Final Report
MODELING ANALYSES CONDUCTED FOR THE COLUMBIA RIVER GORGE NATIONAL SCENIC AREA AIR QUALITY STUDY


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EXECUTIVE SUMMARY

This report describes the meteorological, emissions and air quality modeling conducted by the contractor team of ENVIRON International Corporation and Alpine Geophysics, LLC, as part of the Columbia River Gorge National Scenic Area Air Quality Study (Gorge Study). The modeling analyses reported herein comprise just one component of the entire Gorge Study to assess projected trends in future visibility impairment, to provide a simulation assessment of source apportionment by type and region, and to test several "what-if" scenarios for future year conditions.

BACKGROUND

There are several components of the Gorge Study, including:

Measurement Program: Collect additional visibility, particulate matter (PM) components, gaseous species and meteorological data during 2003-2005 within and surrounding the Gorge. The enhanced measurement program has been completed and provided to the data warehousing and analysis contractor.

Haze Gradient Study: Analyze visibility (nephelometer) and meteorological measurements within the Gorge to better understand the causes and movement of visibility impairment in the Gorge and identify episodes for more detailed analysis. A Haze Gradient Study report is available (Green et al., 2006a).

Causes of Haze in the Gorge (CaHaGo) Study: Enhance understanding of haze in the Gorge through analysis of additional aerosol chemical composition data as a follow-on to the Haze Gradient Study. A CaHaGo draft report is available (Green et al., 2006b).

Modeling Analysis: Conduct numerical grid modeling to assess projected trends in future visibility impairment, to provide a simulation assessment of source apportionment by type and region, and to test several "what-if" scenarios for future year conditions. The modeling analysis is documented in this report.

The ultimate goal of these Gorge Study components is to develop a scientific basis of evidence that can be referenced to answer a set of questions that were originally posed by the Technical Team. Results from the modeling exercises documented in this report are used to answer as many of these questions as possible (see Sections 1 and 8).

To meet the goals of the Gorge Study, chemical transport modeling was performed using ENVIRON's Comprehensive Air Quality Model with extensions (CAMx), in combination with emission inputs from the U.S Environmental Protection Agency's (EPA) Models-3 Sparse Matrix Operating Kernel Emissions (SMOKE) system, and meteorological inputs from the Pennsylvania State University / National Center for Atmospheric Research (PSU/NCAR), Fifth Generation Mesoscale Model (MM5). The general approach for the Gorge Study modeling was to leverage the considerable regional visibility modeling work already conducted by the Western

Regional Air Partnership (WRAP) Regional Planning Organization (RPO) that addresses the requirements of the federal Regional Haze Rule.

Following the WRAP modeling methodology, the Gorge Study modeling component employed CAMx to simulate two season-representative high PM/extinction episodes with a wide array of sensitivity tests and Probing Tool applications for both a 2004 base year and the 2018 future year. Based on visibility measurements during the 2003-2005 enhanced monitoring periods, two multi-day seasonal episodes in 2004 were selected for the Gorge Study modeling: a summer period over August 10-22, and an autumn period over November 3-18. A 10-day "spinup" period was added before each episode to reduce the influence of initial conditions. Modeling was conducted on a series of telescoping nested grids, with the finest high-resolution grid focusing on the Gorge area:

- A 36-km resolution grid covering the continental U.S., most of Canada and Mexico;
- A 12-km resolution grid covering the Pacific Northwest including Idaho, Oregon, and Washington and portions of surrounding states and Canada;
- A 4-km resolution grid covering most of Oregon and Washington.

The Gorge Study Team expended significant effort developing refined episode-specific emissions for the two 2004 modeling episodes on the 4-km Oregon/Washington grid. The 2002 WRAP emission inventory was adjusted to 2004 and used for areas outside the 4-km grid. Base case air quality model performance was evaluated for the two specific episodes simulated using operational and diagnostic techniques. A 2018 future year was also simulated for both episodes to obtain a visibility forecast trend line for the Gorge monitoring sites. The WRAP 2018 emission projections were used for this estimate for all grids, but included additional emission reductions that will be applied to two specific large PM sources by 2018: the Boardman power plant near the eastern end of the Gorge, and the Camas pulp mill at the western end of the Gorge.

The CAMx PM Source Apportionment Technology (PSAT) probing tool was used to assess source category and region-specific attribution to sulfate, nitrate, carbonaceous, and primary particulates at several monitoring sites within the Gorge. PSAT was applied for both 2004 base and 2018 future years. Finally, a group of five "what-if" scenarios were simulated to provide estimated visibility improvements with the removal (or significant reduction) of emissions from specific sources.

Overall the MM5/SMOKE/CAMx modeling system properly replicated the extensive set of PM and light scattering data that was collected as part of the Haze Gradient and "CaHaGo" field studies in 2004. The modeling system performed well in characterizing the distributions of individual PM species concentrations that were important in contributing to visibility-impairing haze over each episode. This further translated to a proper characterization of light scattering levels measured at each site and each episode. Results are as good, and in many ways better, than regional modeling results in the Pacific Northwest area as conducted by the WRAP to address regional visibility/haze rules. The in-depth analyses undertaken in this modeling project have established confidence that the modeling system appropriately projects the individual PM constituent concentrations and resulting visibility impacts into the 2018 future year (according to the WRAP 2018 inventory projections), from which we have constructed visibility trend lines.

As with any modeling exercise, the results and conclusions reached as documented in this report are subject to the specific uncertainties associated with the methodology and datasets applied in this project. The specific uncertainties identified from this modeling effort are discussed in Section 8 of this report. For each we provide our recommendations for future work that should reduce or minimize each uncertainty and thereby improve the robustness of the modeling results.

METEOROLOGICAL MODELING

MM5 version 3.63 was used for the Gorge Study modeling system. Six MM5 simulations were performed and compared in this study for both the August and November 2004 episodes. Two of the model configurations were taken from previous modeling efforts conducted in this region: the University of Washington (UW) forecasting system ("Run 3"), and the Portland Ozone State Implementation Plan (SIP) ("Run 4").

Significant effort was expended to determine the best performing options in MM5. None of the MM5 configurations met all of the commonly accepted benchmarks for statistical performance, meaning that MM5 did not perform as well as it has historically performed in other air quality applications around the country[1]. It is important to note that these benchmarks were established according to a wealth of meteorological modeling applications for mostly urban and regional summertime ozone modeling. The Gorge Study area contains more complex terrain than most other areas modeled to date for air quality applications, and thus the monitors are more likely to be influenced by local and small-scale forcings. Both Gorge Study modeling episodes exhibited rather weak synoptic forcing, but MM5 traditionally performs better under stronger forced conditions, such as storm systems. Another point to consider is that the Gorge Study region includes fewer sites than were used to develop the benchmarks; statistics based on fewer pairings tend to yield poorer statistics. Nevertheless, MM5 performed well in capturing the August up-gorge flow patterns and the November down-gorge flow patterns, to the extent that such flows were characterized by sites along the Gorge itself.

EMISSIONS PROCESSING

The emission inventory is a key component of an air quality modeling exercise. Spatially and temporally resolved estimates of sulfur dioxide (SO_2), volatile organic compounds (VOC), nitrogen oxides (NOx), carbon monoxide (CO), ammonia (NH_3), PM and other chemicals from sources such as electric generating utilities (EGUs), pulping mills, automobiles, commercial marine shipping activities, railroad locomotives, and even natural vegetation (biogenic), to name a few sources, are critical inputs to an air quality model.

A separate Emission Inventory report prepared by ODEQ provides a detailed breakdown and comparison of the resulting episodic emissions by source category and region.

[1] Note that MM5 modeling undertaken by WRAP for the year 2002 also did not meet all of the performance benchmarks in the Pacific Northwest region; specifically MM5 suffered from under prediction tendencies for temperature, and over prediction tendencies for humidity and rainfall. In our experience, as well as the experience of many other air quality modelers throughout the country, this is a common trait of MM5 that is very difficult to resolve.

2004 Base Year Emissions

The Southwest Clean Air Agency (SWCAA) and the Oregon Department of Environmental Quality (ODEQ) provided local 2004 annual stationary, area, and non-road mobile source emissions estimates (projected from the 2002 National Emissions Inventory [NEI]) for counties in Washington and Oregon, respectively (SWCAA, 2006; Kreitzer, 2006a,b,d; Mairose, 2006a-c; Stocum, 2006a-c). SWCAA and ODEQ also provided wildfire and prescribed fire activity data that were used to estimate fire emissions (Kreitzer, 2006c; Swab, 2006). Finally, SWCAA and ODEQ provided day-specific emissions estimates for the Portland General Electric (PGE) Boardman power plant (Mairose, 2006b) and the Georgia Pacific Camas Mill wood pulping facility (Mairose, 2006c). For all other counties within the modeling domain, we used the SMOKE emissions processing system (CEP, 2004) as configured for the WRAP study as a starting point, which included projecting the 2002 WRAP county-level annual stationary and non-road emissions to 2004 (WRAP, 2004). Additionally, all temporal and speciation profiles and cross-reference data were taken from the WRAP emission processing efforts. Spatial allocation of the emissions to the 4- and 12-km modeling grids was based on profiles and surrogate factors developed specifically for this project using population and landuse/landcover distributions provided by EPA (and as used in the WRAP modeling) (EPA, 2006a). Special attention was given to the development of high resolution surrogate distributions in the OR/WA region and within the Gorge itself, especially as they related to commercial marine shipping.

MM5 temperature and wind fields were used to generate day- and grid-specific biogenic, wind-blown dust, and agricultural ammonia emissions for the Gorge modeling episodes. The EPA national landuse/landcover dataset used to develop spatial surrogates was also used in the estimation of agricultural ammonia emissions. The processing of on-road mobile sources required the use of OR/WA-specific and/or WRAP activity data (roadway locations, vehicle miles traveled [VMT], speed distributions, vehicle fleet mix, etc.).

Volcanic emissions from Mt. St. Helens were estimated for SO_2, based on measurements taken in November 2004 (McGee, 2006). This was a period of increasing geologic activity that resulted in escalating emissions from Mt. St. Helens. Based on conversations with scientists at the United States Geological Survey (USGS) (McGee, 2006), there was no volcanic activity during August 2004; hence, volcanic emissions for this episode were set to zero. The USGS does not estimate emissions of ash (McGee, 2006), which could be used as a surrogate for primary PM. However, given that there was no ash plume activity reported in either November or August 2004, primary PM emissions were considered nonexistent. Therefore, only the SO_2 emission estimates were used in this effort.

SMOKE (CEP, 2004) was configured to generate model-ready point, area, non-road mobile, on-road mobile, and fire source emissions for the 36/12/4-km grid system; criteria pollutant emissions were speciated according to the Carbon Bond IV (CB4) chemical mechanism with PM. Certain emission subcategories, such as electric generating units (EGU), on-road mobile sources, fires, etc., were processed through the SMOKE system in separate streams in order to support PSAT applications and to allow maximum flexibility in developing and applying alternate strategies in the modeling. Specialized processing was conducted for certain source categories to provide updated and/or day-specific emission estimates for the episodic conditions modeled in this study: large industrial point sources, wildfires, some prescribed fires, on-road mobile, biogenics, wind-blown dust, and agricultural ammonia.

Upon review of the resulting model-ready emission inventory, several major issues were identified and rectified:

Reduction in Residential Wood Smoke: Annual fine PM emissions from residential wood combustion in Oregon and Washington were found to be overstated by a factor of two, based upon an improper interpretation of a 1999 fireplace survey conducted in both states. We thus applied a 50% reduction to the 2004 annual residential wood combustion categories for both states. Furthermore, since the WRAP 2018 projections for residential wood combustion were found to be too large relative to the revised 2004 estimates, the 2018 emissions for this category were derived from the revised 2004 estimates by applying a 4% growth rate based on published population projections in Oregon and Washington.

Increase in Agricultural Ammonia: Based on a detailed scrutiny of the Oregon and Washington ammonia inventories against recent emission factors published in the literature, two major issues were identified: (1) ammonia emissions from confined area feeding operations (CAFO), such as dairies, were understated by factors of 1.5 to approximately 4; and (2) ammonia emissions from fertilizer application were understated by factors of 2.5 to 3. Ammonia emissions in Oregon and Washington were thus increased on a facility-type (CAFO) and application-type (fertilizers) basis.

Application of Canopy Escape Factors: It is well known in the air quality modeling field that the impact of fugitive dust sources (such as unpaved and paved road dust; roadway, commercial, and residential construction; and agricultural tilling) on air quality is substantially lower than emissions inventories suggest, often by as much as an order of magnitude. Numerous studies suggest that removal of fugitive dust occurring near the source, on a scale of tens to hundreds of meters, is beyond the capability of current Eulerian air quality models (e.g., CMAQ, CAMx, etc.) that address scales of 1-10 km. The county-specific transport factors of Pace (2005; EPA, 2006c) were applied to the fugitive dust categories. This reduced the amount of fugitive dust that the air quality model "sees" by approximately 75%.

2018 Future Year Emissions

Similar to the 2004 base case, SMOKE was configured to generate model-ready point, area, non-road mobile, on-road mobile, and fire source emissions for the 36/12/4-km grid system for the August and November 2018 future year episodes. The 2018 emission estimates were taken entirely from the WRAP 2018 data sets (WRAP, 2004). However there are several upcoming federal programs that will have substantial emission reductions that are not included in this inventory. In addition, each of the WRAP states continues to make refinements to their inventories for 2018. The WRAP 2018 emissions estimates were modified for the following sources per the direction of the sponsors: the PGE Boardman power plant; the Georgia Pacific Camas Mill pulping plant; and residential wood smoke.

Per the direction of the study sponsors, the presumptive Best Achievable Retrofit Technology (BART) limits for NOx and SO_2 were used to model emissions from the Boardman coal-fired

EGU. For NOx, the BART limit is 0.23 lbs NOx/MMBtu or 1,323 lbs NOx/hour. For SO_2, the BART limit is 0.15 lbs SO2/MMBtu or 863 lbs SO2/hour. PM emissions were left unchanged from 2004 though it is anticipated that the PM emissions will decrease once multi-pollutant controls are installed. The study sponsors provided a spreadsheet of hourly NOx, SO_2, CO, and PM emissions estimates to be used to represent the Camas facility (Mairose, 2006d). These estimates are based on the presumptive BART limits and represent a worst case day. As discussed previously, errors were found in the 2004 base case emissions estimates for residential wood combustion, which carried over to the 2018 WRAP data base. The 2004 base case emissions estimates were revised and a growth factor of 4%, representing the expected OR/WA population growth to 2018, was applied to estimate the 2018 emissions for this source category.

The 2004 volcanic, biogenic, wind-blown dust, agricultural ammonia source, wildfire, and other fire emission estimates were used in place of the WRAP 2018 emissions estimates. This is standard practice for "natural" sources. As Mt. St. Helens showed no activity in August 2004, no SO_2 emissions for the volcano were incorporated in the 2018 August episode so that a consistent anthropogenic projection to 2018 could be made for visibility. The November 2004 Mt. St. Helens SO_2 emissions were used in the 2018 November SMOKE modeling, again to remain consistent in the visibility projection. Following the approach used in WRAP, we assumed zero growth in agricultural ammonia emissions.

As with the 2004 base case emissions, certain emission subcategories, such as EGU's, on-road mobile sources, fires, etc., were processed through the SMOKE system in separate streams in order to support the application of CAMx/PSAT and to support additional quality assurance of the emissions estimates.

CAMx BASE CASE PERFORMANCE EVALUATION

August 2004 Performance

Nine individual CAMx simulations were undertaken for the August 10-22, 2004 modeling episode. More than half of these runs addressed improvements in the input emission inventory or the treatment of biogenic secondary organic aerosol (SOA). The remaining runs tested model sensitivity to various input changes that from our experience are associated with the largest uncertainty and have the largest potential impact on the air quality results.

August model performance against Gorge field study measurements was not sensitive to changes in wild fire emissions, or to increases in ammonia emissions. The simulated wild fire emissions occasionally contributed to the performance at the Gorge monitors as the plume edges wafted over the eastern-most sites. The August modeling was also not sensitive to increased ammonia emissions. This was due to the fact that the period was warm and dry, and so the ammonium nitrate formation was thermodynamically limited by the meteorological conditions, as opposed to being limited by available ammonia.

After undertaking several diagnostic and sensitivity tests for the August modeling episode, from which several emission problems were ameliorated, we were able to achieve an acceptable base case replication of the PM components and light scattering/extinction that were measured along the Columbia River. When model performance was quantitatively gauged against 24-hour

average measurements, it was found to meet or beat performance goals and criteria for the most critical PM components observed during the period (organic aerosol and sulfate), and for total light scattering and extinction. Those components that did not meet the performance criteria (nitrate, fine and coarse primary PM) were either both predicted and measured to be very low in concentration (the case for nitrate below 1 $\mu g/m^3$), or did not contribute significantly to light extinction due to low scattering efficiency (the case for fine and coarse primary PM). CAMx performance in replicating the range of 24-hour light scattering among all nine Gorge Study dry nepholometer sites was quite good, indicating a near zero bias tendency with a moderate degree of scatter about the 1:1 line. This level of performance is comparable to some of the best performance results achieved by WRAP.

When hourly predictions were compared to limited hourly measurements taken at two Gorge Study sites, Mt Zion and Bonneville, the model demonstrated a basic ability to replicate the inter-daily trends in PM component concentrations and light scattering during this episode, but the model over stated the diurnal variation of carbonaceous components, and thus total light scattering as well. Overall, the model performed very well in replicating the temporal and spatial variation of key PM species concentrations and light extinction levels that were observed during this episode.

November 2004 Performance

Eight individual CAMx simulations were undertaken for the November 4-18, 2004 modeling episode, which paralleled the run configurations made for August. Most of these runs addressed improvements in the input emission inventory or the treatment of biogenic SOA.

The carbonaceous components tended to be over predicted and were dominated by wood smoke, which was especially concentrated in the Portland area. Over predictions in primary fine/coarse PM were due to over stated emission factors and the application of seasonal profiles in the modeling inventory that do not account for the suppressive effects of episode-specific precipitation events on such categories as road dust and construction and agricultural fugitive dust. Reducing the dust components to near zero to account for specific precipitation events would dramatically improve model performance for primary PM; this would require the development of day-specific dust emission fields (not done in this study).

Sulfate, nitrate and associated ammonium were appropriately predicted to be much higher during this episode, with nitrate exceeding 10 $\mu g/m^3$ in both measurements and predictions. This was due to the fact that the period was much cooler, wetter, and stagnant than the August episode, which are prime conditions for the formation of secondary sulfate and nitrate PM salts. Cloud water is an important heterogeneous chemical pathway for sulfate and nitrate, while high humidity and cool temperatures are critical for correctly characterizing the balance between sulfate, nitrate and ammonium. Nitrate aerosols are formed from the neutralization of nitric acid gas (which is produced by the atmospheric oxidation of NOx emissions) by cations such as ammonium, sodium, calcium, and potassium. Ammonium is by far the most abundant cation available away from oceans, so ammonium nitrate is the most abundant form of nitrate particles. On the other hand, sulfate (which is produced by the atmospheric oxidation of SO_2 emissions) exists as an aerosol regardless of its state of neutralization by the same cations. Thus, there is a "competition" between sulfate and nitrate to react with available cations; the process is complex

and dependent on atmospheric conditions and the mix of chemicals. In very simple terms, ammonia preferentially reacts with sulfuric acid aerosols, and any excess is then available to form nitrate particles.

Our tests with CAMx indicated that ammonium nitrate formation was limited by available ammonia. Indeed, nitrates and ammonium were much higher in tests that doubled ammonia emissions, especially around major urban areas such as Portland and along the Interstate 5 route up through Seattle. Sulfate was not significantly impacted by the doubling of ammonia, as the chemical process described above would suggest. So the doubling of ammonia emissions likely went into neutralizing more sulfate (which would not lead to an obvious change in total sulfate concentrations output by the model), and any excess ammonia went to neutralizing more available nitrate. In other words, even more ammonia emissions would probably lead to additional PM nitrate (i.e., an ammonia-limited system). Higher ammonium nitrate concentrations resulted in the largest increases in light scattering in the western Columbia River area early in the episode, while eastern Gorge sites showed a more modest increase later in the episode.

Several diagnostic and sensitivity tests for the November modeling episode were successful in allowing us to identify problems in the November 2004 emission inventory and to improve certain under performance issues associated with the meteorology of the period. Incremental improvements at each step of the process brought model performance for light scattering and most PM constituents to acceptable levels. Model performance was qualitatively gauged for 24-hour average PM, and found to continually exhibit over prediction tendencies for primary PM components along the western portion of the Columbia River (carbonaceous and fine dust), as described above. Overall, sulfate and SOA were well predicted, although sulfate exhibited an over prediction tendency. On an episode-average basis, nitrate concentrations were well modeled with very small bias, but nitrate performance on a day-to-day basis was not well correlated with observations.

Performance for light scattering indicated a “bifurcated” pattern: light scattering was over predicted in the Portland area and along the western portion of the Columbia River, while it was under predicted along the eastern portion of the river. MM5 model performance suffered from a lack of humidity and clouds during the November episode. As discussed above, the ability to generate the correct amount of nitrate is particularly sensitive to the accuracy of humidity and temperature fields. The MM5 cloud field predictions were improved by simply assigning fog to areas of the air quality modeling grid according to available visible satellite imagery. This was found to help the under predictions in sulfate and nitrate significantly, and improved modeling performance in replicating the observed light scattering in the Gorge. However, we identified other issues associated with how the “dry” nephelometer instruments employed during the Gorge field study over estimated PM light scattering during the very high humidity conditions that occurred over the core November period. This instrument artifact contributed to some uncertainty in our model-observation comparisons for light scattering.

In summary, CAMx performed well in replicating the much higher concentrations of ammonium sulfate and ammonium nitrate along the Columbia Gorge during the cool, foggy, stagnant conditions of the November 2004 episode. The thick haze that formed during the period was observed to be dominated by these secondary salts, as well as from carbonaceous PM from (mostly) wood smoke. The air quality model simulated the elevated concentrations of all of

these key species adequately well, allowing us to have confidence that the model provides the correct conclusions regarding source apportionment and impacts from emission changes under such extreme haze conditions.

BASE YEAR SOURCE APPORTIONMENT MODELING

The CAMx PM Source Apportionment Tool (PSAT) was applied to the August and November 2004 modeling episodes to quantify source attribution at the Mt Zion and Wishram monitoring sites for the 2004 Base Case scenario. A full description of PSAT is provided in the CAMx User's Guide (ENVIRON, 2006). In PSAT, the emissions of PM and gas precursors are stratified by source category and by source region; tracers are used to tag emissions from each category-region pair and track transport, chemical evolution from gas to PM, and deposition. Tracers can be run, separately or in combination, for a sulfur group, a nitrogen group, an organic group, and a primary PM group.

In the PSAT application run for the Gorge Study, twelve source categories and six source regions were defined. The CAMx input emission inventory files were split into ten source categories for the PSAT application. Two additional categories (initial conditions and boundary conditions) are automatically added internally by CAMx. The ten emission categories consisted of nine categories within the 4-km grid, and one category for all sources outside the 4-km grid. The five source regions included the Portland Metropolitan area, the Columbia Gorge between Portland and Wishram, the western portion of the Columbia River northwest of Portland, the portions of Oregon and Washington west of the Cascade crest, and the portions of Oregon and Washington east of the Cascade crest.

PSAT was run for the sulfur, nitrogen, and primary PM groups. The organic group was not run; the main issue concerning SOA is the relative amount of biogenic vs. anthroponic SOA predicted by the model. Since the core SOA module in CAMx generates a biogenic/anthropogenic attribution by design (without the need for PSAT), and biogenic SOA was seen to dominate 24-hour PM predictions across the 4-km grid, it was determined that relying on the biogenic/anthropogenic split provided by the core CAMx model was sufficient and was in fact needed to reduce the computer burden. However, this approach does not provide a source region attribution for anthropogenic SOA.

PSAT Results for August 2004

At Mt Zion, areas outside the 4-km domain contribute to the bulk of sulfate during this episode. Portland and areas along the westernmost area of the Columbia River are the largest local source areas of sulfate, which agrees with the general west-to-east transport direction during this period. A variety of source types in these western areas contribute to sulfate, including non-road sources (heavily dominated by diesel engines), EGUs, pulp mills, and other point sources. Nitrate is primarily attributed to similar local upwind regions from on-road, non-road, and EGU sources. Not surprisingly, ammonium is attributed to mainly local ammonia-specific sources in the Gorge and in Portland. Primary carbonaceous components come mostly from upwind and local areas from mobile and area sources (particularly non-road), suggesting diesel activity. Other carbon sources include area sources and fires. The vast majority of secondary organic aerosol is derived

from biogenic sources. Dust (coarse and fine) is nearly entirely from local on-road sources (road dust). Other fine/coarse fractions of primary PM are mostly from local area sources.

The PSAT application revealed that a large fraction of visibility impairment at Mt Zion during the August 2004 episode was caused by natural sources, including secondary organic aerosols (SOA) from biogenic emissions (30%). Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (18%);
2. Elemental carbon from Portland non-road sources (8%);
3. Sulfate from regional sources outside the 4-km OR/WA grid (7%);
4. Elemental carbon from local Gorge non-road sources (4%); and
5. Sulfate from EGU sources northwest of Portland (4%).

At Wishram, areas outside the 4-km domain also contribute to the bulk of sulfate during this episode. However, there is a stronger influence from wildfires in the eastern portion of the 4-km grid, and a smaller influence from Portland and the western areas. Nitrate is primarily attributed to local and upwind regions to the west, from on-road and non-road sources. Ammonium has a strong source locally in the Gorge and in the eastern area from ammonia-specific sources, which are dominated by agricultural activities. Primary elemental and organic carbon components indicate a rather strong contribution from wildfires occurring in north-eastern Washington during this episode; elemental carbon further shows a large contribution from in-gorge non-road sources, which implicate diesel emissions from railroads, barges, and off-road equipment. Again, nearly all SOA generated by CAMx is from biogenic sources, but there is less total SOA simulated at this site than at the Mt Zion site, probably due to drier and non-forested conditions along the eastern end of the Gorge. Coarse and fine dust are nearly entirely from in-gorge on-road and area sources, while other fine/coarse fractions of primary PM are mostly from area sources (again, mostly agricultural activities) and more uniformly apportioned across several regions.

The PSAT application revealed that the majority of visibility impairment at Wishram during the August 2004 episode was caused by natural sources, including SOA from biogenic emissions (30%) and carbonaceous aerosols from wildfires (30%). Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (19%);
2. Primary organic carbon from eastern OR/WA wildfires (18%);
3. Elemental carbon from eastern OR/WA wildfires (9%);
4. Sulfate from regional sources outside the 4-km OR/WA grid (7%); and
5. Elemental carbon from local Gorge non-road sources (7%).

PSAT Results for November 2004

A very different PM environment is characterized in the November episode, with secondary sulfate/nitrate/ammonium salts dominating the mass budgets. At Mt Zion, almost 3 $\mu g/m^3$ is predicted for episode-average sulfate, and the largest contributor is EGU emissions in the eastern portion of the modeling domain. However, a wide array of source types and areas contribute to

the Mt Zion sulfate, including areas outside the 4-km domain, which indicates the regional nature of this secondary pollutant. Nitrate is also rather high (over 2 $\mu g/m^3$), with large contributions from on-road and non-road NOx sources mainly from Portland and areas to the west and along the Gorge. Ammonium is attributed to specific ammonia sources (mostly agricultural activities such as animal feed lots and fertilizer applications). Again, a vast area of emissions contribute to ammonium, but the most comes from the eastern Gorge area where there are some large agricultural sources. Both elemental and organic carbon show large contributions from on-road and non-road sources within the Gorge and from Portland, and the POA is apportioned in large measure to area sources (residential wood smoke). Elemental carbon in particular has a large non-road component, likely due to heavy duty diesel engines on off-road equipment, barges, and railroads. Coarse/fine dust are mostly locally generated, and given the wetter nature of the November episode, are likely overstated since the modeling emissions inventory does not account for local day-specific rainfall patterns. Most sources of primary fine/coarse PM are very local in origin and are from fugitive and wind-blown dust sources.

The PSAT application revealed that the vast majority of visibility impairment at Mt Zion during the November 2004 episode was caused by anthropogenic sources (94%). Secondary organic aerosols from biogenic emissions contributed ~40% of the episode-average total organic carbon concentration, but only 6% of episode-average visibility impairment. Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from eastern OR/WA EGU sources (12%);
2. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (11%);
3. Nitrate from Portland on-road sources (10%);
4. Nitrate from western OR/WA on-road sources (5%); and
5. Nitrate from super-regional sources outside the 12-km Pacific Northwest grid (4%).

Wishram experiences even more episode-average sulfate than Mt Zion, with nearly a 5 $\mu g/m^3$ episode average. Again the single largest contributor is EGU emissions in the eastern portion of the modeling domain. Unlike Mt Zion, very little contribution is shown for other sources, since this site is much farther from large sources such around the Portland area and transport winds are generally easterly from remote areas of eastern Oregon and Washington. Nitrate is also higher at Wishram (almost 5 $\mu g/m^3$), with contributions primarily from on-road, non-road, area, and EGU NOx sources in the eastern area. NOx sources outside the 4-km grid (mostly well to the east) also contribute to nitrate. Ammonium in nearly entirely attributed to local sources in the eastern area of the domain; large ammonia sources in the area of Wishram are causing a local formation of particle ammonium nitrate as aged nitric acid plumes move into the area from the east, mix with the ammonia, and condense into PM nitrate in the cool humid environment. Carbonaceous PM is much lower than the secondary salts, although episode-average elemental carbon (EC) concentrations of nearly 1 $\mu g/m^3$ are rather high compared to many other IMPROVE sites in the western US. Most EC stems from local non-road sources in the Gorge and in the eastern area, which suggests a large contribution from diesel exhaust. POA at Wishram is lower than at Mt Zion, given it's distance from Portland, and has local origins from non-road, area (residential wood combustion), and fires. Like Mt Zion, coarse/fine dust are mostly locally generated in Gorge and in the eastern area, with mostly area and on-road sources contributing.

The PSAT application revealed that the vast majority of visibility impairment at Wishram during the November 2004 episode was caused by anthropogenic sources (95%). Secondary organic

aerosols from biogenic emissions contributed ~50% of the episode-average total organic carbon concentration, but only 5% of episode-average visibility impairment. Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from eastern OR/WA EGU sources (29%);
2. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (8%);
3. Nitrate from eastern OR/WA on-road sources (8%);
4. Nitrate from super-regional sources outside the 12-km Pacific Northwest grid (7%); and
5. Nitrate from eastern OR/WA non-road sources (6%).

FUTURE YEAR PROJECTIONS AND TREND LINES

CAMx was run for both the August and November modeling episode in exactly the same manner as performed for the final 2004 Base Case application ("Run 10"). The only change to the model inputs included use of the 2018 episode-specific modeling emission inventories. All grid configurations, model options, meteorological and other environmental inputs (including "natural" emissions such as wild fires, prescribed burns, wind-blown dust, ammonia and biogenics) were maintained to be consistent with the Run 10 Base Case simulations. Hence, the future year applications performed for the August and November modeling episodes reflect only changes in the projected 2018 anthropogenic emission inventories via anticipated growth in population and industrial, commercial, and vehicular activity, as well as emission controls that were reflected in the 2018 WRAP inventories and some additional adjustments applied specifically for this project, as described earlier.

The results of the future year CAMx simulations were used to prepare visibility trend lines (or rates) from 2004 to 2018. Trends were calculated for two IMPROVE sites – Mt Zion and Wishram – in order to remain consistent with the PSAT and model performance evaluations for total light extinction and visibility documented in Sections 4, 5, and 7. Keep in mind that the inventory data projected for 2018 is just that, a projection, and that the air quality model has some bias. Therefore the reader should not use these values in an absolute sense. While we have made the best effort to replicate the monitored values for 2004 as closely as possible, the model and the science are not perfect. Furthermore, it will be of little value to attempt to predict what the actual absolute future year visibility measurements will be at specific monitors in the Gorge because ultimately the emissions mix and meteorology will be different (as compared to what we have simulated). Instead, the outcome of this modeling exercise is to better understand the likely relative impacts of all the emissions increases (due to population growth for example) and decreases (due to implementation of currently mandated emission reduction strategies) on future year visibility; this is the trend that were are determining in this exercise. The source apportionment information and emission inventory data helps us understand better who is contributing and how much.

Trend lines for 2004-2018 total extinction and deciview were calculated from peak episode-average conditions, which were determined by averaging the 24-hour extinction values on just the "high" PM days identified from the modeling results in each episode. Trend lines and rates were simply determined from the difference in the 2004 and 2018 episode averages. At both Mt Zion and Wishram, little change in total extinction was seen on each day for the August episode. However, some minor reductions in sulfate and nitrate were noticeable. In general, the lack of

extinction response for this episode was tied mostly to the fact that the inventory is dominated by "natural" emissions such as biogenic SOA and wild fires that cannot be directly controlled, and which were carried over from the 2004 inventory development efforts (see Figure ES-1). For the November episode, reductions in nitrate (NOx) and sulfate (SO_2) resulted in more significant reductions in total PM extinction, especially on the worst visibility days. The cleaner days indicated little change in 2018. Little change to other species (carbonaceous and primary PM) was seen in the 2018 out year (see Figure ES-2).

Concerning visibility trend lines, while Mt Zion was simulated to show just a slight improvement in worst-day extinction out to 2018, the Wishram site actually shows a very slight degredation (Table ES-1). Nevertheless, these changes were not perceptible according to the 1 Deciview (Dv) threshold for perceptible visibility changes. In the November episode, a perceptible improvement was simulated for worst-day visibility at both sites, with reductions in total extinction of over 10% and Dv reduction of about 1 (Table ES-2).

These trends were compared to recent results from WRAP determined for Mt Hood and Mt Adams over a similar time horizon (2004 – 2018). Note that WRAP did not calculate visibility trend lines for Mt Zion or Wishram IMPROVE sites as they are not located in Federal "Class I" areas. Since WRAP conducted modeling over the entire 2002 year, the trend lines are determined from the average of the 20% worst visibility days over the annual simulation. Haze conditions on such days in the WRAP 2002 modeling would be consistent with the hazy episode days in 2004 selected for modeling in the Gorge Study. The WRAP simulated projections are very similar to what we calculated for Mt Zion and Wishram during the August 2004 episode.

Five "what-if" scenarios were run for the 2018 Future Case to estimate the impacts of certain sources on visibility over the two modeling episodes:

- Case 1: Zero Boardman EGU emissions.
- Case 2: Zero ammonia emissions in PSAT region 5 (east of Gorge).
- Case 3: Zero on-road mobile source emissions in PSAT region 2 (Portland and Vancouver).
- Case 4: Zero major point source emission for PSAT region 2 (Portland and Vancouver).
- Case 5: Zero major point source emissions for PSAT region 1 (in Gorge).

Very little sensitivity to any of the what-if scenarios was seen at both of the monitoring sites. Since major SO_2 and NOx emission reductions at the Boardman Plant are already reflected in the 2018 inventory (i.e., presumptive BART controls), practically zero sensitivity to Case 1 is seen. Some increases and decreases in sulfate and nitrate are seen for some cases (e.g., Case 5, in which all point sources in the Gorge were removed). This mixed effect is possible depending upon how the chemical conditions set up for a specific episode. There are two possible non-linear effects at play here:

(1) The amount of ambient NOx relative to organic gasses can lead to ozone (oxidant) production or ozone destruction. In NOx-lean conditions (such as in remote rural locations), controls on NOx can lead to less oxidants that ultimately form less sulfate, while in NOx-rich conditions (e.g., urban areas such as Portland), controls on NOx can lead to more oxidants (less ozone inhibition) and thus more sulfate formation.

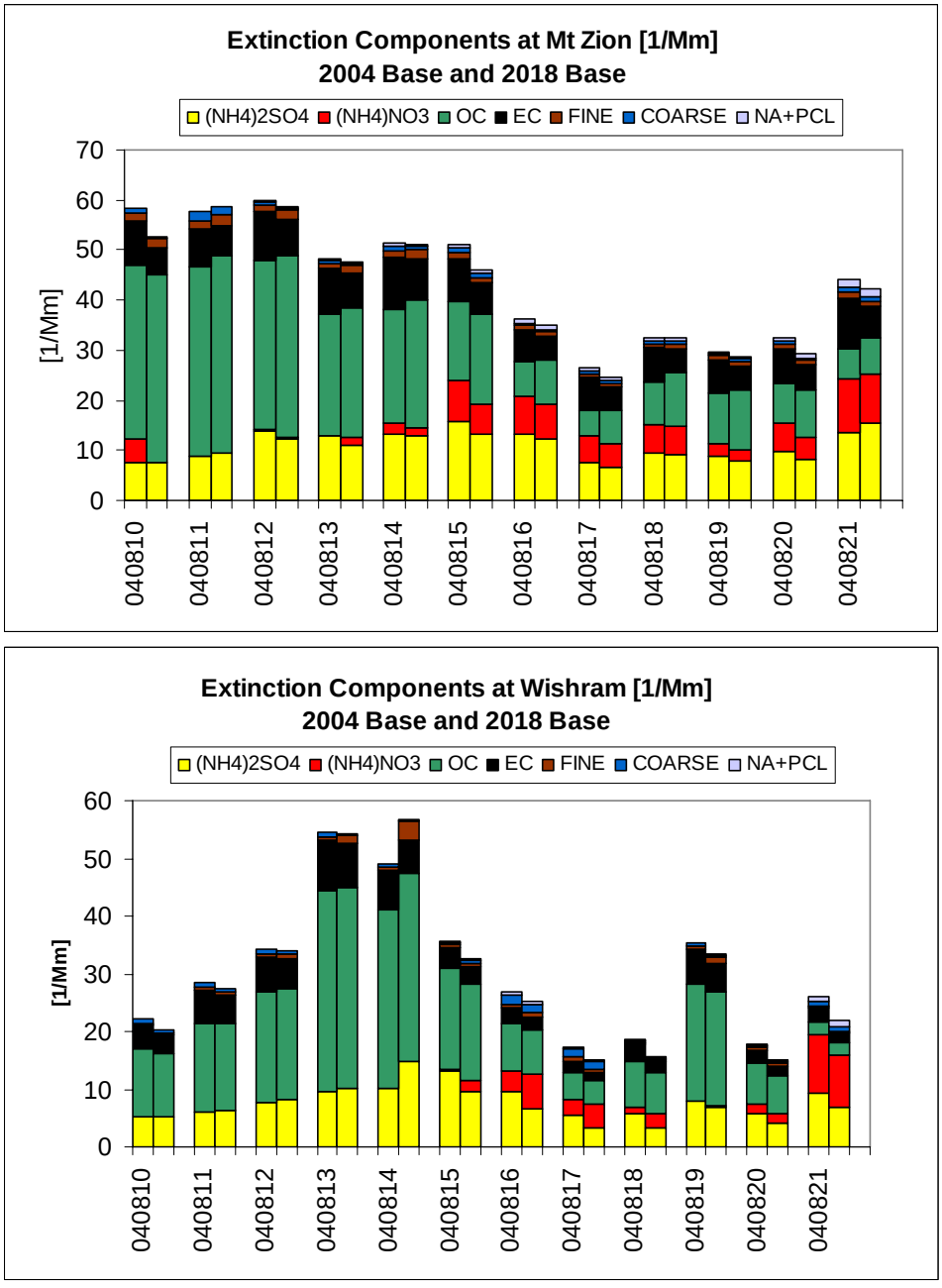


Figure ES-1. Changes in daily light extinction (Mm^{-1}) between the 2004 Base Case (left bar for each day) and 2018 Future Projection (right bar for each day) at Mt Zion and Wishram over the August episode. Contributions from ammonium sulfate ([NH4]2SO4), ammonium nitrate ([NH4]NO3), total organic carbon (OC), elemental carbon (EC), fine PM, coarse PM, and sea salt (NA+PCL) are shown.

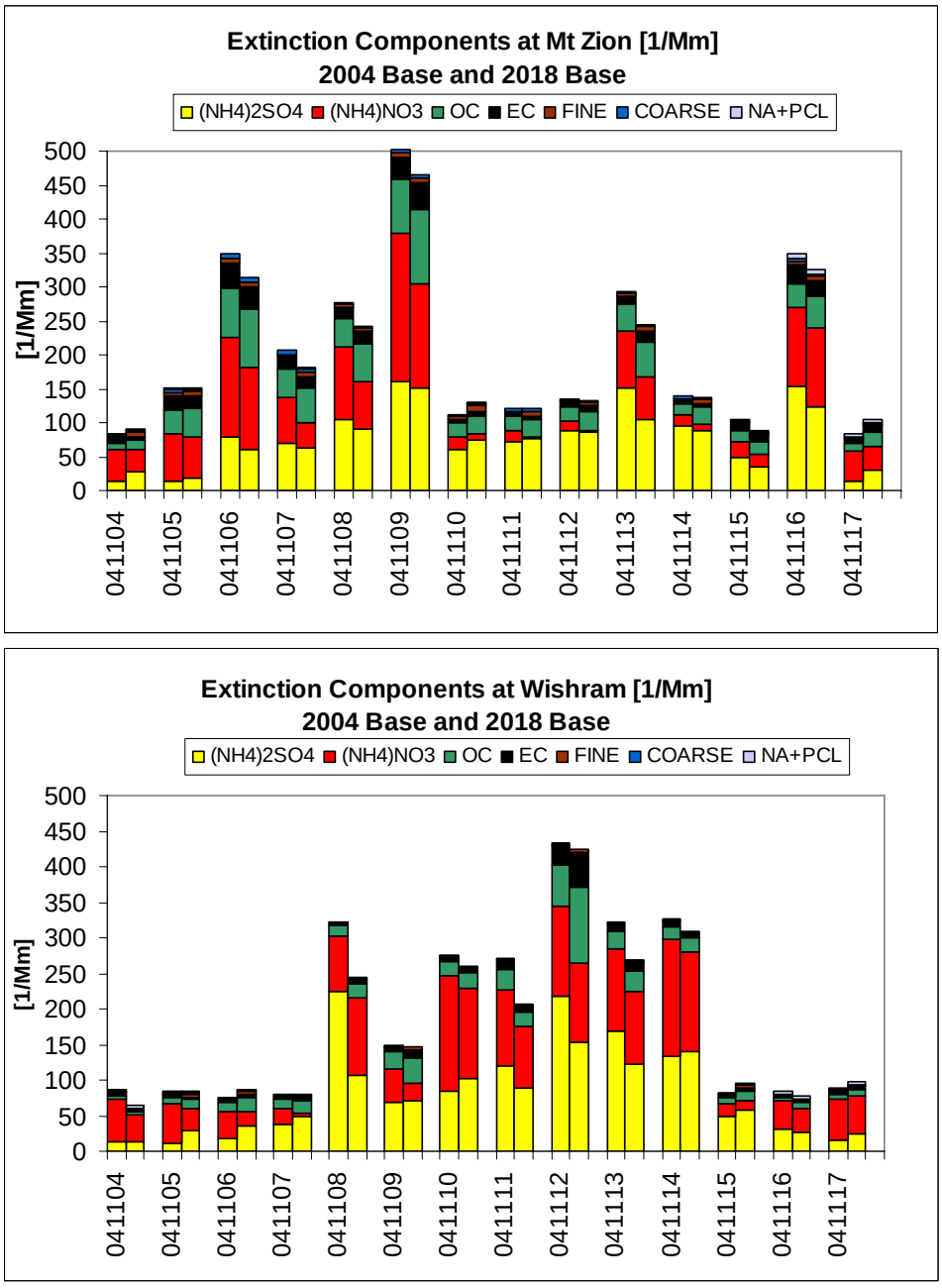


Figure ES-2. Changes in daily light extinction (Mm^{-1}) between the 2004 Base Case (left bar for each day) and 2018 Future Projection (right bar for each day) at Mt Zion and Wishram over the November episode. Contributions from ammonium sulfate ([NH4]2SO4), ammonium nitrate ([NH4]NO3), total organic carbon (OC), elemental carbon (EC), fine PM, coarse PM, and sea salt (NA+PCL) are shown.

Table ES-1. Episode-average trends for extinction and visibility from "high" PM extinction days during the August 2004 episode,

	Mt Zion	Wishram
Total Extinction Change	-1.9 Mm^{-1} (-3%)	0.4 Mm^{-1} (1%)
Extinction Annual Rate	-0.13 $Mm^{-1}yr^{-1}$	0.03 $Mm^{-1}yr^{-1}$
Total Dv Change	-0.3 (not perceptible)	0.08 (not perceptible)
Dv Annual Rate	-0.02 yr^{-1}	0.006 yr^{-1}

Table ES-2. Episode-average trends for extinction and visibility from "high" PM extinction days during the November 2004 episode.

	Mt Zion	Wishram
Total Extinction Change	-35 Mm^{-1} (-10%)	-40 Mm^{-1} (-12%)
Extinction Annual Rate	-2.5 $Mm^{-1}yr^{-1}$	-2.8 $Mm^{-1}yr^{-1}$
Total Dv Change	-1.0 (perceptible)	-1.3 (perceptible)
Dv Annual Rate	-0.07 yr^{-1}	-0.09 yr^{-1}

(2) The amount of particulate nitrate and sulfate that can form depends on the amount of available ammonia that neutralizes these acids. It is very common to see nitrate increases when SO_2 emissions are reduced while NOx and ammonia emissions are held constant. Since ammonium preferentially neutralizes sulfate, with any excess then available for neutralizing nitrate, a reduction in SO_2 leads to a reduction in sulfate, and thus more ammonium is available to form more particulate nitrate.

As we have seen in both the 2018 projection (relative to the 2004 base case) and a few of the "what-if" scenarios, the response of sulfate and nitrate to emissions changes is mixed, reflecting the complex chemistry processes involved. Again, the August episode is dominated by "natural" emissions that were not removed in any of these scenarios. The less obvious signals stemming from the what-if scenarios should be examined in further modeling efforts; but overall these effects are not significant to the overall conclusions of this study.

Somewhat more influence from each what-if scenario is seen on the worst PM days of the November episode, especially Cases 2 and 3 at Mt Zion, which remove Eastern Gorge ammonia and Portland on-road mobile sources, and Cases 1 and 5 at Wishram, which remove major point sources from the in-Gorge area.

FUTURE YEAR SOURCE APPORTIONMENT MODELING

The CAMx PSAT Probing Tool was applied to the August and November 2004 modeling episodes to quantify source attribution at the Mt Zion and Wishram monitoring sites for the 2018 Future Year scenario. The PSAT application for the Future Year scenario was run in exactly the same manner as the PSAT application for the 2004 Base Case.

PSAT Results for August 2018

At Mt Zion, areas outside the 4-km domain continue to contribute the bulk of sulfate during this episode. Portland and areas along the westernmost area of the Columbia River are the largest local source areas of sulfate, which agrees with the general west-to-east transport direction during this period. A variety of source types in these western areas contribute to sulfate, including non-road sources (heavily dominated by diesel engines), EGUs, pulp mills, and other point sources. Nitrate is primarily attributed to similar local upwind regions from on-road, non-road, and industrial sources. Ammonium is attributed to mainly on-road and local ammonia-specific sources in the Gorge and in Portland. Primary carbonaceous components come mostly from upwind and local areas from mobile and area sources (particularly non-road), suggesting diesel activity. Other carbon sources include fires. Dust (coarse and fine) is nearly entirely from local on-road sources (road dust) and local area sources.

Of the projected 2018 non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (16%);
2. Primary organic carbon from Portland area sources (6%);
3. Elemental carbon from Portland non-road sources (5%);
4. Sulfate from pulp mills northwest of Portland (4%); and
5. Primary organic carbon from eastern OR/WA wildfires (4%).

As seen for the Mt Zion site, areas outside the 4-km domain contribute to the bulk of sulfate during this episode at Wishram. However, there is a stronger influence from local Gorge area sources and wildfires in the eastern portion of the 4-km grid, and a smaller influence from Portland and the western areas. Nitrate is primarily attributed to local and upwind regions to the west, from on-road and non-road sources. Ammonium has a strong source locally in the Gorge and in the eastern area from ammonia-specific sources, which are dominated by agricultural activities. Primary elemental and organic carbon components indicate a rather strong contribution from wildfires occurring in north-eastern Washington during this episode; elemental carbon further shows a large contribution from in-gorge non-road sources, which implicate diesel emissions from railroads, barges, and off-road equipment. Primary organics show a relatively large attribution to local Gorge area sources and regional fires. Coarse and fine dust are nearly entirely from in-gorge on-road and area sources, while other fine/coarse fractions of primary PM are mostly from area sources (again, mostly agricultural activities) and fires.

Of the projected 2018 non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Primary organic carbon from eastern OR/WA wildfires (16%);
2. Sulfate from local Gorge area sources (15%);
3. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (11%);
4. Elemental carbon from eastern OR/WA wildfires (9%); and
5. Primary organic carbon from local Gorge area sources (6%).

PSAT Results for November 2018

At Mt Zion, secondary sulfate/nitrate/ammonium salts continue to dominate the mass budgets during the November episode in 2018. Several $\mu g/m^3$ are predicted for episode-average sulfate, but the largest contributor is no longer EGU emissions since SO_2 controls are reflected in the future year inventory. However, a wide array of source types and areas contribute to the Mt Zion sulfate, including local area sources and areas outside the 4-km domain, indicating the regional nature of this secondary pollutant. Nitrate also remains rather high (nearly 2 $\mu g/m^3$), with large contributions from on-road, non-road, and area NOx sources mainly from Portland and areas to the west and along the Gorge. Ammonium is attributed to specific ammonium sources (mostly agricultural activities such as feed lots and fertilizer applications). Again, a vast area of emissions contributes to ammonium, but most comes from the eastern Gorge area where there are some large agricultural sources. Both elemental and organic carbon show some contributions from on-road and non-road sources within the Gorge and from Portland, but now the POA is apportioned in large measure to area sources. Elemental carbon in particular has a large non-road component, likely due to heavy duty diesel engines on off-road equipment, barges, and railroads. The area source contribution to POA is dominated by residential wood smoke, both locally and from the Portland area. Coarse/fine dust are mostly locally generated, and given the wetter nature of the November episode, are likely overstated since the modeling emissions inventory does not account for local day-specific rainfall patterns. Most sources of primary fine/coarse PM are very local in origin and are likely from fugitive and wind-blown dust sources as well as road dust.

Of the projected 2018 non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (12%);
2. Sulfate from local Gorge area sources (10%);
3. Sulfate from Portland area sources (6%);
4. Nitrate from Portland on-road sources (5%); and
5. Nitrate from Portland non-road sources (4%).

Wishram continues to experience more episode-average sulfate than Mt Zion in 2018, with nearly a 4 $\mu g/m^3$ episode average. However, local EGU emissions contribute much less; sources in the eastern portion of the domain dominate, and are fairly evenly spread across several industrial source types, as well as non-road and area source categories. Nitrate is also higher at Wishram for this episode (about 4 $\mu g/m^3$), with contributions primarily from on-road, non-road, area, and EGU NOx sources in the eastern area. NOx sources outside the 4-km grid (mostly well to the east) also contribute to nitrate. Ammonium continues to be nearly entirely attributed to local sources in the eastern area of the domain. Carbonaceous PM is much lower than the secondary salts, and also lower than the 2004 Base Case PSAT results. Most EC stems from local non-road sources in the Gorge and in the eastern area, which suggests a large contribution from diesel exhaust. POA at Wishram has local origins from area sources (residential wood combustion) and fires. Like Mt Zion, coarse/fine dust is mostly locally generated in Gorge and in the eastern area, with mostly area and on-road sources contributing.

1.0 INTRODUCTION

This report describes the meteorological, emissions and air quality modeling conducted by the contractor team of ENVIRON International Corporation and Alpine Geophysics, LLC, as part of the Columbia River Gorge National Scenic Area Air Quality Study (Gorge Study). The modeling analyses reported herein comprise just one component of the entire Gorge Study to assess projected trends in future visibility impairment, to provide a simulation assessment of source apportionment by type and region, and to test several "what-if" scenarios for future year conditions.

1.1 BACKGROUND

In July of 2001, the Columbia River Gorge Technical Team and Interagency Coordination Team, with the assistance of national and global experts in air quality science, developed a phased, technical study plan for the Columbia River Gorge National Scenic Area. In 2003, the Washington Department of Ecology (WDOE), Oregon Department of Environmental Quality (ODEQ) and Southwest Clean Air Agency (SWCAA) requested the Technical Team to develop a "stand alone" study, leveraging other studies and within the available resources, that would:

- Provide an assessment of the causes of visibility impairment in the Columbia River Gorge National Scenic Area;
- Identify emission source regions, emission source categories, and individual emission sources that significantly contribute to visibility impairment in the Gorge;
- Provide predictive modeling tools or methods that will allow the evaluation of emission reduction strategies;
- Provide an initial assessment of air quality benefits to the Gorge from upcoming state and federal air quality programs; and
- Refine or adapt predictive modeling tools already being developed for visibility or other air quality programs, including but not limited to Regional Haze.

1.1.1 Columbia River Gorge Air Quality Study Components

There are several components of the Columbia River Gorge Air Quality Study, including:

Measurement Program: Collect additional visibility, particulate matter (PM) components, gaseous species and meteorological data during 2003-2005 within and surrounding the Gorge. The enhanced measurement program has been completed and provided to the data warehousing and analysis contractor.

Haze Gradient Study: Analyze visibility (nephelometer) and meteorological measurements within the Gorge to better understand the causes and movement of visibility impairment in the Gorge and identify episodes for more detailed analysis. A Haze Gradient Study report is available (Green et al., 2006a).

Causes of Haze in the Gorge (CaHaGo) Study: Enhance understanding of haze in the Gorge through analysis of additional aerosol chemical composition data as a follow-on to the Haze Gradient Study. A CaHaGo draft report is available (Green et al., 2006b).

Modeling Analysis: Conduct numerical grid modeling to assess projected trends in future visibility impairment, to provide a simulation assessment of source apportionment by type and region, and to test several "what-if" scenarios for future year conditions. The modeling analysis is documented in this report.

The ultimate goal of these Gorge Study components is to develop a scientific basis of evidence that can be referenced to answer a set of questions that were originally posed by the Technical Team. These questions are as follows:

1. *What aerosol components are responsible for haze?*
    a. What are the major components for best, worst, and average days and how do they compare?
    b. How variable are they episodically, seasonally, inter-annually, spatially?
    c. How do the relative concentrations of the major components compare with the relative emission rates nearby and regionally?
2. *What is meteorology's role in the causes of haze?*
    a. How do meteorological conditions differ for best, worst and typical haze conditions?
    b. What empirical relationships can be derived between meteorological conditions and haziness?
    c. Are meteorological and climatological conditions between the west end and the east end of the Scenic Area the cause of the observed differences in visibility impairment?
    d. Can haze conditions be predicted solely using meteorological factors?
    e. How well are inter-annual variations in haze accounted for by variations in meteorological conditions?
3. *What are the emission sources responsible for haze?*
    a. What geographic areas are associated with transported air that arrives at sites on best, typical and worst haze days?
    b. Are the emission characteristics of the transport areas consistent with the aerosol components responsible for haze?
    c. What do the aerosol characteristics on best, typical and worst days indicate about the sources?
    d. What does the spatial and temporal pattern analysis indicate about the locations and time periods associated with sources responsible for haze?
    e. What evidence is there for urban impacts on haze and what is the magnitude and frequency when evident?
    f. What connections can be made between sample periods with unusual species concentrations and activity of highly sporadic sources (e.g., major fires and dust storms, point source activity changes such as aluminum plant shut-downs, etc.)?
    g. What can be inferred about impacts from sources in other regions?

4. *Are there detectable and/or statistically significant multi-year trends in the causes of haze?*
    a. Are the aerosol components responsible for haze changing?
    b. Where changes are seen, are they the result of meteorological or emissions changes?
    c. Where emissions are known to have changed, are there corresponding changes in haze levels? (e.g., aluminum plant shutdowns or emission controls on the Centralia Power Plant)?

Results from the modeling exercises documented in this report are used to answer as many of these questions as possible (see Section 8).

1.2 OVERVIEW OF GORGE MODELING APPROACH

To meet the goals of the Gorge Study, the Technical Team, drawing upon the experience of visibility modeling experts across the country, proposed chemical transport modeling as one of the study components. The plan called for using state-of-the-science air quality models, such as the Comprehensive Air Quality Model with extensions (CAMx; ENVIRON, 2006) and EPA's Models-3 Community Multiscale Air Quality (CMAQ; Byun and Ching, 1999) model. These modeling platforms were to be provided emission inputs from the U.S. Environmental Protection Agency's (EPA) Models-3 Sparse Matrix Operating Kernel Emissions (SMOKE; Houyoux and Vukovich, 1999) system, and meteorological inputs from the Pennsylvania State University / National Center for Atmospheric Research (PSU/NCAR), Fifth Generation Mesoscale Model (MM5; Dudhia, 1993; Grell et al., 1994).

The approach for the Gorge Study modeling was to leverage the considerable regional visibility modeling work already conducted by the Western Regional Air Partnership (WRAP) Regional Planning Organization (RPO) in addressing the requirements of the federal Regional Haze Rule (RHR). The ultimate objective of the RHR is to achieve natural visibility conditions (no man-made impairment) at federally protected Class I areas by 2064. Because the Gorge is in close proximity to several Class I areas (e.g., Mount Hood to the south and Mount Adams to the north), efforts to achieve natural visibility conditions at the Class I areas will undoubtedly benefit visibility in the Gorge as well.

The WRAP Regional Modeling Center (RMC), operating out of the University of California at Riverside, has applied the MM5 meteorological model on a 36-km continental U.S. grid and a 12-km western U.S. grid for the 2002 calendar year. The SMOKE emissions model has been used to generate hourly gridded speciated emissions needed for photochemical grid modeling for both the 2002 base year, and the 2018 future year, which includes most (but not all) emission control regulations that are currently promulgated and "on-the-books."[1] WRAP is currently using both the CMAQ and CAMx photochemical grid models to estimate base and future year PM components from which visibility impairment is calculated.

[1] The WRAP 2018 inventories do not reflect emission reduction estimates associated with the Best Achievable Retrofit Technology (BART) or Maximum Achievable Control Technology (MACT) programs.

1.2.1 Modeling Analyses Supported by Gorge Study Funding

Following the WRAP modeling methodology, the Gorge Study modeling component was to employ both CAMx and CMAQ to simulate as many as four season-representative high PM/extinction episodes with a wide array of sensitivity tests and Probing Tool applications for both the base year and the 2018 future year. Modeling was to be conducted on a series of telescoping nested grids with resolution ranging from 36 km (the WRAP continental grid) to 12, 4, and 1.33 km focusing on the Gorge area. The final modeling project budget was established by the SWCAA in late Spring of 2006; coupled with MM5 performance issues and complications in updating the WRAP inventory, the limited budget required a reduction in the original scope. Below we summarize the modeling analyses that were conducted under current funding.

The Gorge Study modeling protocol (ENVIRON and Alpine Geophysics, 2006) provides details on the episode and model selection, modeling domains, data sources, input preparation procedures, and performance evaluation approach. The first element of the Gorge Study modeling component was the selection and prioritization of episodes to be examined. Based on visibility measurements during the 2003-2005 enhanced monitoring periods, several episodic periods were selected and prioritized. Ultimately, two muti-day seasonal episodes in 2004 were selected for the Gorge Study modeling: a summer period over August 10-22, and an autumn period over November 3-18. A 10-day "spinup" period was added before each episode to reduce the influence of initial conditions.

The Gorge Study modeling utilized the MM5 meteorological, SMOKE emissions, and CAMx air quality models. The modeling domain included the WRAP 36-km continental U.S. grid, with a set of smaller nested 12- and 4-km grids focusing on the primary area of study. The Gorge Study Team expended significant effort developing refined episode-specific emissions for the two 2004 modeling episodes for the 4-km Oregon/Washington grid. The 2002 WRAP emission inventory was adjusted to 2004 and used for areas outside the 4-km grid. Base case air quality model performance was evaluated for the two specific episodes simulated using operational and diagnostic techniques.

A 2018 future year was also simulated for both episodes to obtain a visibility forecast trend line for the Gorge monitoring sites. The WRAP 2018 emission projections were used for this estimate for all grids, but included additional emission reductions that will be applied to two specific large PM sources by 2018: the Boardman power plant near the eastern end of the Gorge, and the Camas pulp mill at the western end of the Gorge. The CAMx Particulate Source Apportionment Technology (PSAT) probing tool was used to assess source category and region-specific attribution to sulfate, nitrate, carbonaceous, and primary particulates at several monitoring sites within the Gorge. PSAT was applied for both 2004 base and 2018 future years. Finally, a group of five "what-if" scenarios were simulated to provide estimated visibility improvements with the removal (or significant reduction) of emissions from specific sources.

1.2.2 The Modeling Platforms

1.2.2.1 Introduction to MM5

MM5 is a three-dimensional, limited-area, primitive equation, prognostic meteorological model (Dudhia, 1993; Grell et al., 1994). The basic model has been under continuous development, improvement, testing and open peer-review for more than 20 years (Anthes and Warner, 1978) and has been used world-wide by hundreds of scientists for a variety of mesoscale studies. Over the past decade, MM5 has been used widely to support regional air quality model applications (Seaman, 2000), and has been successfully applied in several continental-scale annual simulations for the years 1996 (Olerud et al., 2000), and 2001 through 2005 (e.g., McNally and Tesche, 2003; Johnson, 2004; Kemball-Cook et al., 2005), to support various regional-to-national air quality modeling programs carried out by the U.S. EPA and the RPOs.

MM5 is based on the prognostic equations for three-dimensional wind components, temperature, water vapor mixing ratio, water condensates, and pressure. The gridded meteorological fields produced by MM5 are directly compatible with the input requirements of "one atmosphere" air-quality models (e.g., CMAQ and CAMx). The model uses an efficient semi-implicit temporal integration scheme and has a nested-grid capability that can use up to ten different domains of arbitrary horizontal and vertical resolution. The interfaces of the nested grids can be either one-way or two-way interactive. MM5 uses a terrain-following non-dimensional pressure, or "sigma", vertical coordinate similar to that used in many operational and research models. The sigma levels are defined according to the initial hydrostatically-balanced reference state so that the sigma levels are also time-invariant.

MM5 possesses many different physics options, each of which provides a spectrum of technical rigor and complexity. Thus, the specific combination of physics choices that a user employs can play a significant role in the ability of the model to perform well in replicating the phenomenon and scale of interest. Various options are available for radiation treatment, cloud and precipitation microphysics, sub-grid scale convective parameterizations, land-surface models, and sub-grid scale turbulent transfer.

In particular, several distinct planetary boundary layer (PBL) parameterizations are available, and they each represent unique approaches to simulate sub-grid-scale vertical turbulent fluxes of heat, moisture and momentum. These parameterizations employ various surface energy budget equations to estimate ground temperature based on solar and terrestrial radiation, atmospheric path length, water vapor, cloud cover, and soil characteristics. The surface physical properties of albedo, roughness length, moisture availability, emissivity and thermal inertia are defined as functions of land-use for numerous categories. One class of PBL schemes uses a first-order eddy diffusivity formulation for stable and neutral environments and a modified first-order scheme for unstable regimes. The other class of schemes uses a prognostic equation for the higher-order turbulent kinetic energy, while diagnosing the other key boundary layer terms.

Initial and lateral boundary conditions are specified from independent periodic large-scale three-dimensional analyses developed by the National Centers for Environmental Protection (NCEP) and archived at NCAR. These datasets range in coverage from the North American continent (e.g., the Eta Data Assimilation System [EDAS] with 3-hourly, 40-km resolution) to global (e.g., the NCAR/NCEP Reanalysis Project with 12-hourly, 2.5-degree resolution). The lateral

boundary data are introduced to the MM5 using an interpolative relaxation technique applied within the outermost five rows and columns of the coarsest grid domain.

A major feature and advantage of the MM5 is its use of Four Dimensional Data Assimilation (FDDA; Stauffer and Seaman, 1990, 1991; Seaman et al., 1992). There are two FDDA options in MM5: "analysis" nudging toward the same large-scale 3-D and 2-D (surface-level) analyses used to prepare initial and boundary conditions; and "observational" nudging to specific arbitrarily-located measurement sites. Analysis nudging controls the entire 3-D grid system on a regular time interval (e.g., 3, 6, or 12-hourly), depending upon the source of the analyses. The analyses are usually improved with local data when translated to the MM5 grids to improve their representation of winds, temperature, and humidity on the smaller-scale, higher-resolution MM5 grids. Observational nudging is usually employed on smaller, high-resolution grids when a sufficiently high density of observations is available. Observation nudging is usually only applied at the surface layer at hourly intervals, within a user-specified radius of influence from each measurement site, so it usually does not impact the entire grid.

The databases required to set up, exercise, and evaluate the MM5 model consist of various fixed and variable inputs:

- Topography: Multiple-resolution topographic data derived from the NCAR Geophysical Data Center global datasets are used to prescribe terrain elevations throughout the various multiple grid domains;
- Vegetation Type and Land Use: Multiple-resolution vegetation type and land use information from NCAR are used for prescribing soil type, vegetative cover, and land use distributions throughout the various multiple grid domains;
- Atmospheric Data: Initial/boundary conditions and FDDA inputs are developed from large-scale operational analyses using standard MM5 pre-processing software, and include horizontal winds, temperature, and humidity at standard pressure levels, plus sea-level pressure and ground/sea surface temperature. These coarse analyses are usually augmented for the MM5 grid structure by blending in surface and upper-air observational data in an objective analysis technique (a separate pre-processing step).

1.2.2.2 Introduction to SMOKE

The EPA Models-3 SMOKE system is an emissions processor that generates hourly, gridded, speciated emissions from on-road mobile, non-road mobile, area, point, fire and biogenic source categories for input to photochemical grid models. As with most "emissions models," SMOKE is principally an *emission processing system* and not a true *emissions modeling system* in which emissions estimates are simulated from "first principles." This means that, with the exception of mobile and biogenic sources, its purpose is to provide an efficient, modern tool for converting emissions inventory data into the formatted emission files required by an air quality simulation model. For mobile sources, SMOKE actually simulates emissions rates based on input mobile-source activity data, emission factors and sometimes output from transportation travel-demand models. SMOKE includes biogenic emissions modeling through a rewrite of the Biogenic Emission Inventory System, version 3 (BEIS3).

The sparse matrix approach utilized throughout SMOKE permits both rapid and flexible processing of emissions data. The processing is rapid because SMOKE utilizes a series of matrix calculations instead of less efficient algorithms used in previous systems. The processing is flexible because the processing steps of temporal projection, controls, chemical speciation, temporal allocation, and spatial allocation have been separated into independent operations wherever possible. The results from these steps are merged together at a final stage of processing.

The SMOKE system prototype was originally developed at MCNC (Houyoux and Vukovich, 1999). SMOKE has been available since 1996, and it has been used for emissions processing in a number of regional air quality modeling applications. In 1998 and 1999, SMOKE was redesigned and improved with the support of the U.S. EPA, for use with EPA's Models-3/CMAQ. The primary purpose of the SMOKE redesign was to support: (a) emissions processing with user-selected chemical mechanisms and (b) emissions processing for reactivity assessments.

Recent computational improvements to SMOKE include: (a) enhanced disk space requirements compared with other emissions processing software; (b) run-time memory allocation, eliminating any need to recompile the programs for different inventories, grids, or chemical mechanisms; and (c) updated I/O API libraries. A number of science features have been incorporated into the "current" version of SMOKE (version 2.2, released in October 2005) including: (a) any chemical mechanism can be used to partition pollutants to model species, as long as the appropriate input data are supplied; (b) integration with the MOBILE6.2 on-road mobile source emissions model including link based processing; (c) support of plume-in-grid (PiG) processing; and (d) integration of the BEIS3 emissions factors in SMOKE.

The databases required to set up and operate SMOKE are as follows:

- County-level seasonal or annual area source emissions in Inventory Data Analyzer (IDA) format;
- County-level seasonal or annual non-road source emissions in IDA format;
- Seasonal or annual stationary point source emissions in IDA format;
- Day-specific point source Continuous Emissions Monitoring (CEM) measurements;
- Seasonal, annual, or day-specific county-level or event-specific wildfire, prescribed burn, and agricultural burn emissions;
- County-level or roadway network on-road motor vehicle activity data;
- MOBILE6.2 emission factor input parameters;
- Temporal, spatial and speciation allocation profiles by source category.

1.2.2.3 Introduction to CAMx

CAMx is a state-of-science "one-atmosphere" multi-scale photochemical/aerosol grid model capable of addressing ozone, particulate matter (PM), visibility, acid deposition, and air toxics (ENVIRON, 2006). CAMx was developed with all new code during the late 1990s using modern and modular coding practices. The flexible CAMx framework has made it a convenient and robust host model for the implementation of a variety of mass balance and sensitivity

analysis techniques (referred to as "Probing Tools"), including Process Analysis (PA), Decoupled Direct Method (DDM), and the Ozone and Particulate Source Apportionment Technology (OSAT/PSAT). CAMx has been widely used in recent years by a variety regulatory agencies for 1-hr and 8-hr ozone and PM10 State Implementation Plan (SIP) modeling studies as well as by several RPOs for regional haze modeling.

Key attributes of the CAMx model include the following:

- Two-way grid nesting that supports multiple levels of fully interactive grid nesting;
- CB4 or SAPRC99 gas-phase photochemical mechanisms;
- Multiple gas-phase chemical solvers;
- Two separate treatments of PM using the same ISOROPIA and RADM chemistry algorithms as CMAQ:
    - A two-mode option comparable to the approach in CMAQ;
    - A multi-section "full-science" approach using the Multi-component Aerosol Dynamics Model (MADM; Pilinis et al., 2000) that treats the effects of condensation/evaporation, coagulation and nucleation upon the particle size distribution.
- Secondary organic aerosol thermodynamics represented using the semi-volatile scheme of Strader and co-workers (1999);
- Multiple numerical algorithms for horizontal transport including the Piecewise Parabolic Method (PPM) and Bott advection solvers;
- Subgrid-scale Plume-in-Grid (PiG) algorithm to treat the near-source plume dynamics and chemistry from point sources;
- Ability to interface with a variety of meteorological models including the MM5, the Regional Atmospheric Modeling System (RAMS), and the Weather Research and Forecasting (WRF) prognostic hydrostatic meteorological models and the CALMET diagnostic meteorological model (others also compatible);
- The Ozone and Particulate Source Apportionment Technology (OSAT/PSAT) that identifies the source contributions from user-defined geographic regions and categories (e.g., mobile, point, biogenic, etc.);
- The Decoupled Direct Method (DDM) sensitivity method that provides first-order sensitivity coefficients for emissions, initial and boundary conditions.
- Process Analysis (PA) tools that provide detailed information on individual chemical and physical process rates over the entire domain or for specific sub-domains as small as a single grid cell.

CAMx provides two key options to users interested in simulating PM. For computer-efficient PM modeling applications, CAMx may be run using a two-mode size representation (fine and coarse) similar to the treatment in CMAQ. Alternatively, more rigorous aerosol simulations (perhaps for shorter episodes) may be addressed using the version that treats N-size sections (N is typically 10) and the rigorous, but computationally-extensive MADM multi-section chemistry module.

The databases required to set up and operate CAMx are as follows:

- Three-dimensional hourly meteorological fields and two-dimensional landuse and topography fields, generated by meteorological models such as MM5 and prepared using available interface pre-processors;
- Two-dimensional low-level (surface layer) emissions and elevated point source emissions generated by the emissions processors such as SMOKE;
- Initial/boundary condition (IC/BC) inputs, either space/time constant or varying depending upon available external datasets, and prepared by available pre-processors;
- Photolysis rates look-up table for several key photolytic gas-phase reactions, prepared by an available radiative transfer model;
- Albedo/Haze/Ozone Column input file prepared from available global satellite-derived datasets and prepared using an available pre-processor;

Like all air quality models, the ability of CAMx to replicate observed conditions and to credibly project chemical concentration and visibility patterns into the future is subject to the accuracy, integrity, and representativeness of the input emissions, meteorological and IC/BC inputs. Key science limitations in the model itself include the nitrate formation chemistry and the secondary organic aerosol (SOA) module. Much of the SOA performance problems are due to deficiencies in the SOA module that fails to account for several known processes important to SOA (e.g., polymerization). Since CAMx and CMAQ share many common chemistry algorithms, performance issues are common to both models. Although CAMx possesses some more advanced PM science modules, they are currently too computationally expensive to use except in focused research applications.

1.2.3 CAMx Probing Tool and Emission Sensitivity Applications

1.2.3.1 Particulate Source Apportionment Technology

CAMx possesses a set of "Probing Tools" that can extract detailed information on model sensitivity and source-receptor relationships from the model. Of particular note for this modeling study is PSAT, which tracks source category and source region contributions to sulfate, nitrate, organics, and primary PM over the entire modeling grid. Thus, source attribution for speciated and total PM (and visibility) can be determined at specific monitoring site locations. The PSAT probing tool was used to evaluate source apportionment to the PM chemical components for both the 2004 and 2018 years. Selection of specific source categories and regions included:

Low-level Emissions in 4-km Grid

- Area (residential/commercial/industrial, dust, biogenic)
- On-road mobile
- Non-road mobile (railroads, river barges, construction/industrial equipment)
- Ammonia sources (feed lots, fertilizers)

Elevated (Point) Emissions in 4-km Grid

- Electric Generating Units (EGU)
- Pulp Mills
- Other industrial sources

- Wild Fires
- Other Fires

Source regions in 4-km Grid

- In Gorge
- Portland/Vancouver metro (by county)
- Northwest of Gorge (northwest of Portland)
- East of Gorge (eastern Oregon/Washington [OR/WA], east of the Cascase crest)
- West of Gorge (western OR/WA, west of the Cascade crest)

Regional Emissions

- In the 12-km modeling grid
- Everything outside the 12-km modeling grid

Thus, the combination of 9 source categories and 5 regions over the 4-km modeling grid, plus the regional emissions, resulted in tracking 60 unique source apportionment tracers each for sulfate, nitrate, and primary PM. Attribution to secondary organic aerosols was determined for only biogenic and anthropogenic sources without a source region breakdown.

1.2.3.2 Emission Sensitivity Tests

The modeling team was funded to perform five "what-if" scenarios applied to the 2018 future year emissions inventory. The set of scenarios conducted in this study included:

- Eliminate the Boardman Power Plant
- Eliminate all ammonia emissions east of the Cascades
- Eliminate on-road mobile emissions in the Portland/Vancouver area
- Eliminate all point source emissions in the Portland/Vancouver area
- Eliminate all point source emissions in the Gorge Scenic Area from eastern Portland to Wishram

1.2.4 Modeling Domains

1.2.4.1 Horizontal Grids

CAMx was run on the 36-km Regional Planning Organization (RPO) unified grid definition established by the all of the RPOs in the U.S. for their RHR modeling. The RPO unified grid consists of a continental-scale Lambert-Conformal map projection based on the parameters listed in Table 1-1. To achieve finer spatial resolution in the Gorge region, we also employed higher resolution nested grids. A 12-km domain was nested within the RPO domain to cover all of Oregon, Washington and portions of neighboring States and Canada. A 4-km grid was in turn nested within the 12-km domain that covers most of Washington and Oregon and extends into western Idaho.

Table 1-1. Projection definition for the RPO unified grid.

Parameter	Value
Projection	Lambert-Conformal
1st True Latitude	33° N
2nd True Latitude	45° N
Projection center longitude	97° W
Projection center latitude	40° N

Each of the three CAMx air quality modeling grids is wholly contained within in their respective MM5 grids. Larger MM5 grids were selected to provide a buffer of at least 10 grid cells around each boundary of the CAMx grids to eliminate any potential boundary artifacts[2] from entering into the air quality model. The buffer region used here exceeds the EPA suggestion of at least 5 grid cell buffer at each boundary.

Table 1-2 lists the number of rows and columns and the definition of the X and Y origin (i.e., the southwest corner) for the MM5 and CAMx 36-, 12-, and 4-km grids. In Table 1-2 "Dot" refers to the MM5 grid mesh defined at the vertices of the grid cells, while "cross" refers to the MM5 grid mesh defined by the grid cell centers. Thus, the dimension of the dot mesh is equal to the cross mesh plus one. The selection of the continental-scale 36-km MM5 domain is described by Johnson (2004). Figure 1-1 displays the MM5 36/12/4 km nested grid modeling domains. Note that SMOKE and CAMx are defined by grid cells only, and that the grid definition for the SMOKE emissions model and CAMx model are identical. The SMOKE/CAMx modeling domains are shown in Figure 1-2.

Table 1-2. Grid definitions for MM5, and SMOKE/CAMx.

Model	Columns Dot (cross)	Rows Dot (cross)	Xorigin (m)	Yorigin (m)
MM5 36-km	165 (164)	129 (128)	-2952000	-2304000
MM5 12-km	145 (144)	130 (129)	-2700000	108000
MM5 4-km	184 (183)	157 (156)	-2196000	612000
SMOKE/CAMx 36-km	148	112	-2736000	-2088000
SMOKE/CAMx 12-km	131	116	-2640000	168000
SMOKE/CAMx 4-km	146	137	-2164000	644000

1.2.4.2 Vertical Grid

The CAMx vertical structure is defined by the vertical grid used in the MM5 modeling. The MM5 model employs a terrain following coordinate system defined by pressure, using 34 layers that extend from the surface to a pressure altitude of 100 mb. Table 1-3 lists the layer definitions for both MM5 and CAMx. As is typical in large-scale model applications such as this, a layer aggregation or "collapsing" scheme was used for CAMx to reduce the computational cost of the air quality simulations. We collapsed 34 layers in MM5 down to 19 layers for the CAMx air quality simulations. The first 8 layers of CAMx, up to approximately 450 m above ground

[2] Boundary artifacts include numerical noise that develops as external (provided by input analysis fields) and internal (self-generated) boundary conditions come into dynamic balance with the MM5 algorithms.

(AGL), match the MM5 vertical layer structure exactly. The CAMx model top is the same as used by MM5, 100mb (approximately 15 km AGL).

When feasible it is desirable to use the same layer structure in the air quality model as in the MM5 to prevent errors associated with aggregating layer data and to maintain consistency between the meteorological model and those used by the chemistry-transport model. The effects of layer averaging were evaluated by WRAP and other RPOs and found to have a relatively minor effect on the model performance metrics when both the 34-layer and 19-layer air quality model simulations were compared to ambient monitoring data (Morris et al., 2004). The same vertical grid was employed for all horizontal grids.

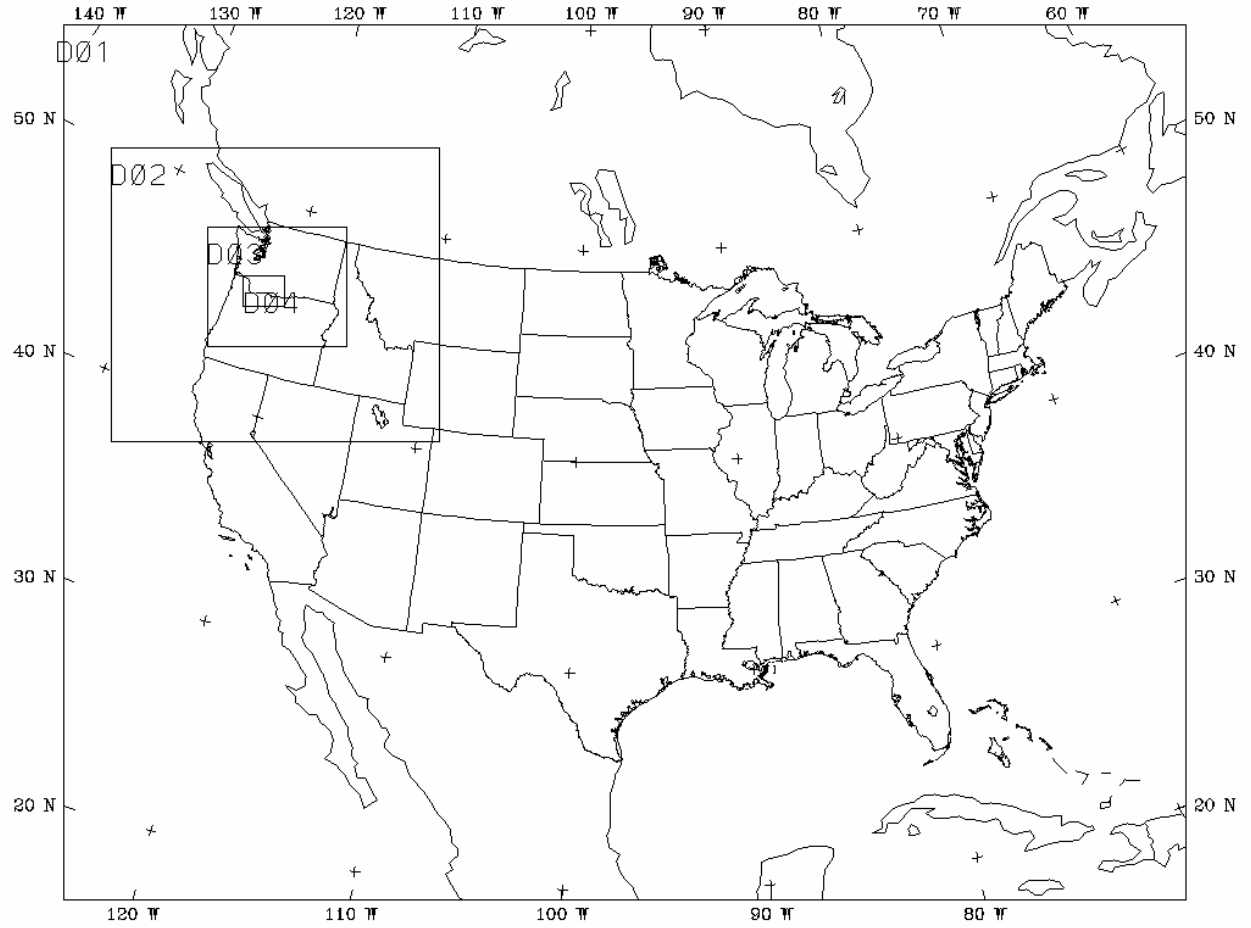


Figure 1-1a. MM5 36 km (D01), 12 km (D02), and 4 km (D03) nested-grid modeling domains. A proposed very high resolution grid (D04) was not used in the Gorge visibility modeling study.

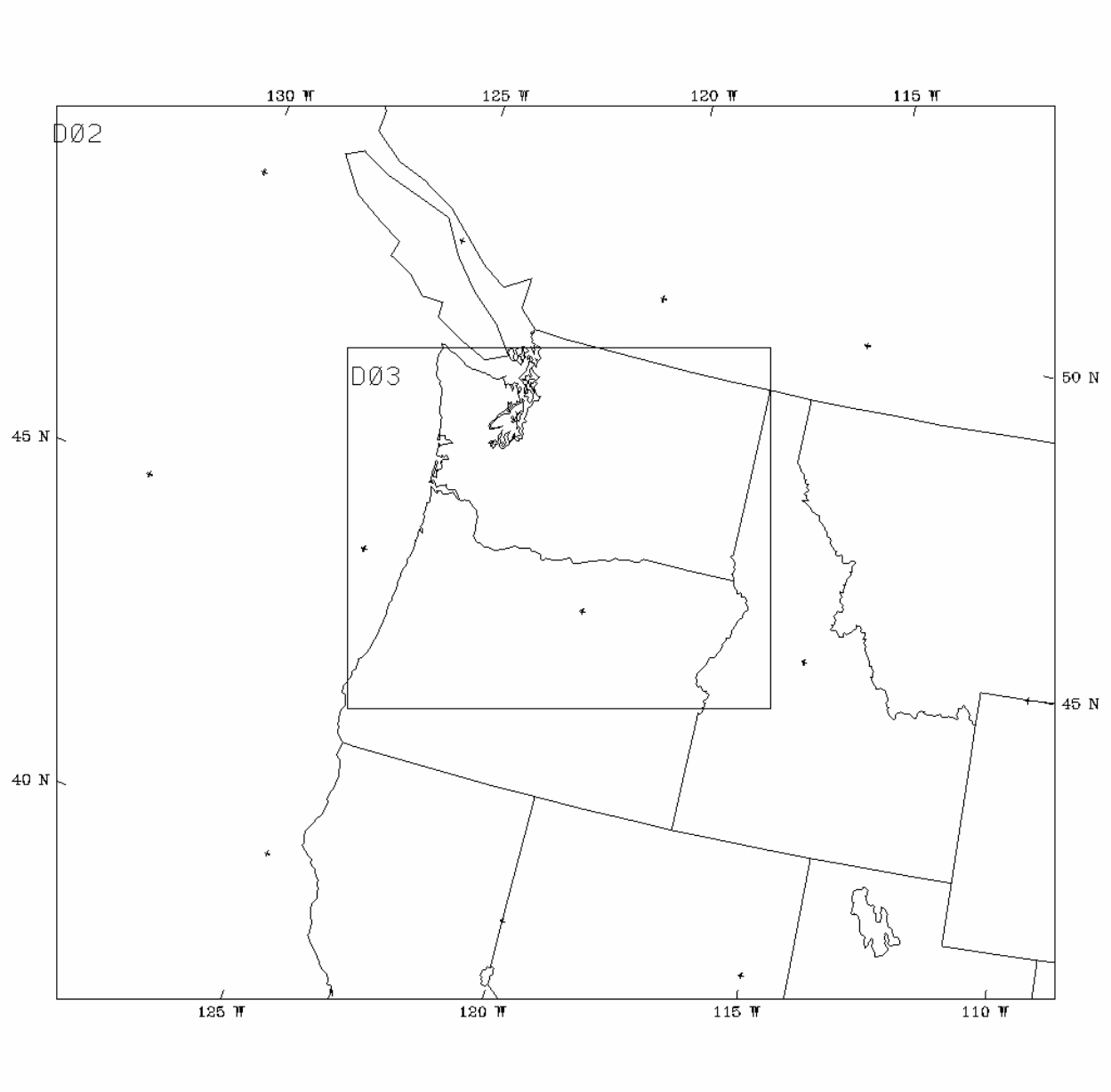


Figure 1-1b. MM5 12 km (D02) and 4 km (D03) nested-grid modeling domains.

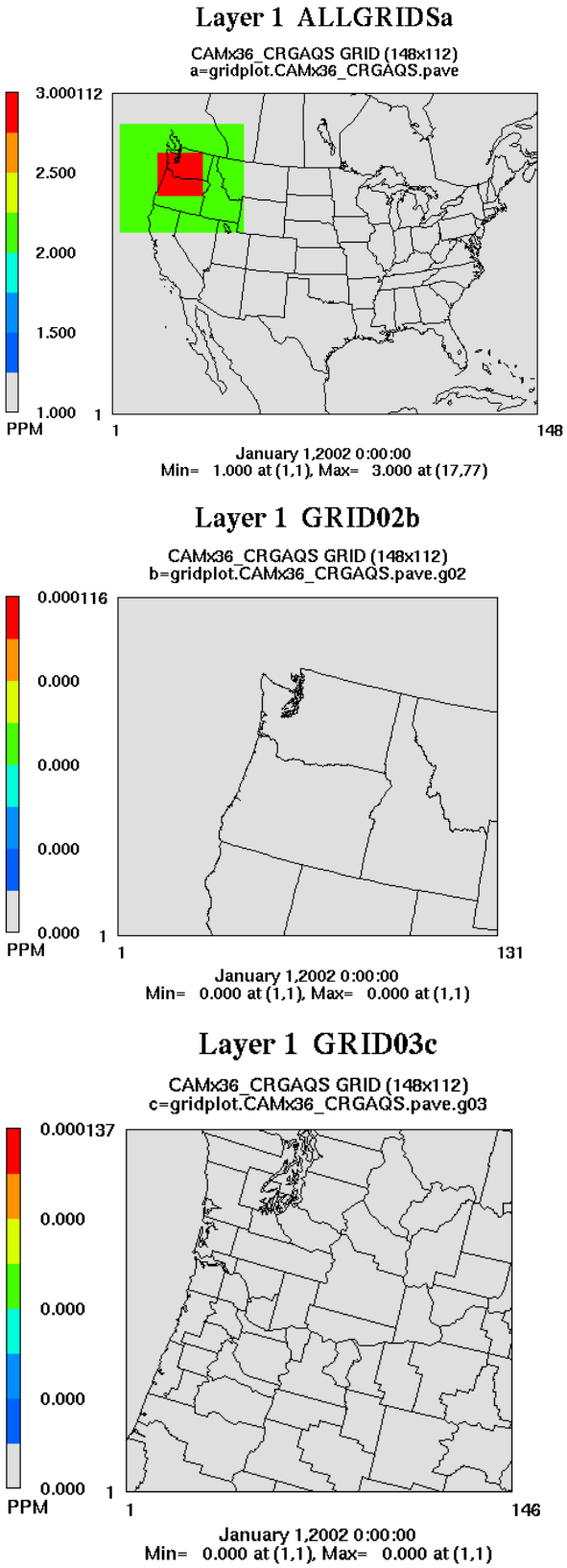


Figure 1-2. SMOKE/CAMx modeling domains for the 36 km (top), 12 km (middle), and 4 km grids.

Table 1-3. Vertical layer definition for MM5 simulations (left-most columns), and approach for reducing CAMx layers by collapsing multiple MM5 layers (right columns).

MM5					CAMx				
Layer	Sigma	Pres(mb)	Height(m)	Depth(m)	Layer	Sigma	Pres(mb)	Height(m)	Depth(m)
34	**0.000**	**100**	**14662**	**1841**	**19**	**0.000**	**100**	**14662**	**6536**
33	0.050	145	12822	1466		0.050	145		
32	0.100	190	11356	1228		0.100	190		
31	0.150	235	10127	1062		0.150	235		
30	0.200	280	9066	939		0.200	280		
29	**0.250**	**325**	**8127**	**843**	**18**	**0.250**	**325**	**8127**	**2966**
28	0.300	370	7284	767		0.300	370		
27	0.350	415	6517	704		0.350	415		
26	0.400	460	5812	652		0.400	460		
25	**0.450**	**505**	**5160**	**607**	**17**	**0.450**	**505**	**5160**	**1712**
24	0.500	550	4553	569		0.500	550		
23	0.550	595	3984	536		0.550	595		
22	**0.600**	**640**	**3448**	**506**	**16**	**0.600**	**640**	**3448**	**986**
21	0.650	685	2942	480		0.650	685		
20	**0.700**	**730**	**2462**	**367**	**15**	**0.700**	**730**	**2462**	**633**
19	0.740	766	2095	266		0.740	766		
18	**0.770**	**793**	**1828**	**259**	**14**	**0.770**	**793**	**1828**	**428**
17	0.800	820	1569	169		0.800	820		
16	**0.820**	**838**	**1400**	**166**	**13**	**0.820**	**838**	**1400**	**329**
15	0.840	856	1235	163		0.840	856		
14	**0.860**	**874**	**1071**	**160**	**12**	**0.860**	**874**	**1071**	**160**
13	0.880	892	911	158	**11**	**0.880**	**892**	**911**	**158**
12	**0.900**	**910**	**753**	**78**	**10**	**0.900**	**910**	**753**	**155**
11	0.910	919	675	77		0.910	919		
10	**0.920**	**928**	**598**	**77**	**9**	**0.920**	**928**	**598**	**153**
9	0.930	937	521	76		0.930	937		
8	**0.940**	**946**	**445**	**76**	**8**	**0.940**	**946**	**445**	**76**
7	**0.950**	**955**	**369**	**75**	**7**	**0.950**	**955**	**369**	**75**
6	**0.960**	**964**	**294**	**74**	**6**	**0.960**	**964**	**294**	**74**
5	**0.970**	**973**	**220**	**74**	**5**	**0.970**	**973**	**220**	**74**
4	**0.980**	**982**	**146**	**37**	**4**	**0.980**	**982**	**146**	**37**
3	**0.985**	**986.5**	**109**	**37**	**3**	**0.985**	**986.5**	**109**	**37**
2	**0.990**	**991**	**73**	**36**	**2**	**0.990**	**991**	**73**	**36**
1	**0.995**	**995.5**	**36**	**36**	**1**	**0.995**	**995.5**	**36**	**36**
0	**1.000**	**1000**	**0**	**0**	**0**	**1.000**	**1000**	**0**	**0**

2.0 METEOROLOGICAL MODELING

2.1 MM5 CONFIGURATION FOR THE GORGE STUDY

MM5 version 3.63 was used for the Gorge Study modeling system. Based on past sensitivity testing carried out by WRAP (Kemball-Cook et al., 2005) and others, the initial configuration of MM5 consisted of the following:

- Nested three-grid system (see Section 1.2.2):
  - 36-km grid covering the continental U.S. with 34 vertical layers;
  - 12-km grid covering the Pacific Northwest including Idaho, Oregon and Washington and portions of surrounding states and Canada;
  - 4-km grid covering most of Oregon and Washington;
  - The 12- and 4-km grids use two-way nesting with no feedback (also called interactive one-way nesting);
- Initial and boundary conditions from EDAS analysis fields (ds609.2) with observational enhancement:
  - NCEP surface obs (ds464.0);
  - NCEP upper-air obs (ds353.4);
- Pleim-Xiu (P-X) land soil model (LSM);
- Pleim-Chang Asymmetric Convective Mixing (ACM) PBL model;
- Kain-Fritsch 2 (KF2) sub-grid cumulus parameterization;
- Mixed-phase (Reisner 1) cloud microphysics;
- Rapid Radiative Transfer Model (RRTM) for solar and terrestrial radiative transfer;
- No Shallow Convection parameterization;
- Standard 3-D FDDA analysis nudging;
- No 2-D surface FDDA analysis nudging; and
- No surface observational nudging.

Although a very similar configuration to that listed above was adopted for the 2002 annual WRAP simulation because it achieved the best model performance overall in the western U.S., there were some concerns raised particularly regarding the overstatement of precipitation amounts and consistent cool bias in the Pacific Northwest (Kemball-Cook et al., 2005). Issues have also been raised concerning the MM5 performance over the western third of the continent in general, especially pertaining to temperature and humidity (Johnson, 2004). While these issues carry weight in the analysis of seasonal and annual western visibility modeling carried out by WRAP and others, they become critically important at the finer temporal and spatial scales addressed in the episodic Gorge Modeling.

As stated in Section 1, MM5 possesses many different physics options that can drastically alter the predicted meteorological fields. MM5 predictions are particularly sensitive to the choice of LSM and PBL model. The MM5 Pleim-Xiu LSM/PBL option used by WRAP and the other RPOs frequently predicts very low PBL heights, and can generate “holes” in the spatial distribution of PBL heights that don’t appear physically realistic and may affect air quality modeling. Furthermore, the model is rather sensitive to the choice of cumulus parameterization, and the use of FDDA and the type of nudging performed can lead to significant differences in the

generated meteorological fields. Therefore, additional MM5 runs were carried out to test the impacts caused by changes in various model options. The most sensitive options listed above were systematically altered to assess the impact of each and to derive a meteorological model configuration that led to optimal model performance in replicating observed conditions in and around the Gorge area.

Table 2-1 lists the six MM5 simulations performed and compared in this study for both the August and November 2004 episodes. The "Run 1" simulation is described above. Note that two of the model configurations were taken from other modeling efforts conducted in this region: the University of Washington (UW) forecasting system ("Run 3"), and the Portland SIP ("Run 4"). The last two simulations were identical to "Run 2", but included additional FDDA surface nudging toward Gorge Study wind data (Runs 5 and 6), and changed the regional-grid cumulus parameterization to the Betts-Miller (BM) scheme (Run 6).

Table 2-1. Configuration of six MM5 simulations conducted for the Gorge Study modeling to provide meteorological inputs for the CAMx air quality simulations.

Model Option	Run1	Run2	Run3 (UW Forecast)	Run 4 (Portland SIP)	Run 5	Run 6
Land Surface Model	P-X	P-X	Simple 5-Layer	NOAH	P-X	P-X
Planetary Boundary Layer	ACM	ACM	MRF	MRF	ACM	ACM
Radiation	RRTM	RRTM	CCM2	RRTM	RRTM	RRTM
Cumulus Parameterization	KF 2 (36/12)	KF 2 (36/12)	KF (36/12)	KF (36/12)	KF 2 (36/12)	BM (36/12)
Moist Physics	Reisner I	Reisner I	Reisner II	GSFC Graupel	Reisner I	Reisner I
Analysis Nudging Surface	None	None	None	None	U/V	U/V
Analysis Nudging Aloft	U/V/T/Q	U/V/T/Q	U/V/T/Q	U/V/T/Q	U/V/T/Q	U/V/T/Q
Surface Obs Nudging	None	U/V (No Gorge)	None	None	U/V (w/ Gorge)	U/V (w/ Gorge)

*U/V/T/Q represents wind components (U and V), temperature, and humidity, respectively.
MRF refers to the Medium Range Forecasting model PBL parameterizations.
GSFC refers to the Goddard Space Flight Center moist physics model.

2.2 EVALUATION OF MM5 PERFORMANCE

2.2.1 Evaluation Approach

The goal of the MM5 model evaluation should be to (a) assess whether and to what extent confidence may be placed in the modeling system to provide three-dimensional wind, temperature, moisture, and turbulent mixing rates to air quality models, and (b) compare and contrast performance against results obtained from previous meteorological model applications across the country. The basis for the assessment is a comparison of the predicted meteorological fields to available surface and aloft data collected by the National Weather Service and other agencies. A specific set of statistics has been identified for use in establishing benchmarks for acceptable model performance, with the idea that these benchmarks, similar to current EPA

guidance criteria for air quality model performance, allow for a consistent comparison of various meteorological simulations for important variables at the surface and in the boundary layer.

Output from MM5 is compared against meteorological observations from the various networks operating in the region of interest. This is carried out both graphically and statistically to evaluate model performance for winds, temperatures, humidity, and the placement, intensity, and evolution of key weather phenomena. Graphical comparisons allow for a qualitative assessment of model performance by comparing results to commonly available analysis maps of wind, temperature, pressure, and precipitation patterns. The purpose of these evaluations is to establish a first-order acceptance/rejection of the simulation in adequately replicating the gross weather phenomena in the region of interest. Thus, this approach screens for obvious model flaws and errors.

Statistical comparisons provide a quantitative assessment of model performance. The problem with evaluating statistics is that the more data pairings that are summarized in a given metric, the better the statistics generally look, and so calculating a single set of statistics for a very large area would not yield significant insight into performance. Therefore, the statistical analysis is refined to sub-regions within the modeling domain. Results from the sub-regional evaluations give clues as to any necessary modifications to be made in the MM5 configuration. Additional plots and graphs are used to present these statistics on both hourly and daily time frames. These measures are calculated for wind speed, wind direction, temperature, and humidity at the surface and in the boundary layer. Below we list and describe the various statistical measures that were calculated in this study.

The statistics used to evaluate meteorological model performance are all given in absolute terms (e.g., wind speed error in m/s), rather than in relative terms (percent error) as is commonly shown for air quality assessments. The major reason for this is that a very different significance is associated with a given relative error for different meteorological parameters. For example, a 10% error for wind speed measured at 10 m/s is an absolute error of 1 m/s, a minor error. Yet a 10% error for temperature at 300 K is an absolute error of 30 K, a ridiculously large error. On the other hand, pollutant concentration errors of 10% at 1 ppb or 10 ppm carry practically the same significance.

Mean Observation (M_o): calculated from all sites with valid data within a given analysis region and for a given time period (hourly or daily):

$$M_o = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I} O_j^i$$

where O^i_j is the individual observed quantity at site i and time j, and the summations are over all sites (I) and over time periods (J).

Mean Prediction (M_p): calculated from simulation results that are interpolated to each observation used to calculate the mean observation (hourly or daily):

$$M_p = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I} P_j^i$$

where P^i_j is the individual predicted quantity at site *i* and time *j*. Note that mean observed and predicted winds are vector-averaged (for east-west component *u* and north-south component *v*), from which the mean wind speed and mean resultant direction are derived.

Least Square Regression: performed to fit the prediction set to a linear model that describes the observation set for all sites with valid data within a given analysis region and for a given time period (daily or episode). The y-intercept *a* and slope *b* of the resulting straight line fit are calculated to describe the regressed prediction for each observation:

$$\hat{P}^i_j = a + bO^i_j$$

The goal is for a 1:1 slope and a "0" y-intercept (no net bias over the entire range of observations), and a regression coefficient of 1 (a perfect regression). The slope and intercept facilitate the calculation of several error and skill statistics described below.

Bias Error (B): calculated as the mean difference in prediction-observation pairings with valid data within a given analysis region and for a given time period (hourly or daily):

$$B = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P^i_j - O^i_j\right)$$

Gross Error (E): calculated as the mean *absolute* difference in prediction-observation pairings with valid data within a given analysis region and for a given time period (hourly or daily):

$$E = \frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left|P^i_j - O^i_j\right|$$

Note that the bias and gross error for winds are calculated from the predicted-observed residuals in speed and direction (not from vector components *u* and *v*). The direction error for a given prediction-observation pairing is limited to range from 0 to ±180°.

Root Mean Square Error (RMSE): calculated as the square root of the mean squared difference in prediction-observation pairings with valid data within a given analysis region and for a given time period (hourly or daily):

$$RMSE = \left[\frac{1}{IJ}\sum_{j=1}^{J}\sum_{i=1}^{I}\left(P^i_j - O^i_j\right)^2\right]^{1/2}$$

The RMSE, as with the gross error, is a good overall measure of model performance. However, since large errors are weighted heavily (due to squaring), large errors in a small subregion may produce a large RMSE even though the errors may be small and quite acceptable elsewhere.

Systematic Root Mean Square Error ($RMSE_S$): calculated as the square root of the mean squared difference in *regressed* prediction-observation pairings within a given analysis region and for a given time period (hourly or daily):

$$RMSE_S = \left[\frac{1}{IJ} \sum_{j=1}^{J} \sum_{i=1}^{I} \left(\hat{P}_j^i - O_j^i \right)^2 \right]^{1/2}$$

where the regressed prediction is estimated for each observation from the least square fit described above. The $RMSE_S$ estimates the model's linear (or systematic) error; hence, the better the regression between predictions and observations, the smaller the systematic error.

Unsystematic Root Mean Square Error ($RMSE_U$): calculated as the square root of the mean squared difference in prediction-regressed prediction pairings within a given analysis region and for a given time period (hourly or daily):

$$RMSE_U = \left[\frac{1}{IJ} \sum_{j=1}^{J} \sum_{i=1}^{I} \left(P_j^i - \hat{P}_j^i \right)^2 \right]^{1/2}$$

The unsystematic difference is a measure of how much of the discrepancy between estimates and observations is due to random processes or influences outside the legitimate range of the model.

A "good" model will provide low values of the RMSE, explaining most of the variation in the observations. The systematic error should approach zero and the unsystematic error should approach RMSE since:

$$RMSE^2 = RMSE_S^2 + RMSE_U^2$$

Index of Agreement (IOA): calculated following the approach of Willmont (1981). This metric condenses all the differences between model estimates and observations within a given analysis region and for a given time period (hourly and daily) into one statistical quantity. It is the ratio of the total RMSE to the sum of two differences – between each prediction and the observed mean, and each observation and the observed mean:

$$IOA = 1 - \left[\frac{IJ \cdot RMSE^2}{\sum_{j=1}^{J} \sum_{i=1}^{I} \left| P_j^i - M_o \right| + \left| O_j^i - M_o \right|} \right]$$

Viewed from another perspective, the index of agreement is a measure of the match between the departure of each prediction from the observed mean and the departure of each observation from the observed mean. Thus, the correspondence between predicted and observed values across the domain at a given time may be quantified in a single metric and displayed as a time series. The index of agreement has a theoretical range of 0 to 1, the latter score suggesting perfect agreement.

Emery et al. (2001) derived and proposed a set of daily statistical performance “benchmarks” for typical meteorological model performance used in air quality modeling applications:

Wind Speed	RMSE:	≤ 2 m/s
	Bias:	≤ ±0.5 m/s
	IOA:	≥ 0.6
Wind Direction	Gross Error:	≤ 30 deg
	Bias:	≤ ±10 deg
Temperature	Gross Error:	≤ 2 K
	Bias:	≤ ±0.5 K
	IOA	≥ 0.8
Humidity	Gross Error:	≤ 2 g/kg
	Bias:	≤ ±1 g/kg
	IOA:	≥ 0.6

These standards were subjectively based upon the evaluation of a variety of about 30 MM5 and RAMS simulations conducted for summertime ozone air quality applications through the 1990's to 2001 as reported by Tesche et al. (2001). When we consider the many more recent meteorological/air quality modeling applications conducted throughout the country since these benchmarks were first established (e.g., RPO and EPA national modeling, various SIP applications, etc.) the benchmarks tend to be somewhat too stringent relative to what should be expected of MM5 meteorological model performance.

The purpose of these benchmarks is not necessarily to give a passing or failing grade to any one particular meteorological model application, but rather to put its results into the proper context. For example, expectations for modeling of complex terrain might not be as high as flat homogeneous terrain. The key to the benchmarks is to understand how poor or good the results are relative to the universe of other model applications run throughout various areas of the U.S. Certainly, an important criticism of the historical EPA guidance statistics for acceptable photochemical performance is that they are relied upon much too heavily to establish an "acceptable" model simulation of a given area and episode. Often lost in the statistical evaluation is the need to critically evaluate all aspects of the model via diagnostic and process-oriented approaches. The same must stressed for the meteorological performance evaluation.

2.2.2 Statistical Results

We begin the evaluation with an overview of statistical model performance for all MM5 simulations within various portions of the MM5 4-km grid. Figure 2-1 displays the statistical analysis regions. For each model run, daily statistical performance for winds, temperature, and humidity in each analysis region were averaged over all days in the core episode periods (August 10-22 and November 3-18) to derive episode-average performance metrics. The statistics for all runs and all analysis regions were then plotted together as a way to simplify the inter-comparison of the various model runs and analysis regions.

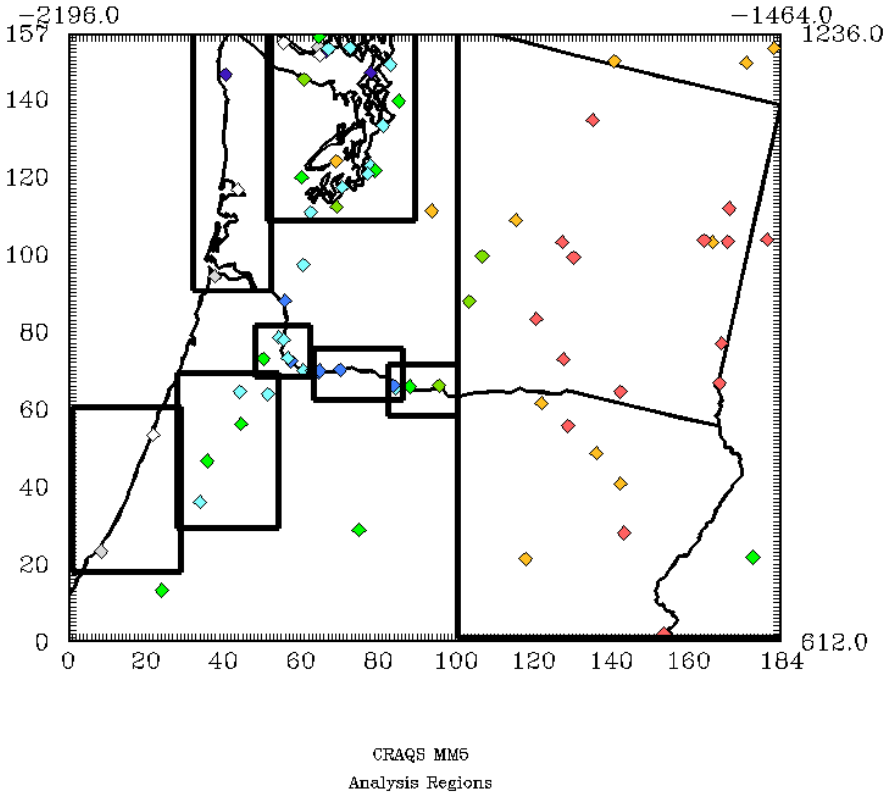


Figure 2-1. MM5 performance analysis regions over the 4-km modeling domain. Areas in the western portion of the domain include: Puget Sound (PS), north coast (NC) including both coastal boxes, Willamette Valley (WV), western Gorge (WG), central Gorge (CG), and eastern Gorge (EG). The entire eastern half of the domain is evaluated as a single region, referred to as east of Cascades (EC). Site colors carry no significance.

2.2.2.1 August 2004 Performance

The "error space" plots provide a simple way to indicate how the bias and gross error compare to the statistical benchmarks described above. The benchmarks for each parameter are plotted as a box, and if bias and error metrics for a particular run and analysis region fall within these boxes, the run would be considered to be performing well relative to the universe of meteorological model simulations used to derive the benchmarks.

Figure 2-2(a) shows the error plot for winds on the 4-km domain; in this case, wind direction gross error is compared to wind speed RMSE, with the benchmark goal shown for <30° direction error and <2 m/s speed RMSE. Note that wind performance for all MM5 runs and analysis regions are outside the benchmarks. Again, it is important to realize that for this high-resolution grid and complex topography, it is difficult to achieve statistical performance on par with other simulations throughout the U.S. using coarser grids and/or simpler/smoother terrain – the benchmarks are not pass/fail criteria. Note also that the statistics for results for each analysis

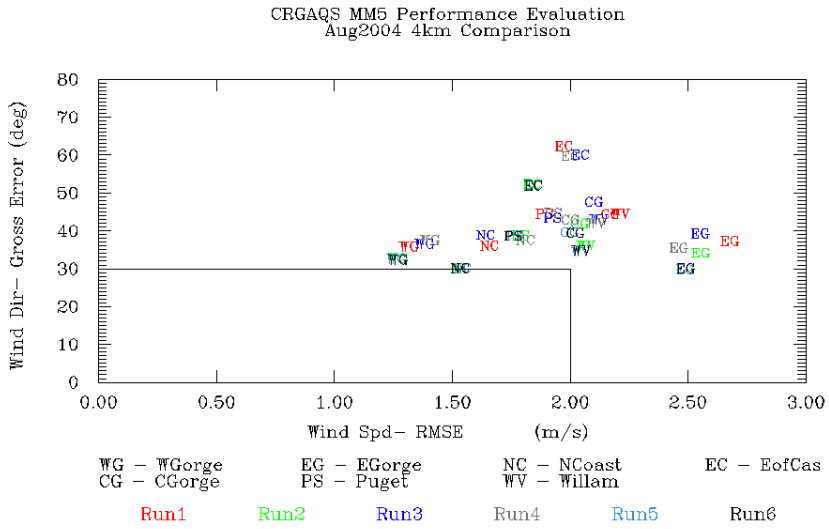


Figure 2-2(a). Error space plot for wind direction gross error vs. wind speed RMSE for the August 2004 episode. Colors represent MM5 run, initials are plotted for each analysis region. Benchmarks for each metric are shown by the box at 30° and 2 m/s.

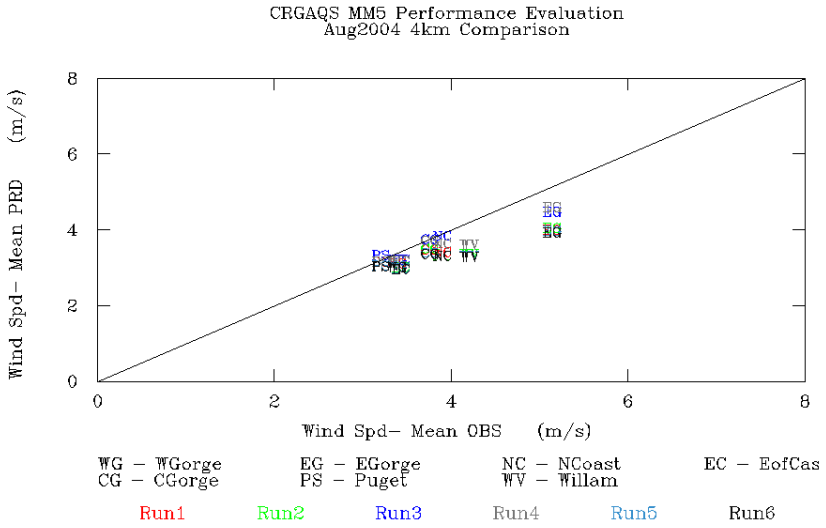


Figure 2-2(b). Episode-mean predicted wind speed vs. mean observed wind speed for each MM5 run and each analysis region.

region are grouped together, indicating that the various MM5 configurations are not leading to significant differences in model performance. The best performance is generally seen for the north coast, western Gorge, and Puget Sound regions. The east of Cascades and eastern Gorge regions are indicating the worst directional and speed performance, respectively.

Figure 2-2(b) shows the episode-mean predicted wind speed against mean observed wind speed. Overall, the correlation is rather good, with MM5 slightly under predicting winds in most analysis regions, and especially east of the Cascades and in the Willamette Valley. Again, MM5 wind performance is quite consistent run-to-run.

Figure 2-3(a) shows the error plot for temperature on the 4-km domain; in this case, temperature gross error is compared to temperature bias, with the benchmark goal shown for <2 K gross error and <0.5 K bias. Temperature performance indicates a much broader spread among the various MM5 simulations and analysis regions. Both under and over predictions are noted, with generally high gross error. The difference among runs is driven by the different LSM, PBL, and radiation options among the runs. The largest differences are seen among Run 3 and Run 4, which are configured significantly different from the other runs. Wide regional differences in performance are seen as well. The best performance is seen for the north coast region (all runs), the western Gorge (most runs), and the central Gorge (most runs). The worst performance is seen as large over predictions in the Puget Sound region, several Run 4 regions, the Willamette Valley (most runs), and large under predictions for Run 3 in the east Gorge. Runs 1, 2, 5, and 6 (all configured similarly) consistently indicate the least amount of bias for all areas except Puget Sound.

Figure 2-3(b) shows the episode-mean predicted temperature against mean observed temperature. Again, the correlation is rather good, with coolest temperatures along the coast, warming inland to the eastern Gorge as the warmest. Puget Sound shows the warm bias, and the eastern Gorge shows a slight cool bias.

Figure 2-4(a) shows the error plot for humidity on the 4-km domain; humidity gross error is compared to humidity bias, with the benchmark goal shown for <2 g/kg gross error and <1 g/kg bias. Like temperature, humidity performance indicates a broad spread among the various MM5 simulations and analysis regions. While both under and over predictions are noted, most runs and regions fall within the statistical benchmarks. Run 4 is the only run that shows a consistent dry bias, while the similarly configured runs (Run 1, 2, 5, and 6) are consistently too moist. Run 3 indicates the best overall balance for humidity, which is likely a result of the simpler 5-layer model in conjunction with the MRF PBL option. The worst performance is seen for the eastern Gorge and east of Cascades region, which are too moist for most runs.

Figure 2-4(b) shows the episode-mean predicted humidity against mean observed humidity. The correlation is not as good as seen for winds and temperature, as indicated by the wider spread among the model runs. Again, Run 4 is the driest, Runs 1, 2, 5, and 6 are too moist in the eastern areas, and Run 3 shows the best correlation. Most runs perform well for the central and western Gorge, and for Puget Sound.

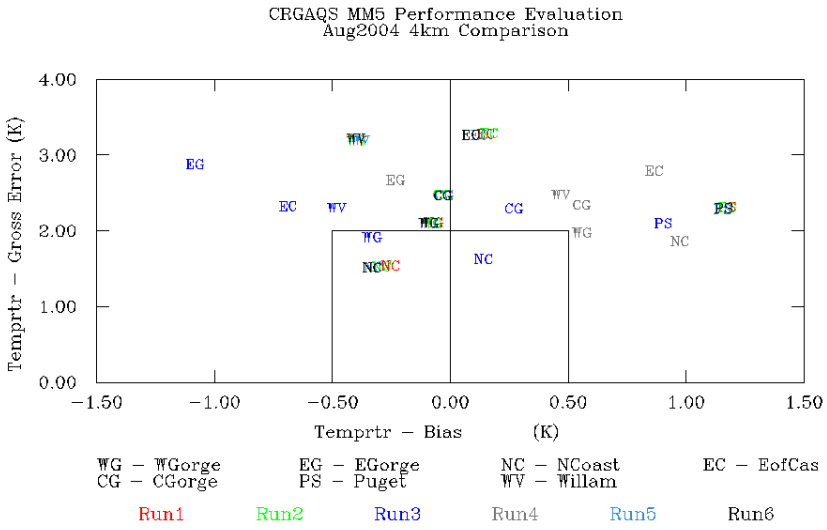


Figure 2-3(a). Error space plot for temperature gross error vs. temperature bias for the August 2004 episode. Colors represent MM5 run, initials are plotted for each analysis region. Benchmarks for each metric are shown by the box at 2 K and ±0.5 K.

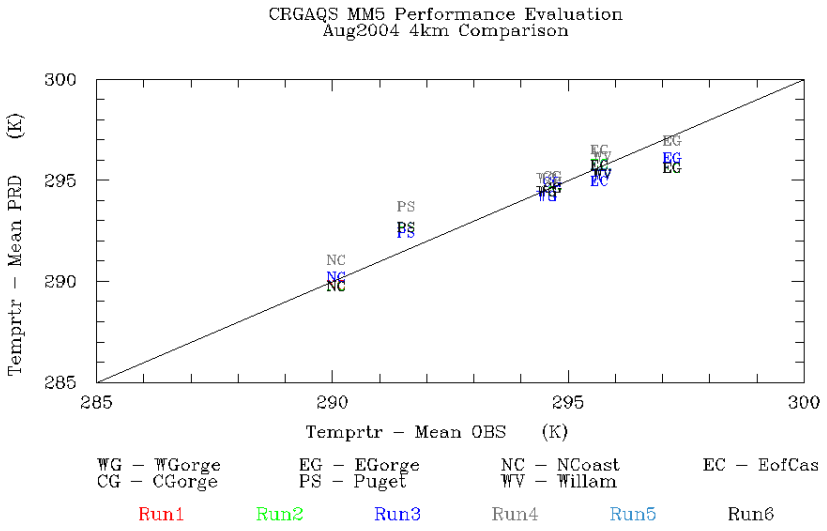


Figure 2-3(b). Episode-mean predicted temperature vs. mean observed temperature for each MM5 run and each analysis region.

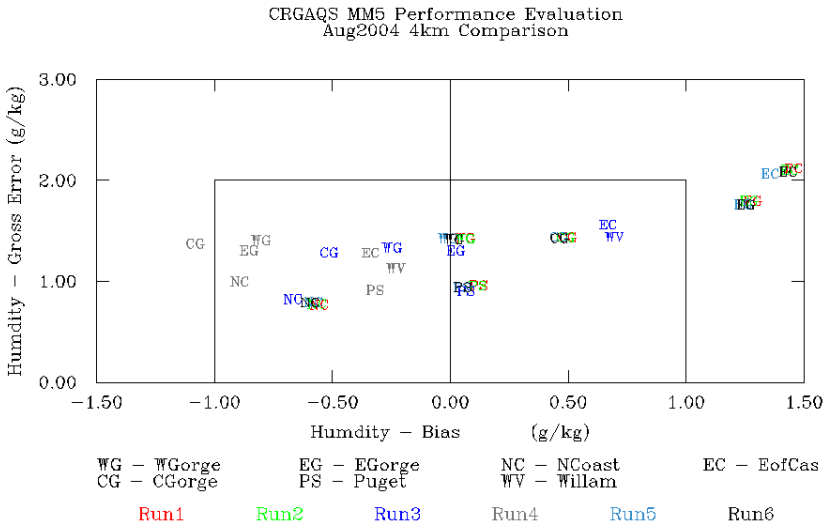


Figure 2-4(a). Error space plot for absolute humidity gross error vs. absolute humidity bias for the August 2004 episode. Colors represent MM5 run, initials are plotted for each analysis region. Benchmarks for each metric are shown by the box at 2 g/kg and ±1 g/kg.

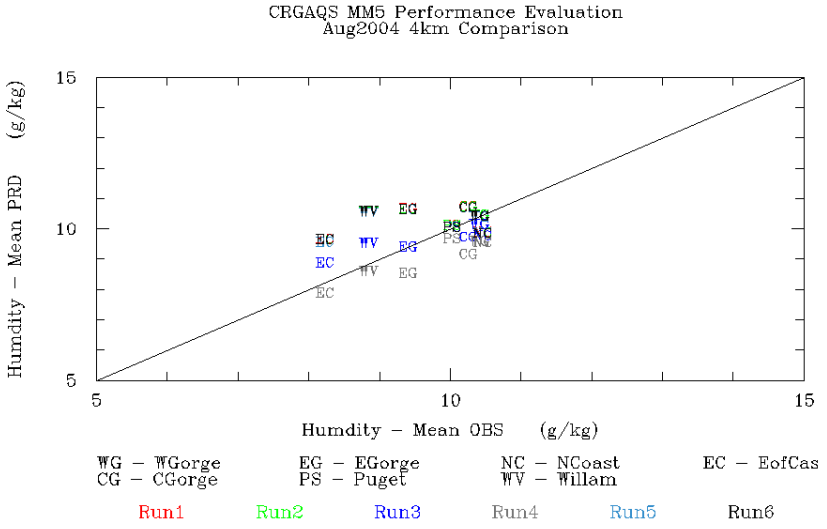


Figure 2-4(b). Episode-mean predicted absolute humidity vs. mean observed absolute humidity for each MM5 run and each analysis region.

2.2.2.2 November 2004 Performance

Figure 2-5(a) shows the error plot for wind speed and direction on the 4-km domain. Like the August episode, wind performance for all MM5 runs and analysis regions are outside the benchmarks. However, speed RMSE is better than the August episode while wind direction error is larger. This is likely caused by the light and variable winds that set up during this episode under strong stagnation conditions. Indeed, episode-mean winds are quite light (Figure 2-5[b]), remaining well below 4 m/s for all regions. MM5 cannot adequately replicate weakly-forced wind regimes in complex terrain, as the unresolved local influences provide the majority of the forcing. Hence, wind direction errors are expected to be larger under these conditions. The various MM5 configurations are not leading to significant differences in model performance.

Figure 2-5(b) shows the episode-mean predicted wind speed against mean observed wind speed. Overall, the correlation is good, but perhaps not as good as in August given the light and variable conditions. All MM5 configurations correctly capture the light wind regimes in each analysis region.

Figure 2-6(a) shows the error plot for temperature on the 4-km domain. Temperature performance indicates a broader spread among the various MM5 simulations and analysis regions. Both under and over predictions are noted, with generally high gross error. Like the August episode, the largest differences are seen among Run 3 and Run 4. Wide regional differences in performance are seen as well. The best performance is seen for the eastern, central, and western Gorge regions (most runs). The worst performance is seen as large over predictions in the Gorge regions for Run 4, and Willamette Valley and Puget Sound regions (most runs). Run 3 is particularly cool in the Willamette Valley, perhaps due to the over abundance of predicted fog.

Figure 2-6(b) shows the episode-mean predicted temperature against mean observed temperature. A wide spread among MM5 runs is seen, and a reversal of spatial tendencies is evident relative to the August episode: in this case, the coolest area is east of the Cascades, while the coastal sites are warmest. This agrees with the conceptual model for late fall temperature distributions. Overall, Run 3 indicates a cool bias relative to episode-mean observations, while the other runs tend to exhibit a warm bias.

Figure 2-7(a) shows the error plot for humidity on the 4-km domain. While there is a broad spread among the various MM5 simulations and analysis regions, all models exhibit a dry bias. While all runs and regions fall within the statistical benchmarks, it is important to note that the benchmarks were developed from meteorological modeling that supported mostly summertime ozone studies. The cooler fall and wintertime conditions lead to lower absolute humidity, and thus MM5 bias/error are lower and easily attain performance within the benchmarks. Overall, Run 3 and Run 6 appear to possess the best performance for this episode.

Figure 2-7(b) shows the episode-mean predicted humidity against mean observed humidity. The correlation is good, with little run-to-run variation. The low late-fall humidity trend is evident, especially in the eastern areas of the domain, along with the general tendency for a dry bias. The dry bias leads to an inability for MM5 to generate adequate fog during this episode (to be discussed later).

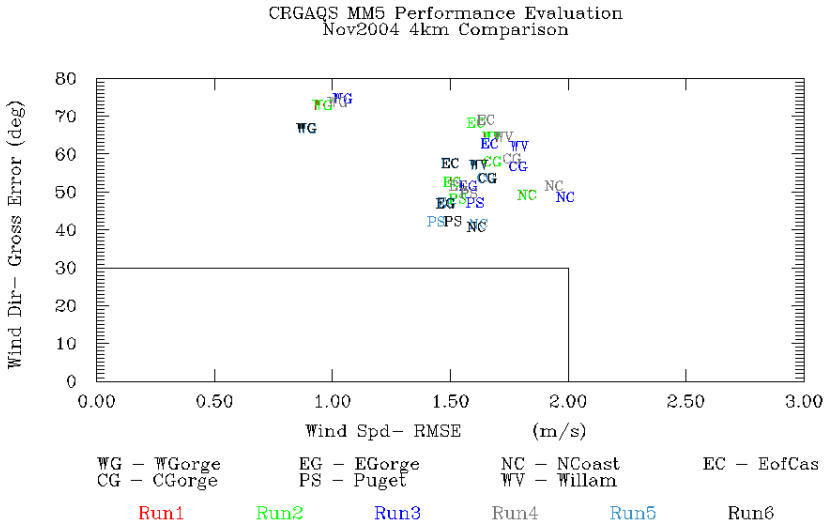


Figure 2-5(a). Error space plot for wind direction gross error vs. wind speed RMSE for the November 2004 episode. Colors represent MM5 run, initials are plotted for each analysis region. Benchmarks for each metric are shown by the box at 30° and 2 m/s.

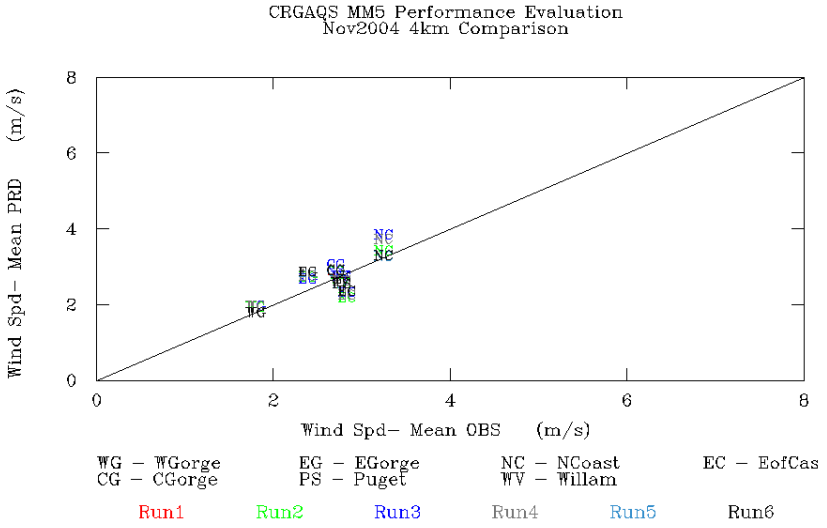


Figure 2-5(b). Episode-mean predicted wind speed vs. mean observed wind speed for each MM5 run and each analysis region.

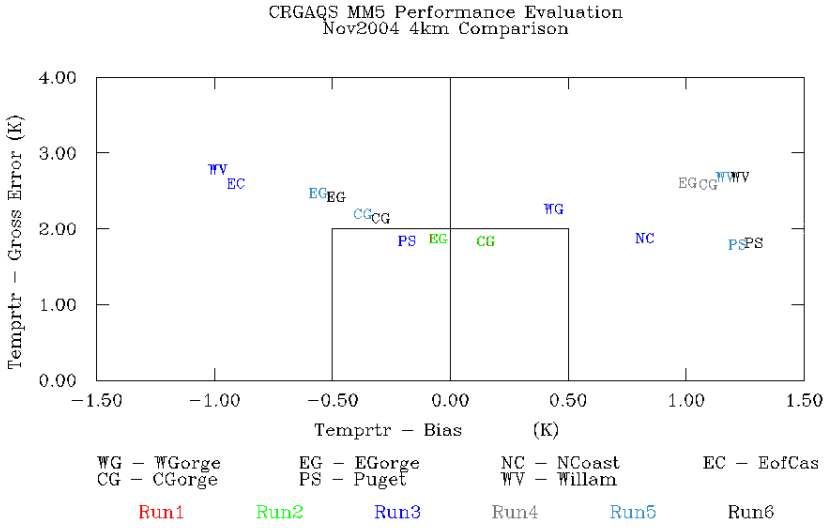


Figure 2-6(a). Error space plot for temperature gross error vs. temperature bias for the November 2004 episode. Colors represent MM5 run, initials are plotted for each analysis region. Benchmarks for each metric are shown by the box at 2 K and ±0.5 K.

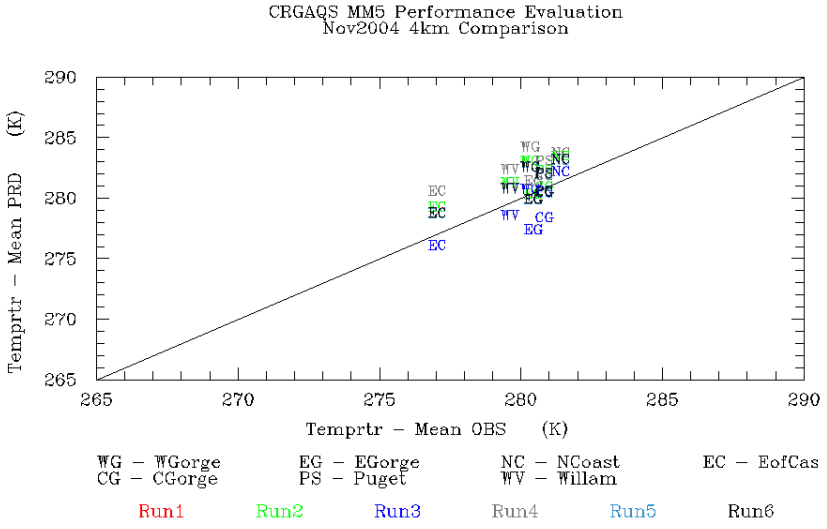


Figure 2-6(b). Episode-mean predicted temperature vs. mean observed temperature for each MM5 run and each analysis region.

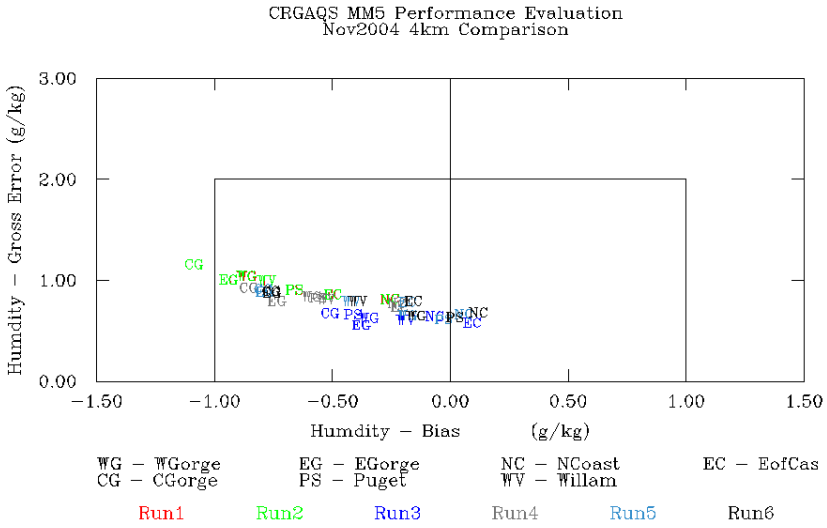


Figure 2-7(a). Error space plot for absolute humidity gross error vs. absolute humidity bias for the November 2004 episode. Colors represent MM5 run, initials are plotted for each analysis region. Benchmarks for each metric are shown by the box at 2 g/kg and ±1 g/kg.

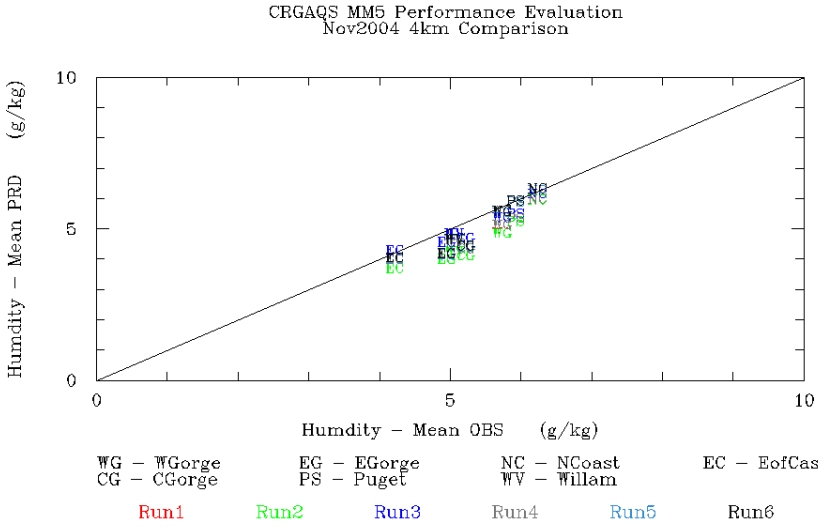


Figure 2-7(b). Episode-mean predicted absolute humidity vs. mean observed absolute humidity for each MM5 run and each analysis region.

2.2.3 Evaluation of Best Performing Runs

Based on the review of the statistical performance discussed above, and an overall synthesis of the candidate simulations, Run 6 was initially chosen as the best performing configuration for both the August and November 2004 episodes. Given that most of the MM5 runs performed similarly in many respects, much of this decision was based on the attribute that Run 6 included both analysis and observational FDDA to help control the simulation. However, when we evaluated Run 6 results in more detail, both August and November simulations on the 4-km grid exhibited some problematic temperature and humidity features. We thus undertook a comprehensive comparison between Run 6 and the best performing alternative configuration in Run 3 (the UW operational forecasting arrangement). Based upon this model inter-comparison, a recommendation was presented to the Gorge Study Technical Team as to which MM5 simulations to use for the PM/visibility modeling.

Figures 2-8 through 2-13 illustrate the Run 6 performance issues identified during the detailed evaluation. These plots display hourly time series of site-averaged Run 6 predictions vs. observations for wind, temperature, and humidity in three critical areas of the Gorge Study modeling: the west Gorge (6 sites; 5 weather service [NWS] and 1 Gorge Study site), central Gorge (6 sites; 1 NWS and 5 Gorge Study sites), and east Gorge (4 sites; 1 NWS and 3 Gorge Study sites). Note that the wind direction plots can appear highly noisy, but this is often associated with winds that cross through North (0/360°) and are thus plotted as vertical lines. Like the statistics plots, humidity is plotted in terms of absolute units (g/kg).

As seen in the wind plots (Figures 2-8 and 2-11) wind speed and direction trends are generally well captured in Run 6 for both episodes. Our concern stems from poor performance for the thermodynamic variables of temperature and humidity. During the August episode, MM5 tends to underestimate daytime and overestimate nighttime temperatures (Figure 2-9). This is a typical performance issue with MM5, which we have seen time and again in a variety of applications, but this pattern is more pronounced than usual, especially for the east Gorge sites. On the other hand, the model overestimates temperatures and the diurnal cycle during the November episode (Figure 2-12). MM5 generally overestimates humidity in August (Figure 2-10) and underestimates in November (Figure 2-13). Note the significant humidity phase difference in the west and east Gorge in mid-August. The reasons for this are not well understood, but may be associated with a numerical (solver or memory) error within MM5.

2.2.3.1 Wind Performance Comparisons

The spatial and temporal patterns of the predicted 4-km wind fields from MM5 Runs 3 and 6 were compared qualitatively to gauge which simulation performed better in simulating observed winds along the Gorge. Figures 2-14 through 2-18 provide examples of August and November 4- and 12-km wind fields along the Gorge from both MM5 runs. Both MM5 runs generally capture up-gorge flow in August, and down-gorge flow in November. Furthermore, the flows follow the gorge observations quite closely, although the Gorge monitors show more variation among nearby monitors than do the MM5 fields. There are many indications that the observations are influenced by small-scale features that MM5 cannot resolve even at 4-km resolution. Wind fields from the two MM5 runs can differ quite substantially away from the Gorge, however.

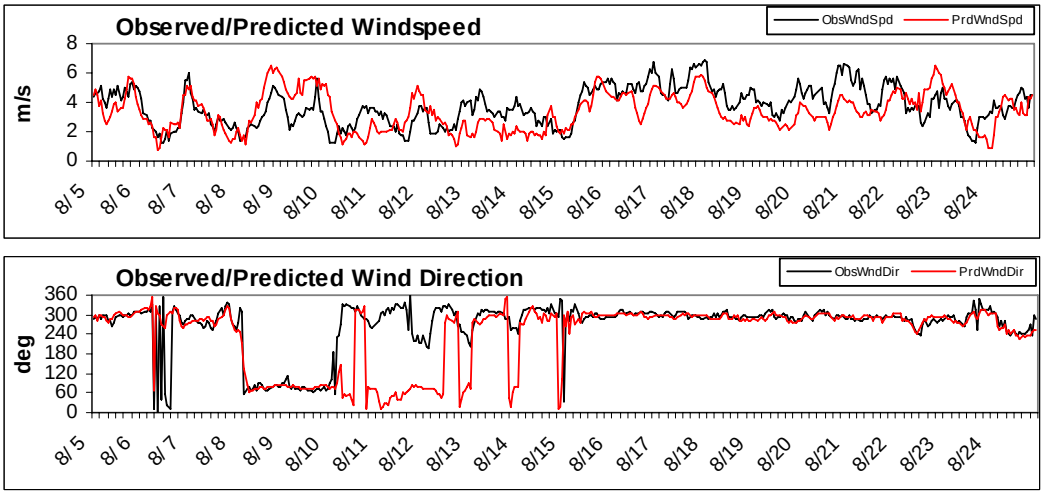


Figure 2-8(a). August MM5 Run 6 hourly site-averaged winds among west Gorge sites.

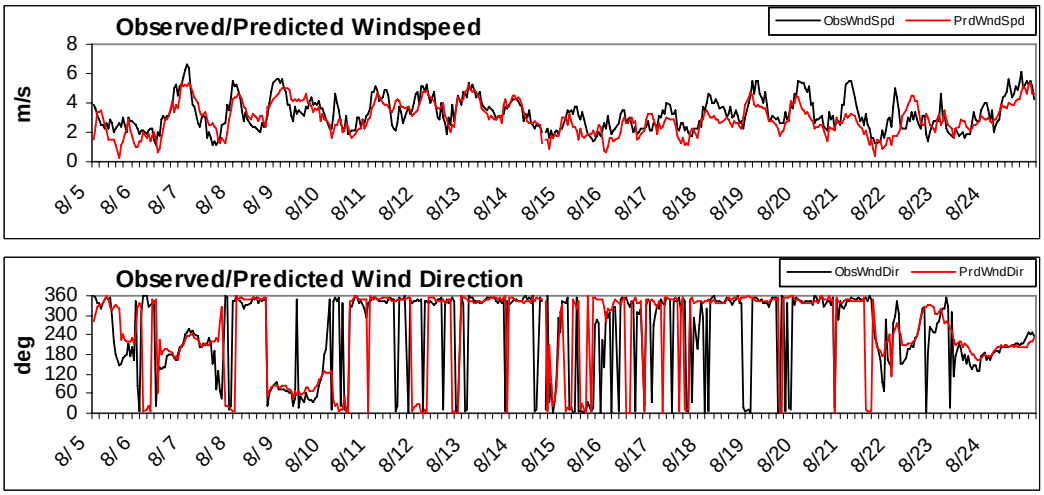


Figure 2-8(b). August MM5 Run 6 hourly site-averaged winds among central Gorge sites.

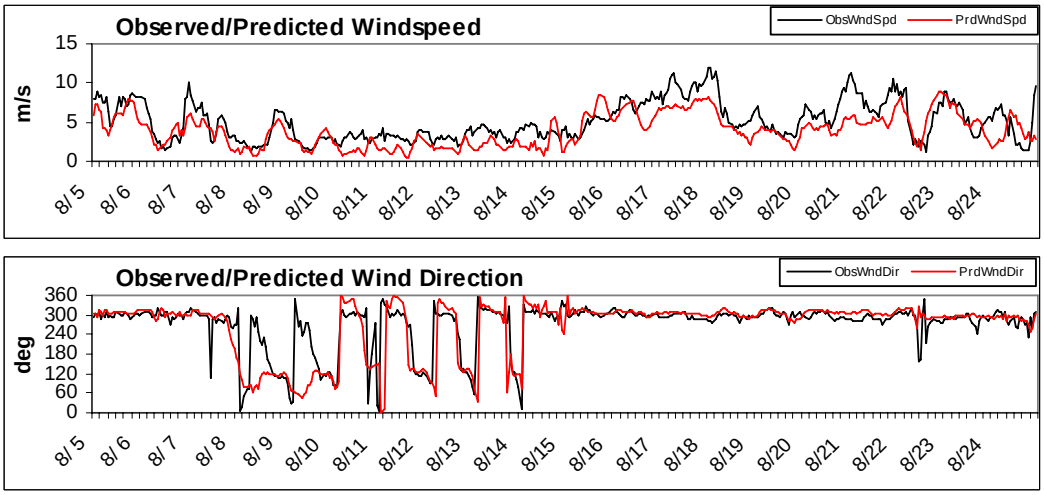


Figure 2-8(c). August MM5 Run 6 hourly site-averaged winds among east Gorge sites.

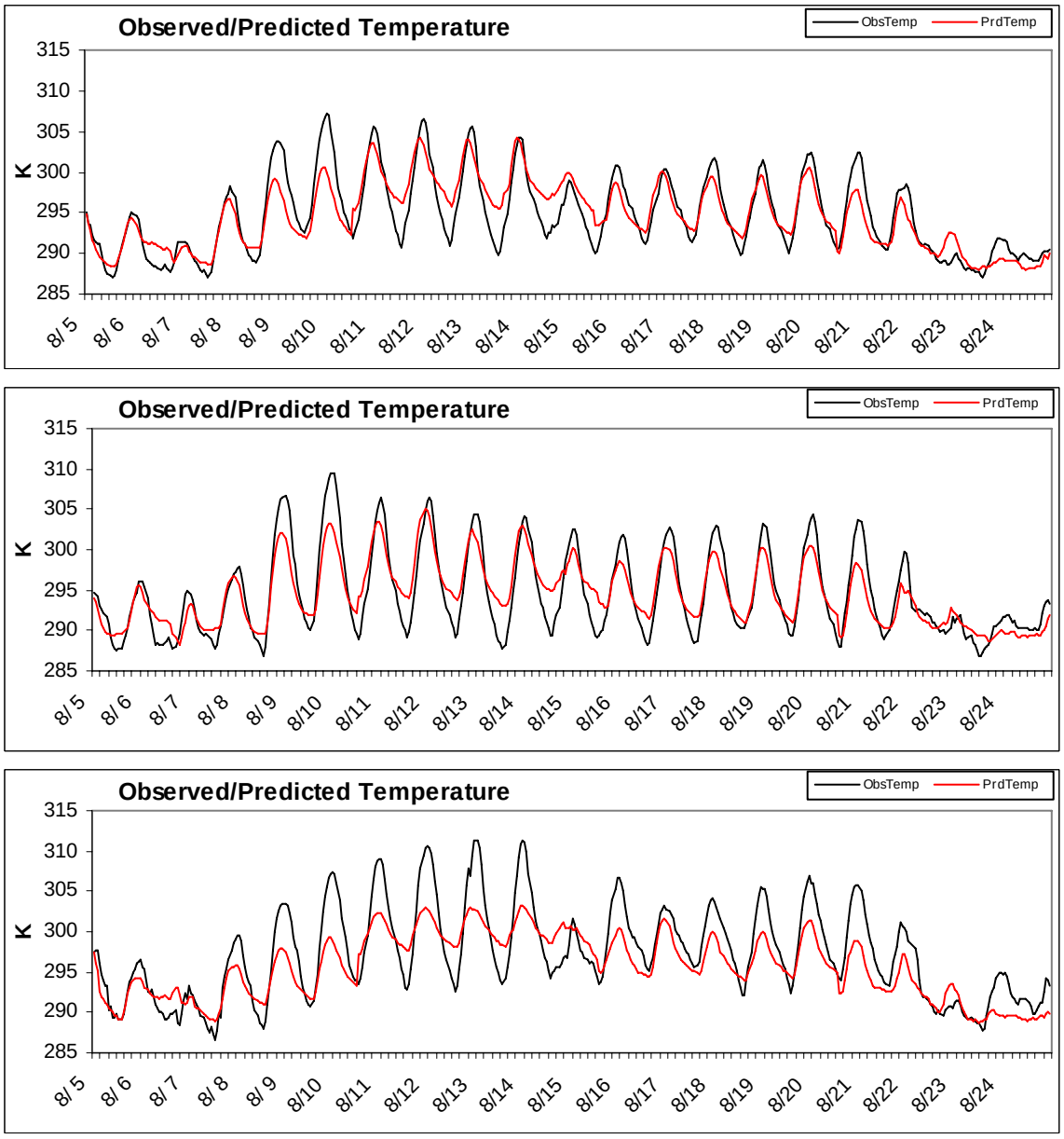


Figure 2-9. August MM5 Run 6 hourly site-averaged temperatures among west (top), central (middle), and east (bottom) Gorge sites.

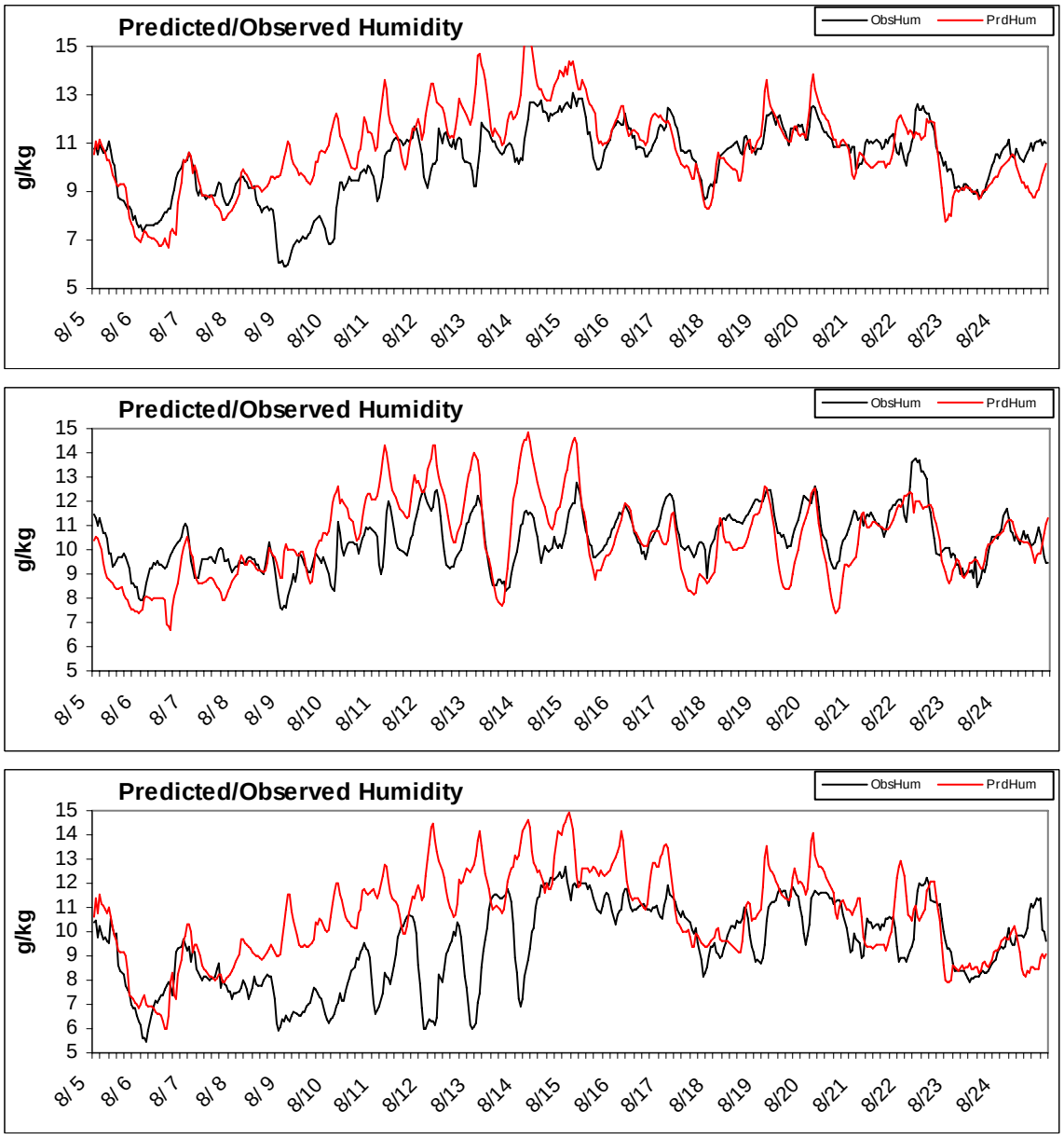


Figure 2-10. August MM5 Run 6 hourly site-averaged absolute humidity among west (top), central (middle), and east (bottom) Gorge sites.

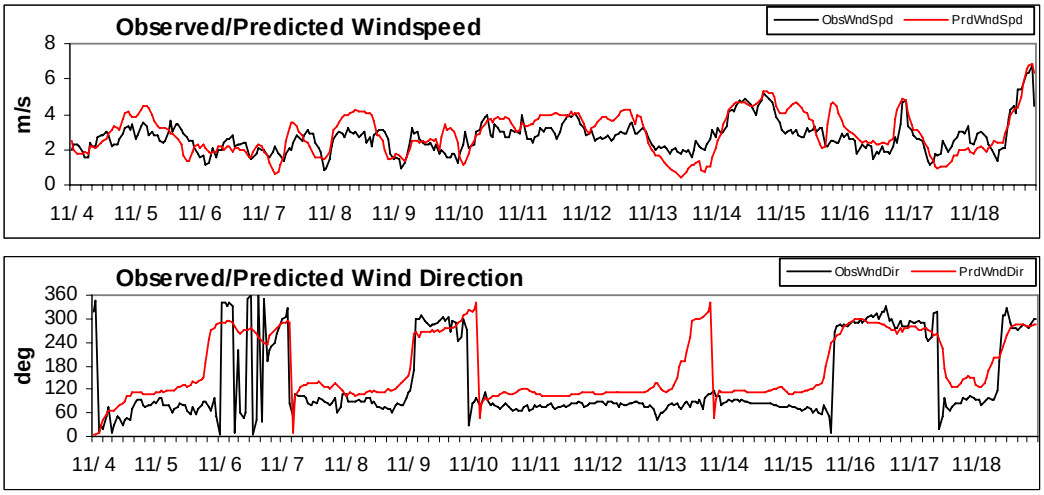


Figure 2-11(a). November MM5 Run 6 hourly site-averaged winds among west Gorge sites.

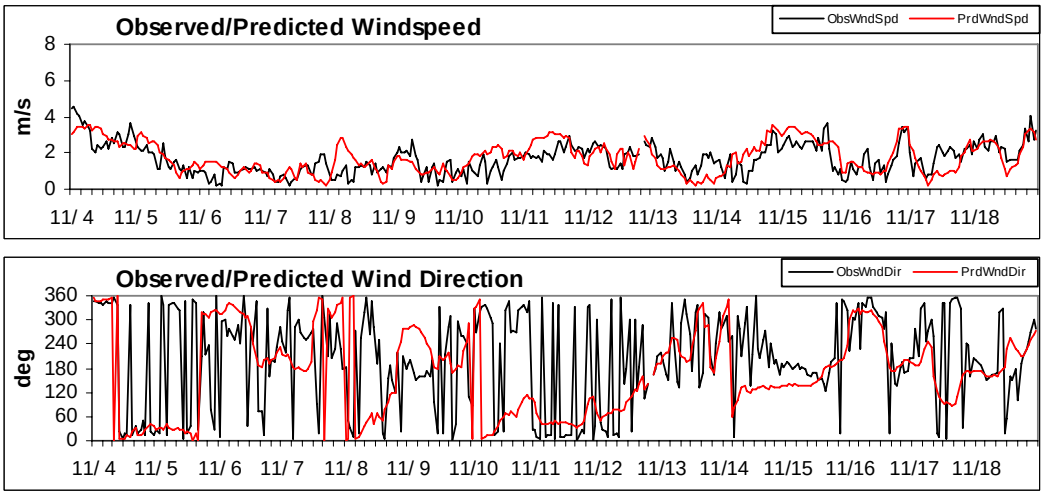


Figure 2-11(b). November MM5 Run 6 hourly site-averaged winds among central Gorge sites.

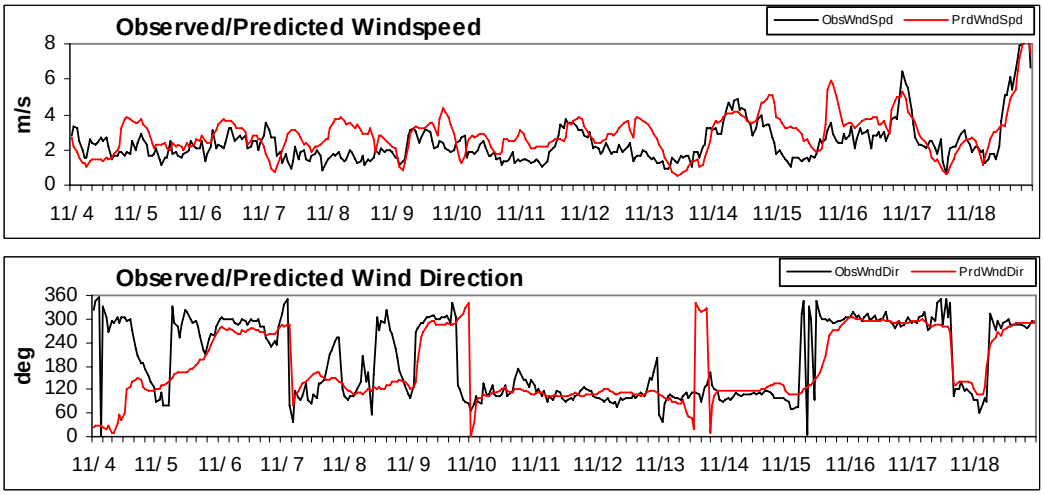


Figure 2-11(c). November MM5 Run 6 hourly site-averaged winds among east Gorge sites.

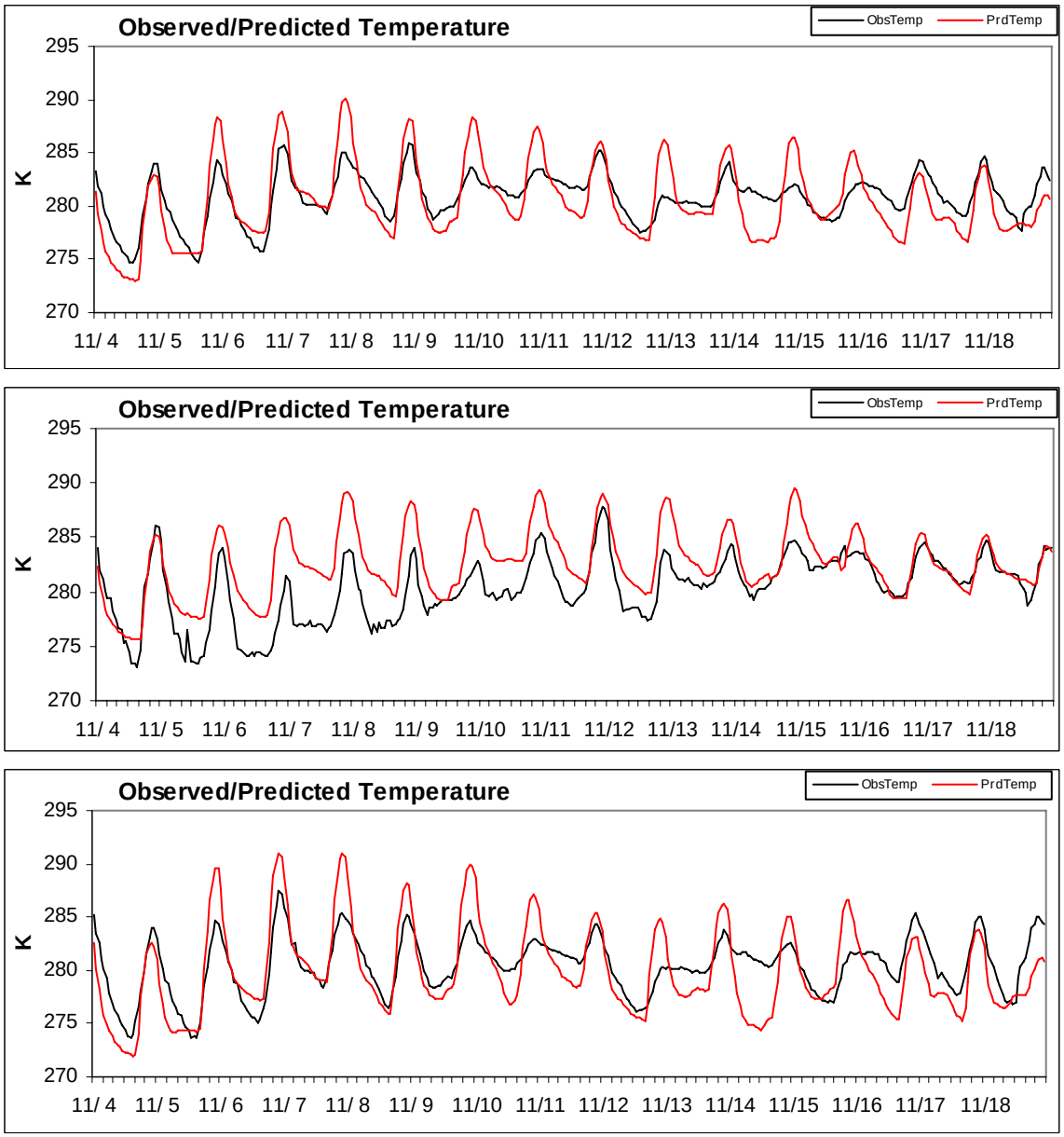


Figure 2-12. November MM5 Run 6 hourly site-averaged temperatures among west (top), central (middle), and east (bottom) Gorge sites.

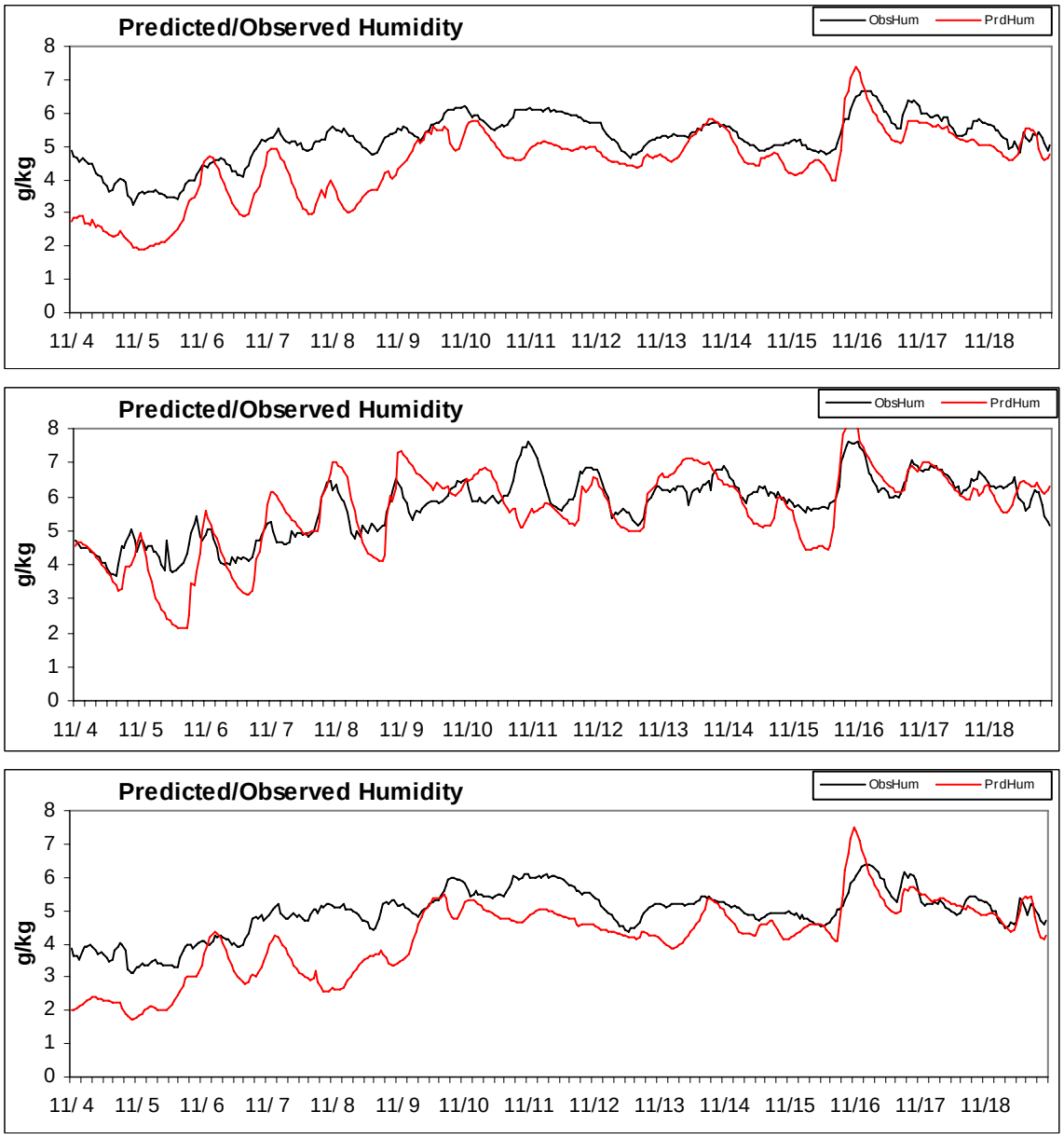


Figure 2-13. November MM5 Run 6 hourly site-averaged absolute humidity among west (top), central (middle), and east (bottom) Gorge sites.

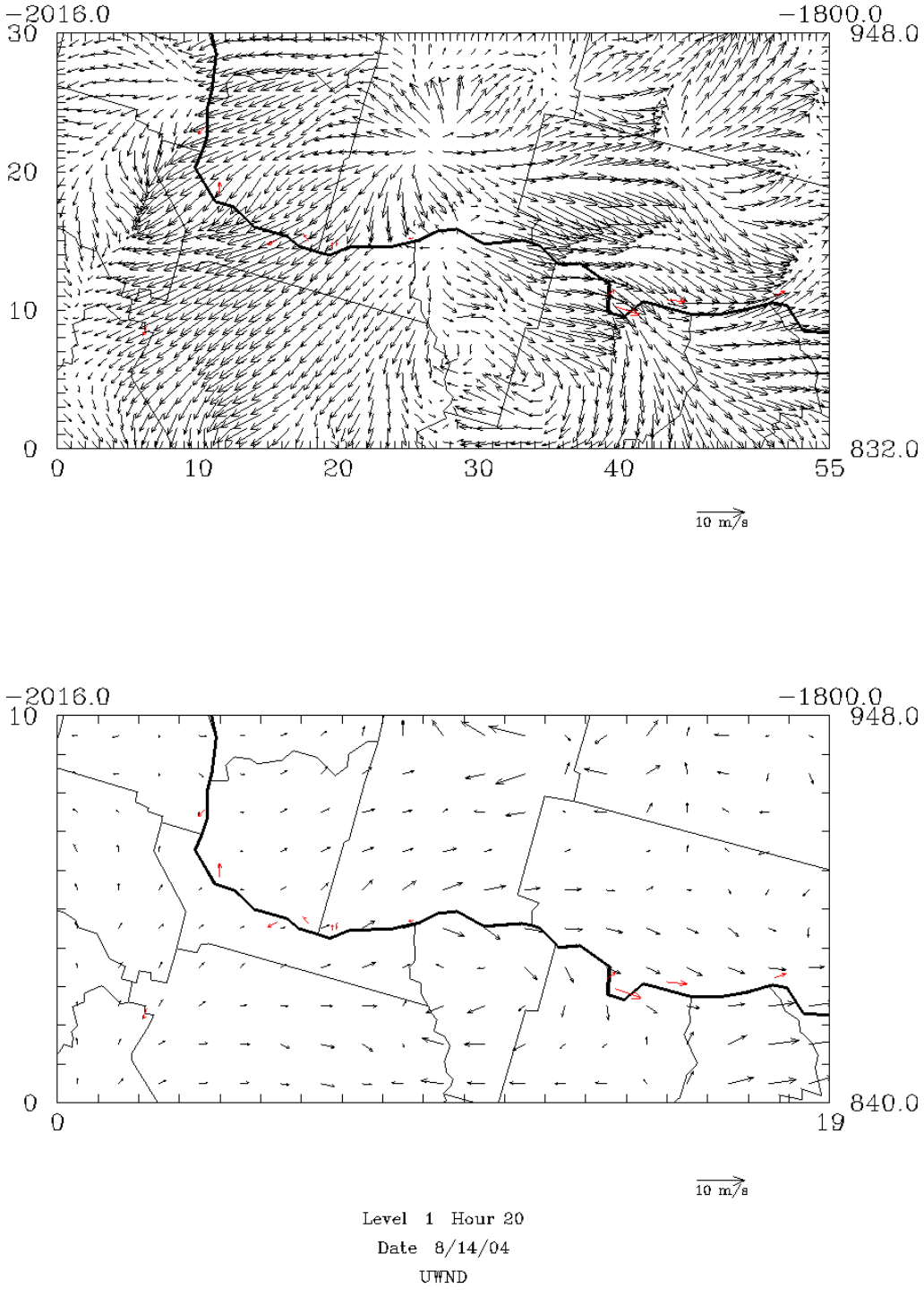


Figure 2-14. Run 3 (UW) 4-km (top) and 12-km (bottom) wind fields in the Gorge Study area on August 14, 2000 UTC. Simulated winds are shown as black vectors, and observations are shown as red vectors.

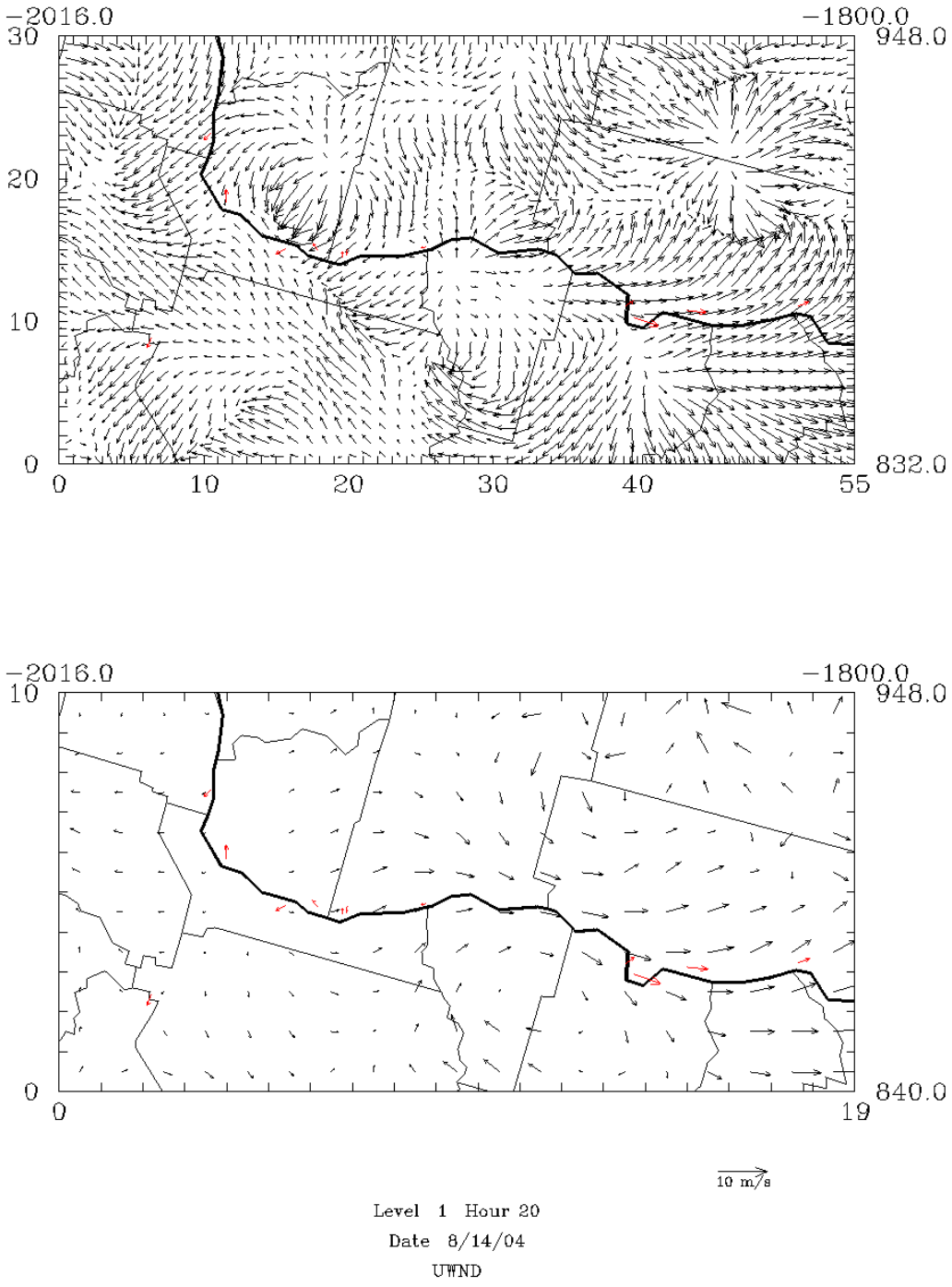


Figure 2-15. Run 6 4-km (top) and 12-km (bottom) wind fields in the Gorge Study area on August 14, 2000 UTC. Simulated winds are shown as black vectors, and observations are shown as red vectors.

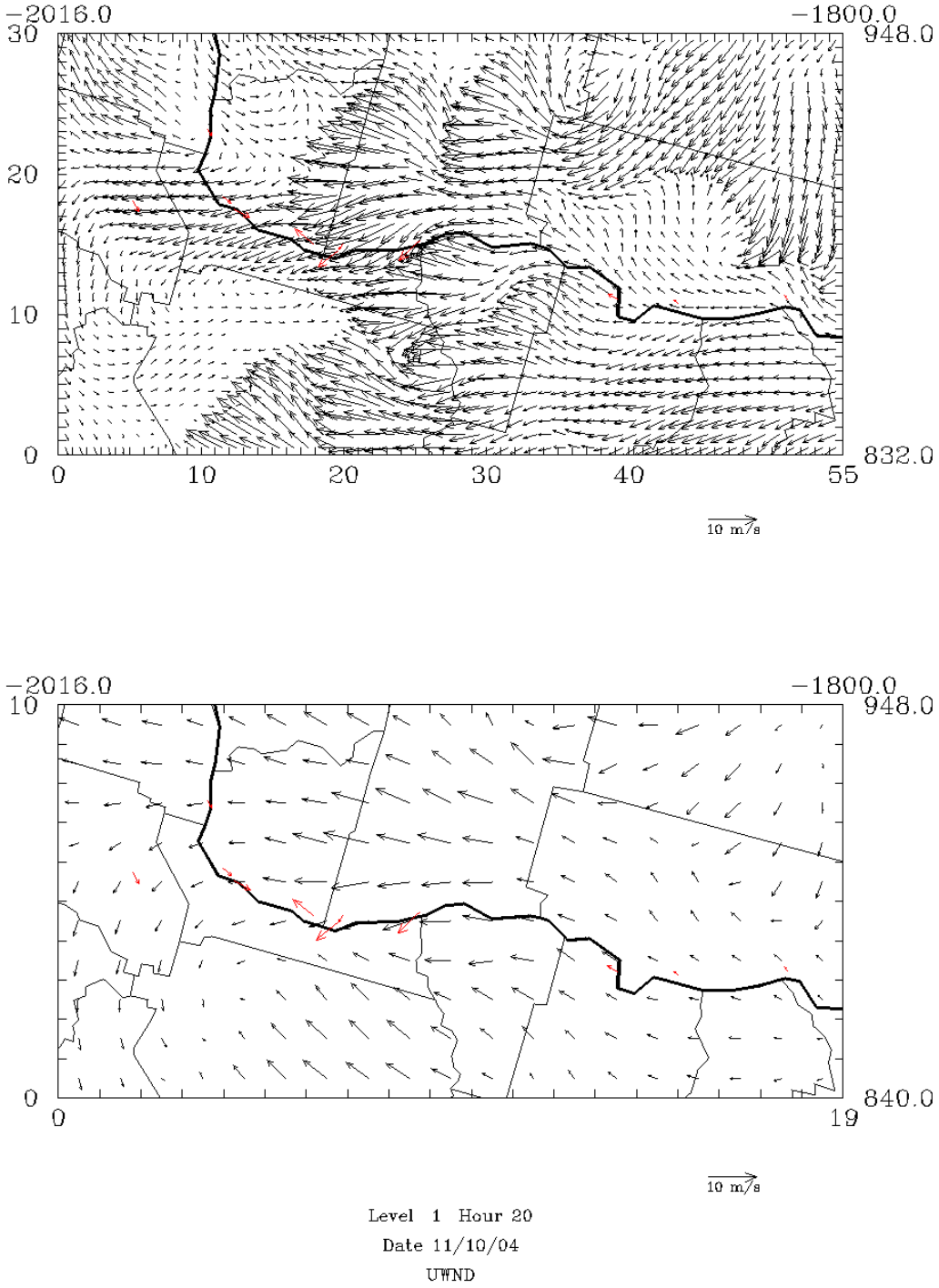


Figure 2-16. Run 3 (UW) 4-km (top) and 12-km (bottom) wind fields in the Gorge Study area on November 10, 2000 UTC. Simulated winds are shown as black vectors, and observations are shown as red vectors.

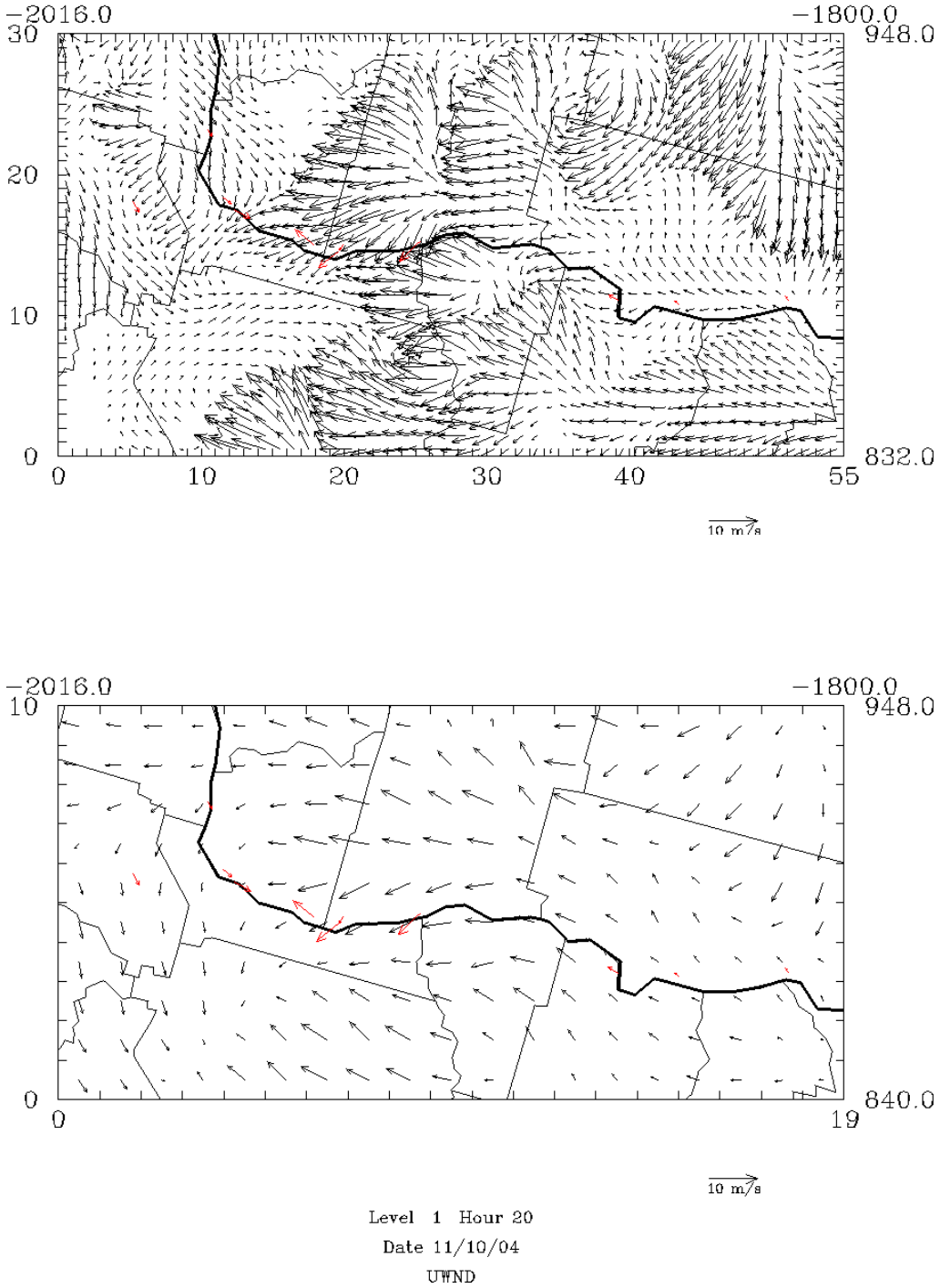


Figure 2-17. Run 6 4-km (top) and 12-km (bottom) wind fields in the Gorge Study area on November 10, 2000 UTC. Simulated winds are shown as black vectors, and observations are shown as red vectors.

Hourly time series plots of wind speed were developed for Runs 3 and 6, and compared to observations at the Wishram monitor for both episodes. Figure 2-18 shows the observed and simulated winds for the August episode. Figure 2-19 presents the same for the November episode.

During the August 2004 episode, the Gorge Study nephelometers measured high levels of aerosol light scattering over August 10-16, and 19; with an intervening windy period over August 17-18. During those periods, both MM5 runs on both 4- and 12-km grids exhibited similar performance in replicating observed winds. Performance was poor at the central sites over August 10-13, with winds in the opposite direction from observations. Generally good performance was noted for August 14-22, with a tendency for under predicted speeds on some days. The inability of the model to resolve terrain channeling may have led to lower simulated speeds and direction bias.

During the November 2004 episode, the Gorge Study nephelometers measured high levels of aerosol light scattering over November 8-13. Again, both MM5 runs on both grids performed similarly. The high scattering periods were characterized by light and variable winds. We found that Run 6 performed a bit better, perhaps because of the FDDA nudging toward wind observations along the Gorge. Overall, MM5 performed better in November than for the August episode, with very good performance over the haze event. Some stagnation during the period led to wind direction errors, and some windy periods were simulated to be too light. Overall, wind speed/direction performance appears acceptable.

2.2.3.2 Temperature and Humidity Performance Comparisons

In contrast to wind performance, Run 6 simulated 4-km temperatures in August were highly suspect. Additionally, the absolute humidity was over predicted; coupled to the temperature problems, relative humidity comparisons against observations were quite poor. Figure 2-20 shows the August temperature and relative humidity performance at the Wishram monitoring site for both Runs 3 and 6, and for 4- and 12-km output fields. The Run 6 12-km temperatures were better than their 4-km counterpart, with a much larger diurnal range that agreed better with observations. But the minimum temperatures remained too warm during haze period. The 4- and 12-km temperatures for Run 3 were also better than Run 6 at 4-km, but maximum temperatures remained too cool during haze period and cooler than Run 6 at 12-km. The higher afternoon temperatures in Run 6 at 12-km would likely lead to a better characterization of afternoon mixing in the air quality modeling.

Relative humidity performance was evaluated at Wishram because the generation of fogs (for aqueous PM chemistry) and the growth of hygroscopic aerosols (for efficient light scattering) depend critically on this parameter. As can be seen in Figure 2-20, the Run 6 4-km humidity was too wet during the daytime hours and too low at night and early morning. While both observed and simulated humidity average 40-50% over the August period, which would not lead to fogs or hygroscopic PM growth, the poor diurnal performance is indicative of an underlying physical problem on the MM5 4-km grid. The Run 6 12-km humidity performance was better because it introduced a stronger diurnal variation (via temperature) that agreed with midday observations. However, humidity was not high enough in early morning (which is related to high minimum temperatures).

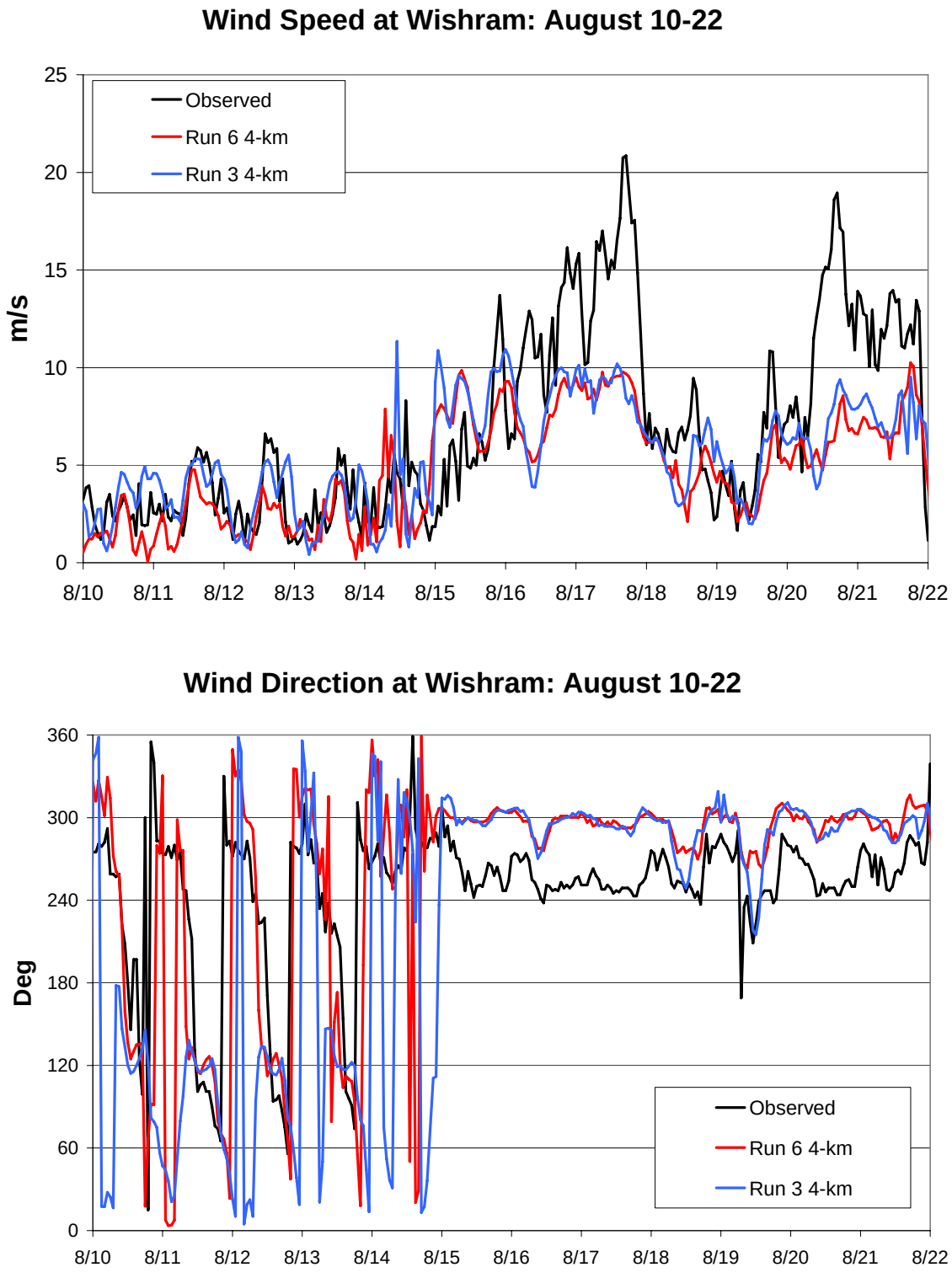
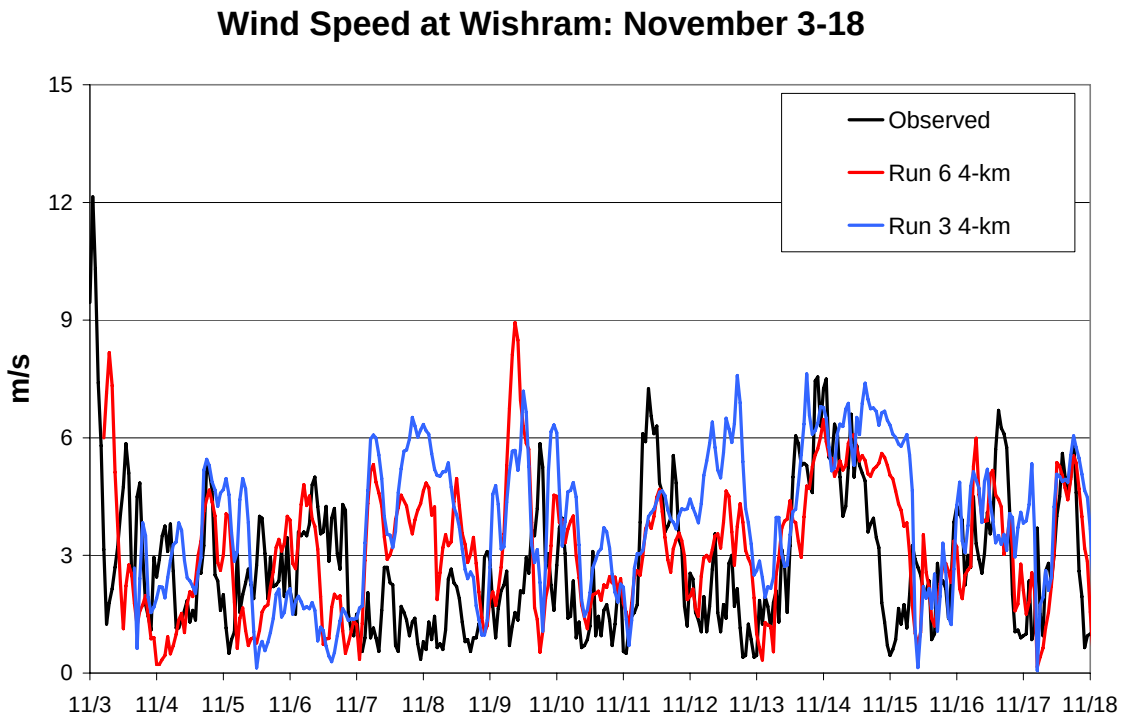


Figure 2-18. Run 3 and 6 simulated hourly wind speed (top) and direction (bottom) at the Wishram monitoring site over the August 2004 episode. Observations are shown in black.



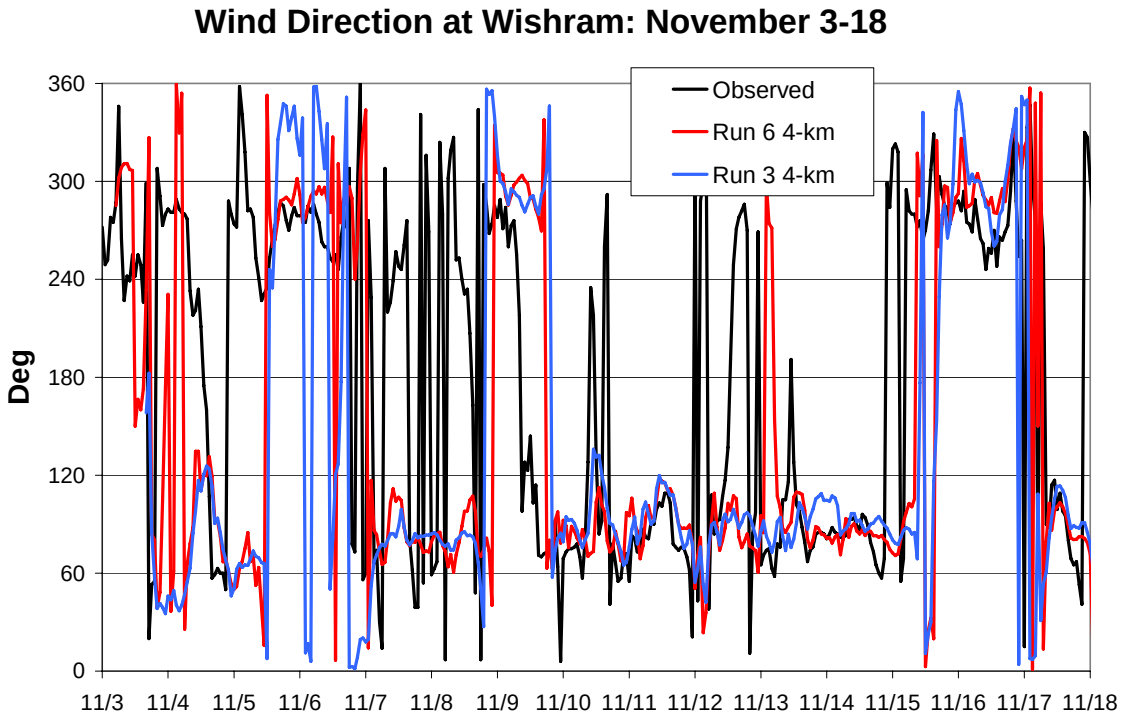


Figure 2-19. Run 3 and 6 simulated hourly wind speed (top) and direction (bottom) at the Wishram monitoring site over the November 2004 episode. Observations are shown in black.

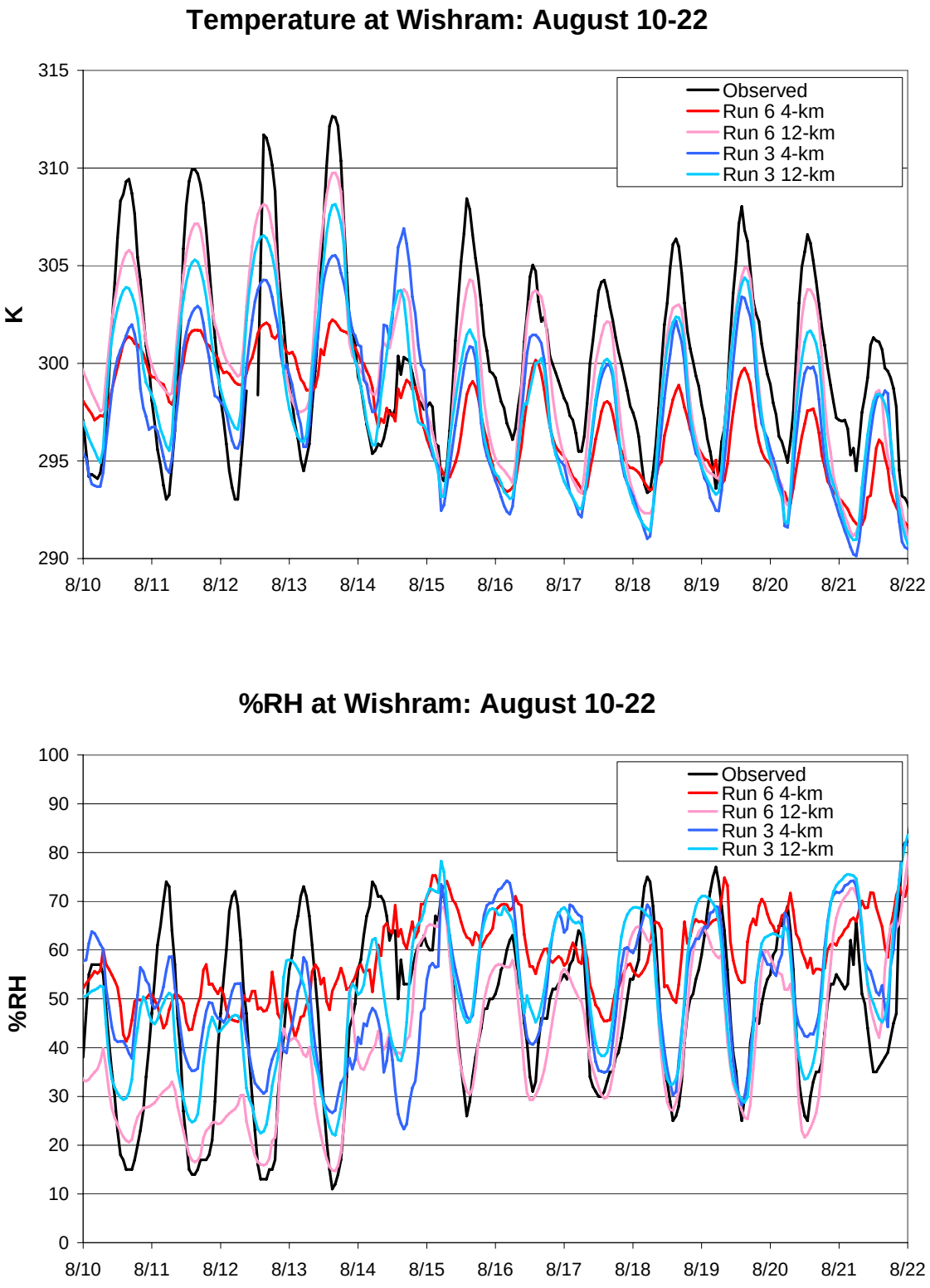


Figure 2-20. Run 3 and 6 simulated hourly temperature (top) and relative humidity (bottom) at the Wishram monitoring site over the August 2004 episode. Observations are shown in black.

The Run 3 humidity results on both the 4- and 12-km grids were also better than Run 6 at 4-km, but not high enough in early morning. Overall, Run 6 12-km temperatures and humidity performed best for the August episode.

Run 6 simulated 4-km temperatures in November did not agree well with observations, but the mechanism for poor performance during this episode was likely different than for August. The high degree of stagnation during the haze events, coupled to local- and regional fogs that developed hour-to-hour and day-to-day, likely had a major influence on observed temperature patterns and was difficult to replicate. Additionally, the under predicted absolute humidity and temperature over prediction tendency led to much drier relative humidity than observed.

Figure 2-21 shows the November temperature and relative humidity performance at the Wishram monitoring site for both Runs 3 and 6 on the 4-km grid. The Run 3 temperature performance provided a much improved alternative to Run 6. Whereas the Run 6 humidity was too low (with no possible potential for generating fog until possibly very late in the episode), Run 3 agreed better with observations during the middle and end of the episode. The period prior to the haze event on November 8-13 was much too dry in both runs. Overall, Run 3 temperatures and humidity performed best for the November episode.

2.2.3.3 Clouds Performance Comparisons

MM5 Run 3 and 6 performance in replicating cloud cover and fog within the 4-km modeling domain was qualitatively evaluated using various graphical information. First, we were able to obtain daily pictures of the Gorge from the Wishram camera (http://www.fsvisimages.com/index.html). Second, we procured free visible satellite imagery from the National Climate Data Center (http://cdo.ncdc.noaa.gov/GOESBrowser/goesbrowser). Modeled cloud fields were extracted from MM5 using the MM5CAMx preprocessor, which determines column-integrated cloud optical depth. These optical depth fields were plotted for two layers to resolve low and total cloud cover: (1) from the surface to ~1000 m (~3,000 ft) AGL; and (2) from the surface to the top of the model at ~14 km. All graphics were compared on a day-to-day basis.

The Forest Service website that provides the Wishram photographs also provides daily notes on visibility conditions. These are listed below for the August episode, with dates noted in bold as the high aerosol scattering days (notes in parentheses were added by the authors to further characterize the conditions in the photographs):

8/10 Scattered clouds < half of sky, No layered haze
8/11 No clouds, No layered haze
8/12 Scattered clouds < half of sky, No layered haze
8/13 No clouds, No layered haze
8/14 (*high*) Overcast > half of sky, No layered haze
8/15 Scattered clouds < half of sky, No layered haze
8/16 (*high thin*) Overcast > half of sky, No layered haze
8/17 (*high thin*) Overcast > half of sky, No layered haze
8/18 (*high thin*) Overcast > half of sky, No layered haze
8/19 Scattered clouds < half of sky, No layered haze

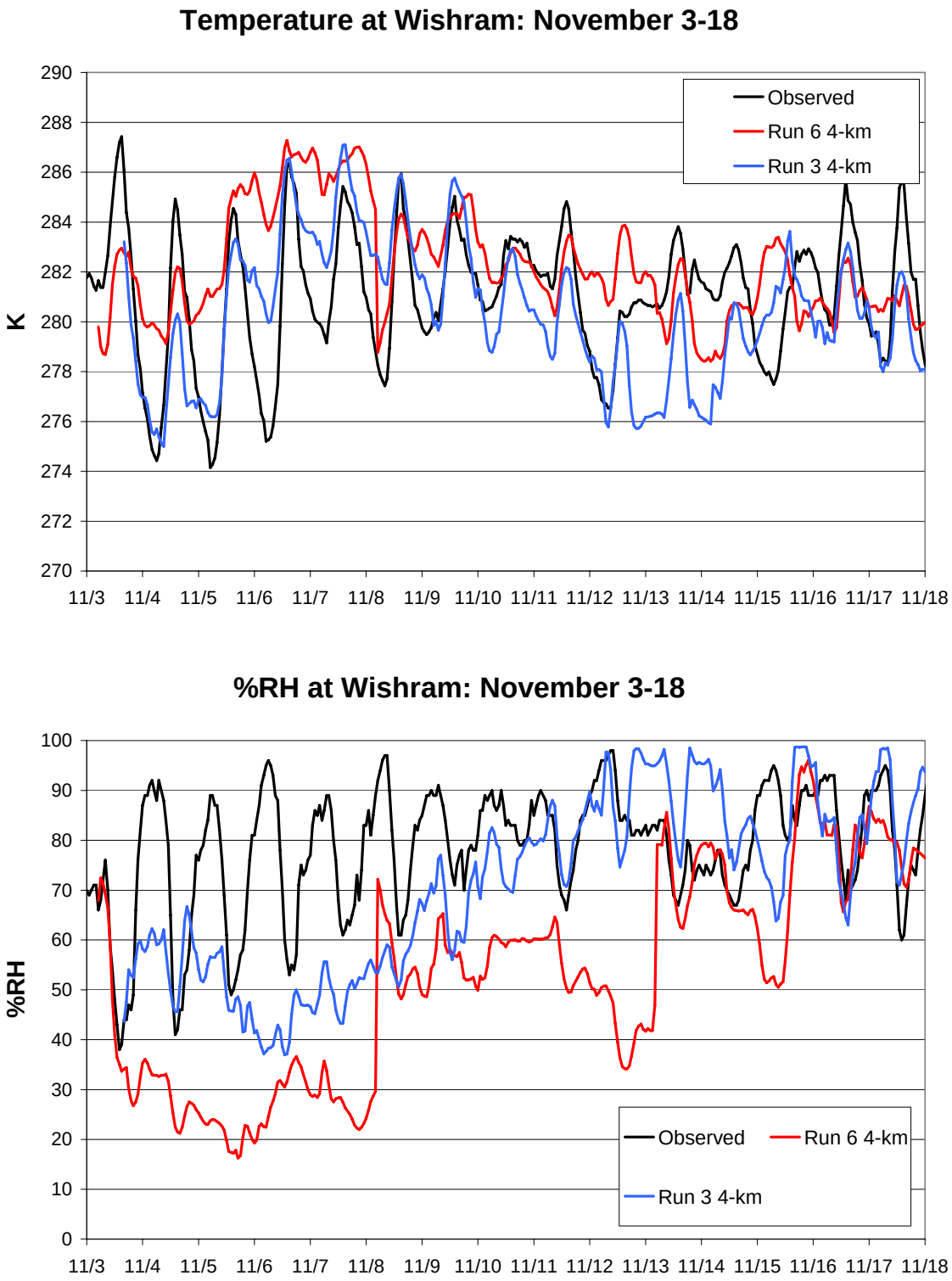


Figure 2-21. Run 3 and 6 simulated hourly temperature (top) and relative humidity (bottom) at the Wishram monitoring site over the November 2004 episode. Observations are shown in black.

8/20 (*high thin*) Overcast > half of sky, No layered haze
8/21 (*high*) Overcast > half of sky, No layered haze
8/22 Overcast > half of sky, No layered haze

An example of the types of plots generated for the August analysis is shown in Figures 2-22 through 2-24. Conditions were fairly dry during this period, with only some afternoon cumulus appearing in some areas during the afternoon of many days. Performance was deemed to be adequate for both MM5 runs. MM5 cannot replicate high thin and wispy cirrus clouds, and it usually underperforms for scattered small-scale afternoon cumulus (as it did in this case). However, these types of clouds should not play significant role in regional PM chemistry. Therefore, the choice of which MM5 run to use for air quality modeling was not particularly important from a cloud performance standpoint.

The daily notes on visibility conditions for the November episode are listed below:

11/3 Scattered clouds < half of sky, No layered haze
11/4 No clouds, Ground-based layered haze only
11/5 (*high thin*) Overcast > half of sky, No layered haze (*hazy*)
11/6 Scattered clouds < half of sky, Ground-based layered haze only
11/7 Overcast > half of sky, No layered haze (*hazy*)
11/8 Overcast > half of sky, Weather concealing scene (*thick haze*)
11/9 Overcast > half of sky, Weather concealing scene (*thick haze*)
11/10 Overcast > half of sky, Weather concealing scene (*fog*)
11/11 Overcast > half of sky, Weather concealing scene (*thick haze*)
11/12 Overcast > half of sky, Weather concealing scene (*fog*)
11/13 Overcast > half of sky, Weather concealing scene (*thick haze*)
11/14 Overcast > half of sky, Weather concealing scene (*distant fog*)
11/15 Overcast > half of sky, Weather concealing scene
11/16 Overcast > half of sky, No layered haze
11/17 Scattered clouds < half of sky, No layered haze
11/18 Overcast > half of sky, No layered haze

An example of the types of plots generated for the November analysis is shown in Figures 2-25 through 2-29. The period was characterized by passing storm systems with wide cloud cover, interspersed with stagnant periods during which large areas of Washington and Oregon were covered in persistent fog. The large-scale higher clouds appear to have been well simulated; Run 6 generated more large-scale (higher) cloudiness than Run 3. However, the low-level cloud/fog events were not well simulated in either run. Run 3 did generate more low-level (foggy) clouds in general, especially on the high scattering days. This characteristic will impact aqueous PM chemistry, and thus Run 3 was deemed to be a better simulation for clouds.

2.2.4 Summary

Significant effort was put into determining the best performing options in MM5. None of the MM5 configurations met all of the commonly accepted benchmarks for statistical performance, meaning that MM5 did not perform as well as it has historically performed in other air quality

Figure 2-22. Wishram camera image of the Gorge at Noon on August 14, 2004 (left), and during pristine conditions (right).

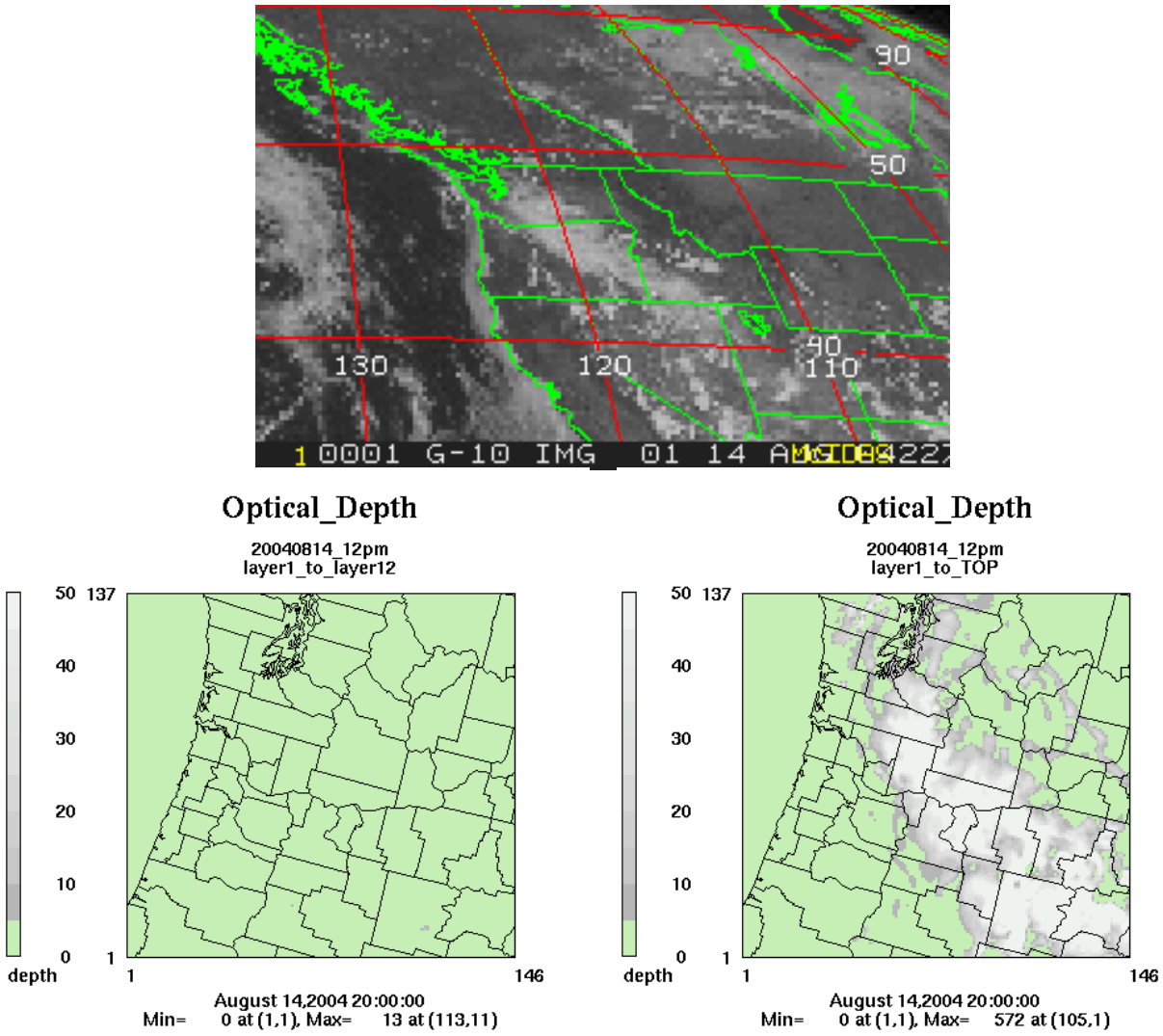


Figure 2-23. Visible satellite image (top), and low-level (left) and total (right) MM5 simulated cloud cover in Run 6 on August 14, 2004.

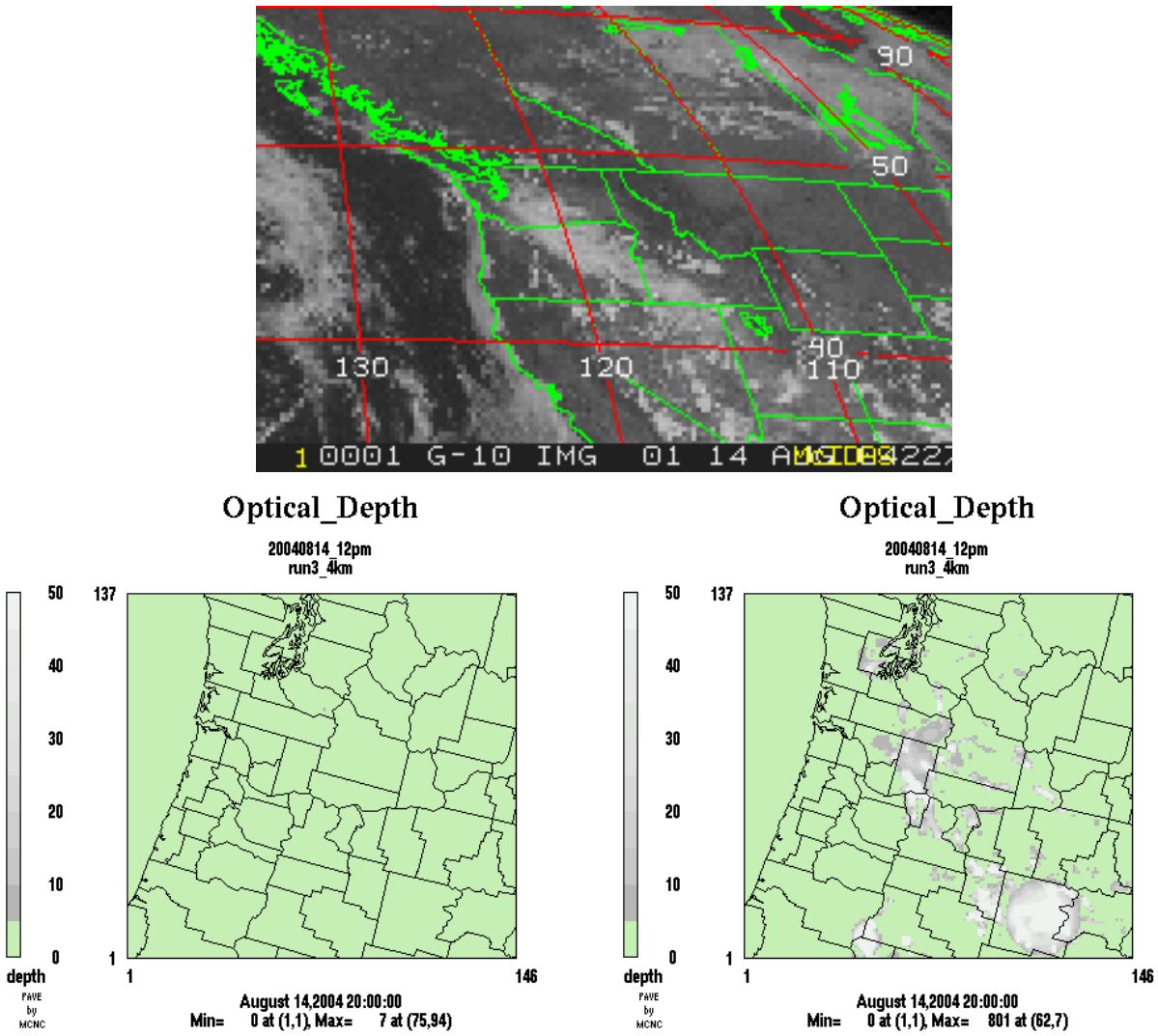


Figure 2-24. Visible satellite image (top), and low-level (left) and total (right) MM5 simulated cloud cover in Run 3 on August 14, 2004.

Figure 2-25. Wishram camera image of the Gorge at Noon on November 10, 2004 (left), and during pristine conditions (right).

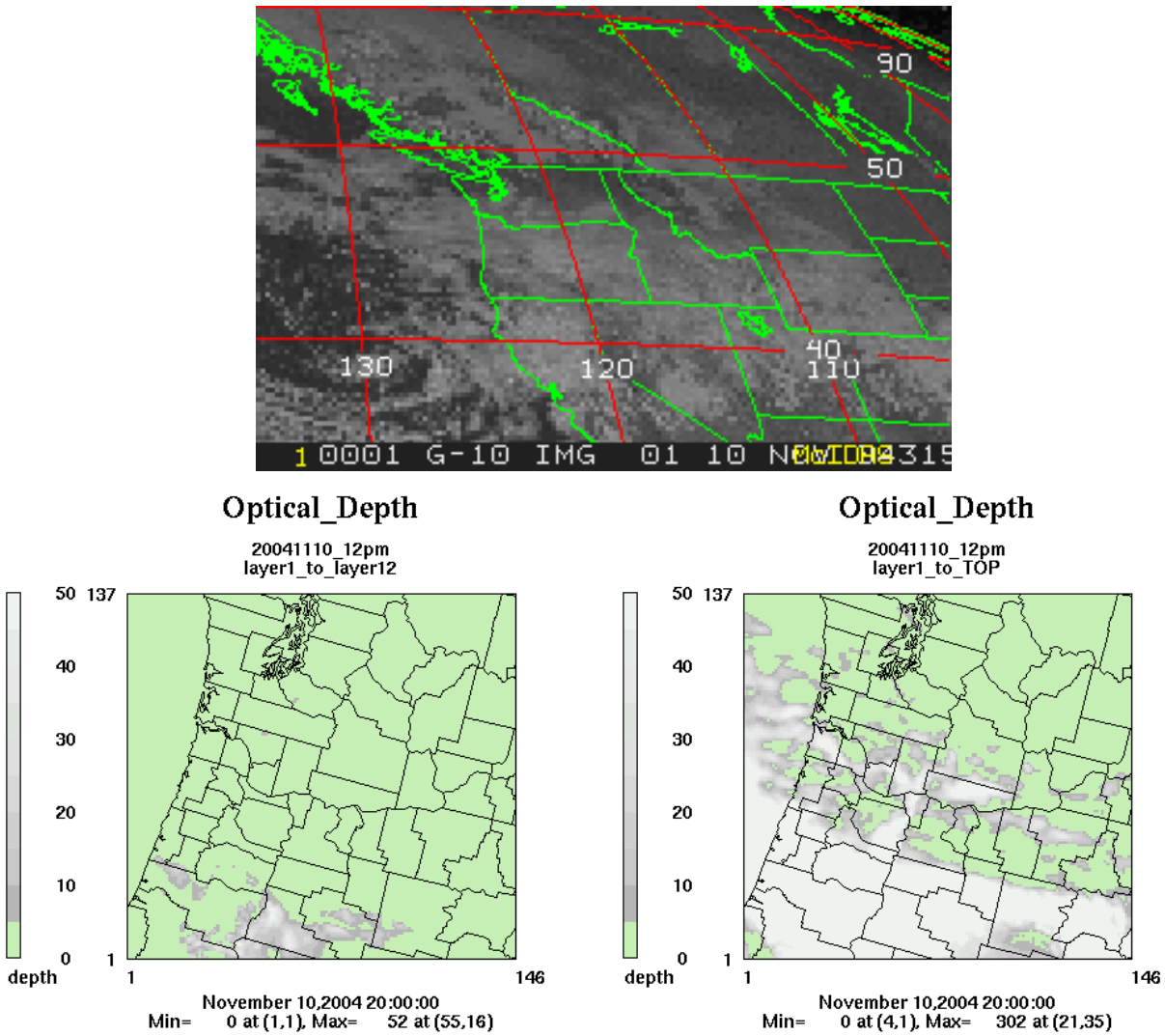
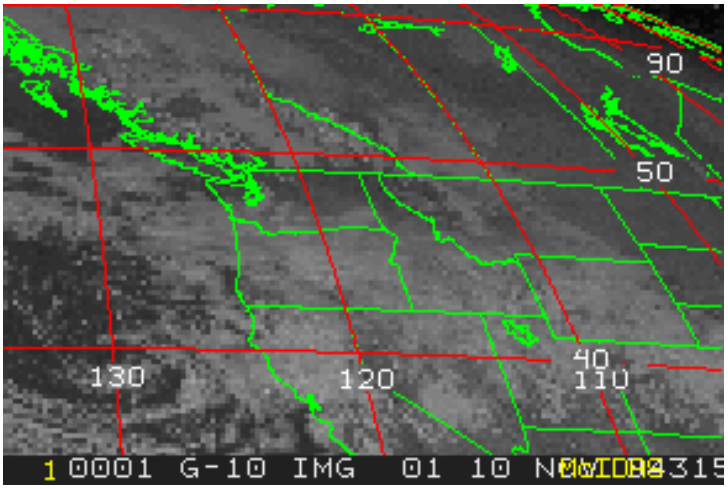


Figure 2-26. Visible satellite image (top), and low-level (left) and total (right) MM5 simulated cloud cover in Run 6 on November 10, 2004.



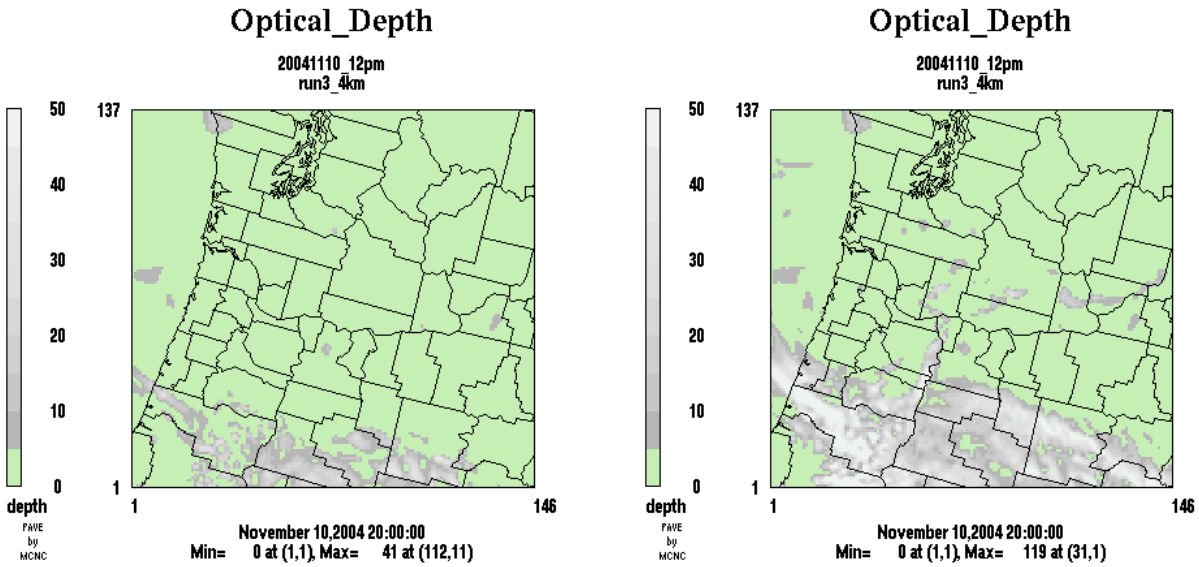


Figure 2-27. Visible satellite image (top), and low-level (left) and total (right) MM5 simulated cloud cover in Run 3 on November 10, 2004.

Figure 2-28. Wishram camera image of the Gorge at Noon on November 13, 2004 (left), and during pristine conditions (right).

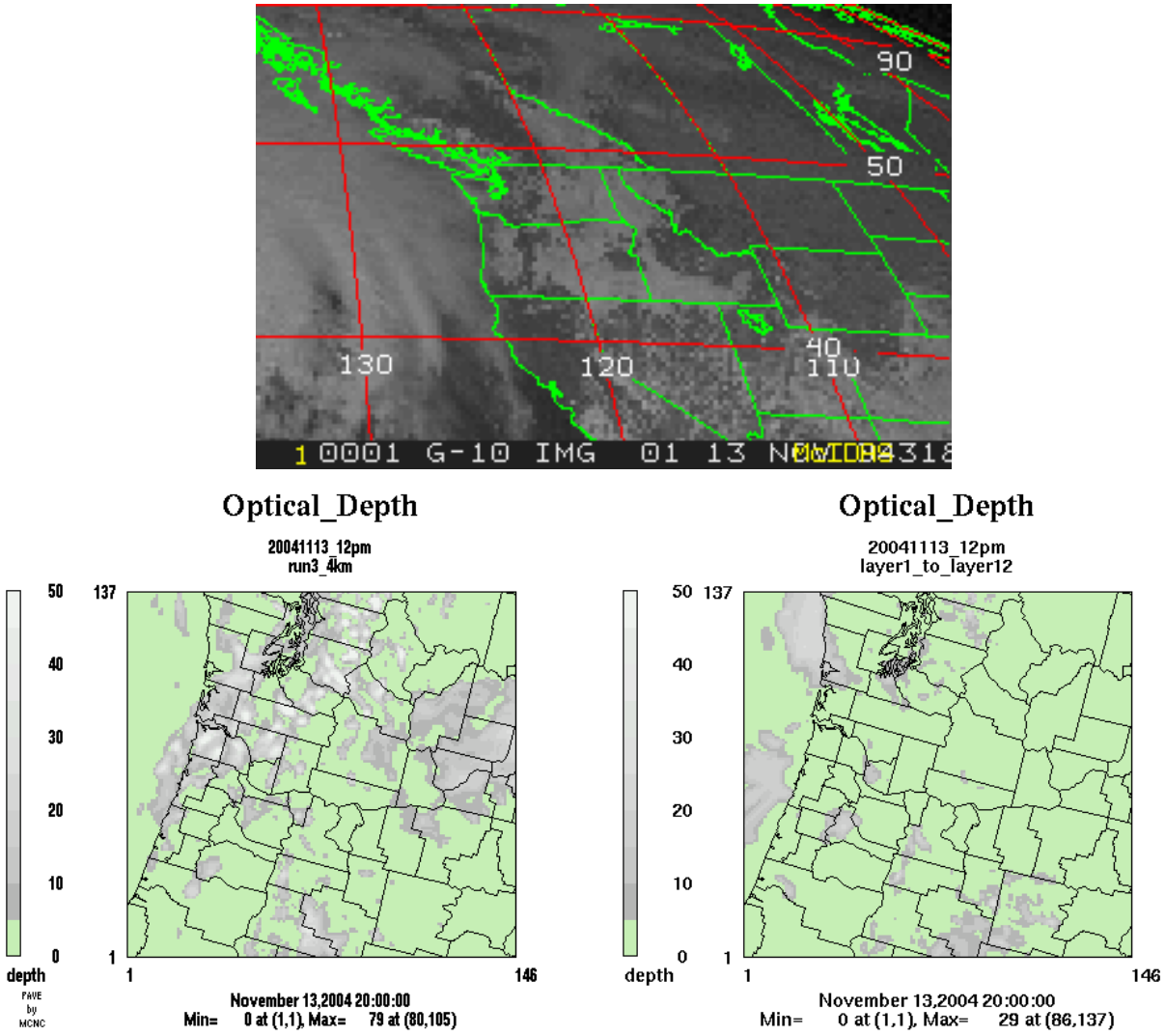


Figure 2-29. Visible satellite image (top), and Run 3 low-level (left) and Run 6 low-level (right) MM5 simulated cloud cover on November 13, 2004.

applications around the country[1]. It is important to note that these benchmarks were established according to a wealth of meteorological modeling applications for mostly urban and regional summertime ozone modeling. The Gorge Study area contains more complex terrain than most other areas modeled to date for air quality applications, and thus the monitors are more likely to be influenced by local and small-scale forcings. Both Gorge Study modeling episodes exhibited rather weak synoptic forcing, but MM5 traditionally performs better under stronger forced conditions, such as storm systems. Another point to consider is that the Gorge Study region includes fewer sites than were used to develop the benchmarks; statistics based on fewer pairings tend to yield poorer statistics. Nevertheless, MM5 performed well in capturing the August up-gorge flow patterns and the November down-gorge flow patterns, to the extent that such flows were characterized by sites along the Gorge itself.

For the August episode, wind speed and direction were fairly well simulated by MM5 Run 3 and 6 over the 4-km domain and specifically along the Gorge. However, Run 6 4-km temperature patterns were highly suspect. Temperature performance was much better in the Run 6 12-km results, with improved diurnal cycles and better daily maximum temperatures, but the minimum temperatures were too warm during the haze period. Run 6 would be expected to give a better characterization of afternoon mixing. Run 3 performed well on both the 4- and 12-km grids, but was too cool during the haze period. Run 6 over predicted humidity on the 4-km grid, but like temperature, performed better on the 12-km grid. Relative humidity was not high enough in the early morning hours (related to the high minimum temperatures). Run 3 humidity performed better on both the 4- and 12-km grids, but again was not high enough in early morning hours. Overall, MM5 Run 6 12-km meteorological fields appeared to provide the best characterization of August 2004 meteorology among all 6 runs considered, and was chosen for the August air quality simulations.

For the November episode, wind speed and direction performance was acceptable for both MM5 Runs 3 and 6. Run 6 appeared to perform a bit better than Run 3 for winds, perhaps because of the observational nudging. Run 6 4-km temperature performance was rather poor, but Run 3 was much better. Run 6 did not perform well for either absolute or relative humidity, showing a very large under prediction bias during the hazy period; no fog was simulated during this period. Run 3 improved humidity performance somewhat, and tended to generate more low clouds and fog, consistent with observations. Overall, MM5 Run 3 4-km meteorological fields appeared to provide the best characterization of November 2004 meteorology among all 6 runs considered, and was chosen for the November air quality simulations.

[1] Note that MM5 modeling undertaken by WRAP for the year 2002 also did not meet all of the performance benchmarks in the Pacific Northwest region; specifically MM5 suffered from under prediction tendencies for temperature, and over prediction tendencies for humidity and rainfall. In our experience, as well as the experience of many other air quality modelers throughout the country, this is a common trait of MM5 that is very difficult to resolve.

3.0 EMISSIONS PROCESSING

3.1 EMISSIONS DATA

The emission inventory is a key component of an air quality modeling exercise. Spatially and temporally resolved estimates of sulfur dioxide (SO_2), volatile organic compounds (VOC), nitrogen oxides (NOx), carbon monoxide (CO), ammonia (NH_3), PM and other chemicals from sources such as electric generating utilities (EGUs), pulping mills, automobiles, commercial marine shipping activities, railroad locomotives, and even natural vegetation (biogenic), to name a few sources, are critical inputs to an air quality model.

The most current year for the National Emissions Inventory (NEI) is 2002. The SWCAA and ODEQ provided local 2004 annual stationary, area, and non-road mobile source emissions estimates (projected from the 2002 NEI) for several counties in Washington and Oregon, respectively (SWCAA, 2006; Kreitzer, 2006a, b, d; Mairose, 2006a-c; Stocum, 2006a-c). SWCAA and ODEQ also provided wildfire and prescribed fire data that were used to estimate emissions (Kreitzer, 2006c; Swab, 2006). Finally, SWCAA and ODEQ provided day-specific emissions estimates for the Portland General Electric (PGE) Boardman power plant (Mairose, 2006b) and the Georgia Pacific Camas Mill wood pulping facility (Mairose, 2006c). Figure 3-1 displays the counties for which local data were provided by the two agencies. For all other counties within the modeling domain, we used the SMOKE (CEP, 2004) setup developed for the WRAP study as a starting point, which included projecting the 2002 WRAP county-level annual stationary and non-road emissions to 2004 (WRAP, 2004). Additionally, all temporal and speciation allocation profiles and cross-reference data were taken from the WRAP emission processing efforts.

Spatial allocation of the emissions to the 4- and 12-km modeling grids was based on profiles and surrogate factors developed specifically for this project. Spatial surrogates were developed from population and landuse/landcover distributions provided by EPA (and as used in the WRAP modeling) (EPA, 2006a). National/continental surrogate fields have been prepared by EPA on a 4-km and a 12-km Lambert Conformal projection grid covering the entire North American continent. These data were processed to each of the Gorge Study modeling grids for emissions processing. Special attention was given to the development of high resolution surrogate distributions in the OR/WA region, and within the Gorge itself, especially as they related to commercial marine shipping.

MM5 temperature and wind fields were used to generate day- and grid-specific biogenic, wind-blown dust, and agricultural ammonia emissions for the Gorge modeling episodes. The EPA BELD3 national landuse/landcover dataset (EPA, 2001; Kinnee, 1997) was used in the BEIS3 module of SMOKE to define the vegetative cover types over the grids. The EPA national landuse/landcover dataset used to develop spatial surrogates was also used in the estimation of agricultural ammonia emissions. The processing of on-road mobile sources required the use of OR/WA-specific and/or WRAP activity data (roadway locations, vehicle miles traveled [VMT], speed distributions, vehicle fleet mix, etc.).

Volcanic emissions from Mt. St. Helens were estimated for SO_2. A Mt. St. Helens eruption chronology is posted at:

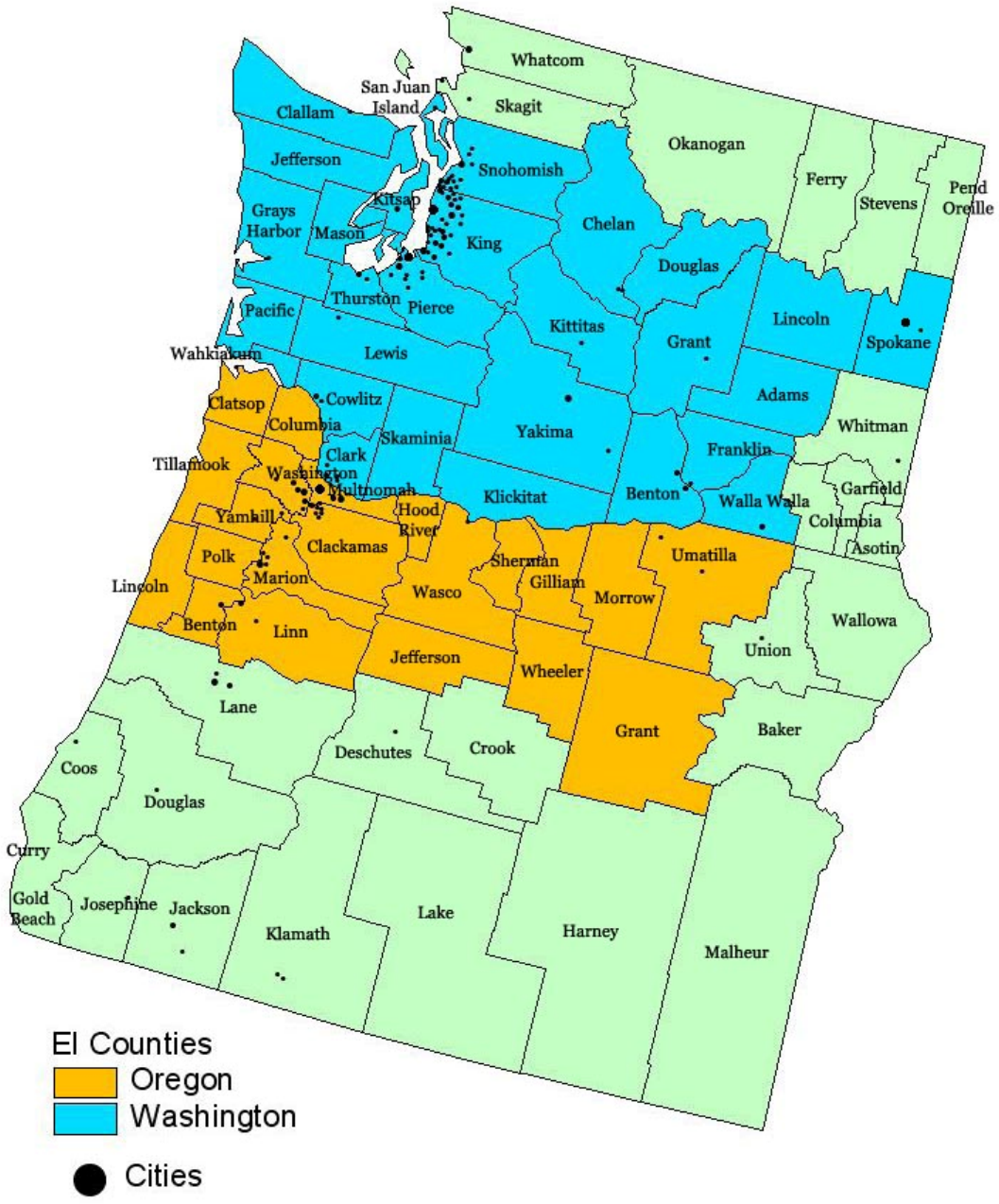


Figure 3-1. Counties where ODEQ and SWCAA assembled emissions for Gorge Study modeling (Spokane is also included).

www.vulcan.wr.usgs.gov/Volcanoes/MSH/Eruption04/Chronology/framework.html. Volcanic emissions estimates were based on three measurements that were performed on 3 November 2004, 10 November 2004, and 12 November 2004 (McGee, 2006). This was a period of increasing geologic activity which resulted in escalating emissions from Mt. St. Helens. Based on conversations with scientists at the United States Geological Survey (USGS) (McGee, 2006),

there was no volcanic activity during August 2004; hence, emissions for this episode was set to zero. The USGS does not estimate emissions of ash (McGee, 2006), which could be used as a surrogate for primary PM. However, given that there was no ash plume activity reported in either November or August 2004, primary PM emissions were considered nonexistent. Therefore, only the SO_2 emission estimates were used in this effort.

3.2 2004 BASE CASE SMOKE PROCESSING

SMOKE (CEP, 2004) was configured to generate model-ready point, area, non-road mobile, on-road mobile, and fire source emissions for the 36/12/4-km grid system. Certain emission subcategories, such as electric generating units (EGU), on-road mobile sources, fires, etc., were processed through the SMOKE system in separate streams in order to support PSAT applications and to allow maximum flexibility in developing and applying alternate strategies in the modeling. Processing steps for each of the source categories are discussed in relevant sub-sections below.

All source categories contained within the OR, WA, and WRAP annual emission inventories were converted to IDA formats. The IDA files were then processed by SMOKE using the month-, day-, and hour- specific temporal profiles from the WRAP modeling and gridded spatial surrogates developed specifically for the grid system. Population was used as a gridding default for all source categories when the assigned surrogate would cause SMOKE to drop emissions. This can be the case when the county-level emission inventories are prepared using surrogates other than those available for modeling purposes.

Specialized processing was conducted for certain source categories to provide updated and/or day-specific emission estimates for the episodic conditions modeled in this study: CEM point sources, wildfires, some prescribed fires, on-road mobile, biogenics, wind-blown dust, and agricultural ammonia. All point sources were treated by SMOKE as potentially elevated. No plume-in-grid sources were modeled. Wildfire and some prescribed fire emissions were handled as point sources as available.

Biogenic, wind-blown dust, and agricultural ammonia emissions were also modeled for each episode day, using the daily meteorology provided by MM5 on each grid. SMOKE meteorological inputs rely on daily (25-hour) files from the Models-3 Meteorological-Chemistry Interface Processor (MCIP), which translates raw MM5 output fields to the formats and variables needed by Models-3 components such as SMOKE.

SMOKE was setup to process criteria pollutant emissions into the CAMx configuration using the Carbon Bond IV (CB4) chemical mechanism with PM. Emissions for the following model species were generated:

- Nitrogen oxides: NO, NO_2
- Volatile organic compounds: ALD2, ETH, FORM, ISOP, OLE, PAR, TERPB, TOL, XYL
- Carbon monoxide: CO
- Ammonia: NH_3

- Sulfur oxides: SO_2, SULF, PSO4
- Primary PM: PEC, POA, PNO3, PMFINE, PMC.

3.2.1 36-km Domain

Emissions for 36-km domain (see Figure 1-2) were based on the WRAP 2002 database and projected to the year 2004. The Economic Growth and Analysis System version 5.0 (EGAS 5.0), an economic activity forecast tool, was used to generate the growth factors by state and by source category (EPA, 2006b). The growth factors were applied to the model-ready gridded emissions for seven basic source categories: area, oil-and-gas, off-road mobile, on-road mobile, fugitive dust, and road dust. Offshore point and other anthropogenic point source emissions were processed through SMOKE using a growth and control module, with growth factors obtained from EGAS. All temporal and speciation allocation profiles and cross-reference data were taken from the WRAP 2002 database.

Fire emissions are always a challenge in developing projections to a different year. Wild fire activities are event-specific and so vary from year to year, and wildfire emissions were rather high in 2002. Thus, using wild fire emissions from WRAP 2002 was not appropriate for this study. On the other hand, agricultural, prescribed and non-federal rangeland burns are common practices and may not have a significant variation from year to year. Therefore, WRAP 2002 wild fire emissions were excluded, but other fire categories were included and processed through SMOKE. Fire emissions were handled as point sources as available.

Other emission categories such as marine commercial shipping, area source ammonia, and biogenics were held constant from the WRAP 2002 database (holding these components constant was done only for the 36-km continental grid – specific daily processing for the biogenic, windblown dust, and ammonia components was performed on the 12- and 4-km grids). No projections were applied to emissions from Canada or Mexico.

Table 3-1(a-g) lists state-level emissions of CO, SOx (SO_2 + SULF + PSO4), NOx, VOC, NH_3, PMFINE (fine particles excluding sulfate), and PMC (coarse particles excluding sulfate) for the western states in the 36-km domain, excluding Oregon and Washington.

Table 3-1(a). CO (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	2209	3440	52	0.5	1416	1747	3223	51	20	433
CALIFORNIA	4589	9029	385	94	1521	4068	9421	345	337	660
COLORADO	2173	3422	110	58	828	1271	4235	107	41	112
IDAHO	771	1054	69	427	622	466	1266	70	925	185
MONTANA	542	1492	104	0.4	1046	342	1765	102	544	244
NEVADA	867	1140	36	0	791	530	1129	34	0	174
NEW MEXICO	570	1499	109	0	1210	488	1740	108	0	230
UTAH	920	1814	159	14	700	683	2172	157	0	93
WYOMING	337	641	204	398	701	226	682	190	0	96

Table 3-1(b). SOx (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	26	10	291	0	0	24	9	299	0	0
CALIFORNIA	73	16	125	0	0	71	16	122	4	0
COLORADO	33	14	294	0	0	29	14	284	1	0
IDAHO	30	5	50	2	0	20	5	50	6	0
MONTANA	31	6	124	0	0	24	6	113	4	0
NEVADA	44	2	149	0	0	43	2	141	0	0
NEW MEXICO	36	7	108	0	0	34	7	102	0	0
UTAH	32	6	127	0	0	26	6	121	0	0
WYOMING	72	4	380	0	0	68	3	287	0	0

Table 3-1(c). NOx (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	246	502	200	0	99	226	530	201	0	56
CALIFORNIA	1301	1676	327	3	193	1253	1737	304	26	133
COLORADO	392	400	353	3	177	290	434	343	3	77
IDAHO	228	126	33	14	66	167	134	33	21	37
MONTANA	246	162	178	0	266	182	155	163	14	145
NEVADA	141	124	183	0	54	116	128	171	0	30
NEW MEXICO	374	203	302	0	173	365	212	291	0	79
UTAH	226	222	272	0	54	178	231	254	0	24
WYOMING	332	129	441	11	76	304	111	353	0	33

Table 3-1(d). VOC (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	406	301	15	0	6654	373	290	15	1	1667
CALIFORNIA	1376	830	132	8	10616	1312	835	129	33	3135
COLORADO	400	275	207	6	4270	340	276	206	3	441
IDAHO	359	83	6	40	3165	328	75	6	42	785
MONTANA	168	123	17	0	4945	149	118	17	25	1021
NEVADA	135	115	5	0	3172	111	99	5	0	614
NEW MEXICO	315	113	38	0	5143	307	112	38	0	846
UTAH	240	137	18	1	3126	213	134	18	0	328
WYOMING	197	42	50	45	3374	186	37	49	0	371

Table 3-1(e). NH_3 (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	86	15	2	0	0	110	15	2	0	0
CALIFORNIA	546	64	1	2	0	413	61	1	6	0
COLORADO	225	13	2	1	0	81	13	2	0	0
IDAHO	207	4	3	9	0	84	4	3	4	0
MONTANA	197	4	1	0	0	62	4	1	3	0
NEVADA	28	6	2	0	0	13	6	2	0	0
NEW MEXICO	114	7	0	0	0	48	7	0	0	0
UTAH	88	8	6	0	0	38	7	5	0	0
WYOMING	94	2	2	8	0	42	2	1	0	0

Table 3-1(f). PMFINE (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	105	20	4	0	0	64	21	4	2	0
CALIFORNIA	346	60	66	10	0	292	59	61	37	0
COLORADO	205	17	0	9	0	91	18	0	4	0
IDAHO	72	5	1	39	0	43	5	1	78	0
MONTANA	136	7	1	0	0	208	6	1	46	0
NEVADA	87	4	3	0	0	18	4	3	0	0
NEW MEXICO	75	9	8	0	0	59	9	8	0	0
UTAH	39	8	14	1	0	20	8	13	0	0
WYOMING	28	5	0	30	0	37	4	0	0	0

Table 3-1(g). PMC (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	520	3	29	0	0	172	3	28	0	0
CALIFORNIA	1000	15	32	1	0	560	15	32	3	0
COLORADO	1093	2	65	0	0	170	2	64	0	0
IDAHO	347	1	2	2	0	153	1	2	13	0
MONTANA	779	1	22	0	0	1490	1	22	7	0
NEVADA	662	1	12	0	0	68	1	11	0	0
NEW MEXICO	405	1	7	0	0	267	1	7	0	0
UTAH	180	1	26	0	0	50	1	26	0	0
WYOMING	61	1	112	1	0	169	0	100	0	0

3.2.2 12-km Domain

Emissions for 12-km domain (see Figure 1-2) were also based on the WRAP 2002 database and projected to the year 2004. SMOKE (CEP, 2004) was configured to process all the low level sources with the growth factors from EGAS (EPA, 2006b) applied to the same seven source categories as previously mentioned.

With partial funding from the California Air Resources Board (ARB) and the Commission for Environmental Cooperation in North America (CEC), gridded emissions for North American marine commercial shipping are available for the 2002 base year at 4-km resolution (Wang et al., 2006). The inventory was estimated using the Waterway Network Ship Traffic, Energy and Environment Model (STEEM) to characterize ship traffic, estimate energy use and assess the environmental impacts of shipping (Corbett et al., 2006). The inventory was spatially distributed based on the Waterway Network Ship Traffic. Because the projection of this inventory is different from the projections used in this study, the following pre-processing steps were performed through ARC/Info:

- Window out the gridded marine emissions to approximately cover the Gorge 12-km domain;
- Reproject the marine emissions to the Lambert projection used in WRAP and this study;
- Intersect the Gorge 12-km grid to the re-projected emissions to create a re-gridding surrogate;
- Use the re-gridding surrogate to distribute emissions from the windowed emissions.

Biogenic, ammonia and wind blown dust emissions were processed outside of SMOKE and will be described in more detail in the next section.

Table 3-2(a-g) lists state-level emissions of CO, SOx (SO_2 + SULF + PSO4), NOx, VOC, NH_3, PMFINE (fine particles excluding sulfate), and PMC (coarse particles excluding sulfate) for the portions of states contained within the 12-km grid, excluding Oregon and Washington.

Table 3-2(a). CO (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	579	640	65	48	1074	548	711	65	125	254
IDAHO	750	1021	69	288	1103	451	1235	69	925	353
MONTANA	296	914	76	0	794	193	1076	74	541	238
NEVADA	164	308	23	0	135	107	381	23	0	39
UTAH	517	938	25	2	58	378	1142	25	0	22
WYOMING	64	90	32	34	70	39	97	31	0	29

Table 3-2(b). SOx (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	7	1	2	0	0	4	1	2	2	0
IDAHO	29	5	50	1	0	18	5	50	6	0
MONTANA	13	4	8	0	0	9	4	8	4	0
NEVADA	12	0	23	0	0	10	0	23	0	0
UTAH	14	3	20	0	0	8	3	20	0	0
WYOMING	7	1	112	0	0	6	1	92	0	0

Table 3-2(c). NOx (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	114	102	24	2	37	76	111	24	11	14
IDAHO	227	140	33	10	146	150	147	33	21	71
MONTANA	84	113	28	0	64	34	106	26	14	27
NEVADA	47	37	49	0	128	17	40	49	0	55
UTAH	121	133	31	0	29	74	138	30	0	14
WYOMING	39	23	76	1	11	24	19	64	0	6

Table 3-2(d). VOC (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	126	62	4	4	6787	126	66	4	13	941
IDAHO	371	79	6	27	4238	339	72	6	42	1236
MONTANA	79	75	7	0	2875	69	72	7	25	814
NEVADA	38	27	3	0	409	32	29	3	0	108
UTAH	121	72	10	0	252	107	70	10	0	75
WYOMING	40	6	4	4	325	37	5	3	0	110

Table 3-2(e). NH3 (TPD) emissions by state in the 12-km domain

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	59	2	0	1	0	45	2	0	2	0
IDAHO	213	4	3	6	0	87	4	3	4	0
MONTANA	74	3	1	0	0	22	2	1	3	0
NEVADA	15	2	1	0	0	6	2	1	0	0
UTAH	26	4	1	0	0	12	4	1	0	0
WYOMING	6	0	0	1	0	3	0	0	0	0

Table 3-2(f). PMFINE (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	46	3	7	5	0	44	3	7	13	0
IDAHO	34	6	1	28	0	24	6	1	78	0
MONTANA	17	5	1	0	0	19	4	1	46	0
NEVADA	20	1	2	0	0	2	1	2	0	0
UTAH	15	5	4	0	0	7	5	4	0	0
WYOMING	3	1	0	3	0	2	1	0	0	0

Table 3-2(g). PMC (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	7	1	4	0	0	5	1	4	1	0
IDAHO	45	1	2	1	0	23	1	2	13	0
MONTANA	3	1	13	0	0	47	1	12	7	0
NEVADA	150	0	1	0	0	1	0	1	0	0
UTAH	47	1	8	0	0	7	1	8	0	0
WYOMING	0	0	9	0	0	0	0	8	0	0

3.2.3 4-km Domain

3.2.3.1 Onroad Mobile Emissions

The MOBILE6.2 emission factor model was used to provide on-road vehicle emission estimates (g/mile) as a function of vehicle type, age distribution, road type, travel speeds, ambient temperature, and year of concern (including forecasts to future years). The MOBILE model can be configured to accept inputs for all of these dimensions (or use defaults), as well as information on local/federal control technologies in place and fuel specifications by county. Emission factors generated by MOBILE are then combined with vehicle activity and ambient data (vehicle counts, vehicle miles traveled [VMT], ambient temperature) to derive either county-level or roadway (link) specific hourly total emissions of NOx, SOx, CO, VOC, and PM. These emissions must then be allocated to the modeling grid and speciated to the individual chemical species using SMOKE.

The states of WA and OR provided default MOBILE6 modeling inputs and annual VMT levels for counties around the Gorge area. Neither of these two states provided information about speed or VMT by vehicle class, or road type distribution data, which are critical elements for estimating on-road emissions. We were informed by WA that the states have relied on the default MOBILE6 speed data and have no new data that would be appropriate to apply to an area as large as the Gorge 4-km domain (see Figure 1-2).

ENVIRON developed the on-road emissions for the WRAP 2002 inventory. The emission inventory was compiled based on the Highway Performance Monitoring System (HPMS) and a survey completed by state and local air quality planning agencies; therefore, the WRAP on-road inventory was based on the most-up-to-date activity data and modeling inputs. The inventory was available and well suited for our work. Details of the methods used to estimate these WRAP 2002 mobile source emissions is described in Pollack et al. (2005).

The basic steps in our methodology to project the on-road emissions from 2002 to 2004 were as follows:

- Start with WRAP 2002 emissions for winter and summer periods – the inputs are in tons per day (TPD) by source category code (SCC) by county;
- Determine VMT projection factors uniformly across seasons, vehicle, and roadway types based on the ratio of 2004 annual VMT by county (provided by WA and OR states) to the 2002 WRAP annual VMT.
- Calculate the fleet turnover control factor. This step involved running MOBILE6 with the inputs provided by WA and OR to obtain the emission factors (EF) for 2002 and 2004. For counties with partial coverage of vehicle Inspection and Maintenance (I/M) programs, the EF ratio was determined as an average of I/M and non-I/M EF ratios weighted by I/M and non I/M VMT.
- Apply the VMT projection factor and the fleet turnover control factor to each 2002 emissions value to project 2004 emissions.

For Idaho and some WA/OR counties for which VMT data were not available, we used the WRAP 2002 inventory and projected the emissions to 2004 using growth factors developed from EGAS (EPA, 2006b). The 2004 emissions were reported as typical summer and winter daily

averaged emissions of each county by SCC by roadway type. SMOKE (CEP, 2004) allocated these emissions temporally and spatially to the Gorge 4-km domain using the WRAP activity profiles.

3.2.3.2 Biogenic Emissions

The Global Biosphere Emissions and Interactions System (GloBEIS) model was used to prepare gridded hourly biogenic emission inventories suitable for input to the CAMx (Yarwood, et al., 2003). GloBEIS runs in Microsoft ACCESS on Windows-based computers. Emissions rates are a function of landcover and environmental conditions. The inputs to GloBEIS model are:

- Landuse/Landcover (LULC): The LULC data were taken from the Biogenic Emissions Landcover Database (BELD3) version 3.1 developed by the US EPA (EPA, 2006; EPA, 2001). This database combines data at 1-km pixel resolution, covering the entire 48 conterminous US states as well as Mexico and Canada (Figure 3-2). The data are available in sections, or tiles (Figure 3-2). To encompass the entire proposed modeling grid, the BELD3 data for tiles 13 and 14 were used for the 4-km domain, with addition of tile 7 and 8 for 12-km domain. ARC/Info was used to determine which BELD3 pixels were contained within the modeling domain, and then a FORTRAN program was used to build the LULC data for each GloBEIS grid cell.
- Surface Temperature Data: Gridded, hourly temperature fields were extracted from MM5 predictions for each episode.
- Photosynthetically active radiation (PAR): The PAR data represents the spectral range of solar radiation that is used by plants for the photosynthesis process. The data were downloaded from the University of Maryland (UMD; 2006) and a FORTRAN program was used to reformat the data. Some of the PAR data were missing. As part of the QA process, the PAR data were inspected, and the missing data were replaced interpolating the missing data between hours.

3.2.3.3 Reduction in Residential Wood Smoke

Annual fine PM emissions from residential wood combustion in Oregon and Washington were found to be overstated by a factor of two. This was due to an improper interpretation of a 1999 fireplace survey conducted in both states. In 2002, the residential wood combustion emissions inventory based on these survey results was submitted to the EPA for inclusion into the National Emissions Inventory (NEI) database. The 2002 NEI datasets formed the basis of the 2004 Oregon and Washington inventory projections developed by the ODEQ and WDOE specifically for this project. Since the NEI comprises annual estimates, wood smoke emissions for August and November were both over estimated in this project because the annual estimates were allocated to each month and day of week according to temporal profiles defined in the SMOKE emissions processor. Furthermore, since the 2002 NEI was used by WRAP to project emissions to 2018, this overestimate carried through to the future year inventory.

In 2005, the ODEQ and WDOE reinterpreted the survey results (independent of this project); coupled with a small revision to ODEQ wood density calculations, the revised residential wood smoke emission estimates were reduced by 50%. Upon ultimately learning of this revision in

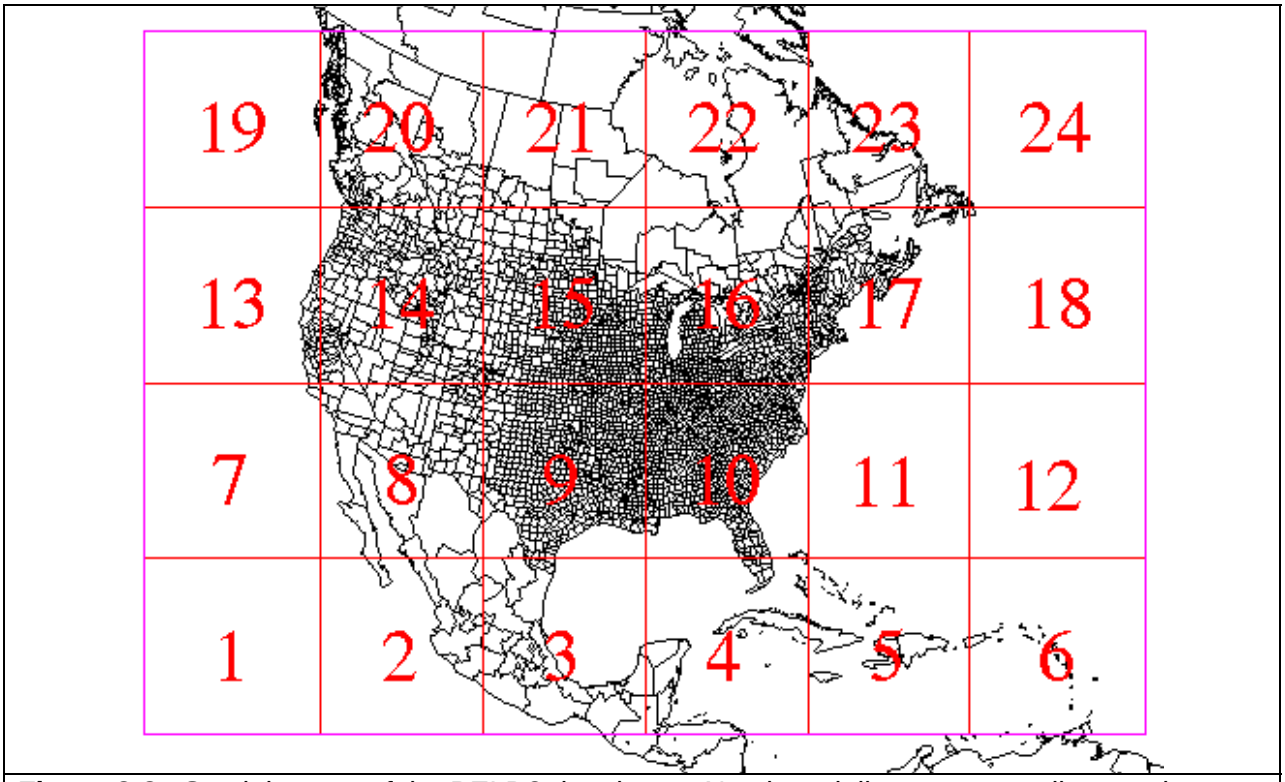


Figure 3-2. Spatial extent of the BELD3 data base. Numbered tiles represent discrete data sets.

early 2007, the project team thus applied a 50% reduction to the 2004 annual residential wood combustion categories for both states. Further comparison between the 2004 county-level Oregon/Washington inventory and the 2018 WRAP inventory revealed 300-700% PM emission increases for this source sector. We confirmed with the WRAP emission modelers that population growth was used to project residential sources such as wood smoke, and that the Oregon and Washington population growth rates are forecast to be only 4% over this period. Given this, the project team applied a 1.04 factor to the reduced 2004 residential wood smoke emission rates to derive a revised 2018 wood smoke inventory for counties in Oregon and Washington.

There remained a concern that the monthly temporal profiles taken from WRAP may have also been in error as there was a perception that, in particular, the August residential wood combustion emissions were too high. The modeling team examined the SMOKE monthly allocation profiles, but found no obvious issues with the values assigned to November and August. Therefore, the monthly profiles were maintained as defined by WRAP.

3.2.3.4 Ammonia (NH_3) emissions

Major sources of NH_3 emissions include livestock operations, fertilizer use, waste management, mobile sources, industrial point sources, and various biological sources including human respiration, wild animals, and soil microbial processes. WRAP estimated 2002 NH_3 emissions

for the 36-km domain for minor NH_3 sources including livestock, fertilizer usage, domestic sources, and wild animals using the NH_3 GIS-based program developed by ENVIRON (Mansell, 2005). The emissions from soil were excluded due to significant uncertainty. Inputs to this program include LULC distributions, county-level activity data, emission factors, and environmental factors. In parallel with the WRAP 2002 emissions, the same approach was adopted to obtain NH_3 emissions in this study.

For the 12-km domain, NH_3 emissions from mobile sources and industrial point sources were obtained from the WRAP 2002 database, then processed using SMOKE. The NH_3 GIS-based program was used to obtain the rest of the NH_3 emissions. The LULC data used in this study were based on the National Land Cover Database (NLCD). Livestock and fertilizer usage have diurnal emission variations depending considerably on temperature and wind speed. The temperature and wind data were day specific based on the MM5 simulation results and were provided as inputs with hourly resolution for this study.

For the 4-km domain, only NH_3 emissions from domestic and wild animals were obtained from the GIS program. However, since SWCAA provided ammonia emissions for domestic animals in Washington, these emissions estimates were used preferentially to those estimated through the application of the GIS-based program developed by Mansell (2005).

3.2.3.4.1 Increases in Agricultural Ammonia

Like residential wood smoke, the 2004 ammonia emission projections developed for this project were based upon the 2002 NEI submittal. The project team conducted a detailed scrutiny of the Oregon and Washington ammonia inventories, and compared the emission factors to published values in the literature. Two major issues were identified:

(1) Ammonia emissions from confined area feeding operations (CAFO), such as dairies, were understated by factors of 1.5 to approximately 3, depending on the type of manure handling conducted at each (i.e., flush, scrape, drylot/pasture, or deep-pit);
(2) Ammonia emissions from fertilizer application were understated by upwards of a factor of three for anhydrous and aqueous ammonia application sources, and by a factor of 2.5 for nitrogen solution fertilizer application sources.

The Three-Mile Canyon Dairy constitutes a major ammonia source in the immediate vicinity of the Columbia Gorge. In the original inventory, total 2004 ammonia emissions for this facility were reported as ~1100 TPY based on the application of an Oregon composite emission factor of 27.96 kg/head/year and a 31,000 head count. Our investigation of this specific facility subsequently identified it as a "flush" operation. Additionally, according to this facility's web site, the head count is reported to be 41,000. Thus the project team increased its ammonia emissions by a factor of 4.3 to account for: (1) a flush emission factor of 92 kg/head/year based on the work of Carnegie Mellon University (CMU; 2004), and (2) the increase in head count to 41,000.

The ODEQ and WDOE attempted to locate additional data concerning the distribution of CAFO operations in both states as a means to improve the characterization of each facility or to improve the state composites. However, no additional information was found in the short time available.

Therefore, ammonia emissions for the remaining Oregon dairies were scaled by a factor of 1.21, while emissions for all Washington dairies were scaled by a factor of 1.4, according to differences between the composite ammonia emissions factor reported by CMU (2004) and the state-specific composite factors used in the original 2002 inventory.

Ammonia emissions from large-scale agricultural fertilizing activities were scaled by 3.3 (anhydrous and aqueous fertilizers) and 2.7 (nitrogen solution fertilizers) according to the difference in CMU (2004) emission factors and the 2002 factors used in the state inventories.

3.2.3.5 Wind Blown Dust emissions

When wind contributes a significant shear on the surface, surface dust particles are either entrained directly by the wind or as larger particles creep and bounce off the surface. The process is known as saltation. Two important factors for characterizing the dust emission process from an erodible surface are the surface wind speed that drives the saltation system and the soil characteristics. This study used the WRAP windblown dust model (Mansell et al., 2006) to generate the gridded estimates of dust emissions for the 12-km and 4-km domains. Data sources required for the implementation were:

- Land Use/Land Cover (LULC): The North America Land Cover (NALC) dataset derived for the year 2000;
- Agricultural crop data: Unlike vacant land, windblown dust emissions from agricultural land are subject to a number of non-climatic influences such as seasonal crop growth, thus some adjustment factors based on agricultural data are necessary. The agricultural crop data were from BELD3 database;
- Soil characteristics from the State Soil Geographic Database (STATSGO), developed by the Natural Resources Conservation Service of the U.S. Department of Agricultural (USDA);
- Gridded hourly meteorological data in netcdf format based on MM5 model simulation results. Data fields required in the dust model include wind speeds, precipitation rates, soil temperature and ice/snow cover.

ARC/Info was used to determine which BELD3, LULC and soil code belonged to the each grid cell in the modeling domain. The windblown dust model is a FORTRAN based program that takes all the input mentioned above and generates the netcdf gridded dust emissions.

3.2.3.6 Wildfire Emissions Estimates

Wildfire data (i.e., name, start date, end date, longitude, latitude, and acres burned) were taken from the National Fire and Aviation Management data archive (NAFM, 2006). For purposes of this effort, "acres burned" is the average acres burned per day. "Acres burned" was computed as the final area burned divided by the total number of days the burn occurred as determined by the difference in the end and start date of the burn. Of note, the National Fire and Aviation Management data archive indicates that there were wildfires only for the month of August 2004; hence, no wildfire emissions were estimated for the November 2004 episode. These data are summarized in Table 3-3.

Table 3-3. Summary of wildfire data in OR and WA during August 2004.

STID	CYID	Wildfire Id	Longitude	Latitude	Start Date	End Date	Avg. Acres Burned (acres/day)
53	65	WA-LPR-000138	-117.719444	48.475	08/18/2004	08/20/2004	14.0
53	73	WA-MSF-000121	-121.685278	48.766944	08/10/2004	08/22/2004	6.3
53	61	WA-MSF-126	-121.179444	48.293333	08/10/2004	08/22/2004	6.4
53	73	WA-MSF-149	-121.848611	48.704444	08/14/2004	08/22/2004	11.1
53	73	WA-MSF-150	-121.714722	48.887778	08/14/2004	08/22/2004	11.1
53	47	WA-NES-464	-119.034722	48.5875	08/17/2004	08/22/2004	90.8
53	73	WA-OWF-248	-120.975833	48.982778	08/10/2004	08/22/2004	13.6
53	7	WA-OWF-271	-120.31	47.937778	08/10/2004	08/22/2004	1345.3
53	77	WA-OWF-553	-121.2575	46.753056	08/10/2004	08/18/2004	156.3
53	7	WA-OWF-639	-120.833333	47.868056	08/10/2004	08/22/2004	16.4
53	57	WA-OWF-666	-120.794722	48.619722	08/10/2004	08/18/2004	17.0
53	7	WA-OWF-689	-120.579222	48.568611	08/10/2004	08/22/2004	1100.0
53	47	WA-OWF-755	-120.536667	48.398056	08/16/2004	08/22/2004	857.0
53	77	WA-SES-693	-120.816667	46.774444	08/10/2004	08/15/2004	571.4
53	77	WA-YAA-100	-120.513056	46.168611	08/11/2004	08/13/2004	266.7
41	19	OR-732-289	-123.13	42.999167	08/20/2004	08/22/2004	1477.0
41	17	OR-DEF-893	-121.5	44.25	08/13/2004	08/15/2004	10.0
41	37	OR-FRF-265	-120.15	42.4	08/13/2004	08/22/2004	450.0
41	61	OR-WWF-091	-117.6125	45.3175	08/10/2004	08/21/2004	72.7
41	63	OR-WWF-103	-117.469167	45.266667	08/10/2004	08/17/2004	11.5

The acres burned were multiplied by the average fuel-loading estimate and the fire emissions factor to yield emissions on a daily basis. The average fuel-loading estimate was 39 tons per acre (Kreitzer, 2006c), and the fire emissions factors that were used in the study are presented in Table 3-4.

Table 3-4. Emissions factors (pounds of chemical per ton of fuel) used to estimate emissions from wildfires in OR and WA during August 2004 (Kreitzer, 2006c).

CO	N2O	NH3	NOx	PM10	PM2.5	SOx	VOC
135.7	0.0	1.0	4.7568	13.8	11.7	2.1	11.54

There are certainly deficiencies in this approach, which include, among others: (1) wildfires are assumed to burn evenly across the event; (2) fuels are assumed to be equivalent in nature; and (3) fuel loading is assumed to be equivalent in nature. Further, a qualitative comparison of the estimates derived based on this approach to the estimates of wildfire emissions from the 2002 WRAP inventory reveals that the estimates derived for this study are roughly 25% higher than those estimated for the 2002 WRAP inventory.

Stack parameters were based simply on the desire to inject a certain fraction of the emissions into a specific layer of the air quality model. The specific layer was determined following the approach of WRAP (WRAP, 2002) where fires are assigned to one of five categories based on total acres burned and fuel loading. The categories are used to determine a representative hourly plume profile which is used to distribute emissions from fires in the vertical. Where plumes were projected to intersect more than the first layer, additional pseudo-stacks were introduced into the modeling. The pseudo-stacks were assigned stack parameters such that the fraction of emissions determined to be injected into a particular layer stayed in that layer. Stack height was determined as the mid-point of the layer. Stack gas exit temperature, stack diameter and stack gas exit velocity were assigned values such that the plume stayed within the layer to which it was

assigned: diameter = 5 meters; temperature = 30 C; and gas exit velocity = 0.001 meters per second.

3.2.3.7 Other Fire Emissions Estimates

ODEQ provided estimates of emissions from prescribed burns and structural fires for Oregon. SWCAA did not do the same for Washington. Therefore, for Washington, prescribed burns emissions estimates were taken from the WRAP 2002 data base and used as is. These emissions were processed using SMOKE and the WRAP-based temporal and spatial profiles to estimate air quality model ready gridded, hourly emissions estimates. For purposes of modeling, these emissions estimates were treated as low-level area source emissions.

3.2.3.8 Mt. St. Helens Emissions Estimates

Estimates are based on three measurements in 2004 that were performed on November 3, November 10, and November 12 (McGee, 2006). There was no significant activity reported during August 2004 (McGee, 2006). November 2004 was a period of increasing geologic activity which resulted in escalating emissions from Mt. St. Helens. Measurements made of emissions from Mt. St. Helens are summarized in Table 3-5.

Based on a conversation with McGee (2006), it was concluded that a simple linear interpolation could be used to estimate emissions for the days of November 4, 9, and 11. For the days November 13 through 19, the estimates are set to the value of November 12. As this was treated as a point source, the stack parameters that were assigned such that all emissions from Mt. St. Helens were allocated to the first level of the modeling domain.

Table 3-5. Summary of observed emissions from Mt. St. Helens during November 2004 (metric tons per day) (McGee, 2006).

Measurement Date	SO2	H2S	CO2
03-Nov-2004 (PST)	65	ND	330
10-Nov-2004 (PST)	110	6	NM
12-Nov-2004 (PST)	140	ND	1000

ND = non-detect
NM = no measurement

3.2.3.9 Georgia Pacific Camas Emissions Estimates

August and November 2004 monthly emissions estimates of TSP, NOx, VOC, and SO_2 were provided for eight units of the Camas pulping facility (Mairose, 2006c). These monthly emissions estimates were assumed to be evenly distributed across all hours of the month unless otherwise noted in the data (Mairose, 2006c). Total suspended particulate (TSP) was treated as PM10. The PM2.5 component of PM10 was determined as a ratio of the PM10 to PM2.5 that exits in the SWCAA data (SWCAA, 2006). SMOKE-ready, hour specific input files were

created, and SMOKE was used to incorporate these data directly into the air quality model ready emissions estimates.

3.2.3.10 PGE Boardman Emissions Estimates

Hour-specific estimates for the episode days in August and November 2004 of NOx, SOx, and PM emissions were provided for a single coal-fired boiler at the Boardman facility (Mairose, 2006b). PM was treated as PM10. The PM2.5 component of PM10 was determined as a ratio of the PM10 to PM2.5 that exits in the SWCAA data (SWCAA, 2006). These estimates were converted into SMOKE-ready hourly input files, and SMOKE was used to incorporate these data directly into the air quality model ready emissions estimates.

3.2.3.11 EPA Continuous Emissions Monitoring Data

Hourly emissions estimates of SO_2 and NOx for facilities and units presented in Table 3-6 were extracted for the US EPA Continuous Emissions Monitoring (CEM) data archive (EPA, 2005) and reformatted for use in SMOKE. The first three columns in Table 3-6 (i.e., Facility Name, ORIS Code, and Unit Id) identify the specific values recognized in the EPA CEM data archive (EPA, 2005). The last four columns of Table 3-6 (i.e., FIPS State Id, FIPS County Id, NEI Facility Id, and SCC) identify the specific values to which the CEM records were mapped to entries in the SMOKE emissions data base. In regards to Boardman, though the sponsors provided hourly-specific emissions estimates for the facility, their data was only representative of the period from August 9-20, 2004. The US EPA CEM data for Boardman were used to supplement the sponsors' data for August 21-22.

Table 3-6. List of facilities for which hour-specific emissions of SO_2 and NOx were extracted from the US EPA CEM data archive.

Facility Name	ORIS Code	Unit Id	FIPS State Id	FIPS County Id	NEI Facility Id	SCC
Oregon Facilities						
PGE Boardman	6106	1SG	41	049	250016	10100222
Coyote Springs	7350	CTG1	41	049	250031	20100101
Coyote Springs	7350	CTG2	41	049	250031	20100201
Hermiston	54761	1	41	059	300113	20100201
Hermiston Power Plant	55328	CTG-1	41	059	300118	10100602
Hermiston Power Plant	55328	CTG-2	41	059	300118	20100201
Morrow Power Project	55683	1	41	049	250003	20100201
Washington Facilities						
Centralia	3845	30	53	041	754	20100201
Centralia	3845	40	53	041	754	20100201
Centralia	3845	50	53	041	754	20100201
Centralia	3845	60	53	041	754	20100201
Centralia	3845	BW21	53	041	754	10100226
Centralia	3845	BW22	53	041	754	10100226
Chehalis Generation Facility	55662	CT1	53	041	1900	20100201

Facility Name	ORIS Code	Unit Id	FIPS State Id	FIPS County Id	NEI Facility Id	SCC
Chehalis Generation Facility	55662	CT2	53	041	1900	20100201
Frederickson Power LP	55818	F1CT	53	053	10645	10200601
Fredonia Plant	607	CT3	53	057	40	20100101
Fredonia Plant	607	CT4	53	057	40	20100201
Goldendale Energy Project	55482	CT-1	53	039	66	20100201
River Road	7605	1	53	011	150	20100201
Finley Combustion Turbine	7945	1	53	005	55	10100602

3.2.3.12 Application of Canopy Escape Factors

It is well known in the air quality modeling field that the impact of fugitive dust sources on air quality is substantially lower than emissions inventories suggest. Fugitive dust categories of interest include unpaved and paved road dust, dust from highway, commercial and residential construction and agricultural tilling (Pace, 2005). Of these, unpaved roads are the highest single emissions category, accounting for about one third of non-windblown fugitive dust emissions. This is followed in importance by dust from tilling, quarrying and other earthmoving. Analysis of the chemical species collected by ambient air samplers suggests that the modeling process may overestimate PM2.5 from fugitive dust sources by as much as an order of magnitude (Pace, 2005). This unduly large impact is problematic for both air quality modeling efforts (e.g., regional haze and visibility) and air quality planning efforts (e.g., conformity budget determination). Multiple problems in the emissions inventory and emissions modeling process are believed to be the root cause of the overestimate among which are the following: faulty emission factor algorithms; imprecise or difficult to obtain activity data to apply emissions factors and emissions estimates algorithms (including the inability to account for the effect of actual meteorological conditions on emissions); the factor used to infer PM2.5 from PM10 emissions; and modeling deficiencies (especially in the treatment of particles near their point of emissions) (Pace, 2005). Further, even if the emissions inventory and emissions modeling processes were improved, it is not clear how much this may help in the air quality modeling process given that the typical Eulerian air quality model currently does not adequately account for the near source removal processes that affect the deposition of fugitive dust.

Numerous studies (e.g., Pace, 2005; Cowherd et al., 2003, 2002; Countess, 2003; Dong et al., 2003; Raupach, 2001; Watson and Chow, 2000; Raupachl, 1999; Slinn, 1982) suggests that removal of fugitive dust that may occur near the source, on a scale of tens to hundreds of meters, is beyond the capability of current Eulerian air quality models (e.g., CMAQ, CAMx, etc.). Therefore, a method is needed to adjust ground level fugitive dust emissions for use in Eulerian models where scales greater than 100 meters are used (indeed, typical modeling scales today are on the order of 4000 meters or more).

Pace (2005) presents a method to adjust fugitive dust emissions estimates that exist in current emissions inventories so that the air quality model "sees" more appropriate values of these particulates. Pace (2005) estimated the fraction of land area assigned to each land cover type in each US County based on the BELD3 dataset (EPA, 2001; Kinnee et al., 1997). Pace (2005) also assigned a "capture fraction" to each land cover type in the BELD3. The "capture fraction" is a value from 0 to 1 representing the ability of that land cover type to entrain suspended dust particles near the source. Pace (2005) estimated the county average "transportable fraction" – the fraction of dust emissions that escape near surface capture and are available to participate in urban- and regional-scale physicochemical atmospheric processes, by combining the "capture fraction" with the corresponding fractional surface of land cover in each county.

The county-specific transport factors of Pace (2005; EPA, 2006c) were applied to the area source categories taken from EPA (2006d) that were contained in the SWCAA and ODEQ emissions estimates (SWCAA, 2006) and the WRAP 2002 emissions estimates (WRAP, 2004). The results of this reduced the amount of fugitive dust that the air quality model "sees" by approximately 75%. This topic is discussed further in Section 4 of this report.

3.2.3.13 Reconciliation of the 2004 ORDEQ/SWCAA and 2002 WRAP Emissions Estimates

Though the project sponsors provided 2004 emissions estimates for the Gorge counties (Figure 3-1), their emissions estimates had to be supplemented with emissions estimates extracted from the WRAP 2002 data set (WRAP, 2004). For example, the WRAP 2002 data set contained estimates of emissions from oil and gas extraction activities that were not included in the ODEQ and SWCAA emissions data set. During this reconciliation process, it was also determined that certain categories of emissions that existed in the WRAP 2002 data set were inappropriate (e.g., residential coal combustion). In consultation with the project sponsors, emissions sources that existed in the WRAP 2002 data set but were not in the ODEQ and SWCAA data set were included in the final emissions inventory. Further, where certain WRAP 2002 emissions source categories were deemed inappropriate, these WRAP 2002 emissions estimates were deleted from the final emissions inventory.

3.2.3.14 4-km SMOKE Results

For presentation purposes, emissions estimates from the 4-km SMOKE data base were extracted for a typical day on each episode: 18-Aug-2004; and 10-Nov-2004. Figures 3-3 through 3-9 present the spatial distribution of daily emissions estimates on the 4-km modeling domain for CO, NOx, NH_3, PM-coarse, PM-fine, SOx, and VOC for emissions classified as area sources, fires, on-road mobile sources, point sources, and biogenics for 18-Aug-2004. Figures 3-10 through 3-16 present the spatial distribution of daily emissions estimates for the same species and source categories for 10-Nov-2004.

Figures 3-17 through 3-23 present the hourly distribution of emissions estimates for CO, NOx, NH_3, PM-coarse, PM-fine, SOx, and VOC for emissions classified as area sources, fires, on-road mobile sources, point sources, and biogenics for 18-Aug-2004. Figures 3-24 through 3-30

present the hourly distribution of emissions estimates for the same species and source categories for 10-Nov-2004. The following abbreviations for the emissions source categories, and there definitions, are used in the legends of Figures 3-17 through 3-30: *ar* represents area sources; *pt* represents stationary sources; *fi* represents fires; *mb* represents on-road mobile sources; and *bi* represents biogenics. Further, the y-axis represents the fraction of daily emissions for each category, and the sum of the 24-hourly fractions by emissions source category is one (1.0).

Table 3-7 presents the emissions estimates summary of CO, NOx, NH_3, PM-coarse, PM-fine, SOx, VOC, isoprene, monoterpenes, and other volatile organic compounds (OVOCs) for Oregon Gorge counties (Figure 3-1) for 18-Aug-2004. Of note, isoprene, monoterpenes, and OVOCs are listed separately as these are biogenic-related chemicals that are a significant fraction of the total VOC load. OVOCs include such chemicals as ethanol, hexanal, and butene to name but a few of the biogenic-related chemicals that are estimated by the emissions model. Table 3-8 presents a similar emissions estimate summary for Washington Gorge counties (Figure 3-1). Table 3-9 presents the emissions estimates summary of CO, NOx, NH_3, PM-coarse, PM-fine, SOx, VOC, isoprene, monoterpenes, and OVOCs for Oregon Gorge counties for 12-Nov-2004. Table 3-10 presents a similar emissions estimate summary for Washington Gorge counties for 12-Nov-2004. Though the days are different for the November episode between Table 3-9, 3-10 and Figures 3-24 through 3-30, the emissions rates and emissions distributions, both temporally and spatially, for the two days are very similar.

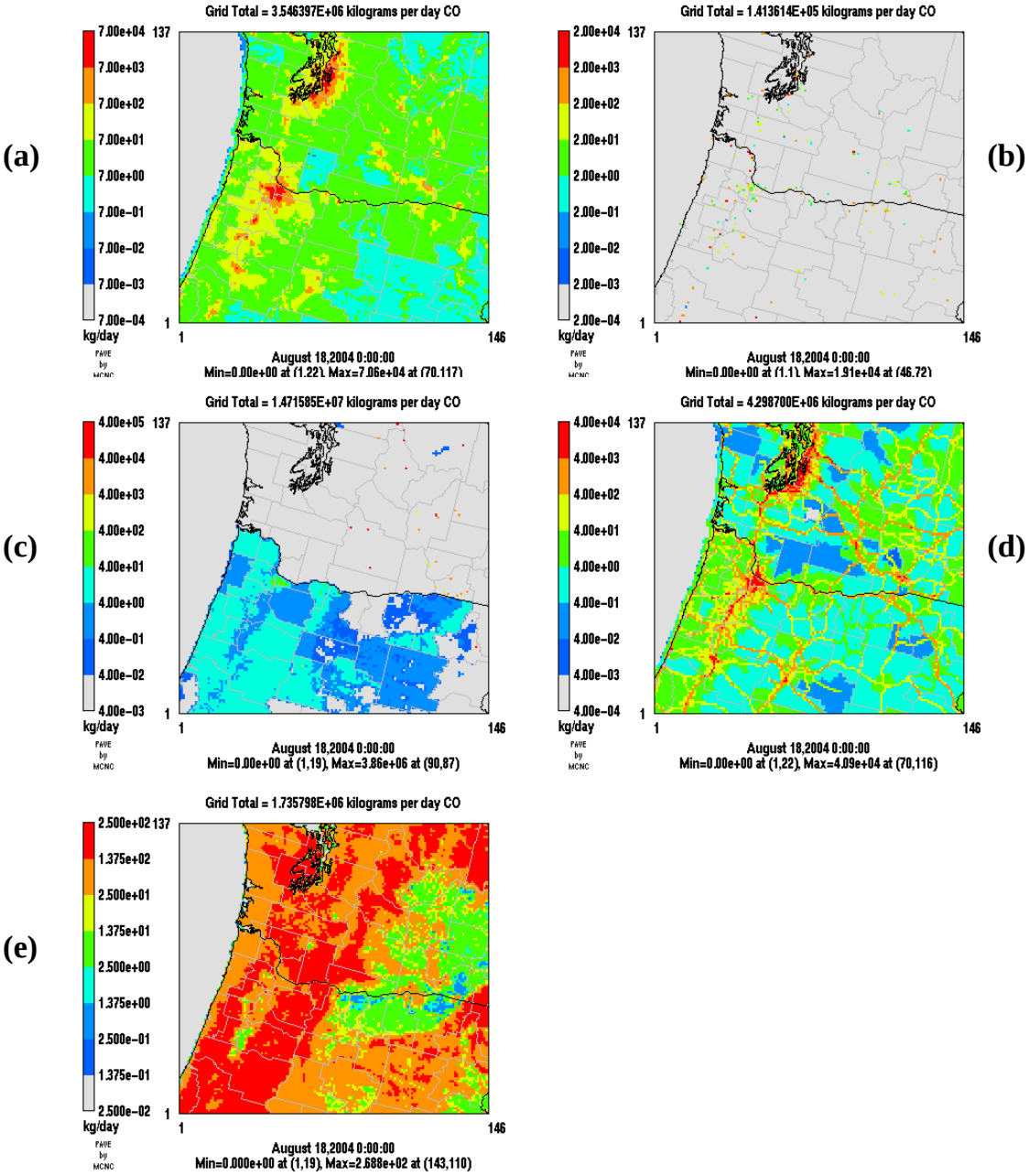


Figure 3-3. Spatial distribution of CO emissions estimates for 18-Aug-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; (d) on-road mobile source emissions; and (e) biogenic emissions.

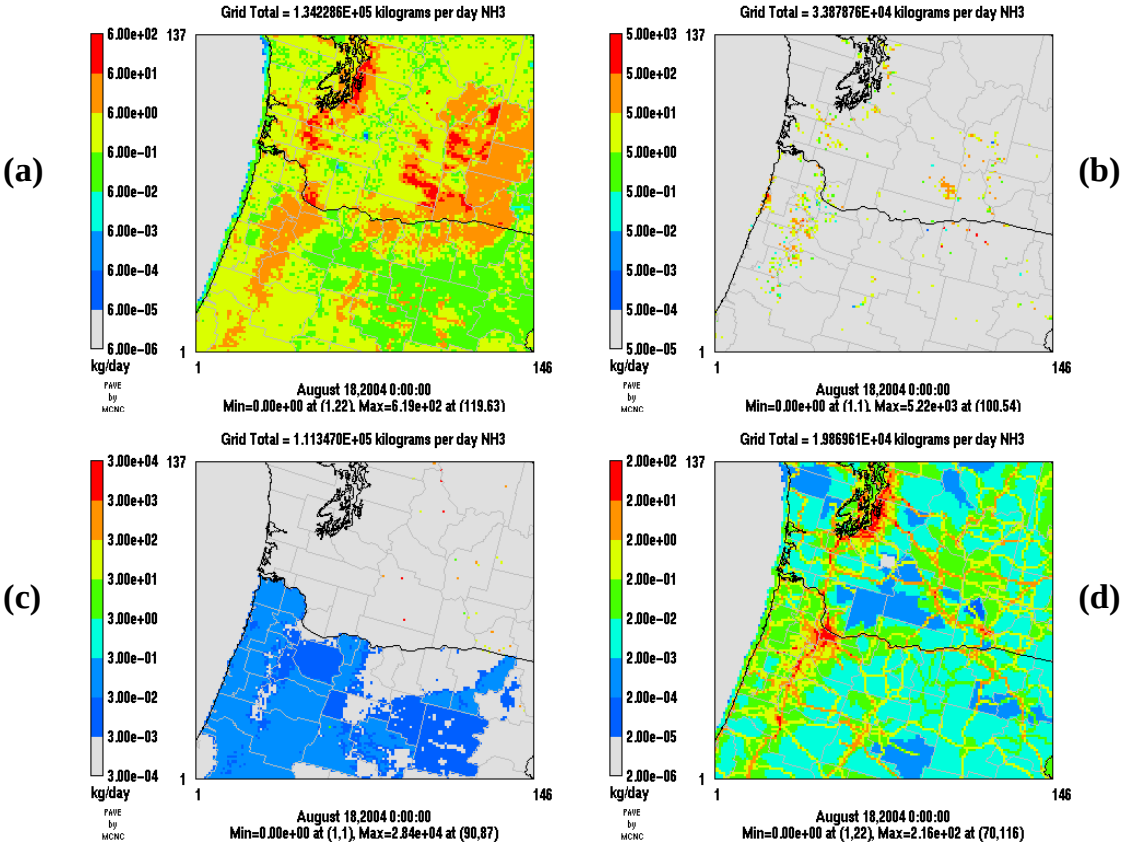


Figure 3-4. Spatial distribution of NH_3 emissions estimates for 18-Aug-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

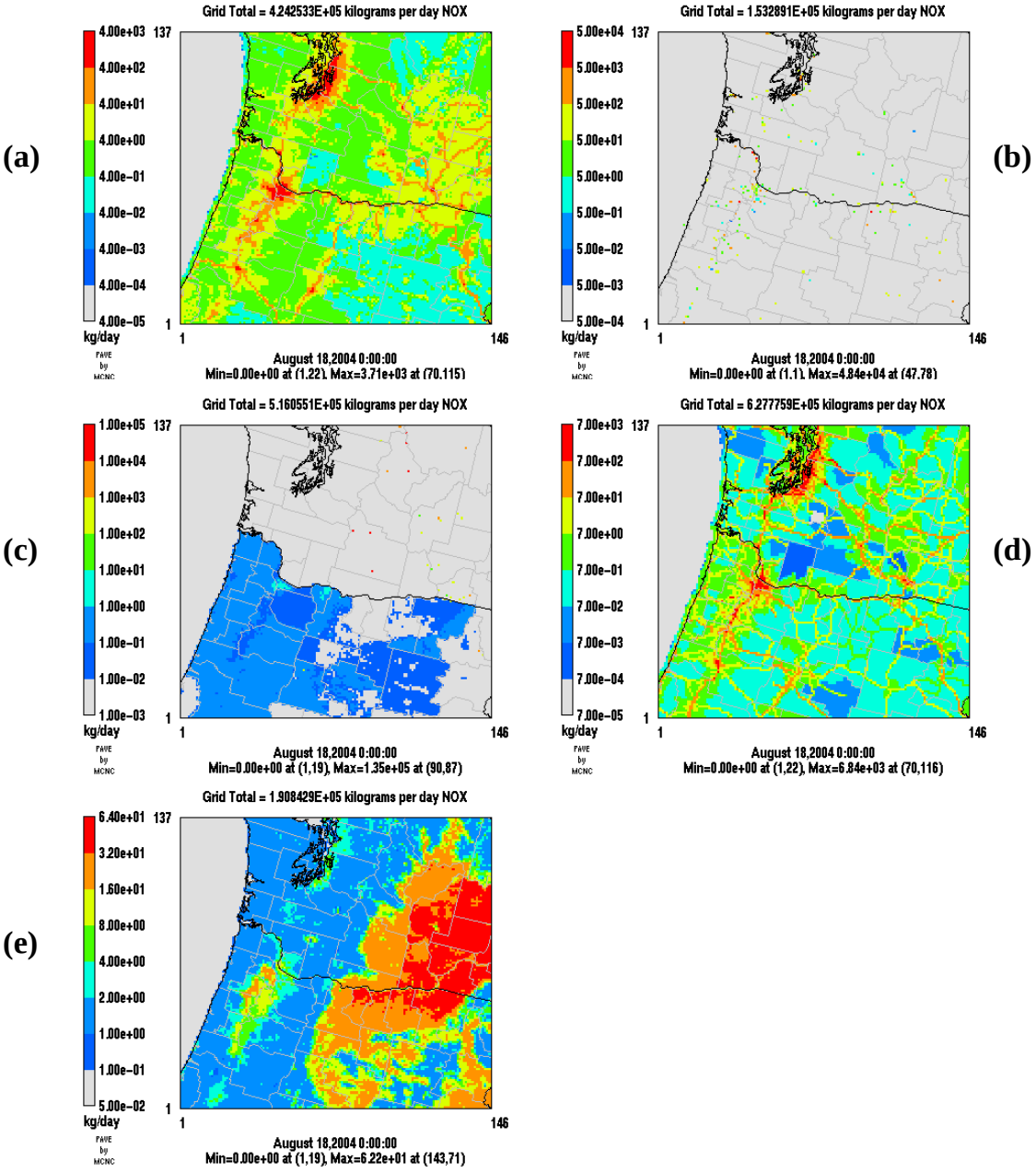


Figure 3-5. Spatial distribution of NOx emissions estimates for 18-Aug-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; (d) on-road mobile source emissions; and (e) biogenic emissions.

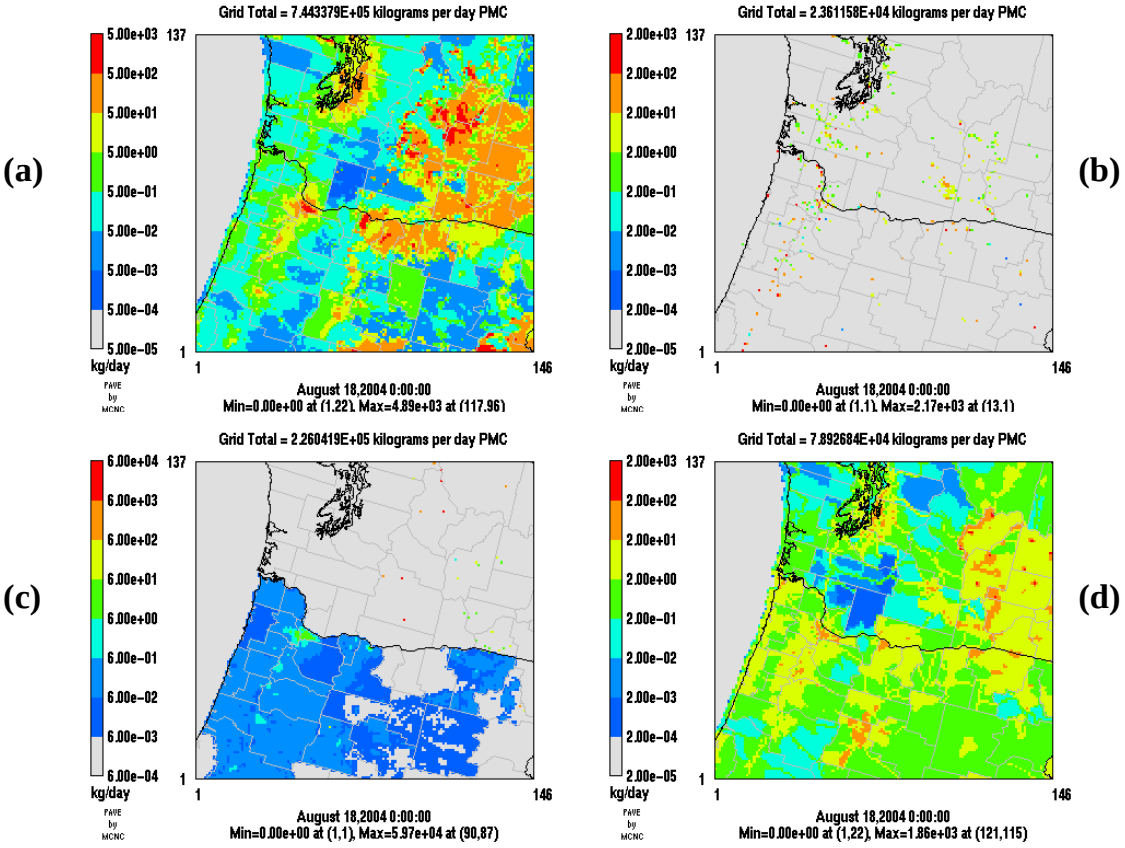


Figure 3-6. Spatial distribution of PMC emissions estimates for 18-Aug-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

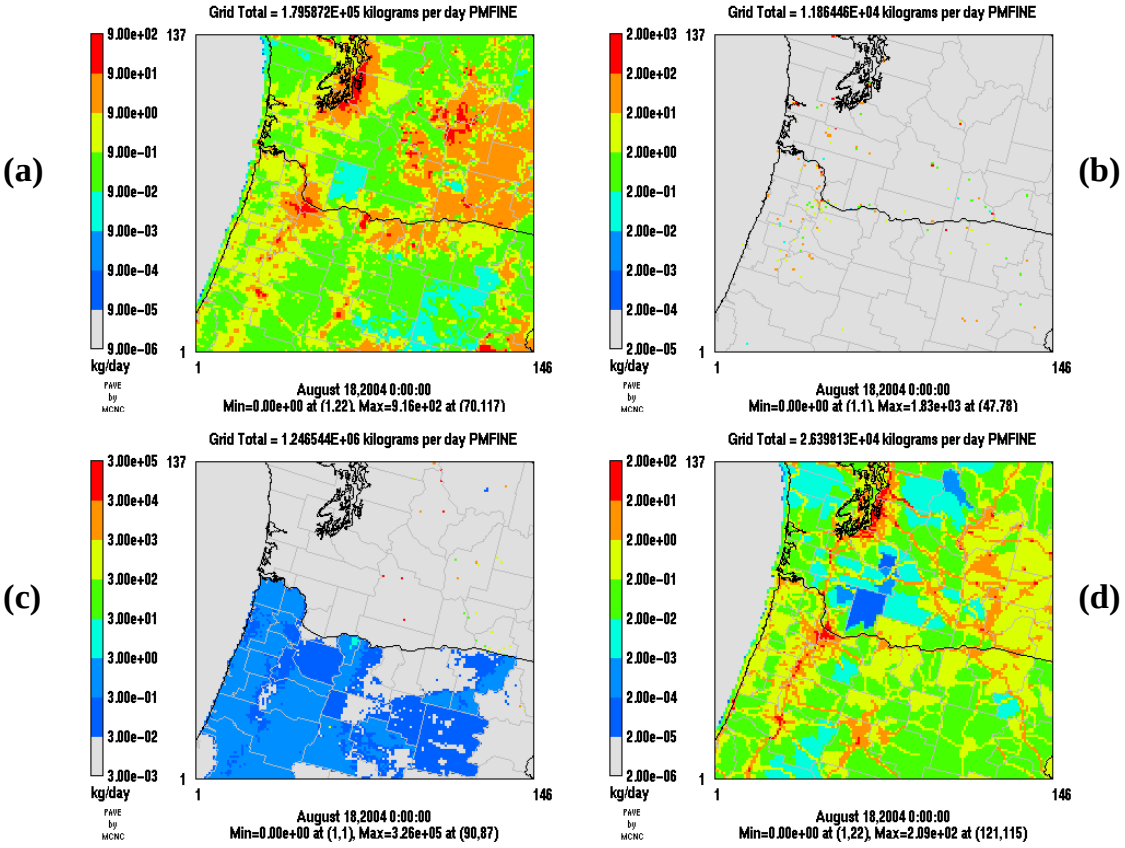


Figure 3-7. Spatial distribution of PMFINE emissions estimates for 18-Aug-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

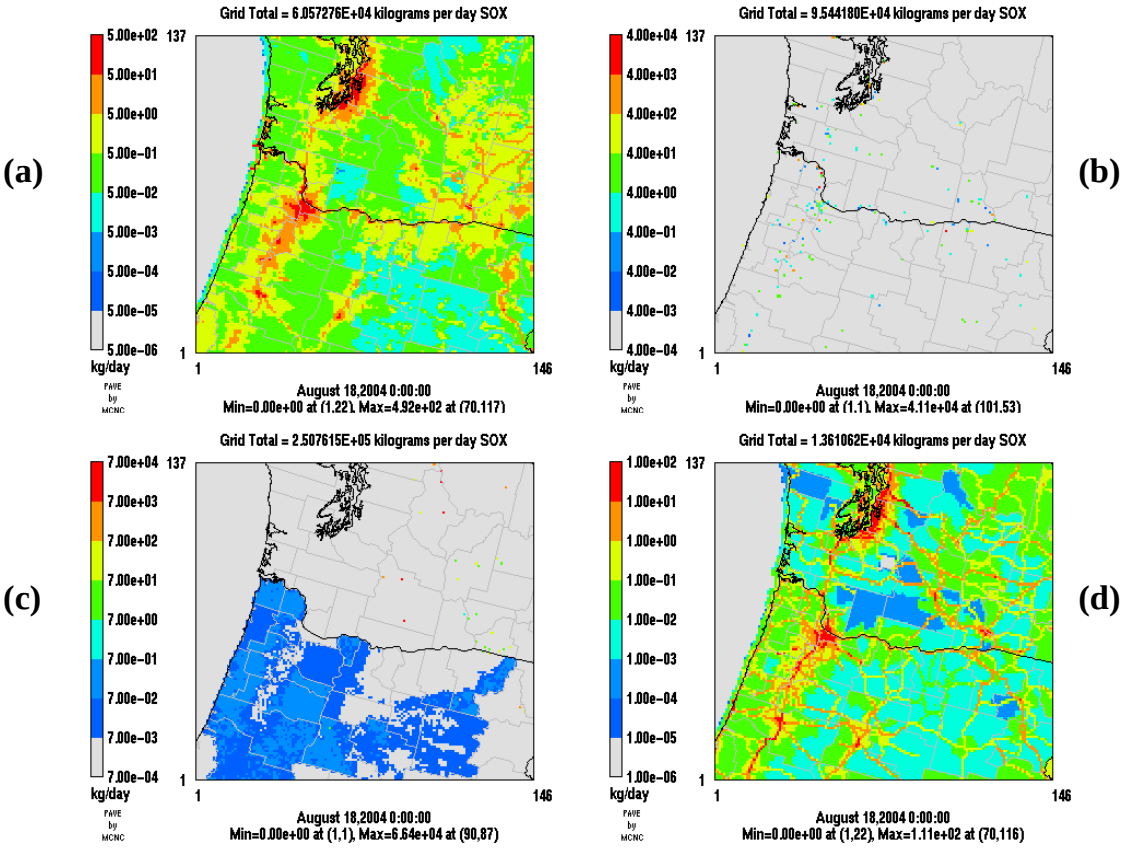


Figure 3-8. Spatial distribution of SOx emissions estimates for 18-Aug-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

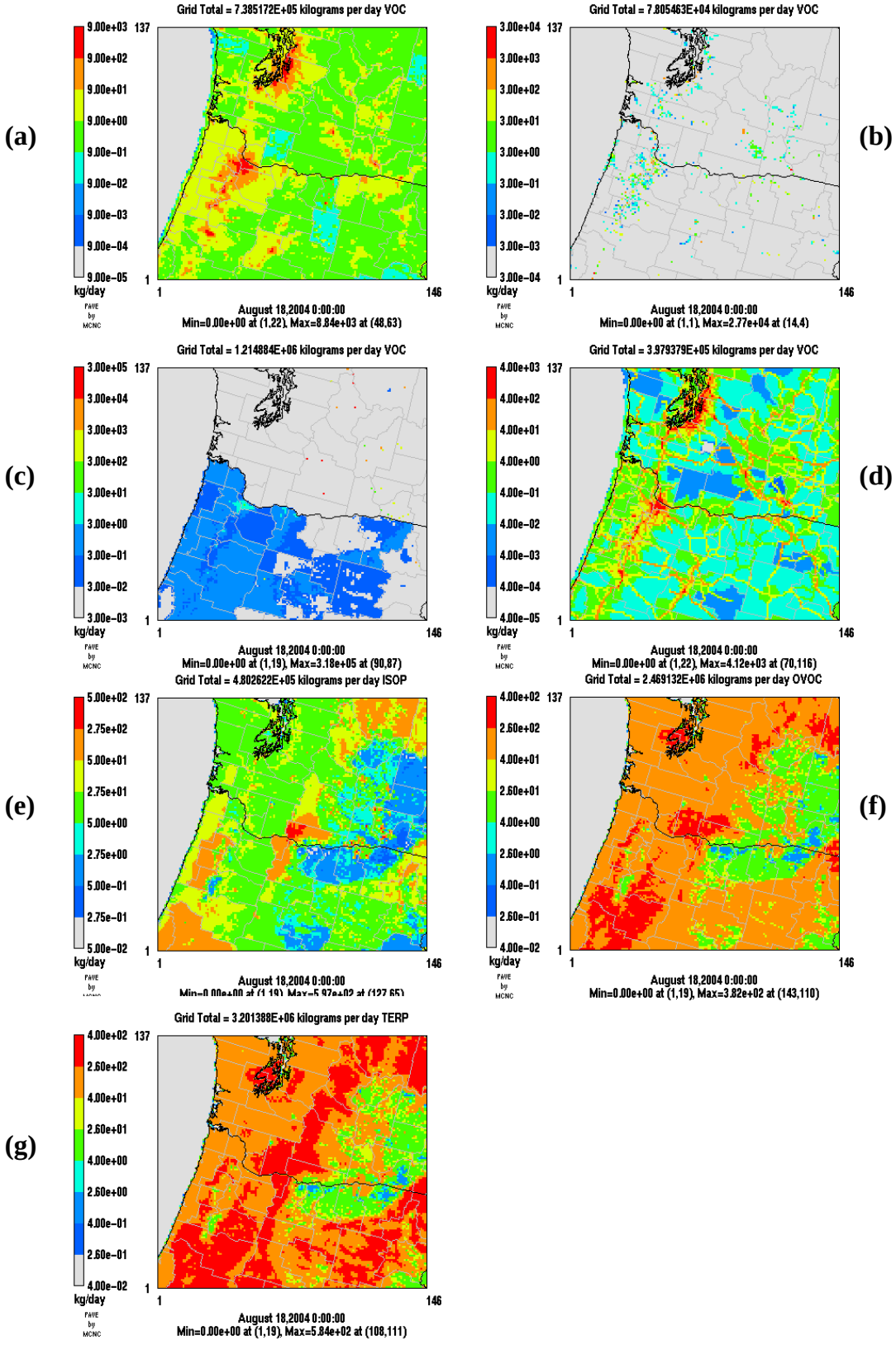


Figure 3-9. Spatial distribution of VOC emissions estimates for 18-Aug-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; (d) on-road mobile source emissions; (e) biogenic emissions – isoprene; (f) biogenic emissions – OVOCs; and (g) biogenic emissions – monterpenes.

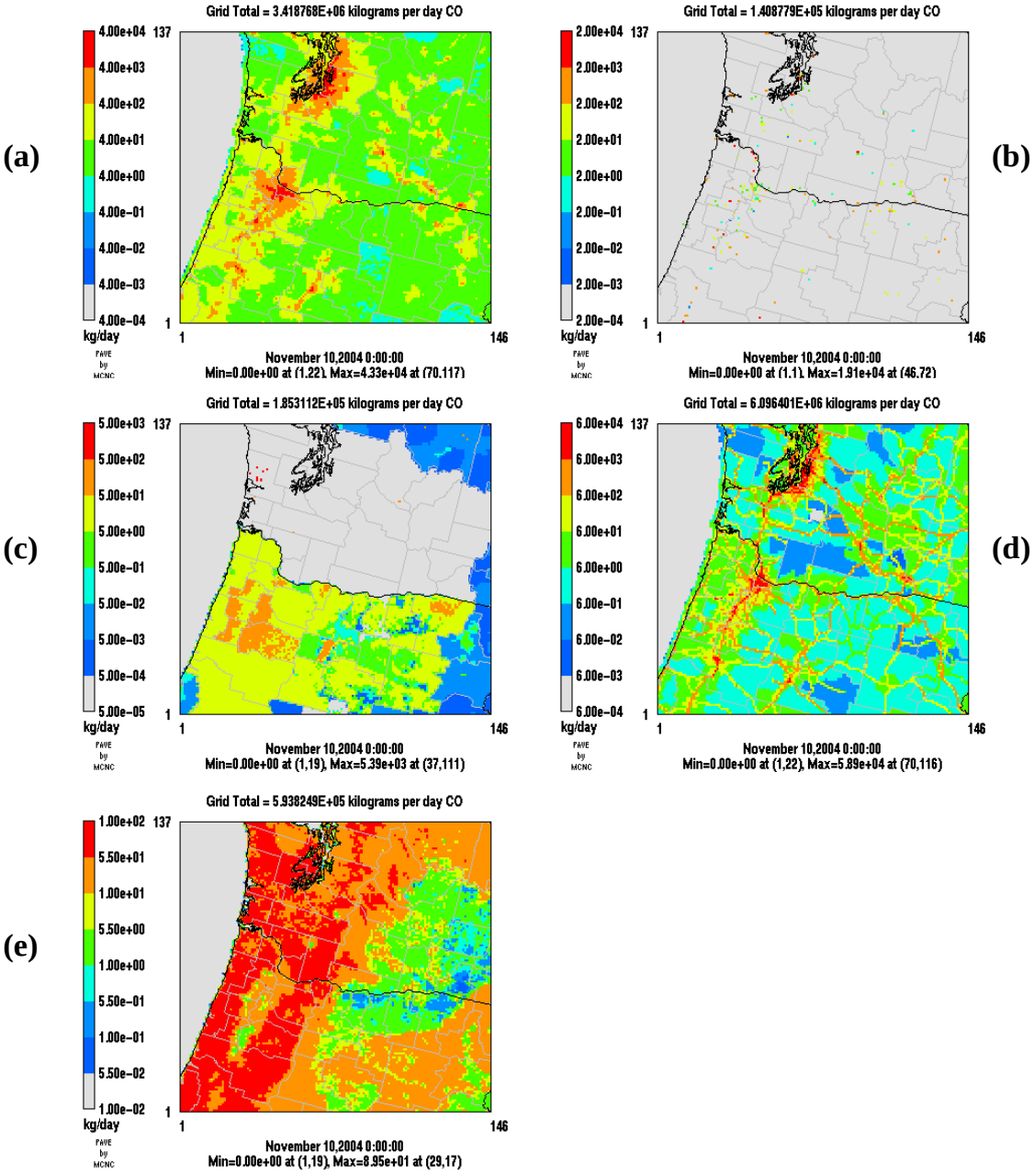


Figure 3-10. Spatial distribution of CO emissions estimates for 10-Nov-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; (d) on-road mobile source emissions; and (e) biogenic emissions.

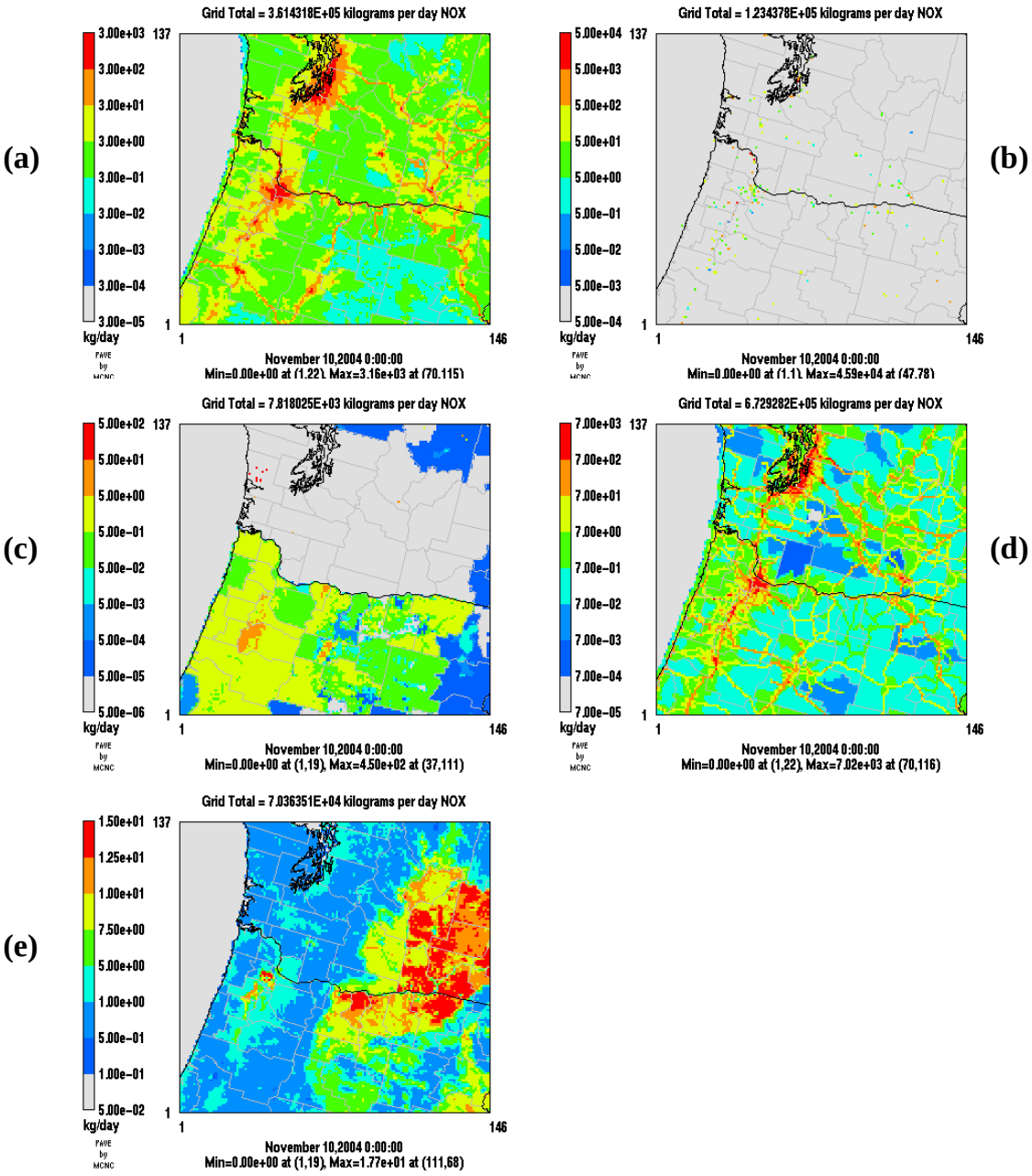


Figure 3-11. Spatial distribution of NOx emissions estimates for 10-Nov-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; (d) on-road mobile source emissions; and (e) biogenic emissions.

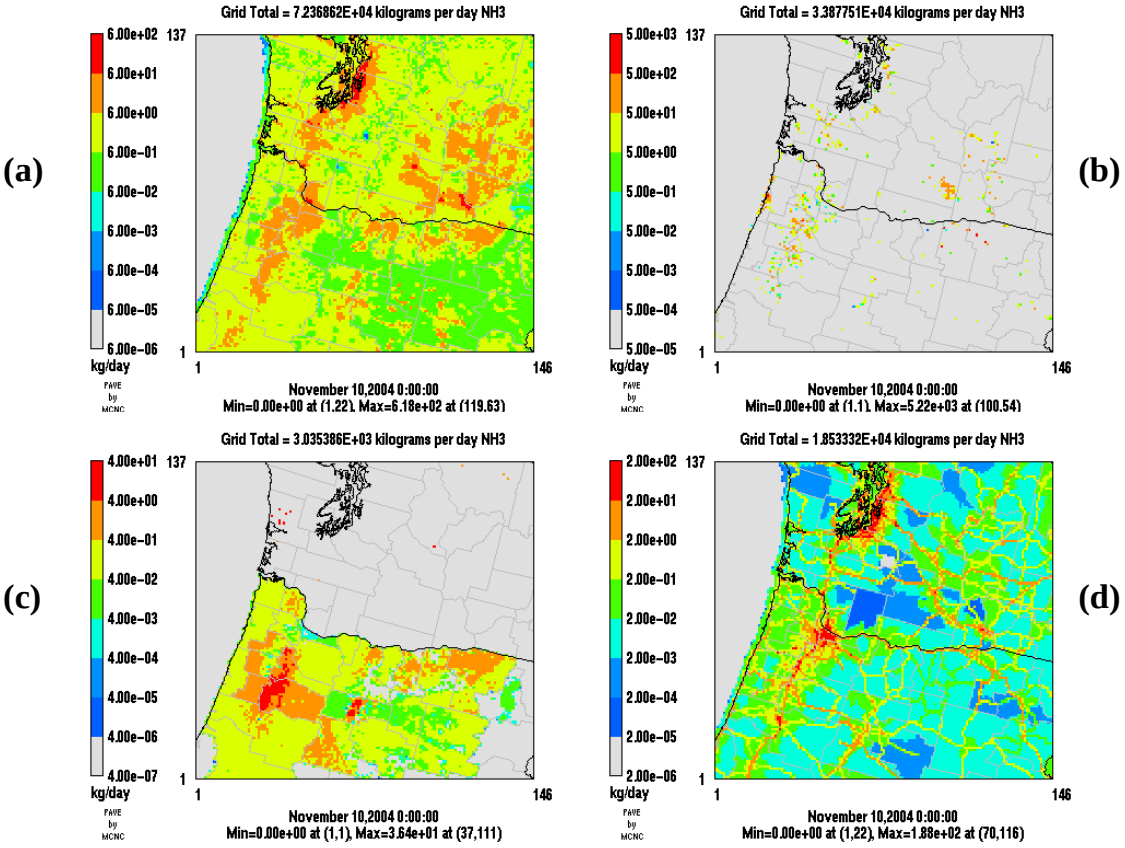


Figure 3-12. Spatial distribution of NH_3 emissions estimates for 10-Nov-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

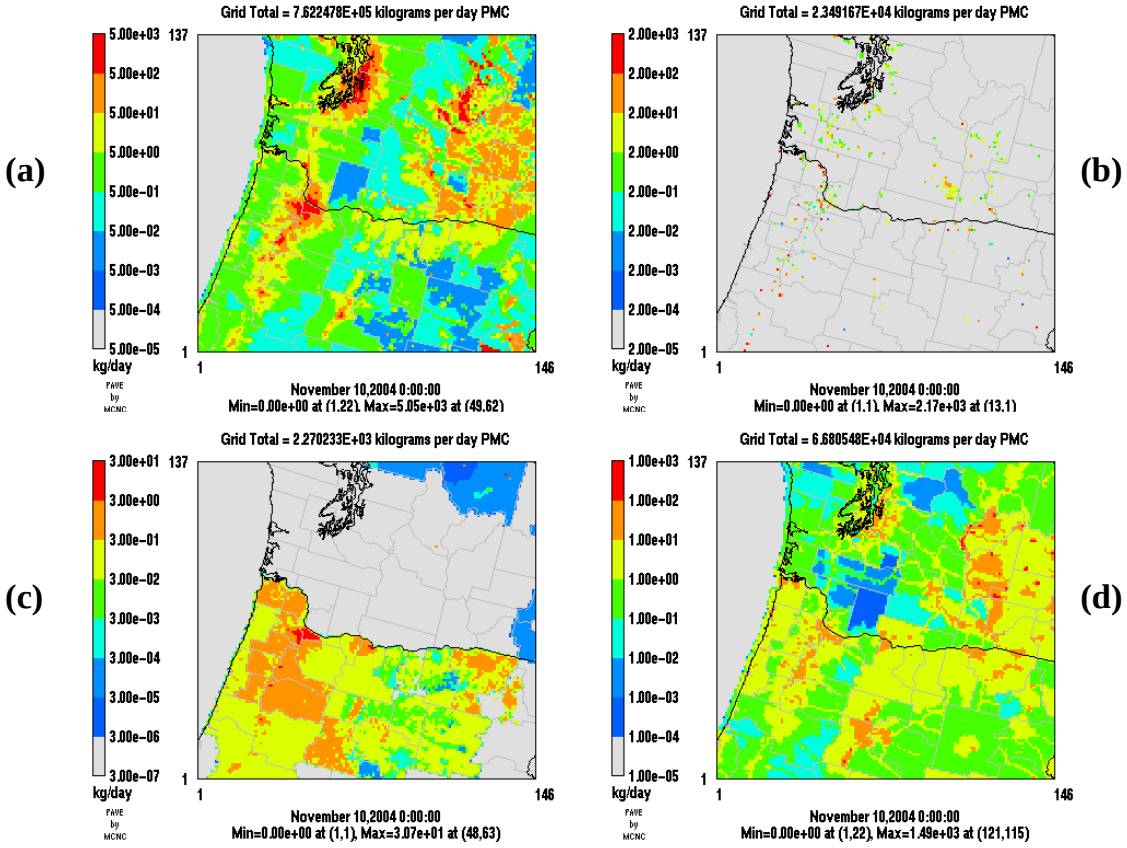


Figure 3-13. Spatial distribution of PMC emissions estimates for 10-Nov-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

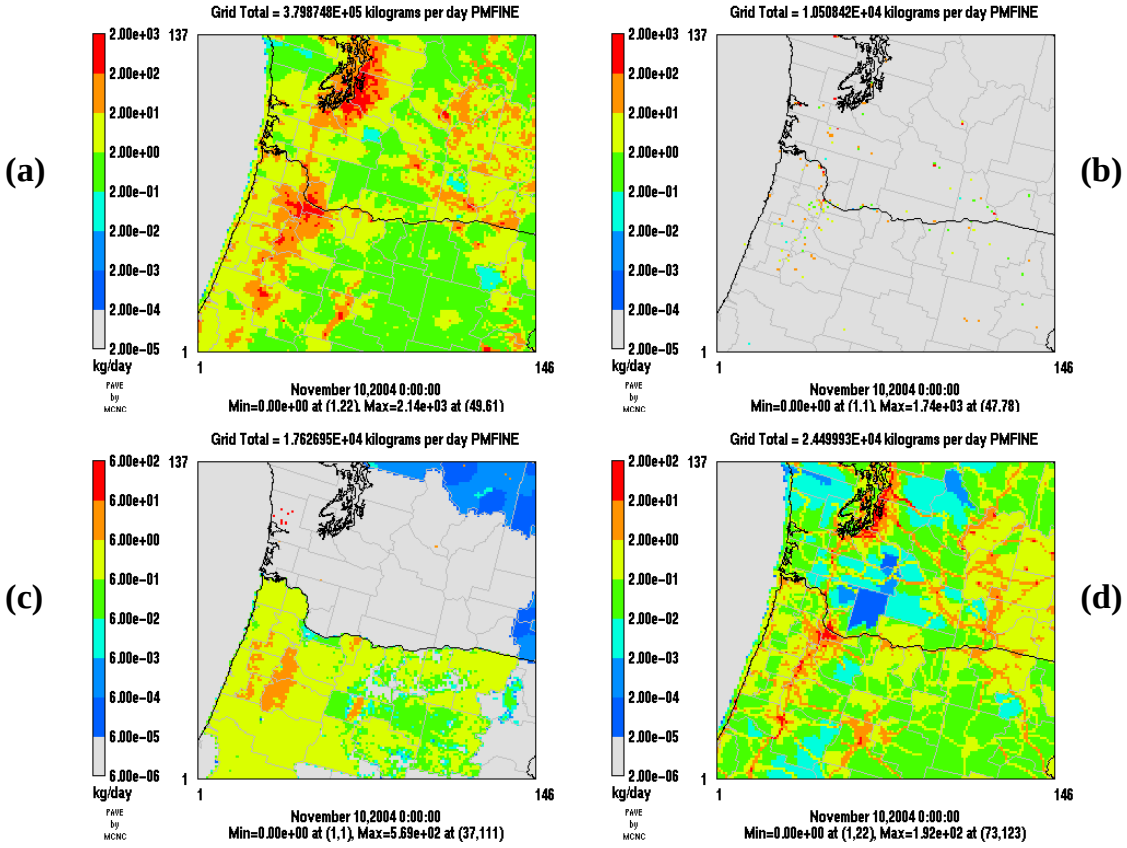


Figure 3-14. Spatial distribution of PMFINE emissions estimates for 10-Nov-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

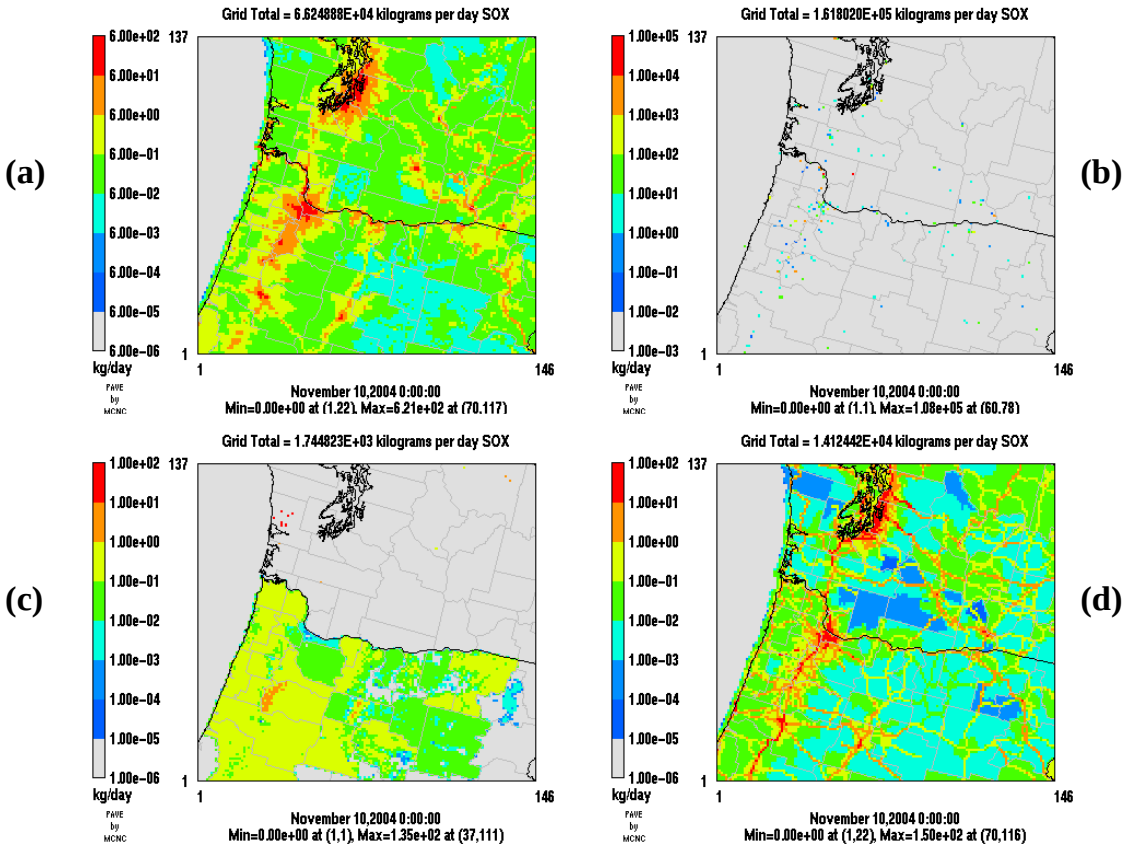


Figure 3-15. Spatial distribution of SOx emissions estimates for 10-Nov-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; and (d) on-road mobile source emissions.

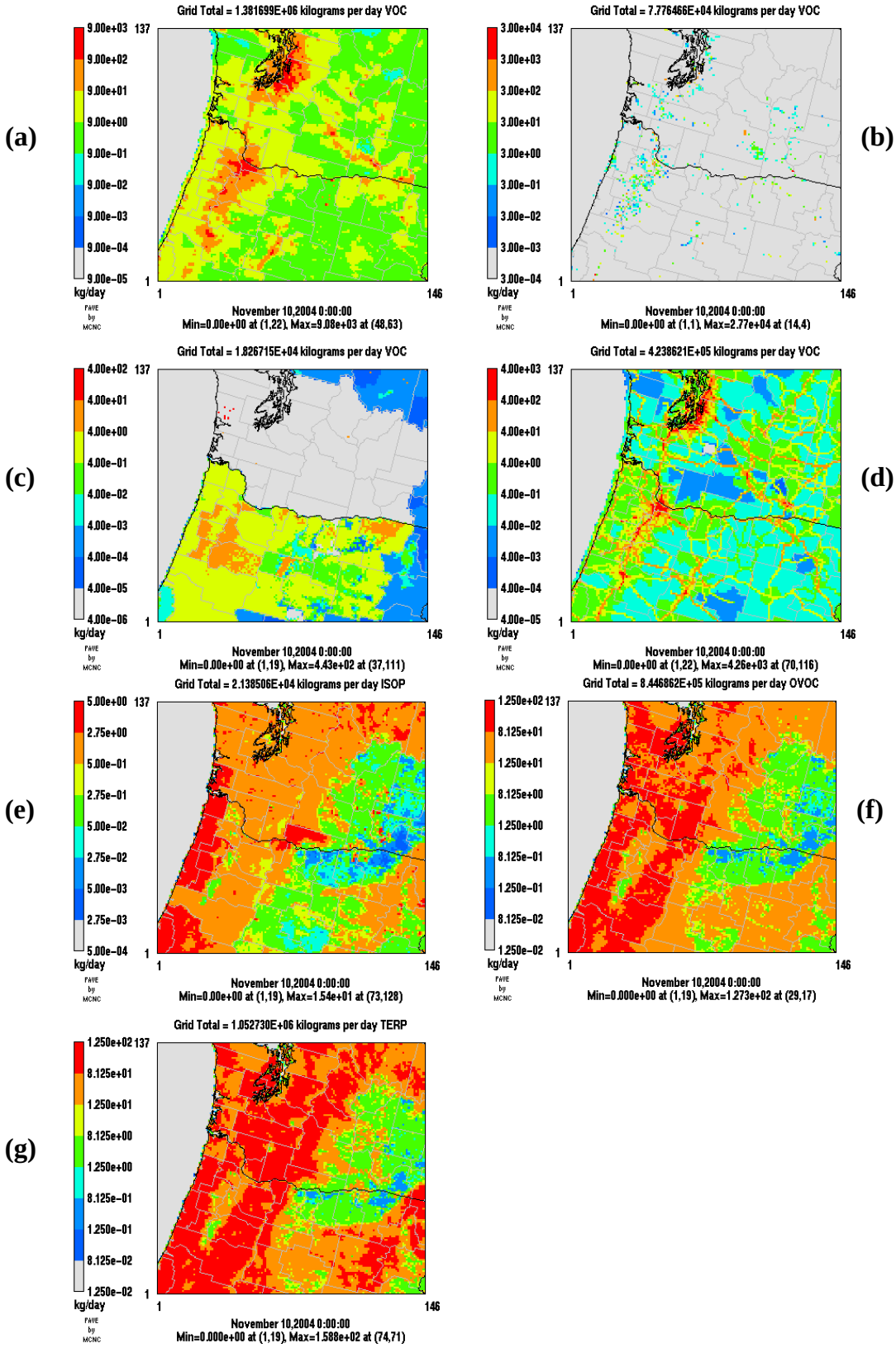


Figure 3-16. Spatial distribution of VOC emissions estimates for 10-Nov-2004. (a) area source emissions; (b) point source emissions; (c) wildfires and prescribed burns emissions; (d) on-road mobile source emissions; (e) biogenic emissions – isoprene; (f) biogenic emissions – OVOCs; and (g) biogenic emissions – monterpenes.

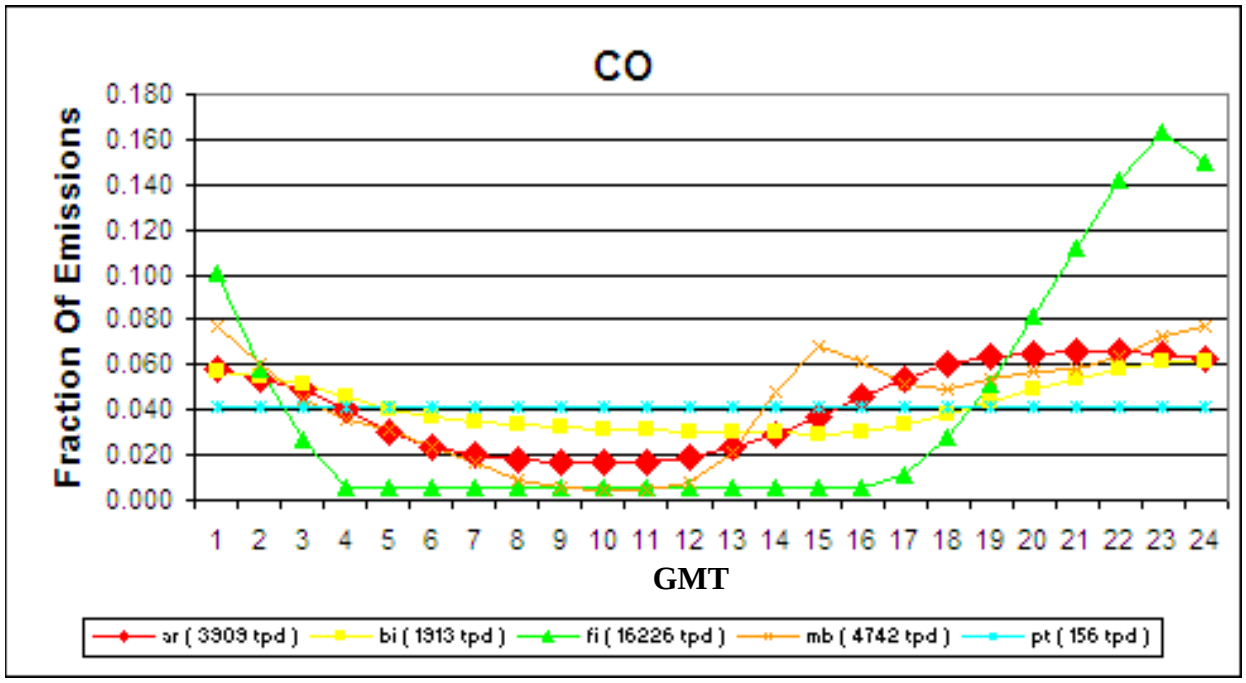


Figure 3-17. Temporal distribution of CO emissions for 18-Aug-2004.

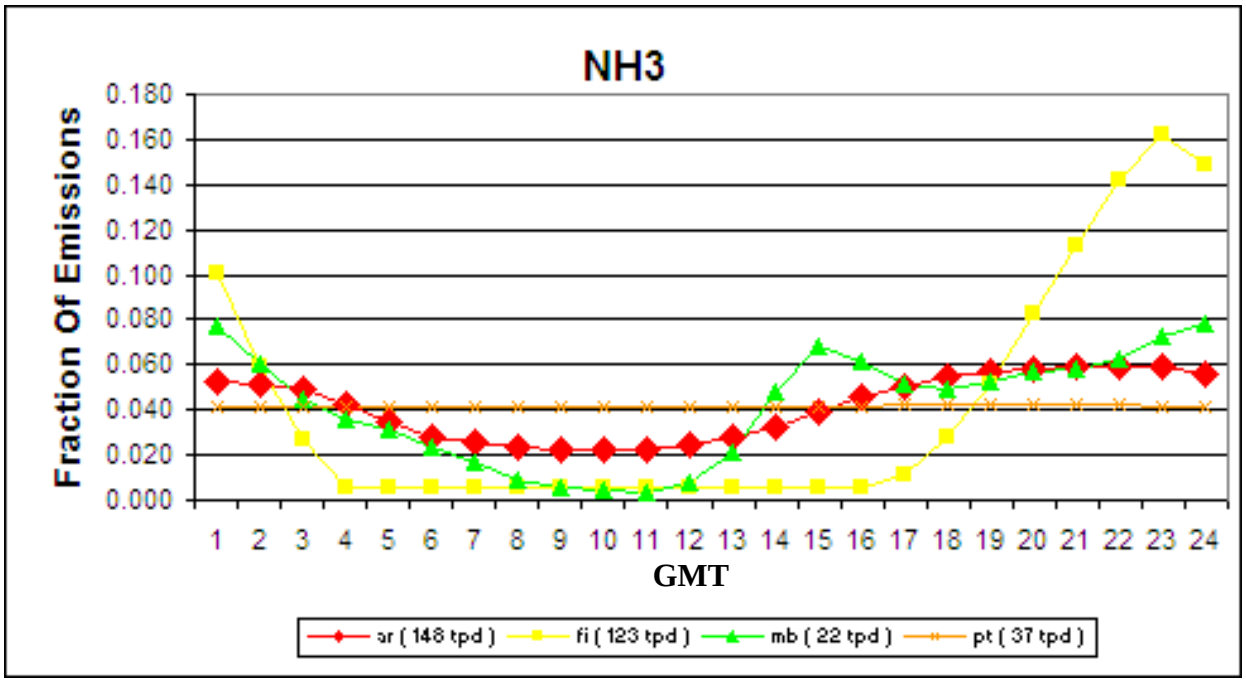


Figure 3-18. Temporal distribution of NH_3 emissions for 18-Aug-2004.

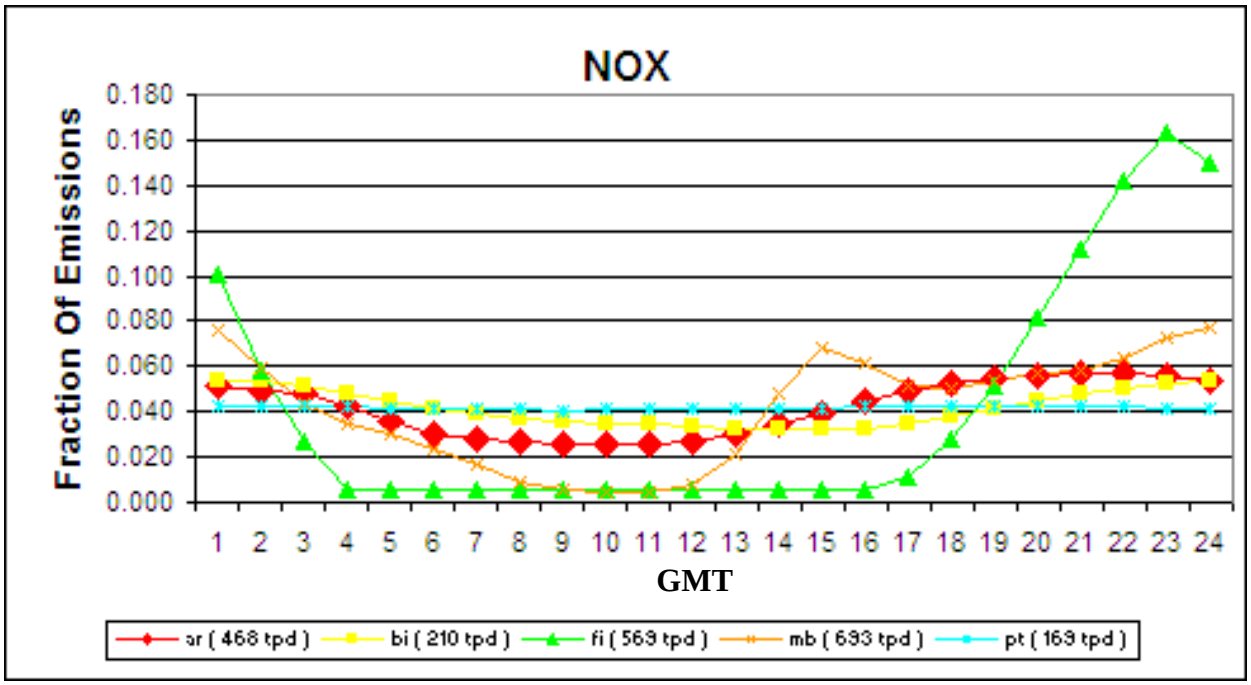


Figure 3-19. Temporal distribution of NOx emissions for 18-Aug-2004.

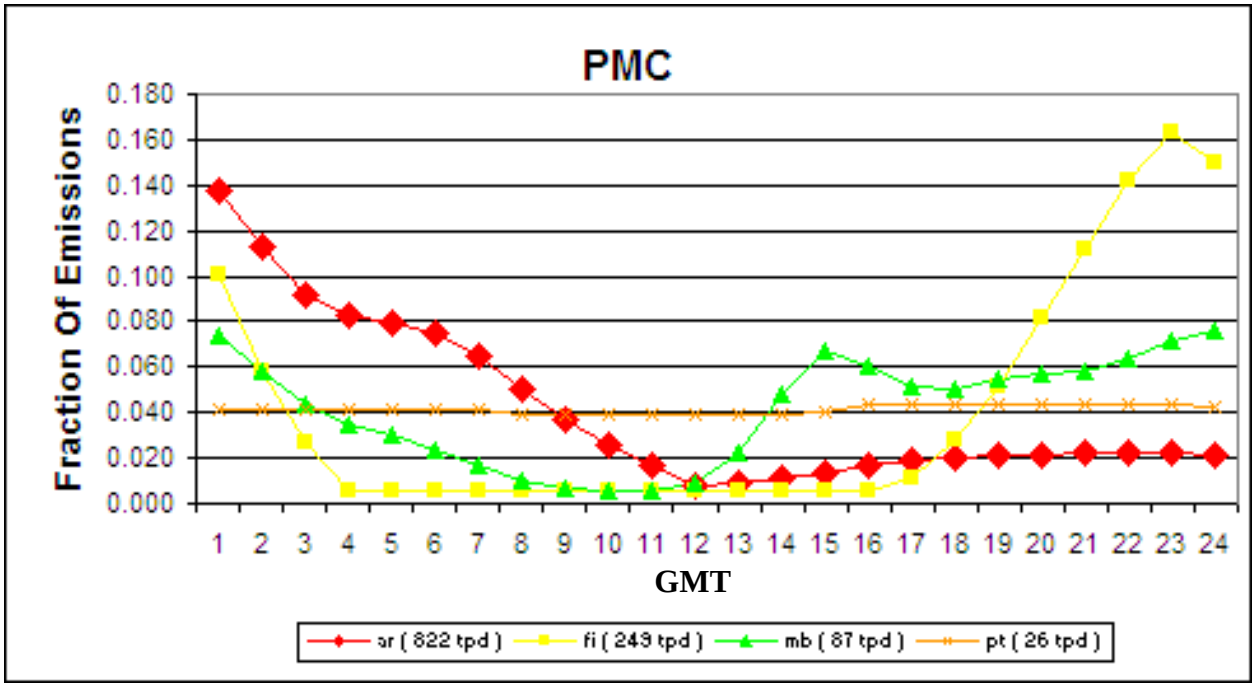


Figure 3-20. Temporal distribution of PMC emissions for 18-Aug-2004.

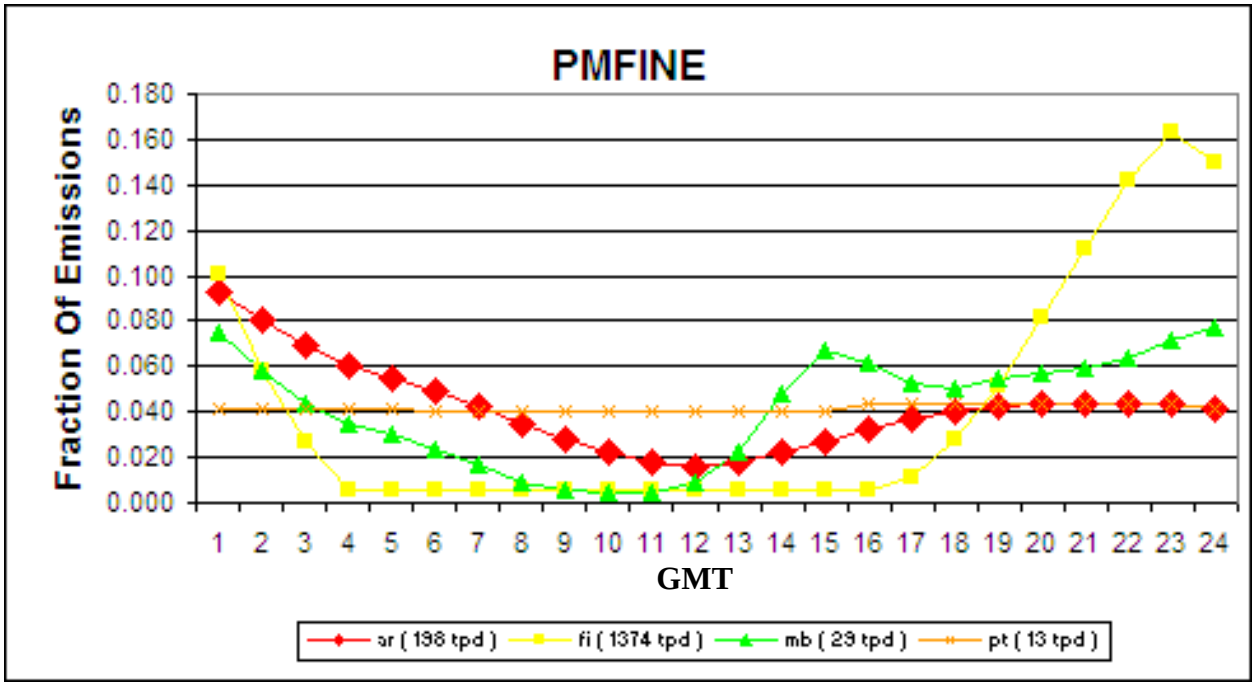


Figure 3-21. Temporal distribution of PMFINE emissions for 18-Aug-2004.

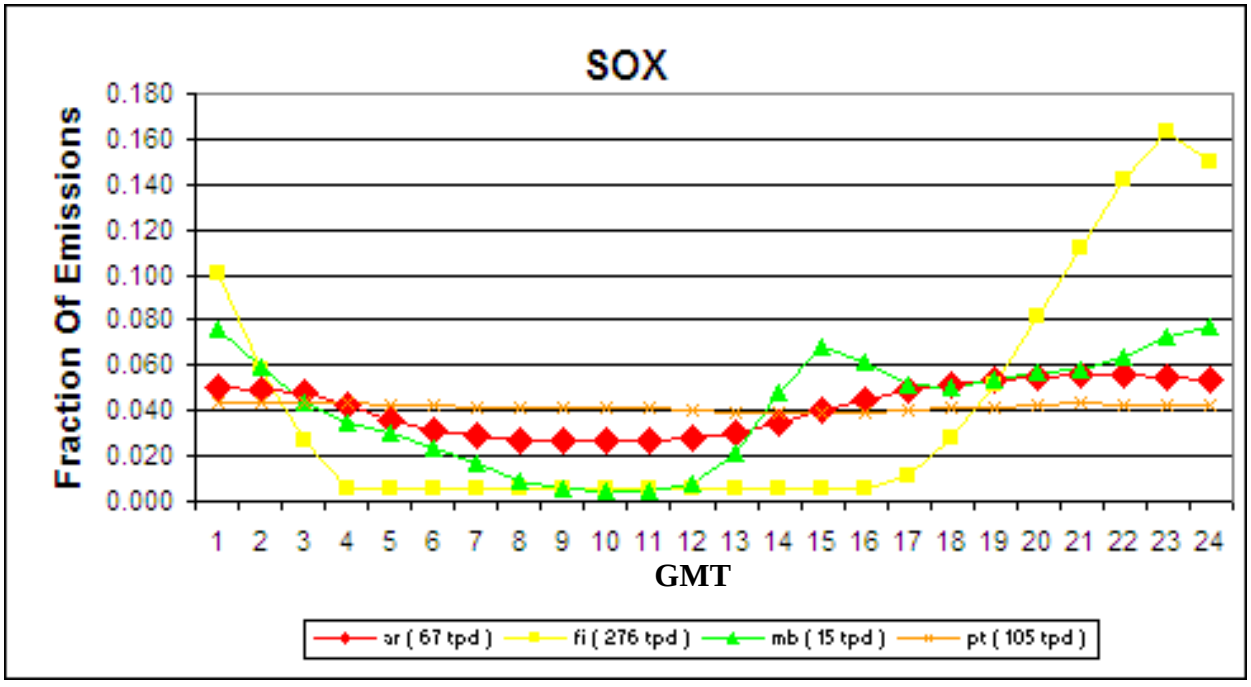


Figure 3-22. Temporal distribution of SOx emissions for 18-Aug-2004.

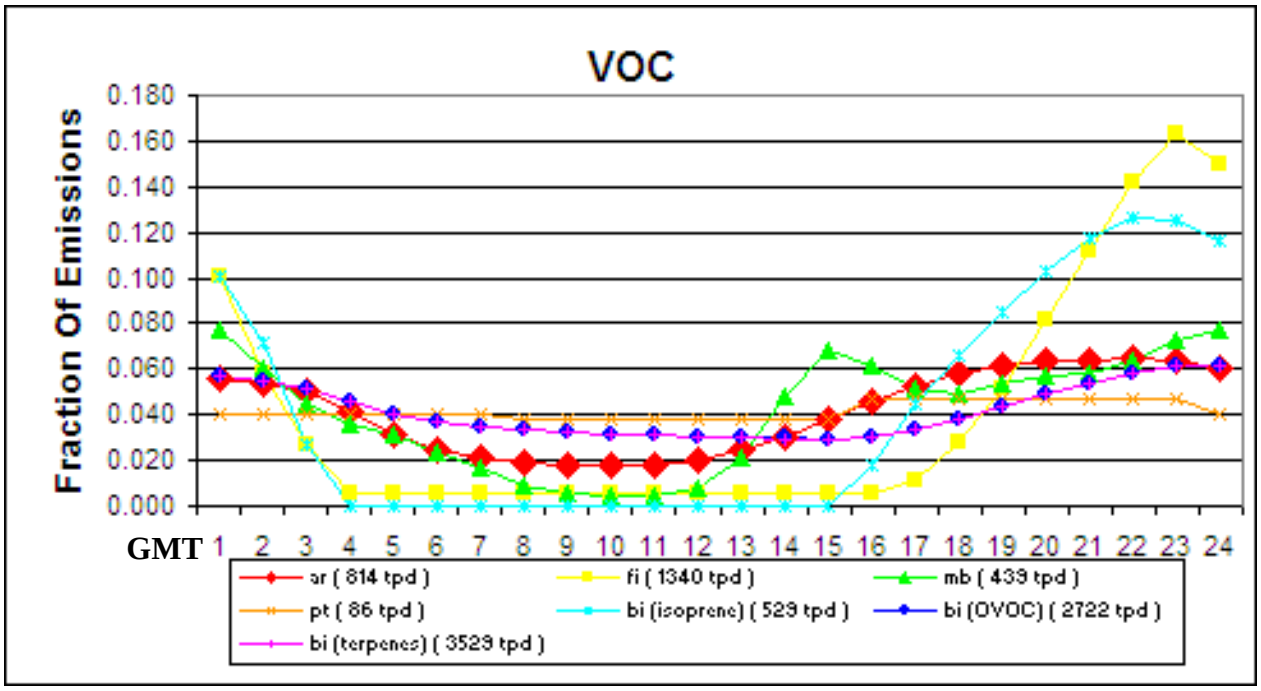


Figure 3-23. Temporal distribution of VOC emissions for 18-Aug-2004.

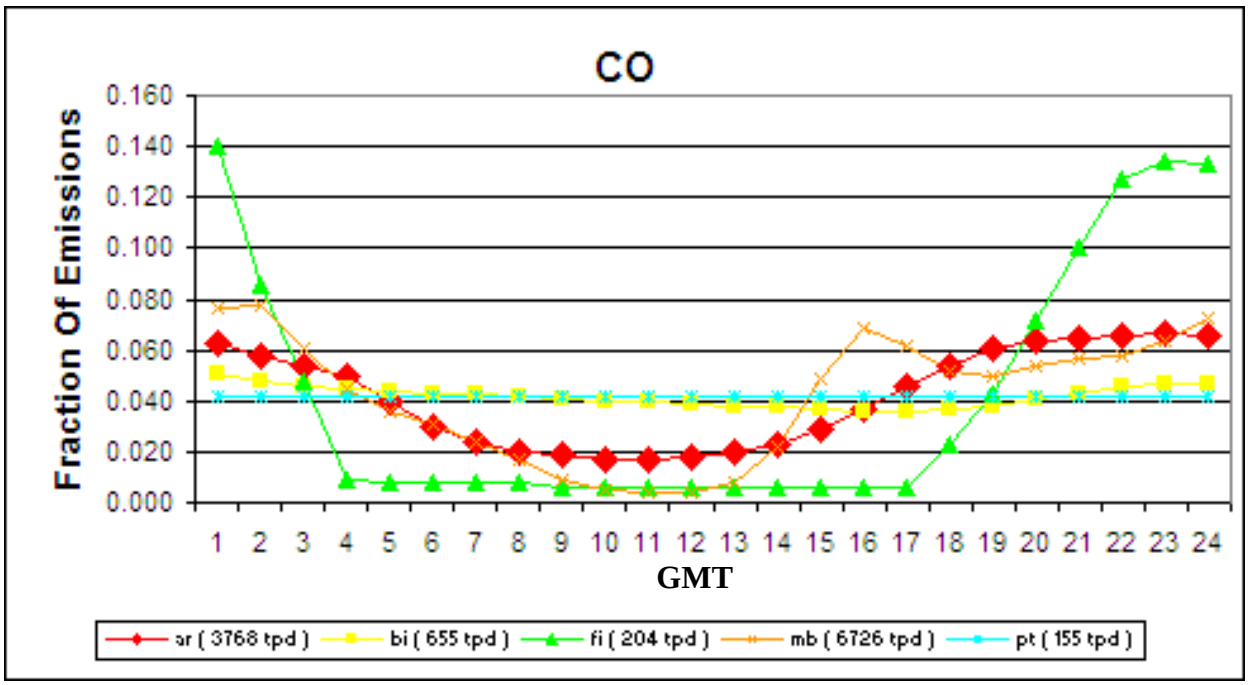


Figure 3-24. Temporal distribution of CO emissions for 10-Nov-2004.

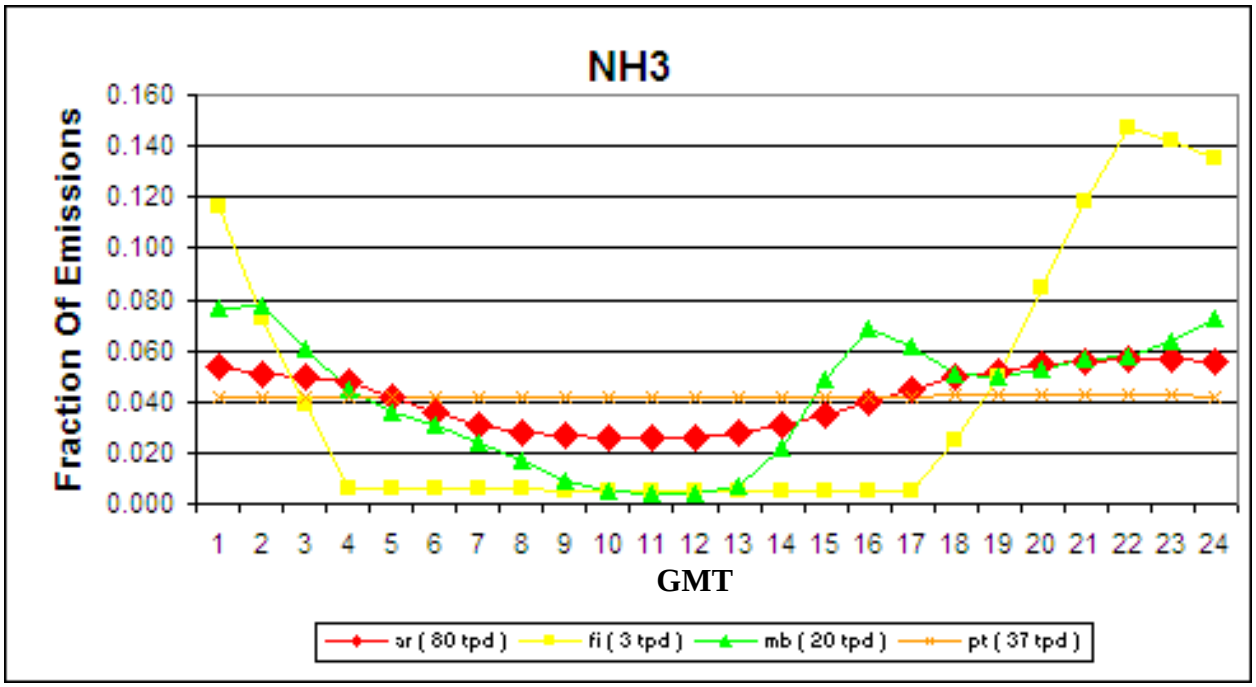


Figure 3-25. Temporal distribution of NH_3 emissions for 10-Nov-2004.

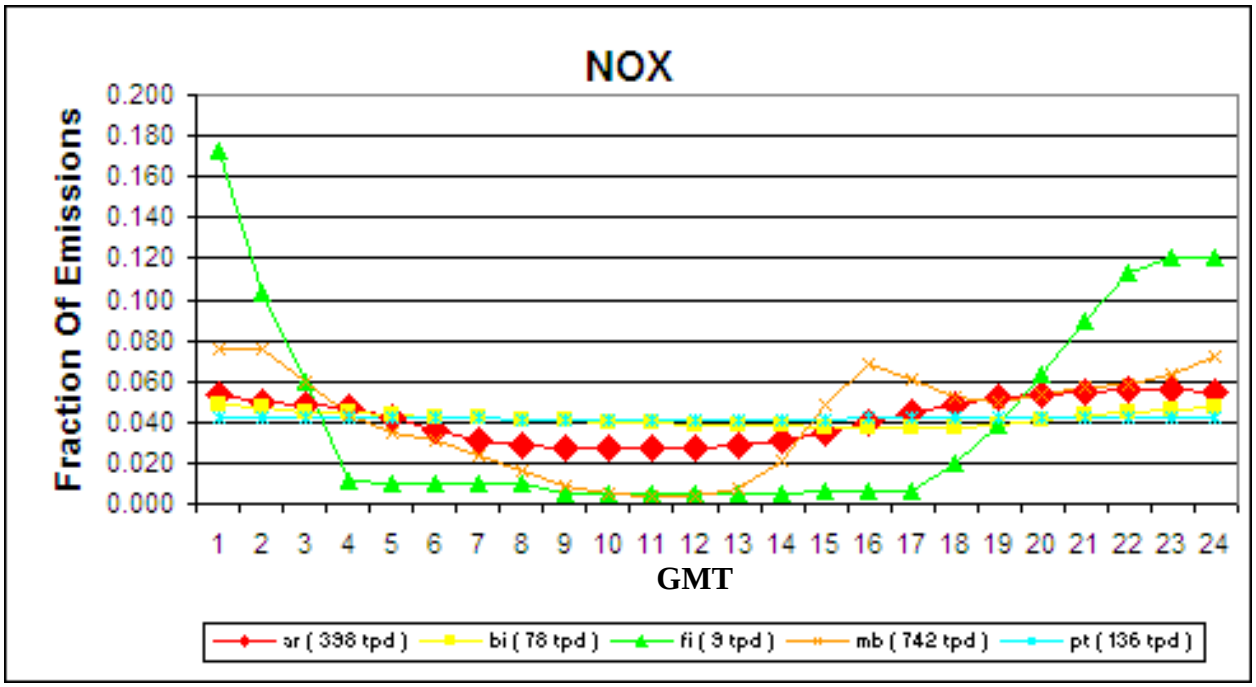


Figure 3-26. Temporal distribution of NOx emissions for 10-Nov-2004.

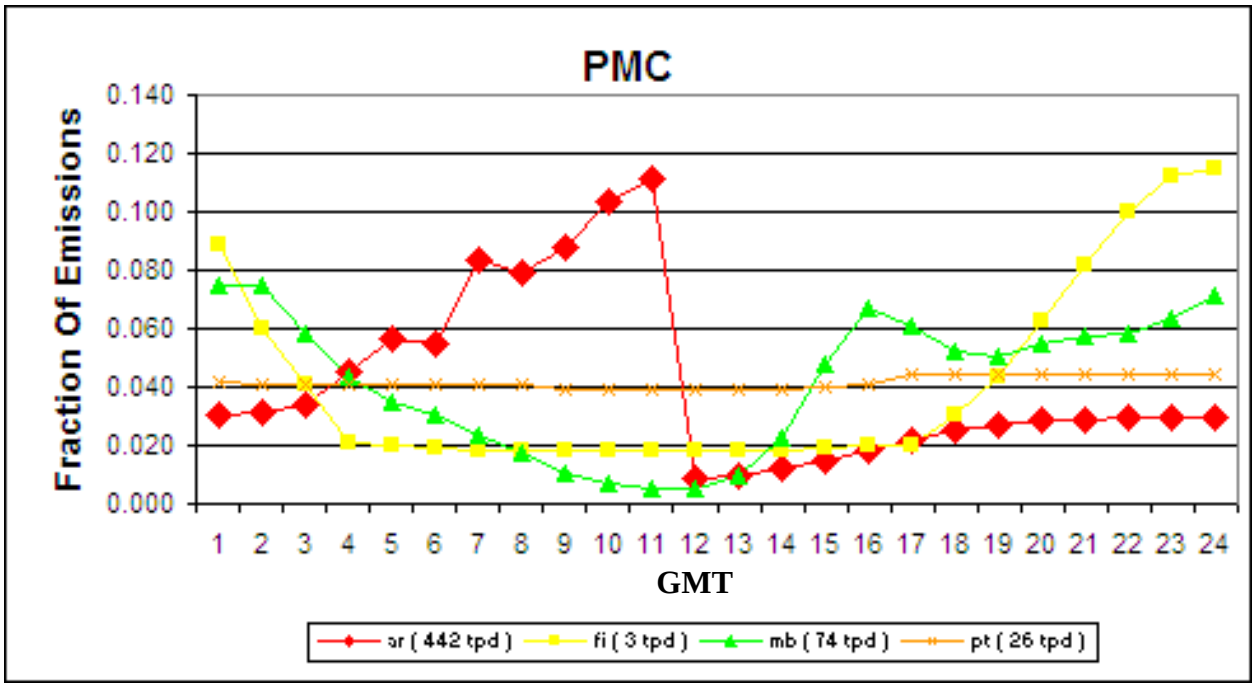


Figure 3-27. Temporal distribution of PMC emissions for 10-Nov-2004.

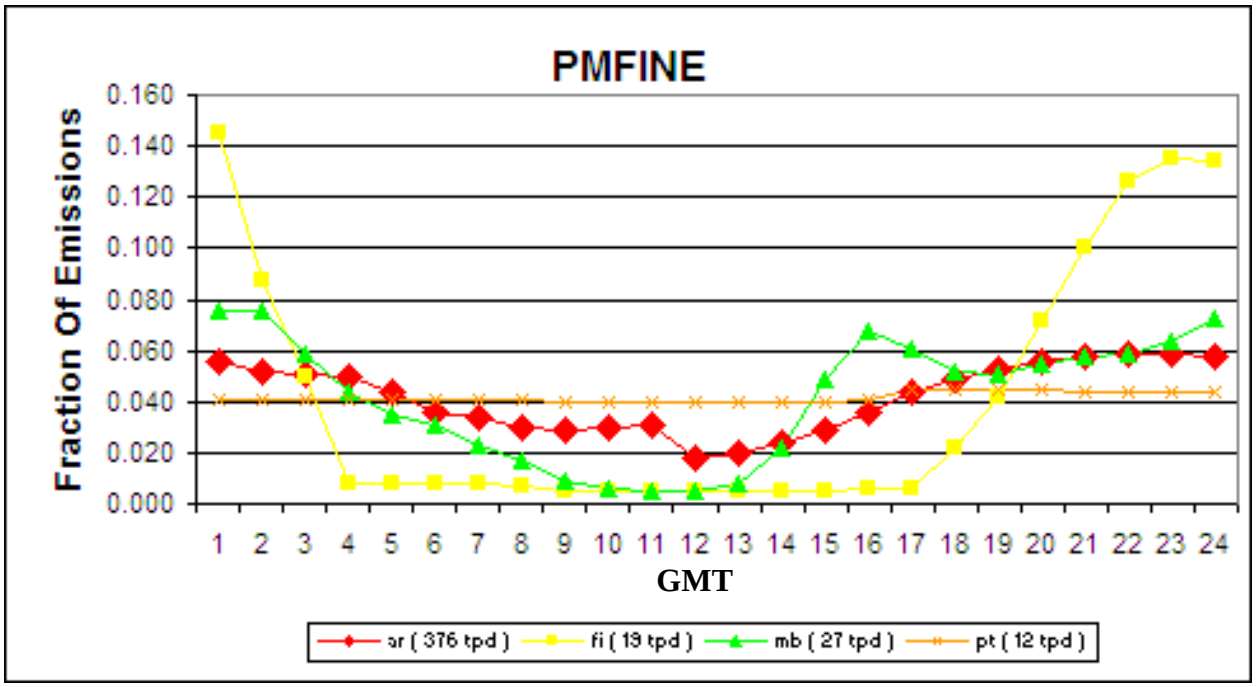


Figure 3-28. Temporal distribution of PMFINE emissions for 10-Nov-2004.

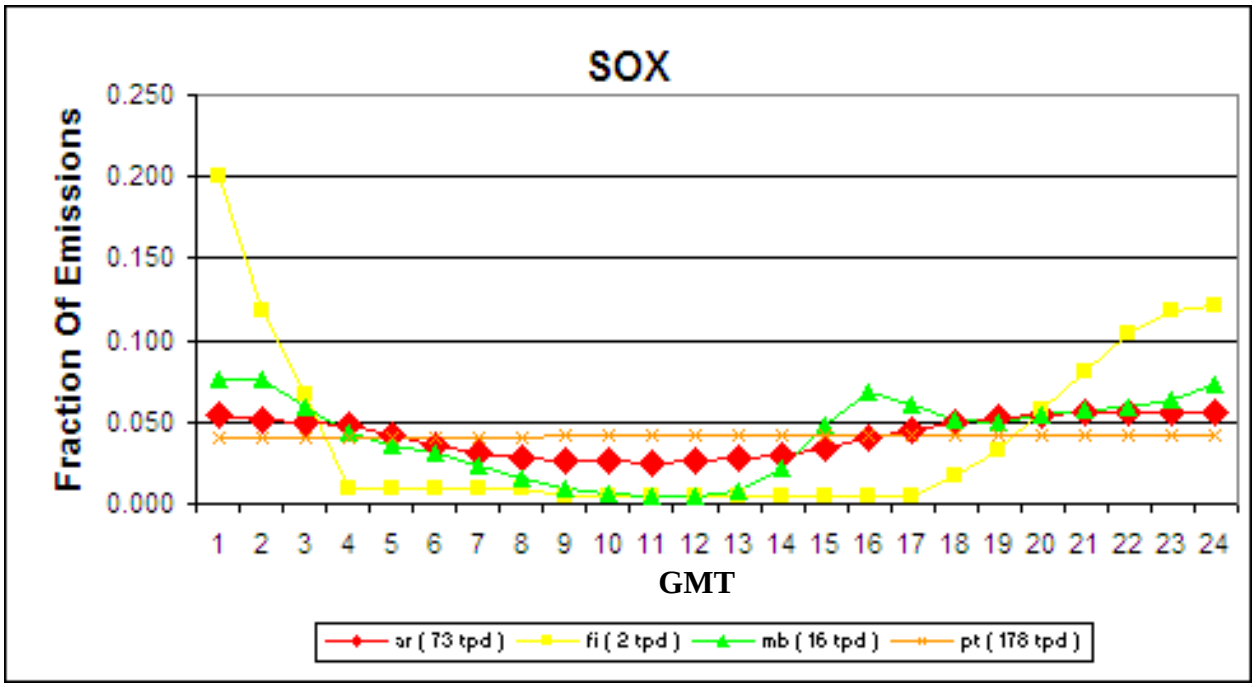


Figure 3-29. Temporal distribution of SOx emissions for 10-Nov-2004.

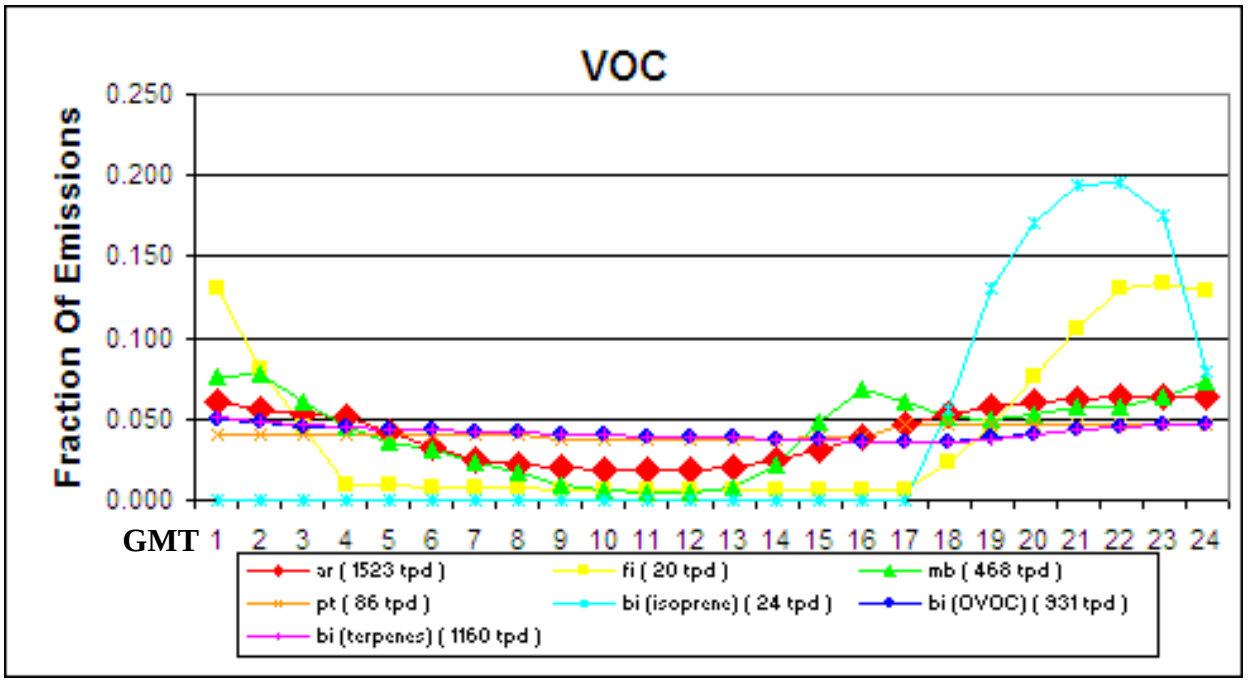


Figure 3-30. Temporal distribution of VOC emissions for 10-Nov-2004.

Table 3-7. 18-Aug-2004 emissions totals (tons per day) for Oregon counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Benton Co	Area	41.81	3.96	13.21	0.58	0.79	0.33	0.48	0	0	0
	Point	0.45	0.35	0.08	0.01	0	0.01	0.03	0	0	0
	On-road Mobile	33.49	4.10	3.11	0.10	0.15	0.31	0.13	0	0	0
	Fires	2.36	0.11	0.20	0.02	0.02	0.03	0.32	0	0	0
	Biogenic	16.67	0.55	0	0	0	0	0	10.79	25.98	23.72
County Total		94.78	9.08	16.60	0.71	0.96	0.68	0.96	10.79	25.98	23.72
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clackamas Co	Area	281.30	12.20	52.07	1.75	3.95	1.28	1.57	0	0	0
	Point	0.48	3.41	1.14	1.45	0.01	0.36	0.08	0	0	0
	On-road Mobile	133.89	20.33	13.53	0.54	0.85	0.71	0.60	0	0	0
	Fires	3.90	0.24	0.26	0.04	0.01	0.07	0.74	0	0	0
	Biogenic	48.12	0.81	0	0	0	0	0	5.93	76.42	68.45
County Total		467.70	36.99	67.00	3.78	4.82	2.42	2.99	5.93	76.42	68.45
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clatsop Co	Area	26.60	5.52	6.93	2.48	0.45	0.54	0.94	0	0	0
	Point	5.97	3.64	1.21	2.48	0.02	0.79	0.23	0	0	0
	On-road Mobile	32.04	3.74	2.99	0.09	0.13	1.44	0.25	0	0	0
	Fires	2.38	0.13	0.17	0.02	0.01	0.03	0.36	0	0	0
	Biogenic	12.88	0.19	0	0	0	0	0	5.12	17.68	18.32
County Total		79.86	13.22	11.30	5.07	0.62	2.81	1.78	5.12	17.68	18.32
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Columbia Co	Area	18.16	6.73	5.80	2.94	0.50	0.11	0.96	0	0	0
	Point	21.31	5.12	8.11	4.53	0.05	1.17	0.19	0	0	0
	On-road Mobile	27.65	3.25	2.75	0.07	0.11	0.17	0.09	0	0	0
	Fires	2.48	0.14	0.17	0.02	0.01	0.04	0.40	0	0	0
	Biogenic	15.53	0.25	0	0	0	0	0	1.63	22.42	22.09
County Total		85.14	15.48	16.83	7.57	0.67	1.48	1.64	1.63	22.42	22.09
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Gilliam Co	Area	2.93	4.07	6.75	0.65	0.75	3.00	0.35	0	0	0
	Point	0.23	0.01	0.10	0.00	0.00	0.07	0.00	0	0	0
	On-road Mobile	13.69	1.56	1.14	0.03	0.05	0.38	0.08	0	0	0
	Fires	0.06	0.00	0.00	0.00	0	0.00	0.01	0	0	0
	Biogenic	2.34	5.75	0	0	0	16.18	1.80	0.44	5.08	3.33
County Total		19.25	11.39	7.99	0.69	0.80	19.63	2.24	0.44	5.08	3.33
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Grant Co	Area	3.53	0.53	3.52	0.07	1.70	0.25	0.12	0	0	0
	Point	0.33	0.58	0.45	0.02	0.02	0.15	0.12	0	0	0
	On-road Mobile	13.44	1.46	1.39	0.03	0.04	0.51	0.09	0	0	0
	Fires	1.42	0.06	0.11	0.01	0.01	0.02	0.17	0	0	0
	Biogenic	80.78	5.33	0	0	0	1.22	0.14	14.84	190.70	114.91
County Total		99.50	7.96	5.48	0.13	1.78	2.14	0.63	14.84	190.70	114.91
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Hood River Co	Area	10.47	2.79	4.46	0.49	0.23	0.08	0.24	0	0	0
	Point	0	0	0.01	0	0	0.00	0.00	0	0	0
	On-road Mobile	21.78	2.60	1.93	0.06	0.09	0.08	0.07	0	0	0
	Fires	1.67	0.10	0.14	0.01	0.01	0.02	0.26	0	0	0
	Biogenic	16.25	0.16	0	0	0	0.12	0.01	7.86	31.66	23.12
County Total		50.17	5.65	6.54	0.56	0.32	0.31	0.57	7.86	31.66	23.12

Table 3-7. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Jefferson Co	Area	11.56	1.45	3.97	0.17	0.78	0.75	0.26	0	0	0
	Point	0.15	0.26	0.89	0.00	0.02	0.04	0	0	0	0
	On-road Mobile	19.64	2.21	1.99	0.05	0.07	2.01	0.28	0	0	0
	Fires	0.78	0.05	0.05	0.01	0.00	0.01	0.15	0	0	0
	Biogenic	24.71	3.67	0	0	0	1.17	0.13	5.32	54.23	35.15
County Total		56.83	7.63	6.90	0.23	0.87	3.99	0.82	5.32	54.23	35.15
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Lincoln Co	Area	25.68	1.15	7.36	0.13	0.29	0.46	0.35	0	0	0
	Point	6.61	2.68	2.42	1.21	0.00	1.89	0.05	0	0	0
	On-road Mobile	33.27	3.99	3.05	0.09	0.14	0.98	0.20	0	0	0
	Fires	2.69	0.14	0.19	0.03	0.01	0.04	0.42	0	0	0
	Biogenic	22.53	0.24	0	0	0	0	0	7.11	32.50	32.05
County Total		90.79	8.21	13.02	1.46	0.45	3.38	1.03	7.11	32.50	32.05
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Linn Co	Area	55.90	5.55	17.06	0.85	2.74	0.85	0.76	0	0	0
	Point	20.03	3.72	3.91	5.21	0.05	2.83	0.45	0	0	0
	On-road Mobile	110.98	12.94	10.54	0.28	0.41	1.14	0.42	0	0	0
	Fires	5.40	0.23	0.45	0.05	0.05	0.07	0.66	0	0	0
	Biogenic	61.21	1.07	0	0	0	0	0	8.96	98.55	87.08
County Total		253.52	23.52	31.97	6.39	3.26	4.90	2.29	8.96	98.55	87.08
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Marion Co	Area	124.22	10.02	32.45	1.50	4.87	2.62	1.57	0	0	0
	Point	0.07	0.82	0.43	0.02	0	0.04	0.01	0	0	0
	On-road Mobile	173.29	21.47	16.57	0.48	0.74	1.65	0.67	0	0	0
	Fires	3.17	0.15	0.28	0.03	0.01	0.05	0.55	0	0	0
	Biogenic	24.82	1.15	0	0	0	0	0	4.49	40.10	35.30
County Total		325.57	33.62	49.73	2.03	5.63	4.35	2.80	4.49	40.10	35.30
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Morrow Co	Area	7.36	2.96	8.15	0.54	20.35	3.89	0.43	0	0	0
	Point	2.53	30.89	0.29	43.96	0.30	0.83	1.60	0	0	0
	On-road Mobile	17.50	2.04	1.52	0.04	0.07	0.93	0.15	0	0	0
	Fires	0.78	0.04	0.06	0.01	0.00	0.01	0.12	0	0	0
	Biogenic	12.11	8.66	0	0	0	13.96	1.55	4.29	26.84	17.23
County Total		40.28	44.59	10.02	44.55	20.72	19.62	3.85	4.29	26.84	17.23
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Multnomah Co	Area	307.37	26.68	88.54	4.02	1.03	17.61	4.33	0	0	0
	Point	1.84	2.54	4.46	0.67	0.00	1.10	0.50	0	0	0
	On-road Mobile	251.62	39.63	25.79	1.03	1.64	1.59	1.21	0	0	0
	Fires	0.41	0.01	0.05	0.00	0.00	0.00	0.09	0	0	0
	Biogenic	8.28	0.29	0	0	0	0	0	1.49	12.14	11.78
County Total		569.53	69.14	118.84	5.72	2.68	20.31	6.13	1.49	12.14	11.78
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Polk Co	Area	19.67	2.27	7.54	0.33	1.62	0.40	0.37	0	0	0
	Point	0.02	0.01	0.70	0.00	0.00	0.04	0.00	0	0	0
	On-road Mobile	38.41	4.69	3.79	0.11	0.16	0.56	0.17	0	0	0
	Fires	2.61	0.13	0.20	0.02	0.02	0.04	0.38	0	0	0
	Biogenic	16.94	0.81	0	0	0	0	0	16.80	25.64	24.10
County Total		77.65	7.91	12.23	0.46	1.80	1.03	0.92	16.80	25.64	24.10
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Sherman Co	Area	2.77	2.84	0.68	0.34	0.91	3.34	0.30	0	0	0
	Point	0.61	0.48	0.04	0.01	0.05	0.02	0	0	0	0
	On-road Mobile	11.66	1.30	1.03	0.03	0.04	0.55	0.09	0	0	0
	Fires	0.06	0.00	0.00	0.00	0	0.00	0.01	0	0	0
	Biogenic	1.31	4.35	0	0	0	26.00	2.89	0.34	2.98	1.86
County Total		16.41	8.98	1.75	0.37	1.00	29.91	3.30	0.34	2.98	1.86

Table 3-7. (concluded)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Tillamook Co	Area	17.34	1.02	6.41	0.13	4.57	0.27	0.27	0	0	0
	Point	1.11	0.21	0.25	0.12	0.01	0.61	0.04	0	0	0
	On-road Mobile	28.58	3.32	2.56	0.08	0.12	0.98	0.19	0	0	0
	Fires	1.37	0.08	0.10	0.01	0.01	0.02	0.22	0	0	0
	Biogenic	21.45	0.27	0	0	0	0	0	7.35	31.92	30.51
County Total		69.86	4.90	9.31	0.34	4.71	1.88	0.73	7.35	31.92	30.51
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Umatilla Co	Area	34.80	12.55	13.90	1.38	5.41	8.13	1.26	0	0	0
	Point	0.72	1.50	0.39	0.20	0.91	0.56	0.05	0	0	0
	On-road Mobile	64.27	7.56	6.02	0.16	0.24	4.02	0.63	0	0	0
	Fires	4.23	0.23	0.30	0.04	0.02	0.07	0.67	0	0	0
	Biogenic	32.78	13.88	0	0	0	0.99	0.11	10.29	73.05	46.62
County Total		136.79	35.73	20.61	1.78	6.58	13.77	2.72	10.29	73.05	46.62
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wasco Co	Area	13.83	5.13	4.94	0.71	1.35	2.00	0.48	0	0	0
	Point	0.01	0.04	0.05	0.00	0	0.02	0.02	0	0	0
	On-road Mobile	36.50	4.29	3.44	0.09	0.13	1.82	0.30	0	0	0
	Fires	1.64	0.09	0.13	0.02	0.01	0.02	0.25	0	0	0
	Biogenic	28.18	6.91	0	0	0	27.27	3.03	18.22	56.57	40.08
County Total		80.17	16.46	8.56	0.82	1.49	31.13	4.08	18.22	56.57	40.08
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Washington Co	Area	355.86	18.59	60.69	3.35	1.84	3.56	2.78	0	0	0
	Point	0.71	0.59	1.30	0.05	0.01	0.42	0.04	0	0	0
	On-road Mobile	127.41	20.45	12.27	0.56	0.92	0.86	0.63	0	0	0
	Fires	1.50	0.09	0.11	0.01	0.01	0.02	0.25	0	0	0
	Biogenic	16.85	1.15	0	0	0	0	0	3.68	26.05	23.98
County Total		502.33	40.87	74.36	3.98	2.78	4.86	3.70	3.68	26.05	23.98
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wheeler Co	Area	0.55	0.16	0.38	0.02	0.64	0.54	0.07	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	3.74	0.41	0.39	0.01	0.01	0.45	0.06	0	0	0
	Fires	0.35	0.02	0.03	0.00	0.00	0.00	0.04	0	0	0
	Biogenic	23.06	3.71	0	0	0	0	0	3.80	51.82	32.80
County Total		27.71	4.30	0.80	0.03	0.65	1.00	0.17	3.80	51.82	32.80
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Yamhill Co	Area	34.33	3.47	14.37	0.61	3.16	0.60	0.52	0	0	0
	Point	5.50	6.86	0.97	1.56	0.11	0.40	0.08	0	0	0
	On-road Mobile	34.92	4.54	3.35	0.11	0.18	0.56	0.17	0	0	0
	Fires	2.48	0.12	0.21	0.02	0.02	0.03	0.34	0	0	0
	Biogenic	16.52	1.16	0	0	0	0	0	8.16	25.99	23.51
County Total		93.75	16.15	18.89	2.30	3.47	1.60	1.12	8.16	25.99	23.51

Table 3-8. 18-Aug-2004 emissions totals (tons per day) for Washington counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Adams Co	Area	10.88	10.98	3.09	1.13	13.07	33.36	8.97	0	0	0
	Point	0	0	0	0	0.00	0	0	0	0	0
	On-road Mobile	37.78	4.88	3.30	0.10	0.15	5.30	0.71	0	0	0
	Fires	0.06	0.00	0.01	0.00	0	0.03	0.02	0	0	0
	Biogenic	3.10	13.76	0	0	0	2.94	0.33	0.90	7.24	4.41
County Total		51.81	29.62	6.40	1.22	13.23	41.62	10.04	0.90	7.24	4.41
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Benton Co	Area	45.59	12.68	12.72	1.60	12.74	23.93	6.01	0	0	0
	Point	0.29	1.24	0.16	0.05	0.41	0.49	0.08	0	0	0
	On-road Mobile	95.24	12.82	9.51	0.24	0.39	1.74	0.51	0	0	0
	Fires	0.43	0.02	0.06	0.00	0	0.02	0.20	0	0	0
	Biogenic	7.57	11.86	0	0	0	1.15	0.13	4.28	17.14	10.77
County Total		149.11	38.61	22.45	1.89	13.54	27.33	6.92	4.28	17.14	10.77
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Chelan Co	Area	22.08	4.15	5.56	0.43	1.24	0.60	0.48	0	0	0
	Point	1.39	0.02	0.01	0.02	0	1.73	1.78	0	0	0
	On-road Mobile	43.02	5.52	4.11	0.11	0.18	0.17	0.15	0	0	0
	Fires	6514.31	228.35	554.01	100.81	48.00	100.82	561.77	0	0	0
	Biogenic	72.05	2.26	0	0	0	34.79	3.87	20.83	157.07	102.49
County Total		6652.85	240.31	563.68	101.37	49.42	138.11	568.05	20.83	157.07	102.49
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clallam Co	Area	20.60	1.23	4.53	0.15	0.97	1.01	0.39	0	0	0
	Point	3.04	0.86	0.16	1.21	0	0.04	0.49	0	0	0
	On-road Mobile	25.69	3.61	2.36	0.09	0.09	0.07	0.17	0	0	0
	Fires	0.45	0.02	0.07	0.00	0	0.02	0.21	0	0	0
	Biogenic	22.64	0.24	0	0	0	3.64	0.40	4.45	29.98	32.21
County Total		72.42	5.96	7.12	1.45	1.06	4.76	1.66	4.45	29.98	32.21
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clark Co	Area	107.80	14.11	19.70	1.94	4.68	2.08	2.20	0	0	0
	Point	1.69	1.92	1.56	0.22	0.02	0.25	0.62	0	0	0
	On-road Mobile	137.86	24.63	15.14	0.39	0.77	0.38	0.60	0	0	0
	Fires	1.98	0.09	0.30	0.02	0	0.08	0.93	0	0	0
	Biogenic	16.84	0.41	0	0	0	0	0	2.31	26.51	23.95
County Total		266.17	41.15	36.70	2.56	5.47	2.79	4.35	2.31	26.51	23.95
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Cowlitz Co	Area	25.77	7.08	9.07	1.25	1.78	0.30	0.88	0	0	0
	Point	10.59	10.11	6.13	5.08	0.32	0.94	1.29	0	0	0
	On-road Mobile	79.26	11.23	7.26	0.17	0.34	0.09	0.25	0	0	0
	Fires	0.49	0.02	0.07	0.00	0	0.02	0.23	0	0	0
	Biogenic	29.76	0.36	0	0	0	0	0	4.97	46.74	42.33
County Total		145.87	28.81	22.53	6.51	2.45	1.35	2.65	4.97	46.74	42.33
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Douglas Co	Area	10.28	3.91	2.68	0.42	7.50	20.00	5.22	0	0	0
	Point	0.00	0.01	0.01	0.00	0	0.01	0.01	0	0	0
	On-road Mobile	26.95	3.54	2.64	0.07	0.12	15.21	1.79	0	0	0
	Fires	0.15	0.01	0.02	0.00	0	0.01	0.07	0	0	0
	Biogenic	8.48	8.93	0	0	0	71.33	7.93	1.94	19.08	12.06
County Total		45.86	16.38	5.34	0.49	7.61	106.56	15.00	1.94	19.08	12.06

Table 3-8. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Franklin Co	Area	19.90	10.14	5.84	1.02	10.70	15.80	4.34	0	0	0
	Point	0	0	0	0	0.01	0	0	0	0	0
	On-road Mobile	43.85	5.91	4.36	0.11	0.19	3.05	0.49	0	0	0
	Fires	10.55	0.43	0.89	0.07	0.21	0.06	0.96	0	0	0
	Biogenic	6.20	8.90	0	0	0	0.00	0.00	5.12	13.69	8.82
County Total		80.50	25.39	11.09	1.20	11.10	18.91	5.78	5.12	13.69	8.82
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grant Co	Area	33.83	10.89	11.99	1.13	22.20	28.63	7.94	0	0	0
	Point	0.00	0.00	0.00	0	0.00	0.00	0	0	0	0
	On-road Mobile	64.17	8.41	6.01	0.17	0.27	8.70	1.18	0	0	0
	Fires	89.15	3.20	10.16	0.57	1.78	0.60	11.59	0	0	0
	Biogenic	12.33	17.68	0	0	0	74.93	8.33	5.19	27.83	17.54
County Total		199.48	40.18	28.16	1.86	24.24	112.85	29.03	5.19	27.83	17.54
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grays Harbor Co	Area	21.34	1.78	6.34	0.18	1.96	0.50	0.44	0	0	0
	Point	4.06	2.60	0.39	1.11	0.12	0.07	1.64	0	0	0
	On-road Mobile	43.94	5.93	4.07	0.10	0.19	0.20	0.16	0	0	0
	Fires	0.39	0.02	0.06	0.00	0	0.02	0.18	0	0	0
	Biogenic	36.79	0.47	0	0	0	0	0	6.43	50.16	52.34
County Total		106.52	10.80	10.85	1.39	2.27	0.78	2.42	6.43	50.16	52.34
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Island Co	Area	19.49	1.23	3.76	0.14	0.78	2.25	0.61	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	28.50	4.02	2.61	0.10	0.10	0.21	0.22	0	0	0
	Fires	0.41	0.02	0.06	0.00	0	0.01	0.17	0	0	0
	Biogenic	2.62	0.07	0	0	0	0	0	0.62	4.16	3.73
County Total		51.02	5.34	6.43	0.24	0.88	2.48	0.99	0.62	4.16	3.73
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Jefferson Co	Area	14.70	1.45	3.13	0.17	0.53	0.29	0.26	0	0	0
	Point	4.42	1.49	0.18	0.96	0.09	0.14	0.68	0	0	0
	On-road Mobile	21.35	2.86	2.00	0.05	0.09	0.19	0.09	0	0	0
	Fires	0.26	0.01	0.04	0.00	0	0.01	0.12	0	0	0
	Biogenic	41.74	0.44	0	0	0	0	0	6.59	58.53	59.38
County Total		82.47	6.26	5.35	1.18	0.71	0.63	1.15	6.59	58.53	59.38
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - King Co	Area	841.00	79.32	128.38	9.39	9.60	14.73	11.75	0	0	0
	Point	8.18	12.92	2.20	2.88	0.01	0.41	0.53	0	0	0
	On-road Mobile	889.26	148.33	93.66	2.37	4.70	2.74	3.69	0	0	0
	Fires	6.42	0.30	0.98	0.05	0	0.27	3.03	0	0	0
	Biogenic	48.51	0.75	0	0	0	0.04	0.00	7.88	80.43	69.00
County Total		1793.35	241.62	225.22	14.69	14.31	18.20	19.01	7.88	80.43	69.00
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kitsap Co	Area	73.25	4.86	14.10	0.61	1.11	4.32	1.56	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	102.59	14.66	10.53	0.23	0.46	0.44	0.39	0	0	0
	Fires	1.61	0.07	0.25	0.01	0	0.07	0.75	0	0	0
	Biogenic	12.42	0.12	0	0	0	0	0	1.61	18.36	17.66
County Total		189.87	19.72	24.87	0.86	1.57	4.83	2.70	1.61	18.36	17.66
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kittitas Co	Area	13.67	2.38	4.53	0.27	3.46	1.89	0.74	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	77.66	10.13	6.26	0.19	0.31	0.31	0.26	0	0	0
	Fires	0.17	0.01	0.03	0.00	0	0.01	0.08	0	0	0
	Biogenic	43.27	3.80	0	0	0	58.63	6.51	6.94	88.54	61.55
County Total		134.77	16.32	10.81	0.46	3.76	60.84	7.59	6.94	88.54	61.55

Table 3-8. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Klickitat Co	Area	8.27	9.56	2.99	1.18	4.29	3.23	1.22	0	0	0
	Point	1.73	0.40	0.32	0.13	0.00	0.23	0.14	0	0	0
	On-road Mobile	16.45	2.15	1.55	0.04	0.07	1.62	0.23	0	0	0
	Fires	0.11	0.00	0.02	0.00	0	0.00	0.05	0	0	0
	Biogenic	31.24	4.22	0	0	0	6.75	0.75	43.61	60.60	44.44
County Total		57.80	16.33	4.87	1.35	4.36	11.83	2.39	43.61	60.60	44.44
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lewis Co	Area	21.37	3.71	6.42	0.38	7.70	0.09	0.45	0	0	0
	Point	17.11	54.45	0.78	23.49	0.05	3.00	3.03	0	0	0
	On-road Mobile	67.42	9.47	6.14	0.15	0.30	0.07	0.22	0	0	0
	Fires	0.49	0.02	0.07	0.00	0	0.02	0.23	0	0	0
	Biogenic	61.07	0.72	0	0	0	0	0	7.73	96.39	86.87
County Total		167.45	68.36	13.41	24.02	8.05	3.17	3.93	7.73	96.39	86.87
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lincoln Co	Area	9.77	7.15	2.29	0.76	10.45	27.34	7.36	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	15.11	1.97	1.35	0.04	0.06	4.62	0.57	0	0	0
	Fires	21.53	0.75	1.75	0.15	0.43	0.10	1.77	0	0	0
	Biogenic	5.87	12.37	0	0	0	1.54	0.17	0.58	12.80	8.34
County Total		52.29	22.24	5.40	0.95	10.94	33.60	9.87	0.58	12.80	8.34
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Mason Co	Area	17.15	1.46	4.38	0.11	0.48	0.28	0.35	0	0	0
	Point	0.97	0.19	0.51	0	0	0.10	0.34	0	0	0
	On-road Mobile	27.34	3.77	2.67	0.06	0.12	0.12	0.10	0	0	0
	Fires	0.55	0.03	0.08	0.00	0	0.02	0.25	0	0	0
	Biogenic	30.45	0.26	0	0	0	0	0	2.09	44.39	43.31
County Total		76.45	5.69	7.65	0.18	0.61	0.53	1.05	2.09	44.39	43.31
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pacific Co	Area	8.43	1.43	2.56	0.54	0.83	0.24	0.31	0	0	0
	Point	0.10	0.20	0.03	0.02	0	0.01	0.04	0	0	0
	On-road Mobile	14.42	1.89	1.29	0.03	0.06	0.20	0.07	0	0	0
	Fires	0.25	0.01	0.04	0.00	0	0.01	0.12	0	0	0
	Biogenic	16.28	0.20	0	0	0	0	0	4.07	21.53	23.15
County Total		39.48	3.73	3.92	0.59	0.90	0.45	0.54	4.07	21.53	23.15
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pierce Co	Area	263.16	42.27	42.98	5.28	4.90	4.01	4.93	0	0	0
	Point	4.27	2.73	1.74	0.89	0	0.36	0.55	0	0	0
	On-road Mobile	328.92	54.60	35.50	0.87	1.72	0.78	1.32	0	0	0
	Fires	3.75	0.17	0.57	0.03	0	0.16	1.75	0	0	0
	Biogenic	38.35	0.56	0	0	0	0	0	5.97	62.86	54.56
County Total		638.44	100.32	80.79	7.07	6.62	5.31	8.55	5.97	62.86	54.56
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Skamania Co	Area	3.74	3.62	1.08	0.46	0.31	0.03	0.16	0	0	0
	Point	0.06	0.08	0.03	0.00	0	0.04	0.03	0	0	0
	On-road Mobile	6.25	0.85	0.59	0.01	0.03	0.01	0.02	0	0	0
	Fires	0.09	0.00	0.01	0.00	0	0.00	0.04	0	0	0
	Biogenic	52.30	0.51	0	0	0	0.07	0.01	5.49	93.31	74.40
County Total		62.44	5.07	1.72	0.48	0.34	0.17	0.26	5.49	93.31	74.40
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Snohomish Co	Area	255.53	25.00	40.62	2.32	7.01	3.24	3.54	0	0	0
	Point	10.42	2.24	1.75	1.04	0.02	0	0.12	0	0	0
	On-road Mobile	376.63	64.49	36.90	1.60	1.57	0.66	2.96	0	0	0
	Fires	20.30	0.75	1.95	0.29	0.12	0.40	3.03	0	0	0
	Biogenic	44.20	0.79	0	0	0	0.05	0.01	7.07	70.97	62.88
County Total		707.08	93.26	81.22	5.23	8.72	4.35	9.67	7.07	70.97	62.88

Table 3-8. (concluded)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Thurston Co	Area	64.28	6.49	16.97	0.74	5.33	0.87	1.18	0	0	0
	Point	0.01	0.02	1.09	0	0	0	0	0	0	0
	On-road Mobile	140.80	19.87	13.63	0.31	0.62	0.26	0.47	0	0	0
	Fires	1.34	0.06	0.20	0.01	0	0.06	0.63	0	0	0
	Biogenic	17.86	0.22	0	0	0	0	0	3.51	27.16	25.40
County Total		224.28	26.67	31.90	1.06	5.95	1.18	2.27	3.51	27.16	25.40
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Wahkiakum Co	Area	1.58	0.10	0.51	0.01	0.45	0.06	0.03	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	2.96	0.39	0.27	0.01	0.01	0.03	0.01	0	0	0
	Fires	0.04	0.00	0.01	0.00	0	0.00	0.02	0	0	0
	Biogenic	5.47	0.07	0	0	0	0	0	0.90	7.09	7.79
County Total		10.04	0.56	0.78	0.02	0.46	0.10	0.06	0.90	7.09	7.79
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Walla Walla Co	Area	20.72	6.86	4.89	0.74	8.51	19.89	5.63	0	0	0
	Point	3.16	3.03	6.41	1.62	0.07	0.02	0.55	0	0	0
	On-road Mobile	29.13	3.87	2.91	0.08	0.12	2.00	0.32	0	0	0
	Fires	124.09	4.34	10.10	0.87	2.48	0.56	10.19	0	0	0
	Biogenic	5.07	9.58	0	0	0	2.99	0.33	4.50	11.13	7.21
County Total		182.17	27.68	24.31	3.31	11.18	25.46	17.02	4.50	11.13	7.21
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Yakima Co	Area	55.66	7.70	19.61	0.82	23.02	4.89	2.17	0	0	0
	Point	2.31	0.34	3.49	0.01	0.00	0.07	0.30	0	0	0
	On-road Mobile	126.64	16.80	12.32	0.32	0.52	2.14	0.62	0	0	0
	Fires	6655.32	233.30	566.02	102.99	49.04	103.01	574.09	0	0	0
	Biogenic	68.09	10.52	0	0	0	50.71	5.63	23.05	159.26	96.86
County Total		6908.03	268.67	601.44	104.14	72.58	160.82	582.82	23.05	159.26	96.86

Table 3-9. 12-Nov-2004 emissions totals (tons per day) for Oregon counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Benton Co	Area	23.32	2.83	16.39	0.56	0.72	0.33	1.62	0	0	0
	Point	0.43	0.34	0.08	0.01	0	0.01	0.03	0	0	0
	On-road Mobile	51.68	4.92	3.69	0.10	0.16	0.29	0.14	0	0	0
	Fires	1.50	0.28	0.60	0.05	0.08	0.08	0.76	0	0	0
	Biogenic	5.84	0.27	0	0	0	0	0	0.47	9.06	8.31
County Total		82.78	8.64	20.76	0.73	0.95	0.71	2.55	0.47	9.06	8.31
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clackamas Co	Area	105.90	9.51	60.48	1.97	3.16	4.24	3.63	0	0	0
	Point	0.47	3.35	1.16	1.40	0.01	0.36	0.08	0	0	0
	On-road Mobile	188.92	24.63	15.02	0.37	0.87	0.67	0.62	0	0	0
	Fires	6.17	0.32	0.50	0.05	0.05	0.10	0.97	0	0	0
	Biogenic	18.86	0.42	0	0	0	0.08	0.01	0.32	29.81	26.83
County Total		320.32	38.24	77.15	3.79	4.08	5.44	5.31	0.32	29.81	26.83
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clatsop Co	Area	19.44	5.45	8.24	2.52	0.37	0.49	1.64	0	0	0
	Point	5.97	3.59	1.19	2.44	0.02	0.79	0.23	0	0	0
	On-road Mobile	46.73	4.47	3.59	0.09	0.14	1.32	0.24	0	0	0
	Fires	5.27	0.24	0.42	0.05	0.05	0.07	0.65	0	0	0
	Biogenic	8.01	0.15	0	0	0	0	0	0.66	11.17	11.40
County Total		85.42	13.89	13.45	5.09	0.58	2.67	2.77	0.66	11.17	11.40
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Columbia Co	Area	15.34	6.50	7.56	2.96	0.44	0.13	1.57	0	0	0
	Point	21.34	5.01	8.00	4.42	0.05	1.16	0.18	0	0	0
	On-road Mobile	38.16	3.93	3.18	0.07	0.11	0.15	0.10	0	0	0
	Fires	4.96	0.23	0.38	0.05	0.04	0.06	0.65	0	0	0
	Biogenic	6.90	0.16	0	0	0	0.02	0.00	0.11	9.97	9.81
County Total		86.70	15.84	19.12	7.51	0.63	1.52	2.50	0.11	9.97	9.81
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Gilliam Co	Area	1.63	2.96	6.71	0.53	0.59	1.01	0.25	0	0	0
	Point	0.23	0.01	0.10	0.00	0.00	0.07	0.00	0	0	0
	On-road Mobile	22.21	1.91	1.35	0.03	0.05	0.36	0.08	0	0	0
	Fires	0.06	0.08	0.31	0.01	0.07	0.01	0.23	0	0	0
	Biogenic	0.52	2.12	0	0	0	0	0	0.01	1.12	0.74
County Total		24.65	7.08	8.47	0.57	0.71	1.45	0.56	0.01	1.12	0.74
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Grant Co	Area	14.59	0.24	8.10	0.05	1.35	0.17	0.50	0	0	0
	Point	0.33	0.58	0.45	0.02	0.02	0.15	0.12	0	0	0
	On-road Mobile	21.97	1.60	1.60	0.03	0.04	0.46	0.09	0	0	0
	Fires	4.21	0.17	0.35	0.04	0.05	0.05	0.45	0	0	0
	Biogenic	22.33	2.27	0	0	0	0.10	0.01	0.39	52.70	31.76
County Total		63.42	4.86	10.51	0.13	1.46	0.94	1.17	0.39	52.70	31.76
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Hood River Co	Area	11.42	2.66	6.45	0.68	0.20	0.09	0.63	0	0	0
	Point	0	0	0.01	0	0	0.00	0.00	0	0	0
	On-road Mobile	35.03	3.15	2.20	0.05	0.09	0.08	0.07	0	0	0
	Fires	4.07	0.23	0.39	0.02	0.02	0.06	0.54	0	0	0
	Biogenic	5.71	0.08	0	0	0	0.01	0.00	0.28	11.10	8.13
County Total		56.23	6.13	9.04	0.75	0.31	0.23	1.25	0.28	11.10	8.13

Table 3-9. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Jefferson Co	Area	10.18	0.92	4.34	0.13	0.64	0.44	0.61	0	0	0
	Point	0.14	0.24	0.87	0.00	0.02	0.03	0	0	0	0
	On-road Mobile	31.10	2.66	2.21	0.04	0.07	1.84	0.26	0	0	0
	Fires	7.75	0.28	0.96	0.03	0.21	0.04	0.79	0	0	0
	Biogenic	6.60	1.48	0	0	0	0	0	0.09	14.44	9.38
County Total		55.76	5.58	8.38	0.21	0.94	2.35	1.66	0.09	14.44	9.38
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Lincoln Co	Area	21.60	1.17	10.02	0.19	0.24	0.46	1.41	0	0	0
	Point	6.61	2.66	2.41	1.19	0.00	1.90	0.05	0	0	0
	On-road Mobile	47.92	4.62	3.63	0.09	0.15	0.90	0.20	0	0	0
	Fires	5.64	0.26	0.44	0.05	0.05	0.07	0.72	0	0	0
	Biogenic	11.95	0.16	0	0	0	0.00	0.00	0.62	17.28	16.99
County Total		93.72	8.88	16.51	1.53	0.44	3.33	2.39	0.62	17.28	16.99
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Linn Co	Area	30.10	3.14	21.03	0.82	2.32	0.79	2.13	0	0	0
	Point	20.66	3.80	3.92	5.46	0.04	2.85	0.46	0	0	0
	On-road Mobile	168.17	15.49	12.40	0.29	0.42	1.06	0.43	0	0	0
	Fires	1.15	1.49	4.67	0.22	0.93	1.77	2.56	0	0	0
	Biogenic	21.97	0.53	0	0	0	0.09	0.01	0.38	35.26	31.25
County Total		242.04	24.44	42.02	6.79	3.72	6.55	5.58	0.38	35.26	31.25
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Marion Co	Area	80.34	7.72	44.30	2.00	4.69	2.56	5.61	0	0	0
	Point	0.07	0.82	0.49	0.02	0	0.04	0.01	0	0	0
	On-road Mobile	268.66	25.85	19.57	0.49	0.76	1.53	0.70	0	0	0
	Fires	18.44	0.69	2.19	0.09	0.42	0.15	2.00	0	0	0
	Biogenic	8.98	0.55	0	0	0	0.01	0.00	0.20	14.41	12.78
County Total		376.49	35.63	66.55	2.60	5.86	4.29	8.32	0.20	14.41	12.78
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Morrow Co	Area	4.18	0.97	7.99	0.34	20.04	2.25	0.39	0	0	0
	Point	2.61	32.93	0.30	46.40	0.29	0.86	1.60	0	0	0
	On-road Mobile	27.89	2.47	1.73	0.04	0.07	0.86	0.15	0	0	0
	Fires	3.46	0.14	0.36	0.02	0.07	0.03	0.37	0	0	0
	Biogenic	2.88	2.99	0	0	0	0	0	0.09	6.37	4.10
County Total		41.03	39.50	10.38	46.79	20.46	4.00	2.51	0.09	6.37	4.10
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Multnomah Co	Area	244.44	25.56	70.73	4.72	1.02	10.92	9.47	0	0	0
	Point	1.86	2.57	4.39	0.67	0.00	1.11	0.46	0	0	0
	On-road Mobile	368.72	48.57	29.21	0.71	1.67	1.55	1.25	0	0	0
	Fires	0.49	0.02	0.06	0.00	0.00	0.00	0.10	0	0	0
	Biogenic	3.44	0.17	0	0	0	0.01	0.00	0.11	5.06	4.90
County Total		618.95	76.89	104.38	6.10	2.70	13.60	11.27	0.11	5.06	4.90
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Polk Co	Area	15.30	1.35	9.86	0.34	1.42	0.33	1.22	0	0	0
	Point	0.02	0.01	0.70	0.00	0.00	0.04	0.00	0	0	0
	On-road Mobile	58.86	5.61	4.46	0.11	0.17	0.51	0.17	0	0	0
	Fires	6.21	0.28	0.52	0.05	0.06	0.08	0.75	0	0	0
	Biogenic	6.20	0.39	0	0	0	0	0	0.86	9.29	8.82
County Total		86.60	7.65	15.53	0.50	1.64	0.96	2.14	0.86	9.29	8.82
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Sherman Co	Area	1.22	1.60	0.59	0.20	0.69	1.90	0.19	0	0	0
	Point	0.58	0.45	0.04	0.01	0.04	0.02	0	0	0	0
	On-road Mobile	18.90	1.61	1.21	0.02	0.04	0.51	0.09	0	0	0
	Fires	0.79	0.03	0.10	0.00	0.02	0.00	0.08	0	0	0
	Biogenic	0.31	1.75	0	0	0	0	0	0.01	0.72	0.45
County Total		21.81	5.44	1.94	0.24	0.80	2.43	0.36	0.01	0.72	0.45

Table 3-9. (concluded)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Tillamook Co	Area	15.57	0.95	7.76	0.15	4.55	0.25	0.89	0	0	0
	Point	1.11	0.21	0.25	0.12	0.01	0.61	0.04	0	0	0
	On-road Mobile	41.34	3.89	3.07	0.08	0.12	0.89	0.19	0	0	0
	Fires	2.75	0.13	0.21	0.03	0.02	0.04	0.36	0	0	0
	Biogenic	12.09	0.19	0	0	0	0.01	0.00	0.77	18.16	17.19
County Total		72.86	5.37	11.29	0.38	4.71	1.80	1.49	0.77	18.16	17.19
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Umatilla Co	Area	27.12	8.83	16.38	1.14	4.86	3.59	2.50	0	0	0
	Point	0.70	1.65	0.38	0.19	0.86	0.53	0.05	0	0	0
	On-road Mobile	101.59	9.12	6.71	0.13	0.25	3.71	0.61	0	0	0
	Fires	8.81	0.73	1.90	0.11	0.35	0.18	1.97	0	0	0
	Biogenic	7.60	4.66	0	0	0	0.00	0.00	0.25	16.94	10.82
County Total		145.83	24.99	25.38	1.58	6.32	8.01	5.14	0.25	16.94	10.82
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wasco Co	Area	10.46	4.28	4.78	0.90	1.05	1.35	0.83	0	0	0
	Point	0.01	0.04	0.05	0.00	0	0.02	0.03	0	0	0
	On-road Mobile	59.54	5.23	3.97	0.07	0.13	1.68	0.29	0	0	0
	Fires	5.00	0.21	0.48	0.04	0.08	0.05	0.61	0	0	0
	Biogenic	7.93	2.89	0	0	0	0	0	0.38	15.85	11.27
County Total		82.94	12.65	9.28	1.01	1.26	3.09	1.76	0.38	15.85	11.27
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Washington Co	Area	129.27	14.75	54.97	3.80	1.71	1.72	10.01	0	0	0
	Point	0.71	0.59	1.30	0.05	0.01	0.42	0.04	0	0	0
	On-road Mobile	184.75	24.67	13.68	0.38	0.94	0.81	0.65	0	0	0
	Fires	2.99	0.16	0.24	0.02	0.02	0.04	0.40	0	0	0
	Biogenic	6.53	0.60	0	0	0	0.11	0.01	0.20	10.03	9.28
County Total		324.24	40.76	70.19	4.26	2.67	3.10	11.10	0.20	10.03	9.28
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wheeler Co	Area	0.70	0.04	0.44	0.01	0.50	0.34	0.10	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	5.99	0.50	0.44	0.01	0.01	0.41	0.06	0	0	0
	Fires	1.07	0.04	0.09	0.01	0.01	0.01	0.11	0	0	0
	Biogenic	5.82	1.53	0	0	0	0.01	0.00	0.08	13.05	8.27
County Total		13.58	2.12	0.97	0.02	0.53	0.77	0.27	0.08	13.05	8.27
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Yamhill Co	Area	25.36	2.30	17.51	0.65	2.72	0.57	1.84	0	0	0
	Point	5.46	6.64	0.96	1.56	0.11	0.39	0.08	0	0	0
	On-road Mobile	47.91	5.30	3.68	0.08	0.18	0.52	0.17	0	0	0
	Fires	6.34	0.30	0.55	0.05	0.05	0.08	0.73	0	0	0
	Biogenic	6.02	0.57	0	0	0	0	0	0.42	9.40	8.57
County Total		91.09	15.10	22.70	2.33	3.06	1.56	2.83	0.42	9.40	8.57

Table 3-10. 12-Nov-2004 emissions totals (tons per day) for Washington counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Adams Co	Area	5.71	6.63	2.64	0.68	2.73	18.49	4.94	0	0	0
	Point	0	0	0	0	0.00	0	0	0	0	0
	On-road Mobile	54.41	5.02	3.18	0.07	0.13	4.48	0.61	0	0	0
	Fires	0.06	0.00	0.01	0.00	0	0.03	0.03	0	0	0
	Biogenic	0.56	4.09	0	0	0	0	0	0.03	1.22	0.79
County Total		60.73	15.75	5.82	0.75	2.87	23.00	5.58	0.03	1.22	0.79
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Benton Co	Area	21.82	9.16	18.30	1.32	6.47	16.30	5.28	0	0	0
	Point	0.29	1.25	0.16	0.05	0.55	0.46	0.08	0	0	0
	On-road Mobile	134.00	13.17	9.10	0.18	0.34	1.56	0.46	0	0	0
	Fires	0.45	0.02	0.07	0.00	0	0.02	0.20	0	0	0
	Biogenic	1.17	3.63	0	0	0	2.30	0.26	0.08	2.66	1.67
County Total		157.73	27.24	27.63	1.55	7.36	20.65	6.27	0.08	2.66	1.67
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Chelan Co	Area	15.94	3.64	4.92	0.42	0.71	0.90	0.85	0	0	0
	Point	1.35	0.02	0.01	0.02	0	1.69	1.74	0	0	0
	On-road Mobile	65.63	5.89	4.14	0.08	0.16	0.15	0.13	0	0	0
	Fires	2.77	0.22	0.26	0.06	0.02	0.01	0.40	0	0	0
	Biogenic	21.82	0.98	0	0	0	7.35	0.82	0.83	47.51	31.04
County Total		107.52	10.75	9.32	0.58	0.88	10.10	3.95	0.83	47.51	31.04
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clallam Co	Area	11.02	0.85	5.68	0.17	0.55	0.95	1.05	0	0	0
	Point	3.04	0.85	0.16	1.16	0	0.03	0.49	0	0	0
	On-road Mobile	29.64	3.57	2.38	0.10	0.08	0.06	0.16	0	0	0
	Fires	7.64	0.62	0.68	0.17	0.05	0.02	0.98	0	0	0
	Biogenic	9.22	0.13	0	0	0	0.12	0.01	0.36	12.27	13.12
County Total		60.56	6.03	8.89	1.59	0.68	1.19	2.69	0.36	12.27	13.12
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clark Co	Area	83.00	12.25	16.46	1.97	2.94	2.21	6.61	0	0	0
	Point	1.76	2.71	1.52	1.34	0.02	0.25	0.65	0	0	0
	On-road Mobile	217.07	25.11	15.88	0.53	0.68	0.35	0.56	0	0	0
	Fires	2.07	0.09	0.31	0.02	0	0.08	0.94	0	0	0
	Biogenic	6.98	0.23	0	0	0	0.26	0.03	0.15	10.97	9.93
County Total		310.89	40.39	34.18	3.86	3.63	3.17	8.79	0.15	10.97	9.93
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Cowlitz Co	Area	24.57	6.69	12.60	1.27	1.09	0.37	2.05	0	0	0
	Point	10.58	10.09	5.95	5.04	0.32	0.95	1.29	0	0	0
	On-road Mobile	113.77	11.54	7.58	0.23	0.30	0.08	0.23	0	0	0
	Fires	18.18	1.50	1.58	0.41	0.12	0.02	2.13	0	0	0
	Biogenic	12.64	0.21	0	0	0	0.12	0.01	0.34	19.85	17.97
County Total		179.73	30.03	27.71	6.96	1.82	1.53	5.72	0.34	19.85	17.97
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Douglas Co	Area	6.96	1.47	3.02	0.18	1.32	11.45	3.18	0	0	0
	Point	0.00	0.01	0.01	0.00	0	0.01	0.01	0	0	0
	On-road Mobile	42.23	3.79	2.67	0.05	0.10	12.79	1.51	0	0	0
	Fires	0.39	0.02	0.05	0.00	0.00	0.01	0.09	0	0	0
	Biogenic	1.77	3.21	0	0	0	84.66	9.41	0.06	3.95	2.51
County Total		51.36	8.50	5.75	0.24	1.43	108.93	14.20	0.06	3.95	2.51

Table 3-10. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Franklin Co	Area	14.22	6.98	6.56	0.67	3.32	9.76	2.94	0	0	0
	Point	0	0	0	0	0.01	0	0	0	0	0
	On-road Mobile	62.50	6.05	4.19	0.08	0.16	2.60	0.42	0	0	0
	Fires	0.14	0.01	0.02	0.00	0	0.01	0.06	0	0	0
	Biogenic	0.89	2.57	0	0	0	0.00	0.00	0.10	1.96	1.27
County Total		77.75	15.61	10.77	0.75	3.48	12.36	3.42	0.10	1.96	1.27
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grant Co	Area	20.71	4.07	10.41	0.40	7.48	16.79	4.89	0	0	0
	Point	0.00	0.00	0.00	0	0.00	0.00	0	0	0	0
	On-road Mobile	96.78	8.89	5.93	0.12	0.24	7.36	1.01	0	0	0
	Fires	0.30	0.01	0.05	0.00	0	0.01	0.13	0	0	0
	Biogenic	2.07	5.63	0	0	0	16.30	1.81	0.15	4.65	2.94
County Total		119.86	18.61	16.38	0.53	7.72	40.46	7.84	0.15	4.65	2.94
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grays Harbor Co	Area	17.51	1.45	8.68	0.23	1.35	0.51	1.37	0	0	0
	Point	4.06	2.60	0.39	1.10	0.12	0.07	1.64	0	0	0
	On-road Mobile	60.25	6.05	4.25	0.13	0.17	0.18	0.15	0	0	0
	Fires	141.44	11.79	12.02	3.23	0.95	0.02	15.37	0	0	0
	Biogenic	19.82	0.33	0	0	0	0	0	0.80	27.13	28.19
County Total		243.08	22.21	25.34	4.69	2.59	0.77	18.53	0.80	27.13	28.19
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Island Co	Area	11.58	0.94	6.16	0.17	0.48	1.98	1.55	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	32.91	3.99	2.63	0.11	0.10	0.20	0.21	0	0	0
	Fires	0.43	0.02	0.06	0.00	0	0.01	0.17	0	0	0
	Biogenic	1.11	0.04	0	0	0	0	0	0.06	1.77	1.58
County Total		46.04	4.99	8.86	0.28	0.57	2.20	1.93	0.06	1.77	1.58
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Jefferson Co	Area	9.19	0.97	3.36	0.16	0.41	0.27	0.70	0	0	0
	Point	4.42	1.48	0.17	0.95	0.09	0.14	0.68	0	0	0
	On-road Mobile	30.01	2.97	2.08	0.06	0.08	0.16	0.08	0	0	0
	Fires	7.16	0.59	0.63	0.16	0.05	0.01	0.87	0	0	0
	Biogenic	17.85	0.26	0	0	0	0.03	0.00	0.59	25.12	25.39
County Total		68.62	6.27	6.24	1.34	0.63	0.61	2.33	0.59	25.12	25.39
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - King Co	Area	550.58	49.74	204.11	9.71	8.83	5.31	31.38	0	0	0
	Point	7.74	10.91	2.23	2.49	0.01	0.35	0.48	0	0	0
	On-road Mobile	1283.87	152.59	97.08	3.22	4.11	2.50	3.44	0	0	0
	Fires	6.72	0.30	1.02	0.05	0	0.27	3.07	0	0	0
	Biogenic	18.67	0.40	0	0	0	1.69	0.19	0.55	30.82	26.56
County Total		1867.58	213.94	304.43	15.47	12.95	10.12	38.56	0.55	30.82	26.56
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kitsap Co	Area	43.68	4.12	21.84	0.98	1.02	4.30	4.67	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	147.89	15.21	11.06	0.32	0.40	0.42	0.37	0	0	0
	Fires	1.69	0.07	0.26	0.01	0	0.07	0.76	0	0	0
	Biogenic	4.21	0.06	0	0	0	0	0	0.10	6.22	5.98
County Total		197.46	19.47	33.16	1.31	1.43	4.79	5.79	0.10	6.22	5.98
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kittitas Co	Area	11.20	1.52	5.98	0.23	1.40	1.20	0.93	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	115.32	10.52	6.39	0.14	0.27	0.28	0.23	0	0	0
	Fires	24.79	2.06	2.11	0.56	0.17	0.01	2.73	0	0	0
	Biogenic	14.31	1.58	0	0	0	5.43	0.60	0.30	29.19	20.35
County Total		165.62	15.68	14.48	0.93	1.83	6.91	4.49	0.30	29.19	20.35

Table 3-10. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Klickitat Co	Area	10.45	8.45	4.49	1.09	1.34	1.86	1.04	0	0	0
	Point	1.63	0.37	0.32	0.12	0.00	0.23	0.14	0	0	0
	On-road Mobile	23.93	2.22	1.50	0.03	0.06	1.37	0.20	0	0	0
	Fires	394.48	32.91	33.46	9.02	2.65	0.00	42.51	0	0	0
	Biogenic	8.17	1.60	0	0	0	2.74	0.30	1.25	15.80	11.62
County Total		438.65	45.56	39.77	10.27	4.07	6.19	44.19	1.25	15.80	11.62
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lewis Co	Area	21.45	3.19	9.13	0.36	4.00	0.13	1.42	0	0	0
	Point	16.02	50.81	0.74	21.89	0.04	2.93	2.87	0	0	0
	On-road Mobile	96.71	9.74	6.38	0.20	0.26	0.06	0.20	0	0	0
	Fires	0.51	0.02	0.08	0.00	0	0.02	0.23	0	0	0
	Biogenic	25.64	0.42	0	0	0	0.00	0.00	0.55	40.44	36.47
County Total		160.33	64.18	16.33	22.45	4.30	3.14	4.72	0.55	40.44	36.47
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lincoln Co	Area	3.63	3.02	1.34	0.35	1.76	15.11	3.94	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	22.97	2.04	1.38	0.03	0.05	3.90	0.48	0	0	0
	Fires	0.04	0.00	0.01	0.00	0	0.00	0.02	0	0	0
	Biogenic	1.08	3.96	0	0	0	1.05	0.12	0.03	2.28	1.54
County Total		27.73	9.02	2.72	0.37	1.81	20.06	4.55	0.03	2.28	1.54
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Mason Co	Area	13.81	1.57	5.50	0.13	0.37	0.29	1.30	0	0	0
	Point	0.97	0.19	0.52	0	0	0.10	0.34	0	0	0
	On-road Mobile	39.34	3.92	2.79	0.09	0.11	0.11	0.10	0	0	0
	Fires	0.57	0.03	0.09	0.00	0	0.02	0.26	0	0	0
	Biogenic	11.95	0.14	0	0	0	0	0	0.16	17.45	17.00
County Total		66.64	5.85	8.89	0.22	0.48	0.52	2.00	0.16	17.45	17.00
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pacific Co	Area	6.64	1.23	3.01	0.55	0.54	0.20	0.76	0	0	0
	Point	0.10	0.20	0.03	0.02	0	0.01	0.04	0	0	0
	On-road Mobile	19.65	1.94	1.35	0.04	0.06	0.17	0.06	0	0	0
	Fires	0.26	0.01	0.04	0.00	0	0.01	0.12	0	0	0
	Biogenic	9.64	0.15	0	0	0	0	0	0.56	12.87	13.71
County Total		36.28	3.53	4.43	0.61	0.60	0.39	0.98	0.56	12.87	13.71
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pierce Co	Area	144.07	21.72	42.69	3.14	4.03	4.37	12.93	0	0	0
	Point	4.28	2.73	1.83	0.89	0	0.36	0.55	0	0	0
	On-road Mobile	485.94	56.40	36.84	1.18	1.51	0.73	1.24	0	0	0
	Fires	3.93	0.17	0.60	0.03	0	0.16	1.77	0	0	0
	Biogenic	15.14	0.30	0	0	0	0.01	0.00	0.39	24.71	21.53
County Total		653.35	81.32	81.96	5.24	5.54	5.63	16.50	0.39	24.71	21.53
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Skamania Co	Area	12.40	3.60	5.23	0.47	0.26	0.04	0.41	0	0	0
	Point	0.06	0.08	0.03	0.00	0	0.04	0.03	0	0	0
	On-road Mobile	9.47	0.90	0.61	0.02	0.02	0.01	0.02	0	0	0
	Fires	0.30	0.02	0.03	0.01	0.00	0.00	0.07	0	0	0
	Biogenic	19.81	0.29	0	148.81	0	0.23	0.03	0.29	35.31	28.18
County Total		42.04	4.89	5.90	149.31	0.29	0.34	0.55	0.29	35.31	28.18
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Snohomish Co	Area	140.22	20.18	63.71	2.08	5.30	1.31	11.12	0	0	0
	Point	10.38	2.23	1.75	1.03	0.02	0	0.12	0	0	0
	On-road Mobile	448.41	63.90	37.14	1.72	1.47	0.64	2.81	0	0	0
	Fires	20.09	1.54	1.94	0.40	0.11	0.14	3.38	0	0	0
	Biogenic	17.41	0.43	0	0	0	0.00	0.00	0.53	27.83	24.77
County Total		636.51	88.28	104.54	5.23	6.90	2.09	17.42	0.53	27.83	24.77

Table 3-10. (concluded)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Thurston Co	Area	47.82	5.61	22.54	0.85	3.16	0.98	4.01	0	0	0
	Point	0.01	0.02	1.09	0	0	0	0	0	0	0
	On-road Mobile	202.23	20.50	14.23	0.42	0.54	0.23	0.44	0	0	0
	Fires	1.41	0.06	0.21	0.01	0	0.06	0.63	0	0	0
	Biogenic	7.13	0.12	0	0	0	0	0	0.21	10.86	10.15
County Total		258.61	26.32	38.08	1.28	3.69	1.26	5.08	0.21	10.86	10.15
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Wahkiakum Co	Area	0.81	0.04	0.47	0.01	0.19	0.04	0.08	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	4.08	0.40	0.28	0.01	0.01	0.03	0.01	0	0	0
	Fires	0.04	0.00	0.01	0.00	0	0.00	0.02	0	0	0
	Biogenic	2.81	0.05	0	0	0	0	0	0.08	3.67	4.00
County Total		7.73	0.49	0.76	0.02	0.20	0.07	0.11	0.08	3.67	4.00
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Walla Walla Co	Area	27.93	3.55	13.18	0.48	1.26	11.49	5.22	0	0	0
	Point	3.15	3.02	6.39	1.62	0.07	0.02	0.56	0	0	0
	On-road Mobile	40.84	3.94	2.78	0.06	0.11	1.70	0.27	0	0	0
	Fires	0.18	0.01	0.03	0.00	0	0.01	0.08	0	0	0
	Biogenic	0.85	2.76	0	0	0	0	0	0.07	1.86	1.21
County Total		72.95	13.28	22.37	2.15	1.44	13.22	6.13	0.07	1.86	1.21
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Yakima Co	Area	44.52	4.93	25.12	0.90	13.28	3.46	3.58	0	0	0
	Point	2.31	0.34	3.49	0.01	0.00	0.07	0.30	0	0	0
	On-road Mobile	184.78	17.42	11.89	0.24	0.46	1.83	0.55	0	0	0
	Fires	34.69	2.86	2.99	0.78	0.23	0.03	3.99	0	0	0
	Biogenic	19.69	3.94	0	0	0	7.88	0.88	0.76	45.99	28.01
County Total		285.99	29.50	43.49	1.93	13.97	13.27	9.29	0.76	45.99	28.01

3.3 2018 FUTURE YEAR SMOKE PROCESSING

Similar to the 2004 base case, SMOKE was configured to generate model-ready point, area, non-road mobile, on-road mobile, and fire source emissions for the 36/12/4-km grid system for the August and November 2018 future year episodes. The 2018 emission estimates were taken entirely from the WRAP 2018 data sets (WRAP, 2004). However, there are several upcoming federal programs that will have substantial emission reductions that are not included in this inventory. In addition, each of the WRAP states continues to make refinements to their inventories for 2018. The WRAP 2018 emissions estimates were modified for the following sources per the direction of the sponsors: PGE Boardman power plant; the Georgia Pacific Camas Mill pulping plant; and residential wood smoke. These modifications are discussed shortly. As with the 2004 base case emissions, certain emission subcategories, such as electric generating units (EGU), on-road mobile sources, fires, etc., were processed through the SMOKE system in separate streams in order to support the application of CAMx/PSAT and to support additional quality assurance of the emissions estimates.

The 2004 Mt. St. Helens, biogenic, wind-blown dust, agricultural ammonia source, wildfire, and other fire emissions estimates were used in place of the WRAP 2018 emissions estimates for the 2018 SMOKE processing. This is standard practice for "natural" sources. As Mt. St. Helens showed no activity in August 2004, no SO_2 emissions for the volcano were incorporated in the 2018 August episode. Only the November 2004 Mt. St. Helens SO_2 emissions were used in the 2018 November SMOKE modeling. This was done for consistency to be able to better understand the contributions and impacts from man-made emissions from 2004 to 2018. Following the approach used in WRAP, we assumed zero growth in agricultural ammonia emissions.

3.3.1 PGE Boardman Emissions Estimates

Per the direction of the study sponsors, the presumptive BART limits for NOx and SO_2 were used to model emissions from the Boardman facility for the coal-fired electricity generating unit. For NOx, the BART limit is 0.23 lbs NOx/MMBtu or 1,323 lbs NOx/hour. For SO_2, the BART limit is 0.15 lbs SO_2/MMBtu or 863 lbs SO_2/hour. PM10 emissions were left unchanged from 2004 though it is anticipated that the PM10 emissions will decrease once multi-pollutant controls are installed.

3.3.2 Georgia Pacific Camas Emissions Estimates

The study sponsors provided a spreadsheet of hourly NOx, SO_2, CO, and PM10 emissions estimates to be used at the Camas facility (Mairose, 2006d). These estimates are based on the presumptive BART limits and represent a worst case day.

3.3.3 Residential Wood Smoke Emissions Estimates

As discussed previously, errors were found in the 2004 base case emissions estimates for this source category, which carried over to the 2018 WRAP data base. The 2004 base case emissions

estimates were revised and a growth factor of 4%, representing the expected OR/WA population growth to 2018, was applied to estimate the 2018 emissions for this source category.

3.3.4 Ammonia Emissions Estimates

The modeling team found that the 2018 WRAP inventory did not include any ammonia emissions from agricultural-related sources. According to discussions with WRAP emission modelers, they assumed a zero ammonia growth rate from 2002 to 2018, and thus incorporated their 2002 ammonia estimates into their 2018 inventory as a last step before running the air quality models. It was decided that emissions for this project should follow suit. After applying the 2004 adjustments for CAFO and fertilizer applications in Oregon and Washington (estimation of the adjustment factors was discussed previously), the modeling team directly transferred those numbers over to the WRAP 2018 inventory before processing with SMOKE.

3.3.5 36-km Domain

Table 3-11(a-g) lists state-level emissions of CO, SOx (SO_2 + SULF + PSO4), NOx, VOC, NH_3, PMFINE (fine particles excluding sulfate), and PMC (coarse particles excluding sulfate) for the western states in the 36-km domain, excluding Oregon and Washington.

Table 3-11(a). CO (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	2717	1345	97	0.5	1416	2148	1642	93	20	433
CALIFORNIA	4007	2884	386	94	1521	3764	3135	331	337	660
COLORADO	2515	1509	165	58	828	1456	2176	161	41	112
IDAHO	852	453	102	427	622	519	644	107	925	185
MONTANA	584	663	177	0.4	1046	378	928	173	544	244
NEVADA	1014	544	59	0	791	618	694	59	0	174
NEW MEXICO	673	630	160	0	1210	575	868	156	0	230
UTAH	1027	814	274	14	700	757	1221	270	0	93
WYOMING	382	261	167	398	701	265	323	169	0	96

Table 3-11(b). SOx (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	13	2	262	0	0	13	3	256	0	0
CALIFORNIA	39	10	139	0	0	38	11	136	4	0
COLORADO	23	2	201	0	0	22	2	194	1	0
IDAHO	8	1	68	2	0	8	1	71	6	0
MONTANA	11	1	139	0	0	10	1	131	4	0
NEVADA	40	1	69	0	0	40	1	73	0	0
NEW MEXICO	44	1	118	0	0	44	1	112	0	0
UTAH	11	1	154	0	0	11	1	148	0	0
WYOMING	65	0	404	0	0	64	0	413	0	0

Table 3-11(c). NOx (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	179	137	230	0	99	170	150	219	0	56
CALIFORNIA	808	579	326	3	193	783	630	296	26	133
COLORADO	290	113	325	3	177	234	129	312	3	77
IDAHO	200	31	38	14	66	164	35	40	21	37
MONTANA	238	60	195	0	266	199	61	184	14	145
NEVADA	95	39	200	0	54	84	42	200	0	30
NEW MEXICO	578	50	215	0	173	574	55	201	0	79
UTAH	164	70	287	0	54	142	77	271	0	24
WYOMING	403	30	369	11	76	385	28	380	0	33

Table 3-11(d). VOC (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	573	142	27	0	6654	552	147	26	1	1667
CALIFORNIA	1260	334	155	8	10616	1283	335	150	33	3135
COLORADO	560	119	271	6	4270	523	121	271	3	441
IDAHO	574	32	9	40	3165	554	30	9	42	785
MONTANA	214	59	29	0	4945	202	55	29	25	1021
NEVADA	171	52	12	0	3172	157	48	11	0	614
NEW MEXICO	1126	43	72	0	5143	1122	45	72	0	846
UTAH	527	65	38	1	3126	509	67	37	0	328
WYOMING	1244	18	75	45	3374	1237	15	76	0	371

Table 3-11(e). NH_3 (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	87	20	2	0	0	112	22	2	0	0
CALIFORNIA	547	85	0	2	0	414	84	0	6	0
COLORADO	226	16	2	1	0	81	17	2	0	0
IDAHO	210	5	5	9	0	85	6	5	4	0
MONTANA	199	6	1	0	0	62	6	1	3	0
NEVADA	28	9	4	0	0	13	10	3	0	0
NEW MEXICO	115	8	0	0	0	49	8	0	0	0
UTAH	89	11	6	0	0	39	11	6	0	0
WYOMING	74	2	2	8	0	42	2	2	0	0

Table 3-11(f). PMFINE (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	46	13	5	0	0	45	14	5	2	0
CALIFORNIA	187	59	57	10	0	182	62	55	37	0
COLORADO	49	10	1	9	0	46	10	1	4	0
IDAHO	26	3	2	39	0	24	3	2	78	0
MONTANA	24	4	2	0	0	21	4	2	46	0
NEVADA	10	3	4	0	0	9	3	4	0	0
NEW MEXICO	24	5	5	0	0	24	5	5	0	0
UTAH	8	5	17	1	0	7	6	16	0	0
WYOMING	18	2	54	30	0	17	2	55	0	0

Table 3-11(g). PMC (TPD) emissions by state in the 36-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
ARIZONA	6	3	23	0	0	6	4	23	0	0
CALIFORNIA	29	18	40	1	0	28	19	39	3	0
COLORADO	4	3	84	0	0	4	3	84	0	0
IDAHO	9	1	3	2	0	9	1	3	13	0
MONTANA	2	1	30	0	0	2	1	30	7	0
NEVADA	3	1	15	0	0	3	1	15	0	0
NEW MEXICO	4	1	6	0	0	4	1	5	0	0
UTAH	8	1	36	0	0	8	2	35	0	0
WYOMING	2	1	84	1	0	2	0	85	0	0

3.3.6 12-km Domain

Table 3-12(a-g) lists state-level emissions of CO, SOx (SO_2 + SULF + PSO4), NOx, VOC, NH_3, PMFINE (fine particles excluding sulfate), and PMC (coarse particles excluding sulfate) for the portions of states contained within the 12-km grid, excluding Oregon and Washington.

Table 3-12(a). CO (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	479	166	73	48	1074	479	197	67	125	254
IDAHO	851	453	102	288	1103	852	643	107	925	353
MONTANA	336	444	125	0	794	336	614	122	541	238
NEVADA	200	163	28	0	135	200	241	28	0	39
UTAH	572	405	31	2	58	572	621	30	0	22
WYOMING	75	38	35	34	70	75	46	35	0	29

Table 3-12(b). SOx (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	4	0	2	0	0	4	0	2	2	0
IDAHO	8	1	68	1	0	8	1	71	6	0
MONTANA	7	0	16	0	0	7	0	15	4	0
NEVADA	11	0	32	0	0	11	0	34	0	0
UTAH	2	1	20	0	0	2	1	20	0	0
WYOMING	7	0	100	0	0	7	0	102	0	0

Table 3-12(c). NOx (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	68	30	29	2	37	68	35	26	11	14
IDAHO	200	31	38	10	146	200	35	40	21	71
MONTANA	64	40	37	0	64	64	40	34	14	27
NEVADA	39	12	59	0	128	39	13	60	0	55
UTAH	72	34	32	0	29	72	38	30	0	14
WYOMING	65	4	55	1	11	65	4	56	0	6

Table 3-12(d). VOC (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	108	21	6	4	6787	108	22	5	13	941
IDAHO	574	32	9	27	4238	574	30	9	42	1236
MONTANA	97	39	12	0	2875	97	36	12	25	814
NEVADA	50	12	6	0	409	50	14	6	0	108
UTAH	169	32	19	0	252	169	33	19	0	75
WYOMING	381	2	8	4	325	381	2	8	0	110

Table 3-12(e). NH_3 (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	60	3	0	1	0	46	30	0	2	0
IDAHO	214	5	5	6	0	88	6	5	4	0
MONTANA	74	4	1	0	0	22	4	1	3	0
NEVADA	16	2	1	0	0	6	2	1	0	0
UTAH	26	6	1	0	0	12	6	1	0	0
WYOMING	6	0	0	1	0	3	0	0	0	0

Table 3-12(f). PMFINE (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	43	2	7	5	0	43	2	7	13	0
IDAHO	26	3	2	28	0	26	3	2	78	0
MONTANA	15	3	1	0	0	15	2	1	46	0
NEVADA	3	1	3	0	0	3	1	3	0	0
UTAH	5	3	4	0	0	5	3	4	0	0
WYOMING	3	0	2	3	0	3	0	2	0	0

Table 3-12(g). PMC (TPD) emissions by state in the 12-km domain.

	August Emissions (tons/day)					November Emissions (tons/day)				
STATE	Area	Onroad	Point-anthro	Point-fire	Biogenic	Area	Onroad	Point-anthro	Point-fire	Biogenic
CALIFORNIA	5	1	4	0	0	5	1	4	1	0
IDAHO	9	1	3	1	0	9	1	3	13	0
MONTANA	2	1	16	0	0	2	1	16	7	0
NEVADA	1	0	2	0	0	1	0	2	0	0
UTAH	4	1	11	0	0	4	1	11	0	0
WYOMING	0	0	5	0	0	0	0	5	0	0

3.3.7 4-km Domain

Emissions estimates from the 4-km SMOKE data base were extracted for a typical day in each episode: 18-Aug-2004; and 12-Nov-2004. A comparison of the spatial and temporal distribution of the emissions between 2004 and 2018 revealed similar patterns; therefore, no temporal and spatial distribution graphics for the 2018 emissions are included

Table 3-13 presents the emissions estimates summary of CO, NOx, NH_3, PM-coarse, PM-fine, SOx, VOC, isoprene, monoterpenes, and OVOCs for Oregon Gorge counties for 18-Aug-2004. Table 3-14 presents a similar emissions estimate summary for Washington Gorge counties. Table 3-15 presents the emissions estimates summary of CO, NOx, NH_3, PM-coarse, PM-fine, SOx, VOC, isoprene, monoterpenes, and OVOCs for Oregon Gorge counties for 12-Nov-2004. Table 3-16 presents a similar emissions estimate summary for Washington Gorge counties for 12-Nov-2004.

Table 3-13. 18-Aug-2018 emissions totals (tons per day) for Oregon counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Benton Co	Area	30.07	2.46	22.05	0.29	0.81	0.15	0.31	0	0	0
	Point	0.09	0.08	0.14	0.00	0	0.02	0.00	0	0	0
	On-road Mobile	18.37	1.67	1.45	0.02	0.20	0.45	0.11	0	0	0
	Fires	2.60	0.12	0.22	0.02	0.02	0.03	0.37	0	0	0
	Biogenic	16.67	0.55	0	0	0	0	0	10.79	25.98	23.72
County Total		67.80	4.87	23.86	0.33	1.03	0.66	0.80	10.79	25.98	23.72
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clackamas Co	Area	263.03	7.83	64.06	1.04	4.00	0.76	1.73	0	0	0
	Point	0.47	2.75	1.39	0.01	0	0.52	0.01	0	0	0
	On-road Mobile	71.55	7.02	6.50	0.13	1.14	1.00	0.62	0	0	0
	Fires	4.92	0.30	0.32	0.05	0.01	0.09	0.95	0	0	0
	Biogenic	48.12	0.81	0	0	0	0	0	5.93	76.42	68.45
County Total		388.10	18.72	72.28	1.23	5.15	2.37	3.32	5.93	76.42	68.45
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clatsop Co	Area	30.97	5.73	7.34	2.48	0.46	0.13	0.95	0	0	0
	Point	7.96	4.97	1.80	4.93	0.15	5.24	0.64	0	0	0
	On-road Mobile	19.10	1.63	1.44	0.02	0.19	2.18	0.11	0	0	0
	Fires	2.73	0.15	0.19	0.03	0.01	0.04	0.44	0	0	0
	Biogenic	12.88	0.19	0	0	0	0	0	5.12	17.68	18.32
County Total		73.64	12.67	10.77	7.46	0.81	7.60	2.13	5.12	17.68	18.32
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Columbia Co	Area	17.80	6.29	6.04	2.92	0.52	0.07	1.04	0	0	0
	Point	34.43	9.56	9.56	4.48	0.75	1.18	1.60	0	0	0
	On-road Mobile	14.63	1.35	1.30	0.02	0.15	0.24	0.09	0	0	0
	Fires	2.92	0.17	0.20	0.03	0.01	0.04	0.49	0	0	0
	Biogenic	15.53	0.25	0	0	0	0	0	1.63	22.42	22.09
County Total		85.31	17.61	17.09	7.45	1.42	1.53	3.22	1.63	22.42	22.09
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Gilliam Co	Area	4.41	4.14	10.41	0.52	0.75	0.13	0.22	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	7.02	0.64	0.57	0.01	0.07	0.57	0.04	0	0	0
	Fires	0.08	0.01	0.00	0.00	0	0.00	0.02	0	0	0
	Biogenic	2.34	5.75	0	0	0	16.18	1.80	0.44	5.08	3.33
County Total		13.84	10.54	10.99	0.53	0.82	16.88	2.08	0.44	5.08	3.33
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Grant Co	Area	4.59	0.83	4.81	0.02	1.71	0.02	0.09	0	0	0
	Point	0.28	0.44	0.25	0.03	0	0.13	0	0	0	0
	On-road Mobile	6.85	0.65	0.70	0.01	0.06	0.75	0.04	0	0	0
	Fires	1.50	0.07	0.12	0.01	0.01	0.02	0.18	0	0	0
	Biogenic	80.78	5.33	0	0	0	1.22	0.14	14.84	190.70	114.91
County Total		94.00	7.33	5.88	0.07	1.78	2.14	0.45	14.84	190.70	114.91
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Hood River Co	Area	8.50	2.31	5.71	0.38	0.24	0.06	0.26	0	0	0
	Point	0	0	0.00	0	0	0	0	0	0	0
	On-road Mobile	12.07	1.10	0.93	0.01	0.12	0.12	0.07	0	0	0
	Fires	1.87	0.11	0.15	0.01	0.01	0.03	0.30	0	0	0
	Biogenic	16.25	0.16	0	0	0	0.12	0.01	7.86	31.66	23.12
County Total		38.69	3.68	6.80	0.40	0.36	0.33	0.64	7.86	31.66	23.12

Table 3-13. (continued).

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Jefferson Co	Area	7.27	1.70	4.00	0.07	0.79	0.03	0.16	0	0	0
	Point	0.24	0.27	1.67	0.01	0	0.08	0	0	0	0
	On-road Mobile	10.42	0.98	0.96	0.01	0.10	3.00	0.06	0	0	0
	Fires	0.97	0.06	0.06	0.01	0.00	0.02	0.19	0	0	0
	Biogenic	24.71	3.67	0	0	0	1.17	0.13	5.32	54.23	35.15
County Total		43.61	6.68	6.69	0.10	0.89	4.30	0.54	5.32	54.23	35.15
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Lincoln Co	Area	24.16	1.26	7.44	0.11	0.31	0.15	0.37	0	0	0
	Point	7.56	2.53	2.66	1.22	0.12	3.41	0.04	0	0	0
	On-road Mobile	19.79	1.70	1.43	0.02	0.19	1.44	0.11	0	0	0
	Fires	3.13	0.17	0.22	0.03	0.01	0.05	0.51	0	0	0
	Biogenic	22.53	0.24	0	0	0	0	0	7.11	32.50	32.05
County Total		77.16	5.92	11.75	1.39	0.63	5.04	1.03	7.11	32.50	32.05
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Linn Co	Area	50.22	6.95	22.42	0.43	2.78	0.18	0.87	0	0	0
	Point	18.18	3.75	6.27	1.58	0.29	4.22	0.02	0	0	0
	On-road Mobile	60.65	5.58	5.13	0.07	0.57	1.67	0.33	0	0	0
	Fires	5.73	0.25	0.48	0.05	0.05	0.08	0.72	0	0	0
	Biogenic	61.21	1.07	0	0	0	0	0	8.96	98.55	87.08
County Total		195.99	17.60	34.29	2.13	3.69	6.15	1.94	8.96	98.55	87.08
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Marion Co	Area	134.03	9.53	42.43	0.92	4.92	0.48	1.10	0	0	0
	Point	0.10	1.50	0.27	0.08	0.02	0.07	0	0	0	0
	On-road Mobile	97.59	9.03	7.91	0.12	1.01	2.40	0.58	0	0	0
	Fires	3.83	0.19	0.34	0.03	0.01	0.07	0.69	0	0	0
	Biogenic	24.82	1.15	0	0	0	0	0	4.49	40.10	35.30
County Total		260.38	21.40	50.95	1.14	5.97	3.02	2.36	4.49	40.10	35.30
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Morrow Co	Area	8.04	5.85	11.11	0.30	20.36	0.20	0.34	0	0	0
	Point	2.29	20.00	0.33	12.47	0.24	3.44	1.91	0	0	0
	On-road Mobile	9.06	0.85	0.73	0.01	0.09	1.40	0.05	0	0	0
	Fires	0.89	0.05	0.06	0.01	0.00	0.01	0.14	0	0	0
	Biogenic	12.11	8.66	0	0	0	13.96	1.55	4.29	26.84	17.23
County Total		32.39	35.41	12.25	12.79	20.69	19.01	3.99	4.29	26.84	17.23
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Multnomah Co	Area	318.06	19.97	128.12	3.14	1.16	2.51	2.00	0	0	0
	Point	4.91	3.04	5.23	1.03	0.10	2.08	0.39	0	0	0
	On-road Mobile	137.65	13.90	12.39	0.26	2.24	2.30	1.22	0	0	0
	Fires	0.54	0.02	0.07	0.00	0.00	0.00	0.11	0	0	0
	Biogenic	8.28	0.29	0	0	0	0	0	1.49	12.14	11.78
County Total		469.43	37.22	145.81	4.43	3.51	6.90	3.73	1.49	12.14	11.78
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Polk Co	Area	30.05	2.29	10.03	0.15	1.63	0.08	0.37	0	0	0
	Point	0	0	0.25	0	0.01	0.02	0	0	0	0
	On-road Mobile	21.75	1.99	1.83	0.03	0.23	0.84	0.13	0	0	0
	Fires	2.94	0.15	0.23	0.03	0.02	0.04	0.45	0	0	0
	Biogenic	16.94	0.81	0	0	0	0	0	16.80	25.64	24.10
County Total		71.67	5.24	12.34	0.20	1.88	0.98	0.94	16.80	25.64	24.10
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Sherman Co	Area	3.85	3.19	1.41	0.19	0.92	0.01	0.18	0	0	0
	Point	0.79	0.29	0.05	0.01	0	0.00	0	0	0	0
	On-road Mobile	6.09	0.56	0.53	0.01	0.06	0.82	0.03	0	0	0
	Fires	0.08	0.01	0.00	0.00	0	0.00	0.02	0	0	0
	Biogenic	1.31	4.35	0	0	0	26.00	2.89	0.34	2.98	1.86
County Total		12.11	8.39	1.99	0.20	0.97	26.84	3.11	0.34	2.98	1.86

Table 3-13. (concluded).

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Tillamook Co	Area	20.36	1.09	6.37	0.47	4.57	0.08	0.28	0	0	0
	Point	1.61	0.19	0.37	0.02	0.00	0.64	0.27	0	0	0
	On-road Mobile	16.71	1.43	1.22	0.02	0.16	1.44	0.09	0	0	0
	Fires	1.62	0.09	0.11	0.02	0.01	0.02	0.27	0	0	0
	Biogenic	21.45	0.27	0	0	0	0	0	7.35	31.92	30.51
County Total		61.75	3.06	8.07	0.53	4.74	2.18	0.91	7.35	31.92	30.51
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Umatilla Co	Area	33.65	16.04	19.54	0.61	5.44	0.14	1.00	0	0	0
	Point	5.31	2.88	0.77	0.06	0.56	0.14	0.01	0	0	0
	On-road Mobile	33.24	3.21	2.94	0.04	0.33	5.99	0.19	0	0	0
	Fires	4.93	0.28	0.34	0.05	0.02	0.09	0.81	0	0	0
	Biogenic	32.78	13.88	0	0	0	0.99	0.11	10.29	73.05	46.62
County Total		109.90	36.28	23.60	0.75	6.36	7.34	2.12	10.29	73.05	46.62
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wasco Co	Area	11.28	4.59	5.06	0.46	1.35	0.21	0.30	0	0	0
	Point	0.01	0	0.00	0	0	0.00	44.17	0	0	0
	On-road Mobile	19.97	1.83	1.70	0.02	0.18	2.70	0.11	0	0	0
	Fires	1.88	0.11	0.14	0.02	0.01	0.03	0.30	0	0	0
	Biogenic	28.18	6.91	0	0	0	27.27	3.03	18.22	56.57	40.08
County Total		61.31	13.44	6.90	0.50	1.54	30.21	47.91	18.22	56.57	40.08
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Washington Co	Area	345.31	13.34	83.46	2.20	2.00	0.87	1.76	0	0	0
	Point	0.57	0.29	0.88	0.02	0.04	0.21	0	0	0	0
	On-road Mobile	70.65	6.82	5.67	0.14	1.23	1.23	0.65	0	0	0
	Fires	1.78	0.11	0.12	0.02	0.01	0.03	0.30	0	0	0
	Biogenic	16.85	1.15	0	0	0	0	0	3.68	26.05	23.98
County Total		435.16	21.70	90.13	2.38	3.27	2.33	2.71	3.68	26.05	23.98
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wheeler Co	Area	0.60	0.20	0.46	0.03	0.64	0.01	0.02	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	1.88	0.18	0.19	0.00	0.02	0.68	0.01	0	0	0
	Fires	0.37	0.02	0.03	0.00	0.00	0.00	0.04	0	0	0
	Biogenic	23.06	3.71	0	0	0	0	0	3.80	51.82	32.80
County Total		25.91	4.11	0.68	0.04	0.66	0.69	0.07	3.80	51.82	32.80
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Yamhill Co	Area	34.33	2.73	18.11	0.36	3.13	0.17	0.63	0	0	0
	Point	9.80	4.07	1.39	2.52	0	1.06	0.00	0	0	0
	On-road Mobile	20.46	1.92	1.48	0.03	0.23	0.83	0.13	0	0	0
	Fires	2.76	0.14	0.23	0.02	0.02	0.04	0.40	0	0	0
	Biogenic	16.52	1.16	0	0	0	0	0	8.16	25.99	23.51
County Total		83.87	10.02	21.20	2.93	3.37	2.09	1.16	8.16	25.99	23.51

Table 3-14. 18-Aug-2018 emissions totals (tons per day) for Washington counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Adams Co	Area	13.32	9.31	4.01	0.12	11.54	0.03	0.45	0	0	0
	Point	0	0	0	0	0.00	0	0	0	0	0
	On-road Mobile	22.64	2.04	1.74	0.03	0.24	5.75	0.16	0	0	0
	Fires	0.07	0.00	0.01	0.00	0	0.00	0.03	0	0	0
	Biogenic	3.10	13.76	0	0	0	2.94	0.33	0.90	7.24	4.41
County Total		39.13	25.12	5.76	0.15	11.78	8.71	0.97	0.90	7.24	4.41
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Benton Co	Area	89.97	9.17	18.29	0.62	14.65	0.10	1.03	0	0	0
	Point	1.06	2.62	0.23	0.07	1.29	0.63	0.17	0	0	0
	On-road Mobile	47.68	4.35	4.24	0.06	0.52	2.04	0.30	0	0	0
	Fires	0.54	0.02	0.08	0.00	0	0.02	0.25	0	0	0
	Biogenic	7.57	11.86	0	0	0	1.15	0.13	4.28	17.14	10.77
County Total		146.82	28.02	22.85	0.75	16.46	3.95	1.88	4.28	17.14	10.77
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Chelan Co	Area	39.88	3.14	6.90	0.18	1.23	0.09	0.57	0	0	0
	Point	76.61	0.27	0.05	14.30	0	0.82	0	0	0	0
	On-road Mobile	22.09	1.86	1.83	0.03	0.24	0.19	0.14	0	0	0
	Fires	6514.32	228.35	554.01	100.81	48.00	100.82	561.78	0	0	0
	Biogenic	72.05	2.26	0	0	0	34.79	3.87	20.83	157.07	102.49
County Total		6724.95	235.88	562.78	115.32	49.47	136.71	566.35	20.83	157.07	102.49
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clallam Co	Area	17.73	1.04	5.07	0.11	0.81	0.03	0.38	0	0	0
	Point	3.82	0.92	0.16	2.44	0.00	0.04	0.40	0	0	0
	On-road Mobile	11.59	0.91	0.86	0.01	0.11	0.08	0.07	0	0	0
	Fires	0.54	0.02	0.08	0.00	0	0.02	0.25	0	0	0
	Biogenic	22.64	0.24	0	0	0	3.64	0.40	4.45	29.98	32.21
County Total		56.32	3.13	6.17	2.57	0.92	3.80	1.49	4.45	29.98	32.21
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clark Co	Area	151.92	10.07	26.75	1.53	3.03	0.20	3.29	0	0	0
	Point	80.85	3.62	3.11	11.02	0.12	4.10	0.35	0	0	0
	On-road Mobile	76.97	6.87	6.77	0.12	1.03	0.45	0.61	0	0	0
	Fires	2.45	0.11	0.37	0.02	0	0.10	1.14	0	0	0
	Biogenic	16.84	0.41	0	0	0	0	0	2.31	26.51	23.95
County Total		329.02	21.09	37.00	12.69	4.19	4.85	5.39	2.31	26.51	23.95
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Cowlitz Co	Area	49.05	6.15	13.14	1.20	0.93	0.13	1.25	0	0	0
	Point	13.00	13.42	8.38	8.98	0.19	1.89	0.76	0	0	0
	On-road Mobile	45.54	3.75	3.38	0.05	0.46	0.09	0.27	0	0	0
	Fires	0.61	0.03	0.09	0.00	0	0.03	0.29	0	0	0
	Biogenic	29.76	0.36	0	0	0	0	0	4.97	46.74	42.33
County Total		137.95	23.71	25.00	10.24	1.57	2.15	2.57	4.97	46.74	42.33
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Douglas Co	Area	16.60	3.55	3.27	0.04	6.95	0.02	0.31	0	0	0
	Point	0.41	0.01	1.24	0.98	0	0.02	0.37	0	0	0
	On-road Mobile	13.18	1.15	1.14	0.02	0.15	16.18	0.09	0	0	0
	Fires	0.18	0.01	0.03	0.00	0	0.01	0.08	0	0	0
	Biogenic	8.48	8.93	0	0	0	71.33	7.93	1.94	19.08	12.06
County Total		38.85	13.65	5.68	1.04	7.10	87.56	8.77	1.94	19.08	12.06

Table 3-14. (continued).

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Franklin Co	Area	20.95	7.60	6.68	0.24	8.28	0.05	0.53	0	0	0
	Point	0	0	0	0	0.01	0	0	0	0	0
	On-road Mobile	22.28	2.02	1.96	0.03	0.25	3.31	0.15	0	0	0
	Fires	10.57	0.44	0.89	0.07	0.21	0.06	0.96	0	0	0
	Biogenic	6.20	8.90	0	0	0	0.00	0.00	5.12	13.69	8.82
County Total		60.00	18.97	9.53	0.33	8.74	3.42	1.64	5.12	13.69	8.82
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grant Co	Area	46.85	9.56	11.38	0.29	15.05	0.07	0.81	0	0	0
	Point	0	0.01	0	0	0	0	0	0	0	0
	On-road Mobile	31.72	2.79	2.65	0.04	0.35	9.34	0.21	0	0	0
	Fires	89.19	3.20	10.17	0.57	1.78	0.60	11.60	0	0	0
	Biogenic	12.33	17.68	0	0	0	74.93	8.33	5.19	27.83	17.54
County Total		180.09	33.24	24.19	0.90	17.18	84.93	20.95	5.19	27.83	17.54
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grays Harbor Co	Area	37.99	1.54	9.36	0.21	1.58	0.05	0.55	0	0	0
	Point	11.65	3.49	0.54	1.02	0.00	1.40	1.07	0	0	0
	On-road Mobile	25.74	2.02	1.86	0.03	0.26	0.22	0.15	0	0	0
	Fires	0.44	0.02	0.07	0.00	0	0.02	0.21	0	0	0
	Biogenic	36.79	0.47	0	0	0	0	0	6.43	50.16	52.34
County Total		112.62	7.54	11.82	1.26	1.84	1.69	1.98	6.43	50.16	52.34
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Island Co	Area	19.74	0.92	3.82	0.06	0.66	0.02	0.37	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	12.81	1.02	0.96	0.01	0.13	0.26	0.08	0	0	0
	Fires	0.55	0.03	0.08	0.00	0	0.02	0.26	0	0	0
	Biogenic	2.62	0.07	0	0	0	0	0	0.62	4.16	3.73
County Total		35.72	2.03	4.87	0.08	0.79	0.31	0.70	0.62	4.16	3.73
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Jefferson Co	Area	15.12	0.42	2.44	0.07	0.43	0.02	0.25	0	0	0
	Point	6.84	1.85	0.26	2.06	0.10	0.10	0.96	0	0	0
	On-road Mobile	11.99	0.95	0.88	0.01	0.12	0.21	0.07	0	0	0
	Fires	0.27	0.01	0.04	0.00	0	0.01	0.13	0	0	0
	Biogenic	41.74	0.44	0	0	0	0	0	6.59	58.53	59.38
County Total		75.96	3.67	3.62	2.14	0.65	0.34	1.40	6.59	58.53	59.38
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - King Co	Area	988.51	67.93	186.67	11.50	9.11	1.96	12.46	0	0	0
	Point	13.20	24.65	14.64	6.92	2.93	0.73	1.14	0	0	0
	On-road Mobile	476.24	41.52	40.81	0.71	6.18	3.13	3.65	0	0	0
	Fires	16.11	0.37	4.14	0.06	0	0.19	5.28	0	0	0
	Biogenic	48.51	0.75	0	0	0	0.04	0.00	7.88	80.43	69.00
County Total		1542.56	135.23	246.26	19.18	18.21	6.05	22.52	7.88	80.43	69.00
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kitsap Co	Area	98.95	3.53	13.91	0.57	1.03	0.74	4.86	0	0	0
	Point	0.18	0.35	0.92	0.20	0.01	0.05	0.14	0	0	0
	On-road Mobile	55.38	4.69	4.57	0.07	0.58	0.54	0.34	0	0	0
	Fires	6.77	0.15	1.73	0.02	0	0.07	2.20	0	0	0
	Biogenic	12.42	0.12	0	0	0	0	0	1.61	18.36	17.66
County Total		173.71	8.85	21.13	0.85	1.62	1.40	7.54	1.61	18.36	17.66
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kittitas Co	Area	19.61	1.65	4.34	0.06	2.07	0.02	0.35	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	38.08	3.03	2.61	0.04	0.37	0.35	0.22	0	0	0
	Fires	0.17	0.01	0.03	0.00	0	0.01	0.08	0	0	0
	Biogenic	43.27	3.80	0	0	0	58.63	6.51	6.94	88.54	61.55
County Total		101.13	8.49	6.97	0.11	2.44	59.01	7.16	6.94	88.54	61.55

Table 3-14. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Klickitat Co	Area	8.63	7.85	2.59	0.38	3.00	0.02	0.40	0	0	0
	Point	88.78	1.26	0.61	2.33	0	1.07	0.57	0	0	0
	On-road Mobile	8.63	0.73	0.70	0.01	0.09	1.73	0.06	0	0	0
	Fires	0.12	0.01	0.02	0.00	0	0.00	0.05	0	0	0
	Biogenic	31.24	4.22	0	0	0	6.75	0.75	43.61	60.60	44.44
County Total		137.39	14.07	3.91	2.72	3.09	9.58	1.83	43.61	60.60	44.44
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lewis Co	Area	35.83	3.52	8.89	0.20	3.20	0.05	0.58	0	0	0
	Point	9.10	47.59	1.97	20.50	0.02	3.84	3.85	0	0	0
	On-road Mobile	38.68	3.16	2.83	0.05	0.40	0.07	0.23	0	0	0
	Fires	0.56	0.03	0.09	0.00	0	0.02	0.26	0	0	0
	Biogenic	61.07	0.72	0	0	0	0	0	7.73	96.39	86.87
County Total		145.23	55.02	13.78	20.75	3.62	3.99	4.92	7.73	96.39	86.87
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lincoln Co	Area	11.76	6.36	2.84	0.05	9.44	0.01	0.33	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	7.92	0.66	0.61	0.01	0.08	4.93	0.05	0	0	0
	Fires	21.53	0.75	1.75	0.15	0.43	0.10	1.77	0	0	0
	Biogenic	5.87	12.37	0	0	0	1.54	0.17	0.58	12.80	8.34
County Total		47.07	20.14	5.20	0.21	9.95	6.58	2.32	0.58	12.80	8.34
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Mason Co	Area	20.18	0.69	4.34	0.10	0.40	0.03	0.42	0	0	0
	Point	1.67	0.23	0.47	0	0.00	0.05	0.66	0	0	0
	On-road Mobile	15.10	1.25	1.18	0.02	0.16	0.14	0.09	0	0	0
	Fires	0.50	0.02	0.08	0.00	0	0.02	0.23	0	0	0
	Biogenic	30.45	0.26	0	0	0	0	0	2.09	44.39	43.31
County Total		67.90	2.45	6.06	0.13	0.56	0.24	1.40	2.09	44.39	43.31
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pacific Co	Area	11.31	1.39	2.35	0.55	0.56	0.01	0.32	0	0	0
	Point	0.52	0.28	0.14	0.04	0	0.03	0.08	0	0	0
	On-road Mobile	8.45	0.65	0.59	0.01	0.08	0.22	0.05	0	0	0
	Fires	0.20	0.01	0.03	0.00	0	0.01	0.09	0	0	0
	Biogenic	16.28	0.20	0	0	0	0	0	4.07	21.53	23.15
County Total		36.77	2.52	3.10	0.60	0.64	0.27	0.54	4.07	21.53	23.15
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pierce Co	Area	274.15	30.90	52.70	4.35	4.22	0.93	6.91	0	0	0
	Point	16.31	8.74	5.26	3.07	0.07	0.98	1.21	0	0	0
	On-road Mobile	175.80	15.48	15.47	0.26	2.30	0.92	1.36	0	0	0
	Fires	10.23	0.24	2.63	0.04	0	0.13	3.34	0	0	0
	Biogenic	38.35	0.56	0	0	0	0	0	5.97	62.86	54.56
County Total		514.85	55.92	76.06	7.71	6.59	2.96	12.81	5.97	62.86	54.56
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Skamania Co	Area	4.23	3.22	1.03	0.16	0.28	0.01	0.17	0	0	0
	Point	0.06	0.12	0.01	0.00	0	0.02	0.05	0	0	0
	On-road Mobile	3.37	0.28	0.26	0.00	0.04	0.01	0.02	0	0	0
	Fires	0.10	0.00	0.01	0.00	0	0.00	0.05	0	0	0
	Biogenic	52.30	0.51	0	0	0	0.07	0.01	5.49	93.31	74.40
County Total		60.07	4.14	1.31	0.17	0.32	0.12	0.30	5.49	93.31	74.40
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Snohomish Co	Area	270.94	17.96	52.39	3.66	5.28	1.19	6.96	0	0	0
	Point	3.03	2.63	5.54	1.61	0.11	0.13	0.08	0	0	0
	On-road Mobile	156.09	13.23	12.94	0.23	2.00	0.71	1.18	0	0	0
	Fires	28.24	0.85	4.34	0.30	0.12	0.39	5.14	0	0	0
	Biogenic	44.20	0.79	0	0	0	0.05	0.01	7.07	70.97	62.88
County Total		502.50	35.47	75.20	5.80	7.51	2.48	13.36	7.07	70.97	62.88

Table 3-14. (concluded)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Thurston Co	Area	100.56	4.74	15.70	0.32	2.62	0.10	1.75	0	0	0
	Point	0.02	0.10	2.04	0.00	0	0.00	0.00	0	0	0
	On-road Mobile	77.62	6.41	6.05	0.09	0.79	0.28	0.47	0	0	0
	Fires	1.66	0.08	0.25	0.01	0	0.07	0.78	0	0	0
	Biogenic	17.86	0.22	0	0	0	0	0	3.51	27.16	25.40
County Total		197.72	11.54	24.05	0.42	3.41	0.45	3.00	3.51	27.16	25.40
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Wahkiakum Co	Area	1.45	0.11	0.52	0.00	0.30	0.00	0.03	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	2.00	0.16	0.14	0.00	0.02	0.04	0.01	0	0	0
	Fires	0.04	0.00	0.01	0.00	0	0.00	0.02	0	0	0
	Biogenic	5.47	0.07	0	0	0	0	0	0.90	7.09	7.79
County Total		8.97	0.34	0.67	0.01	0.32	0.04	0.06	0.90	7.09	7.79
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Walla Walla Co	Area	21.00	5.95	7.42	0.16	8.50	0.06	0.66	0	0	0
	Point	3.28	3.53	9.08	10.85	4.48	0.42	0.00	0	0	0
	On-road Mobile	15.08	1.37	1.34	0.02	0.17	2.16	0.10	0	0	0
	Fires	124.14	4.34	10.10	0.87	2.48	0.57	10.21	0	0	0
	Biogenic	5.07	9.58	0	0	0	2.99	0.33	4.50	11.13	7.21
County Total		168.56	24.78	27.94	11.91	15.62	6.19	11.30	4.50	11.13	7.21
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Yakima Co	Area	79.93	6.67	21.97	0.58	15.60	0.15	1.32	0	0	0
	Point	4.06	0.49	5.95	0.02	4.29	0.46	0.06	0	0	0
	On-road Mobile	62.41	5.48	5.27	0.08	0.66	2.33	0.39	0	0	0
	Fires	6655.51	233.31	566.05	102.99	49.04	103.02	574.17	0	0	0
	Biogenic	68.09	10.52	0	0	0	50.71	5.63	23.05	159.26	96.86
County Total		6870.00	256.46	599.24	103.67	69.59	156.67	581.57	23.05	159.26	96.86

Table 3-15. 12-Nov-2018 emissions totals (tons per day) for Oregon counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Benton Co	Area	42.02	2.89	27.32	0.42	0.74	0.20	1.65	0	0	0
	Point	0.09	0.08	0.14	0.00	0	0.02	0.00	0	0	0
	On-road Mobile	27.50	1.86	1.76	0.02	0.21	0.47	0.12	0	0	0
	Fires	7.01	0.29	0.62	0.06	0.08	0.08	0.81	0	0	0
	Biogenic	5.84	0.27	0	0	0	0	0	0.47	9.06	8.31
County Total		82.46	5.39	29.85	0.50	1.03	0.78	2.58	0.47	9.06	8.31
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clackamas Co	Area	290.95	9.75	83.93	1.71	3.22	3.89	4.45	0	0	0
	Point	0.46	2.71	1.39	0.01	0	0.52	0.01	0	0	0
	On-road Mobile	114.08	7.77	7.87	0.14	1.20	1.04	0.66	0	0	0
	Fires	7.22	0.39	0.57	0.07	0.05	0.14	1.19	0	0	0
	Biogenic	18.86	0.42	0	0	0	0.08	0.01	0.32	29.81	26.83
County Total		431.56	21.05	93.77	1.92	4.47	5.67	6.31	0.32	29.81	26.83
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Clatsop Co	Area	38.25	5.96	10.48	2.56	0.38	0.17	1.76	0	0	0
	Point	7.95	4.88	1.77	4.92	0.15	5.21	0.64	0	0	0
	On-road Mobile	26.44	1.82	1.75	0.02	0.19	2.28	0.11	0	0	0
	Fires	5.62	0.26	0.44	0.05	0.05	0.07	0.73	0	0	0
	Biogenic	8.01	0.15	0	0	0	0	0	0.66	11.17	11.40
County Total		86.28	13.07	14.44	7.55	0.78	7.73	3.24	0.66	11.17	11.40
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Columbia Co	Area	24.06	6.52	8.68	2.99	0.45	0.10	1.74	0	0	0
	Point	34.26	9.28	9.40	4.46	0.75	1.17	1.59	0	0	0
	On-road Mobile	21.96	1.52	1.57	0.02	0.15	0.25	0.09	0	0	0
	Fires	5.40	0.26	0.41	0.05	0.04	0.07	0.74	0	0	0
	Biogenic	6.90	0.16	0	0	0	0.02	0.00	0.11	9.97	9.81
County Total		92.57	17.74	20.05	7.52	1.40	1.61	4.16	0.11	9.97	9.81
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Gilliam Co	Area	4.84	4.15	10.57	0.53	0.59	0.13	0.28	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	10.79	0.73	0.61	0.01	0.07	0.60	0.04	0	0	0
	Fires	2.39	0.08	0.31	0.01	0.07	0.01	0.23	0	0	0
	Biogenic	0.52	2.12	0	0	0	0	0	0.01	1.12	0.74
County Total		18.55	7.08	11.49	0.54	0.73	0.74	0.55	0.01	1.12	0.74
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Grant Co	Area	7.46	0.88	5.53	0.04	1.35	0.03	0.45	0	0	0
	Point	0.28	0.44	0.25	0.03	0	0.13	0	0	0	0
	On-road Mobile	10.46	0.74	0.73	0.01	0.07	0.78	0.04	0	0	0
	Fires	4.29	0.18	0.36	0.04	0.05	0.05	0.47	0	0	0
	Biogenic	22.33	2.27	0	0	0	0.10	0.01	0.39	52.70	31.76
County Total		44.82	4.52	6.87	0.11	1.47	1.09	0.97	0.39	52.70	31.76
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Hood River Co	Area	12.10	2.50	6.92	0.60	0.21	0.08	0.69	0	0	0
	Point	0	0	0.00	0	0	0	0	0	0	0
	On-road Mobile	18.15	1.25	1.03	0.01	0.12	0.12	0.07	0	0	0
	Fires	4.27	0.24	0.40	0.02	0.02	0.06	0.58	0	0	0
	Biogenic	5.71	0.08	0	0	0	0.01	0.00	0.28	11.10	8.13
County Total		40.24	4.07	8.35	0.64	0.35	0.27	1.34	0.28	11.10	8.13

Table 3-15 (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Jefferson Co	Area	11.07	1.82	5.24	0.10	0.65	0.05	0.62	0	0	0
	Point	0.23	0.26	1.67	0.01	0	0.08	0	0	0	0
	On-road Mobile	15.60	1.11	1.02	0.01	0.10	3.13	0.06	0	0	0
	Fires	7.95	0.30	0.97	0.04	0.21	0.05	0.83	0	0	0
	Biogenic	6.60	1.48	0	0	0	0	0	0.09	14.44	9.38
County Total		41.45	4.96	8.90	0.15	0.96	3.30	1.51	0.09	14.44	9.38
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Lincoln Co	Area	34.63	1.58	11.98	0.20	0.25	0.20	1.54	0	0	0
	Point	7.55	2.52	2.66	1.22	0.12	3.41	0.04	0	0	0
	On-road Mobile	27.09	1.86	1.74	0.02	0.20	1.50	0.11	0	0	0
	Fires	6.09	0.29	0.47	0.06	0.05	0.08	0.81	0	0	0
	Biogenic	11.95	0.16	0	0	0	0.00	0.00	0.62	17.28	16.99
County Total		87.30	6.42	16.84	1.50	0.62	5.19	2.50	0.62	17.28	16.99
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Linn Co	Area	60.75	7.55	28.73	0.71	2.37	0.25	2.64	0	0	0
	Point	18.56	3.75	6.26	1.58	0.26	4.23	0.02	0	0	0
	On-road Mobile	90.77	6.24	6.18	0.07	0.60	1.74	0.35	0	0	0
	Fires	41.33	1.51	4.70	0.22	0.93	0.32	4.10	0	0	0
	Biogenic	21.97	0.53	0	0	0	0.09	0.01	0.38	35.26	31.25
County Total		233.38	19.57	45.88	2.58	4.16	6.62	7.12	0.38	35.26	31.25
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Marion Co	Area	175.28	11.15	60.54	1.86	4.75	0.67	5.70	0	0	0
	Point	0.10	1.42	0.27	0.07	0.02	0.07	0	0	0	0
	On-road Mobile	147.18	10.11	9.59	0.12	1.07	2.51	0.61	0	0	0
	Fires	19.15	0.73	2.26	0.09	0.42	0.19	2.14	0	0	0
	Biogenic	8.98	0.55	0	0	0	0.01	0.00	0.20	14.41	12.78
County Total		350.69	23.94	72.66	2.15	6.26	3.44	8.45	0.20	14.41	12.78
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Morrow Co	Area	9.90	5.92	11.81	0.33	20.05	0.20	0.56	0	0	0
	Point	2.27	19.82	0.33	12.36	0.24	3.41	1.89	0	0	0
	On-road Mobile	13.91	0.95	0.80	0.01	0.09	1.46	0.05	0	0	0
	Fires	3.57	0.15	0.37	0.02	0.07	0.03	0.39	0	0	0
	Biogenic	2.88	2.99	0	0	0	0	0	0.09	6.37	4.10
County Total		32.53	29.82	13.31	12.72	20.44	5.11	2.90	0.09	6.37	4.10
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Multnomah Co	Area	427.41	24.30	142.06	4.82	1.20	9.44	7.78	0	0	0
	Point	4.99	3.08	5.13	1.05	0.10	2.07	0.39	0	0	0
	On-road Mobile	221.85	15.39	15.18	0.27	2.36	2.40	1.29	0	0	0
	Fires	0.62	0.02	0.08	0.00	0.00	0.00	0.13	0	0	0
	Biogenic	3.44	0.17	0	0	0	0.01	0.00	0.11	5.06	4.90
County Total		658.31	42.96	162.45	6.15	3.66	13.94	9.59	0.11	5.06	4.90
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Polk Co	Area	39.36	2.62	13.79	0.29	1.43	0.12	1.41	0	0	0
	Point	0	0	0.25	0	0.01	0.02	0	0	0	0
	On-road Mobile	32.28	2.22	2.21	0.03	0.24	0.87	0.14	0	0	0
	Fires	6.60	0.31	0.55	0.05	0.06	0.08	0.82	0	0	0
	Biogenic	6.20	0.39	0	0	0	0	0	0.86	9.29	8.82
County Total		84.45	5.54	16.80	0.38	1.73	1.10	2.36	0.86	9.29	8.82
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Sherman Co	Area	4.25	3.20	1.53	0.19	0.70	0.01	0.22	0	0	0
	Point	0.75	0.27	0.04	0.01	0	0.00	0	0	0	0
	On-road Mobile	9.40	0.64	0.57	0.01	0.06	0.86	0.03	0	0	0
	Fires	0.81	0.03	0.10	0.00	0.02	0.00	0.08	0	0	0
	Biogenic	0.31	1.75	0	0	0	0	0	0.01	0.72	0.45
County Total		15.52	5.89	2.24	0.21	0.78	0.88	0.34	0.01	0.72	0.45

Table 3-15 (concluded)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Oregon - Tillamook Co	Area	26.68	1.26	9.10	0.52	4.56	0.10	0.99	0	0	0
	Point	1.61	0.19	0.37	0.02	0.00	0.64	0.27	0	0	0
	On-road Mobile	22.89	1.57	1.47	0.02	0.17	1.50	0.10	0	0	0
	Fires	3.00	0.15	0.23	0.03	0.02	0.04	0.41	0	0	0
	Biogenic	12.09	0.19	0	0	0	0.01	0.00	0.77	18.16	17.19
County Total		66.26	3.35	11.17	0.58	4.75	2.30	1.76	0.77	18.16	17.19
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Umatilla Co	Area	48.18	16.51	23.91	0.83	4.90	0.20	2.79	0	0	0
	Point	4.23	2.71	0.74	0.05	0.49	0.14	0.01	0	0	0
	On-road Mobile	51.54	3.59	3.21	0.04	0.35	6.24	0.20	0	0	0
	Fires	18.72	0.78	1.95	0.12	0.35	0.22	2.12	0	0	0
	Biogenic	7.60	4.66	0	0	0	0.00	0.00	0.25	16.94	10.82
County Total		130.27	28.25	29.81	1.04	6.09	6.80	5.13	0.25	16.94	10.82
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wasco Co	Area	15.73	4.82	6.47	0.77	1.06	0.23	0.84	0	0	0
	Point	0.01	0	0.00	0	0	0.00	41.20	0	0	0
	On-road Mobile	30.10	2.08	1.85	0.02	0.19	2.81	0.11	0	0	0
	Fires	5.48	0.25	0.54	0.04	0.08	0.06	0.66	0	0	0
	Biogenic	7.93	2.89	0	0	0	0	0	0.38	15.85	11.27
County Total		59.25	10.04	8.85	0.83	1.32	3.10	42.81	0.38	15.85	11.27
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Washington Co	Area	384.84	16.06	92.77	3.26	1.88	1.20	9.90	0	0	0
	Point	0.57	0.29	0.88	0.02	0.04	0.21	0	0	0	0
	On-road Mobile	112.34	7.52	6.95	0.15	1.29	1.28	0.68	0	0	0
	Fires	3.27	0.18	0.26	0.03	0.02	0.04	0.45	0	0	0
	Biogenic	6.53	0.60	0	0	0	0.11	0.01	0.20	10.03	9.28
County Total		507.55	24.64	100.85	3.46	3.23	2.85	11.05	0.20	10.03	9.28
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Wheeler Co	Area	1.09	0.21	0.55	0.04	0.50	0.01	0.08	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	2.87	0.20	0.20	0.00	0.02	0.71	0.01	0	0	0
	Fires	1.09	0.04	0.09	0.01	0.01	0.01	0.12	0	0	0
	Biogenic	5.82	1.53	0	0	0	0.01	0.00	0.08	13.05	8.27
County Total		10.86	1.99	0.84	0.05	0.53	0.74	0.21	0.08	13.05	8.27
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Oregon - Yamhill Co	Area	48.50	3.21	23.10	0.56	2.74	0.23	2.21	0	0	0
	Point	9.79	4.04	1.39	2.52	0	1.06	0.00	0	0	0
	On-road Mobile	31.33	2.14	1.86	0.03	0.24	0.86	0.13	0	0	0
	Fires	6.64	0.31	0.58	0.05	0.05	0.09	0.79	0	0	0
	Biogenic	6.02	0.57	0	0	0	0	0	0.42	9.40	8.57
County Total		102.29	10.27	26.92	3.16	3.03	2.25	3.14	0.42	9.40	8.57

Table 3-16. 12-Nov-2018 emissions totals (tons per day) for Washington counties. A "0" indicates that no emissions estimates were available for this category and pollutant in the raw inventory. A "0.00" indicates that emissions estimates were available for this category and pollutant in the raw inventory though the resulting modeled emissions estimates are smaller than 0.005 tons per day. Of note, isoprene (ISOP), monoterpene (TERP), and other volatile organic compounds (OVOCs) are biogenic-related chemicals and are listed separately as they can be a significant fraction of the total VOC load.

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Adams Co	Area	14.53	9.38	4.77	0.14	1.96	0.04	0.59	0	0	0
	Point	0	0	0	0	0.00	0	0	0	0	0
	On-road Mobile	31.07	2.16	1.69	0.03	0.23	5.99	0.16	0	0	0
	Fires	0.07	0.00	0.01	0.00	0	0.00	0.03	0	0	0
	Biogenic	0.56	4.09	0	0	0	0	0	0.03	1.22	0.79
County Total		46.23	15.64	6.47	0.17	2.20	6.03	0.78	0.03	1.22	0.79
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Benton Co	Area	95.34	9.62	26.39	0.71	8.44	0.27	2.62	0	0	0
	Point	1.02	2.58	0.23	0.07	2.06	0.71	0.16	0	0	0
	On-road Mobile	64.22	4.48	4.16	0.06	0.50	2.12	0.30	0	0	0
	Fires	0.56	0.02	0.09	0.00	0	0.02	0.25	0	0	0
	Biogenic	1.17	3.63	0	0	0	2.30	0.26	0.08	2.66	1.67
County Total		162.32	20.33	30.86	0.84	11.00	5.43	3.59	0.08	2.66	1.67
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Chelan Co	Area	44.75	3.36	7.64	0.23	0.70	0.52	1.09	0	0	0
	Point	74.80	0.27	0.05	13.98	0	0.81	0	0	0	0
	On-road Mobile	30.68	2.00	1.74	0.03	0.23	0.19	0.14	0	0	0
	Fires	2.79	0.22	0.26	0.06	0.02	0.01	0.41	0	0	0
	Biogenic	21.82	0.98	0	0	0	7.35	0.82	0.83	47.51	31.04
County Total		174.85	6.82	9.69	14.30	0.95	8.89	2.46	0.83	47.51	31.04
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clallam Co	Area	21.12	1.20	7.71	0.15	0.47	0.07	1.15	0	0	0
	Point	3.81	0.90	0.16	2.34	0.00	0.04	0.39	0	0	0
	On-road Mobile	14.35	0.96	0.88	0.01	0.11	0.08	0.07	0	0	0
	Fires	7.73	0.62	0.69	0.17	0.05	0.02	1.03	0	0	0
	Biogenic	9.22	0.13	0	0	0	0.12	0.01	0.36	12.27	13.12
County Total		56.23	3.81	9.44	2.67	0.63	0.33	2.64	0.36	12.27	13.12
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Clark Co	Area	193.79	11.64	27.91	1.77	2.07	0.54	8.44	0	0	0
	Point	79.10	3.60	3.07	10.78	0.12	4.06	0.35	0	0	0
	On-road Mobile	101.86	7.10	6.79	0.11	1.00	0.46	0.59	0	0	0
	Fires	2.56	0.11	0.39	0.02	0	0.10	1.16	0	0	0
	Biogenic	6.98	0.23	0	0	0	0.26	0.03	0.15	10.97	9.93
County Total		384.29	22.68	38.16	12.68	3.19	5.42	10.57	0.15	10.97	9.93
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Cowlitz Co	Area	59.96	6.44	18.23	1.27	0.66	0.23	2.59	0	0	0
	Point	12.98	13.39	8.12	8.91	0.18	1.90	0.76	0	0	0
	On-road Mobile	58.31	3.91	3.45	0.05	0.45	0.09	0.27	0	0	0
	Fires	18.30	1.50	1.59	0.41	0.12	0.03	2.19	0	0	0
	Biogenic	12.64	0.21	0	0	0	0.12	0.01	0.34	19.85	17.97
County Total		162.20	25.45	31.39	10.64	1.41	2.36	5.83	0.34	19.85	17.97
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Douglas Co	Area	19.59	3.63	4.71	0.06	1.05	0.05	0.68	0	0	0
	Point	0.45	0.01	1.35	1.06	0	0.03	0.40	0	0	0
	On-road Mobile	18.87	1.25	1.10	0.02	0.14	16.86	0.09	0	0	0
	Fires	0.42	0.03	0.05	0.00	0.00	0.01	0.11	0	0	0
	Biogenic	1.77	3.21	0	0	0	84.66	9.41	0.06	3.95	2.51
County Total		41.10	8.11	7.22	1.14	1.20	101.60	10.68	0.06	3.95	2.51

Table 3-16. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Franklin Co	Area	24.96	7.74	9.16	0.27	2.10	0.10	1.02	0	0	0
	Point	0	0	0	0	0.01	0	0	0	0	0
	On-road Mobile	30.26	2.09	1.93	0.03	0.24	3.45	0.14	0	0	0
	Fires	0.16	0.01	0.02	0.00	0	0.01	0.07	0	0	0
	Biogenic	0.89	2.57	0	0	0	0.00	0.00	0.10	1.96	1.27
County Total		56.27	12.41	11.12	0.30	2.34	3.56	1.23	0.10	1.96	1.27
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grant Co	Area	52.78	9.73	15.01	0.32	3.89	0.15	1.53	0	0	0
	Point	0	0.01	0	0	0	0	0	0	0	0
	On-road Mobile	44.56	2.96	2.57	0.04	0.34	9.73	0.20	0	0	0
	Fires	0.34	0.01	0.05	0.00	0	0.01	0.15	0	0	0
	Biogenic	2.07	5.63	0	0	0	16.30	1.81	0.15	4.65	2.94
County Total		99.75	18.35	17.63	0.36	4.23	26.19	3.69	0.15	4.65	2.94
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Grays Harbor Co	Area	46.66	1.81	13.55	0.26	1.16	0.13	1.62	0	0	0
	Point	11.65	3.49	0.54	1.02	0.00	1.40	1.07	0	0	0
	On-road Mobile	31.16	2.09	1.90	0.03	0.25	0.23	0.15	0	0	0
	Fires	141.49	11.79	12.03	3.23	0.95	0.02	15.39	0	0	0
	Biogenic	19.82	0.33	0	0	0	0	0	0.80	27.13	28.19
County Total		250.78	19.52	28.02	4.54	2.36	1.78	18.24	0.80	27.13	28.19
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Island Co	Area	25.93	1.26	7.44	0.11	0.41	0.08	1.48	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	15.90	1.07	0.98	0.01	0.13	0.27	0.07	0	0	0
	Fires	0.57	0.03	0.09	0.00	0	0.02	0.26	0	0	0
	Biogenic	1.11	0.04	0	0	0	0	0	0.06	1.77	1.58
County Total		43.52	2.39	8.50	0.13	0.54	0.38	1.81	0.06	1.77	1.58
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Jefferson Co	Area	19.43	0.57	4.18	0.11	0.36	0.05	0.79	0	0	0
	Point	6.84	1.85	0.26	2.05	0.10	0.10	0.96	0	0	0
	On-road Mobile	15.03	1.00	0.90	0.01	0.12	0.21	0.07	0	0	0
	Fires	7.17	0.59	0.63	0.16	0.05	0.01	0.87	0	0	0
	Biogenic	17.85	0.26	0	0	0	0.03	0.00	0.59	25.12	25.39
County Total		66.32	4.26	5.96	2.34	0.62	0.41	2.69	0.59	25.12	25.39
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - King Co	Area	1176.04	80.20	289.23	14.27	8.62	4.10	35.40	0	0	0
	Point	12.86	21.65	14.63	5.88	2.98	0.69	1.11	0	0	0
	On-road Mobile	626.43	43.08	40.95	0.69	6.00	3.20	3.56	0	0	0
	Fires	16.11	0.37	4.14	0.06	0	0.19	5.28	0	0	0
	Biogenic	18.67	0.40	0	0	0	1.69	0.19	0.55	30.82	26.56
County Total		1850.11	145.70	348.96	20.90	17.60	9.87	45.54	0.55	30.82	26.56
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kitsap Co	Area	123.19	4.86	25.65	0.90	1.01	1.02	8.85	0	0	0
	Point	0.18	0.35	0.88	0.20	0.01	0.05	0.13	0	0	0
	On-road Mobile	71.11	4.90	4.65	0.06	0.56	0.56	0.33	0	0	0
	Fires	6.79	0.15	1.73	0.02	0	0.07	2.20	0	0	0
	Biogenic	4.21	0.06	0	0	0	0	0	0.10	6.22	5.98
County Total		205.48	10.33	32.90	1.19	1.58	1.70	11.51	0.10	6.22	5.98
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Kittitas Co	Area	23.62	1.84	6.33	0.10	0.70	0.06	0.84	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	53.10	3.30	2.55	0.04	0.36	0.36	0.21	0	0	0
	Fires	24.79	2.06	2.11	0.56	0.17	0.01	2.73	0	0	0
	Biogenic	14.31	1.58	0	0	0	5.43	0.60	0.30	29.19	20.35
County Total		115.81	8.79	10.99	0.71	1.22	5.86	4.38	0.30	29.19	20.35

Table 3-16. (continued)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Klickitat Co	Area	10.65	7.93	3.52	0.40	0.70	0.04	0.65	0	0	0
	Point	86.56	1.20	0.61	2.26	0	1.05	0.56	0	0	0
	On-road Mobile	11.73	0.77	0.68	0.01	0.09	1.81	0.05	0	0	0
	Fires	394.49	32.92	33.46	9.02	2.65	0.00	42.51	0	0	0
	Biogenic	8.17	1.60	0	0	0	2.74	0.30	1.25	15.80	11.62
County Total		511.60	44.42	38.26	11.69	3.44	5.64	44.08	1.25	15.80	11.62
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lewis Co	Area	44.70	3.81	12.66	0.26	1.73	0.12	1.68	0	0	0
	Point	8.87	45.29	1.89	19.52	0.02	3.82	3.72	0	0	0
	On-road Mobile	49.99	3.32	2.89	0.04	0.39	0.07	0.23	0	0	0
	Fires	0.59	0.03	0.09	0.00	0	0.02	0.26	0	0	0
	Biogenic	25.64	0.42	0	0	0	0.00	0.00	0.55	40.44	36.47
County Total		129.79	52.86	17.53	19.83	2.14	4.03	5.88	0.55	40.44	36.47
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Lincoln Co	Area	12.38	6.40	3.24	0.06	1.26	0.02	0.41	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	11.07	0.70	0.58	0.01	0.08	5.14	0.05	0	0	0
	Fires	0.04	0.00	0.01	0.00	0	0.00	0.02	0	0	0
	Biogenic	1.08	3.96	0	0	0	1.05	0.12	0.03	2.28	1.54
County Total		24.58	11.06	3.82	0.07	1.33	6.22	0.59	0.03	2.28	1.54
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Mason Co	Area	28.54	0.92	7.46	0.14	0.33	0.08	1.48	0	0	0
	Point	1.67	0.23	0.47	0	0.00	0.05	0.66	0	0	0
	On-road Mobile	19.44	1.31	1.20	0.02	0.15	0.14	0.09	0	0	0
	Fires	0.52	0.02	0.08	0.00	0	0.02	0.23	0	0	0
	Biogenic	11.95	0.14	0	0	0	0	0	0.16	17.45	17.00
County Total		62.12	2.63	9.21	0.16	0.48	0.29	2.46	0.16	17.45	17.00
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pacific Co	Area	15.56	1.49	4.03	0.59	0.40	0.04	0.84	0	0	0
	Point	0.52	0.28	0.14	0.04	0	0.03	0.08	0	0	0
	On-road Mobile	10.15	0.67	0.60	0.01	0.08	0.22	0.05	0	0	0
	Fires	0.21	0.01	0.03	0.00	0	0.01	0.10	0	0	0
	Biogenic	9.64	0.15	0	0	0	0	0	0.56	12.87	13.71
County Total		36.08	2.60	4.81	0.64	0.49	0.31	1.06	0.56	12.87	13.71
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Pierce Co	Area	322.27	34.76	61.92	4.97	3.65	1.69	16.98	0	0	0
	Point	16.34	8.65	5.34	3.05	0.07	0.98	1.20	0	0	0
	On-road Mobile	232.91	16.04	15.48	0.26	2.23	0.93	1.32	0	0	0
	Fires	10.23	0.24	2.63	0.04	0	0.13	3.34	0	0	0
	Biogenic	15.14	0.30	0	0	0	0.01	0.00	0.39	24.71	21.53
County Total		596.88	59.99	85.37	8.31	5.96	3.75	22.85	0.39	24.71	21.53
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Skamania Co	Area	5.71	3.26	1.60	0.16	0.25	0.01	0.36	0	0	0
	Point	0.06	0.12	0.01	0.00	0	0.02	0.05	0	0	0
	On-road Mobile	4.50	0.30	0.26	0.00	0.04	0.01	0.02	0	0	0
	Fires	0.31	0.02	0.03	0.01	0.00	0.00	0.07	0	0	0
	Biogenic	19.81	0.29	0	148.81	0	0.23	0.03	0.29	35.31	28.18
County Total		30.39	3.99	1.90	148.99	0.29	0.29	0.53	0.29	35.31	28.18
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Snohomish Co	Area	314.00	21.31	84.32	4.15	4.46	1.86	15.88	0	0	0
	Point	2.99	2.62	5.49	1.61	0.11	0.13	0.08	0	0	0
	On-road Mobile	204.70	13.85	13.02	0.22	1.94	0.72	1.15	0	0	0
	Fires	27.89	1.64	4.30	0.42	0.11	0.13	5.46	0	0	0
	Biogenic	17.41	0.43	0	0	0	0.00	0.00	0.53	27.83	24.77
County Total		566.99	39.86	107.13	6.40	6.63	2.84	22.58	0.53	27.83	24.77

Table 3-16. (concluded)

State-County	Group	CO	NOX	VOC	SOX	NH3	PMC	PMF	ISOP	TERP	OVOC
Washington - Thurston Co	Area	126.89	6.02	24.66	0.49	1.76	0.30	5.00	0	0	0
	Point	0.02	0.10	2.04	0.00	0	0.00	0.00	0	0	0
	On-road Mobile	100.30	6.71	6.15	0.09	0.77	0.28	0.46	0	0	0
	Fires	1.74	0.08	0.26	0.01	0	0.07	0.79	0	0	0
	Biogenic	7.13	0.12	0	0	0	0	0	0.21	10.86	10.15
County Total		236.09	13.02	33.12	0.60	2.53	0.65	6.24	0.21	10.86	10.15
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Wahkiakum Co	Area	2.03	0.13	0.73	0.01	0.12	0.00	0.10	0	0	0
	Point	0	0	0	0	0	0	0	0	0	0
	On-road Mobile	2.45	0.16	0.15	0.00	0.02	0.04	0.01	0	0	0
	Fires	0.04	0.00	0.01	0.00	0	0.00	0.02	0	0	0
	Biogenic	2.81	0.05	0	0	0	0	0	0.08	3.67	4.00
County Total		7.34	0.34	0.89	0.01	0.14	0.04	0.13	0.08	3.67	4.00
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Walla Walla Co	Area	38.50	6.48	16.56	0.26	1.26	0.23	2.83	0	0	0
	Point	3.28	3.52	9.06	10.85	4.48	0.42	0.00	0	0	0
	On-road Mobile	20.33	1.41	1.31	0.02	0.16	2.25	0.10	0	0	0
	Fires	0.23	0.01	0.03	0.00	0	0.01	0.10	0	0	0
	Biogenic	0.85	2.76	0	0	0	0	0	0.07	1.86	1.21
County Total		63.19	14.18	26.95	11.12	5.90	2.91	3.03	0.07	1.86	1.21
State-County	**Group**	**CO**	**NOX**	**VOC**	**SOX**	**NH3**	**PMC**	**PMF**	**ISOP**	**TERP**	**OVOC**
Washington - Yakima Co	Area	98.72	7.63	31.78	0.80	9.53	0.35	3.60	0	0	0
	Point	4.06	0.49	5.95	0.02	4.29	0.46	0.06	0	0	0
	On-road Mobile	85.14	5.71	5.08	0.07	0.64	2.42	0.38	0	0	0
	Fires	34.89	2.87	3.02	0.78	0.23	0.04	4.07	0	0	0
	Biogenic	19.69	3.94	0	0	0	7.88	0.88	0.76	45.99	28.01
County Total		242.50	20.65	45.84	1.68	14.69	11.15	8.98	0.76	45.99	28.01

3.4 CONCLUSION

CAMx-ready emissions estimates for episodes in August and November 2004, and for the corresponding episodes in 2018, were primarily prepared using the SMOKE emissions modeling system, though emissions modeling tools such as GloBEIS (for biogenics) and a WRAP model to estimate wind-blown dust were also used. Emissions were estimated for a 36 km, 12 km and 4 km modeling domain. Emphasis in this project was focused on developing emissions estimates within the 4 km modeling domain, which covers most of the states of Oregon and Washington. The base data for the emissions estimates were derived from the 2002 and 2018 WRAP emissions data bases. The 2002 WRAP emissions data were grown to 2004 using EGAS-derived growth factors and were replaced or supplemented with 2004 emissions data that were provided by the project sponsors. Day-specific SO_2 and NOx emissions for a number of EGUs in Oregon and Washington were extracted from EPA-maintained data bases. The study team prepared estimates of episodic wildfire emissions. The study team revised the commercial marine shipping emissions estimates to better account for spatial distribution of the emissions. The study team prepared estimates of SO_2 emissions from Mt. St. Helens. The study team applied canopy escape factors to fugitive dust emissions estimates in an effort to create more realistic estimates from these sources. The study team revised estimates of NH_3 emissions from confined animal feeding operations and for certain fertilizer application categories to reflect more current, higher emissions factors. The study team further revised estimates of emissions from residential wood burning operations to reflect more realistic growth assumptions. The sponsors supplied

very limited 2018 emissions data; therefore, virtually all 2018 emissions estimates for this study were derived from the 2018 WRAP emissions data base.

Although the 2004 CAMx-ready 4 km domain emission estimates were based on data supplied by the sponsors and the 2018 CAMx-ready 4 km domain emissions estimates were based on data from WRAP, a comparison of the two CAMx-ready data bases revealed that the data sets were consistent in terms of the emission source categories included in each. However, the comparison did reveal a number of inconsistencies and errors that should be addressed in future modeling:

- The Centralia Alta Vista power plant in Lewis County, Washington is potentially misplaced in the 2004 or 2018 data bases. Further, the use of Wyoming coal in lieu of local coal at this facility will likely result in a decrease of SO_2 emissions in 2018 (currently, the 2018 WRAP data base reflects SO_2 emissions using local, high sulfur content coal).

- WRAP's 2002 to 2018 emissions growth for "pulp and paper" and "aluminum ore production," and potentially other industrial source categories, has likely been overstated.

- There appears to be inconsistent growth of NOx emissions for industrial point sources between the PSAT regions "West of Gorge" and "East of Gorge."

- There appears to be an inconsistency in temporal allocation of area source emissions estimates between 2018 and 2004 (i.e., 2004 shows a definite seasonal influence between August and November, whereas in 2018 the emissions are essentially the same); this is especially noticeable in the 12km grid.

- Commercial marine shipping emissions estimates in the Puget Sound area are inconsistent between 2004 and 2018, with 2004 showing far lower emissions than are indicated for 2018.

The Emissions Inventory Report that is being prepared by ODEQ provides a full review and comparison of the resulting emission inventories used in the Gorge modeling study. It also provides additional details on the anomalies that have been found in the 2004 and 2018 emissions estimates. Regardless of these anomalies, the fidelity of the emissions estimates from a qualitative perspective is on par with emissions estimated for similar and regulatory studies conducted throughout the U.S.

4.0 CAMx BASE YEAR MODELING

4.1 CAMx MODELING OVERVIEW

Table 4-1 summarizes the base configuration for CAMx. The latest version of CAMx (version 4.40) was employed for the Gorge Study modeling (ENVIRON, 2006). CAMx was run on the single 36-km grid for the first 8 days of a 10 day spin-up period prior to both episodes; the 12-km grid was introduced during the last two days of the spin-up period. The entire 36/12/4 km grid structure (defined in Section 1) was run for the actual episode days using two-way interactive nesting, which allows for both up- and down-scale transfer of information among the grids. CAMx was configured to run with 19 vertical layers up to 100 mb (~15 km AGL) that exactly match those used by CMAQ and CAMx in the WRAP modeling. Initial/boundary condition (IC/BC) inputs were developed from data utilized in the WRAP modeling. CAMx was run in the UTC time zone since all emissions, meteorology, and IC/BC inputs were developed on that schedule.

Table 4-1. Base Gorge Study model configuration for CAMx.

Model Option	CAMx
Model Version	Version 4.40 (2006)
Horizontal Resolution	36/12/4 km
Vertical Layers	19
Horizontal Advection	Bott
Time Zone	UTC/GMT
Horizontal Diffusion	Spatially Varying (Smagorinsky)
Vertical Diffusion	K-theory (O'Brien and CMAQ)
Gas-Phase Chemistry	CB4 (Mechanism 4)
Gas-Phase Chemistry Solver	CMC (fast adaptive-hybrid)
Secondary Organic Aerosol	SOAP
Aqueous-Phase Chemistry	RADM
Inorganic Aerosol Chemistry	ISORROPIA
PM Size Model	Static Coarse/Fine (CF) modes
Dry Deposition	RADM (Wesely)
Wet Deposition	Active
Plume-in-Grid	Off
Initial Concentrations	CMAQ Default
Boundary Conditions	Monthly-Average Diurnally Varying From WRAP GEOS-CHEM

The photochemical/particulate chemistry option, referred to as Mechanism 4 Coarse/Fine (CF), was selected for the Gorge Study modeling. Mechanism 4 employs an enhanced version of the CB4 gas-phase chemical mechanism appropriate for regional ozone and PM modeling. Mechanism 4 CF includes the following PM chemistry algorithms: RADM aqueous-phase chemistry; SOAP secondary organic aerosol equilibrium; and ISORROPIA inorganic equilibrium. The CF approach defines two static PM size modes, fine (<2.5 μm) and coarse (>2.5 μm), and assumes that all secondary PM is formed and remains in the fine mode. CAMx

v4.40 was enhanced for this study to improve the chemical treatment of biogenic terpene yields to secondary organic aerosol (SOA). This follows a similar implementation we made in CMAQ for the RPOs, which has since been adopted by EPA for standard CMAQ distribution.

The vertical diffusion approach in CAMx is based on K-theory, where the vertical eddy diffusivity coefficient (or "Kv") input fields are derived from MM5 PBL output variables via the MM5CAMx interface processor. Alternative vertical diffusivity coefficients were tested in sensitivity tests. Two sets of CAMx vertical diffusivity inputs were generated by MM5CAMx: (1) using the O'Brien profile scheme; and (2) using the local stability scheme in CMAQ.

While CAMx includes a plume-in-grid (PiG) treatment for ozone and PM, it is designed primarily to represent point source plume dispersion and chemistry within coarse grids, and would not provide much benefit on the high resolution grids employed for this study (it adds considerable computer resources). The Bott advection solver was selected over the PPM scheme because it provides for a faster simulation by allowing for larger model time steps. The spatially varying Smagorinsky horizontal diffusion and RADM/Wesely dry deposition algorithms are the only approaches for these processes available in CAMx.

4.2 MODEL INPUTS

4.2.1 Meteorological Inputs

It is necessary to convert raw output from the MM5 meteorological model to formats and variables used by CAMx specifically. The MM5CAMx translation processor was used to complete this task. The software includes the ability to interpolate data from the native map projections used by the meteorological model to any projection to be specified for the air quality model (CAMx may be applied on Lambert Conformal, Polar Stereographic, or UTM Cartesian projections, or in geodetic latitude/longitude).

CAMx requires meteorological input data for the parameters described in Table 4-2. All of these input data were derived from the MM5 results. MM5CAMx performs several functions:

1. Extracts data from the MM5 grids to the corresponding CAMx grids; in this study, the extraction included a simple one-to-one mapping from the MM5 Lambert Conformal grid to the CAMx Lambert Conformal grid, with appropriate windowing to remove the extra row/columns in the MM5 grids.
2. Performs mass-weighted vertical aggregation of data for CAMx layers that span multiple MM5 layers.
3. Diagnoses key variables that are not directly output by MM5 (e.g., vertical diffusion coefficients and some cloud information).

The MM5CAMx program has been written to carefully preserve the consistency of the predicted wind, temperature and pressure fields output by MM5. This is the key to preparing mass-consistent inputs for CAMx, and therefore for obtaining high quality performance from CAMx.

For the August episode, the MM5 "Run 6" 12-km meteorological fields were chosen for the air quality simulation as they provided the best overall characterization of meteorology (see section

Table 4-2. CAMx meteorological input data requirements.

CAMx Input Parameter	Description
Layer interface height (m)	3-D gridded hourly time-varying layer heights
Winds (m/s)	3-D gridded hourly wind vectors (u,v)
Temperature (K)	3-D gridded hourly temperature and 2-D gridded surface temperature
Pressure (mb)	3-D gridded hourly pressure
Vertical Diffusivity (m^2/s)	3-D gridded hourly vertical exchange coefficients
Water Vapor (ppm)	3-D gridded hourly water vapor mixing ratio
Cloud Cover	3-D gridded hourly cloud and precip water contents
Landuse Distribution	2-D gridded static landuse/landcover distribution

2 for a complete description of MM5 performance). The 36- and 12-km meteorological fields from Run 6 were processed through MM5CAMx. We utilized the "flexi-nesting" capability of CAMx to internally interpolate the 12-km fields to the 4-km air quality grid during the core episode when the full 2-way interactive 36/12/4-km grid system was employed.

For the November episode, the MM5 "Run 3" 4-km meteorological fields were chosen for the air quality simulation as they provided the best overall characterization of meteorology. All three 36/12/4-km meteorological fields from Run 3 were processed through MM5CAMx.

The data prepared by MM5CAMx were directly input to CAMx. Vertical diffusivities (Kv) are an important input to the CAMx simulation since they determine the rate and depth of mixing in the planetary boundary layer (PBL) and above. In general, our experience has been that diffusivities from meteorological models require careful examination before they are used in air quality modeling. This may be because the air quality model results are much more sensitive to diffusivities than the meteorological model results. We evaluated the CAMx diffusion inputs by comparing the Kv values from several diagnostic calculation approaches. Two sets of vertical turbulent diffusivity files were generated by MM5CAMx:

- Use of the O'Brien scheme (OB70);
- Use of the CMAQ scheme.

Sensitivity simulations were undertaken with the two variations. Additionally, MM5CAMx was set up to apply both 0.1 m^2/s and 1.0 m^2/s minimum values, which were both evaluated in these same sensitivity tests. The choice of minimum Kv value is an area of ongoing investigation by the CMAQ and CAMx developers. The problem relates to simulating the proper degree of the pollutant buildup during stable (e.g., nighttime) conditions. A value that is too small often results in over predictions of PM and ozone precursors such as NOx that can artificially remove ozone, while a value that is too large may lead to significant under predictions. These problems have been seen to impact daytime photochemistry and the calculation of 24-hour PM levels.

4.2.2 Landuse/Landcover Data

CAMx requires the specification of gridded landuse fields for each grid used in a simulation. The distribution of 11 landuse categories is needed to define dry deposition rates for gas and PM

species. This file can be developed independently using landuse datasets developed for either the meteorological modeling or emission processing (i.e., surrogate data). In this project, the MM5CAMx interface program was used to translate the MM5 landuse fields to the CAMx categories and input formats needed by CAMx.

4.2.3 Photolytic Inputs

4.2.3.1 Photolysis Rates

Several chemical reactions in the atmosphere are initiated by the photo-dissociation of various trace gases. To accurately represent the complex chemical transformations in the atmosphere, accurate estimates of these photolysis rates must be made. The CAMx system includes the TUV pre-processor, which calculates a "look-up" table of clear-sky photolysis rates (or "J" values) for several important photolytic reactions in the chemical mechanisms as a function of solar zenith angle, altitude, surface ultraviolet (UV) albedo, total atmospheric column ozone, and total atmospheric haze opacity. The TUV photolysis rates processor was used to generate the CAMx photolysis rates input files for the two 2004 Gorge Study modeling episodes.

The photolysis lookup table is read by CAMx, and during model integration, specific photolysis rates for each grid cell are estimated by first interpolating the clear-sky photolysis rates from the look-up table according to date, time, grid cell location (latitude/longitude and altitude), and the following environmental parameters: surface UV albedo, column ozone, and haze opacity. The cell-specific rates are then adjusted according to cloud opacity determined from input cloud fields.

4.2.3.2 Albedo/Haze/Ozone Column Data

Gridded column ozone, UV albedo, and haze opacity fields are also provided to the model via an external input file. This file was generated using a CAMx pre-processing program, which uses the CAMx landuse file to define the surface UV albedo distribution by assigning default albedo values to each landuse type. Currently a default haze opacity is set, based on average rural conditions across the U.S. Total atmospheric column ozone data were obtained from Total Ozone Mapping Spectrometer (TOMS) instrumentation aboard polar orbiting satellite platforms. Global 24-hour TOMS data were obtained from http://toms.gsfc.nasa.gov/eptoms/ep.html.

4.2.4 Boundary Conditions

Harvard University was contracted by the RPOs to perform a 2002 GEOS-CHEM global climate model simulation to provide CMAQ boundary conditions. The RPOs have processed the GEOS-CHEM model output and generated day-specific 3-hourly boundary conditions for the 36-km RPO grid in the CMAQ BCON format. Since the two Gorge Study episodes occur in 2004, the 2002 BCON data were processed to obtain monthly-average 3-hourly boundary condition inputs in CAMx format. August- and November-average fields were used to define the concentrations along the edges of the 36-km domain for the respective modeling episodes.

4.2.5 Initial Conditions and Model Spin-Up

CMAQ default initial concentrations were used to develop a CAMx initial conditions (IC) file. A 10-day spin-up period was run before each episode to eliminate any significant influence of the arbitrary CMAQ initial conditions. The first 8 days of the spin-up period was run on the 36-km RPO grid only; the 12-km grid was introduced during the last two spin-up days.

4.3 PERFORMANCE EVALUATION METHODOLOGY

This section describes the range of model testing methodologies that were performed to evaluate the performance of CAMx for the two 2004 modeling episodes. The Modeling Protocol (ENVIRON and Alpine Geophysics, 2006) provides a complete description of the types of procedures that can be used in a PM/visibility model evaluation. Our base effort model performance evaluation was intended to provide a robust assessment of the operational ability of CAMx to predict fine particulates and visibility at sites in and around the Columbia River Gorge National Scenic Area.

The evaluation of the CAMx modeling system for this project was consistent with EPA's guidance on PM model testing (EPA, 2007), enhanced to take advantage of the special study data collected as part of the Gorge Study monitoring program. This guidance essentially calls for an operational evaluation of the model focusing on a specific set of gas phase and aerosol chemical species and a suite of statistical metrics for quantifying model response over the annual cycle. Emphasis is placed upon assessing: (a) how accurately the model predicts observed concentrations; and (b) how accurately the model predicts responses of predicted air quality to changes in inputs.

The CAMx operational model evaluation employed routine operational evaluation methods and standard statistical metrics (Table 4-5) and graphical displays to support the assessment of whether the model is shown to perform with sufficient accuracy and reliably for its intended purpose. Ideally, this operational evaluation should confirm that the modeling system is performing consistently with its scientific formulation, technical implementation, and at a level that is at least as reliable as other current state-of-science methods.

4.3.1 Context for the Gorge Study Model Evaluation

We begin the discussion of the Gorge Study modeling evaluation methodology by reviewing how the CAMx model output is used to estimate visibility impairment. When designing a model performance evaluation, it is important to understand how the modeling results will ultimately be used. EPA has published two versions of draft guidance for fine particulate and regional haze modeling (EPA, 2000; 2001a), utilizing a Fine Particulate Guidance Workgroup to provide technical input in the development of both documents[1]. More recently, EPA provided an informal update on the PM/regional haze modeling guidance (Timin, 2002) and conducted a PM

[1] Members of the Gorge Study modeling team participated on the EPA fine particulate modeling work group over the two-year span of its activities.

model evaluation workshop (see, for example, Timin, 2004; Boylan, 2004) shedding additional light on what the final guidance document would contain (final guidance was released by EPA in April 2007).

4.3.1.1 Quantifying Opacity of a Light-Attenuating Medium

As light transmits through a medium comprised of gasses and aerosols, it is scattered and absorbed by the various constituents. The amount of scattering and absorption, collectively referred to as light extinction, is dependent on how gas molecules and aerosols interact with visible light and on their component densities (concentrations). Air molecules efficiently *scatter* more light on the blue end of the spectrum, thus resulting in a blue sky away from the solar zenith. Given a sufficient "path length" through the atmosphere, such as low sun angle at sunset, so much blue is scattered from the direct solar beam that the sun takes on an orange-red appearance near the horizon. On the other hand, nitrogen dioxide *absorbs* on the blue end of the spectrum; at low concentrations both direct and diffuse light reaching an observer take on a yellowish hue, while at higher concentrations only red light is transmitted through.

Atmospheric aerosols, while very small (~10^{-6} m or 1 μm), are much larger than air molecules and generally attenuate light equally over the visible spectrum. Fine dust, most salts (sea salt, sulfate, nitrates), and organic carbon particles scatter light very efficiently and cause a milky sky. Elemental carbon (soot) particles absorb light almost entirely and appear as a black plume at high concentrations and diffuse to a dark grey haze at lower concentrations.

The reduction in light intensity through a gas/aerosol medium can be simply described using Beer's Law:

$$I = I_0 e^{-bx}$$

where I_0 is the incident intensity, I is the intensity reaching the observer, x is the path length through the medium, and b represents the medium's opacity and is referred to as the extinction coefficient. This coefficient is the composite sum of individual scattering and absorption coefficients for each component of the medium (e.g, air molecules, pollutant gas molecules, and various aerosols). The particular extinction coefficient for a given component i is determined from the product of its concentration c and its extinction cross-section E, or "extinction efficiency:"

$$b_i = E_i \times c_i$$

Extinction coefficients are usually referred to in units of inverse mega-meters (1 Mm^{-1} = 10^{-6} m), and so the path length x must be input to the equation above in units of Mm.

For example, absolutely clean air at sea level has an extinction coefficient of about 10 Mm^{-1}. We can invert Beer's Law to find the path length needed to see a "just perceptible" feature in the distance (referred to as "visual range") for a clean atmosphere. A commonly accepted threshold for a "just perceptible" feature defines an $I:I_0$ ratio of 3%, meaning that only 3% of initial light emanating from that object reaches the observer. Thus, in an absolutely clean atmosphere, the

visual range at that threshold is approximately 350 km. As other constituents are added, the total extinction coefficient (opacity) increases linearly, but the visual range decreases exponentially.

4.3.1.2 Translating CAMx PM Concentrations to Visibility Metrics

CAMx does not directly estimate visibility, instead it estimates PM and gaseous species concentrations from which visibility can be estimated. The most frequent equation to convert PM species concentrations to light extinction is the original IMPROVE reconstructed mass equation[2]:

$$b_{ext} = 3\times f(RH)\left[(NH_4)_2SO_4\right] + 3\times f(RH)\left[NH_4NO_3\right] + 4\times f'(RH)\left[OC\right] + 10\times\left[EC\right] + 1\times\left[IP\right] + 0.6\times\left[CM\right] + b_{rayleigh}$$

where:

b_{ext} is the estimated total extinction coefficient (Mm^{-1});
$[(NH_4)_2SO_4]$ is the sulfate concentration assumed to be ammonium sulfate;
$[NH_4NO_3]$ is the particulate nitrate concentration assumed to be ammonium nitrate;
$[OC]$ is the total organic matter concentration (= POA + SOA);
$[EC]$ is the elemental carbon concentration;
$[IP]$ is the inorganic primary fine particulate (< 2.5 μm) concentration excluding primary sulfates and nitrates;
$[CM]$ is the primary coarse particulate (> 2.5 μm and <10 μm) concentration;
$b_{rayleigh}$ is the natural atmospheric Rayleigh scattering (assumed to be 10 Mm^{-1});
$f(RH)$ is a relative humidity adjustment factor for the sulfate and nitrates; and
$f'(RH)$ is a relative humidity adjustment factor for OC (set to a constant 1.0).

The numerical factors in front of each term of the extinction equation are referred to as "extinction efficiencies." A unique efficiency is used for each PM species, and converts concentration to an extinction coefficient in units of inverse megameters (1/Mm). Total extinction is determined from the sum of scattering components (SO_4, NO_3, OC, IP, CM, and natural atmospheric Rayleigh scattering) and absorbing components (EC). The relative humidity adjustment factor $f(RH)$ accounts for the growth of sulfate and nitrate aerosols as they hydrate with increasing humidity. As these salts absorb water, they grow into sizes that are more efficient at scattering light, and as they continue to take on water near 100% relative humidity, they transform from large haze particles to small cloud droplets. The humidity adjustment function defined by IMPROVE is shown in Figure 4-1.

CAMx model testing concentrated on an operational evaluation of those model predictions that are most necessary for estimating visibility (e.g., SO_4, NO_3, OC, EC, IP and CM). This evaluation focused on the Gorge and surrounding areas. Another key component of the evaluation included comparisons against the Gorge Study nephelometer measurements of PM light scattering. In this case the IMPROVE equation was used with appropriate RH values, only excluding EC in the extinction equation since it is purely an absorber of light, and excluding the natural atmospheric Rayleigh scattering component.

[2] Note that IMPROVE has recently revised their extinction re-construction equation to add more size detail and associated extinction efficiencies for secondary salts. However, we continued to use the original approach for this study to utilize the PM measurements made available from the Gorge field campaign.

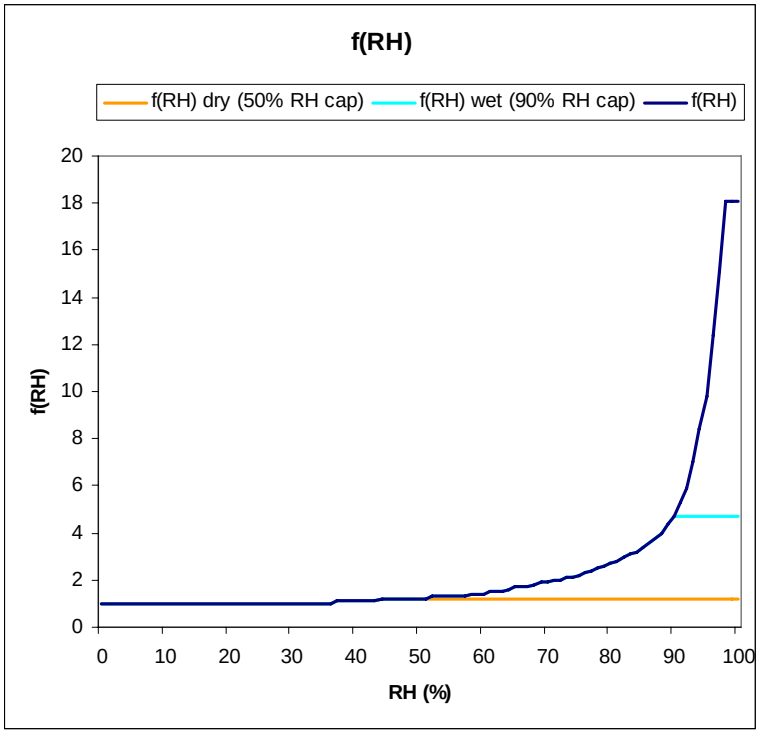


Figure 4-1. The humidity growth function *f*(*RH*) taken from the IMPROVE methodology for reconstructing extinction from ammonium sulfate and ammonium nitrate concentrations. Two alternative curves were used in this study; (1) the cap at 50% is intended to mirror the behavior of "dry" nephelometer scattering, and (2) the cap at 90% was used to compare to "wet" nephelometers and for reconstructing IMPROVE extinction (see text in Section 4.4 for more details on "dry" vs. "wet" nephelometer scattering).

4.3.2 Ambient Monitoring Data Sets

Data from routine ambient monitoring networks as well as the intensive Gorge Study measurement program were used in the model performance evaluation. These are described in the following sub-sections.

4.3.2.1 Routine Monitoring Sites

Table 4-3 summarizes routine ambient monitoring networks present in the Pacific Northwest region of the U.S. The model evaluation database was developed using several of these routine databases. The first is the routine gas-phase concentration measurements for ozone, NO, NO_2 and CO archived in EPA's Aerometric Information Retrieval System (AIRS/AQS) database.

Other sources of information come from the various PM monitoring networks in the U.S., including: (a) Interagency Monitoring of Protected Visual Environments (IMPROVE), (b) EPA $PM_{2.5}$ and PM_{10} Mass Networks (EPA-FRM), (c) EPA Speciation Trends Network (STN); and (d) National Acid Deposition Network (NADP). Typically, these networks provide ozone, other gas phase precursors and product species, PM, and visibility measurements.

As an example, the IMPROVE network gives daily (24-hour) average mass concentrations every 3 days for SO_4, NO_3, organic matter (OC), elemental carbon (EC), soil (IP), CM, $PM_{2.5}$ and PM_{10}. These data are available at 2 sites along the Gorge as well as several sites at nearby Class I Areas in Oregon and Washington. We used data from these and the other observational databases listed in Table 4-3, supplemented with the routine AIRS/AQS data, as appropriate, for CAMx model performance testing.

4.3.2.2 Gorge Study Monitoring Sites

The SWCAA, ODEQ and the US Forest Service routinely measure meteorological parameters and particulate matter (PM) concentrations at various continuous monitoring sites in southwest WA and northwest OR. In addition to the permanent sites at Wishram and Mt Zion, which include IMPROVE Protocol measurements, additional ozone, NOx, SO_2, sulfate, nitrate, carbon, nephelometer, aetholometer, and meteorological monitoring was performed over the period March 1, 2003 to February 28, 2005 as part of the Gorge intensive monitoring studies. The locations of monitors in and around the Gorge are identified in Figure 4-2 with the parameters and equipment used identified in Table 4-4.

Two major components of the intensive monitoring program were developed as funding became available. The first major component was the Haze Gradient Study, which was comprised of a series of nine nephelometers located throughout the Gorge Scenic Area (Figure 4-2). These locations also included surface meteorological monitoring instruments with the exception of the Memaloose location. The second major monitoring component was comprised of aerosol and gaseous pollutant monitoring including sulfates, nitrates, oxides of nitrogen, sulfur dioxide, organic carbon/elemental carbon, particulate matter samplers, high time resolution particulate matter samplers, aethalometers and two SODARs for limited upper air meteorological data.

4.3.3 Statistics

EPA's 2001 PM and regional haze guidance suggests a suite of metrics for use in evaluating model performance. The standard set of statistical performance measures suggested by EPA for evaluating fine particulate models includes: (a) normalized bias; (b) normalized gross (unsigned) error; (c) fractional bias; (d) fractional gross error; and (e) fractional bias in standard deviations. These measures are subsumed within the list of metrics that are calculated on a routine basis using standard model evaluation tools (these are identified in Table 4-5). From past regional PM model evaluations we have found the fractional bias and fractional error to be the most useful summary measures and we focus mainly upon them in the Gorge Study modeling.

Table 4-3. Overview of routine ambient data monitoring networks.

Monitoring Network	Chemical Species Measured	Sampling Period	Data Availability/Source
The Interagency Monitoring of Protected Visual Environments (**IMPROVE**)	Speciated $PM_{2.5}$ and PM_{10}	1 in 3 days; 24-hour average	http://vista.cira.colostate.edu/improve/Data/IMPROVE/improve_data.htm
Clean Air Status and Trends Network (**CASTNET**)	Speciated $PM_{2.5}$, Ozone (O_3)	Hourly, weekly averages	http://www.epa.gov/castnet/data.html
National Atmospheric Deposition Program (**NADP**)	Wet deposition: hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (e.g., calcium, magnesium, potassium and sodium), Mercury	1-week average	http://nadp.sws.uiuc.edu/
Air Quality System (**AQS**), or Aerometric Information Retrieval System (**AIRS**)	Criteria pollutants: CO, NOx, O_3, SO_2, $PM_{2.5}$, PM_{10}, Pb	Hourly average	http://www.epa.gov/air/data/
Speciation Trends Network (**STN**)	Speciated PM	24-hour average	http://www.epa.gov/ttn/amtic/amticpm.html
EPA Federal Reference Method Network (**FRM**)	Total $PM_{2.5}$	1 in 3 days; 24-hour average	www.epa.gov/ttn/amtic/files/ambient/monitorstrat/maps2.pdf

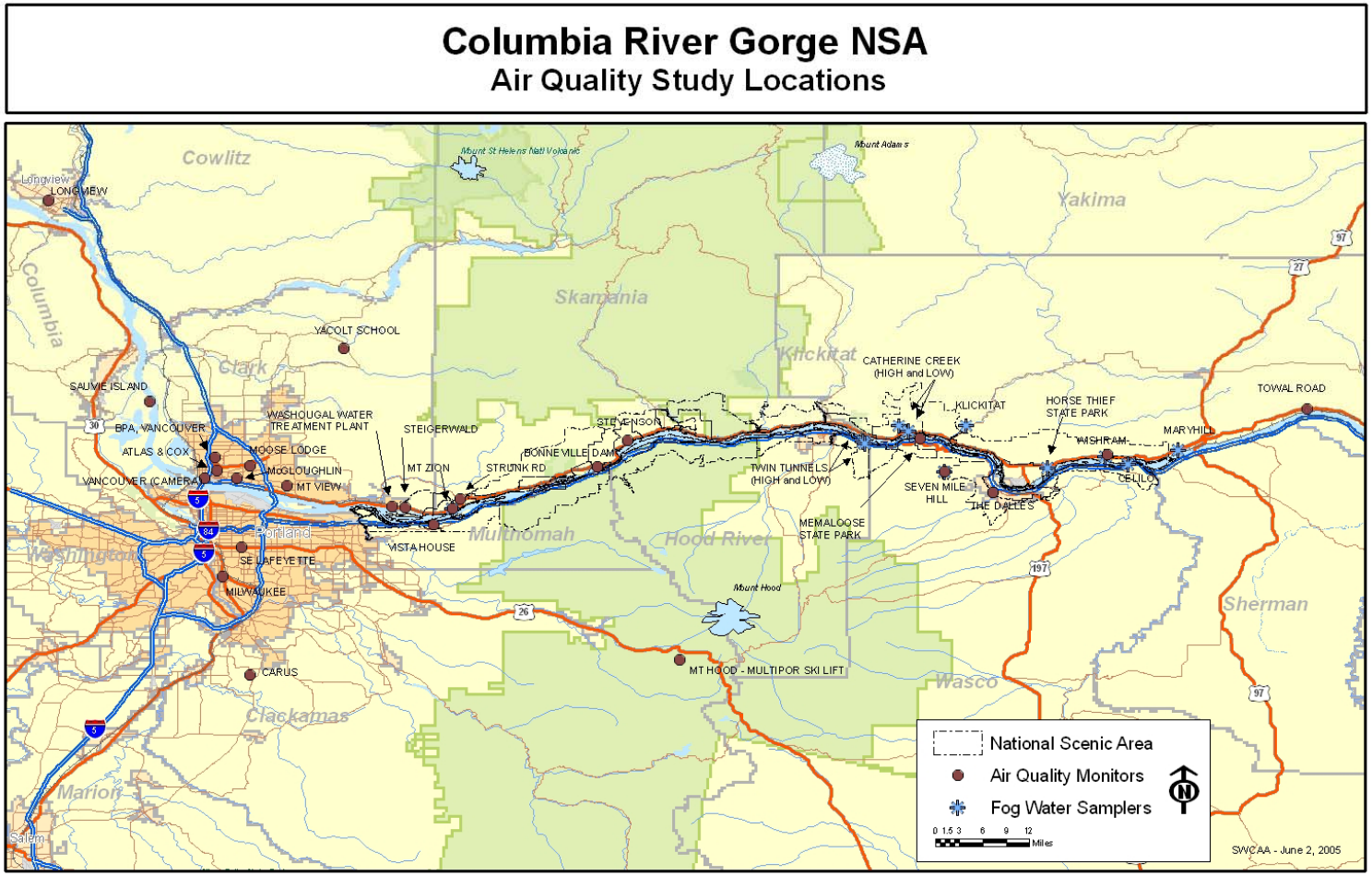


Figure 4-2. Locations of monitoring sites operated during the Gorge Study monitoring program.

Table 4-4. Monitors and equipment in close proximity to Columbia River Gorge Scenic Area.

LONGVIEW Olympic School 1324 30th Ave, Longview, WA lat 46 8' 23.160" long -122 57' 40.260" elev 17 ft msl	dry neph data logger	Radiance M903 ESC 8816
SAUVIE ISLAND Rt 1 Box 442 SS Beach, Portland, Or lat 45 - 46" 6.62 " long -122 46 ' 19.48" elev 18 ft msl Near Scappoose, OR approx 7 mi N of I-5 Bridge on Sauvie Island in Columbia River	ozone analyzer dry neph dry neph WS/WD AT RH $PM_{2.5}$	Dasibi 1003-AH Radiance M903 Radiance M903 Climatronics Climatronics
VANCOUVER Smith Tower - Mid Columbia Manor 515 Washington, Vancouver, WA lat 45 37' 32.08" long -122 40' 18.912" elev 200 ft msl	Vis camera - digital computer enclosure computer	HRDC-1 Olympus Gateway
BPA, Vancouver Ross Substation 5411 NE Hwy 99, Vancouver, WA lat 45 39' 46.33" long -122 39 6.48" elev 255 ft msl	met chart recorder data logger	 Yokogawa 3 channel ESC 8800
ATLAS & COX, Vancouver 2111 E Fourth Plain Blvd, Vancouver, WA lat 45 38' 18.48" long -122 38' 53.100" elev 184 ft msl	CO chart recorder data logger	 L & N ESC 8800
YACOLT SCHOOL 406 W Yacolt Rd, Yacolt, WA lat 45 52' 1.380" long -122 24' 44.880" elev 765 ft msl	*PM2.5 FRM** dry neph data logger	R & P 2025 Radiance M903 ESC 8800
MCLOUGHLIN MIDDLE SCHOOL 5802 MacArthur, Blvd Vancouver, WA lat 45 37' 28.62" long -122 36' 44.100" elev 302 ft msl	dry neph data logger	Radiance M903 ESC 8800
MOUNTAIN VIEW HIGH SCHOOL 1500 SE Blairmont Dr Vancouver, WA lat 45 36' 37.320" long -122 31' 4.440" elev 305 ft msl	ozone analyzer ozone transfer std. data logger chart recorder	Dasibi 1008-AH Dasibi 1008-AH ESC 8816 Yokogawa 1 channel
MOOSE LODGE 8205 NE Fourth Plain Blvd Vancouver, WA lat 45 38' 54.420" long -122 35' 15.300" elev 242 ft msl	$PM_{2.5}$ FRM PM_{10} FRM TEOM Data logger	R & P 2000 R & P 1400a ESC 8816

Table 4.4 (Continued). Monitors and equipment in close proximity to Columbia River Gorge Scenic Area.

PORTLAND – MILWAUKEE 10955 SE 25th St, Milwaukie, Oregon lat 45 26" 35.44" long -122 38' 16.95" elev 95 ft msl	ozone analyzer	Dasibi 1003-AH
PORTLAND - SE LAFAYETTE 5824 SE Lafayette, Portland, OR lat 45 - 29" – 47.83" long -122 36' - 10.52" elev 246 ft msl	ozone analyzer dry neph met gear $PM_{2.5}$ FRM data logger PM10 CO2 NO2 VOC/Aldehyde PUFF Solar Radiation	Dasibi 1003-AH Radiance M903 Met One R&P 2025 Odessa 3260
PORTLAND - CARUS 13575 Spangler Road, Oregon City, OR lat 45 - 15' 33.28" long -122 – 35' 13.33" elev 568.75 ft msl	ozone analyzer dry neph WS/WD sensors AT data logger	Dasibi 1003-AH MRI 1550B Climatronics Climatronics Odessa 3260
STEIGERWALD 2 mi E of Washougal, WA on HWY 14 lat 45 - 34' 10.68" long -122 - 17' 54.600" elev 42'	dry neph met gear chart recorder data logger	Radiance M903 Yokogawa 4 channel ESC 8800
STRUNK ROAD ~5 mi E of Washougal, WA on Strunk Road at Cape Horn lat 45 - 35' 08.220" long -122 - 11' 51.660" elev 1246 ft msl	dry neph met gear chart recorder data logger	Radiance M903 Yokogawa 4 channel ESC 8800
MT ZION 162 Oregon View Lane Washougal, WA 98671 lat 45 34' 4.44" long -122 - 12' 44.04" elev 739 ft msl	dry neph WD/WS sensors Temp sensor RH sensor ambient neph IMPROVE aethelometer chart recorder / met chart recorder / rh data logger / neph room temp sensor Precip Collector Weigh rain guage	Radiance M903 Climatronics RM Young Rotronic OPTEC 4 Modules Anderson AE-16 Yokogawa 3 channel Yokogawa 1 channel ESC 8816 Aerochem/301 Belfort
VISTA HOUSE ~ MP 25 on I-84, Oregon lat 45 32' 20.18" long -122 14' 48.66" elev 800 ft msl	camera	

Table 4-4 (Continued). Monitors and equipment in close proximity to Columbia River Gorge Scenic Area.

BONNEVILLE DAM ~ MP 40 on I-84, OR/WA (winter/summer 03/04 and winter 04/05 study) (winter/summer 03/04 and winter 04/05 study) installed 10/6/04 Cascade Island: lat 45 - 38' 47.10" long -121 - 56' 35.22" elev 76 ft msl	dry neph met gear chart recorder data logger IAS IMPROVE like DRUM sampler SODAR	Radiance M903 L & N ESC 8800 IAS UC Davis Aerovironment model 2000
MT HOOD - Multipor Ski Lift Government Camp, OR lat 45 17' 18.0 " long -121 47' 25.0" elev 5074 ft msl	dry neph IMPROVE WS/WD sensors	Radiance M903 Climatronics
MEMALOOSE STATE PARK MP 68 on I-84, Oregon lat 45 41' 51.96" long -121 20' 39.000" elev 137 ft msl	dry neph data logger	Radiance M903 ESC8800
SEVEN MILE HILL Bob Mc Fadden MP 89 on I-84 2472 Badger View Dr The Dalles, OR lat 45 38' 7.680" long -121 12' 36.600" elev 1845 ft msl	dry neph met gear data looger	Radiance M903 RM Young ESC 8800
THE DALLES 1112 Cherry Heights, The Dalles, OR lat 45 35' 54.360 " long -121 12' 36.60" elev 327 ft msl	$PM_{2.5}$ FRM dry neph	R&P 2025 Radiance M903
WISHRAM Avery near Wishram Hts Wishram, WA 98673 ~MP 92 on I-84 on Washington side ~ MP 92 on US Hwy 14, WA lat 45 - 40' 10.14" long -120 - 59' 53.540" elev 1182 ft msl (winter 03/04 and 04/05 study)	dry neph WS/WD sensors Temp Sensor RH sensor ambient neph IMPROVE samplers aethelometer #1 aethelometer #2 ozone analyzer ozone t. std. chart recorder / met chart recorder / rh chart recorder / ozone chart recorder / neph data logger vis camera - digital desktop computer DRUM sampler	OPTEC RM Young RM Young Rotronic Radiance M903 (4 Modules) Anderson AE-16 OPTEC Dasibi 1008-PC Dasibi 1008-PC Yokogawa 3 channel Yokogawa 1 channel Yokogawa Yokogawa 1 channel ESC 8816 Kodak DC260 Dell (photo uplink) UC Davis custom

Table 4-4 (Continued). Monitors and equipment in close proximity to Columbia River Gorge Scenic Area.

TOWAL ROAD **~ MP 120 on US Hwy 14** **~15 Mi E of HWY 97** elev 496 ft msl lat 45 - 45' 13.867" long -120 - 37' 37.380" (winter 03/04 and 04/05 study)	SODAR dry neph met gear chart recorder data logger desktop computer/SODAR IAS sampler	AeroVironment Radiance M903 Yokogawa 4 channel ESC 8800 Gateway IAS
MOBILE TRAILER 6X10 (Wishram - winter Mt Zion - Summer) Robbins/Bradford Island 11/1/03 to 7/1/04 lat 45 - 38' 32.580" long -121 - 57' 11.04" elev 85 ft msl	trailer OC/EC OC/EC laptop computer sulfates nitrates zero air gas generator SO2 NOx cal dilution system chart recorder data logger air conditioner	Wells Cargo 6 X 10 Sunset Labs RT-3005 Toshiba LT II R&P 8400S Pulse Generator R&P 8400S Pulse Analyzer R&P 8400N Pulse Generator R&P 8400N Pulse Analyzer Teledyne - Adv. Air Pollution Thermo 43C Thermo 42C Environics 6100 Yokogawa 3 channel ESC 8800 Coleman
MOBILE TRAILER 8X12 **(Bonneville Dam)** **Robbins/Bradford Is. OR Winter 03/04** **Cascade Is. WA Summer 04 & Winter 04/05**	Trailer OC/EC OC/EC laptop computer sulfates nitrates zero air gas generator SO2 NOx cal dilution system chart recorder data logger air conditioner	Wells Cargo 8X12 Sunset Labs Mod 3 Compaq Presario 2100 R&P 8400S Pulse Generator R&P 8400S Pulse Analyzer R&P 8400N Pulse Generator R&P 8400N Pulse Analyzer Teledyne - Adv. Air Pollution Thermo 43C Thermo 42C Environics 9100 Yokogawa 3 channel ESC 8800 Coleman TSL

Table 4-4 (Concluded). Monitors and equipment in close proximity to Columbia River Gorge Scenic Area.

PENDLETON - McKAY CREEK 3745 SW Marshall Pl, Pendleton, OR lat 45 39' 10.38" long -118 49' 20.04" elev 1061 ft msl	$PM_{2.5}$ PM_{10} Nephelometer WS/WD AT	
Washougal Water Treatment Plant (when not in use at Towal Rd) lat 45 - 34' 18.960" long -122 - 19' 23.820" elev 29 ft msl	SODAR	AeroVironment

Typically, the statistical metrics are calculated at each monitoring site across the full computational domain for all simulation days. In the Gorge Study evaluation, we stratified the performance statistics across relevant space and time scales. As part of the operational evaluation, the aerosol statistical measures were computed for sites along the Columbia River, stratified by east and western sub-domains as appropriate. Temporally, we computed the statistical measures for 24-hr for sulfate, nitrate, carbon, other primary aerosol species, nephelometer scattering and IMPROVE extinction.

4.3.3.1 Performance Goals and Benchmarks

Establishment of performance goals and criteria for modeling is a necessary but difficult activity, and has been an area of ongoing research and debate (Morris et al., 2005). Here, performance *goals* refer to targets that we believe a good performing PM model should achieve, whereas less stringent performance *criteria* represent a minimal level of model performance that a PM model should achieve for use in regulatory modeling. Performance goals are necessary in order to provide consistency in model applications and expectations across the country, while criteria provide standardization in how much weight may be accorded modeling study results in the decision-making process. It is a problematic activity, though, because many areas present unique challenges and no one set of performance goals is likely to fit all needs. Equally concerning is the very real danger that modeling studies will be truncated when the "statistics look right" before full assessment of the model's reliability is made. This has the potential for breeding built-in compensating errors as modelers strive to achieve good statistics as opposed to searching for the explanations for poor performance and then rectifying them.

Decades ago EPA established performance goals for 1-hour ozone centered on the use of normalized bias (<15%) and error (<35%). However, when these evaluation metrics were later adapted to PM and its components, difficulties arose because performance statistics that divide by low concentration observations (such as nitrate, which is often zero) become practically meaningless. In time, this has led to the introduction of the fractional bias and error metrics. EPA draft fine PM modeling guidance (EPA, 2001a) notes that PM models may not be able to achieve goals similar to those of ozone, and that better performance should be achieved for those PM components that make up the major fraction of total PM mass than those that are minor contributors. In fact, differences in measurement techniques for some PM species likely exceed the more stringent ozone performance goals. For example, recent comparisons of PM

Table 4-5. Routine statistical measures used in evaluating air quality models against observational data.

Statistical Measure	Shorthand Notation	Mathematical Expression	Notes
Accuracy of paired peak (***A_p***)	**Paired_Peak**	$\frac{P - O_{peak}}{O_{peak}}$	P_{peak} = paired (in both time and space) peak prediction
Coefficient of determination (***r^2***)	**Coef_Determ**	$\frac{\left[\sum_{i=1}^{N}(P_i - \overline{P})(O_i - \overline{O})\right]^2}{\sum_{i=1}^{N}(P_i - \overline{P})^2 \sum_{i=1}^{N}(O_i - \overline{O})^2}$	P_i = prediction at time and location i; O_i = observation at time and location i; $\overline{P}$ = arithmetic average of P_i, i=1,2,…, N; $\overline{O}$ = arithmetic average of O_i, i=1,2,…,N
Normalized Mean Error (***NME***)	**Norm_Mean_Err**	$\frac{\sum_{i=1}^{N}\lvert P_i - O_i\rvert}{\sum_{i=1}^{N} O_i}$	Reported as %
Root Mean Square Error (***RMSE***)	**Rt_Mean_Sqr_Err**	$\left[\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2\right]^{1/2}$	Reported as %
Fractional Gross Error (***F_E***)	**Frac_Gross_Err**	$\frac{2}{N}\sum_{i=1}^{N}\left\lvert\frac{P_i - O_i}{P_i + O_i}\right\rvert$	Reported as %
Mean Absolute Gross Error (***MAGE***)	**Mean_Abs_G_Err**	$\frac{1}{N}\sum_{i=1}^{N}\lvert P_i - O_i\rvert$	
Mean Normalized Gross Error (***MNGE***)	**Mean_Norm_G_Err**	$\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert P_i - O_i\rvert}{O_i}$	Reported as %
Mean Bias (***MB***)	**Mean_Bias**	$\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)$	Reported as concentration (e.g., μg/m^3)

Statistical Measure	Shorthand Notation	Mathematical Expression	Notes
Mean Normalized Bias (***MNB***)	**Mean_Norm_Bias**	$\frac{1}{N}\sum_{i=1}^{N}\frac{(P_i - O_i)}{O_i}$	Reported as %
Mean Fractionalized Bias (Fractional Bias, ***MFB***)	**Mean_Fract_Bias**	$\frac{2}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{P_i + O_i}\right)$	Reported as %
Normalized Mean Bias **(*NMB*)**	**Norm_Mean_Bias**	$\frac{\sum_{i=1}^{N}(P_i - O_i)}{\sum_{i=1}^{N}O_i}$	Reported as %
Bias Factor (***BF***)	**Bias Factor**	$\frac{1}{N}\sum_{i=1}^{N}\left(\frac{P_i}{O_i}\right)$	Reported as BF:1 or 1: BF or in fractional notation (BF/1 or 1/BF).

measurements using the IMPROVE and STN technologies found differences of ~20% for sulfate and ~50% for elemental carbon (Morris et al., 2005).

As with ozone in the 1980s, actual experience with PM models has led to the development of the current performance expectations for these models. For example, PM_{10} SIP model performance goals of 30% and 50% (normalized gross error) have been used for southern California (SCAQMD, 1997; 2003) and Phoenix (ENVIRON, 1998), respectively. Boylan and Russell (2006) have proposed fractional bias and error goals of 30% and 50%, and fractional bias and error criteria of 60% and 75%, respectively. Furthermore, they proposed that these goals and criteria values vary as a function of concentration, such that below 2 $\mu g/m^3$, they expand exponentially to 200% (the max of fractional bias and error) at zero observed concentrations. The following levels of model performance criteria have been adopted for RPO regional visibility modeling using CMAQ, and we carry these forth into the Gorge modeling assessment:

Fractional Bias	Fractional Error	Qualitative Performance
≤ ±15%	≤ 35%	Excellent
≤ ±30%	≤ 50%	Good
≤ ±60%	≤ 75%	Average, each PM component should meet for regulatory modeling
> ±60%	> 75%	Poor, indicating fundamental problems with the modeling system

4.3.4 Diagnostic and Sensitivity Testing

Rarely does a modeling team find that the first simulation satisfactorily meets all (or even most) model performance expectations. Indeed, our experience has been that initial simulations that "look very good", occasionally do so as the result of compensating errors. The norm is to engage in a logical, documented process of model performance improvement wherein a variety of diagnostic probing tools and sensitivity testing methods are used to identify, analyze, and then attempt to remove the causes of inadequate model performance. This is invariably the most technically challenging and time consuming phase of a modeling study. The 2004 episodic CAMx base case simulations presented some performance challenges that necessitated focused diagnostic and sensitivity testing in order for them to be resolved. Specific diagnostic and sensitivity tests were carried out within the resources and schedule of this work effort.

Many emission inventory issues were identified from our diagnostic simulations of both the August and November episodes. Some were related to minor problems in processing the raw emissions through the SMOKE program, and were easily fixed. Others related to the raw inventories provided by the states of Oregon and Washington.

In both August and November episodes, simulated light scattering was dominated by very large contributions from primary fine and coarse emissions, as well as carbon (mainly organics in August, and both organics and elemental carbon in November). Furthermore, the diurnal amplitude of the primary and carbon PM components exhibited far too large of a range compared to available hourly speciated data from the Gorge Study sites. In regards to the August episode, our early assumption was that these over predictions in primary PM and carbon were probably a result of over-stated windblown dust and wildfire emissions, respectively. After all, these two natural components have been consistently the most uncertain sectors of any primary PM inventory, and much research has been conducted by WRAP and others to improve upon their estimation methodologies.

Subsequent investigation into several August CAMx test simulations revealed that modeled windblown dust and wildfire emissions were not greatly impacting the Gorge monitoring networks much of the time (although there were some periods when the edges of some fire plumes from northern Washington brushed over the eastern-most Gorge sites). Coupled with the fact that similar performance issues were seen in November, when wildfire activity was nonexistent and windblown dust contributions should be minimal due to moist soil, this finding exonerated these components as the cause of the over predictions.

Further detailed scrutiny into both the 2004 base year emissions inventory and the CAMx results instead indicated that: (1) over predictions of primary PM were caused by excessive amounts of fugitive dust from anthropogenic categories, mostly construction and agriculture; (2) over predictions of carbon in November (both organic and elemental) were caused mainly by wood smoke emissions; (3) the ammonia inventory for certain source sectors were underestimated; and (4) over predictions of secondary organic carbon (i.e., that formed chemically in the atmosphere) in August were entirely linked to biogenic emissions. Additionally, it was found that the counties containing the Portland/Vancouver area contained the vast majority of construction dust and wood smoke emissions in the 4-km grid. Evaluation of hourly time series of simulated primary PM, carbon, and light scattering clearly show that Gorge sites nearest the Portland

metropolitan area exhibit the largest over predictions in these components (details and figures are presented in subsequent sub-sections).

4.3.4.1 Reduction of Fugitive Dust Emissions

We identified two problems with the SMOKE processing of the Oregon and Washington fugitive dust inventories. First, the WRAP speciation profiles used for this project were configured in such a way that SMOKE generated roughly a double-counting of fugitive dust estimates in the model-ready input files. This also impacted wood smoke emissions because a fraction of these are split into non-carbonaceous primary PM. Second, the raw county-level fugitive dust inventory used to prepare the 4-km emissions were taken from an older WRAP inventory and were not part of the specific Oregon/Washington emission updates provided to this project. This older WRAP inventory pre-dated a fairly significant update made in early 2006 in which WRAP had independently identified this same fugitive dust problem and addressed it by developing and applying a county-level "canopy escape factor" for their modeling. WRAP also included a modification to the split of PM into fine and coarse components by source category (mainly shifting more mass to the fine fraction)[3]. The canopy escape factor was developed to account for near-source deposition of fugitive dust emissions onto structures and vegetation prior to dispersing across the scale of model grid cells. WRAP developed county-level escape factors by considering the relative fractions of various landuse/landcover types in each county. For example, urban and forested areas received the smallest factors (most emissions are removed), while open areas received the largest factors (most emissions are passed through to the grid).

For the Gorge modeling, we modified the WRAP speciation profiles to remove the potential for double counting primary PM emissions and to use the WRAP-modified fine/coarse PM splits, and applied the WRAP canopy escape factors for the fugitive dust categories. Significant reductions in PM emissions were realized, especially throughout the Portland metropolitan area. Hence, resulting CAMx performance against Gorge monitoring data was greatly improved for the primary PM component.

4.3.4.2 Reduction in Residential Wood Smoke

Annual fine PM emissions from residential wood combustion in Oregon and Washington were found to be overstated by a factor of two. This was found to be related to an improper interpretation of a 1999 fireplace survey conducted in both states. In 2002, the residential wood combustion emissions inventory based on these survey results was submitted to the EPA for inclusion into the National Emissions Inventory (NEI) database. The 2002 NEI datasets formed the basis of the 2004 Oregon and Washington inventory projections developed by the ODEQ and WDOE specifically for this project. Since the NEI comprises annual estimates, wood smoke emissions for August and November were both over estimated in this project because the annual estimates were allocated to each month and day of week according to temporal profiles defined in the SMOKE emissions processor. Furthermore, since the 2002 NEI was used by WRAP to project emissions to 2018, this overestimate carried through to the future year inventory.

[3] Note: Given consistently large over prediction problems for coarse PM, WRAP has chosen to completely disregard primary coarse PM predictions from their modeling analyses.

In 2005, the ODEQ and WDOE reinterpreted the survey results (independent of this project); coupled with a small revision to ODEQ wood density calculations, the revised residential wood smoke emission estimates were reduced by 50%. Upon ultimately learning of this revision in early 2007, the project team thus applied a 50% reduction to the 2004 annual residential wood combustion categories for both states. Further comparison between the 2004 county-level Oregon/Washington inventory and the 2018 WRAP inventory revealed astronomical 300-700% PM emission increases for this source sector. We confirmed with the WRAP emission modelers that population growth was used to project residential sources such as wood smoke, and that the Oregon population growth rate is forecast to be only 4% over this period. Given this, the project team applied a 1.04 factor to the reduced 2004 residential wood smoke emission rates to derive a revised 2018 wood smoke inventory for counties in Oregon and Washington.

There remained a concern that the monthly temporal profiles taken from WRAP may have also been in error as there was a perception that, in particular, the August residential wood combustion emissions were too high. The modeling team examined the SMOKE monthly allocation profiles, but found no obvious issues with the values assigned to November and August. Therefore, the monthly profiles were maintained as defined by WRAP. The resulting inventory for residential wood smoke was greatly improved for both the base and the future years, and is much more in line with expectations relative to the population distribution in the OR/WA grid.

4.3.4.3 Increases in Agricultural Ammonia

Like residential wood smoke, the 2004 ammonia emission projections developed for this project were based upon the 2002 NEI submittal. The project team conducted a detailed scrutiny of the Oregon and Washington ammonia inventories, and compared the emission factors to published values in the literature. Two major issues were identified:

(1) Ammonia emissions from confined animal feeding operations (CAFO), such as dairies, were understated by factors of 1.5 to approximately 3, depending on the type of manure handling conducted at each (i.e., flush, scrape, drylot/pasture, or deep-pit);
(2) Ammonia emissions from fertilizer application were understated by upwards of a factor of three for anhydrous and aqueous ammonia application sources, and by a factor of 2.5 for nitrogen solution fertilizer application sources.

The Three-Mile Canyon Dairy constitutes a major ammonia source in the immediate vicinity of the Gorge. In the original inventory, total 2004 ammonia emissions for this facility were reported as ~1100 TPY based on the application of an Oregon composite emission factor of 27.96 kg/head/year and a 31,000 head count. Our investigation of this specific facility subsequently identified it as a "flush" operation. Additionally, according to this facility's web site, the head count is reported to be 41,000. Thus the project team increased its ammonia emissions by a factor of 4.3 to account for: (1) a flush emission factor of 92 kg/head/year based on the work of CMU (2004), and (2) the increase in head count to 41,000.

The ODEQ and WDOE attempted to locate additional data concerning the distribution of CAFO operations in both states as a means to improve the characterization of each facility or to improve

the state composites. However, no additional information was found in the short time available. Therefore, ammonia emissions for the remaining Oregon dairies were scaled by a factor of 1.21, while emissions for all Washington dairies were scaled by a factor of 1.4, according to differences between the composite ammonia emissions factor reported by CMU (2004) and the state-specific composite factors used in the original 2002 inventory.

Ammonia emissions from large-scale agricultural fertilizing activities were scaled by 3.3 (anhydrous and aqueous fertilizers) and 2.7 (nitrogen solution fertilizers) according to the difference in emission factors provided by CMU (2004) and the factors used in the original 2002 state inventories.

Finally, the modeling team found that the 2018 WRAP inventory did not include any ammonia emissions. According to discussions with WRAP emission modelers, they assumed a zero ammonia growth rate from 2002 to 2018, and thus incorporated their 2002 ammonia estimates into their 2018 inventory as a last step before running the air quality models. It was decided that emissions for this project should follow suit. After applying the 2004 adjustments for CAFO and fertilizer applications in Oregon and Washington, the modeling team directly transferred those numbers over to the WRAP 2018 inventory before processing with SMOKE.

4.3.4.4 Improvement of CAMx SOA module

Historically, organic PM has been over predicted by both CMAQ and CAMx in the western U.S. (e.g., WRAP). In areas where there have been no obvious wildfire influences, this has been attributed to the biogenic component, which dominates the other forms of SOA that are produced from anthropogenic precursors. Biogenic SOA was certainly the dominant SOA form over the August episode in this study. This prompted us to employ a chemical improvement in CAMx for biogenic SOA, which is based upon a similar update that ENVIRON incorporated into CMAQ for the visibility Regional Planning Organizations. This update essentially involved expanding the biogenic terpene pathway from a single-product mechanism to a two-product mechanism, and included updates to the yields of condensable hydrocarbons and SOA volatility parameters. While SOA chemistry is a highly non-linear problem, our expectation was that this modification should tend to reduce biogenic SOA, mainly because of the higher volatility (i.e., a smaller capability to maintain a condensed SOA form). Surprisingly, and quite opposite to our expectation, the August episode exhibited little sensitivity to this change, and only the November episode showed a reduction in biogenic SOA despite its cooler more humid conditions, both of which should reduce SOA volatility.

4.4 CAMx 2004 BASE CASE RESULTS

The development of the November and August 2004 episode Base Cases required seventeen individual simulations, most of which included diagnostic tests to identify problems with the various model inputs. A few additional sensitivity tests were also run, mostly to check model response to the alternative configurations. The run configurations and major findings of each are listed in Table 4-6 below:

Table 4-6(a). List of CAMx simulations undertaken for the Gorge Study for the August 2004 modeling episode.

August Runs	Configuration	Findings
1	Initial simulation: - O'Brien Kv (0.1 m^2/s min)	Emission problems: - Incorrect temporal allocation for fires - No NH3 from on-road MV in 4-km grid Performance: - SO4/NO3/NH4 mostly under predicted - Carbon mostly over predicted - Primary fine PM mostly over predicted - Primary coarse PM under predicted - $PM_{2.5}$ and light scattering well-predicted (compensating errors)
2	As in Run 1, but: - Fixed temporal allocation of fire emissions - Added on-road mobile NH3 emissions in 4-km grid	New emission problem: - Fires over stated (units problem) Performance: - 24-hr light scattering too high - Huge diurnal spikes in light scattering - Diurnal spikes in OC, fine, coarse PM - Especially at western sites (near Portland) - Not related to fires
3	As in Run 2, but: - Use CMAQ Kv (1.0 m^2/s min)	Performance: - Little improvement to PM and light scattering - Western sites show biggest impact
4	As in Run 2, but:: - Double NH3 inventory	Performance: - Little improvement to PM and light scattering - Some NO3 improvements
5	As in Run 2, but: - Halve primary carbon from fires	Performance: - No significant impact at Gorge sites - Gorge sites not seriously impacted by fires - Carbon over prediction from biogenic SOA
6	As in Run 2, but: - Fix wildfire emissions - Biogenic SOA chemistry modification	Emission problem: - Fugitive dust over stated Performance: - Wildfire impacts similar to Run 1 - SOA modification ineffective
7	As in Run 6, but: - Fix fugitive dust emissions	Performance: - Fine & coarse PM reduced substantially - Carbon still over predicted - Diurnal variations better but still over predicted
8	As in Run 7, but: - Use CMAQ Kv (1.0 m^2/s minimum)	Performance: - Slightly improved over Run 7 - Western sites show biggest impact
10	As in Run 8, but: - Increase NH3 emissions - Decrease woodsmoke emissions	Performance: - Slightly improved ammonium performance - Slightly improved carbon performance

Table 4-6(b). List of CAMx simulations undertaken for the Gorge Study for the November 2004 modeling episode.

November Runs	Configuration	Findings
1	Initial simulation - O'Brien Kv (0.1 m2/s min)	Emission problems: - Incorrect temporal allocation for fires - No NH3 from on-road MV in 4-km grid Performance: - SO4 mostly well predicted - NO3 performance uncorrelated - NH4 under predicted - Carbon mostly over predicted - Primary fine & coarse PM highly over predicted - P2.5 over predicted, light scattering uncorrelated
2	As in Run 1, but: - Fixed temporal allocation of fire emissions - Added on-road mobile NH3 emissions in 4-km grid	Performance: - Similar to Run 1 - Huge diurnal spikes in light scattering - Diurnal spikes in OC, fine, coarse PM - Especially at western sites (near Portland) - Miss big haze event at eastern sites - Insufficient humidity and SO4/NO3/NH4
3	As in Run 2, but: - Use CMAQ Kv (1.0 m2/s min)	Performance: - Higher dilution reduced PM over predictions - Much improved PM and light scattering - Western sites show biggest impact
4	As in Run 2, but:: - Double NH3 inventory	Peformance: - Broad increases in NO3/NH4 - Especially at western sites early in episode - Secondarily at eastern sites late in episode - SO4 less impacted - Insignificant impacts to light scattering
6	As in Run 2, but: - Biogenic SOA chemistry modification	Emission problem: - Fugitive dust over stated Performance: - SOA modification results in less SOA
7	As in Run 6, but: - Fix fugitive dust emissions	Performance: - Light scattering too high at western sites - Dominated by fine PM and woodsmoke carbon - Light scattering too low at eastern sites - Under predicted SO4/NO3/NH4
8	As in Run 7, but: - Added fog based on satellite information	Performance: - Improved SO4/NO3 levels
10	As in Run 8, but: - Increase NH3 emissions - Decrease woodsmoke emissions	Performance: - Improved SO4/NO3/NH4 performance - Improved carbon performance - Improve light scattering performance

Figure 4-3 displays the specific monitoring networks from which speciated and total PM and light extinction/scattering measurements were taken for the model performance evaluation discussed in this Section. Data from IMPROVE sites were available every 3 to 6 days as 24-hour averages; data from the Wishram (CORI1) and Mt. Zion (COGO1) sites were used in these analyses. Data from the EPA FRM/STN sites were mainly clustered in the Portland/Vancouver area, and included daily 24-hour average total $PM_{2.5}$ and 3 to 6 day 24-hour speciated PM constituents. Data from the Gorge Study sites mainly included hourly "dry" nephelometer light scattering from the Radiance instruments (Green et al., 2006b); however, hourly speciated concentrations for SO_4, NO_3, OC, EC were also available at the Mt. Zion and Bonneville Gorge Study sites. No CASTNET sites are located along or near the Columbia River Gorge.

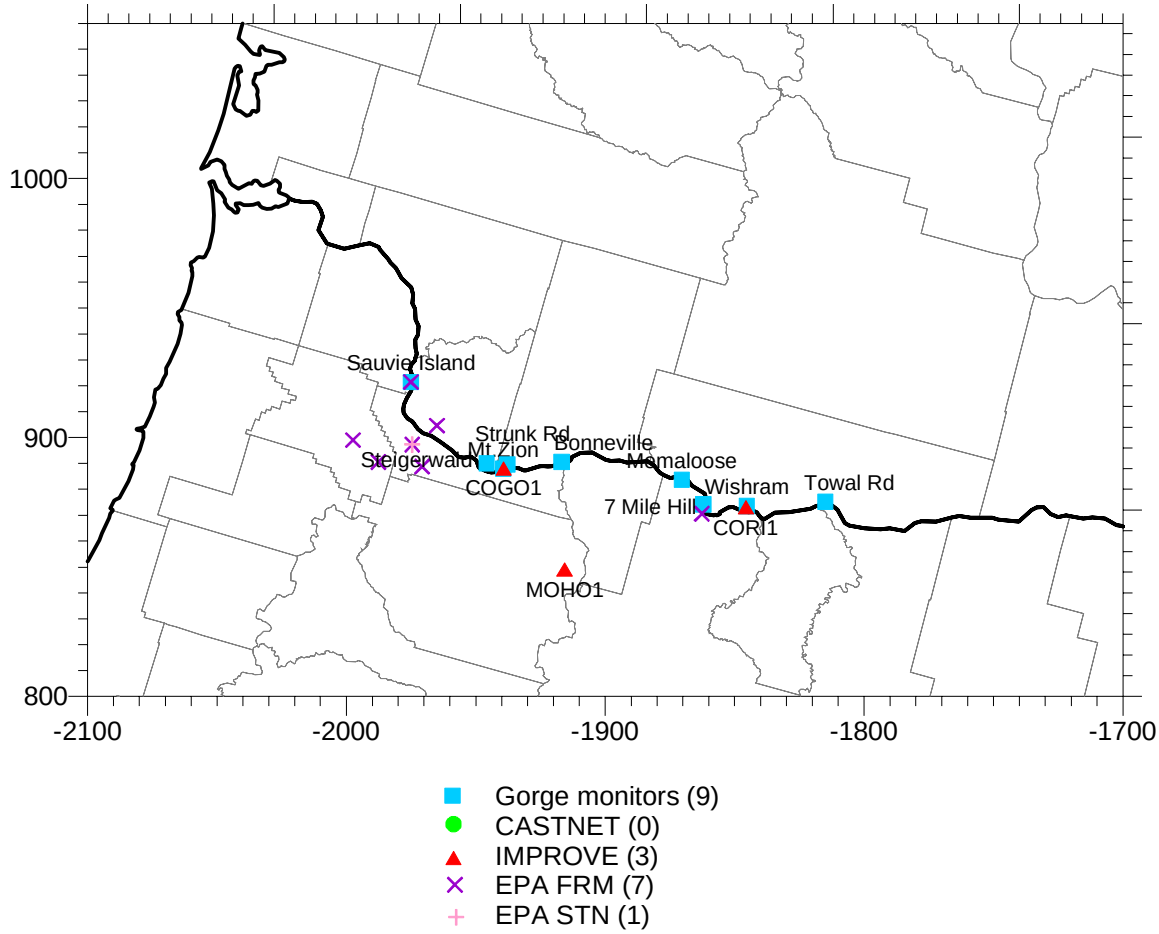


Figure 4-3. Locations of monitoring sites by network used in the model performance evaluation described in this report.

During our performance evaluation of PM chemical species from Runs 1 through 8, we noticed that certain chemical measurements from the Gorge Study site at Mt Zion exhibited a consistent bias relative to co-located IMPROVE data, while others were more balanced. Specifically, sulfate and EC were outliers relative to the other sites and networks. We compared 24-hour average SO_4, NO_3, OC, and EC measurements between co-located IMPROVE and Gorge Study instruments at the Mt Zion site (Figure 4-4). Due to various data outages and the IMPROVE sampling schedule, very limited comparisons could be made in August (see Julian day 232, August 19). Several more sample comparisons were available for the November episode (see Julian days 310 through 322). While the carbon and nitrate measurements agreed fairly well, the sulfate comparisons consistently showed that the Gorge Study measurements were high by about a factor of 2.

Discussions with the Desert Research Institute (DRI) Gorge Study director (Mark Green, personal communication) revealed that they also reported this discrepancy, and had no explanation for it (Green, 2006). However, since there is no information available to substantiate the Bonneville sulfate measurements, we decided to retain the Gorge Study sulfate measurements, but caution that they may generate an artificial bias in the model-measurement comparisons.

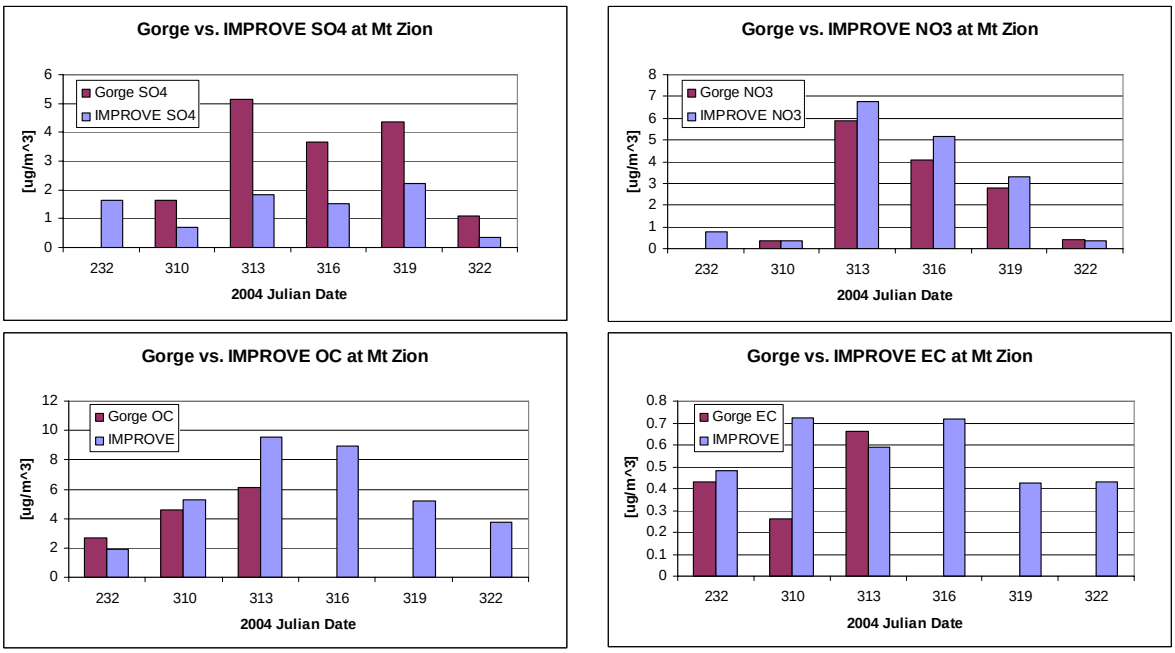


Figure 4-4. Comparison of 24-hour observations between co-located Gorge and IMPROVE instruments at the Mt Zion site. Both August (day 232) and November (days 310-322) episode days are shown when data from both instruments are available.

Furthermore, DRI stated that the carbon instrumentation used at the Gorge Study sites (Sunset Labs EC/OC analyzer) consistently resulted in roughly half the observed EC compared to IMPROVE data (as possibly suggested by the low EC in Figure 4-4 on Julian day 310). The Gorge Study instrumentation fortunately included aetholometers at the Mt Zion and Bonneville sites; aetholometers measure the amount of aerosol light absorption due to EC, from which EC concentrations can be easily determined. As a result, we used the aetholometer-derived EC in place of the Sunset Labs EC measurements for the model-measurement comparisons.

4.4.1 Results of August Episode Simulations

As shown in Table 4-6, nine individual CAMx simulations were undertaken for the August 10-22, 2004 modeling episode. More than half of these runs addressed improvements in the input emission inventory or the treatment of biogenic SOA, as described above. The remaining runs tested model sensitivity to various input changes that from our experience are associated with the largest uncertainty and have the largest potential impact on the air quality results:

- Sensitivity to two methods of deriving the vertical diffusivity (Kv) and its minimum value (O'Brien method vs. CMAQ);
- Sensitivity to doubling ammonia (NH_3) emissions;
- Sensitivity to halving carbon emissions from fires (primary organic aerosol [POA] and elemental carbon [EC]).

The model was most sensitive to the choice of Kv methodology, which is a very common attribute of air quality models. The diffusivity input fields define the rate of vertical turbulent mixing of pollutants in the daytime boundary layer (i.e., the lowest 1-3 km of the atmosphere where daily heating of the ground generates vertical convective eddies). While both O'Brien and CMAQ techniques are similar in that they are considered "profile" methods (i.e., Kv profiles within the well-mixed boundary layer are calculated based on surface heat input, wind shear, and PBL height, as opposed to other approaches), the CMAQ approach leads to much larger mixing rates and usually deeper mixing depths during the daytime period. Furthermore, the CMAQ approach is often used in tandem with a higher minimum Kv "floor", which results in moderately more nocturnal mixing. The CMAQ method resulted in better model performance for those primary PM components that exhibited an over prediction in the diurnal variation. Little impact was seen for secondary PM constituents such as sulfate, nitrate, and SOA.

August model performance against Gorge field study measurements at the sites shown in Figure 4-3 was not sensitive to changes in wild fire carbon emissions, or to increases in ammonia emissions. As described earlier, the simulated wild fire emissions occasionally contributed to the performance at the Gorge monitors as the plume edges wafted over the eastern-most sites. Therefore, sensitivity to fire emissions was low. The August modeling was also not sensitive to increased ammonia emissions. This is due to the fact that the period was warm and dry, and so the ammonium nitrate formation was thermodynamically limited by the meteorological conditions, as opposed to being limited by available ammonia.

4.4.1.1 Final Results from CAMx Run 10

Figure 4-5 displays a scatter diagram of predicted vs. observed 24-hour average light scattering at the Gorge Study nephelometer sites from our final CAMx Run 10. As discussed in Section 4.3.1, the CAMx predictions for sulfate, nitrate, organics, and primary fine and coarse PM are used to construct the predicted light scattering (as opposed to total extinction, which includes light absorption from EC). All light scattering measurement data shown in Figure 4-5, and used throughout the analyses discussed here, were taken from the "dry" nephelometer instruments; these instruments heat the inlet with the aim of maximizing relative humidity of the incoming air at 50%. This results in measuring only the effect of dry aerosols. To parallel this measurement technique in our prediction-observation comparison, the relative humidity adjustment to predicted sulfate and nitrate extinction efficiency was limited to 1.2 at 50% RH, according to the growth functions defined by IMPROVE (see Figure 4-1).

CAMx performance in replicating the range of 24-hour light scattering among all nine Gorge Study dry nepholometer sites is quite good, indicating a near zero bias tendency with a moderate degree of scatter about the 1:1 line. This level of performance is comparable to some of the best performance results achieved by WRAP.

Figure 4-6 displays 24-hour average scatter plots of PM components, total $PM_{2.5}$, and PM_{10} for the final CAMx Run 10. In these plots, comparisons made for the different monitoring networks are color-coded; the networks include the Gorge Study sites, IMPROVE, and EPA FRM/STN. Note that just a few measurements were available from the IMPROVE and STN sites over the August modeling episode due to their sampling schedule. Also note that not all PM components and total mass were measured at all networks. Table 4-7 presents the August episode

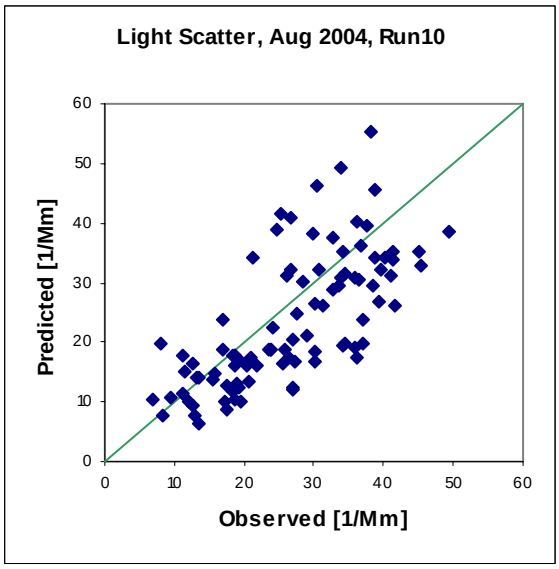


Figure 4-5. Scatter diagram comparing 24-hour average light scattering predicted by CAMx against "dry" nephelometer measurements from nine Gorge Study sites along the Columbia River. Units are inverse megameters; results are from CAMx "Run 10".

performance statistics for the PM components, light scattering, and total reconstructed extinction (extinction could only be reconstructed from a couple of complete IMPROVE datasets during this episode). Note that sulfate performance with and without Gorge sulfate measurements is shown. Sulfate shows an under prediction bias according to single IMPROVE samples at Mt Zion and Wishram on August 19. Performance at the STN site in central Portland also shows consistent under predictions over four days of the episode. Based on comparisons against just the IMPROVE and STN measurements, overall sulfate fractional bias is -37% and fractional error is 43%, which is considered "good" performance. However, the sulfate under prediction becomes rather poor with the addition of the 24-hour average sulfate concentrations from the Gorge Study sites at Bonneville and Mt Zion. As shown in Figure 4-4, sulfate measurements from these sites are questionable compared to IMPROVE data, and the collection of sulfate points in Figure 4-6 at Bonneville further illustrates these outliers.

Nitrate performance is highly uncorrelated and mostly under predicted. Performance for the Gorge Study sites at both Bonneville and Mt Zion showed rather good agreement on some days, but IMPROVE and STN predictions were consistently too low. However, given that observations and predictions for this PM component remain under 1 $\mu g/m^3$, there was insufficient nitrate relative to other PM species to have any significant impact on visibility. The bias and error exceed 100%, but using expanded performance criteria for observed concentrations around 0.5 $\mu g/m^3$, this is actually near acceptable.

Organic carbon is over predicted compared to most measurements, and the highest over predictions are correlated with the highest observations. The largest over predictions among the IMPROVE sites occur at Wishram. The scatter points among the two Gorge Study sites are spatially consistent, but trend in time from large over predictions early in the episode to rather good performance in the latter half of the episode. The fractional bias and error over the entire

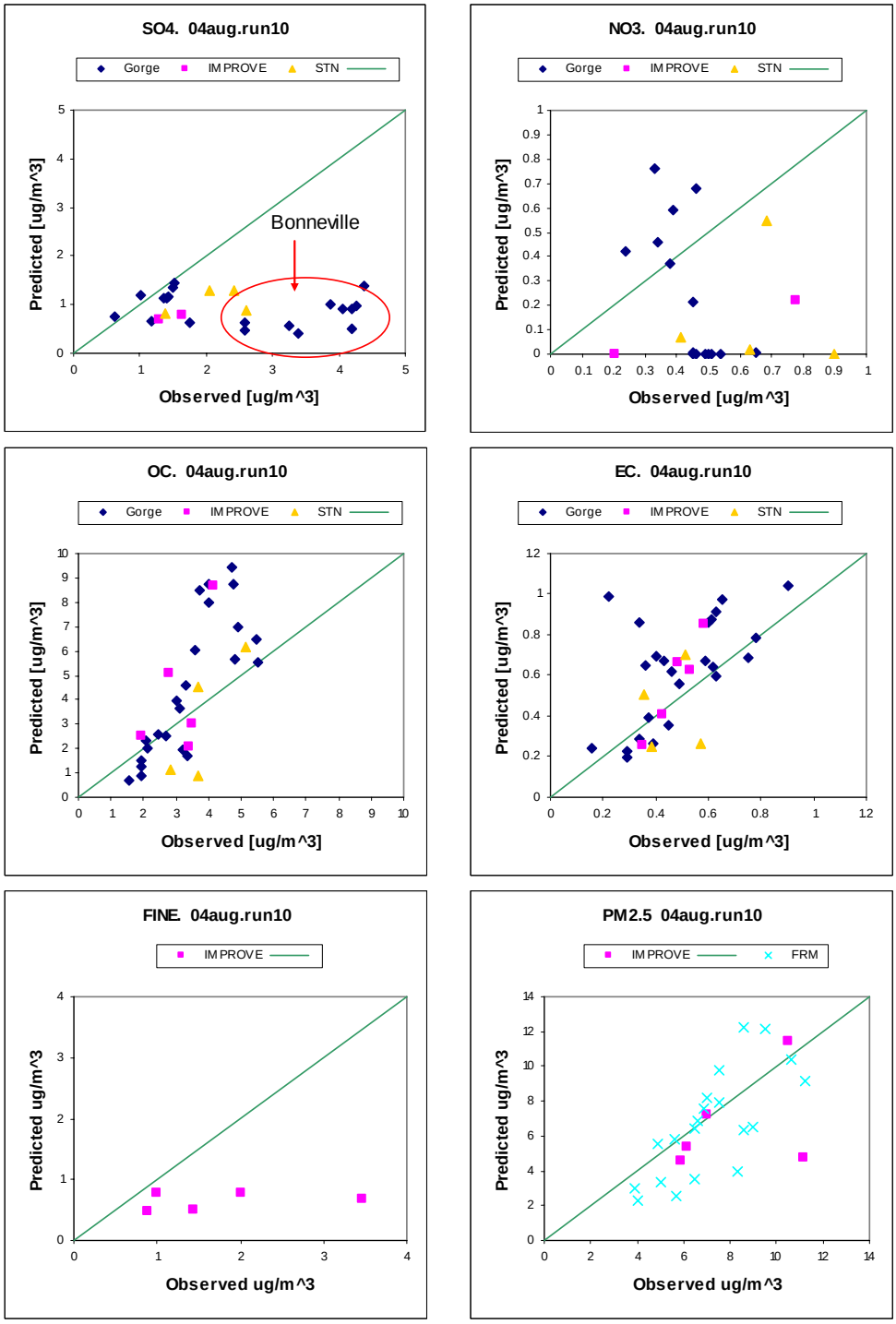


Figure 4-6. Scatter plots of 24-hour average CAMx Run 10 predicted PM components, $PM_{2.5}$, and PM_{10} against available measurements at IMPROVE, EPA FRM/STN, and Gorge Study sites.

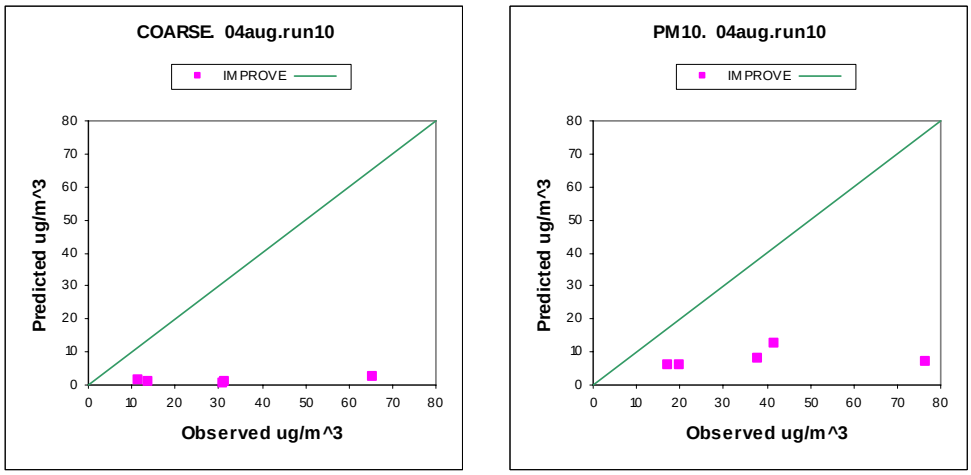


Figure 4-6 (Concluded).

Table 4-7. CAMx performance statistics in replicating 24-hour PM components and light scattering/extinction over the August 2004 modeling episode.

Parameter	Fractional Bias	Fractional Error	Number of Pairs	Qualitative Performance
SO4 (with Gorge)	-76%	79%	25	Poor
SO4 (no Gorge)	-37%	43%	6	Good to average
NO3	-109%	132%	21	Average (for low concentrations)
OC	5%	43%	32	Excellent to good
EC	15%	39%	33	Excellent to good
Primary Fine	-81%	81%	5	Poor
Primary Coarse	-180%	180%	5	Poor
Light Scattering	-15%	30%	94	Excellent
Light Extinction	-45%	45%	2	Good to average

August episode are +5% and 44%, respectively, which leads to very good performance by straddling the performance goals.

Performance for elemental carbon is quite good, showing balanced agreement with IMPROVE and STN measurements. However, EC exhibits an over prediction trend at the Gorge Study sites. Overall statistics over the episode indicate very good performance that is well within performance goals. Like nitrate, EC concentrations remain well below 1 $\mu g/m^3$, but given its high light absorption efficiency, low concentrations of EC can have much larger impacts on light extinction than dry nitrate salts.

Fine primary PM moved from a huge over prediction problem in earlier CAMx runs (prior to the adoption of canopy escape factors in Run 8), to a general under prediction tendency in Run 10. Only the IMPROVE sites provide data for comparison. Statistics show a strong negative bias that suggest poor performance for this component; however, from a light scattering perspective, poor performance will not have much of an impact since its light scattering efficiency is so low compared to other components. Much the same issues translate to the coarse mass component, which also exhibits a very large under prediction bias. The IMPROVE samplers most likely pick up very local coarse dust emissions from nearby fugitive dust sources (road and agriculturally-

derived dust) and natural wind-blown dust mechanisms. Very local sources such as these cannot be resolved by the model.

Total $PM_{2.5}$ was measured at IMPROVE (reconstructed) and EPA/FRM sites. CAMx performance is quite good for total fine PM, likely a result of balancing over and under predictions of the major PM components of OC, primary fine PM, and sulfate. This further translates to excellent model performance in replicating total light scattering (as seen in Figure 4-5 and Table 4-7). PM_{10} performance, on the other hand, is dominated by the under predictions seen in the CM component at IMPROVE sites.

Figure 4-7 displays the 24-hour average total light extinction budget predicted in Run 10 at the Mt Zion and Wishram IMPROVE sites. Note that extinction is calculated similarly to the total scattering described earlier, except that the contribution from light-absorbing EC are included, and humidity growth is incorporated into the sulfate and nitrate scattering using the monthly humidity factors published for these sites by IMPROVE. These extinction budgets are compared to the two available re-constructed extinction budgets from the IMPROVE PM measurements on August 19. Overall, the model replicates total extinction moderately well, but CAMx tends to under predict sulfate and nitrate, and at Wishram, over predicts the contribution from organics. Additionally, the IMPROVE sites include a contribution from coarse mass, which the model misses completely. This is likely due to very local fugitive dust sources (dirt roads, agricultural activity) that the emissions inventory cannot resolve. All of these performance characteristics were discussed previously.

Figure 4-8 shows the breakdown of predicted organic aerosols for each day of the modeling episode at Mt Zion and Wishram. SOA components 1 through 3 are chemically formed in the atmosphere by oxidation of anthropogenic VOC. SOA components 4 and 5 are chemically formed in the atmosphere by oxidation of biogenic VOC. Primary organics (POA) are directly emitted from any combustion source (fires, tailpipes, industrial point sources) and are perceived as visible "smoke." At both sites, a large and sometimes dominant fraction of organic aerosols are attributable to biogenic emissions. POA contributes the balance of the total organic mass; it tends to be dominant at Mt Zion, and is rather large at Wishram as well. Much of the POA in the August simulation is due to wild fire smoke. Note that SOA from anthropogenic sources is minimal or zero, as these compounds tend to be the most volatile and resist condensing in warm dry climates.

Figure 4-9 shows time series of CAMx scattering from Run 10 against hourly nephelometer observations at all nine Gorge Study sites. Note that we have plotted the re-constructed extinction in two ways: (1) using the "dry" assumption, which caps the relative humidity at 50%; and (2) using the "wet" assumption, which caps the relative humidity at 90%. These plots are arranged in the same order that the sites are located along the Columbia River from west to east. The model tends to capture the multi-day episode trends at each site, and the inter-diurnal variations are moderately well simulated. On some days, the simulation exhibits large hourly peaks that in some cases match observations, but are usually too large. Given the dry conditions of this episode, little difference is seen between the "dry" and "wet" reconstructed scattering at most sites, although the western sites closer to the coast do show some diurnal effects.

To investigate those PM components responsible for the large diurnal peaks, we plotted predicted and observed hourly PM at the Bonneville and Mt Zion Gorge Study sites

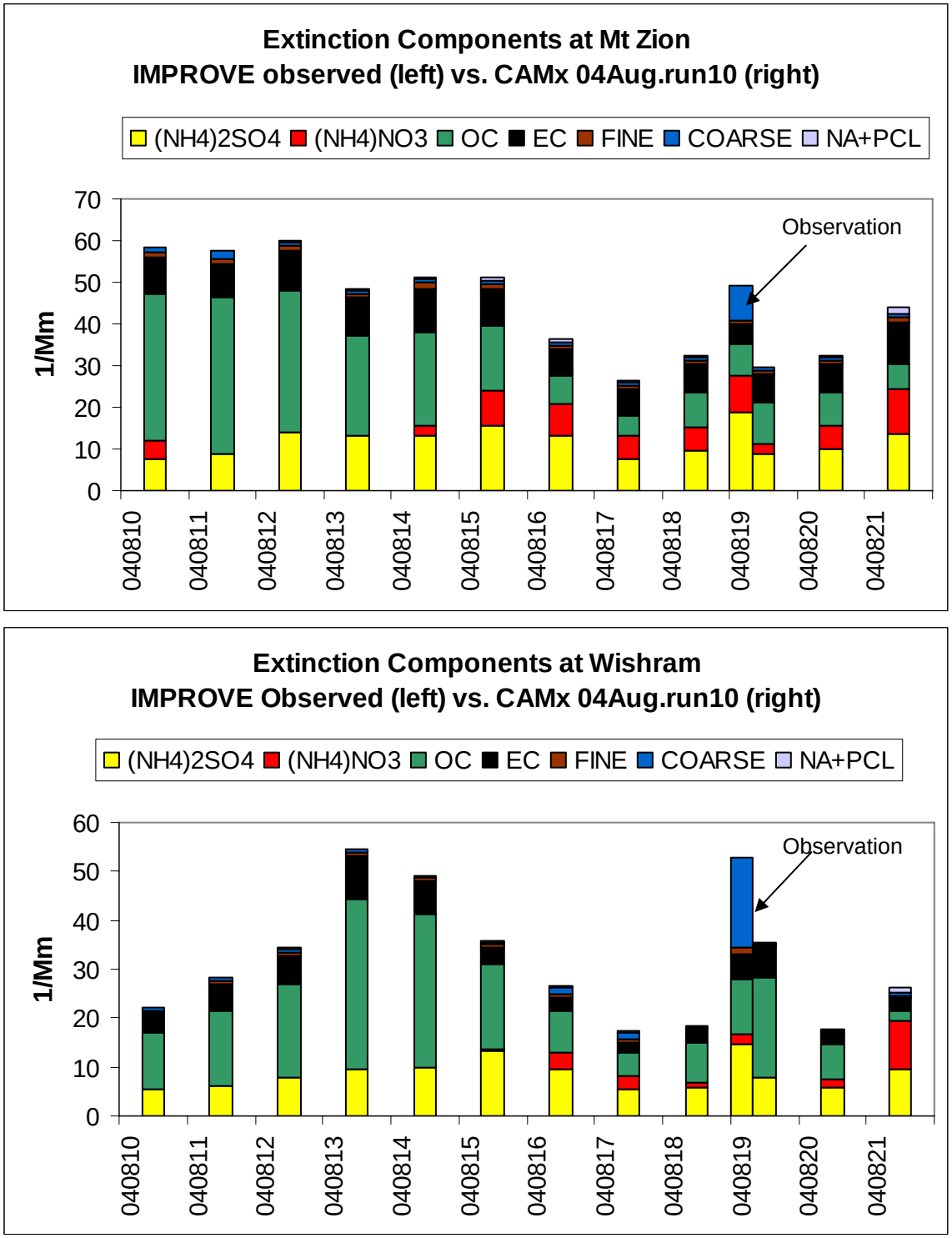


Figure 4-7. Comparison of CAMx predicted (Run 10) extinction components (Mm^{-1}) against a single day (August 19) of re-constructed extinction from PM measurements at IMPROVE sites at Mt Zion (top) and Wishram (bottom). Results for the August 2004 episode.

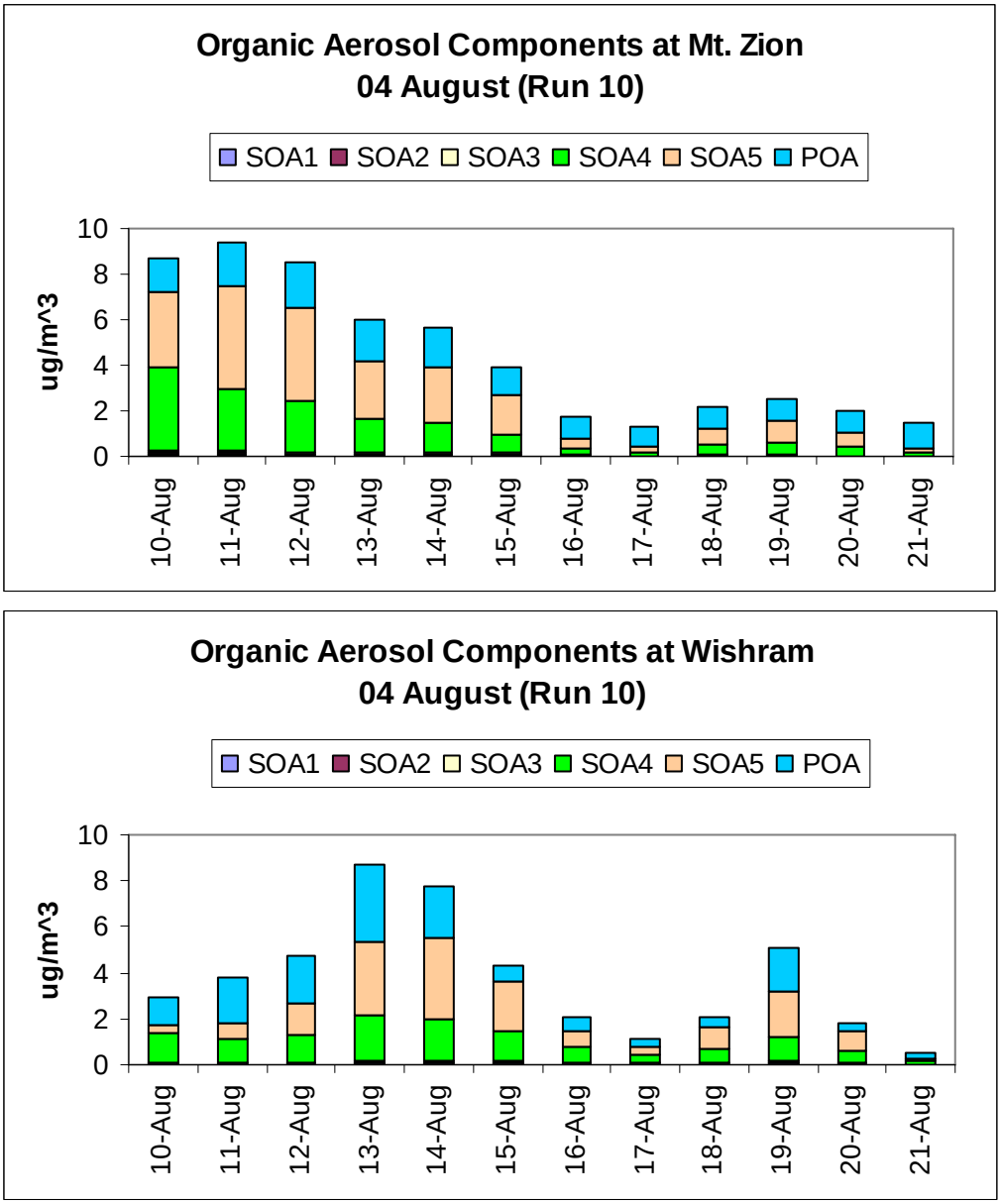


Figure 4-8. Components of total predicted organic aerosols at Mt Zion (top) and Wishram (bottom) IMPROVE sites over the August 2004 episode. SOA1-3 are chemically derived from anthropogenic VOC emissions; SOA4-5 are chemically derived from biogenic VOC emissions; POA is primary (directly emitted) organic aerosol from all combustion sources.

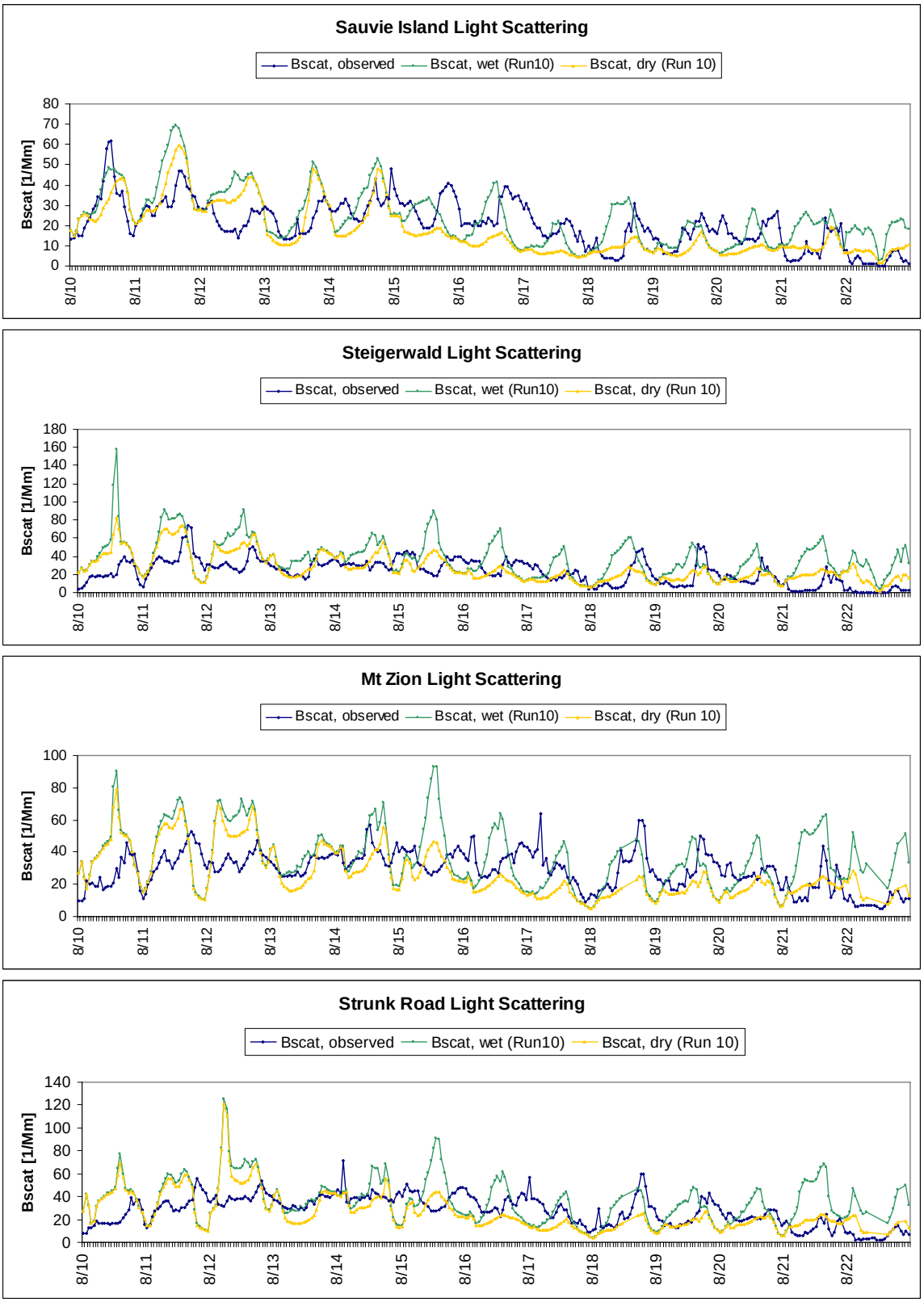


Figure 4-9. Predicted (Run 10) and observed hourly light scattering (Bscat) at Gorge Study sites over the August 2004 modeling episode. Dates are shown at midnight UTC, or 4 PM PST.

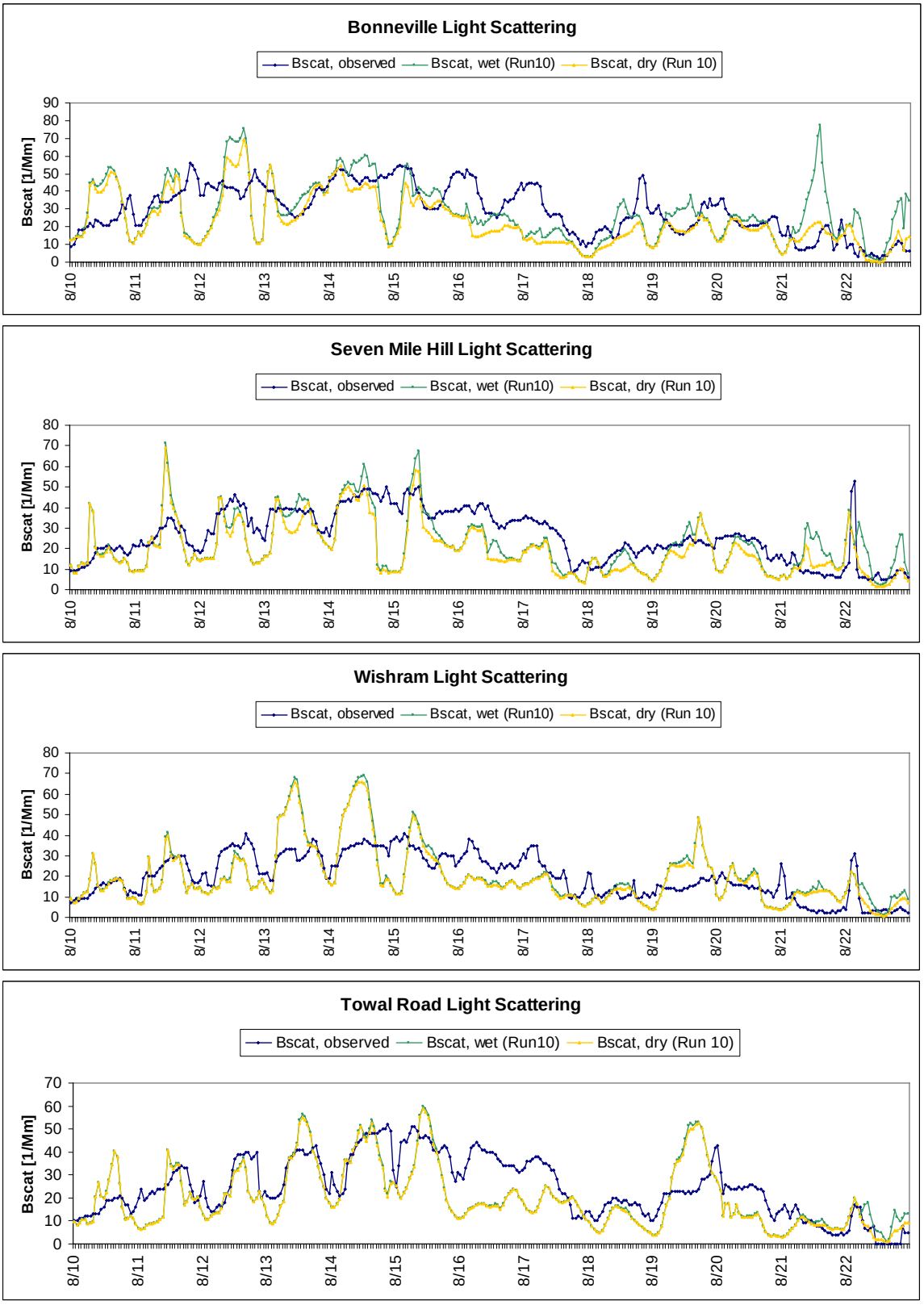


Figure 4-9 (continued). Predicted (Run 10) and observed hourly light scattering (Bscat) at Gorge Study sites over the August 2004 modeling episode. Dates are shown at midnight UTC, or 4 PM PST.

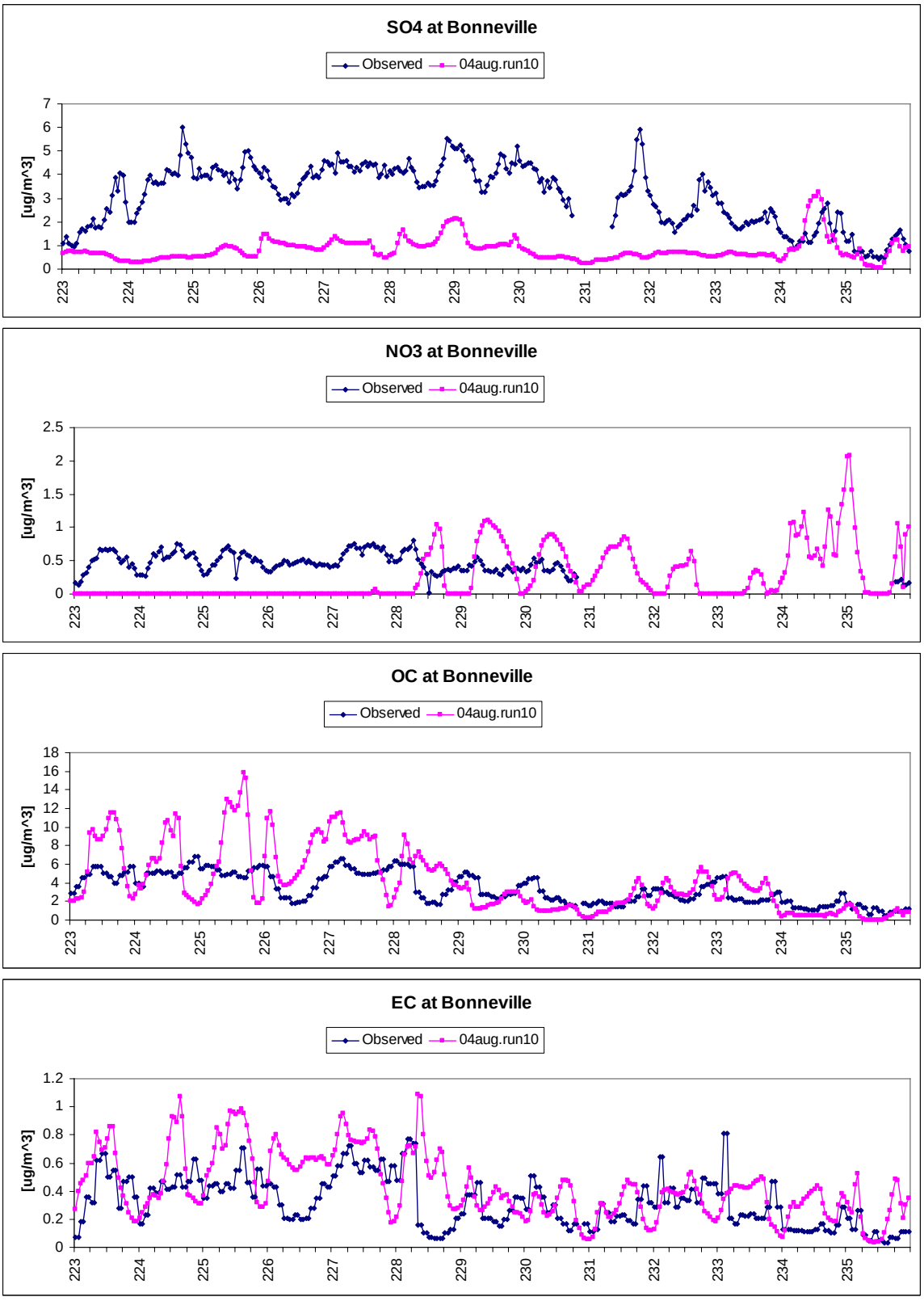


Figure 4-10. Predicted (Run 10) and observed hourly PM components at the Bonneville Gorge Study site over the August 2004 modeling episode. Julian dates are shown at midnight (UTC) , or 4 PM PST.

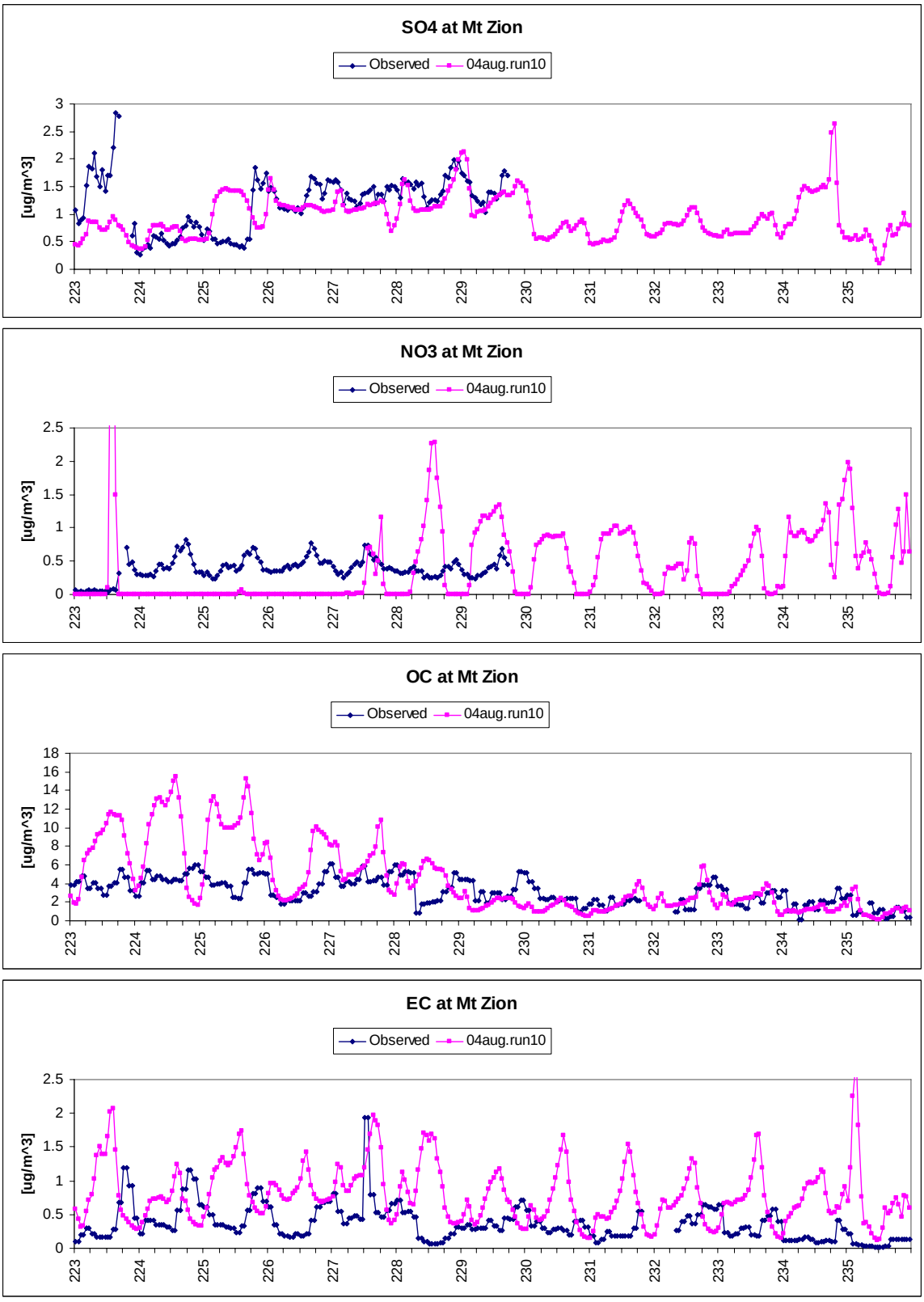


Figure 4-11. Predicted (Run 10) and observed hourly PM components at the Mt Zion Gorge Study site over the August 2004 modeling episode. Julian dates are shown at midnight (UTC) , or 4 PM PST.

(Figures 4-10 and 4-11, respectively). The Mt Zion site is located just east of the Portland metropolitan area, whereas the Bonneville site is located at about the point where the crest of the Cascade mountain range crosses the Columbia River. It is important to remember that the only PM components shown in Figures 4-10 and 4-11 that contribute to the simulated light scattering are sulfate, nitrate, and OC; EC only contributes to absorption (and ultimately total extinction).

At Bonneville (Figure 4-10), we see large sulfate measurements compared to relatively low predictions, while at Mt Zion, we see large EC over predictions. Both of these problems were noted earlier at the beginning of Section 4.4; recall that DRI has questioned the validity of the respective sulfate and EC measurements at these sites. However, none of these would contribute to the large diurnal variations in simulated light scattering. Clearly, this characteristic is related to the OC variations day-to-day, especially in the early portion of the episode. The simulated EC at Mt Zion follows a similar diurnal pattern to the OC, and is simulated to be much higher than at the Bonneville site by about a factor of 2. In these figures, which are plotted in UTC, the dates are located at midnight UTC (4 PM PST), which means that the highest concentrations occur overnight, and the lowest occur in the mid afternoon during maximum boundary layer mixing.

4.4.1.2 Conclusions from August Episode Modeling

After undertaking several diagnostic and sensitivity tests for the August modeling episode, from which several emission problems were ameliorated, we were able to achieve an acceptable base case replication of the PM components and light scattering/extinction that were measured along the Columbia River. When model performance was qualitatively gauged against 24-hour average measurements, it was found to meet or beat performance goals and criteria for the most critical PM components observed during the period (organic aerosol and sulfate), and for total light scattering and extinction. Those components exceeding the performance criteria (nitrate, fine and coarse primary PM) were either both predicted and measured to be very low in concentration (the case for nitrate below 1 $\mu g/m^3$), or do not contribute significantly to light extinction due to low scattering efficiency (the case for fine and coarse primary PM). When hourly predictions were compared to limited hourly measurements taken at two Gorge Study sites, Mt Zion and Bonneville, the model demonstrated a basic ability to replicate the inter-daily trends in PM component concentrations and light scattering during this episode, but the model over stated the diurnal variation of carbonaceous components, and thus total light scattering as well. Overall, the model performed very well in replicating the temporal and spatial variation of key PM species concentration and light extinction levels that were observed during this episode.

4.4.2 Results of November Episode Simulations

As shown in Table 4-6, eight individual CAMx simulations were undertaken for the November 4-18, 2004 modeling episode, which paralleled the run configurations made for August. Most of these runs addressed improvements in the input emission inventory or the treatment of biogenic SOA, as described above. Two sensitivity tests were run for this episode:

- Sensitivity to two methods of deriving the vertical diffusivity (Kv) and its minimum value (O'Brien method vs. CMAQ);
- Sensitivity to doubling ammonia (NH_3) emissions;

The model was most sensitive to the choice of Kv methodology, much more so than seen in the August episode. The combination of the CMAQ method in conjunction with the higher minimum Kv floor dramatically reduced those primary PM components that exhibited large over predictions in the diurnal variation, especially in the Portland area. Large reductions in over predicted light scattering were associated with these changes (by as much as 300 Mm^{-1} at the Steigerwald Gorge Study site). Little impact was seen for secondary PM constituents such as sulfate, nitrate, and SOA. The primary emissions of concern over the November episode included: (1) primary fine and coarse PM, (2) primary organics (POA), and (3) primary elemental carbon (EC). The carbonaceous components were dominated by wood smoke, which was especially concentrated in the Portland area. The over predictions in primary fine/coarse PM were due to over stated emission factors and the application of seasonal profiles in the modeling inventory that do not account for the suppressive effects of recent precipitation on such activities as road dust and construction and agricultural fugitive dust. Reducing the dust components to near zero to account for precipitation would improve model performance for primary PM dramatically; this would require the development of day-specific dust emission fields (not done in this study).

Sulfate, nitrate and associated ammonium were appropriately predicted to be much higher during this episode, with nitrate exceeding 10 $\mu g/m^3$ in both measurements and predictions. This was due to the fact that the period was much cooler, wetter and stagnant than the August episode, which are prime conditions for the formation of secondary sulfate and nitrate PM salts. Cloud water is an important heterogeneous chemical pathway for sulfate and nitrate, while high humidity and cool temperatures are critical for correctly characterizing the balance between sulfate, nitrate and ammonium. Nitrate aerosols are formed from the neutralization of nitric acid gas (which is produced by the atmospheric oxidation of NOx emissions) by cations such as ammonium, sodium, calcium, and potassium. Ammonium is by far the most abundant cation available away from oceans, so ammonium nitrate is the most abundant form of nitrate particles. On the other hand, sulfate (which is produced by the atmospheric oxidation of SO_2 emissions) exists as an aerosol regardless of its state of neutralization by the same cations. Thus, there is a "competition" between sulfate and nitrate to react with available cations; the process is complex and dependent on atmospheric conditions and the mix of chemicals. In very simple terms, ammonia preferentially reacts with sulfuric acid aerosols, and any excess is then available to form nitrate particles.

Our tests indicated that ammonium nitrate formation was most likely limited by available ammonia. Indeed, nitrates and ammonium were much higher with doubling of ammonia emissions, especially around major urban areas such as Portland and along the Interstate 5 route up through Seattle. Nitrate model performance against Gorge Study, IMPROVE, and STN sites (locations shown in Figure 4-3) tended toward a more balanced bias with the doubling of ammonia emissions, although still exhibiting a large degree of uncorrelated scatter and gross error. Sulfate was not significantly impacted by the doubling of ammonia, as the chemical process described above would suggest. So the doubling of ammonia emissions likely went into neutralizing more sulfate (which would not lead to an obvious change in total sulfate concentrations output by the model), and any excess ammonia went to neutralizing more available nitrate. In other words, even more ammonia emissions would probably lead to additional PM nitrate (i.e., an ammonia-limited system). Higher ammonium nitrate concentrations resulted in the largest increases in light scattering by 15-30 Mm^{-1} in the western

Columbia River area early in the episode (November 6-9, Sauvie Island through Strunk Road), while eastern Gorge sites showed a more modest increase of 5-15 Mm^{-1} later in the episode (November 12-14, Bonneville out to Towal Road).

4.4.2.1 Final Results from CAMx Run 10

Figure 4-12 displays a scatter diagram that compares 24-hour predicted light scattering to "dry" nephelometer observations at the nine Gorge Study sites. Note that there are two performance regimes: over predictions at sites nearest Portland, and under predictions at sites in the eastern portion of the Gorge. The reasons for this are discussed below.

Figure 4-13 presents similar scatter diagrams for the PM components (sulfate, nitrate, organics, EC, primary fine, primary coarse, total $PM_{2.5}$, and total PM_{10}), while Table 4-8 displays the performance statistics over the episode. Sulfate performance at Gorge Study sites (Mt Zion and Bonneville) is quite good, but sulfate is over predicted at the IMPROVE at STN sites. Recall that measured sulfate at the Gorge sites were reported to be up to two times higher than co-located IMPROVE measurements during the episode. By removing the Gorge site sulfate measurements from consideration, the over prediction bias increases from 14% to 66% (changing the qualitative performance from "excellent" to "poor").

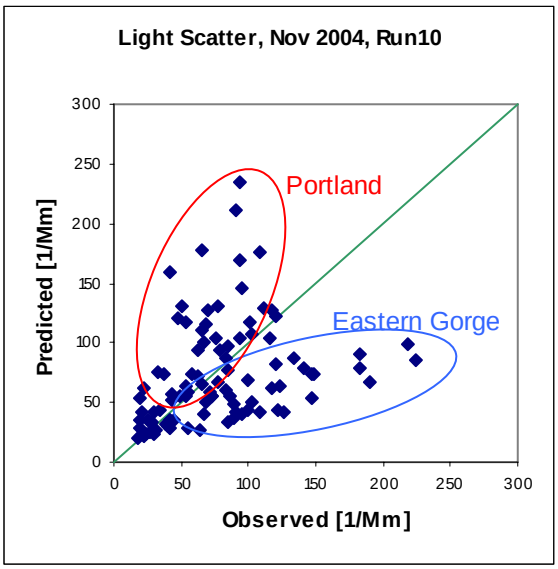


Figure 4-12. Scatter diagram comparing 24-hour average light scattering predicted by CAMx against "dry" nephelometer measurements from nine Gorge Study sites along the Columbia River. Units are inverse megameters; results are from CAMx "Run 10".

Note that nitrate is observed and predicted at much higher concentrations than seen in the August episode. This is driven by the meteorological conditions for this episode. Whereas the nitrate scatter diagram suggests a good balance of over and under predictions (as reflected in the bias), the model is not well correlated to the observations as indicated by the wide spread (or gross

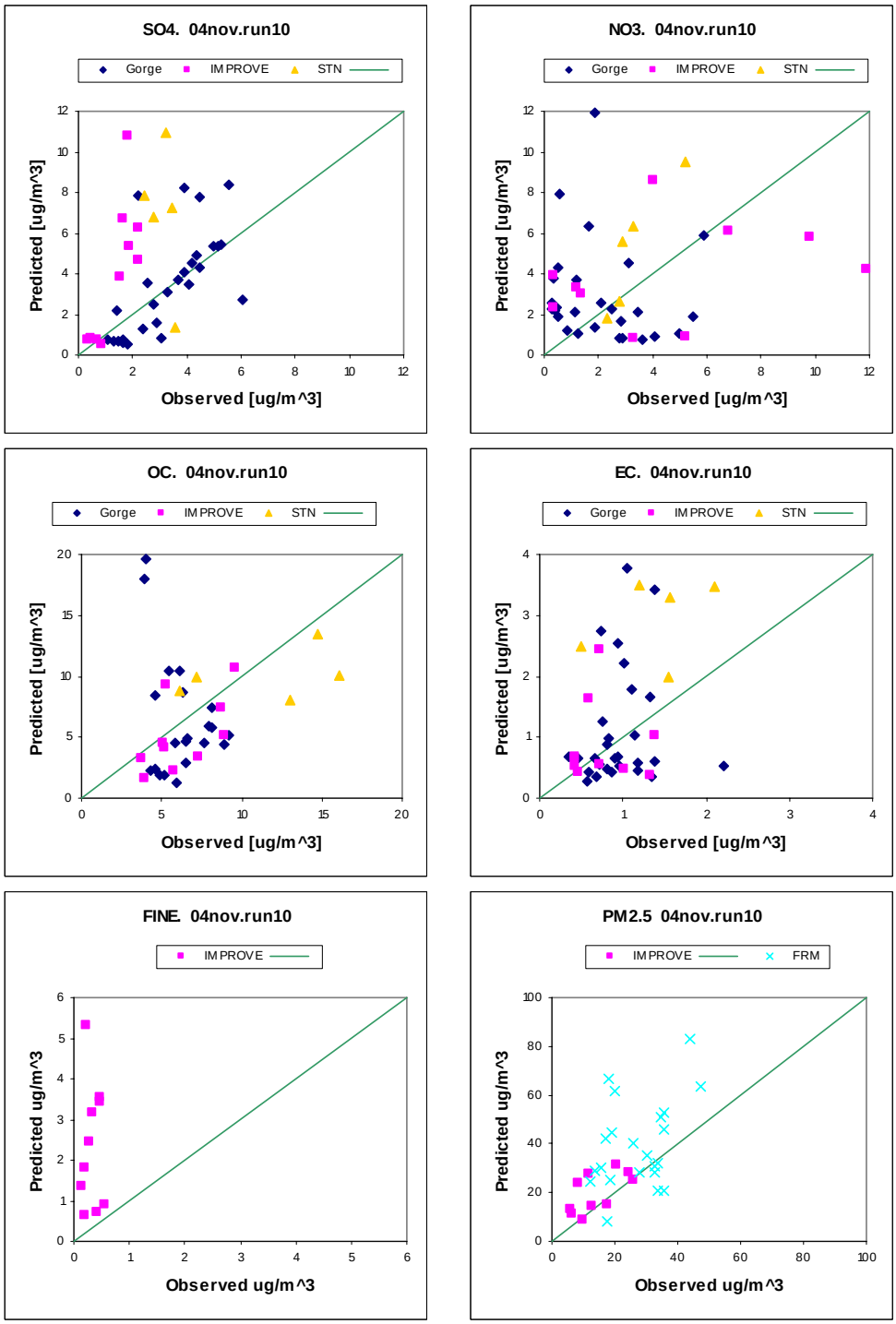


Figure 4-13. Scatter plots of 24-hour average CAMx Run 10 predicted PM components against available measurements at IMPROVE, EPA FRM/STN, and Gorge Study sites.

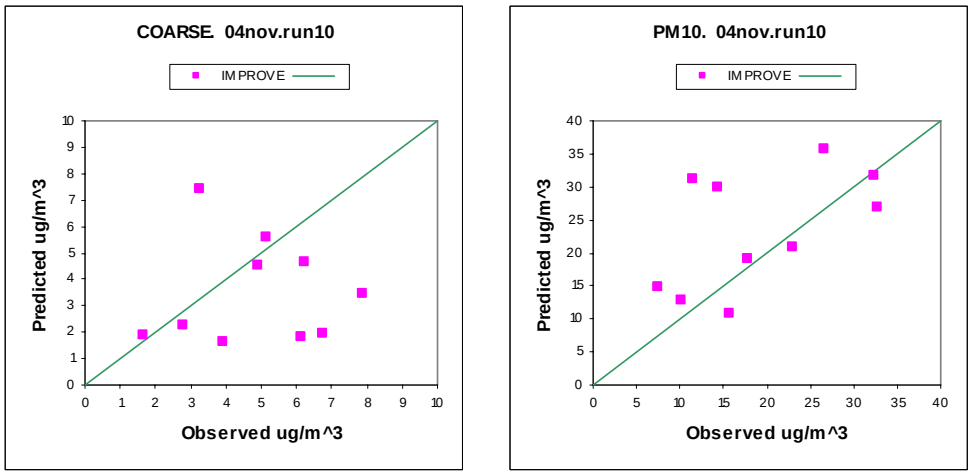


Figure 4-13 (Concluded).

Table 4-8. CAMx performance statistics in replicating 24-hour PM components and light scattering/extinction over the November 2004 modeling episode.

Parameter	Fractional Bias	Fractional Error	Number of Pairs	Qualitative Performance
SO4 (with Gorge)	14%	59%	42	Excellent to average
SO4 (no Gorge)	66%	84%	15	Poor
NO3	30%	91%	43	Good to poor
OC	-20%	53%	36	Good to average
EC	5%	60%	43	Excellent to average
Primary Fine	134%	134%	10	Poor
Primary Coarse	-34%	54%	10	Average
Light Scattering	-4%	45%	94	Excellent to Good
Light Extinction	32%	39%	10	Good to Average

error). It is important to note that higher nitrate concentrations in this episode play a much larger role in light extinction.

Rather large over predictions are seen for elemental carbon and primary fine PM, which suggest that emissions for these components continue to be over stated in the final inventory used in Run 10. EC is mostly over predicted at the Mt Zion site, which is the closest speciated PM Gorge Study site to Portland. Even so, both bias and gross error are acceptable, which is important given the efficiency of light extinction for EC. The primary fine component is due to dust emissions (we assume from fugitive sources as opposed to wind blown dust); this dust component is likely over stated in the emission inventory due to the use of season-average emission factors that do not reflect the episodic (day-specific) effects of surface moisture due to recent precipitation. Statistical performance for primary fine PM is “poor”, but its impact on overall light scattering is not especially important relative to the sulfate, nitrate and carbon.

The organic carbon component shows rather good performance over all types of monitoring sites. OC is dominated by primary organics (POA); with the improvement in the characterization of wood smoke emissions reflected in Run 10, model performance for organics improved dramatically from earlier simulations.

Overall, total $PM_{2.5}$ is simulated well, with some tendency for over predictions at the Portland FRM sites. This is mostly driven by the sulfate, primary EC, and fine PM components in and around Portland (where most EPA/FRM sites reside). As opposed to the August episode, primary coarse PM shows balanced performance (at IMPROVE sites), and this leads to acceptable performance for total PM_{10} at the same sites.

Figure 4-14 displays the 24-hour average total light extinction budget predicted in Run 10 at the Mt Zion and Wishram IMPROVE sites. Many more IMPROVE measurements are available during the November episode for comparison. Overall, the model replicates total extinction rather well on most days, and appropriately simulates more contribution from secondary salts (sulfate and nitrate) relative to the carbonaceous components in accordance with the measurements. While CAMx replicates extinction from sulfate and nitrate combined, it over predicts the sulfate component and under predicts the nitrate component. The carbonaceous components are modeled very well on all days. The measurements do not show any appreciable contribution from fine and coarse mass, even though the primary fine PM component was over predicted.

Figure 4-15 shows the breakdown of predicted organic aerosols for each day of the modeling episode at Mt Zion and Wishram. In the November episode, there is a larger dominance of POA, which we attribute mostly to wood smoke (i.e., fireplaces as opposed to wild fires). A larger POA contribution is seen at Mt Zion, which is closer to the Portland area. There continues to be a large contribution from biogenic emissions, even in this late season. Note also that there are minor contributions from anthropogenic sources. Whereas the photochemical activity should be much less than in the August episode, secondary aerosols tend to stay condensed in the cool moist environment of this episode.

Analysis of Figures 4-16 through 4-18 sheds further information on the west vs. east model performance regimes for light scattering seen in Figure 4-12. Hourly “dry” nephelometer light scattering measurements are plotted along with Run 10 predictions over the modeling episode in Figure 4-16. Both “dry” and “wet” assumptions are plotted from the Run 10 simulation as a way to bracket the range of possible scattering from the nephelometer readings. As before, these plots are arranged in order along the Columbia River from west to east. The westernmost sites (through Strunk Road) show over predictions in diurnal light scattering during the first half of the episode. Performance improves in the latter half of the episode, at least for the “dry” model results. At the eastern sites, however, the major haze event of mid-November is apparently missed by the model, even for the “wet” assumption. This substantiates the “bifurcated” performance seen in the 24-hour scatter plot in Figure 4-12. Note that the model does generate a later haze event on November 17-18 that is not supported by the observations.

Figures 4-17 and 4-18 show the hourly PM component concentrations at the Bonneville and Mt Zion Gorge Study sites. At the Bonneville site located at the crest of the Cascade range (Figure 4-17), sulfate, nitrate, and carbonaceous PM are all fairly well predicted with a tendency for some under predictions during the middle of the episode. Quite different performance is seen at the Mt Zion site closer to Portland (Figure 4-18); here, carbonaceous PM is over predicted with large diurnal “spikes”, especially early in the episode, while sulfate and nitrate performance is rather good. The over predictions in organics early in the episode are directly related to the scattering over predictions at the western Gorge Study sites.

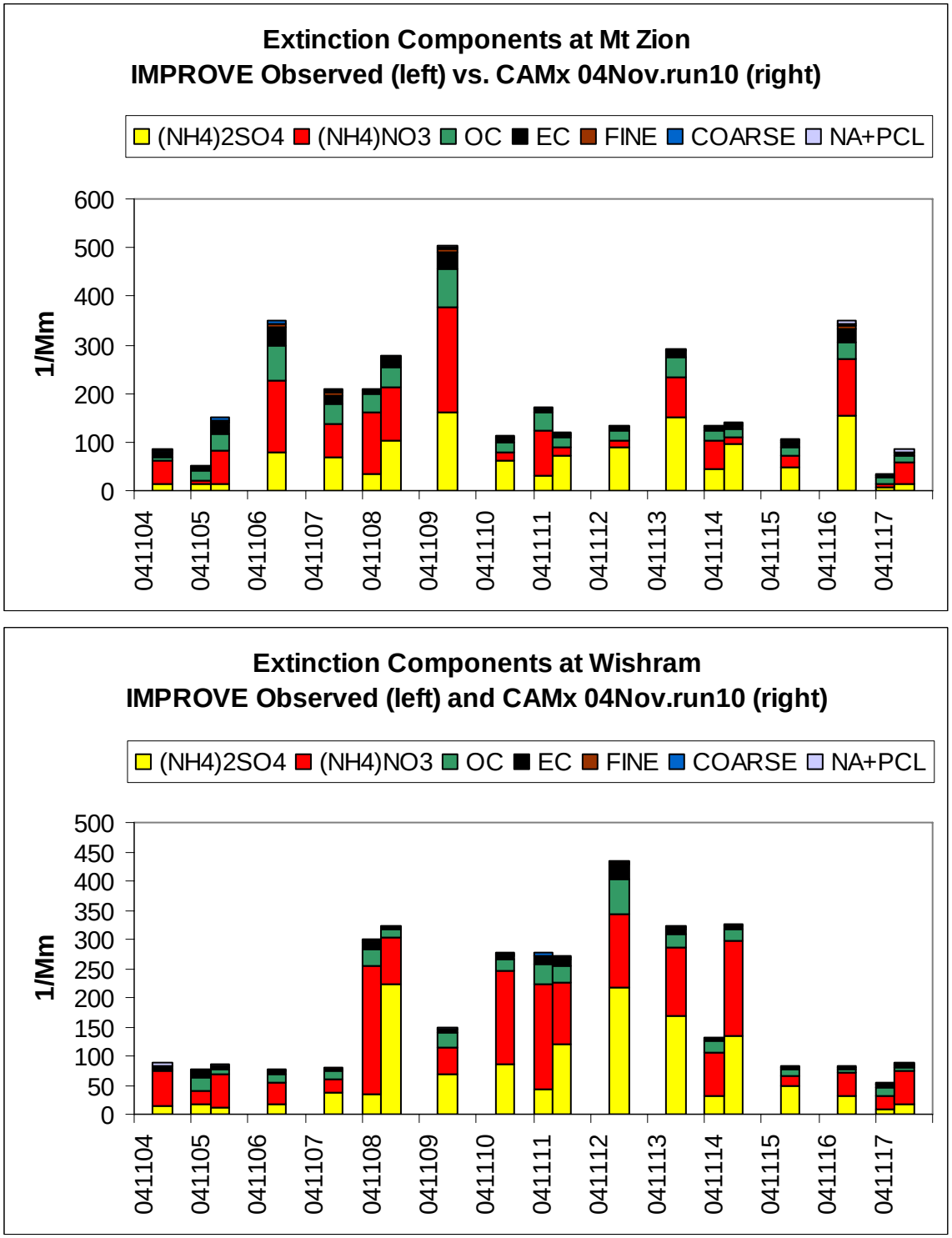


Figure 4-14. Comparison of CAMx predicted (Run 10) extinction components (Mm^{-1}) against available re-constructed extinction from PM measurements at IMPROVE sites at Mt Zion (top) and Wishram (bottom) on November 5, 8, 11, 14, and 17 (left bars on each day). Results for the November 2004 episode.

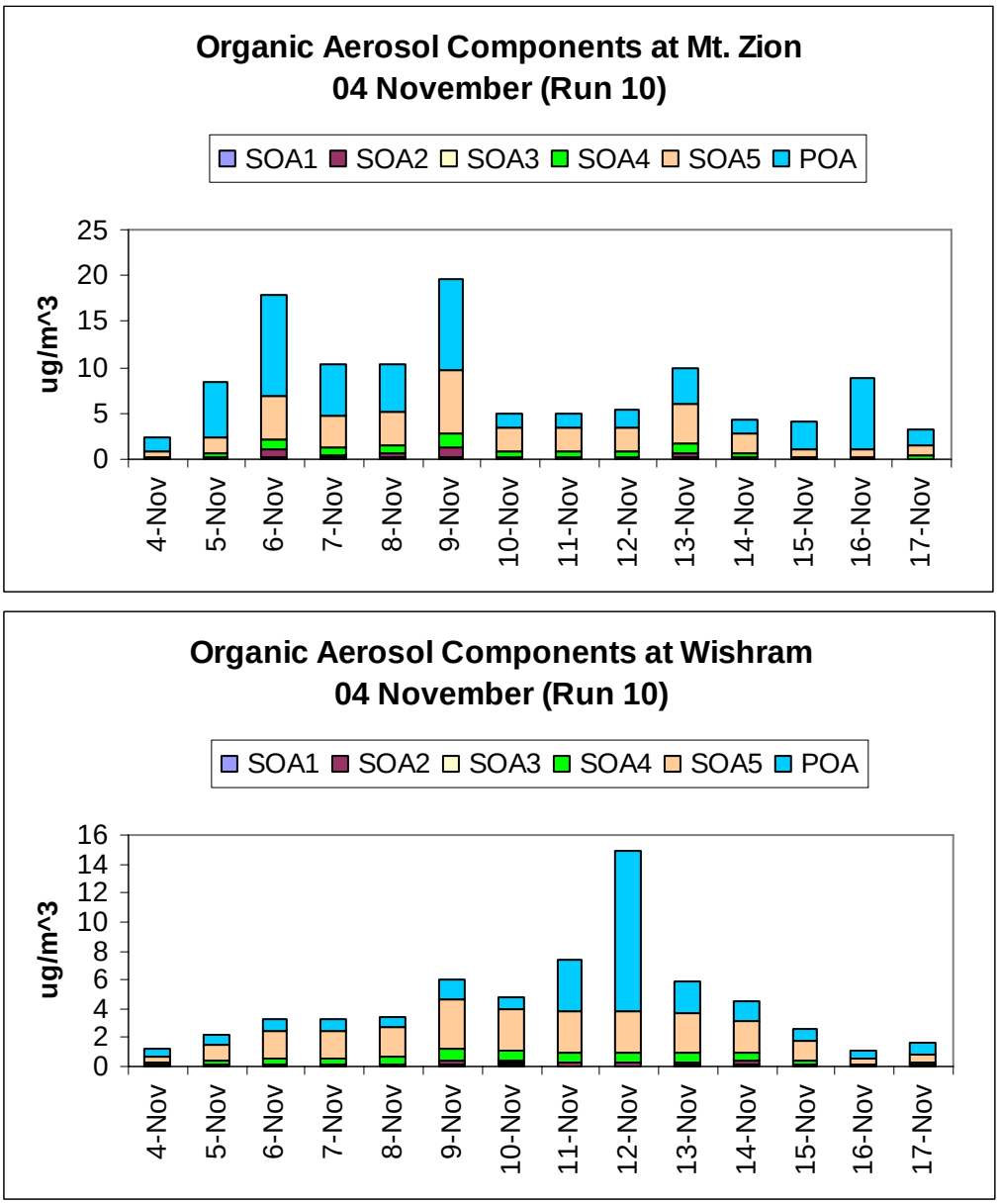


Figure 4-15. Components of total predicted organic aerosols at Mt Zion (top) and Wishram (bottom) IMPROVE sites over the November 2004 episode. SOA1-3 are chemically derived from anthropogenic VOC emissions; SOA4-5 are chemically derived from biogenic VOC emissions; POA is primary (directly emitted) organic aerosol from all combustion sources.

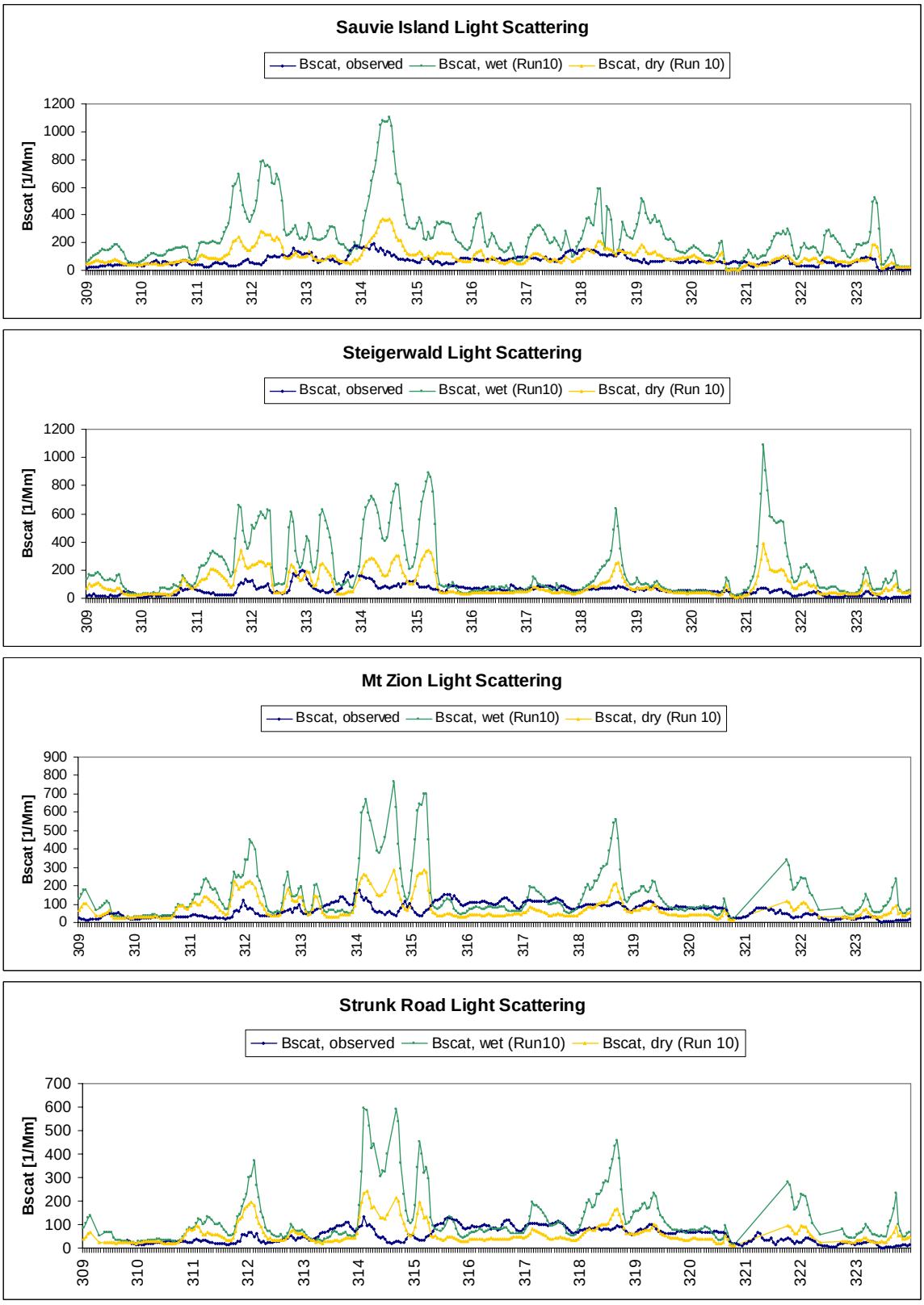


Figure 4-16. Predicted (Run 10) and observed hourly light scattering (Bscat) at Gorge Study sites over the November 2004 modeling episode. Julian dates are shown at midnight UTC, or 4 PM PST.

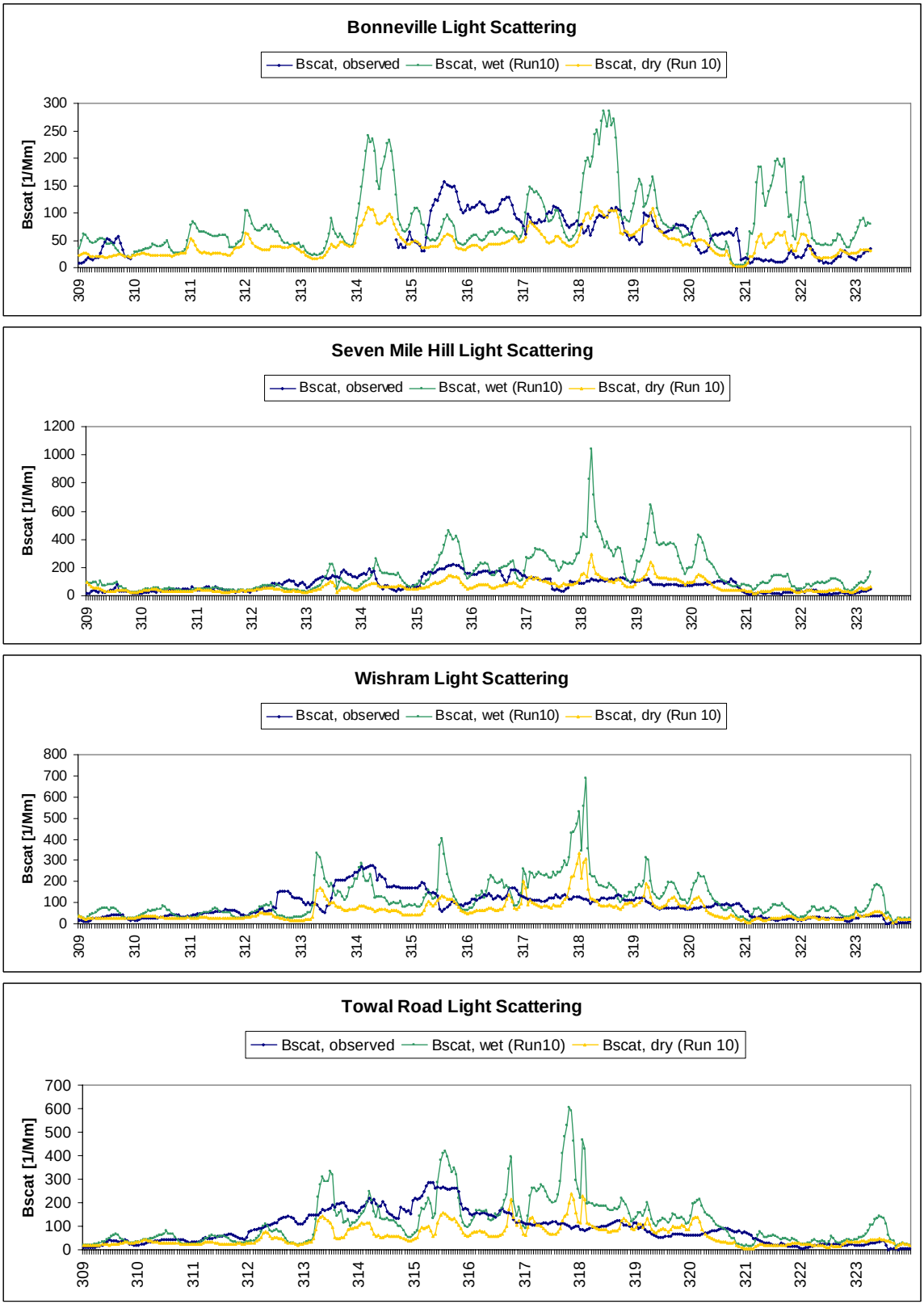


Figure 4-16 (concluded). Predicted (Run 10) and observed hourly light scattering (Bscat) at Gorge Study sites over the November 2004 modeling episode. Julian dates are shown at midnight UTC, or 4 PM PST.

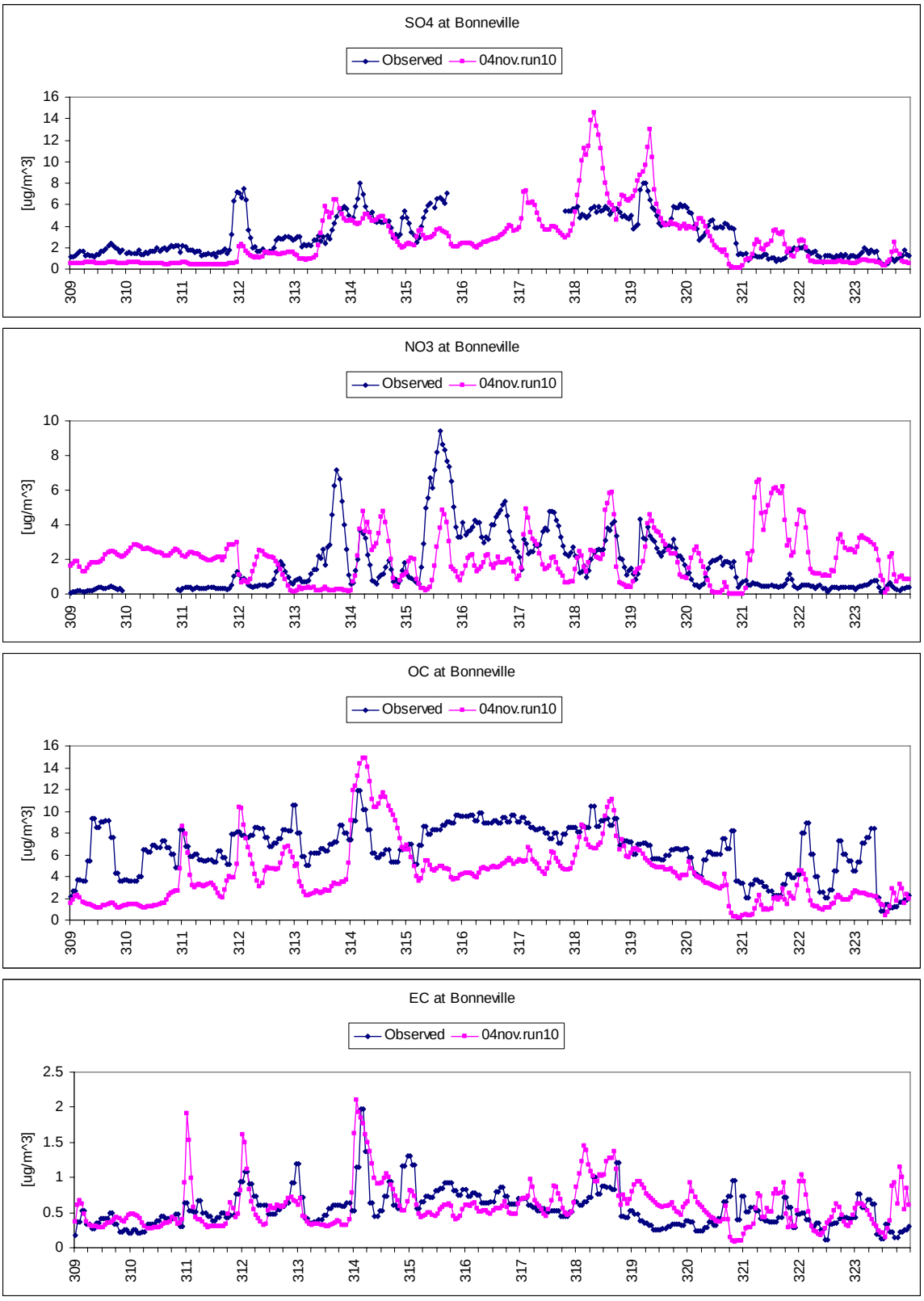


Figure 4-17. Predicted (Run 10) and observed hourly PM components at the Bonneville Gorge Study site over the November 2004 modeling episode. Julian dates are shown at midnight (UTC), or 4 PM PST.

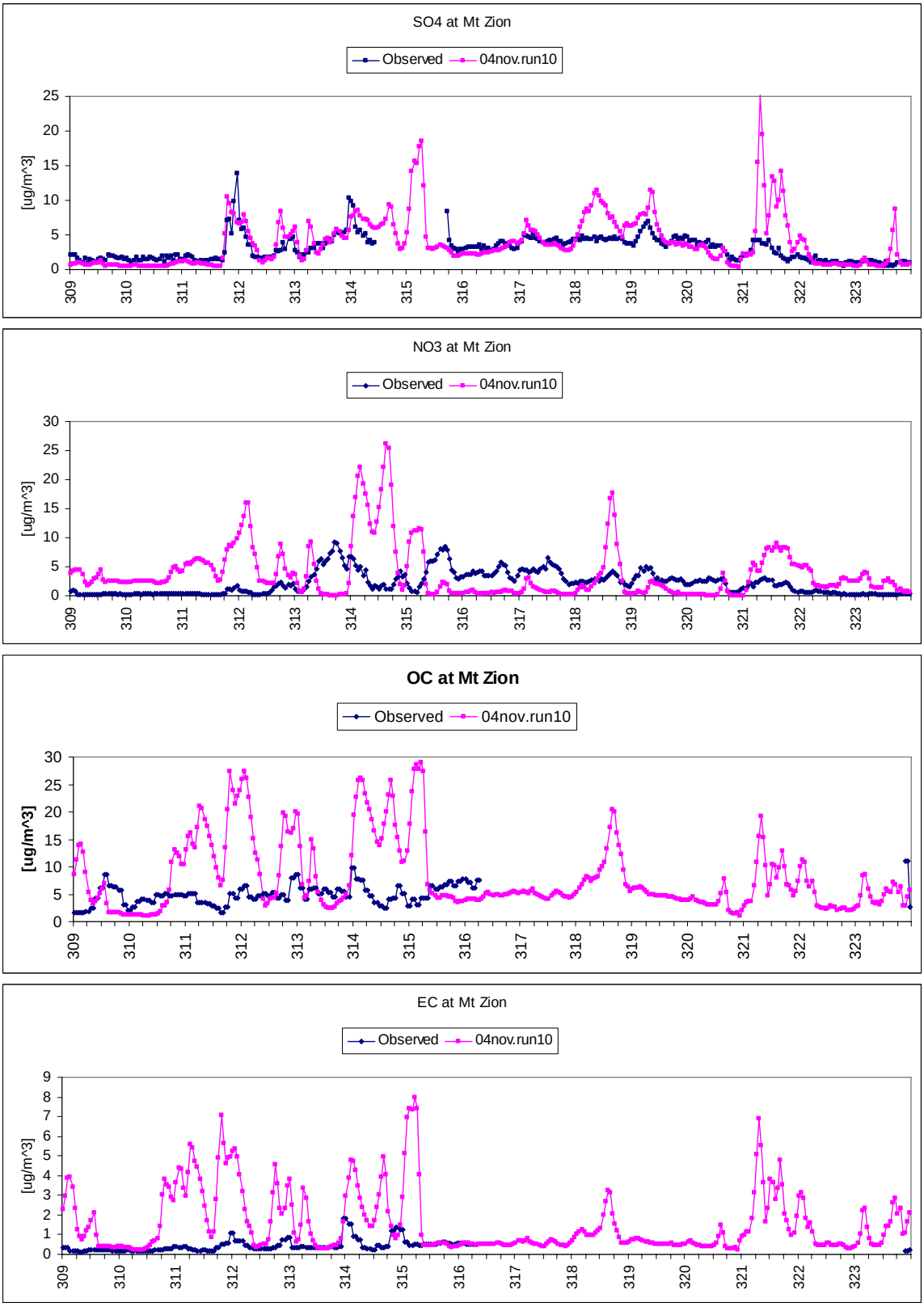


Figure 4-18. Predicted (Run 10) and observed hourly PM components at the Mt Zion Gorge Study site over the November 2004 modeling episode. Julian dates are shown at midnight (UTC), or 4 PM PST.

There is an inconsistency between the fact that PM concentrations exhibit only modest under prediction tendencies at Bonneville and the fact that the nephelometer scattering is under predicted by a factor of 2-3 at the same site. In order to reach measured scattering coefficients of 150-300 Mm^{-1} at the eastern "dry" nephelometer sites, the combined concentrations of sulfate, nitrate, and organics would need to reach 40 to 75 $\mu g/m^3$ under conditions of 50% inlet humidity (see Section 4.4.2.1). However, the combined PM concentrations measured at Bonneville only reach 20-30 $\mu g/m^3$. The Radiance "dry" nephelometer heater is generally designed to provide a 20% humidity depression and is not necessarily designed to take a near 100% humidity event and reduce it to 50% humidity. Additionally, there is a hysteresis effect where aerosols do not dry and shrink as fast as they hydrate and grow (Green, personal communication). Therefore, it is quite possible that under high humidity conditions, the measured scattering by the Radiance instruments are not entirely "dry" as aerosol extinction efficiencies increase for the larger hydrated salts entering the nephelometer. When the predicted sulfate and nitrate concentrations were converted to scattering coefficients using observed relative humidity in combination with humidity growth functions (i.e., the "wet" reconstructed light scattering curve), it was very easy to achieve the measured scattering values at the eastern Gorge Study sites. In fact, most often this led to large over predictions of scattering, so the "dry" nephelometer data reflect conditions somewhere in between 50% inlet humidity conditions and the actual humidity measured each hour.

4.4.2.2 Conclusions from November Episode Modeling

Several diagnostic and sensitivity tests for the November modeling episode were successful in allowing us to identify problems in the November 2004 emission inventory and to improve certain under performance issues associated with the meteorology of the period. Incremental improvements at each step of the process brought model performance for light scattering and most PM constituents to acceptable levels. Model performance was qualitatively gauged for 24-hour average PM, and found to continually exhibit over prediction tendencies for primary PM components along the western portion of the Columbia River (carbonaceous and fine dust). Overall, sulfate and SOA were well predicted, although sulfate exhibited an over prediction tendency. On an episode-average basis, nitrate concentrations were well modeled with very small bias, but nitrate performance on a day-to-day basis was not well correlated with observations. Overall, total $PM_{2.5}$ was somewhat over predicted, yet total PM_{10} performance was well balanced.

Performance for light scattering indicated a "bifurcated" pattern: light scattering was over predicted in Portland area and along the western portion of the Columbia River, while it was under predicted along the eastern portion of the river. MM5 model performance suffered from a lack of humidity and clouds during the November episode. Cloud water is an important heterogeneous chemical pathway for sulfate and nitrate, while high humidity and cool temperatures are critical for correctly characterizing the balance between sulfate, nitrate and ammonium. The ability to generate the correct amount of nitrate is particularly sensitive to the accuracy of humidity and temperature fields. The MM5 cloud field predictions were improved by simply assigning fog to areas of the air quality modeling grid according to available visible satellite imagery. This was found to help the under predictions in sulfate and nitrate significantly. However, we identified other issues associated with how the "dry" nephelometer instruments employed during the Gorge field study over estimated PM light scattering during the

very high humidity conditions that occurred over the core November period. Even with the general over prediction tendencies for organics and sulfate, using a "dry" light scattering re-construction technique to generate light scattering from modeled concentrations led to under predictions of total light scattering at eastern Gorge nephelometer sites. Alternatively, applying a "wet" (based on actual humidity) re-construction technique did result in much higher light scattering, which often improved agreement with observations, but in some cases led to very large over predictions in light scattering. Hence this instrument artifact contributed to some uncertainty in our model-observation comparisons for light scattering.

In summary, CAMx performed well in replicating the much higher concentrations of ammonium sulfate and ammonium nitrate along the Columbia Gorge during the cool, foggy, stagnant conditions of the November 2004 episode. The thick haze that formed during the period was observed to be dominated by these secondary salts, as well as from carbonaceous PM from (mostly) wood smoke. The air quality model simulated the elevated concentrations of all of these key species adequately well, allowing us to have confidence that the model provides the correct conclusions regarding source apportionment and impacts from emission changes under such extreme haze conditions.

5.0 BASE YEAR SOURCE ATTRIBUTION MODELING

The CAMx PM Source Apportionment Tool (PSAT) was applied to the August and November 2004 modeling episodes to quantify source attribution at the Mt Zion and Wishram monitoring sites for the 2004 Base Case scenario. A full description of PSAT is provided in the CAMx User's Guide (ENVIRON, 2006). In PSAT, the emissions of PM and gas precursors are stratified by source category and by source region; tracers are used to tag emissions from each category-region pair and track transport, chemical evolution from gas to PM, and deposition. Tracers can be run, separately or in combination, for a sulfur group (sulfur dioxide gas [SO_2] and particulate sulfate [PSO4]); a nitrogen group (nitrogen oxide gas [NOx], nitrogen oxide chemical products [NOy], nitric acid gas [HNO_3], ammonia [NH_3], particulate nitrate [PNO_3], and particulate ammonium [PNH4]); an organic group (volatile organic compounds [VOC], condensable hydrocarbon products [CG], and SOA components); and a primary PM group (carbonaceous, fine/coarse dust, and fine/coarse other PM).

In the PSAT application run for the Gorge Study, twelve source categories and six source regions were defined. PSAT was run for the sulfur, nitrogen, and primary PM groups. The organic group was not run; the main issue concerning SOA is the relative amount of biogenic vs. anthroponic SOA predicted by the model. Since the core SOA module in CAMx generates a biogenic/anthropogenic attribution by design (without the need for PSAT), and biogenic SOA was seen to dominate 24-hour PM predictions across the 4-km grid (see Section 4.4), it was determined that relying on the biogenic/anthropogenic split provided by the core CAMx model was sufficient and was in fact needed to reduce the computer burden. However, this approach does not provide a source region attribution for anthropogenic SOA.

Figure 5-1 displays how the source regions were defined on the 4-km grid. Note that five regions are shown in the figure. The sixth region was defined to handle all emissions outside the 4-km grid. The CAMx input emission inventory files were split into ten source categories for the PSAT application. Two additional categories (initial conditions and boundary conditions) are automatically added internally by CAMx. The ten emission categories consisted of nine categories within the 4-km grid, and one category for all sources outside the 4-km grid:

1. On-road mobile sources;
2. Non-road mobile sources (railroad, marine shipping, construction, lawn/garden equipment, etc.);
3. Ammonia sources (livestock operations, agricultural fertilizer application, waste treatment);
4. Other area sources (residential, commercial, industrial, etc. not included above);
5. Point source electric generating units (EGU);
6. Point source pulp mills;
7. Wildfires;
8. Other fires (prescribed and agricultural burns, structural fires)[1];
9. Other point sources (not included in the above);
10. All emissions outside the 4-km grid.

[1] The "other fires" category does not include residential wood smoke; that is contained in "other area sources."

The 6 by 10 category/region matrix resulted in tracking 60 unique sets of category-region pairs. The initial and boundary condition tracers are simply represented by 2 tracers (one each). Beyond that, the sulfur, nitrogen, and primary PM groups require tracking 2, 7, and 6 individual tracer species, respectively, for each category-region pair and the initial/boundary conditions. This resulted in running a total of 930 total tracers through the model.

As a way to reduce model run times and computer resources (i.e., to actually be able to "fit" the model into memory), certain aspects of the PSAT application were trimmed down from the Base Case runs described in Section 4.4. First, only the 4- and 12-km modeling grids were run. The 36-km grid results from the final 2004 Base Case simulations were used to extract hourly boundary conditions for the 12-km grid. These 12-km boundary conditions were tracked by the PSAT "BC" tracer. Second, the 10-day spin-up period was not run for PSAT. Instead, the 4- and 12-km grid three-dimensional concentration fields at midnight UTC on August 10 and November 3 from the final Base Case simulations were used as initial conditions for the PSAT runs. These 4- and 12-km initial conditions were tracked by the PSAT "IC" tracer. CAMx/PSAT was run for the core episode period (August 10-22 and November 3-18).

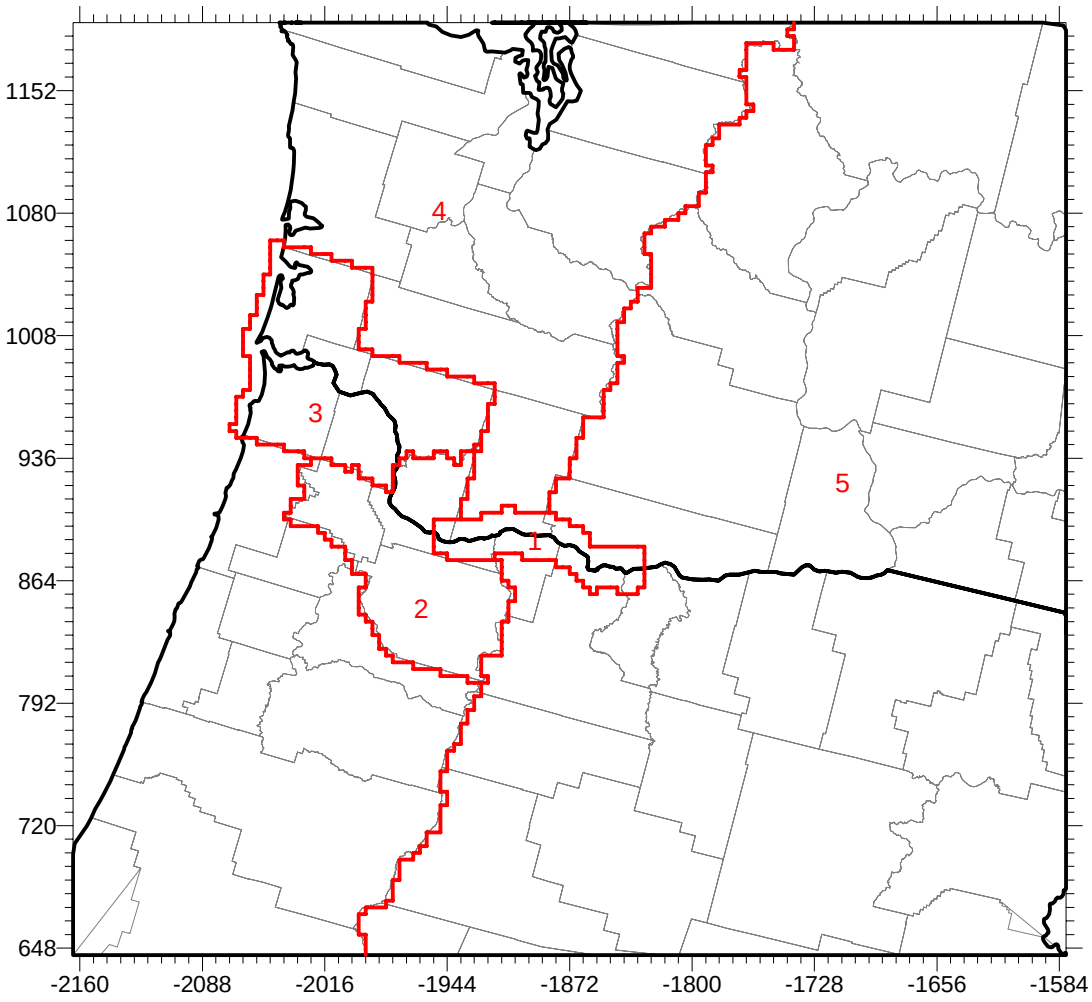
PSAT results were post-processed for two monitoring sites along the Columbia River: Mt Zion, and Wishram. The sub-sections below present results for the analysis of episode-average source apportionment.

5.1 PSAT APPLICATION FOR AUGUST 2004

5.1.1 August 2004 PSAT Results at Mt Zion

Table 5-1 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the August 2004 episode at the Mt Zion monitoring site. The number of category/regions shown for each PM component result in at least 90% of the total episode-average mass concentration for that species. Figure 5-2 presents this information graphically (showing all category/region pairing contributions).

Initial/boundary conditions and areas outside the 4-km domain contribute to the bulk of sulfate during this episode. Portland and areas along the westernmost area of the Columbia River are the largest local source areas of sulfate, which agrees with the general west-to-east transport direction during this period. A variety of source types in these western areas contribute to sulfate, including non-road sources (heavily dominated by diesel engines), EGUs, pulp mills, and other point sources. Nitrate is primarily attributed to similar local upwind regions from on-road, non-road, and EGU sources. Not surprisingly, ammonium is attributed to mainly local ammonia-specific sources in the Gorge and in Portland. Primary carbonaceous components come mostly from upwind and local areas from mobile and area sources (particularly non-road), suggesting diesel activity. Other carbon sources include area sources and fires. Recall from Section 4.4 that the vast majority of secondary organic aerosol is derived from biogenic sources. Dust (coarse and fine) is nearly entirely from local on-road sources (road dust). Other fine/coarse fractions of primary PM are mostly from local area sources.



Source Region Map - 4km domain
1. In-Gorge
2. Portland
3. NorthWest of Gorge
4. West of Gorge
5. East of Gorge

(LCP Definition: -97, 40, 45, 33)

Figure 5-1. Breakdown of the 4-km modeling grid into 5 source regions for use in the CAMx PSAT application. A sixth region was defined for all areas outside the 4-km grid (i.e., within the 12-km grid).

Table 5-1. Top source region-category groups simulated to contribute more than 90% of total August 2004 episode-average PM mass concentrations at the Mt Zion site by PM component species (see Figure 5-2 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.38
Outside 4 km domain	Outside 4 km domain	0.15
NW of Gorge	EGUs	0.08
IC		0.05
NW of Gorge	Other points	0.04
NW of Gorge	Nonroad	0.04
NW of Gorge	Pulp mills	0.03
Portland	Nonroad	0.03
Portland	Other area	0.02
East of Gorge	Wildfires	0.02
Portland	Pulp mills	0.02
Portland	Other points	0.01
West of Gorge	Other points	0.01
Top PNO3 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Onroad mobile	0.07
Portland	Nonroad	0.06
BC		0.05
NW of Gorge	EGUs	0.04
West of Gorge	Onroad mobile	0.04
Outside 4 km domain	Outside 4 km domain	0.03
NW of Gorge	Nonroad	0.02
NW of Gorge	Onroad mobile	0.02
NW of Gorge	Other points	0.02
West of Gorge	Nonroad	0.01
Gorge	Nonroad	0.01
NW of Gorge	Pulp mills	0.01
Portland	Other area	0.01
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Ammonia	0.044
Gorge	Ammonia	0.037
Portland	Onroad mobile	0.015
Gorge	Onroad mobile	0.008
Portland	Other area	0.007
West of Gorge	Ammonia	0.007
East of Gorge	Ammonia	0.004
NW of Gorge	Ammonia	0.004
BC		0.002
Outside 4 km domain	Outside 4 km domain	0.002
Gorge	Other area	0.002
East of Gorge	Wildfires	0.001
West of Gorge	Onroad mobile	0.001

Table 5-1 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Nonroad	0.19
Gorge	Nonroad	0.10
Portland	Onroad mobile	0.07
NW of Gorge	Nonroad	0.07
East of Gorge	Wildfires	0.05
West of Gorge	Nonroad	0.02
Gorge	Onroad mobile	0.02
Portland	Other area	0.02
Outside 4 km domain	Outside 4 km domain	0.02
BC		0.02
West of Gorge	Onroad mobile	0.02
Gorge	Other area	0.01
NW of Gorge	Onroad mobile	0.01
Top POA Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Wildfires	0.21
Portland	Other area	0.13
Portland	Nonroad	0.10
Gorge	Other area	0.08
Portland	Onroad mobile	0.06
Gorge	Nonroad	0.06
BC		0.05
Outside 4 km domain	Outside 4 km domain	0.03
West of Gorge	Other area	0.03
NW of Gorge	Nonroad	0.02
Gorge	Onroad mobile	0.02
NW of Gorge	Other points	0.02
Portland	Other points	0.02
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Onroad mobile	0.0213
Portland	Onroad mobile	0.0113
Outside 4 km domain	Outside 4 km domain	0.0107
IC		0.0047
Portland	Other area	0.0046
NW of Gorge	Onroad mobile	0.0035
BC		0.0035
West of Gorge	Onroad mobile	0.0029
West of Gorge	Other area	0.0021
East of Gorge	Onroad mobile	0.0018
Gorge	Other area	0.0017
NW of Gorge	Other area	0.0016
East of Gorge	Other area	0.0002

Table 5-1 (concluded).

Top Other Fine PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.32
Gorge	Other area	0.05
Outside 4 km domain	Outside 4 km domain	0.05
West of Gorge	Other area	0.05
NW of Gorge	EGUs	0.05
NW of Gorge	Other area	0.04
NW of Gorge	Other points	0.03
Portland	Other points	0.03
East of Gorge	Other area	0.01
East of Gorge	Wildfires	0.01
Portland	Pulp mills	0.01
NW of Gorge	Pulp mills	0.01
Portland	Onroad mobile	0.01
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Onroad mobile	0.1351
Portland	Onroad mobile	0.0462
Gorge	Other area	0.0122
Outside 4 km domain	Outside 4 km domain	0.0071
Portland	Other area	0.0062
West of Gorge	Onroad mobile	0.0047
West of Gorge	Other area	0.0045
East of Gorge	Onroad mobile	0.0031
NW of Gorge	Onroad mobile	0.0025
BC		0.0016
NW of Gorge	Other area	0.0010
IC		0.0006
East of Gorge	Other area	0.0002
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.32
Gorge	Other area	0.09
BC		0.08
Portland	Other points	0.04
Portland	Other fires	0.02
NW of Gorge	Pulp mills	0.02
NW of Gorge	Other points	0.02
NW of Gorge	EGUs	0.02
Portland	Onroad mobile	0.02
East of Gorge	Other area	0.01
West of Gorge	Other area	0.01
Gorge	Onroad mobile	0.01
Portland	Nonroad	0.01

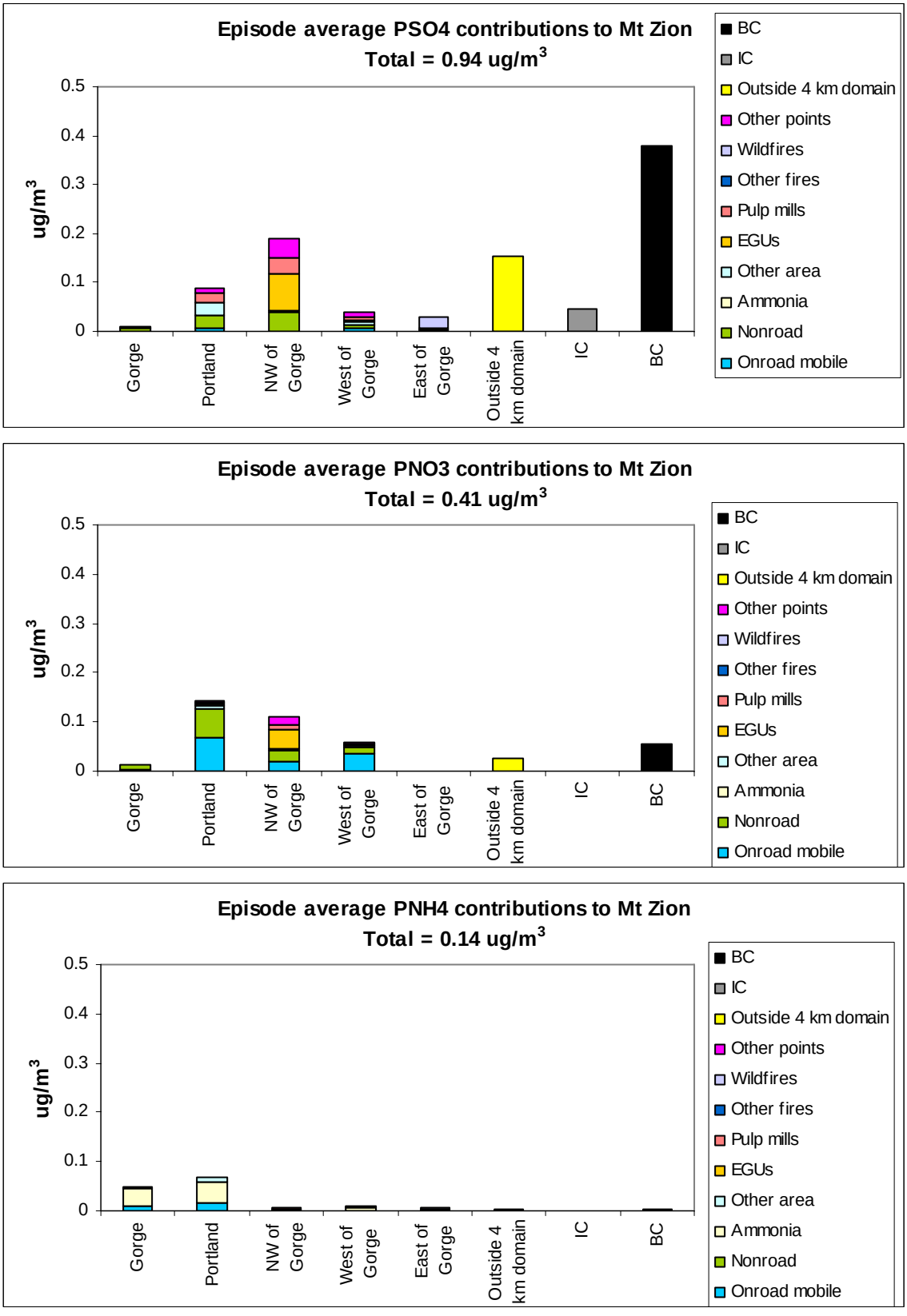


Figure 5-2. PSAT category-region breakdown at Mt Zion for August 2004 episode-average PM concentrations.

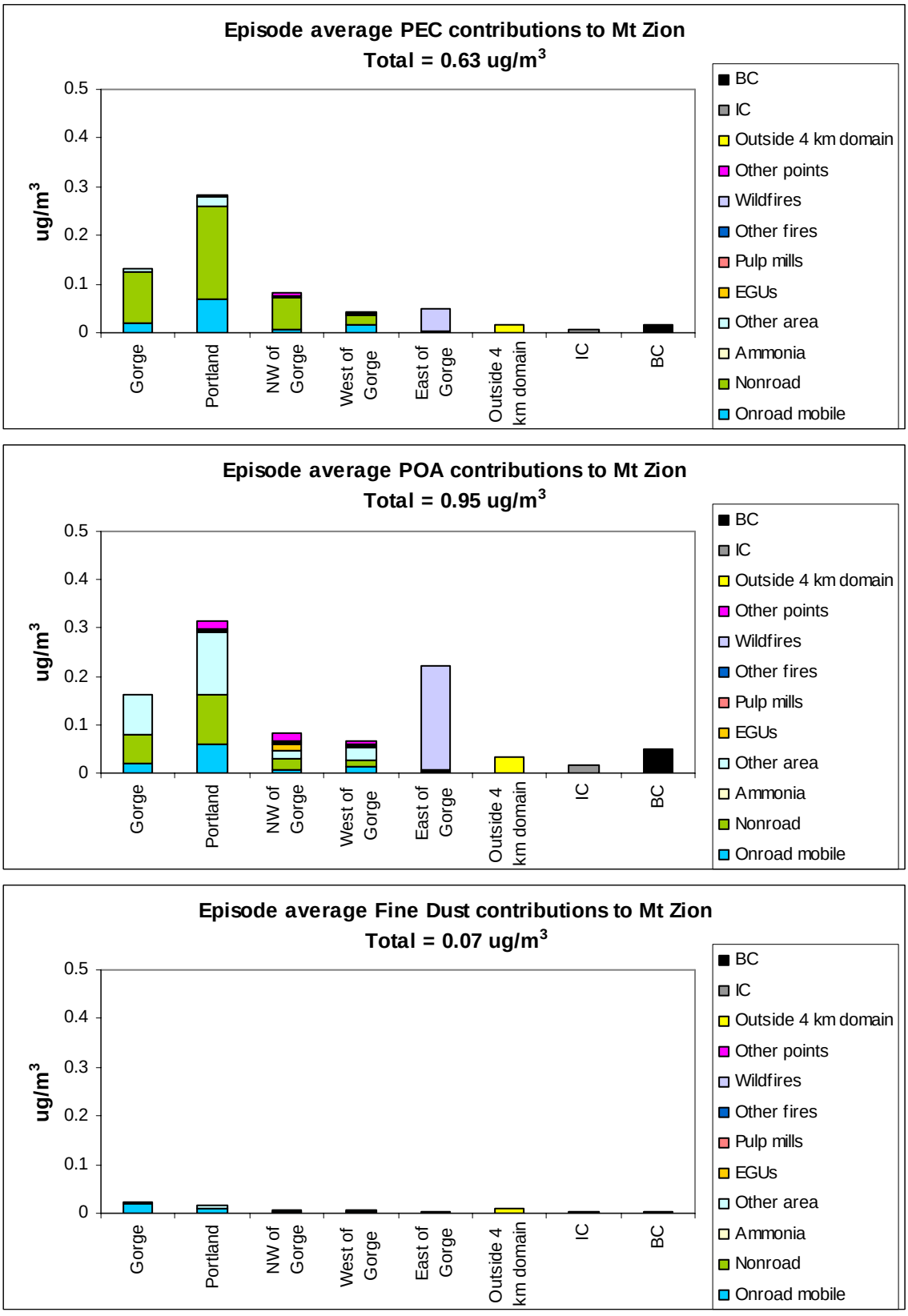
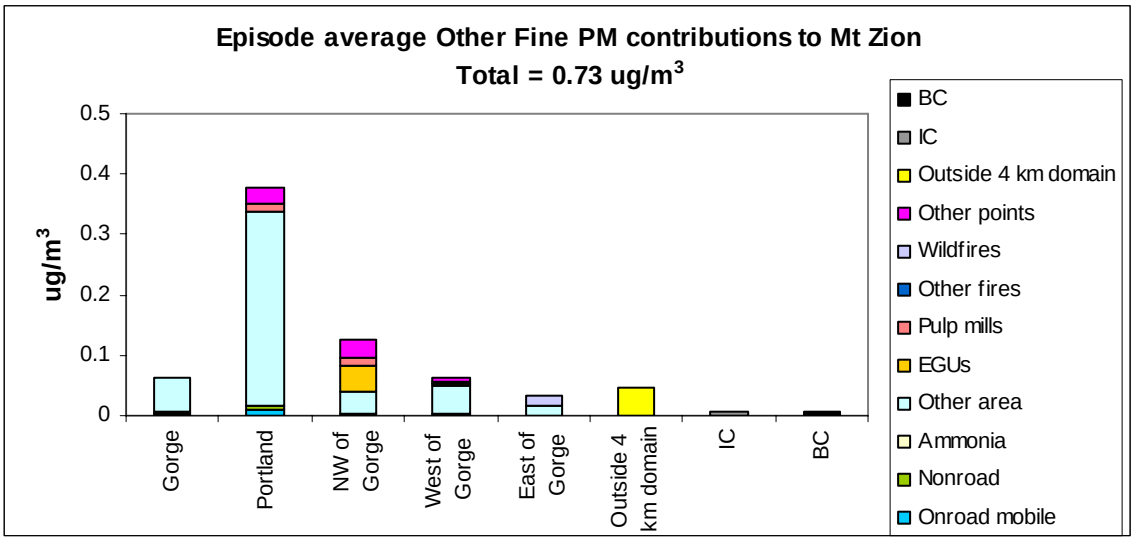
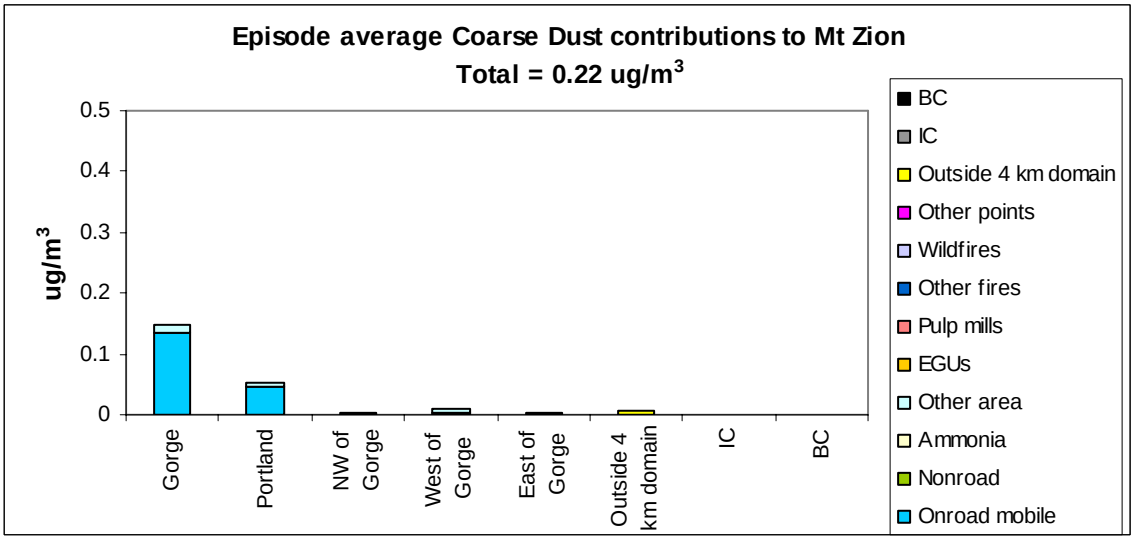


Figure 5-2 (continued).





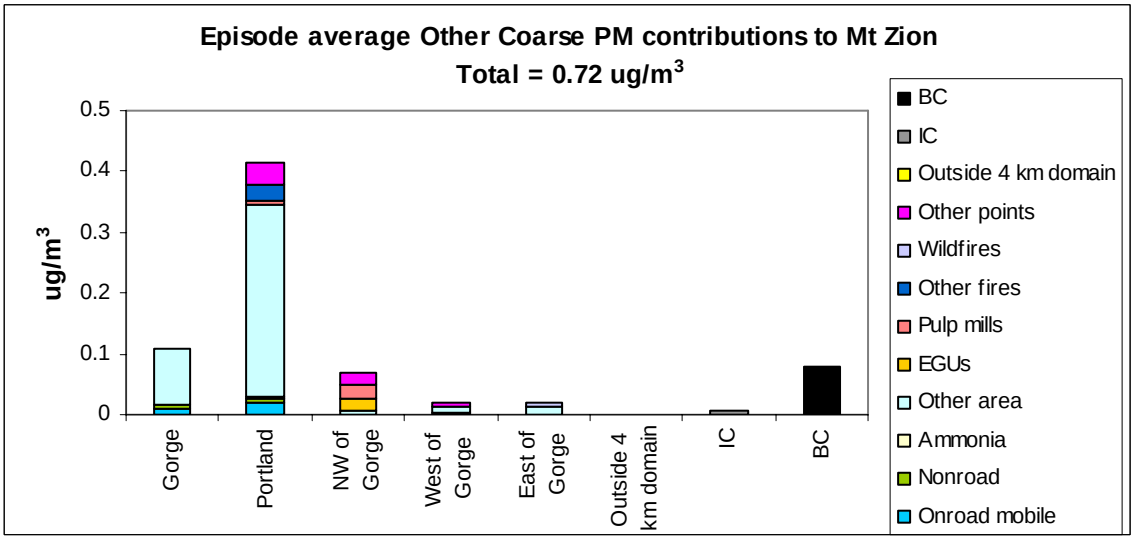


Figure 5-2 (concluded).

When the apportionment of PM concentrations was converted to light extinction, the PSAT application revealed that a large fraction of visibility impairment at Mt Zion during the August 2004 episode was caused by natural sources, including secondary organic aerosols (SOA) from biogenic emissions (~30%). Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (18%);
2. Elemental carbon from Portland non-road sources (8%);
3. Sulfate from regional sources outside the 4-km OR/WA grid (7%);
4. Elemental carbon from local Gorge non-road sources (4%); and
5. Sulfate from EGU sources northwest of Portland (4%).

Table 5-2 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

5.1.2 2004 August PSAT Results at Wishram

Table 5-3 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the August 2004 episode at the Wishram monitoring site. Figure 5-3 presents this information graphically (showing all category/region pairing contributions).

As seen for the Mt Zion site, initial and boundary conditions and areas outside the 4-km domain contribute to the bulk of sulfate during this episode at Wishram. However, there is a stronger influence from wildfires in the eastern portion of the 4-km grid, and a smaller influence from Portland and the western areas. Nitrate is primarily attributed to local and upwind regions to the west, from on-road and non-road sources. Ammonium has a strong source locally in the Gorge and in the eastern area from ammonia-specific sources, which are dominated by agricultural activities. Primary elemental and organic carbon components indicate a rather strong contribution from wildfires occurring in north-eastern Washington during this episode; elemental carbon further shows a large contribution from in-gorge non-road sources, which implicate diesel emissions from railroads, barges, and off-road equipment. Again, nearly all SOA generated by CAMx is from biogenic sources (Section 4.4), but recall that there is less total SOA simulated at this site than at the Mt Zion site, probably due to drier and non-forested conditions along the eastern end of the Gorge. Coarse and fine dust are nearly entirely from in-gorge on-road and area sources, while other fine/coarse fractions of primary PM are mostly from area sources (again, mostly agricultural activities) and more uniformly apportioned across several regions.

The PSAT application revealed that the majority of visibility impairment at Wishram during the August 2004 episode was caused by natural sources, including SOA from biogenic emissions (30%), and carbonaceous aerosols from wildfires (30%). Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (19%);
2. Primary organic carbon from eastern OR/WA wildfires (18%);
3. Elemental carbon from eastern OR/WA wildfires (9%);
4. Sulfate from regional sources outside the 4-km OR/WA grid (7%); and
5. Elemental carbon from local Gorge non-road sources (7%).

Table 5-2. Ranked list of source region/categories contributing to visibility-impairing haze over the August 2004 episode at Mt Zion. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
Sulfate	BC		0.38	4.40	18%
EC	Portland	Nonroad	0.19	1.93	8%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.15	1.78	7%
EC	Gorge	Nonroad	0.10	1.03	4%
Sulfate	NW of Gorge	EGUs	0.08	0.89	4%
POA	East of Gorge	Wildfires	0.21	0.86	4%
Nitrate	Portland	Onroad mobile	0.07	0.74	3%
EC	Portland	Onroad mobile	0.07	0.68	3%
EC	NW of Gorge	Nonroad	0.07	0.65	3%
Nitrate	Portland	Nonroad	0.06	0.63	3%
Nitrate	BC		0.05	0.59	2%
POA	Portland	Other area	0.13	0.52	2%
EC	East of Gorge	Wildfires	0.05	0.47	2%
Sulfate	NW of Gorge	Other points	0.04	0.45	2%
Sulfate	NW of Gorge	Nonroad	0.04	0.43	2%
Nitrate	NW of Gorge	EGUs	0.04	0.43	2%
POA	Portland	Nonroad	0.10	0.40	2%
Nitrate	West of Gorge	Onroad mobile	0.04	0.39	2%
Sulfate	NW of Gorge	Pulp mills	0.03	0.38	2%
POA	Gorge	Other area	0.08	0.32	1%
Fine Other	Portland	Other area	0.32	0.32	1%
Sulfate	Portland	Nonroad	0.03	0.30	1%
Nitrate	Outside 4 km domain	Outside 4 km domain	0.03	0.29	1%
Sulfate	Portland	Other area	0.02	0.28	1%
Sulfate	East of Gorge	Wildfires	0.02	0.27	1%
Nitrate	NW of Gorge	Nonroad	0.02	0.27	1%
POA	Portland	Onroad mobile	0.06	0.24	1%
POA	Gorge	Nonroad	0.06	0.24	1%
Sulfate	Portland	Pulp mills	0.02	0.24	1%
EC	West of Gorge	Nonroad	0.02	0.21	1%
POA	BC		0.05	0.20	1%
EC	Gorge	Onroad mobile	0.02	0.20	1%
EC	Portland	Other area	0.02	0.20	1%
Nitrate	NW of Gorge	Onroad mobile	0.02	0.20	1%
Coarse Other	Portland	Other area	0.32	0.19	1%
Nitrate	NW of Gorge	Other points	0.02	0.17	1%
EC	Outside 4 km domain	Outside 4 km domain	0.02	0.16	1%

Table 5-3. Top source region-category groups simulated to contribute more than 90% of total August 2004 episode-average PM mass concentrations at the Wishram site by PM component species (see Figure 5-3 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.31
Outside 4 km domain	Outside 4 km domain	0.12
East of Gorge	Wildfires	0.07
IC		0.06
NW of Gorge	EGUs	0.03
NW of Gorge	Other points	0.01
West of Gorge	Nonroad	0.01
NW of Gorge	Nonroad	0.01
West of Gorge	Other points	0.01
East of Gorge	EGUs	0.01
Gorge	Nonroad	0.01
Portland	Nonroad	0.01
West of Gorge	Other area	0.01
Top PNO3 Contributors		
Region	**Emission Group**	**[ug/m^3]**
West of Gorge	Onroad mobile	0.029
BC		0.026
Portland	Onroad mobile	0.022
Gorge	Nonroad	0.014
Portland	Nonroad	0.013
NW of Gorge	EGUs	0.012
Outside 4 km domain	Outside 4 km domain	0.011
West of Gorge	Nonroad	0.009
Gorge	Onroad mobile	0.006
NW of Gorge	Nonroad	0.005
NW of Gorge	Onroad mobile	0.005
NW of Gorge	Other points	0.003
West of Gorge	Other points	0.003
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Ammonia	0.032
Gorge	Ammonia	0.027
East of Gorge	Wildfires	0.011
Outside 4 km domain	Outside 4 km domain	0.009
BC		0.007
Gorge	Onroad mobile	0.007
West of Gorge	Ammonia	0.006
Portland	Ammonia	0.004
IC		0.002
West of Gorge	Onroad mobile	0.002
West of Gorge	Other area	0.002
East of Gorge	Other area	0.001
NW of Gorge	Ammonia	0.001

Table 5-3 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Wildfires	0.177
Gorge	Nonroad	0.133
West of Gorge	Nonroad	0.026
Outside 4 km domain	Outside 4 km domain	0.021
West of Gorge	Onroad mobile	0.020
BC		0.018
Portland	Nonroad	0.016
Gorge	Onroad mobile	0.013
NW of Gorge	Nonroad	0.010
East of Gorge	Nonroad	0.008
Portland	Onroad mobile	0.007
IC		0.005
West of Gorge	Other area	0.005
Top POA Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Wildfires	0.85
Outside 4 km domain	Outside 4 km domain	0.05
BC		0.05
Gorge	Nonroad	0.05
West of Gorge	Other area	0.04
West of Gorge	Onroad mobile	0.02
West of Gorge	Nonroad	0.02
IC		0.02
Gorge	Onroad mobile	0.01
Portland	Other area	0.01
Gorge	Other area	0.01
Portland	Nonroad	0.01
East of Gorge	Other fires	0.01
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.0935
Gorge	Onroad mobile	0.0229
Outside 4 km domain	Outside 4 km domain	0.0228
BC		0.0092
East of Gorge	Onroad mobile	0.0083
IC		0.0069
East of Gorge	Other area	0.0029
West of Gorge	Onroad mobile	0.0024
Portland	Onroad mobile	0.0011
Portland	Other area	0.0011
West of Gorge	Other area	0.0010
NW of Gorge	Onroad mobile	0.0006
NW of Gorge	Other area	0.0002

Table 5-3 (concluded).

Top Other Fine PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
West of Gorge	Other area	0.054
Outside 4 km domain	Outside 4 km domain	0.053
East of Gorge	Wildfires	0.051
East of Gorge	Other area	0.048
Gorge	Other area	0.047
Portland	Other area	0.023
BC		0.008
NW of Gorge	EGUs	0.008
West of Gorge	Other points	0.007
NW of Gorge	Other area	0.006
IC		0.006
NW of Gorge	Other points	0.004
Gorge	Other points	0.003
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.3467
Gorge	Onroad mobile	0.1312
Outside 4 km domain	Outside 4 km domain	0.0370
East of Gorge	Onroad mobile	0.0353
East of Gorge	Other area	0.0085
BC		0.0057
West of Gorge	Onroad mobile	0.0020
IC		0.0015
Portland	Onroad mobile	0.0012
Portland	Other area	0.0005
West of Gorge	Other area	0.0003
NW of Gorge	Onroad mobile	0.0002
NW of Gorge	Other area	0.0001
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.098
East of Gorge	Other area	0.089
Gorge	Other area	0.078
East of Gorge	Wildfires	0.060
IC		0.014
West of Gorge	Other area	0.007
Portland	Other area	0.004
Gorge	Other fires	0.004
Gorge	Onroad mobile	0.004
Outside 4 km domain	Outside 4 km domain	0.003
Gorge	Nonroad	0.002
Gorge	Other points	0.002
East of Gorge	Other points	0.002

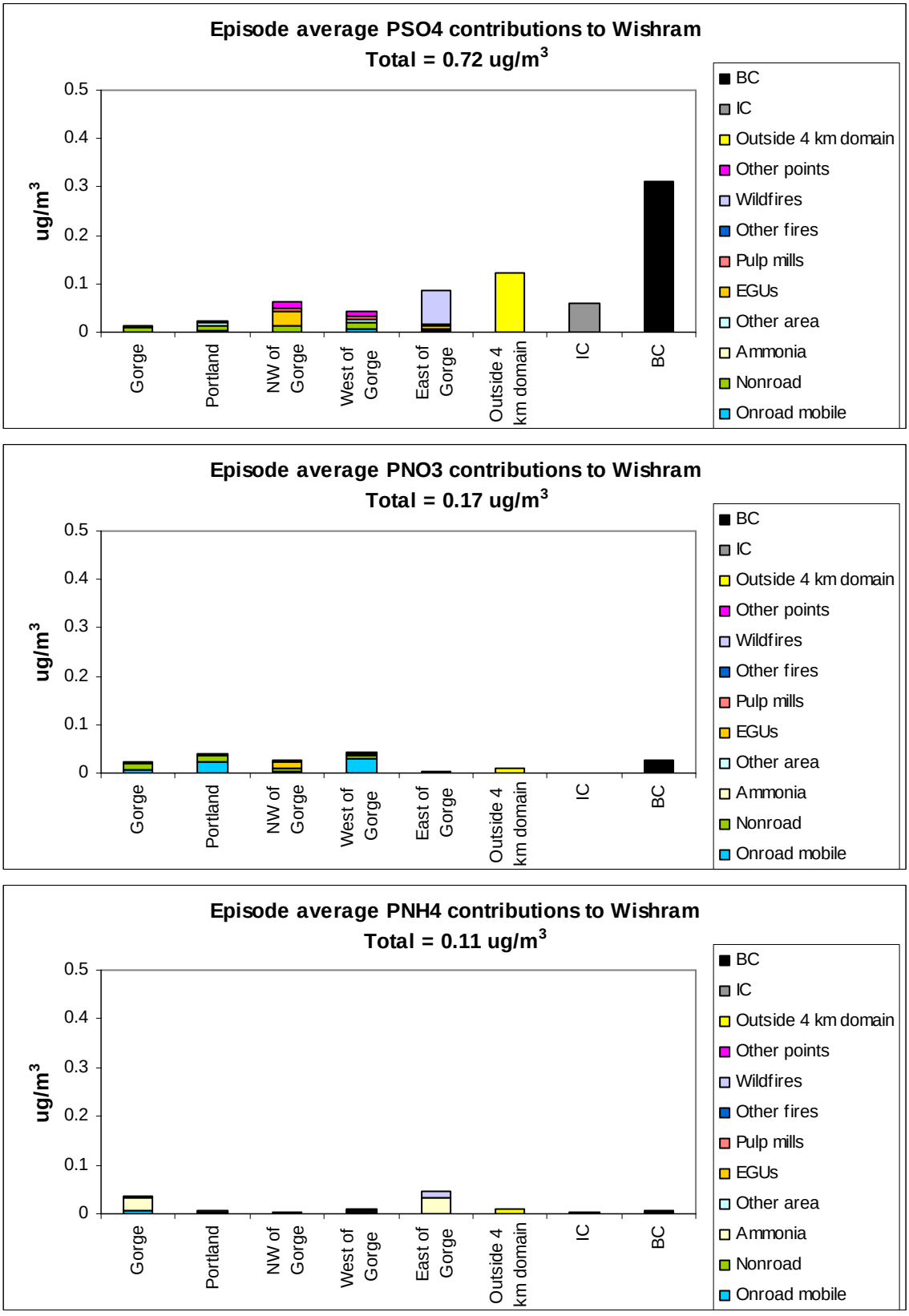


Figure 5-3. PSAT category-region breakdown at Wishram for August 2004 episode-average PM concentrations.

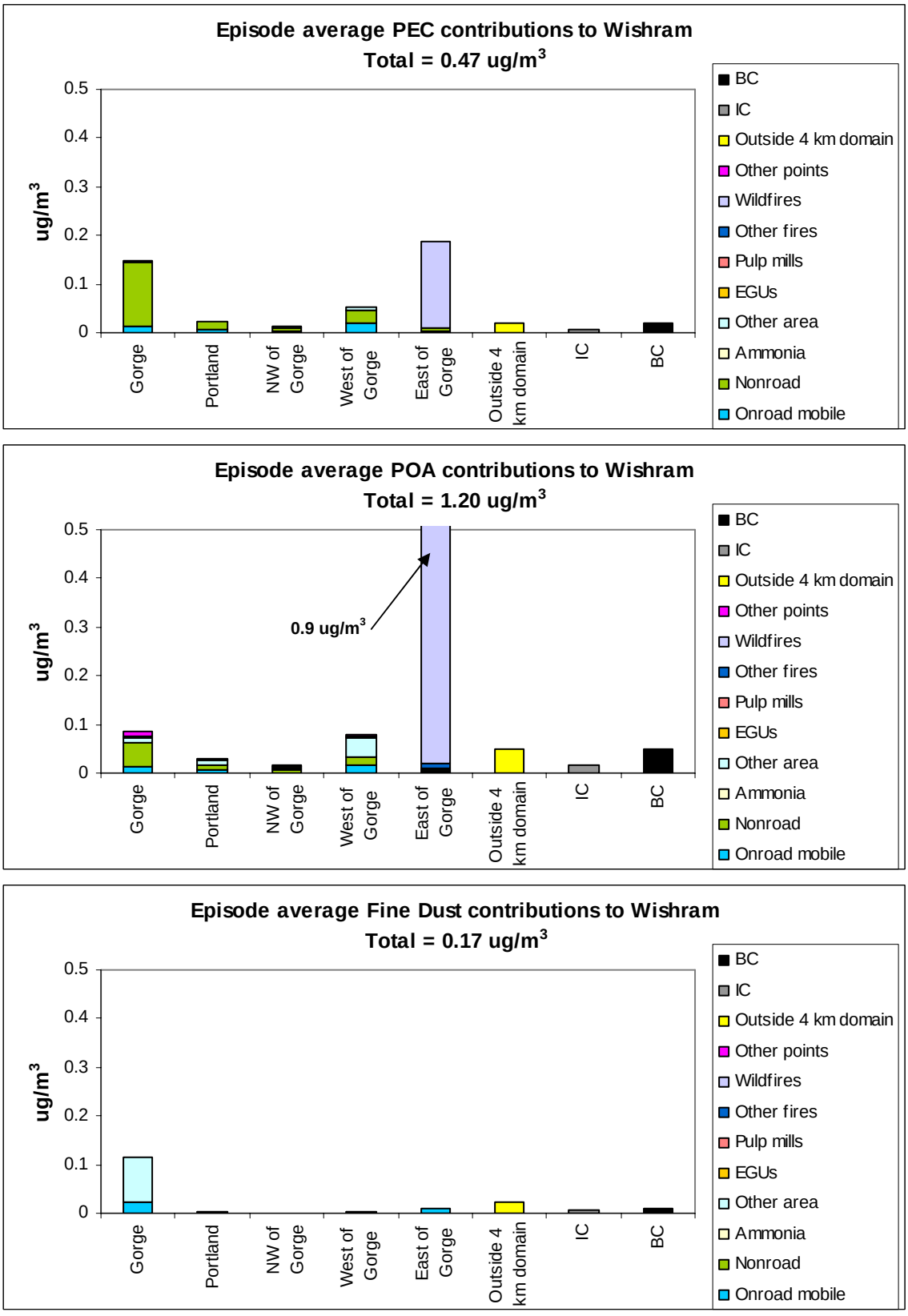
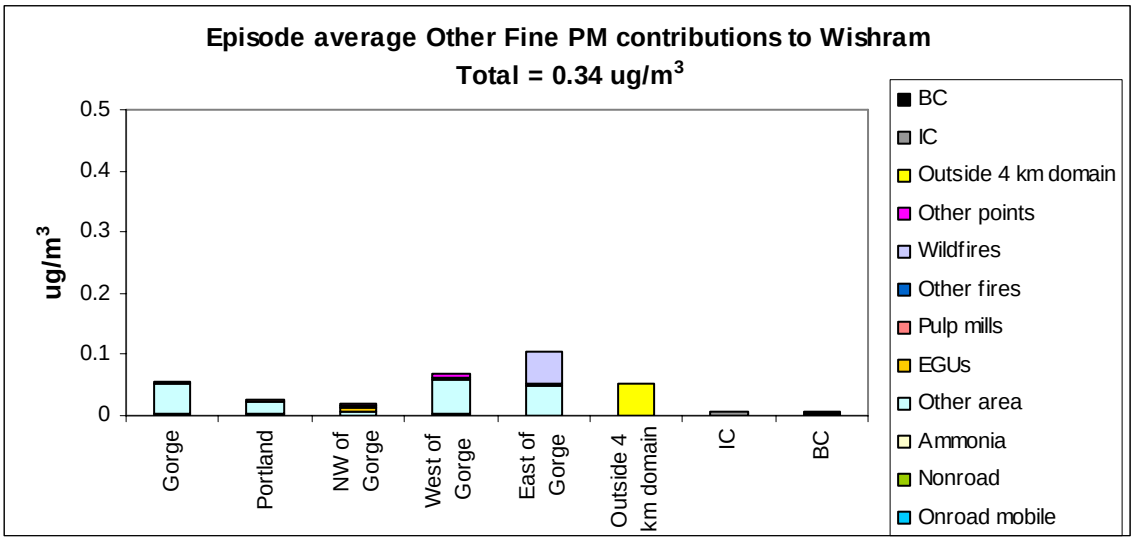
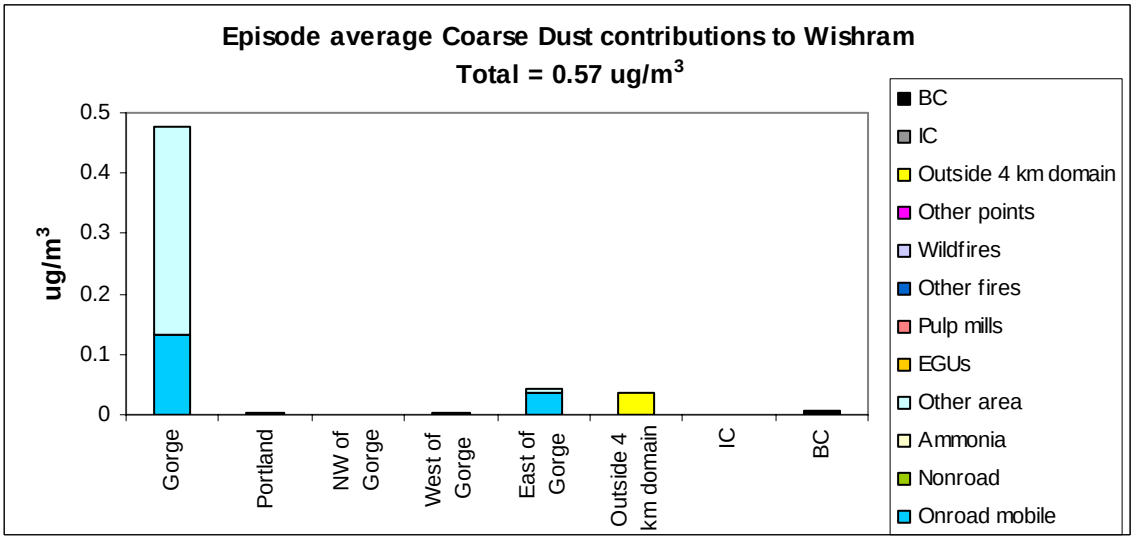


Figure 5-3 (continued).





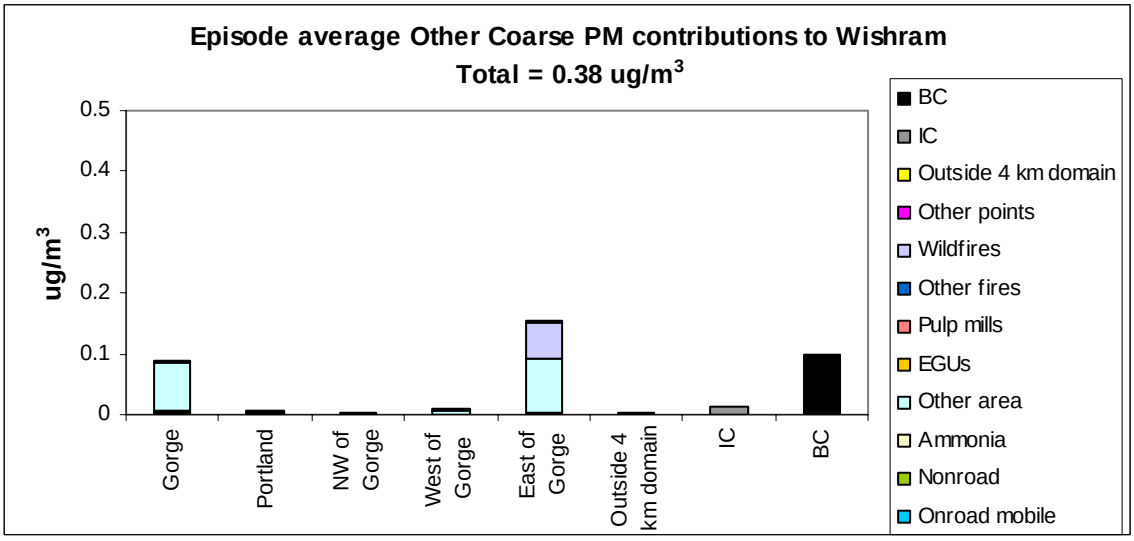


Figure 5-3 (concluded).

Table 5-4 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

Table 5-4. Ranked list of source region/categories contributing to visibility-impairing haze over the August 2004 episode at Wishram. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
Sulfate	BC		0.31	3.49	19%
POA	East of Gorge	Wildfires	0.85	3.42	18%
EC	East of Gorge	Wildfires	0.177	1.77	9%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.12	1.39	7%
EC	Gorge	Nonroad	0.133	1.33	7%
Sulfate	East of Gorge	Wildfires	0.07	0.80	4%
Sulfate	NW of Gorge	EGUs	0.03	0.33	2%
Nitrate	West of Gorge	Onroad mobile	0.029	0.30	2%
Nitrate	BC		0.026	0.28	1%
EC	West of Gorge	Nonroad	0.026	0.26	1%
Nitrate	Portland	Onroad mobile	0.022	0.23	1%
EC	Outside 4 km domain	Outside 4 km domain	0.021	0.21	1%
Coarse Dust	Gorge	Other area	0.3467	0.21	1%
EC	West of Gorge	Onroad mobile	0.020	0.20	1%
POA	Outside 4 km domain	Outside 4 km domain	0.05	0.20	1%
POA	BC		0.05	0.20	1%
POA	Gorge	Nonroad	0.05	0.20	1%
EC	BC		0.018	0.18	1%
EC	Portland	Nonroad	0.016	0.16	1%
POA	West of Gorge	Other area	0.04	0.16	1%
Nitrate	Gorge	Nonroad	0.014	0.15	1%
Nitrate	Portland	Nonroad	0.013	0.14	1%
Sulfate	NW of Gorge	Other points	0.01	0.14	1%
Sulfate	West of Gorge	Nonroad	0.01	0.14	1%
Sulfate	NW of Gorge	Nonroad	0.01	0.13	1%
EC	Gorge	Onroad mobile	0.013	0.13	1%
Nitrate	NW of Gorge	EGUs	0.012	0.12	1%
Nitrate	Outside 4 km domain	Outside 4 km domain	0.011	0.12	1%
Sulfate	West of Gorge	Other points	0.01	0.11	1%
Sulfate	East of Gorge	EGUs	0.01	0.10	1%
Sulfate	Gorge	Nonroad	0.01	0.10	1%
Sulfate	Portland	Nonroad	0.01	0.10	1%

5.2 PSAT APPLICATION FOR NOVEMBER 2004

5.2.1 November 2004 PSAT Results at Mt Zion

Table 5-5 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the November 2004 episode at the Mt Zion monitoring site. The number of category/regions shown for each PM component result in at least 90% of the total episode-

average mass concentration for that species. Figure 5-4 presents this information graphically (showing all category/region pairing contributions).

As described in Section 4, a very different PM environment is characterized in the November episode, with secondary sulfate/nitrate/ammonium salts dominating the mass budgets. Almost 3 $\mu g/m^3$ is predicted for episode-average sulfate, and the largest contributor is EGU emissions in the eastern portion of the modeling domain. However, a wide array of source types and areas contribute to the Mt Zion sulfate, including initial/boundary conditions and areas outside the 4-km domain, indicating the regional nature of this secondary pollutant. Nitrate is also rather high (over 2 $\mu g/m^3$), with large contributions from on-road and non-road NOx sources mainly from Portland and areas to the west and along the Gorge. Ammonium is attributed to specific ammonia sources (mostly agricultural activities such as animal feed lots and fertilizer applications). Again, a vast area of emissions contribute to ammonium, but the most comes from the eastern Gorge area where there are some large agricultural sources. Both elemental and organic carbon show large contributions from on-road and non-road sources within the Gorge and from Portland, and the POA is apportioned in large measure to area sources (residential wood smoke). Elemental carbon in particular has a large non-road component, likely due to heavy duty diesel engines on off-road equipment, barges, and railroads. Coarse/fine dust are mostly locally generated, and given the wetter nature of the November episode, are likely overstated since the modeling emissions inventory does not account for local day-specific rainfall patterns. Most sources of primary fine/coarse PM are very local in origin and are from fugitive and wind-blown dust sources.

When the apportionment of PM concentrations was converted to light extinction, the PSAT application revealed that the vast majority of visibility impairment at Mt Zion during the November 2004 episode was caused by anthropogenic sources (94%). Secondary organic aerosols from biogenic emissions contributed ~40% of the episode-average total organic carbon concentration, but only 6% of episode-average visibility impairment. Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from eastern OR/WA EGU sources (12%);
2. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (11%);
3. Nitrate from Portland on-road sources (10%);
4. Nitrate from western OR/WA on-road sources (5%); and
5. Nitrate from super-regional sources outside the 12-km Pacific Northwest grid (4%).

Table 5-6 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

Table 5-5. Top source region-category groups simulated to contribute more than 90% of total episode-average PM mass concentrations at the Mt Zion site by PM component species (see Figure 5-4 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	EGUs	0.62
BC		0.58
Portland	Other area	0.23
NW of Gorge	Other points	0.18
Gorge	Nonroad	0.17
Outside 4 km domain	Outside 4 km domain	0.15
Portland	Nonroad	0.14
NW of Gorge	EGUs	0.11
Portland	Other points	0.07
IC		0.07
West of Gorge	Other points	0.07
Portland	Onroad mobile	0.07
West of Gorge	Other area	0.07
Top PNO3 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Onroad mobile	0.54
West of Gorge	Onroad mobile	0.28
BC		0.25
Portland	Nonroad	0.17
IC		0.15
Gorge	Nonroad	0.11
NW of Gorge	EGUs	0.11
Gorge	Onroad mobile	0.08
Portland	Other area	0.08
Outside 4 km domain	Outside 4 km domain	0.08
East of Gorge	Onroad mobile	0.07
West of Gorge	Nonroad	0.07
East of Gorge	Nonroad	0.05
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Ammonia	0.27
Portland	Ammonia	0.19
Gorge	Ammonia	0.15
West of Gorge	Ammonia	0.11
Portland	Onroad mobile	0.10
Gorge	Onroad mobile	0.07
BC		0.04
Outside 4 km domain	Outside 4 km domain	0.03
Portland	Other area	0.02
West of Gorge	Onroad mobile	0.02
East of Gorge	Other area	0.01
Gorge	Other area	0.01
West of Gorge	Other fires	0.01

Table 5-5 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Nonroad	0.16
Portland	Other area	0.13
Gorge	Other area	0.10
Portland	Nonroad	0.10
Portland	Onroad mobile	0.08
Gorge	Onroad mobile	0.05
Outside 4 km domain	Outside 4 km domain	0.04
BC		0.03
Gorge	Other fires	0.03
West of Gorge	Other area	0.03
East of Gorge	Nonroad	0.02
East of Gorge	Other fires	0.01
West of Gorge	Onroad mobile	0.01
Top POA Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.71
Gorge	Other area	0.56
Outside 4 km domain	Outside 4 km domain	0.16
West of Gorge	Other area	0.14
Gorge	Other fires	0.13
Gorge	Nonroad	0.10
East of Gorge	Other fires	0.08
BC		0.07
Portland	Onroad mobile	0.07
Portland	Nonroad	0.06
West of Gorge	Other fires	0.06
East of Gorge	Other area	0.05
Gorge	Onroad mobile	0.04
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.1098
Outside 4 km domain	Outside 4 km domain	0.0507
BC		0.0486
Gorge	Onroad mobile	0.0450
East of Gorge	Other area	0.0390
East of Gorge	Onroad mobile	0.0213
Portland	Onroad mobile	0.0167
IC		0.0104
West of Gorge	Onroad mobile	0.0060
West of Gorge	Other area	0.0020
Portland	Other area	0.0015
NW of Gorge	Onroad mobile	0.0003
NW of Gorge	Other area	0.0000

Table 5-5 (concluded).

Top Other Fine PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.62
Gorge	Other area	0.35
East of Gorge	Other area	0.12
West of Gorge	Other area	0.11
Outside 4 km domain	Outside 4 km domain	0.05
East of Gorge	EGUs	0.04
Portland	Other points	0.02
West of Gorge	Other fires	0.02
BC		0.02
IC		0.01
Gorge	Other fires	0.01
Portland	Onroad mobile	0.01
NW of Gorge	Other area	0.01
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.5917
Gorge	Onroad mobile	0.1988
Portland	Onroad mobile	0.0569
East of Gorge	Other area	0.0129
West of Gorge	Onroad mobile	0.0114
BC		0.0078
East of Gorge	Onroad mobile	0.0074
Outside 4 km domain	Outside 4 km domain	0.0073
IC		0.0043
Portland	Other area	0.0009
NW of Gorge	Onroad mobile	0.0005
West of Gorge	Other area	0.0003
NW of Gorge	Other area	0.0000
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.535
Gorge	Other area	0.453
BC		0.067
West of Gorge	Other area	0.016
Portland	Onroad mobile	0.016
Portland	Other points	0.015
Gorge	Onroad mobile	0.014
IC		0.013
East of Gorge	Other area	0.012
Portland	Other fires	0.010
Gorge	Nonroad	0.007
West of Gorge	Other points	0.006
West of Gorge	Other fires	0.004

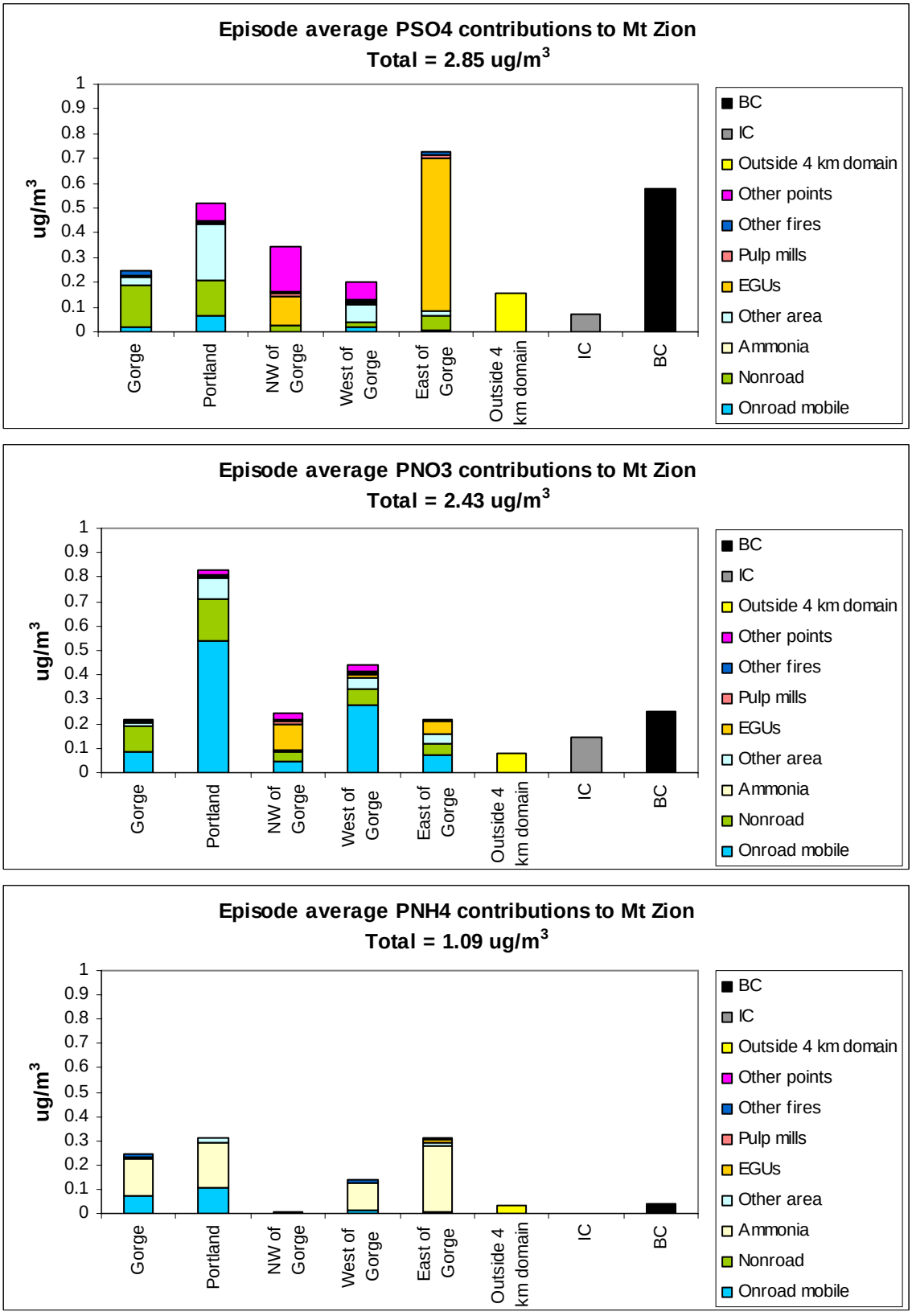
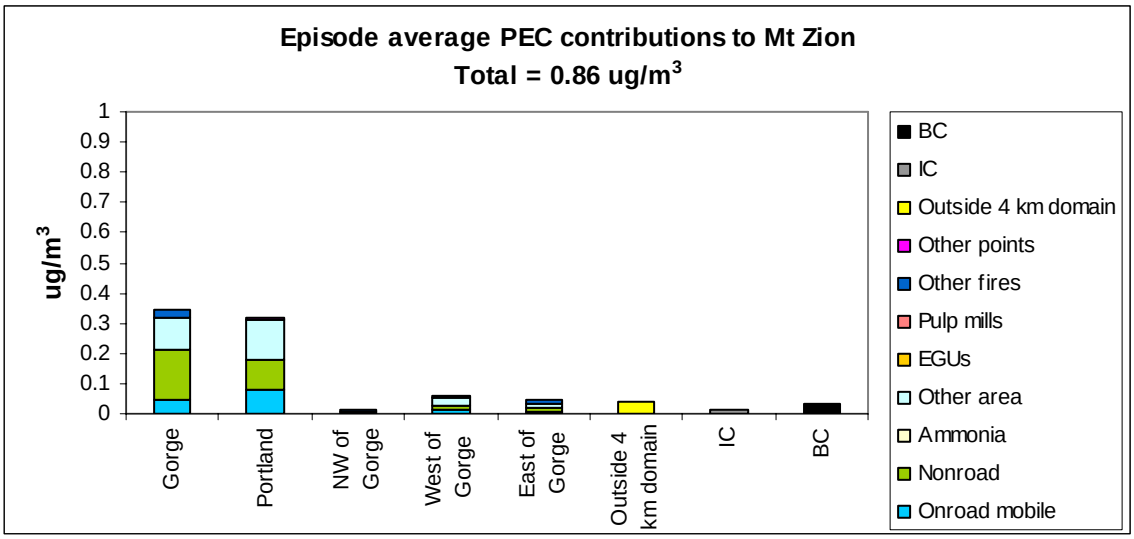
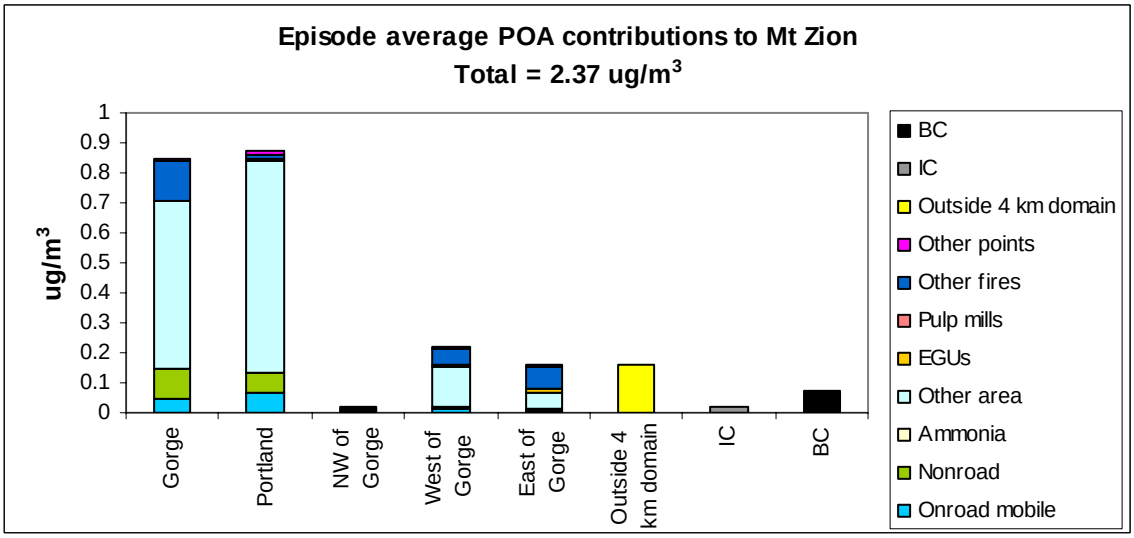


Figure 5-4. PSAT category-region breakdown at Mt Zion for November 2004 episode-average PM concentrations.





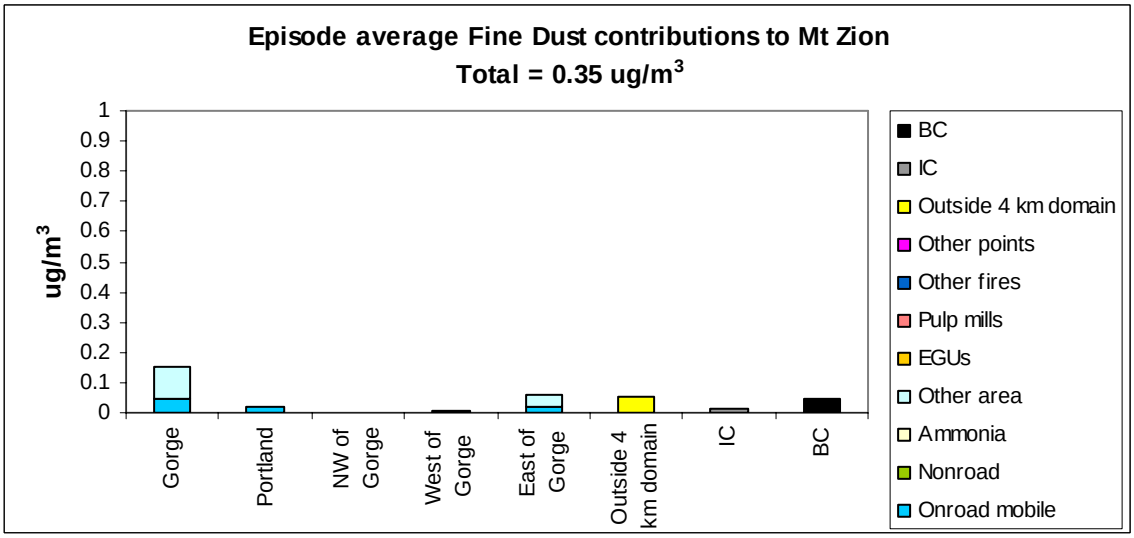
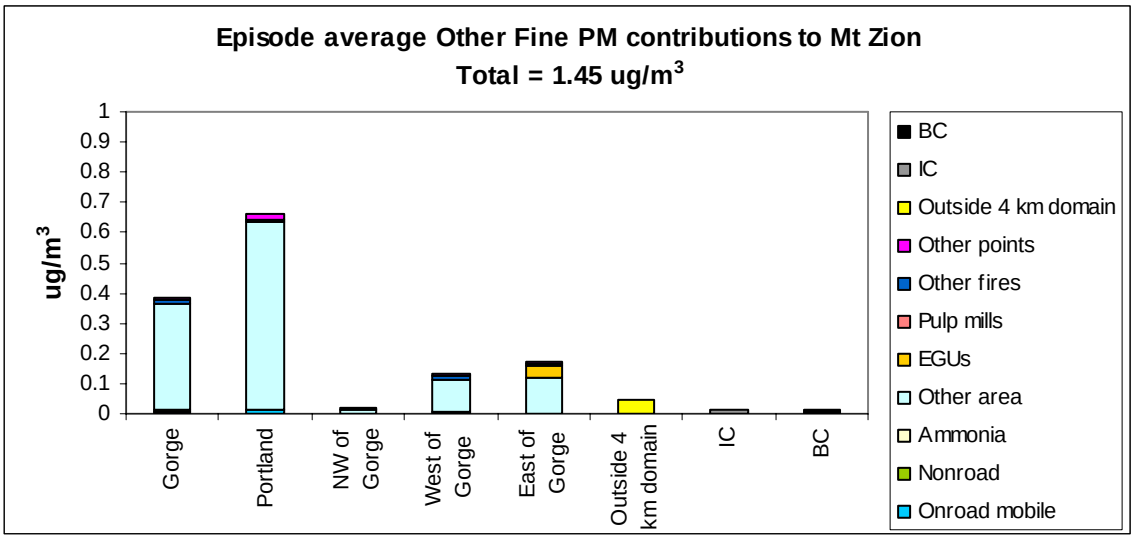
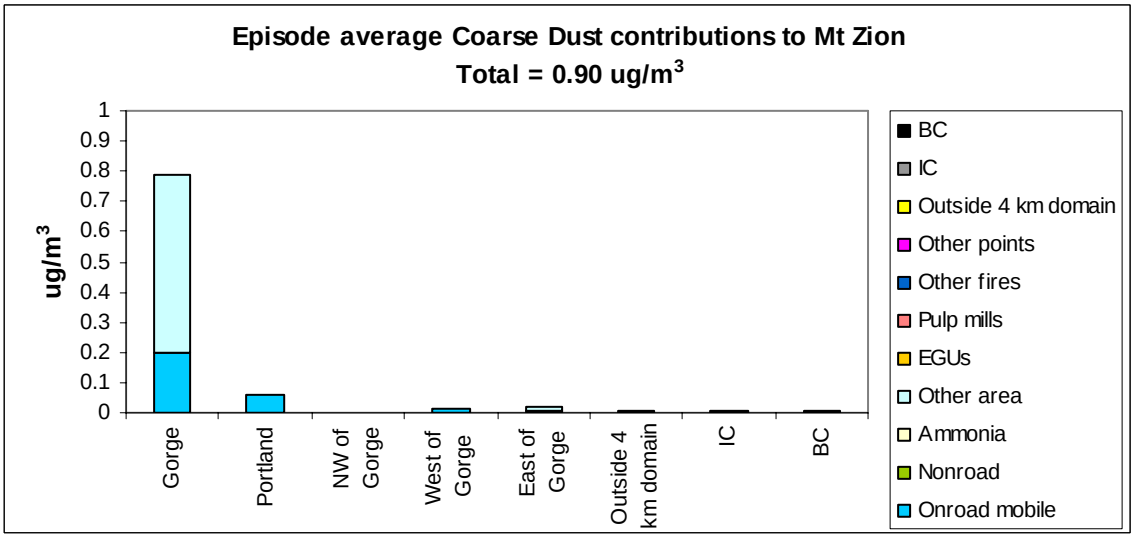


Figure 5-4 (continued).





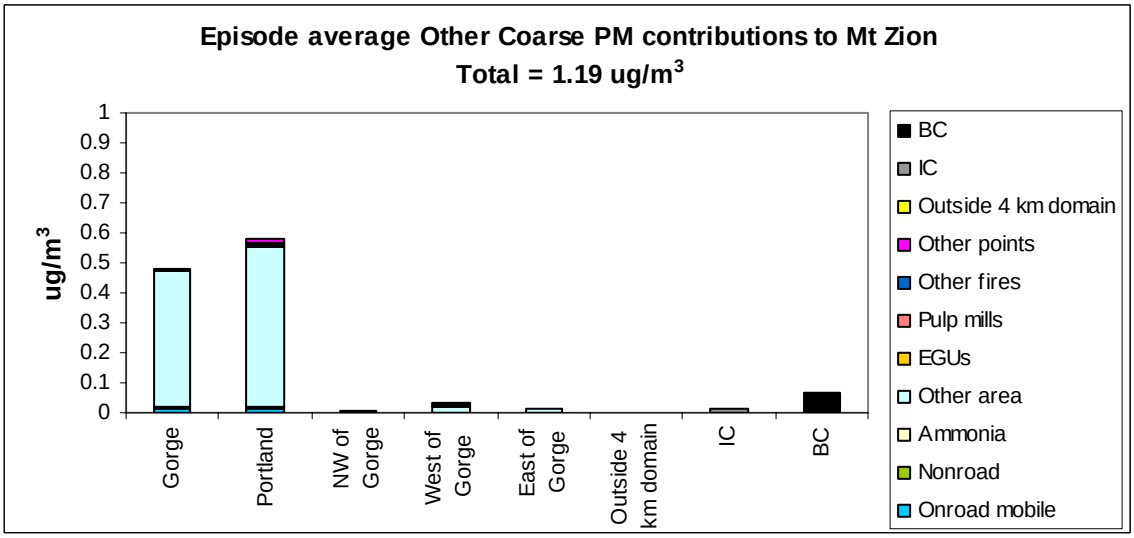


Figure 5-4 (concluded).

Table 5-6. Ranked list of source region/categories contributing to visibility-impairing haze over the November 2004 episode at Mt Zion. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
Sulfate	East of Gorge	EGUs	0.62	12.07	12%
Sulfate	BC		0.58	11.33	11%
Nitrate	Portland	Onroad mobile	0.54	9.86	10%
Nitrate	West of Gorge	Onroad mobile	0.28	5.08	5%
Nitrate	BC		0.25	4.52	4%
Sulfate	Portland	Other area	0.23	4.48	4%
Sulfate	NW of Gorge	Other points	0.18	3.60	4%
Sulfate	Gorge	Nonroad	0.17	3.36	3%
Nitrate	Portland	Nonroad	0.17	3.17	3%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.15	3.00	3%
POA	Portland	Other area	0.71	2.84	3%
Sulfate	Portland	Nonroad	0.14	2.73	3%
POA	Gorge	Other area	0.56	2.23	2%
Sulfate	NW of Gorge	EGUs	0.11	2.18	2%
Nitrate	Gorge	Nonroad	0.11	1.99	2%
Nitrate	NW of Gorge	EGUs	0.11	1.92	2%
EC	Gorge	Nonroad	0.16	1.64	2%
Nitrate	Gorge	Onroad mobile	0.08	1.54	2%
Nitrate	Portland	Other area	0.08	1.50	1%
Sulfate	Portland	Other points	0.07	1.42	1%
Nitrate	Outside 4 km domain	Outside 4 km domain	0.08	1.42	1%
Sulfate	West of Gorge	Other points	0.07	1.38	1%
Sulfate	Portland	Onroad mobile	0.07	1.31	1%
EC	Portland	Other area	0.13	1.30	1%
Sulfate	West of Gorge	Other area	0.07	1.30	1%
Nitrate	East of Gorge	Onroad mobile	0.07	1.27	1%
Nitrate	West of Gorge	Nonroad	0.07	1.22	1%
EC	Gorge	Other area	0.10	1.04	1%
EC	Portland	Nonroad	0.10	1.01	1%

5.2.2 2004 November PSAT Results at Wishram

Table 5-7 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the November 2004 episode at the Wishram monitoring site. The number of category/regions shown for each PM component result in at least 90% of the total episode-average mass concentration for that species. Figure 5-5 presents this information graphically (showing all category/region pairing contributions).

Wishram experiences even more episode-average sulfate than Mt Zion, with nearly a 5 μg/m^3 episode average. Again the single largest contributor is EGU emissions in the eastern portion of the modeling domain. Unlike Mt Zion, very little contribution is shown for other sources, since this site is much farther from large sources such around the Portland area and transport winds are generally easterly from remote areas of eastern Oregon and Washington. Nitrate is also higher at Wishram (almost 5 μg/m^3), with contributions primarily from on-road, non-road, area, and EGU NOx sources in the eastern area. NOx sources outside the 4-km grid (mostly well to the east)

also contribute to nitrate. Ammonium in nearly entirely attributed to local sources in the eastern area of the domain; large ammonia sources in the area of Wishram are causing a local formation of particle ammonium nitrate as aged nitric acid plumes move into the area from the east, mix with the ammonia, and condense into PM nitrate in the cool humid environment. Carbonaceous PM is much lower than the secondary salts, although episode-average elemental carbon (EC) concentrations of nearly 1 $\mu g/m^3$ are rather high compared to many other IMPROVE sites in the western US. Most EC stems from local non-road sources in the Gorge and in the eastern area, which suggests a large contribution from diesel exhaust. POA at Wishram is lower than at Mt Zion, given it's distance from Portland, and has local origins from non-road, area (residential wood combustion), and fires. Like Mt Zion, coarse/fine dust are mostly locally generated in Gorge and in the eastern area, with mostly area and on-road sources contributing.

The PSAT application revealed that the vast majority of visibility impairment at Wishram during the November 2004 episode was caused by anthropogenic sources (95%). Secondary organic aerosols from biogenic emissions contributed ~50% of the episode-average total organic carbon concentration, but only 5% of episode-average visibility impairment. Of the non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from eastern OR/WA EGU sources (29%);
2. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (8%);
3. Nitrate from eastern OR/WA on-road sources (8%);
4. Nitrate from super-regional sources outside the 12-km Pacific Northwest grid (7%); and
5. Nitrate from eastern OR/WA non-road sources (6%).

Table 5-8 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

Table 5-7. Top source region-category groups simulated to contribute more than 90% of total episode-average PM mass concentrations at the Wishram site by PM component species (see Figure 5-5 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	EGUs	2.64
BC		0.72
East of Gorge	Nonroad	0.31
Gorge	Nonroad	0.28
Outside 4 km domain	Outside 4 km domain	0.26
NW of Gorge	Other points	0.13
IC		0.07
East of Gorge	Other area	0.06
East of Gorge	Pulp mills	0.05
NW of Gorge	EGUs	0.04
Gorge	Other area	0.03
East of Gorge	Onroad mobile	0.03
Portland	Other area	0.02
Top PN03 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Onroad mobile	0.75
BC		0.65
East of Gorge	Nonroad	0.62
Outside 4 km domain	Outside 4 km domain	0.56
East of Gorge	EGUs	0.53
East of Gorge	Other area	0.43
Gorge	Nonroad	0.21
IC		0.20
Portland	Onroad mobile	0.15
West of Gorge	Onroad mobile	0.11
Gorge	Onroad mobile	0.11
Portland	Nonroad	0.05
East of Gorge	Other points	0.05
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Ammonia	1.90
Gorge	Ammonia	0.16
East of Gorge	Other area	0.08
Outside 4 km domain	Outside 4 km domain	0.08
BC		0.07
East of Gorge	EGUs	0.06
Gorge	Onroad mobile	0.05
East of Gorge	Onroad mobile	0.04
East of Gorge	Other fires	0.02
West of Gorge	Ammonia	0.02
Gorge	Other fires	0.01
Portland	Ammonia	0.01
East of Gorge	Other points	0.01

Table 5-7 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Nonroad	0.310
East of Gorge	Nonroad	0.103
Outside 4 km domain	Outside 4 km domain	0.060
Gorge	Other fires	0.041
BC		0.036
Gorge	Onroad mobile	0.031
East of Gorge	Other area	0.026
East of Gorge	Onroad mobile	0.024
East of Gorge	Other fires	0.020
Gorge	Other area	0.015
IC		0.012
Portland	Other area	0.009
Portland	Nonroad	0.007
Top POA Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other fires	0.21
Outside 4 km domain	Outside 4 km domain	0.20
East of Gorge	Other area	0.13
East of Gorge	Other fires	0.12
Gorge	Nonroad	0.11
BC		0.07
Gorge	Other area	0.07
East of Gorge	EGUs	0.06
Portland	Other area	0.05
East of Gorge	Nonroad	0.04
West of Gorge	Other area	0.03
Gorge	Onroad mobile	0.03
East of Gorge	Onroad mobile	0.02
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Outside 4 km domain	Outside 4 km domain	0.0856
East of Gorge	Other area	0.0810
BC		0.0751
East of Gorge	Onroad mobile	0.0632
Gorge	Onroad mobile	0.0478
IC		0.0143
West of Gorge	Onroad mobile	0.0014
Portland	Onroad mobile	0.0010
Gorge	Other area	0.0004
West of Gorge	Other area	0.0004
Portland	Other area	0.0003
NW of Gorge	Onroad mobile	0.0001
NW of Gorge	Other area	0.0000

Table 5-7 (concluded).

Top Other Fine PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Other area	0.342
East of Gorge	EGUs	0.187
Gorge	Other area	0.108
Outside 4 km domain	Outside 4 km domain	0.070
Portland	Other area	0.038
West of Gorge	Other area	0.026
East of Gorge	Other fires	0.023
BC		0.020
Gorge	Other fires	0.020
IC		0.015
East of Gorge	Other points	0.015
Gorge	Onroad mobile	0.004
West of Gorge	Other fires	0.004
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Onroad mobile	0.3247
East of Gorge	Onroad mobile	0.2495
East of Gorge	Other area	0.2376
Outside 4 km domain	Outside 4 km domain	0.0929
BC		0.0431
IC		0.0282
West of Gorge	Onroad mobile	0.0025
Portland	Onroad mobile	0.0017
Gorge	Other area	0.0004
Portland	Other area	0.0002
NW of Gorge	Onroad mobile	0.0002
West of Gorge	Other area	0.0002
NW of Gorge	Other area	0.0000
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Other area	0.697
Gorge	Other area	0.243
BC		0.162
East of Gorge	EGUs	0.049
IC		0.037
East of Gorge	Other points	0.029
Portland	Other area	0.013
Gorge	Onroad mobile	0.013
Outside 4 km domain	Outside 4 km domain	0.012
Gorge	Nonroad	0.007
Gorge	Other fires	0.006
East of Gorge	Onroad mobile	0.005
East of Gorge	Ammonia	0.005

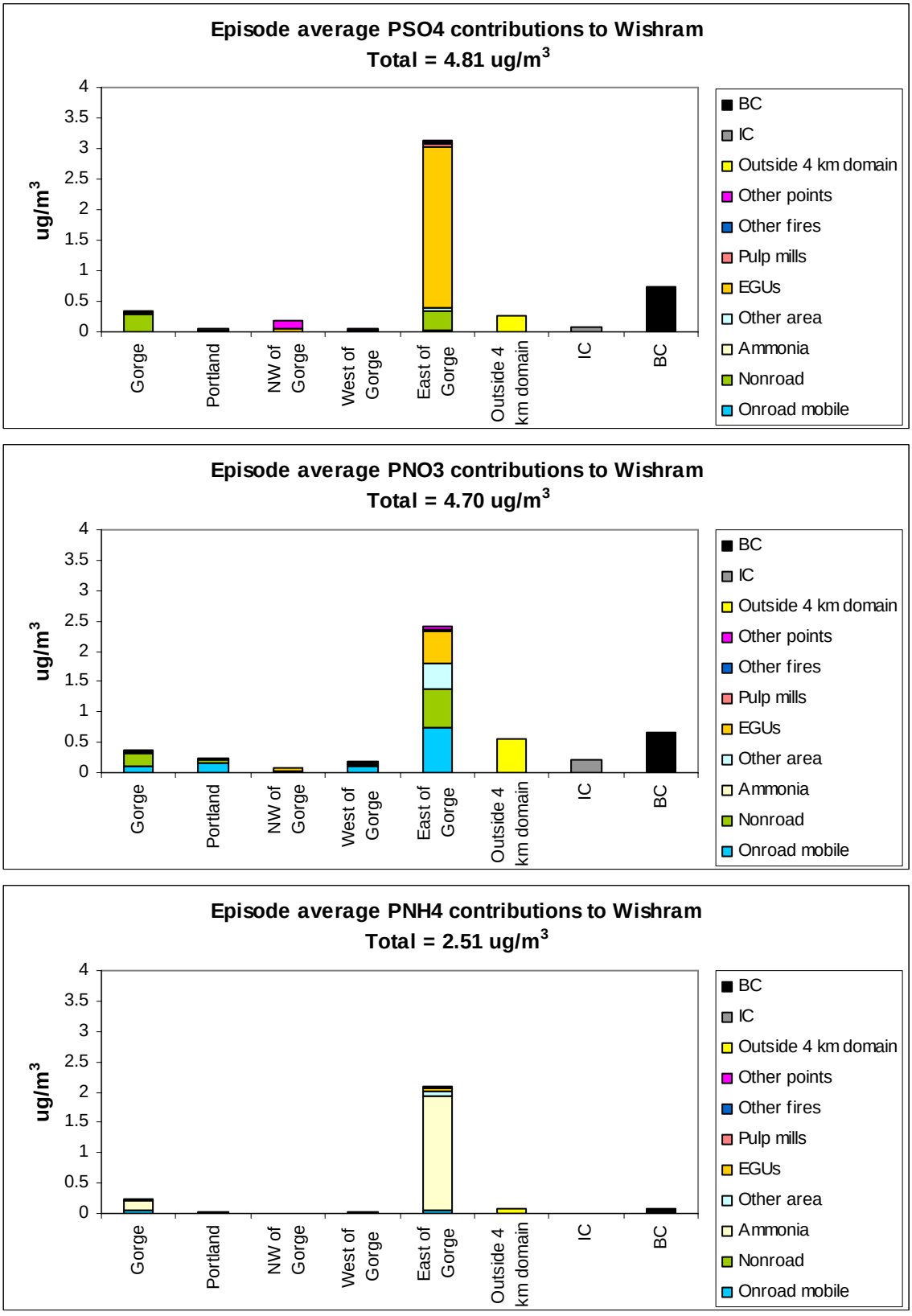
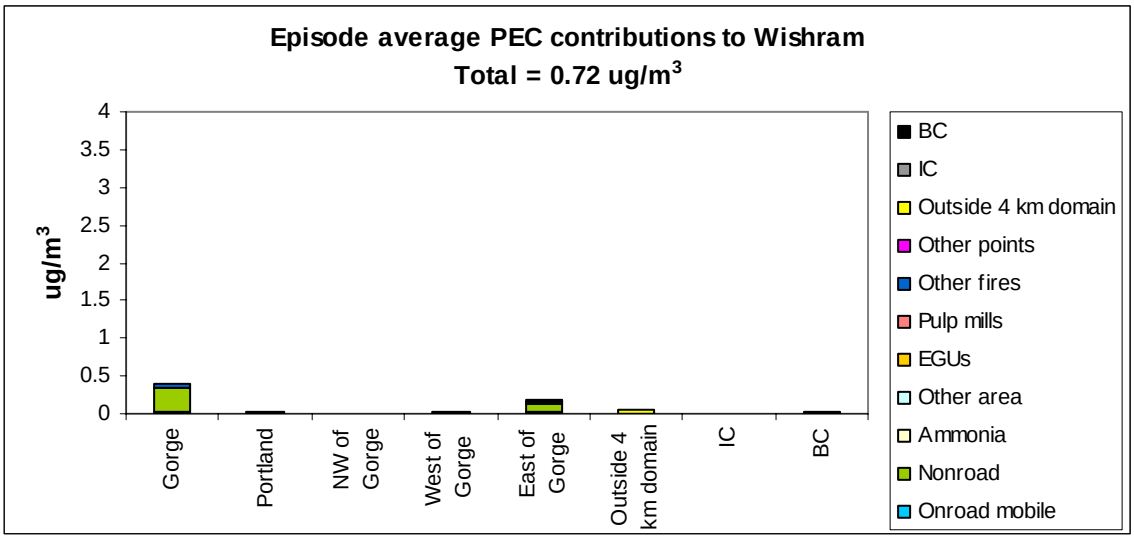
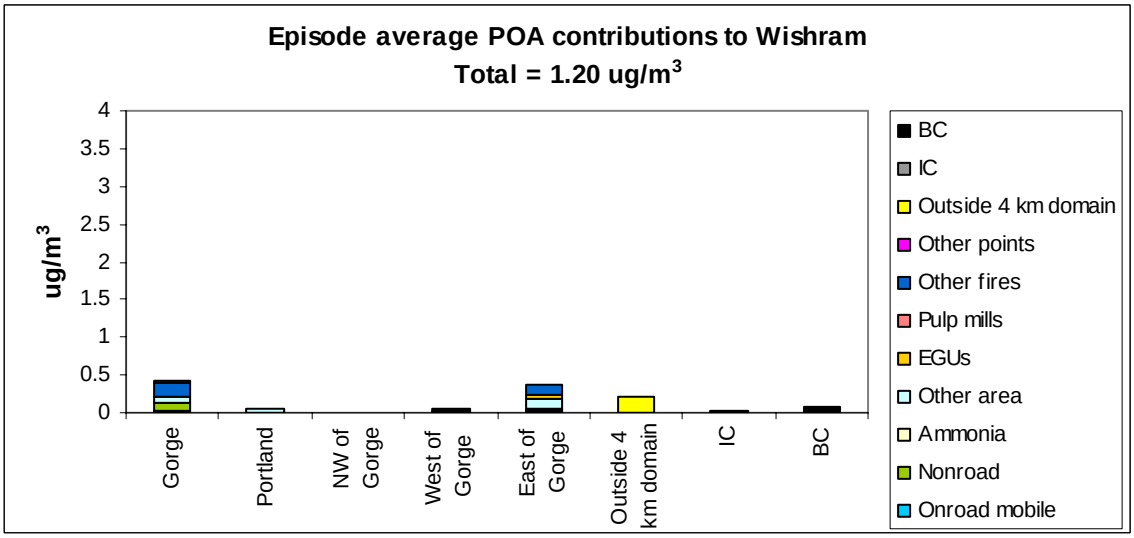


Figure 5-5. PSAT category-region breakdown at Wishram for November 2004 episode-average PM concentrations.





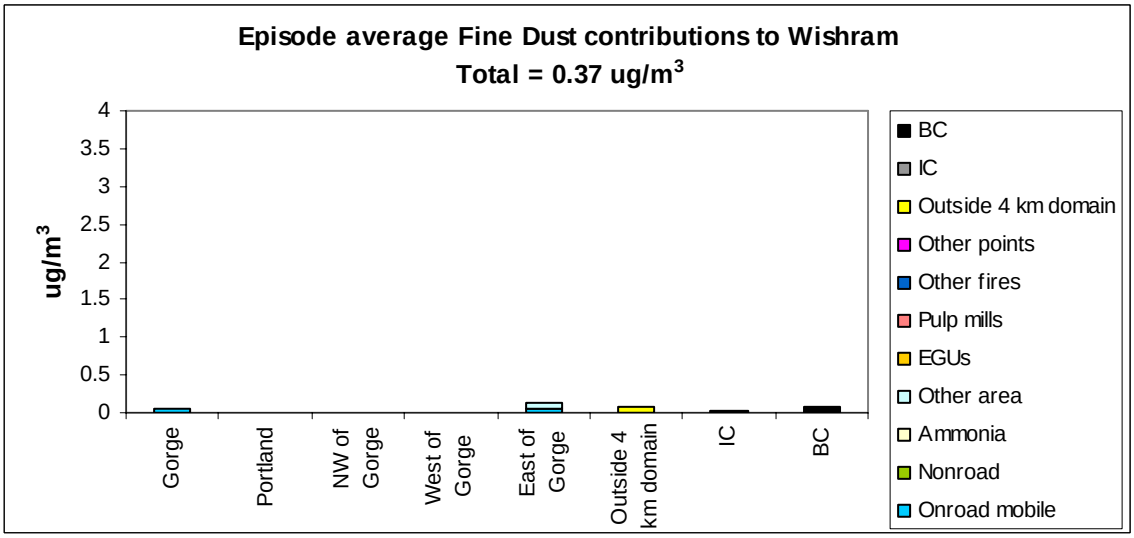
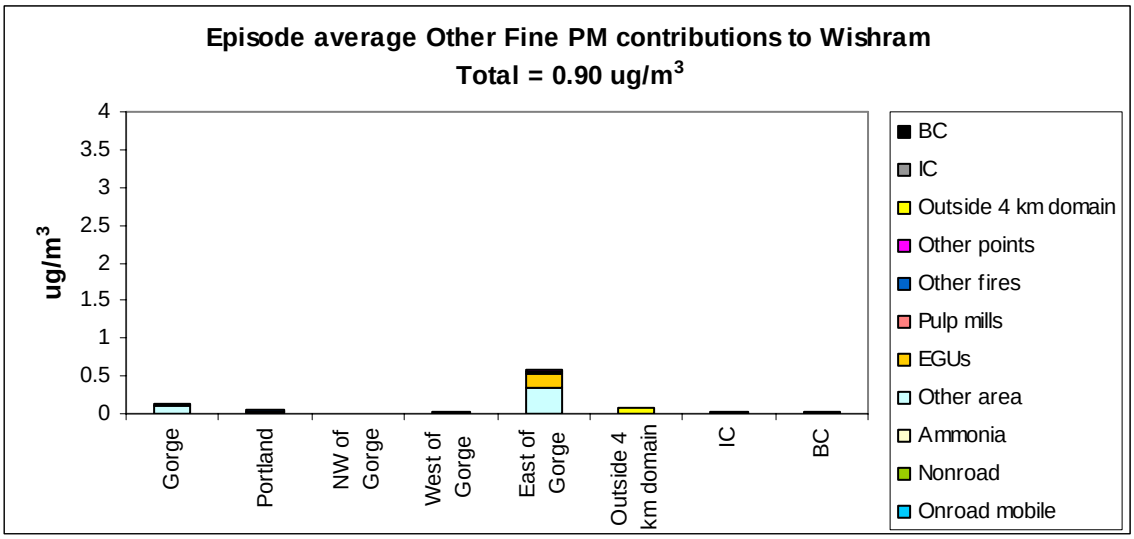
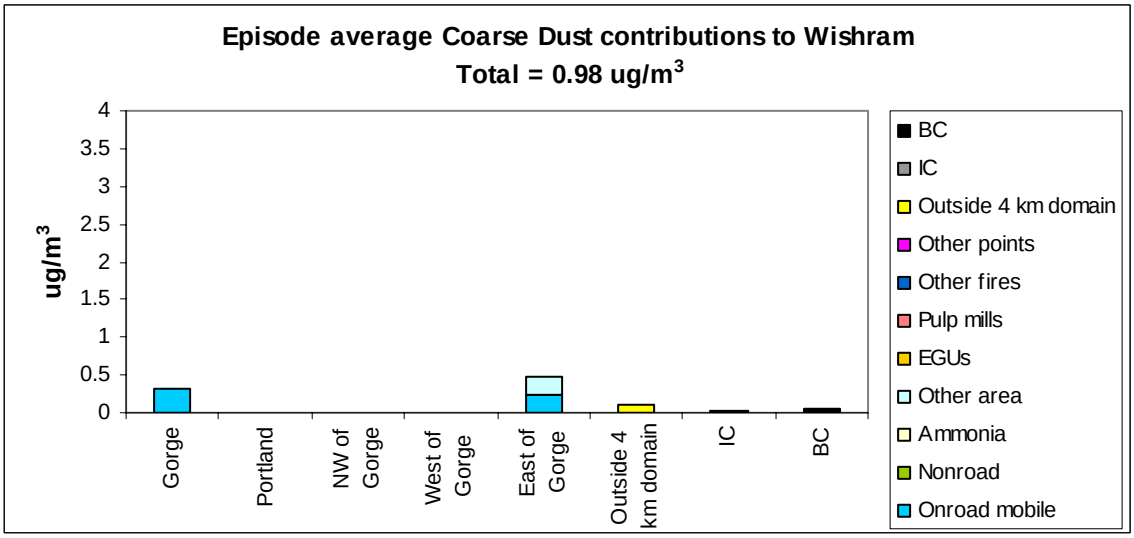


Figure 5-5 (continued).





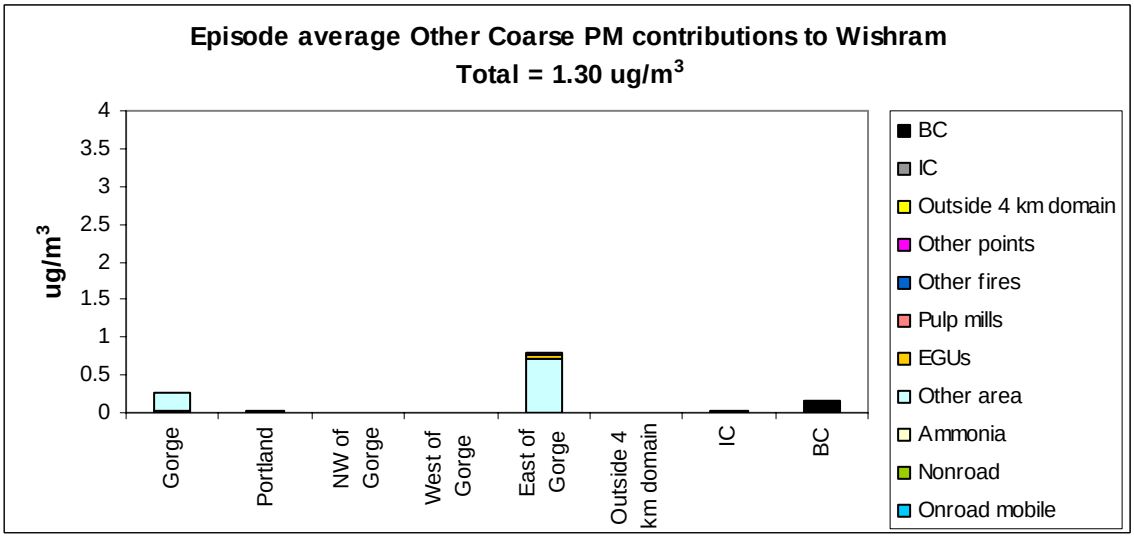


Figure 5-5 (concluded).

Table 5-8. Ranked list of source region/categories contributing to visibility-impairing haze over the November 2004 episode at Wishram. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
Sulfate	East of Gorge	EGUs	2.64	51.64	29%
Sulfate	BC		0.72	14.15	8%
Nitrate	East of Gorge	Onroad mobile	0.75	13.68	8%
Nitrate	BC		0.65	11.93	7%
Nitrate	East of Gorge	Nonroad	0.62	11.44	6%
Nitrate	Outside 4 km domain	Outside 4 km domain	0.56	10.35	6%
Nitrate	East of Gorge	EGUs	0.53	9.64	5%
Nitrate	East of Gorge	Other area	0.43	7.85	4%
Sulfate	East of Gorge	Nonroad	0.31	5.97	3%
Sulfate	Gorge	Nonroad	0.28	5.40	3%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.26	5.08	3%
Nitrate	Gorge	Nonroad	0.21	3.89	2%
EC	Gorge	Nonroad	0.310	3.10	2%
Nitrate	Portland	Onroad mobile	0.15	2.77	2%
Sulfate	NW of Gorge	Other points	0.13	2.49	1%
Nitrate	West of Gorge	Onroad mobile	0.11	2.08	1%
Nitrate	Gorge	Onroad mobile	0.11	1.96	1%

6.0 CAMx FUTURE YEAR MODELING

6.1 CAMx MODELING OVERVIEW

CAMx was run for both the August and November modeling episode in exactly the same manner as performed for the final 2004 Base Case application ("Run 10") as documented in Section 4. The only change to the model inputs included use of the 2018 episode-specific modeling emission inventories described in Section 3. All grid configurations, model options, meteorological and other environmental inputs (including "natural" emissions such as wild fires, prescribed burns, wind-blown dust, ammonia and biogenics) were maintained to be consistent with the Run 10 Base Case simulations. Hence, the future year applications performed for the August and November modeling episodes reflect only changes in the projected 2018 anthropogenic emission inventories via anticipated growth in population and industrial, commercial, and vehicular activity, as well as emission controls that were reflected in the 2018 WRAP inventories and some additional adjustments applied specifically for this project (e.g., power plant emission reductions via BART rules). See Section 3 for more specific information regarding the 2018 modeling inventories prepared for this modeling application.

The 2018 model simulations reported herein are based on the out year inventory as it was prepared by WRAP. It is important to understand that the manner in which the model was applied to treat 2004 is identical to how it is applied to treat 2018; the only component that changes between the two years is the anthropogenic emission inventory. We have made a few adjustments to the 2018 WRAP inventory based on more current emissions data from the States, however there are several upcoming federal programs that will have substantial emission reductions that are not included in this inventory. In addition, each of the WRAP states continues to make refinements to their inventories for 2018. Additionally, WRAP has not included NOx emission reductions yet in their inventory to reflect BART controls for electric generating units. Thus, we have included the BART presumptive limits for the Boardman generating station in the 4-km Oregon/Washington emission inventory.

The results of the future year CAMx simulations were used to prepare visibility trend lines (or rates) from 2004 to 2018. Trends were calculated for two IMPROVE sites – Mt Zion and Wishram – in order to remain consistent with the PSAT and model performance evaluations for total light extinction and visibility documented in Sections 4, 5, and 7. Keep in mind that the inventory data projected for 2018 is just that, a projection, and that the air quality model has some bias. Therefore the reader should not use these values in an absolute sense. While we have made the best effort to replicate the monitored values for 2004 as closely as possible, the model and the science are not perfect. Furthermore, it will be of little value to attempt to predict what the actual absolute future year visibility measurements will be at specific monitors in the Gorge because ultimately the emissions mix and meteorology will be different (as compared to what we have simulated). Instead, the outcome of this modeling exercise is to better understand the likely relative impacts of all the emissions increases (due to population growth for example) and decreases (due to implementation of currently mandated emission reduction strategies) on future year visibility; this is the trend that were are determining in this exercise. The source apportionment information and emission inventory data helps us understand better who is contributing and how much.

6.2 DETERMINING VISIBILITY TRENDS FROM MODEL RESULTS

6.2.1 Expressing Visibility as Deciview

Section 4.3.1 provides our working definition of visibility impairment, expressed as light extinction, and describes the procedure by which it is determined from the sum of light scattering and absorption by various gas and aerosol constituents in the atmosphere. The reduction in light intensity through a gas/aerosol medium can be simply described using Beer's Law, which depends upon the characterization of the medium's opacity and is referred to as the extinction coefficient.

For example, absolutely clean air at sea level has an extinction coefficient of about 10 Mm^{-1}. We can invert Beer's Law to find the path length needed to see a "just perceptible" feature in the distance (referred to as "visual range") for a clean atmosphere. A commonly accepted threshold for a "just perceptible" feature defines an $I:I_0$ ratio of 3%, meaning that only 3% of initial light emanating from that object reaches the observer. Thus, in an absolutely clean atmosphere, the visual range at that threshold is approximately 350 km. As other constituents are added, the total extinction coefficient (opacity) increases linearly, but the visual range decreases exponentially.

For regional haze assessments in the U.S., a linear metric is used to replace Beer's Law for the purposes of characterizing the mean opacity and perceptible visibility changes on the scales of vistas (i.e., more than 1 km). The metric is referred to as Deciview (Dv), which more simply expresses the effects of net pollutant opacity on a linear scale. The Dv scale is defined to start at zero, which is an absolutely pristine atmosphere (a total Rayleigh extinction coefficient of 10 Mm^{-1} and a visual range of ~350 km). A value of 5-10 is representative of a typical rural background level that would include natural aerosols (e.g., dust and biogenic organic aerosols) and some minor component of regional anthropogenic pollutants (a total extinction coefficient of ~15-30 Mm^{-1} and a visual range of ~130-200 km). A value of 15-20 represents a typical urban environment (a total extinction coefficient of 45-75 Mm^{-1} and a visual range of ~50-80 km). A linear change of 1 Dv anywhere on the scale is considered a "just perceptible" extinction change and is generally based on the 3% $I:I_0$ intensity reduction in the exponential relationship described above for path lengths on the scales of vistas.

For example, the addition of only 0.3 $\mu g/m^3$ of sulfate, nitrate, or organics in a dry environment (i.e., no humidity growth) will yield a sufficient extinction coefficient to change the Dv by 1 unit and result in a perceptible haze in an otherwise pristine environment (background of 10 Mm^{-1}). The dirtier the background environment is, the larger the NO_2 increment must be to yield a "just perceptible" change. For the typical rural background conditions described above, an aerosol concentration of 2-6 $\mu g/m^3$ is needed to change the DV by 1 unit, and for the dirty urban conditions above, an aerosol concentration of 11-21 $\mu g/m^3$ is needed.

6.2.2 Trend Line Calculation Methodology

Trend lines for 2004-2018 total extinction and deciview were calculated from episode-average conditions at two IMPROVE sites: Mt Zion and Wishram. The episode-average was determined

from the 24-hour extinction values on just the "high" PM days identified from the modeling results in each episode. The high PM days from the August episode are listed in Table 6-1; the high PM days from the November episode are listed in Table 6-2.

Table 6-1. Days chosen from the August 2004 episode as "high" PM extinction days for the calculation of visibility trend lines.

Mt Zion (Extinction, 1/Mm)	Wishram (Extinction, 1/Mm)
8/10 (58)	8/12 (34)
8/11 (58)	8/13 (55)
8/12 (59)	8/14 (49)
8/13 (48)	8/15 (36)
8/14 (51)	8/19 (35)
8/15 (51)	

Table 6-2. Days chosen from the November 2004 episode as "high" PM extinction days for the calculation of visibility trend lines.

Mt Zion (Extinction, 1/Mm)	Wishram (Extinction, 1/Mm)
11/6 (350)	11/8 (323)
11/8 (277)	11/10 (276)
11/9 (504)	11/11 (272)
11/13 (293)	11/12 (434)
11/16 (348)	11/13 (322)
	11/14 (327)

These days were used to determine episode average extinction and deciview from both the 2004 and 2018 modeling results. Trend lines and rates were simply determined from the difference in the 2004 and 2018 episode averages. Trend lines are discussed later in this section, and are shown in Figure 6-5.

6.3 CAMx RESULTS FOR 2018

6.3.1 Projections of Daily Light Extinction Budgets

Figure 6-1 displays "stacked" bar charts showing the speciated extinction budget and total extinction on each day of the August episode. For each day, the 2004 and 2018 24-hour average results are presented to show how visibility is projected to change throughout the episode. At both Mt Zion and Wishram, little change in total extinction is seen on each day for this episode. However, some minor reductions in sulfate and nitrate are noticeable. Some days show increased extinction (August 11 at Mt Zion, August 14 at Wishram), mainly due to larger carbon and fine dust components. The reasons for this are not clear, but a large low-level point source of primary fine PM near Seven Mile Hill was found to emit at far higher rates in the 2018 WRAP inventory; this location is near Wishram, and appears to impact the total extinction budget on August 14 in particular. In general, the lack of extinction response for this episode was tied mostly to the fact that the inventory is dominated by "natural" emissions such as biogenic SOA and wild fires that cannot be directly controlled, and which were carried over from the 2004 inventory development efforts.

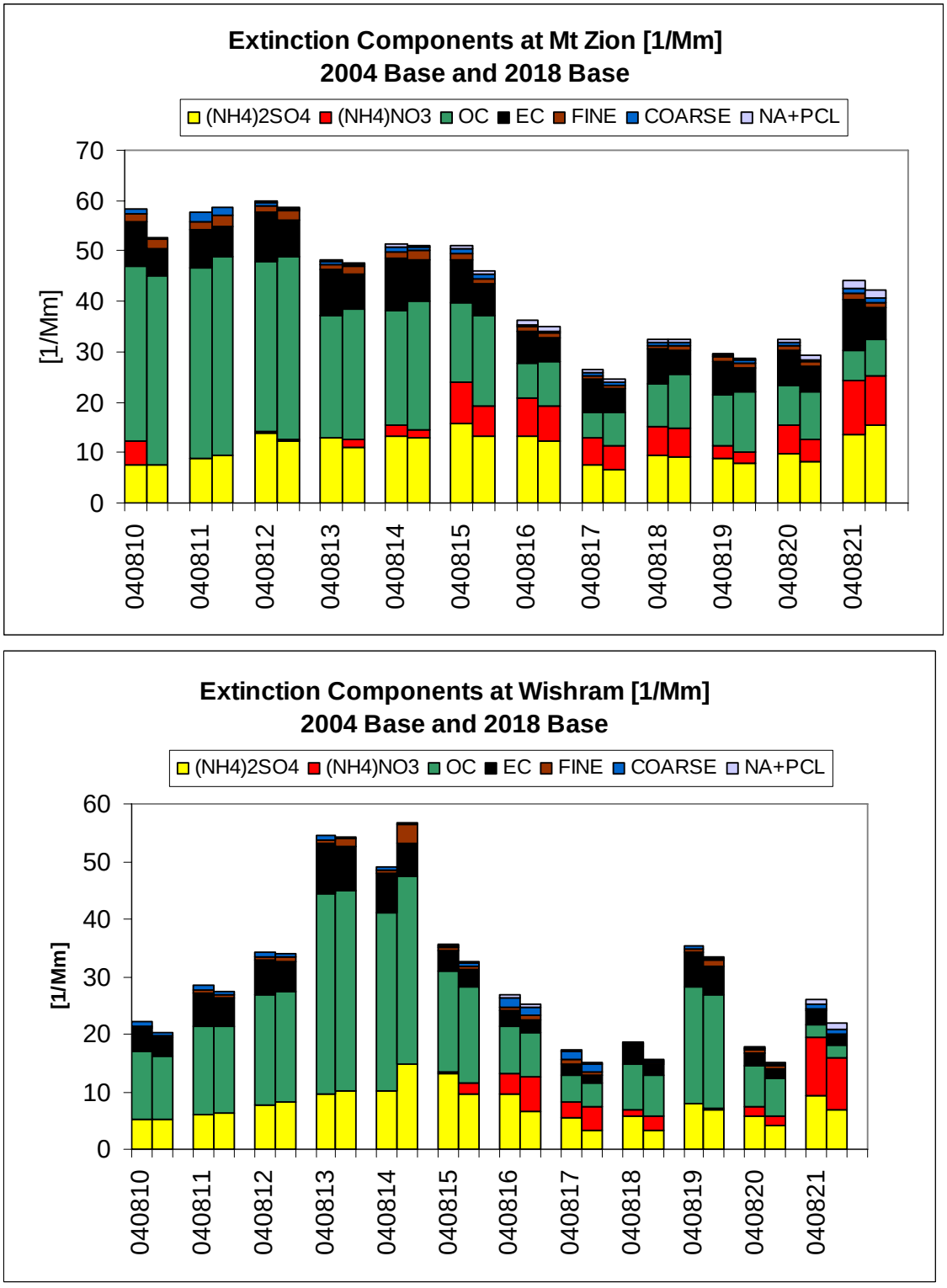


Figure 6-1. Daily speciated and total extinction between the 2004 Base Case (left bar) and the 2018 Future Year case (right bar) at Mt Zion (top) and Wishram (bottom) over the August 2004 episode.

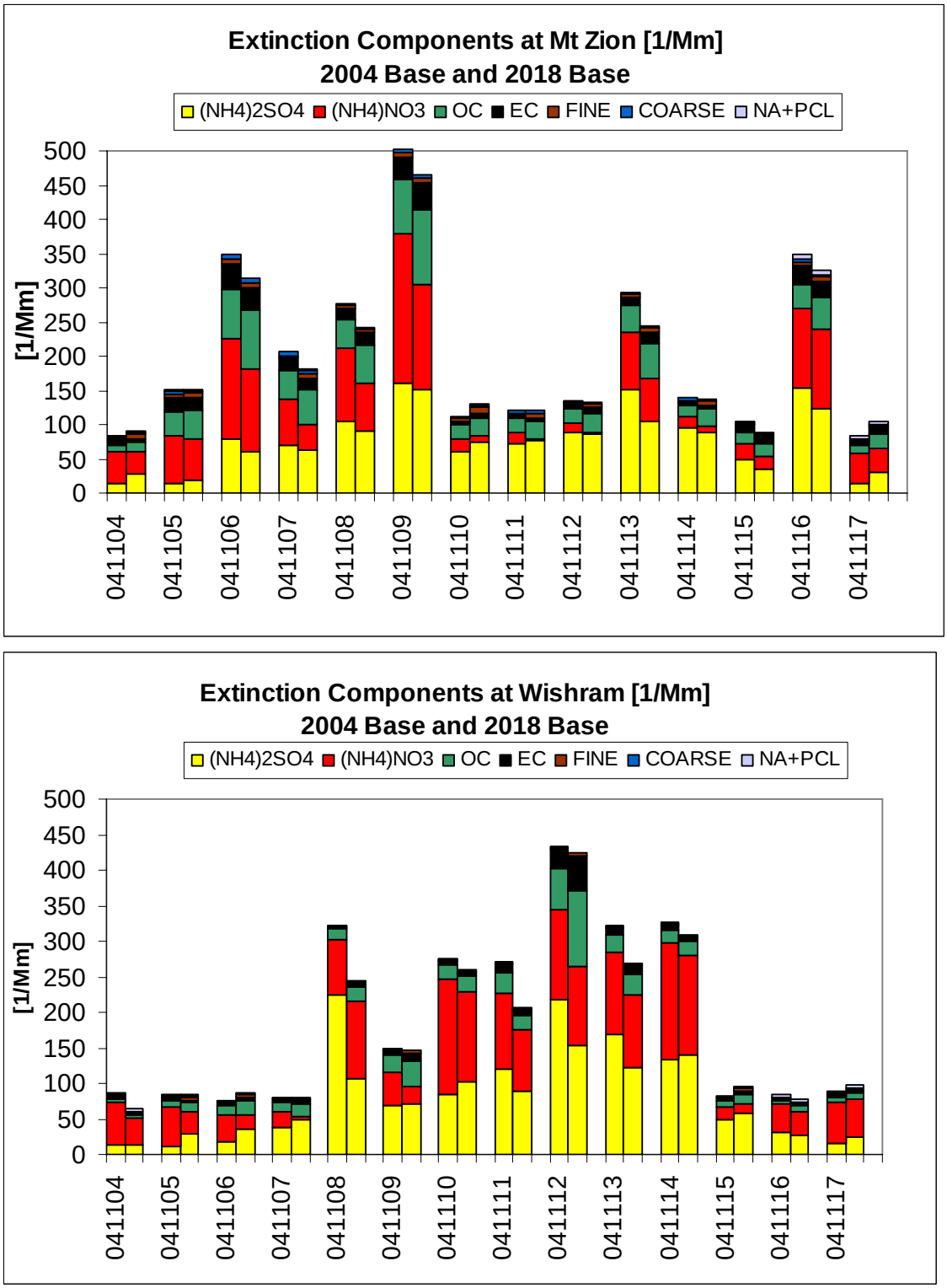


Figure 6-2. Daily speciated and total extinction between the 2004 Base Case (left bar) and the 2018 Future Year case (right bar) at Mt Zion (top) and Wishram (bottom) over the November 2004 episode.

Figure 6-2 shows the same type of chart for the November episode. In this case, reductions in nitrate (NOx) and sulfate (SO_2) result in more significant reductions in total PM extinction, especially on the worst visibility days. The cleaner days indicate little change in 2018; note also that on the cleaner days, the sulfate/nitrate balance is generally modified to show more sulfate and less nitrate, with little change in total sulfate plus nitrate. This may be due to the reduction in ammonia, which will reduce PM nitrate by preferentially neutralizing sulfate. Little change to other species (carbonaceous and primary PM) was seen in the 2018 out year.

6.3.2 Daily Results for What-If Scenarios

Several "what-if" scenarios were run for the 2018 Future Case to estimate the impacts of certain sources on visibility over the two modeling episodes. These included:

- Case 1 – zero Boardman emissions;
- Case 2 – zero ammonia emissions over PSAT region 5 (east of Gorge);
- Case 3 – zero on-road mobile source emissions for PSAT region 2 (Portland and Vancouver);
- Case 4 – zero major point source emissions for PSAT region 2;
- Case 5 – zero major point source emissions for PSAT region 1 (in-Gorge)

Figure 6-3 displays a daily stacked bar chart for August similarly to the earlier figures, but showing the 2018 Future Year scenario and each of the five what-if scenarios together. Very little sensitivity to any of the what-if scenarios is seen at both of the monitoring sites. Since the Boardman EGU plant reflects major sulfate and NOx reductions in the 2018 inventory, practically zero sensitivity to Case 1 is seen. Some increases and decreases in sulfate and nitrate are seen for some cases (e.g., Case 5, in which all point sources in the Gorge were removed). This mixed effect is possible depending upon how the chemical conditions set up for a specific episode. There are two possible non-linear effects at play here:

(1) The amount of ambient NOx relative to organic gasses can lead to ozone (oxidant) production or ozone destruction. In NOx-lean conditions (such as in remote rural locations), controls on NOx can lead to less oxidants that ultimately form less sulfate, while in NOx-rich conditions (e.g., urban areas such as Portland), controls on NOx can lead to more oxidants (less ozone inhibition) and thus more sulfate formation.

(2) The amount of particulate nitrate and sulfate that can form depends on the amount of available ammonia that neutralizes these acids. It is very common to see nitrate increases when SO_2 emissions are reduced while NOx and ammonia emissions are held constant. Since ammonium preferentially neutralizes sulfate, with any excess then available for neutralizing nitrate, a reduction in SO_2 leads to a reduction in sulfate, and thus more ammonium is available to form more particulate nitrate.

As we have seen in both the 2018 projection (relative to the 2004 base case) and a few of the "what-if" scenarios, the model is responding in such a manner. Again, the August episode is dominated by "natural" emissions that were not removed in any of these scenarios. The less

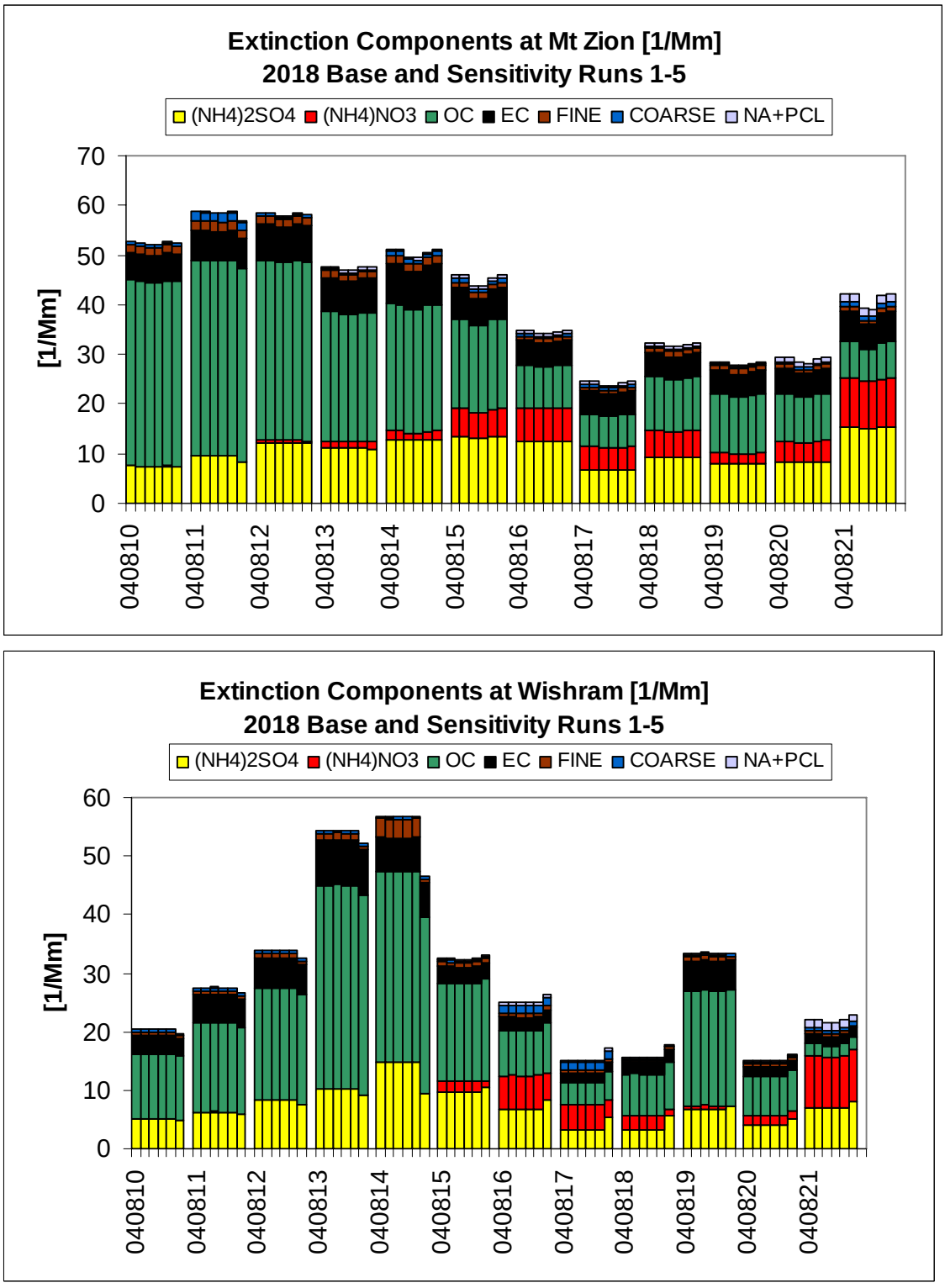


Figure 6-3. Daily speciated and total extinction between the 2018 Future Year case (left-most bar) and five "what-if" scenarios at Mt Zion (top) and Wishram (bottom) over the August 2004 episode.

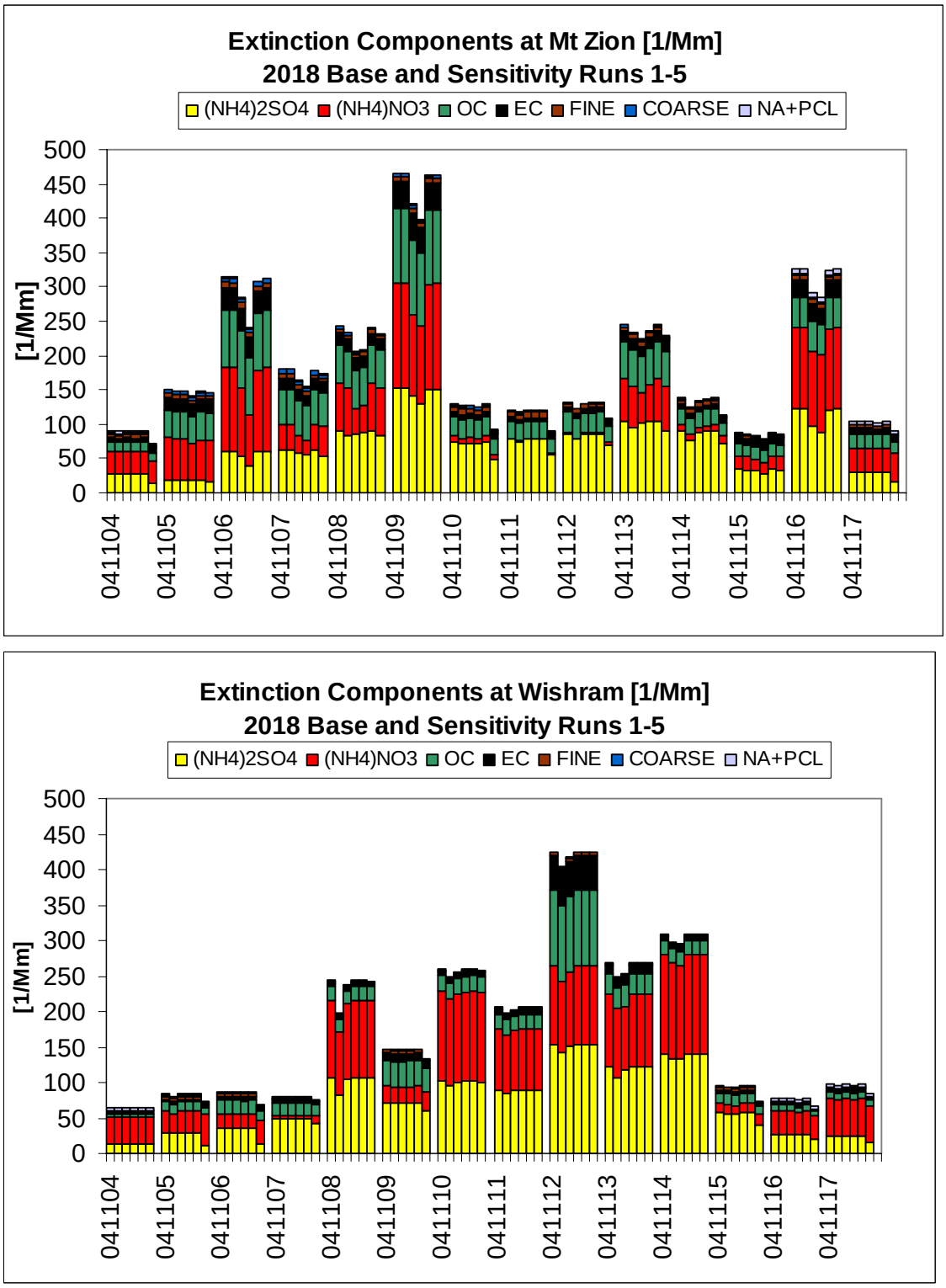


Figure 6-4. Daily speciated and total extinction between the 2018 Future Year case (left-most bar) and five "what-if" scenarios at Mt Zion (top) and Wishram (bottom) over the November 2004 episode.

obvious signals stemming from the what-if scenarios should be examined in further modeling efforts; but overall these effects are not significant to the overall conclusions of this study.

Figure 6-4 presents the same chart for the November episode. Somewhat more influence from each what-if scenario is seen on the worst PM days, especially Cases 2 and 3 at Mt Zion, which remove ammonia and Portland on-road sources, and Cases 1 and 5 at Wishram, which remove major point sources from the in-Gorge area.

6.3.3 Visibility Trend Lines

Figure 6-5 displays the simulated episode-average extinction and visibility trend lines for the August episode and for both Mt Zion and Wishram monitoring sites. The methodology for calculating these trends was discussed in Section 6.2.2. Table 6-3 presents these trends numerically for both sites. While Mt Zion is simulated to show just a slight improvement in worst-day extinction out to 2018 according to these modeling results, the Wishram site actually shows a very slight degredation. Nevertheless, these changes are not perceptible according to the 1 Dv threshold for perceptible visibility changes. Figure 6-6 and Table 6-4 present trend line results for the November episode. In this case, a perceptible improvement is simulated for worst-day visibility at both sites, with reductions in total extinction of over 10% and Dv reduction of over 1.

For comparison, Figure 6-7 displays the results from WRAP for Mt Hood and Mt Adams over a similar time horizon. Note that WRAP did not calculate visibility trend lines for Mt Zion or Wishram IMPROVE sites as they are not located in Federal "Class I" areas. Since WRAP conducted modeling over the entire 2002 year, the trend lines are determined from the average of the 20% worst visibility days over the annual simulation. Haze conditions on such days in the WRAP 2002 modeling would be consistent with the hazy episode days in 2004 selected for modeling in the Gorge Study. The WRAP simulated projections are very similar to what we see for Mt Zion and Wishram during the August 2004 episode.

Table 6-3. Episode-average trends for extinction and visibility from "high" PM extinction days during the August 2004 episode,

	Mt Zion	Wishram
Total Extinction Change	-1.9 Mm^{-1} (-3%)	0.4 Mm^{-1} (1%)
Extinction Annual Rate	-0.13 $Mm^{-1}yr^{-1}$	0.03 $Mm^{-1}yr^{-1}$
Total Dv Change	-0.3 (not perceptible)	0.08 (not perceptible)
Dv Annual Rate	-0.02 yr^{-1}	0.006 yr^{-1}

Table 6-4. Episode-average trends for extinction and visibility from "high" PM extinction days during the November 2004 episode.

	Mt Zion	Wishram
Total Extinction Change	-35 Mm^{-1} (-10%)	-40 Mm^{-1} (-12%)
Extinction Annual Rate	-2.5 $Mm^{-1}yr^{-1}$	-2.8 $Mm^{-1}yr^{-1}$
Total Dv Change	-1.0 (perceptible)	-1.3 (perceptible)
Dv Annual Rate	-0.07 yr^{-1}	-0.09 yr^{-1}

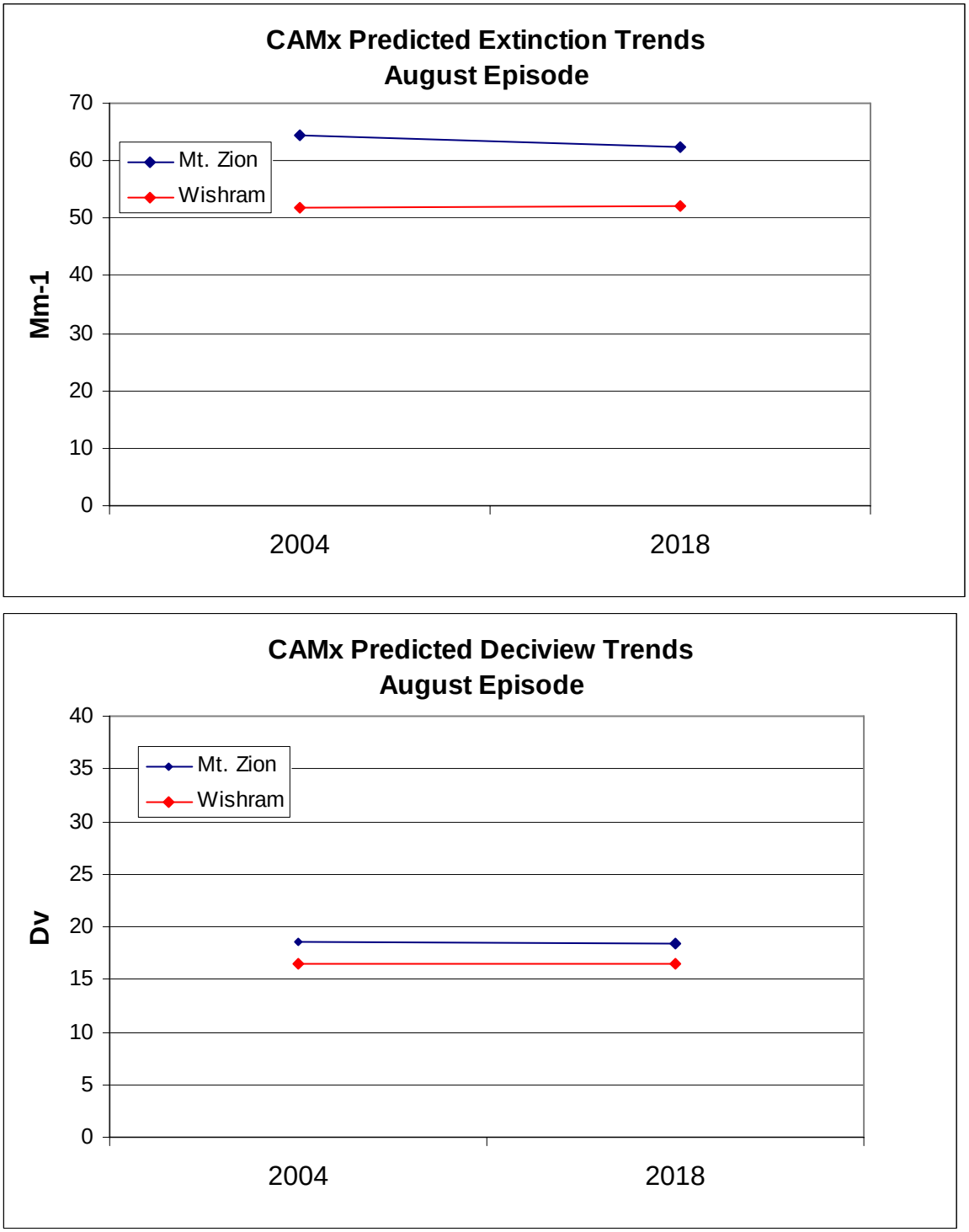


Figure 6-5. Episode-average trend lines for total extinction (top) and visibility (bottom) from "high" PM extinction days during the August 2004 episode.

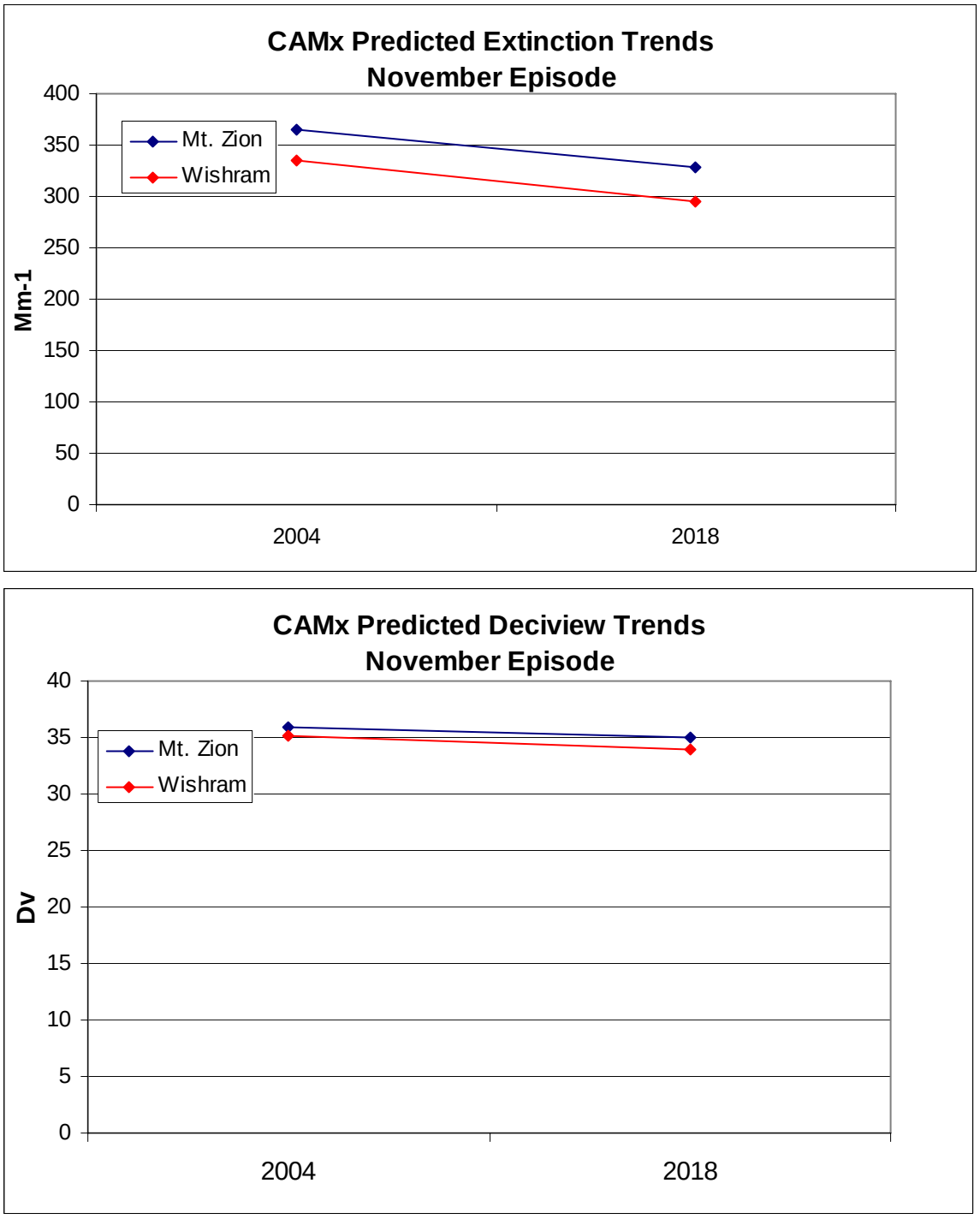


Figure 6-6. Episode-average trend lines for total extinction (top) and visibility (bottom) from "high" PM extinction days during the November 2004 episode.

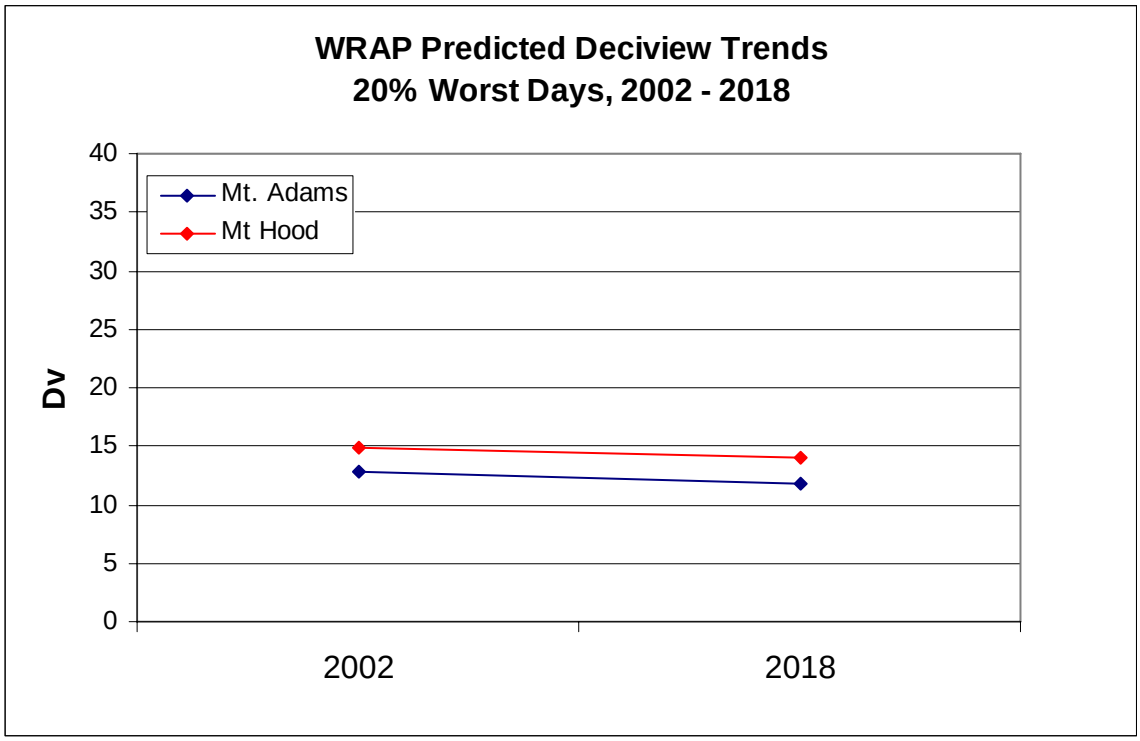


Figure 6-7. Visibility trend lines taken from the WRAP modeling for Mt Hood and Mt Adams. At Mt Adams, total Dv change is -0.9 (-0.06/year), while at Mt Hood, total Dv change is -0.8 (-0.05/year).

7.0 FUTURE YEAR SOURCE ATTRIBUTION MODELING

The CAMx PSAT Probing Tool was applied to the August and November 2004 modeling episodes to quantify source attribution at the Mt Zion and Wishram monitoring sites for the 2018 Future Year scenario. The PSAT application for the Future Year scenario was run in exactly the same manner as the PSAT application for the 2004 Base Case (see Section 5 for a full description and reasoning for the PSAT configuration):

- The same twelve source categories and six source regions were defined;
- PSAT was run for the sulfur, nitrogen, and primary PM groups (the organic group was not run);
- Only the 4- and 12-km modeling grids were run – the 36-km grid results from the final 2018 Future Year simulations were used to extract hourly boundary conditions for the 12-km grid, and these 12-km boundary conditions were tracked by the PSAT "BC" tracer;
- The 4- and 12-km grid three-dimensional concentration fields at midnight UTC on August 10 and November 3 from the final 2018 Future Year simulations were used as initial conditions for the PSAT runs – these 4- and 12-km initial conditions were tracked by the PSAT "IC" tracer and CAMx/PSAT was run for the core episode period (August 10-22 and November 3-18);
- PSAT results were post-processed for two monitoring sites along the Columbia River: Mt Zion, and Wishram.

The sub-sections below present results for the analysis of episode-average source apportionment.

7.1 PSAT APPLICATION FOR AUGUST 2018

7.1.1 August 2018 PSAT Results at Mt Zion

Table 7-1 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the August 2018 episode at the Mt Zion monitoring site. The number of category/regions shown for each PM component result in at least 90% of the total episode-average mass concentration for that species. Figure 7-1 presents this information graphically (showing all category/region pairing contributions).

Initial/boundary conditions and areas outside the 4-km domain continue to contribute the bulk of sulfate during this episode. Portland and areas along the westernmost area of the Columbia River are the largest local source areas of sulfate, which agrees with the general west-to-east transport direction during this period. A variety of source types in these western areas contribute to sulfate, including non-road sources (heavily dominated by diesel engines), EGUs, pulp mills, and other point sources. Nitrate is primarily attributed to similar local upwind regions from on-road, non-road, and industrial sources. Ammonium is attributed to mainly on-road and local ammonia-specific sources in the Gorge and in Portland. Primary carbonaceous components come mostly from upwind and local areas from mobile and area sources (particularly non-road), suggesting diesel activity. Other carbon sources include fires. Dust (coarse and fine) is nearly entirely from local on-road sources (road dust) and local area sources.

Table 7-1. Top source region-category groups simulated to contribute more than 90% of total August 2018 episode-average PM mass concentrations at the Mt Zion site by PM component species (see Figure 7-1 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.30
NW of Gorge	Pulp mills	0.08
Outside 4 km domain	Outside 4 km domain	0.07
NW of Gorge	Other points	0.04
NW of Gorge	Nonroad	0.04
IC		0.04
Portland	Other area	0.03
Portland	Other points	0.03
Portland	Nonroad	0.03
West of Gorge	EGUs	0.03
East of Gorge	Wildfires	0.02
Gorge	Nonroad	0.02
West of Gorge	Other area	0.02
Top PNO3 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Nonroad	0.06
BC		0.05
Portland	Onroad mobile	0.04
NW of Gorge	Nonroad	0.04
NW of Gorge	Other points	0.02
Outside 4 km domain	Outside 4 km domain	0.02
Portland	Other area	0.02
NW of Gorge	Pulp mills	0.02
West of Gorge	Onroad mobile	0.02
West of Gorge	EGUs	0.01
West of Gorge	Nonroad	0.01
Portland	Other points	0.01
NW of Gorge	Onroad mobile	0.01
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Ammonia	0.020
Portland	Onroad mobile	0.018
Portland	Ammonia	0.015
Gorge	Onroad mobile	0.010
Portland	Other area	0.006
East of Gorge	Ammonia	0.004
West of Gorge	Ammonia	0.003
NW of Gorge	Other points	0.003
Outside 4 km domain	Outside 4 km domain	0.002
Portland	Other points	0.002
NW of Gorge	Ammonia	0.002
BC		0.002
East of Gorge	Wildfires	0.001

Table 7-1 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Nonroad	0.111
NW of Gorge	Nonroad	0.072
Gorge	Nonroad	0.055
East of Gorge	Wildfires	0.047
Portland	Other area	0.033
Portland	Onroad mobile	0.031
West of Gorge	Nonroad	0.013
BC		0.013
Outside 4 km domain	Outside 4 km domain	0.013
Gorge	Other area	0.011
Gorge	Onroad mobile	0.009
West of Gorge	Other area	0.008
West of Gorge	Onroad mobile	0.006
Top POA Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.33
East of Gorge	Wildfires	0.22
Gorge	Other area	0.10
Portland	Onroad mobile	0.07
West of Gorge	Other area	0.07
Portland	Nonroad	0.07
BC		0.05
NW of Gorge	Other area	0.04
Gorge	Nonroad	0.04
Outside 4 km domain	Outside 4 km domain	0.03
NW of Gorge	Nonroad	0.03
Gorge	Onroad mobile	0.02
IC		0.02
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Outside 4 km domain	Outside 4 km domain	0.0179
IC		0.0068
BC		0.0049
Portland	Other area	0.0045
West of Gorge	Other area	0.0021
Gorge	Other area	0.0017
NW of Gorge	Other area	0.0016
East of Gorge	Other area	0.0002
Gorge	Onroad mobile	0.0000
Portland	Onroad mobile	0.0000
NW of Gorge	Onroad mobile	0.0000
West of Gorge	Onroad mobile	0.0000
East of Gorge	Onroad mobile	0.0000

Table 7-1 (concluded).

Top Other Fine PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.30
Gorge	Other area	0.09
West of Gorge	Other area	0.09
Outside 4 km domain	Outside 4 km domain	0.08
NW of Gorge	Other area	0.07
Portland	Onroad mobile	0.06
NW of Gorge	Pulp mills	0.04
Gorge	Onroad mobile	0.02
IC		0.02
West of Gorge	EGUs	0.02
East of Gorge	Wildfires	0.02
Portland	Other points	0.01
West of Gorge	Onroad mobile	0.01
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Onroad mobile	0.203
Portland	Onroad mobile	0.069
Outside 4 km domain	Outside 4 km domain	0.013
Gorge	Other area	0.012
West of Gorge	Onroad mobile	0.007
Portland	Other area	0.006
West of Gorge	Other area	0.004
NW of Gorge	Onroad mobile	0.004
East of Gorge	Onroad mobile	0.003
BC		0.002
NW of Gorge	Other area	0.001
IC		0.001
East of Gorge	Other area	0.000
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.223
BC		0.077
Portland	Pulp mills	0.055
Gorge	Other area	0.039
Portland	Other fires	0.025
NW of Gorge	Other points	0.024
NW of Gorge	Pulp mills	0.021
Portland	Onroad mobile	0.019
Portland	Other points	0.014
NW of Gorge	Other area	0.010
Gorge	Onroad mobile	0.009
West of Gorge	Other area	0.007
Portland	Nonroad	0.006

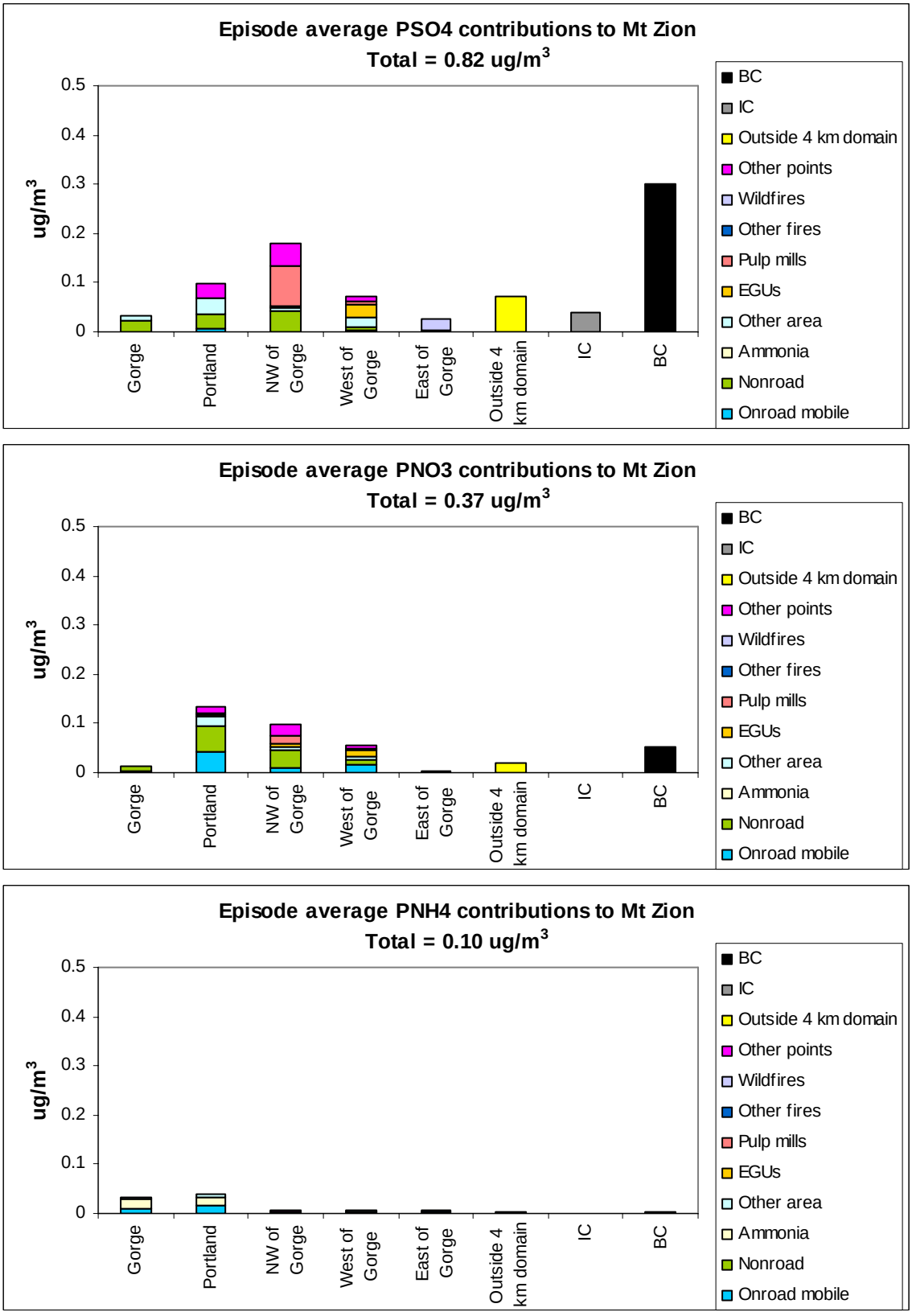
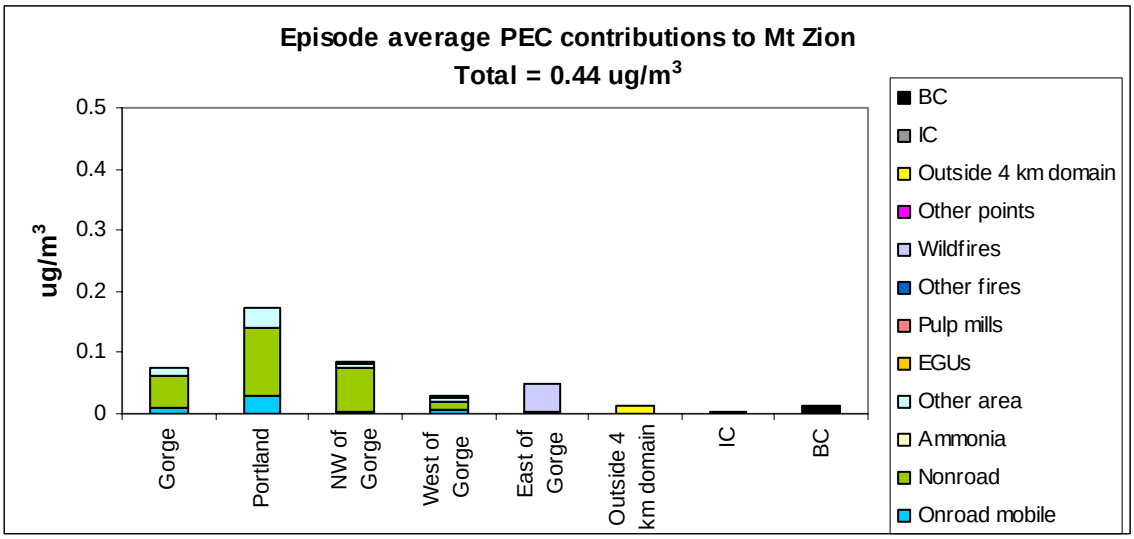
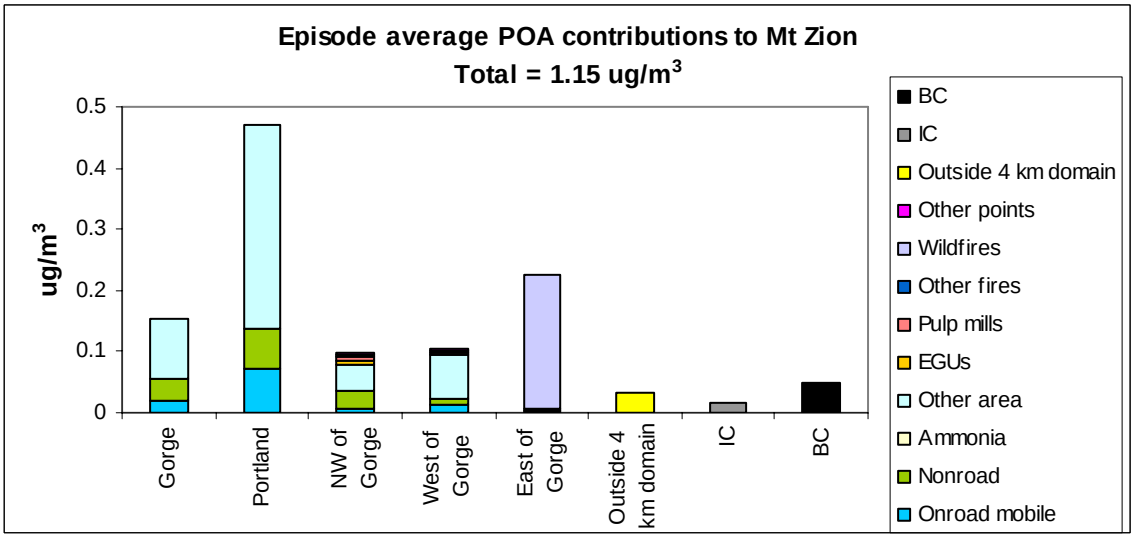


Figure 7-1. PSAT category-region breakdown at Mt Zion for August 2018 episode-average PM concentrations.





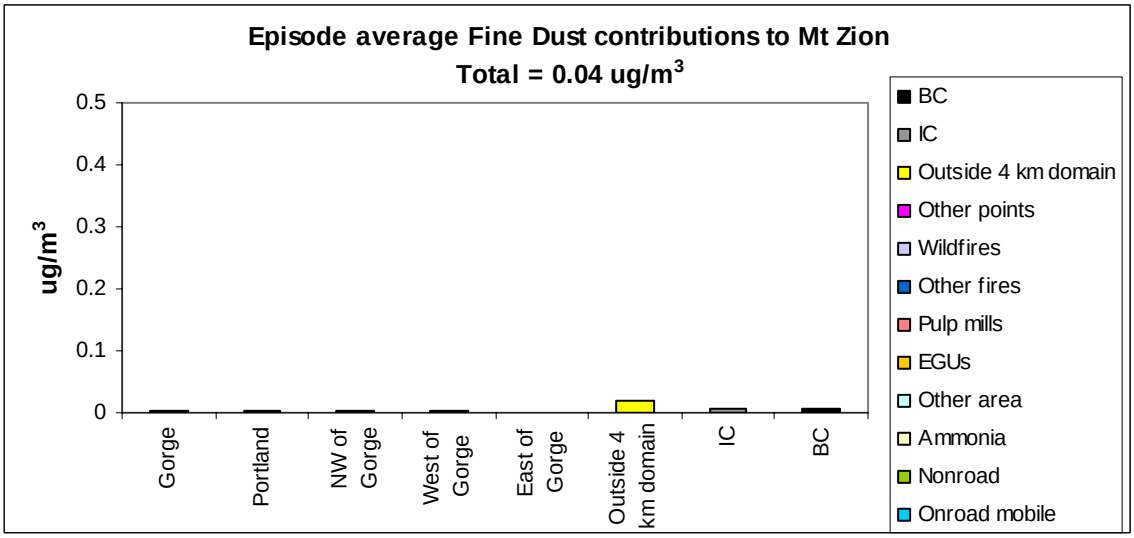
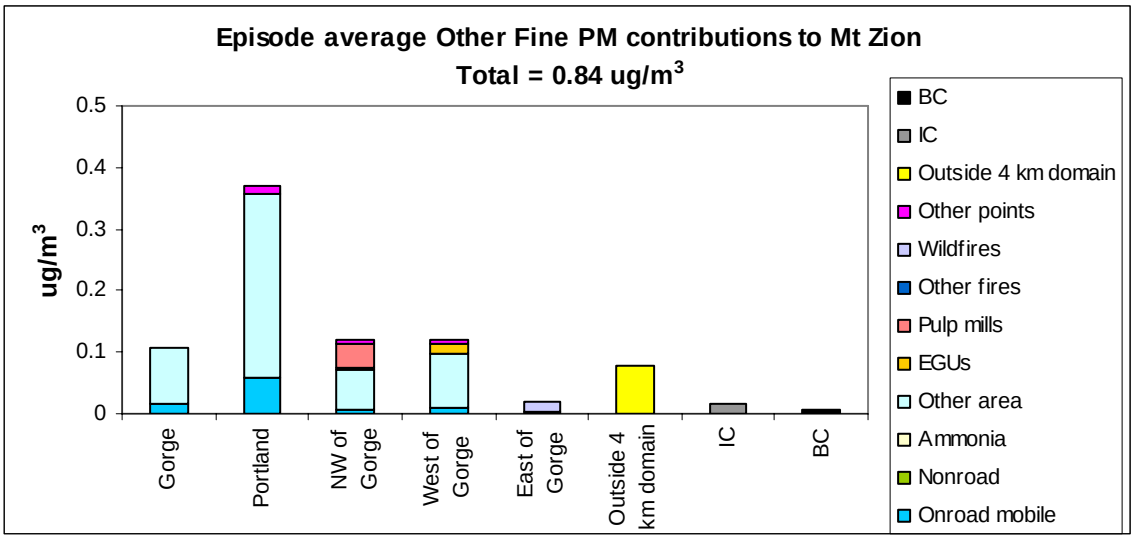
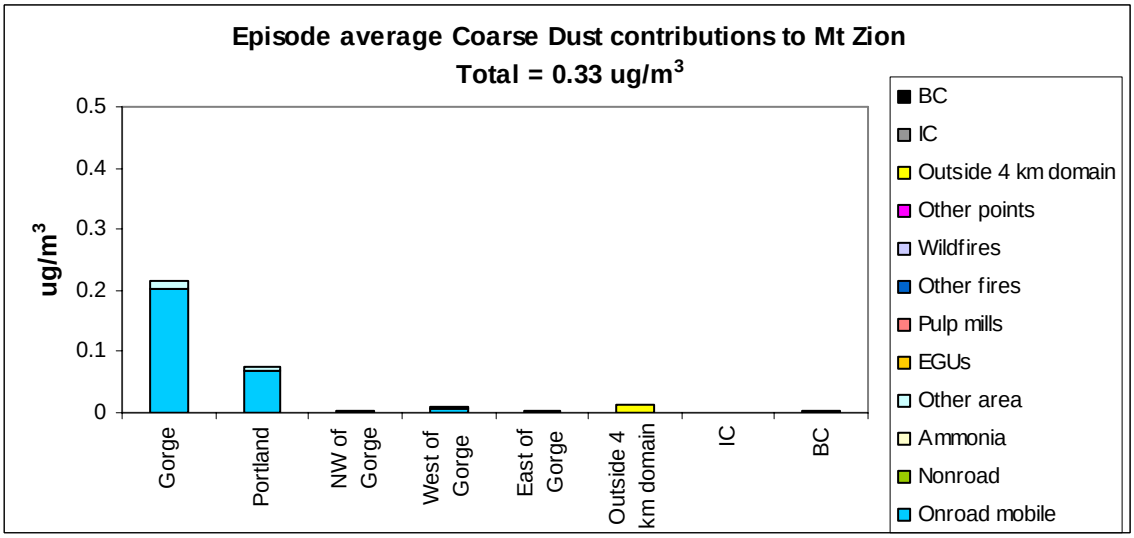


Figure 7-1 (continued).





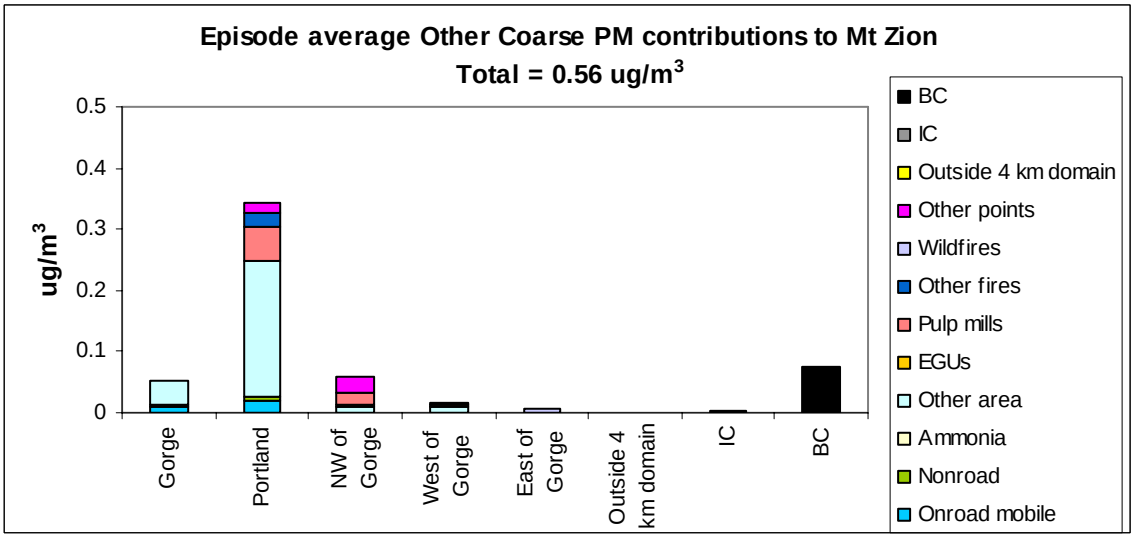


Figure 7-1 (concluded).

When the apportionment of PM concentrations was converted to light extinction, of the projected 2018 non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (16%);
2. Primary organic carbon from Portland area sources (6%);
3. Elemental carbon from Portland non-road sources (5%);
4. Sulfate from pulp mills northwest of Portland (4%); and
5. Primary organic carbon from eastern OR/WA wildfires (4%).

Table 7-2 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

7.1.2 2018 August PSAT Results at Wishram

Table 7-3 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the August 2018 episode at the Wishram monitoring site. Figure 7-2 presents this information graphically (showing all category/region pairing contributions).

As seen for the Mt Zion site, initial and boundary conditions and areas outside the 4-km domain contribute to the bulk of sulfate during this episode at Wishram. However, there is a stronger influence from local Gorge area sources and wildfires in the eastern portion of the 4-km grid, and a smaller influence from Portland and the western areas. Nitrate is primarily attributed to local and upwind regions to the west, from on-road and non-road sources. Ammonium has a strong source locally in the Gorge and in the eastern area from ammonia-specific sources, which are dominated by agricultural activities. Primary elemental and organic carbon components indicate a rather strong contribution from wildfires occurring in north-eastern Washington during this episode; elemental carbon further shows a large contribution from in-gorge non-road sources, which implicate diesel emissions from railroads, barges, and off-road equipment. Primary organics show a relatively large attribution to local Gorge area sources and regional fires. Coarse and fine dust are nearly entirely from in-gorge on-road and area sources, while other fine/coarse fractions of primary PM are mostly from area sources (again, mostly agricultural activities) and fires. Note that the fine and coarse dust contributions from local in-Gorge area sources are much higher in 2018 than seen in the 2004 PSAT results. This was tracked to a particular grid cell near Seven Mile Hill that includes a large source of primary PM emissions in the 2018 WRAP inventory. The cause of this increase from 2004 is not known; but differences such as this can result from the use of two independently-derived emission inventories (i.e., 2004 vs. 2018).

Of the projected 2018 non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Primary organic carbon from eastern OR/WA wildfires (16%);
2. Sulfate from local Gorge area sources (15%);
3. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (11%);
4. Elemental carbon from eastern OR/WA wildfires (9%); and
5. Primary organic carbon from local Gorge area sources (6%).

Table 7-2. Ranked list of source region/categories contributing to visibility-impairing haze over the August 2018 episode at Mt Zion. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
Sulfate	BC		0.3001	3.48	16%
POA	Portland	Other area	0.3314	1.33	6%
EC	Portland	Nonroad	0.1106	1.11	5%
Sulfate	NW of Gorge	Pulp mills	0.08081	0.94	4%
POA	East of Gorge	Wildfires	0.2186	0.87	4%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.0729	0.85	4%
EC	NW of Gorge	Nonroad	0.07233	0.72	3%
Nitrate	Portland	Nonroad	0.055	0.60	3%
Nitrate	BC		0.0517	0.56	3%
EC	Gorge	Nonroad	0.05468	0.55	3%
Sulfate	NW of Gorge	Other points	0.04477	0.52	2%
Sulfate	NW of Gorge	Nonroad	0.04219	0.49	2%
EC	East of Gorge	Wildfires	0.0466	0.47	2%
Nitrate	Portland	Onroad mobile	0.04136	0.45	2%
Nitrate	NW of Gorge	Nonroad	0.03616	0.39	2%
POA	Gorge	Other area	0.09737	0.39	2%
Sulfate	Portland	Other area	0.03332	0.39	2%
Sulfate	Portland	Other points	0.03006	0.35	2%
Sulfate	Portland	Nonroad	0.02875	0.33	2%
EC	Portland	Other area	0.03253	0.33	1%
Sulfate	West of Gorge	EGUs	0.02715	0.31	1%
EC	Portland	Onroad mobile	0.03069	0.31	1%
Fine Other	Portland	Other area	0.3003	0.30	1%
POA	Portland	Onroad mobile	0.07316	0.29	1%
POA	West of Gorge	Other area	0.07061	0.28	1%
POA	Portland	Nonroad	0.0651	0.26	1%
Nitrate	NW of Gorge	Other points	0.02306	0.25	1%
Sulfate	East of Gorge	Wildfires	0.02152	0.25	1%
Sulfate	Gorge	Nonroad	0.02122	0.25	1%
Nitrate	Outside 4 km domain	Outside 4 km domain	0.01929	0.21	1%
Nitrate	Portland	Other area	0.01902	0.21	1%
Sulfate	West of Gorge	Other area	0.01754	0.20	1%
POA	BC		0.05009	0.20	1%
Nitrate	NW of Gorge	Pulp mills	0.01639	0.18	1%
POA	NW of Gorge	Other area	0.04348	0.17	1%
Nitrate	West of Gorge	Onroad mobile	0.01553	0.17	1%
Nitrate	West of Gorge	EGUs	0.01404	0.15	1%
POA	Gorge	Nonroad	0.03587	0.14	1%
EC	West of Gorge	Nonroad	0.01339	0.13	1%
POA	Outside 4 km domain	Outside 4 km domain	0.03342	0.13	1%

Table 7-3. Top source region-category groups simulated to contribute more than 90% of total August 2018 episode-average PM mass concentrations at the Wishram site by PM component species (see Figure 7-2 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.26
BC		0.20
East of Gorge	Wildfires	0.06
Outside 4 km domain	Outside 4 km domain	0.06
IC		0.05
Gorge	Nonroad	0.02
West of Gorge	Other area	0.02
West of Gorge	EGUs	0.02
Portland	Other points	0.01
NW of Gorge	Pulp mills	0.01
NW of Gorge	Other points	0.01
West of Gorge	Other points	0.01
West of Gorge	Nonroad	0.01
Top PNO3 Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.030
West of Gorge	EGUs	0.023
Gorge	Nonroad	0.015
West of Gorge	Onroad mobile	0.015
Portland	Onroad mobile	0.013
Portland	Nonroad	0.013
West of Gorge	Nonroad	0.011
Outside 4 km domain	Outside 4 km domain	0.009
NW of Gorge	Nonroad	0.008
NW of Gorge	Other points	0.006
Portland	Other area	0.006
West of Gorge	Other area	0.005
Gorge	Other area	0.005
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Ammonia	0.032
East of Gorge	Ammonia	0.028
Gorge	Onroad mobile	0.013
East of Gorge	Wildfires	0.011
Outside 4 km domain	Outside 4 km domain	0.008
BC		0.006
East of Gorge	Other area	0.004
West of Gorge	Ammonia	0.003
IC		0.002
West of Gorge	Onroad mobile	0.002
West of Gorge	Other area	0.002
Portland	Ammonia	0.001
East of Gorge	Onroad mobile	0.001

Table 7-3 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Wildfires	0.175
Gorge	Nonroad	0.093
West of Gorge	Nonroad	0.017
BC		0.015
Outside 4 km domain	Outside 4 km domain	0.013
NW of Gorge	Nonroad	0.011
West of Gorge	Other area	0.010
Portland	Nonroad	0.009
West of Gorge	Onroad mobile	0.007
Gorge	Onroad mobile	0.006
East of Gorge	Nonroad	0.005
IC		0.004
Gorge	Other area	0.004
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Wildfires	0.80
Gorge	Other area	0.28
West of Gorge	Other area	0.06
Outside 4 km domain	Outside 4 km domain	0.04
BC		0.03
Gorge	Nonroad	0.02
Portland	Other area	0.02
IC		0.01
West of Gorge	Onroad mobile	0.01
West of Gorge	Nonroad	0.01
Gorge	Onroad mobile	0.01
East of Gorge	Other fires	0.01
NW of Gorge	Other area	0.01
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.0929
Outside 4 km domain	Outside 4 km domain	0.0304
BC		0.0129
IC		0.0105
East of Gorge	Other area	0.0028
Portland	Other area	0.0011
West of Gorge	Other area	0.0010
NW of Gorge	Other area	0.0002
Gorge	Onroad mobile	0.0000
Portland	Onroad mobile	0.0000
NW of Gorge	Onroad mobile	0.0000
West of Gorge	Onroad mobile	0.0000
East of Gorge	Onroad mobile	0.0000

Table 7-3 (concluded).

Top Other Fine PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.908
West of Gorge	Other area	0.065
Outside 4 km domain	Outside 4 km domain	0.059
East of Gorge	Wildfires	0.049
Portland	Other area	0.014
IC		0.013
West of Gorge	Onroad mobile	0.008
BC		0.008
East of Gorge	Other area	0.008
West of Gorge	EGUs	0.007
Gorge	Onroad mobile	0.006
NW of Gorge	Other area	0.006
Portland	Onroad mobile	0.003
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.3472
Gorge	Onroad mobile	0.1719
Outside 4 km domain	Outside 4 km domain	0.0575
East of Gorge	Onroad mobile	0.0391
BC		0.0092
East of Gorge	Other area	0.0087
West of Gorge	Onroad mobile	0.0027
IC		0.0025
Portland	Onroad mobile	0.0017
Portland	Other area	0.0005
West of Gorge	Other area	0.0003
NW of Gorge	Onroad mobile	0.0002
NW of Gorge	Other area	0.0001
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.103
East of Gorge	Wildfires	0.062
Gorge	Other area	0.015
IC		0.014
East of Gorge	Other area	0.007
Portland	Other area	0.004
Gorge	Onroad mobile	0.004
Gorge	Other fires	0.004
West of Gorge	Other area	0.004
Outside 4 km domain	Outside 4 km domain	0.003
East of Gorge	Other points	0.003
Gorge	Nonroad	0.003
West of Gorge	EGUs	0.001

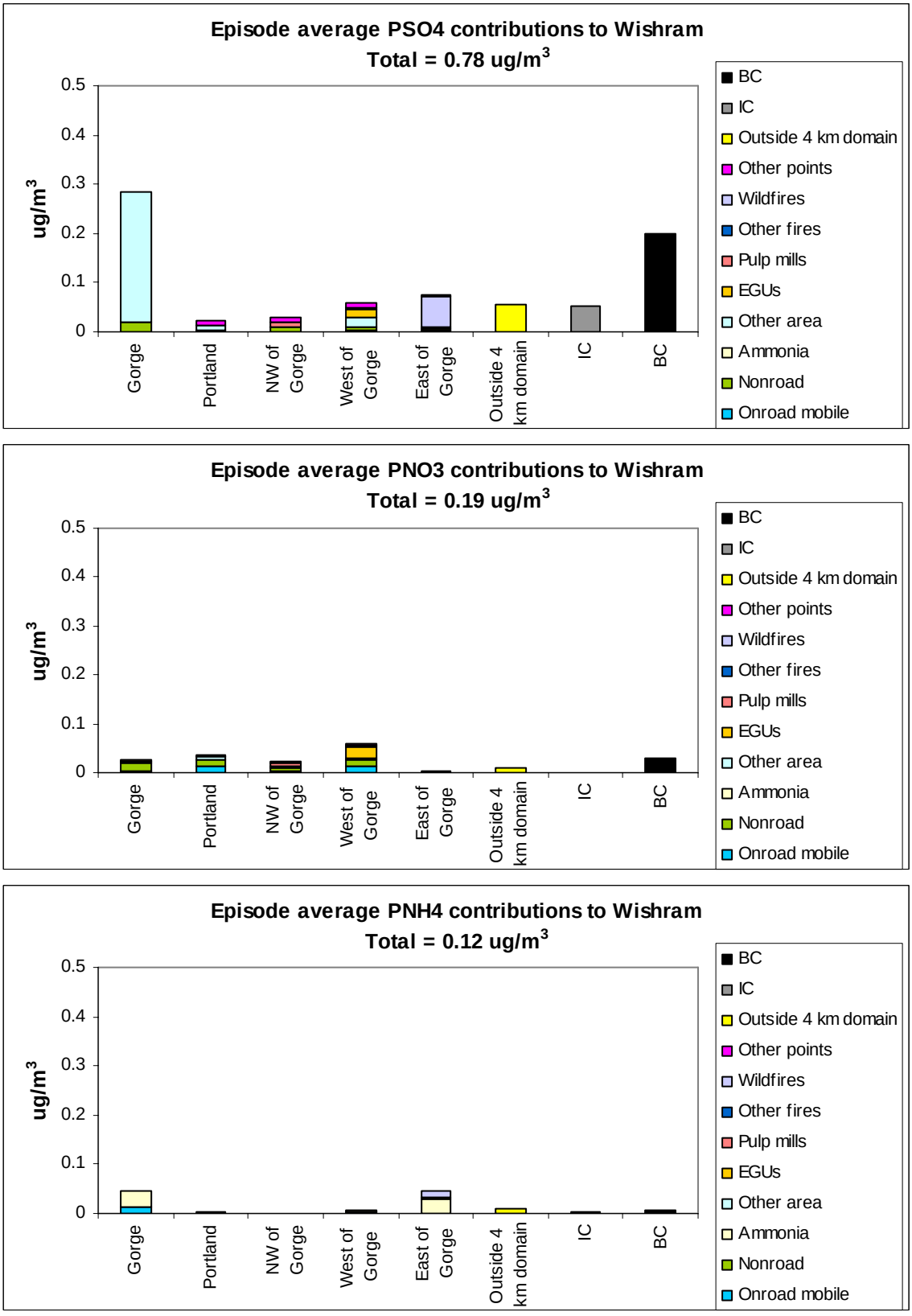
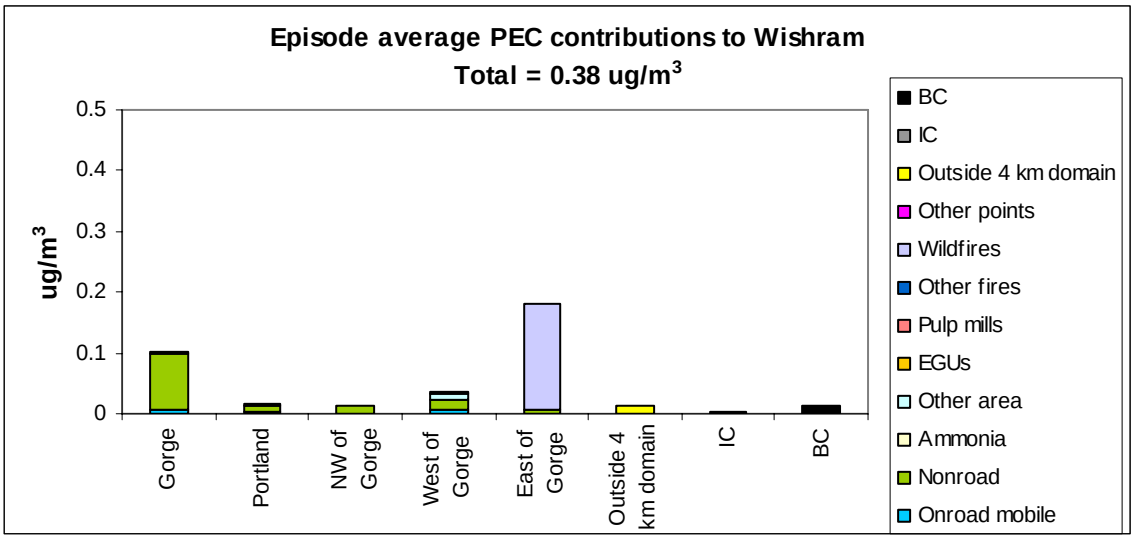
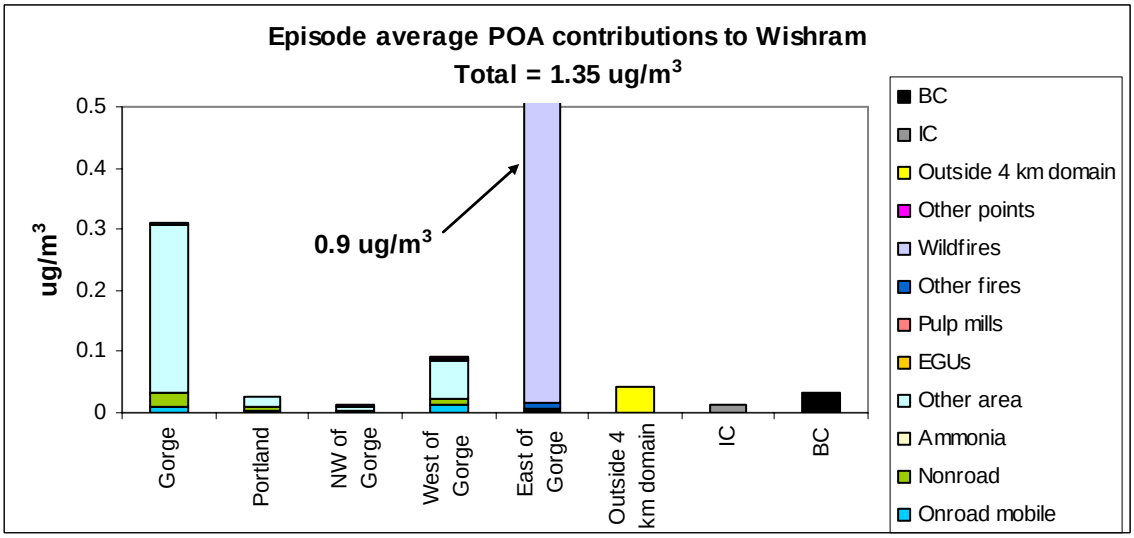


Figure 7-2. PSAT category-region breakdown at Wishram for August 2018 episode-average PM concentrations.





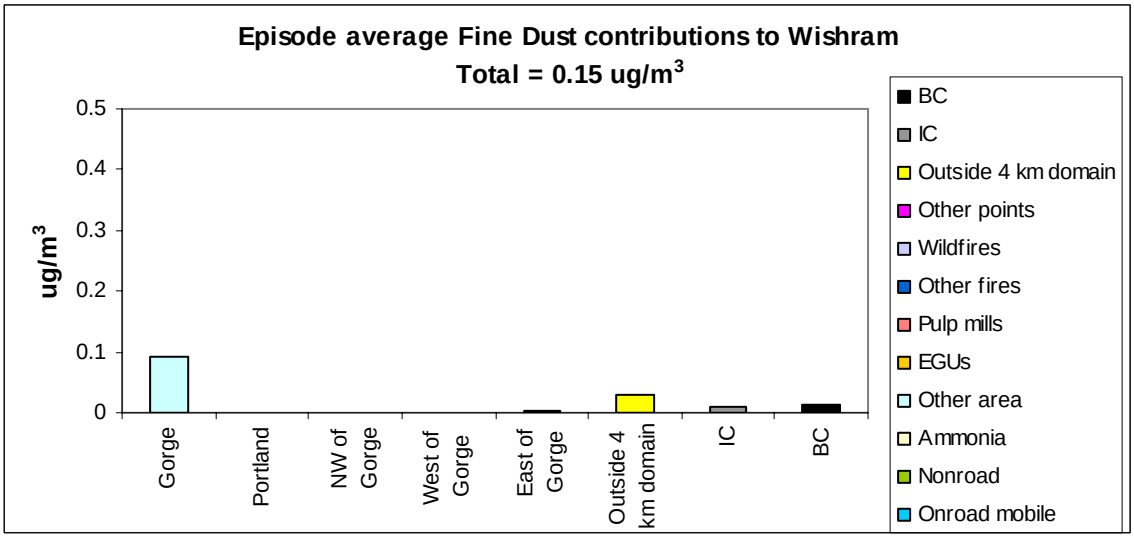
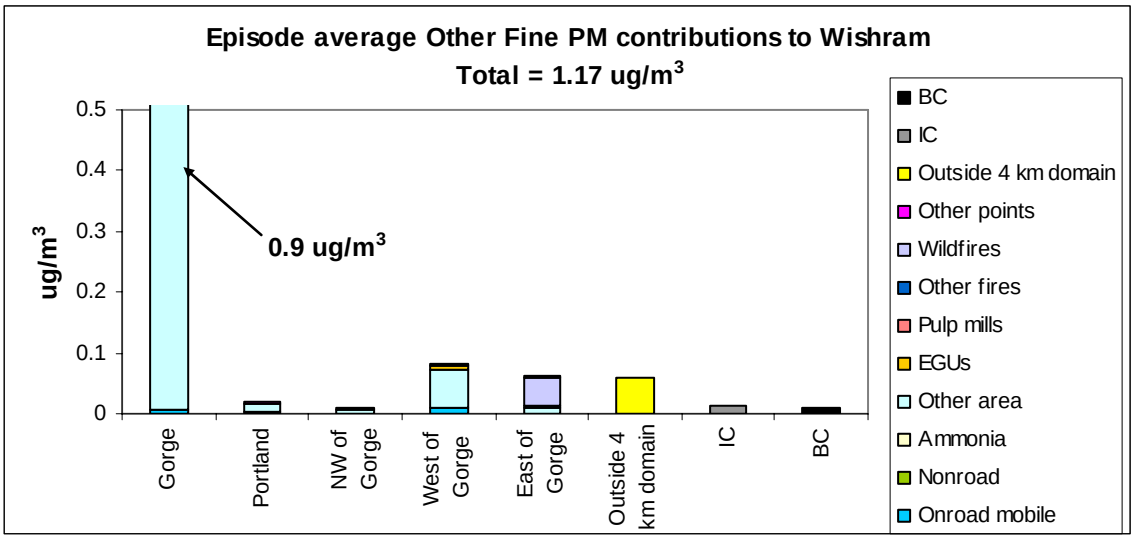
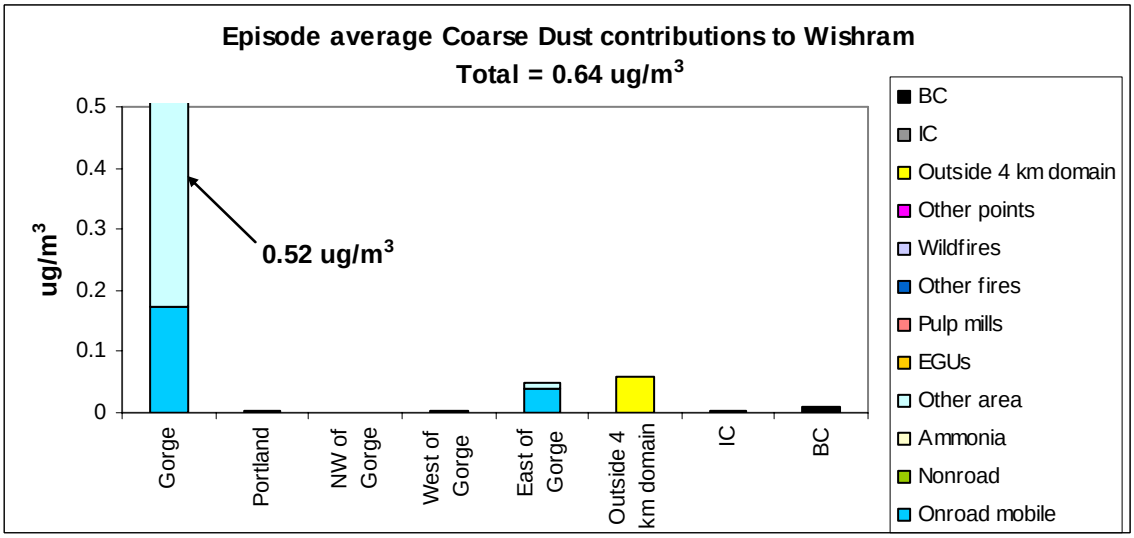


Figure 7-2 (continued).





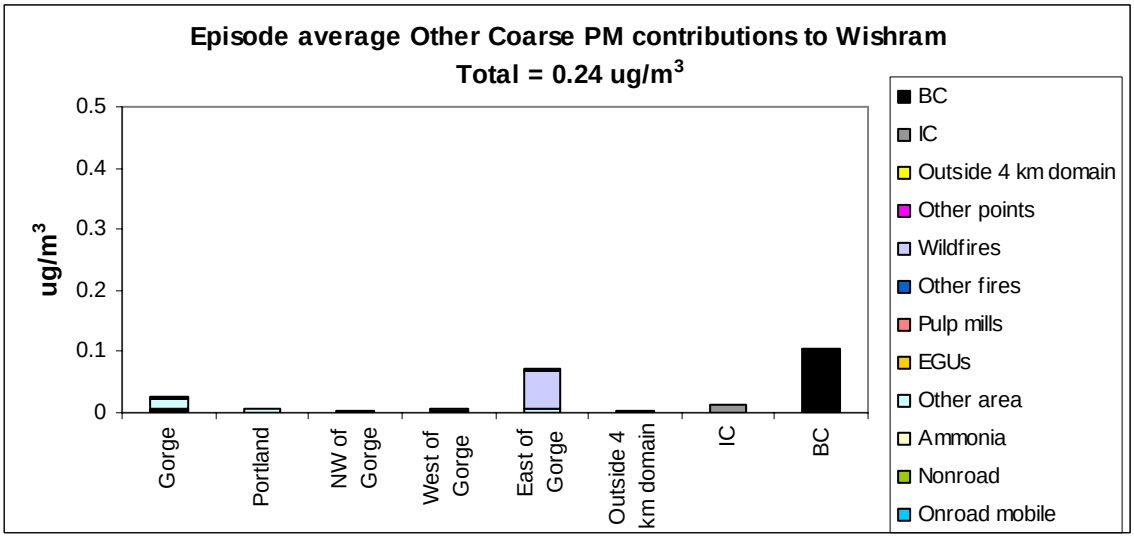


Figure 7-2 (concluded).

Table 7-4 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

Table 7-4. Ranked list of source region/categories contributing to visibility-impairing haze over the August 2018 episode at Wishram. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
POA	East of Gorge	Wildfires	0.8011	3.20	16%
Sulfate	Gorge	Other area	0.2636	2.97	15%
Sulfate	BC		0.1988	2.24	11%
EC	East of Gorge	Wildfires	0.1749	1.75	9%
POA	Gorge	Other area	0.2754	1.10	6%
EC	Gorge	Nonroad	0.09281	0.93	5%
Fine Other	Gorge	Other area	0.9082	0.91	5%
Sulfate	East of Gorge	Wildfires	0.06208	0.70	3%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.05549	0.62	3%
Nitrate	BC		0.02978	0.31	2%
POA	West of Gorge	Other area	0.06417	0.26	1%
Nitrate	West of Gorge	EGUs	0.02343	0.25	1%
Sulfate	Gorge	Nonroad	0.01979	0.22	1%
Coarse Dust	Gorge	Other area	0.3472	0.21	1%
Sulfate	West of Gorge	Other area	0.01733	0.20	1%
Sulfate	West of Gorge	EGUs	0.0172	0.19	1%
POA	Outside 4 km domain	Outside 4 km domain	0.04317	0.17	1%
EC	West of Gorge	Nonroad	0.01702	0.17	1%
Nitrate	Gorge	Nonroad	0.01533	0.16	1%
Nitrate	West of Gorge	Onroad mobile	0.01479	0.16	1%
EC	BC		0.01473	0.15	1%
Nitrate	Portland	Onroad mobile	0.01326	0.14	1%
Nitrate	Portland	Nonroad	0.0127	0.13	1%
EC	Outside 4 km domain	Outside 4 km domain	0.01333	0.13	1%
Sulfate	Portland	Other points	0.01182	0.13	1%
POA	BC		0.03324	0.13	1%
Nitrate	West of Gorge	Nonroad	0.01092	0.12	1%
Sulfate	NW of Gorge	Pulp mills	0.01023	0.12	1%
EC	NW of Gorge	Nonroad	0.01087	0.11	1%
Sulfate	NW of Gorge	Other points	0.009214	0.10	1%

7.2 PSAT APPLICATION FOR NOVEMBER 2018

7.2.1 November 2018 PSAT Results at Mt Zion

Table 7-5 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the November 2018 episode at the Mt Zion monitoring site. The number of category/regions shown for each PM component result in at least 90% of the total episode-average mass concentration for that species. Figure 7-3 presents this information graphically (showing all category/region pairing contributions).

As described in Section 5, secondary sulfate/nitrate/ammonium salts continue to dominate the mass budgets during the November episode in 2018. Several $\mu g/m^3$ are predicted for episode-average sulfate, but the largest contributor is no longer EGU emissions since SO_2 controls are reflected in the future year inventory. However, a wide array of source types and areas contribute to the Mt Zion sulfate, including local area sources and initial/boundary conditions and areas outside the 4-km domain, indicating the regional nature of this secondary pollutant. Nitrate also remains rather high (nearly 2 $\mu g/m^3$), with large contributions from on-road, non-road, and area NOx sources mainly from Portland and areas to the west and along the Gorge. Ammonium is attributed to specific ammonia sources (mostly agricultural activities such as feed lots and fertilizer applications). Again, a vast area of emissions contributes to ammonium, but most comes from the eastern Gorge area where there are some large agricultural sources. Both elemental and organic carbon show some contributions from on-road and non-road sources within the Gorge and from Portland, but now the POA is apportioned in large measure to area sources. Elemental carbon in particular has a large non-road component, likely due to heavy duty diesel engines on off-road equipment, barges, and railroads. The area source contribution to POA is dominated by residential wood smoke, both locally and from the Portland area. Coarse/fine dust are mostly locally generated, and given the wetter nature of the November episode, are likely overstated since the modeling emissions inventory does not account for local day-specific rainfall patterns. Most sources of primary fine/coarse PM are very local in origin and are likely from fugitive and wind-blown dust sources as well as road dust.

Of the projected 2018 non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (12%);
2. Sulfate from local Gorge area sources (10%);
3. Sulfate from Portland area sources (6%);
4. Nitrate from Portland on-road sources (5%); and
5. Nitrate from Portland non-road sources (4%).

Table 7-6 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

Table 7-5. Top source region-category groups simulated to contribute more than 90% of total episode-average PM mass concentrations at the Mt Zion site by PM component species (see Figure 7-3 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.58
Gorge	Other area	0.48
Portland	Other area	0.29
East of Gorge	EGUs	0.16
Outside 4 km domain	Outside 4 km domain	0.16
Portland	Other points	0.11
Gorge	Nonroad	0.10
West of Gorge	Other area	0.09
IC		0.08
East of Gorge	Pulp mills	0.08
Portland	Nonroad	0.06
NW of Gorge	Other points	0.06
East of Gorge	Other points	0.06
Top PNO3 Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Onroad mobile	0.24
Portland	Nonroad	0.23
BC		0.23
Portland	Other area	0.15
West of Gorge	Onroad mobile	0.12
West of Gorge	Nonroad	0.12
Gorge	Nonroad	0.12
IC		0.10
East of Gorge	Nonroad	0.07
West of Gorge	Other area	0.06
Outside 4 km domain	Outside 4 km domain	0.06
NW of Gorge	Nonroad	0.05
East of Gorge	Other area	0.04
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Ammonia	0.21
Portland	Onroad mobile	0.13
Portland	Ammonia	0.11
Gorge	Onroad mobile	0.10
West of Gorge	Ammonia	0.10
Gorge	Ammonia	0.09
East of Gorge	Other area	0.04
BC		0.03
Outside 4 km domain	Outside 4 km domain	0.03
Portland	Other area	0.02
West of Gorge	Onroad mobile	0.02
West of Gorge	Other fires	0.01
East of Gorge	Onroad mobile	0.01

Table 7-5 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.14
Gorge	Nonroad	0.12
Gorge	Other area	0.11
Portland	Nonroad	0.08
Outside 4 km domain	Outside 4 km domain	0.04
Portland	Onroad mobile	0.03
BC		0.03
West of Gorge	Other area	0.03
Gorge	Other fires	0.03
East of Gorge	Nonroad	0.02
Gorge	Onroad mobile	0.02
West of Gorge	Nonroad	0.02
East of Gorge	Other fires	0.01
Top POA Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	1.02
Portland	Other area	0.85
Outside 4 km domain	Outside 4 km domain	0.17
West of Gorge	Other area	0.15
Gorge	Other fires	0.14
Portland	Onroad mobile	0.08
East of Gorge	Other fires	0.08
BC		0.08
East of Gorge	Other area	0.07
Gorge	Nonroad	0.06
West of Gorge	Other fires	0.06
Portland	Nonroad	0.05
Gorge	Onroad mobile	0.05
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.1071
East of Gorge	Other area	0.0395
Outside 4 km domain	Outside 4 km domain	0.0102
West of Gorge	Other area	0.0019
Portland	Other area	0.0014
BC		0.0001
IC		0.0000
NW of Gorge	Other area	0.0000
Gorge	Onroad mobile	0.0000
Portland	Onroad mobile	0.0000
NW of Gorge	Onroad mobile	0.0000
West of Gorge	Onroad mobile	0.0000
East of Gorge	Onroad mobile	0.0000

Table 7-5 (concluded).

Top Other Fine PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	2.32
Portland	Other area	0.57
West of Gorge	Other area	0.12
Outside 4 km domain	Outside 4 km domain	0.10
BC		0.08
East of Gorge	Other area	0.07
Portland	Onroad mobile	0.06
Gorge	Onroad mobile	0.04
IC		0.03
West of Gorge	Other fires	0.02
East of Gorge	EGUs	0.02
NW of Gorge	Other area	0.01
Gorge	Other fires	0.01
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.5920
Gorge	Onroad mobile	0.3320
Portland	Onroad mobile	0.1037
West of Gorge	Onroad mobile	0.0196
East of Gorge	Other area	0.0122
East of Gorge	Onroad mobile	0.0114
Outside 4 km domain	Outside 4 km domain	0.0032
NW of Gorge	Onroad mobile	0.0009
Portland	Other area	0.0009
West of Gorge	Other area	0.0002
BC		0.0000
NW of Gorge	Other area	0.0000
IC		0.0000
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Portland	Other area	0.511
Gorge	Other area	0.441
BC		0.073
IC		0.016
Portland	Pulp mills	0.014
Portland	Other fires	0.010
West of Gorge	Other area	0.010
West of Gorge	Other points	0.006
Gorge	Nonroad	0.005
West of Gorge	Pulp mills	0.005
West of Gorge	Other fires	0.005
Portland	Nonroad	0.004

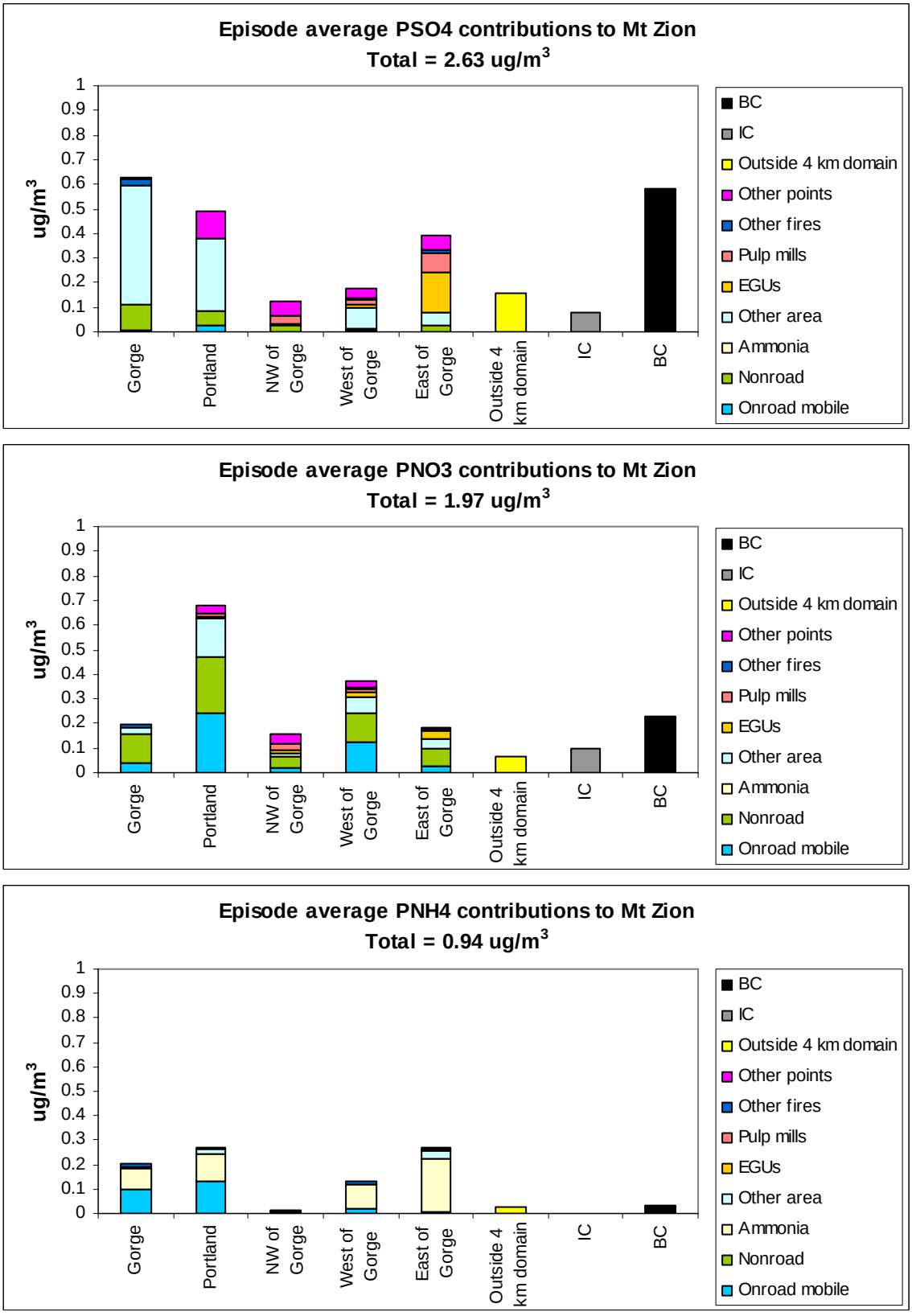
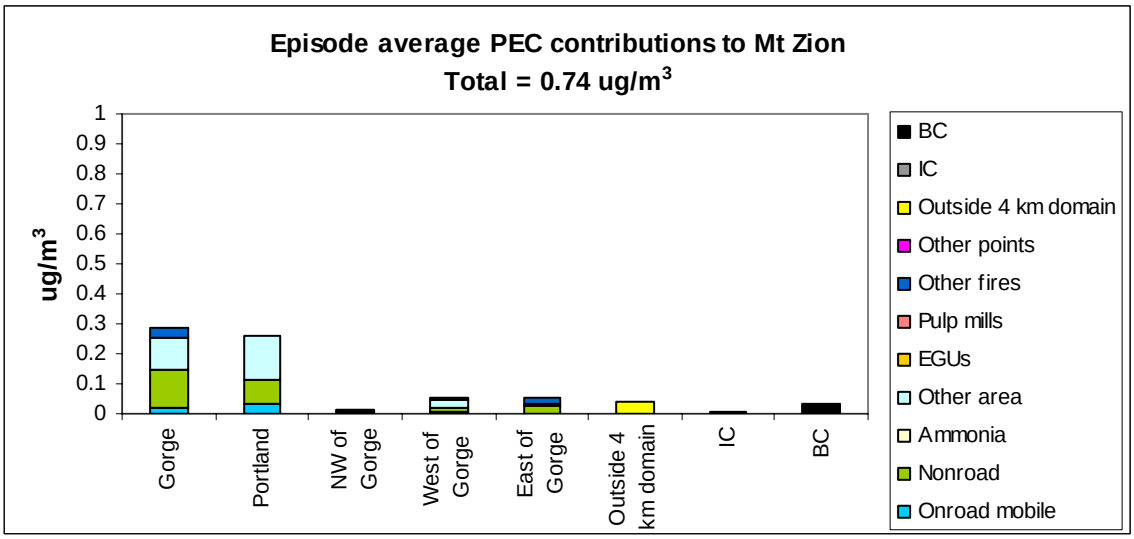
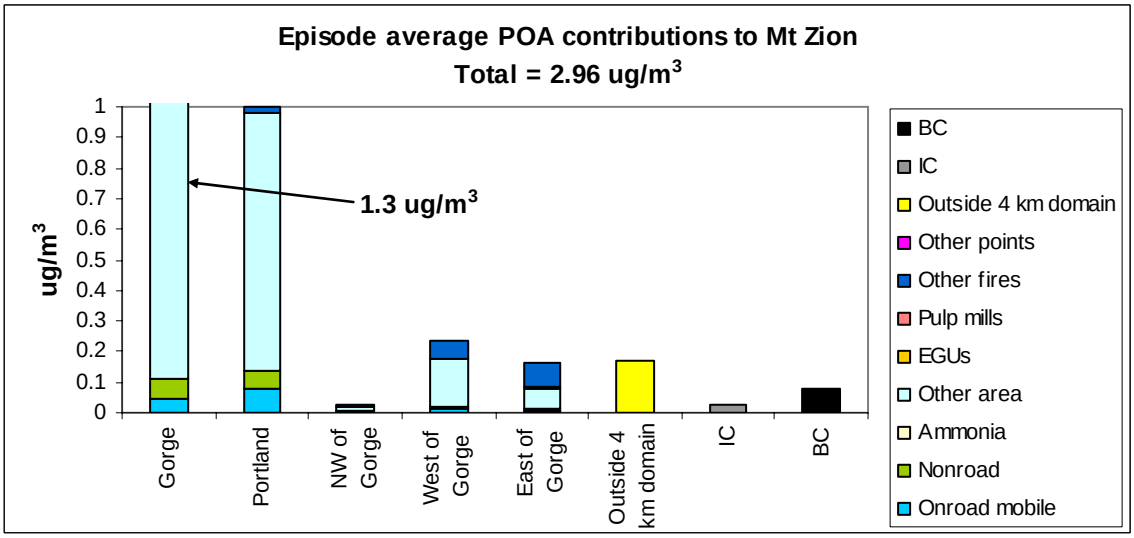


Figure 7-3. PSAT category-region breakdown at Mt Zion for November 2018 episode-average PM concentrations.





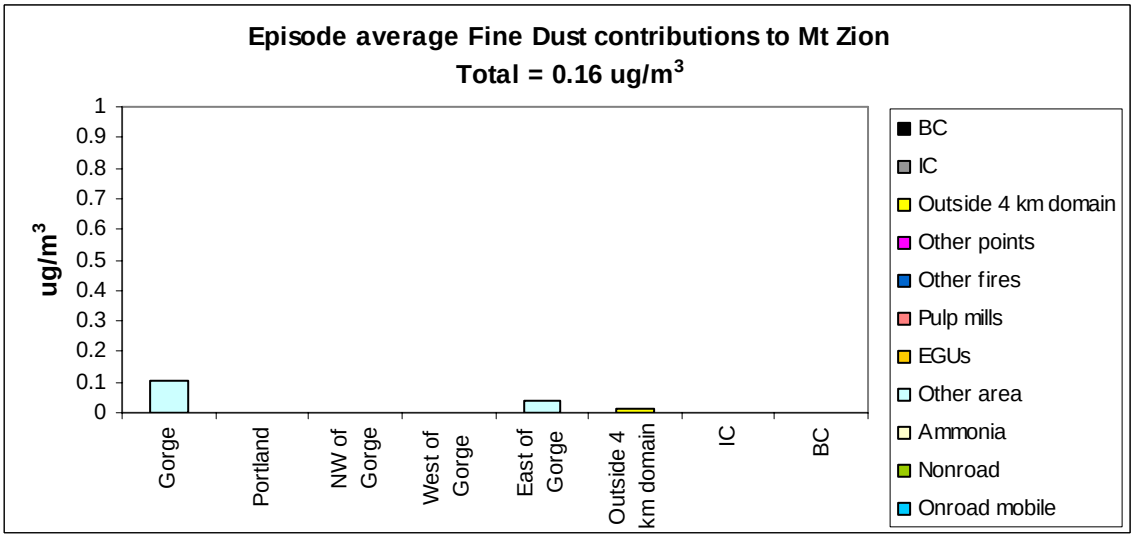
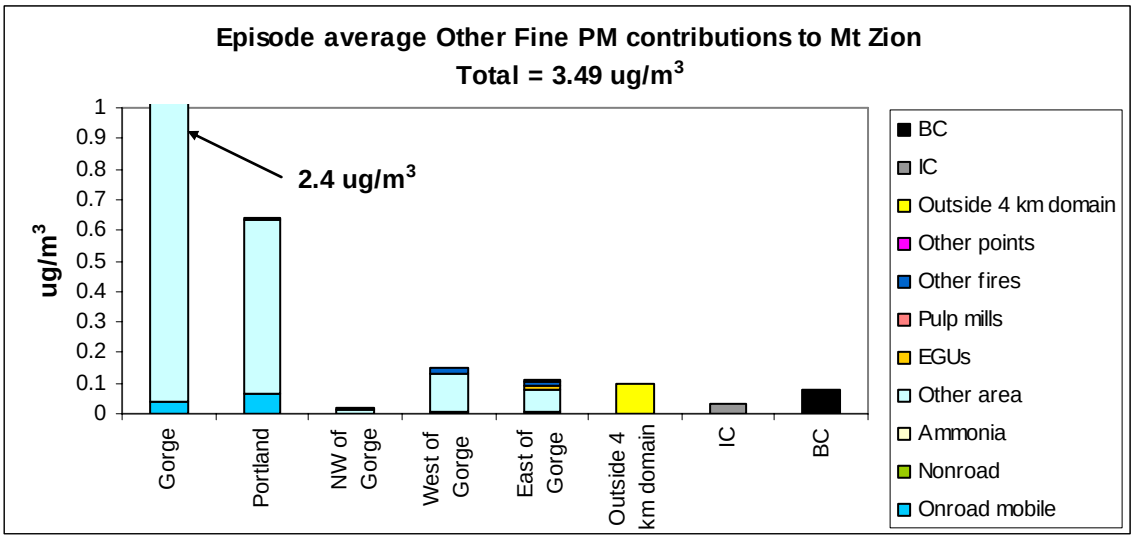
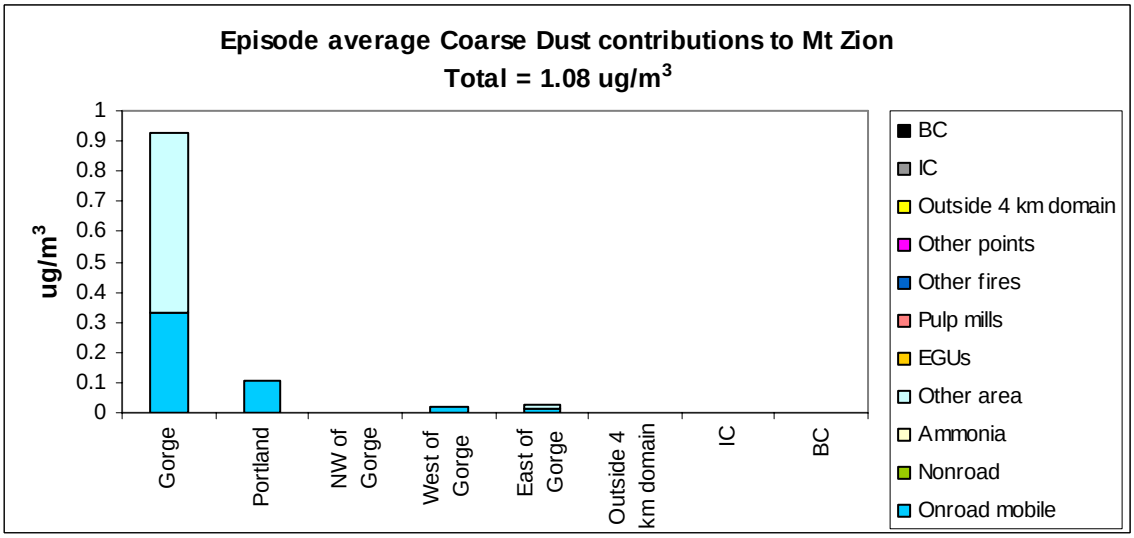


Figure 7-3 (continued).





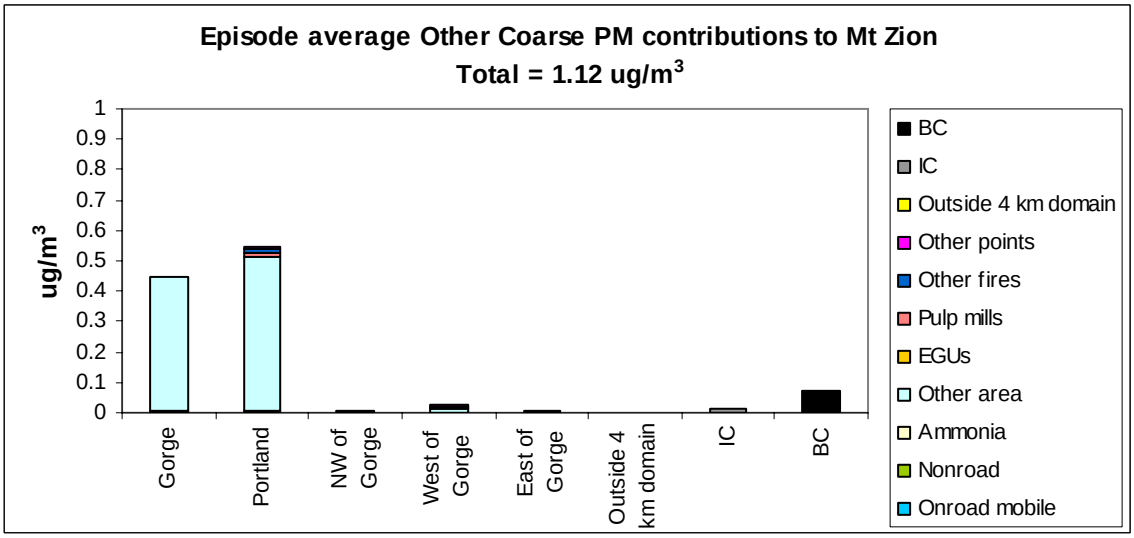


Figure 7-3 (concluded).

Table 7-6. Ranked list of source region/categories contributing to visibility-impairing haze over the November 2018 episode at Mt Zion. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
Sulfate	BC		0.58	11.31	12%
Sulfate	Gorge	Other area	0.48	9.43	10%
Sulfate	Portland	Other area	0.29	5.73	6%
Nitrate	Portland	Onroad mobile	0.24	4.43	5%
Nitrate	Portland	Nonroad	0.23	4.22	4%
Nitrate	BC		0.23	4.17	4%
POA	Gorge	Other area	1.02	4.07	4%
POA	Portland	Other area	0.85	3.39	4%
Sulfate	East of Gorge	EGUs	0.16	3.19	3%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.16	3.02	3%
Nitrate	Portland	Other area	0.15	2.82	3%
Fine Other	Gorge	Other area	2.32	2.32	2%
Nitrate	West of Gorge	Onroad mobile	0.12	2.28	2%
Nitrate	West of Gorge	Nonroad	0.12	2.17	2%
Sulfate	Portland	Other points	0.11	2.17	2%
Nitrate	Gorge	Nonroad	0.12	2.12	2%
Sulfate	Gorge	Nonroad	0.10	1.94	2%
Sulfate	West of Gorge	Other area	0.09	1.71	2%
Sulfate	East of Gorge	Pulp mills	0.08	1.48	2%
EC	Portland	Other area	0.14	1.43	2%
Nitrate	East of Gorge	Nonroad	0.07	1.34	1%
EC	Gorge	Nonroad	0.12	1.25	1%
Nitrate	West of Gorge	Other area	0.06	1.17	1%
Sulfate	Portland	Nonroad	0.06	1.17	1%
Nitrate	Outside 4 km domain	Outside 4 km domain	0.06	1.14	1%
Sulfate	NW of Gorge	Other points	0.06	1.14	1%
Sulfate	East of Gorge	Other points	0.06	1.13	1%
EC	Gorge	Other area	0.11	1.10	1%
Nitrate	NW of Gorge	Nonroad	0.05	0.90	1%
EC	Portland	Nonroad	0.08	0.80	1%

7.2.2 2018 November PSAT Results at Wishram

Table 7-7 presents the top category/region pairings that contribute to each of the PM components tracked by PSAT over the November 2018 episode at the Wishram monitoring site. The number of category/regions shown for each PM component result in at least 90% of the total episode-average mass concentration for that species. Figure 7-4 presents this information graphically (showing all category/region pairing contributions).

Wishram continues to experience more episode-average sulfate than Mt Zion in 2018, with nearly a 4 μg/m^3 episode average. However, local EGU emissions contribute much less; sources in the eastern portion of the domain dominate, and are fairly evenly spread across several industrial source types, as well as non-road and area source categories. Nitrate is also higher at Wishram for this episode (about 4 μg/m^3), with contributions primarily from on-road, non-road, area, and EGU NOx sources in the eastern area. NOx sources outside the 4-km grid (mostly well

to the east) also contribute to nitrate. Ammonium continues to be nearly entirely attributed to local sources in the eastern area of the domain. Carbonaceous PM is much lower than the secondary salts, and also lower than the 2004 Base Case PSAT results. Most EC stems from local non-road sources in the Gorge and in the eastern area, which suggests a large contribution from diesel exhaust. POA at Wishram has local origins from area sources (residential wood combustion) and fires. Like Mt Zion, coarse/fine dust are mostly locally generated in Gorge and in the eastern area, with mostly area and on-road sources contributing. The larger area source component is again seen at Wishram, similarly to the signal identified in August from an apparently large source near Seven Mile Hill.

Of the projected 2018 non-SOA fraction tracked by PSAT, the top five ranked sources contributing to haze included:

1. Nitrate from eastern OR/WA non-road sources (12%);
2. Sulfate from super-regional sources outside the 12-km Pacific Northwest grid (9%);
3. Sulfate from eastern OR/WA EGU sources (7%);
4. Nitrate from super-regional sources outside the 12-km Pacific Northwest grid (7%);
5. Sulfate from local Gorge area sources (6%);

Table 7-8 provides a ranked list of light extinction source attribution that accounts for 90% of the total non-SOA fraction tracked by PSAT.

Table 7-7. Top source region-category groups simulated to contribute more than 90% of total episode-average PM mass concentrations at the Wishram site by PM component species (see Figure 7-4 for total episode-average concentrations for each PM component).

Top PSO4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
BC		0.70
East of Gorge	EGUs	0.58
Gorge	Other area	0.51
East of Gorge	Other area	0.48
East of Gorge	Other points	0.36
East of Gorge	Pulp mills	0.35
Outside 4 km domain	Outside 4 km domain	0.26
Gorge	Nonroad	0.18
East of Gorge	Nonroad	0.15
IC		0.07
Portland	Other area	0.03
Portland	Other points	0.03
East of Gorge	Other fires	0.02
Top PNO3 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Nonroad	1.05
BC		0.61
East of Gorge	Other area	0.53
Outside 4 km domain	Outside 4 km domain	0.49
East of Gorge	EGUs	0.37
East of Gorge	Onroad mobile	0.30
Gorge	Nonroad	0.19
IC		0.12
East of Gorge	Other points	0.06
East of Gorge	Other fires	0.04
Portland	Nonroad	0.04
Portland	Onroad mobile	0.04
Gorge	Other area	0.04
Top PNH4 Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Ammonia	1.41
East of Gorge	Other area	0.18
Gorge	Ammonia	0.13
Gorge	Onroad mobile	0.07
Outside 4 km domain	Outside 4 km domain	0.05
East of Gorge	Onroad mobile	0.05
BC		0.05
East of Gorge	EGUs	0.03
East of Gorge	Other points	0.02
East of Gorge	Other fires	0.02
West of Gorge	Ammonia	0.01
Gorge	Other fires	0.01
Portland	Onroad mobile	0.01

Table 7-7 (continued).

Top PEC Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Nonroad	0.26
East of Gorge	Nonroad	0.14
Outside 4 km domain	Outside 4 km domain	0.05
Gorge	Other fires	0.04
East of Gorge	Other area	0.04
BC		0.03
East of Gorge	Other fires	0.02
Gorge	Other area	0.02
Gorge	Onroad mobile	0.01
Portland	Other area	0.01
East of Gorge	Onroad mobile	0.01
IC		0.01
West of Gorge	Other area	0.01
Top POA Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	0.52
Gorge	Other fires	0.21
Outside 4 km domain	Outside 4 km domain	0.19
East of Gorge	Other area	0.16
East of Gorge	Other fires	0.12
Gorge	Nonroad	0.08
BC		0.07
Portland	Other area	0.05
East of Gorge	Nonroad	0.05
West of Gorge	Other area	0.04
Gorge	Onroad mobile	0.03
IC		0.02
East of Gorge	Onroad mobile	0.02
Top Fine Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Other area	0.0826
Outside 4 km domain	Outside 4 km domain	0.0188
West of Gorge	Other area	0.0004
Gorge	Other area	0.0004
Portland	Other area	0.0003
BC		0.0002
IC		0.0000
NW of Gorge	Other area	0.0000
Gorge	Onroad mobile	0.0000
Portland	Onroad mobile	0.0000
NW of Gorge	Onroad mobile	0.0000
West of Gorge	Onroad mobile	0.0000
East of Gorge	Onroad mobile	0.0000

Table 7-7 (concluded).

Top Other FIne PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Other area	2.09
East of Gorge	Other area	0.47
Outside 4 km domain	Outside 4 km domain	0.11
BC		0.10
East of Gorge	Other points	0.08
East of Gorge	EGUs	0.05
Portland	Other area	0.04
West of Gorge	Other area	0.03
IC		0.03
East of Gorge	Other fires	0.02
Gorge	Onroad mobile	0.02
Gorge	Other fires	0.02
East of Gorge	Onroad mobile	0.02
Top Coarse Dust Contributors		
Region	**Emission Group**	**[ug/m^3]**
Gorge	Onroad mobile	0.5188
East of Gorge	Onroad mobile	0.4136
East of Gorge	Other area	0.2292
Outside 4 km domain	Outside 4 km domain	0.0465
West of Gorge	Onroad mobile	0.0040
Portland	Onroad mobile	0.0030
Gorge	Other area	0.0004
NW of Gorge	Onroad mobile	0.0004
Portland	Other area	0.0002
West of Gorge	Other area	0.0002
BC		0.0001
IC		0.0000
NW of Gorge	Other area	0.0000
Top Other Coarse PM Contributors		
Region	**Emission Group**	**[ug/m^3]**
East of Gorge	Other area	0.493
BC		0.189
East of Gorge	Other points	0.129
East of Gorge	EGUs	0.095
IC		0.052
Gorge	Other area	0.032
Portland	Other area	0.013
Outside 4 km domain	Outside 4 km domain	0.013
Gorge	Nonroad	0.009
Gorge	Other fires	0.006
East of Gorge	Nonroad	0.004
East of Gorge	Pulp mills	0.003
East of Gorge	Other fires	0.003

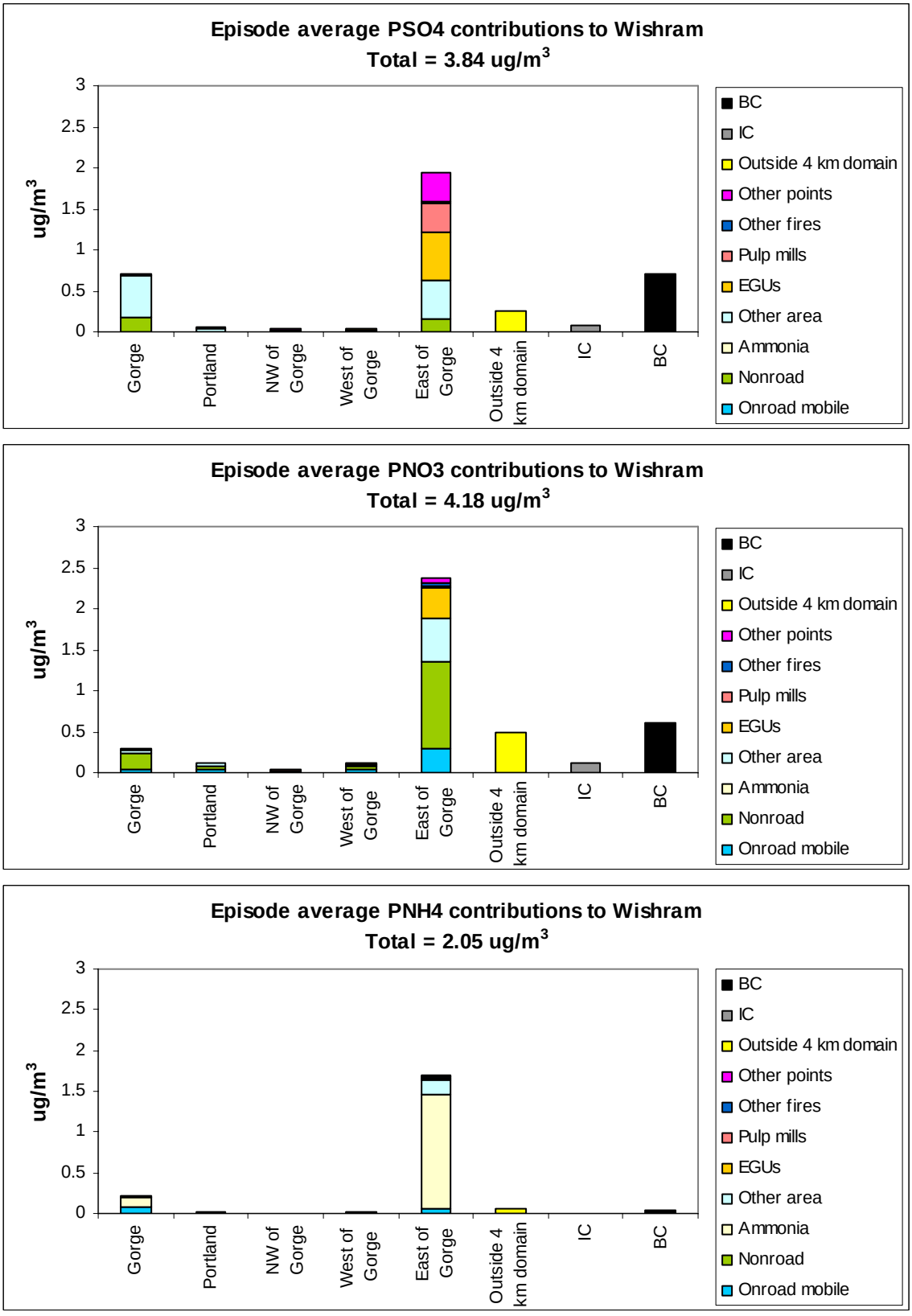
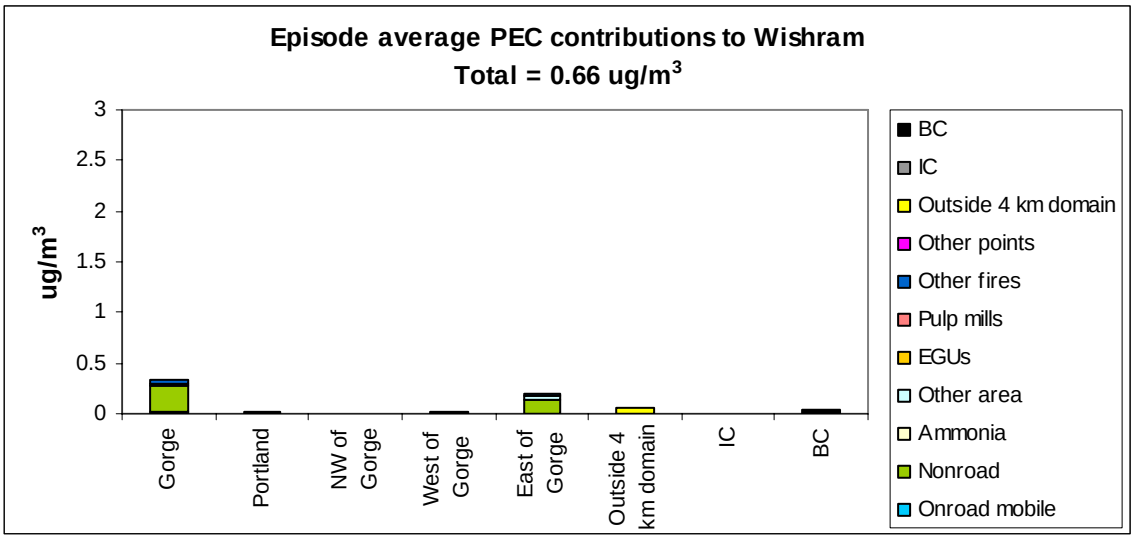
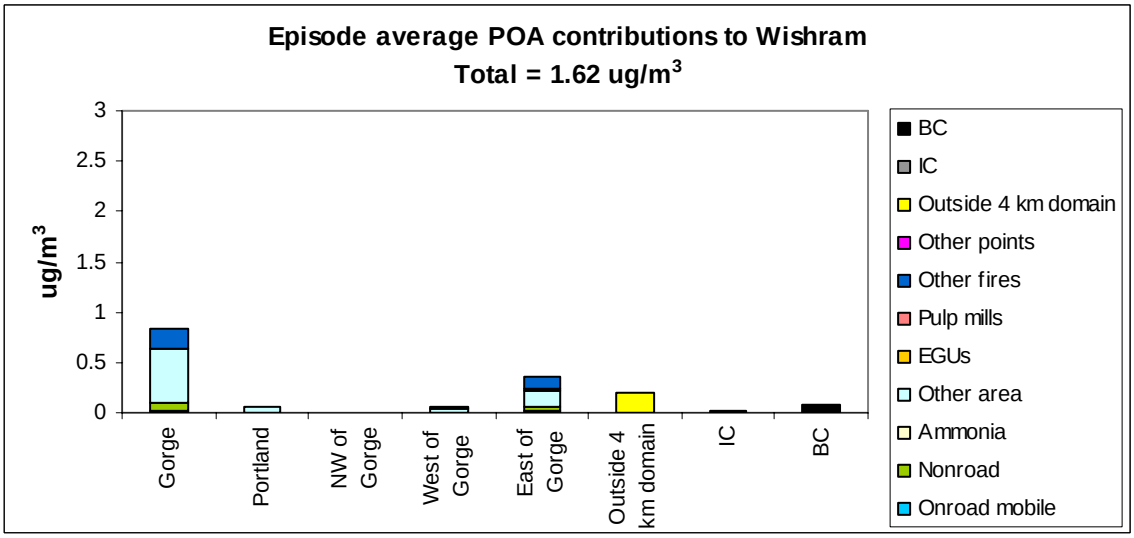


Figure 7-4. PSAT category-region breakdown at Wishram for November 2018 episode-average PM concentrations.





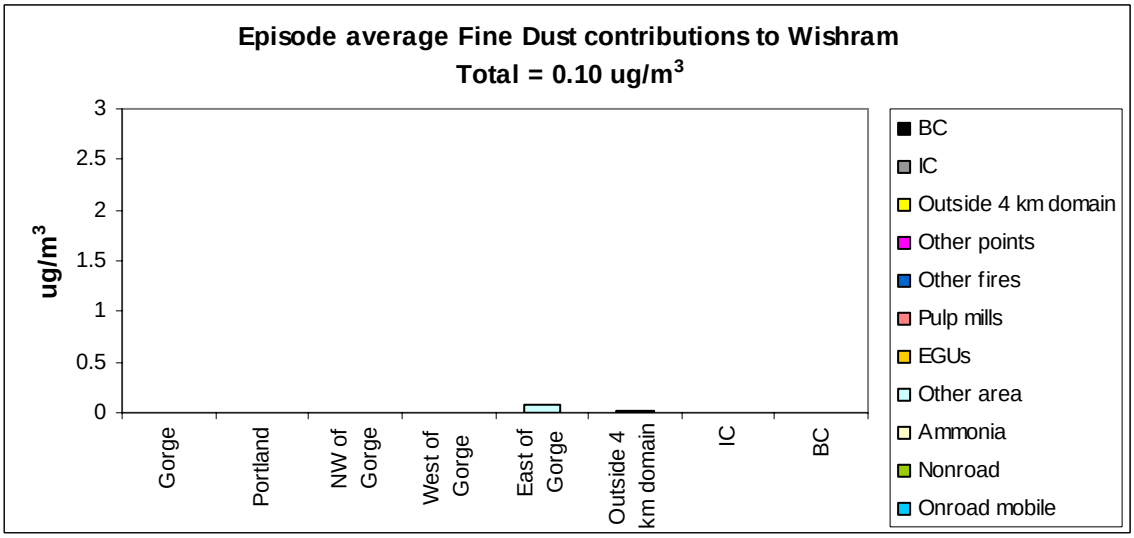
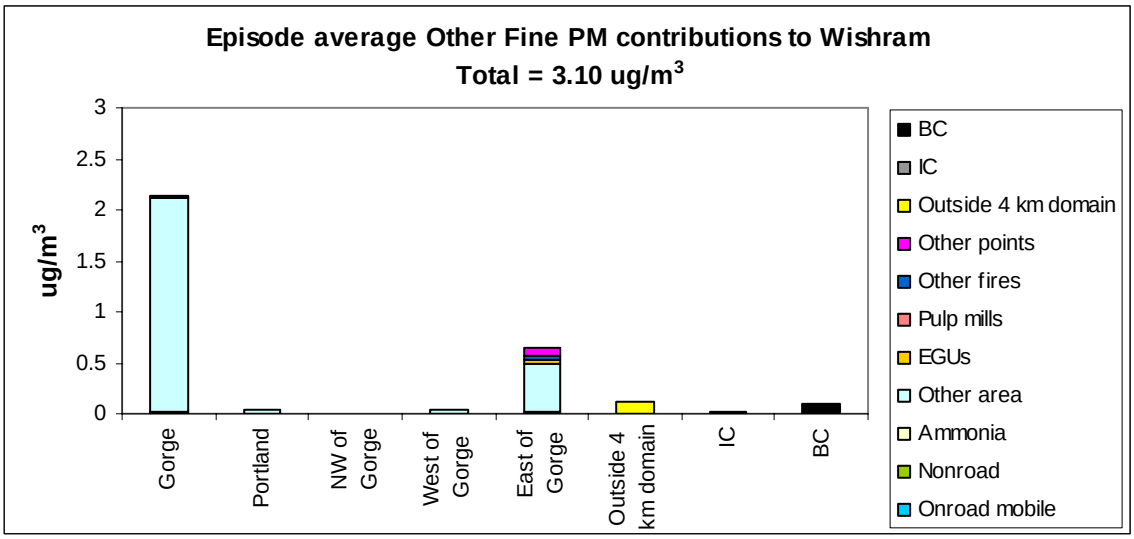
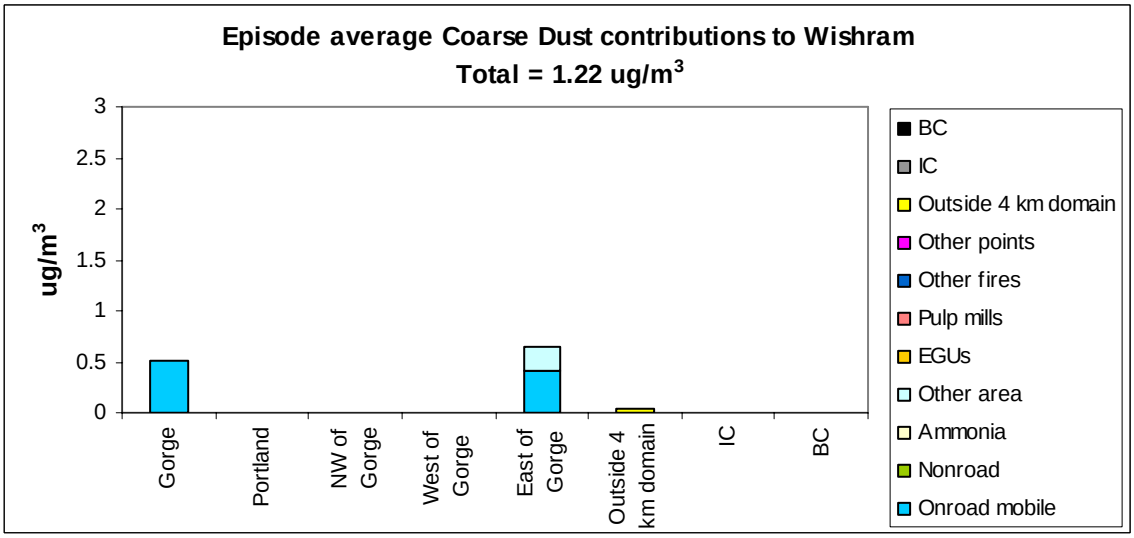


Figure 7-4 (continued).





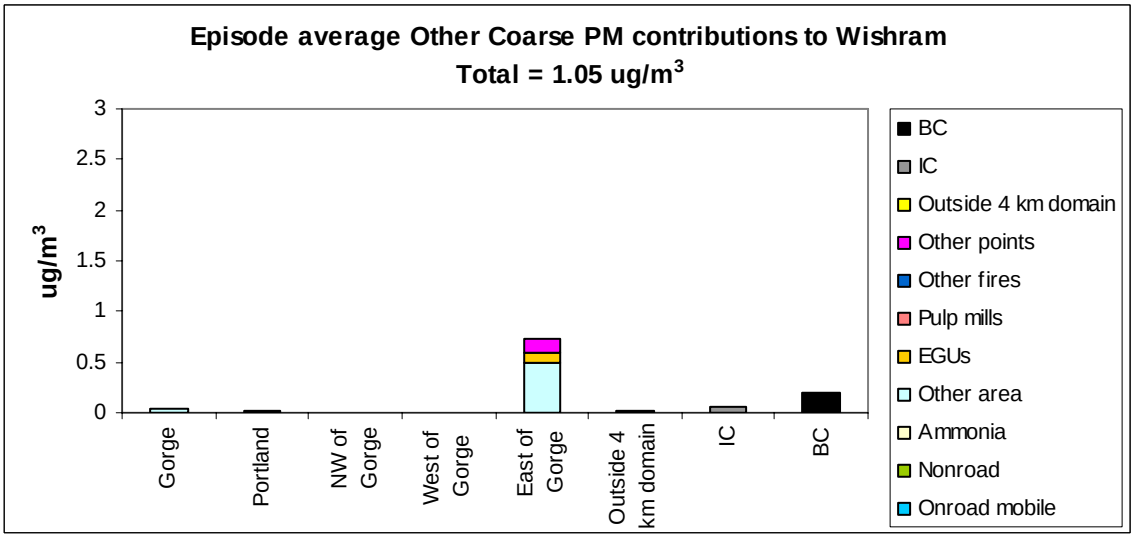


Figure 7-4 (concluded).

Table 7-8. Ranked list of source region/categories contributing to visibility-impairing haze over the November 2018 episode at Wishram. Source regions/categories shown account for 90% of the non-SOA contribution tracked by PSAT.

Species	Region	Source	ug/m^3	Mm^{-1}	Contribution
Nitrate	East of Gorge	Nonroad	1.05	19.30	12%
Sulfate	BC		0.70	13.70	9%
Sulfate	East of Gorge	EGUs	0.58	11.42	7%
Nitrate	BC		0.61	11.21	7%
Sulfate	Gorge	Other area	0.51	9.97	6%
Nitrate	East of Gorge	Other area	0.53	9.77	6%
Sulfate	East of Gorge	Other area	0.48	9.30	6%
Nitrate	Outside 4 km domain	Outside 4 km domain	0.49	9.00	6%
Sulfate	East of Gorge	Other points	0.36	6.98	4%
Sulfate	East of Gorge	Pulp mills	0.35	6.86	4%
Nitrate	East of Gorge	EGUs	0.37	6.86	4%
Nitrate	East of Gorge	Onroad mobile	0.30	5.43	3%
Sulfate	Outside 4 km domain	Outside 4 km domain	0.26	5.10	3%
Sulfate	Gorge	Nonroad	0.18	3.47	2%
Nitrate	Gorge	Nonroad	0.19	3.41	2%
Sulfate	East of Gorge	Nonroad	0.15	2.89	2%
EC	Gorge	Nonroad	0.26	2.58	2%
POA	Gorge	Other area	0.52	2.10	1%
Fine Other	Gorge	Other area	2.09	2.09	1%

8.0 CONCLUSION

8.1 SUMMARY

This report describes the meteorological, emissions and air quality modeling conducted by the contractor team of ENVIRON International Corporation and Alpine Geophysics, LLC, as part of the Columbia River Gorge National Scenic Area Air Quality Study (Gorge Study). The modeling analyses reported herein comprise just one component of the entire Gorge Study to assess projected trends in future visibility impairment, to provide a simulation assessment of source apportionment by type and region, and to test several "what-if" scenarios for future year conditions.

To meet the goals of the Gorge Study, chemical transport modeling was performed using ENVIRON's CAMx model, in combination with emission inputs from the EPA's Models-3 SMOKE system, and meteorological inputs from the PSU/NCAR MM5 prognostic meteorological model. The general approach for the Gorge Study modeling was to leverage the considerable regional visibility modeling work already conducted by WRAP in addressing the requirements of the federal Regional Haze Rule. Following the WRAP modeling methodology, the Gorge Study modeling component employed CAMx to simulate two season-representative high PM/extinction episodes with a wide array of sensitivity tests and Probing Tool applications for both a 2004 base year and the 2018 future year. Modeling was conducted on a series of telescoping nested grids with resolution ranging from 36 km (the WRAP continental grid) to 12 km, to 4 km focusing on the Gorge area. Based on visibility measurements during the 2003-2005 enhanced monitoring periods, two multi-day seasonal episodes in 2004 were selected for the Gorge Study modeling: a summer period over August 10-22, and an autumn period over November 3-18. A 10-day "spinup" period was added before each episode to reduce the influence of initial conditions.

The Gorge Study Team expended significant effort developing refined episode-specific emissions for the two 2004 modeling episodes on the 4-km Oregon/Washington grid. The 2002 WRAP emission inventory was adjusted to 2004 and used for areas outside the 4-km grid. Base case air quality model performance was evaluated for the two specific episodes simulated using operational and diagnostic techniques. A 2018 future year was also simulated for both episodes to obtain a visibility forecast trend line for the Gorge monitoring sites. The WRAP 2018 emission projections were used for this estimate for all grids, but included additional emission reductions that will be applied to two specific large PM sources by 2018: the Boardman power plant near the eastern end of the Gorge, and the Camas pulp mill at the western end of the Gorge.

The CAMx PSAT probing tool was used to assess source category and region-specific attribution to sulfate, nitrate, carbonaceous, and primary particulates at several monitoring sites within the Gorge. PSAT was applied for both 2004 base and 2018 future years. Finally, a group of five "what-if" scenarios were simulated to provide estimated visibility improvements with the removal (or significant reduction) of emissions from specific sources.

Overall the MM5/SMOKE/CAMx modeling system properly replicated the extensive set of PM and light scattering data that was collected as part of the Haze Gradient and "CaHaGo" field studies in 2004. The modeling system performed well in characterizing the distributions of

individual PM species concentrations that were important in contributing to visibility-impairing haze over each episode. This further translated to a proper characterization of light scattering levels measured at each site and each episode. Results are as good, and in many ways better, than regional modeling results in the Pacific Northwest area as conducted by the WRAP to address regional visibility/haze rules. The in-depth analyses undertaken in this modeling project have established confidence that the modeling system appropriately projects the individual PM constituent concentrations and resulting visibility impacts into the 2018 future year (according to the WRAP 2018 inventory projections), from which we have constructed visibility trend lines.

8.1.1 MM5 Results

MM5 version 3.63 was used for the Gorge Study modeling system. Six MM5 simulations were performed and compared in this study for both the August and November 2004 episodes. Two of the model configurations were taken from other modeling efforts conducted in this region: the University of Washington (UW) forecasting system ("Run 3"), and the Portland Ozone State Implementation Plan (SIP) ("Run 4").

Significant effort was expended to determine the best performing options in MM5. None of the MM5 configurations met all of the commonly accepted benchmarks for statistical performance, meaning that MM5 did not perform as well as it has historically performed in other air quality applications around the country[1]. It is important to note that these benchmarks were established according to a wealth of meteorological modeling applications for mostly urban and regional summertime ozone modeling. The Gorge Study area contains more complex terrain than most other areas modeled to date for air quality applications, and thus the monitors are more likely to be influenced by local and small-scale forcings. Both Gorge Study modeling episodes exhibited rather weak synoptic forcing, but MM5 traditionally performs better under stronger forced conditions, such as storm systems. Another point to consider is that the Gorge Study region includes fewer sites than were used to develop the benchmarks; statistics based on fewer pairings tend to yield poorer statistics. Nevertheless, MM5 performed well in capturing the August up-gorge flow patterns and the November down-gorge flow patterns, to the extent that such flows were characterized by sites along the Gorge itself.

8.1.2 CAMx Base Case Performance Evaluation

8.1.2.1 August 2004 Performance

Nine individual CAMx simulations were undertaken for the August 10-22, 2004 modeling episode. More than half of these runs addressed improvements in the input emission inventory or the treatment of biogenic SOA. The remaining runs tested model sensitivity to various input

[1] Note that MM5 modeling undertaken by WRAP for the year 2002 also did not meet all of the performance benchmarks in the Pacific Northwest region; specifically MM5 suffered from under prediction tendencies for temperature, and over prediction tendencies for humidity and rainfall. In our experience, as well as the experience of many other air quality modelers throughout the country, this is a common trait of MM5 that is very difficult to resolve.

changes that from our experience are associated with the largest uncertainty and have the largest potential impact on the air quality results.

August model performance against Gorge field study measurements was not sensitive to changes in wild fire emissions, or to increases in ammonia emissions. The simulated wild fire emissions occasionally contributed to the performance at the Gorge monitors as the plume edges wafted over the eastern-most sites. The August modeling was also not sensitive to increased ammonia emissions. This was due to the fact that the period was warm and dry, and so the ammonium nitrate formation was thermodynamically limited by the meteorological conditions, as opposed to being limited by available ammonia.

After undertaking several diagnostic and sensitivity tests for the August modeling episode, from which several emission problems were ameliorated, we were able to achieve an acceptable base case replication of the PM components and light scattering/extinction that were measured along the Columbia River. When model performance was quantitatively gauged against 24-hour average measurements, it was found to meet or beat performance goals and criteria for the most critical PM components observed during the period (organic aerosol and sulfate), and for total light scattering and extinction. Those components that did not meet the performance criteria (nitrate, fine and coarse primary PM) were either both predicted and measured to be very low in concentration (the case for nitrate below 1 $\mu g/m^3$), or did not contribute significantly to light extinction due to low scattering efficiency (the case for fine and coarse primary PM). CAMx performance in replicating the range of 24-hour light scattering among all nine Gorge Study dry nepholometer sites was quite good, indicating a near zero bias tendency with a moderate degree of scatter about the 1:1 line. This level of performance is comparable to some of the best performance results achieved by WRAP.

When hourly predictions were compared to limited hourly measurements taken at two Gorge Study sites, Mt Zion and Bonneville, the model demonstrated a basic ability to replicate the inter-daily trends in PM component concentrations and light scattering during this episode, but the model over stated the diurnal variation of carbonaceous components, and thus total light scattering as well. Overall, the model performed very well in replicating the temporal and spatial variation of key PM species concentrations and light extinction levels that were observed during this episode.

8.1.2.2 November 2004 Performance

Eight individual CAMx simulations were undertaken for the November 4-18, 2004 modeling episode, which paralleled the run configurations made for August. Most of these runs addressed improvements in the input emission inventory or the treatment of biogenic SOA.

The carbonaceous components tended to be over predicted and were dominated by wood smoke, which was especially concentrated in the Portland area. Over predictions in primary fine/coarse PM were due to over stated emission factors and the application of seasonal profiles in the modeling inventory that do not account for the suppressive effects of episode-specific precipitation events on such categories as road dust and construction and agricultural fugitive dust. Reducing the dust components to near zero to account for specific precipitation events

would dramatically improve model performance for primary PM; this would require the development of day-specific dust emission fields (not done in this study).

Sulfate, nitrate and associated ammonium were appropriately predicted to be much higher during this episode, with nitrate exceeding 10 $\mu g/m^3$ in both measurements and predictions. This was due to the fact that the period was much cooler, wetter, and stagnant than the August episode, which are prime conditions for the formation of secondary sulfate and nitrate PM salts. Cloud water is an important heterogeneous chemical pathway for sulfate and nitrate, while high humidity and cool temperatures are critical for correctly characterizing the balance between sulfate, nitrate and ammonium. Nitrate aerosols are formed from the neutralization of nitric acid gas (which is produced by the atmospheric oxidation of NOx emissions) by cations such as ammonium, sodium, calcium, and potassium. Ammonium is by far the most abundant cation available away from oceans, so ammonium nitrate is the most abundant form of nitrate particles. On the other hand, sulfate (which is produced by the atmospheric oxidation of SO_2 emissions) exists as an aerosol regardless of its state of neutralization by the same cations. Thus, there is a "competition" between sulfate and nitrate to react with available cations; the process is complex and dependent on atmospheric conditions and the mix of chemicals. In very simple terms, ammonia preferentially reacts with sulfuric acid aerosols, and any excess is then available to form nitrate particles.

Our tests with CAMx indicated that ammonium nitrate formation was limited by available ammonia. Indeed, nitrates and ammonium were much higher in tests that doubled ammonia emissions, especially around major urban areas such as Portland and along the Interstate 5 route up through Seattle. Sulfate was not significantly impacted by the doubling of ammonia, as the chemical process described above would suggest. So the doubling of ammonia emissions likely went into neutralizing more sulfate (which would not lead to an obvious change in total sulfate concentrations output by the model), and any excess ammonia went to neutralizing more available nitrate. In other words, even more ammonia emissions would probably lead to additional PM nitrate (i.e., an ammonia-limited system). Higher ammonium nitrate concentrations resulted in the largest increases in light scattering in the western Columbia River area early in the episode, while eastern Gorge sites showed a more modest increase later in the episode.

Several diagnostic and sensitivity tests for the November modeling episode were successful in allowing us to identify problems in the November 2004 emission inventory and to improve certain under performance issues associated with the meteorology of the period. Incremental improvements at each step of the process brought model performance for light scattering and most PM constituents to acceptable levels. Model performance was qualitatively gauged for 24-hour average PM, and found to continually exhibit over prediction tendencies for primary PM components along the western portion of the Columbia River (carbonaceous and fine dust), as described above. Overall, sulfate and SOA were well predicted, although sulfate exhibited an over prediction tendency. On an episode-average basis, nitrate concentrations were well modeled with very small bias, but nitrate performance on a day-to-day basis was not well correlated with observations.

Performance for light scattering indicated a "bifurcated" pattern: light scattering was over predicted in the Portland area and along the western portion of the Columbia River, while it was under predicted along the eastern portion of the river. MM5 model performance suffered from a

lack of humidity and clouds during the November episode. As discussed above, the ability to generate the correct amount of nitrate is particularly sensitive to the accuracy of humidity and temperature fields. The MM5 cloud field predictions were improved by simply assigning fog to areas of the air quality modeling grid according to available visible satellite imagery. This was found to help the under predictions in sulfate and nitrate significantly, and improved modeling performance in replicating the observed light scattering in the Gorge. However, we identified other issues associated with how the "dry" nephelometer instruments employed during the Gorge field study over estimated PM light scattering during the very high humidity conditions that occurred over the core November period. This instrument artifact contributed to some uncertainty in our model-observation comparisons for light scattering.

In summary, CAMx performed well in replicating the much higher concentrations of ammonium sulfate and ammonium nitrate along the Columbia Gorge during the cool, foggy, stagnant conditions of the November 2004 episode. The thick haze that formed during the period was observed to be dominated by these secondary salts, as well as from carbonaceous PM from (mostly) wood smoke. The air quality model simulated the elevated concentrations of all of these key species adequately well, allowing us to have confidence that the model provides the correct conclusions regarding source apportionment and impacts from emission changes under such extreme haze conditions.

8.1.3 Future Year Projections and Trend Lines

CAMx was run for both the August and November modeling episode in exactly the same manner as performed for the final 2004 Base Case application ("Run 10") as documented in Section 4. The only change to the model inputs included use of the 2018 episode-specific modeling emission inventories described in Section 3. All grid configurations, model options, meteorological and other environmental inputs (including "natural" emissions such as wild fires, prescribed burns, wind-blown dust, ammonia and biogenics) were maintained to be consistent with the Run 10 Base Case simulations. Hence, the future year applications performed for the August and November modeling episodes reflect only changes in the projected 2018 anthropogenic emission inventories via anticipated growth in population and industrial, commercial, and vehicular activity, as well as emission controls that were reflected in the 2018 WRAP inventories and some additional adjustments applied specifically for this project (e.g., power plant emission reductions via BART rules). See Section 3 for more specific information regarding the 2018 modeling inventories prepared for this modeling application.

Trend lines for 2004-2018 total extinction and deciview were calculated from peak episode-average conditions at two IMPROVE sites: Mt Zion and Wishram. The episode-average was determined by averaging the 24-hour extinction values on just the "high" PM days identified from the modeling results in each episode. Trend lines and rates were simply determined from the difference in the 2004 and 2018 episode averages. At both Mt Zion and Wishram, little change in total extinction was seen on each day for the August episode. However, some minor reductions in sulfate and nitrate were noticeable. In general, the lack of extinction response for this episode was tied mostly to the fact that the inventory is dominated by "natural" emissions such as biogenic SOA and wild fires that cannot be directly controlled, and which were carried over from the 2004 inventory development efforts. For the November episode, reductions in nitrate (NOx) and sulfate (SO_2) resulted in more significant reductions in total PM extinction,

especially on the worst visibility days. The cleaner days indicated little change in 2018. Little change to other species (carbonaceous and primary PM) was seen in the 2018 out year.

Concerning visibility trend lines, while Mt Zion was simulated to show just a slight improvement in worst-day extinction out to 2018, the Wishram site actually shows a very slight degredation. Nevertheless, these changes were not perceptible according to the 1 Dv threshold for perceptible visibility changes. In the November episode, a perceptible improvement was simulated for worst-day visibility at both sites, with reductions in total extinction of over 10% and Dv reduction of about 1.

These trends were compared to recent results from WRAP determined for Mt Hood and Mt Adams over a similar time horizon (2004 – 2018). Note that WRAP did not calculate visibility trend lines for Mt Zion or Wishram IMPROVE sites as they are not located in Federal "Class I" areas. Since WRAP conducted modeling over the entire 2002 year, the trend lines are determined from the average of the 20% worst visibility days over the annual simulation. Haze conditions on such days in the WRAP 2002 modeling would be consistent with the hazy episode days in 2004 selected for modeling in the Gorge Study. The WRAP simulated projections are very similar to what we calculated for Mt Zion and Wishram during the August 2004 episode.

Five "what-if" scenarios were run for the 2018 Future Case to estimate the impacts of certain sources on visibility over the two modeling episodes. Very little sensitivity to any of the what-if scenarios was seen at both of the monitoring sites. Since the Boardman EGU plant reflects major sulfate and NOx reductions in the 2018 inventory, practically zero sensitivity to Case 1 is seen. Some increases and decreases in sulfate and nitrate are seen for some cases (e.g., Case 5, in which all point sources in the Gorge were removed). This mixed effect is possible depending upon how the chemical conditions set up for a specific episode. There are two possible non-linear effects at play here:

(1) The amount of ambient NOx relative to organic gasses can lead to ozone (oxidant) production or ozone destruction. In NOx-lean conditions (such as in remote rural locations), controls on NOx can lead to less oxidants that ultimately form less sulfate, while in NOx-rich conditions (e.g., urban areas such as Portland), controls on NOx can lead to more oxidants (less ozone inhibition) and thus more sulfate formation.

(2) The amount of particulate nitrate and sulfate that can form depends on the amount of available ammonia that neutralizes these acids. It is very common to see nitrate increases when SO_2 emissions are reduced while NOx and ammonia emissions are held constant. Since ammonium preferentially neutralizes sulfate, with any excess then available for neutralizing nitrate, a reduction in SO_2 leads to a reduction in sulfate, and thus more ammonium is available to form more particulate nitrate.

As we have seen in both the 2018 projection (relative to the 2004 base case) and a few of the "what-if" scenarios, the model is responding in such a manner. Again, the August episode is dominated by "natural" emissions that were not removed in any of these scenarios. The less obvious signals stemming from the what-if scenarios should be examined in further modeling efforts; but overall these effects are not significant to the overall conclusions of this study.

Somewhat more influence from each what-if scenario is seen on the worst PM days of the November episode, especially Cases 2 and 3 at Mt Zion, which remove Eastern Gorge ammonia and Portland on-road sources, and Cases 1 and 5 at Wishram, which remove major point sources from the in-Gorge area.

8.2 DISCUSSION

The ultimate goal of the overall Gorge Study components is to develop a scientific basis of evidence that can be referenced to answer a set of questions that were originally posed by the Technical Team. The following discussion refers to the results from the modeling results documented in this report to answer as many of these questions as possible.

1. What aerosol components are responsible for haze?

a. What are the major components for best, worst, and average days and how do they compare?

Given that the modeling was conducted for two specific hazy episodes occurring in 2004, it is not possible to use these modeling results to glean information on the PM mass or light extinction budgets and their variability during the best, worst, and average days over a full seasonal cycle. However, the modeling does provide us with such information for the episodes examined. The modeling supports the idea that a wide variety of chemical species, source types, source areas contribute to haze in the Columbia River Gorge. Furthermore, this mix is in fact different along different portions of the Gorge itself, which demonstrates the variety of source mixtures, transport pathways, and chemical conditions at work in each of the episodes modeled (see Sections 4 and 5).

The major haze components during the summer (August) episode included smoke from wildfires and secondary organic aerosols from biogenic (vegetative) sources. Primary inert PM from dust sources and motor vehicle combustion sources in the Gorge and from Portland (i.e., elemental and organic carbonaceous material) were also rather large contributors. Secondary PM such as sulfate and nitrate were relatively low. Ammonium sulfate typically existed at low concentrations (~1 $\mu g/m^3$ or less). Ammonium nitrate was usually very low or zero in the summer due to the fact that it is it does not form in warm, dry conditions.

The majority of haze during the winter (November) episode was comprised of secondary PM salts, including both sulfate and nitrate. Carbonaceous PM also comprised a large fraction of wintertime haze, mostly from residential wood smoke. Very little secondary organics were attributed to anthropogenic sources, although biogenic source continued to contribute even in this late season given the abundance of evergreen forests. Primary PM from dust sources was mostly squelched due to wet surface from precipitation.

b. How variable are they episodically, seasonally, inter-annually, spatially?

c. How do the relative concentrations of the major components compare with the relative emission rates nearby and regionally?

We have combined our answer to these two questions because they are interrelated. Again, the episodic modeling conducted in this study cannot answer questions related to inter-annual variability. On the episodic scale, there can be dramatic diurnal and day-to-day variations in haze levels and the PM mass budgets, according to variations in meteorology (discussed below) and the influences from very specific, localized, intermittent emission events (such as fire activity). On the seasonal scale, both meteorology and emissions influence the components of haze, as discussed below (see also Sections 3, 4, and 5).

In the summer, wildfires are obviously very episodic and spatially variable; thus they can play a major role, and can even dominate the PM and extinction budgets during certain summertime haze events. Wildfire impacts are entirely dependent upon the location of the fires relative to the location of interest in combination with the transport patterns that set up during the episode. Biogenic organics are also dominant (especially in the absence of fires), and are more diffuse and widespread; thus this component exhibits little spatial or temporal variation. Dust is greatly affected by wind speeds and is generally concentrated in areas of disturbed dry soil (agricultural, mining, and construction activities). Carbonaceous PM from anthropogenic sources contribute a large fraction near Portland and all along the Gorge due to on-road and non-road (barges, railroads) sources. Sulfate stems from very regional sources well outside the Gorge, including surrounding states, Canada, and off-shore sources. There are also some impacts from local sulfur sources, such as coal-fired power plants and pulp mills, depending on atmospheric transport patterns and the specific location of focus in the Gorge. Ammonia is mostly attributed to local agricultural activities (feed lots and fertilizer applications in the eastern areas of Oregon and Washington).

In the winter, much of the secondary inorganic PM (sulfate and nitrate) is attributed to regional sources over Oregon, Washington, neighboring states, Canada, and even off-shore. These salts form from SO_2 and NOx emissions in cool humid climates – the episode examined in this modeling study was driven in large measure by persistent fogs that set up in the basin of Oregon and Washington, which dramatically increased the chemical formation of sulfate and nitrate. Local sources include power plants, other industries, on-road, and non-road sources. Ammonia is mostly attributed to local agricultural activities (feed lots and fertilizer applications in the eastern areas of Oregon and Washington). Carbonaceous PM has a very large contribution from residential wood smoke (with Portland being a very large source region) and non-road sources. Thus the carbon PM tends to exhibit stronger spatial and temporal variations than sulfate and nitrate.

2. What is meteorology's role in the causes of haze?

a. How do meteorological conditions differ for best, worst and typical haze conditions?

Given that the modeling was conducted for two specific hazy episodes occurring in 2004, it is not possible to use these modeling results to glean information on the meteorological conditions and their variability during the best, worst, and average days over a full seasonal cycle.

b. What empirical relationships can be derived between meteorological conditions and haziness?

The modeling study was not designed to address the derivation of empirical relationships between meteorological conditions and haziness. Analysis of observation data over an extended period of five or more years would be needed.

c. Are meteorological and climatological conditions between the west end and the east end of the Scenic Area the cause of the observed differences in visibility impairment?

According to the episodic modeling results described herein, there is sufficient evidence to suggest that indeed meteorological and climatological differences between the western and eastern ends of the Gorge do contribute to observed differences in visibility impairment. The meteorological differences that we have identified between the Portland end and the Wishram end include major gradients in temperature, humidity, turbulent mixing rates, and precipitation rates (see Sections 2 and 4).

d. Can haze conditions be predicted solely using meteorological factors?

The modeling study was not designed to ascertain an answer to this question. Our experience, however, suggests that haze events could not be predicted solely using meteorological factors, especially when very specific large emission events occur in the region of the Gorge (e.g., wild fires). Haze conditions result from a complex interaction between meteorology and emissions.

e. How well are inter-annual variations in haze accounted for by variations in meteorological conditions?

The modeling study was not designed to address this question. Analysis of observation data over an extended period of five or more years would be needed.

3. What are the emission sources responsible for haze?

a. What geographic areas are associated with transported air that arrives at sites on best, typical and worst haze days?

Given that the modeling was conducted for two specific hazy episodes occurring in 2004, it is not possible to use these modeling results to glean information on the geographic areas associated with transported air during the best, worst, and average days over a full seasonal cycle.

b. Are the emission characteristics of the transport areas consistent with the aerosol components responsible for haze?

According to our episodic modeling results, it is apparent that the emission characteristics of the transport areas, both within the Oregon/Washington area as well as super-regional areas in the Pacific Northwest and Canada, are consistent with the aerosol components responsible for haze in the Columbia River Gorge (see Section 5).

c. What do the aerosol characteristics on best, typical and worst days indicate about the sources?

Given that the modeling was conducted for two specific hazy episodes occurring in 2004, it is not possible to use these modeling results to glean information on the source types and source regions during the best, worst, and average days over a full seasonal cycle.

d. What does the spatial and temporal pattern analysis indicate about the locations and time periods associated with sources responsible for haze?

e. What evidence is there for urban impacts on haze and what is the magnitude and frequency when evident?

According to these modeling results, there is a strong connection between urban emissions and haze in the Gorge, especially from the Portland/Vancouver metropolitan area. The magnitude and frequency of urban impacts is very dependent upon the specific area of the Gorge considered. For example, simulated PM concentrations at the Mt Zion site was consistently impacted by urban emissions from area (residential wood smoke and fugitive dust), on-road, and non-road sources. The urban contributions at Mt Zion dominated the anthropogenic PM mass and extinction budgets. On the other hand, simulated PM at the Wishram site was occasionally impacted by Portland emissions, mainly during periods of strong transport coupling (e.g., the August episode), and the magnitude of the anthropogenic PM mass and extinction budgets was much smaller relative to other sources in the eastern Gorge area (see Section 5).

f. What connections can be made between sample periods with unusual species concentrations and activity of highly sporadic sources (e.g., major fires and dust storms, point source activity changes such as aluminum plant shut-downs, etc.)?

The modeling and associated observational data analysis conducted as part of the model performance evaluation shows a strong connection between sporadic sources and jumps in particular aerosol species. For example, occasionally large spikes from primary carbonaceous species was observed and simulated during periods when wildfire smoke was transported into the Wishram area. Given the shear magnitude of mass emitted into the atmosphere from such sources, this is not surprising. However, we were also aware of some specific point source fluctuations during the modeling episode in 2004 (e.g., the PGE Boardman facility was down for a short period in the November episode), but an associated signal in sulfate and nitrate concentration was not obvious. To check this more explicitly, a run with such facilities emitting

at a constant rate could be compared with the original run to identify a signal in the resulting PM concentrations (see Section 4 and 5).

g. What can be inferred about impacts from sources in other regions?

The modeling demonstrated that a rather large fraction of anthropogenic emissions from sources outside the states of Oregon and Washington contribute to secondary sulfate and nitrate, as well as primary PM such as carbonaceous species, in both modeling episodes. This strengthens our conclusions that haze in the Columbia River Gorge is caused by a wide variety of source types and source regions, and that no single facility, category, or region can be singled out as the dominant cause of haze (see Section 5).

4. Are there detectable and/or statistically significant multi-year trends in the causes of haze?

a. Are the aerosol components responsible for haze changing?

b. Where changes are seen, are they the result of meteorological or emissions changes?

c. Where emissions are known to have changed, are there corresponding changes in haze levels? (e.g., aluminum plant shutdowns or emission controls on the Centralia Power Plant)?

The modeling component of the Gorge Study did not address these questions. Answers can only be developed by analyzing longer-term trends in observational data and emission inventories.

8.3 MODELING UNCERTAINTIES AND RECOMMENDATIONS

As with any modeling exercise, the results and conclusions reached as documented in this report are subject to the specific uncertainties associated with the methodology and datasets applied in this project. These are discussed below, and for each we provide our recommendations for future work that should reduce or minimize each uncertainty and thereby improve the robustness of the modeling results.

Episodic vs. Annual Modeling

The modeling performed for the Gorge Study focused on episodic conditions within two specific seasons of 2004. This decision was based on schedule, available resources and the types of data available from the field studies. Episodic modeling can only address conditions over the few specific days of concern, and thus the simulated trend lines are specific only to these unique episodes that will never repeat in exactly the same manner. Generally, regional visibility modeling such as conducted by WRAP is performed over an entire year, or at least over longer "representative" periods of each season. This allows for a much broader assessment of emission projection impacts over the entire spectrum of the seasonal visibility frequency distribution (i.e., how the distribution of the worst/best visibility days are projected to change). Annual modeling

lessens the heavy burden required of episodic modeling to replicate hour-by-hour and day-by-day meteorology, emissions, and air quality, and shifts the focus to the easier task of representing the seasonal variations in a statistical sense. We recommend that future visibility modeling assessments for the Gorge be expanded to include an entire year, and that visibility trends be determined in terms of changes to frequency distributions.

"Typical" vs. "Actual" Emission Estimates

As described in Section 3, the 2004 Base Case inventory was developed for "actual" conditions, meaning that where possible, actual hourly emission rates were used so that we could assess the performance of the air quality model in replicating actual measured data. Actual emissions are most often incorporated for point sources, where equipment such as Continuous Emission Monitoring (CEM) instruments report actual hourly stack-specific emission rates of criteria pollutants. In this project, other sources such as Mt St. Helens and large fires were included on an episode-specific basis. However, these latter sources were kept constant into the future year.

On the other hand, the 2018 Future Year case developed from the WRAP inventory is based on "typical" seasonal and daily profiles, since obviously hour- and day-specific emission rates for each point source are unknown. This leads to a dichotomy between the 2004 and 2018 inventories that is difficult to reconcile in the resulting air quality model results, and which does impact the calculation of trend lines in cases where CEM point sources impact specific receptors. For example, some days might show a major PM reduction relative to the base case (actual emission are much higher than the typical future year projection), while other days show PM increases (actual emissions are lower than the typical projection). We recommend that follow-on visibility modeling generate two base year inventories: (1) an "actual" base year inventory for the purposes of model performance evaluation; and (2) a "typical" base year inventory that provides a more consistent inventory with the future year methodology, and thus allows for a more consistent base-to-future year comparison. This is the approach taken by WRAP.

Meteorological Uncertainties

After extensive experimentation, the MM5 simulations captured the overall conditions of each episode adequately well. To reiterate an earlier point, it is imperative that the meteorological model appropriately replicate each hour of each day of an episodic application since a limited number of days are addressed in the air quality assessment. Episode-specific modeling places far more emphasis on tacking the correct transport, temperature, moisture, and mixing patterns on a short term basis, and this in turn increases the level of uncertainty over an annual run that only needs to replicate the seasonal frequency distributions without an exact match in time.

The MM5 model does not perform well in stagnant conditions – in fact, according to its formulation and the time/space resolution employed (hourly, 4-km grid spacing), it *cannot* be expected to perform well in such situations. There is simply too much influence from stochastic mechanisms at sub-grid local scales that cannot be resolved by the model (e.g., local terrain channeling, up/downslope flows, small eddies that generate meandering winds, etc.).

MM5 was unable to replicate low temperature/high humidity events with prevalent fogs. This is not unique to the present study, as several MM5 applications with which we are familiar lack an ability to maintain the ubiquitous summertime maritime fog banks along the California coastline. Unfortunately, there is a feedback mechanism associated with the lack of fog: surface temperatures remain too warm without the fog, which increases mixing, dries the surface, and moves the system even farther away from conditions to form and maintain fog. Realizing this, we did not attempt to spend potentially much more time forcing MM5 to work correctly in this regard. Instead, we developed an ad-hoc methodology to ameliorate this problem within the air quality model itself by specifying fogs in space and time according to available satellite imagery. We recommend that any new modeling should continue to focus on assessing and quantifying meteorological model performance during periods of stagnant foggy conditions.

Emission Uncertainties

The emission inventories represent the largest source of uncertainty in the entire modeling system, especially in regards to the future year projections. The problem is rooted in two issues: (1) emissions inventories for most sources (other than point sources) are based on very rough estimates; and (2) the process to translate these estimates to time-resolved, space-resolved, speciated model inputs is very complex and introduces an additional set of assumptions, simplifications, and estimates. Except for point sources, other emission sources must be estimated according to a combination of emission factors per unit source and county-level population estimates (vehicles, humans, animals, trees, commercial activity, etc). These are then adjusted for assumed activity schedules (hour, day of week, season) and in some cases for environmental conditions (e.g., temperature, winds, humidity, precipitation, often taken from meteorological modeling that contains its own uncertainties and performance issues). Finally, county-level estimates for criteria pollutants must be uniquely allocated to the modeling grid, and speciated to the chemicals needed by the model for chemistry, using assumed profiles for each source category. Every step introduces the potential for more uncertainty and processing mistakes.

It must be realized that the 2004 and 2018 inventories represent two completely different starting points. Much work went into developing the 2004 “actual” inventories to replicate the episodes; these inventories are much improved over original 2002 inventories upon which the WRAP emissions are based. However, the 2018 inventory was taken entirely from WRAP (with some adjustments for a few specific point sources), according to projections applied by WRAP from their original 2002 inventory. There are some significant discrepancies that must be recognized and understood when considering these results, especially related to industrial point source emission growth rates. We have identified some significant emission differences between the 2004 and 2018 inventories that result purely from their separate lineages, aside from differences derived from projection techniques and assumptions.

Wild fire emission influences were present in the August episode – there are huge uncertainties associated with these estimates and it has some impact on the simulated visibility trend lines. Ammonia sources exhibit a large influence in the November episode when high sulfate and nitrate levels play significant roles in total light extinction. Ammonia emissions also remain highly uncertain, even from the largest well-known sources in the region (mostly large cattle feedlots and fertilizer application).

Areas sources, especially wood smoke and fugitive dust sources, inflict major influences in the modeling results, and are associated with large uncertainties, particularly on a day-to-day (and hour-by-hour) basis. The base year estimates for these sources are simply grown based on population estimates to 2018. This methodology should be validated before undertaking additional modeling analyses.

Emission inventories and processing methodologies for modeling are continuously developed, reviewed, and improved, and for good reason. While perhaps an obvious statement, we recommend continuous update and review of the regional emission inventories and processing methods as a central component of any future modeling activities.

Air Quality Model Uncertainties

Given all of the uncertainties discussed above, CAMx performed generally well in replicating the air quality patterns of both episodes, but was rather unskilled in replicating the hour-by-hour concentration variations for some PM species. The uncertainties in CAMx are primarily associated with the chemical conversion of primary emitted compounds to secondary pollutants. However, there is always a danger of accepting a model that appears to be working correctly, but perhaps serendipitously. We have attempted to identify compensatory errors by undertaking detailed analyses of the modeling results from diagnostic and sensitivity tests.

SOA from biogenic emissions was a large contributor to the overall PM load, especially in August. SOA volatility remains an uncertain component, and SOA yields from condensable organic gases are the least well-understood components of the chemistry. SOA chemistry is expected to be updated significantly over the next few years as new experimental data become available and new mechanisms are incorporated into the models.

The sulfate/nitrate/ammonia balance is highly sensitive to concentrations of each, as well as to fluctuations in environmental parameters. This leads to large uncertainty due to the complexity of the thermodynamic relationships among these species (as well as with naturally occurring inorganic compounds such as sea salt and dust). This is most obviously demonstrated by the uncorrelated (but balanced) performance for particulate nitrate. The degree of nitrate volatilization is very important, and is dependent on temperature, humidity, grid resolution, accuracy of gas-phase chemistry, and emissions.

Our recommendation concerning air quality modeling is to continue to pursue the most up-to-date, peer-reviewed modeling system available for any future air quality applications for this region. The selected model should continue to provide important Probing Tools that allow for source apportionment and sensitivity capabilities.

Monitoring Uncertainties

As noted in Section 4 of this report, some performance issues were identified with the nephelometer and PM sampling instruments employed specifically for the Gorge Study, as well as with the more routine operational sites. Specific problems were noted for sulfate and carbon concentrations from the Gorge PM samplers when compared to the techniques used by

IMPROVE and EPA-method sites (FRM and STN). The "dry" nephelometers indicated a "hysteresis" effect under very high humidity conditions, during which time the reported aerosol light scattering appeared to be influenced by remaining water associated with the aerosols. It is often difficult to gauge model performance against specific measurements, since we must emulate "how" the PM is measured (i.e., dry vs. wet nephelometer, the form of sulfate reported, loss of carbon and nitrate via volatilization, etc.). Such measurement issues can introduce an apparent model bias that may not be truly there. In other words, measurements do not necessarily always represent "truth"; as modelers, we must build in a large margin for what is "acceptable" performance when comparing model results to measurement data.

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