Emissions Inventory Development and Processing for the Seasonal Model for Regional Air Quality

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ABSTRACT

The Seasonal Model for Regional Air Quality (SMRAQ) project is an effort to model ozone formation and transport from May to September of 1995 for the eastern two-thirds of the continental United States using a 36-km grid resolution. The emissions inventory was derived from the 1990 and 1995 Ozone Transport Assessment Group (OTAG) inventories. This paper describes the experiences and insight gained from inventory preparation and emissions processing for the SMRAQ project.

The OTAG biogenic inventory and area-, mobile-, and point-source inventories all have been updated to some extent for use in SMRAQ; the changes to point sources were the most extensive. Changes included new gridded biogenic land use data, updated mobile-source vehicle-miles-traveled and speeds, prognostic meteorology, and updated 1990-to-1995 point-source projections with modifications based on the Continuous Emissions Monitoring data. The magnitude and seasonal variation of the resulting emissions are presented and discussed.

The Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system was used for processing the emissions. SMOKE provides benefits that help to address the high computational demands arising from the regional and seasonal features of processing emissions for SMRAQ. This paper also describes several other emissions processing issues and our experience addressing those issues with SMOKE.

INTRODUCTION

The mission of the Seasonal Model for Regional Air Quality (SMRAQ) project is to investigate the scientific issues involved with simulating air quality on a seasonal basis; to develop, evaluate, and apply a seasonal air quality modeling system for the eastern United States; and to explore seasonal and episodic responses of ozone concentrations to control strategies. SMRAQ is part of a larger effort of the Southern Oxidants Study (SOS)[1] for researching ozone formation and transport. The seasonal aspect of the project is a step beyond other regional ozone modeling efforts, such as those of the Ozone Transport Assessment Group (OTAG),[2] and many unique requirements for emissions data arise because of this seasonal feature. In this paper, we document the emissions inventory data development, emissions processing issues, and emissions data and processing results for the SMRAQ project.

In the background section, we describe the system configuration and models used for emissions processing, and we summarize the automation methods for emissions processing and quality assurance. In the methods section, we summarize the initial inventory, describe the inventory changes for addressing seasonal modeling, identify processing issues for seasonal modeling, and describe how the processing issues were addressed in SMRAQ. In the results section, we report on the performance of the system and summarize the resulting emissions. Finally, in the conclusions we address inventory and processing improvements that might be useful for future seasonal modeling.

BACKGROUND

In this section, we summarize the major components of the SMRAQ project needed for the purposes of this paper. These components are the modeling episode and domain, the models, and the computational environment and processing structure.

Modeling Episode and Domain

The episode for the SMRAQ modeling is May 15 to September 13, 1995. The horizontal gridded domain (Figure 1) is 72 columns by 74 rows of 36-km-square grid cells using a Lambert projection with a spherical-Earth assumption (to match the meteorology model). The vertical resolution is 22 layers, and the sigma coordinates (constant pressure ratios to the surface pressure) of the layer boundaries used are 1, 0.995, 0.990, 0.985, 0.980, 0.970, 0.956, 0.938, 0.916, 0.890, 0.860, 0.826, 0.788, 0.746, 0.702, 0.656, 0.588, 0.5, 0.4, 0.3, 0.2, 0.1, and 0.0. The point-source plume rise in SMOKE is part of the emissions processing, and we limited the number of layers used for emissions to 12 (~2000 meters) because this is a realistic maximum plume rise height. Test simulations and the full seasonal simulation confirmed that 12 layers are an appropriate choice because very few modeled plumes exceeded that height.

Models

The models used for the SMRAQ project are the Multiscale Air Quality SImulation Platform (MAQSIP) for ozone chemistry and transport,[3] the Penn State/National Center for Atmospheric Research Mesoscale Modeling System, version 1 (MM5) for meteorology,[4] and the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system for emissions.[5] MAQSIP was configured for the CB-IV chemical mechanism.[6] Here we provide additional detail only for the SMOKE system.

SMOKE was developed to demonstrate using matrix-vector multiplication for efficient emissions processing. It reproduces the core functions of emissions processing (i.e., spatial allocation, temporal allocation, chemical speciation, and control of inventory emissions). SMOKE contains a driver for the MOBILE5a and MOBILE5b models,[7,8] and as described in a companion paper,[9] it has a modified version of the Biogenic Emissions Inventory System, version 2 (BEIS2).[10] The version of SMOKE used in the SMRAQ project was a prototype for which the outputs had been successfully compared to outputs from the Emissions Preprocessing System 2.0 (EPS-2.0)[11] and the Emissions Modeling System, 95 (EMS-95).[2] For a five-day test case, SMOKE has previously been shown to be 27 times faster than EMS-95 for point sources, 38 times faster for area sources, and 68 times faster for mobile sources.[12] Consequently, it was an appropriate choice for handling the large processing needs of this project.

Computational Environment and Processing Structure

Our emissions processing environment was highly automated to help ease the manpower burden needed for processing emissions for such a long episode. To implement this automation, we used the Study Planner in the Environmental Decision Support System (EDSS).[13] The EDSS-SP allowed us to group parts of the emissions processing into “plans,” and we used four types of plans: (a) point-source inventory growth, (b) inventory import, (c) monthly point-source adjustments based on Continuous Emissions Monitoring (CEM) data, and (d) meteorology-dependent steps. Plans (a) and (b) needed to be run once per inventory, although in practice we ran these many times as the inventory was updated. Plan (c) was used once per month. Plan (d) was used in five-day periods, which were the same periods used to run the meteorology and air quality models. The plans were useful for automation because they made sure all of the inputs were available before a run, and they monitored the progress of the various programs in the plan, providing us feedback about whether a run was working successfully or had stopped running. The plans also created log files, which recorded the processing steps and the files that were used for each step of the processing.

Emissions quality assurance (QA) steps, which were built into the EDSS-SP plans using UNIX scripts, included creating state and county totals, other groups of totals, and gridded plots. Each script controlled one QA step; for example, one script controlled inventory-based, area-source QA, while another controlled post-SMOKE, point-source QA. Each script was responsible for driving one or more programs related to its specific purpose. Another script was used to generate gridded emissions plots. All of the scripts were automatically started by the plans when the outputs were available from SMOKE.

Our computing resources were a dedicated IBM 590 workstation with 256 MB of RAM, 45 GB of local disk space, and remote file storage using a Cray data migration facility (DMF). The EDSS-SP was run on a desktop Sun workstation, and it monitored the progress of the plans on the remote workstation. The system and automation efforts allowed each five-day period to be run overnight and required only one person to check the runs, QA reports, plots, and transfer files to the DMF.

METHODS

In this section, we summarize the emissions inventory and processing issues that were considered for the SMRAQ work, and we describe how we addressed them.

Initial SMRAQ Inventory

The OTAG 1995 inventory used in the OTAG base-case modeling was released in May 1996.[2] The original SMRAQ plan called for using these OTAG emissions directly; however, several errors in the inventory were found during the OTAG and SMRAQ projects. Therefore, we obtained updated data from U.S. Environmental Protection Agency (EPA) contractors and we implemented some corrections ourselves. Here we call the resulting inventory the *initial SMRAQ inventory*. The inventory contains average-summer-weekday or average-July-weekday emissions for all states east of and including Texas, Oklahoma, Kansas, Nebraska, North Dakota, and South Dakota, and it includes portions of Eastern Canada. Mexican emissions to zero because no reliable data were readily available.

Here, we compare the initial SMRAQ inventory and the 1995 OTAG inventory. For point sources, 27 out of 38 states had changes to stack parameters, facility locations, temporal profiles, and emissions data. The SMRAQ project did not call for hour-specific data for major point sources, so where the OTAG inventory had such data, we obtained updated average-day emissions for those sources. Also, 19 tons of Canadian volatile organic compounds (VOC) were moved from the point-source inventory to the area-source inventory because they lacked coordinates. For area sources, we corrected the Georgia and Florida off-road data, which cut those emissions by about half. Also. area sources were added in Ohio and Wisconsin, and duplicated area sources were deleted in Michigan. For mobile sources, the vehicle-miles-traveled (VMT) mix was corrected primarily in Pennsylvania, moving emissions from other vehicles to light-duty gasoline vehicles, and new VMT mix data were inserted for North Carolina. The mobile-source average-speed data were also modified to match the data used elsewhere in OTAG. For computing biogenic emissions, we obtained land use data specifically for our grid.

Emissions Inventory Issues

In addition to the inventory corrections for creating the initial inventory, we considered improving the monthly variation of the anthropogenic inventory instead of using the initial inventory's average-summer-weekday or average-July-weekday emissions.

Area Sources

No modifications were made to the average-summer-weekday inventory. Readily available, reliable data were not available for supporting a month-specific approach for area sources.

Mobile Sources

The initial SMRAQ inventory contained average-summer-day (not weekday) VMT data and monthly temporal profile factors that are simply seasonal factors adjusted by the number of days in each month. We considered using the 1995 Traffic Volume Trends report from the U.S. Department of Transportation (USDOT) to improve the monthly adjustments. The report contains estimates of monthly traffic variation for urban and rural roads, which are based on data from about 4000 automatic traffic recorders (nationally distributed) and then reconciled with the Highway Performance Monitoring Station data.[14]

We concluded that state-specific monthly factors would not be accurate because of the small number of sampling locations. We considered using the whole data set, and we found that the variation in rural road travel in 1995 was approximately 6.3% from a May low to a July high. The largest variation in urban road travel was about 3.3% between a September low and a June high. We decided that these variations were too small to warrant the extra effort needed to apply them, so they were not applied.

Point sources

The initial point sources inventory contained average-July-weekday emissions for some major sources, and average-summer-weekday emissions other sources. The July-specific emissions had been projected from 1990 to 1995 based on the ratio of fuel use between 1990 and 1994, because the 1995 fuel-use data were not available for OTAG. We did not believe that the July-specific emissions or the projection method were acceptable for use in SMRAQ, so we used the 1995 fuel-use data to update the initial SMRAQ inventory separately for each month. This update affected about 600 sources (i.e., unique combinations of state and county Federal Information Processing Standards (FIPS) code, Source Classification Code (SCC), plant, and stack). The formula we used to grow the emissions was

$$Month-specific\ 95\ EM = Summer\ 90\ EM \cdot (1-CE)\frac{Month-specific\ 95\ FU}{Summer\ 90\ FU} \tag{1}$$

where *EM* is emissions, *CE* is control efficiency, and *FU* is fuel use.

Using fuel-use data for emissions growth is an approximation that can have errors, but it is an accepted method for point-source growth. To help identify and correct potential problems, we implemented a method that uses the 1995 CEM data, which are hourly emissions data that are collected primarily at power plants with capacities greater than 25 MW. We did not use the hourly CEM emissions data directly, because doing so was outside of the project's scope. Instead, we used average-daily CEM data by month to replace the fuel-use-based emissions when the percent difference between the CEM emissions and the fuel-use-based emissions was outside a ±25% range. The exception to this rule occurred when only one or two complete days' worth of CEM data for a given facility were available for computing a monthly average. In this case, we increased the range for comparison to ±100%. All CEM-based adjustments affected 166 facilities.

Emissions Processing Issues

Here we describe the many issues that we considered for SMRAQ emissions processing. All issues regarding biogenic emissions processing for SMRAQ are described in a companion paper.[9]

The Relationship between Meteorology and Emissions

Various meteorological data are inputs to meteorology-specific stages of processing, as described in the "Computational Environment and Processing Structure" section. For point-source plume rise, biogenic emissions, and mobile-source emissions, we used the same MM5-based prognostic meteorology data used for the air quality modeling. In SMOKE, point-source plume rise is affected by temperature, wind speed and direction, and boundary layer height; mobile-source emissions are affected by temperature; and biogenic emissions are affected by temperature and solar radiation. A biogenic sensitivity analysis to cloud effects is documented elsewhere.[9]

We investigated whether mobile-source emissions might be artificially reduced in coastal areas because MM5 assumes uniform land use in each cell, resulting in reduced temperatures for cells treated as water-only when the cells actually have both water and land. We used the original SMRAQ domain, which had 54-km cells, to perform this investigation. We compared the results from two simulations, one with original temperatures and one with temperatures from water/land cells set to temperatures in nearby all-land cells. The nitrogen oxides (NO_x) and VOC emissions differences between the two cases were all less than 5%, and usually much less. Consequently, we did not pursue the issue further.

We also considered the appropriate height for temperatures used in computing the biogenic and mobile emissions. Because the OTAG project used observational temperatures at a height of 1.5 m, we had originally planned to interpolate our MM5 temperatures to this height. We subsequently realized, however, that the so-called "ground temperature" (T_g) in MM5 is actually the temperature at the top of the canopy, when a canopy exists.[15] Since this is the closest available temperature to that experienced by mobile sources, and since temperatures cannot be interpolated closer to the ground if no actual ground temperatures are available, the T_g from MM5 was used directly. For biogenic emissions, we also used the T_g from MM5 in SMOKE-BEIS2, as is described in more detail elsewhere[9].

Temporal Considerations and Adjustments

In this subsection, we review four issues relating to temporal allocation of emissions during the season that were not addressed in creating the initial SMRAQ inventory. First, we considered adjusting Reid's Vapor Pressure (RVP) of motor vehicle fuels if we found that different fuels were used during the seasonal episode. According to a contact at EPA,[16] fuel distributors require several months of use for each fuel in order make distributing the fuel economically feasible. Consequently, the fuels are consistent enough during the May-to-September ozone season that no particular adjustments for fuel type are needed for modeling mobile sources.

The second issue is the treatment of the holidays in the seasonal scenario: May 29, July 4, and September 4. The three holidays all occurred on weekdays, but activity patterns for holidays are more similar to weekend days; for example, mobile-source activity would be lower and lawn mowing would be higher. We were unable to find solid evidence to help us choose between Saturday or Sunday, so we arbitrarily selected Sunday as the day to use for holiday emissions.

The third issue is adjustment of weekly profiles based on the time zones of the sources. SMOKE was designed to consider time zones when applying diurnal temporal profiles. However, during the SMRAQ project, we realized that SMOKE was not using the time zone information to adjust the weekly temporal profiles. This caused all sources to simultaneously change from one weekly profile value to another, even though the start of each day should depend on the time zone. Furthermore, we discovered that this same problem also existed in EMS-95 and EPS2.0. We updated SMOKE so that the time zone of a source can be considered when applying the weekly and monthly temporal files.

The fourth issue is how to correctly implement a "weekday-Saturday-Sunday" approach with the new version of SMOKE. When all of the sources do not change days on the same hour, a single 24-hour file does not contain only one day's worth of emissions. The SMRAQ domain crosses four time zones, so the first four hours of a Monday file have sources that still show Sunday emissions. We accounted for this detail by changing to a "Monday-weekday-Saturday-Sunday" approach.

Model Science and Corrections

We encountered three issues regarding either configuring the modeling science used in SMOKE or correcting errors resulting from external programs incorporated into SMOKE. The first two we present here; the biogenic error introduced by BEIS2 is described elsewhere.[9]

First, we configured SMOKE to use the MOBILE5b[8] emissions factors model for mobile-source emissions processing. For use in SMOKE, we slightly modified MOBILE5b based on MOBILE5a modifications from OTAG to separate the evaporative and diurnal emissions. To quantify the emissions differences between MOBILE5a and MOBILE5b, we performed a sensitivity study for July 8-11, 1995 (Saturday through Tuesday). In the study, all inputs of the mobile-source emissions processing were identical; we varied only the version of the MOBILE model. For each of the four days, the domain-total CO emissions using MOBILE5b were 2.8%–5.2% greater than when using MOBILE5a, the domain-total NO_x emissions were 1.7%–2.8% greater, and the domain-total VOC emissions were reduced by 0.3%–1.2%.

Second, we adjusted the plume-rise algorithm in SMOKE, which is based on the Briggs algorithm[17] and is taken from the Regional Acid Deposition Model (RADM)[18] plume-rise code. The changes correct errors introduced by the RADM code, and they keep the SMOKE plume rise implementation consistent with that of the EPA's Models-3 system.[19] The differences between the SMOKE and the original RADM implementations of plume rise are described elsewhere.[20]

RESULTS

In Figures 2 and 3, we show the magnitude of daily NO_x and reactive organic gases (ROG) base-case emissions for all days of the 120-day episode. Figure 2 shows that the biogenic component of NO_x emissions is the smallest, followed in increasing order of magnitude by area-, mobile-, and point-source emissions. Figure 3 shows that the mobile- and point-source ROG emissions are roughly equal, and area-source ROG emissions are more than double those categories. Biogenic ROG far exceeds the other categories by several orders of magnitude. All of these trends are consistent throughout the season.

The other characteristics of the two plots are fairly similar. The Monday-weekday-Saturday-Sunday approach for area and point sources is clearly visible in the figures (the markers are on Mondays), and the month-to-month variation in point sources is noticeable in Figure 2, although subtle. The temporal variability of the biogenic emissions results from meteorology alone, and the temporal variability of mobile emissions results from both weekly profiles and meteorology. The emissions decrease for the three holidays is apparent for area, mobile, and point sources.

We found two errors in the point-source emissions processing. The first error was that some point-source emissions were grown too much using the fuel-use data because the 1990-to-1995 conversion factors were mistakenly applied to the 1995 emissions. The CEM-based checks corrected some of these, but the result was a 5% increase in total NO_x, with a few facilities affected greatly. Subsequent comparisons of the original air quality modeling results to a 10-day period with corrected emissions showed that the error's impact on ozone levels was localized to the regions around the sources most effected by the emissions error. The second error was a coding error in SMOKE that caused a small increase in plume rise because stack temperatures were 17 K too warm. The project's review panel did not consider the impact of these two errors large enough to require rerunning the entire episode. In Figures 2 and 3, we have included the corrected point-source emissions for July 12-21.

The percentage contributions of each source category vary some throughout the season, especially because of the large variations in biogenic ROG. The percentages of total NO_x for the source categories are area, 9%–18%; biogenic, 3%–9%; mobile, 21%–30%; and point, 48%–58%. The percentages of total ROG for the source categories are area, 9%–22%; biogenic, 60%–84%; mobile, 4%–10%; and point, 3%–9%. These percentages vary regionally, however, the format of this document does not allow enough space to present state or regional statistics.

In Table 1, we summarize the state-total average July weekday emissions for each of the source categories. We have provided these data so that the reader may compare our inventory data to other inventories, but we do not have the space to describe such comparisons here.

Finally, we compared the emissions from the CEM database to facility-total emissions from the SMRAQ inventory after CEM-based adjustments. The extent and type of the differences varied greatly from facility to facility. In Figure 4, we show one example of these differences for Carolina Power and Light's H. F. Lee plant. The average-day emissions during the seasonal period of the CEM emissions were 21.2 tons/day and the SMRAQ inventory emissions for this facility were similar at 22.5 tons/day. Even though the total emissions are similar, the figure shows that the temporal variations of the hourly minima, means, and maxima from day to day are significantly different in the two databases.

The total wall-clock time for running the seasonal simulation on the IBM 590 workstation was 95 hours (including 66 QA hours). Each five-day period took an average of 3.8 hours, including 2.6 hours for QA. One person was responsible for monitoring the runs and keeping track of disk space, file compression, and remote storage; these tasks took about 1.5 hours per day on average for about 33 days. The first period took about 4 days, because extra analysis was done before the simulation was continued.

CONCLUSIONS

Although some work was needed to create the EDSS-SP plans and QA scripts, we have concluded that the benefits of the decreased manpower needs during the run were well worth the effort. Our automated processing and QA worked well, with the exception of the point-source projection error that we did not catch until after the air quality modeling results were well under way.

Our system configuration helped us complete the seasonal emissions processing with great efficiency; however, much more time than anticipated was spent updating and checking the inventory. The processing improvements resulted from using the SMOKE modeling system. A similar leap forward is needed in the inventory collection to allow further dramatic improvements in the quality and timeliness of emissions inputs for air quality modeling. In the remainder of this section, we address issues that we believe would benefit emissions processing for seasonal air quality modeling.

Addressing a few common complaints about emissions inventory inputs would also benefit seasonal air quality modeling. For example, the volatile speciation profiles and cross-references should be updated; the current values have not been updated since the 1970's in many cases. Also, the default temporal profiles and cross-references have not been seriously reviewed in a long time.

If the air quality modeling community continues to pursue seasonal modeling efforts, it would be useful to develop a guidance document for seasonal inventory development and emissions processing. In this paper, we have attempted to provide a starting point, but a more detailed treatment is needed to provide adequate guidance.

Monthly and week-to-week variations in emissions are potentially more important for seasonal modeling than for traditional episodes of a few days to a couple of weeks, because more weeks are covered. Based on our cursory comparisons of the SMRAQ point-source emissions to the CEM data, emissions estimates are perhaps much less variable than they should be for seasonal modeling. Along these lines, future investigations should first determine the shortcomings in temporal variability for all source categories. Then, the importance of these differences to air quality modeling should be assessed, and if the differences are important, improved emissions data collection may be warranted. Existing inventory data collection is not at a resolution that would permit modeling of week-to-week variations, so if such variations are important, the inventory collection approach would need to be revised.

Another approach for improving temporal variation is to implement adjustments based on other data. For example, we used fuel-use data to adjust point-source emissions estimates by month, and we considered using the USDOT Traffic Volume Trends report. We implemented the point-source projections ourselves because 1995 fuel-use data were not available until April of 1997, which was too late for inclusion in the OTAG inventory development or subsequent corrections by EPA contractors. Inventory development would greatly benefit from earlier release dates of data that can be used to supplement emissions inventories. It might be a better use of emissions inventory resources to improve the turnaround time of those data than to attempt to change the inventory data collection methods.

Our final suggestion concerns the transfer of meteorology data from MM5 to emission factor models such as MOBILE5 and BEIS2. MM5 is now commonly used for providing meteorology inputs for emissions processing, and in fact is the method used in Models-3. Consequently, it makes sense for emission factor models that use temperature and other meteorology inputs to expect MM5 inputs. For example, the BEIS2 model could be more useful for air quality modeling if the input temperature were the temperature at top of the canopy, also known as the MM5 “ground temperature.”

In this paper, we have summarized the base-case emissions inventory and processing for the SMRAQ project, and we have presented summaries of the resulting model-ready emissions data. We hope that this paper is a useful reference for others who perform seasonal emissions processing. While the use of SMOKE with the EDSS-SP allows fairly low manpower requirements, the emissions inventory development process can be very time consuming and error prone. We have made several suggestions about how emissions inventories could be improved for the purposes of seasonal air quality modeling.

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DISCLAIMER

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REFERENCES

1. Cowling, E. B.; Chameides, W. L.; Kiang, C. S.; Fehsenfeld, F. S.; Meagher, J.F. “Introduction to special section: Southern Oxidants Study Nashville/Middle Tennessee Ozone Study”, *Journal of Geophysical Research.* 1998, 103 - D17, 22209-22212.

2. "OTAG Emissions Inventory Development Report, Volume II: Base Year Modeling Inventory Development"; Pechan Report No. 96.08.001/1775, Prepared for U.S. Environmental Protection Agency, by Lake Michigan Air Directors Consortium, Des Plains, IL, and E.H. Pechan & Associates, Inc., Durham, NC. 1996.
3. Odman, M. T.; Ingram, C. L. "Technical Report: Multiscale Air Quality SImulation Platform (MAQSIP): Source Code Documentation and Validation"; MCNC Environmental Programs, Research Triangle Park, NC, 1996; ENV-96TR002-v1.0.
4. Grell, G. A.; Dudhia, J.; Stauffer, D. R. "A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5)," National Center for Atmospheric Research, Boulder, CO, 1994; NCAR/TN-389+STR.
5. Coats, C. J., Jr.; Houyoux, M. R. "Fast Emissions Modeling with the Sparse Matrix Operator Kernel Emissions Modeling System," Presented at *The Emissions Inventory: Key to Planning, Permits, Compliance, and Reporting,* Air & Waste Mgt. Assoc., New Orleans, LA, September 1996.
6. Wheeler, N.; Houyoux, M.; Mathur, R.; McHenry, J.; Olerud, D.; Smith, W. T.; Vukovich, J.; Xiu, A.; and Kasibahtla, P. "Development and Implementation of a Seasonal Model for Regional Air Quality," Presented at the *91st Annual Meeting of the Air & Waste Management Association*, paper 98-A739, San Diego, CA, June 1998.
7. *User's Guide to MOBILE5 (Mobile Source Emission Factor Model)*, EPA-AA-AQAB-94-01; Office of Air and Radiation/ Office of Mobile Sources, U.S. EPA: Ann Arbor, May 1994.
8. "EPA/OMS MOBILE5 Vehicle Emission Modeling Software: MOBILE5b" URL: <http://www.epa.gov/oms/m5.htm#m5b>.
9. Vukovich, J. M. "Development of Biogenic Emissions for the 1995 Summer Season Using SMOKE-BEIS2," Presented at *The Emission Inventory: Living in a Global Environment,* Air & Waste Mgt. Assoc., New Orleans, LA, December 1998.
10. Pierce, T.; Dudek, M.; "Biogenic Emission Estimates for 1995," Presented at *The Emissions Inventory: Key to Planning, Permits, Compliance, and Reporting,* Air & Waste Mgt. Assoc., New Orleans, LA, September 1996.
11. *User's Guide for the Urban Airshed Model Volume IV: User's Manual for the Emission Preprocessor System 2.0*; Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1992; EPA-450/4-90-007D(R).
12. Houyoux, M. R.; Coats, C. J., Jr.; Eyth, A.; Lo, S. "Emissions Modeling for SMRAQ: A Seasonal and Regional Example Using SMOKE," Presented at *Computing in Environmental Resource Management,* Air & Waste Mgt. Assoc., Research Triangle Park, NC, December 1996.
13. Smith, W. T.; Coats, C. J., Jr.; Eyth, A.; Fine, S.; Hils, D.; Wheeler, N. "Managing Processing and Data in Seasonal Modeling of Regional Air Quality," Presented at *Computing in Environmental Resource Management,* Air & Waste Mgt. Assoc., Research Triangle Park, NC, December 1996.
14. *Traffic Volume Trends, January 1997*; U.S. Department of Transportation, Washington, DC, 1997; Federal Highway Administration Publication No. FHWA-PL-97-004.
15. Aijun, Xiu, 1997. MCNC Environmental Programs, Research Triangle Park, NC, *personal communication*.
16. Wayland, R, 1997. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, *personal communication*.
17. Briggs, G. A. "Plume rise and buoyancy effects," *Atmospheric Science and Power Production*, Randerson, D., Ed.; Technical Information Center, U.S. Department of Energy, Oak Ridge, TN, 1984; DOE/TIC-27601 (DE84005177).
18. Chang, J. S.; Brost, R. A.; Isaken, L. S. A.; Madronich, S.; Middleton, P.; Stockwell, W. R; Walcek, C. J. "A Three-Dimensional Eulerian Acid Deposition Model: Physical Concepts and Formulation", *Journal of Geophysical Research.* 1987, 92, 14681-14700.

19. *EPA Third-Generation Air Quality Modeling System, Models-3 Volume 9b: User Manual*; U.S. Environmental Protection Agency, Research Triangle Park, NC, and U.S. EPA Systems Development Center, Arlington, VA, 1998; EPA 600/R-98/069(b).
20. Houyoux, M. R. “Technical Report: Plume Rise Algorithm Summary for SMOKE”; MCNC Environmental Programs, Research Triangle Park, NC, 1998; ENV-98TR004-v1.0.

Table 1. State July average weekday emissions totals [tons/day]

State	Point NO$_x$	Area NO$_x$	Motv NO$_x$	Biog NO$_x$	Point ROG	Area ROG	Motv ROG	Biog ROG	Point CO	Area CO	Motv CO
AL	990	336	417	55	249	661	352	12298	610	1339	3258
AR	227	215	227	78	69	481	153	13252	317	809	1450
CT	109	110	214	3	51	369	154	644	46	849	1211
DE	82	39	79	5	45	94	54	155	32	198	400
DC	5	18	21	0	1	29	16	22	2	139	137
FL	1226	428	906	75	109	1540	724	7548	202	3656	6841
GA	844	300	722	78	225	877	595	11504	573	2233	5480
IL	1838	675	732	405	964	1482	540	2378	1511	3190	4216
IN	2103	394	481	227	508	989	409	1840	1107	1291	3415
IA	526	202	242	435	40	568	178	1153	38	841	1556
KS	601	434	215	376	157	672	152	1256	172	1994	1435
KY	1218	420	363	83	536	591	258	5306	376	954	2179
LA	1285	746	275	71	390	752	227	8926	1879	1839	2140
ME	42	25	109	7	28	112	64	3515	55	182	575
MD	493	155	317	27	90	459	215	1145	377	1291	1813
MA	192	228	304	3	96	649	211	953	59	1545	1782
MI	1972	369	628	109	580	990	546	3794	534	2172	4798
MN	493	221	382	264	250	886	281	4874	406	1947	2519
MS	381	350	280	77	169	649	177	11352	255	1430	1670
MO	1190	269	424	192	221	859	283	11869	334	2344	2345
NE	298	174	138	390	57	381	102	611	31	984	906
NH	74	43	99	4	36	98	64	1183	64	175	557
NJ	506	263	408	8	381	623	287	988	161	1489	2164
NY	477	386	829	76	492	1198	640	2695	144	2710	5609
NC	1313	253	583	87	555	1010	316	8107	437	3105	3075
ND	436	88	54	159	8	172	31	280	35	289	282
OH	2226	502	724	156	638	1145	622	2004	2798	2133	5551
OK	419	378	318	140	78	555	237	6797	148	846	2225
PA	2334	412	644	82	527	876	581	4847	3192	1721	5042
RI	3	22	55	1	26	91	42	247	8	203	345
SC	547	161	347	43	211	642	266	5123	176	1064	2502
SD	59	32	64	249	3	154	41	521	0	213	361
TN	2039	481	472	70	633	1098	358	6940	363	2569	3384
TX	2995	851	1250	468	936	2235	957	16767	961	7449	8375
VT	3	13	63	8	5	55	37	898	2	85	354
VA	400	361	569	42	361	816	409	7344	145	1719	3660
WV	2031	132	160	16	234	278	108	3602	769	498	991
WI	646	220	350	161	209	704	250	4381	414	1414	2223
CAN	743	722	2488	36	621	2306	487	17500	2235	5909	3449

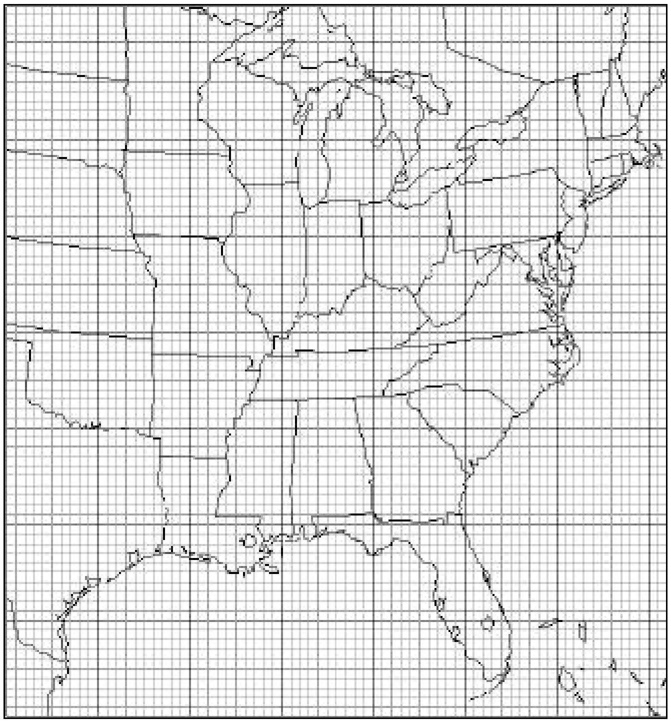

Figure 1. SMRAQ modeling domain.

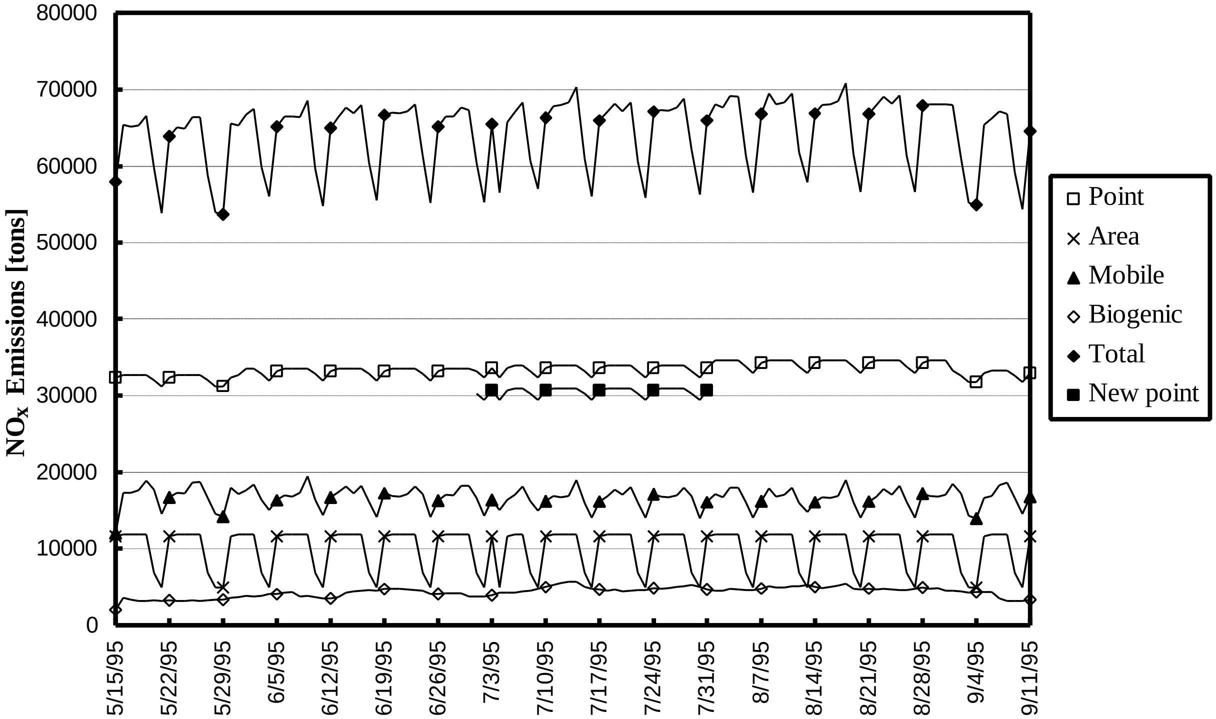

Figure 2. SMRAQ daily NO_x emissions by source category for the 1995 ozone season.

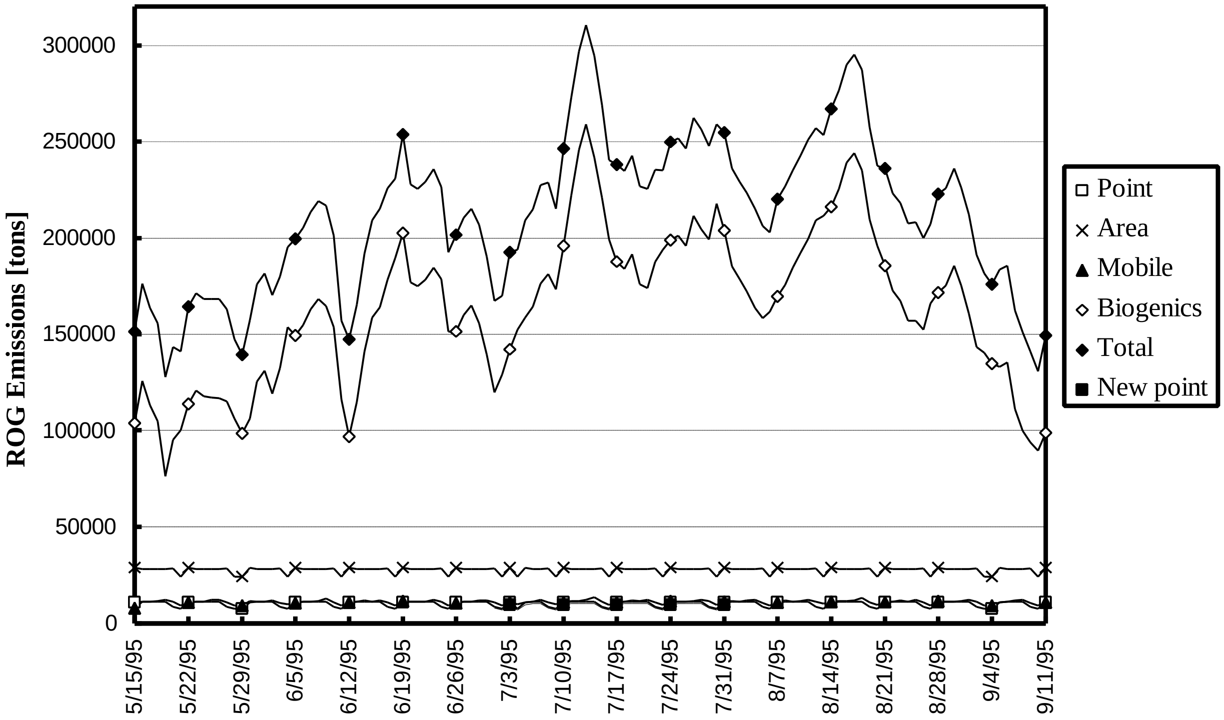

Figure 3. SMRAQ daily ROG emissions by source category for the 1995 ozone season.

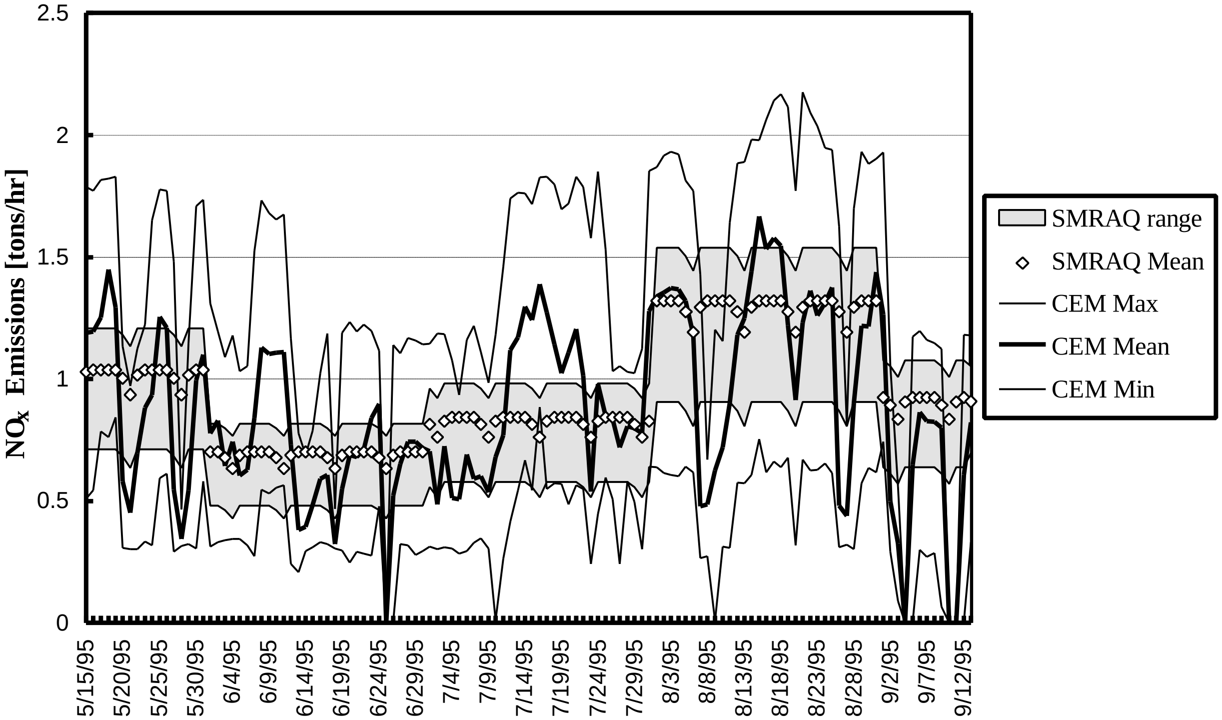

Figure 4. Hourly SMRAQ NO$_x$ emissions versus CEM data for Carolina Power and Light's H. F. Lee Facility (shown using minimum, maximum, and mean values).

Seasonal, Emissions, SMOKE, Inventory, SMRAQ, Air