A NUMERICAL DAILY AIR QUALITY FORECAST SYSTEM FOR THE PACIFIC NORTHWEST

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Forecasts using mesoscale meteorological modeling and a photochemistry grid model, running nightly, provide air quality predictions for a high-resolution Puget Sound domain via the Web.

The expanding need for information that pervades our society extends to a need to know about the environment in which we live. At the same time, the explosion of information and computer technology coupled with new and improved weather forecast systems provides a foundation for conveying detailed environmental information to the public in near–real time. In the Pacific Northwest, recognition of the need for timely environmental information led first to the establishment of the Northwest Modeling Consortium, and second to the development of an advanced operational numerical weather forecast system as described by Mass et al. (2003). This system is based on the fifth-generation Pennsylvania State University (PSU)–National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) and provides twice daily forecasts covering Washington, Oregon, and part of Idaho down to a horizontal grid scale of 4 km. The success of the consortium and the MM5 forecast system has now led to the development of a numerical photochemical air quality (AQ) forecast system for the Northwest. Initially developed with support from the Environmental Protection Agency (EPA) Environmental Monitoring for Public Access and Community Tracking (EMPACT) program, and now operating with support from various consortium members, the Air Indicator Report for Public Access

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and Community Tracking (AIRPACT) system runs on a daily basis year-round. It produces detailed hourly maps of ozone and other pollutant concentrations, including primary particulate matter (PM), for a 24-h forecast period. These predictions are available by 1400 UTC on the morning of the forecast on a public Web site (see www.airpact.wsu.edu). AIRPACT is unique nationally as the sole numerical modeling system producing daily, year-round, high-resolution regional AQ forecasts with daily verification. In this paper, we discuss the motivation for building a numerical AQ forecast system, describe the basic components of the system, present examples of forecast results, and show how the forecast compares to available observations.

Until recently, AQ forecasts were based upon analysis of forecast meteorological conditions with consideration of pollutant ventilation conditions. Currently, a number of metropolitan areas take the meteorological analyses a step further and incorporate use of statistical empirical methods to predict probable concentrations of ozone or other pollutants (U.S. Environmental Protection Agency 1999a, see www.epa.gov/airnow/). AIRNow forecasts are produced manually by AQ meteorologists. Beyond these forecasts, numerical forecasts employing photochemical Eulerian grid models have been employed on a summer-only basis in the eastern United States to predict ozone concentrations with various and nested domains (McHenry et al. 1999) and in support of special field study campaigns (Cai et al. 2002; Grell et al. 2000). In Canada, there is a substantial ongoing effort to provide operational numerical forecasts for tropospheric ozone and particulate matter through the Canadian Hemispheric and Regional Ozone and NO_x System (CHRONOS, see http://gfx.weatheroffice.ec.gc.ca/chronos/index_e.html). This system shares many of the attributes of the AIRPACT system, but operates with a 21-km grid scale for a large portion of the United States and Canada. Together, the CHRONOS and AIRPACT systems represent the state of the art in operational, year-round, daily AQ forecast systems.

The motivation for forecasting AQ begins with the need of AQ agencies to provide the public with health alerts when air pollution levels are expected to exceed stipulated levels. This is most often done using an air quality index (AQI) that applies throughout a metropolitan area. Improving the confidence in these forecasts and providing more spatial and temporal information about elevated pollutant levels will help sensitive sectors of the public make better decisions regarding their daily activities. In addition to cuing health alerts, forecasting pollution episodes can trigger emission control efforts to reduce the impact of an episode. Offering free public transportation on high ozone days is an example of this approach that is used in some areas. More detailed forecasts that have a demonstrated reliability will improve the effectiveness of these control efforts. Also, AQ forecasts related to prescribed forest fires and agricultural field burning are valuable for minimizing smoke impact on local populations or regional haze. The United States Department of Agriculture (USDA) BlueSky program has just begun forest fire smoke predictions in the Northwest (see www.blueskyrains.org). In northern Idaho, we successfully ran the ClearSky smoke forecast system for management of smoke from agricultural field burning (see www.ClearSky.wsu.edu) beginning in the autumn 2002 burn season. The ClearSky system runs in parallel with the AIRPACT system described herein, and models smoke plume dispersion.

Generating numerical AQ forecasts for the Puget Sound region poses two primary problems. The first problem is in generating a reasonably accurate meteorological forecast for the complex Puget Sound region; consider the scale and diversity of landscapes that are involved: the peaks of the Olympic and Cascade Mountains reach elevations as high as 4400 m; maritime straits exist in a variety of sizes and orientations; surfaces range from seawater to farmland, mountain forest, and snowfields; and incoming weather arrives from seaward, all characterized by a dearth of meteorological stations. This regional topography is starkly different from that of other areas in the United States that are the focus of Eulerian AQ modeling efforts: the southeastern United States, Texas Gulf coast, and Los Angeles areas, for example. Thus, many of the challenges associated with AQ forecasting for the Puget Sound area are inherited from the difficulty in weather forecasting for this area. Fortunately, the mesoscale meteorology group at the University of Washington has developed a system for high-resolution weather forecasts for the Puget Sound (Mass et al. 2003). The second major problem is in using the scarce resources available, in terms of emissions data, manpower, computational power, and (critically) AQ simulation codes, in a balanced manner to get the best predictions possible. The AIRPACT approach to this second problem is the general topic for this paper.

In addition to addressing AQ management issues, detailed daily numerical forecast operations can also reveal new information concerning pollutant behavior in a region. As will be noted later, AIRPACT predicted the periodic occurrence of an ozone "hot spot" west of downtown Seattle that had not been previously identified. The AQ monitoring network has now been modified as a result of AIRPACT. Archiving the daily AIRPACT runs builds an extended simulation that can be analyzed to investigate a range of scientific questions. For example, the AIRPACT-archived results from a 6-month period are being used for an initial analysis of the health risk associated with Seattle-area diesel particulate emissions. Finally, automated evaluation of the model performance on an ongoing daily basis builds a comprehensive picture covering a wide range of conditions for determining how well current models represent atmospheric processes.

Given the uses for reliable AQ forecasts, it is not surprising that there is growing interest in the development of numerical AQ forecast systems. In the United States, the Air Quality Research Subcommittee of the Committee on the Environment and Natural Resources (CENR) recently published a review of federal programs and research needs related to AQ forecasts (CENR 2001). This was followed by a workshop conducted as part of the U.S. Weather Research Program; results from the workshop have been summarized in Dabberdt et al. (2004). In both cases, there was a call for more substantial efforts to build and operate numerical AQ forecast systems. In this regard, AIRPACT is a prototype of what we can expect in the future.

AIRPACT SYSTEM. *Domain.* The AIRPACT domain (Fig. 1) encompasses the Puget Sound, the major metropolitan areas of Seattle and Tacoma, and the north–south I-5 interstate highway corridor. The domain consists of 67 (N–S) by 62 (E–W) grid cells (4 km × 4 km each), forming a subset of the cells in the 4-km domain used in the MM5 forecast system. The vertical coordinate system is the sigma system used in MM5, but MM5 layers have been combined to provide for 13 layers reaching an elevation of ~5 km. This domain was selected based on results from earlier photochemical AQ simulations using a much larger domain (Barna et al. 2000; Barna and Lamb 2000) that showed little transport of pollutants from the Vancouver, British Columbia, Canada, metropolitan area into the urban Puget Sound region. Experience shows that the domain appropriate for a modeling application typically changes over time as policy requirements and/or computational and/or informational resources change. For this reason, the AIRPACT system automates the sharing of domain-specific information that must be universally available among AIRPACT system components. Thus, the fullest use of metadata defining the domain is a significant implementation detail throughout the system implementation.

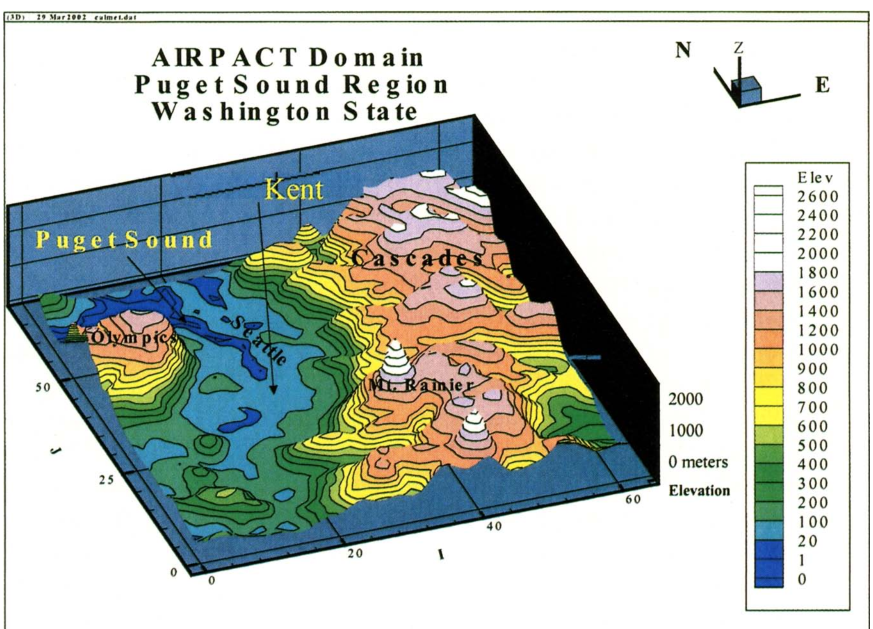

FIG. 1. Map of the AIRPACT domain.

System design for AIRPACT. As shown in Fig. 2, the AQ forecast system consists of the MM5 (Grell et al. 1995), the California Meteorological wind field model (CALMET; Scire et al. 1995), a dynamic emission processing scheme, and the Eulerian California photochemical grid model (CALGRID; Yamartino et al. 1992). The MM5 forecasts are produced at the University of Washington as described by Mass et al. (2003) for a set of nested domains with grid scales of 36, 12, and 4 km, with the outermost 36-km model run being initialized at 0000 and 1200 UTC each day. AIRPACT currently uses forecast hours 12–36 from a 4-km simulation based on a 12-km MM5 run initialized at 0000 UTC. The CALMM5 and CALMET processors pass MM5 wind fields to CALGRID. Thus, the CALGRID 24-h simulation begins at 1200 UTC. In processing MM5 hourly data, CALMM5 extracts

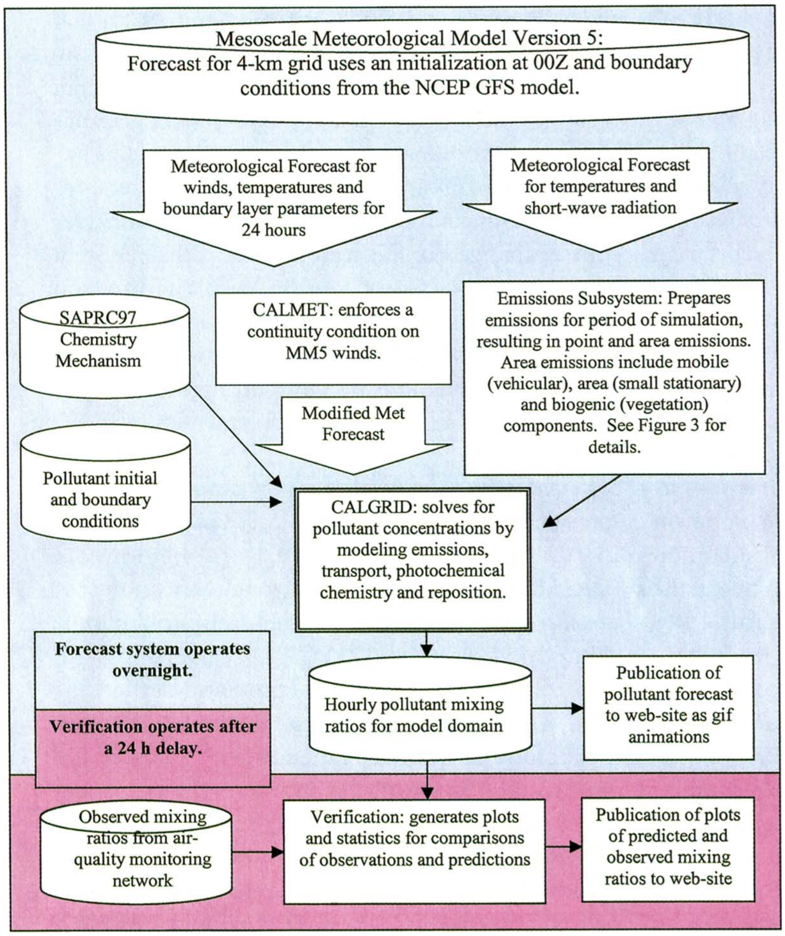

FIG. 2. Major system components for AIRPACT.

temperature and shortwave radiation fields that are made available for emissions processing, as discussed in a subsequent section. Previous applications of CALMET/CALGRID in this region have examined historical ozone episodes of interest, such as the Puget Sound event of 11–14 July 1996 (Barna et al. 2001; Jiang et al. 2003), where meteorological data (surface analyses and vertical soundings) and MM5 simulations were both used to drive CALMET. In the AIRPACT forecast application, however, no observational meteorological data are available—only the forecast results provided from MM5.

The CALGRID version being used in AIRPACT employs a detailed atmospheric chemistry kinetic mechanism called Statewide Air Pollution Research Center 1997 (SAPRC 97; Carter 1996; Carter et al. 1997) to account for the gas phase chemical reactions that lead to the production of ozone and related products, such as formaldehyde. In this mechanism, explicit reactions are included for inorganic and some organic species (i.e., NO, NO_2, isoprene) while most volatile organic compounds (VOCs) are represented by a few surrogate or lumped species (e.g., OLE1 represents fast-reacting olefins). Chemical boundary conditions are based upon results for clean maritime and continental conditions taken from the literature, as well as from previous episodic model simulations in the area (Jiang et al. 2003). Optionally, results from the last hour of a forecast are fed back into the next forecast as chemical initial conditions.

To implement the numerical forecast system, scripts were developed in a Unix environment to automatically execute the various data processors and model codes. Model results, including gridded emission predictions, are converted to network Common Data Form (netCDF) format and visualization postprocessing is done using the Package for Analysis and Visualization of Environmental Data (PAVE), an AQ visualization package (Environmental Modeling for Policy Development project at the Carolina Environmental Program, see www.cep.unc.edu/empd/EDSS/pave_doc/index.shtml). All of the scripts and codes are run on a single processor Compaq/DEC Alpha system; a 24-h simulation requires approximately 70 min of computer time. Each forecast is complete and results available through the Web site by approximately 1400 UTC on the day of the forecast.

Emissions calculations. Preparation of emissions for CALGRID is a critical aspect of AIRPACT. Due to the fantastically multifaceted variety of relevant emission sources, getting accurate emissions data is a virtual impossibility; thus, required emissions inputs are estimated through the artful use of available data and plausible calculations. AIRPACT explicitly treats major point-source emissions (e.g., from power plants) and three types of area emissions: 1) mobile vehicle emissions, 2) biogenic emissions, and 3) anthropogenic emissions (small point sources treated collectively as area sources). The emissions subsystems for biogenic and mobile emissions are shown in Fig. 3. Area emissions from all three contributing types are generated for each hour of CALGRID simulation.

Vehicles generate emissions through engine exhaust and also through six types of evaporative loss:

hot soak, diurnal, crankcase, running, resting, and refueling. The first three of these evaporative loss types are combined into a single EVAPORATIVE category, while evaporative losses during refueling are relegated to anthropogenic area emissions (such as gas stations). Thus, mobile vehicular emissions are treated in four categories: EVAPORATIVE, EXHAUST, RESTING, and RUNNING. The Washington Department of Ecology prepared the AIRPACT base case mobile emissions through a multistep process utilizing MOBILE5b software, with modifications for the anticipated TIER2 standards (Koupal 1999; Kremer 1999). Figure 3 illustrates how AIRPACT generates a gridded mobile emissions inventory with hourly time resolution, utilizing gridded MM5 surface layer temperatures, and reflecting observed temporal variability of traffic. The traffic activity adjustments include the effects of the day of the week and hour of the day.

Figure 3 also shows how AIRPACT generates biogenic emissions by using a third generation biogenic emission modeling system called the Global Biosphere Emissions and Interactions System (GLOBEIS; Guenther et al. 2000), and hourly MM5 data. To avoid the need to run GLOBEIS in real time, uniform MM5 fields of surface temperature and shortwave downward radiation were used as inputs to a single run of GLOBEIS. The base case temperature was set to 30°C and the photon flux was set to 1000 μmol m^{-2} s^{-1}. The resulting biogenic emissions (isoprene, terpenes, and other VOCs) were then converted to the SAPR 97 chemical species and used as a base case for emissions processing. Specifically, these gridded biogenic emissions are modified on a run-time basis using hourly gridded temperatures and shortwave downward radiative flux from MM5, according to equations for isoprene, terpenes, and other VOCs from Guenther et al. (1993). Thus, for each hour of CALGRID simulation, a base map of speciated biogenic emissions is modified for predicted temperature and light levels to project hourly biogenic emissions.

Because point source emissions data generally reflect steady industrial operating conditions and typically are available only on an annual average basis, we adapted an existing point-source emission inventory for the region from our previous episodic modeling studies (Barna et al. 2000). In this case, the Washington Department of Ecology constructed a point-source emissions inventory from annually reported data with some modification for current operating conditions specific to the July 1996 period originally simulated. In AIRPACT, we used this inventory to produce emission files for weekday, Friday, Saturday, and Sunday, each defined as per local time. Then hourly data are read as required from these four single-day files to construct a time sequence of hourly point emissions to match the days of the week and the hours required for the CALGRID run. Development of a more current point source inventory with adjustment for specific conditions remains a future task for improving AIRPACT.

Anthropogenic area emissions are also available for four generic days: weekday, Friday, Saturday, and Sunday. As with the point emissions, anthropogenic area emissions are recast to construct the time sequence required for the CALGRID run.

An example of mobile NO_x (NO and NO_2) emissions is shown in Fig. 4 that illustrates the domination of the Puget Sound mobile emissions by the Se-

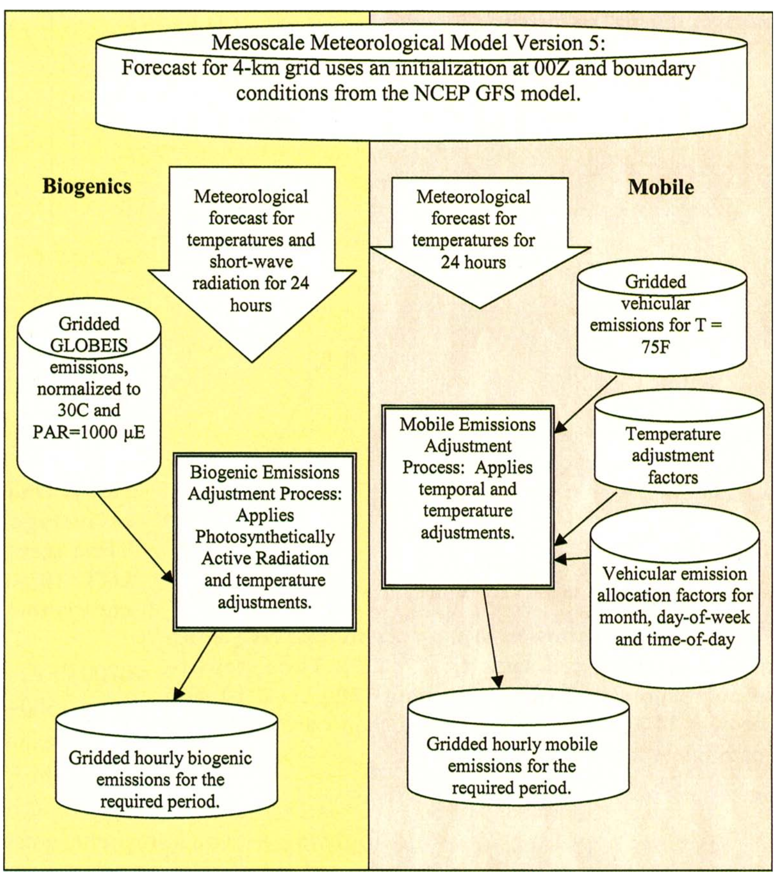

Fig. 3. Schematic for processing biogenic and mobile emissions.

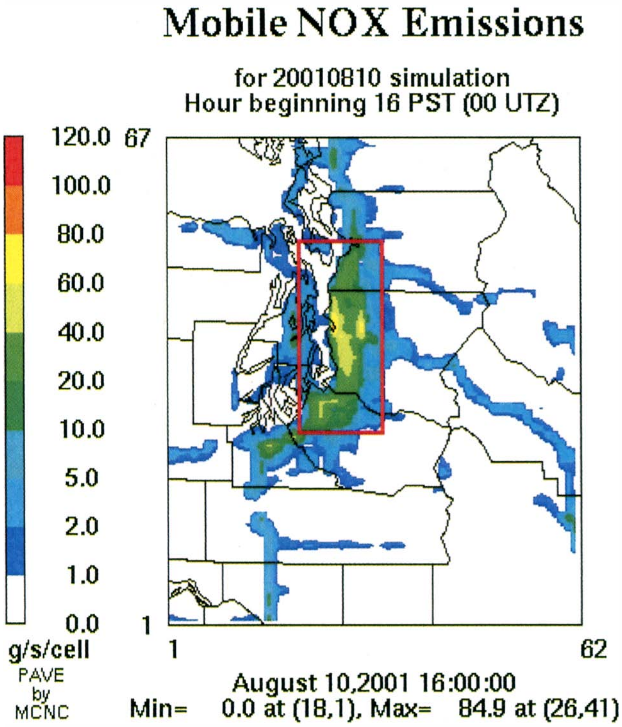

FIG. 4. Emissions contour map for mobile NO_x emissions during the afternoon rush hour. The red rectangle shows the subdomain averaged to represent the Seattle and Tacoma urban core areas, as shown in subsequent plots of diurnal patterns.

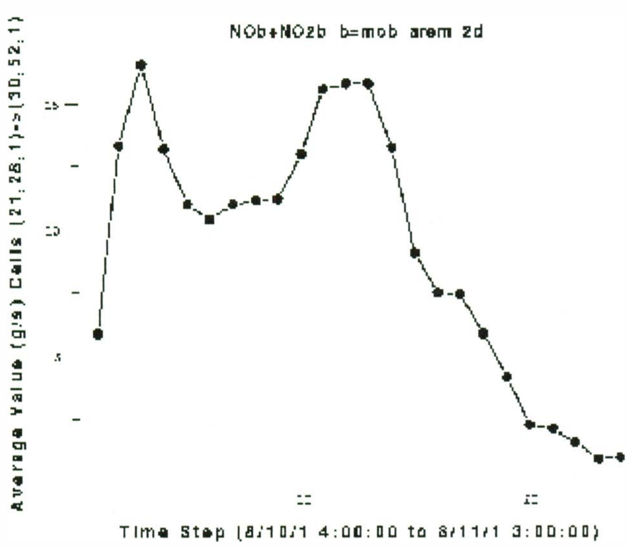

FIG. 5. Diurnal pattern of urban-core mobile NO_x emissions as average cell value (g s^{-1} $cell^{-1}$). Time steps 1–24 correspond to hours beginning 1200 UTC 10 Aug through 1100 UTC 11 Aug. The urban core is the red rectangle shown in Fig. 4.

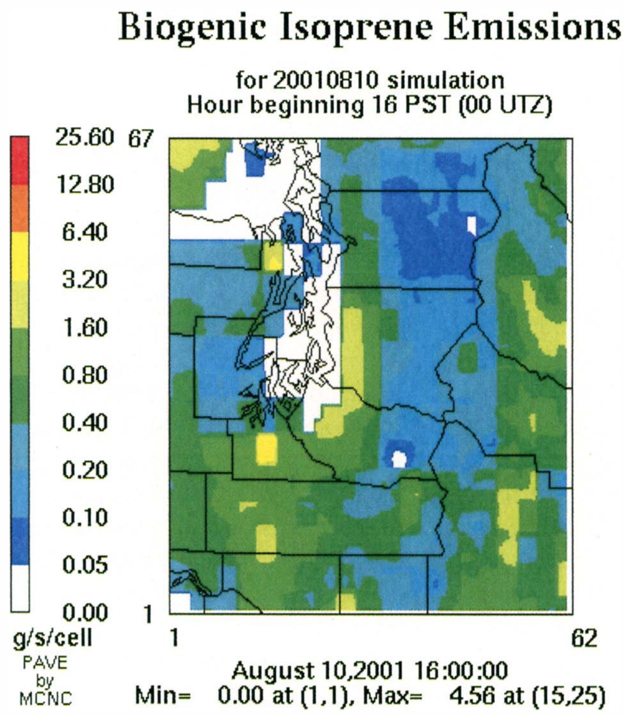

FIG. 6. Emissions contour map for biogenic isoprene emissions.

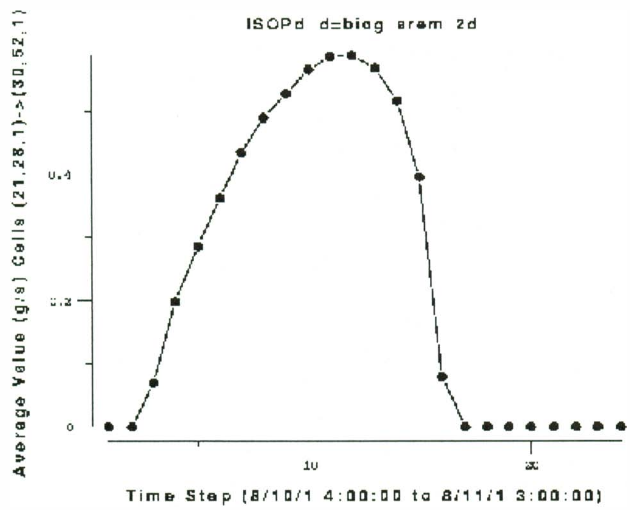

FIG. 7. Diurnal pattern of biogenic isoprene emissions as average cell value (g s^{-1} $cell^{-1}$) for the urban core. Time steps 1–24 correspond to hours beginning 1200 UTC 10 Aug through 1100 UTC 11 Aug. The urban core is the red rectangle shown in Fig. 4.

attle metropolitan area and highway network. Figure 5 shows the urban-core diurnal mobile NO_x emissions pattern with a rush hour peak in the 0600–0700 PST (1400–1500 UTC) hour and a broader peak from 1500–1800 PST (2300–0200 UTC).

An example of biogenic isoprene emissions is shown in Figs. 6 and 7; the latter displays a diurnal cycle that reflects the functional dependence of isoprene emissions on light and temperature. Area NO_x emissions are shown in Fig. 8 and illustrate how area emissions reflect population density.

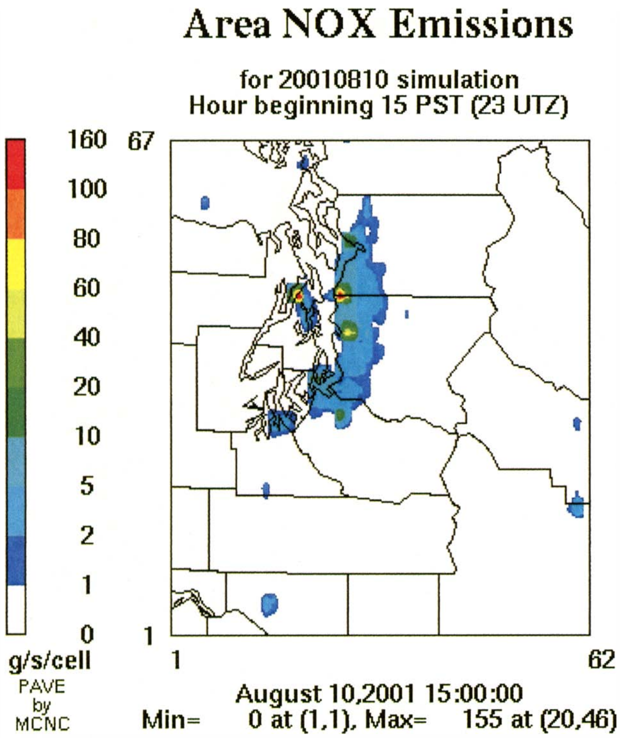

FIG. 8. Emissions contour map for area NO_x emissions.

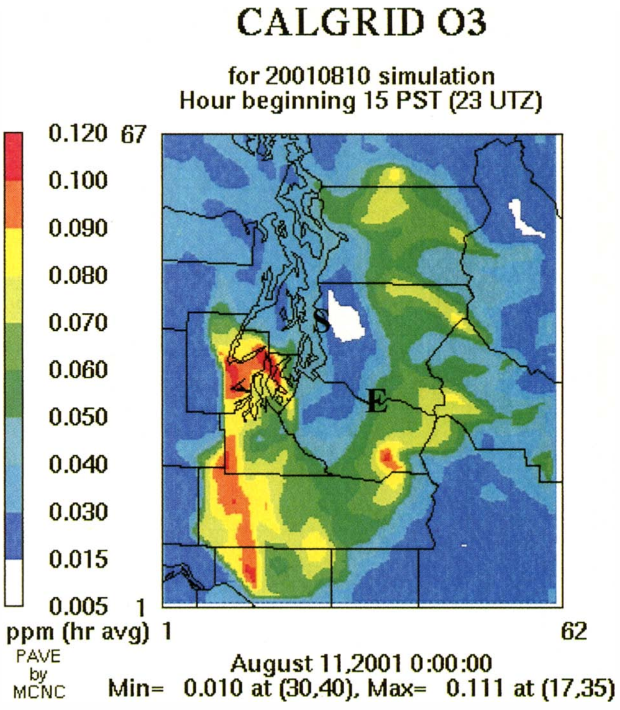

FIG. 9. The O_3 simulation results for Puget Sound area. Urban Seattle is marked as S. Enumclaw is marked as E.

Simulation results. CALGRID results are generated nightly with animations of selected emissions, pollutant mixing ratios and statistics being made available via the project Web site (see www.airpact.wsu.edu). Examples of CALGRID forecasts for O_3 and NO_x mixing ratios are shown in Figs. 9 and 10 for a day from the Pacific Northwest 2001 (PNW2001) field program (discussed later). During this day, weather conditions were mild with warm temperatures and light to moderate northwest winds. These conditions are quite typical of periods with elevated ozone within the region (Barna et al. 2000). These examples illustrate the expected pattern for ozone formation downwind of Puget Sound with elevated NO_x and reduced ozone concentrations in the urban core and a "fishhook" pattern of elevated ozone downwind and surrounding the urban core. The relatively high ozone concentrations that appear to the west and southwest of the urban core had not previously been identified; subsequent monitoring generally confirmed existence of this AIRPACT-predicted ozone hot spot.

By generating daily forecast results, the AIRPACT system makes possible the analysis of (predicted) cumulative pollutant impact. For example, results accumulated during August 2001 are shown in Fig. 11 for the number of hours with predicted O_3 mixing ratios above 80 ppb. Also, results accumulated during the winter of 2001–02 for diesel PM emissions (Fig. 12) were provided to the Washington Department of Ecology for an initial evaluation of population exposure associated with diesel emissions.

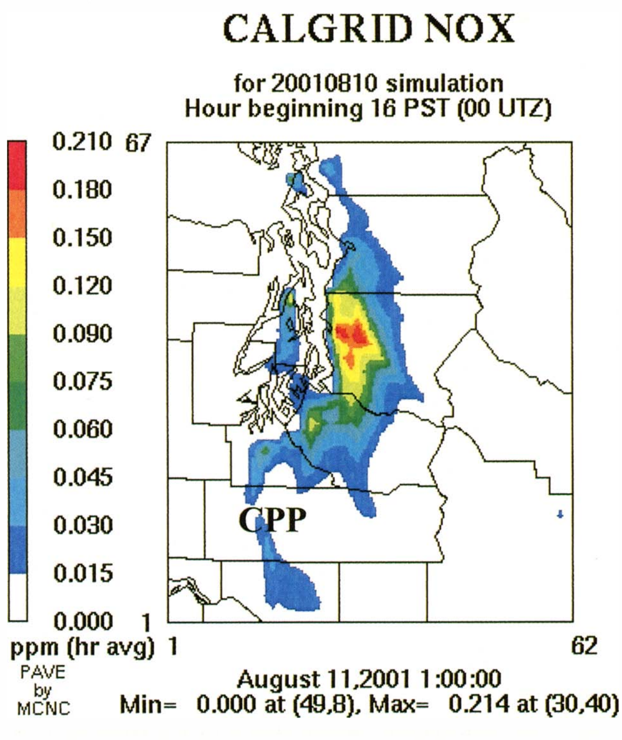

FIG. 10. The NO_x simulation results for Puget Sound area. The location of a power plant in Centralia, WA, is marked as CPP.

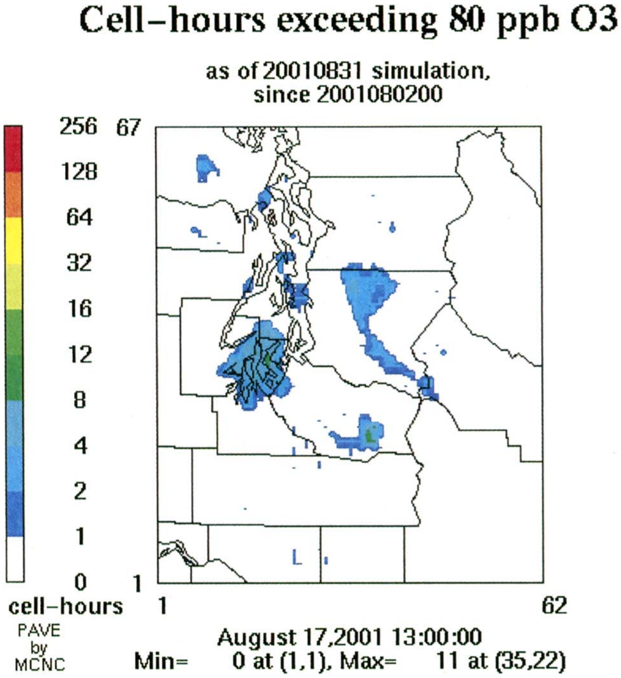

FIG. 11. Accumulated grid cell hours with simulated ozone greater than 80 ppb during Aug 2001.

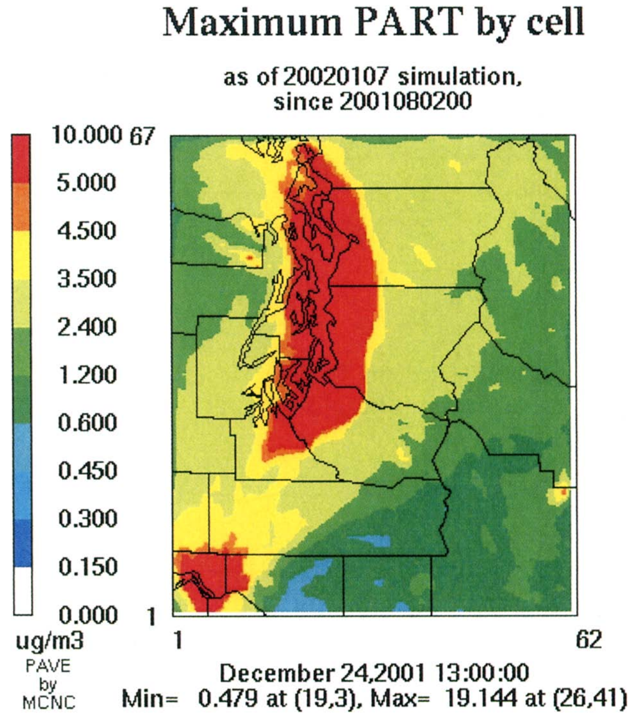

FIG. 12. Grid cell maximum 24-h average particulate matter concentration due to PM diesel emissions during winter 2001–02.

Verification using surface and airborne sensors. AIRPACT simulation results are automatically compared (1 day later) with AQ observations from an automated instrument network operated by the Washington Department of Ecology. These comparisons of observed and predicted mixing ratios are displayed as time series on the Web site on the day following the forecast, such as shown in Fig. 13. This figure is a good illustration of the variability in the skill of the system for simulating ozone. A summary of these evaluation results from a number of ozone monitoring sites during the PNW2001 field campaign in August 2001 is shown in Fig. 14. There is considerable scatter of the ratio of observed/predicted O_3 mixing ratio at low mixing ratios and a tendency to underpredict the maximum observed mixing ratios. Efforts are underway to investigate why this underestimation occurs and whether it is the result of errors in meteorological, boundary condition, emission, or chemical factors.

Model performance statistics for O_3 for August 2001 are given in Table 1. Note that maximum ozone observed during August was 98 ppb, while the maximum predicted ozone (at monitor locations only) was 101 ppb. For analysis of historical ozone episodes using photochemical grid models, the EPA defines acceptable model performance in terms of a bias within 15% and a normalized gross error less than 35%. For the forecast system, the August results generally meet the bias criterion, but exceed somewhat the gross error criterion. This is not surprising since the forecast results cannot take advantage of meteorological observations to improve the meteorological simulation, as is typically done in historical episode analyses. We have previously employed the MM5 using observational nudging to improve the predicted wind fields for modeling a specific ozone episode (Barna and Lamb 2000). In that case, incorporating observed winds in the MM5 simulation improved the O_3 model performance statistics; the mean bias improved from −22% to −9% and the gross error improved from 31% to 24%. Key questions for numerical AQ systems are, 1) What are useful measures of forecast performance?, and 2) What is an acceptable level of forecast skill? These questions need to be addressed in terms of both scientific needs as well as the needs of the public for AQ forecast products.

Additional data for model verification come from an August 2001 North America Research Strategy for Tropospheric Ozone (NARSTO) aircraft study called PNW2001, conducted collaboratively by the Pacific Northwest National Laboratory, EPA Region 10, the Washington State Department of Ecology, the University of Washington, and Washington State University. PNW2001 was conducted in coordination with the Canadian Pacific 2001 study in the Vancouver,

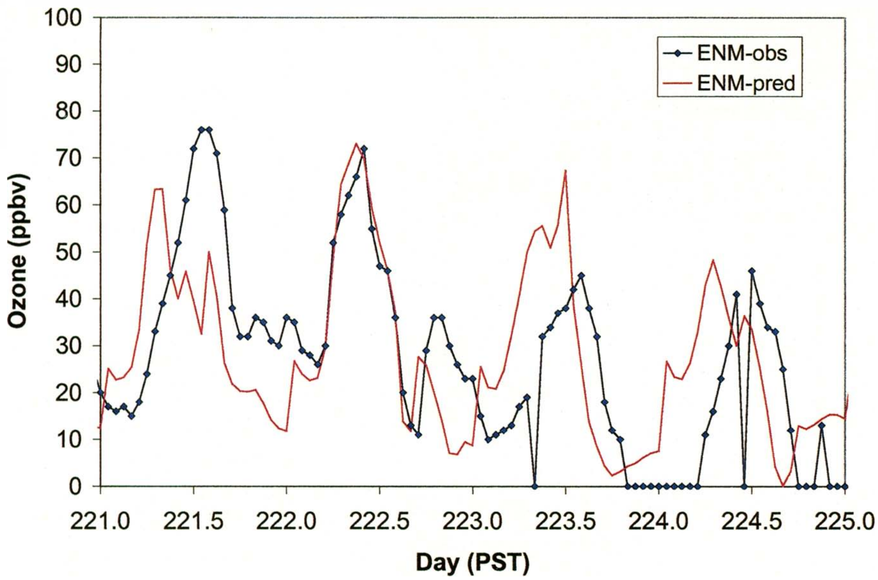

FIG. 13. Diurnal observed and predicted O_3 mixing ratios at the Enumclaw site during 9–12 Aug 2001.

area. For particulate matter, AIRPACT was modified to treat primary particulate emissions from onroad diesel sources, but available monitoring data captures both primary and secondary particulate from all sources. These difficulties in a rigorous evaluation of the system highlight the need for better coupling of urban monitoring networks and numerical modeling tools such as AIRPACT.

In spite of the shortcomings of the monitoring system for evaluation purposes, we have examined the ability of AIRPACT to simulate pollutant concentrations during several different months through the year. For example, results for CO predictions shown in Fig. 15 indicate that the model overestimates CO at low concentrations, but has relatively good performance for CO at elevated levels during July and October. However, in December the model significantly underestimates CO during periods of elevated CO. This may be due to a larger impact of local sources during periods with significant stagnation. For NO_2, the results for these different months (not shown) indicate overestimation at low concentrations and underestimation at elevated concentrations, simi-

British Columbia, area. AIRPACT results are being evaluated by comparison to aircraft and ozonesonde data from PNW2001.

An area of high ozone SW of Seattle–Tacoma in Fig. 9 is seen in Fig. 11 to be a commonly predicted feature. This region of frequently elevated O_3 was predicted by AIRPACT but had not been observed prior to August 2001. Snow et al. (2003) found from the 10 August PNW2001 sampling flight that this heretofore unobserved O_3 plume appears to have existed much as predicted, lending credence to the basic correctness of the AIRPACT system. These predictions both stimulated interest in using model results to guide monitoring efforts to discover previously uncharted O_3 plumes and motivated the extension of the monitoring network to collect data from the vicinity of the AIRPACT-predicted hot spot.

In addition to the PNW2001 field program, preliminary evaluation of AIRPACT has been completed using the routine monitoring system. This evaluation is complicated since 1) CO monitors are typically placed at traffic hot spots, and 2) such hot spot monitoring reports elevated CO levels that are not well represented in the 4-km grid of the AIRPACT system. Further, there are no VOC observations made on a routine basis and there is only one NO_x monitor in the

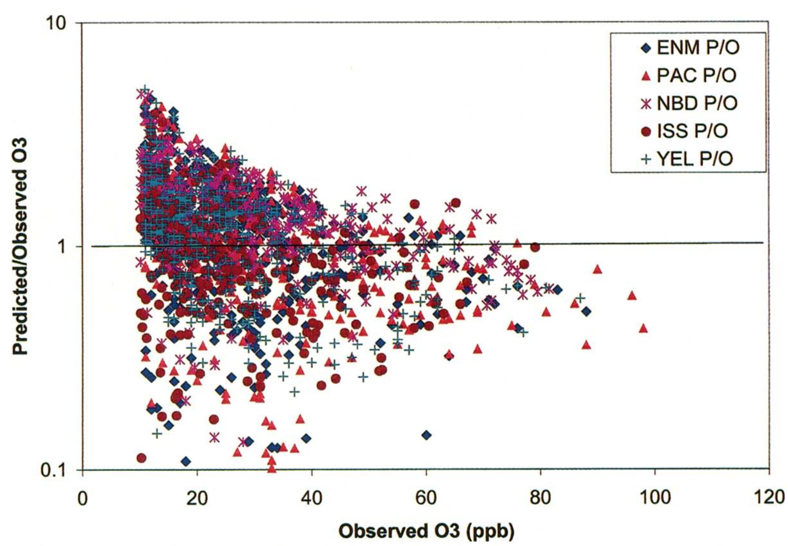

FIG. 14. Ratio of predicted/observed O_3 vs observed O_3 mixing ratio at five rural sites downwind of Seattle during Aug 2001.

Table 1. Summary of model ozone performance statistics for Aug 2001. Mean, standard deviation, and maximum are shown as parts per billion for observed and predicted ozone for each site and sites combined. Mean and standard deviation for ratio of predicted over observed (P/O) ozone are given and as simple ratios for each site and sites combined. Mean bias and gross error are given as percentages for each site and sites combined.

	Mean	Std dev	Max	Bias (%)	Gross error (%)
Enumclaw				23	60
Obs (ppb)	26	15	88		
Pred (ppb)	26	17	76		
P/O	1.2	0.8			
Seattle				–5	56
Obs (ppb)	21	9	59		
Pred (ppb)	15	13	56		
P/O	0.9	0.7			
Pack forest				22	53
Obs (ppb)	27	16	98		
Pred (ppb)	27	15	83		
P/O	1.2	0.7			
Rainier				–6	35
Obs (ppb)	40	14	81		
Pred (ppb)	34	12	92		
P/O	0.9	0.4			
North Bend				46	63
Obs (ppb)	30	17	82		
Pred (ppb)	29	17	95		
P/O	1.5	0.7			
Issaquah				2	47
Obs (ppb)	25	14	79		
Pred (ppb)	16	12	101		
P/O	1.0	0.6			
Yelm				27	54
Obs (ppb)	26	14	87		
Pred (ppb)	25	14	70		
P/O	1.3	0.7			
All sites				15	51
Obs (ppb)	29	15	98		
Pred (ppb)	25	16	101		
P/O	1.1	0.7			

lar to that shown previously for O_3. For particulates, AIRPACT underestimated observed levels, but this was expected since the system only simulates primary diesel emissions. However, it appears the degree of underestimation is more than can be explained by the fraction of diesel PM in the emission inventory. Collectively, these preliminary evaluations of forecast performance suggest a general underestimation of elevated pollutant levels. However, it is not yet clear whether this is caused by underestimation of emissions, overestimation of mixed layer depth or wind speed, or by the inherent problems of comparing point observations to gridded model output.

Because of interest in the application of AIRPACT in providing public alerts, it is also important to evaluate the use of the system to simulate the correct AQI. In this regard, we need to recognize that the AQI has very distinct cutoffs based on pollutant concentrations: good, moderate, unhealthy for sensitive groups, and unhealthy. Thus, the model can miss the correct AQI even if it is predicting a pollutant level within a few parts per billion. In terms of the 1- and 8-h ozone standards, AIRPACT correctly predicted the AQI category in 98.4% and 97.6% of the possible observations, respectively (all sites, all hours). However, the tendency of the system to underestimate peak ozone values is evident in the AQI summary in Table 2; the number of cases with moderate to unhealthy conditions is slightly underestimated.

CONCLUSIONS. Several aspects of the AIRPACT system promise to provide modelers with ample feedback, helping them to focus available resources on model skill, emissions accuracy or other science, and code or data issues. For example, during the 10 August 2001 simulation discussed herein, gaps in roadways can be seen in the mobile emissions results in Fig. 4; since this simulation the mobile emissions data have been updated to correct this problem. Also, strong area emissions for

NO_x have been detected in suspicious areas (Fig. 8) and traced back to spatial allocation problems for marine (ship fuel combustion) emissions; the spatial allocation of marine emissions merits further review. Last, the blocky pattern visible in biogenic isoprene emissions (Fig. 6) suggests that our use of GLOBEIS results in relatively coarse-scale emissions, prompting a review of our biogenics processing. In general, AIRPACT's automated animations and automated verification support the identification of desired corrections and enhancements.

Despite minor problems identified by exercising AIRPACT, this AQ simulation system is proving to be a unique tool to study the performance (accuracy) of the CALGRID AQ model, the correctness of the emissions subsystems, and the adequacy of the associated emissions inventories. Evaluation of AQ forecast verification statistics with reference to categories of meteorological conditions can 1) help identify weak areas in the AQ modeling components, and 2) guide improvements to these models, or 3) may motivate the replacement of CALGRID with another model, for example the Community Multiscale Air Quality model (CMAQ; U.S. Environmental Protection Agency 1999b).

While AIRPACT's automated verification component has provided useful feedback for model evaluation and correction of errors, there is still a pressing need for a robust and capacious data storage and analysis system to fully support post hoc analysis of model performance, in concert with observed meteorology data and a wide variety of AQ data. We are working to identify a database and analysis system (hardware and software) well suited to supporting this AIRPACT requirement.

The AIRPACT project is demonstrating a highly automated real-time AQ forecasting approach in application to the Puget Sound area. The AIRPACT design targets linkage of real-time monitoring to forecasting for purposes of verification and seeks to apply AQ modeling both to educate the public and to alert sensitive individuals to potentially dangerous pollution episodes. AIRPACT is operating with a full flow of emissions and generating daily AQ forecasts for review. It is very indicative of the interest in the system that there has been a recent push to extend AIRPACT coverage both north into Canada and south into Oregon. Accordingly, the 4-km domain is being expanded to include Vancouver, British Columbia, in the north, and Salem, Oregon, in the south. Also, additional tracer species are being added to AIRPACT for tracing air-toxics emissions. Thus, AIRPACT will soon provide an automated, long-term simulation of air toxics for two major metropolitan areas in the Northwest, and these results will be directly comparable to ongoing air-toxics monitoring programs in both cities.

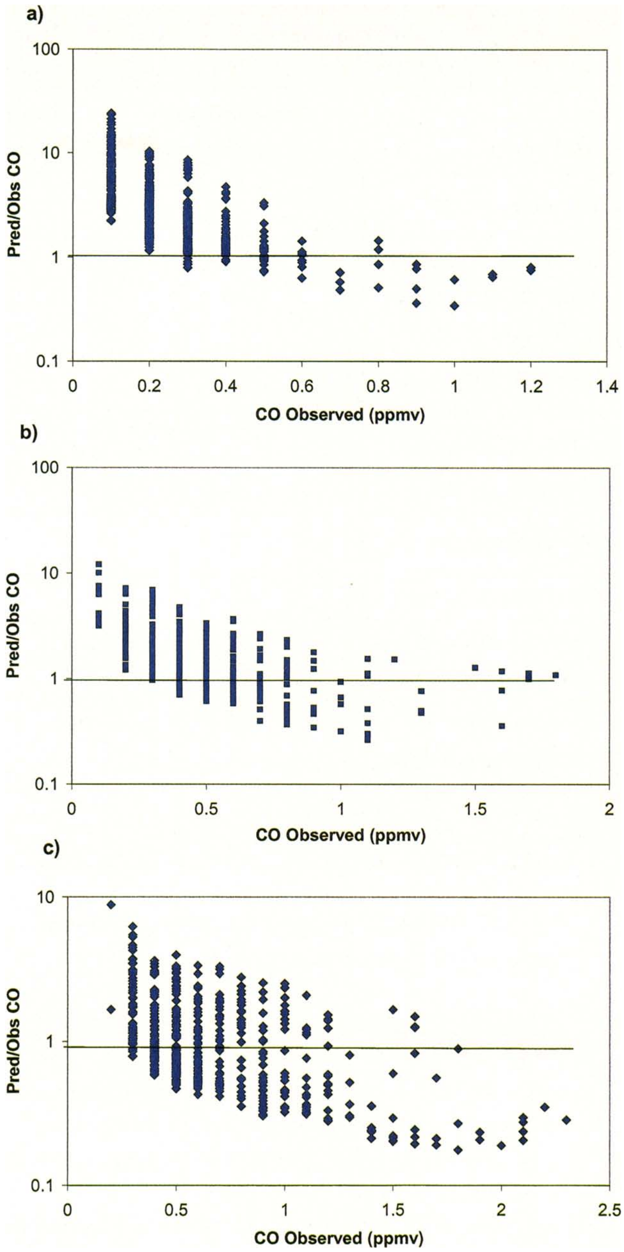

FIG. 15. Ratio of predicted/observed CO vs observed CO mixing ratios at an urban Seattle monitoring site during (a) Jul, (b) Oct, and (c) Dec in 2002.

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Table 2. Summary of observed and predicted AQI for Puget Sound during Jul 2002 for ozone.

AQI range	Observed AQI occurrences	Predicted AQI occurrences
1-h average O3		
Good (O3 < 50 ppb)	3648	3666
Moderate (51 ppb to 100 ppb)	56	39
Unhealthy for sensitive individuals (101 to 120 ppb)	3	2
Unhealthy (> 120 ppb)	0	1
8-h average O3		
Good (O3 < 50 ppb)	4248	4270
Moderate (51 ppb to 100 ppb)	29	22
Unhealthy for sensitive individuals (101 to 120 ppb)	7	0
Unhealthy (> 120 ppb)	5	0

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