AIRPACT: A Real-Time Air Quality Forecast System for the Pacific Northwest

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ABSTRACT
A real-time air quality forecast system has been implemented for the Puget Sound area of the Pacific Northwest as part of AIRPACT (Air Indicator Report for Public Awareness and Community Tracking), an EPA sponsored EMPACT project. This forecast system is based upon daily numerical weather forecasts from the Mesoscale Meteorological Model Version 5 (MM5) coupled to automated operation of the CALMET/CALGRID photochemical grid modeling pair. Hourly forecasts of pollutant concentrations are produced for urban Seattle and its environs with a gridded domain measuring 62 (E-W) x 67 (N-S) cells (4 km x 4 km per cell) with 13 vertical layers of variable spacing. Detailed gridded emission inventories adjusted for time of day, day of the week, month, and gridded ambient temperatures are used as inputs to the modeling system. The forecast system has only recently become operational. In this paper, the details of the forecast system are described and initial pollutant emission and ambient concentrations are presented to illustrate the primary products of the system.

INTRODUCTION

With the goals of promoting the use of innovative technology for developing environmental information and providing that environmental information to the public in a timely manner, the U.S. Environmental Protection Agency established the Environmental Monitoring for Public Access and Community Tracking (EMPACT) Program in 1998. The EMPACT Program works with communities via financial grants for projects that will make timely, accurate, and understandable environmental information available to millions of people in the largest metropolitan areas so that communities and individuals can make informed, day-to-day decisions about their lives. One such project, called the Air Indicator Report for Public Access and Community Tracking (AIRPACT), is underway in the greater Puget Sound Metropolitan Area of the State of Washington.

To increase public awareness of air quality issues in the Puget Sound region, and to promote changes in lifestyle to improve the region's air quality, EPA Region 10 (Seattle), the Washington Department of Ecology, and the Puget Sound Clean Air Agency are collaborating with the University of Washington and Washington State University in the AIRPACT project.

The intent of the Puget Sound AIRPACT program is to couple real-time air quality monitoring data with daily numerical forecasting of weather and air quality to provide the public, government agencies, other groups, and sensitive populations, with timely information regarding air quality. It will include the distribution of current and forecast air quality conditions to a wide audience through the web and regional media outlets as well as direct communication of air quality alerts to sensitive individuals through an Air Alert Hotline. In addition, the AIRPACT will promote a better understanding of air quality issues in the Northwest and better science by facilitating regional development and evaluation of air quality modeling systems. By linking to the EPA AIRNOW program, AIRPACT will also contribute to the national knowledge base.

BODY

Previous Work

The motivation for developing a regional air quality simulation system for the Pacific Northwest and for the Puget Sound, in particular, arises from a history of periodic exceedances of the National Ambient Air Quality Standard (NAAQS) for ozone[1] and elevated levels of PM10 and PM2.5. Although the region is currently in attainment of the ozone standard, past history suggests that the occurrence of high temperatures and stagnant winds can lead to elevated photochemical pollutant concentrations and possible exceedance of the NAAQS. Previous observational data and modeling results also indicate that the region will be affected negatively by a change in the ozone standard to 80 ppb averaged over eight hours.

In our recent development of a regional photochemical modeling system for the Cascadia region, we employed the prognostic Mesoscale Meteorological Model Version 5 (MM5) [2] to predict meteorological fields for this region of extremely complex terrain. The output from MM5 was re-formatted using the CALMET diagnostic model[3] in a mode where minimal changes to the MM5 winds were made. The resulting CALMET winds and boundary layer parameters were used as input to CALGRID, a state-of-the art Eulerian photochemical air quality model.[4] Hourly, gridded emissions data were compiled by the Washington Department of Ecology, and the modeling system was used to simulate an ozone episode that occurred during July 11-14, 1996. Results from this simulation showed that the modeling system demonstrated good performance in comparison to ozone observations at monitoring sites in the Puget Sound area and downwind of Portland, OR.[1] Further analysis of this episode was completed where meteorological observations were incorporated into the MM5 solution using observational nudging. In this case, model performance was improved compared to cases with no wind observations employed and with observations incorporated via interpolation using CALMET.

Current Work

The AIRPACT program involves several components: 1) ongoing operation of an existing real-time air quality monitoring network and enhanced publication and distribution of hourly air quality data; 2) merging of existing MM5 daily weather forecasts and a gridded emissions inventory with a photochemical air quality model to produce detailed hourly maps of pollutant concentrations and air quality indices forecast 24 to 48 hours into the future; 3) implementation of an Air Quality Alert Hotline to families of children with asthma regarding forecast periods of poor air quality; and 4) public outreach and education to promote a clear understanding of the air quality data and forecasts through the Air Watch Program of the Puget Sound Clean Air Agency. The AIRPACT program plans to take advantage of a variety of media for dissemination of the daily air quality information including an established web site, transfer of information and useful graphics to the broadcast media and newspapers, and development of a direct communication air quality alert system for asthmatic children using automated phone systems. A variety of products ranging from charts of Air Quality Indices (AQI) to actual pollutant concentrations for ozone, $PM_{2.5}$, and PM_{10}, will insure that the public can access air quality information at an appropriately useful technical level.

The AIRPACT program seeks to exploit several technological resources available in the Puget Sound region to demonstrate the potential to educate and inform the public about air quality issues. The technological capital being leveraged in this effort includes:

1) Expertise and computer infrastructure for meteorological modeling at the University of Washington, Department of Atmospheric Sciences,
2) Expertise in emissions inventory preparation at the Washington Department of Ecology (Ecology, hereafter),
3) Real-time air quality monitoring data from a multi-site network operated by Ecology, and the Puget Sound Clean Air Agency (PSCAA)
4) Expertise in air quality modeling at Washington State University, Department of Civil and Environmental Engineering.

The AIRPACT project can be summarized as the automated application of current state-of-the-art meteorological and air quality models to short term air quality forecasting, with feedback from an air quality sensor network, coupled with a public education program and a targeted outreach program for vulnerable populations. Whereas the AIRPACT air quality forecasting is highly automated, generating air quality prediction results by each morning for the day, decisions to issue air quality alerts are decided by meteorologists and public health experts and will not be automated for the foreseeable future. This paper presents the basics of the AIRPACT air quality forecasting system, with an emphasis on emissions inventory preparation for mobile sources, and shows examples of both emissions processing results and air quality forecasts.

Domain

The AIRPACT domain is rendered as a Lambert Conformal projection grid bounded on the southwest corner by 46.07° N. latitude, 123.66° W longitude and on the northeast corner by 48.54° N and 120.35° W, and is defined to be 13 layers in depth. The gridded domain is composed of 62 columns (E-W) by 67 rows (N-S) of 4-km cells. The domain is shown in Figure 1, and extends from the shoulders of the Olympic Mountains on the Olympic Peninsula in the west, eastward over the Puget Sound, past Mt. Rainier and into the middle of the Cascade Mountain Range in the east, and from near the Canadian border with Washington State in the north to the vicinity of Longview, Washington, and the mouth of the Columbia River in the south. The domain thus encompasses the Puget Sound, the major metropolitan areas of Seattle and Tacoma, and the north-south I-5 (interstate highway) corridor. The vertical resolution varies; the tops of the 13 layers are at elevations (above the surface elevation) of {20, 100, 220, 350, 450, 550, 650, 750, 850, 1200, 2000, 3000, 5000} meters. This domain was selected based on results from earlier photochemical air quality simulations using a much larger domain[1,5] that showed little transport of pollutants from the Vancouver, BC. Metropolitan area into the Puget Sound region. However, experience shows that the domain appropriate for a modeling application, such as AIRPACT, 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 design.

System Design for AIRPACT

As shown in Figure 2, the air quality forecasting system for AIRPACT utilizes MM5 meteorological forecasts. These forecasts are produced by running the MM5 (Penn State Mesoscale Meteorological Model, version 5) for a set of nested domains at resolutions ranging from 36-km to 12-km to 4-km, with model runs being initialized at 00Z and 12Z each day. AIRPACT uses the 00Z 4-km MM5 simulation results beginning with the 12Z forecast hour. The CALMM5 and CALMET processors pass MM5 wind fields to CALGRID. Thus the CALGRID simulation begins at 4:00 AM PST. In processing MM5 hourly data, CALMM5 extracts temperature fields that are then made available for emissions processing, discussed in a subsequent section. Typical applications of CALMET/CALGRID have been to examine historical ozone episodes of interest, such as the 1996 July 11-14 Puget Sound event.[5] In such applications, meteorological data from surface analyses and vertical soundings are used with CALMET. In the AIRPACT forecast application, however, no such data is available beyond the simulation results provided from MM5. Thus, AIRPACT seeks to maximize the utility of the MM5 data for producing useful CALMET results. The version of CALGRID being used in AIRPACT employes the SAPRC97 chemistry mechanism.[6,7] Various enhancements are envisioned for the air quality forecasting system as shown in Figure 2. Although emissions are currently being processed for mobile (vehicular) and point sources, additional work is needed to automate preparation of biogenic and anthropogenic area emissions (not shown). Also, as indicated in the schematic of Figure 2, the option of extracting initial conditions for a subsequent CALGRID run is required, although not yet implemented for testing. Although the AIRPACT air quality simulation system is operating in an automated manner for testing, operational verification using data from Ecology's real-time air quality network is not yet automated.

System Implementation

AIRPACT is built primarily of processors (CALMM5, CALMET and CALGRID) written in FORTRAN77. Visualization post-processing is being done (currently and experimentally) using the North Carolina Supercomputing Center's PAVE package; PAVE requires netCDF data files, which are generated using file conversion codes written in FORTRAN90. The automation of the AIRPACT system is accomplished using perl and cshell scripts. Performance on a University of Washington Compaq/DEC Alpha system for a single processor run is ~70 minutes for a 24 hour simulation.

Emissions Processing

Emissions preparation for the CALGRID run is a critical aspect of the AIRPACT forecasting system. CALGRID accepts emissions in various input files; AIRPACT identifies emissions of four types: 1) point source emissions, 2) mobile vehicle emissions, 3) anthropogenic emissions treated as area (aggregates of small point sources), and 4) area biogenic emissions. Currently, only the mobile vehicle emissions and point source emissions files are implemented in an automated manner, as shown in Figure 2 and Figure 3. These two emissions processing sub-systems will be discussed in greater detail.

Mobile emissions representing the vehicular sources of emissions are generated for each hour of CALGRID simulation. Two aspects warranting detailed discussion are the preparation of the base gridded mobile emissions inventory (with adjustment factors) and the run-time emissions preparations.

Vehicles generate emissions both through engine exhaust and through a variety of evaporative losses. These evaporative losses have been further identified as being of six types: hot soak, diurnal, crankcase, running, resting, and refueling. Ecology's treatment combines the first three into a single evaporative category, and relegates evaporative losses during refueling to anthropogenic area emissions (such as gas stations), resulting in four classes of vehicle emissions: EVAPORATIVE, EXHAUST, RESTING, and RUNNING. Ecology prepared the AIRPACT mobile emissions through a multi-step process.

1. Using TIER2 software (based on MOBILE5B) representative vehicle fleet data corresponding to three types of areas were processed for emissions over a range of temperatures.[8,9,10] The three types of areas treated are the two inspection and maintenance (I/M) jurisdictions of Puget Sound and Vancouver (WA), and other non I/M areas. These simulations were performed for both summer and winter conditions, with fuel Reid Vapor Pressure (RVP) values of 7.8 and 12.8 p.s.i., respectively. (Summer RVP is controlled to be no greater than 9.0 p.s.i. by law in Washington.)

2. Base emission rates for 75° F for the three types of areas, for summer and Winter RVPs, were extracted from the TIER2 results.

3. The emission rates sensitivity for temperature was determined by analysis of the TIER2 results, for both summer and Winter RVP.

4. January 2001 Vehicle Miles Traveled (VMT) estimations were obtained by updating data from 1994—1997, based on traffic projections by the Washington Department of Transportation and other local transportation planning agencies.

5. Road segment-based estimates for January 2001 VMT were regridded to a 5-km grid.

6. Washington Department of Transportation data were used to develop weighting functions for time of day, day of week and month for levels of vehicular activity (VMT).

7. Emissions (seasonal and area specific) were mapped to the gridded base VMT activity levels to obtain a gridded base emissions inventory by season representing a daily speciated emission inventory for a base day, with an implicit reference temperature of 75°F.

AIRPACT has chosen to produce a detailed mobile emissions inventory, as described in the steps above, to support generation of highly realistic vehicle emissions throughout any simulation period. Thus, by using descriptions of temperature sensitivity and temporal variability, mobile emissions can be generated on an hourly basis, utilizing gridded MM5 surface layer temperatures, and reflecting observed traffic temporal variability. A schematic showing this real-time preparation of temperature-adjusted mobile emissions is shown in Figure 3.

Point emissions for AIRPACT are likewise constructed on an hourly basis for each AIRPACT CALGRID run. The basic point emissions inventory consists of a list of point sources with descriptive metadata, including the point location, constructed for a four-day period in July 1996, a Thursday through Sunday period. This inventory of point emitters is windowed to reject those points not found within the AIRPACT domain. Point emissions for all hours of this period are then recast into files for Weekday, Friday, Saturday and Sunday, each of 24 hours. These data are then 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.

The cyclic diurnal nature of the mobile emissions are evident in Figure 4 which shows gird average mobile CO emissions as having a sharp morning peak at 6 AM PST and an afternoon peak from 2 to 4 PM PST. This pattern seems credible for March 8, 2001, a Thursday. Examples of AIRPACT gridded mobile emissions are shown for CO and for NOx in figures 5 and 6, respectively. These two figures show domination of the Puget Sound mobile emissions area by the Seattle metropolitan area. The PAVE tile plots show the minimum and maximum mobile emission rates for 4 PM PST at the bottom of the figure. In Figures 5 and 6 the scale has been set to expose the spatial distribution of the lower emission cells to illustrate the transportation network pattern associated with mobile emissions.

Simulation Results

CALGRID concentration forecasts for 4 PM PST March 8, 2001 are shown in Figures 7 and 8, respectively, to illustrate typical results. (Note that CALGRID time steps are denoted in UTZ in the Figure 7 and 8 PAVE graphics.) The NOx pattern shows domination of the Seattle area by a major plume that appears to originate south of Seattle at the Centralia power plant (a major point source at Centralia in Lewis County—see CPP in Figure 1). PAVE animations (not shown here) show this plume behavior quite clearly. The high NOx in the immediate vicinity of the Seattle urban plume appears to be responsible for titration of ozone down to relatively low levels. Two smaller plumes are also visible in the vicinity of Bellingham WA.

System Feedbacks

Several aspects of the AIRPACT system promise to provide ample opportunities for feedback to modelers, helping them to focus available resources on model skill, emissions accuracy or other science, code or data issues. The AIRPACT air quality simulation system design, with automated verification using air quality monitoring data, offers a unique opportunity to study the performance (accuracy) of the air quality modeling system including the emissions subsystems and associated inventories. This paradigm parallels the verification process implemented for the MM5 forecasting system by the University of Washington Mesoscale Modeling Group. Evaluation of air quality forecast verification statistics with reference to categories of meteorological conditions can 1) help identify weak areas in the air quality modeling components, and 2) guide improvements to these models, or 3) motivate their replacement with another model, e.g. CMAQ. Also, verification statistics should provide a means for evaluating the adequacy of the emissions being generated in the AIRPACT system for forecast use. Due to the nascent stage of development for this verification aspect of AIRPACT, further discussion of this prospect will be deferred to a future paper.

CONCLUSIONS

The AIRPACT project is demonstrating a highly automated real-time air quality 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 air quality modeling both to educate the public and to alert sensitive individuals to potentially dangerous pollution episodes. AIRPACT is operating in a test mode and generating daily air quality forecasts for review.

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Figure 1. AIRPACT domain with elevation and geographical reference points.

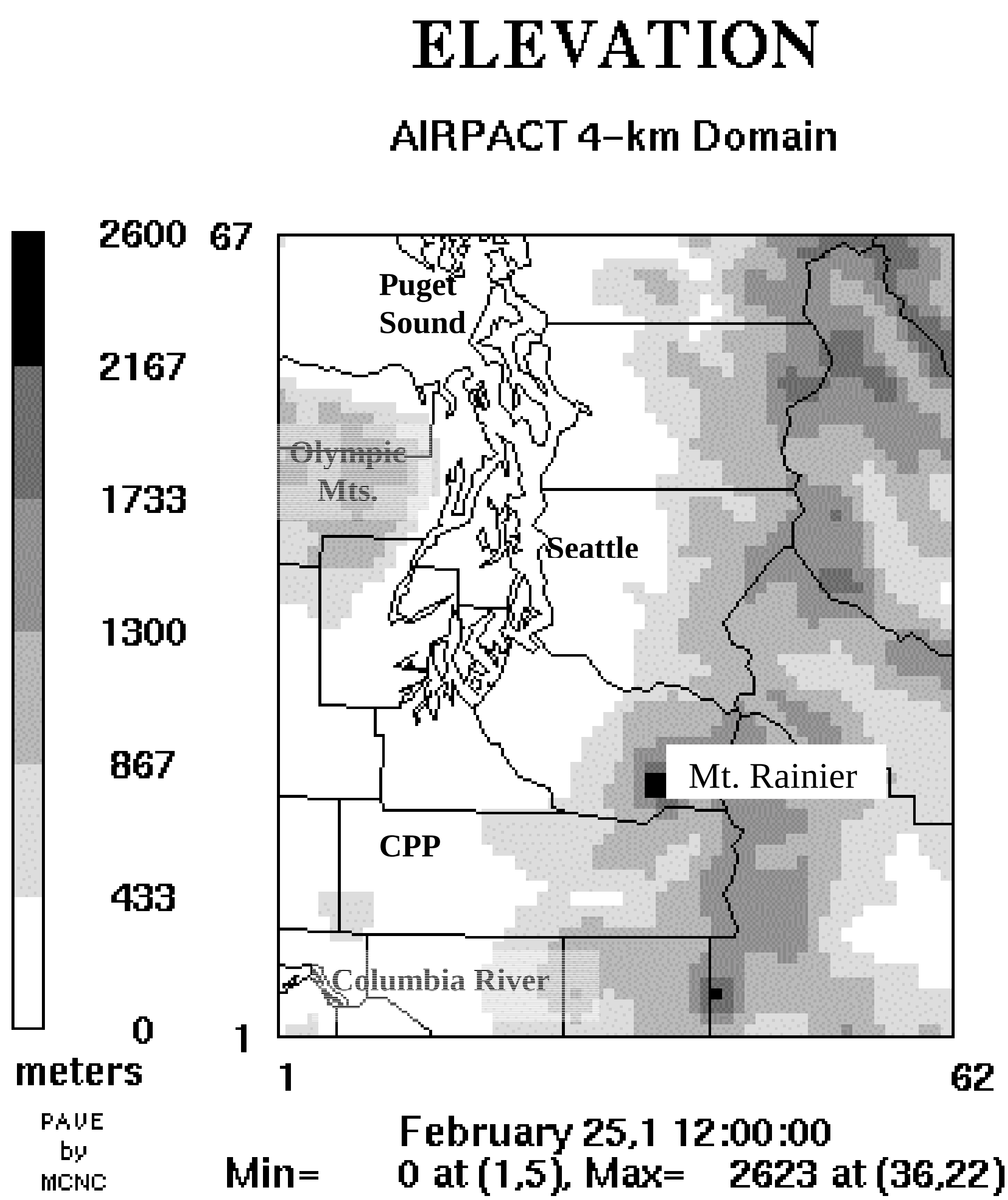


Figure 2. AIRPACT air quality simulation system schematic. Processors are shown in boxes and files as cans. A gray background indicates a processor still being developed. The supervisory scripting that automates the entire air quality forecast process is not represented in this schematic.

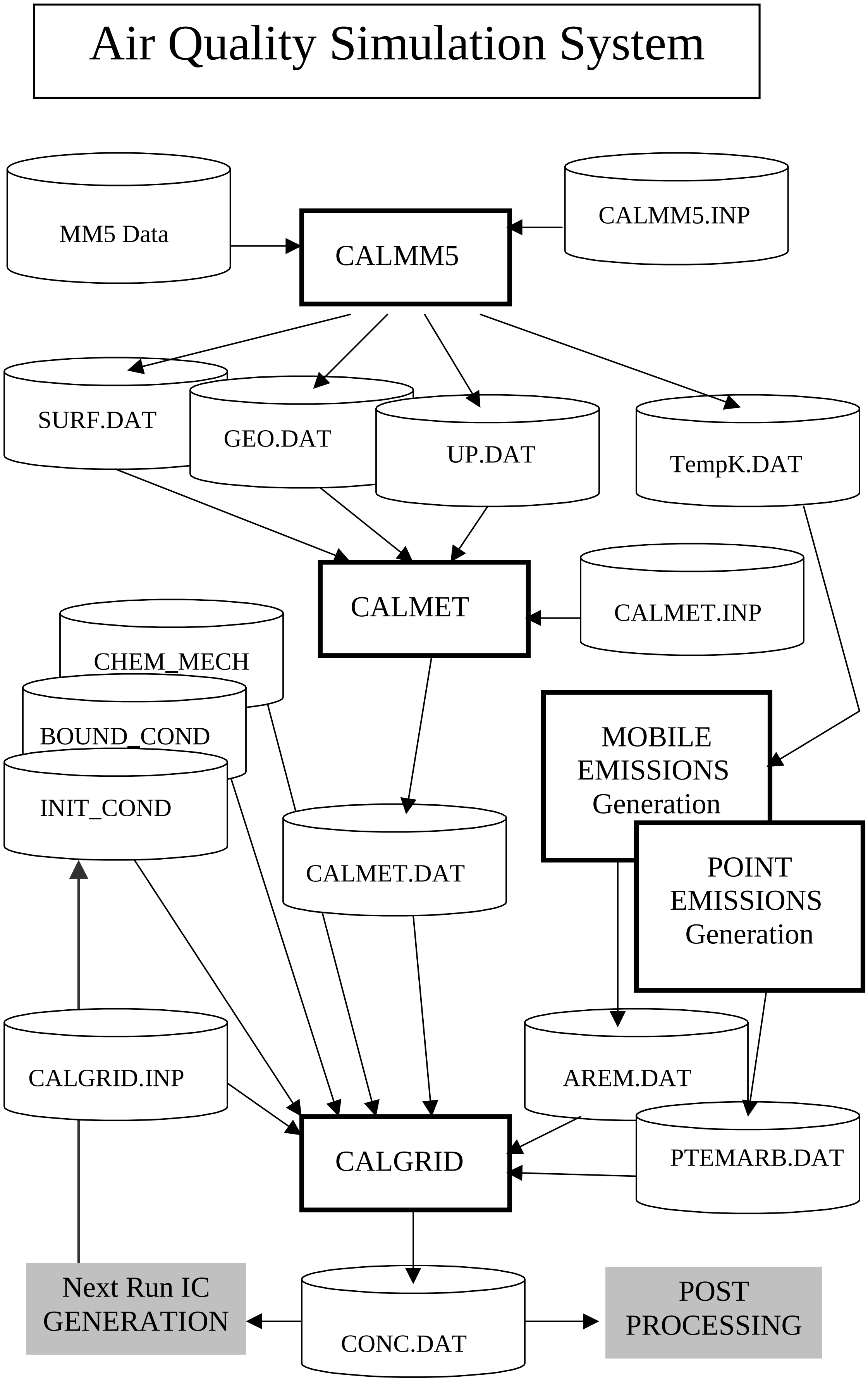


Figure 3. Mobile emissions processing for AIRPACT using hourly gridded temperatures.

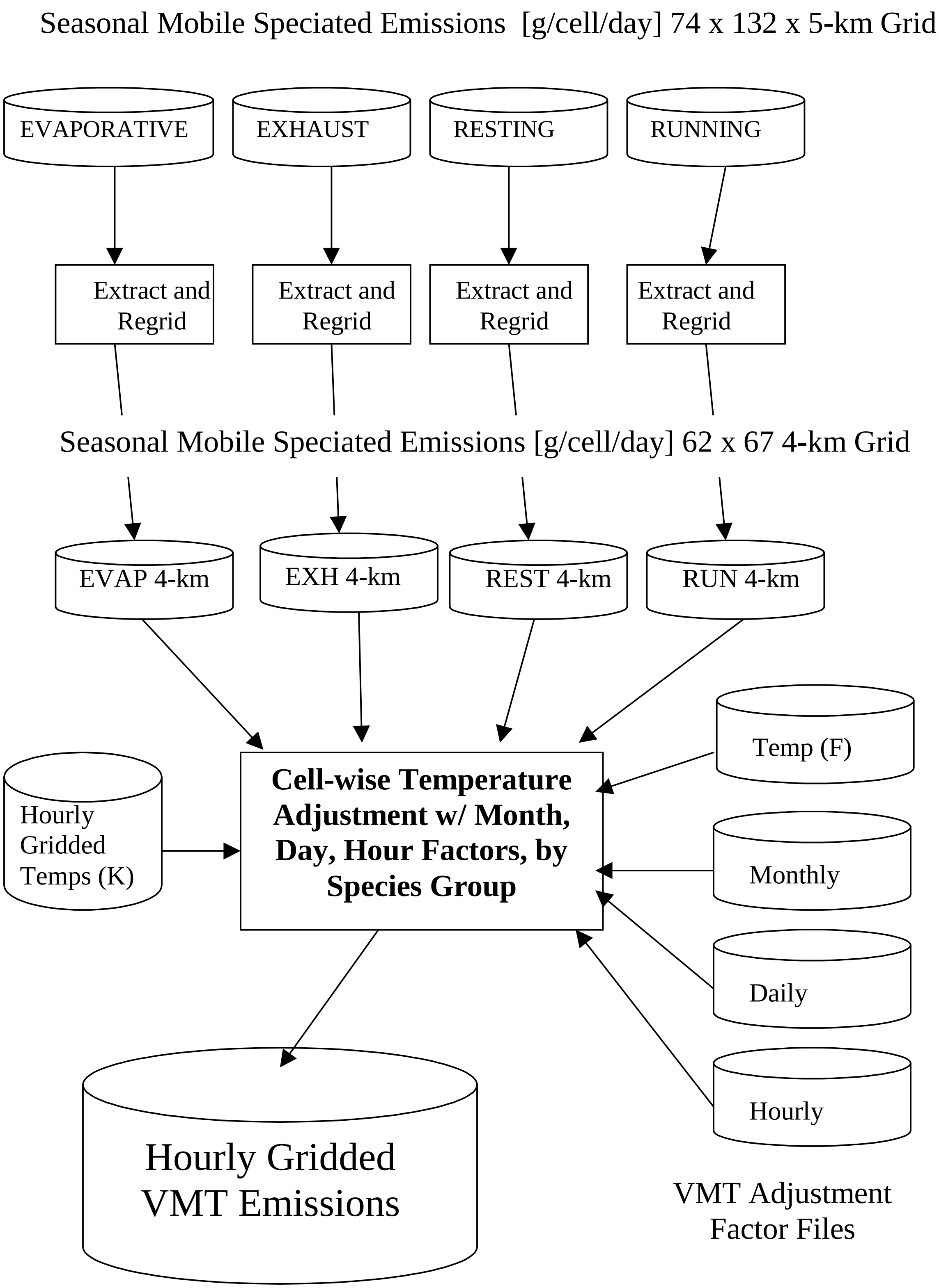


Figure 4. Diurnal pattern of Mobile CO Emissions for 4 AM March 8 through 3 AM March 9, 2001.

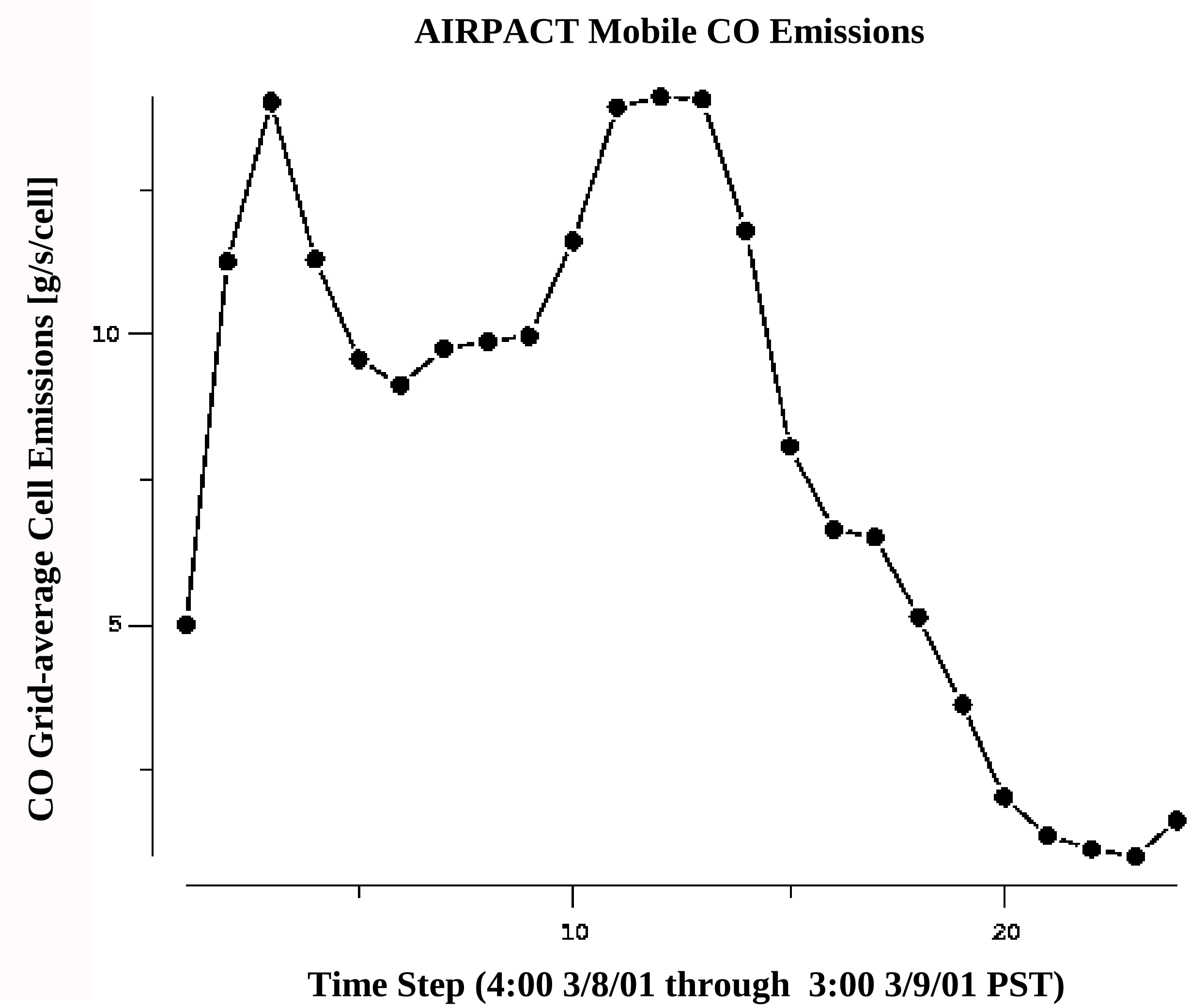


Figure 5. Mobile CO emissions from AIRPACT for 4 PM PST, March 8, 2001.

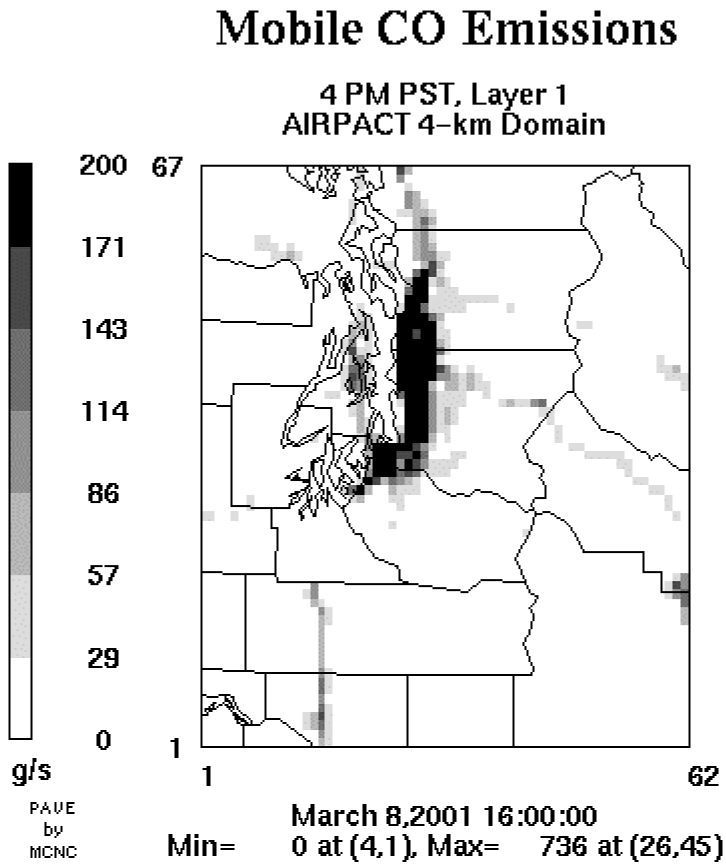


Figure 6. Mobile NOx emissions from AIRPACT for 4 PM PST, March 8, 2001.

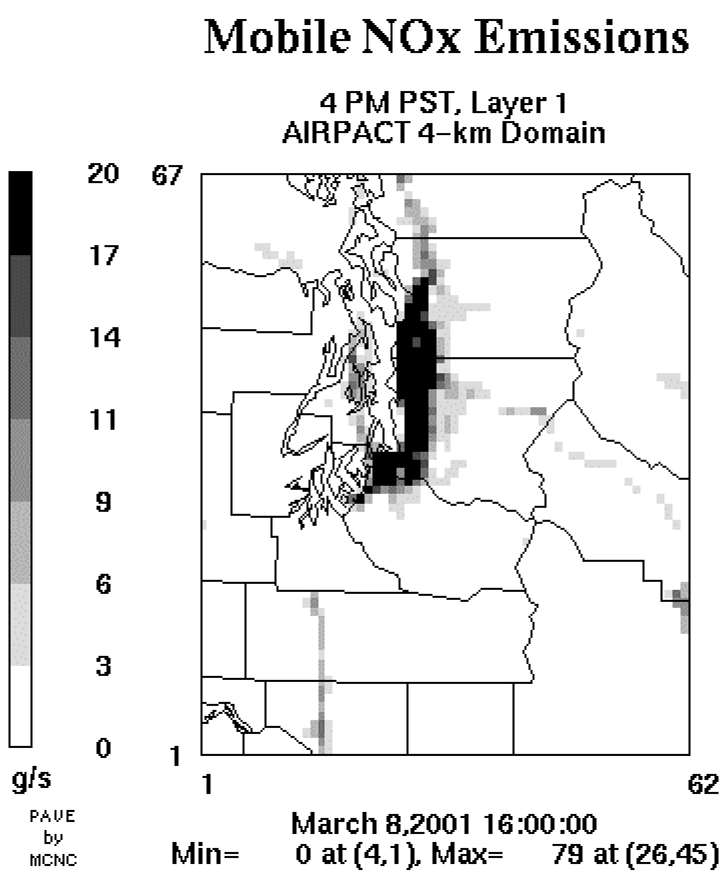


Figure 7. CALGRID NOx concentrations from AIRPACT for 4 PM PST, March 8, 2001.

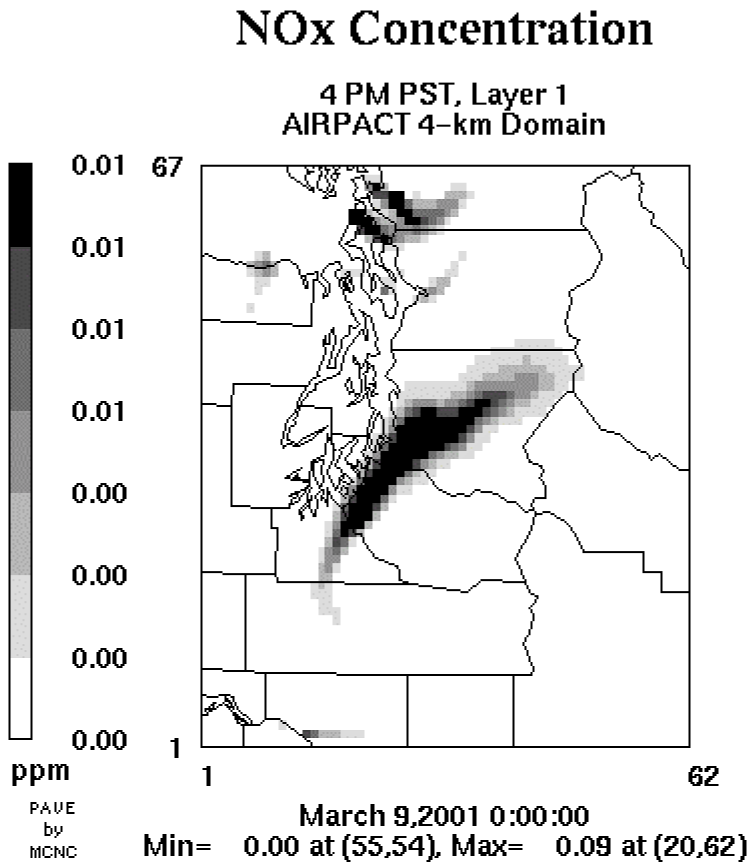
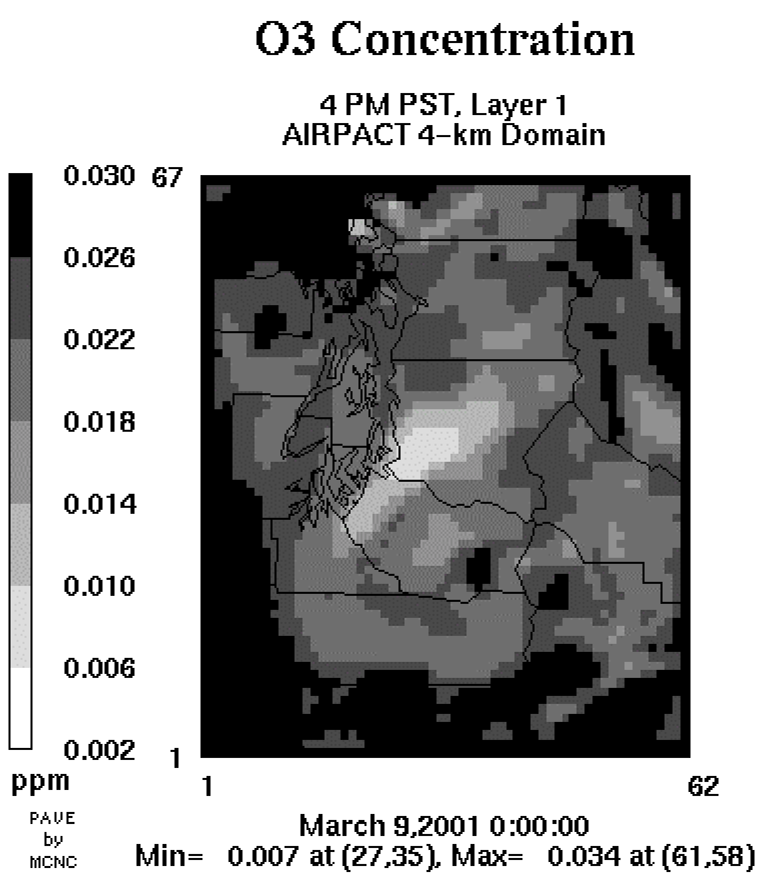


Figure 8. CALGRID O3 concentrations from AIRPACT for 4 PM PST, March 8, 2001.



KEYWORDS

Emissions Inventory
Mobile Emissions
Emissions Forecasting
Ozone
Photochemical Grid Model