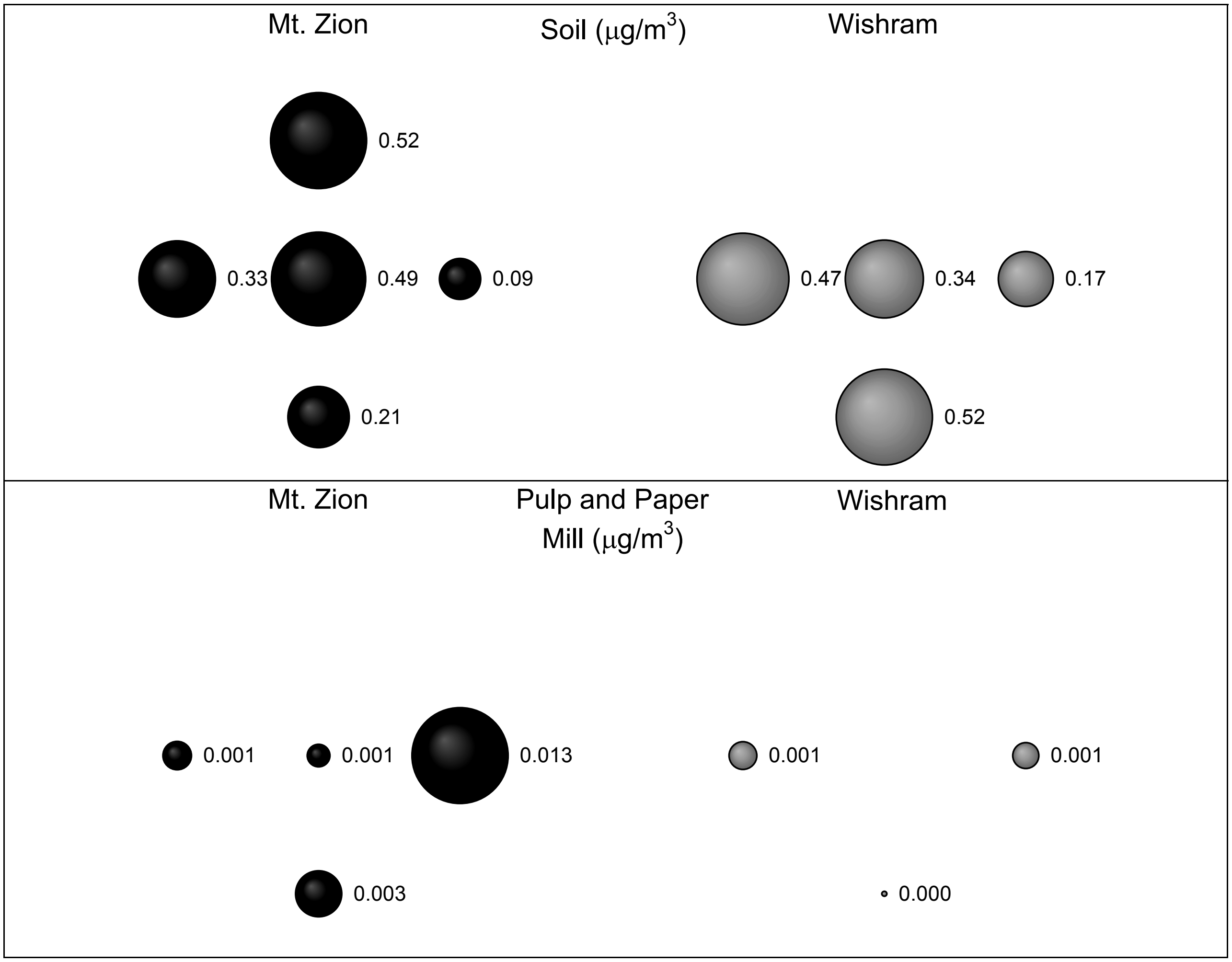

Figure 5-11. Surface wind classification grouping of average SCE's of geologic material (soil) and pulp and paper . Black markers correspond to the Mt. Zion site and grey markers correspond to the Wishram site. The middle marker of each set represents the average attribute during calm conditions (daily average wind speed < 5 mph). The top, right, bottom, and left markers correspond to average attribute when winds are from the north, east, south, and west, respectively.

5.4 Source Attribution of the 25% Best and 25% Worst Visibility Days

The 25% worst and 25% best visibility days were identified at each site using reconstructed fine mass extinction. Daily average *f*(RH) values were calculated for the Mt. Zion site using relative humidity data from the Troutdale meteorological station and for the Wishram site using its own monitor. The CIRA method of discarding RH values greater than 98% was applied prior to calculation the of daily *f*(RH).

5.4.1 Fine Mass Source Apportionment

Source attributions results were grouped representing the 25% best visibility (lowest B_{ext}) sample days, all sample days, and the 25% worst visibility (highest B_{ext}) sample days. Average $PM_{2.5}$ source attributions were calculated for each of the three groups. The relative contributions to $PM_{2.5}$ mass are shown in the pie charts in Figure 5-12. A high degree of consistency is observed at both locations for all types of visibility days. Carbonaceous aerosol sources (the sum of mobile sources and vegetative burning) dominate the $PM_{2.5}$ SCEs accounting for 50% and

47% of the apportioned mass on the worst visibility days and for 53% and 49% of the mass on the best days at the Mt. Zion and Wishram sites respectively. The relative contribution of sulfate to total mass is higher at Mt. Zion on the worst days (30%) than on the best days (17%). At Wishram the relative contribution of sulfate is 23% on both best and worst visibility days. On both good and bad visibility days, the soil contribution is a constant 6% at Mt. Zion. The aerosol at Wishram on the best 25% visibility days is 11% soil compared to 8% on poor visibility days. The combination of ammonium nitrate and aged marine aerosol (sodium nitrate) account for ~11% of the aerosol mass on both good and bad visibility days. At Wishram, the nitrate aerosols account for 14% of the mass on the worst days and only 9% of the mass on the best days. The presence of fresh marine aerosol (sodium chloride) is seldom observed on the worst visibility days. Sea salt accounts for 12% of the $PM_{2.5}$ mass at Mt. Zion and 4% of the $PM_{2.5}$ mass at Wishram on the clearest days.

These results are consistent with the conceptual model that coastal winds carrying sea spray and soil clear out secondary ammonium sulfate and ammonium nitrate on the 25% best visibility days. On the 25% worst visibility days, stagnant airflow allows the secondary precursors SO_2, NO_x, NH_3, and VOC to react and form ammonium nitrate and ammonium sulfate.

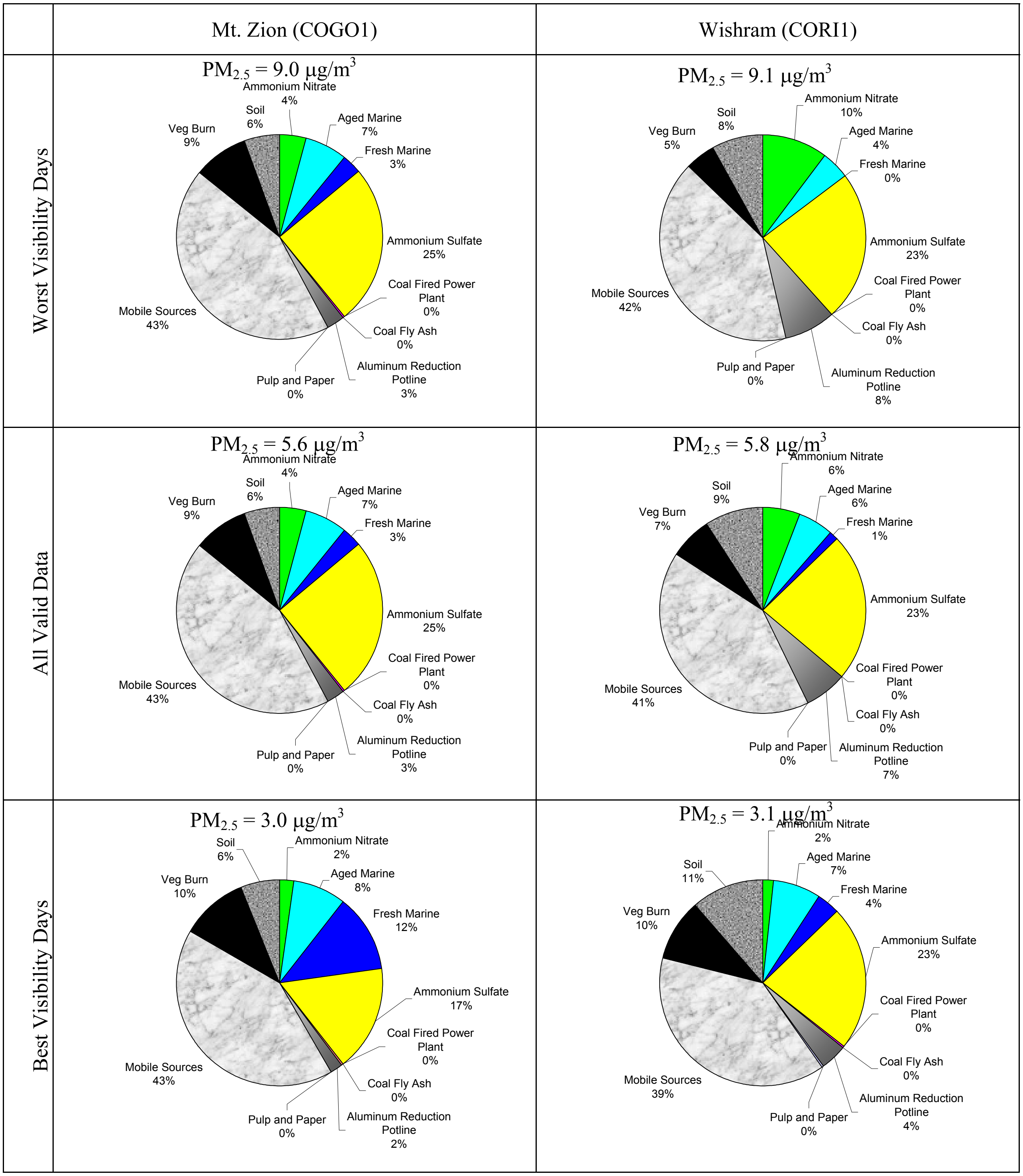

Figure 5-12. $PM_{2.5}$ Source Attribution Pie Charts for 25% worst, all, and 25% best visibility days in the Columbia River Gorge. These results reflect the output of the CMB model. Note that the carbonaceous SCE's of Mobile Sources and Vegetative Burning were not well resolved from each other. Their combined contribution should be considered as the source contribution of both sources. In addition, although the primary contribution of coal fired power plants is quite small, these facilities are the largest regional emitters of SO_2 that is a precursor to ammonium sulfate aerosol shown on the pie charts.

5.4.2 Visibility Source Apportionment

The CMB source apportionment was performed on $PM_{2.5}$ mass only. No speciation data exists for the coarse aerosol fraction at these sites precluding the apportionment of light extinction to the sources coarse mass in the aerosol. Individual components of the $PM_{2.5}$ scatter and absorb light with varying efficiencies. For hygroscopic aerosols, the ambient relative humidity can increase an aerosol component's efficiency to scatter light. An excellent discussion of the derivation of the reconstructed light extinction equation is available on the IMPROVE web site (IMPROVE, 2002).

The reconstructed aerosol extinction is defined by the following equation:

$$b_{ext} = 3 f_T(RH)\big([SULFATE] + [NITRATE]\big) + 4[OMC] + 10[LAC] + [SOIL] + 0.6[CM]$$

where b_{ext} is the reconstructed aerosol light extinction (Mm^{-1}), f_T(RH) is the relative humidity scattering enhancement factor, [SULFATE] and [NITRATE] are the fine (< 2.5 μm diameter) ammoniated ion concentrations (4.125[S] and 1.29[NO_3], respectively) in (μg/m^3), [OMC] is the fine organic material by carbon analysis concentration 1.4*[OC1 + OC2 + OC3 + OC4 +OP] in μg/m^3, [LAC] is the fine light absorbing carbon [EC1 + EC2 + EC3- OP] in μg/m^3, [SOIL] is the fine inorganic oxides of crustal species 2.2*[Al] + 2.49*[Si] + 1.63*[Ca] + 2.42*[Fe] + 1.94*[Ti] in μg/m^3, and [CM] is the coarse mass concentration [PM_{10}] – [$PM_{2.5}$]. Using the IMPROVE definition above, fine sea salt is not considered in the reconstructed light extinction equation. Since hygroscopic marine aerosol appear to account for a significant fraction (5 to 20%) of the $PM_{2.5}$ mass, we approximate the marine scattering efficiency here by including the mass of fresh (sodium chloride) marine aerosol [MARINE] = 1.74*[Cl^-] with the sulfate and nitrate in the hygroscopic term of the equation above. Note that light scattering of aged marine aerosol (sodium nitrate) is treated as ammonium nitrate in the extinction equation above.

The $PM_{2.5}$ CMB source profiles are arrays of the relative abundances of chemical species (A_i for species i) in the emissions from a particular source category. A source extinction efficiency for $PM_{2.5}$ with units of (Mm^{-1})/(μg/m^3) can be derived for each profile using the reconstructed aerosol equation above. The source extinction efficiency is defined here as:

$$\eta_{ext} = a + b \cdot f_T(RH)$$

where a is the non-hygroscopic light extinction efficiency of the source profile ($4A_{[OMC]}+10A_{[LAC]}+A_{[Soil]}$) and b is the hygroscopic light extinction efficiency of the source profile ($3A_{[SULFATE]} + 3A_{[NITRATE]} + 3A_{[MARINE]}$). Conceptually, the source extinction efficiency indicates how much extinction would result from one μg/m^3 of $PM_{2.5}$ from a source for a particular f_T(RH).

Table 5-4 shows the mass component fractions and light extinction efficiencies based on the abundances in each of the source profiles used in the CMB source attribution. Due to the abundance of light absorbing carbon (EC) in their source profiles, mobile sources followed by vegetative burning sources have the highest non-hygroscopic extinction efficiencies. Sulfates, nitrates, and marine aerosols have the potential to extinguish more light per unit mass when f(RH) > 2 (RH > 60%). Primary emissions from coal fly ash and pulp and paper mills have the least light extinction efficiency.

Table 5-4. Mass component fractions and light extinction efficiencies of the source profiles used in the CMB source attribution.

		$PM_{2.5}$ Mass Component Fractions						Light Extinction Efficiencies ($Mm^{-1}/(\mu g/m^3)$)	
Source ID	Profile	SULFATE	NITRATE	MARINE	OMC	LAC	SOIL	Non-hygroscopic *A*	Hygroscopic *b*
AMNIT	Ammonium Nitrate	0.00	1.00	0.00	0.00	0.00	0.00	0.00	3.00
AMSUL	Ammonium Sulfate	1.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00
ARPL	Aluminum Potline Reduction	0.21	0.01	0.00	0.49	-0.04	0.05	1.59	0.65
BVCFPP	Primary Coal Fired Power Plant	0.34	0.01	0.02	0.38	0.01	0.70	2.35	1.09
BVCLFA	Primary Coal Fly Ash	0.10	0.01	0.00	0.02	0.01	0.63	0.86	0.32
BVRDMV	Mobile Source Exhaust	0.06	0.00	0.01	0.82	0.37	0.03	7.03	0.20
KTSSOIL	Soil	0.01	0.00	0.00	0.11	0.01	0.83	1.34	0.03
MAR0	Aged Marine	0.08	0.91	0.00	0.00	0.00	0.01	0.01	2.96
MAR100	Fresh Marine	0.11	0.00	1.00	0.00	0.00	0.02	0.02	3.32
SAPPILK1	Pulp and Paper Mill	0.00	0.01	0.00	0.11	0.01	0.16	0.64	0.04
BURN3-7	Vegetative Burning	0.03	0.00	0.15	0.67	0.07	0.01	3.42	0.53

For each sample day with valid aerosol mass and speciated concentration data, f(RH), and CMB source attribution, each $PM_{2.5}$ mass SCE was multiplied by its respective source extinction efficiency for that day $\eta_{ext}(f(\mathrm{RH}))$. The product of these terms is the $PM_{2.5}$ light extinction SCE for each source. The sum of all $PM_{2.5}$ light extinction SCE's is compared with the reconstructed fine mass light extinction (RFME) observed at the Mt. Zion and Wishram sites in Figure 5-13. Excellent agreement is observed between the two datasets at both sites. The quality of the fit is an indicator to how well the CMB attribution reproduces the concentrations of species that are most significant to fine mass light extinction. A small positive bias of ~5% of the slope and an intercept of 5 Mm^{-1} is observed because the $PM_{2.5}$ light extinction SCEs includes a marine component and the RFME does not.

The relative attributions of haze below refer only to fine aerosol light extinction. Coarse particles (i.e. from particles with diameters between 2.5 μm and 10 μm) and atmospheric gases also contribute to visual haze. Coarse mass was measured at the Wishram site only. On average, coarse mass extinction accounts for 12%, fine aerosol light extinction accounts 65%, and Rayleigh scattering accounts for 23% of the total reconstructed light extinction.

The $PM_{2.5}$ light extinction SCE's were averaged based on the 25% worst, all, and 25% best visibility days. Figure 5-14 shows 6 pie charts indicating the relative contributions of each source to light extinction at both the Mt. Zion and Wishram site on the the 25% worst, all, and 25% best visibility days. The relative distribution of the SCEs indicate that on the worst visibility days carbonaceous aerosol sources (mobile sources and vegetative burning) account for 44% of the light extinction at Mt. Zion and 42% of the $PM_{2.5}$ light extinction at Wishram. On the cleanest 25% of days, these sources are responsible for 50% and 61% of the $PM_{2.5}$ light extinction at the Mt. Zion and Wishram sites respectively. On poor visibility days, ammonium sulfate accounts for 40% of the $PM_{2.5}$ light extinction at Mt. Zion and 30% at Wishram. On the clearest 25% of days, ammonium sulfate is responsible for less than 22% of the fine aerosol haze at both sites. Ammonium nitrate and aged sea salt each account for 7% of the fine aerosol haze at Mt. Zion on the worst days. On poor visibility days at Wishram, 13% of the haze is due to ammonium nitrate and 8% is due to aged marine aerosol. Fresh marine aerosol is responsible for less than 1% of the $PM_{2.5}$ light extinction on poor visibility days. On the cleanest days however, fresh marine aerosol accounts for 18% of the fine aerosol light extinction at Mt. Zion and 4% at the Wishram site.

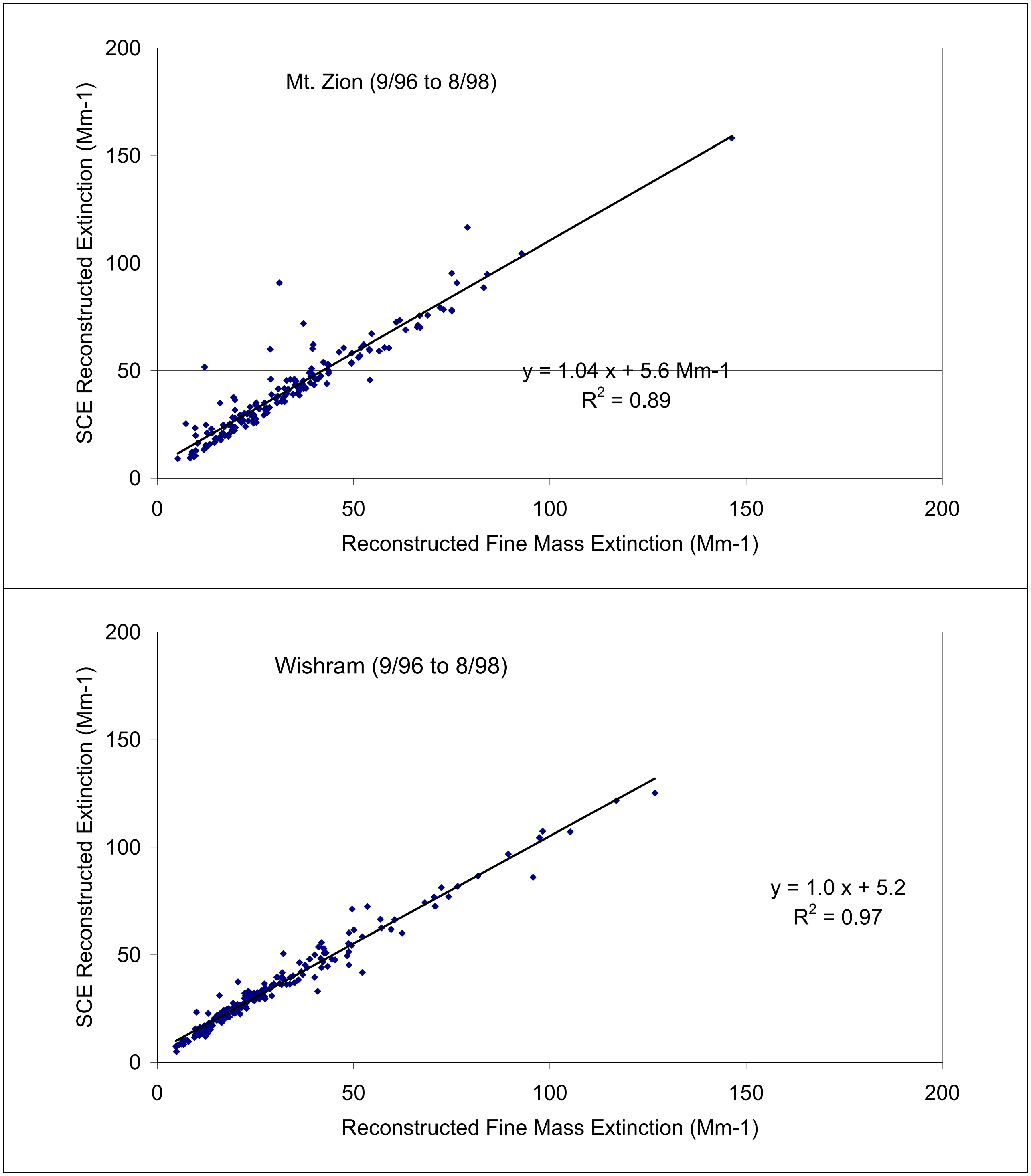

Figure 5-13. Comparison of the sum of all light extinction SCE's with the reconstructed fine mass extinction at the Mt. Zion and Wishram sites in the CRG.

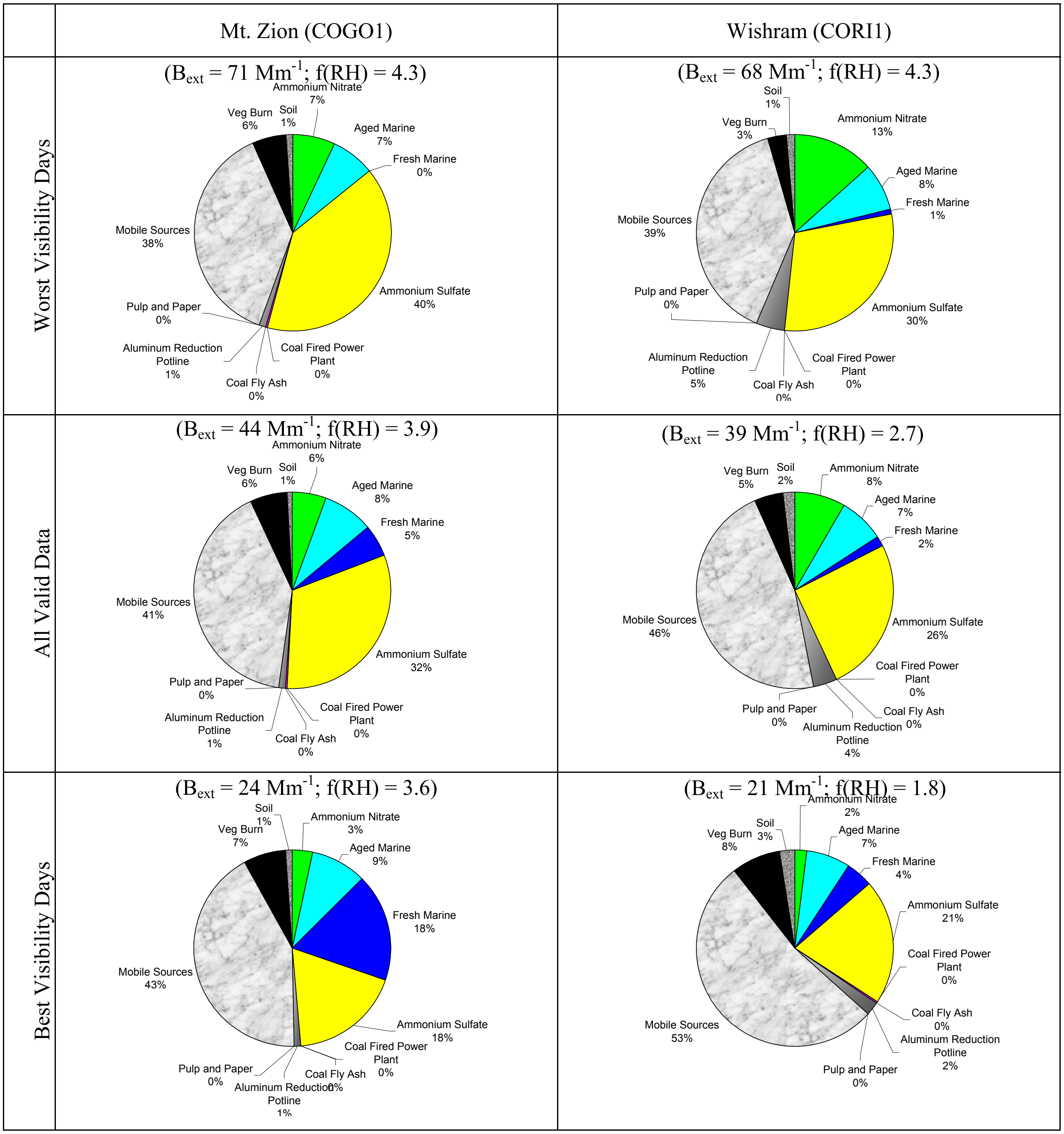

Figure 5-14. $PM_{2.5}$ Source Attribution Pie Charts for 25% worst, all, and 25% best visibility days in the Columbia River Gorge. These results reflect the output of the CMB model. Note that the carbonaceous SCE's of Mobile Sources and Vegetative Burning were not well resolved from each other. Their combined contribution should be considered as the source contribution of both sources. In addition, although the primary contribution of coal fired power plants is quite small, these facilities are the largest regional emitters of SO_2 that is a precursor to the ammonium sulfate fraction shown on the pie charts.

6. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the findings of previous sections and draws conclusions about ambient measurements, emissions characterization, and source contributions. Recommendations are given for improvements in ambient and source characterization of $PM_{2.5}$.

6.1 Summary

A two-year mass and chemically-speciated aerosol data base for the Columbia River Gorge Scenic Area was downloaded from the IMPROVE web site. Twenty-four hour samples obtained on Wednesdays and Saturdays were documented and evaluated. $PM_{2.5}$ for each sample with valid chemical concentrations was apportioned to sources identified in the region.

6.1.1 Data Quality

An evaluation of the $PM_{2.5}$ measurements showed the following:

- $PM_{2.5}$ was reasonably reproduced by a weighted sum of major chemical components.
- Sulfate measured by ion chromatography on the nylon-membrane was three times the total sulfur measured by PIXE on Teflon-membrane filters for nearly every sample. This means that: 1) all of the sulfur is in the soluble form of the sulfate; 2) IMPROVE modules A and B sampled the same aerosol with equivalent sample volume; and 3) the ion chromatography and PIXE analyses are accurate, precise, and traceable to equivalent calibration standards.
- On individual cases, inconsistencies were observed between the ambient chloride measured by PIXE and the chloride measured by IC. The stated uncertainties did not account for all of the discrepancies between the two measurement methods.

6.1.2 $PM_{2.5}$ Mass and Chemical Concentrations

Temporal and spatial variations of $PM_{2.5}$ mass and chemical compositions showed the following characteristics:

Worst 25% Visibility Days:

- The average $PM_{2.5}$ concentration on the 25% worst visibility days in the CRG during the modeling period was 9.0 μg/m3 at Mt. Zion and 9.1 μg/m3 at Wishram.
- The largest component of the aerosol mass in the organic material that accounts for 39% of the fine aerosol mass at Mt. Zion and 38% of the fine aerosol mass at Wishram.
- The next largest component is ammonium sulfate that accounts for 30% and 24% of the aerosol mass on the worst days at Mt. Zion and Wishram, respectively.
- Ammonium nitrate and soil account for nearly equal amounts of the worst days aerosol mass at both sites: 9% to 10% each at Mt. Zion and 12% each at Wishram.
- Elemental carbon accounts for the least amount of fine mass on the 20% worst visibility days: 6% at Mt. Zion and 7% at Wishram.

Average Visibility Days

- The two year average $PM_{2.5}$ at the Mt. Zion site on the western end of the Gorge was 5.5 $\mu g/m^3$ and was 5.8 $\mu g/m^3$ at the Wishram site on the east end of the Gorge. The highest concentrations of $PM_{2.5}$ occurred on 04/29/1998 at both sites with 23.5 $\mu g/m^3$ at Mt. Zion 26.4 $\mu g/m^3$ at Wishram. This event coincided with satellite observations of an Asian dust storm originating in the Gobi Desert impacting the states of Washington and Oregon in the US.
- Chemical concentrations were consistent at both ends of the Gorge. Organic carbon was the largest $PM_{2.5}$ component at each site (26% to 29%), followed by sulfate (18%).
- Organic carbon concentrations were highest during fall at both sites. Elemental carbon was highest in fall and winter at the Mt. Zion site and highest during summer and fall at the Wishram site.
- Sulfate concentrations showed a strong seasonal cycle with a summertime peak. Summertime sulfate was highest at the Mt. Zion site when compared to the Wishram site. Nitrate concentrations were more than 2 times higher in winter (0.78 $\mu g/m^3$) than any other season at the Wishram site. At Mt. Zion, seasonal average nitrate levels only ranged from 0.38 $\mu g/m^3$ to 0.41 $\mu g/m^3$ for all seasons.
- Regional events such as the Asian dust storm on 4/29/1998 and the forest fire on 9/24/1997 are examples where the visual haze was dominated by emissions from a particular source type. These samples provide information on the source profiles for these sources that may be useful for attributing $PM_{2.5}$ and visibility impacts on days when these sources are less dominant.

6.1.3 Receptor Modeling

The Chemical Mass Balance (CMB) receptor model estimated $PM_{2.5}$ source contributions to 401 samples. Primary mobile source exhaust, primary vegetative burning, secondary ammonium sulfate, secondary ammonium nitrate, primary marine aerosol, aged marine aerosol (sodium nitrate), geological material, and industrial point sources (e.g., aluminum smelting, coal fired power plants, and paper mills) were test fitted on every sample. Eight carbon fraction species were used as fitting species in the source attribution. CMB performance measures were within acceptable limits on most of the samples, with R-SQUARE above 0.80, CHI-SQUARE less than 4, and PERCENT MASS between 80% and 120%.

6.2 Conclusions

6.2.1 $PM_{2.5}$ Source Attribution

The data summarized below are the results of the CMB model output. The Source Contribution Estimates (SCEs) were calculated from the CMB model and represent an estimate of the relative source contribution based on the all of the assumptions made when applying the model (Section 5.1).

The major findings for this study are as follows:

All Days

- Primary mobile source exhaust, secondary ammonium sulfate, primary vegetative burning, and soil were the major contributors to $PM_{2.5}$ at both sites.
- The ability of the CMB model to distinguish mobile source and vegetative burning source contributions using the selected profiles was tested for samples collected on 9/24/1997. The highest levels of organic and elemental carbon concentrations were observed at both sites on this day. The regional distribution of these extreme concentrations and the late summer timing is consistent with a wildfire event impacting the region. The SCE's at the two receptor sites attributed the mass to mostly mobile sources at the Wishram site and to mostly vegetative burning at the Mt. Zion site. The lack of consistency of the SCEs at the two sites implies that of attributions to mobile sources and vegetative burning should be joined to represent contributions from the combination of the two sources.
- On average, 50% of the $PM_{2.5}$ mass was attributed to carbonaceous aerosol (mobile source and vegetative burning) and ~24% to ammonium sulfate at both the Mt. Zion and Wishram sites.
- The aerosol at Wishram contained 50% more soil than at Mt. Zion (9% and 6% of $PM_{2.5}$, respectively).
- The combination of ammonium nitrate and aged marine aerosol (sodium nitrate) accounted for ~12% of the aerosol mass at both locations. Fresh marine aerosol (sodium chloride) was accounted for 3% of the $PM_{2.5}$ at Mt. Zion and 1% at Wishram.
- The aluminum smelter SCE accounted for 7% of the fine aerosol mass at Wishram but only 2% at Mt. Zion. Contributions from paper mill and coal power plants were low (<1 %) and their chemical composition was indistinguishable from primary soil and secondary sulfate SCEs.
- During summer months, most of the marine aerosol is neutralized to sodium nitrate by nitric acid generated by photochemical conversion of oxides of nitrogen emissions.
- Elevated geological material contributions were found during spring and late summer.

Worst Visibility Days

- Carbonaceous aerosol SCE's (the sum of mobile sources and vegetative burning) dominate the $PM_{2.5}$ SCEs accounting for 50% and 47% of the apportioned mass.
- The relative contribution of sulfate SCE to total measured mass is 30% at Mt. Zion and 23% at Wishram. Coal fired power plants are the largest emitters of SO_2 that is a precursor for sulfate aerosol
- The soil SCE is 6% at Mt. Zion and 8% at Wishram.
- The aluminum smelter SCE accounted for 3% of the fine mass at Mt. Zion and 8% of the fine mass at Wishram.
- Ammonium nitrate SCE was a larger component of the fine aerosol mass at Wishram (10%) than at Mt. Zion (5%).

- At Mt. Zion and Wishram, aged marine aerosol SCE accounted for 6% and 4% of the aerosol mass respectively.
- SCE's of primary emissions from coal fired power plants, pulp and paper mills, and fresh marine are less than 1%.

Wind Direction Analysis

- At both locations fine aerosol light extinction is greatest when winds are calm due to both high aerosol mass and the aerosol growth term *f*(RH).
- The average marine SCE (i.e. the sum of the fresh and aged marine SCE) is largest when surface winds are blowing from the north and west at Mt. Zion and when they are blowing from the south and west at Wishram.
- At the Wishram site, ammonium sulfate SCE is largest with winds are from the east in the direction of the Portland General Electric Power Station. At Mt. Zion ammonium sulfate is elevated when winds blow from the north and west where the Pacificorp-Centrailia Coal Fired Power Plant is located.
- The largest aluminum reduction potline SCE's occur during calm conditions at Wishram. This is consistent with the location of aluminum companies to the east and west of the monitoring site.
- Mobile source and biomass burning SCE's are the least dependent of all sources on wind classification.
- Geologic material or soil SCE's are highest when winds are from the north or calm at Mt. Zion and from the west or south at Wishram.

6.2.2 Visibility Source Attribution

Fine aerosol visibility SCEs were estimated by calculating a light extinction efficiency for each source profile. The source extinction efficiency permitted the estimation of $PM_{2.5}$ light extinction based on the $PM_{2.5}$ SCE and the f_T(RH) relative humidity scattering enhancement factor for that day.

The relative attributions of haze below refers only to fine aerosol light extinction. Coarse particles (i.e. from particles with diameters between 2.5 μm and 10 μm) and atmospheric gases also contribute to visual haze. Coarse mass was measured at the Wishram site only. On average, coarse mass extinction accounts for 12%, fine aerosol light extinction accounts 65%, and Rayleigh scattering accounts for 23% of the total reconstructed light extinction.

Average Visibility Days

- SCE's of carbonaceous aerosol were responsible for 47% and 51% of the $PM_{2.5}$ light extinction at the Mt. Zion and Wishram sites, respectively.
- Ammonium sulfate SCEs were responsible for 32% of the haze at Mt. Zion and 26% at Wishram.
- The aluminum smelting SCE accounted for 4% of the fine aerosol light extinction at Wishram, but only 1% at Mt. Zion.

- Fresh and aged marine aerosol SCE's caused 13% of the haze at Mt. Zion, but only 9% at Wishram.
- SCE's of fine geologic material was responsible for less than 2% of the light extinction at both sites.
- The SCE's of primary emissions from paper mills and coal fired power plants were not distinguishable from the impacts caused by fine geologic material.
- Ammonium nitrate SCE was responsible for 6% of the fine particle haze at Mt. Zion and 8% at Wishram.

Worst Visibility Days

- The relative distribution of the SCEs indicate that carbonaceous aerosol sources (mobile sources and vegetative burning) account for 44% of the light extinction at Mt. Zion and 42% of the $PM_{2.5}$ light extinction at Wishram.
- Ammonium sulfate SCE accounts for 40% of the $PM_{2.5}$ light extinction at Mt. Zion and 30% at Wishram.
- Ammonium nitrate SCE and aged sea salt SCE each account for 7% of the fine aerosol haze at Mt. Zion.
- At Wishram, 13% of the haze is due to ammonium nitrate SCE and 8% is due to aged marine aerosol SCE.
- Fresh marine aerosol SCE is responsible for less than 1% of the $PM_{2.5}$ light extinction on poor visibility days.

6.3 Recommendations

The following subsections identify possible improvements for future monitoring and modeling efforts. Given limited resources, priority should be given to resolution of biomass burning and motor vehicle source contributions. Efforts should be directed toward the collection of independent corroborative data through a combination of emissions inventory improvement, ambient monitoring, source characterization, and modeling. A multifaceted approach will provide more confidence in results that agree across various technique when compared with a result from a single approach.

6.3.1 Emissions Inventory

The emissions inventory (EI) is an independently derived database that can be used to support or contradict receptor model source apportionments. The EI serves as the foundation of all air quality simulation models and is frequently the basis for determining control strategies. An inaccurate EI can lead to erroneous evaluations of the causes of haze and may also lead to the implementation of controls that are not cost-effective.

Large discrepancies (factor of 4 to 10) were observed between the NEI forest fire emissions and the state produced fire inventory. The source of these discrepancies should be resolved. Because fires occur for brief episodes and at inconsistent location, an improved database of fire emissions should be developed that is resolved in space, time, and intensity of emissions.

Improvements in the estimation of mobile source emissions are also needed in concert with improvements in fire emissions. The current PART5 PM emissions model uses outdated emissions factors (light duty gasoline vehicles of model year 1993 and older) to estimate emissions from the current in-use fleet. Efforts should be made to incorporate modern fleet emissions factors into the estimation of mobile sources.

Fugitive dust emissions remain the largest source of PM_{10} in the emissions inventory yet their contribution ambient PM concentrations is much less than the emissions inventory would imply. An improved quantitative handling of the deposition of coarse particles needs to be incorporated either in the emissions inventory or within the air quality models. This processing should take into consideration the various types of vegetation coverage that may scavenge particles close to their sources. The ambient data show large seasonal variations in the SCE's of fugitive dust. The emissions inventory should be able to reflect these seasonal changes in emissions that occur due to changes in soil moisture levels.

Residential wood combustion (RWC) is a dominant source of $PM_{2.5}$ in the emissions inventory, but there is little or no increase in organic aerosol concentrations during wintertime in the CRG. Estimates of RWC emissions need further analysis. Surveys of RWC activities are quite useful for improving estimation of this source.

A focused effort to develop an accurate emissions inventory is an involved undertaking. Resources may be best expended by contributing to a larger effort such as the WRAP emissions inventory forum or focusing efforts on a limited scope to address the greatest sources of uncertainty (i.e. resolving mobile source and fire emissions).

6.3.2 Chemical Analysis

Ammonium is an important chemical component in the CRG area, this species should be measured along with sulfate and nitrate. The ammonium measurements can be used to verify anion and cation balance, to understand the extent of ion neutralization, and to serve as a validation check for sulfate and nitrate which compares the measured ammonium with the ammonium concentrations estimated from the stoichiometry of different chemical compounds.

Given the magnitude of vegetative burning and marine aerosol contributions in the study areas, chemical speciation for water-soluble potassium and sodium are needed to better distinguish these contributors from other sources. Soluble potassium is enriched in burning emissions that evidence themselves in ambient samples by high (> 0.9) soluble potassium to total potassium ratios.

Several specialized measurements can now be taken in ambient and source emissions, such as organic compounds (heavy organics, polycyclic aromatic hydrocarbon [PAHs]), isotopes (e.g., ^{14}C), and individual particles by electron microscopy (e.g., particle shape, color, number, composition). A subset of ambient and source samples should be selected for further chemical speciation to better separate the mobile source and vegetative burning contributions. For future apportionment of carbonaceous components, it may be useful to add canister sampling for light hydrocarbon (C_2 to C_{10}), Tenax sampling for heavy hydrocarbons (C_8 to C_{20}), and PUF/XAD/Filter sampling for gaseous and particle PAHs in the ambient and source samples to separate gasoline-versus diesel-fueled vehicle exhaust contributions, and to better distinguish between vegetative burning and cooking. In addition, measurement of the isotopic ratios of carbon in the aerosol mass can indicate if the origin of carbonaceous aerosol is modern (i.e. vegetative burning and cooking) or ancient (i.e. fossil fuel combustion).

Coarse mass in coastal environments may be due to either marine aerosol or to crustal species. In order to better apportion the sources of haze in the CRG, coarse mass should be measured at the Mt. Zion site in addition to the Wishram site. A select number of these filter samples should be chemically analyzed to determine what fraction of the coarse mass is naturally emitted from the ocean and what fraction is generated by human activities such as road dust and soil disturbance.

6.3.3 Ambient Monitoring

Recent advances in continuous measurement of carbonaceous aerosol and sulfate aerosol permit half hour or better sampling of these species. When used in conjunction with on site meteorological data similar to the wind classification analysis in section 5.3, more detailed spatial data about the major sources of haze can be inferred. Continuous carbon, sulfate, and nitrate monitors should be deployed at sites within the Gorge to better resolve the sources of the major haze components.

6.3.4 Source Profiles

A major limitation of this source apportionment study is the lack of source profiles specific to the Columbia River Gorge that are applicable to the measurement period, sampling sites, and chemical species on the ambient samples. Where possible, detailed organic compounds should be acquired along with the elemental, ionic, and carbon measurements that are normally applied to source and receptor samples. Profiles are needed for the following sources:

- On-road gasoline- and diesel-fueled vehicles by road-side tests in source-dominated environments such as underpasses, parking garages, and tunnels.
- Vegetative burning in modern wood stoves and fireplaces with different types of appliances, control device, and fuels.
- Vegetative burning from agricultural fields, slash burns, and forest fires for different crops, wood types, and burning conditions.
- Geologic material from the forested and urban areas near the Western Gorge and desert areas on the Eastern end of the Gorge.
- Geologic material associated with Asian dust storms.

6.3.5 Attribution Methods

The CMB attribution technique fits measured profiles of sources thought to be significant at the receptor to ambient data to produce source attributions. Other techniques such as Positive Matrix Factorization (PMF) (Paatero and Tapper, 1994) or UNMIX (Henry, 2002) extract the principle factors (i.e. source profiles) along with their uncertainties from speceiated ambient data sets. Assigning specific sources to these factors requires the user to make assumptions. These assumptions may be verified by comparing these calculated factors with profiles sampled directly from sources.

Using this approach more representative source profiles for local geologic material, Asian dust, vegetative burning, and mobile source emissions may be calculated that better explain the measured concentrations at the receptor sites.

A recent PMF analysis for the same modeling period as this report was conducted by Keith Rose of EPA Region 9 (Appendix E). The preliminary report identifies 8 sources that explain the variance of measured specieated aerosol concentrations between 9/1/96 an 9/1/98. These sources have been labeled with a tentative source description based on their annual timing of peak concentration, chemical specieation, and comparison with emissions inventories.

Additional effort is needed to compare the timing and specieation of the PMF factors with the CMB attributions. Wind classification analysis of the PMF results should be compared to the emissions inventory maps to develop conceptual models of major important source regions. The focus of this effort should be to identify similarities and differences of the two attribution results.

Ultimately, an improved set of source profiles should be obtained using factorization methods and using ambient data from days known to be impacted by distinct sources (i.e. Asian dust on 4/29/98 and fire on 8/24/97). These profiles may be used with CMB model to more accurately attribute the sources of haze in the Columbia River Gorge.

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A. EMISSIONS INVENTORY MAPS OF OREGON, WASHINGTON, AND CANADA

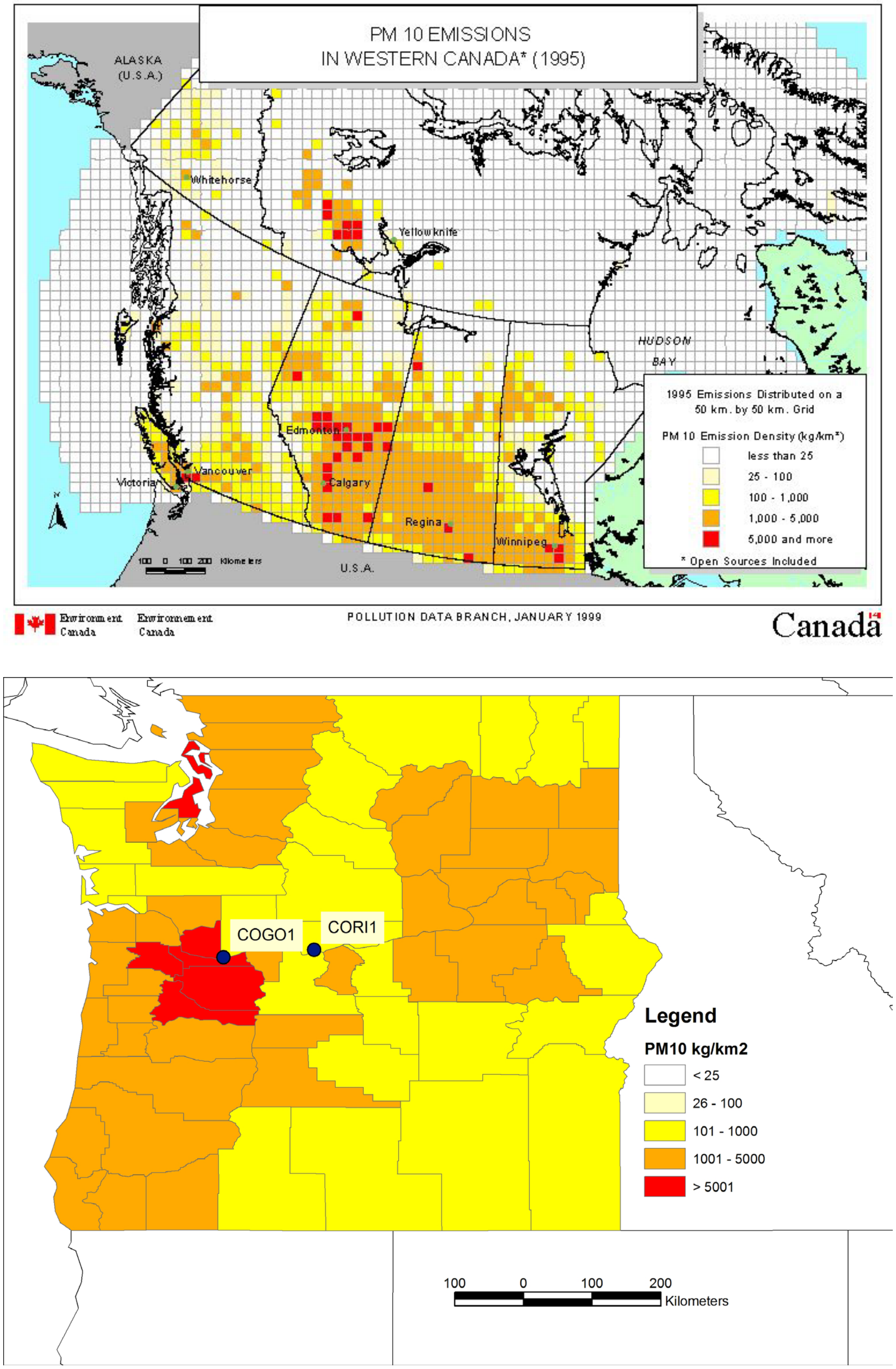

Figure A-1. PM$_{10}$ Emissions Inventory maps for Washington, Oregon, and Western Canada.

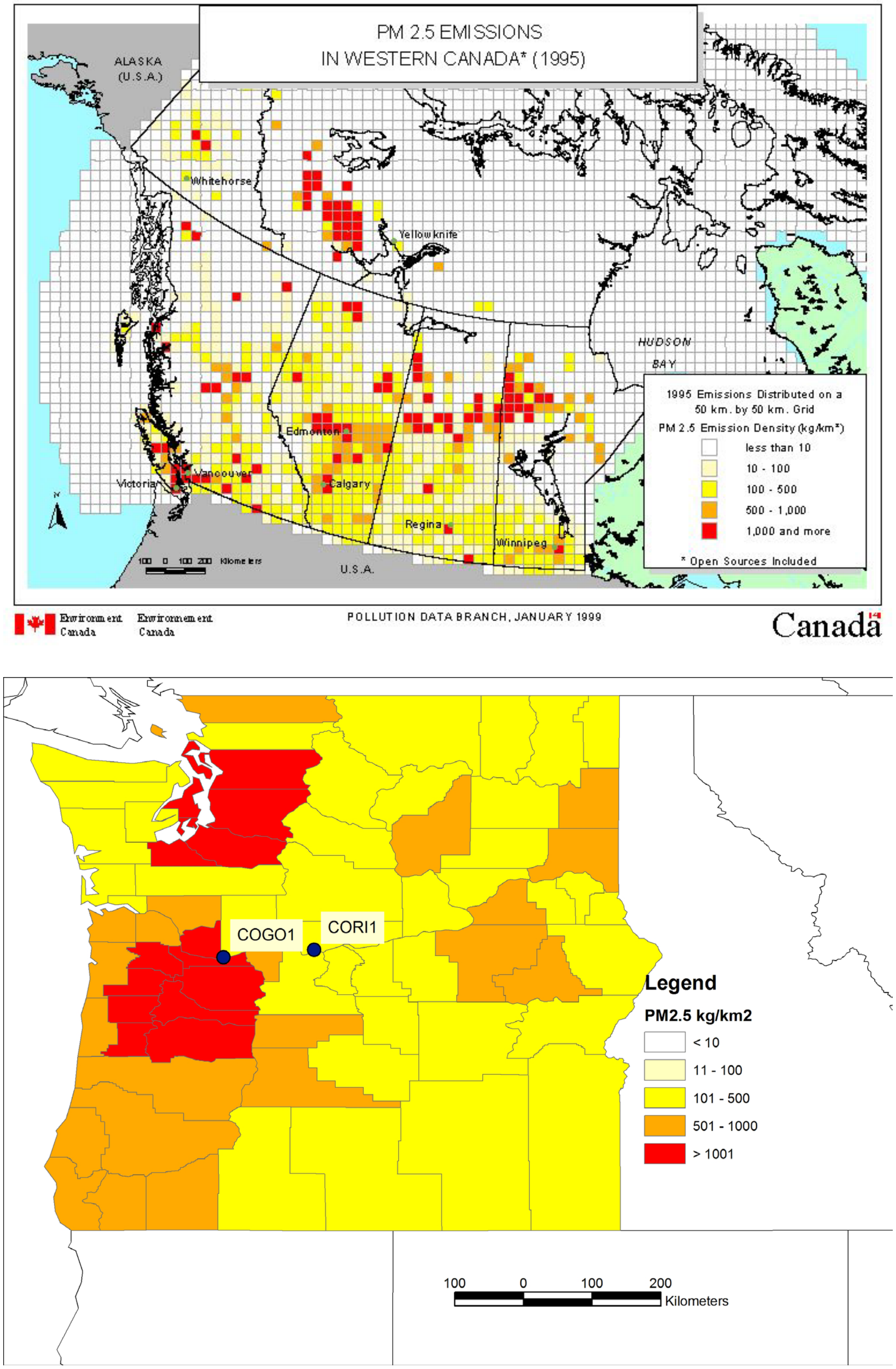

Figure A-2. PM$_{2.5}$ Emissions Inventory maps for Washington, Oregon, and Western Canada.

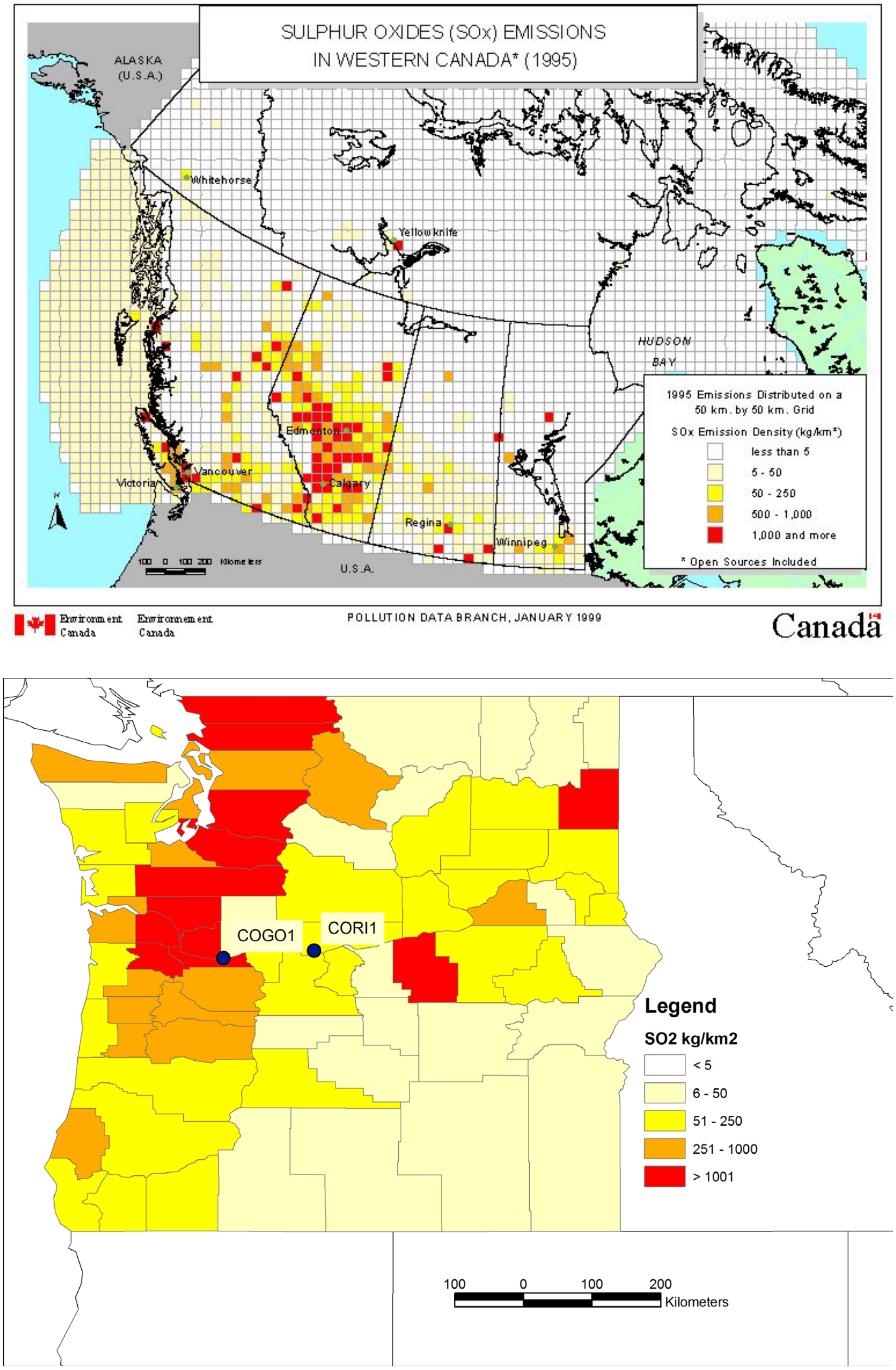

Figure A-3. SO_2 Emissions Inventory maps for Washington, Oregon, and Western Canada.

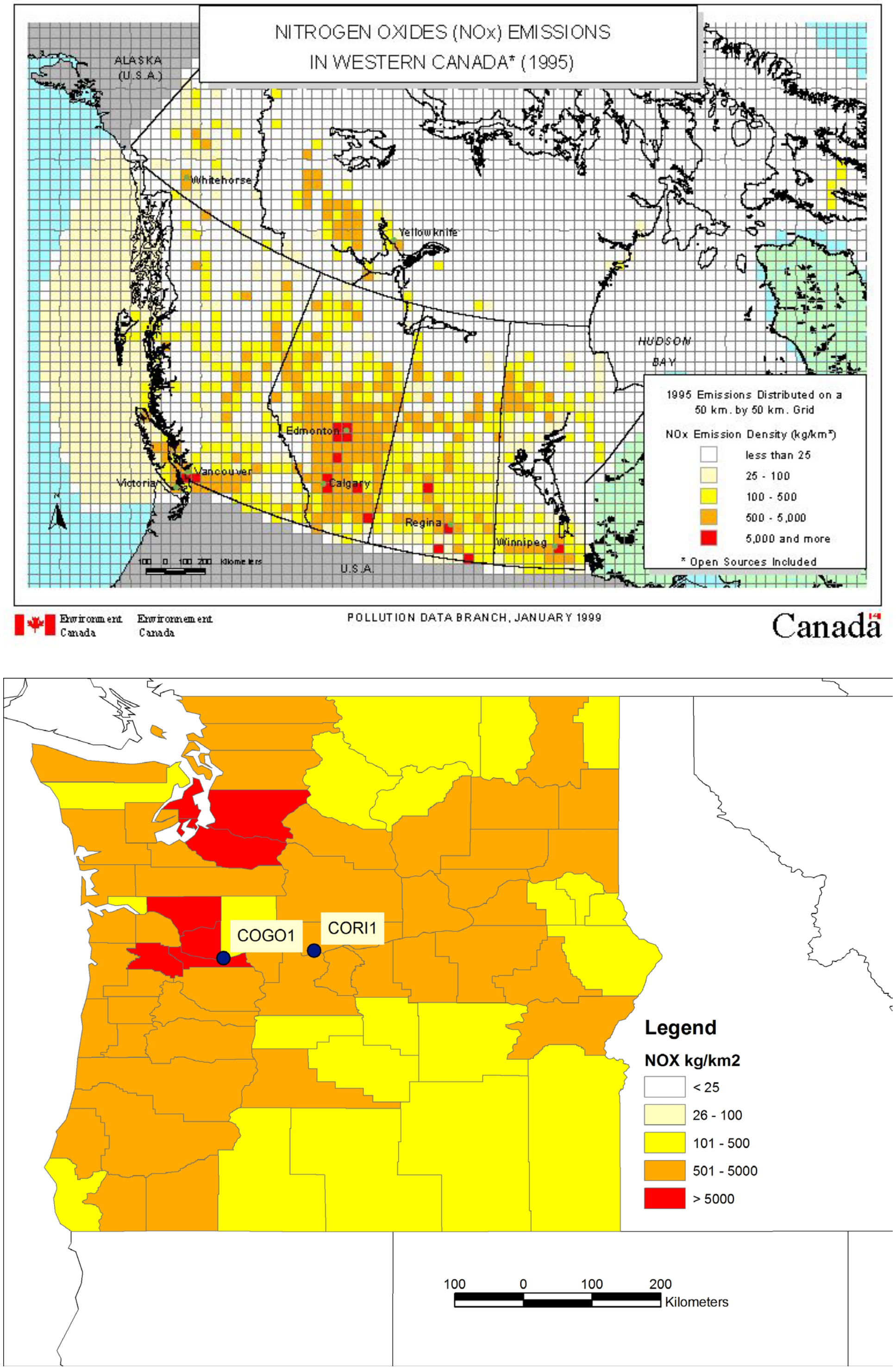

Figure A-4. NO$_x$ Emissions Inventory maps for Washington, Oregon, and Western Canada.

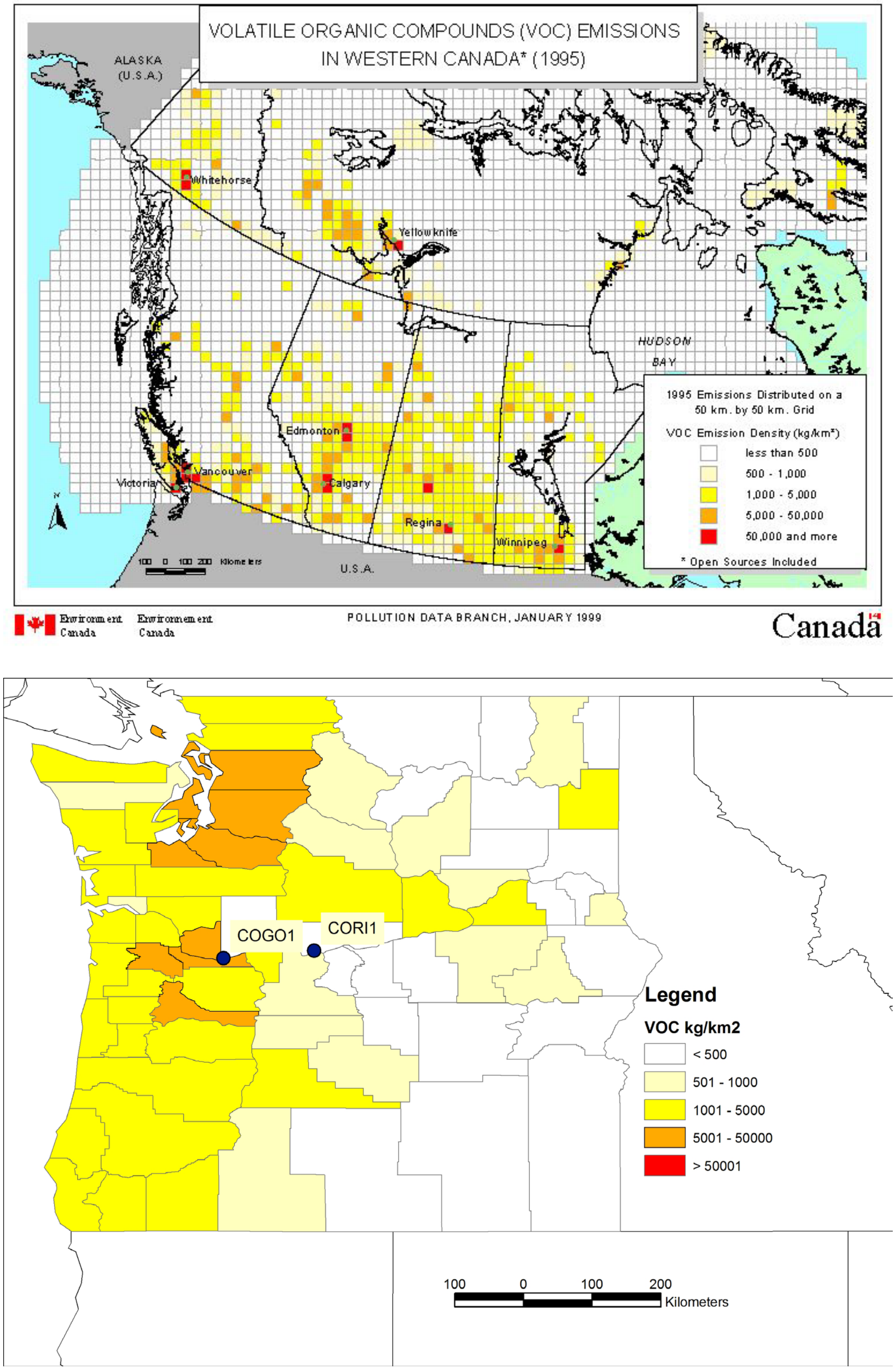

Figure A-5. . VOC Emissions Inventory maps for Washington, Oregon, and Western Canada.

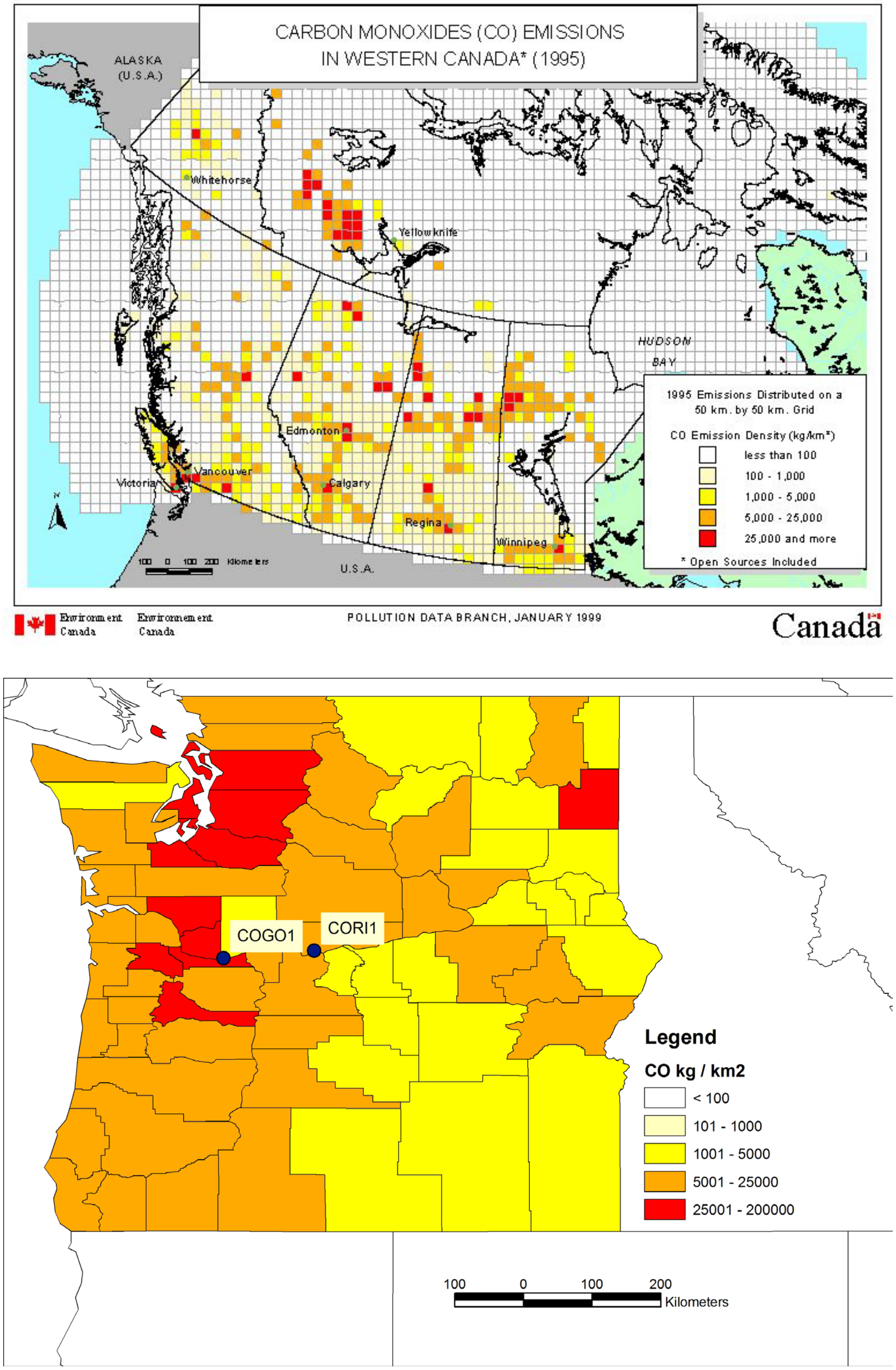

Figure A-6. . CO Emissions Inventory maps for Washington, Oregon, and Western Canada.

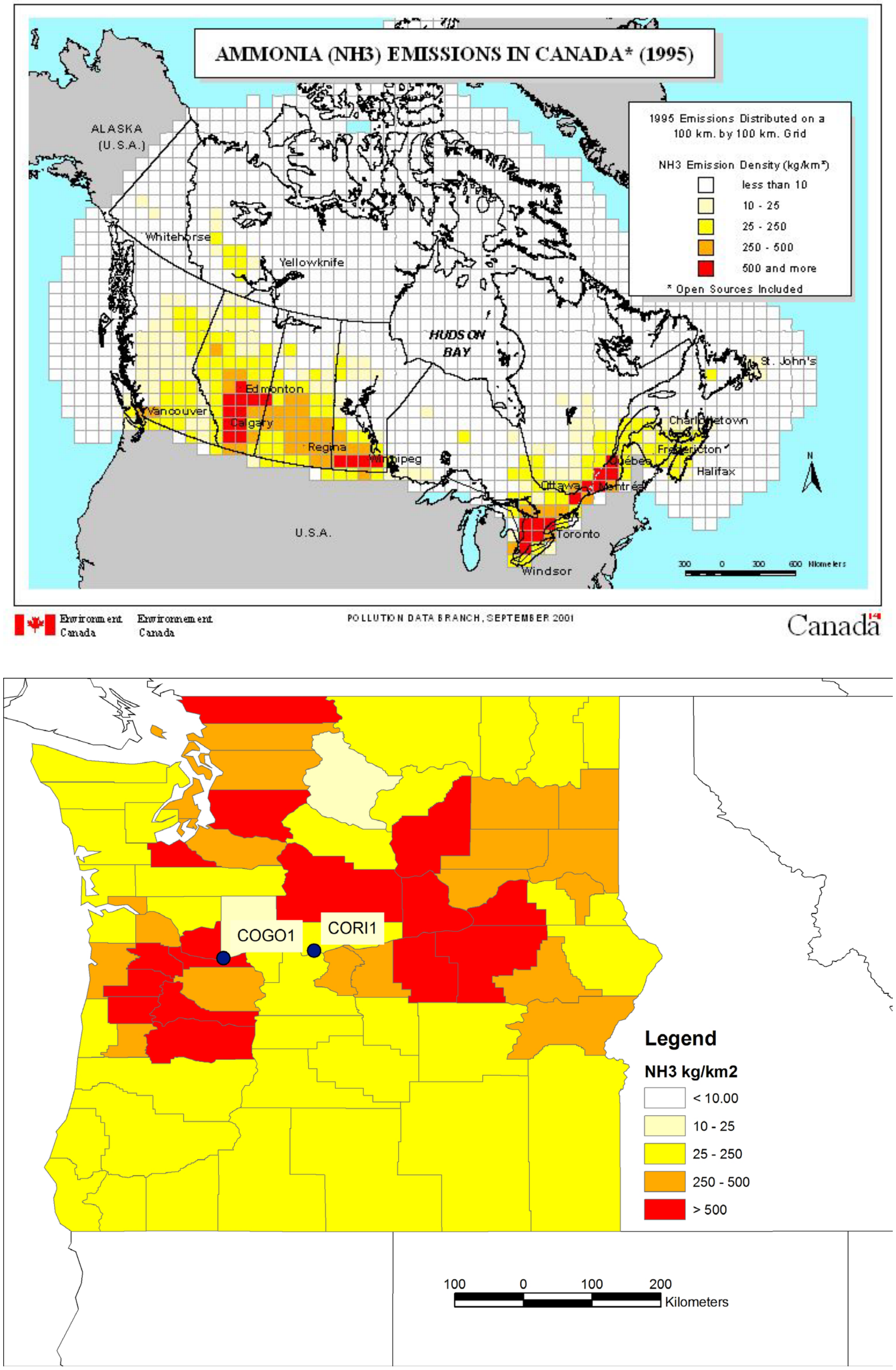

Figure A-7. NH_3 Emissions Inventory maps for Washington, Oregon, and Western Canada.

B. EMISSIONS INVENTORY TABLES OF MAJOR SOURCES IN OREGON AND WASHINGTON

Emissions data shown in the tables below were obtained from the 1999 base year National Emissions Inventory (NEI99) version 200. Supplemental data on prescribed and wild fires were obtained from staff Sally Otterson at the Washington Department of Ecology and Jeffery Stocum at the Oregon Department of Environmental Quality (Personal communications, 2/1/2003). The results of the fire data are shown in a separate column for comparison with the NEI data.

Table B-1. Major carbon monoxide (CO) sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	CO_TPY
Miscellaneous Area Sources	Other Combustion	Prescribed Burning for Forest Management	0.21	1,033,928
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Vehicles (LDGV)	0.40	871,991
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5)	0.47	362,704
Mobile Sources	Off-highway Vehicle Gasoline, 4-Stroke	Lawn and Garden Equipment	0.54	350,694
Miscellaneous Area Sources	Other Combustion	Forest Wildfires	0.61	330,746
Mobile Sources	Off-highway Vehicle Gasoline, 2-Stroke	Logging Equipment	0.66	212,916
Mobile Sources	Off-highway Vehicle Gasoline, 4-Stroke	Recreational Equipment	0.70	193,861
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Trucks 3 & 4 (M6) = LDGT2 (M5)	0.73	178,123
All Other Sources			1	1,277,812
			TOTAL	**4,812,775**

Table B-2. Major ammonia (NH3) sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	NH3_TPY
Miscellaneous Area Sources	Agriculture Production - Livestock	Cattle and Calves Composite	0.59	70,056
Miscellaneous Area Sources	Agriculture Production - Crops	Fertilizer Application	0.81	25,685
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Vehicles (LDGV)	0.86	5,601
Miscellaneous Area Sources	Agriculture Production - Livestock	Poultry and Chickens Composite	0.89	3,907
Waste Disposal, Treatment, and Recovery	Wastewater Treatment	Public Owned	0.92	3,141
All Other Sources			1	9,571
			TOTAL	**117,961**

Table B-3. Major nitrogen oxide (NOx) sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	NOX_TPY	State NOX_TPY
Mobile Sources	Highway Vehicles - Diesel	All HDDV including Buses (use subdivisions -071 thru -075 if possible)	0.19	121,600	
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Vehicles (LDGV)	0.34	98,484	
Mobile Sources	Off-highway Vehicle Diesel	Construction and Mining Equipment	0.41	50,729	
Mobile Sources	Marine Vessels, Commercial	Diesel	0.48	44,818	
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5)	0.54	39,090	
Mobile Sources	Railroad Equipment	Diesel	0.59	33,326	
External Combustion Boilers	Electric Generation	Bituminous/Subbituminous Coal	0.64	30,817	
Miscellaneous Area Sources	Other Combustion	Prescribed Burning for Forest Management	0.67	23,288	3,218*
Mobile Sources	Off-highway Vehicle Diesel	Agricultural Equipment	0.71	23,257	
External Combustion Boilers	Electric Generation	Lignite	0.74	21,555	
All Other Sources			1	169,009	
			TOTAL	**655,973**	

*NO_x fire emissions provided by the state of Oregon only. Oregon data represents the sum of prescribed and wildfire emissions.

Table B-4. Major filterable PM10 (PM10-FIL) sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	PM10-FIL_TPY	State PM10_TPY
Mobile Sources	Unpaved Roads	All Unpaved Roads	0.29	190,971	
Miscellaneous Area Sources	Agriculture Production – Crops	Agriculture - Crops	0.46	113,328	
Miscellaneous Area Sources	Other Combustion	Prescribed Burning for Forest Management	0.61	98,238	26,157*
Mobile Sources	Paved Roads	All Paved Roads	0.72	74,901	
Miscellaneous Area Sources	Other Combustion	Forest Wildfires	0.77	30,712	7,271**
All Other Sources			1	151,235	
			TOTAL	**659,385**	

*State level prescribed fire PM_{10} emissions represent the sum of Washington state prescribed fires and Oregon state prescribed and wild fires for total PM_{10}. No designation was made for filterable, condensable, and primary emissions within the state EI's.

**State wildfire PM_{10} emissions are only from the state of Oregon.

Table B-5. Major primary PM10 (PM10-PRI) sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	PM10-PRI_TPY
Stationary Source Fuel Combustion	Residential	Wood	0.42	17,378
Waste Disposal, Treatment, and Recovery	Open Burning	Residential	0.52	4,015
External Combustion Boilers	Industrial	Wood/Bark Waste	0.58	2,539
Industrial Processes	Pulp and Paper and Wood Products	Plywood Operations	0.63	2,144
Industrial Processes	Pulp and Paper and Wood Products	Sulfate (Kraft) Pulping	0.67	1,843
Mobile Sources	Marine Vessels, Commercial	Diesel	0.72	1,835
Industrial Processes	Pulp and Paper and Wood Products	Sawmill Operations	0.75	1,249
All Other Sources			1	10,465
			TOTAL	**41,468**

Table B-6. Major filterable PM2.5 (PM25-FIL) sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	PM25-FIL_TPY	State PM2.5_TPY
Miscellaneous Area Sources	Other Combustion	Prescribed Burning for Forest Management	0.34	89,654	22,726*
Mobile Sources	Unpaved Roads	All Unpaved Roads	0.45	28,646	
Miscellaneous Area Sources	Other Combustion	Forest Wildfires	0.55	27,641	6161**
Miscellaneous Area Sources	Agriculture Production - Crops	Agriculture – Crops	0.64	22,666	
Mobile Sources	Paved Roads	All Paved Roads	0.71	18,725	
Miscellaneous Area Sources	Agriculture Production - Crops	Agricultural Field Burning - whole field set on fire	0.78	18,351	
Waste Disposal, Treatment, and Recovery	Open Burning	All Categories	0.83	14,079	
All Other Sources			1	45,337	
			TOTAL	**265,099**	

*State level prescribed fire $PM_{2.5}$ emissions represent the sum of Washington state prescribed fires and Oregon state prescribed and wild fires for total $PM_{2.5}$. No designation was made for filterable, condensable, and primary emissions within the state EI's.

**State wildfire $PM_{2.5}$ emissions are only from the state of Oregon.

Table B-7. Major primary PM2.5 (PM25-PRI) sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	PM25-PRI_TPY	State PM2.5_TPY
Stationary Source Fuel Combustion	Residential	Wood	0.67	17,061	
Waste Disposal, Treatment, and Recovery	Open Burning	Residential	0.82	3,876	
Mobile Sources	Marine Vessels, Commercial	Diesel	0.89	1,689	
Mobile Sources	Railroad Equipment	Diesel	0.92	743	
Mobile Sources	Marine Vessels, Commercial	Residual	0.94	450	
Miscellaneous Area Sources	Other Combustion	Prescribed Burning for Forest Management	0.95	433	22,726*
Stationary Source Fuel Combustion	Residential	Natural Gas	0.96	264	
All Other Sources			1	893	
			TOTAL	**25,409**	

*State level prescribed fire $PM_{2.5}$ emissions represent the sum of Washington state prescribed fires and Oregon state prescribed and wild fires for total $PM_{2.5}$. No designation was made for filterable, condensable, and primary emissions within the state EI's. These data should not be double counted with the state PM2.5 emissions in Table B-6.

Table B-8. Major sulfur dioxide sources in Oregon and Washington (NEI99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	SO2_TPY
External Combustion Boilers	Electric Generation	Bituminous/Subbituminous Coal	0.33	104,347
External Combustion Boilers	Electric Generation	Lignite	0.60	87,754
Industrial Processes	Primary Metal Production	Aluminum Ore (Electro-reduction)	0.67	20,157
Stationary Source Fuel Combustion	Industrial	Distillate Oil	0.72	15,884
Mobile Sources	Marine Vessels, Commercial	Residual	0.77	15,566
Mobile Sources	Off-highway Vehicle Diesel	Construction and Mining Equipment	0.80	10,409
External Combustion Boilers	Industrial	Process Gas	0.82	5,499
All Other Sources			1	58,347
			TOTAL	**317,963**

Table B-9. Major VOC emissions in Oregon and Washington (NEI 99).

SCC1_DESC	SCC3_DESC	SCC6_DESC	CUMFRAC	VOC_TPY	State VOC_TPY
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Vehicles (LDGV)	0.12	89,580	
Mobile Sources	Off-highway Vehicle Gasoline, 2-Stroke	Logging Equipment	0.23	76,812	13,085*
Miscellaneous Area Sources	Other Combustion	Prescribed Burning for Forest Management	0.31	59,603	5,987**
Miscellaneous Area Sources	Other Combustion	Forest Wildfires	0.38	45,359	
Mobile Sources	Highway Vehicles - Gasoline	Light Duty Gasoline Trucks 1 & 2 (M6) = LDGT1 (M5)	0.43	36,807	
Stationary Source Fuel Combustion	Residential	Wood	0.47	31,476	
Mobile Sources	Pleasure Craft	Gasoline 2-Stroke	0.50	23,572	
All Other Sources			1	356,418	
			TOTAL	**719,627**	

*State level prescribed fire VOC emissions represent the sum of Washington state prescribed fires and Oregon state prescribed and wild fires for VOC.

**State wildfire VOC emissions are only from the state of Oregon.

C. SOURCE PROFILES

Table C-1. Source Profile Abundances for Columbia River Gorge CMB Analysis

	Ammonium Nitrate	Ammonium Sulfate	Aluminum Reduction	BRAVO Coal Fired Power	BRAVO Coal Fly Ash	BRAVO Road Dust
Profile	CRG006	CRG008	CRG010	CRG071	CRG072	CRG107
Source ID	AMNIT	AMSUL	ARPL	BVCFPP	BVCLFA	BVPVRD1
SIZE	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$
Al	0.000000 ± 0.000010	0.000000 ± 0.000010	0.152000 ± 0.017000	0.052985 ± 0.032609	0.068116 ± 0.006640	0.035633 ± 0.009495
As	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000220 ± 0.000140	0.000025 ± 0.000550	0.000059 ± 0.000062	0.000005 ± 0.000092
Br	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000220 ± 0.000080	0.000269 ± 0.000573	0.000000 ± 0.000024	0.000019 ± 0.000033
Ca	0.000000 ± 0.000010	0.000000 ± 0.000010	0.001000 ± 0.001400	0.165546 ± 0.105262	0.188276 ± 0.036996	0.217346 ± 0.032736
Cl-	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000628	0.008937 ± 0.015668	0.000120 ± 0.000658	0.000837 ± 0.001143
Cl	0.000000 ± 0.000010	0.000000 ± 0.000010	0.008000 ± 0.001600	0.007851 ± 0.015625	0.000000 ± 0.001108	0.000219 ± 0.001453
Cr	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000255 ± 0.000191	0.000105 ± 0.000093	0.000088 ± 0.000083
Cu	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000180 ± 0.000080	0.000898 ± 0.000746	0.000564 ± 0.000212	0.000219 ± 0.000041
EC1	0.000000 ± 0.000010	0.000000 ± 0.000010	0.008933 ± 0.026800	0.021321 ± 0.019696	0.006435 ± 0.008295	0.013395 ± 0.007754
EC2	0.000000 ± 0.000010	0.000000 ± 0.000010	0.008933 ± 0.026800	0.014929 ± 0.010761	0.007470 ± 0.008570	0.006781 ± 0.005757
EC3	0.000000 ± 0.000010	0.000000 ± 0.000010	0.008933 ± 0.026800	0.001009 ± 0.001646	0.000000 ± 0.000858	0.000000 ± 0.001522
ECT	0.000000 ± 0.000010	0.000000 ± 0.000010	0.026800 ± 0.003200	0.013836 ± 0.022247	0.013894 ± 0.016839	0.017896 ± 0.012710
Fe	0.000000 ± 0.000010	0.000000 ± 0.000010	0.001140 ± 0.000950	0.036133 ± 0.020193	0.034730 ± 0.007845	0.027493 ± 0.005249
K	0.000000 ± 0.000010	0.000000 ± 0.000010	0.005270 ± 0.004700	0.005199 ± 0.002561	0.002664 ± 0.001710	0.009314 ± 0.003168
Mg	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.008439 ± 0.008588	0.015464 ± 0.002137	0.002603 ± 0.000908
Mn	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000080 ± 0.000110	0.001150 ± 0.001063	0.000796 ± 0.000572	0.000399 ± 0.000060
NO_3^-	0.775000 ± 0.077500	0.000000 ± 0.000010	0.006900 ± 0.001300	0.006865 ± 0.010917	0.007303 ± 0.005646	0.000584 ± 0.001077
Na	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.009090 ± 0.017783	0.002232 ± 0.002291	0.000199 ± 0.000947
Ni	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000140 ± 0.000080	0.000198 ± 0.000166	0.000080 ± 0.000020	0.000045 ± 0.000030
OC1	0.000000 ± 0.000010	0.000000 ± 0.000010	0.070500 ± 0.282000	0.075339 ± 0.101529	0.002929 ± 0.004300	0.005570 ± 0.007425
OC2	0.000000 ± 0.000010	0.000000 ± 0.000010	0.070500 ± 0.282000	0.093705 ± 0.096312	0.005044 ± 0.003889	0.014066 ± 0.007288
OC3	0.000000 ± 0.000010	0.000000 ± 0.000010	0.070500 ± 0.282000	0.051512 ± 0.058271	0.004143 ± 0.004484	0.058017 ± 0.028477
OC4	0.000000 ± 0.000010	0.000000 ± 0.000010	0.070500 ± 0.282000	0.026892 ± 0.024109	0.003196 ± 0.003679	0.066222 ± 0.025854
OCT	0.000000 ± 0.000010	0.000000 ± 0.000010	0.282000 ± 0.050000	0.271762 ± 0.257663	0.015322 ± 0.008982	0.146155 ± 0.058452
OP	0.000000 ± 0.000010	0.000000 ± 0.000010	0.070500 ± 0.282000	0.024314 ± 0.025173	0.000010 ± 0.003596	0.002279 ± 0.008118
Pb	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000720 ± 0.000260	0.000551 ± 0.000895	0.000322 ± 0.000315	0.000391 ± 0.000104
Ph	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000300 ± 0.000300	0.002912 ± 0.004551	0.006428 ± 0.005727	0.001133 ± 0.000988
Rb	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000050 ± 0.000010	0.000034 ± 0.000039	0.000025 ± 0.000019	0.000047 ± 0.000030
SO_4^{2-}	0.000000 ± 0.000010	0.727000 ± 0.072700	0.174110 ± 0.093000	0.287433 ± 0.225634	0.063898 ± 0.037301	0.007127 ± 0.002393
Se	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000030 ± 0.000030	0.005776 ± 0.008325	0.000114 ± 0.000023	0.000001 ± 0.000035
Si	0.000000 ± 0.000010	0.000000 ± 0.000010	0.003400 ± 0.000400	0.106944 ± 0.068068	0.090606 ± 0.024365	0.122295 ± 0.040591
Sr	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000100	0.004831 ± 0.003969	0.004763 ± 0.000489	0.000742 ± 0.000336
S	0.000000 ± 0.000010	0.242700 ± 0.024270	0.050000 ± 0.038000	0.082267 ± 0.053390	0.023807 ± 0.012292	0.005897 ± 0.001613
Ti	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000020 ± 0.000020	0.008501 ± 0.005164	0.009592 ± 0.000944	0.002564 ± 0.000796
Va	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000150 ± 0.000040	0.000790 ± 0.000810	0.000628 ± 0.000585	0.000053 ± 0.000360
Zn	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000070 ± 0.000010	0.003103 ± 0.003334	0.000493 ± 0.000188	0.001429 ± 0.000264
Zr	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000100	0.000250 ± 0.000879	0.000219 ± 0.000071	0.000088 ± 0.000050

Table C-2. Source Profile Abundances for Columbia River Gorge CMB Analysis

	BRAVO Motor Vehicles	Puget Sound Soil	Aged Marine	Fresh Marine	South Africa Kraft Paper	BRAVO Vegetative Burning
Profile Number	CRG108	CRG720	CRG282	CRG283	CRG623	CRG721
Source ID	BVRDMV	KTSSOIL	MAR0	MAR100	SAPPILK1	BURN3-7
SIZE	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$
Al	0.000878 ± 0.002117	0.050100 ± 0.017632	0.000000 ± 0.000010	0.000000 ± 0.000010	0.003100 ± 0.000300	0.001092 ± 0.000649
As	0.000019 ± 0.000197	0.000006 ± 0.000017	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000008 ± 0.000009
Br	0.000224 ± 0.000150	0.000001 ± 0.000003	0.001375 ± 0.000171	0.001984 ± 0.000238	0.000000 ± 0.000010	0.000873 ± 0.000318
Ca	0.002105 ± 0.006048	0.172333 ± 0.043614	0.008457 ± 0.001053	0.012201 ± 0.001463	0.088500 ± 0.005400	0.002926 ± 0.001953
Cl-	0.003676 ± 0.009508	0.000583 ± 0.000047	0.000000 ± 0.000300	0.573724 ± 0.068802	0.000000 ± 0.000010	0.083479 ± 0.027682
Cl	0.000202 ± 0.001949	0.000147 ± 0.000061	0.000000 ± 0.000010	0.573724 ± 0.068802	0.000000 ± 0.000010	0.089041 ± 0.035345
Cr	0.000209 ± 0.000403	0.000115 ± 0.000032	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000016 ± 0.000023
Cu	0.000409 ± 0.000258	0.000236 ± 0.000026	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000036 ± 0.000028
EC1	0.156022 ± 0.092854	0.004929 ± 0.004023	0.000000 ± 0.000010	0.000000 ± 0.000010	0.007057 ± 0.021170	0.092623 ± 0.036426
EC2	0.232996 ± 0.104132	0.002516 ± 0.003407	0.000000 ± 0.000010	0.000000 ± 0.000010	0.007057 ± 0.021170	0.001828 ± 0.001168
EC3	0.026180 ± 0.043094	0.000000 ± 0.002418	0.000000 ± 0.000010	0.000000 ± 0.000010	0.007057 ± 0.021170	0.001104 ± 0.001332
ECT	0.371657 ± 0.155277	0.005167 ± 0.000393	0.000000 ± 0.001000	0.000000 ± 0.001000	0.021170 ± 0.002120	0.072195 ± 0.038342
Fe	0.006096 ± 0.003545	0.040933 ± 0.003151	0.000000 ± 0.000010	0.000000 ± 0.000010	0.001200 ± 0.000600	0.000559 ± 0.000458
K	0.000005 ± 0.001006	0.008400 ± 0.001943	0.008211 ± 0.001022	0.011845 ± 0.001421	0.000000 ± 0.000010	0.060232 ± 0.038718
Mg	0.001474 ± 0.002563	0.008700 ± 0.006836	0.000000 ± 0.000010	0.000000 ± 0.000010	0.005000 ± 0.000200	0.000396 ± 0.000221
Mn	0.000295 ± 0.000202	0.000937 ± 0.000081	0.000000 ± 0.000010	0.000000 ± 0.000010	0.001000 ± 0.000200	0.000021 ± 0.000004
NO_3^-	0.003664 ± 0.011901	0.000637 ± 0.000502	0.704532 ± 0.087677	0.000037 ± 0.000004	0.010200 ± 0.000100	0.002552 ± 0.000746
Na	0.015007 ± 0.022472	0.003033 ± 0.000285	0.221700 ± 0.027590	0.319822 ± 0.038354	0.000000 ± 0.000010	0.006420 ± 0.009792
Ni	0.000248 ± 0.000572	0.000069 ± 0.000006	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000009 ± 0.000004
OC1	0.160528 ± 0.123180	0.013079 ± 0.010824	0.000000 ± 0.000010	0.000000 ± 0.000010	0.015200 ± 0.060800	0.166027 ± 0.051038
OC2	0.179671 ± 0.070030	0.011762 ± 0.007242	0.000000 ± 0.000010	0.000000 ± 0.000010	0.015200 ± 0.060800	0.091445 ± 0.023103
OC3	0.133611 ± 0.054852	0.021980 ± 0.009017	0.000000 ± 0.000010	0.000000 ± 0.000010	0.015200 ± 0.060800	0.120319 ± 0.044813
OC4	0.069339 ± 0.033074	0.032635 ± 0.007768	0.000000 ± 0.000010	0.000000 ± 0.000010	0.015200 ± 0.060800	0.079226 ± 0.018298
OCT	0.580611 ± 0.178053	0.081000 ± 0.014667	0.000000 ± 0.000010	0.000000 ± 0.001000	0.060800 ± 0.006080	0.480376 ± 0.076093
OP	0.043652 ± 0.046221	0.001545 ± 0.007291	0.000000 ± 0.000010	0.000000 ± 0.000010	0.015200 ± 0.060800	0.023360 ± 0.021591
Pb	0.000279 ± 0.000362	0.001662 ± 0.000193	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000017 ± 0.000010
Ph	0.000042 ± 0.000685	0.000707 ± 0.000376	0.000001 ± 0.000010	0.000001 ± 0.000010	0.014000 ± 0.000400	0.000016 ± 0.000085
Rb	0.000005 ± 0.000088	0.000038 ± 0.000004	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000043 ± 0.000026
SO_4^{2-}	0.021563 ± 0.032352	0.001553 ± 0.000123	0.055425 ± 0.006898	0.079955 ± 0.009588	0.369500 ± 0.025500	0.022496 ± 0.011647
Se	0.000018 ± 0.000085	0.000004 ± 0.000014	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000013 ± 0.000003
Si	0.003430 ± 0.003707	0.163333 ± 0.061147	0.000062 ± 0.000008	0.000089 ± 0.000011	0.002900 ± 0.000500	0.002101 ± 0.001620
Sr	0.000205 ± 0.000860	0.000368 ± 0.000027	0.000162 ± 0.000020	0.000234 ± 0.000028	0.000000 ± 0.000010	0.000045 ± 0.000023
S	0.013358 ± 0.011940	0.001800 ± 0.000137	0.018475 ± 0.002299	0.026652 ± 0.003196	0.000000 ± 0.000010	0.007162 ± 0.005689
Ti	0.000419 ± 0.002298	0.003270 ± 0.000268	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000073 ± 0.000109
Va	0.000234 ± 0.001005	0.000120 ± 0.000159	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000005 ± 0.000045
Zn	0.002657 ± 0.002492	0.000117 ± 0.000009	0.000000 ± 0.000010	0.000000 ± 0.000010	0.010200 ± 0.005300	0.000259 ± 0.000126
Zr	0.000032 ± 0.002260	0.000117 ± 0.000014	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000000 ± 0.000010	0.000006 ± 0.000107

D. DAILY CMB SOURCE ATTRIBUTIONS

Table D-1. CMB Source Attribution Results for 3rd Quarter 1996 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (µg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (µg/m^3)	Fresh Sea Salt SCE (µg/m^3)	Ammonium Nitrate SCE (µg/m^3)	Ammonium Sulfate SCE (µg/m^3)	Aluminum Reduction SCE (µg/m^3)	Coal Fired PP SCE (µg/m^3)	Coal Fly Ash SCE (µg/m^3)	Kraft Paper Mill SCE (µg/m^3)	Puget Soil SCE (µg/m^3)	Motor Vehicles SCE (µg/m^3)	Vegetative Burning SCE (µg/m^3)
COGO1		*	19960918	8.6 ± 0.3	0.89	1.55	75.8	0.6 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	2.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.9 ± 0.5	0.7 ± 0.4
COGO1			19960921	6.5 ± 0.2	0.89	1.72	84.9	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 0.1	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.0 ± 0.4	1.2 ± 0.3
COGO1			19960925	7.6 ± 0.3	0.84	2.19	73.9	0.1 ± 0.2	0.1 ± 0.1	0.1 ± 0.2	0.8 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	2.6 ± 0.6	0.9 ± 0.5
COGO1			19960928	11.5 ± 0.4	0.88	1.83	81.7	0.6 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	2.7 ± 0.3	0.3 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	3.9 ± 0.8	1.3 ± 0.7

Table D-2. CMB Source Attribution Results for 4th Quarter 1996 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
COGO1	*		19961002	5.6 ± 0.2	0.87	2.77	85.2	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.4 ± 0.2	1.0 ± 0.2	0.4 ± 0.2
COGO1		*	19961005	7.5 ± 0.3	0.89	1.27	92.2	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.7 ± 0.5	0.5 ± 0.2
COGO1			19961009	4.8 ± 0.2	0.87	0.64	81.6	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.7 ± 0.5	0.5 ± 0.2
COGO1		*	19961012	11.4 ± 0.4	0.88	2.21	67.5	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.1 ± 0.2	0.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 0.2	2.1 ± 0.5	0.5 ± 0.2
COGO1			19961016	5.6 ± 0.2	0.95	0.64	75.3	0.8 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.9 ± 0.4	0.5 ± 0.3
COGO1	*		19961019	3.0 ± 0.2	0.94	0.51	62.9	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.0 ± 0.2	0.3 ± 0.2
COGO1			19961023	5.5 ± 0.2	0.91	0.72	75.9	0.6 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	2.5 ± 0.5	0.5 ± 0.3
COGO1		*	19961026	9.0 ± 0.3	0.89	1.35	68.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.4 ± 0.4	0.5 ± 0.2
COGO1			19961030	6.2 ± 0.2	0.89	0.81	70.3	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.7 ± 0.5	0.3 ± 0.1
COGO1		*	19961102	13.0 ± 0.4	0.92	0.84	60.2	0.1 ± 0.4	0.0 ± 0.0	0.8 ± 0.4	1.5 ± 0.2	0.4 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	4.2 ± 0.8	0.5 ± 0.2
COGO1			19961106	3.9 ± 0.2	0.91	0.84	91.5	0.3 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.9 ± 0.4	0.6 ± 0.3
COGO1			19961109	5.5 ± 0.2	0.85	1.00	78.5	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.8 ± 0.5	0.4 ± 0.2
COGO1	*		19961116	1.3 ± 0.2	0.84	0.79	88.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	0.2 ± 0.1
COGO1			19961120	2.8 ± 0.2	0.92	0.79	91.2	0.3 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.3 ± 0.3	0.3 ± 0.2
COGO1		*	19961123	6.1 ± 0.2	0.94	0.71	89.6	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	2.2 ± 0.2	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.1 ± 0.4	0.2 ± 0.1
COGO1			19961127	1.5 ± 0.2	0.92	0.78	124.6	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.2	0.2 ± 0.1
COGO1			19961204	2.7 ± 0.2	0.94	0.76	98.5	0.2 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	1.4 ± 0.3	0.2 ± 0.1
COGO1	*		19961207	1.2 ± 0.2	0.85	0.57	83.4	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.1 ± 0.1
COGO1	*		19961211	2.5 ± 0.2	0.89	1.12	88.0	0.3 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	1.2 ± 0.3	0.2 ± 0.2
COGO1			19961214	3.2 ± 0.2	0.90	1.38	89.0	0.7 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.3	0.2 ± 0.2
COGO1			19961218	4.5 ± 0.2	0.93	0.81	110.2	0.1 ± 0.2	0.0 ± 0.0	1.1 ± 0.2	0.6 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.4 ± 0.5	0.3 ± 0.2
COGO1	*		19961221	1.7 ± 0.2	0.87	1.49	111.3	0.2 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.2	0.2 ± 0.1
COGO1	*		19961225	1.0 ± 0.2	0.82	2.15	90.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.1 ± 0.0
COGO1			19961228	5.4 ± 0.2	0.92	1.65	96.0	0.0 ± 0.0	0.8 ± 0.1	0.7 ± 0.1	1.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.1 ± 0.3	1.5 ± 0.4

Table D-3. CMB Source Attribution Results for 1st Quarter 1997 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
COGO1	*		19970101	4.2 ± 0.2	0.90	2.74	66.8	0.0 ± 0.0	1.5 ± 0.1	0.2 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.5 ± 0.2
COGO1			19970104	3.5 ± 0.2	0.94	0.69	70.5	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.1 ± 0.0	0.9 ± 0.2	0.5 ± 0.1
COGO1		*	19970108	7.0 ± 0.3	0.83	1.59	108.1	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.2	0.1 ± 0.1	4.5 ± 0.8	0.6 ± 0.2
COGO1		*	19970111	4.6 ± 0.2	0.91	0.65	95.8	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 0.5	0.3 ± 0.1
COGO1			19970115	7.0 ± 0.3	0.92	1.00	98.6	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	0.9 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.9 ± 0.6	0.3 ± 0.1
COGO1			19970118	4.7 ± 0.2	0.91	1.03	85.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	1.0 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.9 ± 0.4	0.3 ± 0.1
COGO1	*		19970122	1.9 ± 0.2	0.81	0.71	101.6	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.3	0.2 ± 0.1
COGO1			19970125	3.3 ± 0.2	0.92	1.06	111.8	0.5 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.8 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.6 ± 0.3	0.3 ± 0.1
COGO1		*	19970129	7.3 ± 0.3	0.93	1.25	96.1	0.3 ± 0.2	0.0 ± 0.0	0.9 ± 0.2	2.5 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.4 ± 0.5	0.4 ± 0.2
COGO1	*		19970201	2.9 ± 0.2	0.78	4.41	91.6	0.2 ± 0.0	1.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.2	0.1 ± 0.1
COGO1	*		19970205	3.1 ± 0.2	0.94	0.93	106.4	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.7 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.5 ± 0.3	0.2 ± 0.1
COGO1			19970208	6.5 ± 0.2	0.93	1.06	81.3	0.1 ± 0.1	0.0 ± 0.0	0.9 ± 0.2	2.0 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.8 ± 0.3	0.3 ± 0.1
COGO1	*		19970212	5.1 ± 0.2	0.78	5.45	85.4	0.4 ± 0.1	2.1 ± 0.2	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.2 ± 0.2	0.1 ± 0.1
COGO1	*		19970219	2.2 ± 0.2	0.91	1.36	98.2	0.2 ± 0.0	0.8 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.9 ± 0.2	0.1 ± 0.1
COGO1	*		19970222	3.2 ± 0.2	0.94	0.60	90.2	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.6 ± 0.3	0.2 ± 0.1
COGO1			19970226	3.8 ± 0.2	0.91	1.37	91.3	0.3 ± 0.0	0.8 ± 0.1	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.3	0.1 ± 0.1
COGO1	*		19970301	2.1 ± 0.2	0.93	0.93	61.1	0.1 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.1 ± 0.1
COGO1			19970305	3.2 ± 0.2	0.89	1.19	95.3	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	1.6 ± 0.3	0.2 ± 0.1
COGO1		*	19970308	8.5 ± 0.3	0.70	5.19	106.5	1.8 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	2.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.2	0.0 ± 0.0	4.2 ± 0.8	0.7 ± 0.4
COGO1			19970315	1.7 ± 0.2	0.92	1.05	115.5	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.7 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.2	0.1 ± 0.1
COGO1			19970319	2.5 ± 0.2	0.91	1.18	106.5	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.2 ± 0.3	0.2 ± 0.1
COGO1			19970322	4.6 ± 0.2	0.92	0.75	100.3	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.8 ± 0.5	0.4 ± 0.2
COGO1	*		19970326	2.8 ± 0.2	0.93	0.88	108.5	0.3 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.4 ± 0.3	0.3 ± 0.2

Table D-4. CMB Source Attribution Results for 2nd Quarter 1997 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ ($\mu g/m^3$)	R^2	CHI^2	% MASS	Aged Sea Salt SCE ($\mu g/m^3$)	Fresh Sea Salt SCE ($\mu g/m^3$)	Ammonium Nitrate SCE ($\mu g/m^3$)	Ammonium Sulfate SCE ($\mu g/m^3$)	Aluminum Reduction SCE ($\mu g/m^3$)	Coal Fired PP SCE ($\mu g/m^3$)	Coal Fly Ash SCE ($\mu g/m^3$)	Kraft Paper Mill SCE ($\mu g/m^3$)	Puget Soil SCE ($\mu g/m^3$)	Motor Vehicles SCE ($\mu g/m^3$)	Vegetative Burning SCE ($\mu g/m^3$)
COGO1		*	19970402	5.8 ± 0.2	0.91	0.72	132.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	4.4 ± 0.8	0.4 ± 0.2
COGO1	*		19970405	4.0 ± 0.2	0.91	0.97	96.4	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	1.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.8 ± 0.3	0.2 ± 0.1
COGO1			19970409	5.6 ± 0.2	0.93	1.00	97.5	1.0 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	1.0 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.5 ± 0.5	0.4 ± 0.3
COGO1			19970412	8.4 ± 0.3	0.89	1.47	97.7	0.1 ± 0.4	0.0 ± 0.0	0.3 ± 0.4	2.6 ± 0.3	0.3 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	4.0 ± 0.7	0.3 ± 0.2
COGO1			19970416	4.8 ± 0.2	0.92	0.88	96.7	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.3 ± 0.4	0.4 ± 0.2
COGO1	*		19970419	1.6 ± 0.2	0.88	0.61	119.3	0.0 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.2 ± 0.2	0.2 ± 0.1
COGO1	*		19970423	1.9 ± 0.2	0.93	1.09	96.5	0.3 ± 0.0	0.4 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.7 ± 0.1	0.1 ± 0.1
COGO1			19970426	4.1 ± 0.2	0.90	1.14	97.6	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.7 ± 0.1	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.3 ± 0.4	0.3 ± 0.1
COGO1	*		19970430	3.0 ± 0.2	0.95	1.01	87.7	0.3 ± 0.1	0.8 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.2	0.2 ± 0.1
COGO1			19970503	7.2 ± 0.3	0.94	1.31	50.1	0.4 ± 0.1	0.5 ± 0.1	0.0 ± 0.0	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.1 ± 0.2	0.5 ± 0.3
COGO1	*		19970507	3.5 ± 0.2	0.89	1.39	96.6	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.4 ± 0.3	0.4 ± 0.1
COGO1			19970510	7.3 ± 0.3	0.89	1.47	92.2	0.4 ± 0.3	0.0 ± 0.0	0.1 ± 0.3	1.3 ± 0.2	0.4 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.2	3.3 ± 0.7	0.3 ± 0.2
COGO1			19970514	7.3 ± 0.3	0.87	1.57	87.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.1	0.4 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.2	3.0 ± 0.6	0.4 ± 0.2
COGO1	*		19970517	5.5 ± 0.2	0.89	1.53	100.4	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.3 ± 0.5	0.5 ± 0.2
COGO1		*	19970521	9.0 ± 0.3	0.85	2.75	97.4	2.0 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	1.6 ± 0.2	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	3.5 ± 0.6	0.4 ± 0.3
COGO1			19970524	4.3 ± 0.2	0.94	0.68	91.3	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.8 ± 0.3	0.3 ± 0.1
COGO1			19970528	5.2 ± 0.2	0.88	0.64	59.2	0.0 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.4 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.2 ± 0.4	0.2 ± 0.1
COGO1	*		19970531	2.5 ± 0.2	0.92	0.51	77.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.2 ± 0.2	0.2 ± 0.1
COGO1	*		19970604	4.1 ± 0.2	0.87	2.52	60.5	0.3 ± 0.0	0.4 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.9 ± 0.2	0.2 ± 0.1
COGO1	*		19970607	3.6 ± 0.2	0.78	3.52	101.6	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.2 ± 0.3	0.9 ± 0.2
COGO1			19970611	5.4 ± 0.2	0.93	0.94	85.4	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.0 ± 0.4	0.4 ± 0.2
COGO1			19970614	8.5 ± 0.3	0.91	1.00	82.7	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.5 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.2 ± 0.6	0.5 ± 0.2
COGO1	*		19970618	4.1 ± 0.2	0.70	6.46	103.2	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.9 ± 0.2	1.6 ± 0.3
COGO1	*		19970621	2.7 ± 0.2	0.92	0.94	59.9	0.1 ± 0.1	0.1 ± 0.0	0.0 ± 0.1	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.2	0.3 ± 0.2
COGO1			19970625	4.5 ± 0.2	0.93	0.56	93.7	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.6 ± 0.5	0.3 ± 0.1
COGO1			19970628	4.7 ± 0.2	0.91	1.14	103.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.2 ± 0.4	0.4 ± 0.2

Table D-5. CMB Source Attribution Results for 3rd Quarter 1997 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	PM$_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
COGO1			19970702	4.5 ± 0.2	0.95	0.49	113.8	0.3 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	1.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.8 ± 0.5	0.4 ± 0.2
COGO1			19970705	7.9 ± 0.3	0.87	2.42	89.9	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.8 ± 0.2	0.3 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.4 ± 0.5	0.9 ± 0.2
COGO1	*		19970709	2.7 ± 0.2	0.84	1.88	87.7	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.0 ± 0.2	0.4 ± 0.1
COGO1			19970712	5.2 ± 0.2	0.88	1.45	106.6	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	2.3 ± 0.4	0.4 ± 0.2
COGO1			19970716	7.4 ± 0.3	0.89	1.52	101.8	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	3.0 ± 0.6	0.4 ± 0.2
COGO1		*	19970719	12.4 ± 0.4	0.86	2.21	96.2	1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	4.3 ± 0.4	0.7 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.2	4.4 ± 0.9	0.5 ± 0.2
COGO1			19970723	6.1 ± 0.2	0.87	1.91	112.6	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.3 ± 0.2	0.6 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.7 ± 0.6	0.4 ± 0.2
COGO1			19970726	9.4 ± 0.3	0.86	2.15	81.7	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	3.1 ± 0.3	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.5 ± 0.5	0.3 ± 0.2
COGO1			19970730	9.3 ± 0.3	0.87	1.67	92.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	0.3 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.2	3.7 ± 0.7	0.4 ± 0.2
COGO1			19970802	6.4 ± 0.2	0.88	1.48	98.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.5 ± 0.5	0.3 ± 0.1
COGO1		*	19970806	11.0 ± 0.4	0.89	1.51	96.1	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	3.3 ± 0.3	0.6 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	4.6 ± 0.9	0.3 ± 0.2
COGO1	*		19970809	3.7 ± 0.2	0.85	2.36	105.9	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	1.3 ± 0.3	0.2 ± 0.1
COGO1		*	19970813	10.8 ± 0.4	0.86	1.94	90.9	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 0.2	0.5 ± 0.3	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.3	4.1 ± 0.8	0.4 ± 0.2
COGO1			19970816	6.1 ± 0.2	0.80	5.07	89.8	1.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 0.1	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.9 ± 0.2	0.1 ± 0.1
COGO1		*	19970820	7.2 ± 0.3	0.90	1.10	102.4	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.2	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	3.9 ± 0.7	0.4 ± 0.2
COGO1			19970823	3.5 ± 0.2	0.92	0.75	112.9	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.1 ± 0.4	0.3 ± 0.1
COGO1			19970827	4.0 ± 0.2	0.88	2.24	103.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.1	1.1 ± 0.2	0.2 ± 0.1
COGO1		*	19970830	6.7 ± 0.3	0.90	1.07	94.9	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.2	0.3 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.4 ± 0.6	0.3 ± 0.1
COGO1			19970903	8.0 ± 0.3	0.89	1.48	115.0	0.5 ± 0.3	0.0 ± 0.0	0.2 ± 0.3	3.2 ± 0.3	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	4.2 ± 0.8	0.4 ± 0.2
COGO1			19970906	5.9 ± 0.2	0.88	1.76	102.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	2.1 ± 0.2	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.3 ± 0.5	0.6 ± 0.3
COGO1		*	19970910	11.8 ± 0.4	0.88	1.72	89.9	0.4 ± 0.5	0.0 ± 0.0	0.7 ± 0.5	3.0 ± 0.3	0.1 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	5.1 ± 0.9	0.8 ± 0.3
COGO1			19970913	4.1 ± 0.2	0.95	0.79	85.7	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	1.0 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.6 ± 0.3	0.2 ± 0.1
COGO1			19970917	4.0 ± 0.2	0.93	1.50	95.7	0.3 ± 0.0	0.6 ± 0.1	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.4	0.5 ± 0.3
COGO1			19970920	3.8 ± 0.2	0.86	1.04	93.5	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.3 ± 0.4	0.2 ± 0.1
COGO1		*	19970924	17.5 ± 0.5	0.79	2.70	110.3	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	0.7 ± 0.2	0.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 0.3	4.4 ± 1.3	11.3 ± 2.1
COGO1			19970927	10.1 ± 0.3	0.95	1.86	88.6	0.3 ± 0.1	5.3 ± 0.5	0.0 ± 0.0	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.4	1.0 ± 0.5

Table D-6. CMB Source Attribution Results for 4th Quarter 1997 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
COGO1			19971001	4.4 ± 0.2	0.84	0.84	94.5	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.8 ± 0.5	0.7 ± 0.2
COGO1			19971004	3.0 ± 0.2	0.91	1.60	96.2	0.2 ± 0.0	1.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.2	0.2 ± 0.2
COGO1			19971008	6.1 ± 0.2	0.75	1.50	78.4	0.3 ± 0.4	0.0 ± 0.0	0.1 ± 0.3	0.4 ± 0.1	0.1 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	3.5 ± 0.6	0.5 ± 0.2
COGO1			19971011	3.7 ± 0.2	0.95	1.49	113.7	0.5 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	2.3 ± 0.5	0.7 ± 0.4
COGO1		*	19971015	10.3 ± 0.3	0.80	1.57	77.2	0.0 ± 0.5	0.0 ± 0.0	0.3 ± 0.5	0.9 ± 0.2	0.4 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	5.2 ± 1.0	0.6 ± 0.2
COGO1			19971018	7.3 ± 0.3	0.87	1.44	85.5	0.9 ± 0.4	0.0 ± 0.0	0.2 ± 0.3	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.3 ± 0.6	0.5 ± 0.2
COGO1		*	19971022	17.3 ± 0.5	0.84	1.76	77.6	0.4 ± 0.8	0.0 ± 0.0	1.1 ± 0.7	2.9 ± 0.4	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	7.7 ± 1.4	0.9 ± 0.3
COGO1			19971025	7.5 ± 0.3	0.79	1.31	76.6	0.1 ± 0.4	0.0 ± 0.0	0.2 ± 0.4	0.6 ± 0.2	0.1 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	4.2 ± 0.8	0.5 ± 0.2
COGO1			19971029	4.9 ± 0.2	0.78	4.87	93.7	0.3 ± 0.1	1.8 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.3	0.3 ± 0.2
COGO1			19971101	6.2 ± 0.2	0.92	1.51	78.8	1.0 ± 0.1	1.3 ± 0.1	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.9 ± 0.4	0.3 ± 0.2
COGO1		*	19971105	11.1 ± 0.4	0.91	0.96	90.6	0.0 ± 0.4	0.0 ± 0.0	1.2 ± 0.4	2.6 ± 0.3	0.3 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	5.3 ± 1.0	0.4 ± 0.2
COGO1			19971108	4.3 ± 0.2	0.92	1.04	82.0	0.4 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.7 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.8 ± 0.3	0.2 ± 0.1
COGO1		*	19971112	9.8 ± 0.3	0.87	1.74	77.7	0.0 ± 0.4	0.0 ± 0.0	1.2 ± 0.4	1.4 ± 0.2	0.4 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	3.6 ± 0.7	0.5 ± 0.2
COGO1		*	19971115	12.3 ± 0.4	0.90	1.42	89.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	4.0 ± 0.3	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	4.1 ± 0.8	0.4 ± 0.2
COGO1	*		19971119	3.1 ± 0.2	0.94	1.12	95.8	0.1 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.0 ± 0.2	0.3 ± 0.2
COGO1			19971122	3.7 ± 0.2	0.89	1.28	114.4	0.2 ± 0.2	0.0 ± 0.0	0.6 ± 0.2	0.5 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.2 ± 0.4	0.3 ± 0.1
COGO1			19971126	3.3 ± 0.2	0.92	1.03	121.2	0.2 ± 0.2	0.0 ± 0.0	0.4 ± 0.2	0.8 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.1 ± 0.4	0.3 ± 0.1
COGO1			19971129	3.2 ± 0.2	0.93	0.91	81.2	0.2 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.3	0.3 ± 0.2
COGO1			19971203	5.3 ± 0.2	0.94	0.81	106.9	0.0 ± 0.2	0.0 ± 0.0	0.9 ± 0.2	2.4 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.8 ± 0.4	0.2 ± 0.1
COGO1			19971206	7.6 ± 0.3	0.91	1.17	93.3	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	2.7 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.7 ± 0.5	0.3 ± 0.1
COGO1		*	19971210	3.4 ± 0.2	0.95	0.58	117.3	0.2 ± 0.2	0.0 ± 0.0	0.7 ± 0.2	0.7 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.9 ± 0.4	0.4 ± 0.1
COGO1			19971213	7.0 ± 0.3	0.94	0.83	103.9	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 0.2	2.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.9 ± 0.4	0.2 ± 0.1
COGO1			19971220	3.6 ± 0.2	0.90	0.70	89.0	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	1.9 ± 0.4	0.8 ± 0.2
COGO1		*	19971224	5.3 ± 0.2	0.93	0.95	95.6	0.4 ± 0.3	0.0 ± 0.0	0.5 ± 0.2	1.3 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.1	2.5 ± 0.5	0.3 ± 0.1
COGO1			19971227	5.6 ± 0.2	0.90	1.97	84.3	0.7 ± 0.1	1.1 ± 0.1	0.0 ± 0.0	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.4	0.5 ± 0.3
COGO1			19971231	6.5 ± 0.2	0.90	1.26	81.9	0.5 ± 0.3	0.0 ± 0.0	0.4 ± 0.3	1.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	2.8 ± 0.5	0.4 ± 0.2

Table D-7. CMB Source Attribution Results for1st Quarter 1998 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
COGO1			19980103	2.4 ± 0.2	0.93	1.14	109.8	0.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.1	1.0 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.9 ± 0.2	0.2 ± 0.1
COGO1			19980107	2.9 ± 0.2	0.89	0.91	122.5	0.2 ± 0.2	0.0 ± 0.0	0.3 ± 0.2	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.1	2.2 ± 0.4	0.3 ± 0.1
COGO1			19980110	4.9 ± 0.2	0.94	0.72	94.2	0.1 ± 0.2	0.0 ± 0.0	1.3 ± 0.2	0.8 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.9 ± 0.4	0.3 ± 0.1
COGO1			19980114	2.7 ± 0.1	0.93	1.63	76.8	0.0 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.5 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.1 ± 0.1
COGO1	*		19980117	9.1 ± 0.3	0.86	2.58	56.4	0.5 ± 0.1	3.2 ± 0.2	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.2	0.0 ± 0.0
COGO1	*		19980124	2.9 ± 0.2	0.89	1.88	75.8	0.2 ± 0.0	1.0 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.1 ± 0.1
COGO1			19980128	4.2 ± 0.2	0.95	0.77	117.4	0.6 ± 0.2	0.0 ± 0.0	0.5 ± 0.2	1.3 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	2.1 ± 0.4	0.2 ± 0.1
COGO1			19980131	4.0 ± 0.2	0.95	0.74	103.9	0.1 ± 0.2	0.0 ± 0.0	0.9 ± 0.2	1.3 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.1 ± 0.0	1.5 ± 0.3	0.2 ± 0.1
COGO1			19980204	3.6 ± 0.2	0.94	0.54	91.2	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.6 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.7 ± 0.3	0.2 ± 0.1
COGO1	*		19980207	2.2 ± 0.2	0.89	0.80	107.3	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 0.3	0.2 ± 0.1
COGO1	*		19980211	2.0 ± 0.2	0.94	0.66	105.6	0.1 ± 0.1	0.2 ± 0.0	0.2 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	1.2 ± 0.2	0.3 ± 0.2
COGO1	*		19980214	1.5 ± 0.2	0.83	1.29	106.0	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.2	0.3 ± 0.1
COGO1	*		19980218	1.6 ± 0.2	0.87	0.63	131.6	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	1.5 ± 0.3	0.2 ± 0.1
COGO1	*		19980221	5.1 ± 0.2	0.95	0.50	18.3	0.0 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.1 ± 0.1
COGO1			19980225	3.1 ± 0.2	0.95	2.04	113.7	0.4 ± 0.1	0.4 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	1.7 ± 0.3	0.3 ± 0.2
COGO1			19980228	1.7 ± 0.2	0.93	0.83	95.3	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.2	0.1 ± 0.1
COGO1			19980307	4.9 ± 0.2	0.91	1.36	81.1	0.0 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	1.3 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.6 ± 0.3	0.3 ± 0.1
COGO1	*		19980311	2.2 ± 0.2	0.87	0.84	116.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.3 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.7 ± 0.3	0.2 ± 0.1
COGO1			19980318	4.2 ± 0.2	0.93	0.91	101.3	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	1.2 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.0 ± 0.4	0.3 ± 0.1
COGO1		*	19980321	7.4 ± 0.3	0.85	1.16	94.3	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	4.4 ± 0.8	0.5 ± 0.2
COGO1			19980325	4.6 ± 0.2	0.87	1.49	126.0	0.3 ± 0.3	0.0 ± 0.0	0.4 ± 0.2	1.1 ± 0.1	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.2 ± 0.6	0.4 ± 0.2

Table D-8. CMB Source Attribution Results for 2nd Quarter 1998 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (µg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (µg/m^3)	Fresh Sea Salt SCE (µg/m^3)	Ammonium Nitrate SCE (µg/m^3)	Ammonium Sulfate SCE (µg/m^3)	Aluminum Reduction SCE (µg/m^3)	Coal Fired PP SCE (µg/m^3)	Coal Fly Ash SCE (µg/m^3)	Kraft Paper Mill SCE (µg/m^3)	Puget Soil SCE (µg/m^3)	Motor Vehicles SCE (µg/m^3)	Vegetative Burning SCE (µg/m^3)
COGO1		*	19980401	8.3 ± 0.3	0.89	1.63	79.4	0.3 ± 0.2	0.0 ± 0.0	0.3 ± 0.2	3.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.6 ± 0.3	0.3 ± 0.1
COGO1		*	19980404	8.1 ± 0.3	0.91	1.82	75.4	0.2 ± 0.1	0.0 ± 0.0	0.7 ± 0.1	3.1 ± 0.3	0.1 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.8 ± 0.3	0.7 ± 0.3
COGO1			19980408	2.7 ± 0.2	0.88	0.88	193.6	0.5 ± 0.3	0.0 ± 0.0	0.1 ± 0.3	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.1 ± 0.6	0.9 ± 0.2
COGO1		*	19980415	5.9 ± 0.2	0.94	0.60	111.6	0.6 ± 0.4	0.0 ± 0.0	0.1 ± 0.4	1.7 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.7 ± 0.7	0.4 ± 0.2
COGO1			19980418	5.3 ± 0.2	0.91	1.06	104.0	0.3 ± 0.3	0.0 ± 0.0	0.2 ± 0.3	1.3 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.0 ± 0.6	0.4 ± 0.2
COGO1			19980425	3.6 ± 0.2	0.91	0.88	110.8	0.4 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.1 ± 0.4	0.4 ± 0.1
COGO1		*	19980429	23.5 ± 0.7	0.54	20.7	56.2	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	2.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.2	0.0 ± 0.0	6.8 ± 0.5	1.0 ± 0.3	1.4 ± 0.3
COGO1			19980502	5.9 ± 0.2	0.89	2.08	93.8	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.1	1.3 ± 0.3	0.3 ± 0.1
COGO1			19980509	4.0 ± 0.2	0.92	0.85	104.0	0.6 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.9 ± 0.4	0.7 ± 0.3
COGO1			19980513	1.2 ± 0.2	0.89	1.01	131.8	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.2	0.2 ± 0.1
COGO1		*	19980516	6.5 ± 0.2	0.94	0.73	69.4	0.0 ± 0.2	0.0 ± 0.0	0.4 ± 0.2	1.3 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.3 ± 0.4	0.3 ± 0.1
COGO1		*	19980520	5.0 ± 0.2	0.94	0.65	111.4	0.1 ± 0.3	0.0 ± 0.0	0.4 ± 0.3	1.7 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.9 ± 0.5	0.3 ± 0.1
COGO1			19980523	4.3 ± 0.2	0.89	1.09	100.3	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.9 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.4 ± 0.4	0.3 ± 0.1
COGO1	*		19980527	3.1 ± 0.2	0.96	0.41	109.5	0.3 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.8 ± 0.3	0.2 ± 0.1
COGO1			19980530	3.2 ± 0.2	0.93	0.82	92.5	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.3	0.2 ± 0.1
COGO1		*	19980603	8.6 ± 0.3	0.89	1.40	99.9	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	3.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.2 ± 0.6	0.5 ± 0.2
COGO1			19980606	9.8 ± 0.3	0.88	1.73	86.7	0.5 ± 0.3	0.0 ± 0.0	0.2 ± 0.3	3.2 ± 0.3	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	3.4 ± 0.7	0.6 ± 0.2
COGO1			19980610	1.7 ± 0.2	0.83	1.54	110.1	0.0 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.2	0.2 ± 0.1
COGO1			19980613	7.8 ± 0.3	0.91	2.06	82.2	1.1 ± 0.1	1.2 ± 0.1	0.0 ± 0.0	2.0 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.6 ± 0.3	0.5 ± 0.3
COGO1		*	19980617	7.6 ± 0.3	0.90	1.49	100.8	1.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	3.1 ± 0.3	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.4 ± 0.5	0.5 ± 0.2
COGO1			19980620	6.7 ± 0.3	0.88	1.52	93.3	0.2 ± 0.3	0.0 ± 0.0	0.3 ± 0.3	2.4 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.7 ± 0.5	0.5 ± 0.2
COGO1	*		19980624	1.6 ± 0.2	0.94	0.58	96.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.7 ± 0.2	0.2 ± 0.1
COGO1		*	19980627	6.5 ± 0.2	0.92	0.97	82.7	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.4 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	1.9 ± 0.4	0.3 ± 0.1

Table D-9. CMB Source Attribution Results for 3rd Quarter 1998 at the Mt. Zion (COGO1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
COGO1		*	19980701	5.3 ± 0.2	0.93	0.82	105.6	0.2 ± 0.2	0.0 ± 0.0	0.4 ± 0.2	2.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	2.0 ± 0.4	0.3 ± 0.1
COGO1			19980704	3.9 ± 0.2	0.85	3.12	87.8	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.8 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.3	0.6 ± 0.2
COGO1		*	19980708	10.0 ± 0.3	0.92	1.08	99.4	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	4.5 ± 0.4	0.4 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.6 ± 0.7	0.5 ± 0.2
COGO1		*	19980711	6.5 ± 0.2	0.92	1.28	114.7	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	3.7 ± 0.3	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.3 ± 0.5	0.3 ± 0.1
COGO1			19980715	6.8 ± 0.3	0.81	1.36	97.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.7 ± 0.2	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	4.2 ± 0.8	0.4 ± 0.2
COGO1		*	19980718	7.5 ± 0.3	0.92	1.29	93.3	0.2 ± 0.2	0.0 ± 0.0	0.3 ± 0.2	3.1 ± 0.3	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.3 ± 0.5	0.4 ± 0.2
COGO1			19980801	7.1 ± 0.3	0.90	1.34	99.0	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	3.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.3 ± 0.4	0.4 ± 0.2
COGO1			19980805	4.9 ± 0.2	0.89	1.24	91.5	0.1 ± 0.2	0.0 ± 0.0	0.3 ± 0.2	1.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.3 ± 0.4	0.3 ± 0.1
COGO1		*	19980808	8.6 ± 0.3	0.92	1.08	81.4	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.9 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.6 ± 0.5	0.3 ± 0.1
COGO1		*	19980812	8.3 ± 0.3	0.90	1.40	99.2	0.3 ± 0.3	0.0 ± 0.0	0.2 ± 0.2	3.3 ± 0.3	0.5 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	3.1 ± 0.6	0.3 ± 0.2
COGO1	*		19980815	3.3 ± 0.2	0.91	1.19	104.9	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.0 ± 0.2	0.2 ± 0.1
COGO1			19980819	6.6 ± 0.3	0.92	0.91	106.5	0.2 ± 0.3	0.0 ± 0.0	0.2 ± 0.3	2.3 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	3.3 ± 0.6	0.3 ± 0.1
COGO1			19980822	6.6 ± 0.3	0.89	1.37	102.2	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.8 ± 0.5	0.5 ± 0.2
COGO1		*	19980826	7.1 ± 0.3	0.93	0.71	100.9	0.1 ± 0.4	0.0 ± 0.0	0.3 ± 0.3	2.6 ± 0.2	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	3.5 ± 0.6	0.3 ± 0.1

Table D-10. CMB Source Attribution Results for 2nd Quarter 1996 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (µg/m³)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (µg/m³)	Fresh Sea Salt SCE (µg/m³)	Ammonium Nitrate SCE (µg/m³)	Ammonium Sulfate SCE (µg/m³)	Aluminum Reduction SCE (µg/m³)	Coal Fired PP SCE (µg/m³)	Coal Fly Ash SCE (µg/m³)	Kraft Paper Mill SCE (µg/m³)	Puget Soil SCE (µg/m³)	Motor Vehicles SCE (µg/m³)	Vegetative Burning SCE (µg/m³)
CORI1	*		19960904	2.6 ± 0.2	0.86	1.58	109.7	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.2 ± 0.2	0.2 ± 0.1
CORI1			19960907	4.2 ± 0.2	0.89	1.25	106.2	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.4 ± 0.4	0.3 ± 0.1
CORI1		*	19960911	10.4 ± 0.3	0.84	2.30	101.4	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.6 ± 0.4	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 0.4	4.0 ± 0.8	0.6 ± 0.2
CORI1			19960914	2.7 ± 0.2	0.87	1.67	118.5	0.3 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.4 ± 0.3	0.3 ± 0.1
CORI1			19960918	5.2 ± 0.2	0.90	1.25	114.0	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.6 ± 0.5	0.3 ± 0.1
CORI1	*		19960921	2.0 ± 0.2	0.87	1.80	116.7	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.2	0.5 ± 0.1
CORI1			19960925	7.7 ± 0.3	0.83	2.00	88.7	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	0.6 ± 0.1	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 0.2	2.6 ± 0.6	1.4 ± 0.3
CORI1			19960928	5.8 ± 0.2	0.86	1.46	102.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	3.0 ± 0.6	1.1 ± 0.3

Table D-11. CMB Source Attribution Results for 3rd Quarter 1996 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ ($\mu g/m^3$)	R^2	CHI^2	% MASS	Aged Sea Salt SCE ($\mu g/m^3$)	Fresh Sea Salt SCE ($\mu g/m^3$)	Ammonium Nitrate SCE ($\mu g/m^3$)	Ammonium Sulfate SCE ($\mu g/m^3$)	Aluminum Reduction SCE ($\mu g/m^3$)	Coal Fired PP SCE ($\mu g/m^3$)	Coal Fly Ash SCE ($\mu g/m^3$)	Kraft Paper Mill SCE ($\mu g/m^3$)	Puget Soil SCE ($\mu g/m^3$)	Motor Vehicles SCE ($\mu g/m^3$)	Vegetative Burning SCE ($\mu g/m^3$)
CORI1			19961002	7.0 ± 0.3	0.79	4.28	111.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.6 ± 0.3	1.4 ± 0.4	1.6 ± 0.3
CORI1			19961005	2.6 ± 0.2	0.82	2.57	130.8	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.2 ± 0.3	1.0 ± 0.2
CORI1		*	19961009	11.3 ± 0.4	0.84	2.91	87.1	0.3 ± 0.3	0.0 ± 0.0	0.4 ± 0.3	1.9 ± 0.2	0.6 ± 0.4	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 0.3	3.3 ± 0.8	0.5 ± 0.2
CORI1			19961012	5.3 ± 0.2	0.88	1.12	99.9	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.9 ± 0.6	0.5 ± 0.2
CORI1			19961016	4.1 ± 0.2	0.84	3.14	118.3	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	1.1 ± 0.3	1.5 ± 0.3
CORI1	*		19961019	1.5 ± 0.2	0.82	2.66	106.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.4 ± 0.1	0.6 ± 0.1
CORI1		*	19961023	7.5 ± 0.3	0.82	1.88	87.9	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	1.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.1 ± 0.7	0.3 ± 0.1
CORI1		*	19961026	6.8 ± 0.3	0.85	1.20	80.4	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.3 ± 0.6	0.4 ± 0.2
CORI1			19961030	5.4 ± 0.2	0.86	0.91	79.8	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.6 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.8 ± 0.5	0.3 ± 0.1
CORI1		*	19961102	11.4 ± 0.4	0.90	1.20	73.2	0.3 ± 0.3	0.0 ± 0.0	1.1 ± 0.3	1.4 ± 0.2	0.8 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	4.3 ± 0.9	0.3 ± 0.2
CORI1	*		19961106	4.4 ± 0.2	0.87	1.47	68.8	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.3 ± 0.3	0.6 ± 0.2
CORI1		*	19961109	8.4 ± 0.3	0.87	1.09	83.9	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.2	0.9 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	4.2 ± 0.8	0.4 ± 0.2
CORI1			19961113	5.4 ± 0.2	0.90	1.15	85.2	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.1 ± 0.5	0.3 ± 0.1
CORI1			19961116	4.3 ± 0.2	0.84	1.16	106.5	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.9 ± 0.6	0.2 ± 0.1
CORI1			19961120	2.9 ± 0.2	0.93	0.54	92.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.5 ± 0.3	0.2 ± 0.1
CORI1		*	19961123	9.0 ± 0.3	0.94	0.74	88.3	0.1 ± 0.3	0.0 ± 0.0	2.7 ± 0.4	1.9 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.8 ± 0.5	0.3 ± 0.1
CORI1		*	19961127	7.6 ± 0.3	0.92	1.07	91.5	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 0.3	1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.1 ± 0.5	0.1 ± 0.1
CORI1		*	19961130	6.3 ± 0.2	0.79	2.00	101.2	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.7 ± 0.8	0.4 ± 0.2
CORI1			19961204	4.3 ± 0.2	0.83	1.61	84.9	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 0.4	0.1 ± 0.1
CORI1			19961207	2.8 ± 0.2	0.84	1.25	103.4	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.1 ± 0.1	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.4	0.2 ± 0.1
CORI1			19961211	4.7 ± 0.2	0.82	1.40	74.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 0.5	0.2 ± 0.1
CORI1			19961214	3.2 ± 0.2	0.86	1.89	113.3	0.8 ± 0.1	0.3 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.4	0.2 ± 0.2
CORI1			19961218	8.0 ± 0.3	0.90	1.15	67.3	0.2 ± 0.2	0.0 ± 0.0	1.7 ± 0.3	0.5 ± 0.1	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.0 ± 0.4	0.2 ± 0.1
CORI1		*	19961221	5.3 ± 0.2	0.89	1.36	86.7	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.2	1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 0.4	0.0 ± 0.1
CORI1			19961225	1.8 ± 0.2	0.91	1.05	102.4	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.2 ± 0.1
CORI1			19961228	7.5 ± 0.3	0.92	1.84	69.4	1.1 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	1.3 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.6 ± 0.4	0.3 ± 0.2

Table D-12. CMB Source Attribution Results for 1st Quarter 1997 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
CORI1	*		19970101	2.9 ± 0.2	0.83	3.22	66.2	0.2 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.1 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.1
CORI1		*	19970104	6.7 ± 0.3	0.91	0.92	92.6	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.2	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.7 ± 0.6	0.2 ± 0.1
CORI1			19970108	3.6 ± 0.2	0.88	1.38	110.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.9 ± 0.4	0.3 ± 0.1
CORI1			19970111	2.8 ± 0.2	0.86	1.75	106.1	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	1.4 ± 0.3	0.2 ± 0.1
CORI1		*	19970115	10.8 ± 0.4	0.89	1.66	78.4	0.2 ± 0.2	0.0 ± 0.0	3.0 ± 0.4	1.1 ± 0.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	2.7 ± 0.6	0.3 ± 0.2
CORI1	*		19970122	3.4 ± 0.2	0.83	0.87	65.3	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.5 ± 0.3	0.2 ± 0.1
CORI1			19970125	4.1 ± 0.2	0.89	1.45	100.4	0.4 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	0.7 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	1.7 ± 0.4	0.2 ± 0.1
CORI1		*	19970129	16.9 ± 0.5	0.92	1.58	75.1	0.3 ± 0.3	0.0 ± 0.0	4.1 ± 0.5	4.0 ± 0.3	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	3.2 ± 0.6	0.4 ± 0.2
CORI1			19970201	2.2 ± 0.2	0.77	3.03	132.2	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.2	1.3 ± 0.2
CORI1			19970205	5.3 ± 0.2	0.89	2.77	90.6	0.2 ± 0.2	0.0 ± 0.0	0.6 ± 0.2	0.9 ± 0.1	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.7 ± 0.4	0.1 ± 0.1
CORI1		*	19970208	9.0 ± 0.3	0.93	1.01	84.8	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 0.3	2.0 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.7 ± 0.5	0.3 ± 0.1
CORI1			19970212	5.5 ± 0.2	0.94	1.04	46.0	0.0 ± 0.0	0.4 ± 0.1	0.3 ± 0.0	0.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.8 ± 0.2	0.4 ± 0.2
CORI1	*		19970215	2.6 ± 0.2	0.89	0.78	121.7	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.0 ± 0.4	0.3 ± 0.1
CORI1			19970219	2.0 ± 0.2	0.92	0.91	100.8	0.0 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.9 ± 0.2	0.3 ± 0.2
CORI1			19970222	5.1 ± 0.2	0.93	0.71	99.7	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.6 ± 0.1	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.6 ± 0.6	0.2 ± 0.1
CORI1	*		19970226	1.7 ± 0.2	0.95	0.88	110.8	0.0 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.4 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.6 ± 0.2	0.3 ± 0.1
CORI1			19970301	3.7 ± 0.2	0.95	0.59	110.5	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.8 ± 0.1	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	1.7 ± 0.4	0.3 ± 0.1
CORI1			19970305	4.8 ± 0.2	0.90	1.25	108.5	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.7 ± 0.1	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.6 ± 0.6	0.2 ± 0.1
CORI1			19970308	5.8 ± 0.2	0.88	2.45	101.9	0.0 ± 0.0	0.4 ± 0.1	0.9 ± 0.1	1.9 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.0 ± 0.4	0.5 ± 0.3
CORI1	*		19970312	1.7 ± 0.2	0.91	1.38	84.3	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.1	0.2 ± 0.1
CORI1		*	19970315	5.3 ± 0.2	0.84	2.06	95.5	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.7 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.5 ± 0.5	0.1 ± 0.1
CORI1		*	19970319	5.3 ± 0.2	0.85	1.82	115.3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.1 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.2	3.2 ± 0.6	0.4 ± 0.2
CORI1			19970322	3.9 ± 0.2	0.90	0.99	108.4	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.3 ± 0.5	0.3 ± 0.1
CORI1	*		19970326	2.9 ± 0.2	0.86	2.25	60.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.2 ± 0.0	0.7 ± 0.2	0.2 ± 0.1
CORI1			19970329	7.4 ± 0.3	0.79	6.12	98.4	0.0 ± 0.0	0.3 ± 0.1	1.1 ± 0.1	2.3 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	1.3 ± 0.4	1.1 ± 0.5

Table D-13. CMB Source Attribution Results for 2nd Quarter 1997 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	PM$_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
CORI1			19970402	4.2 ± 0.2	0.91	1.22	106.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.1 ± 0.4	0.3 ± 0.1
CORI1			19970405	7.1 ± 0.3	0.89	1.63	63.3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	1.5 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	1.6 ± 0.3	0.2 ± 0.1
CORI1			19970409	5.6 ± 0.2	0.92	1.55	84.9	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.1	0.9 ± 0.2	0.3 ± 0.1
CORI1			19970412	7.1 ± 0.3	0.92	1.31	105.2	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.8 ± 0.2	0.7 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	2.4 ± 0.6	0.3 ± 0.1
CORI1			19970416	5.7 ± 0.2	0.90	1.04	89.5	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.7 ± 0.5	0.5 ± 0.2
CORI1		*	19970419	11.3 ± 0.4	0.93	0.80	61.8	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	1.2 ± 0.2	0.9 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.4 ± 0.7	0.4 ± 0.2
CORI1	*		19970423	1.4 ± 0.2	0.83	2.33	109.8	0.2 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.6 ± 0.1	0.1 ± 0.1
CORI1			19970426	4.9 ± 0.2	0.89	1.11	86.6	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.3 ± 0.5	0.2 ± 0.1
CORI1	*		19970430	2.6 ± 0.2	0.93	1.06	116.2	0.4 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.3 ± 0.3	0.3 ± 0.2
CORI1	*		19970503	3.2 ± 0.2	0.90	1.70	97.1	0.3 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.3 ± 0.3	0.3 ± 0.2
CORI1	*		19970507	3.5 ± 0.2	0.89	1.63	78.7	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	1.0 ± 0.2	0.2 ± 0.1
CORI1			19970510	7.2 ± 0.3	0.88	1.61	91.0	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.2	0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.2	2.9 ± 0.6	0.4 ± 0.2
CORI1			19970514	8.4 ± 0.3	0.88	1.56	82.5	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.2 ± 0.1	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	2.9 ± 0.6	0.4 ± 0.2
CORI1	*		19970517	6.7 ± 0.3	0.90	1.14	56.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	1.8 ± 0.4	0.3 ± 0.1
CORI1			19970521	8.8 ± 0.3	0.85	2.37	73.5	1.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	2.2 ± 0.4	0.5 ± 0.2
CORI1	*		19970524	3.3 ± 0.2	0.91	1.38	98.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.1 ± 0.2	0.2 ± 0.1
CORI1			19970528	8.4 ± 0.3	0.85	1.33	53.3	0.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.3	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.7 ± 0.5	0.4 ± 0.2
CORI1			19970531	5.9 ± 0.2	0.88	0.90	56.9	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.1 ± 0.4	0.2 ± 0.1
CORI1	*		19970604	4.1 ± 0.2	0.79	4.87	76.2	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.8 ± 0.1	0.4 ± 0.1	0.9 ± 0.2
CORI1	*		19970607	4.7 ± 0.2	0.89	1.58	68.9	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.3 ± 0.3	0.3 ± 0.1
CORI1			19970611	4.5 ± 0.2	0.89	1.40	94.4	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	1.9 ± 0.4	0.3 ± 0.1
CORI1			19970614	5.7 ± 0.2	0.92	1.01	88.2	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.1 ± 0.4	0.3 ± 0.1
CORI1	*		19970618	2.8 ± 0.2	0.92	1.50	77.1	0.4 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.6 ± 0.1	0.1 ± 0.1
CORI1	*		19970621	1.4 ± 0.2	0.89	1.02	126.9	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.9 ± 0.2	0.2 ± 0.1
CORI1	*		19970625	4.5 ± 0.2	0.90	1.00	91.2	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.2 ± 0.4	0.3 ± 0.1
CORI1	*		19970628	3.9 ± 0.2	0.80	2.09	95.6	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.1 ± 0.4	0.2 ± 0.1

Table D-14. CMB Source Attribution Results for 3rd Quarter 1997 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ ($\mu g/m^3$)	R^2	CHI^2	% MASS	Aged Sea Salt SCE ($\mu g/m^3$)	Fresh Sea Salt SCE ($\mu g/m^3$)	Ammonium Nitrate SCE ($\mu g/m^3$)	Ammonium Sulfate SCE ($\mu g/m^3$)	Aluminum Reduction SCE ($\mu g/m^3$)	Coal Fired PP SCE ($\mu g/m^3$)	Coal Fly Ash SCE ($\mu g/m^3$)	Kraft Paper Mill SCE ($\mu g/m^3$)	Puget Soil SCE ($\mu g/m^3$)	Motor Vehicles SCE ($\mu g/m^3$)	Vegetative Burning SCE ($\mu g/m^3$)
CORI1	*		19970702	4.0 ± 0.2	0.90	1.07	87.4	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.7 ± 0.3	0.2 ± 0.1
CORI1			19970705	12.2 ± 0.4	0.89	2.83	77.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 0.2	0.6 ± 0.3	0.0 ± 0.0	0.2 ± 0.3	0.0 ± 0.0	2.0 ± 0.4	2.1 ± 0.6	1.7 ± 0.5
CORI1	*		19970709	2.8 ± 0.2	0.84	1.59	48.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.1	0.1 ± 0.1
CORI1	*		19970712	5.4 ± 0.2	0.93	0.89	74.5	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.6 ± 0.3	0.3 ± 0.1
CORI1	*		19970716	6.3 ± 0.2	0.90	1.15	65.7	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.8 ± 0.4	0.2 ± 0.1
CORI1			19970719	6.8 ± 0.3	0.89	1.70	80.3	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.2	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.0 ± 0.4	0.3 ± 0.1
CORI1			19970723	6.2 ± 0.2	0.90	1.37	84.9	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	1.8 ± 0.4	0.3 ± 0.1
CORI1			19970726	5.6 ± 0.2	0.88	1.72	85.8	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.8 ± 0.4	0.2 ± 0.1
CORI1			19970730	7.4 ± 0.3	0.84	1.84	69.3	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	2.5 ± 0.5	0.3 ± 0.2
CORI1			19970802	6.8 ± 0.3	0.88	1.47	95.0	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.6 ± 0.5	0.3 ± 0.1
CORI1		*	19970806	15.1 ± 0.5	0.85	2.49	82.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	5.1 ± 0.4	0.6 ± 0.3	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.1 ± 0.3	3.7 ± 0.8	0.4 ± 0.2
CORI1			19970809	5.5 ± 0.2	0.83	3.26	84.5	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	1.2 ± 0.3	0.3 ± 0.1
CORI1			19970813	7.8 ± 0.3	0.83	2.12	83.4	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.2	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.2	3.0 ± 0.6	0.3 ± 0.2
CORI1			19970816	6.5 ± 0.2	0.88	2.55	90.8	1.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	1.3 ± 0.3	0.4 ± 0.2
CORI1			19970820	6.3 ± 0.2	0.82	2.51	84.6	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	2.1 ± 0.5	0.4 ± 0.2
CORI1	*		19970823	3.4 ± 0.2	0.92	1.00	87.8	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.4 ± 0.3	0.3 ± 0.1
CORI1	*		19970827	3.5 ± 0.2	0.88	1.92	79.7	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.9 ± 0.2	0.2 ± 0.1
CORI1			19970830	5.9 ± 0.2	0.88	1.19	87.3	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.9 ± 0.5	0.5 ± 0.2
CORI1			19970903	7.7 ± 0.3	0.90	1.33	96.4	0.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.3	2.9 ± 0.3	0.4 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.9 ± 0.6	0.4 ± 0.2
CORI1	*		19970906	3.5 ± 0.2	0.90	1.64	102.6	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	1.1 ± 0.2	0.2 ± 0.1
CORI1		*	19970910	11.8 ± 0.4	0.85	2.15	76.3	0.2 ± 0.4	0.0 ± 0.0	0.2 ± 0.4	2.5 ± 0.2	0.5 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.2	4.2 ± 0.8	0.7 ± 0.2
CORI1			19970913	3.7 ± 0.2	0.91	1.31	117.1	0.1 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	1.0 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.8 ± 0.4	0.6 ± 0.3
CORI1	*		19970917	2.6 ± 0.2	0.92	1.50	102.1	0.0 ± 0.0	0.4 ± 0.0	0.2 ± 0.0	0.4 ± 0.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.2	0.2 ± 0.2
CORI1			19970920	4.4 ± 0.2	0.91	1.01	85.9	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	0.7 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.0 ± 0.4	0.2 ± 0.1
CORI1			19970924	18.5 ± 0.6	0.79	1.43	75.7	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	1.0 ± 0.3	0.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.3	9.5 ± 1.7	0.9 ± 0.3
CORI1			19970927	6.9 ± 0.3	0.89	3.28	88.0	0.8 ± 0.1	3.0 ± 0.2	0.0 ± 0.0	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.9 ± 0.2	0.3 ± 0.2

Table D-15. CMB Source Attribution Results for 4th Quarter 1997 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
CORI1			19971001	5.7 ± 0.2	0.83	1.75	80.6	0.3 ± 0.3	0.0 ± 0.0	0.2 ± 0.3	0.4 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.6 ± 0.5	0.6 ± 0.2
CORI1	*		19971004	1.4 ± 0.2	0.95	0.85	93.3	0.1 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.5 ± 0.1	0.1 ± 0.1
CORI1		*	19971008	9.3 ± 0.3	0.87	1.40	56.0	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	0.8 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.9 ± 0.6	0.4 ± 0.2
CORI1	*		19971011	3.1 ± 0.2	0.65	6.95	76.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.8 ± 0.2	0.6 ± 0.3
CORI1		*	19971015	8.6 ± 0.3	0.86	1.52	90.9	0.2 ± 0.5	0.0 ± 0.0	0.3 ± 0.4	1.0 ± 0.2	0.7 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	4.6 ± 0.9	0.4 ± 0.2
CORI1			19971018	5.3 ± 0.2	0.88	1.46	86.8	0.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.2	1.0 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.4 ± 0.5	0.2 ± 0.1
CORI1		*	19971022	11.1 ± 0.4	0.82	1.79	81.3	0.0 ± 0.5	0.0 ± 0.0	0.5 ± 0.5	1.9 ± 0.2	0.2 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	5.4 ± 1.0	0.6 ± 0.2
CORI1			19971025	8.3 ± 0.3	0.82	1.90	77.0	0.4 ± 0.4	0.0 ± 0.0	0.1 ± 0.3	0.6 ± 0.2	1.0 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	3.5 ± 0.8	0.3 ± 0.2
CORI1		*	19971029	6.8 ± 0.3	0.88	2.65	71.6	0.6 ± 0.1	0.9 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	1.8 ± 0.4	0.6 ± 0.3
CORI1			19971101	7.5 ± 0.3	0.91	1.76	92.4	1.7 ± 0.2	1.6 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.4	0.5 ± 0.3
CORI1		*	19971105	13.0 ± 0.4	0.93	1.04	83.3	0.3 ± 0.3	0.0 ± 0.0	1.6 ± 0.4	3.3 ± 0.3	0.7 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	4.3 ± 0.8	0.3 ± 0.2
CORI1			19971108	4.9 ± 0.2	0.91	1.15	98.9	0.7 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.8 ± 0.1	0.5 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.4 ± 0.5	0.2 ± 0.1
CORI1		*	19971112	13.7 ± 0.4	0.92	1.29	69.2	0.5 ± 0.3	0.0 ± 0.0	1.1 ± 0.3	2.2 ± 0.3	1.4 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	3.4 ± 0.8	0.3 ± 0.2
CORI1		*	19971119	5.6 ± 0.2	0.94	0.83	101.9	0.2 ± 0.3	0.0 ± 0.0	0.8 ± 0.3	1.4 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.7 ± 0.5	0.3 ± 0.1
CORI1		*	19971122	5.0 ± 0.2	0.91	1.13	102.6	0.3 ± 0.2	0.0 ± 0.0	0.7 ± 0.2	0.7 ± 0.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.4 ± 0.5	0.3 ± 0.1
CORI1			19971126	4.7 ± 0.2	0.95	0.66	109.2	0.2 ± 0.2	0.0 ± 0.0	0.7 ± 0.2	1.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.4 ± 0.5	0.3 ± 0.1
CORI1		*	19971129	6.4 ± 0.3	0.86	1.16	97.2	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	1.8 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.4 ± 0.8	0.2 ± 0.1
CORI1		*	19971203	7.0 ± 0.3	0.92	0.88	103.8	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.2	2.7 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.6 ± 0.5	0.3 ± 0.1
CORI1		*	19971206	10.8 ± 0.4	0.89	1.38	93.7	0.0 ± 0.0	0.0 ± 0.0	2.4 ± 0.3	4.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.1 ± 0.6	0.3 ± 0.1
CORI1		*	19971210	6.8 ± 0.3	0.89	1.54	100.0	0.3 ± 0.2	0.0 ± 0.0	1.2 ± 0.3	1.3 ± 0.2	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.9 ± 0.6	0.5 ± 0.2
CORI1		*	19971213	9.2 ± 0.3	0.88	1.36	116.1	0.0 ± 0.0	0.0 ± 0.0	3.8 ± 0.4	2.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.8 ± 0.7	0.3 ± 0.1
CORI1	*		19971217	2.6 ± 0.2	0.91	1.43	90.0	0.4 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	0.9 ± 0.2	0.3 ± 0.2
CORI1			19971220	7.8 ± 0.3	0.86	1.26	74.4	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.2	1.2 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.9 ± 0.7	0.4 ± 0.2
CORI1		*	19971224	6.8 ± 0.3	0.92	1.23	94.5	0.2 ± 0.2	0.0 ± 0.0	1.4 ± 0.2	2.5 ± 0.2	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.7 ± 0.3	0.2 ± 0.1
CORI1	*		19971227	4.8 ± 0.2	0.93	1.60	86.4	0.6 ± 0.1	2.2 ± 0.2	0.0 ± 0.0	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.2	0.3 ± 0.2
CORI1		*	19971231	5.7 ± 0.2	0.93	0.98	89.0	0.2 ± 0.2	0.0 ± 0.0	0.5 ± 0.2	1.3 ± 0.1	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	2.2 ± 0.5	0.3 ± 0.1

Table D-16. CMB Source Attribution Results for 1st Quarter 1998 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ ($\mu g/m^3$)	R^2	CHI^2	% MASS	Aged Sea Salt SCE ($\mu g/m^3$)	Fresh Sea Salt SCE ($\mu g/m^3$)	Ammonium Nitrate SCE ($\mu g/m^3$)	Ammonium Sulfate SCE ($\mu g/m^3$)	Aluminum Reduction SCE ($\mu g/m^3$)	Coal Fired PP SCE ($\mu g/m^3$)	Coal Fly Ash SCE ($\mu g/m^3$)	Kraft Paper Mill SCE ($\mu g/m^3$)	Puget Soil SCE ($\mu g/m^3$)	Motor Vehicles SCE ($\mu g/m^3$)	Vegetative Burning SCE ($\mu g/m^3$)
CORI1			19980103	3.0 ± 0.2	0.95	0.90	108.5	0.3 ± 0.1	0.0 ± 0.0	0.4 ± 0.1	1.2 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.0 ± 0.2	0.2 ± 0.1
CORI1	*		19980107	2.7 ± 0.2	0.88	1.47	98.2	0.2 ± 0.1	0.0 ± 0.0	0.3 ± 0.1	0.4 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.2 ± 0.3	0.4 ± 0.1
CORI1			19980110	5.0 ± 0.2	0.89	0.98	103.6	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	2.1 ± 0.4	0.3 ± 0.1
CORI1		*	19980114	11.2 ± 0.4	0.92	1.20	57.9	0.7 ± 0.2	0.0 ± 0.0	1.0 ± 0.2	1.7 ± 0.2	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.0	1.6 ± 0.4	0.2 ± 0.1
CORI1			19980117	3.9 ± 0.2	0.90	1.91	88.5	0.6 ± 0.1	1.2 ± 0.1	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.2	0.1 ± 0.1
CORI1		*	19980121	5.4 ± 0.2	0.90	0.93	97.4	0.5 ± 0.3	0.0 ± 0.0	0.0 ± 0.3	0.9 ± 0.1	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 0.6	0.3 ± 0.1
CORI1		*	19980124	5.9 ± 0.2	0.89	1.08	94.0	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	1.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.0	2.4 ± 0.6	0.3 ± 0.1
CORI1		*	19980128	7.5 ± 0.3	0.93	0.88	100.1	0.9 ± 0.4	0.0 ± 0.0	0.7 ± 0.4	1.3 ± 0.2	0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	3.6 ± 0.7	0.2 ± 0.1
CORI1		*	19980131	5.9 ± 0.2	0.96	0.57	98.1	0.1 ± 0.2	0.0 ± 0.0	1.1 ± 0.2	1.8 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.3 ± 0.4	0.2 ± 0.1
CORI1		*	19980204	4.9 ± 0.2	0.93	0.81	113.8	0.3 ± 0.3	0.0 ± 0.0	0.8 ± 0.3	0.6 ± 0.1	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.0 ± 0.6	0.2 ± 0.1
CORI1			19980207	4.8 ± 0.2	0.86	1.38	101.7	0.4 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	0.3 ± 0.1	1.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.6 ± 0.6	0.1 ± 0.1
CORI1		*	19980211	5.4 ± 0.2	0.93	0.86	107.5	0.5 ± 0.2	0.0 ± 0.0	0.4 ± 0.2	0.8 ± 0.2	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.7 ± 0.6	0.3 ± 0.1
CORI1			19980214	2.4 ± 0.2	0.90	1.03	112.6	0.3 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.4 ± 0.3	0.2 ± 0.1
CORI1			19980218	3.2 ± 0.2	0.85	1.45	127.7	0.2 ± 0.2	0.0 ± 0.0	0.2 ± 0.2	0.2 ± 0.1	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	2.4 ± 0.5	0.2 ± 0.1
CORI1	*		19980221	1.1 ± 0.2	0.89	1.16	119.8	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.7 ± 0.2	0.1 ± 0.1
CORI1			19980225	5.0 ± 0.2	0.94	0.95	76.3	0.4 ± 0.2	0.1 ± 0.0	0.1 ± 0.1	0.8 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.7 ± 0.3	0.4 ± 0.2
CORI1		*	19980228	3.7 ± 0.2	0.94	0.75	143.1	0.2 ± 0.2	0.0 ± 0.0	0.9 ± 0.2	1.2 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.3 ± 0.4	0.2 ± 0.1
CORI1			19980304	2.2 ± 0.2	0.91	1.25	158.8	0.0 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	1.3 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.2 ± 0.3	0.5 ± 0.2
CORI1			19980307	5.0 ± 0.2	0.92	1.32	103.8	0.2 ± 0.2	0.0 ± 0.0	0.4 ± 0.2	1.7 ± 0.2	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.8 ± 0.4	0.2 ± 0.1
CORI1		*	19980311	5.6 ± 0.2	0.74	2.35	137.4	0.2 ± 0.5	0.0 ± 0.0	0.6 ± 0.5	0.8 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	5.1 ± 0.9	0.5 ± 0.2
CORI1			19980314	5.6 ± 0.2	0.92	0.80	104.2	0.4 ± 0.3	0.0 ± 0.0	0.3 ± 0.3	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	3.4 ± 0.6	0.4 ± 0.2
CORI1			19980318	4.7 ± 0.2	0.90	1.42	109.6	0.5 ± 0.3	0.0 ± 0.0	0.1 ± 0.2	1.3 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.3 ± 0.5	0.3 ± 0.1
CORI1		*	19980321	10.8 ± 0.4	0.88	1.54	89.6	0.5 ± 0.4	0.0 ± 0.0	0.7 ± 0.4	1.5 ± 0.2	0.7 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.2	5.0 ± 1.0	0.5 ± 0.2
CORI1	*		19980325	2.8 ± 0.2	0.94	0.74	102.4	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.2 ± 0.3	0.4 ± 0.1
CORI1	*		19980328	1.9 ± 0.2	0.93	1.14	116.6	0.1 ± 0.1	0.0 ± 0.0	0.2 ± 0.1	0.6 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.8 ± 0.2	0.2 ± 0.1

Table D-17. CMB Source Attribution Results for 2nd Quarter 1998 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	PM$_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
CORI1			19980401	4.1 ± 0.2	0.85	1.59	112.8	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.8 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.2 ± 0.4	0.3 ± 0.1
CORI1			19980404	5.0 ± 0.2	0.91	1.00	108.8	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	2.4 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	2.2 ± 0.4	0.3 ± 0.1
CORI1			19980408	4.3 ± 0.2	0.93	0.97	87.1	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.4 ± 0.3	0.5 ± 0.1
CORI1	*		19980411	2.3 ± 0.2	0.91	1.37	129.7	0.2 ± 0.1	0.0 ± 0.0	0.3 ± 0.1	0.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.3 ± 0.3	0.3 ± 0.2
CORI1			19980415	4.8 ± 0.2	0.90	1.36	105.5	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	2.2 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	1.8 ± 0.4	0.2 ± 0.1
CORI1			19980418	5.6 ± 0.2	0.90	1.39	99.4	0.2 ± 0.3	0.0 ± 0.0	0.1 ± 0.3	1.5 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.7 ± 0.5	0.3 ± 0.1
CORI1		*	19980422	11.2 ± 0.4	0.81	3.06	67.4	0.5 ± 0.3	0.0 ± 0.0	0.1 ± 0.2	1.3 ± 0.2	1.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.2	2.2 ± 0.6	0.7 ± 0.3
CORI1	*		19980425	2.7 ± 0.2	0.92	0.90	111.8	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.4 ± 0.3	0.3 ± 0.1
CORI1		*	19980429	26.4 ± 0.8	0.50	21.7	54.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.1	2.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	8.2 ± 0.6	1.4 ± 0.4	1.0 ± 0.3
CORI1	*		19980502	3.8 ± 0.2	0.84	3.18	92.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.8 ± 0.1	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.1	0.7 ± 0.2	0.2 ± 0.1
CORI1		*	19980506	13.7 ± 0.4	0.85	2.85	86.3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.0	5.8 ± 0.5	0.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.5 ± 0.3	2.3 ± 0.6	0.4 ± 0.2
CORI1	*		19980509	5.8 ± 0.2	0.88	2.31	60.5	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.1	0.9 ± 0.2	0.2 ± 0.1
CORI1	*		19980513	1.2 ± 0.2	0.79	3.27	115.9	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.5 ± 0.1	0.3 ± 0.1	0.2 ± 0.1
CORI1	*		19980516	2.5 ± 0.2	0.92	0.88	110.2	0.2 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.5 ± 0.3	0.2 ± 0.1
CORI1			19980520	3.4 ± 0.2	0.90	0.93	87.9	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.5 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	1.6 ± 0.3	0.2 ± 0.1
CORI1	*		19980523	2.3 ± 0.2	0.88	1.21	101.4	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.2 ± 0.2	0.2 ± 0.1
CORI1	*		19980527	2.3 ± 0.2	0.90	1.35	116.7	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.8 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.2 ± 0.2	0.2 ± 0.1
CORI1			19980530	2.2 ± 0.2	0.93	0.75	107.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.1	0.7 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	1.1 ± 0.2	0.1 ± 0.1
CORI1			19980603	7.0 ± 0.3	0.91	0.98	95.6	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	3.3 ± 0.6	0.3 ± 0.1
CORI1			19980606	7.9 ± 0.3	0.91	0.92	60.3	0.1 ± 0.3	0.0 ± 0.0	0.2 ± 0.2	1.0 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.6 ± 0.5	0.3 ± 0.1
CORI1	*		19980610	2.4 ± 0.2	0.89	1.08	86.4	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.9 ± 0.2	0.2 ± 0.1
CORI1			19980613	6.0 ± 0.2	0.89	1.80	84.1	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.5 ± 0.3	0.5 ± 0.3
CORI1			19980617	5.3 ± 0.2	0.91	1.29	92.4	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.8 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.9 ± 0.4	0.3 ± 0.1
CORI1			19980620	5.1 ± 0.2	0.91	1.12	82.5	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	1.4 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.8 ± 0.4	0.2 ± 0.1
CORI1	*		19980624	1.7 ± 0.2	0.87	1.67	123.9	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.9 ± 0.2	0.1 ± 0.0
CORI1	*		19980627	2.5 ± 0.2	0.92	1.09	96.8	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.9 ± 0.1	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.9 ± 0.2	0.2 ± 0.1

Table D-18. CMB Source Attribution Results for 3rd Quarter 1998 at the Wishram (CORI1) site.

SITEID	25% Best Day	25% Worst Day	DATE	$PM_{2.5}$ (μg/m^3)	R^2	CHI^2	% MASS	Aged Sea Salt SCE (μg/m^3)	Fresh Sea Salt SCE (μg/m^3)	Ammonium Nitrate SCE (μg/m^3)	Ammonium Sulfate SCE (μg/m^3)	Aluminum Reduction SCE (μg/m^3)	Coal Fired PP SCE (μg/m^3)	Coal Fly Ash SCE (μg/m^3)	Kraft Paper Mill SCE (μg/m^3)	Puget Soil SCE (μg/m^3)	Motor Vehicles SCE (μg/m^3)	Vegetative Burning SCE (μg/m^3)
CORI1			19980701	5.5 ± 0.2	0.89	1.07	89.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	2.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.0 ± 0.4	0.2 ± 0.1
CORI1	*		19980704	2.7 ± 0.2	0.84	1.61	100.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.2 ± 0.3	0.3 ± 0.1
CORI1		*	19980708	9.5 ± 0.3	0.86	1.59	94.5	0.1 ± 0.4	0.0 ± 0.0	0.1 ± 0.3	4.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	3.4 ± 0.6	0.4 ± 0.2
CORI1			19980711	8.1 ± 0.3	0.89	1.71	104.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	3.2 ± 0.3	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 0.2	2.4 ± 0.5	0.5 ± 0.2
CORI1			19980715	6.9 ± 0.3	0.78	1.76	97.8	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.7 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	4.1 ± 0.8	0.8 ± 0.3
CORI1			19980718	4.2 ± 0.2	0.92	0.85	100.7	0.0 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	0.8 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.1	2.1 ± 0.4	0.3 ± 0.1
CORI1		*	19980722	13.9 ± 0.4	0.89	1.35	85.9	0.1 ± 0.5	0.0 ± 0.0	0.4 ± 0.5	3.8 ± 0.4	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.3	5.4 ± 1.0	0.5 ± 0.2
CORI1			19980725	8.3 ± 0.3	0.91	1.12	84.7	0.1 ± 0.3	0.0 ± 0.0	0.1 ± 0.3	3.0 ± 0.3	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.8 ± 0.5	0.3 ± 0.1
CORI1		*	19980729	13.1 ± 0.4	0.82	1.56	72.7	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	2.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.2	5.5 ± 1.0	0.4 ± 0.2
CORI1			19980801	4.8 ± 0.2	0.88	1.48	91.6	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.2	1.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	1.8 ± 0.4	0.3 ± 0.1
CORI1			19980805	8.6 ± 0.3	0.85	2.67	89.8	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 0.2	0.6 ± 0.2	0.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.6 ± 0.2	2.2 ± 0.5	0.3 ± 0.2
CORI1			19980808	5.1 ± 0.2	0.91	1.18	101.0	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	2.0 ± 0.4	0.3 ± 0.1
CORI1			19980812	7.7 ± 0.3	0.85	2.45	90.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	2.2 ± 0.2	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 0.2	2.1 ± 0.5	0.3 ± 0.1
CORI1	*		19980815	3.6 ± 0.2	0.85	3.59	114.6	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.1	0.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.1 ± 0.2	0.4 ± 0.1	0.1 ± 0.1
CORI1			19980819	5.6 ± 0.2	0.89	1.82	96.6	0.1 ± 0.2	0.0 ± 0.0	0.1 ± 0.2	1.9 ± 0.2	0.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.2	1.6 ± 0.4	0.3 ± 0.1
CORI1			19980822	9.0 ± 0.3	0.90	1.37	72.4	0.2 ± 0.3	0.0 ± 0.0	0.1 ± 0.3	2.4 ± 0.2	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.8 ± 0.5	0.3 ± 0.2
CORI1			19980826	6.2 ± 0.2	0.82	1.72	87.9	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	1.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.1	2.9 ± 0.5	0.3 ± 0.1

E. DRAFT PMF ANALYSIS OF AMBIENT PM$_{2.5}$ CONCENTRATIONS IN THE COLUMBIA RIVER GORGE (9/1/96 TO 9/1/98)

03/26/2003

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POSITIVE MATRIX FACTORIZATION (PMF) ANALYSIS OF COLUMBIA GORGE IMPROVE DATA

Introduction

PMF is a variant of Factor Analysis with non-negative factor elements. It is a factor analysis method with individual weighting of matrix elements first described by Paatero and Tapper (1994) and Paatero (1997). PMF2 is a 2-dimensional factor analytic model which solves the equation:

$$\mathbf{X = GF + E}$$

In this equation, X is the matrix of measured values, G and F are the factor matrices to be determined, and E is the matrix of residuals, the unexplained part of X. In the PMF model, the solution is a weighted Least Squares fit, where the known standard deviations for each value of X are used for determining the weights of the residuals in matrix E. The objective of PMF is to minimize the sum of the weighted residuals. PMF uses information from all samples by weighting the squares of the residuals with the reciprocals of the squares of the standard deviations of the data values.

In environmental pollution problems, one row of X would consist of the concentrations of all chemical species in one sample, and one column of X would be the concentration of one species for each of the samples. One row of the computed F matrix would be the source profile for one source, and the corresponding column of G would be the amount of this source in each individual sample. To run PMF, required input matrices are X, the measured values, and $X_{\text{std-dev}}$, the standard deviations (uncertainties) of the measured values. PMF requires that all values and uncertainties are positive values, therefore missing data and zero values must be omitted or replaced with appropriate substitute values. Output matrices include F (source profiles), G (source contribution to each sample), EV (explained variations of each species), X-GF (matrix of residual values), X-GF/s (matrix of residuals scaled by standard deviations), and rotmat (matrix of standard deviations of rotations).

Methods

Model Operating Parameters

For analysis of the Columbia Gorge IMPROVE data, PMF2 was run in the robust mode suggested for analyzing environmental data (Paatero, 1996). In the robust mode, the standard deviations used for weighting the residuals are dynamically readjusted through an iterative process. This process prevents excessively large values in the data set from disproportionally affecting the results.

PMF2 provides several options (error models) to calculate the standard deviations of the data values. According to Paatero (1996), recommended error models for environmental data include the lognormal distribution model and the heuristically-computed model. The heuristically-computed model was chosen for the Columbia Gorge data analysis. PMF2 can also be run in various normalization modes. For this study, the normalization mode was set to F = 1 (total of each factor = 1).

Determining the Number of Factors and F_{peak} Values

In PMF, the choice of the number of factors to use in finding a viable solution depends on examining certain PMF outputs and a knowledge of the major sources potentially impacting the monitoring site where the data were collected. The information in the scaled-residual matrix (X-GF/s) or the rotational matrix (rotmat) can be used to determine the maximum number of factors and reduce ambiguity in the solution (Lee et. al., 1999). In this study, rotmat results were used to determine the maximum number of factors. The method of using rotmat is to observe how the largest element in rotmat varies as a function of the number of factors. When the largest rotmat element is plotted against the number of factors, the maximum number of factors occurs at the point where the largest element shows a significant increase. For the Columbia Gorge data, the largest number of factors identified by this method was 8. This results was in agreement with the CMB analysis of the Columbia Gorge data, which indicated that there were 7 significant sources impacting the Mt. Zion and Wishram monitoring sites. Since PMF was expected to resolve gasoline and diesel sources, which CMB did not resolve, this would indicate a total of 8 significant sources at each site.

There are two practical alternatives for handling excessive rotational freedom to optimize the PMF results. The most straightforward method is to use positive values for the user-specified parameter F_{peak}. According to Lee et. al. (1999), the objective is to have small rotational freedom and small residuals at the same time, which requires that F_{peak} be less than 0.7. For this study, an F_{peak} value of 0.2 was used for the Wishram data and a value of 0.3 was used for the Mt. Zion data.

Data Selection

Data used for this study were the 1996-98 IMPROVE data from the Mt. Zion and Wishram sites in the Columbia Gorge. Species for which there was substantial missing data for this time period were eliminated. Sampling dates with one or more missing data were also eliminated. This resulted in the elimination of several metal tracer species and of a significant number of sampling dates. In this study the Mt. Zion data consisted of 109 sampling days and the Wishram data consisted of 166 sampling days. Lee et. al. (1999) suggest that median values can be substituted for missing data and a large standard deviation can be assigned to such substituted values. In this way, there is no need to reject sampling days containing a few missing values.

Species for which there was a high degree of uncertainty (value/uncertainty ratio < 2.0) were also eliminated. For the Columbia Gorge data this included the OC1 organic carbon fraction and the EC3 elemental carbon fraction.

Regression Correction and Mass Allocation Determination

In order to get correct factor allocation for each sampling date, the elements of the G matrix were regressed against the total mass measured for each sampling date. In this study, this was accomplished by using the "LINEST" function in Microsoft Excel. This function performs a linear regression fitting the equation: $m_i = s_j \Sigma x_{ij}$, where m_i = measured mass of sample i, s_j = slope of factor j, and x_{ij} = factor allocation to sample ij.

Percent mass allocation by each factor (source) to all samples was calculated by summing the individual allocations to each sample. This total was then multiplied by the appropriate regression correction factor and divided by the total calculated mass to get a percent mass allocation for each source.

Results and Discussion

Source Identification

The PMF explained variation output matrices for Mt. Zion and Wishram indicated that the identified sources accounted for 80-99% of the variation in all species except for EC2. The unexplained variation in EC2 was about 40%. This may have been due to the fact that the EC2 value/uncertainty ratio was slightly greater than 2, indicating a greater degree of uncertainty in the EC2 values than in the values of other species used in this analysis.

PMF source profiles for the Mt. Zion site are shown in Figures 1-8. PMF source profiles for the Wishram site are shown in Figures 9-16. Identification of source profiles was accomplished by comparing PMF profiles to profiles of sources identified by the CMB analysis of the Columbia Gorge IMPROVE data, and to source profiles identified by Chow and Watson (1998) for western Washington. For both the Mt. Zion and Wishram data sets, PMF generated profiles that were dominated by species unique to sources identified in the CMB analysis. These species and their associated sources are shown in Table 1:

Table 1. Species and Associated Sources

Species	Source
Sulfate	Secondary sulfate
Nitrate	Secondary nitrate
Silicon, iron, aluminum	Soil/Road dust
Sodium	Marine aerosols

For both the Mt. Zion and Wishram data, PMF generated a similar profile with a high OC/EC ratio (OC/EC ~ 4), very small amount of EC2, a large OC3 fraction, and potassium. This profile was identified as a vegetative burning profile. For Mt. Zion, PMF generated a profile with a large percent of potassium, organic carbon, sulfur, and sulfate. This profile was identified as a pulp mill profile.

The resolution of diesel and gasoline (automobile) sources was the most difficult objective for PMF. The organic carbon fractions and metals (aluminum, iron, lead, and zinc) emitted by diesels are very similar to those emitted by automobiles. The primary distinction between these two sources is their EC1/EC2 ratios. Quantifying the EC1/EC2 ratios for automobiles and diesels is difficult because of the variability in elemental carbon and organic carbon fractions in all mobile sources. However, the results of the diesel and automobile emission study by Watson et. al. (1994) show that the EC1 fraction is larger than the EC2 fraction in automobiles, and that the EC2 fraction is larger than the EC1 fraction in diesels. For both Mt. Zion and Wishram data, PMF generated a combustion profile with an EC1/EC2 ~ 1, which included lead, zinc, and iron. This profile was identified as a diesel profile. For Mt. Zion, PMF generated a combustion profile with an EC1/EC2 >> 1, with iron and zinc peaks. This profile was identified as an automobile profile. For Wishram, PMF generated a combustion profile that could not be identified, and another profile with a mixture of aluminum, elemental carbon (EC1), and organic carbon fractions that appeared to be a combination of aluminum reduction and combustion sources.

Source Percent Mass Allocation

Results of percent mass allocation to each source at the Mt. Zion and Wishram sites are shown in Table 2. The PMF mass allocations for secondary sulfate, secondary nitrate, soil, and marine aerosols were similar to CMB results. The major difference between the results of these two models was in the allocation to motor vehicle sources and vegetative burning. CMB predicted a 9% allocation to vegetative burning at Mt. Zion and a 7% allocation at Wishram. PMF predicted a 26-27% allocation to vegetative burning at both locations. CMB predicted a 43% allocation to motor vehicles at Mt. Zion and 41% at Wishram. PMF predicted a 5.2% allocation to diesel and 6.5% allocation to automobiles at Mt. Zion. CMB was not able to determine the allocation from pulp mills at Mt. Zion, but PMF allocated 11% to pulp mills at this site. PMF made a 3% allocation to diesel sources at Wishram. PMF did not generate an automobile profile for Wishram, but allocated 6.8% to an unidentified combustion source. PMF also allocated 15.8% to the aluminum reduction-combustion source profile for Wishram.

Table 2. PMF Source Percent Mass Allocations

Source	**Mt. Zion**	**Wishram**
Vegetative burning	26.4	26.8
Secondary Sulfate	25.7	27.1
Secondary Nitrate	10.5	9.1
Marine aerosols	5.9	4.2
Soil/Road Dust	8.9	7.2
Pulp Mills	11.1	0
Diesel	5.2	3.0
Automobile	6.5	N/A
Unidentified Combustion Source	N/A	6.8
Aluminum Reduction – Combustion Mix	N/A	15.8

Source Temporal Variation

Temporal variation of the Mt. Zion PMF sources are shown in Figures 17-24, and temporal variation of the Wishram sources are shown in Figures 25-32. The soil time series for

Mt. Zion and Wishram show seasonal variation with broad peaks occurring from July through October. The vegetative burning time series for Mt. Zion shows seasonal variation with a broad peak from August through November. The time series for vegetative burning at Wishram shows a less distinct peak from August through December and has numerous peaks at irregular frequency throughout the year. The Mt. Zion pulp mill source shows peaks occurring from July through October. The secondary sulfate source shows summer-fall peaks at Mt. Zion and Wishram. The secondary nitrate source shows peaks at Mt. Zion and Wishram lasting from November through March. The marine source shows seasonal variation with a broad peak from April through August at Mt. Zion, but less seasonal variation and peaks at irregular frequency at Wishram. Diesel and automobile sources show little seasonal variation at either site. The aluminum reduction/combustion source shows seasonal variation with a broad peak from about August through December.

Source to Wind Direction Correlation

Source contributions were correlated with 24-hour average wind directions on the days that samples were collected. Average wind speeds less than 5 mph were classified as "calm". Source percent mass contributions as a function of wind direction for the Mt. Zion site are shown in Table 3. Vegetative burning impacted the Mt. Zion site primarily (32%) when the wind was calm but remaining contributions came almost equally from all four directions. A majority (51%) of the contribution from pulp mills occurred when the wind was calm or from the north, but significant contributions also occurred when winds were from the south and west. 34% of the secondary sulfate was measured when wind was from the north, but westerly winds and calm wind each contributed 20.5%. The largest contribution (29%) from automobiles occurred when the wind was calm, but significant contributions also occurred when the wind was westerly or northerly. The largest secondary nitrate component (27%) occurred when the wind was easterly, but the remaining secondary nitrate came almost equally from all four other wind categories. The majority (42%) of the marine aerosols came from the northerly direction, with about 22% coming from the west.

Table 3. Mt. Zion Source Percent Mass Contribution by Wind Direction

Wind Direction	**Vegetative Burning**	**Pulp Mill**	**Second. Sulfate**	**Autos**	**Second. Nitrate**	**Marine**	**Diesel**	**Soil**
Calm	31.5	26.8	20.5	28.7	18.8	18.0	24.9	19.2
Easterly	16.9	10.0	12.2	13.6	27.1	6.8	24.7	4.6
Northerly	16.9	24.6	33.9	20.8	19.8	42.5	10.9	33.8
Southerly	20.6	18.7	13.0	16.3	16.8	10.8	21.3	19.5
Westerly	14.1	19.9	20.5	20.6	17.4	21.9	18.2	22.8

About 50% of the diesel source contribution occurred when the wind was calm or from the east, but the next 39% was from the south and west. Soil came primarily from the north, but most of the remainder came almost equally from the south, west, and when the wind was calm.

Source percent mass contributions as a function of wind direction for the Wishram site are shown in Table 4. A majority (65%) of the marine aerosol mass was measured at Wishram when the winds were from the southerly and westerly directions. Vegetative burning contribution primarily occurred when the wind was calm, but significant (24%) contributions came equally from the south and west. Aluminum reduction sources impacted Wishram mostly (39%) when the wind was calm, but 26% came from the south and 21% from the east. Diesel and secondary sulfate sources were almost equally split among the east, south, west, and calm wind categories. The largest soil contribution (36%) occurred when the 24-hour average wind speed was calm, with the next most significant contribution (28%) from the west. Almost half (48%) of the secondary nitrate came from the east. Contribution from the unidentified combustion source was almost equally split among the four wind categories.

Table 4. Wishram Source Percent Mass Contribution by Wind Direction

Wind Direction	Marine	Vegetative Burning	Aluminum Reduction	Diesel	Second. Sulfate	Soil	Second. Nitrate	Combustion Source
Calm	21.1	37.3	38.8	31.7	21.1	36.3	25.7	27.4
Easterly	14.1	14.7	21.2	25.7	24.6	14.5	47.9	30.0
Southerly	39.1	24.0	25.7	21.0	27.0	21.3	19.1	21.6
Westerly	25.6	24.0	14.3	21.6	27.3	27.8	7.3	21.1

Conclusions

PMF demonstrated that it is a good tool for resolving sources impacting monitoring sites based on IMPROVE speciated particulate monitoring data. PMF also appears to resolve burning and combustion sources if elemental carbon fractions (EC1 and EC2) and organic carbon fractions (OC2, OC3, and OC4) are available from the monitoring data. Resolution of combustion sources at the Mt. Zion and Wishram sites was compromised in this study because a substantial portion of the data of several key metal species (such as copper, manganese, and nickel) were missing, which caused these species to be eliminated in the analysis. Source resolution was also impacted by the elimination of sampling days which had one or more missing values. Better source resolution and allocation could be obtained with a greater number of sampling days included in the PMF analysis. Sampling days with only a few missing values can also be retained if median values are substituted for missing values. The next step would be to look at the Mt. Zion and Wishram IMPROVE data over a longer time period.

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Paatero, P., 1997. Least squares formulation of robust non-negative factor analysis, Chemometrics and Intelligent Laboratory Systems, 37, 23-35.

Watson, J., et. al., 1994. Difference in the Carbon Composition of Source Profiles for Diesel- and Gasoline-Powered Vehicles, Atmos. Environ., 28, 2493-2505.

Mt. Zion Time Series Plots

Figure 17 - Vegetative Burning

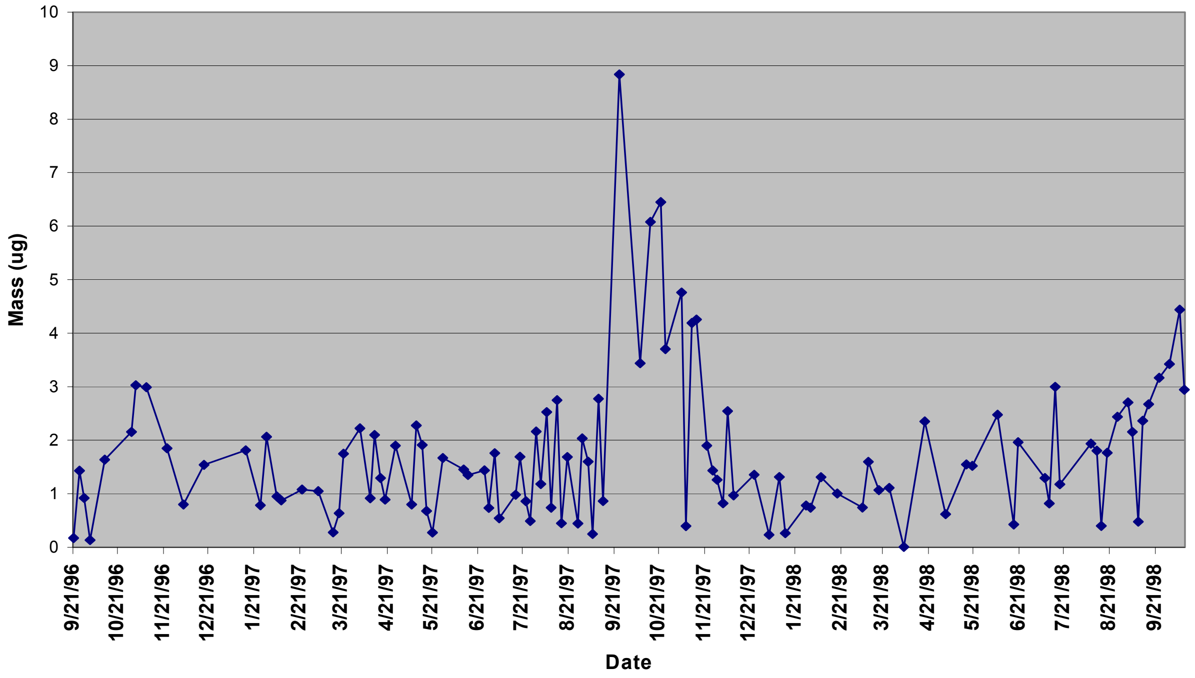


Figure 18 - Pulp Mills

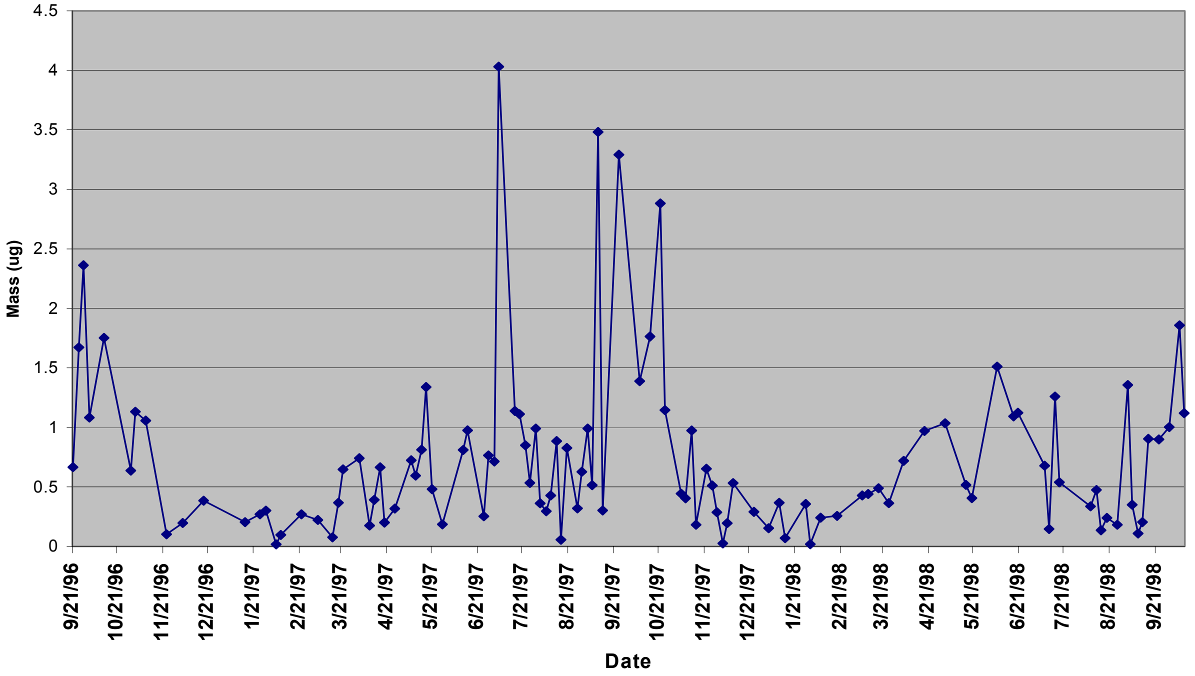


Figure 19 - Secondary Sulfate

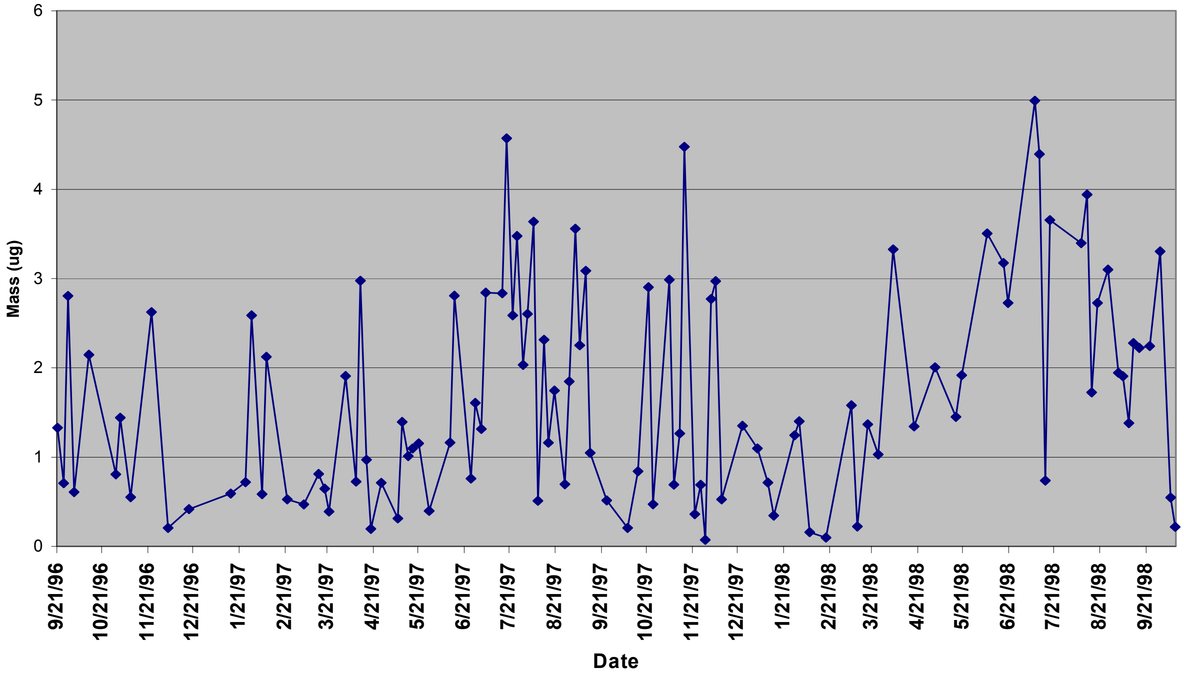


Figure 20 - Automobiles

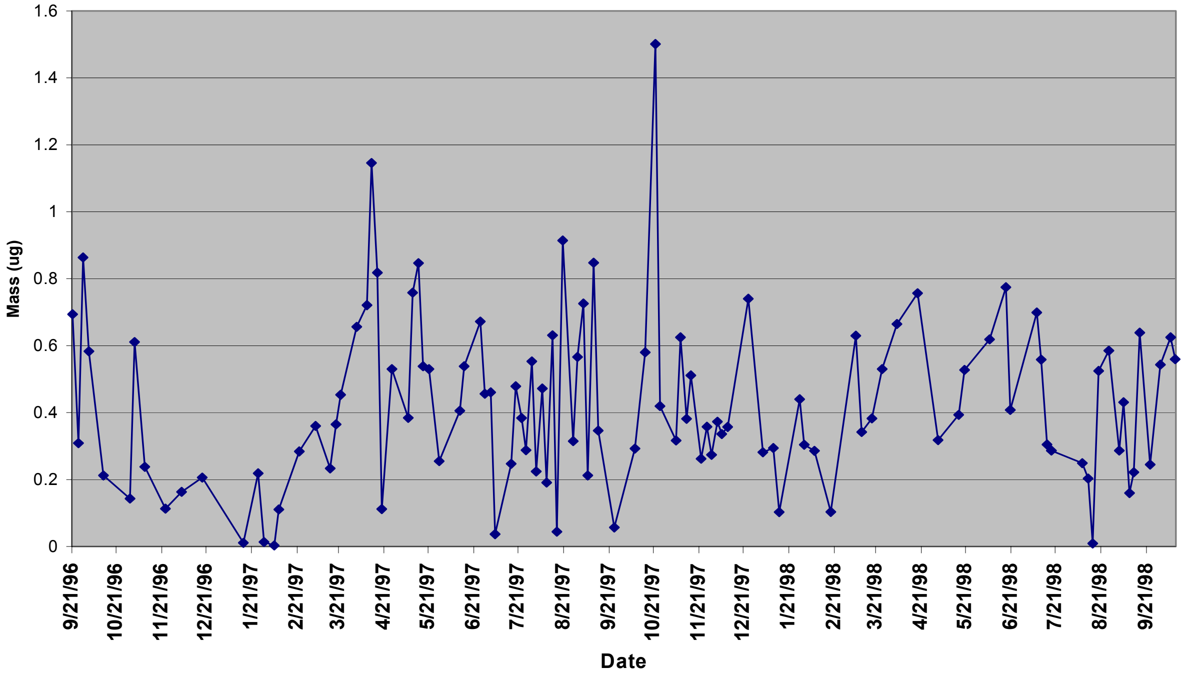


Figure 21 - Secondary Nitrate

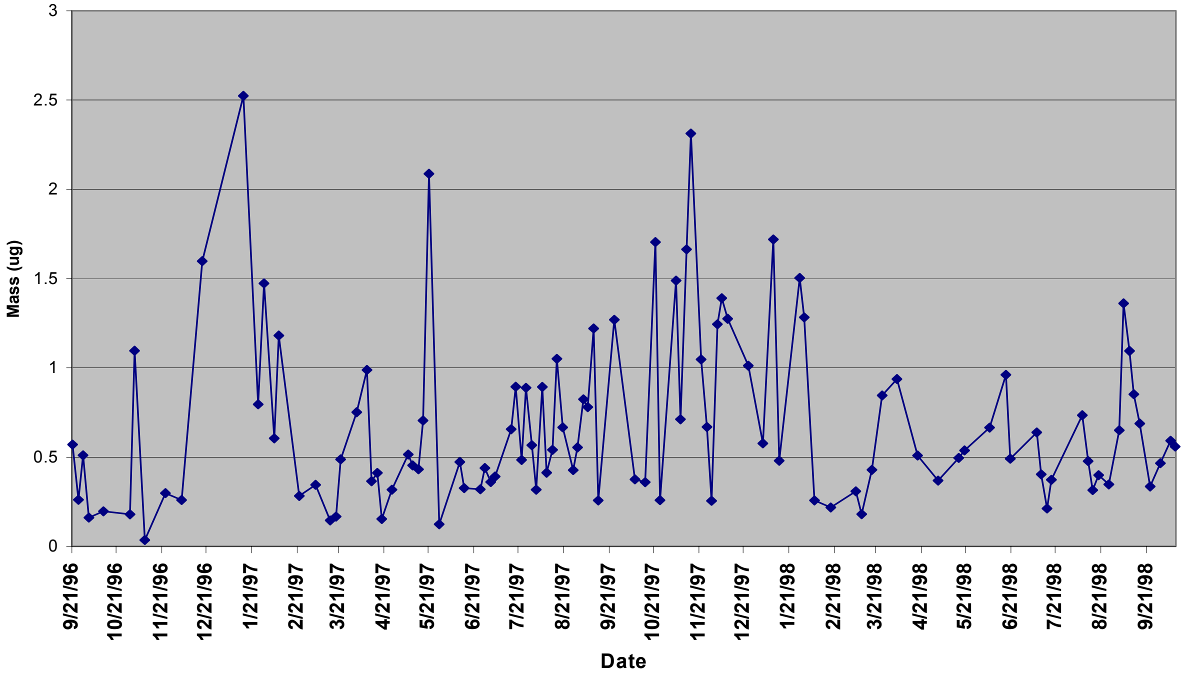


Figure 22 - Marine Aerosols

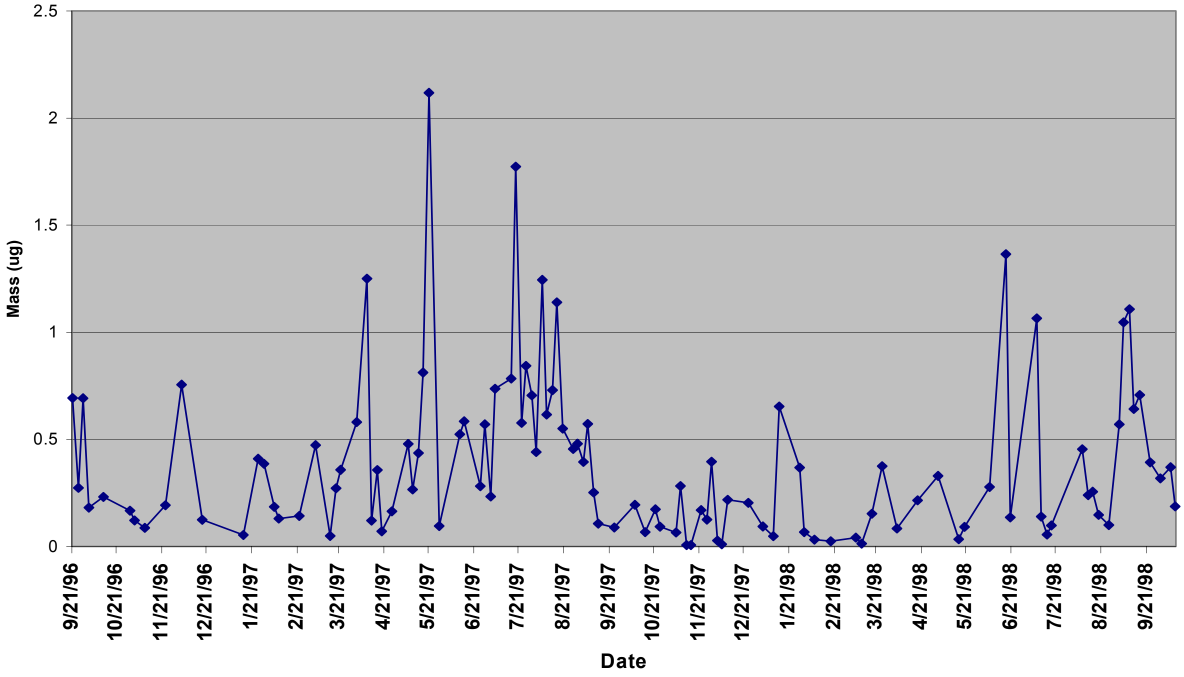


Figure 23 - Diesel

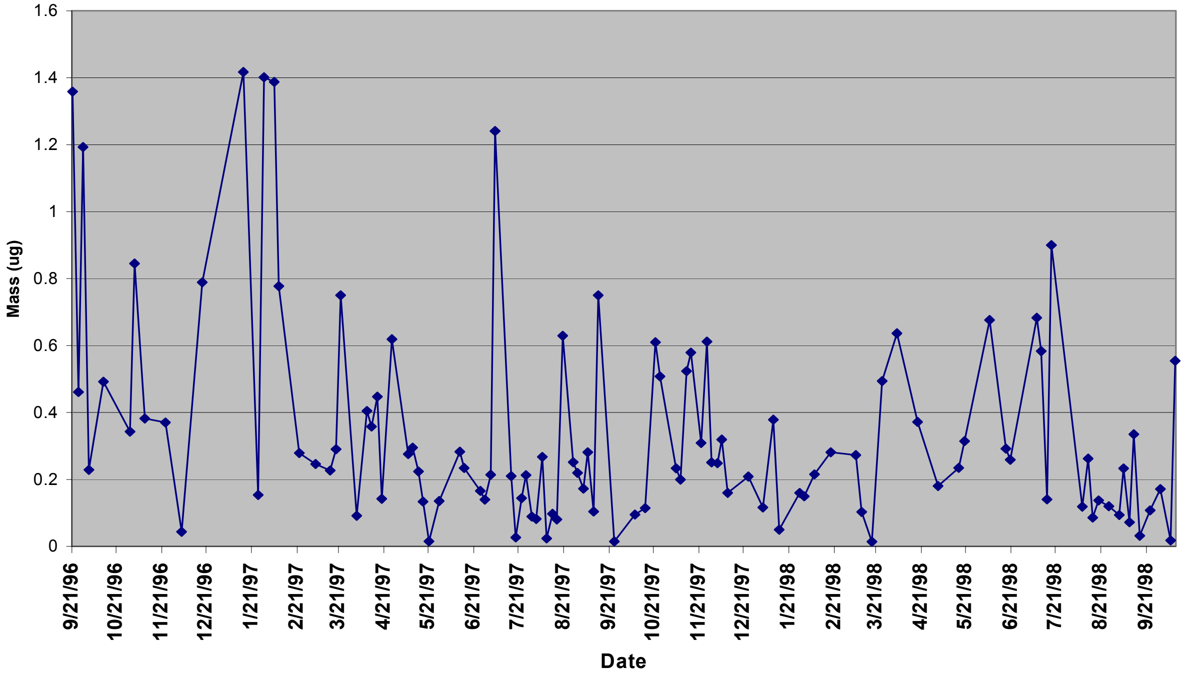
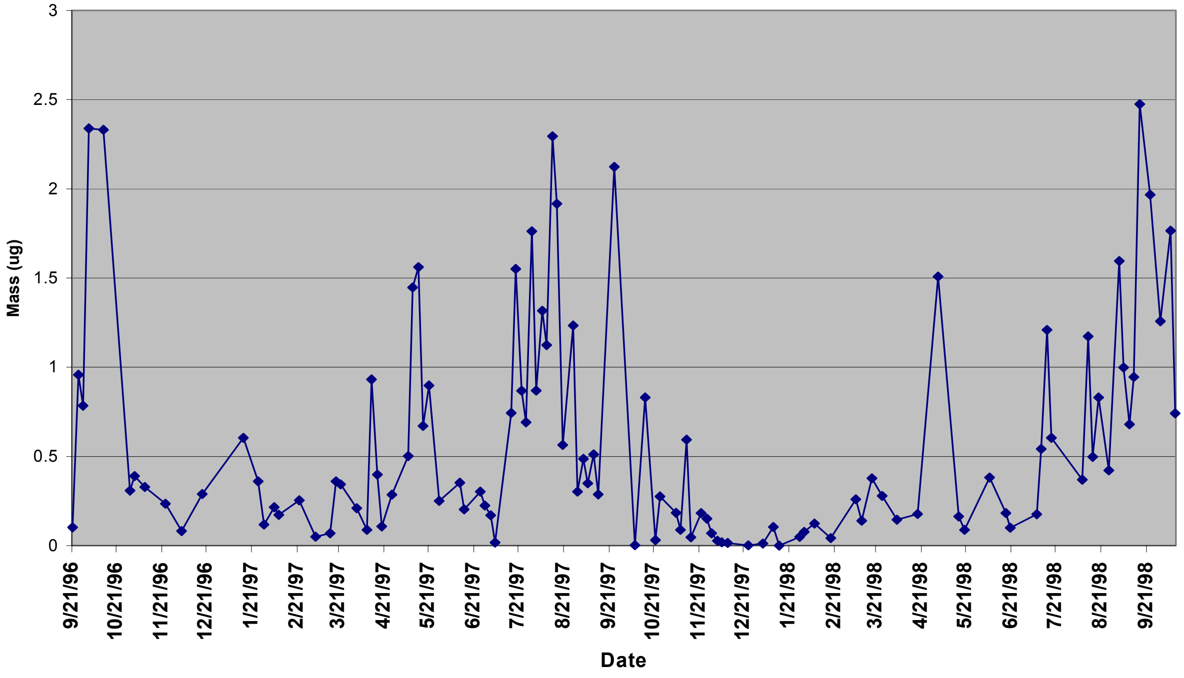


Figure 24 - Soil/Road Dust



Wishram Time Series Plots

Figure 25 - Marine Aerosols

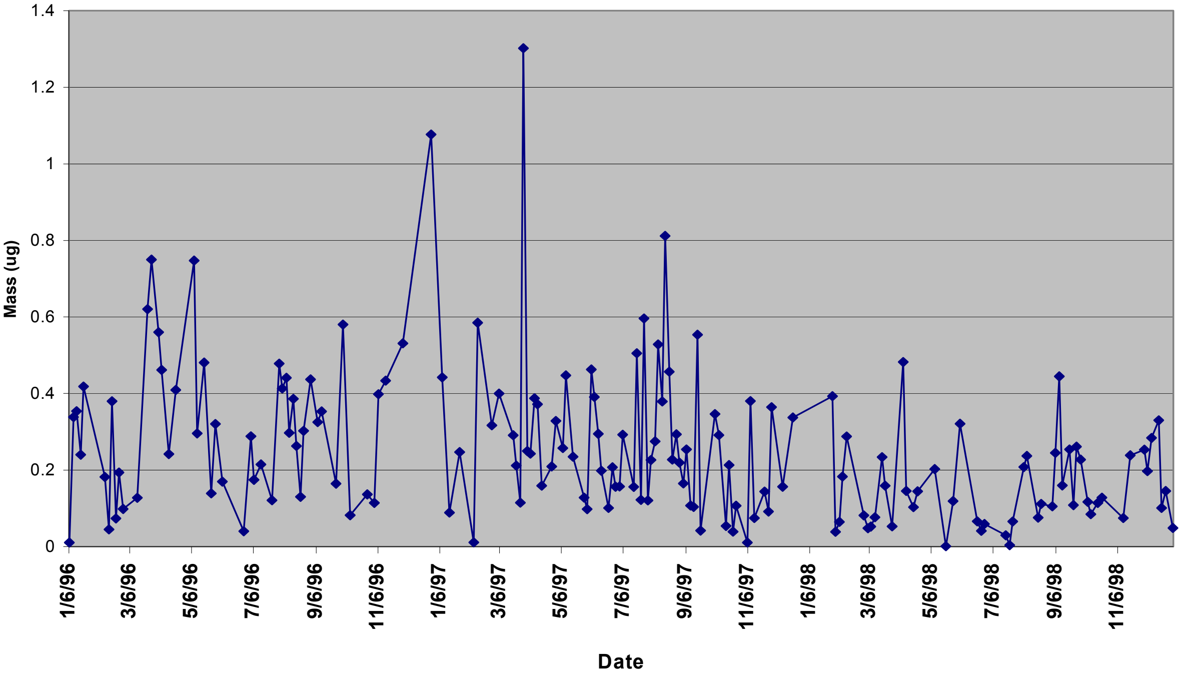


Figure 26 - Combustion Source

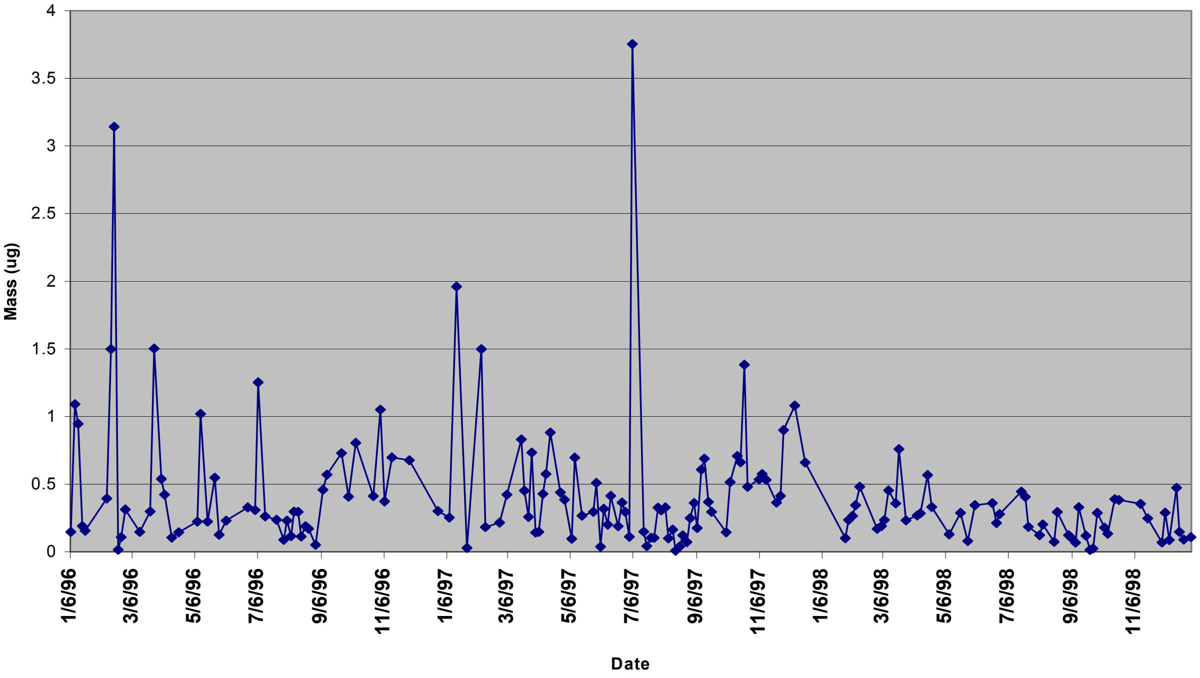


Figure 27 - Aluminum Reduction-Combustion Source Mix

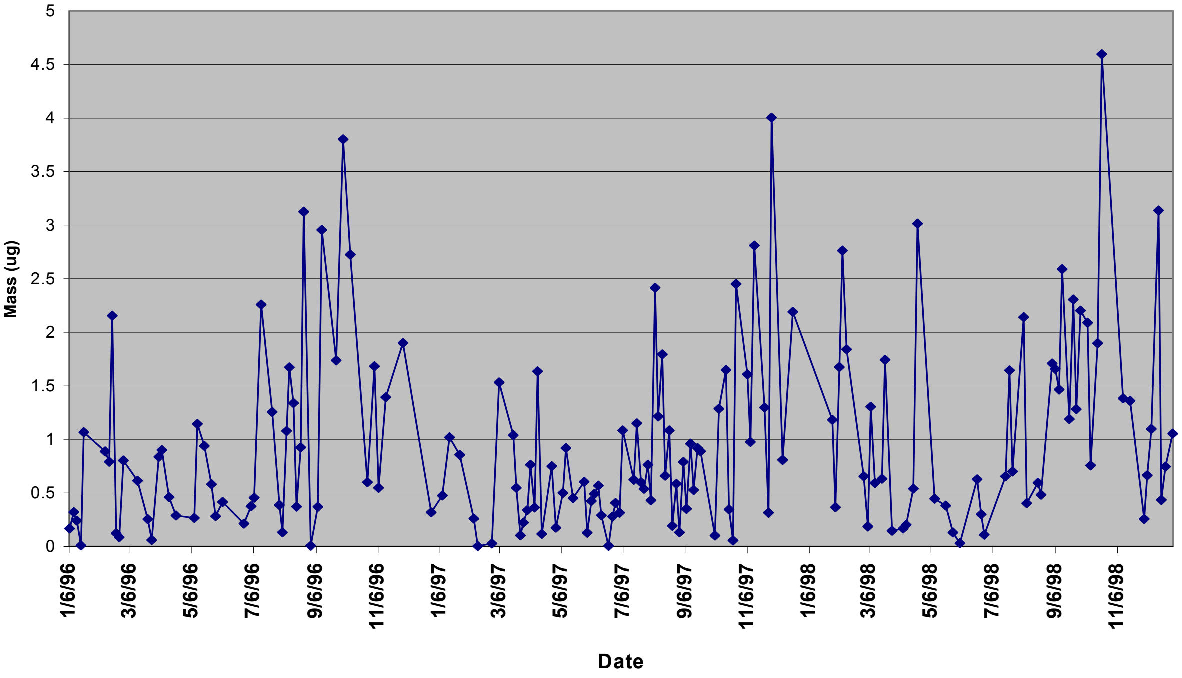


Figure 28 - Diesel

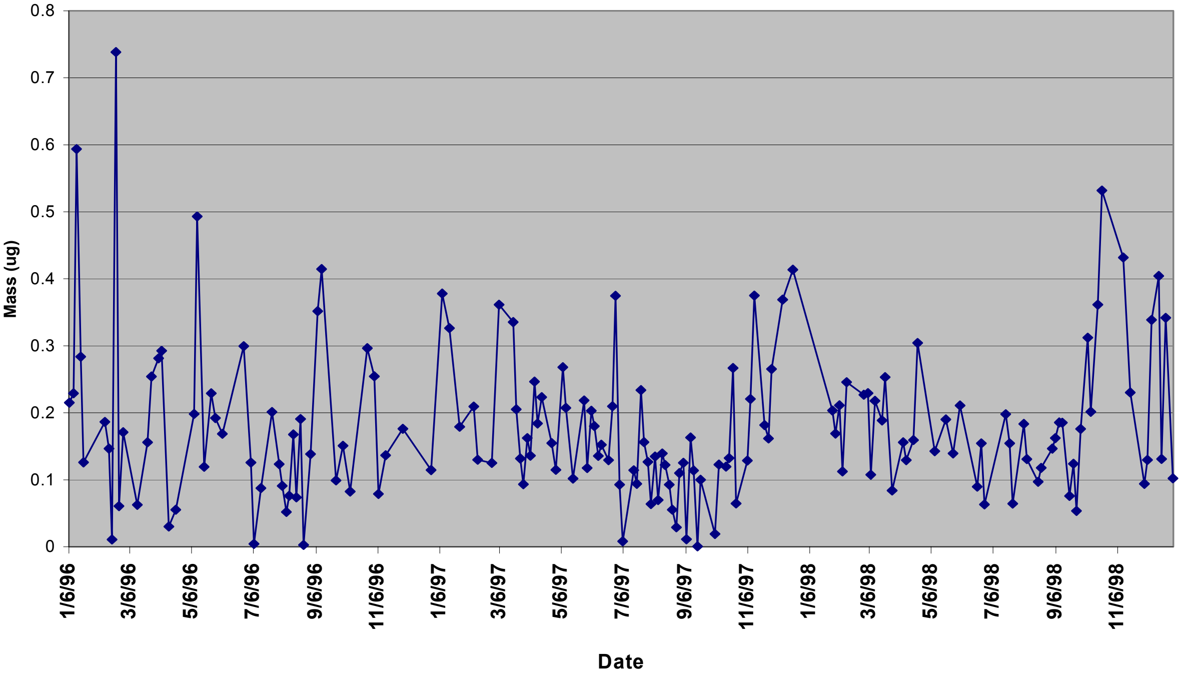


Figure 29 - Secondary Sulfate

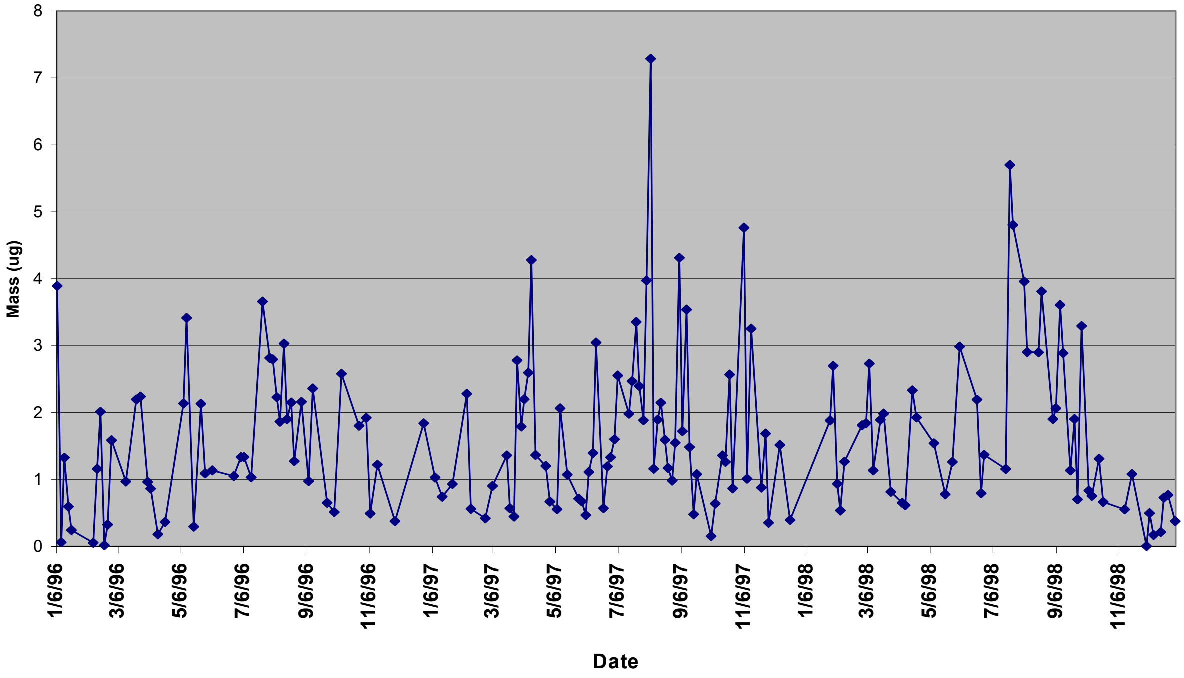


Figure 30 - Soil/Road Dust

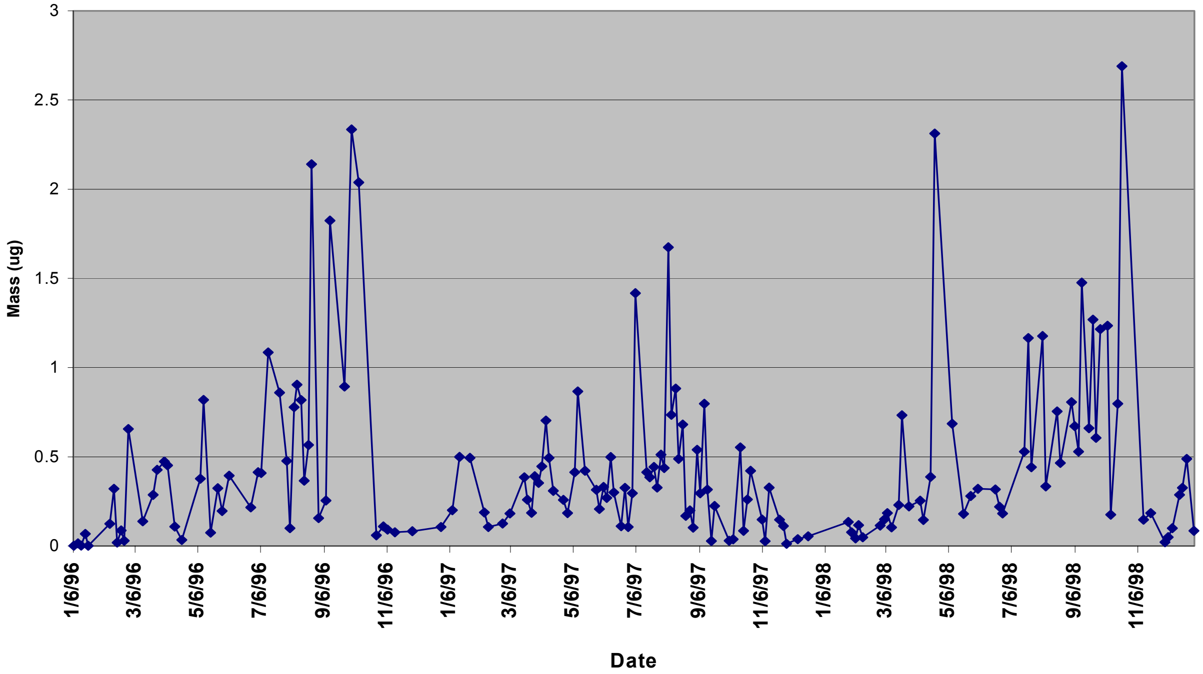


Figure 31 - Vegetative Burning

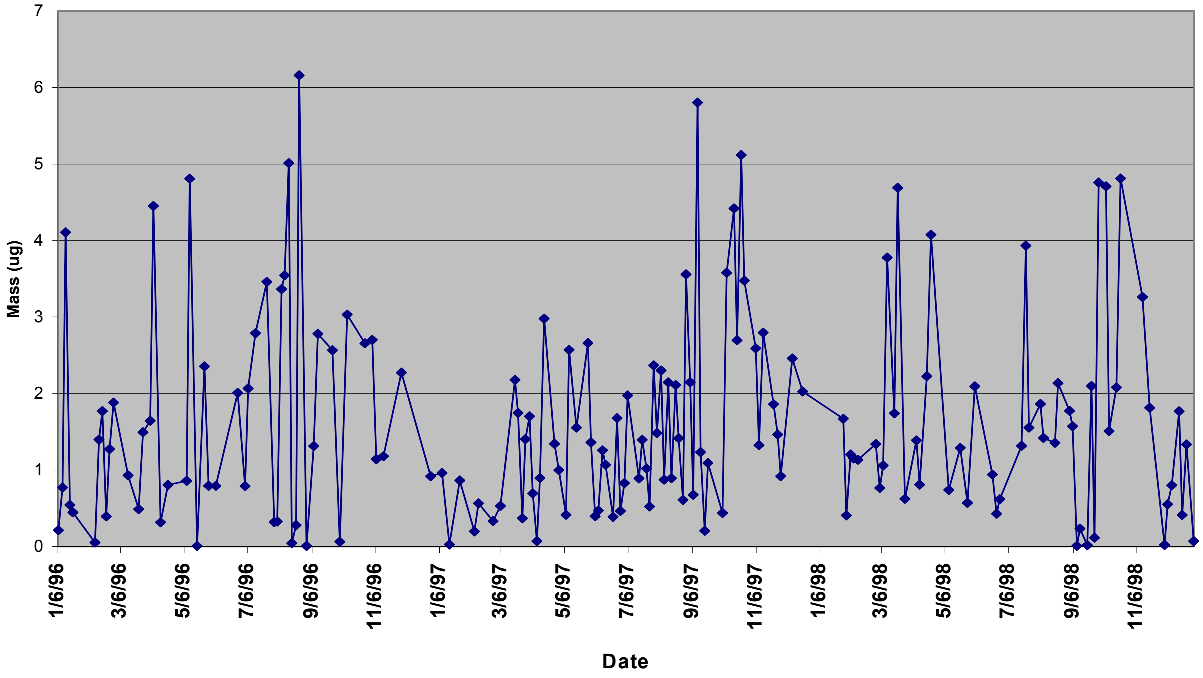
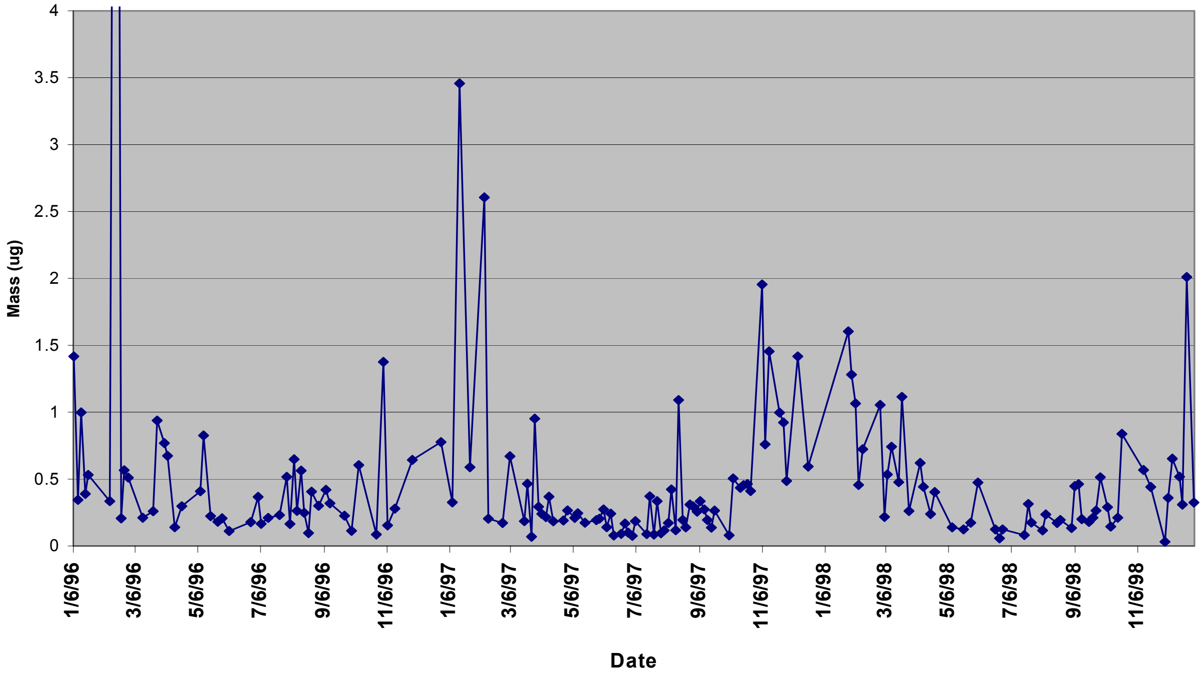


Figure 32 - Secondary Nitrate



Mt. Zion PMF Profiles

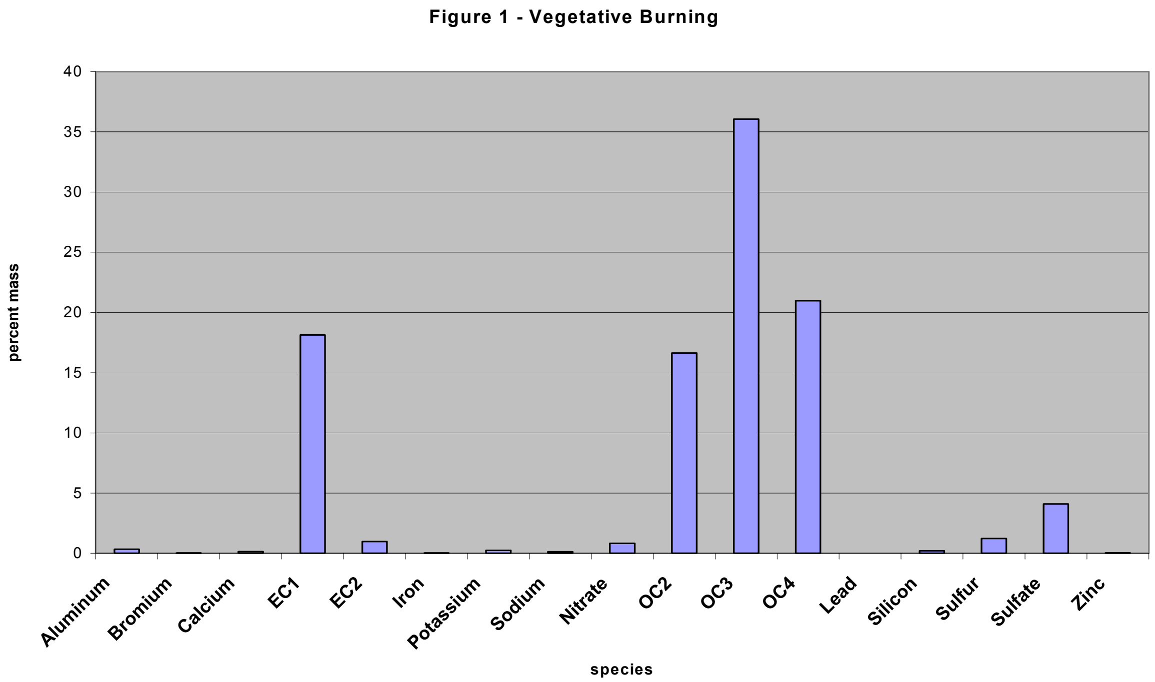


Figure 2 - Pulp Mills

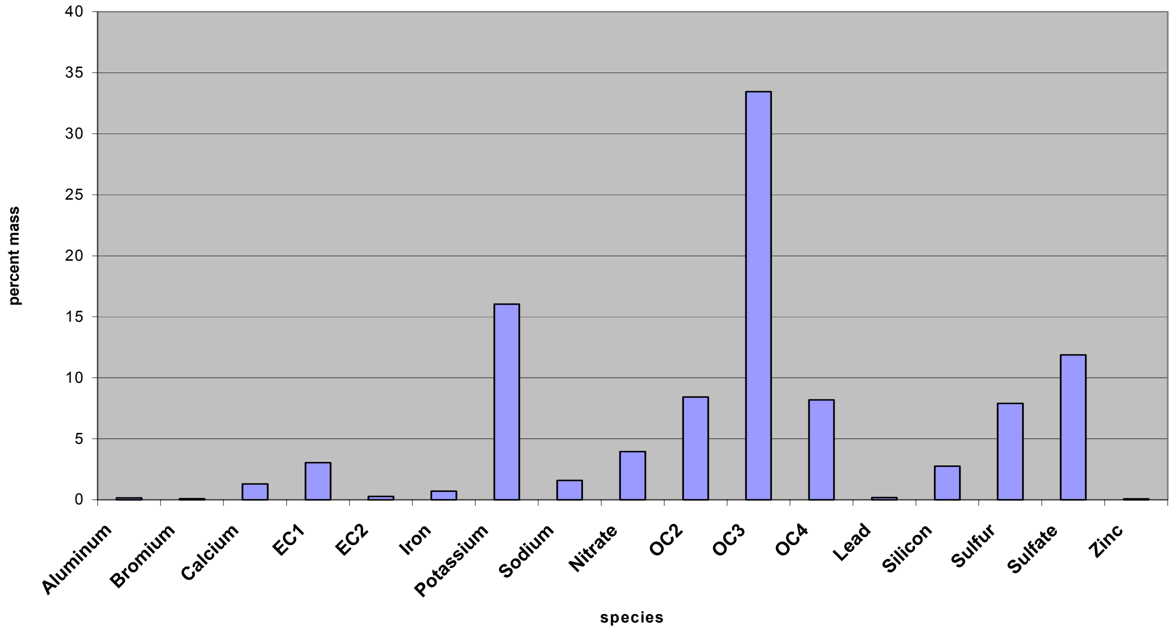


Figure 3 - Secondary Sulfate

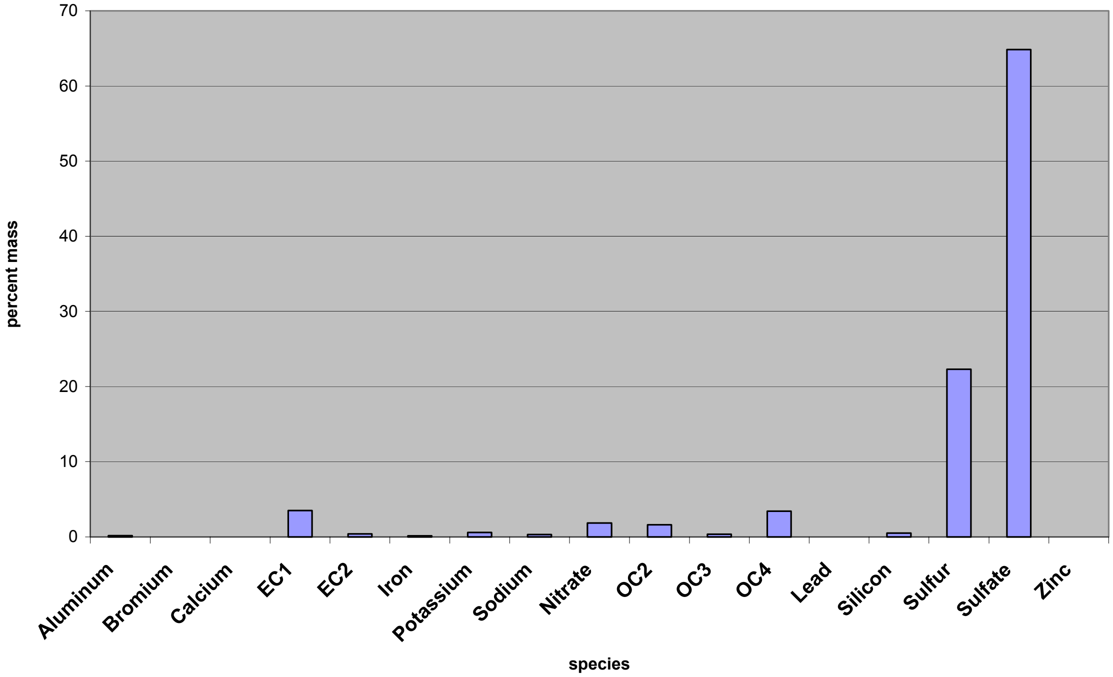


Figure 4 - Automobiles

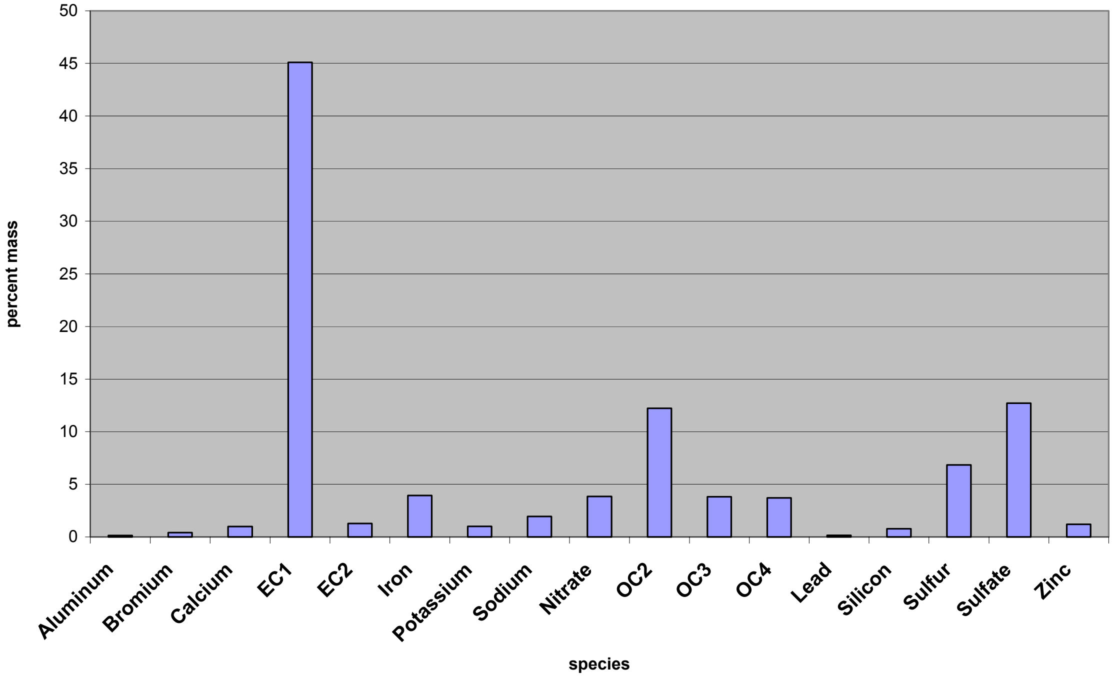


Figure 5 - Secondary Nitrate

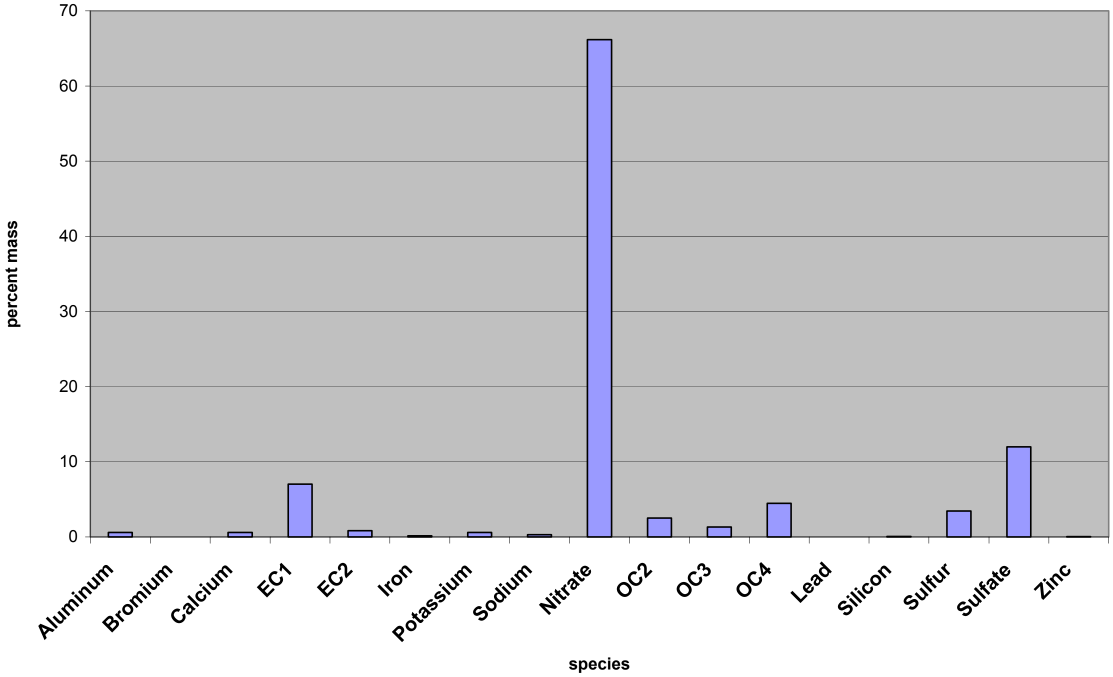


Figure 6 - Marine Aerosols

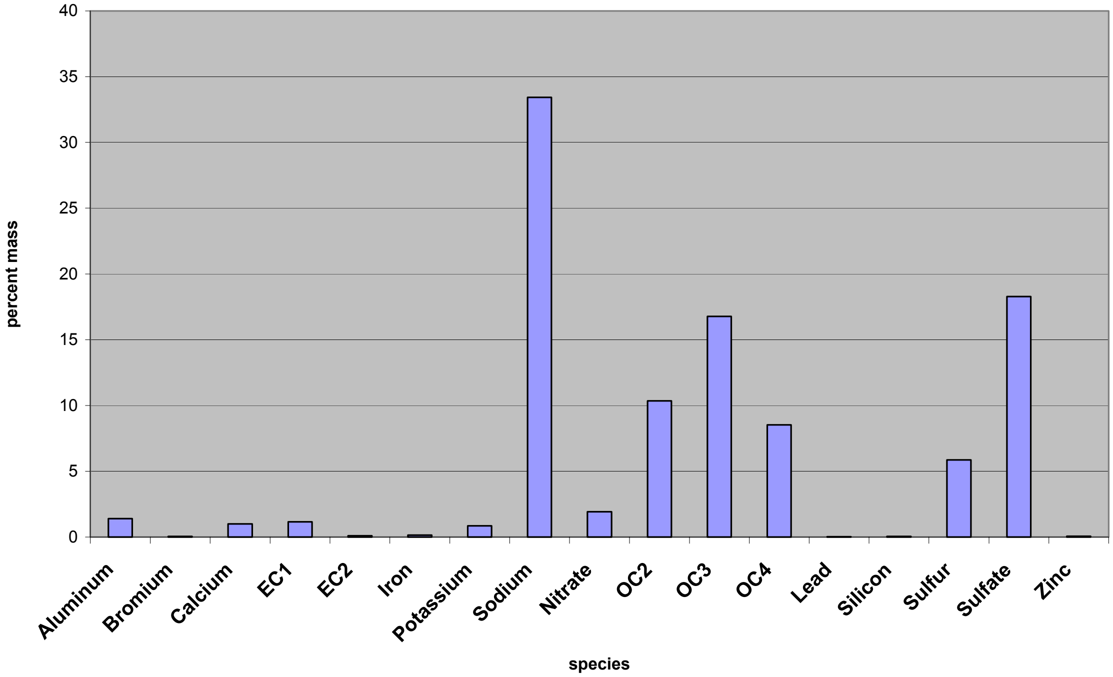


Figure 7 - Diesel

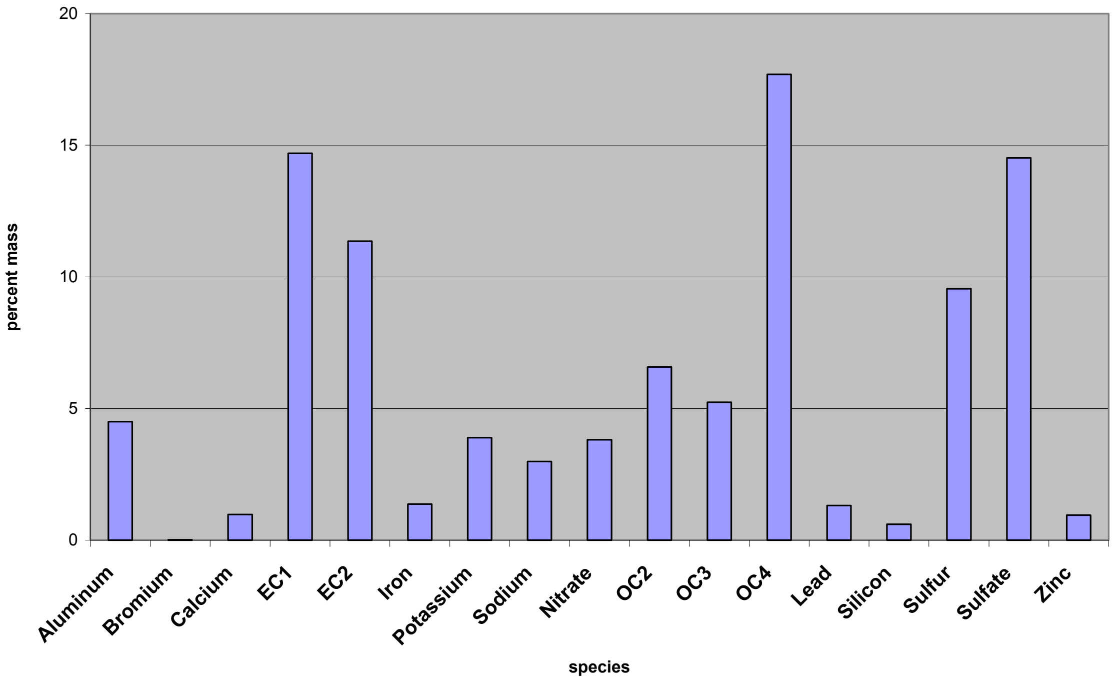
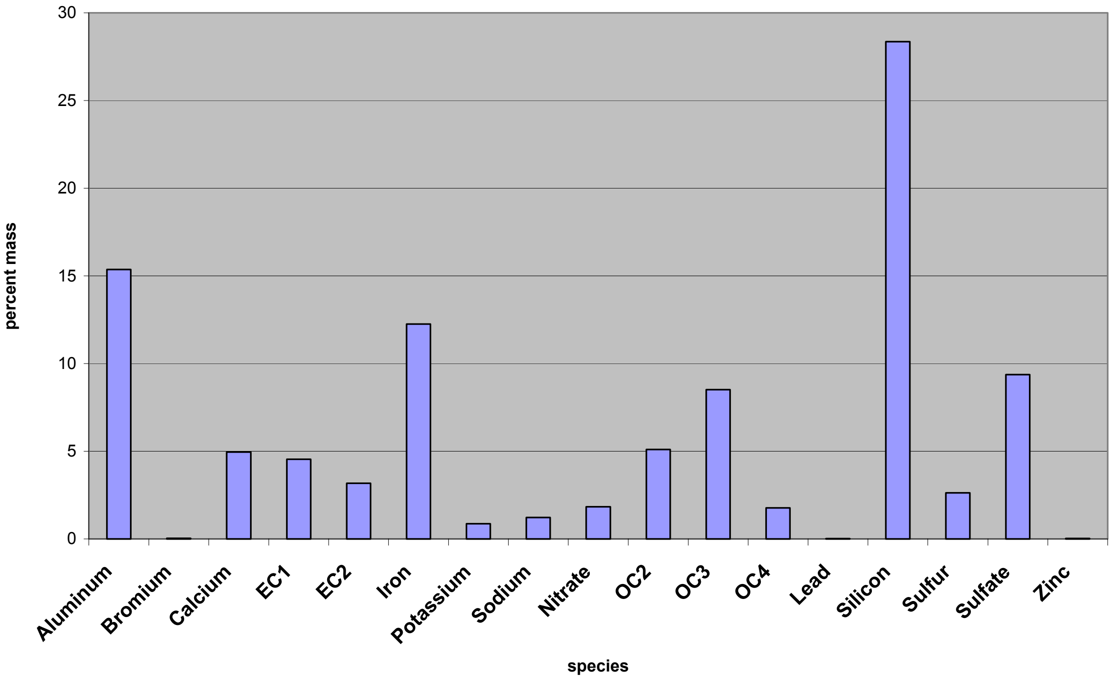


Figure 8 - Soil/Road Dust



Wishram PMF Profiles

Figure 9 - Marine Aerosols

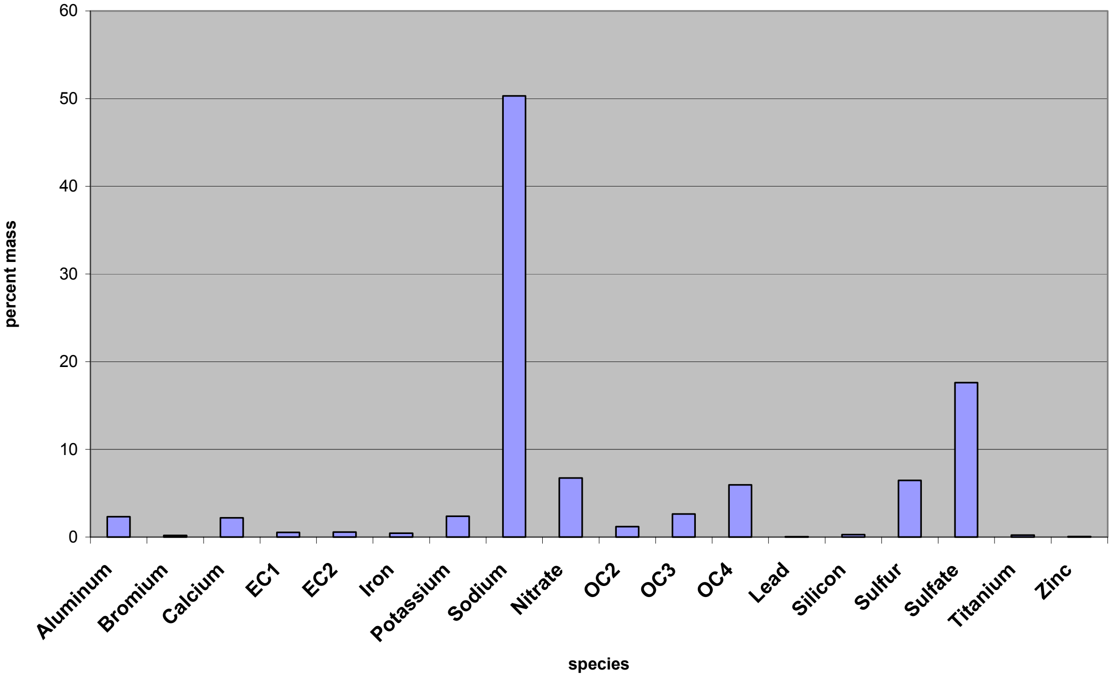


Figure 10 - Combustion/Secondary Sulfate

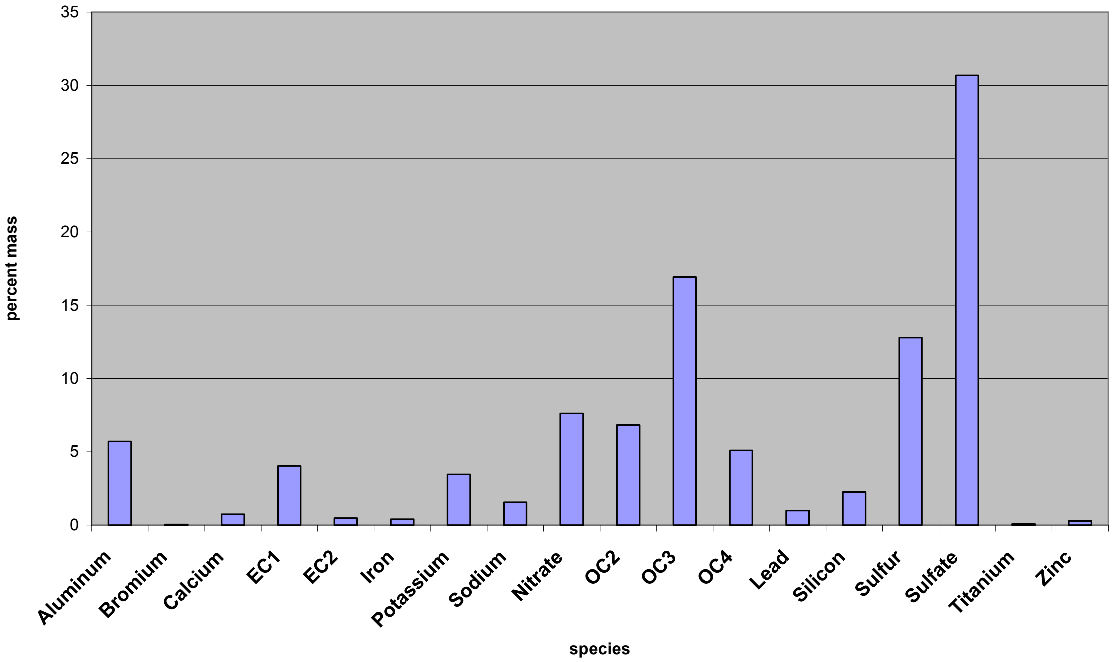


Figure 11 - Aluminum Reduction/Combustion Mix

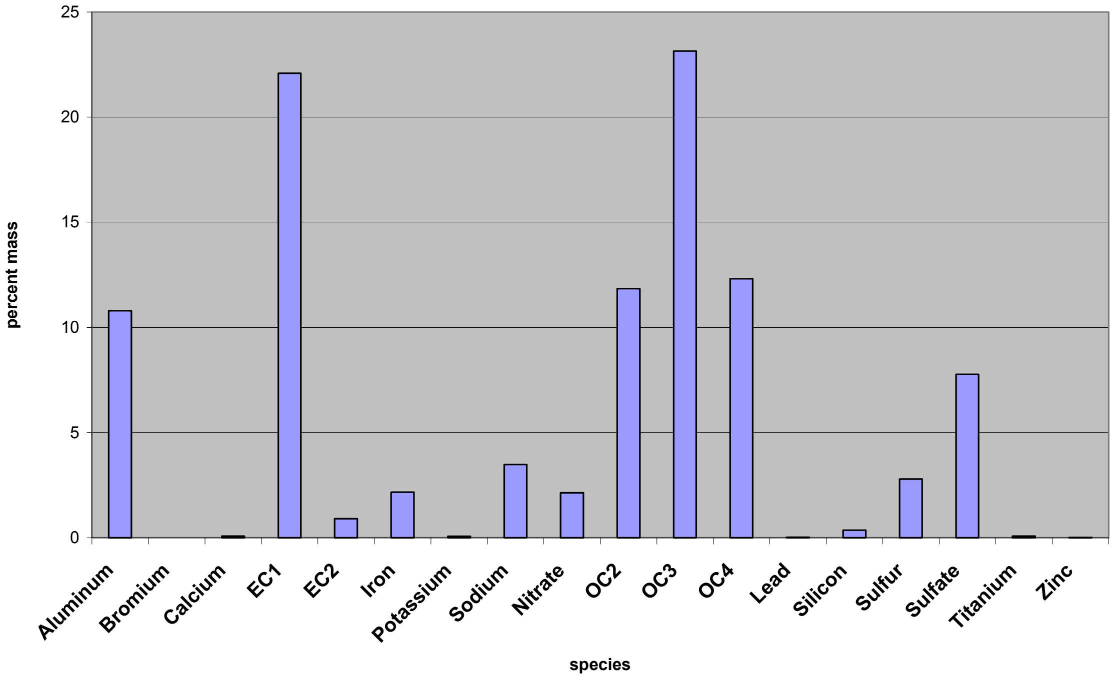


Figure 12 - Diesel

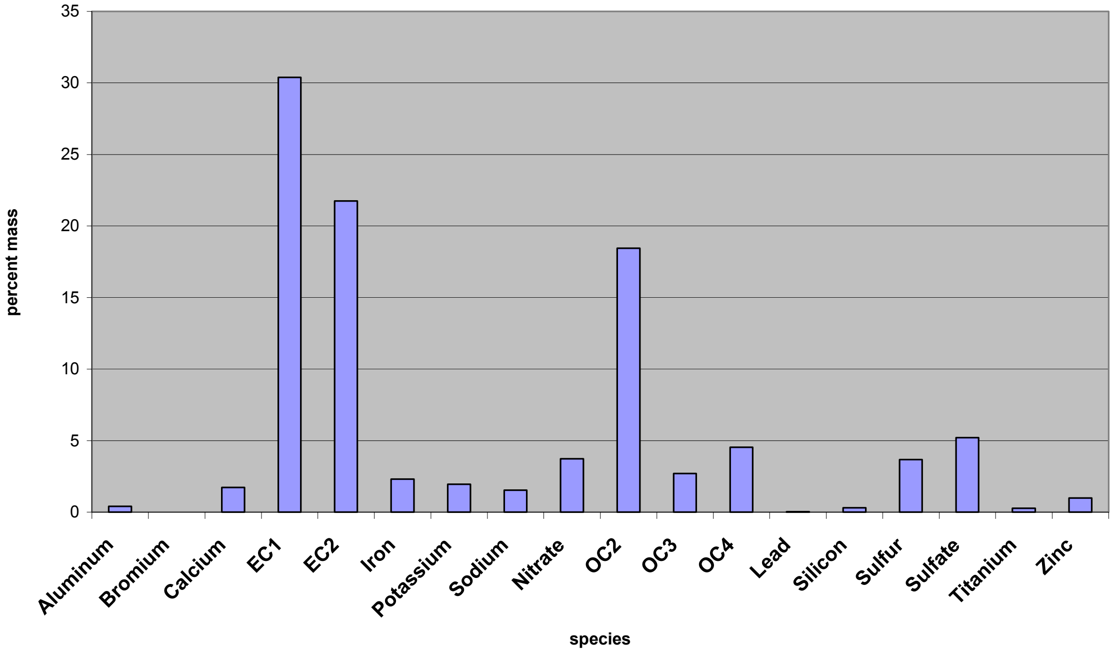


Figure 13 - Secondary Sulfate

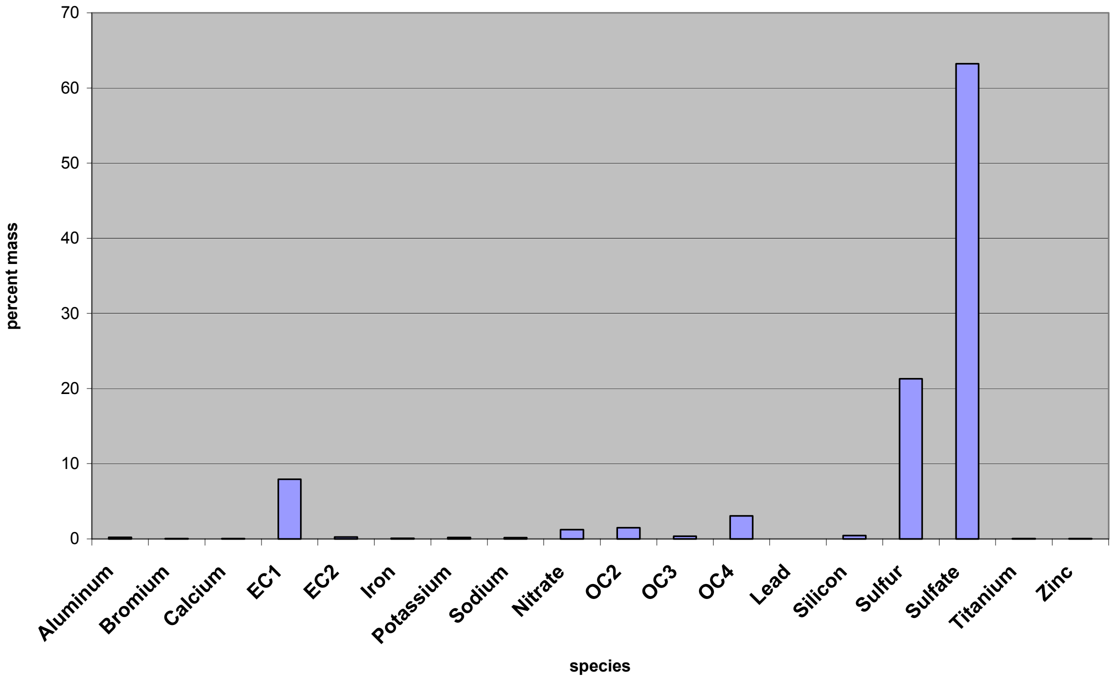


Figure 14 - Soil/Road Dust

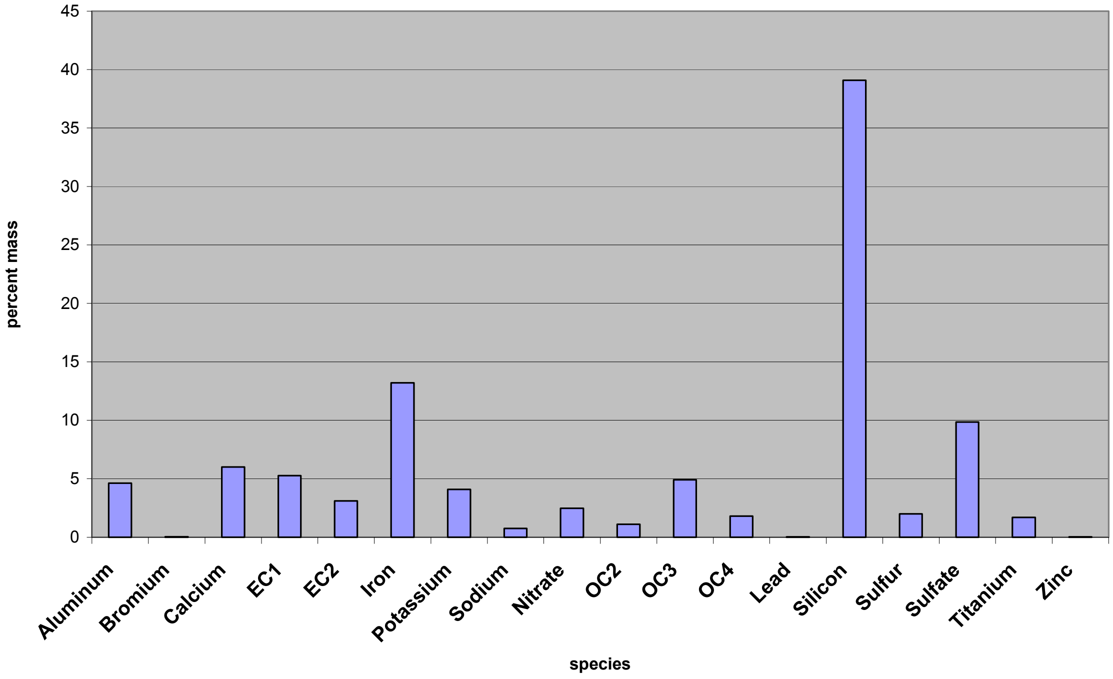


Figure 15 - Vegetative Burning

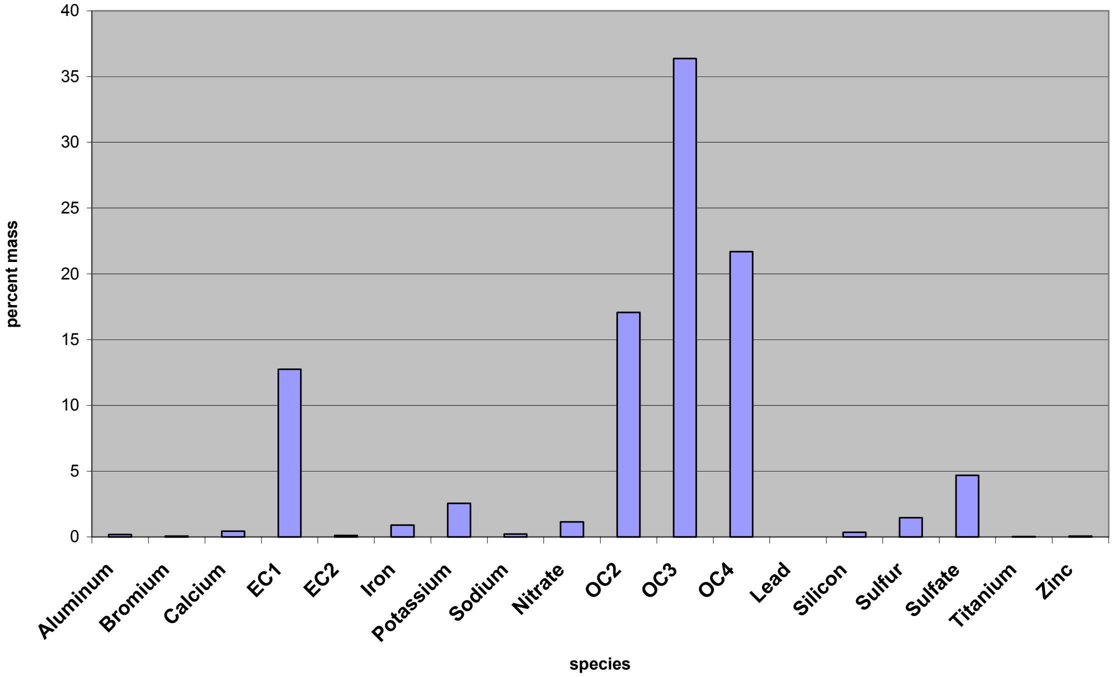
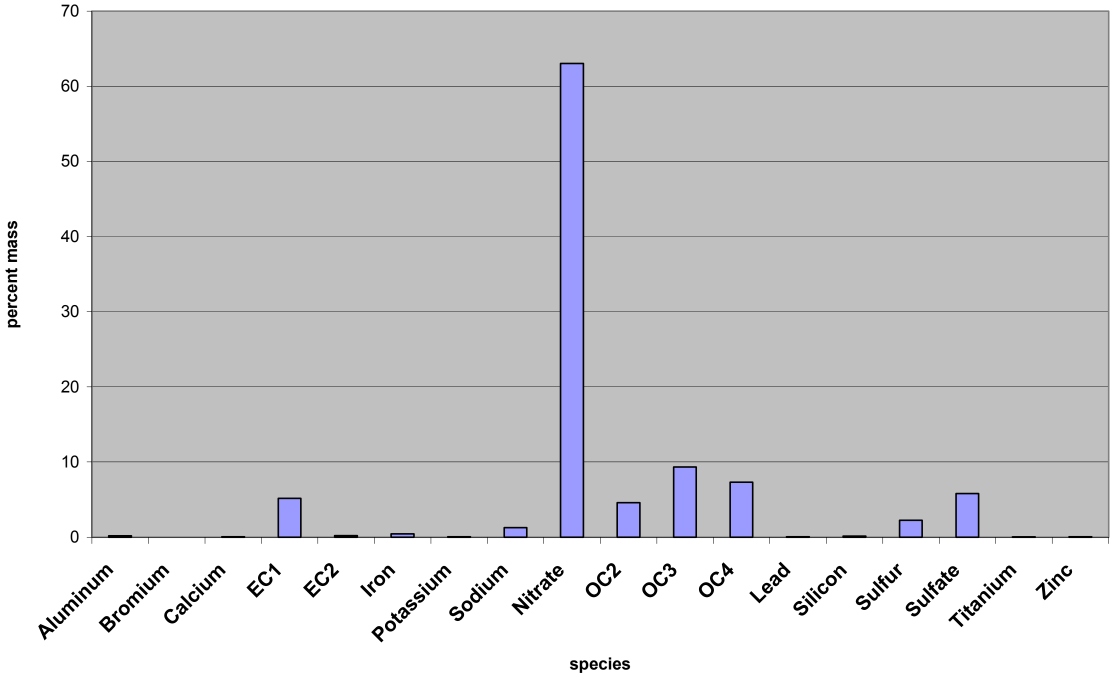


Figure 16 - Secondary Nitrate



1. Christiana will send Hampden reference of organic speciation analysis on IMPROVE filters. Results of specieated organic analysis may provide insight into the appropriate attribution of carbonaceous aerosol to mobile emissions and vegetative burning.

I sent email to Phillip Fine of Caltech requesting reference of his research on 3/11/03. He never returned my email is now no longer listed as a graduate student at Caltech. I could only find two published papers by Phillip Fine and each concerned organic speciation of wood smoke but not source attribution of ambient aerosols for the IMPROVE network.

2. Keith Rose will obtain list of dates from Hampden and Frank indicating periods to test the PMF source attribution for resolving mobile emissions from vegetative burning.

Keith is running PMF on all dates with valid data for same period as DRI CMB analysis.

3. Hampden will stratify CMB results by wind direction and wind speed to better interpret CMB source attributions and their locations in the Gorge.

Section 5.3 relates the CMB SCE's to resultant wind direction and average wind speed nearby surface meteorolocal stations. The section describes how average source contribution estimates vary with wind classification (calm, N, S, E, or W).

4. Hampden will revise wording in executive summary and body of report to better distinguish between CMB source contribution estimates and "reality". In particular, coal fired power plants source attribution is not limited to th primary particle SCEs, but they are likely to be associated with much of the ammonium sulfate.

Captions were modified in source attribution pie charts to indicate that coal fired power plant are the largest contributor of SO2 that is a precursor to sulfate. The SCE acronym was inserted in many locations to better distinguish that results are modeled and not fact.

5. Hampden will explain the limitations of interpreting nitrate/sea salt mix without measured ammonium.

A description of the limitations of using only XRF sodium, IC nitrate, and IC chloride to apportion marine and ammonium nitrate was added to section 5.2.1.

6. Hampden will add recommendations and description of worst visibility days to executive summary.

Additional text has been added to Section 6.2.

7. Hampden will describe aerosol composition for best, average, and worst days with pie charts showing: ammonium sulfate, ammonium nitrate, organic carbon, elemental carbon, and geologic material.

These figures have been inserted into section 2.6 to provide a basis for understanding the chemical composition of ambient PM2.5 in the Gorge of best, avg, and worst days.

A summary of meteorological conditions during 1996-1998 will be added and compared with 30 year climatology.

Section 2.6 compares monthly mean temperatures with the 30 year climatology at the Dallesport (east of CRG) and the Troutdale (west of CRG) sites.

8. Hampden will change "motor vehicles" to "mobile sources".

A global replace has been applied to all instances of motor vehicle(s) to replace with mobile source(s).

9. Hampden will email data from Appendix D to Clint and he will make box wisker plots to summarize results.

Cliff received the data from appendix D and sent some plots back to me. I did not follow up with Cliff regarding the finalize form of the source attribution plots.

10. Sally will send Washington state prescribed fire emissions to Hampden for inclusion in Section 3 and Appendix. If someone from Oregon could do the same, that would be very helpful.

I have received the estimates of biomass burning emissions from Sally in Washington and Jeff in Oregon. State produced fire emissions have been appended to the tables in Appendix B. A brief discussion of the discrepancies between State and National fire emissions was added to section 3.1.

11. Frank will send Hampden marked up copy of report with. Other reviewers are invited to send comments until Jan. 21.

I have received Franks comments and incorporated then into the final report.

12. Hampden will deliver final report in mid Frebruary.

A no cost estension was received until March 31, 2003 for the delivery of the final report.