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REGIONAL OZONE MODELING FOR NORTHEAST TRANSPORT (ROMNET)

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REGIONAL OZONE MODELING FOR NORTHEAST TRANSPORT (ROMNET)

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EXECUTIVE SUMMARY

by

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INTRODUCTION

Purpose and Intent of ROMNET

The Regional Ozone Modeling for Northeast Transport (ROMNET) Project was initiated by the U.S. Environmental Protection Agency (EPA) and State and local agencies in the Northeast, as part of a joint effort to address the problem of regional transport in developing effective and equitable control programs to attain the ozone National Ambient Air Quality Standards (NAAQS) in this region.[1]

The specific goals of ROMNET are:

1. to evaluate the relative effectiveness of regional controls on ozone levels in the Northeast;
2. to provide quantitative estimates of ozone and precursor concentrations transported between urban areas following the application of regional control measures; and
3. to provide procedures and guidance for incorporating ozone and precursor transport in future State Implementation Plan (SIP) development.

The intent of ROMNET is for EPA and State decision-makers to use the findings in guiding ozone-policy development and planning for potential regional control programs, as well as in urban area-specific strategy evaluations. The urban-scale analyses are to be conducted by the States as part of the SIP process. The results and guidance from the project will enable States to quantify changes in future levels of ozone and precursor transport expected to follow implementation of nationwide Federal measures, local control programs in upwind cities, and potential regional strategies.

The remainder of the Executive Summary provides a brief overview of the major components of the project including:

a. the project scope and organization;
b. the ROMNET technical program;
c. the findings from ROM simulations conducted to address "strategic" issues regarding the effectiveness of regional control scenarios;
d. the mechanisms and procedures developed to enable States to explicitly consider regional and interurban transport in preparing ozone (SIP's); and
e. a summary of the major accomplishments of the project.

1. An exceedence of the NAAQS is defined as a daily maximum 1-hour ozone concentration > 0.12 ppm (124 ppb). The NAAQS is not to be exceeded more than once per year at any location.

Readers interested in a detailed description of these topics and other aspects of ROMNET are referred to the main sections of the final report. Figures and tables referred to herein are provided at the end of the Executive Summary.

Project Scope and Organization

A fundamental concept of ROMNET was the active involvement of State and local agencies with the EPA in designing and conducting the project. This began with the development of a protocol by EPA and State representatives. The protocol established the project goals, direction, organizational structure, technical tasks, and schedule. The ROMNET protocol is included in Appendix A of this report. The organizations participating in ROMNET are listed in Table ES-1. The geographic area covered by the project is shown in Figure ES-1.

The participation by States in the management and technical aspects of ROMNET was fostered by the organizational structure shown in Figure ES-2. This structure provided a means for States and other participants to have a major role in the project decision-making process, and for communicating information on project activities to all participants.

The Management Review Committee consisted of senior managers from State/local agencies and EPA Regional Offices, the Office of Air Quality Planning and Standards (OAQPS), and the Atmospheric Research and Exposure Assessment Laboratory (AREAL). The responsibility of this committee was to provide overall direction for the project. The three technical committees consisted of representatives from the participating organizations having expertise in one or more of the technical areas.

To ensure close coordination among the committees, the Program Director, Technical Coordinator, and Chair of the Management Review Committee and three technical committees were drawn from OAQPS. The Program Director had the overall responsibility of ensuring the technical adequacy of the study, making sure that participants were informed of the project's status, and that the project was as responsive as feasible to directions from the Management Review Committee. The Technical Coordinator assisted the Program Director by managing day-to-day activities of the project, establishing priorities for a diverse set of technical tasks, making sure these priorities were observed, and ensuring that technical activities were integrated appropriately.

Decisions by the committees were made through a consensus building process. For technical issues, straw man proposals were typically formulated by the EPA for discussion by committee members.

Consensus recommendations from the technical committees on issues such as strategy selection were made to the Management Review Committee which, through consensus, provided resolution or direction on the particular topic.

THE ROMNET TECHNICAL PROGRAM

The ROMNET technical program consisted of three major components:

1. simulations using the Regional Oxidant Model (ROM) for various emissions scenarios designed to address "strategic" issues relative to the impacts of regional control measures on ozone levels in the Northeast;
2. the development of the Gridded Model Information Support System (GMISS) to manage ROM data sets and provide a means for States to easily access and retrieve data necessary to develop transport estimates and certain other inputs required for urban scale SIP modeling; and
3. the development of the ROM/Urban Airshed Model (UAM) Program System which, through a series of computer programs, translates and reformats ROM data sets into inputs to the UAM.

The remainder of this part of the Executive Summary provides an overview of the ROM and the procedures followed for simulating the impacts of control strategies. The results of strategy simulations are presented later, as is a brief description of GMISS and the ROM/UAM Interface.

The Regional Oxidant Model

The Regional Oxidant Model (ROM), Version 2.1, (Milich *et al.*, 1990) was used for estimating ozone concentrations across the Northeast under various emissions scenarios selected for evaluation as part of ROMNET. ROM is a three-dimensional photochemical grid model having horizontal grid resolution of $^1/_6°$ of latitude by $^1/_4°$ of longitude (approximately 18.5 km x 18.5 km in the Northeast). Vertically, there are three layers of cells between the ground and the base of a subsidence inversion serving as a vertical lid on pollutant dispersion during fair weather conditions. Dimensions of the three vertical layers vary diurnally in response to physical processes occurring in the atmosphere.

As shown in Figure ES-3, five broad classes of input information are needed to drive the ROM model. The ROM Processor Network is a series of computer programs (i.e., preprocessors) that convert raw input data into the variables required by the core model. The ROM core model performs the horizontal and vertical transport and chemistry calculations that estimate ozone concentrations (and concentrations for 34 other chemical species) for each grid cell in the domain. Chemistry assumed in the core model is described by the Carbon Bond 4 (CB-IV) mechanism. This mechanism is identical to the one

contained in the Urban Airshed Model, recommended by the EPA for use in SIP attainment demonstrations. The ROM generates hourly concentrations that represent grid cell average values. A more detailed discussion of the ROM is contained in Section 2.

Procedure to Address Strategic Issues

The following steps were followed to address strategic issues on the relative effectiveness of control strategies:

1. meteorological episodes were selected for simulation by the ROM;
2. a base case inventory was developed, and an evaluation of the ROM was performed by comparing predicted base case ozone levels with observed values;
3. base case emissions were projected to an agreed upon future year, and "future baseline" predictions were simulated;
4. control measures were applied to future baseline emissions to derive control strategy (CS) scenarios, and postcontrol ozone levels were simulated; and
5. predictions for the different strategies and the future baseline scenario were analyzed and intercompared relative to the strategic issues.

Steps 1-3 are described next, followed by the strategic issues, the associated emissions control strategies, and the conclusions drawn from ROM simulations.

Episode Selection

Two factors were considered in selecting episodes to simulate with ROM: ambient ozone concentrations and wind flow patterns. Since the primary focus of the study was the Northeast Corridor, the selection of episodes focused on conditions in this portion of the domain. First, ozone data reported in the EPA's Aerometric Information and Reporting System (AIRS) were reviewed for the years 1983-88 to identify episodes having at least three consecutive days with ozone levels > 125 ppb within the Corridor. The 27 episodes identified by this process were then ranked in terms of the magnitude of daily maximum ozone levels and the frequency of high concentrations.

The ten top-ranked episodes were next examined to ascertain the occurrence of key wind flow patterns. The goal was to choose episodes featuring a variety of wind flow regimes typically associated with high ozone including, in order of priority, along Corridor transport, stagnation/recirculation, and westerly wind flow.

The period July 2-17, 1988, was identified by the above process as the most severe in terms of ozone concentrations and as having a high frequency of along Corridor and westerly wind flow patterns. Thus, all control strategies were simulated with this episode. A second episode, June 9-20, 1983, also contained high ozone levels but was characterized by recirculation conditions. This period was chosen for simulating with a subset of emissions scenarios in order to test the robustness of conclusions drawn from simulations with the July 1988 episode. In addition, the two most highly ranked 1985 episodes, August 7-16, 1985, and July 7-22, 1985, were chosen for a ROM performance evaluation. A more complete discussion of the episodes selected and the selection process is given in Section 3.

ROMNET Base Case Inventory

Inventories for volatile organic compounds (VOC), nitrogen oxides (NO_x), and carbon monoxide (CO) used in ROMNET were derived from the 1985 inventories compiled as part of the National Acid Precipitation Assessment Program (NAPAP) (see Section 4). The following modifications were made to the NAPAP 1985 inventories as part of ROMNET:

1. Biogenic emissions were calculated and included in ROM simulations. These are of greatest importance for VOC, and reflect emissions from vegetation. The EPA Biogenic Emissions Inventory System (BEIS) was used to derive hourly biogenic emissions estimates for the ROMNET domain.
2. The MOBILE4 model was used to obtain estimates for mobile-source exhaust and evaporative emissions, as opposed to an earlier version of the MOBILE model used in NAPAP. MOBILE4 considers such recently-identified phenomena as evaporative running losses, and also contains an improved treatment of mobile-source emissions as a function of temperature.

Both mobile evaporative emissions and biogenic emissions can be very temperature sensitive. Emissions of certain biogenic species are also sensitive to sunlight intensity. Since mobile and biogenic emissions constitute major portions of the VOC inventory, day-specific meteorological data were used to derive gridded hourly emissions for these categories. In addition, emission factors and/or activity levels from six stationary source VOC categories were adjusted to reflect higher temperatures and enhanced activity levels likely on typical sunny and warm episode days.

A more complete description of the 1985 base ROMNET inventory is contained in Section 4.

ROM Evaluation

Predictions obtained with the ROM using the 1985 base inventory described above were compared with ozone observations made on 26 days during the two selected 1985 episodes. Three types of tests were performed:

1. unpaired aggregate distributions of observations and predictions were compared for each of five subregions of the domain;
2. predicted and observed spatial patterns for daily maximum ozone were compared through inspection of contours of observed and predicted concentrations; and
3. the model's ability to specify boundary concentrations for an urban scale domain was assessed by comparing boundary condition ozone concentrations calculated from ROM predictions with concentrations derived subjectively from ambient ozone measurements.

Results of the first test indicate agreement within ±10 percent between the predicted upper 50th percentile of the distributions (except for the very highest values) and the observed distributions, except in the southwestern portion of the domain. In this area, there was a tendency to underpredict the higher end of the observed distributions. Also, there was a uniform tendency to overpredict the lowest end of the observed distributions. A more detailed discussion of the ROM evaluation is provided in Section 2. Based on the findings for all of the tests, ROM performance appears satisfactory for estimating episodic ozone levels for use in assessing regional scale concentrations and patterns. Results tend to confirm a previously held view that the simulation of peak urban ozone concentrations and strategies to reduce them are best performed with urban scale models.

Future Baseline Emissions

The year 2005 was selected for the "future baseline" scenario. This year represents a period far enough in the future to allow for widespread penetration of new control measures, and it is within the bounds of credible growth forecasts.

The 2005 baseline reflects composite effects of growth, retirement of old sources, and the impact of control programs in place or committed to as of 1988. Emissions projected to 2005 also consider the best assessment of State participants concerning rule effectiveness and penetration for existing control measures. In essence, the 2005 baseline addresses the question: "What might happen in 2005 under existing or already planned control programs, if no new measures were added?"

Regionwide reductions in VOC, NO_x, and CO emissions between 1985 and the 2005 baseline were 35 percent, 4 percent, and 45 percent, respectively. Within the Corridor, the net change in VOC and NO_x emissions between 1985 and 2005 was 34 percent and 6 percent, respectively. Section 4 contains more detailed specifications on the development of the 2005 baseline emissions scenario.

Results from applying the ROM for the 2005 baseline using the July, 1988, episode indicate that present control measures (i.e., pre-1990 Clean Air Act amendments) will be insufficient to reduce maximum daily ozone to below 125 ppb everywhere in the domain. In the Corridor, episode maximum ozone concentrations are reduced by 5 to 15 percent, with predicted peak values remaining over 200 ppb in and near New York City. In the western part of the domain, ozone is also reduced by 5 to 15 percent near several major cities. However, the areal extent of predicted episode maxima $\geq$ 125 ppb has been reduced (see Section 5 for greater detail).

STRATEGIC ISSUES AND SIMULATED CONTROL STRATEGIES

Strategic Issues

The ROMNET control strategies were formulated to examine five strategic issues:

1. What are the relative benefits of VOC and NO_x controls in reducing required ozone levels?
2. What is the impact of reducing regional transport on ozone concentrations in the Northeast Corridor?
3. What levels of VOC and/or NO_x emissions reductions are necessary to reduce predicted ozone levels in the Northeast to below 125 ppb?
4. What are the effects of reactivity-based strategies in reducing regional ozone levels?
5. How does uncertainty in biogenic emissions affect conclusions drawn about the benefits of controlling anthropogenic sources?

Twenty-four control strategies were simulated to address these issues. Table ES-2 summarizes the strategies, and notes the corresponding strategic issues.

Simulations for the 2005 baseline and CS19 were repeated with the June 9-20, 1983, episode to note the sensitivity of conclusions relative to differing meteorological conditions. Details of the control measures in each strategy, as well as the resulting net changes in VOC, NO_x, and CO emissions, are provided in Section 4.

Findings for Strategy Simulations

Conclusions drawn relative to the five strategic issues addressed by ROMNET control strategies are summarized below. The analyses which led to these findings are contained in Section 5 of the report.

Issue #1

What are the relative benefits of VOC controls versus NO_x controls in reducing ozone levels across the region?

- Maximum technology NO_x controls appear to produce larger ozone reductions than stringent VOC controls in many areas of the Northeast. This is particularly notable in the western portion of the region, where biogenic VOC emissions are highest and a large component of NO_x emissions are rural point sources. In the Corridor, except for New York City, NO_x controls tend to reduce the spatial extent of high ozone levels, whereas VOC controls are more effective in reducing the peak values. Combining VOC and NO_x controls provides both benefits by reducing the magnitude and spatial extent of high ozone concentrations.
- In the presence of stringent VOC controls, peak ozone levels appear to be more sensitive to mobile- rather than point-source NO_x emissions reductions in several cities (e.g., Philadelphia, Boston, Detroit, and Cleveland). In areas dominated by NO_x point sources, (e.g., Pittsburgh and Charleston, WV), point-source controls are more effective than mobile-source reductions.
- In New York City, NO_x controls alone or with VOC controls are counterproductive relative to VOC controls for short-term peak concentrations and population exposure. This effect is most prominent in the core of the urban plume and appears to be associated with high NO_x emissions in the center of the urban area. Outside the main plume, ozone levels are actually reduced by NO_x controls. For longer averaging times (e.g., episode mean 8-hour daily maximum averages) NO_x plus VOC controls produce lower ozone levels than VOC controls alone.
- The relative benefit of VOC versus NO_x controls varies by day (i.e., as a function of meteorology) in some cities. This was particularly evident in the Baltimore/Washington, DC area.

Issue #2

What is the impact of reducing regional transport on Northeast Corridor ozone levels?

- In the precontrol scenario, 2005 baseline ozone levels are not substantially impacted by reducing transport into the Corridor except in Baltimore/Washington, DC, and in southeast Pennsylvania. These areas are closest to the portion of the Corridor boundary having the greatest incoming ozone levels during this episode. It is possible that conditions in other episodes might produce a greater impacts in other portions of the Corridor. Still, even in these two areas, the impacts are small relative to the level of predicted ozone for the 2005 baseline.

- In the postcontrol scenario, the results suggest that without stringent upwind controls, ozone levels in parts of the Corridor may not be reduced to below the concentration specified in the NAAQS even with stringent controls along the entire length of the Corridor. Again, the effects are most pronounced for cities near the upwind boundary of the Corridor.

Issue #3

What levels of VOC and/or NOx emissions reduction are necessary to reduce predicted ozone concentrations in the Northeast to below 125 ppb?

- Stringent maximum technology VOC and NO_x controls may be necessary in all areas of the Northeast Corridor.
- Additional reductions of VOC on the order of 64 percent in New York City and 54 percent in Baltimore/Washington, DC also may be needed. At present, this level of emissions reductions is beyond known or envisaged control technologies.
- The effectiveness of the most stringent control strategy in reducing ozone to $\leq$ 125 ppbwas confirmed using an alternate meteorological episode.
- Application of stringent NO_x controls in New York City is counterproductive. Ozone levels approach 125 ppb as VOC controls are increased. It appears that even without NO_x controls, stringent VOC technology and reactivity-based measures may be needed in this urban area.
- Considering rule effectiveness and a more realistic representation of control programs (e.g., fleet turnover), results show predicted episode maximum ozone levels of just above 125 ppb in most sections of the Northeast Corridor with the most stringent VOC/NO_x/reactivity-reduction strategy simulated. The exception is New York City, where the peak ozone level is predicted to be 140 ppb.

Issue #4

What are the effects of reactivity-based strategies on regional ozone levels?

- Reactivity-based strategies similar to those simulated in ROMNET may provide the greatest benefit in large urban areas that are VOC-limited, and thus are more responsive to changes in VOC emissions. In such areas, reactivity-based measures could provide reductions in ozone levels comparable with that provided by a stringent technology-based approach. Also, reactivity measures may counterbalance the negative impact of NO_x controls in New York City and other areas that show a similar response.
- In other Northeast Corridor cities, and by extension, cities that respond to both VOC and NO_x controls, reactivity measures may produce a notable reduction in daily maximum ozone levels $\geq$ 125 ppb. However, for the Corridor cities, the reduction provided by the reactivity measures was only half of that from the technology-based VOC controls, and four times less than that from the VOC plus NO_x controls.

- In other, more peripheral sections of the Corridor, the relative benefits of VOC technology controls alone or with NO_x controls far outweigh the benefits of reactivity-based controls.
- In cities outside of the Corridor that were found to be most sensitive to NO_x controls, there was less reduction in ozone from the reactivity measure compared with the technology-based controls.

Issue #5

How does the large uncertainty in biogenic emissions alter conclusions regarding the effectiveness of control measures?

- ROM simulations with "best estimate" biogenic emissions yield predicted ozone concentrations closer to observed values than biogenic emissions at either end of the uncertainty range ($\pm$ a factor of three), which provides some added confidence in the emissions rates used in ROM strategy simulations.
- The sensitivity of predicted ozone levels and population exposure to biogenic uncertainty varies considerably from city to city. In general, there is a greater sensitivity with increasing biogenics at the high end of the uncertainty range than at the lower end.
- Grid hours $\geq$ 125 ppb are much more sensitive to an increase in biogenic emissions than the other metrics. If biogenics were at the "low" end of the range, predicted ozone in Pittsburgh and Detroit would fall below 125 ppb with the controls implied by proposed 1989 Clean Air Act legislation (CS05); all other cities would still be above this level (note that predicted ozone in Charleston, WV, is below 125 ppb with "best estimate" biogenics).
- With the application of stringent controls that reduced peak ozone to below 125 ppb with "best estimate" biogenics (CS19), ozone levels rise well above this level in the "high" biogenics scenario in all cities except Pittsburgh and Charleston. Thus, if biogenics are actually near the high end of the uncertainty range, then additional controls providing reductions in emissions beyond those in CS19 will be needed in many of the Northeast cities.

Caveats

There are three broad caveats to the findings and conclusions discussed above:

1. *The relatively coarse grid cell size in the ROM (a horizontal grid size of ~ 18.5 x 18.5 km) and limited vertical differentiation (two layers within the daytime atmospheric boundary layer).* Emissions are injected as a total flux by layer for each grid, and thus the fate of emissions from individual point sources is not treated explicitly. Concentration estimates are grid cell (horizontal and vertical) average values for each layer. This may in part explain why the model tends to underpredict observed peak ozone concentrations associated with sharp concentration gradients and overpredict minimum values affected by titration from local sources of NO. In ROMNET, the large grid size may affect conclusions regarding NO_x control, since a large fraction of NO_x emissions emanate from

individual point sources, particularly in areas outside the Northeast Corridor. Also, the tendency to smooth out peak values may affect findings on the level of emissions controls necessary to reduce ozone to < 125 ppb.

2. *The emissions inventories used in ROMNET.* As indicated previously, there are large uncertainties in biogenic emissions. Also, even though the NAPAP emissions data were subjected to extensive quality assurance, there remains some unquantified level of uncertainty in anthropogenic emissions. In this regard, the findings from ROMNET should be used to help establish control directions and approximate starting points for States to begin strategy evaluations using more recent (1990), locale-specific, quality assured inventories.
3. *This study concentrated heavily on one episode (July 2-17, 1988).* This episode was the most severe of all episodes in the Northeast, at least as far back as 1980. Although the episode included several of the meteorological conditions typical of ozone episodes in this region, consideration of a wide range of meteorological scenarios was not possible for the strategy simulations.

TECHNOLOGY TRANSFER

Need for Technology Transfer

In ROMNET, the use of the ROM to estimate effects of regional control strategies on ozone levels was demonstrated. There are four reasons why using ROM-system data to assist in developing required ozone NAAQS attainment demonstrations would be advantageous.

1. The ROM data provide a means for ensuring consistency among States in the procedures used to derive transport assumptions in the design of urban strategies.
2. The ROM provides a means for simulating the combined effects from numerous urban areas across the region.
3. The model provides the most technically defensible way to estimate future ozone/precursor concentrations transported into urban areas.
4. The ROM system provides data for use in SIPs which may be very difficult or expensive to obtain otherwise.

For reasons noted previously, using the ROM as the sole modeling tool to demonstrate attainment of the ozone NAAQS may not be the best approach. The Urban Airshed Model (UAM) has been designated as the preferred method for attainment demonstrations. However, the ROM is most useful in conjunction with "nesting" the UAM within a ROM domain. In this approach, the ROM system is used to provide initial and boundary conditions estimates, as well as other inputs, for UAM applications.

Although the concept of nesting is straightforward, its implementation is not. Part of the difficulty lies in managing the large quantity of data generated as part of ROM simulations, and in providing an easy means for States to access and retrieve selected data sets needed in UAM applications. Also, although ROM and UAM are both three-dimensional photochemical grid models, they are dissimilar in many aspects. For example, the horizontal and vertical structure and resolution of the two models differ. Also, the UAM preprocessors require input data formats which are unlike those used for ROM data sets. These technical problems have been overcome as part of ROMNET through the development of two computer systems. These are the Gridded Model Information Support System (GMISS) and the ROM/UAM Interface Program System (Interface).

Gridded Model Information Support System (GMISS)

GMISS contains an archive of ROM-system databases, as well as utilities for retrieving these data, and can be easily accessed by the States. The data types in GMISS include ROM-predicted pollutant concentrations, selected meteorological inputs to the ROM, biogenic emissions calculated for ROM simulations, and topographic information. The UAM subsystem of GMISS is designed to provide all of the ROM-system data necessary to use the ROM/UAM Interface for developing UAM inputs. GMISS resides on the EPA IBM 3090, and is accessible by States from their local terminals via a user-friendly menu system. Data can be retrieved for user-specified dates and subregions of the ROM domain. Additional information on GMISS is provided in Section 6 of this report.

ROM/UAM Interface Program System (Interface)

The ROM/UAM Interface is a set of computer programs that convert ROM data files accessed from GMISS into input files used directly by the UAM and four of its 13 preprocessor programs. The Interface does not handle mixing heights or anthropogenic emissions, both of which must be supplied by the user. The Interface is sufficiently flexible to allow the user to substitute user-derived inputs (e.g., wind fields) for ROM-system data. Interface programs prescribe a series of algorithms that match and interpolate ROM data to the resolution used by UAM. The structure of the ROM/UAM Interface Program System is described in greater detail in Section 6.

ACCOMPLISHMENTS OF THE ROMNET PROJECT

The ROMNET project was successful in achieving the goals set forth at its inception. This success was attained through the accomplishment of several major milestones. First, ROMNET brought together

numerous State/local agencies and EPA offices to focus their energies in a cooperative manner to address long-standing issues concerning problems of ozone transport in the Northeast. During ROMNET, State agency representatives played an active role along with the EPA in the management and technical decision-making aspects of the project. The organizational structure and communications processes adopted in ROMNET may be useful as a framework for future joint efforts among States and the EPA.

Second, the Regional Oxidant Model (ROM) was demonstrated to be a practical tool for addressing policy-related issues concerning the efficacy of various regional control strategies. The ROMNET program has provided insights to Federal, State, and local policymakers on a number of such issues, including: (a) the relative effects of VOC and NO_x controls; (b) the role of transport into and within the Northeast Corridor; (c) the magnitude of controls potentially needed to reduce ozone to the level specified in the NAAQS; (d) the usefulness of strategies that incorporate changes in the photochemical reactivity of VOC emissions; and (e) the effects of the large uncertainty in biogenic emissions on conclusions regarding the efficacy of control strategies.

Finally, as a result of ROMNET, computer systems and databases have been developed which will enable State agencies to explicitly consider regional and interurban transport in preparing ozone SIPs. The infrastructure containing these systems gives States access to ROM-system databases and provides methodologies and guidance for using these data to support urban-level attainment demonstrations. These systems are generic in nature and can be used by States in other portions of the United States where ROM simulations are planned as part of future EPA-State regional modeling projects.

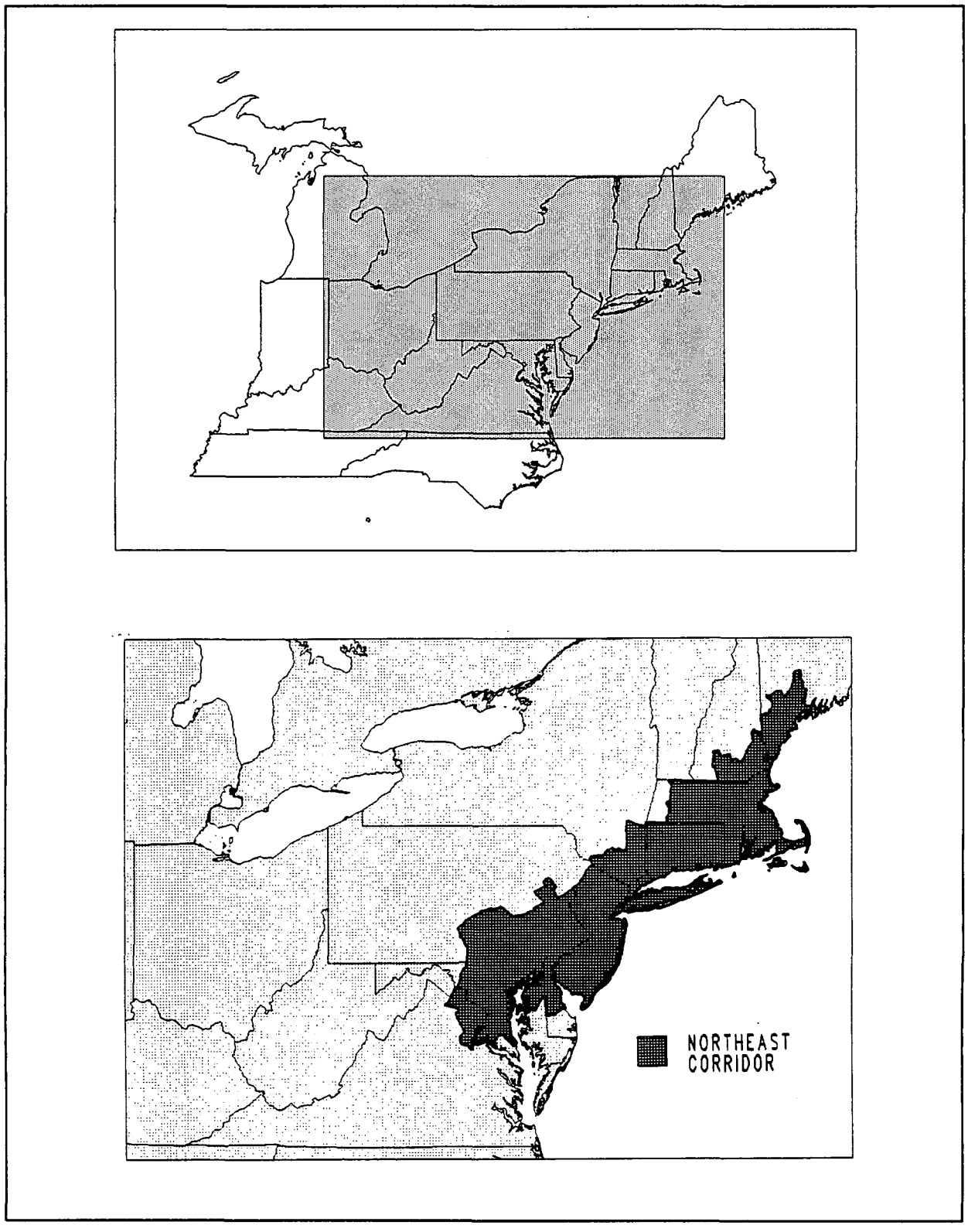

Figure ES-1. The ROMNET region.

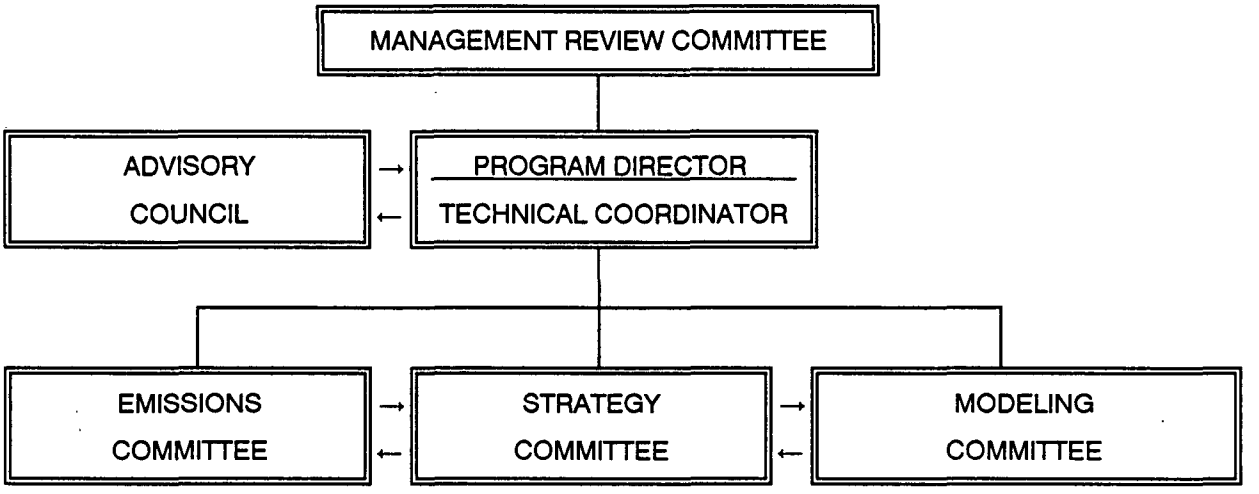

Figure ES-2. ROMNET management structure.

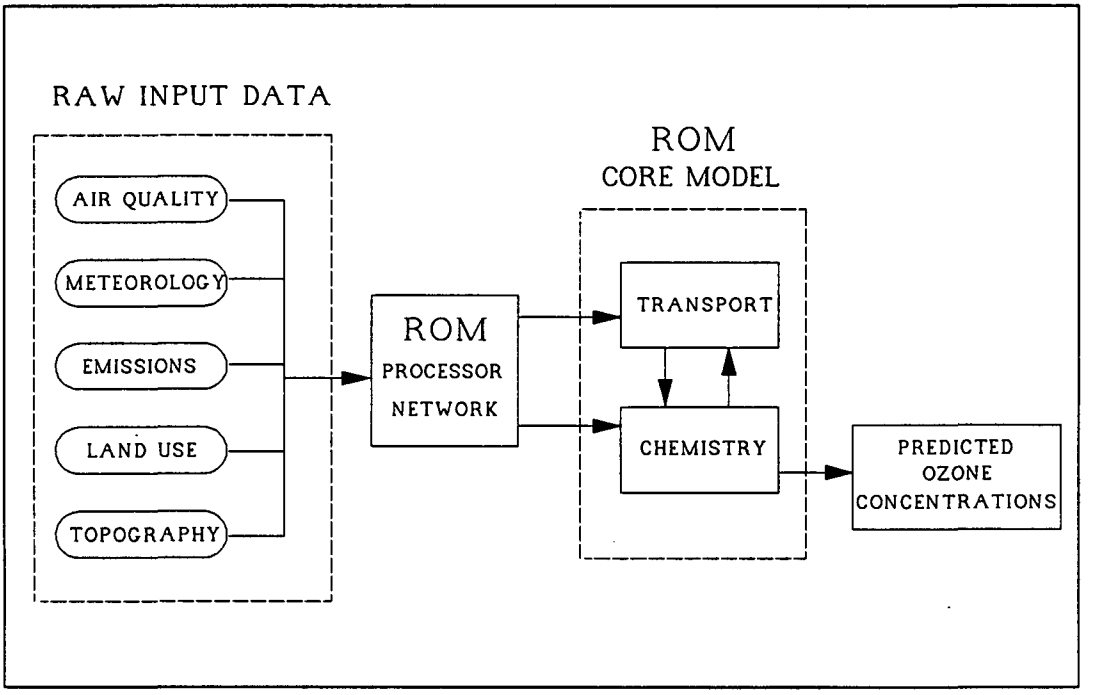

Figure ES-3. Components of the ROM.

TABLE ES-1. ORGANIZATIONS PARTICIPATING IN ROMNET

State/local air pollution control agencies:

Connecticut	New York
Delaware	Ohio
Kentucky	Pennsylvania
Maine	Philadelphia
Maryland	Rhode Island
Massachusetts	Vermont
Michigan	Virginia
New Hampshire	Washington, DC
New Jersey	West Virginia

Northeast States for Coordinated Air Use Management (NESCAUM)

EPA Regions I through V

EPA Headquarters Offices:

- Office of Air Quality Planning and Standards (OAQPS)
- Atmospheric Research and Exposure Assessment Lab (AREAL)
- Office of Policy Analysis and Review
- Office of Policy Planning and Evaluation
- Office of Mobile Sources

Contractors:

- Computer Sciences Corporation (CSC)
- Alliance Technologies

TABLE ES-2. ROMNET CONTROL STRATEGIES

Control Strategy Number	Controls	Issue(s) Addressed	Rationale
CS01 (MOBILE 3.9)	Maximum technology VOC regionwide; NO_x at 2005 baseline levels	2, 3	Test effects of strategies emphasizing VOC reductions by comparison with 2005 baseline.
CS02 (MOBILE 3.9)	Maximum technology VOC in NE Corridor only; NO_x at 2005 baseline	2	Test effect of VOC controls outside Corridor on ozone in Corridor by comparison with CS01.
CS03 (MOBILE 3.9)	Maximum technology VOC in NE Corridor and in other nonattainment areas; only 2005 baseline elsewhere	2	Test effect of "rural" VOC controls outside Corridor on ozone Corridor by comparison with CS01 and CS02.
CS04	Not performed		
CS05	VOC and NO_x controls prescribed in HR3030 with October 1989 Waxman-Dingell tailpipe standards	3	Test effects of proposed Clean Air Act legislation.
CS06-CS09	CS01 and CS05 varying biogenic emissions by ± a factor of 3	5	Test sensitivity of conclusions to uncertainty in biogenics.
CS10	Enhanced maximum technology VOC and NO_x controls applied regionwide	1, 3	Test effects of VOC and NO_x controls.
CS11	Maximum technology NO_x; VOC at 2005 baseline	1, 3	Compare effects of NO_x controls with VOC and NO_x (CS10).
CS12	Maximum technology VOC; NO_x at 2005 baseline	1, 3	Compare effects of VOC controls with VOC and NO_x controls (CS10) and NO_x controls above.
CS13-CS14	Maximum technology VOC with NO_x point source controls (CS13) or NO_x mobile source controls (CS14)	1, 3	(CS11). Test whether it is appropriate to focus controls on certain NO_x source types.

continued

TABLE ES-2 (continued)

Control Strategy Number	Controls	Issue(s) Addressed	Rationale
CS15	Maximum technology VOC and NO_x controls but with methanol (M100) vehicles in the NE Corridor and low-reactivity solvent substitution regionwide	3, 4	Test implications of reducing reactivity.
CS16	CS10 controls plus across-the-board VOC reductions in New York City and Baltimore/Washington, DC. Also NO_x point source emissions at 2005 baseline in New York City	3	Reduce maximum ozone to < 125 ppb throughout the U.S. portion of the region.
CS17	Maximum technology NO_x controls (CS11) with "low" biogenics	5	Examine effectiveness of NO_X control within uncertainty range in biogenics.
CS18	CS15 with additional across-the-board VOC reductions in New York City and Baltimore/Washington, DC; also NO_x point-source emissions at 2005 baseline in New York City	3	Test relative importance of reactivity reduction and VOC technology controls by comparison with CS12 and CS16.
CS19	CS18 but with NO_x point source emissions at 2005 baseline in Baltimore/Washington, DC	2, 3	Reduce maximum ozone to < 125 ppb throughout the U.S. portion of the region.
CS20	2005 baseline with methanol (M100) vehicles in NE Corridor and low-reactivity solvents regionwide	4	Compare effectiveness of reactivity reductions in base *vs.* postcontrol scenarios and with VOC technology controls.
CS21, CS22	Biogenics sensitivity tests with CS19 varying biogenic emissions by ± a factor of 3	5	Test effect of biogenic emissions uncertainty on a strategy that reduces ozone to < 125 ppb.

continued

TABLE ES-2 (concluded)

Control Strategy Number	Controls	Issue(s) Addressed	Rationale
CS23	CS19, but with more realistic "rule effectiveness" assumptions and vehicle fleet penetration estimates	3	Test sensitivity of results to limitations in control program effectiveness.
CS24	CS19 in NE Corridor; 2005 baseline elsewhere	2	Assess relative importance of transport from outside the Corridor *vs.* controls on emissions within the Corridor.
CS25	CS19 outside Corridor; 2005 baseline in NE Corridor	2	

SECTION 1

PROJECT GOALS AND SCOPE

by

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1.1 PURPOSE AND INTENT OF ROMNET

The Regional Ozone Modeling for Northeast Transport (ROMNET) Project was initiated by the U.S. Environmental Protection Agency (EPA) and State and local agencies in the Northeast, as part of a joint effort to address the problem of regional transport in developing effective and equitable control programs to attain the ozone National Ambient Air Quality Standards (NAAQS)[1] in this region. The specific goals of ROMNET are:

(1) to evaluate the relative effectiveness of regional controls on ozone levels in the Northeast;

(2) to provide quantitative estimates of ozone and precursor concentrations transported between urban areas following the application of regional control measures; and

(3) to provide procedures and guidance for incorporating ozone and precursor transport in future State Implementation Plan (SIP) development.

The intent of ROMNET is for EPA and State decision-makers to use the findings in guiding ozone-policy development and planning for potential regional control programs, as well as in urban-area specific strategy evaluations. The urban-scale analyses are to be conducted by the States as part of the SIP process. The results and guidance from the project will enable States to quantify changes in future levels of ozone and precursor transport expected to follow implementation of nationwide Federal measures, local control programs in upwind cities, and potential regional strategies.

1.2 STRUCTURE OF THE FINAL REPORT

This report was prepared to document the activities and findings of ROMNET. The following is a brief description of the contents of each section:

- Executive Summary -- presents an overview of ROMNET and the principal findings and conclusions of the project;
- Section 1, Project Goals and Scope -- provides the background to ROMNET, the goals and structure of the project, and the technical approach adopted to meet the project objectives;
- Section 2, The ROMNET Modeling System -- describes the Regional Oxidant Model (ROM) and the evaluation of the ROM conducted as part of ROMNET;
- Section 3, Ozone Episodes Selection -- describes the episode selection process, and the ozone levels and meteorological conditions during episodes simulated;

1. An exceedance of the NAAQS is defined as a daily maximum 1-hour ozone concentration greater than 0.12 ppm (124 ppb). The NAAQS is not to be exceeded on average more than once per year at any location.

- Section 4, Emissions Scenario Development -- describes the base case emissions scenario, future baseline scenario and control strategies, as well as the procedures used to develop inventories that reflect these scenarios;
- Section 5, Regional Modeling Results and Project Findings -- presents the results of ROM simulations conducted to evaluate the effectiveness of control strategies;
- Section 6, State Access and Use of ROMNET Databases -- describes the Gridded Model Information Support System (GMISS) and the ROM-Urban Airshed Model (UAM) Interface; and
- Appendices -- includes supporting information for sections of this report.

Note that all figures and tables are placed at the end of the Section in which they are referenced.

1.3 BACKGROUND TO ROMNET

Since the early 1970's, there has been a growing awareness that ozone and ozone precursors are transported beyond the political jurisdiction of source areas to impact air quality levels at considerable distances downwind. This phenomenon is now well documented by the scientific community and has been recognized by policymakers at the EPA. Transport effects are especially acute where several urban areas are in close proximity to one another, as in the Northeast. There, five major urban areas, from Washington, DC to Boston and adjacent medium-size cities and suburbs, nearly overlap to provide an almost continuous corridor of sources emitting ozone precursors, as shown in Figure 1-1. Aside from these source areas, emissions in other less populated areas of the Northeast and/or cities such as Pittsburgh, Buffalo, Cleveland, Detroit, etc., are likely to contribute to the regional ozone burden transported within the Northeast. A compounding factor is the meteorological conditions that frequently exist in this region during the summer. In particular, the wind flow often favors ozone and precursor transport both between urban areas in the Corridor, and into the Corridor from other parts of the Northeast. These conditions, coupled with the time scales of ozone photochemistry, can result in multiday episodes of high ozone concentrations across broad areas of the region, as shown in Figure 1-2.

As a consequence of the prevalence of interurban and intraregional transport, a regional perspective is necessary for the development of control programs in the Northeast. At the request of States in this region, the EPA initiated ROMNET in October 1987 as a three year effort to provide a quantitative technical means to support such a regional approach. The State/local agencies, EPA organizations, and EPA contractors participating in ROMNET are listed in Table 1-1.

The first task of the ROMNET project was the development of a protocol which sets forth the goals, scope, technical approach, schedule, and organizational structure agreed to by the participants. This document is included as Appendix A. The remainder of this Section describes the rationale for the goals and scope of ROMNET and the objectives designed to address these goals; the project organizational structure; and the major technical tasks conducted to meet the objectives. As indicated in Section 1.2, details on the individual technical tasks are provided in other portions of this report. More information on the organizational structure can be found in the ROMNET Protocol in Appendix A.

1.4 RATIONALE FOR THE GOALS AND SCOPE OF ROMNET

This Section describes the rationale for each of the major goals of ROMNET identified in Section 1.1.

The rationale for the first goal of ROMNET follows from the premise that equitable and effective strategies for attainment in both urban and rural areas of the Northeast will require relatively stringent control measures along the Corridor and potentially throughout the entire region. Such a broad strategy may be needed to reduce interurban and intraregional impacts associated with ozone and precursor transport. Thus, it is important to identify strategies that are most effective in reducing regional ozone concentrations.

The rationale for the second goal is based upon prior urban scale modeling analyses, which indicate that the effectiveness of emissions controls is strongly sensitive to assumptions about the levels and mixture of ozone and precursor concentrations transported into the modeling area. Present EPA policy, as well as provisions of the 1990 Clean Air Act legislation, require that urban-scale modeling be used in identifying and evaluating control measures for certain nonattainment areas. Therefore, it is critical that meaningful representative estimates of urban boundary conditions be developed and used in SIP modeling.

The third goal reflects the practicality of deriving urban boundary conditions from transport concentrations. Procedures and guidance are needed on how to link regional and urban models so that data from the large scale model will mesh in a cohesive manner with the smaller scale model. For this, an infrastructure or system is required to store, manage, manipulate and transfer regional databases to States for their use in urban modeling. These databases provide estimates of transport under various regional emissions scenarios.

Meeting the three project goals is not straightforward because of the complexity of the transport problem and the structure of available models. For example, regionally-high ozone concentrations that make transport considerations important are not the result of a few easily identifiable plants or source types. Rather, ozone levels result from the combination of various sources, including numerous, but individually small, sources of volatile organic compounds (VOC), such as dry cleaners, gasoline service stations, bakeries, etc.; mobile source emissions of VOC, oxides of nitrogen (NO_x), and carbon monoxide (CO) from passenger vehicles, trucks etc.; and large point sources of NO_x, VOC, and/or CO, such as power plants, industrial facilities, and gasoline terminals, etc. Thus, evaluating regional strategies requires specification of both emissions and controls for multiple pollutants from numerous source types of different sizes, some of which are clustered in urban areas while others tend to be in rural areas or spread throughout the region. Also, the specification of boundary conditions for urban modeling is difficult, in part because of a lack of spatial and temporal resolution of ozone and precursor measurements at the surface and aloft. This is further complicated by the need to estimate expected future-year boundary conditions. Such future-year scenarios account for the effects of anticipated changes in emissions between the current base year and the projected or mandated attainment date. Factors that are considered in these scenarios include population growth, existing control programs, and strategies required but not yet fully implemented in upwind areas. Finally, fully-nested regional-to-urban scale photochemical models are presently unavailable. As a consequence, procedures are needed for providing State agencies with standard methods and access to regional modeling results, from which the regional databases can be applied to urban-scale modeling.

The EPA Regional Oxidant Model (ROM) was selected as the tool to quantify transport and evaluate the effectiveness of regional strategies. The ROM is appropriate for such use for the following reasons: (1) it is designed to simulate the photochemistry and meteorology associated with ozone formation and pollutant transport across regional spatial scales for multiday summertime episodes; (2) emissions from ozone-precursor source types are explicitly input to the ROM, and thus growth factors and control measures can be specified by source category, pollutant, and location; and (3) the ROM produces gridded three-dimensional estimates of ozone and precursor concentrations with a spatial resolution and time step interval suitable for providing boundary condition estimates for urban scale models.

Three primary objectives were identified for using ROM in ROMNET in order to meet the project goals. They are:

(1) to apply ROM to selected base and control strategy scenarios for various ozone episodes;

(2) to interpret the predictions in order to evaluate the relative effectiveness of simulated regional strategies for reducing ozone levels; and

(3) to provide the ROM predictions and ancillary input data sets to States for purposes of urban modeling, along with methods and guidance on how to use this information.

The scope of ROMNET was limited to the organizational interactions and technical tasks required to meet these objectives. As noted in Section 1.1, it is intended that the databases, methodologies, and guidance developed in ROMNET be used by States in subsequent urban scale modeling, as part of the SIP development process. The project findings and conclusions concerning the efficacy of regional strategies are to be used by the EPA, States, and a possible future regional commission to support development of the policies and legislation needed to provide consistent, coordinated SIPs along the Northeast Corridor, and for the potential implementation of regional control measures.

1.5 ROMNET ORGANIZATIONAL STRUCTURE

A multilayered organizational structure was adopted to achieve the project objectives given in Section 1.4. The management and technical components of this structure are shown in Figure 1-3. This concept was designed to involve as many of the interested agencies as possible in the activities and decision-making process, and to allow individual expertise from both States and the EPA to be utilized in the technical tasks. Members of the various committees, the Program Director, Technical Coordinator and contractor teams are listed in Appendix B.

The Management Review Committee was formed to provide a forum to ensure that the focus of ROMNET was maintained within the interests of the multiple agencies involved. Specific functions included:

(1) review of the status of technical tasks to ensure that the project goals were being met on schedule, and

(2) the review and approval of proposed strategies and episodes selected by the technical committees for simulation.

The Program Director was given responsibility for the overall technical adequacy of the program. Part of this function included informing and consulting with the Management Review Committee on the progress of technical activities and ensuring that consensus recommendations of the Management Review Committee were integrated into the technical program. The Program Director was assisted by the Technical Coordinator, who was responsible for managing the day-to-day activities of the project and coordinating activities of the technical committees, EPA participants, and contractors.

Three technical committees were established as an avenue for participants to provide input and review of the design and implementation of the technical program. All three committees were chaired by a staff member of the EPA's Office of Air Quality Planning and Standards (OAQPS). Functions of the Modeling Committee included episode selection, upgrades to the ROM, development of the ROM-Urban Airshed Model (UAM) Interface, the supplemental evaluation of the ROM, ROM simulations, and development of the Gridded Model Information Support System (GMISS). The Emissions Committee was responsible for oversight of regional emissions inventory development for base case, future baseline, and control strategy scenarios. The Strategy Committee was charged with the design of future baseline and control strategies. Finally, the Advisory Council was established to advise the Program Director on major issues involving resources, schedules, cooperation, technical activities, and program directives. The Program Director was to use this group as a platform for discussion of options and alternative recommendations to be made to the Management Review Committee on issues involving these topics. Members of the Advisory Council are listed in Appendix B. In reality, there was little consultation with this group largely because no major problems were encountered relative to these issues. Minor problems were either resolved at the technical committee level or were brought directly to the attention of the Management Review Committee for consideration.

1.6 OVERVIEW OF THE ROMNET TECHNICAL PROGRAM

The technical tasks conducted under the purview of each of the Committees are listed below.

Modeling Tasks

- An objective ranking procedure was developed and implemented to identify candidate episodes for ROM simulation.
- The ROM was upgraded to version 2.1 in order to:
  (1) expand the domain to include all of Ohio and Virginia,
  (2) upgrade components related to the chemical mechanism,
  (3) improve the efficiency of emissions processing, and
  (4) alter several meteorological processors to produce closer representation of observed ozone plume orientation.
- ROM was applied for over thirty combinations of episodes and emissions scenarios.
- A supplemental evaluation of ROM was conducted using selected ROMNET episodes.
- The ROM-Urban Airshed Model (UAM) Interface was developed to provide a means for using ROM predictions to derive UAM boundary conditions. The Interface also contains procedures for using ROM system data sets to generate meteorological, air quality, topographical, and biogenic emissions input for UAM.

- The Gridded Model Information Support System (GMISS) was developed to:
  (1) archive ROM predictions and system data sets needed for the ROM-UAM Interface, and
  (2) provide a user-friendly menu-based system to enable States to retrieve data sets directly via their local terminals from the EPA National Computer Center.

OAQPS was responsible for episode selection and, together with Computer Sciences Corporation (CSC), the development of GMISS. AREAL and their contractor, CSC, designed and implemented the upgrades to the ROM, the development of the ROM-UAM Interface, and the supplemental evaluation of the ROM. The ROM simulations, including processing ROM inputs, execution of ROM simulations, and post-processing of output for statistical summaries and graphical displays, were performed by CSC as specified by the OAQPS and AREAL. State and Regional Office Committee members were instrumental in the review and analysis of ozone and meteorology data to select episodes for simulation. In addition, the New York State Department of Environmental Conservation provided review and input to the development of the ROM-UAM Interface.

Emissions Inventory Development

- The Biogenic Emissions Inventory System was developed to provide estimates of biogenic emissions for VOC and NO_x. As part of this task, a canopy module was implemented to provide more representative treatment of the effects of meteorological conditions on VOC emissions from forested areas.
- The 1985 National Acid Precipitation Assessment Program (NAPAP) anthropogenic emissions inventory was obtained for use in ROMNET and modified to:
  (1) upgrade mobile source emissions to MOBILE 4,
  (2) provide procedures for altering mobile source emissions to reflect grid and day-specific temperatures, and
  (3) adjust seasonal emissions from selected VOC stationary sources to represent temperature and activity levels typical of ozone episodes.
- Procedures were developed to create emissions inventories for projected future baseline scenarios and control strategies. Estimates of expected emissions growth rates, the efficiency, effectiveness, and penetration of existing control measures were developed and used in generating these inventories, as were estimates of the efficiencies of maximum technology controls.
- Inventories of anthropogenic emissions were created for two future baseline scenarios and six technology-based scenarios.

A majority of the emissions inventory work was conducted by Alliance Technologies, Inc., under contract to EPA OAQPS. The Biogenic Emissions Inventory System was developed by the AREAL and CSC. The EPA Office of Mobile Sources provided inputs for treating evaporative emissions, temperature effects, and clean-fuel vehicles to support development of mobile emissions estimates. Principal activities

involving the State and Regional Office committee members were (1) the review of the 1985 base case emissions, and (2) the development of growth rates and existing control efficiency, rule effectiveness, and rule penetration estimates for use in the projected future baseline scenario.

Strategy Design and Interpretation

- Twenty-four control strategies were designed and simulated using various combinations of the future baseline and technology-based scenarios together with across-the-board and reactivity reductions, and biogenic-uncertainty sensitivity scenarios.
- Strategies were designed for simulation in various phases. Results of each phase were examined and interpreted to reveal the effectiveness of control measures in order to prescribe strategies for the subsequent phase.
- Participants in ROMNET, and EPA management were briefed on the results of strategy simulation following the completion of each phase.
- The findings of ROMNET strategy simulations are documented in this report.

For the most part, straw man proposals of strategies were prepared by the OAQPS for discussion and development by Strategy Committee members. Strategies formulated by the Committee were presented to the Management Review Committee for approval. Translation of strategies into emissions reductions were performed by Alliance Technologies, under contract to the OAQPS, and by CSC, under contract to the AREAL.

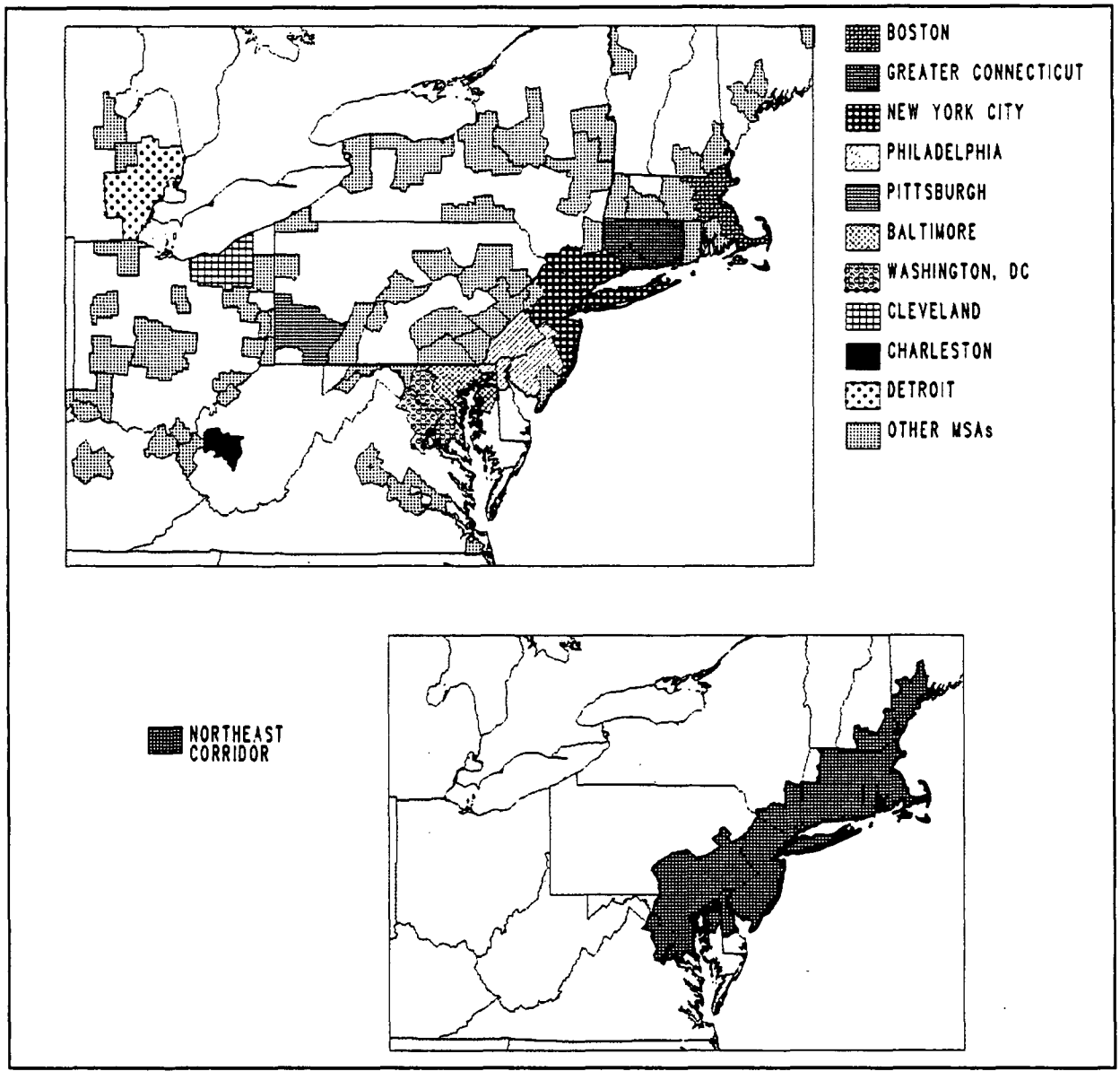

Figure 1-1. The Northeast Corridor and other Metropolitan Statistical Areas (MSA's) in the ROMNET region.

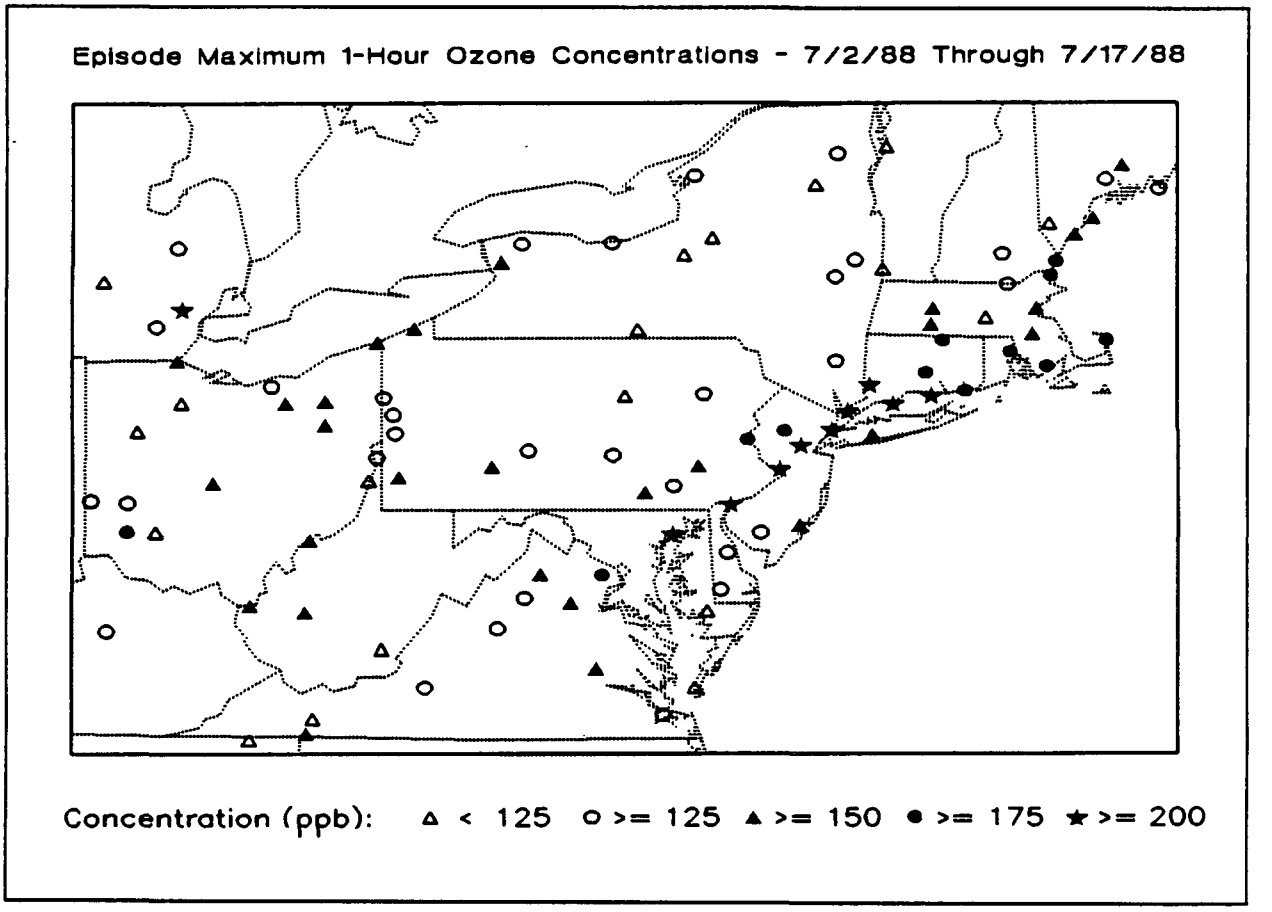

Figure 1-2. Observed maximum 1-hour ozone concentrations for July 2 - 17, 1988 across the ROMNET region.

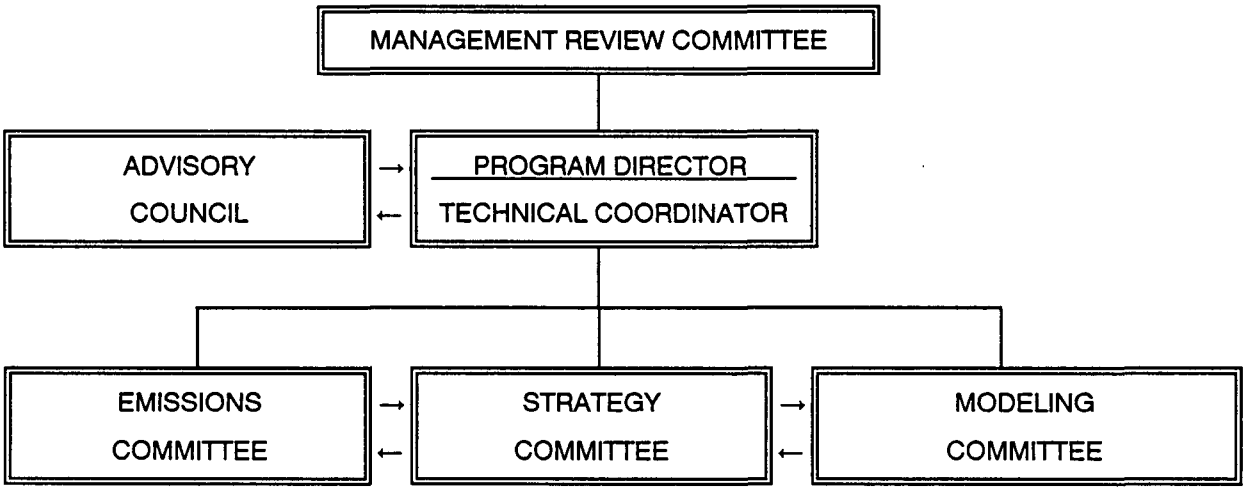

Figure 1-3. ROMNET management structure.

TABLE 1-1. ORGANIZATIONS PARTICIPATING IN ROMNET

State/local air pollution control agencies:

Connecticut	New York
Delaware	Ohio
Kentucky	Pennsylvania
Maine	Philadelphia
Maryland	Rhode Island
Massachusetts	Vermont
Michigan	Virginia
New Hampshire	Washington, DC
New Jersey	West Virginia

Northeast States for Coordinated Air Use Management (NESCAUM)

EPA Regions I through V

EPA Headquarters Offices:

- Office of Air Quality Planning and Standards (OAQPS)
- Atmospheric Research and Exposure Assessment Lab (AREAL)
- Office of Policy Analysis and Review
- Office of Policy Planning and Evaluation
- Office of Mobile Sources

Contractors:

- Computer Sciences Corporation (CSC)
- Alliance Technologies

SECTION 2

THE ROMNET MODELING SYSTEM

by

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2.1 INTRODUCTION

The Regional Oxidant model (ROM) was used as the tool for estimating regional ozone concentrations expected to result from applying the various ROMNET emissions control strategies. This Section of the report describes the characteristics of the ROM, the associated input-processor system, quality assurance procedures followed for ROM simulations, and limitations to the use of the model. An evaluation of the ROM, conducted as part of ROMNET, is also summarized in this Section.

2.2 GENERAL CHARACTERISTICS OF THE REGIONAL OXIDANT MODEL (ROM)

The ROM was designed to simulate most of the important chemical and physical processes that are responsible for the photochemical production of ozone over a domain of 1000 km and for episodes of up to 15 days in duration (Lamb, 1983). These processes include (1) horizontal transport, (2) atmospheric chemistry and subgrid-scale chemical processes, (3) nighttime wind shear and turbulence associated with the low-level nocturnal jet, (4) the effects of cumulus clouds on vertical mass transport and photochemical reaction rates, (5) mesoscale vertical motions induced by terrain and the large-scale flow, (6) terrain effects on advection, diffusion, and deposition, (7) emissions of natural and anthropogenic ozone precursors, and (8) dry deposition. The processes are mathematically simulated in a three-dimensional Eulerian model with three vertical layers, including the boundary layer and the capping inversion or cloud layer. Horizontal grid resolution is $^1/_4°$ longitude by $^1/_6°$ of latitude, or about 18.5 km $\times$ 18.5 km. The modeling domain adopted for use in ROMNET is shown in Figure 2-1.

2.2.1 Physical Processes within Layers 1, 2 and 3

In general, the three model layers are free to locally expand and contract in response to changes in the physical processes occurring within them. During an entire simulation period, horizontal advection and diffusion and gas-phase chemistry are modeled in all three layers. ROM predictions from layer 1 are used as surrogates for surface concentrations. Although the time-scale of output concentrations is 30 minutes, ROM predictions are aggregated into 1-hour average concentrations. Figure 2-2 shows the ROM layers during the day and at night, and describes some of their features.

Layers 1 and 2 model the depth of the well-mixed layer during the day. Some special features of layer 1 include the modeling of (1) the substantial wind shear that can exist in the lowest few hundred meters above ground in local areas where strong winds exist and the surface heat flux is weak, (2) the thermal internal boundary layer that often exists over large lakes or near sea coasts, and (3) deposition onto

terrain features that protrude above the layer. At night, layer 2 represents what remains of the daytime mixed layer. As stable layers form near the ground and suppress turbulent vertical mixing, a nocturnal jet forms above the stable layer and can transport aged pollutant products and reactants considerable distances. At night, emissions from tall stacks and warm cities are injected directly into layers 1 and 2. Surface emissions are specified as a mass flux through the bottom of layer 1.

During the day, the top model layer, layer 3, represents the synoptic-scale subsidence inversion characteristic of high ozone-concentration periods; the base of layer 3 is typically 1 to 2 km above the ground. Relatively clean tropospheric air is assumed to exist above layer 3 at all times. If cumulus clouds are present, an upward flux of ozone and precursor species is injected into the layer by penetrative convection. At night, ozone and the remnants of other photochemical reaction products may remain in this layer and be transported long distances downwind.

When cumulus clouds are present in a layer 3 cell, the upward vertical mass flux from the surface is partially diverted from injection into layer 1 to injection directly into the cumulus cloud of layer 3. In the atmosphere, strong thermal vertical updrafts, primarily originating near the surface in the lowest portion of the mixed layer, feed growing fair weather cumulus clouds with vertical air currents that extend in one steady upward motion from the ground to well above the top of the mixed layer. These types of clouds are termed "fair weather cumulus" since atmospheric conditions are such that they do not grow to the extent that precipitation forms. The dynamic effects of this transport process and daytime cloud evolution can have significant effects on the chemical fate of pollutants. For example, fresh emissions from the surface layer can be injected into a warm thermal and rise, essentially unmixed, to the top of the mixing layer where they enter the base of a growing cumulus cloud. Within the cloud, the chemical processes of ambient pollutant species are suddenly altered by the presence of liquid water and the attendant attenuation of sunlight. The presence of fair weather cumulus clouds implies that the atmosphere above the earth's boundary layer is too stably stratified for thermals to penetrate higher. In this case the air comprising the tops of these clouds returns to the mixed layer and is heated on its descent since it is being compressed by increasing atmospheric pressures. Ultimately, the air again arrives at the surface level where new emissions can be injected into it and ground deposition may occur, and the process may begin again. The time required for one complete cycle is typically 30 to 50 minutes with perhaps one-tenth of the time spent in the cloud stage.

Within the ROM system, a submodel parameterizes the above cloud flux process and its impact on mass fluxes among all the model's layers. In the current implementation of the chemical kinetics, liquid-phase chemistry is not modeled, and thus part of the effects from the cloud flux processes are not accounted for in the simulations. Future versions of the chemical kinetics may include liquid-phase reactions. The

magnitude of the mass flux proceeding directly from the surface layer to the cloud layer is modeled as being proportional to the observed amount of cumulus cloud coverage and inversely proportional to the observed depth of the clouds.

Horizontal transport within the ROM system is governed by hourly wind fields that are interpolated from periodic wind observations made from upper-air soundings and surface measurements. During the nighttime simulation period, the lowest few hundred meters of the atmosphere above the ground may become stable as a radiation inversion forms. Wind speeds increase just above the top of this layer, forming the nocturnal jet. This jet is capable of carrying ozone, other reaction products, and emissions injected aloft considerable distances downwind. This phenomenon is potentially significant in modeling regional-scale air quality and is implicitly treated by the model, where the definition of layer 1 attempts to account for it.

Because standard weather observations do not have the spatial or temporal resolution necessary to determine with confidence the wind fields in layer 1, a submodel within the ROM system was developed to simulate the nighttime flow regime in layer 1 only. This prognostic flow submodel is activated only when a surface inversion is present over most of the model domain. At all other times the flow in layer 1 is determined from interpolation of observed winds. The nighttime flow regime within layer 1 is influenced by buoyancy, terrain, warm cities, pressure-gradient forcing, and frictional forces, all of which are accounted for in the model's flow formulation. Solution of the wind submodel equations produces estimates of the wind components as well as the depth of the inversion layer for all grid cells in layer 1.

2.2.2 ROM Chemistry

The chemical kinetic mechanism embedded in the current version of the ROM is the Carbon Bond IV (CB-IV) set of reactions (Gery *et al.*, 1989). This mechanism simulates the significant reaction pathways responsible for gas-phase production and destruction of the constituents of photochemical smog on regional scales. The mechanism consists of 82 reactions encompassing 35 individual species; these species are listed in Table 2-1. The ROM's chemical solution scheme makes no *a priori* assumptions concerning local steady states. Therefore, all species are advected, diffused, and chemically reacted in the model simulations.

The CB-IV contains a standard set of reactions for atmospheric inorganic chemical species, including O_3, NO, NO_2, CO, and other intermediate and radical species. Organic chemistry is partitioned along reactivity lines based on the carbon structures of the organic molecules. Ten individual categories of organics are represented to account for the chemistry of the hundreds of organic molecules existing in

the ambient atmosphere: ETH, an explicit representation of ethene; FORM, an explicit representation of formaldehyde; OLE, a double-bonded lumped structure including two carbons (e.g., olefins); PAR, a single-bond, single-carbon structure (i.e., paraffins); ALD2, the oxygenated two-carbon structure of the higher aldehydes; TOL, the aromatic structure of molecules with only one functional group (e.g., toluene); XYL, the structure of molecules with multifunctional aromatic rings (e.g., xylene); ISOP, the five-carbon isoprene molecule; and NONR, a single-carbon organic structure not significantly participating in the reaction sequence. In addition, MTHL, (methanol) was included in the mechanism for use with control strategies that include methanol-powered vehicles.

2.2.3 System Components

The three components of the ROM system are shown in Figure 2-3. The first component specifies the five types of "raw" data that are required for input to the ROM: air quality, meteorology, emissions, land use, and topography.

Raw Data

Air quality data consist of hourly ozone observations obtained from the U.S. Environmental Protection Agency's National Air Data Branch. These hourly observations are used to specify the initial and upwind-boundary ozone concentrations required by the ROM. Initial conditions are derived from the mean tropospheric background concentrations listed in Table 2-2 (Killus and Whitten, 1984) using the temperature-dependent rate constants calculated by the ROM system. Background concentrations are used since ROM simulations begin on relatively-low ozone days, several days prior to observations of ozone levels > 120 ppb. This approach is designed to minimize the impact of initial conditions on ozone levels during the period of most interest (i.e., high ozone days).

The twice-daily (daytime and nighttime) gridded equilibrated concentrations for the 35 species used in the ROM, for the north, south, east, and west boundaries of each model layer are derived as follows: each boundary is assigned a single value for ozone, based on average ambient measurements at rural monitoring sites. The remaining 34 species are then equilibrated to this ozone concentration, generating the set of concentration values for that boundary.

Meteorology input data consist of the regular hourly surface and upper-air observations from the U.S. National Weather Service and Environment Canada. Surface-weather station reports include wind speed and direction, air temperature and dew point temperature, atmospheric pressure, and cloud amounts and heights. Twice-daily sounding data from the upper-air observation network are included in

the meteorology database, and consist of atmospheric pressure, wind speed and direction, and air temperature and dew point temperature. Additional meteorology data are obtained from the National Climate Data Center and consist of buoy and Coastal Marine Automated Station data; parameters typically reported are wind speed and direction, and air and sea temperatures. Meteorology data are used to specify the meteorological parameters in ROM simulations. Detailed descriptions of meteorology data and meteorology data preprocessing can be found in Milich *et al.* (1990).

Emissions input data consist of annual point-source emissions, with stack parameters and seasonal, day-type factors; area-source emissions for typical summertime Saturdays, Sundays, and a "generic" weekday; and mobile-source emissions. Biogenic emissions data are obtained and preprocessed prior to inclusion in the emissions database. Detailed descriptions of emissions data used in ROMNET are included in Section 4.

Land use input data consist of 11 land use categories in $^1/_4°$ longitude by $^1/_6°$ latitude grid cells. Data are provided for the U.S. and Canada as far as 55 °N. The land use categories are (1) urban land, (2) agricultural land, (3) range land, (4) deciduous forests, (5) coniferous forests, (6) mixed forest with wetlands, (7) water, (8) barren land, (9) nonforested wetland, (10) mixed agricultural land and range land, and (11) rocky, open places occupied by low shrubs and lichens. The data were obtained from the EPA Environmental Monitoring Systems Laboratory, Las Vegas, NV. Land use data are used to obtain biogenic emissions estimates as a function of the area of vegetative land cover, and for the determination of surface heat fluxes.

Topography input data consist of altitude matrices of elevations for 30″ × 30″ cells in a $7^1/_2° \times 7^1/_2°$ grid. The data are obtained from the GRIDS database operated by the U.S. Environmental Protection Agency's Office of Information Resources Management. Topography data are used in the calculation of layer heights.

Processor System

The second component of the ROM system is the ROM processor network. The raw input data to the ROM are manipulated by a hierarchical network of 35 processors that range in function from simple reformatting of emissions data to generating the complex wind fields that drive the atmospheric transport. These processors are interconnected by their requirements for and production of data. The ultimate product of the processor network is a collection of data files that can be categorized into two types: processor files (PF) and model files (MF). PF's contain partially processed data required as input

to higher level processors. MF's contain the parameter fields that are transformed into the variables required by the model algorithms; however, they also provide input to a number of higher level processors.

The processors are organized into nine distinct hierarchical stages, numbered 0 - 8. Stage 0 processors produce output files such as the gridded land use data. Stage 1 processors interface directly with the preprocessed and extensively quality-reviewed meteorological and emissions input data sets. Subsequent stages transform the input data into the gridded fields of temporally and spatially varying parameter values needed by the highest stages of the processing network. Processors at any stage can interface directly with the B-Matrix compiler, described below, through the production of model input files (MF's). This multistage organization is important to the network because it clearly delineates the sequence of program execution. Processors at the same stage may execute simultaneously. A processor at any given stage, however, must wait until all processors from lower stages along its input data paths have been completed. Formal definition of all data/processor relationships and automation of processor executions are essential to ensure consistency and validity of MF's. Appendix C contains a description of the function(s) of each processor.

The B-Matrix Compiler (BMC) serves as the interface between the model input files and the algorithms that solve the coupled set of finite difference equations describing the governing processes in each layer of the model. The program functions similarly to a computer language compiler that transforms high-level language commands into a machine or algorithm-specific representation. The BMC mathematically combines physical parameters such as layer thicknesses, air densities, etc., into the complex coefficients required for solution of the governing equations. These coefficients can no longer be equated with physical quantities; they are purely mathematical entities related specifically to the form of the finite difference algorithms used by the ROM.

Core Model

The third component of the ROM system is the Core Model. The governing equations in the Core Model are expressed in a form that allows the chemical kinetics, advection, and vertical flux to be treated independently. The chemistry module exchanges information with algorithms of the governing equations via two vectors: (1) a vector that contains the net production rate of each species, and (2) a vector that contains the net destruction rate. Such design simplifications enhance the flexibility of the model and are not limited to the interchanges of the chemical mechanism; they apply to all theoretical formulations of the physical and meteorological processes (i.e., to all the processors).

2.2.4 Quality Assurance Procedures for ROM Data Sets

Quality assurance on inputs to the ROM begin with a review of the "raw" data elements. Meteorological data are examined to ensure that data sets are complete for the entire episode being modeled. Missing values are filled in through interpolation and extrapolation from available data and knowledge of the expected variation in meteorological conditions. In addition, surface and upper-air data are screened against a typical range of values for each parameter to identify possible outliers. Calculated and time/space-interpolated values, such as layer heights, heat fluxes, wind fields, temperature, etc., are reviewed to ensure that representative, consistent, and coherent spatial fields and temporal patterns are produced.

Emissions input data are quality-assured by review of (1) State-level and urban-level emissions summaries by point, area, and mobile category for VOC, NO_x and CO; (2) regional aggregate diurnal profiles; and (3) spatial patterns of gridded data. This information is then compared against the expected changes in emissions given the specification of growth and/or controls in the scenario under review. Comparisons are also made between the processed data and the precursor "raw" emissions data.

Quality assurance of the ROM predictions focuses on a review of daily maximum ozone concentrations from layer 1 for each day simulated. Spatial contours and fields of gridded ozone values are reviewed shortly after the model runs are completed. For base-case scenarios, predictions are examined for consistency with measured concentration levels and patterns. Predictions for future baseline and strategy scenarios are compared against base case concentrations while considering the changes in emissions from the base scenario.

2.2.5 ROM Simulations for ROMNET

The ROM was typically applied over multiday periods that contain "episodes" consisting of periods when high ozone concentrations were measured across broad areas of the ROMNET region. The selection of episodes for simulation in ROMNET is discussed in Section 3.

The ROM system is constructed for simulating episodes in 3-day (72-hour) blocks starting at noon EST. The ROM processor network is run for each episode, and specifies inputs of meteorological data and biogenic and anthropogenic emissions. Anthropogenic emissions processors output data for each emissions scenario and episode since hourly mobile-source emissions are adjusted by grid cell for day-specific temperatures.

The ROM processors are run on the EPA-NCC VAX ™ cluster, which consists of a VAX 8650, a VAX 6420, and a VAX 8600.[1] The CPU time for a typical 72-hour run is approximately 12 hours on the VAX 8650.

Data from the processor network are used to create the B-matrix data files, which are then transferred to the EPA's IBM ® 3090 where the Core Model is run.[2] The Core Model generates 35 species concentrations for the three ROM prognostic layers for each of the 3,328 grid cells. The CPU time for a typical 72-hour run is approximately 9.5 hours. A total of 1.26×10^8 predicted 1-hour data values are generated for each episode/scenario simulated. Following completion of each simulation, predictions are archived and selected species extracted for subsequent review and analysis.

2.2.6 ROM Limitations for ROMNET

There are several limitations inherent in the use of the model for ROMNET. Among the most important of these are: (1) the ROM, with its current 18.5 km x 18.5 km grid resolution, is not designed to provide detailed information at local scales that are significantly influenced by local source distributions or by mesoscale meteorological conditions that are not reflected in the space/time scales of surface and upper-air meteorology measurements; (2) the model is designed to represent only fair-weather conditions, and does not take into account any aqueous-phase chemistry; and (3) cumulus cloud processes are such that when a cloud is created in a grid cell, it remains there for a full hour (i.e., cloud physics are not considered), and the cloud is not advected.

1. VAX is a trademark of the Digital Equipment Corporation.
2. IBM is a registered trademark of the International Business Machines Corporation.

2.3 EVALUATION OF ROM 2.1

2.3.1 Introduction

An evaluation of the ROM was conducted as part of ROMNET to supplement the extensive evaluation performed on a predecessor version of the model by Schere and Wayland (1989). The primary difference between the two evaluations is that Schere and Wayland used a special field-study data set from 1980, and 1980 NAPAP emissions for the ROM simulations. The ROMNET evaluation used the ROM version 2.1 applied to the ROMNET 1985 base case emissions scenario (see Section 4.3). Routinely-measured ozone data from 1985 were compared with predicted values. Schere and Wayland had access to extensive field measurement data for ozone, hydrocarbons, and nitrogen oxides as well as aircraft transects, whereas the ROMNET evaluation was limited to routine data stored in the EPA's Aerometric and Information Retrieval System (AIRS). After surveying AIRS, it was concluded that there was insufficient nitrogen oxide and hydrocarbon measurements for a rigorous model evaluation. Therefore, the evaluation of ROM2.1 focused on hourly observations of surface ozone from State and local agency monitoring sites.

This section compares observed and modeled ozone concentrations for selected episodes of high ozone observed during the summer of 1985. Episodes from 1985 were chosen because they correspond to the base year emissions inventory. The objectives of the ambient evaluation were '(1) to examine overall evaluation statistics to determine whether a general bias exists in the model calculations, (2) to look at spatial patterns of maximum concentration to determine whether a spatial bias exists, and (3) to examine the model's applicability for determining UAM boundary conditions.

2.3.2 Description of Evaluation Episodes

Two ozone episodes during the summer of 1985 were selected for evaluating ROM. Two episodes, July 7-22 and August 7-16, were identified as the most "severe" during the 1985 summer season in terms of the magnitude and spatial extent of ambient ozone concentrations in the Northeast. This is evident from the seasonal distribution of ozone > 120 ppb as shown in Figure 2-4. The procedures used to select these episodes are described more fully in Section 3.2. Brief descriptions of the meteorological conditions and observed ozone concentrations are given in Appendix D.

2.3.3 Database Development

Two types of databases were needed for the ambient evaluation: hourly concentrations of ozone from model estimates and ambient observations. Development of these two data bases is described below.

Model Estimates

To produce the model-predicted database, the ROM was run for the two 1985 episodes. Ozone concentrations predicted for layer 1 were extracted for use in this evaluation. Three different model databases were developed for the evaluation:

1. Point estimates from gridded data: For the portion of the evaluation concerned with general statistics, gridded ozone values were interpolated to actual monitoring locations using a biquintic interpolation scheme (Lamb, 1985) that is consistent with the methodology used in the model.

2. Contoured values of gridded data: For analyzing spatial patterns, an objective contouring algorithm was used to produce computer graphics depicting concentration fields based on the gridded ROM data.

3. Interpolated values derived using the ROM/UAM Interface methodology: For the portion of the evaluation concerned with boundary conditions, an interpolation scheme was used that is described below; the scheme is consistent with the ROM/UAM Interface described in Section 6. This procedure allowed the transformation of boundary conditions from a 18.5-km grid size to the grid size of the selected UAM domain, 8 km.

   a. A band of three ROM grid cells surrounding the UAM New York Metropolitan area domain (OMNYMAP: Rao, 1987) was defined (Figure 2-5).

   b. Three-hour running averages, centered on the hour, were calculated for each hour for each ROM grid cell noted in the three-cell band.

   c. Using the hourly concentration averages from step b, an hourly spatial average was taken of each three-cell set normal to the UAM outer boundary and the result noted on the UAM boundary.

   d. These concentrations were then spatially interpolated (using linear averages) to the UAM grid cell centers along the boundary.

Ambient Observations

The following three observational databases, which are analogous to the three model databases, were developed: (1) a set of observations used for developing overall statistics; (2) a set of observations used for creating contour plots; and (3) a set of observations used for developing UAM boundary conditions. Ozone concentrations were obtained from monitoring data archived in AIRS. Hourly ozone concentrations were selected for sites located in the U.S. portion of the ROMNET domain for the two episodes.[3] An extensive review and screening of the data was performed. Only daytime values (0800 LST to 1900 LST) were included in the evaluation because nighttime observations are influenced by localized processes that often include scavenging of ozone by NO emissions and therefore do not reflect vertically-integrated ozone concentrations in layer 1 of the ROM (Schere and Wayland, 1989). Furthermore, data for sites on days missing more than 25 percent of their observations were excluded. The data were examined for extremely high or low values; several sites, such as Poughkeepsie, NY, were eliminated because mean daytime ozone concentrations were consistently below 50 ppb and may have reflected local NO scavenging. Of the more than 200 sites in the original database, 187 of these were used in computing general statistics. For portions of the analysis, the data were divided into five geographical groups (Figure 2-6).

For the spatial plots, little effort was made to eliminate sites because only maximum concentrations were considered. As a result, the plots showed a few locations with extremely low values (due either to poor data recovery or local NO scavenging). These sites were ignored when manually contouring the data.

The monitoring data used for developing the UAM boundary condition database were given special consideration. The approach followed is consistent with the guidance given by Rao *et al.* (1987). Because so few monitoring sites were available for developing boundary concentrations, the monitored data were distributed among six locations along the UAM boundary: south, southwest corner, west, northwest corner, north, and east (Table 2-3). The assignment of particular sites to a boundary location depended on the prevailing wind direction for that day. If more than one site was available for a location, the hourly concentrations were averaged. Monitors used in this analysis of boundary conditions are shown in Figure 2-7. After averaging at the six locations, concentrations were spatially interpolated (using linear averaging) along the UAM boundary. To be consistent with the ROM/UAM Interface methodology, the hourly concentrations were used to create three-hour running averages as described earlier.

3. Canadian ozone monitoring data are not included on AIRS and were not readily available for this analysis.

2.3.4 AMBIENT EVALUATION

To emphasize different aspects of model performance, the ambient evaluation of ROM2.1 is separated into three parts: overall statistics, spatial patterns, and UAM boundary conditions.

Overall Statistics

Using the separated modeled and observed databases of hourly ozone concentrations, descriptive statistics were computed using SAS (1985) procedures to assess the ROM's overall temporal and spatial performance. Summary statistics for all modeled and observed daytime hourly concentrations (July and August episodes combined) are shown in Table 2-4, together with statistics for daily maxima at all sites. The mean observed and modeled values agree fairly closely: the hourly means agree to within 10 ppb and the daily maximum means agree to within 1 ppb, which are not significant differences at the 99 percent confidence level. Although the model overestimated the mean hourly value, it tended to underestimate the hourly and daily maximum values in the upper extremes of the frequency distributions. The 95th-percentile hourly value was underestimated by 1 ppb, and the maximum was underestimated by 50 ppb; daily maximum values show a similar tendency.

Statistics for the individual July and August episodes, shown in Table 2-5, are similar to those for the combined episodes. Because results for the two episodes are similar, discussion is limited primarily to the July episode.

To examine spatial trends in the data, the monitoring sites were grouped into five geographical clusters: (1) Northern Corridor, (2) Southern Corridor, (3) Ohio Valley-Middle Atlantic, (4) Interior Northeast, and (5) Great Lakes. The spatial grouping is shown in Figure 2-6. Statistics for each group are summarized in Table 2-6. Depending on the statistic, model performance was better in some groups than in others. The preferred statistic examined was the 95th-percentile value from the daily maximum concentrations, because it is more robust than the absolute maximum value and more appropriate for use in evaluating predictions from a regional-scale model. As shown in this table, all concentrations at the 95th percentile were underestimated except for group 1, which was overestimated by 5 percent. It is encouraging to note that, except for group 3 which was underestimated by 19 percent, all estimated and observed concentrations at the 95th percentile agreed to within 10 percent. The large underprediction for the absolute maximum concentrations, while significant, is not unexpected given the sharp spatial gradients typical of ambient peak concentrations when compared to the large grid size of the model.

A valuable tool for assessing model performance is a quantile-quantile plot, which can be used to compare the frequency distributions of sorted observed and sorted estimated concentrations. The concentrations are sorted from highest to lowest and then plotted on an *x-y* plot. The *x*-axis depicts observed data, and the *y*-axis depicts estimated data.

Quantile-quantile (hereafter referred to as QQ) plots of hourly daytime concentrations for each of the five geographical groups during the July episode are shown in Figure 2-8. In each of these plots, the solid line denotes a perfect fit, and the dashed lines show a ten percent deviation from this line. The findings from the QQ plots are consistent with overall statistics shown previously. In general, except for group 3, predictions in the upper portion of the distributions were within 10 percent of observations. Model estimates from groups 2, 3, and 4 tended to be lower than observations in the higher quantiles; underestimates were evident in the top 30 percent of group 2, top 50 percent of group 3, top 20 percent of group 4. Group 1 showed general overestimates in the upper quantiles (except for the top 1 percent), and group 5 ranged from good agreement to overestimates at the upper values. Overestimates were evident at the lower ends of the frequency distribution for all five groups. Median values in general agreed quite well. In groups 1 and 5, median values were overestimated by about 20 percent (around 10 ppb); in groups 2, 3, and 4, the median was overestimated by 10 percent or less. In the Northeast Corridor, differences between the northern portion of the Corridor (group 1) and the southern portion (group 2) were evident. Group 2 estimates agreed much better with observations than did group 1. Similar to what Schere and Wayland (1989) noted in their evaluation of ROM2.0, estimates in the southern part of the Corridor tended to be lower than the observations at the upper end of the frequency distribution, although estimates were within 10 percent of observations except for the maximum value. The tendency to underestimate peak concentrations in group 2 is discussed below in the spatial analysis section. The region showing the greatest underestimate in the upper values was group 3, an area removed from the extensive metropolitan area along the Northeast Corridor. In groups 4 and 5, agreement was quite good.

In an effort to understand how well the ROM tracked daily maximum concentrations, frequency distributions of maximum (observed and estimated) ozone concentrations from the data in each group for each day were computed. Figure 2-9 compares box plots of modeled and observed daily maximum concentrations for all but the first two days of the July episode. The first two days are not shown because the model is strongly influenced by initial conditions and tends to underestimate ozone concentrations during this "start-up" period. The box plots denote the maximum, 75th percentile, 50th percentile (or median), 25th percentile, and minimum value. These plots show similar results to those noted in the QQ plots for hourly concentrations; however, they also provide temporal information.

On a daily basis, the model tended to track the observations fairly well. However, due to the factors described previously, the highest daily maximum values are largely underpredicted on several days. For all of the regions combined, there were about equal numbers of days with underestimates and overestimates. As discussed for the QQ plots, group 1 tended to experience the most overestimates (12 out of 14 daily medians were overestimated) while group 3 tended to experience the most underestimates (medians for 12 out of 14 days were underestimated). The daily maximum plots also show that west of the Corridor (i.e., west of groups 1 and 2), median daily maximum concentrations tended to approach background values.

One of the ROM's most important uses is to simulate days having ozone exceedances (hourly concentrations greater than 120 ppb). In group 1, eight exceedance days were observed while ten exceedance days were estimated, thus indicating that the ROM tends to slightly overestimate in the northern portion of the Corridor. Further to the south in group 2, however, ten exceedance days were observed but only six were estimated. In group 3, six exceedance days were observed but none were estimated. The monitors reporting these six exceedances were in smaller urban areas such as Richmond, VA, Norfolk, VA, and Charleston, WV, than those found in the Northeast Corridor. This suggests that the coarse grid resolution (19 km) of the ROM may be too large to adequately resolve smaller urban plumes. Also, naturally-occurring hydrocarbon and NO_x emissions are probably more important in these areas than in the Corridor. Thus, uncertainties in estimating naturally-occurring emissions may have contributed to poor performance in group 3. Despite the relatively poor model performance in the southern portion of the domain, performance in the Great Lakes, Interior Northeast, and the Northern Corridor groups seems quite good.

Spatial Patterns

For this portion of the evaluation, spatial patterns of maximum hourly ozone were examined for four distinct three-day episodes that represent a range of meteorological conditions and model performance.

July 9-11

This was a period of unsettled weather with weak pressure gradients. For much of the period, a weak surface trough was draped from Long Island to Virginia to northeastern Ohio to Illinois. By the 10th, southwesterly flow became better defined in advance of a cold front moving eastward through the Great Lakes. Of special interest on this day was a mesoscale high pressure area associated with a line of thunderstorms in central Pennsylvania, which eventually moved through the southern part of the

Corridor and significantly reduced ozone concentrations. This feature will be discussed below in the section on background concentrations. By the morning of the 11th, less humid conditions and northwesterly flow prevailed as the cold front had pushed off the East Coast.

During this period, monitors picked up ozone plumes above 120 ppb from Wilmington, DE, to Boston. Observed and estimated maximum hourly concentrations greater than 160 ppb were observed near central New Jersey and coastal Connecticut (Figure 2-10). Agreement over southern Connecticut was good, although the modeled plume appears to be shifted slightly east and south of observed values. The model also shifted the high concentrations just off the coast of New Jersey near Atlantic City. Simulating small-scale features during this period was particularly difficult because of the weak wind flow, the occurrence of the mesoscale high, and the persistence of a coastal trough. Overall, however, estimates of maximum ozone for this period agreed fairly well with observed data.

July 13-15

During this period, the meteorological scenario typically associated with elevated ozone concentrations in the Northeast occurred. A weak cool high pressure system centered over New York on the 13th gave way to a warm front on the 14th. By the 15th, southwesterly flow was fully established. Unsettled conditions prevailed in the western portion of the model domain. Showers were reported on the 14th and the 15th in western New York and Pennsylvania in advance of a slow moving cold front.

During this period, two separate areas of high ozone values were observed. A modest area of exceedances (maximum of 132 ppb) was noted from Boston to the southern coast of Maine. High concentrations were also noted in distinct plumes near Philadelphia and New York City. Concentrations greater than 200 ppb were observed near Wilmington, DE, (211 ppb) and Bayonne, NJ (218 ppb). Although an area of observed exceedances stretched from Washington, DC, to central Long Island, no well-defined plume downwind of New York City was apparent.

Except for the area north of New York City, estimated ozone concentrations were lower than those observed during this episode. However, Figure 2-11 shows that the spatial patterns of the high ozone concentration areas were well represented. Near Boston, the modeled and observed concentrations agreed closely as noted by the placement of the 140 ppb contour on both plots. Downwind of Wilmington, DE, the model underestimated the peak observed concentration by about 80 ppb. Part of the poor performance may be due to a coastal trough that existed during this episode. Pagnotti (1987) points out that small-scale features such as this trough tend to produce localized pockets of high ozone that would not be well-represented by a regional model such as the ROM.

July 18-20

High pressure held firmly over the Northeast, gradually shifting southward and weakening. By the 19th, southerly flow had become fully established over the Corridor. On the 20th, a coastal trough was evident along the Atlantic Coast. Under light wind conditions, high concentrations were once again positioned in small, distinct areas. Values above the standard stretched from the Delmarva peninsula to central Massachusetts. The highest concentration (164 ppb) was observed near Trenton, NJ. A small area of high concentrations (maximum of 152 ppb) was observed along the coast of Maine. With minor exceptions, the model showed reasonable agreement to the peak observed values during this period (Figure 2-12). A plume over 120 ppb extended from near Baltimore northward to off the coast of Maine. Pockets over 160 ppb were estimated near New York, which generally agreed with the observed values. Except for missing the high concentrations over the Delmarva peninsula, ROM appears to do a good job predicting the magnitude and placement of the maximum ozone plume during this period.

August 13-15, 1985

This period was similar to July 13-15. Weak cool high pressure was positioned over the Northeast on the 13th. The system had moved eastward by the 14th allowing weak southwesterly flow to ensue. By the 15th, a cold front began moving through the western portion of the domain. Southwesterly flow strengthened, but a hint of a coastal trough was evident in the surface weather map.

Monitoring data revealed an extensive area of ozone exceedances that stretched from Wilmington, DE, to coastal Maine. Highest concentrations were observed near Hartford, CT (219 ppb). An isolated area of high concentration (maximum of 187 ppb) was observed just north of Baltimore.

The general orientation of the modeled ozone plume is excellent when compared with observations (Figure 2-13). The highest estimates, however, only approached 200 ppb, more than 20 ppb less than the highest observation. The model did simulate an area of high concentrations (greater than 180 ppb) off the coast of Maine, close to where relatively high concentrations were observed. While the model did not replicate the extreme peaks, it satisfactorily estimated the pattern and shape of the ozone plume near the Northeast Corridor.

Boundary Conditions

One of the major uses of the databases generated by ROM is to estimate boundary conditions for the Urban Airshed Model (UAM). As part of the evaluation, ROM-generated boundary conditions were

compared to measured ozone concentrations near the New York City OMNYMAP domain. The procedures used to aggregate and match observed and predicted data sets is described in Section 2.3.3.

This analysis was limited to near-surface concentrations because measurements were available only from surface-based monitors. The 73 UAM grid points used stretch from the coast of New Jersey clockwise to the coast of Connecticut. Grid boundaries over the Atlantic Ocean were excluded because of the lack of oceanic ozone monitoring data.

The analysis was started by looking at the overall performance of the ROM in estimating daytime boundary conditions. Table 2-7 shows summary statistics for the 20,155 data points available. These data were taken from valid combinations of estimated and observed daytime (0800 LST to 1900 LST) hourly concentrations for 73 grid locations for 24 days of data. The model slightly overestimated the mean concentrations (by 5 ppb or 7.6 percent). At higher quantiles, however, the model tended to underpredict in a manner consistent with the statistics presented earlier. In addition, the larger standard deviation of the observed concentrations shows that observations exhibited more variability than the model estimates.

Because there was no overwhelming bias apparent in the model, the boundary condition calculations were examined in further detail. Table 2-8 compares estimated with observed mean concentrations on a daily basis. While the mean values summed over all the days agreed to within 10 percent, there was some day to day variability. Percent differences for individual days ranged from -24 percent to +49 percent. However, estimated and observed mean values were within +10 ppb on 14 of the 22 days. Other pertinent information on mean wind persistence, wind speed, and wind direction is also noted in this table.

Figure 2-14 displays model performance as a function of wind persistence. Surprisingly, the more persistent flow conditions were associated with greater overestimates, as noted by the mean fractional errors which dropped from 23 percent percent during very persistent conditions to -18 percent during low persistence.

Next, the relationship between model performance and daily average wind direction was examined. Figure 2-15 shows that southerly and southwesterly winds were most prevalent during the model simulations. In terms of model performance, model estimates and observations agreed more closely when southerly winds prevailed. With southerly winds, there were 10 days of overestimates and 8 days of underestimates, for an average error of 5 percent. With northerly winds, the model overestimated on all five days, and the average error was +26 percent.

The data set was then geographically stratified to look for spatial biases in the estimates. Figure 2-16 shows the eight groups of grid cells formed, with group 1 located in the south and group 8 located in the east. Mean observed and estimated concentrations for the eight groups are shown in Figure 2-17. The highest observations and estimates occurred in group 1, which is located in the center of the Northeast Corridor and would experience high ozone concentrations typical of southwesterly flow conditions. It is noteworthy that the observed and modeled patterns in Figure 2-17 resemble each other: Both show a minimum along the northern boundary and a maximum for group 1. Best agreement occurred for groups 3 and 5.

The above statistics include all grid points regardless of the wind direction. Using the same eight grid cell groups, model performance for individual groups experiencing incoming flow on a given day were next examined. For example, if southwesterly winds predominated, the daytime concentrations for group 2 were then analyzed. Figure 2-18 shows the mean residuals for each group for days having upwind flow. As in Table 2-8, residuals shown in Figure 2-18 varied appreciably from day-to-day, ranging from -15 percent to +25 percent. However, 8 of 13 days experienced mean residuals less than 10 percent.

There were a few days when the model performance was admittedly disappointing. In particular, day 191 showed a 25 percent overestimate in group 2. Although resources to analyze every day in detail were lacking, this day was examined in detail in order to gain some insight on model performance.

The 1200 GMT surface weather map for 10 July 1985 (Julian day 191) gave some indication as to why observed concentrations were lower than expected in eastern Pennsylvania and western New Jersey. This map shows a mesoscale high over south central Pennsylvania which was apparently induced by a cluster of thunderstorms. A stationary front extending from a low over central Indiana stretched eastward to northern Virginia and merged into a surface trough that stretched northeastward along the Atlantic seaboard. The main weather feature was a combined cold and occluded front positioned along the St. Lawrence Valley southward through the Ohio Valley.

To examine why the daytime ozone observations were underestimated in group 2, hourly plots were generated from both the observations and the estimates. Figure 2-19 shows the observed and estimated concentration fields for 0800 EST on July 10, 1985 (one hour after the 1200 GMT surface weather map). Two features are given on the observed plot: weather data reported at each National Weather Service surface observing site, and measured hourly ozone concentrations. The circled ozone measurements denote the sites used in generating the observed UAM boundary conditions for group 2. The 18 gridded model values used in defining group 2's boundary conditions are enclosed by a rectangle.

At 0800 EST, estimates averaged more than 20 ppb higher than the observed values. The weather data indicate that the surface trough is still located along the Atlantic Seaboard. Ahead of this trough, winds were generally from the south; behind the trough, winds were generally from the west.

Moving to 1000 EST, estimates were still about 20 ppb higher than the observations (Figure 2-20). Ozone concentrations in northeastern Pennsylvania were particularly low. This area was experiencing overcast skies, temperatures around 22°C, and high relative humidity. This suggests the likelihood of shower activity which may have caused lower ozone concentrations by allowing increased vertical transport and reduced photochemical production.

By 1200 EST, thunderstorm activity had begun (Figure 2-21) as indicated by the Wilmington, DE, observation. Overestimates by the model continued throughout group 2. Although overcast and relatively cool conditions predominated in eastern Pennsylvania, Atlantic City experienced hot, sunny conditions as indicated by a temperature there of 93°F. The estimated concentration field shows a strong gradient across group 2, ranging from 79 ppb in the northwest to 102 ppb in the southeast. The observed concentrations, in contrast, range from 40 ppb to 69 ppb. Observed concentrations as high as 111 ppb were reported in central New Jersey but these were not prescribed for use in the UAM/ROM Interface methodology. After investigating additional sources of meteorological data, it was found that Philadelphia reported a wind gust of 45 miles per hour. This information, which was not available in the routine modeling database, strongly suggests the nearby presence of organized convective activity such as a squall line.

Figure 2-22 shows that by 1400 EST, shower activity had moved into Atlantic City. The temperature in Atlantic City dropped more than 9°F in two hours and observed ozone concentrations in the area declined over 50 ppb. Easterly winds reported at both Philadelphia and Wilmington are probably indicative of outflow from thunderstorm activity in central New Jersey. Meanwhile over northeastern PA, skies were beginning to clear although ozone concentrations remained low. Predictions in group 2 seem less affected by the storm activity and are as high as 112 ppb.

By 1600 EST (Figure 2-23), observed ozone concentrations near Scranton had rebounded to near modeled values (65 ppb versus 75 ppb). In the area near Atlantic City, which was still experiencing shower activity, estimated concentrations were as high as 125 ppb but observed concentrations were only around 30 ppb.

The meteorological data used in the ROM offer some clues as to why the ROM overestimated concentrations in group 2. Figure 2-24 shows the time series of selected meteorological parameters that were calculated for grid cell (45,21), the center cell of the third row from the top of the rectangle outlined in the

previous five figures. The simulated cloud cover and solar fluxes in Figure 2-24 did show some effect of the observed cloudy conditions but probably not enough. Cloud cover increased to more than 90 percent by 1300 EST but only slightly reduced the computed solar flux. The model layer heights (Figure 2-24) show some increase, with layer 3 growing to 1700 m by 1100 EST. However, the localized convective activity probably caused more vigorous vertical and horizontal mixing than was simulated in the model. Horizontal dilution in the model also was probably smaller than actual dilution as indicated by the relatively low modeled wind speeds in Figure 2-24. Apparently the small-scale (relative to the model) cluster of thunderstorms was not captured in the overall interpolation of meteorological data.

This case study is noteworthy because it highlights some of the ROM's limitations. ROM is a regional-scale model that was designed for application in relatively benign, steady-state summertime conditions. The occurrence of a mesoscale surface trough and localized thunderstorm activity resulting in dynamic subgrid-scale atmospheric processes seems to have affected the ROM's ability to estimate boundary conditions along portions of the UAM domain on day 191. The results indicate that development of UAM boundary conditions from either observed or modeled data should include careful examination of the effects of mesoscale meteorological conditions, which as has been shown, can cause localized perturbations in ozone concentrations.

2.3.5 Summary

The Regional Oxidant Model, Version 2.1, (ROM2.1) has been evaluated with ozone monitoring data collected during 1985 in the northeastern United States.

In the study, good overall agreement between observed and modeled ozone concentrations was observed. The mean concentrations of the estimated and observed daily maxima agreed to within one percent. Concentrations at the higher ends of the frequency distribution were slightly underestimated; at the 95 percent level, observed concentrations were 127 ppb while estimated concentrations were 119 ppb. As noted previously, the tendency to underestimate peak concentrations is to be expected with a coarse-grid model such as the ROM because of the spatial averaging that occurs with Eulerian grid computations. Given this caveat, model performance was particularly good in the northern portion of the Northeast Corridor, especially around New York City. The model also did an excellent job capturing high ozone levels along coastal sections of Maine. The improvement in model performance in these areas relative to the previous version of ROM (Version 2.0), seems to result from the correction of westerly bias in low level wind flows.

Model performance was not as good in Ohio, West Virginia, and Virginia. Although estimated and observed median daily concentrations in these areas agreed to within 5 ppb, concentrations at the 95 percent frequency level were underestimated by about 15 ppb. Underestimates of the peak concentrations in these areas might be attributed to the relatively small-scale urban plumes and uncertainties in estimating naturally-occurring emissions of NO_x and hydrocarbons. However, deficiencies in anthropogenic emission inventories may still exist despite efforts that have been made to improve them.

Spatial patterns of the three-day maximum concentrations usually showed reasonable model performance. Differences in model and estimated plumes were most evident during episodes experiencing sea breezes, coastal troughs, and squall lines. Underestimates that were reported in the ROM2.0 evaluation by Schere and Wayland (1989) were again noted in the Washington, DC, area. In addition, ROM2.1 tended to underpredict peak rural concentrations of ozone by about 20 ppb. More monitoring data are needed for evaluating model performance in rural areas because of the current sparseness of these data. It is hoped that measurements being taken under the auspices of the National Acid Precipitation and Assessment Program (NAPAP) will aid in future evaluation of ozone concentrations. However, agreement of the magnitude and orientation of ozone plumes in the northern portion of the Northeast Corridor was good.

The most rigorous portion of this analysis was an evaluation of the model to estimate boundary conditions for UAM application. Although the application of ROM in a deterministic manner is not recommended, some type of reliable estimation scheme is needed for prescribing boundary conditions when the UAM is to be applied for future-year emission-control strategies. As was shown in the analysis, using monitoring data for estimating boundary conditions requires a great deal of subjectivity and is fraught with uncertainty.

Overall, the model compared quite well with the monitoring data for estimating UAM boundary conditions in the OMNYMAP domain. Mean concentrations for all daytime hours agreed to within 5 ppb (less than 10 percent error). However, significant day-to-day variability in model performance was noted. A case study performed on July 10, 1985, demonstrated that small-scale features can cause dramatic effects on model performance. On this day, it was shown that a squall line produced a significant overprediction in ozone concentrations along the western boundary (the inflow boundary on this day) of the UAM domain. Thus, users of the UAM should carefully screen ROM estimates and be aware of mesoscale flow conditions. On most days, however, the model did a reasonable job estimating boundary conditions.

This evaluation has suggested that further improvements to the ROM are warranted. Improving the specification of layer thicknesses and the computation of naturally-occurring emissions are topics currently being examined. In future years, it is hoped that a dynamic meteorological processor can be incorporated that will simulate nonsteady-state flows. To continue making advances in model development, additional monitoring data are needed to examine other chemical species (such as NO_x, isoprene, formaldehyde, and HNO_3) and to fully evaluate model performance in rural areas.

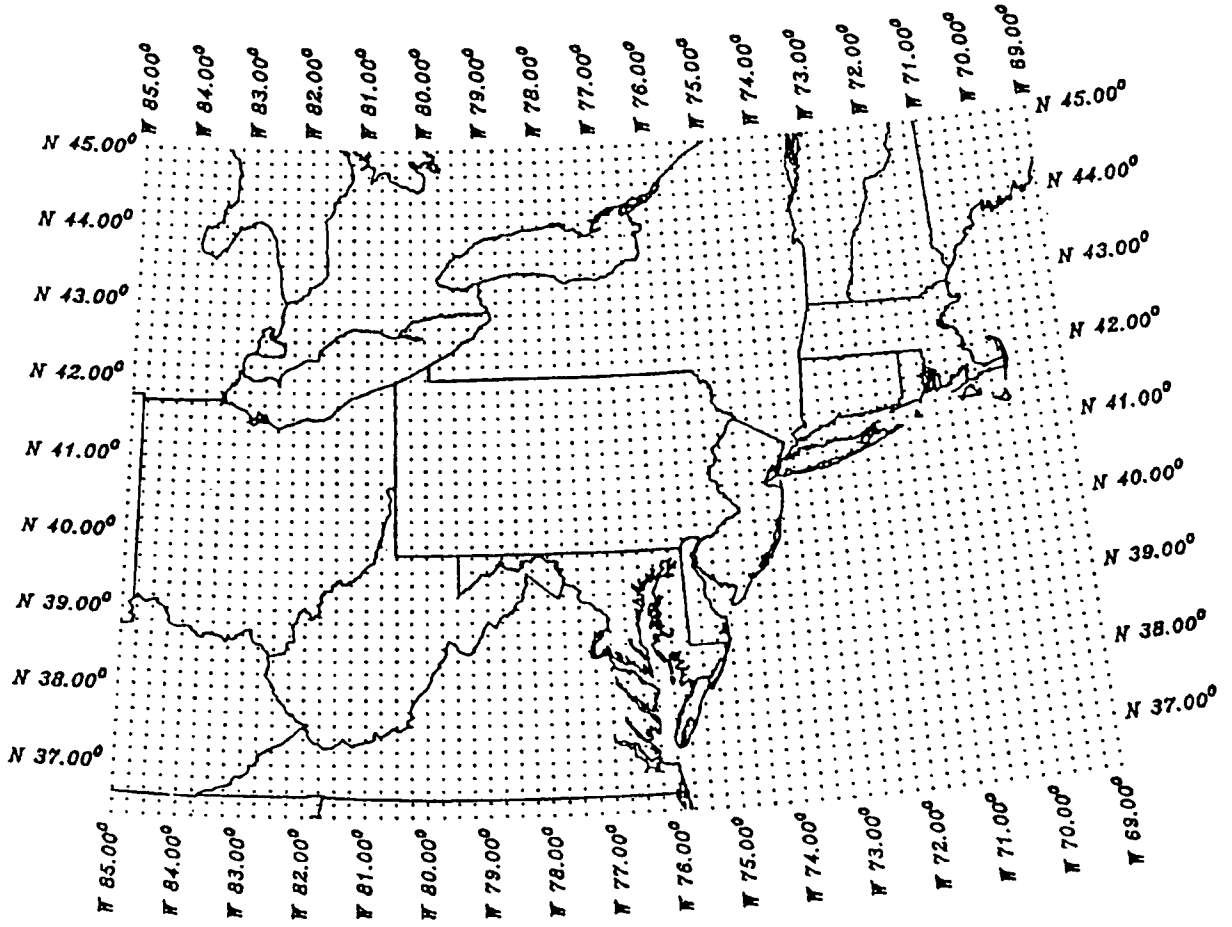


Figure 2-1. The ROMNET modeling domain; points represent the southwest corner of each grid.

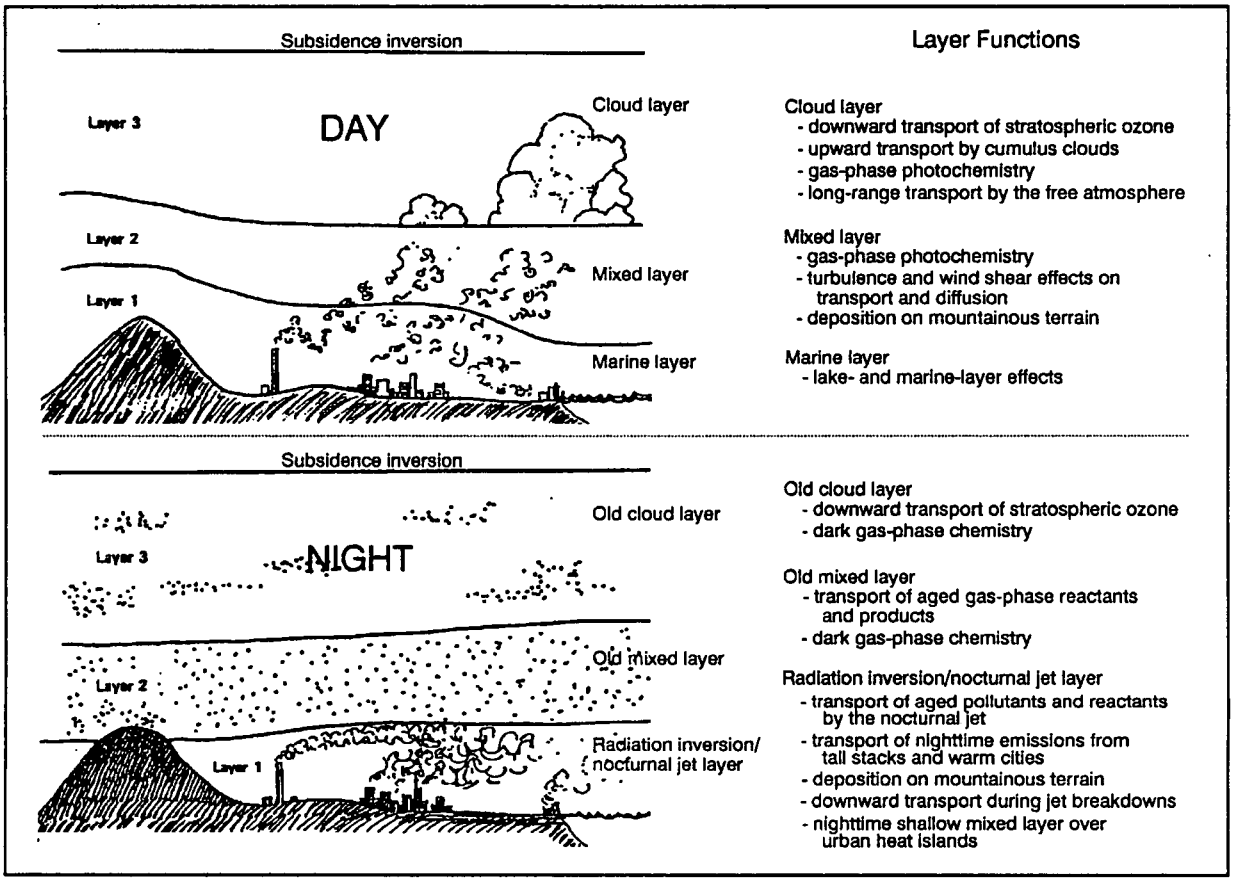


Figure 2-2. The ROM vertical layers and their functional features.

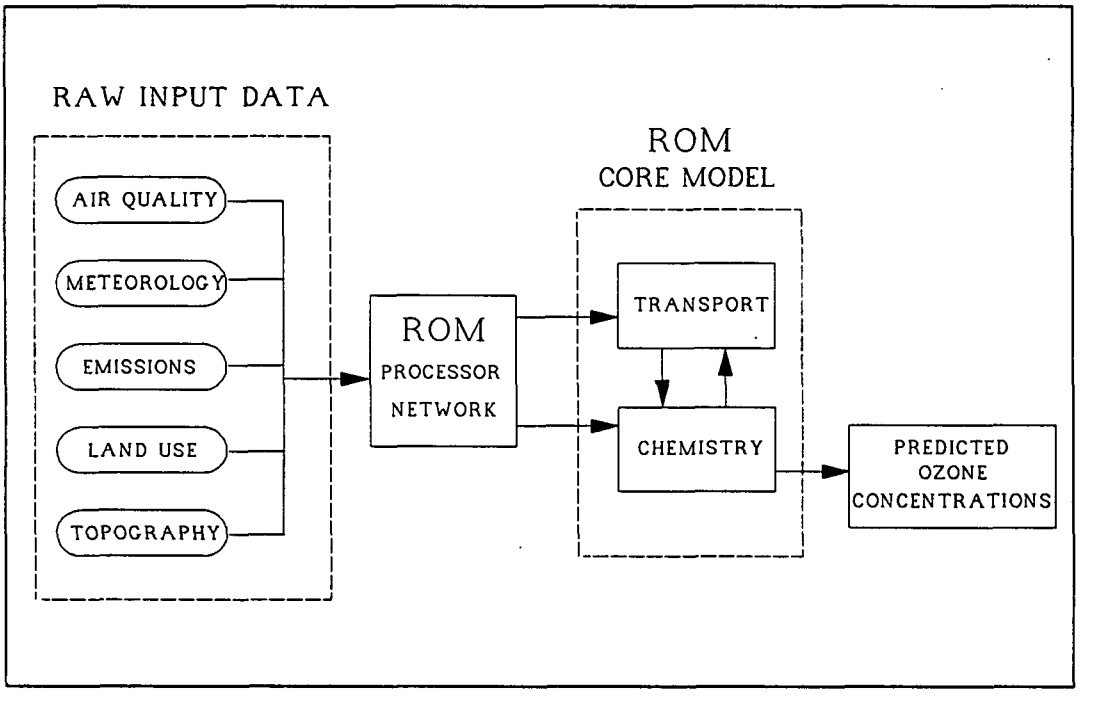


Figure 2-3. Components of the ROM.

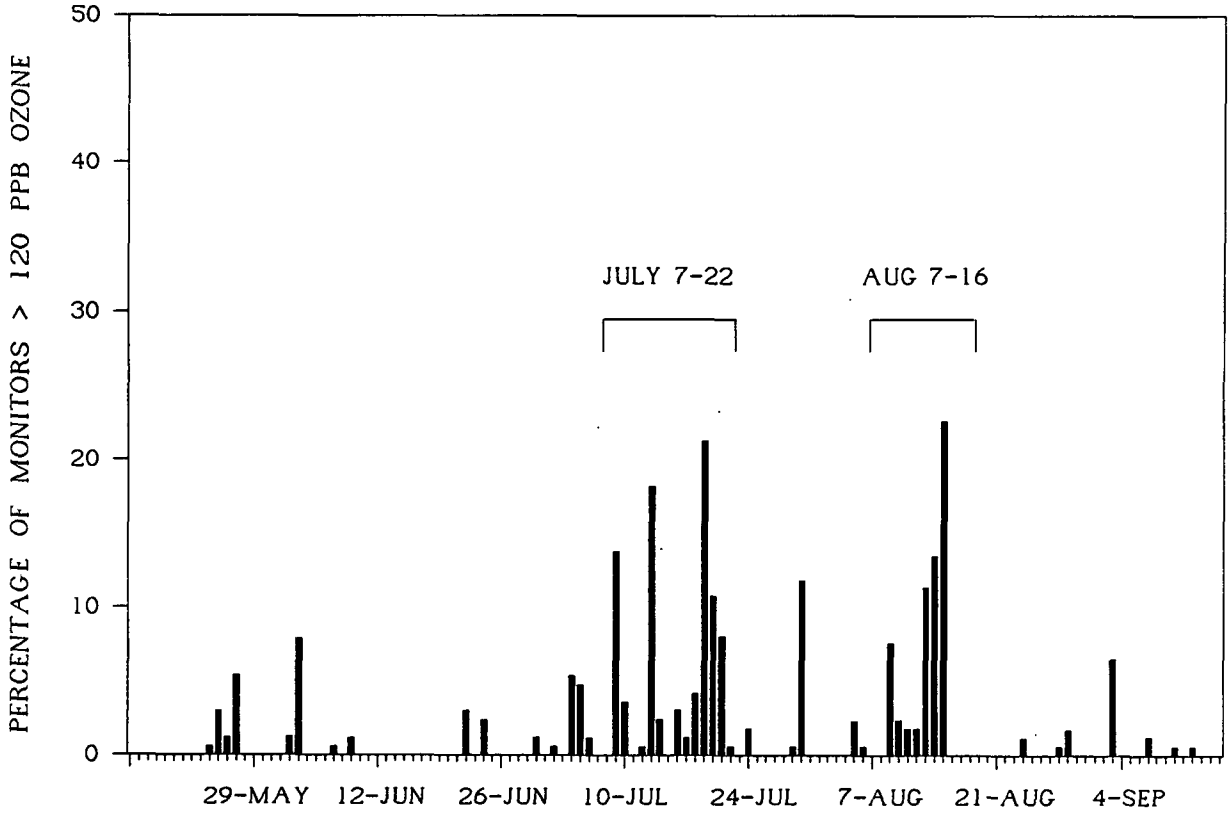


Figure 2-4. Percentage of monitors with daily maximum ozone exceeding 120 ppb in the northeastern U.S.

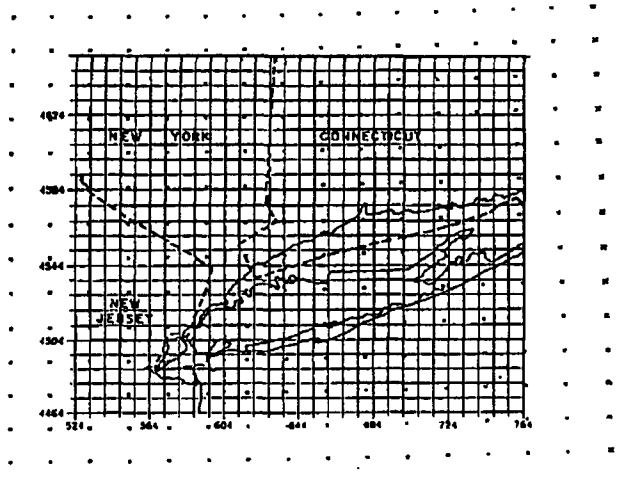


Figure 2-5. ROM grid points overlaying the UAM domain for the New York City metropolitan area.

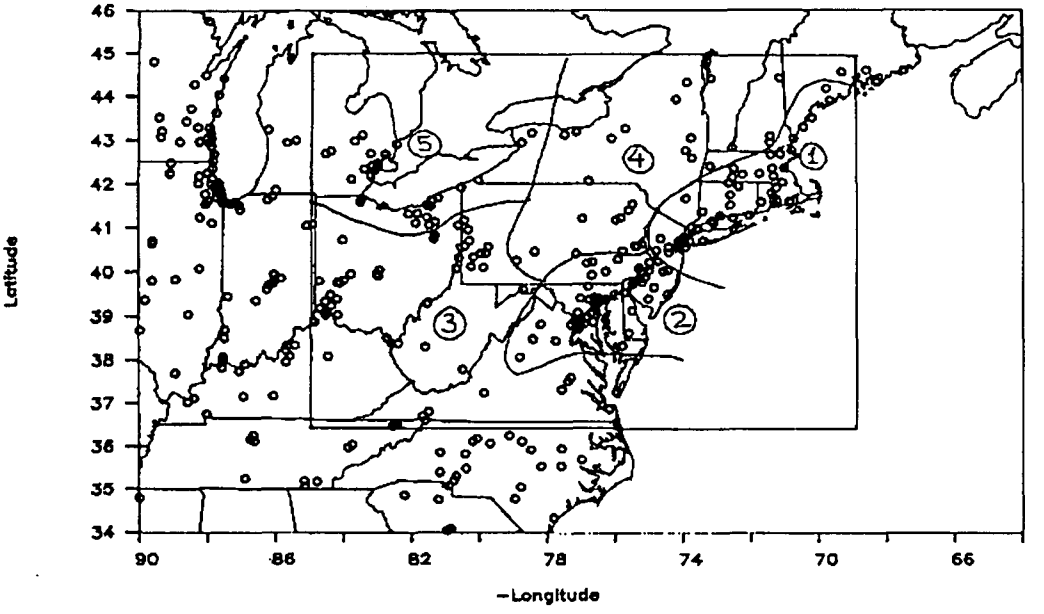


Figure 2-6. AIRS ozone monitoring sites divided into five geographical groups.

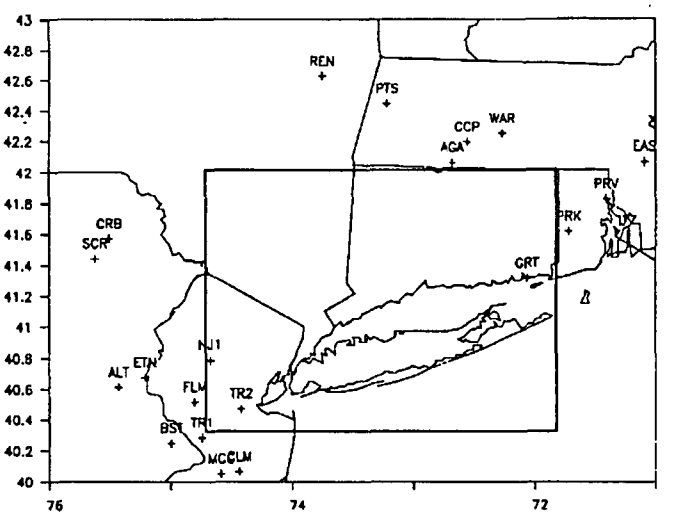
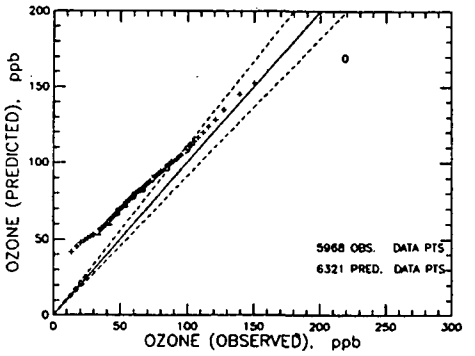
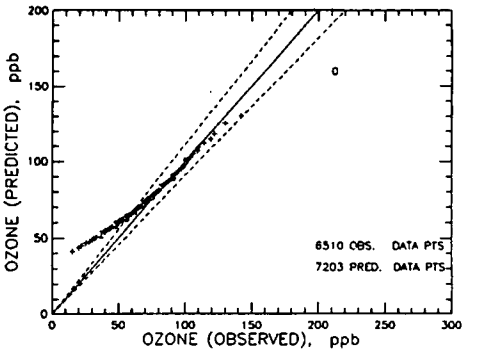


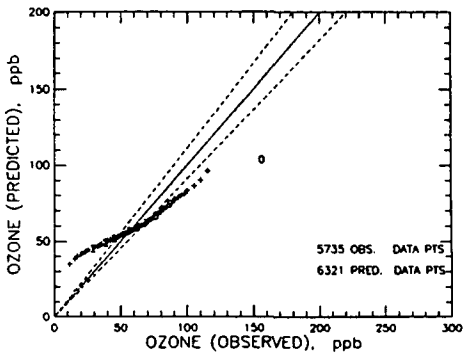
Figure 2-7. Monitoring sites used for developing boundary conditions for the OMNYMAP domain. REN = Rensselaer, NY; PTS = Pittsfield, MA; WAR = Ware, MA; CCP = Chocopee, MA; AGA = Agawam, MA; PRV = Providence, RI; PRK = Kent County, RI; GRT = Groton, CT; CRB = Carbondale, PA; SCR = Scranton, PA; NJ1 = Morris County, NJ; ETN = Easton, PA; ALT = Allentown, PA; FLM = Flemington, NJ; BST = Bristol, PA; TR1 and TR2 = Trenton, NJ; MCG = McGuire AFB, NJ; CLM = Ocean County, NJ.



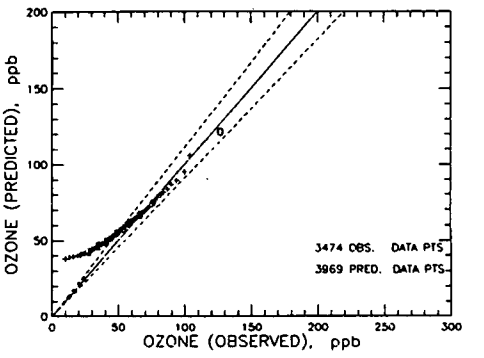
(a) Group 1: Northern Corridor



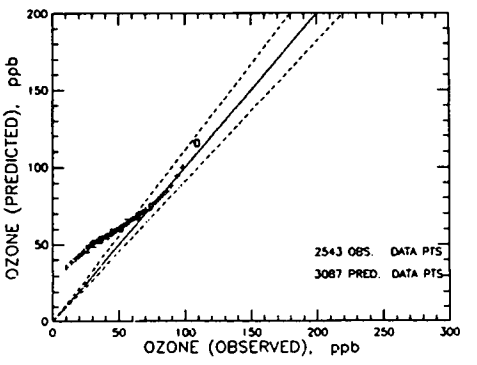
(b) Group 2: Southern Corridor



(c) Group 3: Ohio Valley-Mid Atlantic

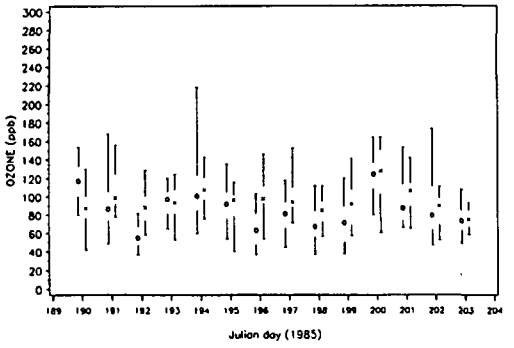


(d) Group 4: Interior Northeast

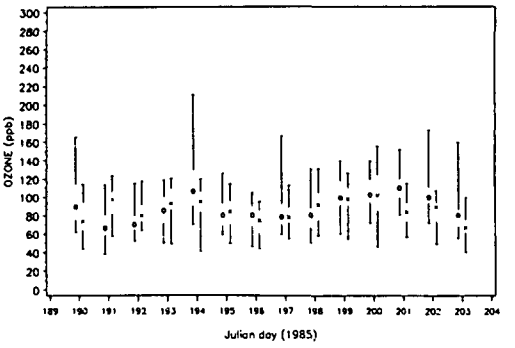


(e) Group 5: Great Lakes

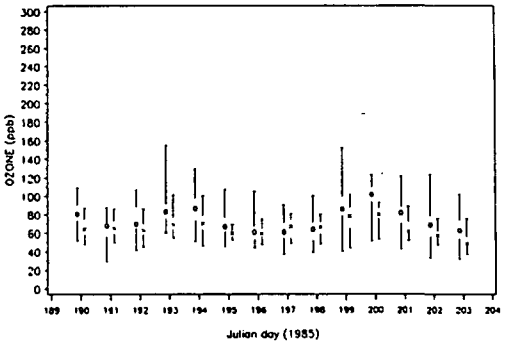
Figure 2-8. Quantile-quantile plots of daytime hourly ozone for the July 1985 episode.



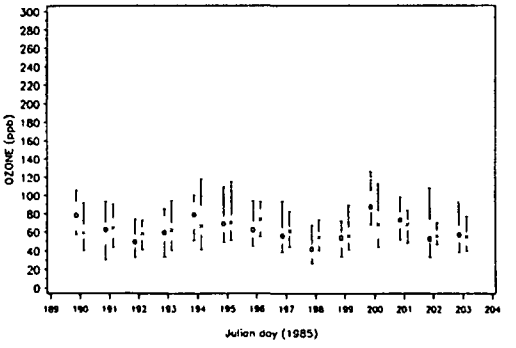
(a) Group 1: Northern Corridor



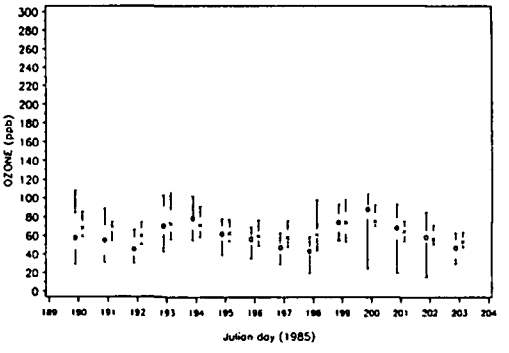
(b) Group 2: Southern Corridor



(c) Group 3: Ohio Valley-Mid Atlantic



(d) Group 4: Interior Northeast



(e) Group 5: Great Lakes

Figure 2-9. Comparison of observed (o) and modeled (x) maximum ozone for the July 1985 episode.

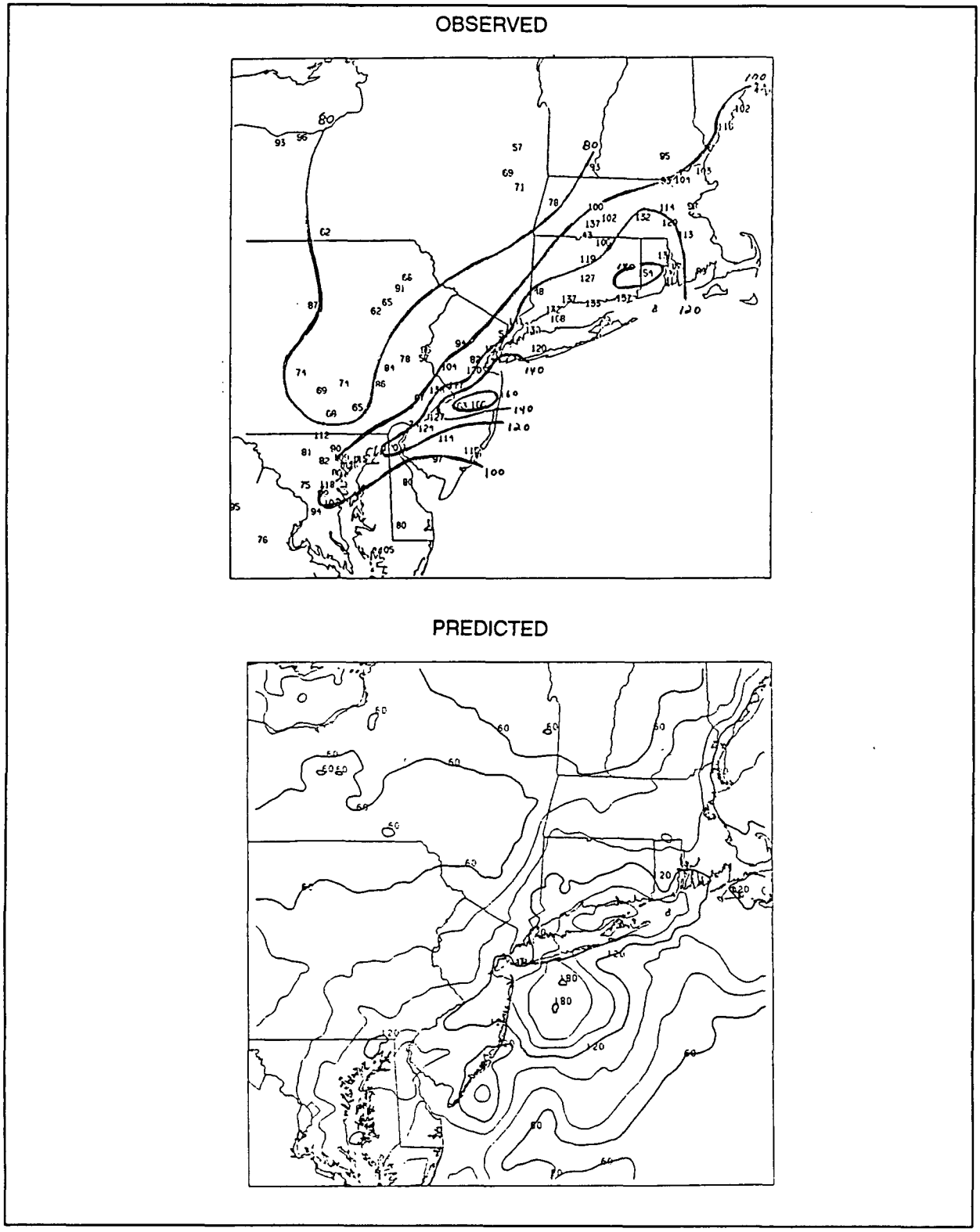


Figure 2-10. Spatial patterns of maximum ozone for July 9 - 11, 1985.

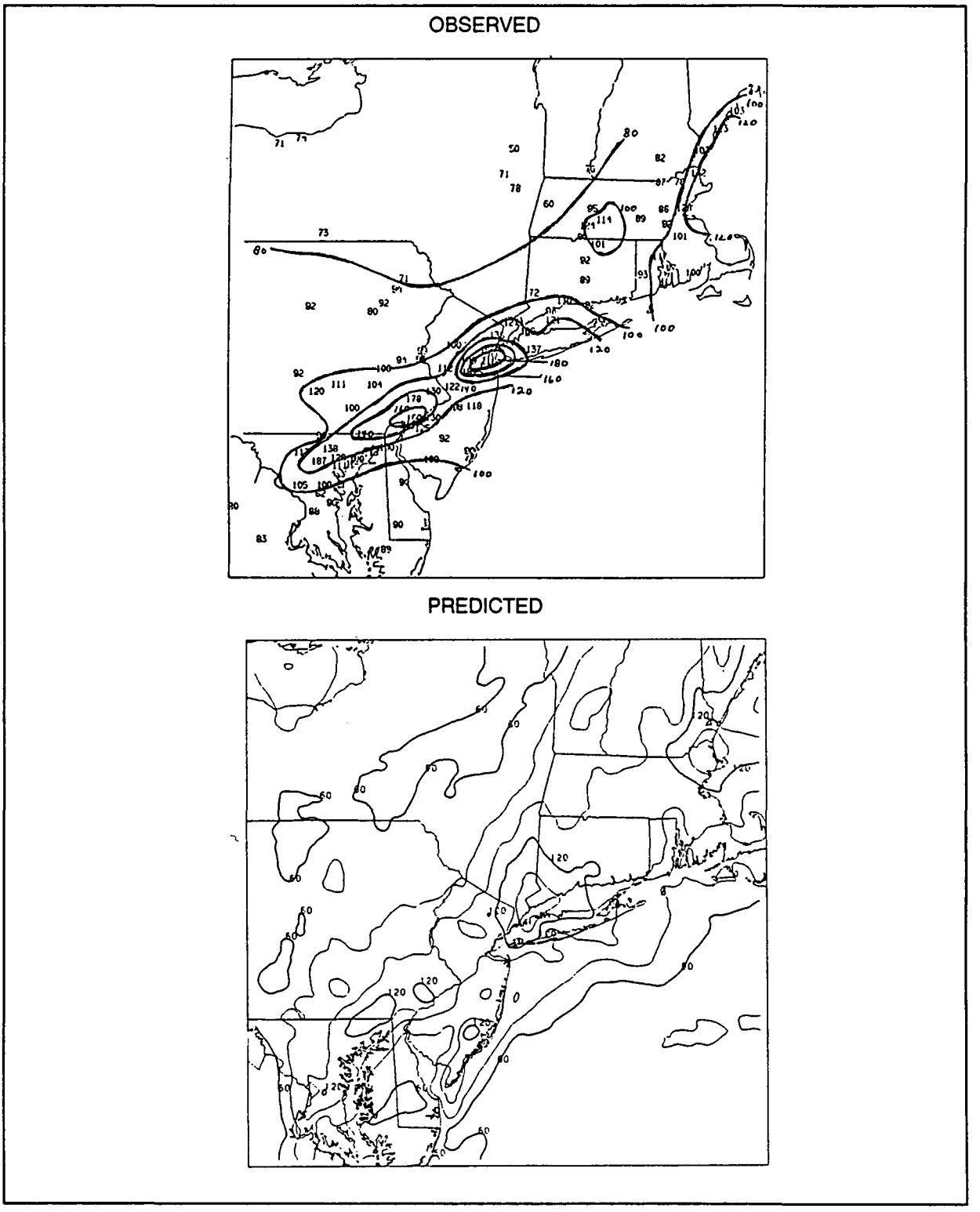


Figure 2-11. Spatial patterns of maximum ozone for July 13 - 15, 1985.

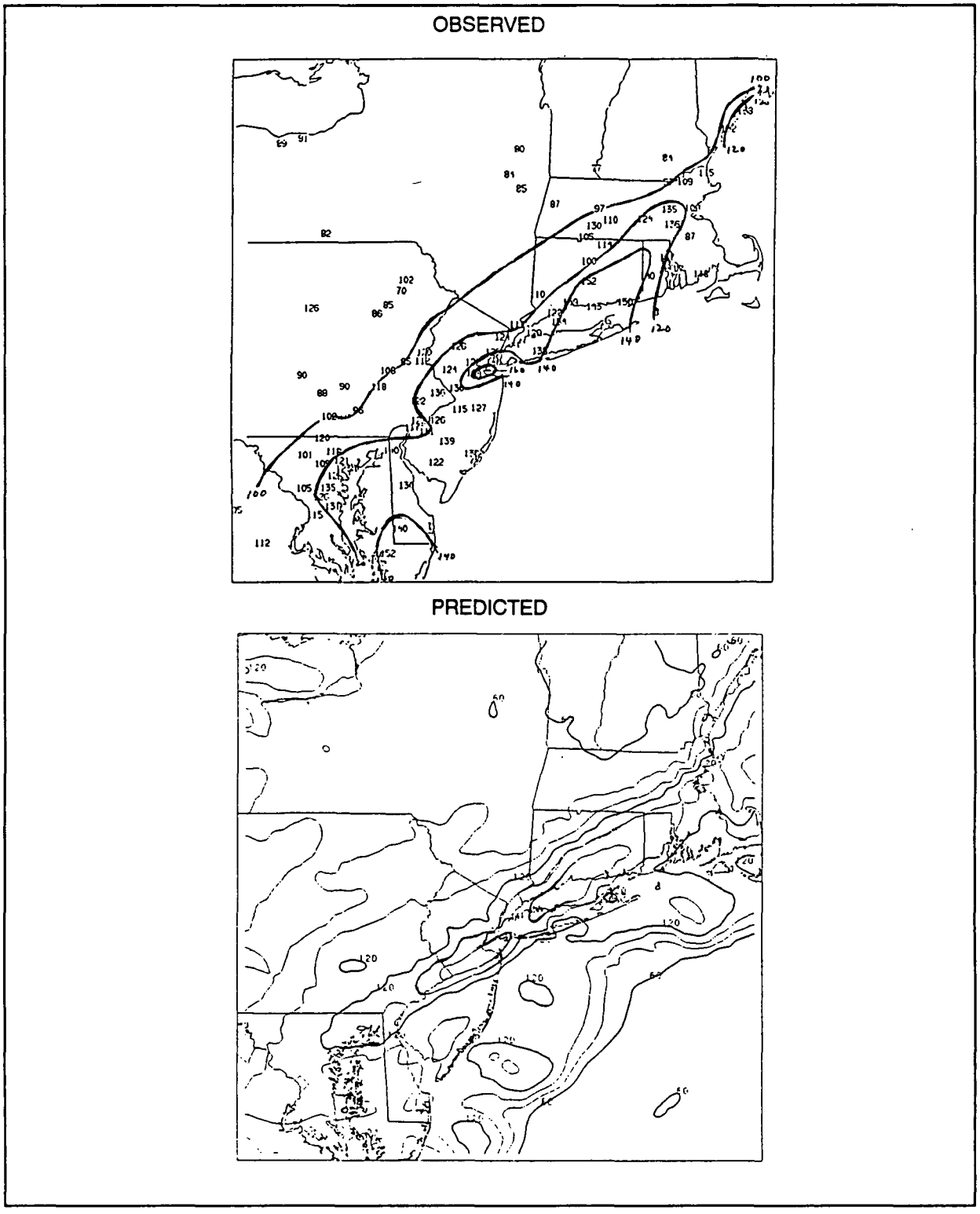


Figure 2-12. Spatial patterns of maximum ozone for July 18 - 20, 1985.

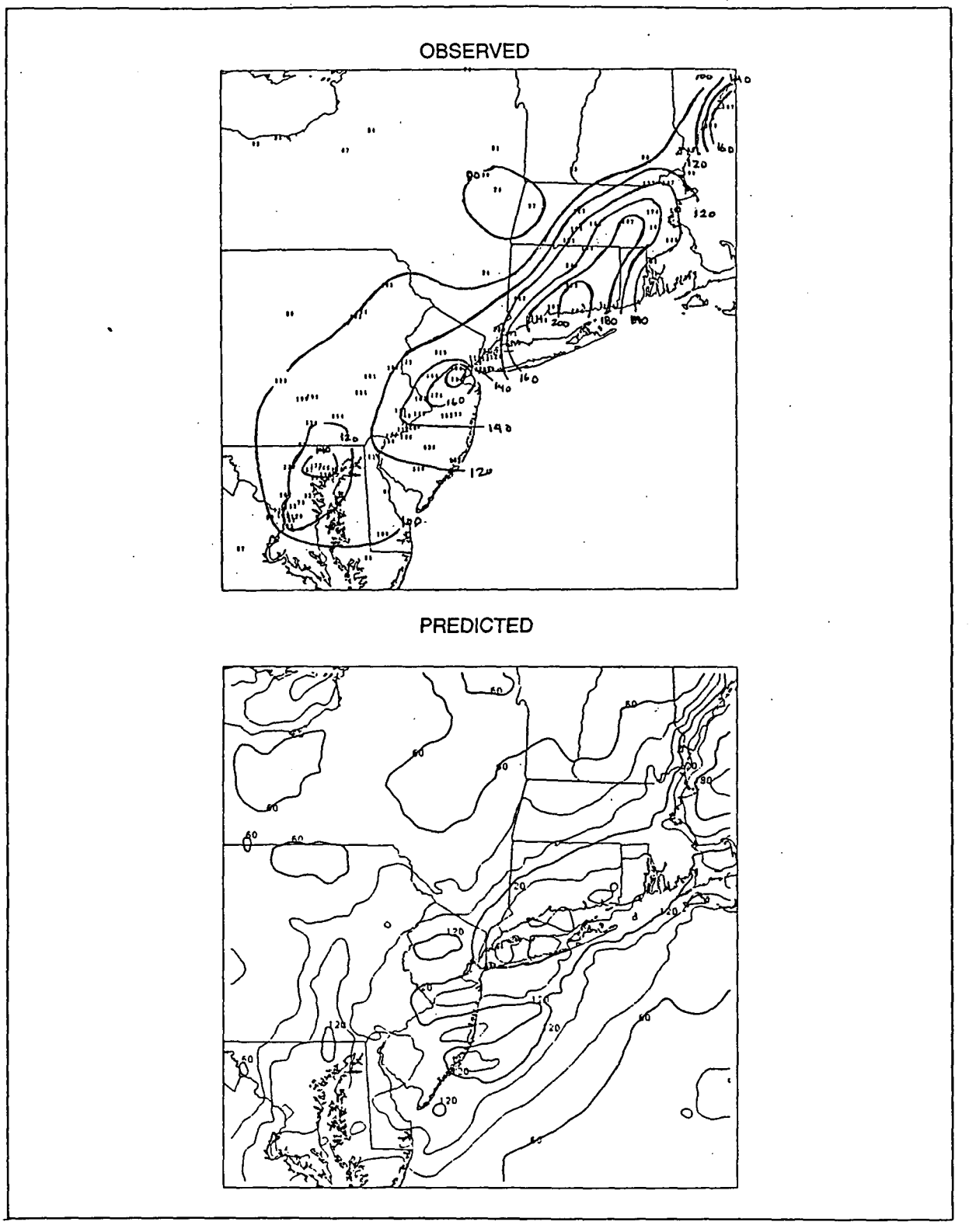


Figure 2-13. Spatial patterns of maximum ozone for August 13 - 15, 1985.

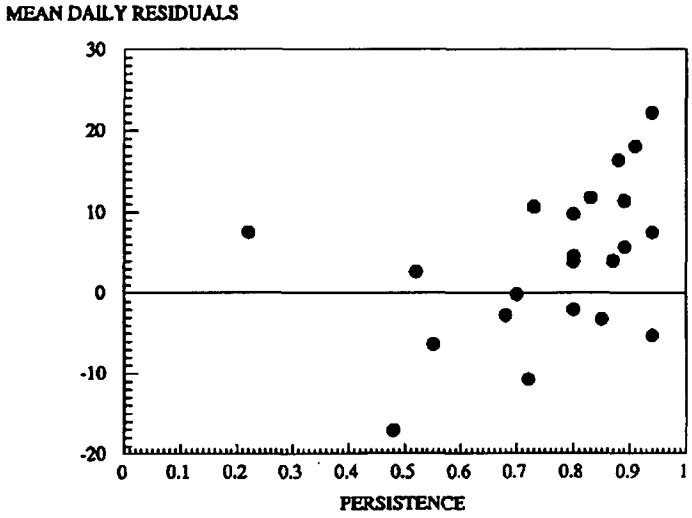


Figure 2-14. Mean residuals versus wind persistence for the UAM boundary; positive values are overprediction, negative values are underprediction.

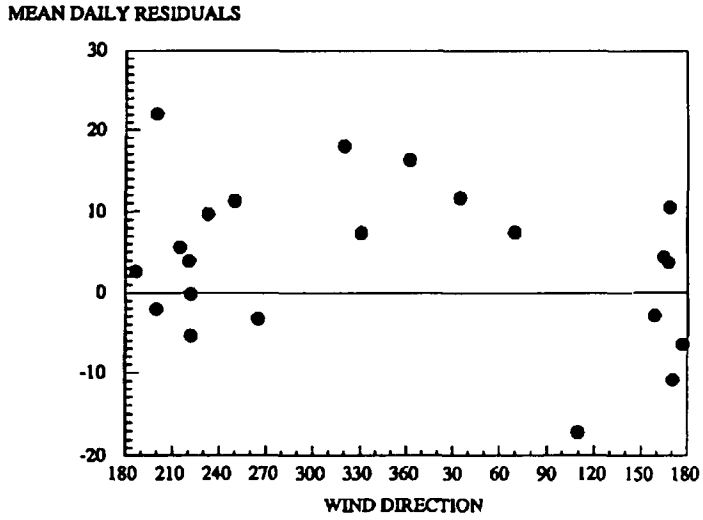


Figure 2-15. Mean residuals versus daily average wind direction for the UAM boundary; positive values are overprediction, negative values are underprediction.

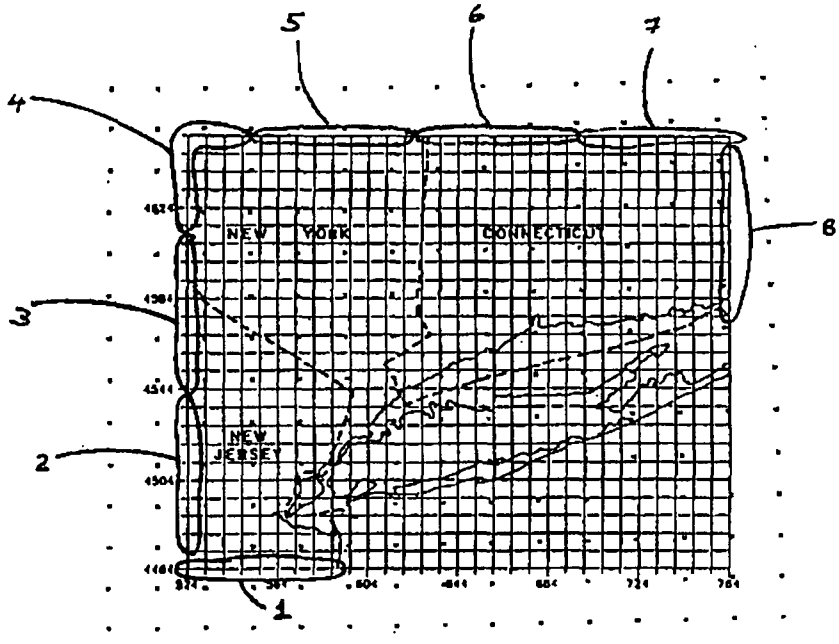


Figure 2-16. Division of the OMNYMAP boundary into eight groups.

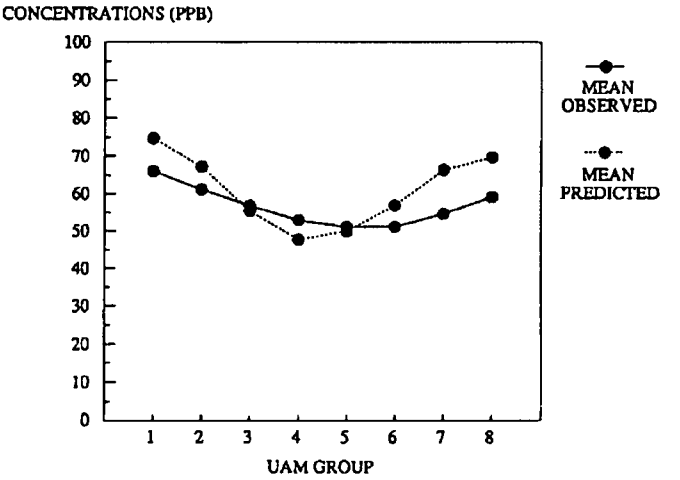


Figure 2-17. Mean daytime ozone concentrations by UAM group along the UAM boundary.

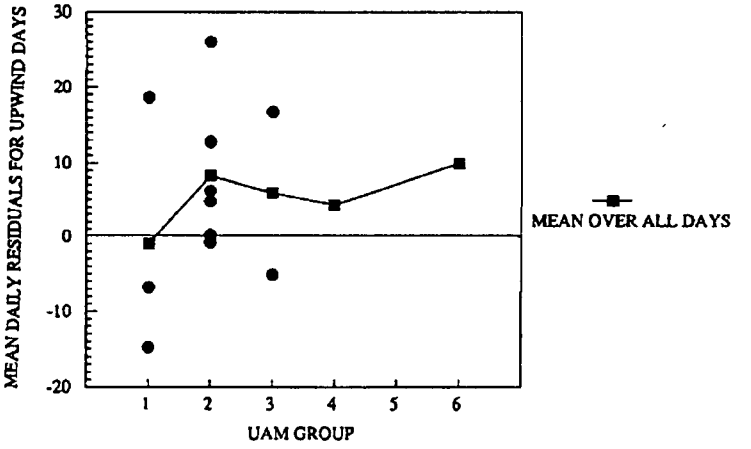


Figure 2-18. Mean residuals for each UAM group experiencing incoming flow.

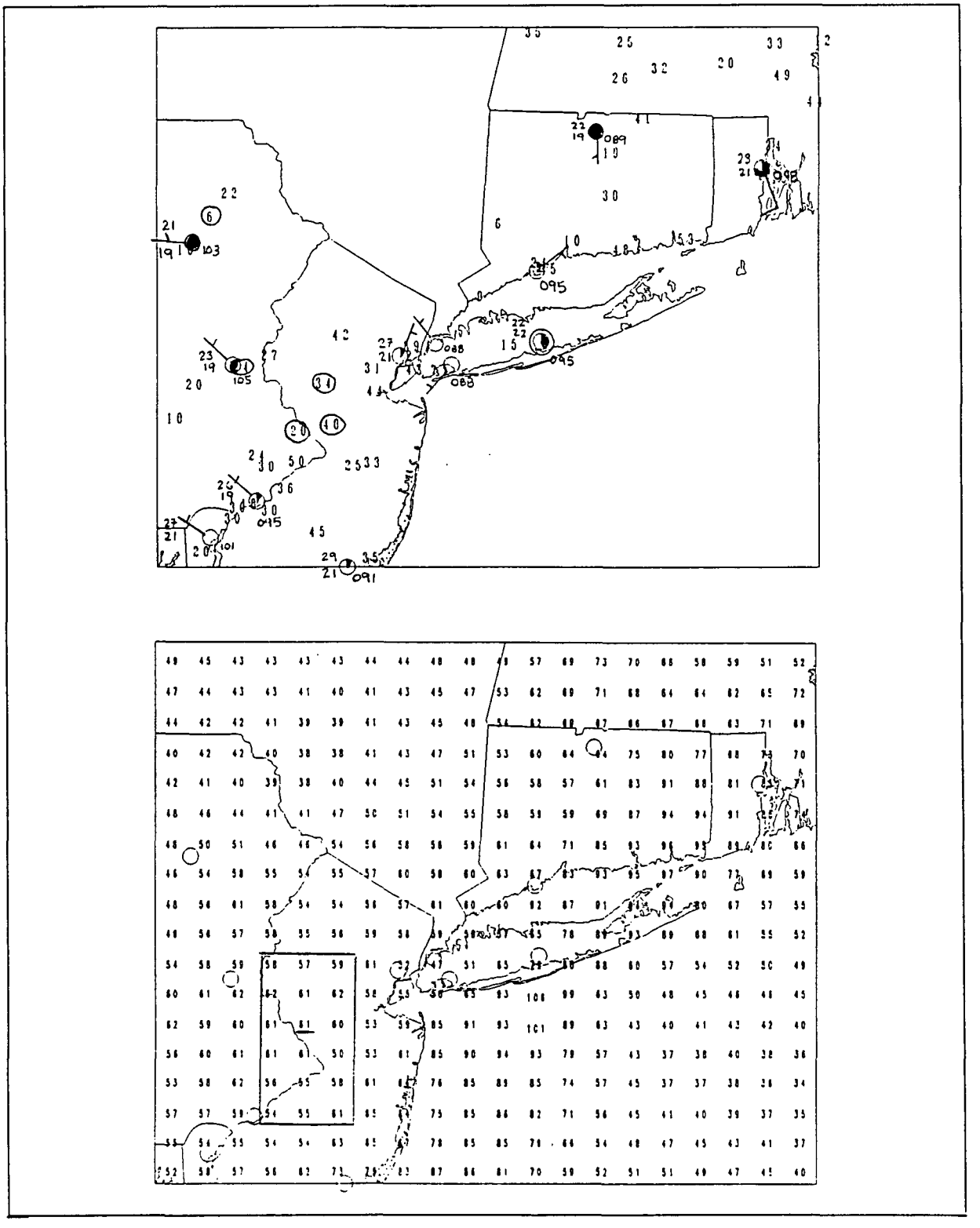


Figure 2-19. Ozone concentrations for 0800 EST July 10, 1985; observed (top), predicted (bottom).

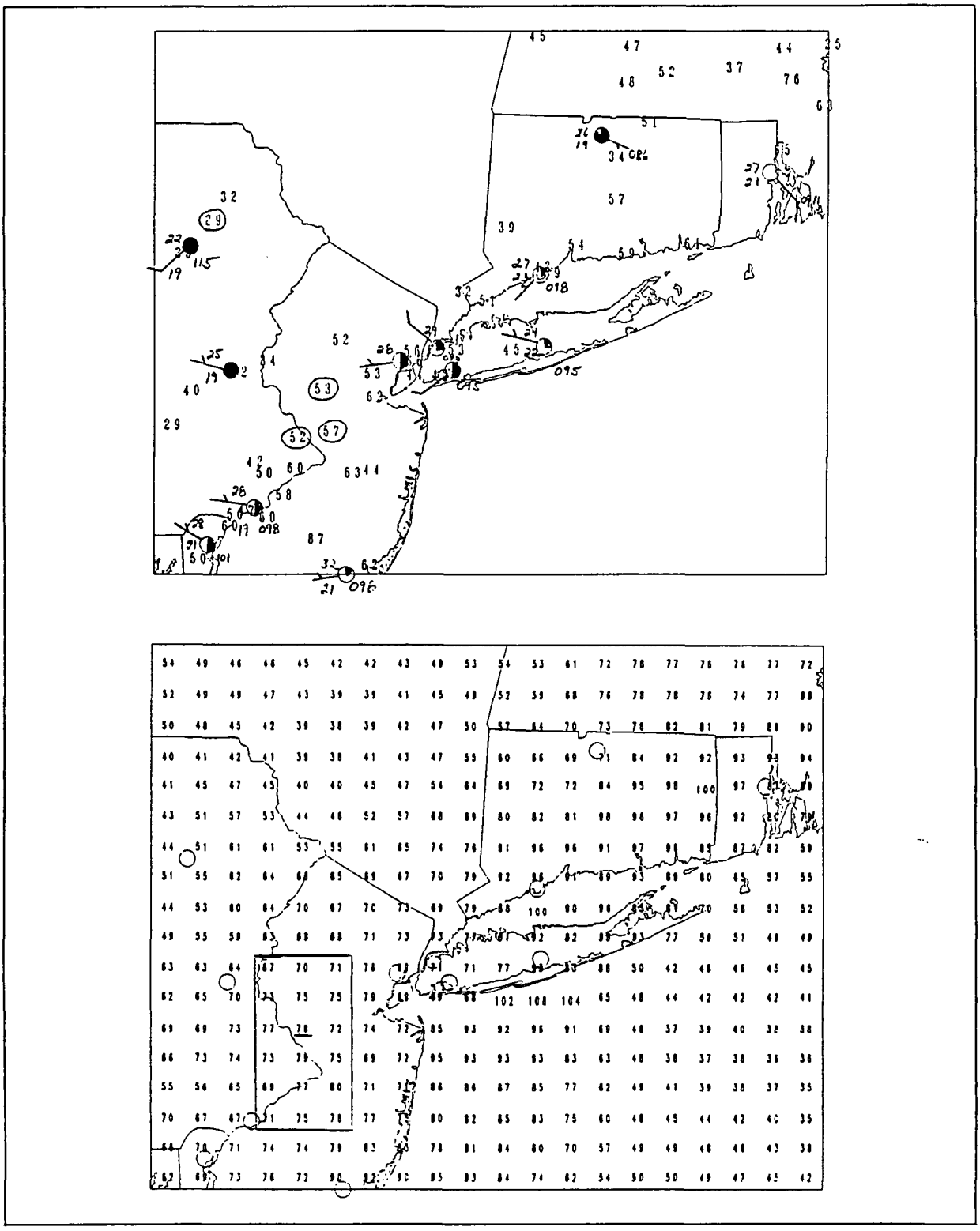


Figure 2-20. Ozone concentrations for 1000 EST July 10, 1985; observed (top), predicted (bottom).

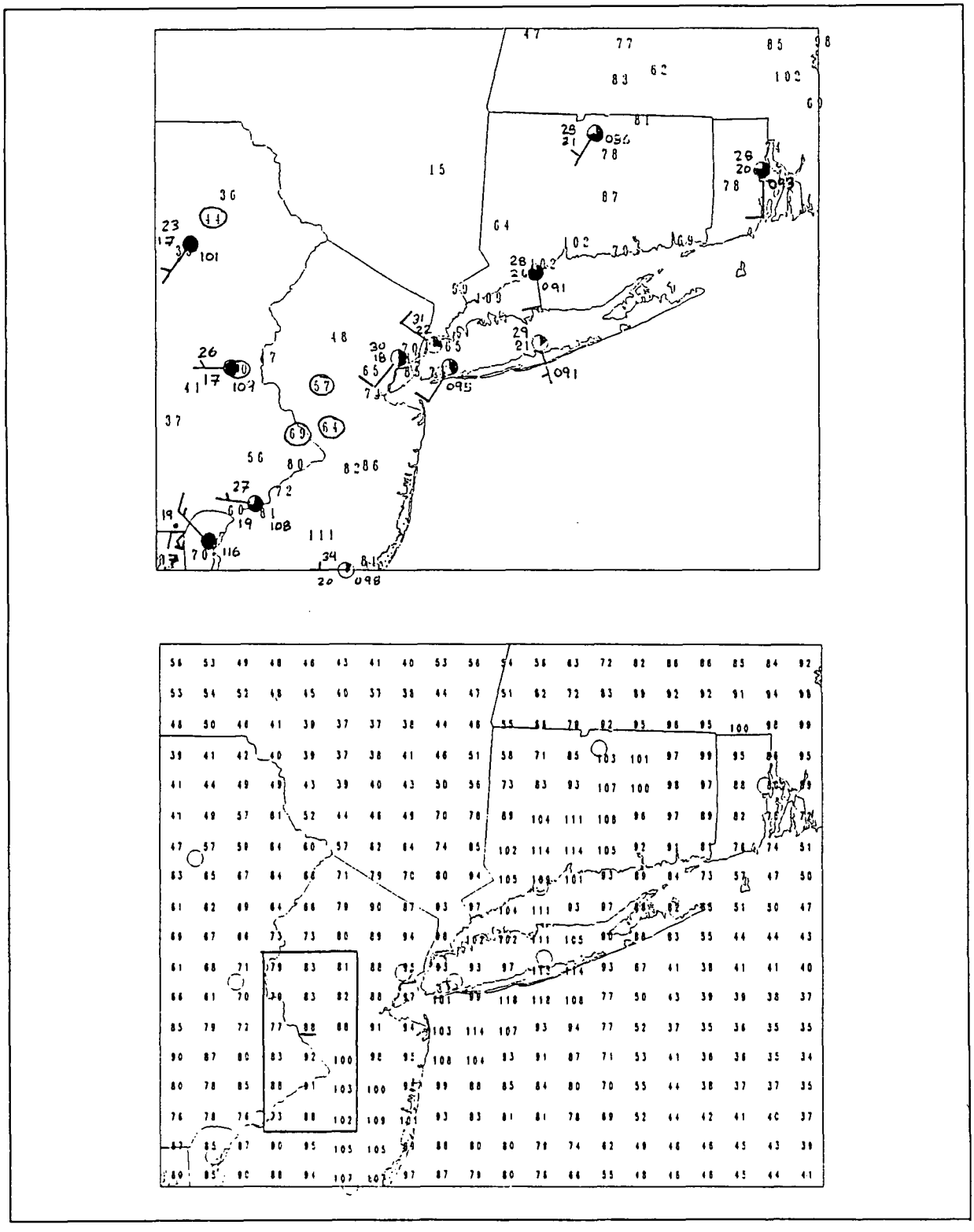


Figure 2-21. Ozone concentrations for 1200 EST July 10, 1985; observed (top), predicted (bottom).

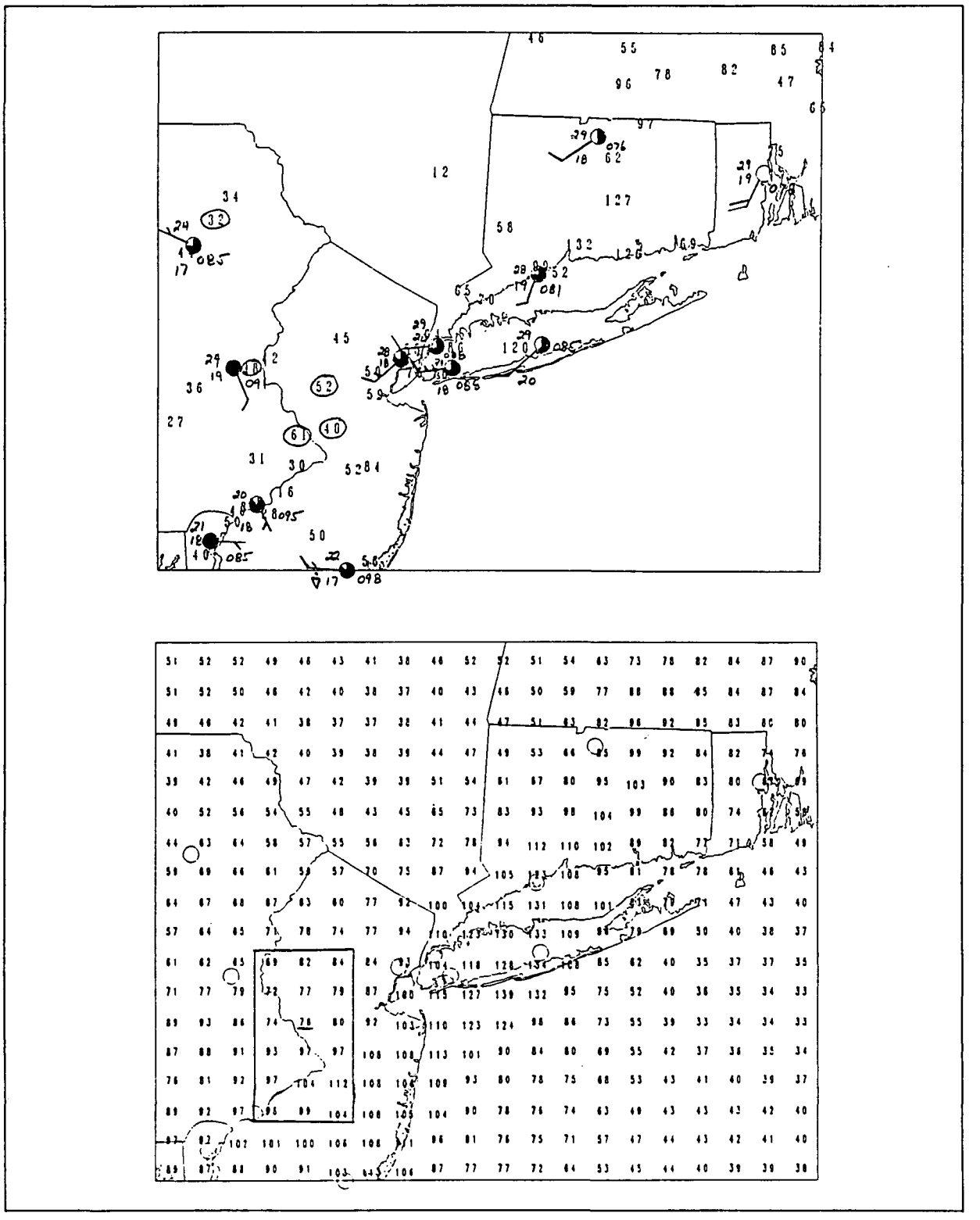


Figure 2-22. Ozone concentrations for 1400 EST July 10, 1985; observed (top), predicted (bottom).

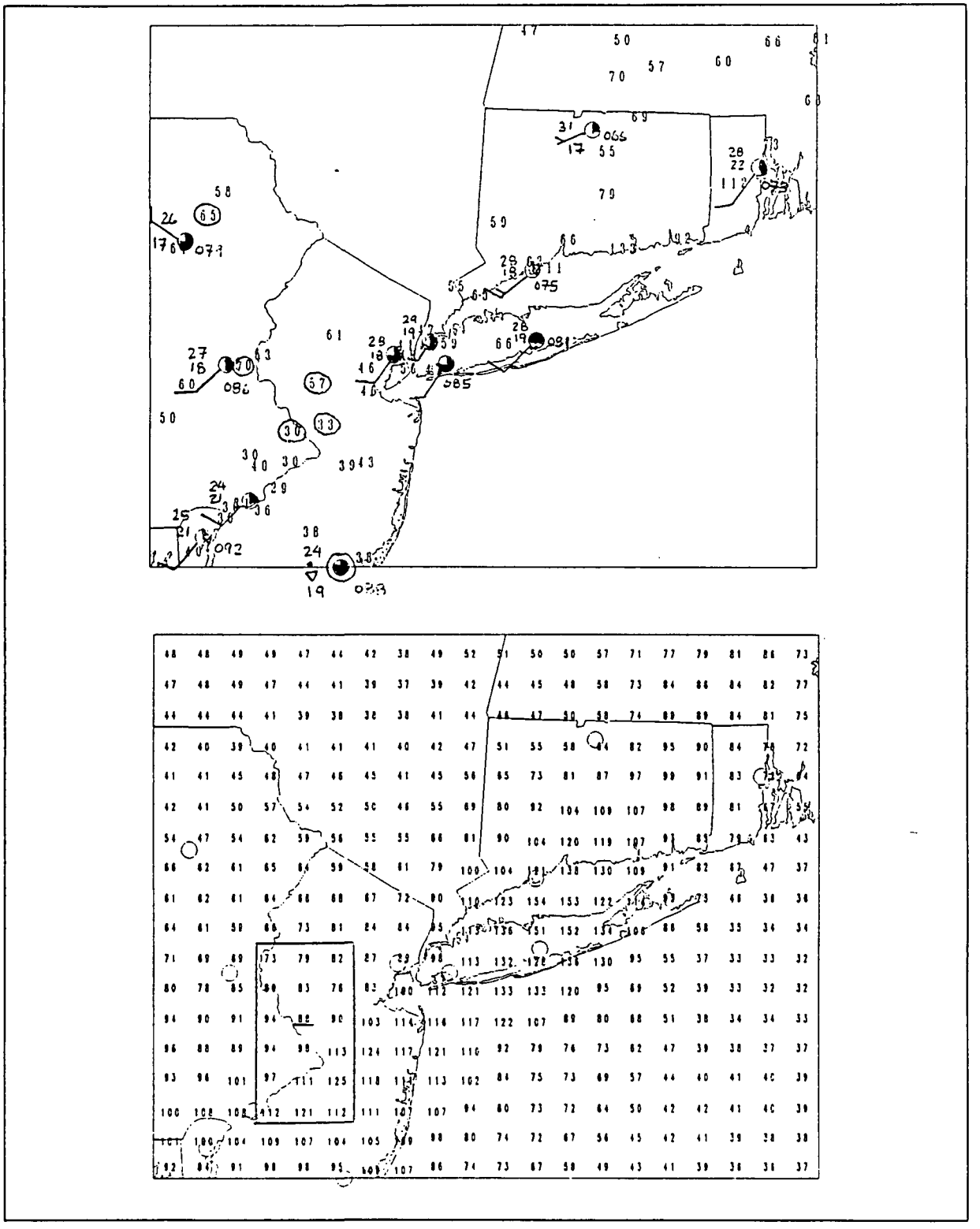


Figure 2-23. Ozone concentrations for 1600 EST July 10, 1985; observed (top), predicted (bottom).

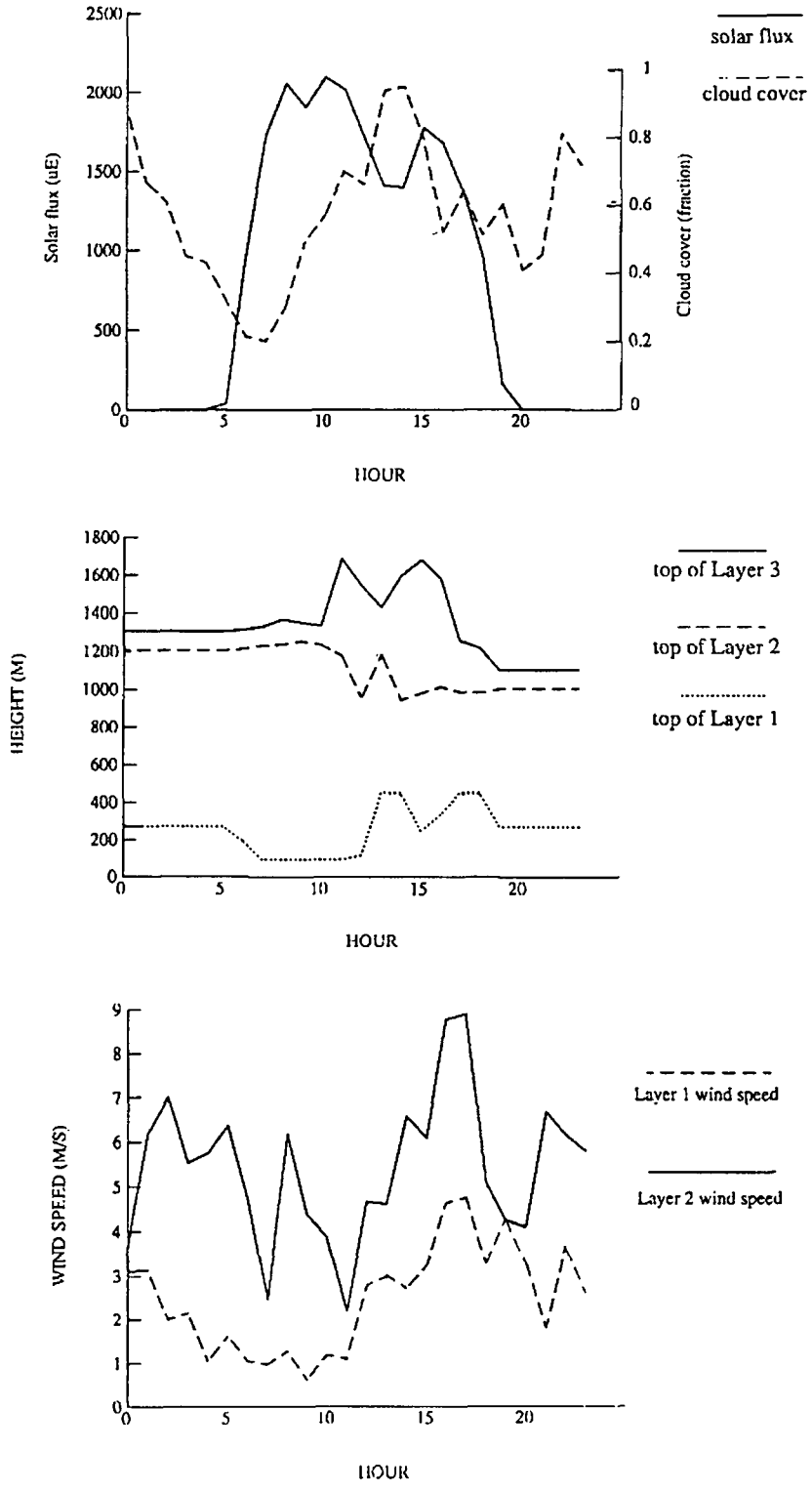


Figure 2-24. Time series of selected meteorological parameters for grid cell (45,21) on July 10,1985.

TABLE 2-1. ROM CHEMICAL SPECIES

Symbol	Description	Symbol	Description
ALD2	High molecular weight aldehydes	O1D	O^1D atom
C2O3	Peroxyacetyl radical	O3	Ozone
CO	Carbon monoxide	OH	Hydroxyl radical
CRES	Cresol and high MW phenols	OLE	Olefinic carbon bond
CRO	Methylphenoxy radical	OPEN	High molecular weight aromatic oxidation ring fragment
ETH	Ethene		
FORM	Formaldehyde	PAN	Peroxyacetyl nitrate
H2O2	Hydrogen peroxide	PAR	Paraffinic carbon bond
HNO2	Nitrous acid	PNA	Peroxynitric acid
HNO3	Nitric acid	ROR	Secondary organic oxy radical
HO2	Hydroperoxy radical	TO2	Toluene-hydroxyl radical adduct
ISOP	Isoprene structures	TOL	Toluene
MGLY	Methylglyoxal	XO2	NO to NO_2 reaction
N2O5	Dinitrogen pentoxide	XO2N	NO to nitrate (NO_3^-) reaction
NO	Nitric oxide	XYL	Xylene
NO2	Nitrogen dioxide	MTHL	Methanol
NO3	Nitrogen trioxide	NONR	Nonreactive hydrocarbons
O	O^3P atom	TRAC	Tracer species

TABLE 2-2. INITIAL MEAN TROPOSPHERIC BACKGROUND CONCENTRATIONS, PRECURSOR SPECIES

Species	Concentration (ppm)	Species	Concentration (ppm)
CO	0.1	Aldehydes	1.12×10^{-3}
NO_2	1.0×10^{-3}	Formaldehyde	1.4×10^{-3}
NO	1.0×10^{-3}	Toluene	1.4×10^{-4}
Ethanol	3.5×10^{-4}	Xylene	1.05×10^{-4}
Olefins	2.1×10^{-4}	Paraffins	7.42×10^{-3}
		All others	1.0×10^{-16}

TABLE 2-3. OZONE MONITORING SITES USED FOR DEVELOPING UAM BOUNDARY CONDITIONS ALONG THE OMNYMAP DOMAIN [1]

	JULY															
Monitoring site	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
Ocean Co, NJ							S									
McGuire AFB, NJ			S			S	SW	S	S				S		S	
Trenton, NJ	S	S	S	S	S	S	S		S	S	S	S		S	SW, S	S
Trenton, NJ		SW, S	S	SW, S		SW, S	SW	S	SW, S	S		S	SW, S		SW, S	
Flemington, NJ	S	W	SW, W	SW, W	S	W	W	W	W	SW, W	W	W	W	SW, W	W	SW, W
Bristol, PA		SW	SW	SW		SW		SW	SW	SW			SW		SW	
Morris Co, NJ							W				W	W			W	
Allentown, PA		W	W	W	W	W		W	W	W			W	W	W	W
Easton, PA	W	W	W		W	W		W	W	W			W	W		W
Scranton, PA	W	W	W	W	W			NW	NW	W			NW	W	NW	W
Carbondale, PA	W				W			NW	NW				NW		NW	
Rensselaer, NY	N				N									N		N
Agawam, MA	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pittsfield, MA	N				N						N	N		N		N
Chicopee, MA											N	N				
Ware, MA											N	N				
Groton, CT	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E
Kent Co, RI			E								E	E				
Providence, RI											E	E				

	AUGUST									
Monitoring site	07	08	09	10	11	12	13	14	15	16
Ocean Co, NJ					S		S			
McGuire AFB, NJ	S	S			S		S	S		
Trenton, NJ	S	S	S	SW, S	S	S	S	S	S	S
Trenton, NJ	SW, S	SW, S		SW	S	S	S	S	S	
Flemington, NJ	W	W	W	W	W	SW, W	SW, W	W	W	SW, W
Bristol, PA	SW	SW			SW	SW	SW	SW	SW	
Morris Co, NJ			W	W						
Allentown, PA	W	W			W	W	W	W	W	W
Easton, PA	W	W			W	W	W	W	W	W
Scranton, PA	NW				NW	W		NW	NW	W
Carbondale, PA	NW				NW			NW	NW	
Rensselaer, NY										N
Agawam, MA	N	N	N	N	N	N	N	N	N	N
Pittsfield, MA								N		N
Chicopee, MA			N		N	N	N			
Ware, MA			N		N	N	N			
Groton, CT	E	E	E	E	E	E	E	E	E	E
Kent Co, RI			E							
Providence, RI										

1. Compass points indicate which sites were used on each day of the episode; the direction indicates the location(s) along the boundary where the data were used.

TABLE 2-4. SUMMARY STATISTICS FOR ALL DAYTIME HOURLY AND DAILY MAXIMUM OZONE CONCENTRATIONS (ppb) FOR THE ROMNET REGION (JULY AND AUGUST 1985 DATA MERGED)

Conc. type	*n*	Mean obs.	Mean model	Std. dev. obs.	Std. dev. model	95th percentile obs.	95th percentile model	Maximum obs.	Maximum model
Daytime hourly	40,534	55.2	64.5	26.8	19.2	102.0	101.1	219.0	169.2
Daily max.	3,707	78.6	77.5	26.7	22.2	127.0	118.7	219.0	169.2

TABLE 2-5. COMPARISON OF DAYTIME HOURLY AND DAILY MAXIMUM STATISTICS (ppb) FOR THE JULY AND AUGUST 1985 EPISODES

Episode	*n*	Mean obs.	Mean model	Std. dev. obs.	Std. dev. model	95th percentile obs.	95th percentile model	Maximum obs.	Maximum model
				Daytime hourly					
July	25,129	56.8	66.6	26.0	19.3	102.0	103.2	218.0	169.2
August	15,405	52.7	61.1	28.0	18.7	102.0	97.0	219.0	161.3
				Daily maximum					
July	2,271	79.9	79.6	25.1	22.5	125.0	120.9	218.0	169.2
August	1,436	76.6	74.1	29.0	21.3	131.0	114.1	219.0	161.3

TABLE 2-6. STATISTICAL SUMMARY BY GEOGRAPHIC GROUP FOR THE JULY 1985 EPISODE: DAYTIME HOURLY AND DAILY MAXIMUM CONCENTRATIONS (ppb)

		Mean		Std. dev.		95th percentile		Maximum	
Group	*n*	obs.	model	obs.	model	obs.	model	obs.	model
				Daytime hourly					
1	6,206	60.2	78.4	27.8	21.9	111.0	118.7	218.0	169.2
2	6,776	65.2	72.6	27.5	19.0	110.0	107.6	211.0	159.8
3	5,902	54.3	57.3	23.7	11.8	95.0	79.4	155.0	103.5
4	3.604	47.8	56.4	20.1	12.8	83.0	81.3	126.0	121.4
5	2,641	45.2	57.9	19.5	11.3	80.0	78.5	108.0	108.0
				Daily maximum					
1	558	88.0	97.8	28.9	23.1	138.0	144.9	218.0	169.2
2	609	90.7	87.9	23.8	19.5	130.0	120.8	211.0	159.8
3	537	75.1	65.9	19.1	12.1	109.0	88.0	155.0	103.5
4	328	66.1	64.7	17.9	14.5	96.0	91.7	126.0	121.4
5	239	63.4	67.2	17.8	11.7	94.0	89.3	108.0	108.0

TABLE 2-7. SUMMARY STATISTICS FOR UAM BOUNDARY CONDITIONS (HOURLY DAYTIME OZONE, ppb) FOR THE JULY AND AUGUST 1985 EPISODES

Statistic	Modeled	Observed	Percent difference
n	20,155	20,155	
Mean	60.9	56.6	+7.6
Std. deviation	17.7	25.2	-29.8
95th percentile	92.9	102.0	-8.9
Maximum	146.7	179.3	-18.2

TABLE 2-8. DAILY SUMMARIES OF UAM BOUNDARY CONDITIONS [1]

Date (1985)	Mean ozone Modelled (ppb)	Mean ozone Observed (ppb)	Percent diff.	Mean wind Speed (ms^{-1})	Mean wind Direction (°)	Persistence [2]
July 8	46.4	35.1	+32.2	5.2	250	0.89
July 9	59.3	70.1	-15.4	3.8	171	0.72
July 10	66.8	57.1	+17.0	4.6	233	0.80
July 11	63.5	45.5	+40.0	4.7	320	0.91
July 12	61.0	56.5	+8.0	4.6	165	0.80
July 13	72.6	70.0	+3.7	3.1	187	0.52
July 14	64.5	58.9	+9.5	5.9	215	0.89
July 15	67.0	44.9	+49.2	5.2	200	0.94
July 16	61.7	51.1	+20.7	3.0	169	0.73
July 17	57.8	46.1	+25.4	4.4	35	0.83
July 18	56.2	48.9	+14.9	3.7	70	0.22
July 19	74.2	79.6	-6.8	5.9	222	0.94
July 20	70.8	74.1	-4.5	4.4	265	0.85
July 21	53.8	60.2	-10.6	4.1	177	0.55
August 8	46.2	42.3	+9.2	4.7	221	0.87
August 9	54.9	72.0	-23.8	8.7	110	0.48
August 10	55.9	52.1	+7.3	3.6	168	0.80
August 11	52.5	54.5	-4.0	4.0	200	0.80
August 12	56.6	40.3	+40.4	4.4	2	0.88
August 13	59.7	62.5	-4.5	4.1	159	0.68
August 14	69.2	69.7	-0.7	3.8	222	0.70
August 15	80.1	72.7	+10.2	5.4	331	0.94

1. All land-based UAM boundary grid cells were used, during daytime hours only.
2. Persistence = (vector mean wind speed)/(scalar mean wind speed). Data are based on all daytime hourly wind observations from National Weather Service stations near the OMNYMAP domain.

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SECTION 3

OZONE EPISODE SELECTION

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3.1 INTRODUCTION

This Section summarizes the procedures adopted for selecting ozone episodes for simulating the ROMNET emissions scenarios presented in Section 4. Two episodes were selected to examine the effectiveness of various regional strategies. Two other episodes were selected for the ROMNET supplemental evaluation of the ROM. In choosing these episodes particular attention was given to high ambient ozone concentrations and the meteorological flow regimes in the Northeast Corridor. The intent was to simulate conditions that represent a variety of typical meteorological transport patterns associated with high ozone levels in the Corridor. Included in Appendix D are descriptions of the meteorological conditions and observed ozone concentrations during the selected episodes.

3.2 TECHNICAL APPROACH

The selection of ozone episodes for use in the ROM simulations was one of the principal objectives for the ROMNET Modeling Committee. The following five step process was followed by the Committee to select episodes for modeling:

1. 1983-1988 ambient ozone monitoring data in the Aerometric Information Retrieval System (AIRS) were reviewed to identify candidate episodes with ambient ozone levels $\geq$ 125 ppb;
2. quantitative episode selection criteria were identified;
3. a ranking procedure based on these criteria was designed and applied to establish the relative priority of each episode for simulation;
4. meteorological conditions within the ten top-ranked episodes were examined to characterize transport flow regimes; and
5. the highest ranked episodes with the flow regimes of importance were selected for modeling.

In addition to candidate episodes identified from 1983-1988, one 1980 episode (July 12 - 23, 1980) was included in the list of candidate episodes. Prior analyses showed that this episode contained meteorological conditions of potential interest for the ROM modeling.

3.2.1 Initial Ambient Data Review

All hourly ozone data for the period May through September of 1983 through 1988 from over 150 State/local monitoring sites in the ROMNET domain were extracted from AIRS for review. The resulting

database was summarized into a time series of the frequency distribution of maximum ozone concentrations by day for each year. An example is shown in Figure 3-1. The plots were then examined to identify periods of at least three consecutive days when ozone levels were $\geq$ 125 ppb (an exceedance day) within the domain. From these summaries, 27 candidate episodes were identified as listed in Table 3-1.

3.2.2 Episode Selection Criteria

The criteria developed for prioritizing these candidate episodes focused on (1) the magnitude and spatial distribution of high ozone concentrations with emphasis on areas along and adjacent to the Northeast Corridor; (2) the frequency of ozone exceedances; and (3) the representativeness of meteorological conditions to those typically associated with high ozone within the Northeast Corridor.

The following approach was adopted for evaluating the candidate episodes against these criteria and for ultimately selecting the episodes for modeling. First, the 27 candidate episodes were ranked based on an objective analysis of ambient ozone data. This established a relative priority of the episodes for model simulation. Next, for the ten top-ranked episodes, meteorological analyses were conducted to characterize the flow regimes within each episode. The frequency of key flow regimes (described below) were determined for each episode to assess whether a reranking of the episodes was needed to capture the meteorological conditions of importance.

3.2.3 Episode Ranking Scheme

An objective ranking scheme was developed to prioritize the candidate episodes based on ambient ozone concentrations. This scheme consisted of two independent parts. Together, these components provided a comparison between episodes of (1) the magnitude of daily maximum hourly ozone concentrations; and (2) the number of days with an observed exceedance.

The ranking scheme was applied for ozone measurements spatially aggregated within three subregions along the Northeast Corridor and adjacent areas as shown in Figure 3-2. In this scheme, each subregion was weighted equally. The ranking for each part and subregion were combined to obtain a final overall ranking score. A description of the decision rules applied to rank the candidate episodes starts on the next page.

Part 1 - Maximum Hourly Ozone

First, a comparison was made between episodes by subregion (i.e., comparisons were made for subregion 1 for each episode, etc.) as follows:

1. The number of monitoring sites reporting maximum hourly ozone ≥150 ppb over the episode was compared. The episode with the highest reported number of sites was ranked first; the lowest was ranked last.

2. If the number of reporting sites was the same for two or more episodes, the episode with the highest maximum hourly concentration was ranked first; the episode with the lowest concentration was ranked last.

3. If the concentrations were < 150 ppb, then the number of sites with concentrations ≥125 ppb were compared. The episode with highest number of sites reporting ≥125 ppb was ranked first; the lowest number was ranked last.

4. If the number of sites with ozone ≥125 ppb were the same for two or more episodes, the episode with the highest concentration was ranked first; the lowest was ranked last.

5. If concentrations were < 125 ppb, the episode with the highest concentration was ranked first; the lowest was ranked last.

6. If two or more regions had identical characteristics, each episode was ranked equally.

Note: a first ranking was assigned a value of 1, a last ranking was assigned a value of 27. Once all episodes were ranked for each subregion, the rankings assigned to each of the three regions were summed to obtain a total score for each episode (e.g., for episode 7/4/88 - 7/18/88, subregion 1=2, subregion 2=1, subregion 3=1, total=4).

Part 2 - Number of Exceedance Days (≥125 ppb)

In this part of the process a comparison was made by subregion for the number of days with ozone ≥125 ppb, as follows:

1. The number of days with ozone ≥125 ppb at all monitoring sites was compared. The episode with the most number of monitors reporting ≥ 3 exceedance days was ranked first. The episode with the least number of monitors reporting ≥ 3 days was ranked last.

2. If the number of monitoring sites reporting ≥3 exceedance days was the same for two or more episodes, the episode with the highest reported number of exceedance days (e.g., 5 days) was ranked first; the second-highest number of days was ranked second, etc.

3. If the number of monitoring sites reporting ≥3 exceedance days was the same for two or more episodes and the highest reported number of exceedance days was the same for two or more episodes, then the total number of exceedance days reported among all monitoring sites in the subregion was compared. The episode with the highest total was ranked first, etc.

4. For those episodes in which the number of exceedance days reported was < 3 days for all monitors in the subregion, the total number of exceedance days reported among all monitors in the subregion was compared. The episode with the highest total was ranked first, etc.

5. If two or more subregions had identical characteristics, the episodes were ranked equally.

Once all regions and episodes were ranked, the rankings assigned to each of the three subregions were summed to obtain a total score for the episode (e.g., for episode 7/4/88 - 7/18/88, subregion 1=1, subregion 2=1, subregion 3=1, total=3).

The final step in the ranking procedures was to obtain an overall ranking for each episode by combining the Part 1 and Part 2 scores. This is illustrated as follows:

For the episode 7/4/88 - 7/18/88	Score
Part 1 - maximum hourly ozone:	4
Part 2 - number of exceedance days:	3
	Total = 7

The total scores were compared for each episode. The episode with the lowest score was ranked first, etc. Table 3-2 shows the total score and ranking for each of the 27 candidate episodes.

3.2.4 Trajectory/Meteorology Analyses

After ranking the candidate episodes, detailed meteorological analyses were conducted on the ten top-ranked episodes. This was done to characterize the meteorological conditions and transport flow regimes associated with each episode to (1) rerank the order of the top ten episodes if necessary based on meteorology, and (2) select those episodes that best represent the key transport flow regimes and meteorological conditions considered most useful for ROM simulation.

The Modeling Committee determined that the key transport regimes of interest for the modeling were:

- along-Corridor (southwesterly) flow;
- interurban recirculation conditions; and
- westerly flow.

These flow regimes have been historically associated with episodes of high ozone. Because of the geographic location of major ozone precursor source areas in the Northeast, these regimes favor inter-urban and/or intraregional transport of ozone and its precursors. Thus, it is important to simulate such episodes in order to assess the effectiveness of control strategies during transport conditions.

The analysis to identify the occurrence of key flow regimes consisted of two parts. The first was designed to describe the daytime transport flows which actually occurred within the Corridor on days with observed exceedances. Each exceedance day was classified according to one of seven synoptic meteorological patterns. These patterns, and the corresponding within-Corridor flow regimes, are listed in Table 3-3. These patterns were identified based upon a review of midday surface weather maps and summaries of individual National Weather Service surface meteorological observations. Additionally, three-day forward trajectories were constructed using the Atmospheric Transport and Dispersion Model (ATAD) from four Corridor cities to facilitate the determination of the flow regimes within the Corridor.

The second part of the analysis focused on the direction of transport into the Corridor from upwind areas. Each exceedance day was classified according to one of four incoming flow regime classes as follows:

(A) southwesterly (along-Corridor);
(B) westerly;
(C) interurban recirculation;
(D) northwesterly.

For this part, three-day backward trajectories were constructed from five Corridor cities: Portland, Providence, New York City, Philadelphia, and Washington, DC. Additionally, forward trajectories were constructed from four cities in the western part of the domain: Detroit, Pittsburgh, Charleston, and Danville.

Each day of the top ten episodes was classified according to both the synoptic pattern/within-Corridor flow regimes shown in Table 3-3 and the transport flow direction into the Corridor (A through D above). This information was then reviewed to identify the frequency of days during each episode that were characterized by the key transport regimes.

In addition to flow regimes, meteorological data summaries were prepared for each day of the top ten episodes. These summaries provided information on temperature, cloud cover, wind speed, and direction. This information was used in conjunction with the flow regimes to better understand the meteorological conditions characteristic of each episode.

The flow regimes, meteorology conditions, and ozone concentration data were summarized for each exceedance day of each top ten episode. This information was condensed and submitted to the Modeling Committee for review and final selection of episodes for simulation.

3.2.5 Flow Regimes During the Top Ten Episodes

This section summarizes the occurrence of the key flow regimes during the ten top-ranked episodes. Each episode is described below in rank order as given in Table 3-2.

Episode #1: July 4 - July 18, 1988

This episode was characterized by a persistent trough along the Corridor. Flow into the Corridor was generally from the west to southwest on most days. Within the Corridor, along-Corridor flow occurred on 10 of the 15 episode days with weak westerly or recirculation flow on other days.

Episode #2: June 13 - June 23, 1988

A persistent surface trough along the Corridor was also the main feature of this episode. The flow coming into the Corridor was from the west on eight of the episode days. Within the Corridor, along-Corridor flow was noted on only three days with recirculation conditions on two days. The remainder of the days had westerly flow.

Episode #3: July 12 - July 23, 1980

High pressure systems over the east coast and just offshore dominated this episode. Along-Corridor flow occurred on eight of nine days during this episode. The flow into the Corridor was from the southwest or west on eight days.

Episode #4: June 9 - June 20, 1983

This episode was characterized by fronts and a weak pressure pattern within the Corridor. Recirculation conditions occurred on six of the ten days. A west to northwest flow occurred on other days.

Episode #5: August 9 - August 17, 1988

A high pressure system off the east coast was the main meteorological feature during this episode with a weak trough along the Corridor on several days. Flow into and along the Corridor was from the southwest on seven days. A northwest flow occurred on other days.

Episode #6: July 26 - August 5, 1988

A trough along the east coast with weak high pressure over western Pennsylvania were the main meteorological features of this episode. Flow into much of the Corridor was from the southwest on eight days and from the northwest on other days. Within the Corridor, along-Corridor flow occurred on seven days with variable flow on other days.

Episode #7: June 4 - June 13, 1984

A high pressure system was located off the east coast during much of this episode. Flow into the Corridor was from the west on eight of the nine days. Within the Corridor, along-Corridor flow occurred on six days with westerly flow on other days.

Episode #8: July 16 - July 26, 1987

Weak surface flow and fronts were the main meteorological features in the Corridor during this episode resulting in recirculation conditions on most days. Flow into the Corridor was generally from the west or northwest.

Episode #9: August 6 - August 16, 1985

High pressure systems moved across the east coast during much this episode. Flow into and within the Corridor was from the west and/or northwest on three days. Recirculation conditions occurred on four days and along-Corridor flow on four days.

Episode #10: July 26 - August 1, 1983

A high pressure system moved across the Corridor during the first part of the episode followed by a cold front which remained near the east coast for several days. Flow into the Corridor was from the southwest on three days and from the west to northwest on three days. Within the Corridor, along-Corridor flow occurred on three days with variable flow associated with the front on other days.

3.2.6 Episodes Selected for ROM Simulations

The July 4 - July 18, 1988 (July 88) episode produced some of the highest ozone concentrations observed throughout the Corridor since 1980, as indicated from the episode ranking analysis. Additionally, exceedances were observed in rural areas and across much of the western portion of the domain with peak values from 150 to 175 ppb. None of the other top ten episodes displayed a similar spatial extent of high ozone levels. Also, from the meteorological analysis, this episode contains the greatest number of days with along-Corridor flow and transport flow into the Corridor from the western portion of the region. Given the magnitude and frequency of high ozone levels and the frequency of the most important transport flow regimes, this episode was selected for use in simulating the ROMNET control strategy scenarios.

Another episode, representing one of the other key flow regimes, was selected to test the robustness of conclusions drawn from the July 88 episode. The intent was to simulate the final strategy, which reduced predicted ozone to below 125 ppb, with an alternate type of flow regime also associated with high ozone in the Corridor. However, examining the remaining top ten episodes in order of ranking indicates that the second and third ranked episodes (June 88 and July 80) contained flow regimes that were, to a large extent, represented in the July 88 episode (i.e., along-Corridor and westerly flow). Additionally, there was some concern that the dominating westerly flow in the June 88 episode would transport the predicted Corridor ozone plumes offshore over water, and thus complicate the interpretation of model predictions.

The fourth-ranked episode (June 83) was characterized by interurban recirculation conditions, which was quite distinctive from that in other top ten episodes. Thus, June 83 was chosen to complement the July 88 episode for strategy simulations.

In addition to the July 88 and June 83 episodes, two 1985 episodes were selected for use in the ROMNET evaluation of the ROM. Episodes from 1985 were needed since 1985 was the year of the ROMNET base emissions inventory. For this, the highest and second highest 1985 episodes were selected. These episodes are: August 6 - 16, 1985 and July 7 - 22, 1985. The August episode was ranked 9th and the July episode was ranked 23rd.

A detailed description of the meteorological conditions and ambient ozone levels during the four episodes selected for simulation is provided in Appendices D, E, and F. Note that an extra day was added on to the front of three of the episodes in order to initiate ROM simulations on a "clean" day, as described in Section 2.

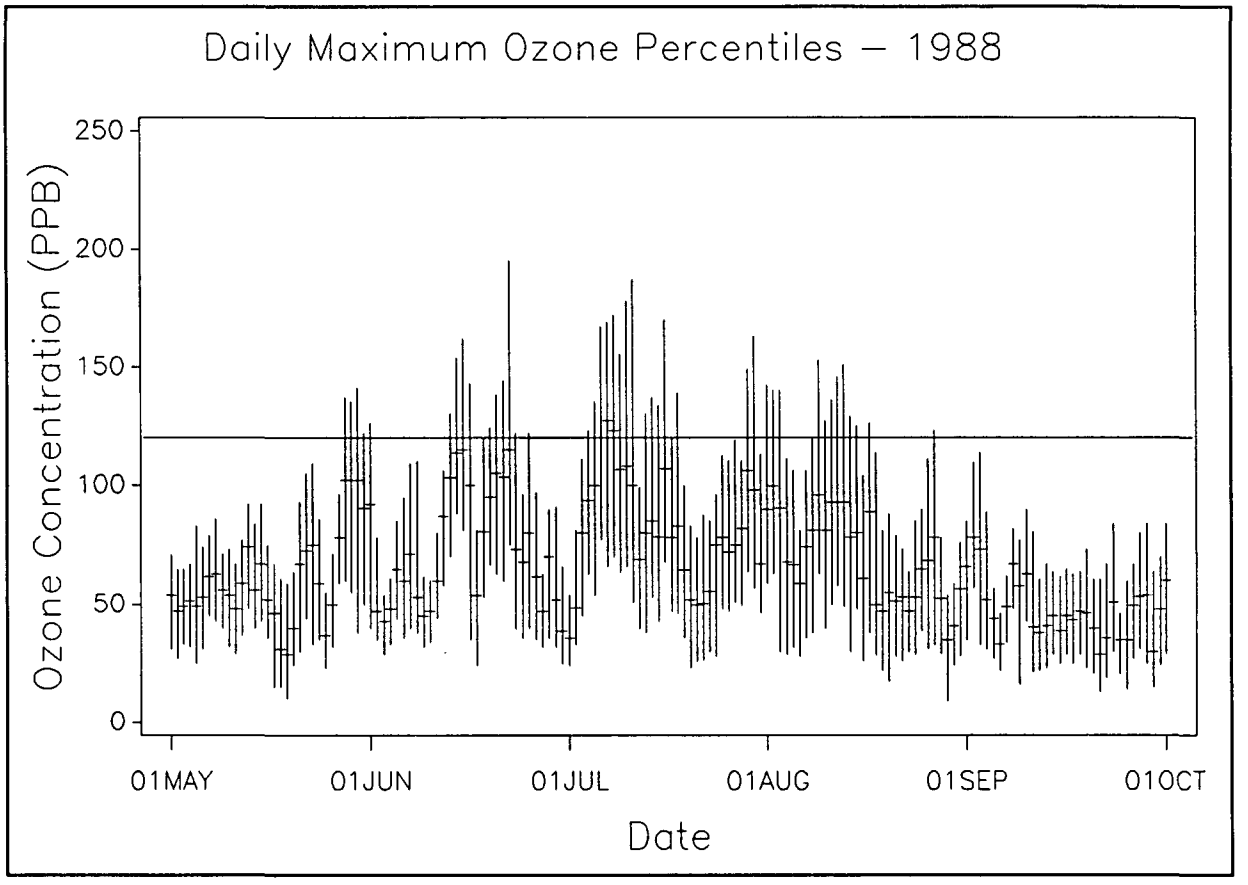

Figure 3-1. Box-plot time series showing the frequency distribution of daily maximum ozone concentrations - May through September, 1988.

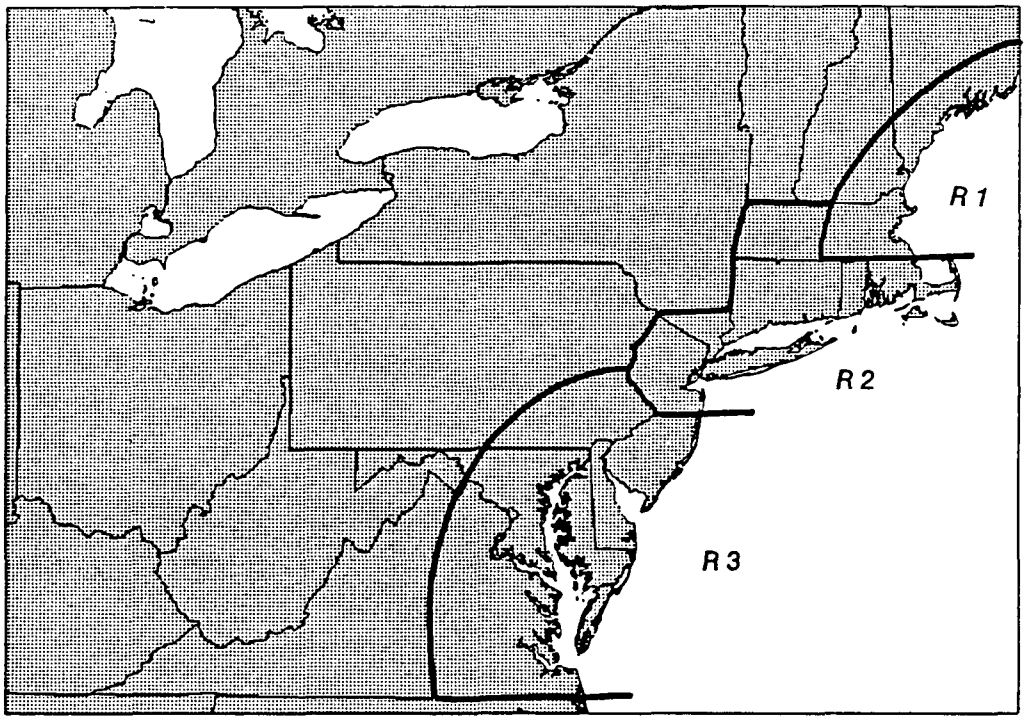

Figure 3-2. Subregions of the Northeast Corridor used for aggregating observed data in the episode selection process. R1: subregion 1; R2: subregion 2; R3: subregion 3.

TABLE 3-1. CANDIDATE EPISODES: 1983 - 1988

1983	1986
June 9 - June 20	May 25 - June 2
July 26 - August 1	June 18 - June 28
August 13 - August 21	July 3 - July 9
August 31 - September 7	
September 8 - September 14	
1984	**1987**
June 4 - June 13	May 27 - June 2
July 9 - July 16	June 14 - June 21
July 29 - August 5	July 6 - July 14
	July 16 - July 26
	August 13 - August 18
1985	**1988**
June 27 - July 6	May 28 - June 1
July 7 - July 14	June 13 - June 23
July 15 - July 23	July 4 - July 18
August 6 - August 16	July 26 - August 5
September 13 - September 23	August 9 - August 17

TABLE 3-2. SUMMARY RANKING OF 27 CANDIDATE EPISODES

Episode	Total Score	Ranking
July 4 - July 18, 1988	7	1
June 13 - June 23, 1988	16	2
July 12 - July 23, 1980	19	3
June 9 - June 20, 1983	26	4
August 9 - August 17, 1988	28	5
July 26 - August 5, 1988	43	6
June 4 - June 13, 1984	47	7
July 16 - July 26, 1987	57	8
August 6 - August 16, 1985	70	9
July 26 - August 1, 1983	74	10
August 31 - September 7, 1983	76	11
July 29 - August 5, 1984	80	12
July 6 - July 14, 1987	80	13
August 13 - August 21, 1983	84	14
June 14 - June 21, 1987	86	15
July 9 - July 16, 1987	90	16
September 8 - September 14, 1983	91	17
May 28 - June 1, 1988	98	18
July 15 - July 23, 1985	103	19
May 27 - June 2, 1987	107	20
August 13 - August 18, 1987	116	21
September 13 - September 23, 1987	120	22
July 7 - July 14, 1985	125	23
May 27 - June 2 1986	131	24
July 3 - July 9, 1986	133	25
June 27 - July 6, 1985	138	26
June 18 - June 28, 1986	140	27

TABLE 3-3. WITHIN-CORRIDOR FLOW REGIMES

Type	Synoptic meteorological pattern and regime description
1	Dominated by high pressure; no fronts/troughs near Corridor: generally weak flow; within-Corridor flow generally light northerly (front side of HIGH); flow in western part of modeling domain generally light southerly (back side of HIGH).
2	Transition regime - high pressure along east coast extending SE and NW: weak surface flow.
3	High pressure system off the east coast: westerly or along-Corridor flow (back side of HIGH).
4	Pre-frontal: along Corridor flow.
5	Cold front or trough along east coast: variable or southwesterly flow.
6	Frontal pattern between New York and Boston: easterly flow north of front; along-Corridor flow south of front.
7	Frontal pattern between New York and Philadelphia; frontal pattern around Baltimore/Washington, DC, and south; low or weak pressure pattern: variable or recirculating flow.

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SECTION 4

EMISSIONS SCENARIO DEVELOPMENT

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4.1 INTRODUCTION

During ROMNET, three types of emissions scenarios were simulated by the ROM: base year, projected future baseline, and control strategies (CS) applied to the future baseline. The base year was 1985 and the future baseline selected was 2005. Two variations of the 2005 baseline were examined along with 24 strategies. All of the ROMNET scenarios are listed in Table 4-1.

This Section of the report describes each of these scenarios and the development of the corresponding anthropogenic and biogenic emissions inventories. An overview of the basic emissions inventory structure common to all scenarios is presented first, along with a description of the methodologies used for spatial, temporal, and species allocation of the emissions data (Section 4.2). This is followed by a discussion of the development and characteristics of the 1985 base year scenario (Section 4.3). Presented next is the development of the 2005 scenarios and control strategies (Section 4.4). Control efficiencies and details on specific control measures are provided in Section 4.5. Finally, biogenic emissions inventory development is explained in Section 4.6.

4.2 OVERVIEW AND STRUCTURE OF EMISSIONS INVENTORIES

4.2.1 Features of the ROMNET Inventories

In general, ROMNET inventories provide emissions data for volatile organic compounds (VOC), nitrogen oxides (NO_x), and carbon monoxide (CO), which are precursors in tropospheric ozone formation. NO_x emissions are partitioned into NO and NO_2. VOC emissions are assigned into one of ten reactivity classes: olefin (OLE), paraffin (PAR), toluene (TOL), xylene (XYL), formaldehyde (FORM), other aldehydes (ALD2), ethene (ETH), isoprene (ISOP), nonreactive (NONR), and methanol (MTHL). VOC classifications are based on the Carbon Bond IV system, discussed in depth by Gery *et al.* (1988). Emission rates have been adjusted to reflect activity levels and temperatures characteristic of episodes with exceedences of the ozone NAAQS in the Northeast.

Anthropogenic emissions data are provided separately for point sources, stationary area sources, and mobile sources. Point sources include all plants emitting 100 tons per year or more of any criteria pollutant (VOC, NO_x, or CO) that were handled on an individual point basis in the EPA's National Emissions Data System (NEDS).

The area-source inventory does not address individual sources, but instead contains emissions for aggregated groups of sources that are too small or numerous to be covered by the point source inventory. Area sources in the ROMNET inventory include minor fuel combustion sources; open burning and solid waste disposal; structural and forest fires; non-highway transportation sources, such as trains, airplanes and off-highway vehicles; solvent evaporation from paints and other solvent uses; and some industrial fugitive emissions and process vent emissions. The mobile source inventory includes aggregates of highway vehicle emissions. The mobile-source data further classify VOC emissions into evaporative emissions from gasoline vehicles, exhaust emissions from gasoline vehicles, and exhaust emissions from diesels (evaporation emissions from diesels are negligible).

Both the mobile- and stationary area-source inventories include emissions for three separate day types: typical weekdays, Saturdays, and Sundays. Each of these contains hourly emission profiles for the 13 pollutant species categories listed above. Emissions in these inventories are spatially allocated into the ROM grid system.

The point-source inventory contains hourly allocation factors for the three day types, as well as the location of each source, along with other pertinent data such as stack height, emission temperature, operating rate, source classification code (SCC), and Standard Industrial Classification (SIC).

The point-, area-, and mobile-source emissions inventories representing the various ROMNET scenarios were developed by Alliance Technologies and delivered to Computer Sciences Corporation for processing and preparation for input to the ROM. An overview of the methodologies used by Alliance to generate these inventories is discussed next. Emissions input processing procedures followed by CSC are described in Section 2.2.

4.2.2 Emissions Allocation Methodologies

The ROMNET inventory development effort relied heavily on a data management software system developed under the National Acid Precipitation Assessment Program (NAPAP). This software, known as the Flexible Regional Emissions Data System (FREDS), is used to prepare a gridded hourly database suitable for input to the ROM emissions-processing system. Figure 4-1 summarizes the modules used in FREDS and the input data required by each module.

The initial annual inventory has only one field for organic compound emissions, in which either VOC or THC is entered, depending on the source category. The Hydrocarbon Preprocessor uses methane emission data to calculate emissions of the missing pollutant, so that the output from this step contains

both THC and VOC emissions. Other nonreactive pollutants are treated as VOC in this step. For some source categories, the Hydrocarbon Preprocessor adjusts THC and VOC to add formaldehyde, which is not detected by some hydrocarbon measurement techniques.

The annual inventory also contains data on a number of pollutants besides VOC, THC, NO_x, and CO. Entries for these other pollutants are removed in the Model Data Extraction step, in order to reduce computer processing time.

The Speciation Module divides THC and VOC into reactivity classes, and NO_x into NO and NO_2, using speciation factor files compiled by the PSPLIT program. The Spatial Allocation Module assigns emissions to modeling grids, and the Temporal Allocation Module resolves annual emission rates into hourly rates for different seasons and day-types. The order in which these three modules are run depends on the inventory subset being processed. For mobile- and area-source inventories, the modules are run in the above order. For point sources, spatial allocation is performed first, followed by temporal allocation and speciation. The last module of FREDS is the Model Input Preprocessor, which produces a final resolved inventory that is input to the ROM emissions-processing system.

For point sources, spatial allocation to modeling grids is based on point-specific UTM coordinates in the NEDS inventory. Temporal allocation for point sources is based mainly on operating data provided in the inventory. State- and category-specific operating profiles were developed for certain utility groups based on data provided by the Department of Energy and the Tennessee Valley Authority.

Spatial and temporal allocation for area and mobile sources is performed using average factors, since these sources are handled as county and source category aggregates in the NAPAP annual inventory. Spatial allocation factors are based on land use patterns, population distributions, and spatial distributions of other emission surrogates; thus, they are specific to counties and source categories.

Speciation factors for point sources as well as area and mobile sources are source-category averages based on average emission composition. Additional detail on FREDS and on the various allocation factors can be found elsewhere (EPA, 1989; Modica *et al.,* 1988; and Walters *et al.,* 1988).

4.3 1985 ROMNET BASE CASE EMISSIONS DEVELOPMENT

4.3.1 Parent Emissions Inventories

The ROMNET base year inventory is derived from the NAPAP 1985 emissions database, which in turn is derived from the NEDS. The NAPAP database provides a number of benefits as a starting point for ROMNET. Chief among these benefits is the extensive data gathering and quality control effort that went into the NAPAP database. The NAPAP database also provides a consistent inventory for the entire ROMNET domain, including Canada. Finally, data management software developed under NAPAP allows the flexibility to make the modifications needed for ozone modeling, including VOC speciation and adjustments for temperature effects.

The 1985 NAPAP emissions database covers the 48 contiguous United States, the District of Columbia, and Canada to 60 °N latitude. Emissions data are included for VOC, THC, CO, SO_2, NO_x, NO, NO_2, four other acid gases, 32 hydrocarbon classes, and 15 classes of particulate matter. The overall database includes two basic inventory types: an annual inventory, and a set of 12 temporal scenario inventories representing a typical weekday, Saturday, and Sunday in each of the four seasons. Further information on the NAPAP inventories is provided by Saeger *et al.* (1989).

4.3.2 Adjustments to the NAPAP Inventories

A number of modifications were made to the 1985 NAPAP database in order to produce the ROMNET 1985 base year anthropogenic inventories. The key changes included (1) adjustment of VOC emissions for several stationary source categories to reflect meteorological conditions and activity patterns typical of high ozone episodes, and (2) upgrades to mobile source emissions to reflect the latest version of the MOBILE model and to adjust mobile emissions for grid-specific daily temperatures. Procedures for implementing these adjustments and upgrades are described in this Section. Other changes made to the NAPAP inventory, including quality control review of both major CO point sources and VOC emissions from hazardous waste treatment, storage, and disposal facilities (TSDFs) are described in Alliance Technologies Corp. (1989). The outcome of the adjusted VOC emissions combined with other portions of the NAPAP inventories resulted in the 1985 ROMNET base case emissions inventories for VOC, NO_x, and CO.

Stationary-Source Adjustments

In the NAPAP seasonal allocation methodology, calculation of area-source summer emissions is based on typical seasonal "activity" patterns and average temperatures. "Activity" in this sense is similar to a throughput for a point source. Thus, the NAPAP allocation factors do not take into account increases in emissions due to the greater activity and higher temperatures that accompany fair-weather conditions associated with ozone episodes. In addition, data are lacking on seasonal activity patterns for a number of VOC area source categories; therefore emissions from these categories are assumed in NAPAP to be uniform throughout the year.

In order to obtain emissions levels more representative of ozone episodes, VOC emissions from six different area source categories were adjusted for temperature and expected enhanced activity patterns during episodes. Three categories were adjusted for temperature effects on vapor pressure:

- Gasoline marketing (Category 54)
- Bulk gas terminals and plants (Category 103)
- Hazardous waste treatment, storage, and disposal facilities (Category 109).

Another three categories were adjusted for effects of weather on activity patterns:

- Gasoline vessels (Category 52)
- Architectural coating (Category 82)
- Miscellaneous solvent use (Category 95).

The adjustment for gasoline vessels accounts for increased activity levels on the use of pleasure boats, which make up the bulk of this category. The adjustment for miscellaneous solvent use accounts for activity effects on pesticide use. For architectural surface coating, one might expect the main influence to be the effect of temperature on evaporation rate. However, temperature effects on evaporation rate are small in comparison with the uncertainty of hourly solvent usage profiles. The main activity effect for this category is higher usage of external oil-based paint on rain-free days.

These six categories contribute a total of about 6 percent to the overall VOC inventory for the ROMNET region. The maximum contribution for any single category is 2 percent (for gasoline marketing). Since none of the six categories rivals mobile sources for VOC emissions, a day-specific adjustment was judged to be unnecessary. Rather, emissions were adjusted to reflect conditions on a typical episode day. The adjustments were accomplished by changing the summer temporal allocation factors for these categories. The values adopted for the ROMNET program are shown in Table 4-2. The procedures

used to calculate these factors are described in Alliance Technologies Corp. (1989). The effect of these adjustments was to increase total 1985 anthropogenic VOC in the ROMNET region by 6.5 percent compared with the NAPAP inventory.

Adjustments were also considered for a number of point-source categories and other area-source categories, including degreasing and other industrial solvent use categories. However, these operations are conducted indoors in controlled environments, and hence are not influenced by outside temperatures or weather effects. Adjustments were also considered for point-source volatile organic liquid storage, because emissions from this category are sensitive to temperature in the same way as bulk gasoline terminals and bulk plants. However, adjustments of point-source emissions would have been much more difficult than area sources, and the combined contribution from point source storage categories was only about 0.4 percent of the overall VOC inventory. Thus, no adjustments were made to VOC point source emissions.

Mobile Source Adjustments

The purpose of mobile source adjustments in ROMNET was to produce emissions estimates that reflect the EPA's latest revisions to the MOBILE emission factor model (EPA, 1989), and that are representative of the high temperatures during ozone episodes. In addition, emission estimates in the mobile inventory were revised to reflect the sensitivity to temperature of motor vehicle inspection and maintenance (I/M) program control efficiency estimates.

MOBILE is an empirical model used by the EPA to calculate emission factors from mobile sources under different conditions. Maintained by the EPA's Office of Mobile Sources (OMS), it calculates emission factors on a gram per mile basis for different types of vehicles at different speeds. These emission factors depend on average daily temperature, diurnal temperature variation, and other model inputs such as vehicle age distribution and operating conditions.

Emission rates in the NAPAP inventory were generated with MOBILE3.0 using annual average ambient temperatures at the State level. However, following the completion of the NAPAP inventories, upgrades to the MOBILE model were made by EPA. In order to use the most current methodologies in ROMNET, mobile emissions were revised twice during the program as new versions of the MOBILE model became available. At the start of ROMNET MOBILE4 had not been released, but a predecessor version, MOBILE3.9, was available. Thus, the NAPAP emissions were first revised using MOBILE3.9 for the original ROMNET 1985 base case inventory. This inventory was later upgraded with MOBILE4.

The major differences between the three versions of MOBILE pertain to the treatment of evaporative emissions. MOBILE3.0, used in NAPAP, includes temperature-dependence functions for exhaust emission factors, but not for evaporative VOC. MOBILE3.9 relates evaporative emission factors to average ambient air temperature, diurnal temperature variation, and fuel volatility expressed in terms of Reid vapor pressure (RVP). MOBILE4 adds calculations for running loss and excess evaporation based on recent test data. Both of these latter terms refer to evaporative emissions caused by the inability of existing carbon adsorption fuel vapor control systems to handle recent increases in fuel volatility. Running losses occur while the vehicle is running and excess evaporation occurs while the vehicle is standing.

Figure 4-2 and Figure 4-3 show the impacts of average daily temperature and diurnal temperature variation, respectively, on VOC emission factors predicted by MOBILE4. The figures also illustrate the estimated additional contribution of running loss and excess evaporation to total VOC. NO_x and CO emissions also vary with average ambient temperature, although to a lesser extent than VOC. These latter two pollutants are not affected by the range in diurnal temperature changes.

As Figure 4-2 shows, the effect of average daily temperature on VOC emissions is minimal up to about 70°F but is substantial at the higher temperatures representative of ozone episodes. Because of this strong dependence on temperature, and because the mobile-source inventory accounts for a substantial portion of the overall inventory, the ROMNET mobile methodology was designed to adjust mobile emissions based on grid-specific, daily average temperature and diurnal variation for each ozone episode day that is modeled.

Development of the mobile-source adjustment methodology was complicated by the volume of data in the mobile-source inventory. The general goals in developing the adjustment methodology were to: (1) limit data processing requirements, and (2) minimize the errors introduced by any simplifying assumptions. There are twelve categories of highway mobile sources for each county in the inventory, made up of a matrix of four vehicle types by three roadway types. The vehicle types included in the inventory are light duty gasoline vehicles, light-duty gasoline trucks, heavy-duty gasoline vehicles, and heavy-duty diesel vehicles. The roadway types are limited-access highways (50 mph), rural roads (45 mph), and urban roads (19.6 mph). Each combination of vehicle type and road type is derived from a separate MOBILE emission factor and is entered separately in the inventory.

Day- and grid-specific temperature adjustment on a category-by-category basis would have required production of a set of gridded, hourly inventories for each of the twelve mobile source categories. On

the other hand, lumping the twelve categories together prior to the adjustment would not allow county-level variations in vehicle- and road-type distributions to be reflected in the adjustment factors, causing errors in the county- and grid-level emissions.

Other factors also complicated the design of an adjustment methodology. For example, the use of mobile-source inspection and maintenance (I/M) programs varies across the region, and the effectiveness of these programs in reducing emissions has been shown to vary widely from State to State. In addition, evaporative emission factors, exhaust emission factors for gasoline vehicles, and diesel exhaust emission factors respond differently to temperature and have significantly different VOC species compositions. Thus, the distribution of VOC across reactivity classes varies with temperature.

The final methodology adopted for ROMNET involved a two-step approach that satisfied both of the above goals. The basic approach was to make most of the necessary adjustments on a category-specific basis with the annual mobile inventory.

In Step 1, each mobile source category in the annual inventory was adjusted separately to reflect emission factors from new versions of the MOBILE model. For MOBILE3.9, running loss and excess evaporative emissions are added in this step as described by Alliance Technologies Corp. (1989). The temperature used in generating the inventory was changed from the State-specific annual averages used in NAPAP (ranging from about 45°F to 58°F for the ROMNET region) to a common daily average temperature of 85°F and a diurnal variation of 20°F. These values yield the median emission factor for the expected diurnal temperature range over the ROMNET region in an ozone episode (approximately 75°F to 95°F). VOC emissions in this step were separated into evaporative emissions, gasoline exhaust, and diesel exhaust to account for changes in VOC speciation as the mix of emissions from these categories changes with temperature. Also, I/M control efficiency assumptions used in the NAPAP inventory were removed in Step 1.

At the end of Step 1, mobile source VOC, NO_x, and CO emissions were aggregated to county totals, retaining separate totals for the evaporative emissions, gasoline exhaust, and diesel exhaust. The resulting interim mobile inventory was then processed through FREDS to produce gridded, speciated, hourly inventories for the three summer day-types (weekday, Saturday, and Sunday).

In Step 2, the mobile emission estimates were altered at the grid level to reflect observed temperatures on each episode day modeled. This step was performed in the ROM emissions processors using a table of mobile source emission factors for different daily average temperatures and diurnal ranges. The table (given in Appendix G for MOBILE4) covers average daily temperatures ranging from 40°F to 90°F and diurnal variations of 0°F to 40°F. Because vehicle and road classes in the original inventory are

grouped together at Step 2, the final adjustment table contains "composite" emission factors, or weighted averages of factors for the various classes which represent typical distributions in vehicle and road types over the ROMNET region. However, VOC emission factors are divided into evaporative, gasoline exhaust, and diesel exhaust components to allow recalculation of VOC species breakdowns based on final grid- and day-specific temperatures. In this step, emissions control efficiencies are also revised to reflect grid-specific temperatures and are then applied to the "uncontrolled" inventory.

After the final adjustment of VOC emissions, VOC species profiles were recalculated for each grid and day. This was done by using three separate sets of VOC speciation factors to calculate molar emissions by reactivity class for the evaporative, gasoline exhaust, and diesel exhaust components of VOC. Total moles of each reactivity class were then calculated by combining the results for the three VOC components. With this recalculation, the final speciation was representative of grid- and day-specific temperatures.

The result of Step 2 was a gridded hourly inventory for each day modeled, in which the emissions of VOC, NO_x, and CO, as well as VOC speciation in each grid, reflect the day-specific temperatures in that grid. These mobile emissions were merged with point and area emissions categories in the ROM emissions processors.

4.3.3 Characteristics of the 1985 Base Case Emissions

Source Category Distribution

The distribution of emissions between major source categories (point, area, and mobile) and within each of these categories is an important component of an emissions inventory. While the distribution varies from State to State, the discussion in this subsection will focus on the distribution of emissions within the US portion of the ROMNET domain. For mobile sources, a daily average temperature of 85°F with a diurnal range of 75°F to 95°F was used in calculating emissions. A detailed listing of the ROMNET typical weekday VOC, NO_x and CO emissions by category for all States in the domain is contained in Appendix H.

Figure 4-4a illustrates the relative contributions of VOC emissions from point, area and mobile sources. The portion of the VOC inventory due to area and mobile sources are nearly equal, while point-source emissions contribute only 7.5 percent of the total VOC emissions. Point source emissions have been broken into seven categories: utilities, chemical processes, industrial/institutional boilers, surface coat-

ings, storage tanks, solvent use, and other. The relative contributions from these categories are also shown in Figure 4-4b. VOC emissions from chemical processes, surface coating and solvent use account for more than half of all VOC emissions from point sources.

The distribution of VOC area-source emissions is shown in Figure 4-4c. Major categories include: solvent use; treatment, storage, and disposal facilities (TSDFs); combustion; fires; gasoline marketing; off-highway vehicles; and other. Over half of all VOC area source emissions come from solvent use.

Mobile-source VOC emissions are split into three categories: evaporative, exhaust, and diesel. As shown in Figure 4-4d, evaporative emissions comprise nearly three-quarters of the VOC emissions from mobile sources. This is based upon a Reid Vapor Pressure (RVP) of 11.5 pounds per square inch for gasoline. As the RVP is lowered in future years or in control strategy simulations, the relative contributions of evaporative and exhaust emissions can change significantly.

Over half of the NO_x emissions in the ROMNET domain are released by point sources, one third from mobile sources, and the remainder from area sources, as illustrated in Figure 4-5a. Major categories of point source NO_x emissions include: utilities, chemical processes, industrial/institutional boilers, and other. The majority of the point-source NO_x emissions, over eighty percent, are from utilities, as shown in Figure 4-5b.

Major NO_x area-source categories include: off-highway vehicles, combustion, and fires. As shown in Figure 4-5c, off-highway vehicles and combustion comprise over 99 percent of the area-source NO_x emissions.

Spatial Patterns

County-level emissions were allocated to grid cells based upon land use patterns, population distributions, and spatial distributions of other emission surrogates. Figure 4-6 displays the spatial distribution of VOC and NO_x emissions across the domain. High emission densities for VOC are noted near several cities: Detroit, Cleveland, Cincinnati, Charleston, Richmond, Washington DC, Baltimore, Philadelphia, Pittsburgh, New York, and Boston. Several grids in the core of New York City have the highest level of VOC emissions in the region. As shown in Figure 4-4, most VOC emissions are derived from mobile or area sources. Both of these source categories are clustered near large cities.

However, the high NO_x emission densities seen in Figure 4-6 are not related to large cities, but are associated with large combustion sources. This is further illustrated in Figure 4-7, which shows the

locations of industrial boilers and utilities with greater than 500 tons per year of NO_x. While large combustion sources are located in the Northeast Corridor, the majority of the large utilities are located in the western and southern portion of the domain, in Ohio, Pennsylvania, West Virginia, and Virginia.

Temporal Patterns

As indicated in Section 4.2.1, emission rates for individual days are treated as one of the following: a weekday, a Saturday, or a Sunday. Due to varying operating schedules, emission rates for these three categories differ. Emission totals for VOC, NO_x and CO for each day type are shown in Figure 4-8. The pattern of highest emissions on weekdays, then Saturdays, and finally Sundays are shown for all three pollutants.

Daily emission rates are converted to hourly values by applying operating schedules for point sources or temporal profiles for area and mobile sources. Figure 4-9 and Figure 4-10 show the results of applying these profiles for VOC, NO_x, and CO emissions for a typical weekday. VOC hourly emission rates for area and mobile sources show considerable diurnal variation. Point-source VOC emissions are relatively constant throughout the day.

Diurnal NO_x emission rates for mobile sources contain large variations due to the assumed traffic pattern. Both area- and point-source NO_x emissions show higher emission rates during daylight hours, but little variation overall. Hourly CO mobile-source emissions also show considerable hourly variation due to the assumed traffic pattern. Area-source CO emissions increase during daylight hours, while point-source CO emissions do not change significantly throughout the day. On an overall basis, approximately 60 percent of the VOC, NO_x, and CO emissions are emitted between 0600 EST and 1500 EST.

Effects of Temperature on Mobile Emissions

Mobile-source emissions, especially VOC and CO, are sensitive to the average daily temperature. Hourly emission rates for mobile sources are computed by using a daily average temperature value for each individual grid cell. Appendix G lists emission rates for selected temperatures and temperature ranges. Figure 4-11 illustrates the spatial distribution of mobile-source VOC emissions at 1500 EST on a "cool" and a "warm" simulated as part of ROMNET. Domain average daily temperatures for these days were 71.7°F and 78.7°F, respectively.

Due to the relatively small difference in temperature between the two days, there is little variation in the emissions pattern. On an overall basis, VOC emissions are approximately 20 percent higher on the warm day than on the cool day.

Figure 4-12 and Figure 4-13 illustrate the domain total mobile-source VOC, NO_x and CO emissions for each day of the July 1988 episode (refer to Appendices D, E, and F for a description of the daily meteorology during ROMNET episodes). The values reflect both temperature effects and temporal profiles for weekdays versus Saturday and Sunday. VOC mobile source emissions vary between approximately 7,000 and 12,000 tons per day, NO_x between 4,800 and 6,200 tons per day and CO, emissions vary between 32,000 and 48,000 tons per day.

4.4 PROJECTION YEAR AND CONTROL STRATEGY SCENARIOS

The 2005 future baseline was derived from the 1985 ROMNET base case inventories. The year 2005 was selected because it was considered to be far enough into the future to provide the time needed for implementation of stringent control measures and yet not beyond the outer bound for developing credible projections of population and industrial growth.

In essence, the future baseline includes the net effect on emissions of expected growth as well as reductions associated with controls from existing State measures and Federal programs. As indicated earlier, 24 control strategies were developed and simulated during ROMNET. These strategies were derived by applying controls to the 2005 baseline, and in general, they fall into the following categories:

- technology-based controls on sources of VOC and/or NO_x;
- "across-the-board" VOC reductions beyond that achieved by technology; and
- reactivity-based strategies.

In addition, simulations were conducted to address the efficacy of controls relative to uncertainty in biogenic emissions and rule effectiveness assumptions. The ROM simulations were conducted in two Phases as indicated in Table 4-1. In Phase I, MOBILE3.9 was used for all scenarios, whereas MOBILE4 was used in Phase II. Also, as described below, there were some differences between Phase I and Phase II future baseline scenarios in the treatment of existing VOC and NO_x controls. The remainder of this Section provides an overview description of the future baseline and control strategy scenarios. The impacts on regional VOC, NO_x, and CO emissions of projection and control measures applied in the Phase II scenarios are shown in Figure 4-14 through Figure 4-16. The change in regional emissions resulting from the Phase I scenarios are given in Appendix I, which also contains the changes to emissions for individual urban areas resulting from both Phase I and Phase II scenarios. Section 4.5 contains specific control levels used in generating the baseline and strategy emissions inventories.

4.4.1 Overview of Future Baseline Scenarios

This section provides a description of the Phase I and Phase II baseline scenarios. Control measures in these scenarios are summarized in Table 4-3.

BS05 - Phase I 2005 Baseline: Constant NO_x

The Phase I 2005 baseline takes into account New Source Performance Standards (NSPS), the Federal Motor Vehicle Control Program (FMVCP), a proposed gasoline Reid vapor pressure (RVP) standard of

9.0 psi, and existing State regulations for VOC. Existing State rules include inspection and maintenance (I/M) programs for mobile sources, and State Implementation Plan (SIP) regulations for point and area sources. Throughout Phase I, mobile source emissions were evaluated using MOBILE3.9, with some adjustments to VOC factors to account for running losses and excess evaporative emissions. The Phase I baseline also incorporates the concepts behind the protocol of an international convention on long-range transboundary air pollution, which caps national annual NO_x emissions at 1987 levels.[1] Because 1987 NO_x emissions estimates were preliminary at the time this inventory was created, and also to simplify the analysis of modeling results, NO_x emissions were actually capped at the levels in the 1985 ROMNET inventory. Caps were applied at the State level, meaning that total point, area and mobile source NO_x emissions in each State were held to the 1985 level. This was done by controlling growth in utility and industrial boiler emissions at the levels necessary to offset overall NO_x emissions growth, taking into account reductions already achieved by NSPS and FMVCP rules. The NO_x protocol caps were kept for all of the Phase I strategy inventories, and no further NO_x controls were applied.

BS05 - Phase II 2005 Baseline: NO_x Growth

Two important changes were made between Phase I and Phase II of the ROMNET strategy analysis. First, MOBILE4 replaced MOBILE3.9 for evaluations of highway vehicle emissions. Second, the NO_x emission caps in Phase I were replaced by growth and controls applied to specific NO_x emissions categories. Refinements for the projection algorithms were also made between Phase I and Phase II, resulting in minor changes in emissions for some categories.

The Phase II baseline projection, like its Phase I counterpart, takes into account existing control measures: NSPS, FMVCP, the proposed RVP standard of 9.0 psi, and existing State regulations. In addition, emissions in the utility sector were reduced by a five percent energy-efficiency conservation factor, applied to initial growth estimates for all utility sources. This factor accounts for efficiency improvements expected to be realized by 2005, both in the generation and use of electricity. Such improvements would reduce utility fuel consumption, thereby reducing emissions of all pollutants.

Differences between MOBILE3.9 and MOBILE4 resulted in a 32 percent reduction in highway vehicle emissions of VOC between the Phase I and Phase II 2005 baseline inventories. This translates to a five percent reduction in overall VOC emissions. A similar reduction, about 29 percent or 1100 tons per day regionwide, occurred in mobile-source NO_x emissions. This was offset by a 1200 ton per day (14 per-

1. Revised Draft Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution Concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes. United Nations Economic and Social Council. May 10, 1988.

cent) increase in point-source emissions, due to the removal of NO_x emissions caps. Overall, NO_x emissions from all sources increased by less than one percent between the Phase I and Phase II baseline projections.

2005 Baseline Canadian Emissions

A single set of growth and emissions control assumptions was used for Canadian emissions in the 2005 baseline and control strategy scenarios. There were some differences between the Phase I and Phase II Canadian inventories, however, in that MOBILE3.9 was used to evaluate highway vehicle emissions in Phase I and MOBILE4 was used in Phase II.

Environment Canada provided information on the control measures anticipated for Ontario for the 2005 baseline. For VOC, current US FMVCP standards were applied to Ontario mobile sources, and the emissions controls in Strategy 1 (see below) were applied to point and area sources. Current US FMVCP standards were also applied to mobile source NO_x emissions, but no point or area source NO_x controls were applied. The changes in Canadian emissions between the 1985 and 2005 Phase II scenarios are a 42 percent reduction in VOC, a 10 percent reduction in NO_x, and a 33 percent reduction in CO.

4.4.2 Overview of the Control Strategy Scenarios

The ROMNET control strategies were designed to address several issues that were determined by the Management Review and Technical Committees to be of greatest importance in achieving the goals of ROMNET. These issues - posed as questions - are listed below along with the control strategies (CS) to address them:

1. What are the relative benefits of VOC versus NO_x controls in reducing ozone levels?
   [CS10 - CS14]
2. What is the impact of reducing regional transport on ozone concentrations in the Northeast Corridor?
   [CS01, CS02, CS03, CS24, CS25]
3. What levels of VOC and/or NO_x emissions reductions are necessary to reduce predicted ozone levels in the Northeast to below 125 ppb?
   [2005 baseline, CS01, CS05, CS10 - CS16, CS18, CS19, CS23]
4. What are the effects of reactivity-based strategies in reducing regional ozone levels?
   [CS15, CS20]

5. How does uncertainty in biogenic emissions affect conclusions drawn about the benefits of controlling anthropogenic sources?
   [1985H, 1985L, CS06 - CS09, CS17, CS21, CS22]

An overview of each strategy scenario is provided below. Details on specific control measures are provided in Section 4.5. Strategies are numbered in the chronological order of simulation. The rationale for this sequence of strategies was determined in part by the following considerations:

- a technology-based approach for control (i.e., iteratively adding source-specific controls) was adopted for ROMNET rather than starting with large across-the-board reductions to seek target combinations likely to reduce ozone to < 125 ppb;
- the initial focus was on VOC controls with subsequent incorporation of NO_x controls, then measures that affect reactivity;
- across-the-board reductions were applied on top of technology-based controls on an urban area specific basis when maximum technology was insufficient to reduce ozone to < 125 ppb;
- the extent of NO_x controls was reduced in selected urban areas where NO_x control appeared to be counterproductive as determined from earlier simulations;
- the impact of considering control (rule) effectiveness was simulated as one of the last strategies in order to use, as a starting point, the strategy that reduced ozone to < 125 ppb assuming all controls are 100 percent effective; and
- biogenic sensitivity scenarios, which are easy to handle because they combine previous strategies with across-the-board changes in biogenics, were simulated during various "windows of opportunity" while inventories for other strategies were being developed.

Several strategies were applied to the Northeast Corridor only and/or to nonattainment urban areas in the region. The Corridor and nonattainment areas are shown in Figure 4-17.

CS01: Phase I Maximum Technology VOC

Strategy I is the Phase I maximum technology scenario which includes the same FMVCP, RVP and NO_x cap as the Phase I baseline. In addition, enhanced I/M was included for the entire ROMNET domain. A number of control measures were also applied to point- and area-source VOC emissions. NSPS controls, which currently cover only new sources, were applied to all applicable categories in the maximum technology inventory. EPA Control Techniques Guidelines (CTG) were also applied to area- and point-source categories, regardless of size. Controls were also extended to non-CTG and non-NSPS surface-coating categories by assuming technology transfer. Stage I and Stage II evaporative emissions controls were applied to gasoline marketing; prescribed forest and agricultural burning were eliminated during the ozone season; and architectural-coating emissions were reduced by 52

percent through substitution for oil-based coatings with water-based coatings. Finally, miscellaneous nonindustrial (commercial/consumer) solvent emissions were reduced by 20 percent. Control measures in this scenario are summarized in Table 4-3. Overall, VOC emissions in CS01 were reduced by about 45 percent from the Phase I 2005 baseline inventory. Emissions of NO_x are unchanged and CO was reduced by 13 percent.

CS02 and CS03: Spatial Analyses of VOC Controls - Transport Sensitivity Scenarios

Strategies 2 and 3 (CS02 and CS03) were permutations of the Phase I 2005 baseline and CS01 maximum technology inventories. These scenarios were developed to study the impact of applying maximum technology VOC controls in different portions of the ROMNET domain. In CS02, maximum technology controls were applied to the Northeast Corridor, while emissions in the remainder of the ROMNET domain were left at the 2005 baseline levels. In the Corridor, the effect was a reduction of 45 percent in VOC and 10 percent in CO with NO_x emissions unchanged compared to the 2005 Phase I baseline. Outside the Corridor emission in CS02 are the same as the 2005 baseline.

CS03 applied maximum technology VOC controls to the Corridor and nonattainment areas outside the Corridor, again maintaining the rest of the domain at the 2005 baseline. In CS03, emissions in the US portion of the region outside the Corridor were reduced by 24 percent for VOC and 7 percent for CO with NO_x unchanged.

CS04: Rule Effectiveness Sensitivity Scenario

In the technology-based, reactivity, and across-the-board strategies, emissions controls are assumed to be 100 percent effective. For the reasons listed in Section 4.5, this is not the case in "real world" operations. The intent of this scenario was to apply more realistic estimates of control effectiveness to the VOC controls in CS01. However, the results of CS01 indicated that considerably more VOC control and, most likely, NO_x controls would be needed to reduce predicted ozone to below 125 ppb. Thus, it was decided to apply the concept of control effectiveness to a more stringent strategy. This was done in CS23, and thus CS04 was not simulated.

CS05: 1989 Proposed Clean Air Act Legislation

In September 1989, the then-pending draft Clean Air Act legislation was simulated in ROMNET Strategy 5. The legislation analyzed was House Resolution 3030 with the October 1989 Waxman-Dingell tailpipe

standards for highway vehicles. As with other ROMNET projection and strategy inventories, emissions were estimated for the year 2005. The draft legislation substantially reduced tailpipe emissions from the current FMVCP standards in a phased program, to 0.4 g/mile for NO_x and 0.25 g/mile for VOC. Gasoline RVP was reduced to 9.0 psi (as was assumed in the ROMNET baseline). Requirements for mobile-source I/M programs varied in different areas of the ROMNET domain, depending on the severity of the ozone problem. These programs were applied at the Metropolitan Statistical Area (MSA) level. For moderate nonattainment areas, basic I/M programs were upgraded to EPA standards for waiver and compliance rates. Enhanced I/M programs were applied in areas with serious and severe ozone nonattainment problems.

Low-NO_x burners were required for all coal-fired utility boilers with generating capacity greater than 75 Megawatts. Point- and area-source VOC controls were also applied at the MSA level depending on the severity of the ozone problem. In addition, across-the-board reductions were applied to point-, area-, and mobile-source emissions to meet various target reductions proposed in the draft legislation. Non-attainment areas with moderate ozone concentrations were required to reduce overall VOC emissions by 15 percent, in addition to any reductions that would result from Federal control programs. The legislation required areas with serious and severe ozone problems to reduce emissions by 3 percent per year (in addition to reductions from Federal programs) from the year of enactment (the assumption was 1990) until the ozone NAAQS is met. In the ROMNET analysis, this requirement was simulated by applying a 30 percent reduction in serious areas (estimated attainment date 2000) and a 45 percent reduction in severe areas (estimated attainment date 2005). (See Section 4.5 for a definition of ozone severity categories.)

In addition to the above VOC controls, phased clean fuels programs were implemented in four metropolitan areas in the ROMNET domain -- Baltimore, New York City, Philadelphia, and Greater Hartford. The phased fuel program had the effect of replacing about 4.5 percent of the total VOC in these areas with methanol, reducing the photochemical reactivity of the VOC emissions in these areas.

The control measures applied in the Clean Air Act legislation strategy are listed in Table 4-4. In the US portion of the region, CS05 achieved a 32 percent reduction in VOC emissions and a 32 percent reduction in NO_x emissions from the Phase II 2005 baseline scenario. Emissions of CO were reduced by 4 percent.

CS06 - CS09, 1985L and 1985H: Biogenic Sensitivity Scenarios for CS01 and CS05 and the 1985 Base Case

These scenarios were designed to test the sensitivity of ozone predictions to uncertainty in biogenic emissions for base case and selected post-control scenarios. Included are ROM applications for the 1985 base case, CS01, and CS05 scenarios with biogenic emissions altered to reflect the possible range of uncertainty (± a factor of 3). Each of the three anthropogenic scenarios are run with (1) biogenic emissions reduced by a factor of 3 ("Low" biogenics) and (2) biogenic emissions increased by a factor of 3 ("High" biogenics). In all scenarios, biogenic emissions are altered in an across-the-board manner from the "best available science" estimates generated by the Biogenic Emissions Inventory System (BEIS). The following are the specific scenarios modeled:

1985L:	1985 anthropogenics - Low biogenics
1985H:	1985 anthropogenics - High biogenics
CS06:	CS05 anthropogenics - Low biogenics
CS07:	CS01 anthropogenics - Low biogenics
CS08:	CS05 anthropogenics - High biogenics
CS09:	CS01 anthropogenics - High biogenics

CS10: Phase II Maximum Technology NO_x and Enhanced Maximum Technology VOC

Strategy 10 (CS10) incorporates maximum technology VOC and NO_x controls. This inventory retains all of the VOC controls from the Phase I maximum technology case (CS01), with some added control measures. First, highway vehicle tailpipe standards were reduced to levels substantially below the current FMVCP standards, and even below the levels in the Clean Air legislation analysis (CS05). The hydrocarbon standard for automobiles in CS10 was 0.125 g/mile. In addition, the mobile source controls (including exhaust emissions standards and effects of evaporative emissions testing) were assumed to be at full penetration (i.e., entire fleet), even though they would not reach this level until after 2005. Enhanced I/M was also applied across the entire ROMNET domain, including antitampering provisions. Finally, gasoline RVP was reduced to 7.0 psi.

For area-source VOC, CS10 eliminated residential wood burning as well as all open burning during the ozone season. This measure also affected NO_x and CO emissions. VOC controls were applied to off-highway diesel vehicles, locomotives, and diesel ships. Controls were added for four new point-source categories and to generic non-CTG point sources.

For utilities, the five percent emissions reduction for energy-efficiency improvements from the Phase II 2005 baseline was retained in CS10. This last reduction applied to utility NO_x and CO emissions as well as to VOC.

CS10 also included several maximum technology NO_x emissions controls. The automobile tailpipe standard was reduced to 0.2 g/mile, with reductions in other highway vehicle standards. As with the mobile-source VOC, these lower standards were simulated at full penetration. NO_x controls were also applied to off-highway diesels, locomotives, and diesel ships in the area source category. Selective catalytic reduction (SCR) was applied to all utility combustion sources. Finally, low-NO_x burner or comparable technology was applied to industrial boilers, internal combustion engines, and process heaters, as well as to commercial and institutional boilers in the point-source inventory. The control measures in CS10 (Phase II Maximum Technology NO_x and Enhanced Maximum Technology VOC) are summarized in Table 4-3.

Overall, CS10 achieved a 57 percent reduction in NO_x emissions, a 63 percent reduction in VOC emissions, and a 21 percent reduction in CO from the Phase II 2005 baseline scenario.

CS11 - CS14: Analyses of VOC Versus NO_x Controls

CS11 and CS12 were designed to analyze the relative impact of VOC and NO_x control measures. CS11 matches 2005 baseline VOC controls with maximum technology NO_x (CS10) controls, while CS12 matches maximum VOC controls from CS10 with NO_x emissions from the 2005 baseline.

Strategies 13 and 14 analyze the relative impacts of point- and mobile-source NO_x controls. CS13 applies maximum technology controls to VOC emissions and to NO_x point-source emissions, while keeping mobile- and area-source NO_x emissions at their 2005 baseline levels. CS14 applies maximum technology controls to VOC emissions and mobile-source NO_x emissions, keeping point- and area-source NO_x emissions at 2005 baseline levels. The point-source controls in CS13 reduced NO_x emissions in the US portion of the region by 45 percent. In contrast, mobile-source controls in CS14 reduced NO_x emissions by 9 percent.

CS15: Maximum VOC and NO_x Technology with Reduced VOC Reactivity

CS15 includes all of the VOC and NO_x control measures in CS10, as well as two additional measures designed to reduce VOC reactivity. The first reactivity reduction measure was applied to solvent emissions over the entire ROMNET region. A cap was placed on the reactivity of all solvent emissions, at a

level midway between the reactivities of isopropanol and ethyl acetate. Any solvents with higher reactivities, in either the point- or area-source portions of the inventory, were assumed to be replaced with the low-reactivity solvent. Maximum technology controls were also retained for solvent emissions so that overall solvent emissions remained the same as in CS10.

The second reactivity reduction measure was the conversion of the entire Northeast Corridor highway fleet to 100 percent methanol fuel vehicles. This produced a 33 percent increase in mobile VOC emissions over those attained for gasoline under the tight maximum technology tailpipe standards. However, since most of this VOC was methanol, the overall reactivity of mobile source emissions was reduced. Outside the Corridor, mobile source emissions were kept the same as in CS10.

To quantify the impact of reactivity reduction measures on emissions, an average reactivity term was calculated. This average reactivity was essentially the weighted average reaction rate of VOC emissions with hydroxyl radicals. By this criterion, the solvent substitution measure reduced the overall reactivity of point- and area-source emissions by about 28 percent for the US portion of the region. Methanol conversion reduced the overall reactivity of mobile source emissions in the Corridor by about 57 percent. Total reactivity-weighted VOC emissions in the Corridor were reduced by 29 percent compared to the 2005 baseline as a result of combining the mobile- and stationary-source components of this strategy.

CS16: Maximum Technology with Additional Across-the-Board Reductions

CS16 includes the maximum VOC technologies of CS10, with additional VOC reductions in the Baltimore/Washington, DC, Consolidated Metropolitan Statistical Areas (CMSAs) and the New York City CMSA.

VOC emissions in CS10 were reduced by an additional 64 percent in New York City and by an additional 54 percent in Baltimore/Washington, DC. These reductions were taken across-the-board on point, area, and mobile sources, and applied in addition to the reductions already achieved by maximum technology VOC controls. For New York City, CS16 represents an 85 percent reduction in VOC from the Phase II 2005 baseline, and a 91 percent reduction from the 1985 base case. For Baltimore/Washington, DC, VOC was reduced by 80 percent from the 2005 baseline, and 88.5 percent from 1985 levels.

For NO_x, maximum technology controls are applied as in CS10, except in New York City, where mobile sources are controlled but point-source emissions are at the 2005 baseline level. The NO_x emissions reduction in this area for CS16 was 32 percent rather than 58 percent as in CS10.

CS17: Maximum Technology NO_x with "Low" Biogenics

Strategy 17 was designed to examine the effectiveness of NO_x controls if biogenic emissions were at the low end of the uncertainty range. Anthropogenic emissions are the same as in CS11 (maximum technology controls in NO_x with VOC and CO at the 2005 baseline). Biogenic emissions are reduced by a factor of 3 from base case levels as in scenarios 1985L, CS06, and CS07.

CS18: Maximum Technology, Reduced Reactivity and Additional Across-the-Board Reductions

In this strategy, VOC emissions from CS15 (maximum technology with reduced reactivity) were lowered further by the across-the-board reductions used in CS16 (64 percent in New York City and 54 percent in Baltimore/Washington, DC). Emissions of NO_x and CO were identical to that in CS16.

CS19: CS18 with Alteration of NO_x Controls in Baltimore/Washington, DC

CS19 was identical to CS18 except for the treatment of NO_x controls in Baltimore/Washington, DC. In these cities, maximum technology controls were placed on NO_x emissions from mobile and area sources. However, point source NO_x emissions were maintained at the 2005 baseline level. Thus, NO_x reduction in this areas was 28 percent, rather than 46 percent as in CS18.

CS20: 2005 Baseline with Reduced Reactivity

The purpose of this strategy was to isolate the impact of using low-reactivity solvents and methanol vehicles from the effects of technology-based stationary source controls and lower tailpipe emissions standards. (Technology plus reactivity reductions are combined in CS15). In CS20, methanol fuel conversion was adopted in the Northeast Corridor as in CS15, again at full fleet penetration. In addition, the solvent reactivity reduction measure was adopted as in CS15. However, instead of applying maximum technology controls, solvent emissions were left at 2005 baseline levels (although at a reduced reactivity). All other VOC point- and area-source emissions, as well as mobile emissions outside the Northeast Corridor, were left at 2005 baseline levels. Emissions of NO_x and CO were at the 2005 baseline level across the domain.

CS21 and CS22: Biogenic Sensitivity Scenarios for CS19

These two strategies were designed to examine the effects of uncertainty in biogenic emissions on the effectiveness of anthropogenic controls in CS19. Thus, in both CS21 and CS22, anthropogenic emissions are identical to CS19. In CS21, biogenic VOC emissions are at the "Low" end of the uncertainty range and in CS22 biogenics are at the "High" end of this range (± a factor of 3 from base case levels).

CS23: Control Effectiveness Strategy

The purpose of this strategy was to provide a "realistic" consideration of the types of control measures in CS19 (maximum technology, reactivity reduction, and across-the-board VOC reductions). Recall that controls in CS19 were assumed to be 100 percent effective. It was also assumed that the entire passenger car fleet in the Northeast Corridor was comprised of M100 vehicles, and that stringent tailpipe standards were in place on all vehicles outside the Corridor.

These controls were relaxed in CS23 by adding effectiveness factors in the calculation of overall control efficiencies and by assuming a more likely projection for fleet turnover with clean fuel and reduced exhaust/evaporative emissions vehicles. For this, the following specific changes were imposed on CS19 control measures:

- an 80 percent effectiveness factor was applied for all point and area source controls;
- an 80 percent effectiveness factor was applied to vehicle inspection and maintenance programs;
- gasoline RVP was increased from 7.0 psi to 7.8 psi;
- use of low-reactivity solvents was reduced by assuming that only 80 percent of the potentially affected sources comply with a solvent substitution program;
- the alternative fuel vehicle program in the Northeast Corridor was changed to reflect the schedule and M85/M100 vehicle fleet fractions used in CS05 (Clean Air Act legislation strategy); and
- light-duty passenger vehicle emissions for conventional engines were changed to reflect a "phased" approach to lowering emissions standards: 1994 - NMHC 0.25 g/mi, NO_x 0.4 g/mi; 2003 - NMHC 0.125 g/mi, NO_x 0.2 g/mi.

As a result of considering rule effectiveness, VOC emissions in CS19 were increased by 64 percent, NO_x by 25 percent, and CO by 7 percent in the US portion of the region. Still, considering rule effectiveness with CS19 controls, emissions in CS24 are lower than those in the 2005 baseline by 48 percent for VOC, 40 percent for NO_x , and 16 percent for CO.

CS24 and CS25: Spatial Analysis of VOC and NO_x Controls - Transport Sensitivity Scenarios

In CS24, the CS19 controls were applied to all counties inside the Northeast Corridor, with emissions at 2005 baseline levels elsewhere in the domain. For strategy CS25, emissions in the Northeast Corridor are at the 2005 baseline and the controls used in CS19 are applied in areas outside the Corridor. The purpose of these two strategies, through comparisons with the 2005 baseline scenario and CS19 results, was to examine the effects on ozone levels in the Northeast Corridor of changes to ozone and precursor transport into the Corridor as a consequence of regional strategies.

4.5 EMISSIONS CONTROL MEASURES

This section contains the specific control efficiencies, emissions standards, etc., contained in the 2005 baseline scenarios and the ROMNET control strategies described in the previous section. Projection and control methodologies together with emissions growth factors used in developing these scenarios are provided in Appendix J.

For point sources, controls were generally specified by emissions "pod." Each pod represents an aggregate group of numerous point source SCCs that are treated similarly for control purposes. The point-source inventory was divided into 80 such pods. Stationary area-source emissions were divided into 64 categories (area-source SCCs) that emit VOC, NO_x, or CO. The specific pods and area-source categories are listed in Appendix J.

In the remainder of this Section, information on stationary- and mobile-source controls included in the Phase I and Phase II 2005 baseline scenarios is presented first. This is followed by a description of the control measures used in the maximum-technology-based strategies. Controls in the Clean Air Act strategy are presented next. Details on the reactivity-based strategies are provided last.

4.5.1 VOC Stationary-Source Controls for 2005 Baseline Scenarios

The 2005 stationary-source baseline inventories include two major sets of controls: NSPS controls applied to new sources at the national level, and State controls applied at the State or county level. Table 4-5 lists the NSPS efficiencies used for new, modified, and reconstructed point and area sources. These were taken from a compilation of NSPS efficiencies in an EPA cost assessment of alternative National Ambient Air Quality Standards for ozone (Battye *et al.,* 1987). For the 2005 baseline analysis, the NSPS efficiencies were multiplied by an 80 percent rule effectiveness factor.

As indicated in Appendix J, Table J-1, Equation 3, there are two types of State- and county-level efficiencies that were used in developing the 2005 baseline inventories: 1985 efficiencies (Eff_{1985}) and 2005 efficiencies (Eff_{2005}). The approach for obtaining values for each of these efficiencies for VOC area and point sources is described next.

Area Sources

For solvent categories (78 through 95 - see Appendix J), 1985 efficiencies were obtained from a survey of State ROMNET participants on the level of existing controls. Solvent categories were distinguished

from other area source categories because of the methods used to generate initial 1985 NEDS emissions estimates. In general, the 1985 NEDS area source inventory began with the development of national emissions estimates for various area source categories. Emissions were then allocated to subcategories, States and counties based on industrial employment and population statistics. Within this overall framework, national emissions estimates were developed using the two basic methodologies of mass balance and emission factors. Solvent emissions in categories 78 through 95 were ultimately derived from a nationwide mass balance on solvent sales. All other emissions estimates in the 1985 NEDS area source inventory were from standard emission factors and national assumptions on the average level of emissions control. For the two "emission factor" categories controlled in 1985 (103 - bulk terminals/plants and 104 - refinery fugitives), the 1985 control efficiencies used in the 2005 baseline projections were taken from the national efficiency assumptions used in the original NEDS inventory.[2] It would be inappropriate to use the actual control efficiencies from the State survey, because these efficiencies were not reflected in the 1985 inventory. Conversely, 1985 emissions estimates for solvents do reflect actual controls, at least on a gross national level, because of the mass balance approach used for the solvent categories. Therefore, the control efficiencies from the State survey were thought to provide the best estimates of 1985 efficiencies for these categories (78 through 95). The 2005 efficiencies for all area-source categories to which additional controls are applied in the 2005 baseline were also obtained from the State survey.

Point Sources

The NEDS point source inventory includes an emissions control efficiency entry for each separate emissions source. In general, the 1985 efficiencies for ROMNET projections were obtained by taking these NEDS efficiency entries and multiplying by an 80 percent rule-effectiveness factor. However, the Emissions Committee was concerned that many existing controls may not be listed in the "control efficiency" field. This field was designed mainly to handle add-on controls, although process modifications can also be entered as controls. The Committee was concerned about low-solvent coatings, which they felt might not be listed as control techniques in the inventory. In these cases, controlled emissions would reflect the low-solvent coating, but emissions reductions already achieved by the coating would not be noted. Therefore, in control strategy evaluations, potential emissions reductions would be counted for controls that were already in place. To avoid this problem, the State control survey results for area source surface coating categories were extended to the corresponding point source surface

2. 58.5 percent for category 103 and 48.2 percent for category 104.

coating categories. Thus, for surface coating categories, overall efficiency values from the State survey were substituted for the control efficiency entries in the point source inventory. For point sources, the State- and county-level controls for the 2005 baseline were left at 1985 control levels (including the changes discussed above for point source solvent category efficiencies).

State Survey of Control Efficiencies

As indicated above, State Emissions Committee representatives were surveyed on VOC control technologies in place as of 1985. This survey provided inputs both for selected 1985 control efficiencies and for all 2005 baseline control efficiencies. The survey initially was designed to address area sources, but results were also extended to some point-source categories.

States were asked to quantify overall reduction efficiency and indicate the geographic coverage of any rules applying to area sources. In quantifying overall reduction efficiency, the States were asked to use three separate parameters: control technology efficiency, rule effectiveness, and rule penetration into the inventory. These parameters were defined as follows:

- Control technology efficiency is the efficiency (in percent) of controls or work practices required by a regulation, based on uncontrolled emissions.
- Rule effectiveness reflects the assumption that regulations typically were not 100 percent effective due to limitations of control techniques or shortcomings in the enforcement process. Several factors were taken into account in estimating rule effectiveness, including:
  - ambiguity in how the regulation should be applied
  - differences between the long-term performance of control equipment and the performance measured in performance tests
  - fugitive emissions not routed to the control device
  - clarity of procedures used in determining compliance
  - frequency of inspections
  - potential for significant violations of the regulation
  - follow-up activities at sources violating the regulation.
- Rule penetration is the portion (in percent) of the area source category that is covered by the regulation, in terms of uncontrolled emissions.

The product of these three factors can be used to estimate the overall reduction efficiency for a given area-source category:

$$\text{Overall efficiency} = [\text{control technology efficiency}] \times [\text{rule effectiveness}/100] \times [\text{penetration}/100]$$

$$\text{Actual emissions} = [\text{uncontrolled emissions}] \times [1 - (\text{overall efficiency}/100)]$$

The initial State survey produced such a wide range of responses that there was concern that parameter estimates might cause inconsistencies in emissions projections for neighboring States. Further, some States expressed very low confidence in their estimates. Therefore, the survey was repeated after States had the opportunity to review the preliminary estimates made by others in the region. In addition, States were asked in the second round to indicate their level of confidence in the parameter estimates. This was expressed by letter "grades" from A to E, with A representing the highest degree of confidence and E the lowest.

State responses from across the region were then averaged for each area-source category. That is, the mean control technology efficiency was computed for each category by taking the average of all non-zero responses. The same calculations were made for rule effectiveness and penetration. Table 4-6 summarizes the average responses for each parameter, as well as the range of responses and the average level of confidence. The table also gives the "average" overall efficiency, obtained by multiplying the mean values for control technology efficiency, rule effectiveness, and penetration. If a State did not express a high level of confidence in all of its control factor estimates for a given category (A or B for control technology and A for rule effectiveness and penetration), the overall reduction efficiency for that category was defaulted to the average overall efficiency from Table 4-6. Otherwise, the overall reduction was computed from the State's responses for control technology efficiency, rule effectiveness, and penetration. Values for 1985 and 2005 control efficiencies used in developing the 2005 baseline VOC emissions reflect the overall efficiency. The State-wide and county-specific 2005 control efficiencies are provided in Appendix K.

4.5.2 NO_x Stationary-Source Controls for 2005 Baseline Scenarios

Both the Phase I and Phase II 2005 baseline scenarios incorporate NSPS NO_x emissions limits. NSPS limits on NO_x emissions were reflected in the Advanced Utility Simulation Model (AUSM) utility growth factors, and also in the methodology used to generate industrial combustion growth factors. Additional control measures specific to Phase I or Phase II baselines are described below.

Phase I - 2005 Baseline NO_x

In addition to FMVCP, I/M and NSPS controls, all Phase I inventories include a State-level cap on total NO_x emissions so that total point-, area-, and mobile-source NO_x emissions in each State were held to

the 1985 level. The cap was implemented by applying sufficient point source control measures in each State to offset overall NO_x emissions growth, taking into account reductions already achieved by NSPS and FMVCP rules.

Point source controls were applied preferentially to new sources and to utilities. Low-cost controls such as low-NO_x burners (LNB), staged combustion air, reduced air-to-fuel ratio, and steam injection were used before selective catalytic reduction (SCR). The following list details the priority system used to apply point source measures, with controls and emissions categories listed in descending order of preference:

A. Low NO_x burners, staged combustion air, reduced air-to-fuel ratio, or steam injection used on:
1) New sources
   Utilities
      Coal
      Oil
      Natural gas
   Industrial combustion
      Coal
      Oil
      Natural gas
2) Existing sources - with the same rankings as above for source categories and fuels
B. Selective catalytic reduction - applied to new sources before existing sources and with the same rankings as above for source categories and fuels.

Table 4-7 summarizes the point source control measures needed to meet the NO_x cap in each ROMNET State.

Phase II - 2005 Baseline NO_x

The Phase II 2005 baseline inventory, like all of the Phase I inventories, includes the effects of current FMVCP standards for mobile source NO_x emissions. However, mobile NO_x emissions in the Phase II baseline were based on MOBILE4 rather than on MOBILE3.9.

In addition to FMVCP and NSPS programs, the Phase II baseline includes a 5 percent reduction for NO_x from all utilities. This factor accounts for expected improvements to energy efficiency that were expected to reduce fuel consumption. The energy-efficiency factor is applied to pods 50 through 53 (utility external combustion of coal, oil, natural gas, and other fuels), and pods 74 through 77 (utility oil and gas turbines and reciprocating engines).

4.5.3 VOC, NO_x, and CO 2005 Baseline Mobile Source Controls

To create the Phase I and Phase II mobile source baseline inventories for 2005, emission factors were calculated using MOBILE3.9 and MOBILE4, respectively. MOBILE4 inputs for the Phase II baseline are given in Appendix L. The effects of current inspection/maintenance (I/M) programs on baseline emissions in 2005 were estimated by assuming that all areas in which I/M existed in 1985 will have a typical "basic" I/M program operating at the estimated 1985 program effectiveness level for the area in question. The basic I/M program consists of the following characteristics:

ROMNET "BASIC" I/M PROGRAM CHARACTERISTICS	
I/M PROGRAM:	
START YEAR (JANUARY 1):	1983
PRE-1981 MYR STRINGENCY RATE:	20%
MECHANIC TRAINING PROGRAM?:	NO
FIRST MODEL YEAR COVERED:	1970
LAST MODEL YEAR COVERED:	2020
VEHICLE TYPES COVERED:	LDGV, LDGT1, LDGT2
1981+ MYR TEST TYPE:	IDLE ONLY
1981+ MYR TEST CUTPOINTS:	1.2% CO, 220 PPM HC
ANTI-TAMPERING PROGRAM SELECTED:	NONE
ADDITIONAL MOBILE4 I/M INPUTS	
WAIVER RATES:	5% (ALL YEARS)
COMPLIANCE RATE:	100%
INSPECTION TYPE:	CENTRALIZED
INSPECTION FREQUENCY:	ANNUAL

MOBILE4 runs produce the following ideal I/M control efficiencies, weighted across the 2005 vehicle fleet:

	Percent Control
Total VOC	12.1
Gasoline exhaust	18.1
Gasoline evaporation	9.3
Diesel	0.0
Nitrogen oxides	4.0
Carbon monoxide	19.9

The following I/M program effectiveness percentages were obtained from program assessments performed by the EPA Office of Mobile Sources and were developed from comprehensive reviews of the characteristics and performance of each program.[3] Program effectiveness for NO_x is taken to be the same as for VOC. These effectiveness ratings combine the effects of program deviations from the prototypical 5 percent waiver, 100 percent compliance rate, and centralized annual program on which the basic I/M reductions were based.

3. Information provided by David Brzezinski, EPA Office of Mobile Sources, Ann Arbor, MI, to Edwin L. Meyer, EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC. Revised I/M Program Effectiveness Data. December 20, 1989.

	1985 Program Effectiveness (Percent)	
State	VOC	CO
Connecticut	84	81
Delaware	80	80
District of Columbia	84	81
Indiana	53	53
Kentucky	90	88
Maryland	87	85
Massachusetts	63	56
New Jersey	84	81
New York	50	50
Pennsylvania	78	74
Rhode Island	44	33
Virginia	44	34

A Reid vapor pressure of 9.0 psi was included regionwide in the 2005 baseline in anticipation of gasoline volatility regulations by the NESCAUM States. The Phase II 2005 baseline inventory also assumes, based on the January 19, 1990 Notice of Proposed Rulemaking (55 FR 1914), a basic evaporative test procedure for new vehicles. This rule is projected to result in 36 percent control of diurnal and hot-soak emissions, and 71 percent control of running losses beginning with the 1993 model year.[4]

4.5.4 VOC Maximum Technology Stationary Source Controls

Maximum VOC technology efficiencies used in Phase I and in Phase II are listed in Table 4-8 for point sources and Table 4-9 for area sources. The tables also give brief descriptions of the control techniques that form the basis for the maximum technology efficiencies. The major references for maximum technology controls were the Ozone NAAQS Cost Analysis (Battye *et al.,* 1987), and the Emissions Reduction and Cost Analysis Model (ERCAM) for VOC (Pechan, 1989). Efficiencies given in these references were based on primary sources such as EPA Control Techniques Guidelines and NSPS Background Documents. As the tables show, maximum technology efficiencies for a number of surface coating categories were based on incinerators and other add-on controls. Comparable efficiencies can be achieved for some of these categories with low-solvent coatings. All of the maximum technology efficiencies match or supersede any applicable NSPS rules, and all efficiencies were assumed to be 100 percent effective.

4. Information provided by Lois Platte, EPA Office of Mobile Sources, Ann Arbor, MI, to Mark G. Smith, Alliance Technologies Corporation. MOBILE4 Input for EPA Evaporative Test Procedure Proposal. January 30, 1990.

4.5.5 NO_x Maximum Technology Stationary Source Controls

Maximum NO_x technology efficiencies used in Phase II for point and area sources are listed in Table 4-10. Efficiencies given in the table are based on selective catalytic reduction (SCR) for utilities, low-NO_x burners or comparable technology for industrial combustion sources, and the best identified controls for off-highway mobile sources (Johnson, 1988; Ellison, 1988).[5] All of the maximum technology efficiencies match or supersede any applicable NSPS rules. The location of NO_x point sources affected by maximum technology controls are shown in Figure 4-18.

4.5.6 Mobile-Source VOC, NO_x, and CO Maximum Technology Controls

Mobile-source controls used in Phase I consist of the following "enhanced" I/M program applied region-wide, with 100 percent program effectiveness instead of the State-specific measures used in the base-line:

```
CS1 I/M PROGRAM
 I/M PROGRAM SELECTED
   START YEAR (JANUARY 1):                    1983
   PRE-1981 MYR STRINGENCY RATE:              20%
   MECHANIC TRAINING PROGRAM?:                NO
   FIRST MODEL YEAR COVERED:                  1970
   LAST MODEL YEAR COVERED:  2020
   VEHICLE TYPES COVERED:                     LDGV, LDGT1, LDGT2
   1981+ MYR TEST TYPE:                       LOADED / IDLE
   1981+ MYR TEST CUTPOINTS:  1.2% CO / 220 PPM HC
 ANTI-TAMPERING PROGRAM SELECTED
   START YEAR (JANUARY 1):                    1990
   FIRST MODEL YEAR COVERED:                  1970
   LAST MODEL YEAR COVERED:  2020
   VEHICLE TYPES COVERED:                     LDGV
   ANNUAL INSPECTION:                         AIR PUMP, CATALYST, FUEL INLET,
                                              PLUMBTESMO LEAD TEST
```

For Phase II, the Phase I enhanced I/M program was modified to add heavy duty vehicles and additional variables required by MOBILE4 (5 percent waiver rate, 100 percent compliance, centralized/annual program type). Reid vapor pressure was reduced to 7.0 psi from 9.0 psi. Tailpipe emissions standards simulated in CS10, as shown below, reflect the most stringent control level proposed in Senate Bill 1630, the December 20, 1989 Clean Air Act legislation. A heavy duty diesel NO_x emissions standard reduction from 5 to 4 grams/brake-horsepower-hour was also included in CS10 as an approximation of the control limit of current diesel technology.

5. Information provided by Larry Jones, Acid Deposition Branch, US Environmental Protection Agency, Research Triangle Park, NC. Typical efficiencies for low-cost NO_x controls.

	HC	NO_x	Units
Light Duty Vehicles	0.125	0.20	grams per mile
Light Duty Trucks			
1) 3750 - 5750 lb	0.380	0.70	grams per mile
2) 5750 - 8500 lb	0.460	1.10	grams per mile
Heavy Duty Diesels	None	4.00	grams per brake horsepower hour

The following set of MOBILE4 base emissions and deterioration rates was used to simulate these emissions standards:

	HC		NO_x		
	ZM	DR	ZM	DR	Units
Light Duty Vehicles	0.085	0.028	0.127	0.017	grams per mile
Light Duty Trucks 1	0.14	0.05	0.35	0.03	grams per mile
Light Duty Trucks 2	0.22	0.08	0.64	0.04	grams per mile
Heavy Duty Diesels	0.0	0.0	3.11	0.0	grams per brake horsepower hour

ZM = Zero mile rate, DR = Deterioration rate per 10,000 miles

To approximate full penetration of these standards into the fleet, this MOBILE4 run included introduction of these standards for light duty vehicles and trucks in 1995, and resulting emission factors for 2020 were used, since the modeled fleet in that year is anticipated to reach a steady state consisting of only such vehicles. The combined effect of the resulting maximum technology for mobile sources is the following reductions over the 2005 baseline uncontrolled and "basic" I/M composite emission factors:

	Percent Reduction Over:	
	Uncontrolled	Basic I/M
Total VOC	62.0	56.2
Gasoline exhaust	66.3	65.5
Gasoline evaporation	56.7	52.2
Diesel	0.0	0.0
Nitrogen oxides	49.9	47.8
Carbon monoxide	37.8	22.2

Inputs to MOBILE4 used for the Phase II maximum technology VOC strategy are given in Appendix L.

4.5.7 Controls Applied in the CS05 Clean Air Act Strategy

In this strategy, various VOC stationary source controls were applied at the urban level by MSA or CMSA, depending on the severity of the ozone problem as indicated by the ozone design value. The attainment categories, based upon ambient monitoring data from 1986 through 1988, are listed below.

Attainment Category	Design Value*	Attainment Date
1 - attainment	≤ 0.12 ppm	—
2 - marginal nonattainment	0.13 ppm	December 31, 1995
3 - moderate nonattainment	0.14 - 0.15 ppm	December 31, 1995
4 - serious nonattainment	0.16 - 0.15 ppm	December 31, 2000
5 - severe nonattainment	0.19 ppm	December 31, 2010

* based on 4th highest daily maximum concentration over 3 years.

The VOC point- and area-source control measures applied by attainment category are provided in Table 4-11 and Table 4-12, respectively. In the areas listed below, controls were also applied to dry cleaners (70 percent control), bakeries (80 percent control) and miscellaneous industrial solvents (50 percent control).

Baltimore/Washington, DC	Massachusetts
Philadelphia	Manchester - Nashua, NH
Atlantic City	Portland, ME
New York City	Harrisburg, PA
Poughkeepsie, NY	Huntington - Ashland, WV-KY-OH
Hartford, CT	Toledo, OH
Providence, RI	

Vehicle tailpipe standards included in this strategy are given below:

	HC	NO_x	Units	Start Year
Light Duty Vehicles	0.25	0.40	grams per mile	1994
Light Duty Trucks				
1) 3750 - 5750 lb	0.25	1.00	grams per mile	1995
2) 5750 - 8500 lb	0.50	1.00	grams per mile	1995

Inputs to MOBILE4 used to generate mobile source emission factors for this strategy are given in Appendix L.

In addition to these category-specific controls, across-the-board reductions were applied to point, area, and mobile sources in order to meet various VOC target reductions enumerated in the draft legislations. These reductions are listed by urban area in Table 4-13.

4.5.8 Development of Reactivity-Reduction Scenarios

For VOC, CS15 and CS20 were based on CS10 and the 2005 baseline, with two additional measures to reduce VOC reactivity. The first measure is a cap on the reactivity of solvent emissions. For the purposes of this cap, reactivity is defined as the overall reaction rate with hydroxyl radical per unit weight of the solvent:

$$\text{Reactivity} = \sum_i RR_i \times SF_i$$

where:

i refers to the different Carbon Bond-IV classes;

RR_i is the reaction rate of CB-IV class *i* with the hydroxyl radical at 85°F:

43,187 reactions·kg^{-1}·min^{-1} for olefin;
1,203 reactions·kg^{-1}·min^{-1} for paraffin;
9,315 reactions·kg^{-1}·min^{-1} for toluene;
36,433 reactions·kg^{-1}·min^{-1} for xylene;
15,000 reactions·kg^{-1}·min^{-1} for formaldehyde;
24,335 reactions·kg^{-1}·min^{-1} for other aldehydes;
12,194 reactions·kg^{-1}·min^{-1} for ethene;
142,000 reactions·kg^{-1}·min^{-1} for isoprene;
1 reaction·kg^{-1}·min^{-1} for nonreactive hydrocarbons;
1,600 reactions·kg^{-1}·min^{-1} for methanol);

and

SF_i is the speciation factor for CB-IV class *i* (moles·kg^{-1} solvent).

The solvent reactivity cap was set at 35,000 ·kg^{-1}·min^{-1}, which is midway between the reactivities of isopropanol (30,000 ·kg^{-1}·min^{-1}) and ethyl acetate (40,000 ·kg^{-1}·min^{-1}). Both of these solvents are commonly used in surface coatings. Any solvents with higher reactivities in either the point or area source portions of the inventory were assumed to be replaced. The replacement solvent is a mixture of the above two solvents, with a reactivity at the level of the cap and a speciation of 29 moles paraffin per kilogram solvent and 14 moles nonreactive hydrocarbons per kilogram.

The second reactivity reduction measure involves conversion of the entire Northeast Corridor highway vehicle fleet to 100 percent methanol fuel (M100) vehicles.[6] It is estimated that complete conversion of the vehicle fleet to M100 would result in a 71 percent reduction in fleet-wide evaporative emissions, and an increase in exhaust emissions of 325 percent relative to the CS10 maximum control scenario. This is based on M100 evaporative and exhaust emission factors of 0.055 and 0.565 grams/mile, respectively.

6. Special Report: Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel. EPA Office of Mobile Sources, Ann Arbor, MI. September 1989.

Changes in speciation also affect these categories, resulting in a net reduction in reactivity even for exhaust emissions. Table 4-14 lists speciation factors for VOC emissions from methanol-fueled vehicles. These speciation factors were based on primary factors which included a breakdown of the exhaust emissions into methanol, formaldehyde and other nonmethane hydrocarbons as 88.5, 2.7 and 8.8 percent by weight, respectively. The other nonmethane hydrocarbons were further speciated using previously-existing data for exhaust hydrocarbon speciation.[7]

7. Memorandum from Charles Gray, EPA Office of Mobile Sources, Ann Arbor, MI, to John Calcagni, EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC. Motor Vehicle VOC Speciation for SIP Development. March 23, 1989.

4.6 DEVELOPMENT OF A BIOGENIC-SOURCE EMISSIONS INVENTORY

4.6.1 Introduction

The abundance of naturally-occurring hydrocarbons in the atmosphere has been recognized for at least 20 years (Arnts and Meeks, 1981; Peterson and Tingey, 1980; Rasmussen, 1972). It was not until recently, however, that modeling studies suggested the need to consider biogenic hydrocarbon emissions for estimating the production of photochemical oxidant smog (Chameides *et al.,* 1988; Trainer *et al.,* 1987). Even before the publication of these studies, the EPA reported on the development of a computer algorithm for estimating biogenic emissions (Novak and Reagan, 1986). This system, called the Biogenic Emissions Software System (BESS), was designed to produce hourly gridded hydrocarbon emissions for an early version of the ROM. More or less parallel to the efforts at the EPA, researchers at Washington State University devised a method for estimating seasonal, county-wide hydrocarbon emissions across the United States (Lamb *et al.,* 1987). These estimates were used for early parts of the NAPAP. In preparing for the 1985 NAPAP emissions inventory and while testing later versions of the ROM, researchers at Washington State University and EPA collaborated on combining features of their two biogenic emission systems (Young *et al.,* 1989). An outcome of this collaboration was the development of a generalized scheme that could estimate hourly gridded biogenic hydrocarbon emissions for use with either the ROM or the Regional Acid Deposition Model (RADM). This Section discusses the formulation of this system, called the Biogenic Emissions Inventory System (BEIS). More-detailed information on the BEIS can be found in Milich *et al.* (1990); and discussions of BEIS estimates are in Pierce *et al.* (1990).

4.6.2 Description of the System

Calculations with the Biogenic Emissions Inventory System (BEIS) require consideration of biomass, emission factors, and environmental factors. The basic equation for these calculations can be expressed as follows:

$$\mathrm{ER}_i = \sum_j [\mathrm{BF}_j \mathrm{EF}_{ij} \mathrm{F}(S, T)]$$

where ER is the emission rate (g/s/model grid cell), i is the chemical species (such as isoprene or monoterpene), j is the vegetation type, BF is the leaf biomass factor (g/m^2), EF is the emission factor (μg/g-leaf biomass/h),and F(S,T) is an environmental factor that accounts for solar radiation S and leaf temperature T.

Biomass Factors

Leaf biomass for forested areas and surface areas for nonforested areas were derived from land use data in the Oak Ridge National Laboratory's Geoecology Data Base (Olson *et al.,* 1980). The land use data, some of it dating back to the early 1970's, consist of county-level acreages for forest types, agricultural crops, and other areas such as urban, grassland, and water.

In the Geoecology Data Base, forested areas were classified as one of about 100 forest types. Lacking detailed information on forest biomass and emission factors, each forest type was simply aggregated into three groups: oak, other deciduous, or coniferous. Relationships suggested by Lamb *et al.* (1987) were used to partition the leaf biomass for each forest group into four emission categories: (1) high isoprene deciduous, (2) low isoprene deciduous, (3) no isoprene deciduous, and (4) coniferous. These biomass factors (g/m^2) are listed below:

	Emission Category			
Forest group	High isoprene deciduous	Low isoprene deciduous	Non-isoprene deciduous	Non-isoprene coniferous
Oak	185	60	60	70
Other deciduous	60	185	90	135
Coniferous	39	26	26	559

Non-forest vegetation types were assigned to one of twenty categories. Agricultural crops not having an explicit emission factor were categorized as a miscellaneous crop. Based on a review of land use data, urban areas were assumed to contain 20 percent forests and 20 percent grassland. Forested regions in urban areas were divided equally among oak, other deciduous, and coniferous groups.

Seasonal adjustments of biomass were based on frost dates for each county using a simple step function. For each month, deciduous vegetation (any non-coniferous vegetation class) within a county is assumed to have either full biomass or no biomass. For oxidant modeling, this is not a critical assumption because most high ozone episodes occur during the summer months.

Emission Factors

The emission factors in BEIS were largely based on Zimmerman's Tampa Bay Study (1979), primarily because of the lack of standardized measurements from other biogenic emissions field programs. Emission factors ($\mu g/g/h$),standardized for full sunlight and 30°C, are listed below for the four forest emission categories. By multiplying these emission factors by the corresponding biomass factors, emission fluxes ($\mu g/m^2/h$)can be compared for vegetation types, as shown in Table 4-15.

Chemical species	Emission Category			
	High isoprene deciduous	Low isoprene deciduous	Non-isoprene deciduous	Non-isoprene coniferous
Isoprene	14.69	6.60	0.0	0.0
α-pinene	0.13	0.05	0.07	1.13
Monoterpene	0.11	0.05	0.07	1.29
Unidentified	3.24	1.76	1.91	1.38

Emission fluxes in Table 4-15 are expressed in terms of total non-methane hydrocarbons and were partitioned as isoprene, monoterpene, alpha-pinene, and unidentified. In most instances, the emission fluxes from forested areas were significantly higher than the fluxes for agricultural areas. An exception is corn, which has an overall hydrocarbon emission flux of 3542 $\mu g/m^2/h$. Most of the emissions flux from corn is assigned to the unidentified category because the gas chromatography analysis did not identify specific hydrocarbon compounds. Rather than ignore the unidentified portion of the flux estimate, it is tentatively assumed that unidentified hydrocarbons can be treated as 50 percent terpene, 45 percent paraffin, and 5 percent nonreactive.

Sources of naturally-emitted NO include biomass burning, lightning, microbial activity in soils, and ammonia oxidation. Although these natural sources were reportedly much smaller than anthropogenic sources (Logan, 1983), concerns about air quality in rural areas (where anthropogenic emissions tend to be small) suggest the need to consider natural NO emissions. Lacking sufficiently detailed emission factors for other sources, only NO emissions from grasslands were considered in this version of BEIS. The equation used is (Fehsenfeld, 1990):

$$Q = 0.74 \exp(0.079\, T_s)$$

where Q is the nitrogen flux (ng of N $m^{-2}s^{-1}$), and T_s is the soil temperature (°C) as estimated from $T_s = 0.70\, T_a + 3.6$, where T_a is the ambient air temperature (°C). It is assumed that the nitrogen emitted into the air from grasslands is emitted in the form of NO.

Environmental Factors

Laboratory studies have shown that biogenic emissions from most plant species react strongly to changes in temperature and isoprene emissions are also sunlight dependent (Tingey, 1981; Tingey *et al.,* 1980, 1981). BEIS includes adjustments for temperature and sunlight using these relationships. It also attempts to simulate the vertical variation of leaf temperature and sunlight within a forest canopy.

BEIS incorporates an adjustment factor for isoprene emissions (Tingey *et al.,* 1981) that is given by the following:

$$F(S,T) = \frac{\left(10^{\left[\frac{a}{1+\exp(-b(T-c))} - d\right]}\right)}{e}$$

where *a*, *b*, *c*, *d*, and *e* are empirical coefficients that vary as a function of solar intensity *S* as given below. The leaf temperature (*T*) is expressed in °C. The above relationship is quite sensitive to temperature and sunlight as shown in Figure 4-19. For example, only a 2°C change of temperature during conditions of bright sunlight and 30°C can result in a 50 percent change in the isoprene emission rate. At night, isoprene is usually not emitted and is assumed to be zero in BEIS.

Light intensity	Empirical Coefficients				
$\mu E/m^2/s$	*a*	*b*	*c*	*d*	*e*
800	1.200	0.400	28.30	0.796	1.00
400	0.916	0.239	29.93	0.462	1.95
200	0.615	0.696	32.79	0.077	4.75
100	0.437	0.312	31.75	0.160	10.73

Existing laboratory data for non-isoprene emitting plants have thus far identified only leaf temperature as an important variable (Tingey *et al.,* 1980; Tingey, 1981). The environmental adjustment factor used in BEIS for non-isoprene emitting plants is given by:

$$F(T) = \exp(a[T-30])$$

where values for the coefficient *a* are given below.

	Empirical Coefficient
Compound	*a*
α-pinene	0.067
Monoterpene	0.0739
Unidentified	0.0739

A major refinement for BEIS was to include a canopy model for estimating profiles of leaf temperature and sunlight within forest canopies. The model was adapted from research initially performed at Washington State University (Gay, 1987). Sunlight is assumed to decrease exponentially through hypothetical forest canopies with the rate of attenuation depending on the assumed biomass distribution. Both visible and total radiation were calculated for eight levels in the canopy. The visible portion of the solar spectrum is assumed to decrease more quickly than the total spectrum, because leaves are

more effective at absorbing visible light than other portions of the spectrum (Baldocchi *et al.,* 1984). The calculated total solar radiation is used to compute the leaf temperature at each level using a radiational balance equation described by Gates and Papian (1971). The estimated leaf temperatures and visible radiation values are then used with the Tingey adjustment factors which were discussed above.

Adjustments for temperature are also important for estimates of NO emission rates from grasslands. The adjustment factor for NO is noted explicitly in the emission factor equation.

4.6.3 Computational Processes

As in ROMNET, ROM applications typically involve a simulation for about a two-week period. BEIS is used to provide biogenic emissions for these simulations through the steps indicated in the system flow diagram (Figure 4-20).

First, the biomass for the simulation period is computed with BEIS using the monthly adjustment flags. The outputs of this process are data files of gridded canopy and noncanopy biomass. The next step is to compute standardized (30°C and full sunlight conditions) emission fluxes at each grid cell. This calculation is performed once per model simulation. The computer intensive portion of BEIS involves hourly corrections for sunlight and temperature. For noncanopy vegetation, Tingey adjustment factors were computed using surface temperature and solar radiation data that were provided by the ROM meteorology-input processors. For canopy vegetation, values for surface temperature, wind speed, relative humidity, and solar radiation were fed into the canopy model which computes profiles of leaf temperature and sunlight. These profiles were used to compute Tingey adjustment factors as a function of height using the assumed biomass distribution. The adjustment factors were then multiplied by the standardized emission fluxes, and the noncanopy and canopy emission rates were merged. Emission rates were finally converted into the appropriate chemical species. For example, the ROM uses the following conversions (Gery *et al.,* 1988):

- 1 mol isoprene is treated as 1 mol ISOP,
- 1 mol monoterpene or alpha-pinene is treated as 0.5 mol OLE, 6 mol PAR, and 1.5 mol ALD2,
- 1 mol unidentified (or unknown) is treated as 0.5 mol OLE, 8.5 mol PAR, and 0.5 mol NONR,

where ISOP, OLE, PAR, ALD2, and NONR were surrogate species used in the Carbon Bond IV mechanism and refer respectively to isoprene, olefin, paraffin, higher aldehydes, and nonreactives.

Estimates of NO emissions require the grassland area in a grid cell (available from the Geoecology Data Base, Olson *et al.,* 1980) and the surface temperature (provided by the ROM meteorological input pro-

cessors). Emissions were generated for each grid cell in units of moles of NO. The final grid- and day-specific emissions of VOC and NO_x derived from BEIS are merged with the anthropogenic emissions derived from the ROM emission-processor system (refer to Section 2).

In ROMNET, biogenic emissions rates are assumed to be unaffected by growth in anthropogenic emissions. For example, it was not possible to consider the potential impact on biogenic emissions of future urbanization of current agricultural or forest lands. Thus, the base case, 2005 baseline, and control strategy scenarios all used a single set of day-specific biogenic emissions.

As indicated in Section 4.4.2, several scenarios were designed to examine the relative effectiveness of various anthropogenic emissions strategies considering the range of uncertainty in biogenic emissions. Uncertainty is believed to be large for biogenic emissions due to a lack of extensive data sets for specifying critical factors such as biomass emissions rates for various vegetation species and the effects on emissions of environmental stress (e.g., insects, drought, etc.), as well as changes in land-use patterns over the past 10 to 20 years. Although it was not possible to estimate the uncertainty in each biogenic emissions component, an uncertainty of ± a factor of 3 is believed to be representative of the overall range of uncertainty in biogenic emissions calculated for ROMNET. This factor was used for scaling biogenic emissions calculated by BEIS in the biogenic sensitivity scenarios 1985H, 1985L, CS06 - CS09, CS17, CS21, and CS22.

4.6.4 Characteristics of the Biogenic VOC Emissions Inventory

As discussed Section 4.6.3, biogenic VOC emissions are very sensitive to ambient temperature levels. A principal biogenic species is isoprene. Figure 4-21 and Figure 4-22 present spatial distributions of isoprene for a cool and a warm day for 1000 EST and 1500 EST. These biogenic emission estimates are based on hourly temperatures for each grid cell for the hours shown.

Two comparisons are described. The first relates isoprene emissions on the same day (morning versus afternoon). From the "cool" day plots (Figure 4-21), the most noticeable effect is the increase in emissions between the morning and afternoon across southeastern Ohio, central Pennsylvania and upstate New York. On an overall basis, isoprene emissions increased approximately 25 percent from 1000 EST and 1500 EST on the "cool" day. The "warm" day plots (Figure 4-22) show that isoprene emissions increase in eastern Kentucky, and from western West Virginia across central Virginia and northeastward into upstate New York, New Hampshire, and Vermont. On an overall basis, isoprene emissions increased approximately 20 percent from 1000 EST and 1500 EST on the "warm" day.

The second comparison is for isoprene emissions on different days (cool versus warm days). Figures 4-21 (top) and 4-22 (top) indicate that isoprene emission levels are significantly higher in the morning for the warm day. This is especially evident for much of the inland areas (West Virginia, Virginia, Pennsylvania, and New York). On an overall basis, isoprene emissions were approximately 70 percent higher during the morning of the warm day than on the cool day. Figures 4-21 (bottom) and 4-22 (bottom) show that a very similar pattern can be observed in the afternoon isoprene emission levels. The overall increase in afternoon isoprene emissions between the "cool" and the "warm" day was approximately 60 percent.

Figure 4-23 displays daily total biogenic emission rates for each day of the July 1988 episode. These totals include not only isoprene, but alpha-pinene, monoterpene, and unidentified biogenic VOC emission estimates as well. Total regionwide biogenic VOC emission rates vary between 18,000 and 32,000 tons per day compared with an average regionwide anthropogenic VOC emission rate of 24,000 tons per day.

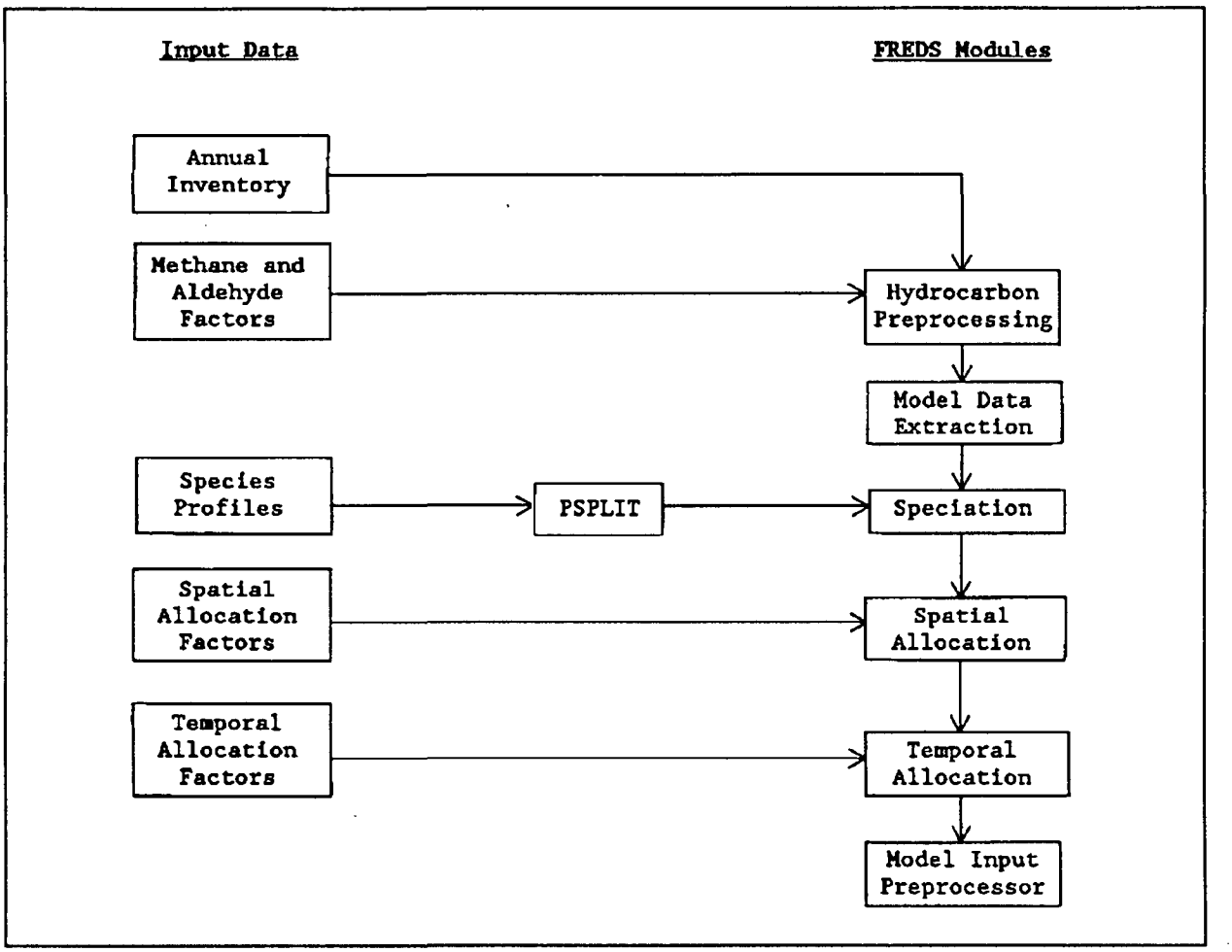

Figure 4-1. Summary of software modules and input data used in FREDS.

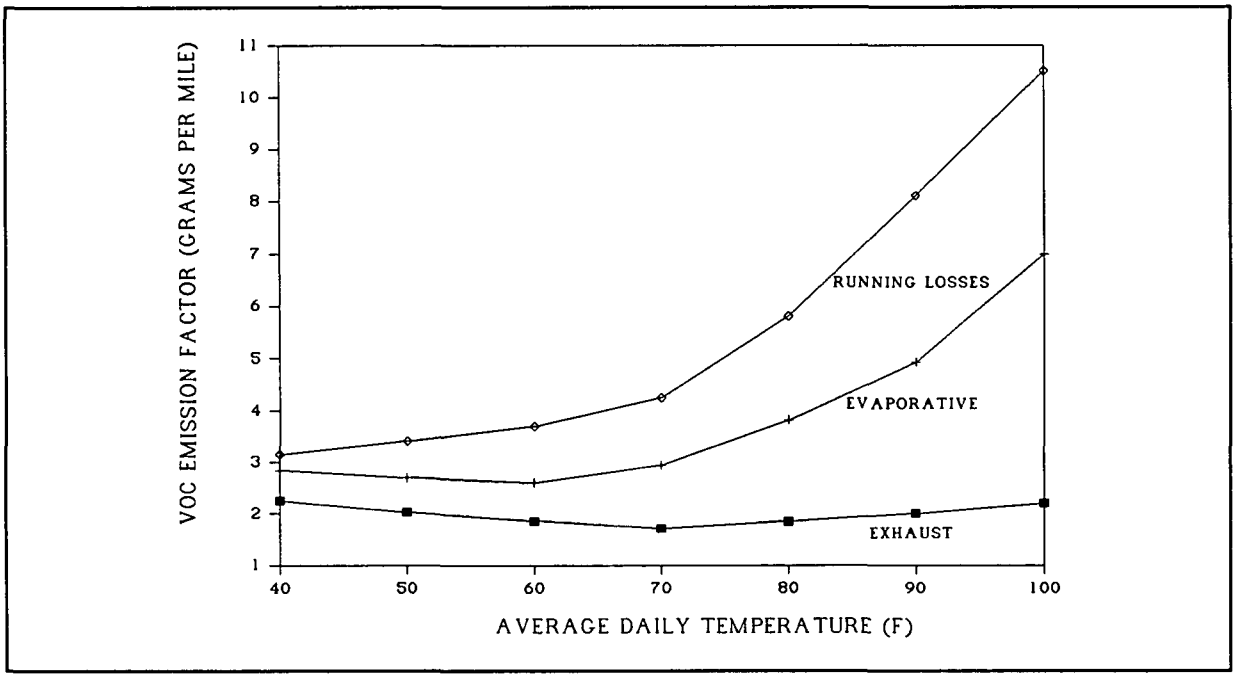

Figure 4-2. Effect of average daily temperature on VOC emissions. (Emissions are given for a composite of vehicle types and speeds for a diurnal temperature range of 20°F.)

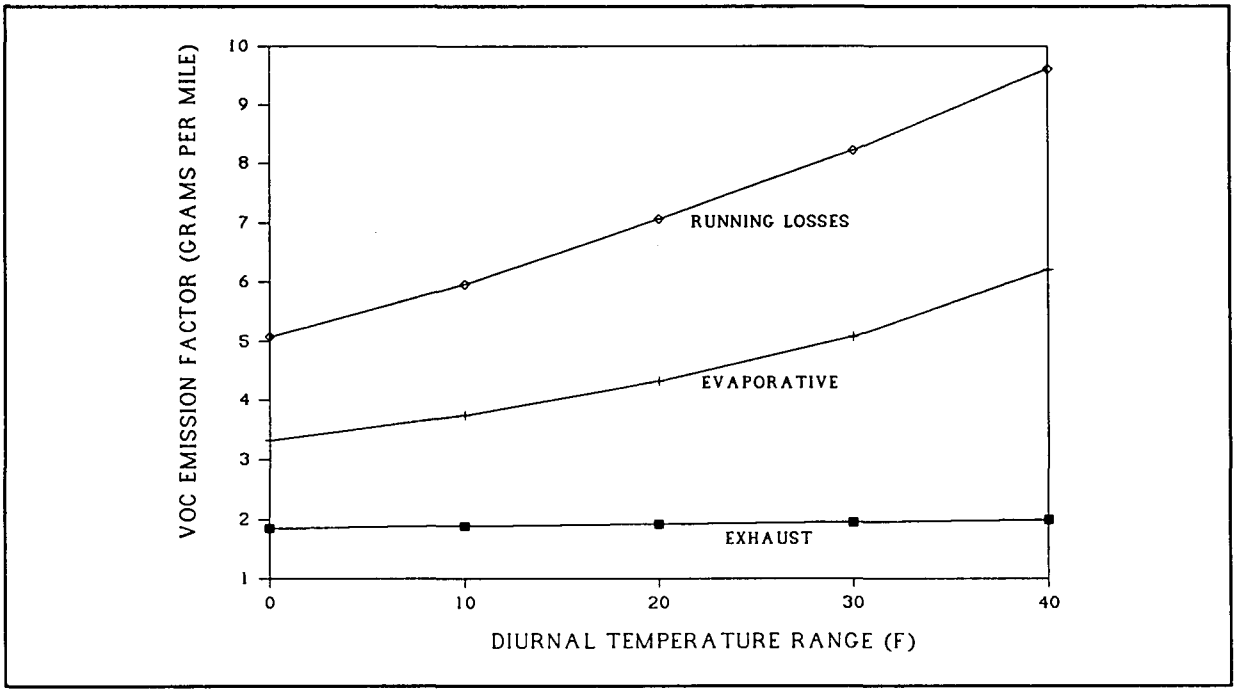

Figure 4-3. Effect of diurnal temperature range on VOC emissions. (Emissions are given for a composite of vehicle and speed classes at an average daily temperature of 85°F.)

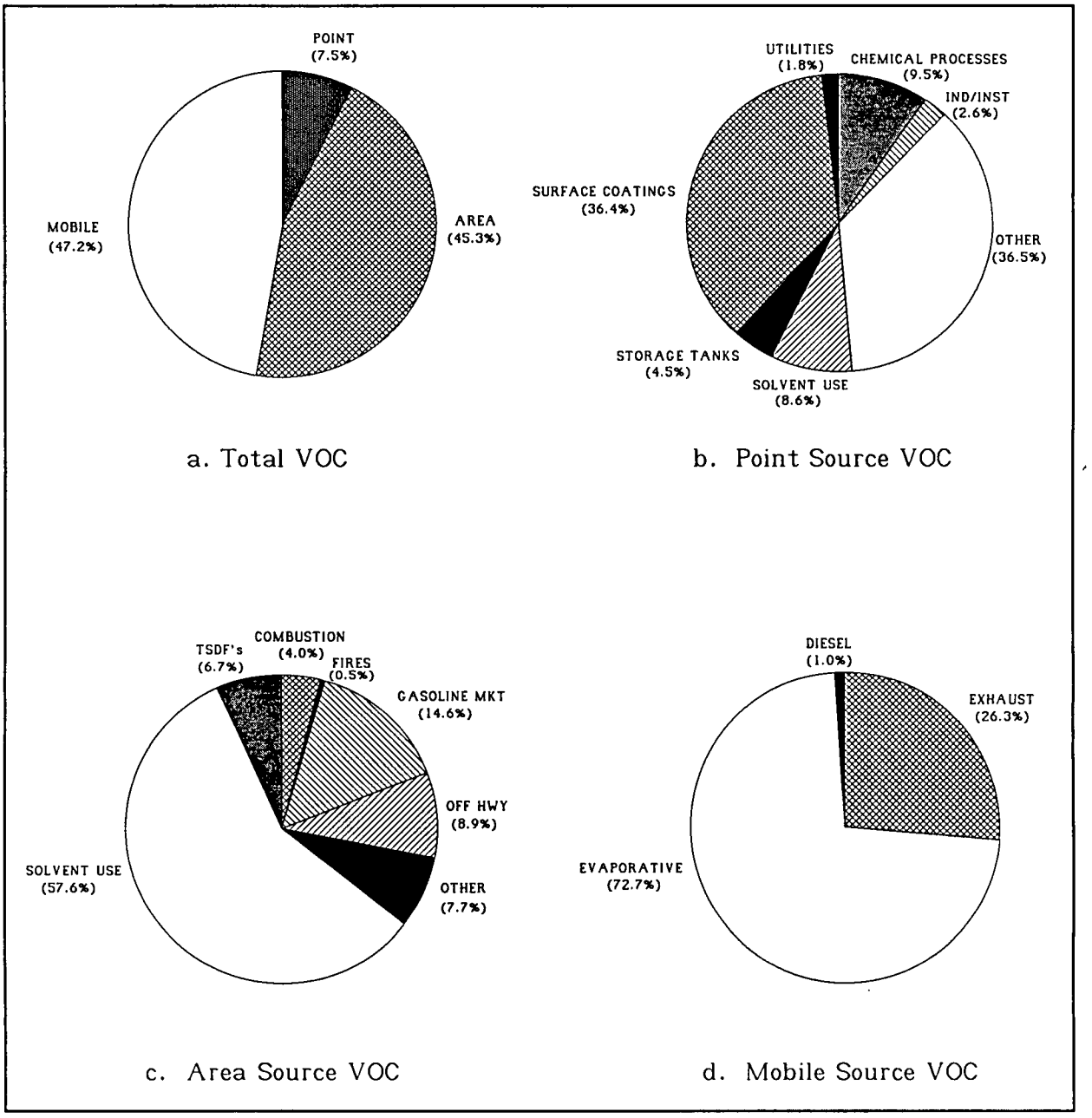

Figure 4-4. Distribution of regionwide 1985 VOC emissions.

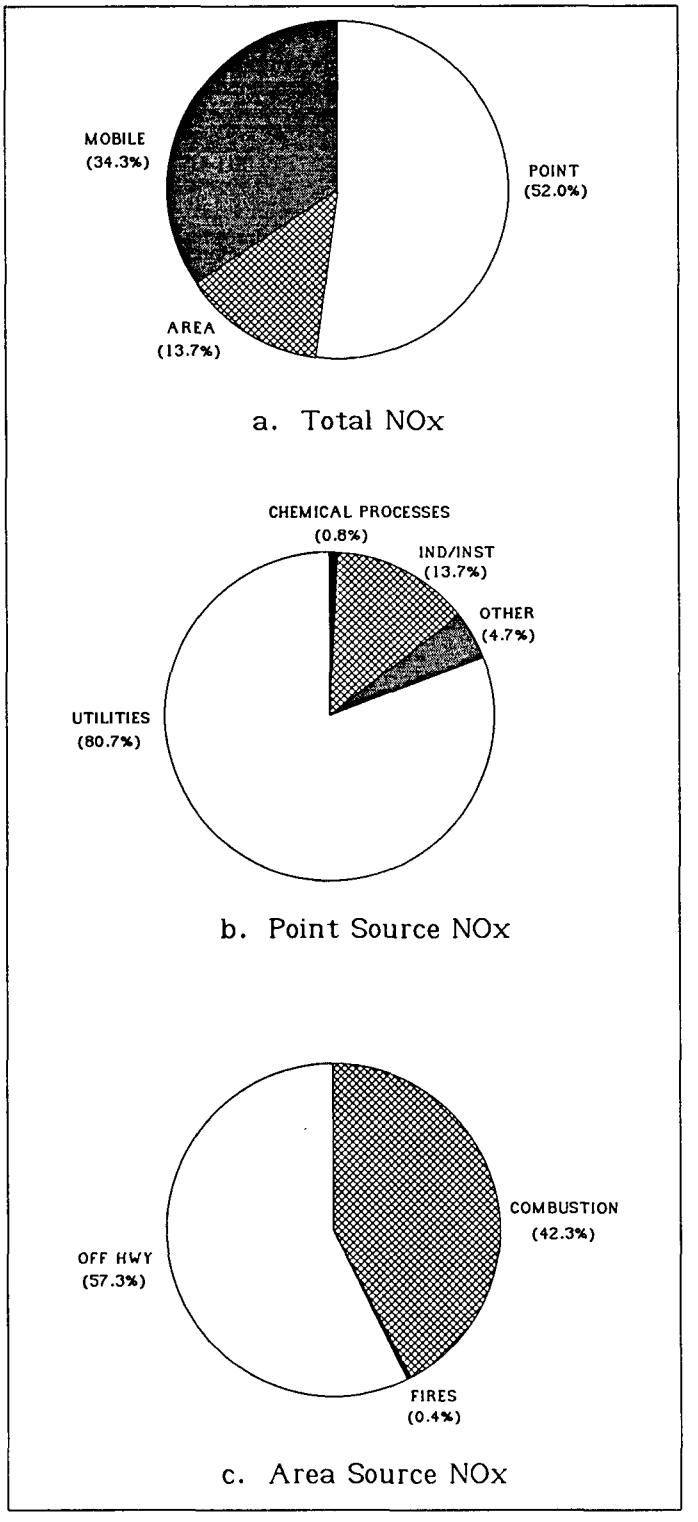

Figure 4-5. Distribution of regionwide 1985 NO_x emissions.

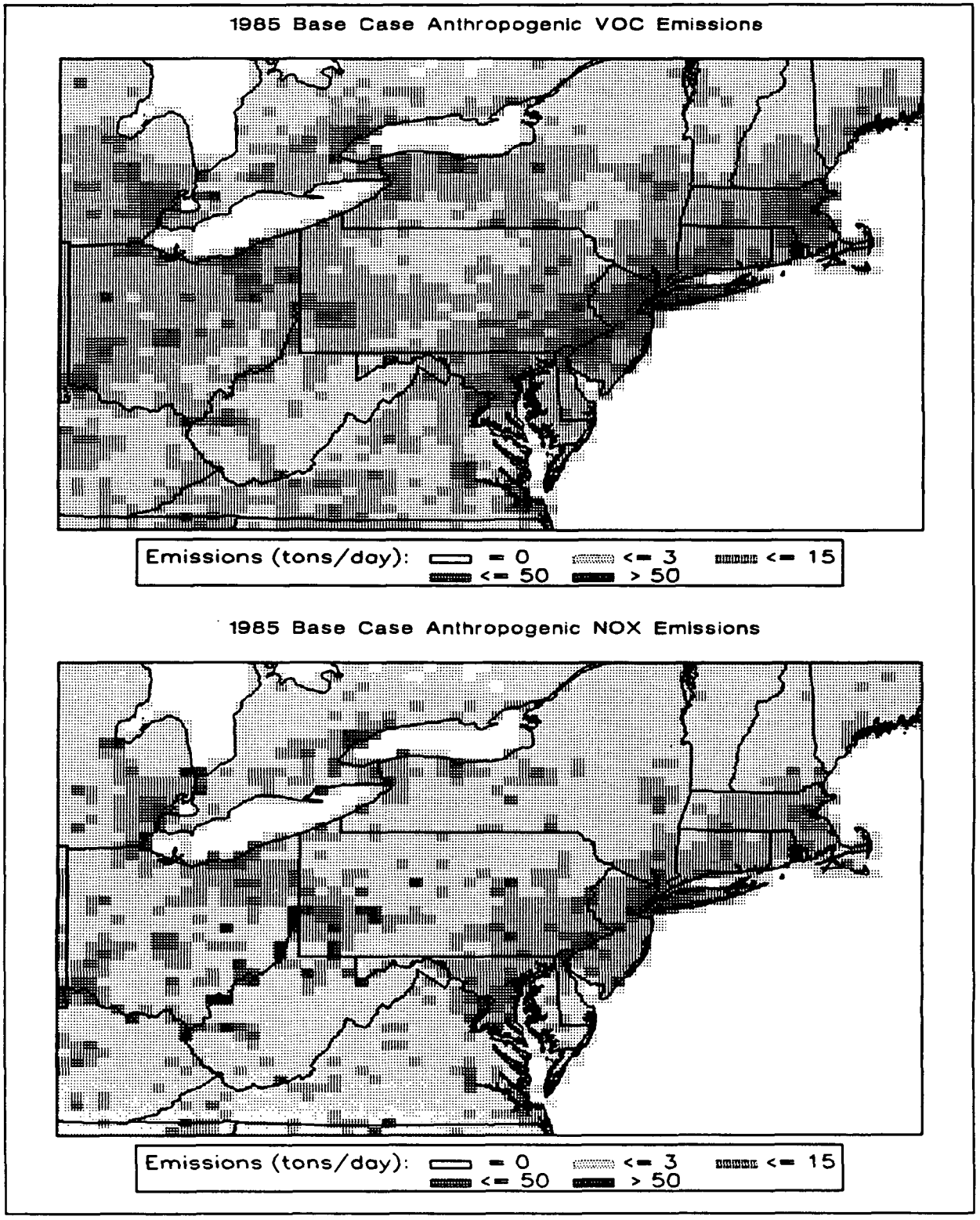

Figure 4-6. 1985 base case anthropogenic emissions (tons/day) of VOC and NO_x.

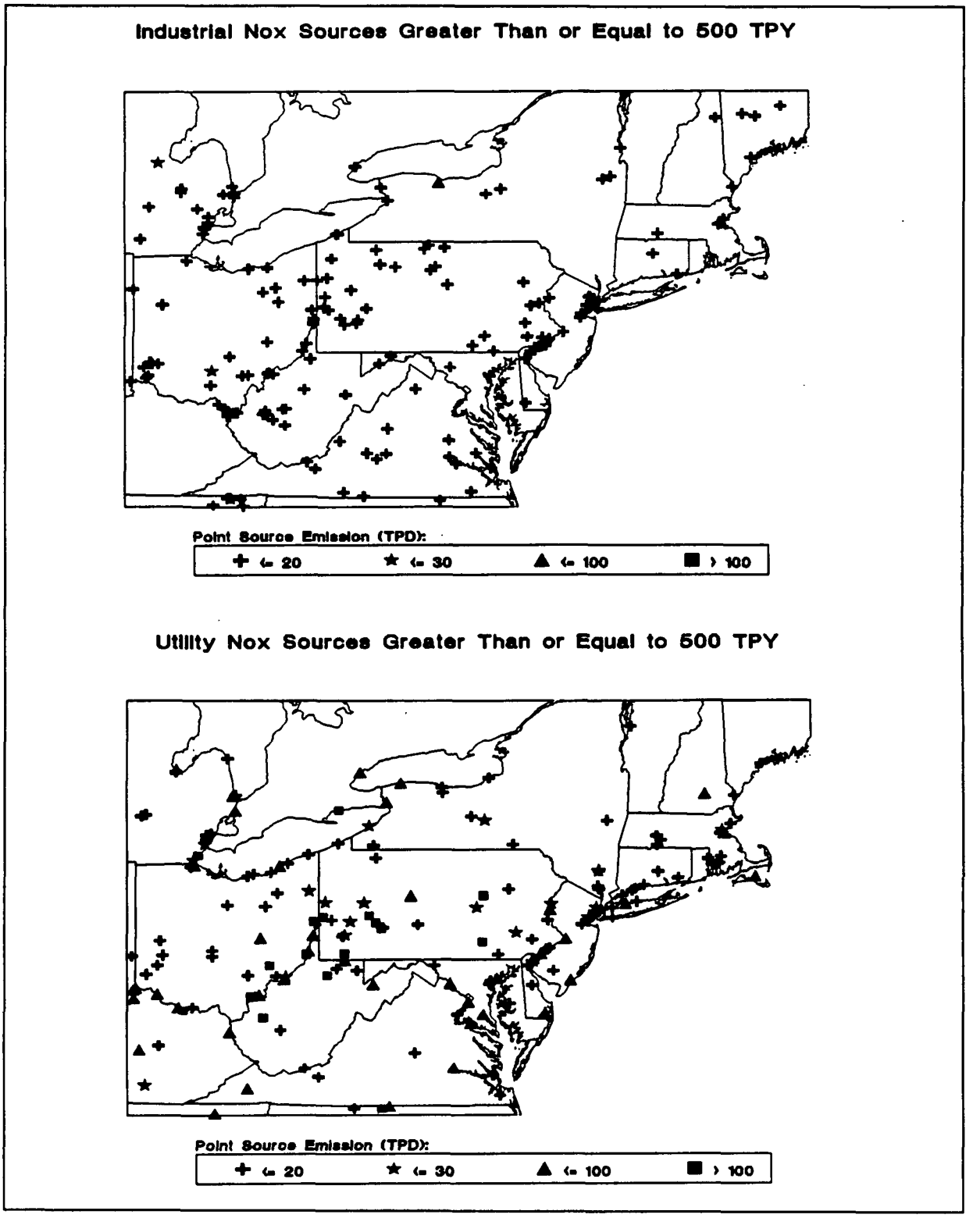

Figure 4-7. 1985 base case anthropogenic emissions (tons/day) of NO_x from industrial plants and utilities.

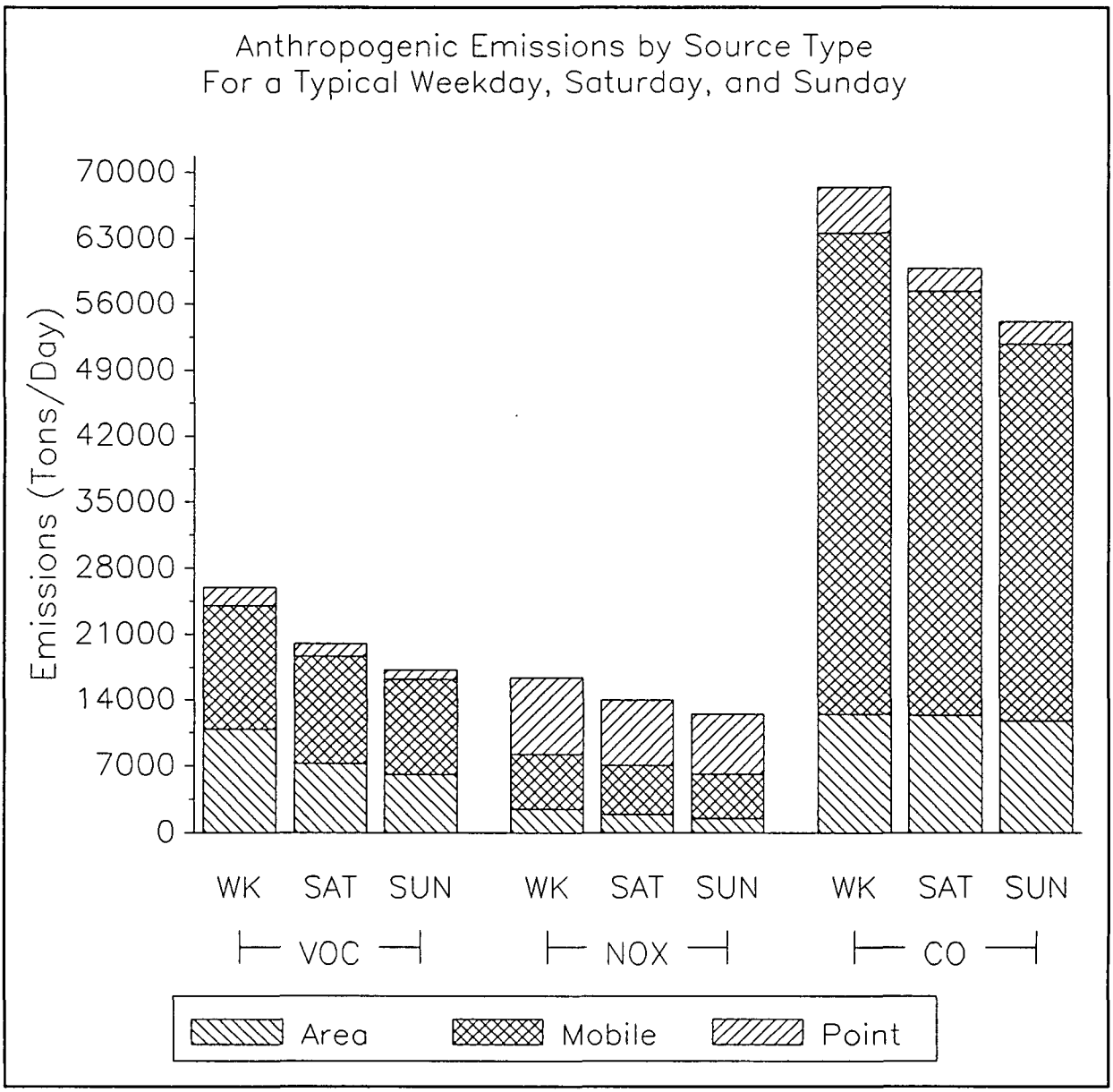

Figure 4-8. 1985 base case emissions (tons/day) by day type (weekday, Saturday, and Sunday).

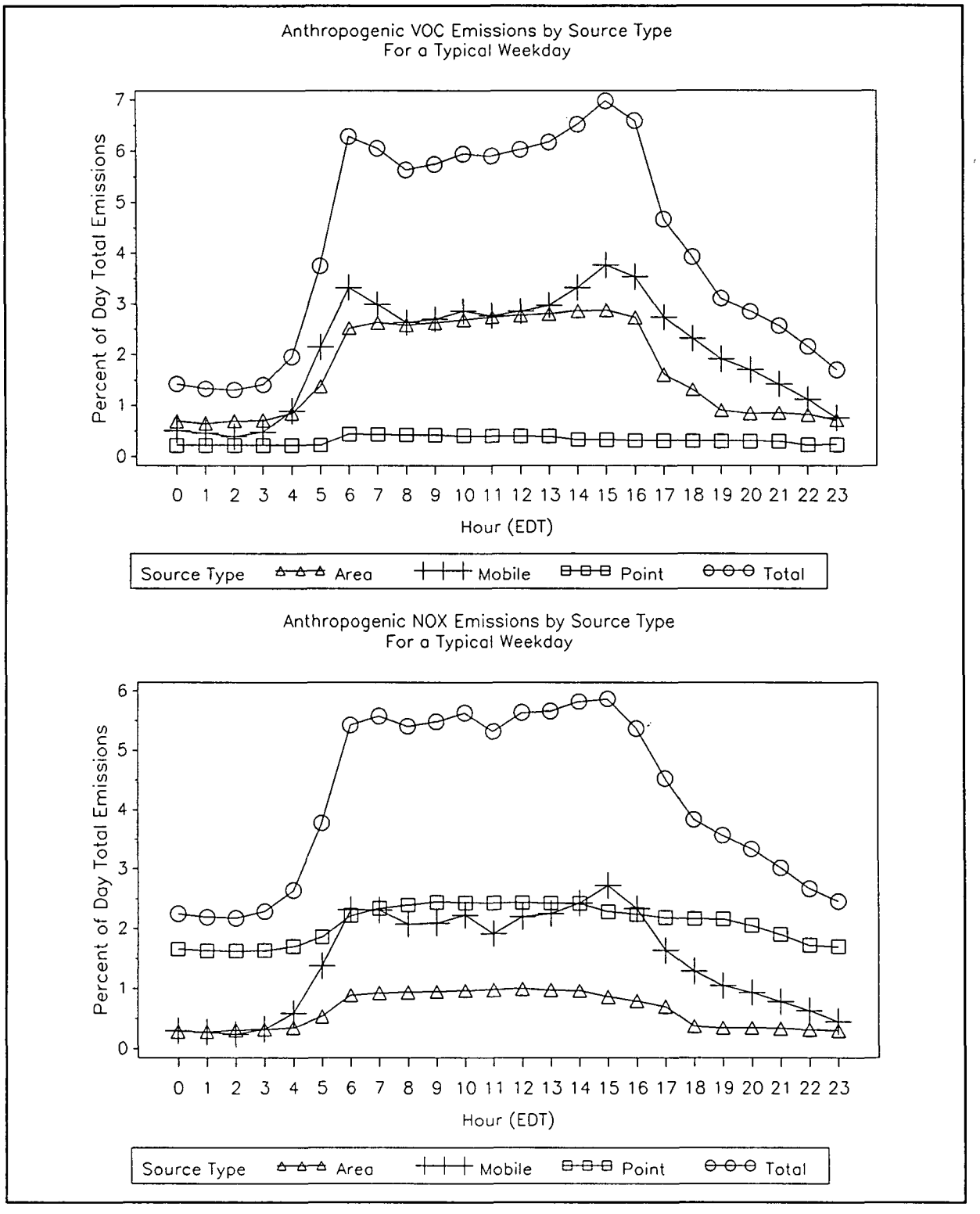

Figure 4-9. Diurnal profiles of point, area, and mobile sources of VOC and NO_x.

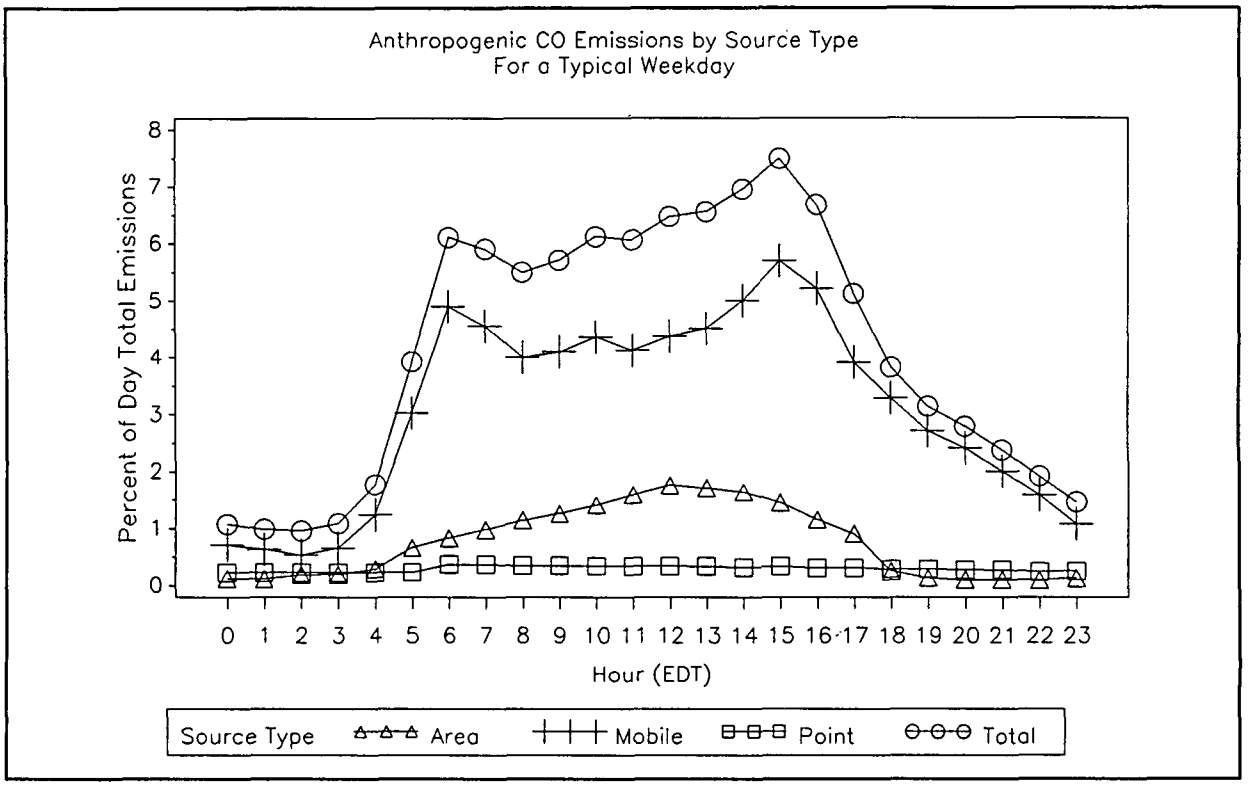

Figure 4-10. Diurnal profiles of point, area, and mobile sources of CO.

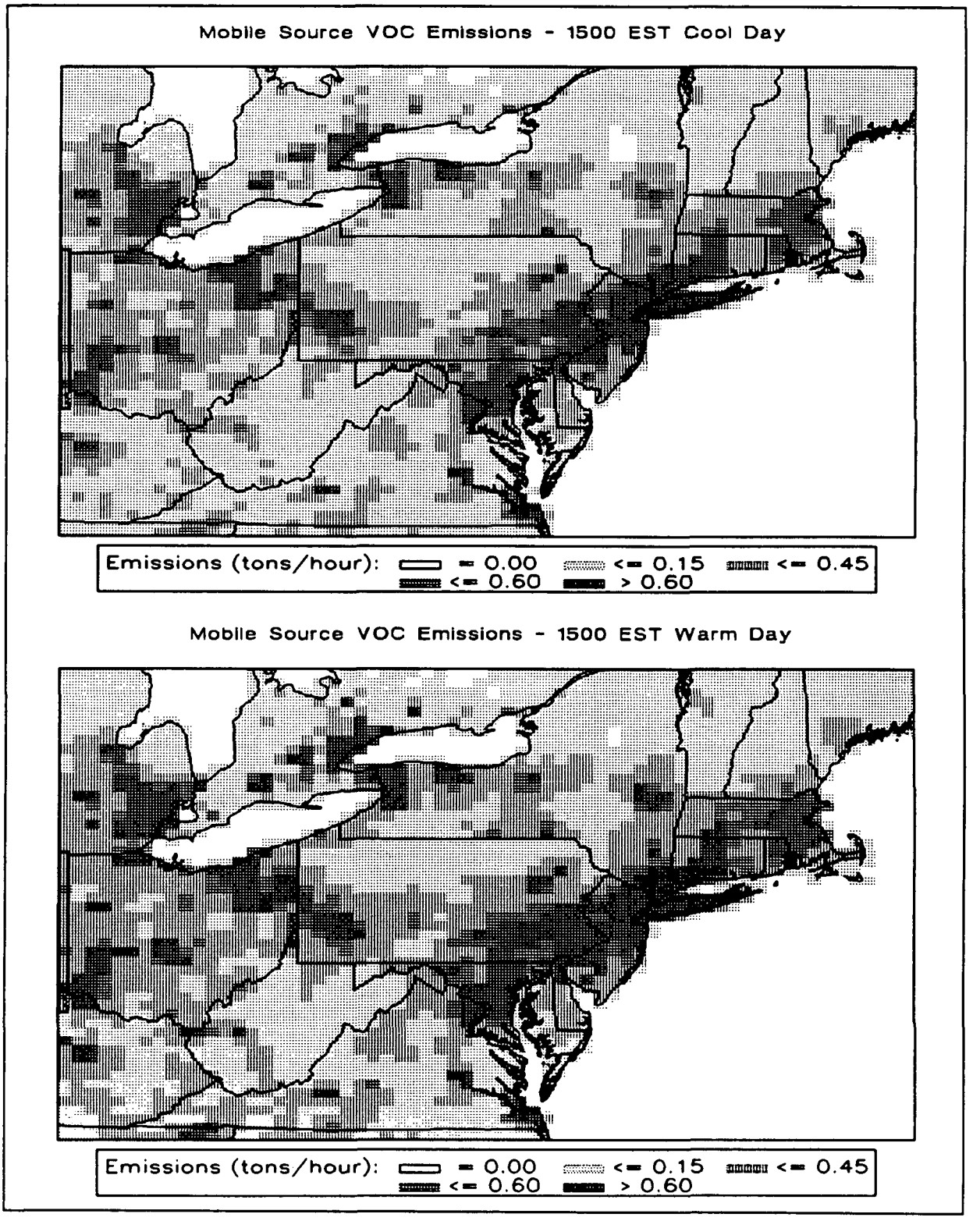

Figure 4-11. Mobile-source emissions (tons) at 1500 EST on a "cool" day and a "warm" day.

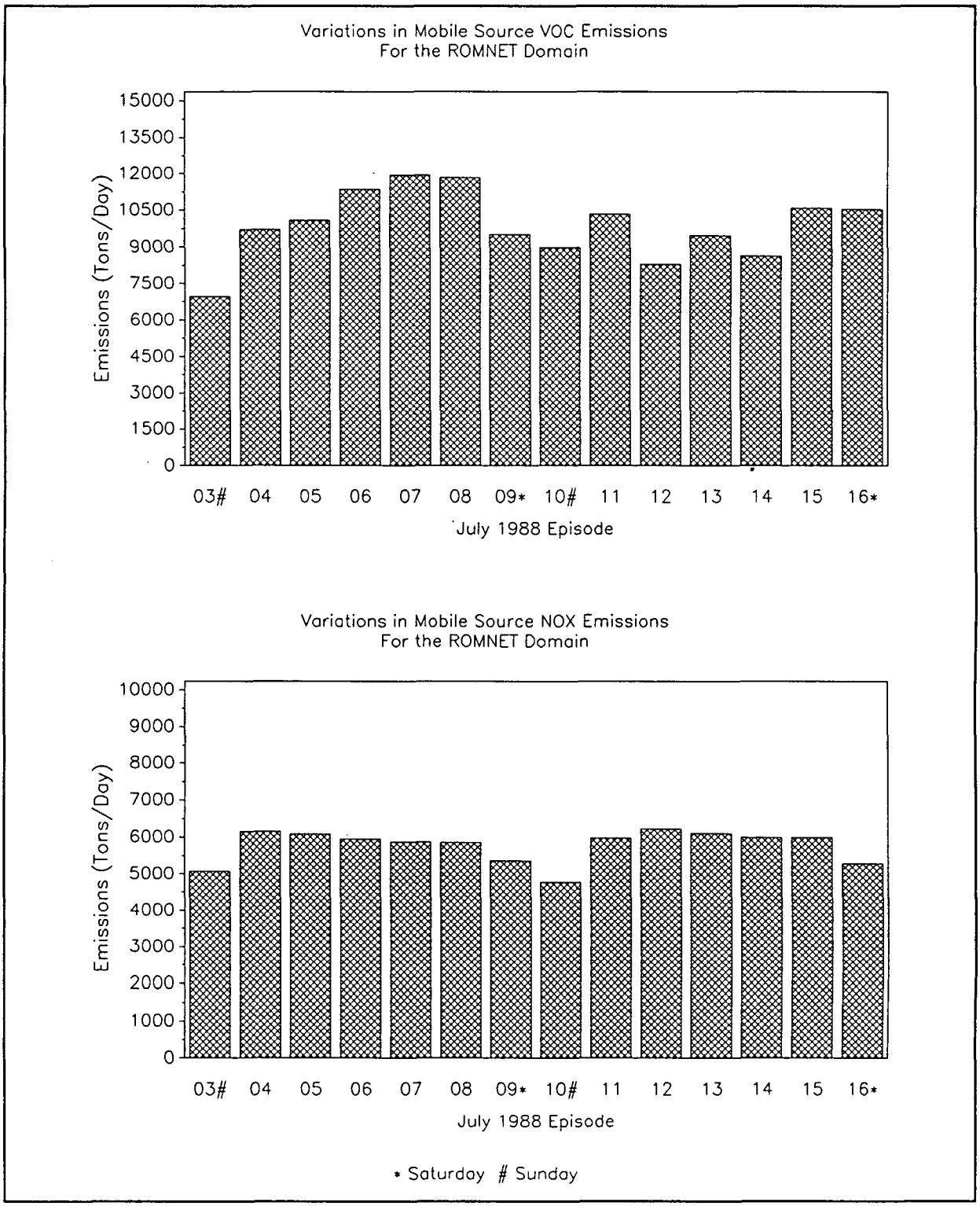

Figure 4-12. Regionwide daily total mobile-source VOC and NO_x emissions (tons/day), July 1988 episode.

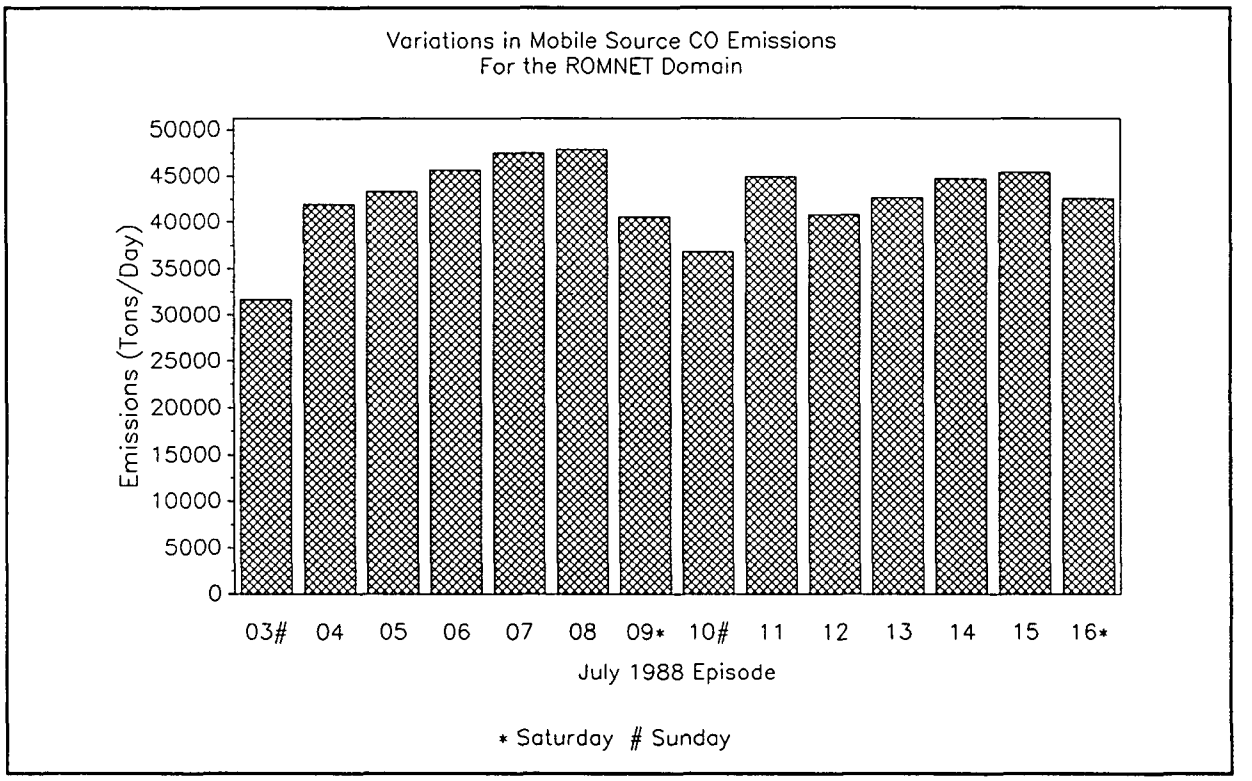

Figure 4-13. Regionwide daily total mobile-source CO emissions (tons/day), July 1988 episode.

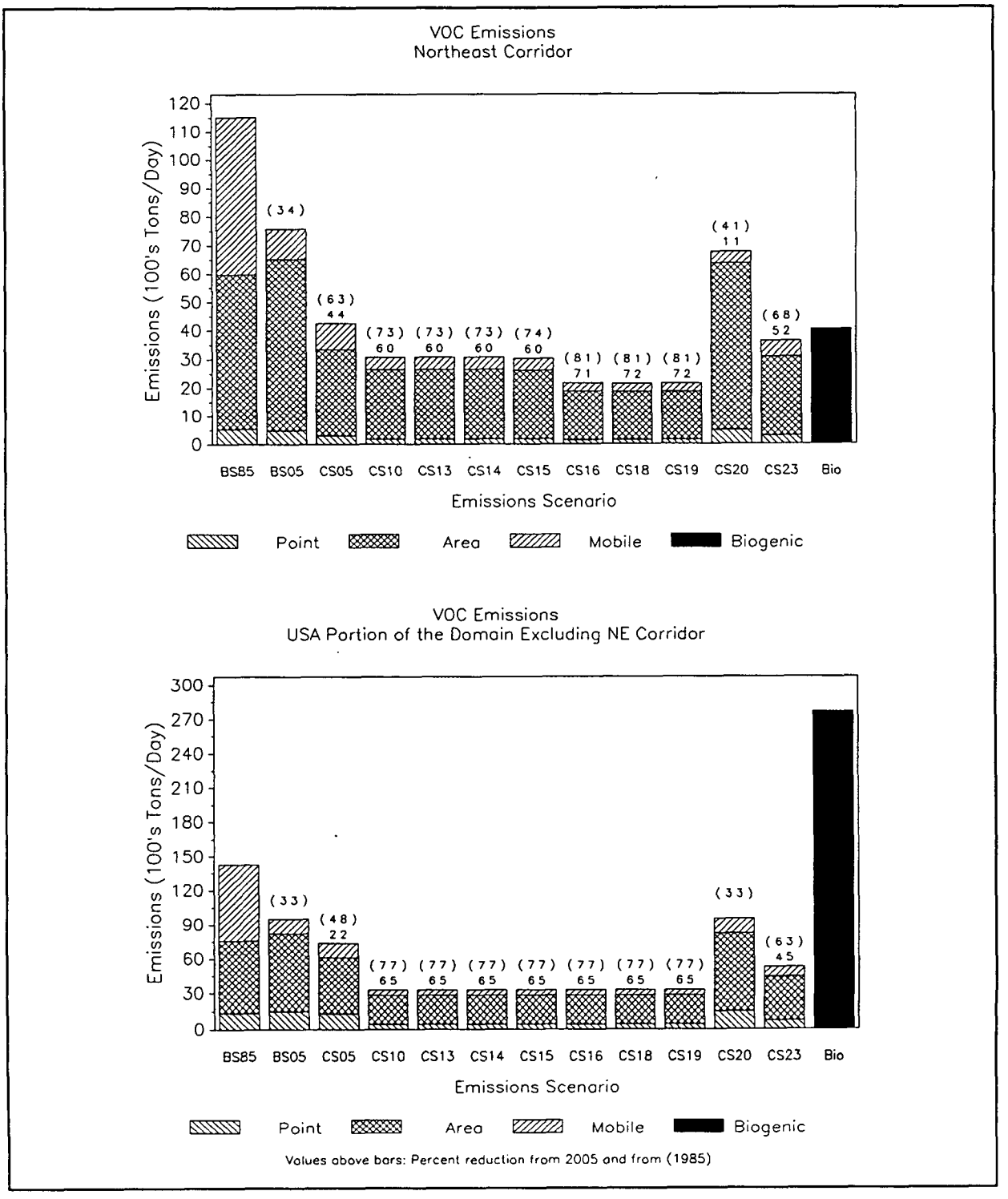

Figure 4-14. VOC emissions for the Phase II scenarios and the percent reduction from the 1985 base case and the 2005 baseline.

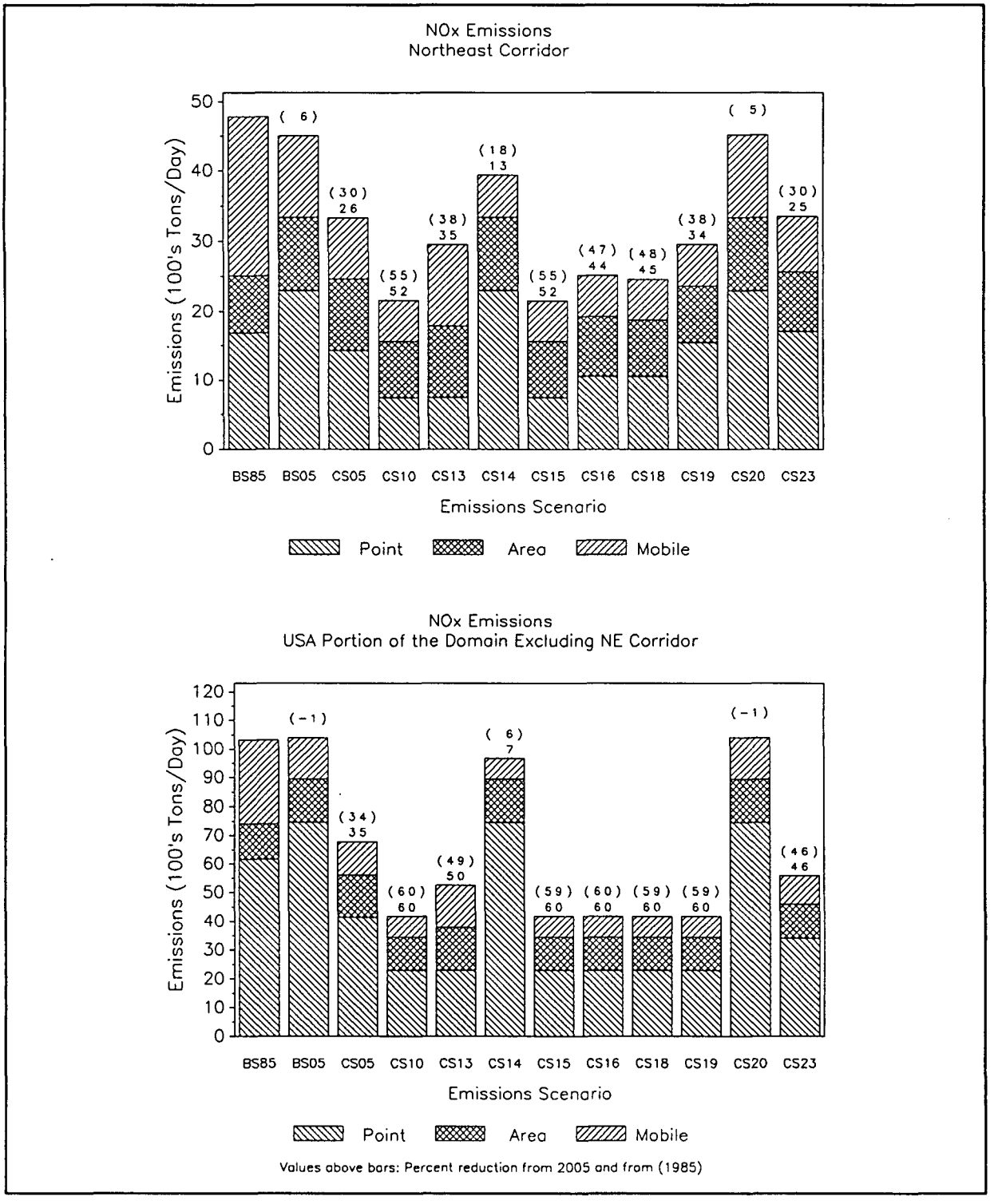

Figure 4-15. NO_x emissions for the Phase II scenarios and the percent reduction from the 1985 base case and the 2005 baseline.

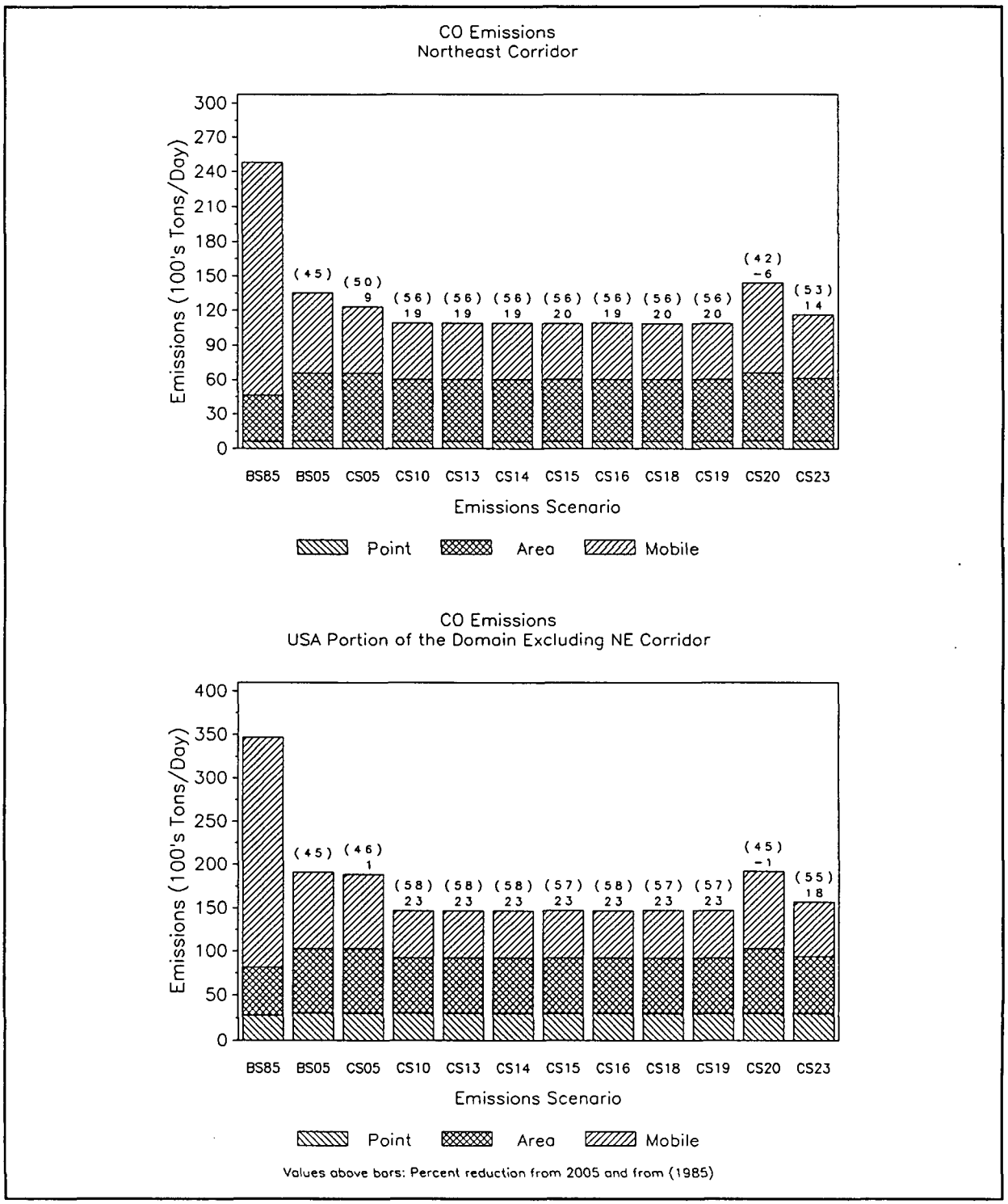

Figure 4-16. CO emissions for the Phase II scenarios and the percent reduction from the 1985 base case and the 2005 baseline.

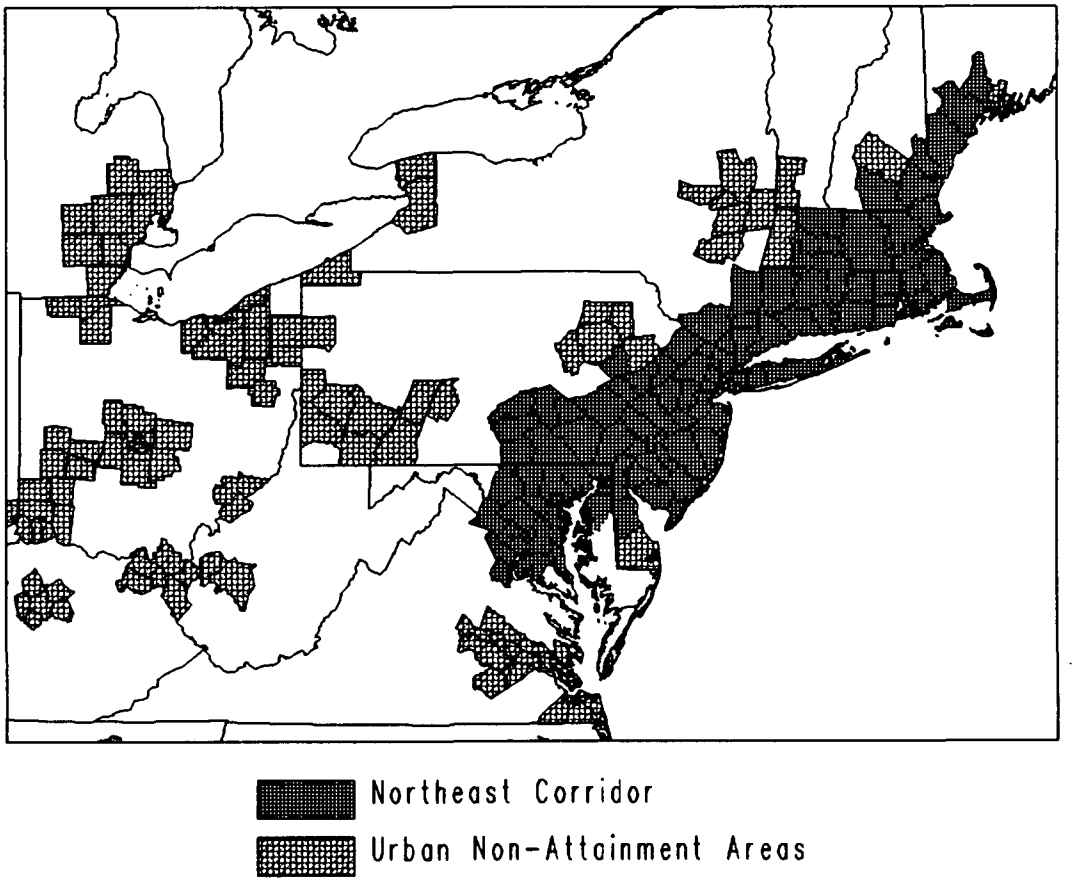

Figure 4-17. The Northeast Corridor and nonattainment areas outside the Corridor.

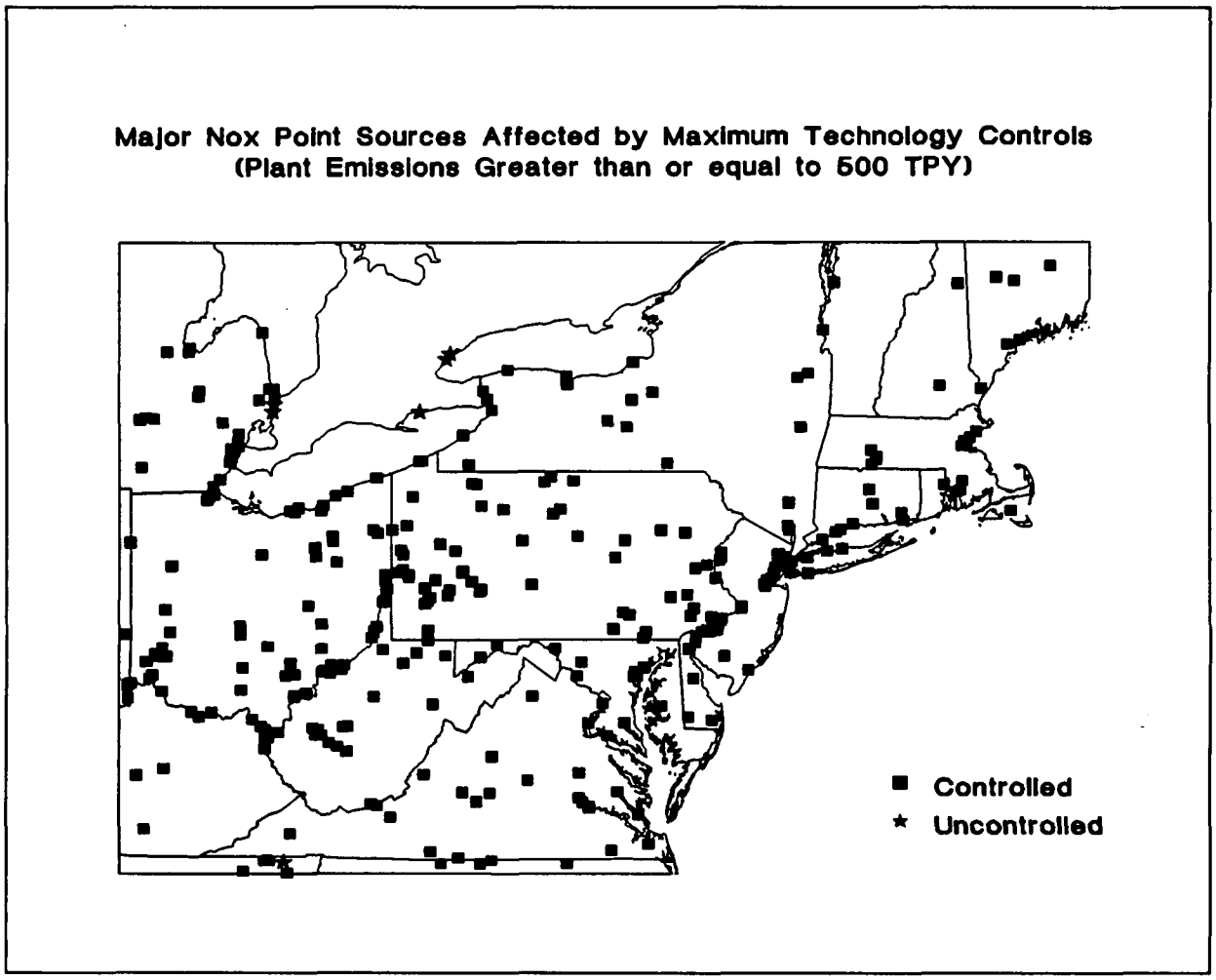

Figure 4-18. Location of major NO_x point sources controlled in the maximum technology strategy.

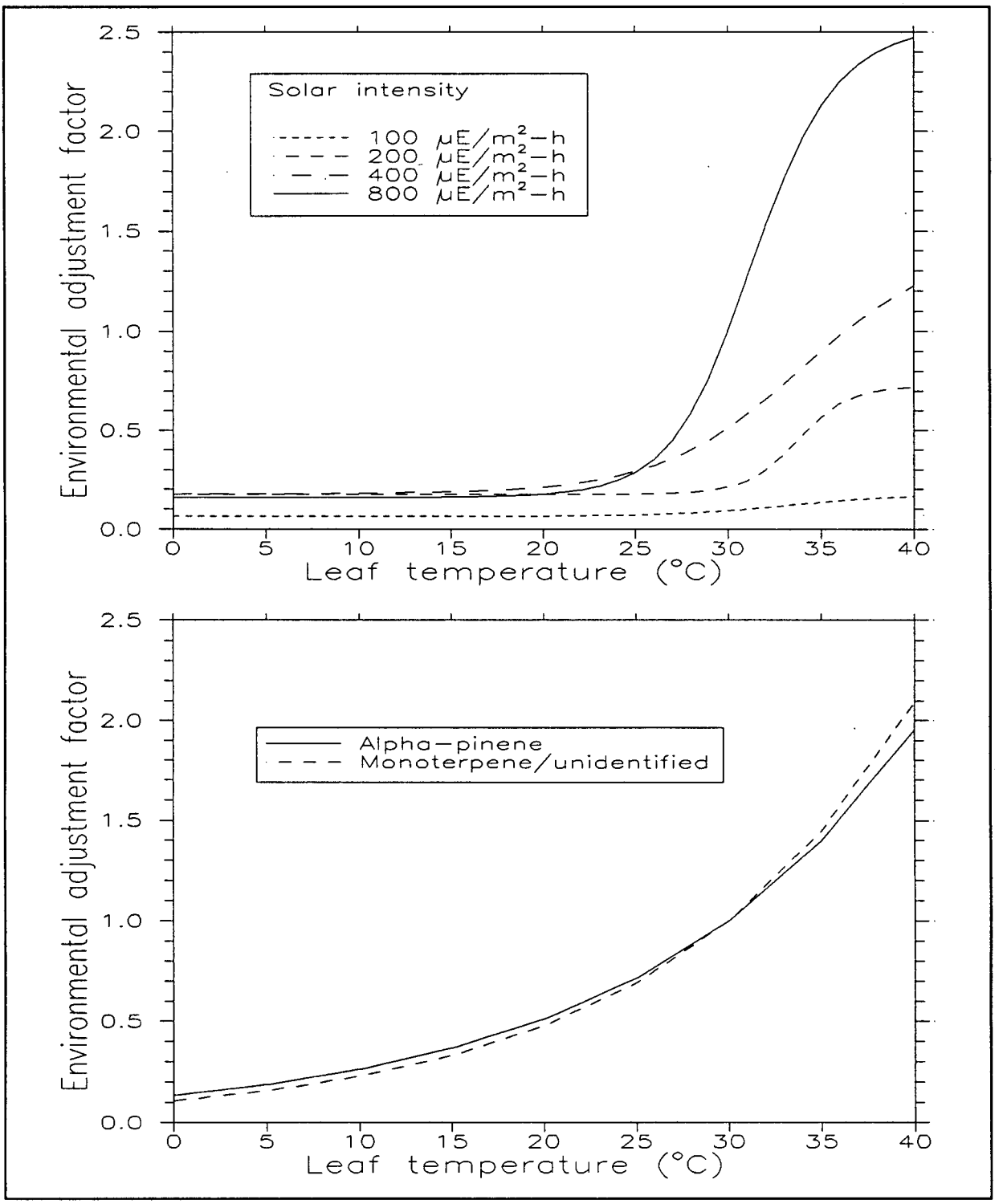

Figure 4-19. Relationship between meteorological temperature and (1) isoprene and alpha-pinene emissions, (2) monoterpenes/unidentified hydrocarbon emissions (Tingey *et al.*, 1980).

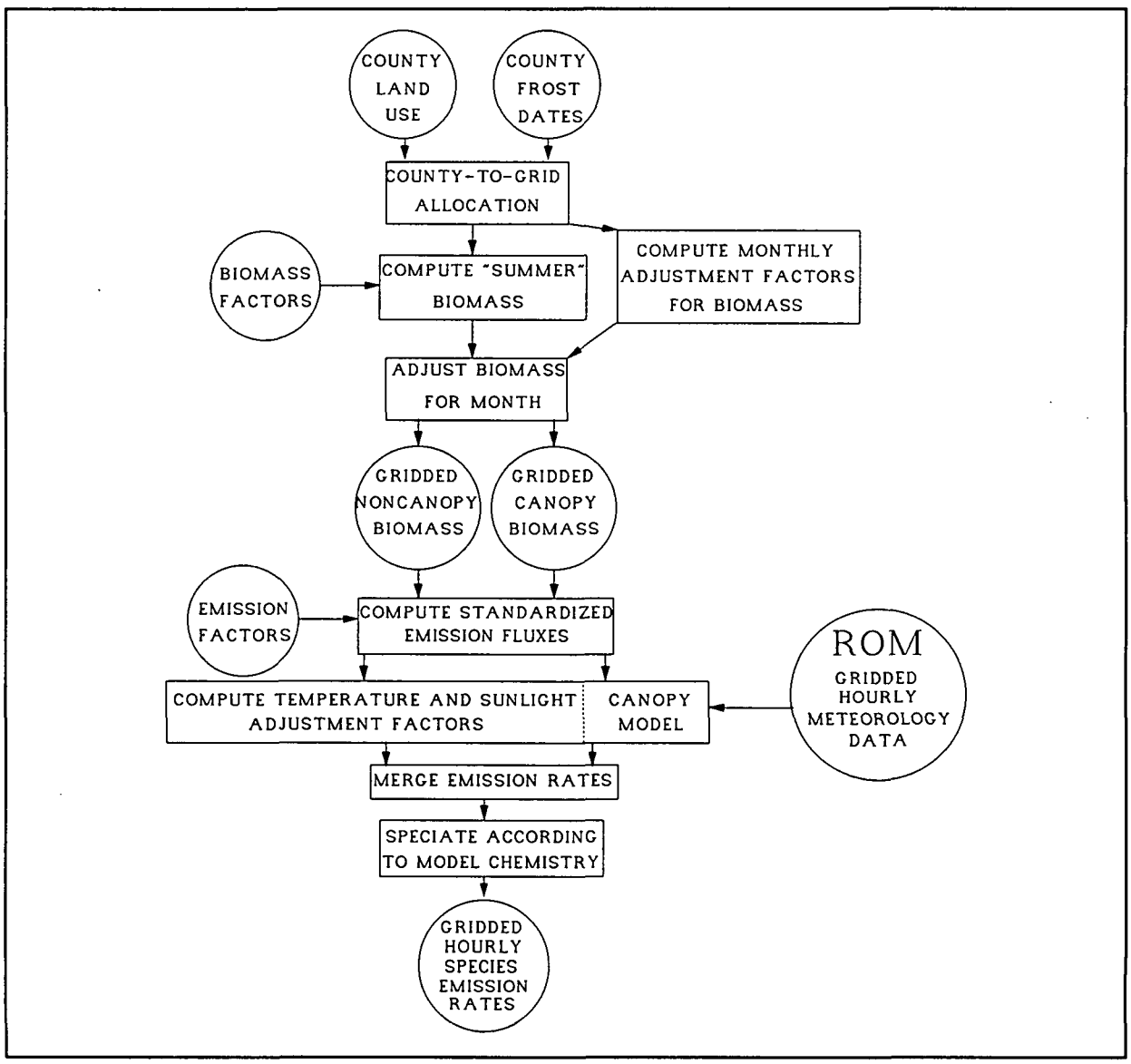

Figure 4-20. Flowchart of the Biogenic Emissions Inventory System.

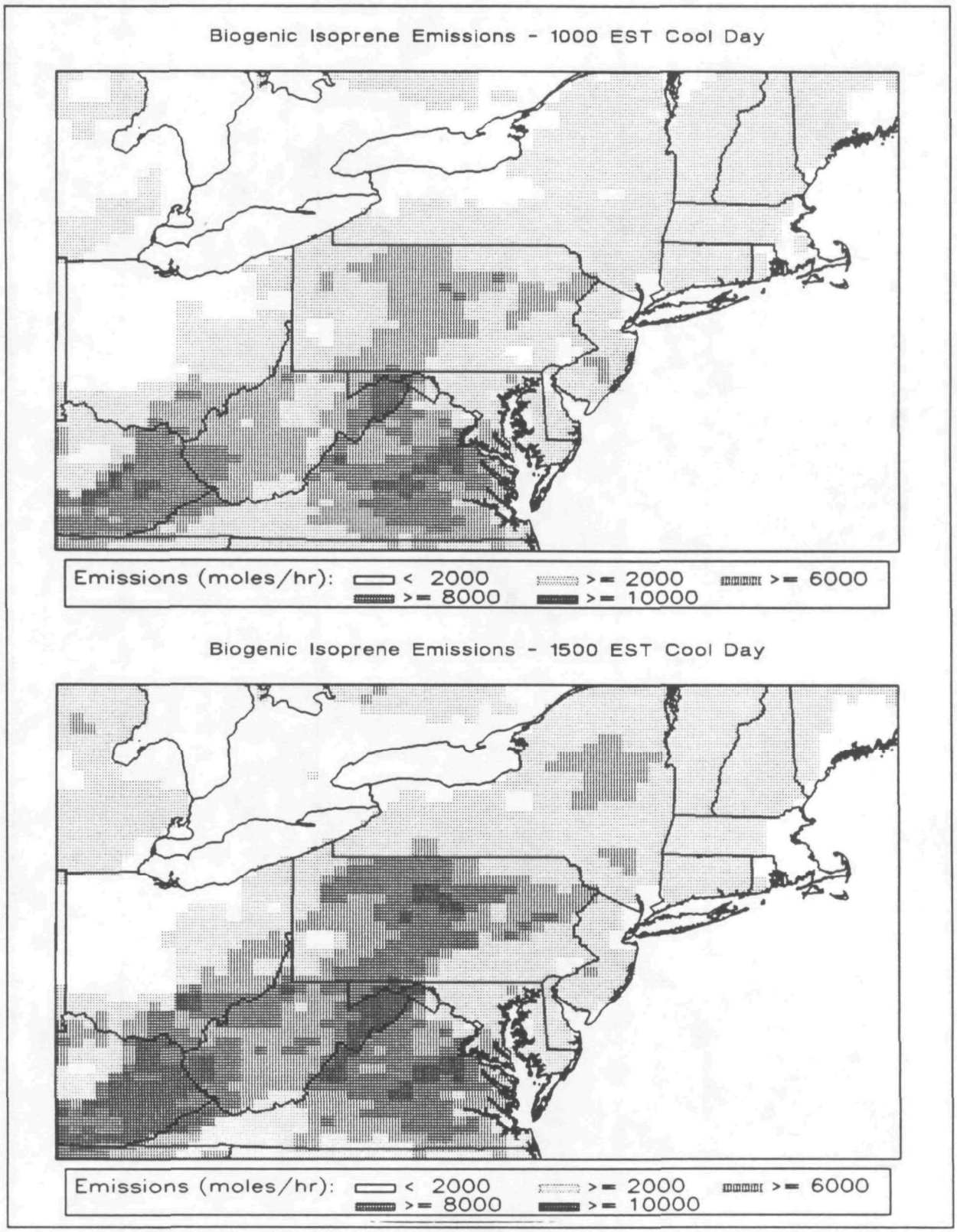

Figure 4-21. Biogenic isoprene emissions (mol C/h) for 1000 EST and 1500 EST on a "cool" day.

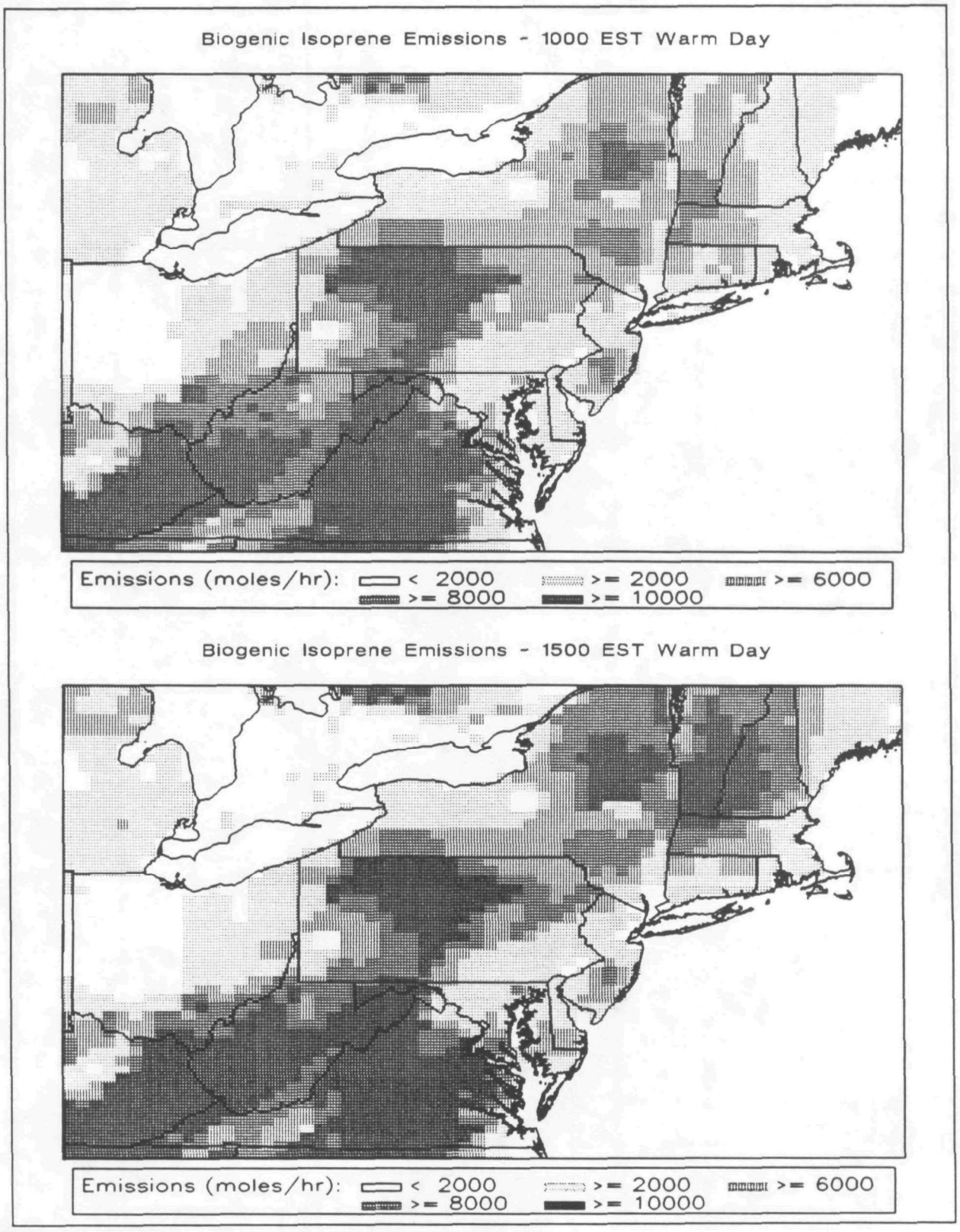

Figure 4-22. Biogenic isoprene emissions (mol C/h) for 1000 EST and 1500 EST on a "warm" day.

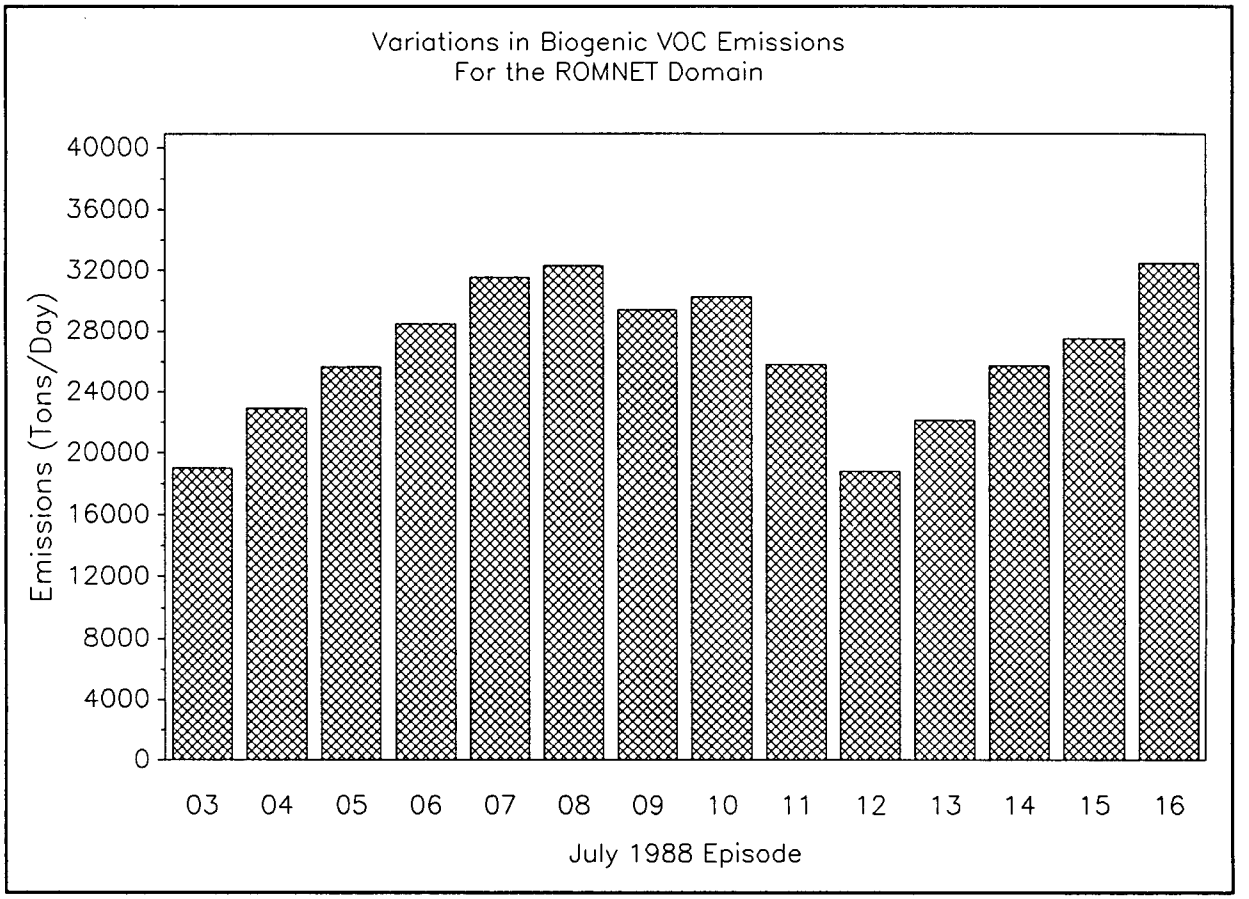

Figure 4-23. Regionwide daily total biogenic VOC emissions (tons/day), July 1988 episode.

TABLE 4-1. ROMNET EMISSIONS SCENARIOS

PHASE I SCENARIOS (MOBILE3.9)	
1985 Base Case	
2005 Baseline:	No Growth NO_x Scenario
CS01:	Phase I VOC Maximum Technology Controls
CS02 and CS03:	Spatial Analyses of VOC Controls--Transport Sensitivity Scenarios
CS04:	CS01 Rule Effectiveness Sensitivity Scenario (not simulated--replaced by CS23)
PHASE II SCENARIOS (MOBILE4)	
1985 Base Case	
2005 Baseline:	NO_x Growth Scenario
CS05:	October 1989 Proposed Clean Air Act Legislation
CS06 - CS09, 1985L & 1985H:	Biogenic Sensitivity Scenarios for Phase I 1985 Base Case and CS01, and Phase II CS05 Strategies
CS10:	Maximum Technology NO_x Controls and Enhanced Maximum Technology VOC Controls
CS11:	Maximum Technology NO_x Controls; VOC at 2005 Baseline
CS12:	Enhanced Maximum Technology VOC Controls; NO_x at 2005 Baseline
CS13:	Point Source Maximum Technology NO_x Controls; Enhanced Maximum Technology VOC Controls
CS14:	Mobile Source Maximum Technology NO_x Controls; Enhanced Maximum Technology VOC Controls
CS15:	Maximum Technology VOC and NO_x Controls With Reactivity-Based Measures
CS16:	Maximum Technology Controls With Additional Across-The-Board VOC Reduction in New York City and Baltimore/Washington, DC and Alteration of NO_x Controls in New York City
CS17:	Biogenic Sensitivity Scenario for Maximum Technology NO_x Controls
CS18:	CS16 With Reactivity Based Measures
CS19:	CS18 With Alteration of NO_x Controls in Baltimore/Washington, DC
CS20:	2005 Baseline With Reactivity-Based Measures
CS21 and CS22:	Biogenic Sensitivity Scenarios for CS19
CS23:	CS19 Rule Effectiveness Sensitivity Scenario
CS24 and CS25:	Spatial Analysis of VOC and NO_x Controls--Transport Sensitivity Scenarios

TABLE 4-2. REVISED SUMMER ALLOCATION FACTORS FOR AREA-SOURCE CATEGORIES [a]

	Gasoline vessels (52)	Gasoline marketing (54)	Architectural coating (82)	Miscel-laneous solvent use (95)	Bulk gas terminals and bulk plants (103)	Hazardous waste TSDF (109)
Connecticut	0.425	0.385	0.500	0.251	0.398	0.300
Delaware	0.425	0.368	0.425	0.266	0.380	0.300
DC	0.375	0.363	0.425	0.250	0.380	0.300
Indiana	0.425	0.358	0.425	0.264	0.365	0.300
Kentucky	0.425	0.310	0.425	0.308	0.315	0.300
Maine	0.500	0.398	0.600	0.254	0.405	0.300
Maryland	0.425	0.365	0.425	0.265	0.378	0.300
Massachusetts	0.425	0.370	0.500	0.252	0.380	0.300
Michigan	0.500	0.430	0.500	0.288	0.445	0.300
New Hampshire	0.500	0.413	0.600	0.257	0.423	0.300
New Jersey	0.425	0.378	0.425	0.253	0.393	0.300
New York	0.425	0.380	0.500	0.262	0.390	0.300
North Carolina	0.325	0.353	0.425	0.268	0.368	0.300
Ohio	0.425	0.360	0.425	0.283	0.370	0.300
Pennsylvania	0.425	0.360	0.425	0.262	0.370	0.300
Rhode Island	0.500	0.385	0.500	0.251	0.395	0.300
Tennessee	0.325	0.345	0.425	0.268	0.360	0.300
Vermont	0.500	0.413	0.600	0.308	0.423	0.300
Virginia	0.325	0.345	0.425	0.267	0.358	0.300
West Virginia	0.425	0.315	0.425	0.262	0.323	0.300

Note: The numbers in parentheses under the column headings are area source classification codes.

[a] The original allocation factor in the NAPAP inventory was 0.25 for all of these categories, corresponding to no increase in emissions during summer.

TABLE 4-3. SUMMARY OF CONTROL MEASURES IN THE BASELINE PROJECTION AND MAXIMUM TECHNOLOGY INVENTORIES

Inventory	VOC control measures	NO_x control measures
Phase I: 2005 Baseline	Highway vehicles: - current FMVCP - RVP = 9 psi - existing I/M programs Point and area sources: - State controls in place as of 1985 - NSPS controls	Highway vehicles: - current FMVCP Area sources: no controls Point sources: - NSPS controls - additional controls as necessary to offset overall NO_x emission growth at the State level
Phase I: Maximum Technology VOC	Highway vehicles: - current FMVCP - RVP = 9 psi - enhanced I/M region-wide Point and area sources: - maximum technology for industrial sources - low solvent coatings for architectural uses - 20 percent reduction of consumer solvent use - on-board or Stage II controls for gasoline marketing emissions	Same as Phase I baseline
Phase II: 2005 Baseline	Highway vehicles and area sources: - same as Phase I baseline but with evaporative test procedure Point sources: - 5% reduction of utility emissions (after growth) to reflect enhanced energy efficiency	Highway vehicles and area sources: - same as Phase I baseline Point sources: - 5% reduction of utility emissions (after growth) to reflect enhanced energy efficiency
Phase II: Maximum Technology NO_x and Enhanced Maximum Technology VOC	Highway vehicles: - 0.125 g/mi tailpipe standard - enhanced I/M with anti-tampering - RVP = 7 psi - full implementation for all measures Point and area sources: - same controls as Phase I, and: - 5% energy-efficiency reduction for utilities - maximum technology for off-highway vehicles - prohibition of residential wood burning and all open burning during ozone season	Highway vehicles: - 0.2 g/mi tailpipe standard - 4 g/bk-hp-hr standard for trucks - full implementation of all measures Point sources: - 5% control for energy-efficiency enhancement for utilities - selective catalytic reduction (SCR) for utilities - low-NO_x burners or equivalent for industrial and institutional combustion units Area sources: - maximum technology for off-highway vehicles - prohibition of residential wood burning and all open burning during ozone season

TABLE 4-4. CONTROL MEASURES FOR THE DRAFT CLEAN AIR ACT ANALYSIS

Source category	VOC controls	NO_X controls
Highway vehicles	Tailpipe standards (phased in 1994-96): Passenger cars: 0.25 g/mi Light-duty trucks 1: 0.25 g/mi Light-duty trucks 2: 0.5 g/mi RVP = 9 psi Alternative fuels for 4 urban areas Enhanced I/M for serious and severe nonattainment areas	Tailpipe standards (phased in 1994-96): Passenger cars: 0.4 g/mi Light-duty trucks 1: 1.00 g/mi Light-duty trucks 2: 1.00 g/mi
Point sources	Various controls implemented depending on the severity of the ozone problem in each MSA	Low-NO_X burners or equivalent for utility boilers larger than 75 MWe
Area sources	Various controls implemented depending on the severity of the ozone problem in each MSA	None
General	Across-the-board reductions at the MSA level, to achieve an overall reduction of 3 percent per year from 1990 to the projected attainment date	None

TABLE 4-5. NSPS EFFICIENCIES FOR POINT AND AREA SOURCES

Pod	Category name	NSPS efficiency (%)	Technology
	Point Sources		
2	Printing and publishing	85	Carbon adsorber
3	Dry cleaning	70	Recovery dryers
4	Fixed roof tanks - crude oil	98	Internal floating roof
5	Fixed roof tanks - gasoline	96	Internal floating roof
6	Ext. float. roof tanks - crude	90	Secondary seal
7	Ext. float. roof tanks - gas	95	Secondary seal
8	Bulk gas terminals - splash	91	Subm./bal./ads./truck tests
9	Bulk gas terminals - subm. fill	87	Balanced/ads./truck tests
10	Bulk gas terminals - not balanced	79	Carbon adsorber/truck tests
15	Ethylene oxide manufacturing	98	Incinerator
16	Phenol manufacturing	98	Incinerator
17	Terephthalic acid manufacturing	98	Incinerator
18	Acrylonitrile manufacturing	98	Incinerator
19	SOCMI fugitives	56	Equipment/maintenance
20	Petroleum refinery fugitives	93	Equipment/maintenance
21	Cellulose acetate manufacturing	72	Carbon adsorber
30	Rubber tire manufacturing	83	Carbon adsorber
31	Green tire spray	90	Solvent change
33	Automobile surface coating	88	Incinerator
34	Beverage can surface coating	57	Incinerator
36	Paper surface coating	90	Incinerator
	Area Sources		
79	Dry cleaning	70	Recovery dryer
102	SOCMI fugitives	56	Equipment/maintenance
103	Bulk gasoline terminals/plants	91	Balance/adsorber/truck tests
104	Petroleum refinery fugitives	93	Equipment/maintenance
107	Synthetic fiber mfg.	83	Carbon adsorber

TABLE 4-6. SUMMARY OF STATE ESTIMATES FOR EXISTING AREA-SOURCE CONTROLS

				Control technology efficiency			Rule effectiveness			Penetration in area-source inventory		
SCC	Category name	No. states respon-ding	Overall effi-ciency (%)	Mean (%)	Range	Avg. confi-dence	Mean (%)	Range	Avg. confi-dence	Mean (%)	Range	Avg. confi-dence
54	Gasoline marketing	11	69.0	91	84- 95	A-	83	30- 98	B	91	75-100	B+
61	Prescribed burning	4	85.6	100	na	A	93	75-100	B+	93	75-100	B+
62	Agricultural burning	3	71.4	93	80-100	A-	85	75-100	B	90	75-100	B
78	Degreasing	10	31.1	64	50- 90	C+	70	50- 98	C	70	40- 95	C
79	Dry cleaning	9	28.2	69	57- 85	B-	67	40- 99	C+	61	30- 90	C
80	Graphic arts/printing	10	40.9	79	65- 90	B	77	50- 95	C+	68	25- 90	C
81	Rubber/plastics mfg.	5	56.5	87	80- 90	B+	89	75-100	B-	73	10-100	C+
82	Architectural coating	1	34.2	90	na	B	40	na	B	95	na	B
83	Auto repair coating	1	22.5	90	na	B	50	na	C	50	na	C
84	Motor vehicle mfg.	10	64.7	86	70- 92	B+	85	40- 96	B	89	58-100	B
85	Paper coating	10	58.5	81	50- 95	B	82	69- 95	B	88	70-100	B
86	Fabricated metal coat.	8	47.9	80	70- 90	B-	81	50- 95	C	74	60- 95	C-
87	Machinery mfg.	8	48.0	79	70- 90	B-	81	50- 95	C	76	60- 95	C-
88	Furniture mfg.	7	39.4	72	25- 90	B-	71	50- 95	C	76	50- 95	C-
89	Flat wood products	4	37.3	66	50- 85	B	74	50- 90	D+	76	60- 90	C
90	Other transp. equip.	7	49.5	78	70- 90	B-	82	50- 95	B	77	62-100	C+
91	Electrical equip. mfg.	8	41.5	77	60- 90	B-	77	50- 95	C+	70	50- 90	C-
92	Ship bldg./repair	3	43.7	69	47- 90	B+	75	na	C+	85	75- 95	B-
93	Misc. ind. mfg.	4	38.4	79	60- 90	B-	75	50- 90	C-	65	50- 90	C
94	Misc. ind. solvents	3	29.6	78	50-100	B-	67	50- 80	D	57	50- 70	C-
95	Misc. nonind. solvents	0	0.0									
100	POTWs	0	0.0									
101	Cutback asphalt	10	85.2	99	95-100	A	94	80-100	B+	92	65-100	B+
102	SOCMI fugitives	4	31.9	56	40- 62	C+	87	75- 95	C	66	20-100	D+
103	Bulk terminals/plants	12	66.5	85	n- 90	B+	87	60-100	B-	89	67-100	B-
104	Refinery fugitives	6	51.0	68	60- 70	B-	83	65- 95	B-	92	75-100	C+
105	Bakeries	1	13.6	85	na	A	80	na	E	20	na	D
106	Pharmaceuticals mfg.	9	62.9	87	70- 90	B	84	60- 99	B-	86	75-100	B-
107	Synthetic fibers	1	54.4	85	na	A	80	na	E	80	na	E
108	Oil/gas production	0	0.0									
109	TSDFs	1	11.9	95	na	A	25	na	D	50	na	C

TABLE 4-7. SUMMARY OF NO_x CONTROL MEASURES FOR PHASE I

State and pod	Level of control needed	Approx. % of sources needing control: New	Approx. % of sources needing control: Existing	Overall reduction for category (%)	Statewide point source reduction (%)
Connecticut					4.5
52 Util. ext. comb. - gas	LNB	17	0	8	
Kentucky					30.7
50 Util. ext. comb. - coal	SCR	100	24	39	
84 Cogeneration - other	LNB	100	100	48	
87 Ind. ext. comb. - oil > 100 TPY	LNB	100	100	42	
Maryland					38.5
50 Util. ext. comb. - coal	SCR	100	69	52	
51 Util. ext. comb. - oil	SCR	100	58	44	
52 Util. ext. comb. - gas	SCR	100	58	76	
74 Util. oil turbine	SCR	100	100	70	
75 Util. oil recip.	SCR	100	100	30	
76 Util. gas turbine	SCR	100	100	71	
77 Util. gas recip.	SCR	100	100	30	
84 Cogeneration - other	LNB	100	100	50	
87 Ind. ext. comb. - oil >100 TPY	LNB	100	100	42	
90 Ind. ext. comb. - gas >100 TPY	LNB	100	100	42	
Massachusetts					17.4
50 Util. ext. comb. - coal	LNB	100	88	45	
51 Util. ext. comb. - oil	LNB	100	88	21	
52 Util. ext. comb. - gas	LNB	100	88	48	
76 Util. gas turbine	LNB	100	88	32	
Michigan					5.7
50 Util. ext. comb. - coal	LNB	76	0	7	
New Hampshire					2.4
50 Util. ext. comb. - coal	LNB	100	8	7	
51 Util. ext. comb. - oil	LNB	100	8	2	
New Jersey					13.0
50 Util. ext. comb. - coal	LNB	100	18	17	
51 Util. ext. comb. - oil	LNB	100	18	27	
74 Util. oil turbine	LNB	100	20	45	
75 Util. oil recip.	LNB	100	18	13	
76 Util. gas turbine	LNB	100	20	31	
New York					12.1
50 Util. ext. comb. - coal	LNB	80	0	23	
Ohio					1.9
50 Util. ext. comb. - coal	LNB	29	0	2	
52 Util. ext. comb. - gas	LNB	29	0	13	
76 Util. gas turbine	LNB	29	0	17	
Pennsylvania					1.3
50 Util. ext. comb. - coal	LNB	22	0	2	
52 Util. ext. comb. - gas	LNB	22	0	9	
76 Util. gas turbine	LNB	22	0	13	
Virginia					36.4
50 Util. ext. comb. - coal	SCR	78	63	59	
51 Util. ext. comb. - oil	SCR	78	63	29	
52 Util. ext. comb. - gas	SCR	78	63	62	
74 Util. oil turbine	SCR	100	100	22	
76 Util. gas turbine	SCR	100	100	70	
84 Cogeneration - other	LNB	100	100	50	
87 Ind. ext. comb. - oil > 100 TPY	LNB	100	100	42	

SCR = selective catalytic reduction; LNB = low-NO_x burners.

TABLE 4-8. MAXIMUM TECHNOLOGY FOR POINT SOURCES

Pod	Description	Maximum technol. efficiency (%) Phase I	Phase II	Control tech. basis
1	Solvent metal cleaning	54	54	Carbon adsorber
2	Printing and publishing	85	85	Carbon adsorber
3	Dry cleaning	70	70	Recovery dryers
4	Fixed roof tanks - crude oil	98	98	Internal floating roof
5	Fixed roof tanks - gasoline	96	96	Internal floating roof
6	Ext. float. roof tanks - crude	90	90	Secondary seal
7	Ext. float. roof tanks - gasoline	95	95	Secondary seal
8	Bulk gas terminals - splash fill	91	91	Subm./bal./ads./truck tests
9	Bulk gas terminals - subm. fill	87	87	Balanced/ads./truck tests
10	Bulk gas terminals - not balanced	79	79	Carbon adsorber/truck tests
11	Service stations - Stage I	95	95	Vapor balance
15	Ethylene oxide manufacturing	98	98	Incinerator
16	Phenol manufacturing	98	98	Incinerator
17	Terephthalic acid manufacturing	98	98	Incinerator
18	Acrylonitrile manufacturing	98	98	Incinerator
19	SOCMI fugitives	56	56	Equipment/maintenance
20	Petroleum refinery fugitives	93	93	Equipment/maintenance
21	Cellulose acetate manufacturing	72	72	Carbon adsorber
22	Styrene-butadiene rubber mfg.	20	20	Incinerator
23	Propylene manufacturing	98	98	Flare
24	Polyethylene manufacturing	98	98	Flare
25	Ethylene manufacturing	98	98	Flare
26	Refinery wastewater treatment	95	95	Covers
27	Refinery vacuum distillation	100	100	Firebox piping
28	Vegetable oil processing	42	42	Stripper
29	Paint and varnish mfg.	92	92	Afterburner
30	Rubber tire manufacturing	83	83	Carbon adsorber
31	Green tire spray	90	90	Solvent change
32	Carbon black manufacturing	90	90	Flare
33	Automobi le surface coating	88	88	Incinerator
34	Beverage can surface coating	57	57	Incinerator
35	Genl. wood surface coating	70	70	Process change
36	Paper surface coating	90	90	Incinerator
37	Miscellaneous surface coating	90	90	Incinerator
38	Food/agricultural starch mfg.	90	90	None specifically
39	Coke oven byproducts plants	63	63	Equipment/maintenance
40	Ferrosilicon production	88	88	None specifically
43	Marine vessel loading	90	90	Incinerator
46	Charcoal manufacturing	80	80	Afterburner
47	Fermentation/whiskey prodn.	85	85	Carbon adsorber
48	Plastics parts coating	--	80	Low-solvent coating
49	Wood furniture coating	--	60	Low-solvent coating
95	Aircraft coating	--	88	Incinerator
96	SOCMI reactors	--	85	Equipment/maintenance
97	SOCMI distillation	--	97	Equipment/maintenance
98	Furniture manufacturing	--	41	Low-solvent coating
99	Misc. noncombustion sources	--	81	Generic rule

TABLE 4-9. MAXIMUM TECHNOLOGY FOR AREA SOURCES

SCC	Description	Maximum technol. efficiency (%) Phase I	Phase II	Control tech. basis
6	Residential wood burning	--	100	Ban
24	Open burning	--	100	Ban
25	Open burning	--	100	Ban
26	Open burning	--	100	Ban
44	Off-highway diesels	--	80	Highway diesel technology
45	Railroad locomotives	--	65	Highway diesel technology
50	Diesel vessels	--	55	Highway diesel technology
54	Gasoline marketing	85	93	RVP reduction/vapor balance
61	Prescribed forest burning	100	100	Ban
62	Agricultural field burning	100	100	Ban
63	Orchard heaters	--	100	Ban
78	Degreasing	83	83	Cover/carbon adsorber
79	Dry cleaning	70	70	Recovery dryer
80	Graphic arts and printing	85	85	Carbon adsorber
81	Rubber and plastics mfg.	83	83	Carbon adsorber, etc.
82	Architectural coating	52	52	Low solvent coatings
83	Auto body repair	88	88	Low solvent coatings
84	Motor vehicle manufacturing	88	88	Incinerator
85	Paper coating	90	90	Incinerator
86	Fabricated metals coating	57	57	Low solvent coatings
87	Machinery mfg. coating	90	90	Incinerator
88	Furniture mfg. coating	90	90	Incinerator
89	Flat wood product coating	90	90	Incinerator
90	Other transp. equip. coating	88	88	Low solvent coatings
91	Electrical equip mfg. coating	90	90	Incinerator
92	Ship coating	47	47	Low solvent coatings
93	Misc. ind. mfg. coating	85	85	Low solvent coatings
94	Misc. ind. solvent use	85	85	Carbon adsorber, etc.
95	Misc. nonindustrial solvents	50	50	Product reformulation
100	POTWs	90	90	Pretreatment
101	Cutback asphalt paving	100	100	Ban
102	SOCMI fugitives	56	56	Equipment/maintenance
103	Bulk gasoline terminals/plants	91	91	Balance/adsorber/truck tests
104	Petroleum refinery fugitives	93	93	Equipment/maintenance
105	Bakeries	90	90	Incinerator
106	Pharmaceuticals manufacture	90	90	Condensers
107	Synthetic fibers mfg.	83	83	Carbon adsorber
108	Oil/gas production fields	93	93	Equipment/maintenance
109	Hazardous waste TSDF	95	93	Pretreatment, etc.

TABLE 4-10. MAXIMUM TECHNOLOGY EFFICIENCIES FOR NO_x

Pod/SCC	Category description	Technology[a]	Efficiency (%)
	Point sources		
50	Utility ext. comb. - coal	SCR	81.00[b]
51	Utility ext. comb. - oil	SCR	81.00[b]
52	Utility ext. comb. - gas	SCR	81.00[b]
53	Utility ext. comb. - other	Energy eff.	5.00
55	Industrial process heaters	Low-NO_x	45.00
58	Commercial/institutional coal	Low-NO_x	36.00
59	Commercial/institutional oil	Low-NO_x	42.00
60	Commercial/institutional gas	Low-NO_x	42.00
70	Industrial oil turbines	Low-NO_x	70.00
71	Ind. oil recip. engines	Low-NO_x	30.00
72	Industrial gas turbines	Low-NO_x	70.00
73	Ind. gas recip. engines	Low-NO_x	30.00
74	Utility oil turbines	SCR	94.30[c]
75	Util. oil recip. engines	SCR	81.00[b]
76	Utility gas turbines	SCR	94.30[c]
77	Util. gas recip. engines	SCR	81.00[b]
84	Industrial ext. comb. - coal	Low-NO_x	36.00
85	Industrial ext. comb. - oil	Low-NO_x	42.00
86	Industrial ext. comb. - oil	Low-NO_x	42.00
87	Industrial ext. comb. - oil	Low-NO_x	42.00
88	Industrial ext. comb. - gas	Low-NO_x	42.00
89	Industrial ext. comb. - gas	Low-NO_x	42.00
90	Industrial ext.comb. - gas	Low-NO_x	42.00
	Area sources		
6	Residential wood burning	ban	100.00
24	Open burning	ban	100.00
25	Open burning	ban	100.00
26	Open burning	ban	100.00
44	Off hwy. diesel	hwy. dies.[d]	40.00
45	Railroad locomotives	hwy. dies.[d]	60.00
50	Diesel vessels	hwy. dies.[d]	55.00

[a] Low-NO_x technology includes low-NO_x burners, staged combustion air, reduced air-to-fuel ratio, and steam injection. SCR refers to selective catalytic reduction.

[b] 80 percent for SCR with a 5 percent energy efficiency reduction.

[c] 94 percent for SCR with a 5 percent energy-efficiency reduction.

[d] Transfer from highway diesel technology.

TABLE 4-11. STRATEGY 5 POINT-SOURCE CONTROL EFFICIENCIES BY ATTAINMENT CATEGORY

		VOC reductions by Attainment Category (%)				
POD	Pod description	1	2	3	4	5
1	Solvent metal cleaning	0	54	54	54	54
2	Printing/publishing	0	85	85	85	85
3	Dry cleaning	0	70	70	70	70
4	Fixed roof tanks - crude	0	98	98	98	98
5	Fixed roof tanks - gas	0	96	96	96	96
6	EFR tanks - crude	0	90	90	90	90
7	EFR tanks - gasoline	0	95	95	95	95
8	Bulk term. - splash fill	0	91	91	91	91
9	Bulk term. - subm. bal.	0	87	87	87	87
10	Bulk term. - not bal.	0	79	79	79	79
11	Stage I	0	95	95	95	95
15	Ethylene oxide	0	98	98	98	98
16	Phenol	0	98	98	98	98
17	Terephthalic acid	0	98	98	98	98
18	Acrylonitrile	0	98	98	98	98
19	SOCMI fugitives	0	37	37	37	37
20	Refinery fugitives	0	83.4	83.4	83.4	83.4
21	Cellulose acetate	0	64.8	64.8	64.8	64.8
22	Styrene butadiene	0	70	70	70	70
23	Propylene	0	98	98	98	98
24	Polyethylene manufacturing	0	98	98	98	98
25	Ethylene	0	98	98	98	98
26	Refinery WW treatment	0	0	50	50	50
27	Refinery vacuum dist.	0	100	100	100	100
28	Vegetable oil	0	42	42	42	42
30	Rubber tire manufacturing	0	83	83	83	83
31	Green tire spray	0	90	90	90	90
32	Carbon black	0	90	90	90	90
33	Automobile coating	0	88	88	88	88
34	Can coating	0	57	57	57	57
36	Paper coating	0	78	78	78	78
37	Miscellaneous surface coating	0	90	90	90	90
39	Coke oven leaks	0	90	90	90	90
39	Coke byproduct plants	0	63	63	63	63
43	Marine vessel loading	0	90	90	90	90
46	Charcoal manufacturing	0	80	80	80	80
47	Whiskey production	0	85	85	85	85
48	Plastic parts coating	0	0	80	80	80
49	Wood furniture coating	0	0	24	24	24
95	Aircraft coating	0	84.4	84.4	84.4	84.4
96	SOCMI reactors	0	0	85	85	85
97	SOCMI distillation	0	0	85	85	85
99	Miscellaneous noncombustion	0	90	90	90	90

TABLE 4-12. STRATEGY 5 AREA-SOURCE CONTROL EFFICIENCIES BY ATTAINMENT CATEGORY

		VOC reductions by Attainment Category (%)				
SCC	SCC description	1	2	3	4	5
54	Service stations (Stage I)	0	38	71	71	71
78	Degreasing	0	35	35	35	35
80	Printing	0	0	24	24	24
81	Rubber/plastics manufacturing	0	65	65	65	65
82	Architectural coating	65	65	65	65	65
83	Auto body repair	0	0	60	60	60
85	Paper coating	0	80	80	80	80
88	Furniture manufacture	0	0	16.4	16.4	16.4
95	Nonindustrial solvents	27	27	27	27	27
100	POTWs	0	0	75	75	75
101	Cutback asphalt	0	100	100	100	100
102	SOCMI fugitives	0	44.6	44.6	44.6	44.6
103	Bulk terminals/plants	0	51	51	51	51
104	Refinery fugitives	0	43	43	43	43
106	Pharmaceuticals	0	44.6	44.6	44.6	44.6
107	Synthetic fibers	0	54	54	54	54
108	Oil/gas production	0	37	37	37	37
109	TSDFs	93	93	93	93	93

TABLE 4-13. STRATEGY 5 ATTAINMENT CATEGORIES AND ACROSS-THE-BOARD VOC REDUCTIONS

Area	Attainment Category	Across-the-board reduction [a] %
Albany-Schenectady-Troy, NY	2	9
Allentown-Bethlehem, PA-NJ	3	5
Altoona, PA	2	3
Atlantic City, NJ	3	2
Baltimore, MD	4	21
Boston, MA	4	31
Buffalo, NY	2	14
Canton, OH	3	2
Charleston, WV	3	0
Cincinnati, OH	4	0
Cleveland, OH	3	4
Columbus, OH	2	12
Dayton-Springfield, OH	3	4
Detroit, MI	3	18
Erie, PA	2	6
Harrisburg-Lebanon-Carlisle, PA	3	0
Hartford, CT	4	27
Huntington-Ashland, WV-KY-OH	4	12
Johnstown, PA	2	8
Lancaster, PA	2	12
Lexington-Fayette, KY	2	17
Massachusetts (except Boston, Pittsfield, Springfield)	4	34
New York, NY-NJ-CT	5	41
Norfolk-Virginia Beach-Newport, VA	2	13
Parkersburg-Marietta, WV-OH	3	0
Philadelphia, PA-NJ	4	12
Pittsburgh, PA	3	1
Pittsfield, MA	4	36
Portland, ME	4	23
Portsmouth-Dover-Rochester, NH	4	38
Poughkeepsie, NY	3	9
Providence-Pawtucket-Woonsocket, RI	4	22
Reading, PA	3	0
Richmond-Petersburg, VA	3	10
Scranton-Wilkes-Barre, PA	2	4
Sharon, PA	2	8
Springfield, MA	4	31
Toledo, OH	3	0
Washington, DC-MD-VA	4	18
York, PA	2	8
Youngstown-Warren, OH	2	3

a. Applied equally to point, area and mobile sources.

TABLE 4-14. VOC SPECIATION FACTORS FOR METHANOL VEHICLES

Species class	Speciation factors (mol/kg) Exhaust	Evaporative
Olefin	0.177	0.00
Paraffin	1.775	0.00
Toluene	0.058	0.00
Xylene	0.003	0.00
Formaldehyde	0.817	0.00
Other aldehydes	0.056	0.00
Ethene (ethylene)	1.307	0.00
Isoprene	0.003	0.00
Nonreactive hydrocarbons	0.515	0.00
Methane	4.725	0.00
Methanol	25.523	31.20

TABLE 4-15. EMISSION FLUXES FOR VEGETATION TYPES IN THE BIOGENIC EMISSIONS INVENTORY SYSTEM (BEIS) [a]

Vegetation type	NMHC flux	Percent Contribution			
		Isoprene	α-pinene	Monoterpene	Unidentified
Oak	4258	73	3	3	21
Corn	3542	0	10	10	80
Other deciduous	3353	63	5	6	26
Coniferous	3106	24	21	23	32
Peanuts/Rice	510	20	25	25	30
Tobacco	294	0	10	10	80
Grass/Pasture	281	20	25	25	30
Hay/Scrub/Range	189	20	25	25	30
Potato	48	0	25	25	50
Sorghum	39	20	25	25	30
Alfalfa	38	50	10	10	30
Barley/Oats/Rye/Misc.	38	20	25	25	30
Wheat	30	50	10	10	30
Soybeans	22	100	0	0	0
Water	0	0	0	0	0

[a] Total non-methane hydrocarbons ($\mu g/m^2/h$) and percent contribution from individual chemical species, standardized for full sunlight and 30°C.

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SECTION 5

REGIONAL MODELING RESULTS AND PROJECT FINDINGS

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5.1 INTRODUCTION

During the course of ROMNET, the Management Review Committee and other participants identified several key issues relative to the effectiveness of regional control strategies which were to be addressed through ROM simulations. As stated in Section 4.4.2, these issues are:

1. ***What are the relative benefits of VOC controls versus NO_x controls in reducing ozone levels across the region?***

2. ***What is the impact of reducing regional transport on Northeast Corridor ozone levels?***

3. ***What levels of VOC and/or NO_x emissions reductions are necessary to reduce predicted ozone concentrations in the Northeast to below 125 ppb?***

4. ***How effective are potential reactivity-based strategies in reducing regional ozone levels?***

5. ***How does the large uncertainty in biogenic emissions alter conclusions regarding the effectiveness of control measures?***

This section of the report presents the results of ROM simulations conducted to address these issues. The ozone concentrations and spatial patterns for the Phase II 1985 base case and 2005 baseline scenarios are described first.[1] This is followed by a discussion of the findings relative to each of the above issues. A summary of the implications drawn from these findings is given at the end of the section.

5.2 1985 BASE CASE AND 2005 BASELINE PREDICTIONS

A fifteen day episode during the summer of 1988, July 2-17, was used to simulate all emissions scenarios. The rationale for selecting this episode, and a description of the meteorological conditions and measured ozone levels during the episode, are provided in Section 3.

5.2.1 1985 Base Case Ozone Predictions - July 1988 Episode

The maximum 1-hour ozone concentrations predicted for this episode are shown in Figure 5-1. These data are the highest concentrations in each ROM grid which are predicted for any hour during the

1. Ozone predictions for the Phase I scenarios are not described in this report since all of the key strategies were run with MOBILE4 as part of Phase II. However, spatial plots of gridded maximum 1-hour concentrations are provided for all Phase I and Phase II scenarios in Appendix M.

15-day episode. Thus, this figure represents the overall impact during the episode, not a snapshot of the concentrations on a single day or hour. The values in Figure 5-1 are taken from layer 1 of the ROM, which is the lowest layer of the model.

Examining Figure 5-1 indicates that high ozone concentrations $\geq$ 125 ppb are predicted along the entire length of the Northeast Corridor. Levels exceeding 200 ppb are predicted over the New York City area with concentrations above 160 ppb near or downwind of Baltimore/Washington, DC, Philadelphia, and Boston. Ozone concentrations in the range of 140 to 160 ppb are predicted over sections of southern New England extending into coastal Maine.

Elsewhere in the region, concentrations exceeding 140 ppb are predicted near or downwind of Pittsburgh, Cleveland, Detroit, and Toronto. Surrounding these plumes is a rather broad area with ozone just below 125 ppb in the range of 100-124 ppb. Moderate ozone levels of 80 to 100 ppb were predicted in more rural, remote portions of the region. The elevated ozone levels extending across northern West Virginia into central Virginia appear to be associated with transport flow regimes which pass over Cleveland and other source areas in eastern Ohio, western Pennsylvania, and northwest West Virginia.

5.2.2 2005 Baseline Ozone - July 1988 Episode

The episode maximum ozone levels for the 2005 baseline scenario are shown in Figure 5-2. This scenario reflects the net effects of growth and existing control programs. In general, emissions of VOC and NO_x in the Corridor are less than the 1985 base case by 34 percent and 6 percent, respectively. Outside the Corridor, VOC is reduced by 33 percent and NO_x is increased by 1 percent. In Ontario, Canada, VOC is 42 percent lower and NO_x is 10 percent lower than the 1985 base. A detailed description of the Phase II 2005 baseline emissions is given in Section 4.4. The results of these emission changes on predicted ozone levels can be seen by comparing Figures 5-1 and 5-2. In the Corridor, maximum ozone is reduced by 10 to 15 percent across much of New Jersey and from central Connecticut northeastward into Maine. Over New York City maximum ozone levels remain $\geq$ 200 ppb. In the vicinity of Baltimore/-Washington, DC, ozone levels were reduced by $\leq$ 10 percent.

In the western portion of the domain, reductions in maximum ozone of 10 to 15 percent are predicted for areas around Pittsburgh, Cleveland, and Detroit with a 5 to 10 percent reduction near Charleston. Also, the spatial extent of ozone $\geq$ 125 ppb has been greatly reduced near Detroit and Cleveland and peak values are now below 140 ppb.

5.3 RESULTS OF CONTROL STRATEGY SIMULATIONS FOR KEY ISSUES

The relative effectiveness of control strategies is examined by comparing the ROM layer 1 ozone predictions using various measures or metrics. Included are:

(1) episode maximum 1-hour concentrations, i.e., "acute" metric (spatial plots of gridded 1-hour episode maximum concentrations for each ROMNET strategy are included in Appendix M);

(2) episode mean 8-hour daily maximum ozone concentrations, i.e., "chronic" metric;

(3) daily maximum 1-hour concentrations;

(4) diurnal time series of urban area peak hourly concentrations; and

(5) population exposure to hourly ozone concentrations exceeding 100 ppb and 125 ppb.

These metrics were chosen to highlight different facets of the response of predicted ozone levels to control strategies. Not all metrics were examined for each issue. Metrics 1 through 4 are fairly straightforward. For metric 5, population exposure was calculated using the equation shown in Table 5-1. As an example, the population exposure to ozone exceeding 125 ppb in New York City is calculated as the product of gridded population and the number of hours in each grid with ozone $\geq$ 125 ppb, summed for all 88 grids covering the New York City area. Areas in the domain referred to in the discussion of several of the issues are shown in Figure 5-3.

ISSUE #1

What are the relative benefits of VOC control versus NO_x control in reducing ozone levels across the region?

Analysis Approach

The importance of this issue stems from the highly nonlinear role of NO_x and VOC in ozone formation. Basically, NO_x can act as a source or sink of ozone, depending on the amount of reactive organics present, meteorological conditions, and proximity to sources of NO_x. In areas where the ratio of VOC to NO_x is relatively high, ozone formation is determined by the availability of NO_x (i.e., ozone formation is said to be "NO_x limited"). In such areas, controlling NO_x may be an effective approach to reduce ozone levels. In areas where the VOC to NO_x ratio is low, VOC control may be most effective, and controlling NO_x may actually increase ozone concentrations in some areas. The following five strategies were designed to determine where and to what extent NO_x and/or VOC controls provide the most effective pathway to reduce ozone concentrations in the Northeast.

CS10: Combined VOC and NO_x maximum technology controls
[NO_x + VOC control]

CS11: Maximum technology NO_x controls with VOC at the 2005 baseline
[NO_x-only controls]

CS12: Maximum technology VOC controls with NO_x at the 2005 baseline
[VOC only control]

CS13: Maximum technology VOC and NO_x point-source controls with NO_x mobile sources at the 2005 baseline
[VOC + NO_x point-source control]

CS14: Maximum technology VOC and NO_x mobile-source controls with NO_x point sources at the 2005 baseline
[VOC + NO_x mobile-source controls]

Specifications of the control measures in these strategies are given in Section 4.4.2. The total anthropogenic VOC and NO_x emissions for each of these strategies and the reduction from the 2005 baseline are shown in Figure 5-4 for the U.S. portion of the region. Emissions for 1985 are included in this figure for reference as are biogenic emissions. Emissions reductions for selected urban areas are given in Appendix I.

It is important to note the effect of biogenic VOC emissions on the amount of reduction in total VOC (anthropogenic plus biogenic) achieved by the control measures in CS12. This is illustrated in Figure 5-5, which shows the effects of the CS12 controls on anthropogenic emissions across the region. In most areas of the domain anthropogenic emissions are reduced by 50 to 70 percent. However, when biogenic emissions are also considered, the net reduction in VOC is on the order of 20 percent or less across much of the region outside the core grids of urban areas. This reflects the high level of biogenic emissions in rural areas, which often exceeds emissions from anthropogenic sources. In contrast, the reductions in NO_x emissions achieved by CS11 (point-, mobile-, and area-source NO_x controls), as shown in Figure 5-6, are 30 to 50 percent across the region with greater reductions of 60 to 80 percent in grids containing large point sources.

Discussion of Results

The impacts of the VOC and NO_x strategies on the episode maximum 1-hour ozone metric are presented first, followed by a comparison of acute versus chronic ozone metrics. Differential, day-to-day effects are presented next and the impact of controls on population exposure is presented last.

Episode Maximum Concentrations

Impact on NO_x Controls Alone

The application of NO_x controls (CS11) to the 2005 baseline results in a dramatic reduction in ozone levels across much of the region, as evident in examining Figure 5-7. In fact, except for Toronto, ozone levels outside the Northeast Corridor have been reduced to below 125 ppb. (Recall that Canadian emissions were kept at the 2005 baseline with maximum technology controls applied only in the US portion of the region.) In most of the area outside the Corridor ozone is less than 100 ppb with only 7 ROM grids containing peak values as high as 110 to 115 ppb. Reductions in episode maximum l-hour ozone across individual urban areas are as follows: Pittsburgh, 25 to 30 percent; Cleveland, 15 to 25 percent; Detroit, 15 to 20 percent; and Charleston, 30 to 40 percent.

Along the Northeast Corridor, episode peak values have also declined substantially as a result of NO_x controls, except within the New York City urban area. In New York, ozone levels following NO_x controls are predicted to increase on the order of 15 percent relative to the 2005 baseline scenario. Elsewhere in the Corridor, ozone levels declined to below the NAAQS, except near Baltimore. From the center of Baltimore southeastward along the Chesapeake Bay, ozone levels remain at 125 ppb. Also, the highest predictions near Philadelphia were reduced to the level of the NAAQS.

Impact on VOC Controls Alone

The ROM predictions for episode maximum ozone following the VOC controls in CS12 are shown in Figure 5-8, along with the predictions for the 2005 baseline. A comparison of these two scenarios indicates some reduction outside the Northeast Corridor. However, ozone levels are 15 to 25 percent higher in this area than with the NO_x control strategy (CS11). Ozone levels $\geq$ 125 ppb are predicted near Pittsburgh and Cleveland and levels between 120 and 124 ppb near Detroit, Charleston, and Buffalo. Also, a fairly broad area with peak values of 100 to 120 ppb remain from Detroit southeastward to northern Virginia and in western New York State. Recall from Figure 5-5 that the overall net VOC emissions reduction in this part of the domain was only 20 percent due to the dominance of natural VOC emissions.

Along the Northeast Corridor the episode peak ozone values predicted for the 2005 baseline scenario are reduced by 10 to 15 percent following the VOC controls in CS12, with reductions in ozone greater than 50 percent in the New York City area. Compared to NO_x controls in CS11, the VOC controls produce substantially lower peak values in the New York City area and also somewhat lower ozone levels near Baltimore. However, although the peak values are lower with VOC control, the spatial coverage of concentrations $\geq$ 125 ppb in most sections of the Corridor outside of New York City is much less with NO_x controls than with VOC controls.

Impact of Combined VOC and NO_x Controls

The impact of combining the VOC maximum technology controls with the NO_x controls was examined in three strategies. In CS13, the VOC controls are combined with NO_x controls on point sources. Mobile-source NO_x emissions are held at the 2005 baseline levels. The complementary strategy, CS14, contains mobile-sources NO_x controls and VOC controls. Point-source NO_x emissions are at the 2005 baseline. Finally, in CS10, the maximum technology NO_x controls on point, area, and mobile sources are combined with VOC controls. The point-only controls in CS13 reduced total NO_x emissions from the 2005 baseline by 40 percent in the Corridor and 53 percent elsewhere in the region. In contrast, the reduction in total NO_x due to mobile-source controls was less, showing an 18 percent reduction in the Corridor and 10 percent elsewhere.

The episode maximum ozone for these three strategies (CS10, 13, and 14) are shown in Figure 5-9. The most noticeable differences between the predictions for these strategies are across West Virginia, eastern Ohio, and western Pennsylvania, where large numbers of point sources are located (see Figure 4-12). Near Charleston, for example, point-source controls reduced peak ozone to below 100 ppb, whereas with mobile-source controls, predicted episode peak ozone was 122 ppb. In southwestern

Pennsylvania, episode peak ozone levels in the range of 120 to 125 ppb were predicted in 11 grids following mobile-source controls, but the peak value in these grids with point-source controls was only 116 ppb. Near Cleveland and Detroit the point-source and mobile-source controls yield nearly equivalent impacts on episode maximum ozone levels even though emissions are lower with point-source controls. This suggests that predicted ozone is more sensitive to mobile-source NO_x controls on a per-ton-removed basis. This is not unexpected given that mobile-sources emit both VOC and NO_x, which are spatially concentrated, and are greatest in urban areas, where emissions from other sources are also high.

Along the Corridor, point-source controls appear to be more effective than the mobile-source controls in the area from Washington, DC northeastward to just outside of New York City. This is evident by comparing the spatial extent of ozone $\geq$ 100 ppb and $\geq$ 125 ppb between CS13 and CS14 in Figure 5-9. In New York City, where NO_x controls produce a "disbenefit," peak ozone is less with mobile-source controls. This most likely reflects the fact that the mobile-source controls did not reduce NO_x emissions to the extent of the point-source controls. In the general downwind direction from New York into southern and central New England, ozone appears to be more sensitive to mobile-source NO_x controls than to point-source controls. For example, in Boston the reduction in total NO_x was 34 percent due to point-source controls but only 15 percent from mobile-source controls. However, the highest and second highest daily maximum values were, respectively, 7 and 13 ppb lower with mobile-source than with point-source controls.

In New York City, both CS13 and CS14 produce lower ozone than the 2005 baseline. However, ozone levels following NO_x point-source controls in CS13 are higher than with the NO_x mobile-source controls in CS14 or the VOC only controls in CS12. That is, adding the mobile-source NO_x controls with VOC controls does not significantly deteriorate ozone levels in New York relative to VOC controls alone. For example, the number of grids with ozone $\geq$ 140 ppb differ by one between CS12 (VOC control) and CS14 (VOC + mobile-source NO_x controls). Also, the mean episode maximum concentration for grids $\geq$ 140 ppb is 144 ppb for CS12 and 147 ppb for CS14. Another important point is that the spatial extent of ozone $\geq$ 125 ppb downwind of New York City over Connecticut is reduced by adding the mobile-source NO_x controls.

When the NO_x mobile-source and point-source controls are combined and added to the VOC controls (CS10), peak ozone responds in several different ways across the region. The differences are evident by comparing the ozone predictions for CS10 with those for CS11, CS13, and CS14 (see Figures 5-7 and 5-9). In general, ozone levels for CS10 are lower than either CS13 or CS14 in all areas except New York City and Baltimore/Washington, DC.

Outside the Corridor, it appears that a major portion of the large reductions achieved by the combined VOC and NO_x controls in CS10 are attributable to the controls on NO_x point sources. The results also indicate that adding maximum technology VOC controls may provide little, if any, further reductions in peak ozone beyond that achieved by NO_x controls.

Inside the Corridor, ozone levels for the combined VOC and NO_x strategy (CS10) are below the NAAQS in all areas except near and downwind of New York City and Baltimore/Washington, DC. In Baltimore/-Washington, DC, the spatial extent of ozone $\geq$ 125 ppb has been reduced compared to either CS13 or CS14. However, in New York City, there is a fairly large increase in ozone by combining point-source and mobile-source controls even in the presence of maximum technology VOC controls. For example, the number of grids with peak values $\geq$ 140 ppb doubles and the maximum concentration increases to 181 ppb from 165 ppb in CS13 and 158 ppb in CS14.

Comparison of Impacts for Acute and Chronic Metrics

For New York City, Greater Connecticut, and Baltimore/Washington, DC, where disbenefits of NO_x controls were indicated in the episode maximum values, the analysis was extended to examine a more long-term, chronic metric of ozone concentration. Here, the acute measure is derived from the episode maximum 1-hour concentrations for all grids within each of the above areas. The chronic measure is based on the episode mean of the daily maximum 8-hour average ozone concentrations in each grid. This metric is the highest of the running 8-hour averages on each day, averaged for the episode by grid.

The acute and chronic metrics are presented in quantile-quantile (Q-Q) plots for each of the three areas for CS10 (VOC plus NO_x control) versus CS12 (VOC controls only). The data points in these plots represent the rank ordered ozone values with VOC controls prior to NO_x control (CS12) and the corresponding rank ordered ozone values after adding NO_x control to VOC control (CS10). For Baltimore/Washington, DC, the Q-Q plots of acute ozone (Figure 5-10, top) indicate a sharp curvature throughout the distribution of gridded values. Since all but one of the data values falls below the diagonal line, the overall impact of NO_x and VOC controls is projected to be more beneficial than VOC controls alone. However, the benefit varies substantially across the distribution of grid cells with largest benefits near the 50th percentile and smallest benefits projected near the minimum and maximum of the distribution. The corresponding plot for the chronic ozone measure (Figure 5-10, bottom) shows much less curvature and indicates a more uniform improvement across the grid cells than was the case for 1-hour peaks.

In New York City and Connecticut the Q-Q plots are contained in Figure 5-11 and Figure 5-12, respectively. These figures indicate that the impact of controls varies considerably depending upon which percentile is being examined. In particular, for New York City, there appears to be a clear benefit of NO_x control for the lower percentiles of the acute ozone metric and a clear disbenefit (increases in ozone) above the 50th percentile. Interestingly, the crossover between benefit and disbenefit is at a concentration level just below the NAAQS. That is, the disbenefit increases with concentration for ozone levels above the NAAQS. It is important to note that for the chronic measure, adding NO_x controls in New York City is actually beneficial relative to VOC controls alone. This is seen along the entire distribution although the benefit diminishes with increasing concentration to where the highest mean 8-hour values are nearly equivalent for the VOC only and VOC plus NO_x controls. For Connecticut, the disbenefit begins closer to the upper end of the distribution for the acute metric. As in New York City, the addition of NO_x controls appears to be beneficial for the chronic metric.

Day-To-Day Variations in the Impact of NO_x and VOC Controls

A more complex picture of the role of NO_x emerges by examining the impact of controls on individual days during the episode simulated. For this part of the analysis, hourly ozone concentrations were extracted for each scenario from ROM grids corresponding to the areas shown in Figure 5-3. For each individual area, and each scenario, diurnal profiles of hourly ozone concentrations for all days in the July 1988 episode were created using the highest hourly ozone concentrations from among the grids contained within the area for the particular scenario. The diurnal profiles for CS11 and CS12 for selected areas are shown in Figure 5-13 and Figure 5-14. The shaded portions of the plots reveal when and to what extent ozone predictions differed between the two scenarios. The diurnal profiles in Figure 5-13 for the New York City area indicate that the relative disbenefits of NO_x controls, as evident from the episode maximum concentrations, are replicated each day during the episode. The values following NO_x controls are approximately twice as high as levels predicted with VOC controls (CS12). In fact, on most days the predicted daily maximum ozone with NO_x controls (CS11) is close to or above that predicted for the 2005 baseline scenario.

For Greater Connecticut, the highest ozone levels with VOC controls tend to occur during mid-afternoon, several hours earlier than the much larger peak concentration with the NO_x control scenario (see Figure 5-13). Also, this mid-afternoon peak predicted in the VOC only strategy is largely reduced by NO_x controls. The early peak, which is reduced by NO_x controls, appears to be due to ozone formation from local

emissions coupled with transported ozone and precursors from the day before. The enhanced ozone levels that occur late in the day with NO_x control are apparently due to transport of the New York City urban plume across portions of Connecticut.

For the Baltimore/Washington, DC area, the profiles in Figure 5-14 indicate that the benefits of NO_x controls resulted in ozone levels lower than with VOC controls on six days (CS11 < CS12 in the figure), but the opposite occurred for eight days on which VOC controls were more beneficial. Thus, it appears that the relative benefits of VOC and NO_x controls can vary from day to day. This reflects the variation in meteorological conditions that determines such factors as local source-receptor relationships, long-range transport, biogenic emissions, and ozone production rates.

The diurnal plots for hourly peak ozone predicted for the area around Pittsburgh (see Figure 5-14) indicate that for most days ozone levels with NO_x controls are less than with VOC controls. The few days on which ozone is higher under NO_x controls have relatively low to moderate ozone concentrations (75 to 100 ppb) in the precontrol 2005 baseline scenario. The behavior of diurnal patterns for other areas including Philadelphia, Boston, Cleveland, Detroit, and Charleston are similar to that shown for Pittsburgh.

NO_x Control: New York City Case Study

A fuller understanding of the effects of NO_x controls on ozone levels in New York City is evident by examining predictions on an individual day. For this, the July 9, 1988 ozone and NO_x concentrations predicted for the 2005 baseline were compared to predictions following NO_x controls in CS11. Figure 5-15 presents the daytime maximum ozone predictions for the 2005 baseline and the change due to NO_x controls. The 2005 values show an area of ozone $\geq$ 125 ppb extending from near Philadelphia northeastward over the central core of New York City, then eastward across much of Connecticut. The position of this high ozone plume reflects the general boundary layer flow on this day, as indicated from the ROM layer 1 and layer 2 wind fields. Winds were generally light and variable with near stagnation conditions until mid-afternoon when a southwesterly flow developed. Thus, the peak concentrations over southwestern Connecticut and southeast New York State (160 to 180 ppb) appear to be associated with morning emissions from the New York City urban area. Concentrations exceeding 160 ppb over northern New Jersey likely reflect the combined impact of local emissions and interurban transport from Philadelphia.

The change in ozone levels resulting from NO_x controls (see Figure 5-15) indicates that the large increase in ozone is limited to the central core of the urban area extending along the centerline of the plume into southern Connecticut. In other more peripheral portions of the plume, ozone levels actually decline following NO_x controls, as do ozone levels downwind of Philadelphia.

Examining the levels and patterns of emissions in this area provides further insight into these results. The spatial distributions of morning (0500 to 1100 EST) total VOC and NO_x emissions are provided in Figure 5-16. These data show the high emissions density for both pollutants over the core of New York City including several grids surrounding Manhattan [i.e., the Central Business District (CBD)]. The highest emissions from these grids are 132 tons of VOC and 46 tons of NOx. This is more than double that of surrounding grids and an order of magnitude greater than in other portions of the metropolitan area. Even in Philadelphia, the highest gridded VOC and NO_x emission are only 50 tons and 21 tons, respectively. By comparing Figures 5-15 and 5-16, it appears that the large disbenefit of NO_x control is confined to areas over and downwind of the New York CBD grids.

Examining the time history of predicted ozone and NO_x concentrations during the course of the day for the 2005 and CS11 scenarios provides an explanation for the increase in ozone following NO_x controls. In the 2005 scenario, very high NO_x concentrations are predicted within the four to six high-NO_x emissions grids in the New York CBD. In the morning (0600 EST), NO_x levels are in the range of 60 to 80 ppb. Concentrations increase with time to 75 to 200 ppb by 1000 and remain at this level for several hours before declining to 50 to 100 ppb at 1300. Elsewhere in the urban area, NO_x concentrations are an order of magnitude less. In Philadelphia, NO_x concentrations are a factor of 3 less than in the New York CBD. Due to the high level of NO emissions, ozone concentrations in the New York CBD are suppressed by 40 to 50 ppb compared to surrounding areas. During the day, ozone formation in the 2005 baseline scenario is greatest around the periphery of the CBD, particularly on the northern fringe of the city.

In the NO_x control strategy, NO_x concentrations in the CBD are reduced by 40 to 50 percent during the morning, with greater reductions up to 75 percent into midday. Correspondingly, ozone levels in the CDB are higher than in the 2005 scenario. Until 1100 EST, ozone concentrations across the urban area (including the CBD) are higher in the 2005 scenario than in the NO_x strategy. By noon, however, ozone in the CBD has increased rapidly to 182 ppb, which is 124 ppb higher than in the 2005 scenario at this hour. In contrast, in most areas where ozone was at a peak in the 2005 scenario (i.e., northern New Jersey and southwest Connecticut), concentrations following NO_x controls are reduced by 20 to 30 ppb. This trend continues into the early afternoon with ozone levels in the CBD rising to well over 200 ppb. With the onset of a southwesterly flow in mid-afternoon, the area of enhanced ozone in the CBD is transported northeastward into southwest Connecticut.

Thus, the results indicate that the high levels of NO_x emissions in the 2005 baseline play a major role in scavenging ozone in the core of the city. When NO_x emissions are reduced by controls, ozone levels increase substantially. The widespread disbenefit of NO_x controls across much of the New York urban area seen from the analysis of episode maximum concentrations reflects the composite impact of the day to day path of the plume emanating from the New York CBD. This indicates that NO_x controls may indeed be beneficial for certain sections of the New York urban area, if targeted away from the core of the city.

A major caveat to these results is the added uncertainty introduced by the lack of spatial resolution of emissions in the ROM for an urban-level analysis such as this. Thus, the further investigation of this issue is warranted using an urban scale model to better quantify the magnitude and spatial extent of the disbenefit of NO_x controls in the New York City area.

Population Exposure

An alternative approach to quantify and compare the impacts of VOC and NO_x strategies is by examining the effects on population exposure. This metric is perhaps a more robust indicator than the episode or hourly maximum values since it considers the frequency of high ozone hours during the episode and any shifts in spatial patterns in predicted ozone relative to the locations of highly populated areas. For most urban areas along the Corridor, population exposure to ozone $\geq$ 125 ppb is the chosen metric. For Massachusetts and coastal New England, and areas outside the Corridor where ozone is below 125 ppb in several strategies, exposure to ozone $\geq$ 100 ppb was examined. The exposures calculated for the 2005 baseline and strategies CS10 through CS14 are presented in Figure 5-17 through Figure 5-20 for selected urban areas in the region. The figures indicate that reductions in exposure from the 2005 baseline on the order of 90 percent were achieved for Massachusetts and vicinity by the NO_x-only controls. The VOC-only, and VOC plus NO_x controls produce less of a benefit (Figure 5-17). In Baltimore/Washington, DC and Philadelphia, NO_x controls alone or with VOC controls produce reductions of 90 to 100 percent in exposure to ozone $\geq$ 125 ppb (Figure 5-18). With just VOC controls, exposures are higher than for the other strategies. Note that the disbenefit of NO_x-only controls seen in episode peak ozone downwind of Baltimore is not evident in the population exposure metric. As indicated earlier, this occurs because the grids associated with the NO_x disbenefit are over areas with low population on the eastern shore of the Chesapeake Bay. As shown in Figure 5-19 for New York City, the VOC controls alone or combined with point-source or mobile-source NO_x controls produce nearly equivalent exposure levels. However, adding the two types of NO_x controls without any VOC controls has essentially no benefit relative to the 2005 baseline. Adding VOC controls with full NO_x

controls (CS10) does reduce exposure considerably, but not to the extent of strategies with less NO_x control (CS12, CS13, CS14). Over Connecticut and Rhode Island (downwind of New York City), a greater reduction in exposure is obtained when VOC controls are combined with point or mobile NO_x controls than with VOC controls alone, as is evident in Figure 5-19.

Outside the Corridor, NO_x controls produce the greatest reduction in population exposure to ozone $\geq$ 100 ppb. Adding VOC controls yields little additional benefit. Note from Figure 5-20 that in Cleveland and Detroit comparable benefits were achieved with the NO_x point-source and NO_x mobile-source controls even though emissions reductions were larger in the point-source NO_x control strategy (CS13 *vs.* CS14).

Findings

The following are the key findings for ISSUE #1:

What are the relative benefits of VOC controls versus NO_x controls in reducing ozone levels across the region?

- Maximum technology NO_x controls appear to produce larger ozone reductions than stringent VOC controls in many areas of the Northeast. This is particularly notable in the western portion of the region where biogenic VOC emissions are highest and a large component of NO_x emissions are rural point sources. In the Corridor, except for New York City, NO_x controls tend to reduce the spatial coverage of high ozone levels, whereas VOC controls are more effective in reducing the peak values. Combining VOC and NO_x controls provides both benefits by reducing the magnitude and spatial extent of high ozone concentrations.

- In the presence of stringent VOC controls, peak ozone levels appear to be more sensitive to mobile- rather than point-source NO_x emissions reductions in several cities (e.g., Philadelphia, Boston, Detroit, and Cleveland). In areas dominated by NO_x point sources (e.g., Pittsburgh and Charleston, WV), point-source controls are more effective than mobile-source reductions.

- In New York City, NO_x controls alone or with VOC controls are counter-productive relative to VOC controls for short-term peak concentrations and population exposure. This effect is most prominent in the core of the urban plume and appears to be associated with high NO_x emissions in the center of the urban area. Outside the main plume, ozone levels are actually reduced by NO_x controls. For longer averaging time (e.g., episode mean 8-hour daily maximum averages) NO_x plus VOC controls produce lower ozone levels than VOC controls alone.

- The relative benefits of VOC versus NO_x controls varies by day (i.e., meteorology) in some cities. This was particularly evident in the Baltimore/Washington, DC area.

The above findings underscore the complexity of the role of NO_x in both ozone formation and in reducing ozone levels by controlling emissions. In addition, the results clearly indicate the need to carefully select and examine a breadth of emissions and meteorological conditions before drawing conclusions on the benefits of NO_x controls. Also, given the local urban structure indicated by some of the results, further, more spatially refined analyses are warranted.

ISSUE #2

What is the impact of reducing regional transport on ozone concentrations in the Northeast Corridor?

Analysis Approach

A key issue for the Northeast States concerns the impact of emissions outside the Corridor on ozone concentrations within the Corridor. This concern is fostered by the regional nature of ozone levels and the transport patterns typical of many of the most severe episodes in this region (see Section 3). Of interest is whether, and to what extent, controls outside the Corridor make a difference to in-Corridor ozone levels. There are two parts to this issue:

a. What is the impact of reducing transport on projected future baseline ozone levels in the Corridor?

b. What is the impact of reducing transport on postcontrol ozone levels in the Corridor?

Two types of strategies were designed and simulated by the ROM to address these questions:

1. Stringent emissions controls were applied outside the Corridor while maintaining emissions at the 2005 baseline inside the Corridor; and

2. Stringent emissions controls were applied inside the Corridor while maintaining emissions at the 2005 baseline outside the Corridor.

Predictions from the first type of strategy were compared to the 2005 baseline region-wide . This comparison was designed to quantify the impact of transported ozone and precursors on the future baseline ozone levels in the Corridor. The second type of strategy was compared to strategies with controls applied across the entire region. This comparison was used to determine the extent to which controls outside the Corridor affect postcontrol ozone levels inside the Corridor.

The specific scenarios included in this analysis are as follows:

- 2005 baseline scenario;
- CS19: The most stringent controls on VOC, NO_x, and CO applied region-wide;
- CS24: CS19 controls applied *inside* the Corridor - 2005 baseline elsewhere; and
- CS25: CS19 controls applied *outside* the Corridor - 2005 baseline elsewhere.

The 2005 baseline predictions were compared to those of CS25 to quantify the impacts of controls outside the Corridor on baseline levels inside the Corridor. The CS24 predictions were compared to those from CS19 to quantify the impact of controls outside the Corridor on postcontrol ozone levels inside the Corridor.[2]

The analysis of the two transport impact questions listed above is divided into four components. First, an assessment is made of the impact of controls outside the Corridor on ozone levels transported into the Corridor. Second, the effects of reducing transport on 2005 baseline concentrations are presented. This is followed by a discussion of the impact on postcontrol Corridor ozone levels due to controls in upwind areas. Finally, a case study analysis is included to examine the impact of transport into and along the Corridor more closely.

The effect of controls on ozone levels transported into the Corridor was analyzed by examining the layer 1 and layer 2 ozone predictions for a string of ROM grids located just beyond the far western edge of the Northeast Corridor. The 72 grids included in this string are shown in Figure 5-21. Daily mean and maximum concentrations were calculated by State for three segments of this boundary: Virginia (VA), Pennsylvania (PA), and New York State (NY). Forward trajectories using ROM layer 1 and layer 2 were used to identify those days with transport flow regimes from this boundary into the Corridor. Examples are shown in Figure 5-22. The layer 2 mean and maximum ozone concentrations along the boundary for these days are provided in Figure 5-23, for the 2005 baseline (precontrol) and CS19 (postcontrol) scenarios. The layer 2 values were selected because this layer represents the bulk of the atmospheric boundary layer during the day and the layer containing transport of pollutants aloft overnight.

The following procedures were used to quantify impacts on the 2005 baseline ozone levels in the Corridor due to the upwind controls in CS25. First, all grids with daily maximum ozone concentrations $\geq$ 125 ppb for the 2005 baseline scenario were identified. The difference in daily maximum ozone between CS25 and the 2005 baseline was then computed for each of these grids and averaged by urban area by day and for the episode. Similar procedures were followed to quantify the impacts on postcontrol ozone levels in CS19 except that grids with daily maximum values $\geq$ 100 ppb were examined. In addition, a case study analysis was conducted to describe the effects of transport on selected high ozone events in several Corridor cities.

2. Initially, CS01 (Phase I maximum technology VOC controls region-wide) and CS02 (Phase I VOC controls in the Corridor only) and CS03 (Phase I VOC controls in nonattainment areas) were included in this analysis. However, it was found that these VOC controls did not appreciably reduce ozone levels outside the Corridor. Thus, there was little change in both ozone transport into the Corridor and peak ozone concentrations in the Corridor.

Discussion of Results

Impacts of Upwind Controls on Ozone Transport into the Corridor

The data in Figure 5-23 indicate that there is quite a large day-to-day and spatial variation in the levels of ozone along the Corridor boundary. The highest concentrations lie along the PA and VA segments. On 4 days during this episode, plumes with peak values ≥ 100 ppb in the 2005 scenario apparently entered the Corridor through these segments. Following the application of controls outside the Corridor, the peak values are reduced to 84 ppb or less. On average for the episode, the daily mean and peak transport values are reduced by controls on the order of 20 percent for both segments. For the NY segment, ozone transport levels are reduced somewhat less at 16 percent. The greatest reduction along the boundary tended to occur on days with the highest concentrations. For example, on the highest days, mean and peak values are reduced by 30 percent and 35 percent, respectively. The data indicate that applying maximum technology controls to areas outside the Corridor reduces predicted mean and peak ozone transported into the Corridor to levels well below the NAAQS for this episode.

Impacts of Reducing Ozone Transport on 2005 Baseline Ozone in the Corridor

The impact of reducing transport into the Corridor was most noticeable in the Baltimore/Washington, DC area and in sections of southeast Pennsylvania. These areas are adjacent to the portions of the boundary having the highest concentrations and greatest reduction in ozone transport. For example, in Baltimore/Washington, DC the space/time average and peak reduction for all grids with daily maximum ozone ≥ 125 ppb were 8 ppb and 13 ppb, respectively. Looking at the grid with the highest predicted concentration on each day in the episode shows an average reduction of 6 percent for those days with ozone ≥ 125 ppb. The impacts tend to diminish northeastward along the Corridor as indicated below:

		BAL/DC	PHL	NYC	CT	BOS
Reduction for all grids ≥ 125 ppb	spatial average:	8 ppb	5 ppb	4 ppb	3 ppb	4 ppb
	peak:	13 ppb	10 ppb	8 ppb	7 ppb	5 ppb
% change in daily maximum ozone	episode average:	6%	4%	2%	2%	2%
	peak:	9%	9%	5%	5%	3%

BAL/DC: Baltimore/Washington, DC
PHL: Philadelphia
NYC: New York City
CT: Portions of Connecticut outside the NYC urban area
BOS: Boston

Thus, the reduction in future year transport may have a relatively small impact on future baseline ozone levels within the major Corridor cities. Even with stringent controls in all areas outside the Corridor, peak values along much of the Corridor would still be well above the NAAQS, without additional controls in the Corridor beyond those in the 2005 baseline. This is evident from the plots in Figure 5-24, which show the episode maximum 1-hour ozone concentrations for the 2005 baseline and CS25. As described above, the largest change relative to the level of the NAAQS inside the Corridor occurs in southeast Pennsylvania and from the Baltimore/Washington, DC area eastward across Delaware. For the conditions simulated, little impact relative to the magnitude of baseline episode maximum ozone is predicted for areas in the northern sections of the Corridor.

Impacts of Reducing Transport on Postcontrol Ozone in the Corridor

The impacts of reducing transport on postcontrol ozone in the Corridor is more significant than the impacts on 2005 baseline levels. This is evident by comparing daily maximum predictions for CS19 (region-wide application of maximum controls) versus CS24 (emissions controls in the Corridor, but 2005 baseline emissions elsewhere). In CS19, peak ozone levels along the Corridor are reduced to below 125 ppb. Values for individual cities are listed below along with the corresponding values for CS24.

Episode Maximum 1-Hour Ozone Concentrations		
	Region-wide controls (CS19)	No controls outside Corridor (CS24)
Baltimore/Washington, DC	122 ppb	139 ppb
Philadelphia	115 ppb	123 ppb
New York City	118 ppb	123 ppb
Boston	107 ppb	113 ppb

The data indicate that the difference in ozone levels between CS19 and CS24, in ppb ozone, is comparable with that predicted for the precontrol analysis. Now, however, in the postcontrol environment (CS19), Corridor ozone levels are much lower than in the 2005 baseline, and the additional increment due to transport becomes much more significant. For example, in both Philadelphia and New York City, peak values *without* controls outside the Corridor are increased to the threshold range of the NAAQS. As shown in Figure 5-25, episode maximum values in CS24 rise to levels near or above the NAAQS over a large part of Baltimore/Washington, DC urban area.

Transport Case-Study Analysis

A case study analysis was conducted to provide a more detailed picture of the effects of upwind controls on ozone concentrations within the Northeast Corridor. For this, the daily maximum ozone concentrations in the Corridor were examined for the 2005 baseline and the CS19, CS24, and CS25 strategies to identify grids showing the largest impact of upwind controls. Forward and backward trajectories were constructed for these grids from the hour of maximum ozone using the ROM layer 2 wind fields. Predictions of ozone, NO_x, and reactive organics (ROG) were extracted for points along the trajectories in order to provide a "quasi" Lagrangian history of species concentrations before and after the application of controls.

The case selected for presentation is shown in Figure 5-26. The starting point for the forward/backward trajectories was a grid near Trenton, NJ. Daily maximum predicted ozone in this grid on July 8, 1988 (145 ppb in the 2005 scenario) was reduced by 10 ppb as a result of controls on sources upwind of the Corridor. The trajectory start time was the hour of the maximum predicted concentration, 1500 EST. The trajectory path shown in Figure 5-26 indicates transport into the Corridor from West Virginia, over portions of the Pittsburgh urban area, then across northern Pennsylvania during the two days prior to July 8. The air parcel enters the Corridor northwest of Philadelphia on the evening of July 7. After passing over Philadelphia during the morning, this air parcel continues northeastward across New York City on the evening of July 8. On the following day, July 9, the air parcel tracks through Connecticut and on up across Boston. Concentrations of ozone, NO_x, and ROG along the trajectory are provided in Figure 5-27 for the 2005 baseline and CS25, and in Figure 5-28 for CS19 and CS24. The trajectory and time series profiles are divided into several segments in order to explain the behavior of pollutant concentrations. Transport into and within the Corridor for the 2005 baseline scenario is described first, along with the impact on baseline concentrations of upwind controls. The impact of reducing transport following the application of stringent controls inside the Corridor is presented last.

Impacts of Transport on 2005 Baseline Ozone

a. Upwind Patterns

Examining the data in Figure 5-27 indicates that ozone levels along segment A-B for the 2005 baseline scenario show a gradual decline from 85 ppb to 65 ppb as the air parcel approaches the Corridor. A NO_x source is encountered just upwind of the Corridor near point B as indicated from the NO_x concentration profile. In response, ozone levels increase to 90 ppb. When controls are applied outside of the Corridor (CS25), ozone levels are reduced to about 50 to 55 ppb along the entire upwind portion of the

trajectory path. Concentrations of ROG upwind are actually slightly higher with the application of controls outside the Corridor. As indicated in the discussion of Issue #1, this part of the region is "NO_x limited" due to the relatively large amount of biogenic sources. With the application of stringent NO_x controls, less VOC is consumed in forming ozone.

b. Corridor Transport Patterns

As the air parcel approaches and crosses the Philadelphia area on the morning of July 8 (segment D-E in Figure 5-27) precursor concentrations increase substantially in response to the injection of fresh emissions. Note that the small changes in incoming precursor levels due to upwind controls are overwhelmed by Corridor emissions and have little effect on precursor levels inside the Corridor.

Ozone levels rise in the Philadelphia plume with the maximum concentrations over central New Jersey and near New York City by late afternoon. The peak concentrations along this segment are reduced by about 10 ppb due to controls upwind of the Corridor. The remains of the Philadelphia plume continue to track across the New York City area during the evening and into Connecticut overnight (Segment E-F). Precursor levels increase sharply over New York City and ROG levels remain relatively high during the night. Ozone levels decline somewhat but remain at around 100 ppb. In this segment, the effects of upwind controls on ozone levels are still evident from the CS25 profiles, but the reduction is now only about 5 ppb. The following day (segment F-G), ozone levels remain at 100 ppb until 1100 when NO_x levels increase, indicating an injection of fresh emissions from layer 1. Ozone then rises back to near 140 ppb. The impact of controls outside the Corridor continues for the remainder of the trajectory at about 3 ppb. Thus, the effects of upwind controls on 2005 baseline ozone levels are small compared with the quantity of ozone produced by Corridor emissions. The amount of reduction in ozone (due to upwind controls), which starts out at 25 ppb just upwind of Philadelphia, declines with time as the air parcel progresses along the Corridor and additional large precursor sources are encountered.

This particular trajectory also reveals a "second day" effect over Connecticut. That is, ozone levels remaining from the Philadelphia plume combine with evening precursors injected over New York City and with fresh emissions in Connecticut to produce ozone levels comparable with those in the plume the day before. It is interesting to note that with controls in place outside the Corridor, the second-day peak over Connecticut is actually several ppb greater than the peak on the previous day over central New Jersey.

Impacts of Transport on Postcontrol Ozone

In this part of the analysis, ozone concentrations are reduced inside the Corridor by stringent controls placed on Corridor sources. In CS19, controls are applied regionwide and peak ozone levels fall below 125 ppb across the US portion of the region. In CS24, controls are maintained within the Corridor but emissions outside the Corridor are increased to the 2005 baseline level. The difference in ozone and precursor concentrations outside the Corridor between CS19 and CS24 is identical to that found by comparing the 2005 baseline with CS25, since in this part of the region the CS19 emissions were used for CS25 and the 2005 baseline emissions were used for CS24.

Inside the Corridor, significant reductions in ozone and precursors are evident between the 2005 baseline and CS19. For example, comparing ROG concentrations from Figures 5-27 and 5-28 indicates that ROG inside the Corridor (beyond C on the trajectory path) is reduced by 50 to 80 percent to levels comparable to those upwind of the Corridor. The impact on postcontrol Corridor precursor levels due to upwind controls is similar to that found in the analysis of 2005 baseline scenario above.

When controls are applied regionwide (CS19), ozone concentrations are reduced, with peak levels on the first and second day inside the Corridor at about 110 ppb (see Figure 5-28). Without controls on upwind sources (CS24), ozone increases by 10 to 15 ppb in segment D-E and the peak concentration rises to near 120 ppb. A lesser increase is noted in the second-day peak.

Thus, the results of this trajectory analysis suggest that without reducing transport, ozone produced by Corridor cities that are adjacent to the upwind boundary of the Corridor, namely Philadelphia and Baltimore/Washington, DC, may approach the level of the NAAQS even with stringent controls on Corridor emissions. The effects are less for areas further away from the Corridor boundary.

Findings

The following are the key findings for ISSUE #2:

What is the impact of reducing regional transport on Northeast Corridor ozone levels?

- In the precontrol scenario, 2005 baseline ozone levels are not substantially impacted by reducing transport except in Baltimore/Washington, DC and around Pennsylvania. These areas are closest to the portion of the Corridor boundary having the greatest incoming ozone levels during this episode. It is possible that conditions in other episodes might produce a greater impact in other portions of the Corridor. Still, even in these two areas, the impacts are small relative to the level of predicted ozone in the 2005 baseline.

- In the postcontrol scenario, the results suggest that *without* stringent upwind controls ozone levels in parts of the Corridor may not be reduced to below the NAAQS *even with* stringent controls along the entire length of the Corridor. Again, the effects are most pronounced for cities near the upwind boundary of the Corridor. For episodes with higher ozone transport into the Corridor from a northwesterly direction, larger impacts due to transport might be seen in New York City and New England.

ISSUE #3

What levels of VOC and/or NO_x emissions reductions are necessary to reduce predicted ozone concentrations in the Northeast to below 125 ppb?

Analysis Approach

This question was examined to provide a general indication of the level of emissions reductions which may be needed to reduce peak 1-hour ozone concentrations to below 125 ppb across the Northeast. As discussed in Section 1, urban scale modeling by State agencies will be required to develop specific emissions targets which demonstrate attainment. This is a consequence of the regional nature of ROM. Another important point to make with respect to this issue is that the most effective ROMNET strategy for an area may not be unique. That is, other combinations of controls may be at least as effective. However, at least one strategy has been identified that is sufficiently stringent to reduce predicted ozone levels to below 125 ppb in all sections of the US portion of the modeling domain throughout the episode simulated.

A technology-based approach was adopted to identify strategies that reduce ozone to below 125 ppb. That is, existing or envisaged control measures were applied to the 2005 baseline on a source category basis. For areas where such controls were insufficient, additional reductions were applied in an across-the-board manner (i.e., all source categories were reduced by an equivalent percentage) until ozone levels dropped below 125 ppb. The ROMNET strategies simulated to address this issue are listed below. Unless specified, sources not affected by specific controls are at the 2005 baseline level. Emissions of CO were reduced by certain maximum technology controls in CS10, and in CS12 through CS19.

- 2005 baseline: existing State and Federal control programs
- CS05: VOC, NO_x, and CO controls in October 1989 Clean Air Act proposed legislation
- CS10: combined VOC and NO_x maximum technology controls (CS12 + CS11)
- CS11: maximum technology NO_x controls on point, area, and mobile sources
- CS12: CS01 VOC controls plus stringent VOC tailpipe standards
- CS13: maximum technology NO_x point-source controls with CS12 VOC controls
- CS14: maximum technology NO_x mobile-source controls with CS12 VOC controls
- CS15: CS10 technology controls plus alternate-fueled (M100) vehicles along the Corridor and low-reactivity solvent substitution regionwide.

The remaining strategies focused on controls in New York City and Baltimore/Washington, DC. Ozone levels in these areas persisted above the NAAQS even with the previous technology-based strategies.

- CS16: CS10 plus

  (a) in New York City a 64 percent across-the-board VOC reduction applied in addition to maximum technology controls; no maximum technology NO_x point-source controls; and

  (b) in Baltimore/Washington, DC a 54 percent across-the-board VOC reduction applied in addition to maximum technology controls.
- CS18: CS15 with CS16 measures in New York City and Baltimore/Washington, DC
- CS19: CS18 except without maximum technology NO_x point-source controls in Baltimore/-Washington, DC.

The rationale for applying VOC controls and removing NO_x controls in the last three strategies was based on the response to VOC, NO_x, and reactivity-based controls in these cities. These findings are discussed in this Section and as part of Issues 1 and 4.

Control measures in the above strategies were assumed to be 100 percent effective. A final strategy, CS23, was simulated to examine to what extent ozone levels might increase above those predicted for CS19 if rule effectiveness and other more realistic assumptions about emissions control programs were considered.

Meteorological conditions for the July 1988 episode were simulated for all of the above scenarios. In addition, the June 1983 episode was simulated for the 2005 baseline and CS19 to determine if CS19 controls would maintain ozone below 125 ppb under different meteorological conditions.

Discussion of Results

The overall emissions for each strategy relative to the 2005 baseline are given in Figure 5-29 for major urban areas in the US portion of the region with 1985 base case ozone levels $\geq$ 125 ppb. The highest and second highest daily maximum 1-hour ozone concentrations for the July 1988 episode are also included in these figures.

Several general observations are evident from the results:

- Existing control programs are predicted to produce a 10 to 15 percent reduction in maximum ozone levels in most cities by the year 2005. Lesser reductions are estimated in Boston and Charleston, WV. Still, existing programs are not sufficient to reduce ozone to below 125 ppb in any of the major Northeast cities.
- Explicit control measures in the October 1989 Clean Air Act legislation produce a 15 to 20 percent reduction in maximum ozone levels in most areas. Peak concentrations fall below 130 ppb in Pittsburgh and Detroit, but only Charleston drops below 125 ppb.

The emissions reductions that lowered predicted ozone concentrations to below the NAAQS are described below by urban area. A summary of these emissions reductions is given in Table 5-2.

New York City and Vicinity:

Peak ozone levels in the core of the New York City urban plume are reduced by VOC controls and increased by NO_x controls. In the presence of stringent NO_x tailpipe standards, VOC reductions on the order of 90 percent may be needed to lower ozone to below 125 ppb (CS16). Even without stringent NO_x controls, VOC reductions beyond 75 percent may be necessary (CS12). Reactivity-based strategies may provide some additional benefits in reducing ozone in the presence of NO_x controls (see results for Issue #4).

Considering more realistic control effectiveness assumptions (CS23), peak predictions rise from 120 ppb to 140 ppb, indicating that further reductions may be required.

Baltimore/Washington, DC and Vicinity:

Peak ozone levels are right at the NAAQS with the combined VOC and NO_x maximum technology controls in CS10. Adding the across-the-board VOC reductions in CS16 changes the VOC control level from 56 percent to 80 percent and lowers peak ozone to 118 ppb.

It should be noted that one grid remained above 125 ppb downwind of Baltimore over the eastern shore of the Chesapeake Bay in the CS16 scenario. This value (133 ppb) appears to be greatly influenced by a NO_x point source in the same ROM grid. The highest concentration adjacent to this grid is 119 ppb. Also, CS19, which removes point-source NO_x controls, reduced this value to 103 ppb. Given the limitations of ROM for such localized effects the importance of this value was discounted. Also, without point-source NO_x controls, ozone levels in other parts of this urban area increase to between 120 ppb and 122 ppb on several days.

The application of reasonable control assumptions in CS23 increased ozone levels in Baltimore/Washington, DC to 128 ppb, or just above the level of the NAAQS.

Philadelphia and Vicinity:

The peak ozone concentrations is reduced to 124 ppb with CS11, the NO_x only control strategy. Addition VOC controls reduce the peak to 117 ppb (CS10). Given the results for CS13 and CS14

(mobile-source controls vs. point-source NO_x controls) it appears that the full complement of NO_x controls in addition to stringent VOC controls may be needed. Considering more realistic control effectiveness assumptions increases the peak value to 125 ppb.

Boston and Vicinity:

Peak ozone levels are near 120 ppb for both CS11 (NO_x only controls) and CS14 (VOC and stringent NO_x tailpipe standards). It appears that the full complement of NO_x controls plus the maximum technology VOC measures (CS10) may be necessary in this urban area.

The combined effects of the CS10 controls, reactivity reduction measures, and potentially the additional upwind controls in New York City, reduce the CS10 peak of 116 ppb to 113 ppb in CS19. Considering the realistic control effectiveness assumptions increases the CS19 peak to 125 ppb.

Pittsburgh/Cleveland/Detroit:

In all three urban areas, the peak value is in the range of 120 to 125 ppb with VOC maximum technology controls plus mobile-source NO_x controls. Lower ozone levels, well below 125 ppb, are produced by combining the full complement of NO_x controls even without the VOC measures.

Peak values in all three cities remain well below 125 ppb when realistic effectiveness considerations were applied to the most stringent VOC and NO_x strategy (CS19).

Thus, it would appear that control strategies for these areas should emphasize NO_x controls more so than VOC control measures.

Charleston, WV:

Peak ozone concentrations in this area are most sensitive to point-source NO_x controls as evident by comparing the predictions for CS11 and CS13 (point-source plus mobile-source NO_x controls and point-source NO_x plus VOC controls) with those of CS12 (VOC control) and CS14 (mobile-source NO_x plus VOC controls). Without the point-source controls, ozone levels remain close to the level of the NAAQS. Concentrations drop dramatically with the application of the point-source NO_x controls. Also, the results suggest point-source NO_x controls at the maximum technology level may be "overkill" for this area. Even the Clean Air Act NO_x point-source controls (low-NO_x burners on coal fired utilities) may provide more than enough emissions reduction.

Results for the June 1983 episode

As indicated above, the most stringent control strategy (CS19) was also applied to the June 1983 episode. The purpose of this was to confirm that the CS19 controls would also reduce ozone to below 125 ppb under different meteorological conditions. The June 1983 episode, as described in Section 3, was characterized by multiday recirculation flows within the Corridor. In contrast, the July 1988 episode, which was used for all strategies, was dominated by general southwest to westerly flow regimes with only some instances of recirculation. The episode maximum ozone concentrations predicted for the June 1983 episode are shown in Figure 5-30 for the 2005 baseline and CS19 scenarios.

These data indicate that high baseline concentrations of ozone are predicted near most major cities in the Corridor during the June 1983 episode. Areas of highest ozone are located inland in a general southwest through northwest direction from the center of each urban area. For example, the impact of the New York City plume is over northern New Jersey and southeast New York State rather than over Connecticut and Long Island as on many days in the July 1988 episode. Also note the area of ozone above 125 ppb extending into central Vermont. Peak ozone in this area for the July 1988 episode was < 100 ppb.

In the postcontrol scenario (CS19) ozone levels in most areas are reduced to well below the NAAQS. The highest value is 124 ppb in a single grid southwest of Washington, DC. Surrounding values, however, are at most 111 ppb. A comparison of the July 1988 and June 1983 episode maximum 1-hour concentrations for the 2005 baseline and CS19 is shown in Table 5-3 for several major cities. The CS19 controls appear to reduce peak ozone in the June 1983 episode to levels near or below those for the July 1988 episode.

FINDINGS

The following are key findings for Issue #3:

What levels of VOC and/or NO_x emissions reductions are necessary to reduce predicted ozone concentrations in the northeast to below 125 ppb?

- Stringent maximum technology VOC and NO_x controls may be necessary in all areas of the Northeast Corridor.
- Additional reductions of VOC on the order of 64 percent in New York City and 54 percent in Baltimore/Washington, DC also may be needed. At present, this level of emissions reductions is beyond known or envisaged control technologies.

- Application of stringent NO_x controls in New York City is counterproductive. Ozone levels approach 125 ppb as VOC controls are increased. It appears that even without NO_x controls, stringent VOC technology and reactivity-based measures may be needed in this urban area.

- Even considering rule effectiveness and a more realistic representation of control programs (e.g., fleet turnover) ozone levels may still be near or just above 125 ppb in most sections of the Northeast Corridor with the most stringent VOC/NO_x/reactivity-reduction strategy simulated. The exception is New York City, where the peak ozone level is predicted to be 140 ppb.

- The effectiveness of the most stringent control strategy in reducing ozone to < 125 ppb was confirmed using an alternate meteorological episode.

ISSUE #4

What are the effects of reactivity-based strategies on regional ozone level?

Analysis Approach

The use of "clean fuels" (e.g., methanol, liquified natural gas, and reformulated gasoline) along with other reactivity-based controls have recently been given a wider consideration by the EPA, States, and industry as part of potential strategies to reduce ozone in areas having severe ozone problems, such as the Northeast Corridor. Thus, several ROMNET strategies were designed to examine the relative effectiveness of several of these measures on Northeast ozone levels.

The effects of reactivity-based strategies on regional ozone levels were addressed in CS15 and CS20 through comparisons with the 2005 baseline, CS10 (maximum technology VOC and NO_x controls), and CS12 (maximum technology VOC controls only). As described in Section 4, CS15 and CS20 contain two control measures that alter the reactivity of VOC emissions:

a. substituting low-reactivity compounds for all solvent emissions categories across the entire US portion of the region; and
b. changing the passenger car fleet along the Northeast Corridor to M100 (methanol-powered) vehicles.

The difference between CS15 and CS20 is that CS15 also contains maximum technology controls on VOC and NO_x, whereas CS20 does not. Emissions levels in CS20 reflect the 2005 baseline except for mobile sources in the Northeast Corridor. There, mobile emissions are greater due to the higher emission rate of M100 vehicles, though the reactivity-weighted emissions are less, as described in Section 4.

To assess the impact of reactivity reductions alone, in the absence of other VOC and NO_x control measures, the predictions for CS20 are compared with the 2005 baseline. The effectiveness of CS20 is also compared with the reductions provided by the maximum technology VOC controls in CS12. Then, the impact of combining reactivity-based and VOC plus NO_x technology-based controls is examined from the predictions for CS15. Results from CS15 are compared with predictions for CS10 to determine the additional benefit obtained by adding reactivity-based controls on top of technology-based measures.

The ozone metrics selected for this analysis are as follows:

- The average change in daily maximum ozone levels (ppb) for days $\geq$ 125 ppb in the 2005 baseline;
- The number of days with ozone levels $\geq$ 125 ppb; and
- Percent reduction in population exposure to 1-hour concentrations $\geq$ 125 ppb.

In the presentation of results, these metrics were calculated for selected portions of the region. The data were aggregated for areas showing a similar response for the first two metrics. (There was less consistency among cities in the effects of controls on population exposure.) Data for Philadelphia, Baltimore/-Washington, DC, and Boston comprised Group 1. New York City, Greater Connecticut, and Rhode Island show a different response to the controls and are examined individually. Other, more peripheral areas of the Corridor, are combined in Group 2. Finally, Pittsburgh, Cleveland/Canton/Akron, and Detroit comprise Group 3.

The first metric was calculated as follows. For each area, all days with daily maximum ozone concentrations ≥125 ppb in the 2005 baseline scenarios were identified. The difference in daily maximum ozone between two scenarios (e.g., CS20 and CS12) was calculated for each of these days, and then averaged for the days with ozone ≥ 125 ppb. Finally, Group averages were computed from the average values for individual urban areas. The other two ozone metrics are fairly straightforward. A summary of the ozone metrics for each of the above areas is provided in Table 5-4.

Discussion of Results

Impact of Reactivity Controls Alone

The data in Table 5-4 indicate that, in general, the reactivity-based strategies are by far the most effective in the New York City area and in the two areas directly downwind, Greater Connecticut and Rhode Island.

In the New York plume, the largest reduction in daily maximum ozone appears to occur close by, within New York City itself. The magnitude of the reduction, although still substantial, tends to level off with distance downwind. Also, the frequency of high concentrations and population exposure are greatly reduced by this strategy. For example, the population exposure was reduced by 75 percent in New York City and by 69 percent in Greater Connecticut.

The benefits of the reactivity-based strategy is less notable in other Corridor cities (Group 1), and decreased further in peripheral areas (Group 2). For example, the average reduction in daily maximum ozone provided by CS20 vs the 2005 baseline is only 8 ppb in Group 1, and 5 ppb in Group 2. However, in terms of population exposure, there is a moderate reduction in Group 1 (46 percent) with a lesser benefit for Group 2 (33 percent reduction). The difference between the effects on daily maximum ozone and population exposure indicates that the reductions from this scenario are occurring close to the urban areas where population is greatest and/or that the number of hours and spatial extent of exceedances is being reduced to a greater extent than the daily maximum concentration.

In the large urban areas outside the Corridor, as represented by Group 3, there was very little reduction (2 ppb) in daily maximum ozone levels $\geq$ 125 ppb for a 23 percent reduction in reactivity-weighted emissions. (Recall that only the solvent substitution component of the reactivity strategy was applied outside the Corridor.) Population exposure to ozone above $\geq$ 125 ppb was, however, reduced by nearly 30 percent.

Although there was consistency between areas within each group, there were some notable day-to-day differences in individual cities. For example, the reduction in 2005 baseline daily maximum ozone (i.e., "delta ozone") ranged from 3 to 20 ppb on different days in Baltimore/Washington, DC; 30 to 144 ppb in New York City, and 5 to 22 ppb in Boston. Also, on the July 10 simulation day, ozone levels actually increased following the application of the reactivity-based measures. This occurred across a substantial portion of the Washington, DC area, and sections of eastern Maryland and Delaware. In these areas, ozone levels, which were already $\geq$ 125 ppb in the 2005 baseline, increased by up to 9 ppb, and population exposure more than doubled. The event occurred on the last day of a 3-day period with moderately high ozone levels (125 ppb $\leq O_3 <$ 150 ppb)and a recirculation/near-stagnation wind regime in this area. On the first two days of this period, ozone levels in CS20 were lower than the baseline by 9 to 11 ppb. This suggests that under certain meteorological conditions a reactivity-based strategy may provide disbenefits in the absence of further emission reductions.

Reactivity *vs.* Technology Controls

To consider the relative benefits of reactivity versus technology controls, the predictions for CS20 are compared with CS12. In the New York City plume, the average reduction in daily maximum ozone is comparable between the two strategies, but the reduction in the number of high ozone days and population exposure is greater with the technology-based controls. For the Group 1, 2, and 3 areas, the reductions in all three ozone metrics are much greater with the technology-based controls.

The benefits of combining reactivity-based measures with maximum technology VOC and NO_x controls is examined by comparing the predictions from CS15 (reactivity plus technology) with CS20 (reactivity only) and CS10 (technology only). The ozone metrics in Table 5-4 indicate that for the Group 1, 2, and 3 areas, the average *reduction* in daily maximum ozone provided by CS15 is four to ten times greater than with CS20 (reactivity controls alone). However, the vast majority of the reduction in CS15 appears to be associated with the technology-based controls rather than the reactivity measures (CS15 vs CS10). Thus, in some areas where maximum technology controls containing large emissions reductions are applied, adding reactivity-based measures may only lead to small additional benefits.

In New York City, the lower reactivity does appear to counteract the disbenefits of NO_x controls described in Issue #1. This is evident from the average 36 ppb reduction in daily maximum ozone between CS10 and CS15. However, this effect decreased with downwind distance in Greater Connecticut and Rhode Island.

FINDINGS

The following are the key findings for Issue #4:

What are the effects of reactivity-based strategies on regional ozone levels?

- Reactivity-based strategies similar to those simulated in ROMNET may provide the greatest benefit in large urban areas which are VOC-limited and thus are more responsive to changes in VOC emissions. In such areas, reactivity-based measures could provide reductions in ozone levels comparable with that provided by a technology-based approach. Also, reactivity measures may counterbalance the negative impact of NO_x controls in New York City and other areas that show a similar response.

- In other Northeast Corridor cities, and by extension, cities that respond to both VOC and NO_x controls, reactivity measures may produce a notable reduction in daily maximum ozone levels $\geq$ 125 ppb. However, for the Corridor cities, the reduction provided by the reactivity measures was only half of that from the technology-based VOC controls, and four times less than that from the VOC plus NO_x controls

- In other, more peripheral sections of the Corridor, the relative benefits of VOC technology controls alone or with NO_x controls far outweigh the benefits of reactivity-based controls

- In cities outside of the Corridor that were found to be most sensitive to NO_x controls, there was less reduction in ozone from the reactivity measure compared with the technology-based controls.

ISSUE #5

How does the large uncertainty in biogenic emissions alter conclusions regarding the effectiveness of control measures?

Analysis Approach

Biogenic emissions are believed to be among the most uncertain of the various input parameters that contribute to ozone concentrations predicted by the Regional Oxidant Model (ROM). Specification of biogenic emissions rates is critical because of the high photochemical reactivity of principal biogenic species, particularly isoprene, and the large amount of biogenic VOC mass believed to be emitted on typical hot summer days. In fact, on a regional basis, total daily biogenic VOC emissions are comparable in magnitude with emissions of 1985 anthropogenic VOC. Domain total biogenic VOC, based upon the meteorology for July 11, 1988, is 25,800 tons per day, while the anthropogenic VOC total is 21,000 tons per day. The Northeast Corridor is not as dominated by biogenic VOC emissions. Corridor biogenic VOC, based upon the meteorology for July 11, 1988, is 3,700 tons per day, while the anthropogenic VOC total is 8,700 tons per day. Previous simulations with the ROM indicate that biogenic emissions play a significant role in the formation of regional ozone concentrations and the development of ozone plumes from major source areas.

Given the importance of biogenic emissions and the large uncertainty in emission estimates, it is important to determine whether the conclusions regarding the effectiveness of control strategies are likely to differ if biogenic emissions are substantially different from the state-of-the-science "best" estimates currently used for the ROMNET model simulations. A series of ROM simulations were conducted to examine the sensitivity of ozone predictions to uncertainty in biogenic emissions. The cases which were analyzed are listed in Table 5-5. These strategies were modeled with biogenic emissions set at the "low" and "high" end of the range of probable uncertainty. The uncertainty range was taken as ± a factor of three, based on recommendations from the EPA Office of Research and Development. This represents an overall uncertainty estimate since it was not possible to adequately infer the uncertainties of individual components of these emissions, namely biomass data, emission factors, the functional relationship to meteorological conditions, forest canopy effects, and speciation.

In the uncertainty scenarios, biogenic emissions were altered in an "across-the-board" manner. For example, in CS06, all biogenic species, in all grids, for all hours were reduced by a factor of three and modeled with the anthropogenic emissions from CS05.

The discussion of the results of the biogenic sensitivity simulations will focus on eight urban areas, listed below:

Baltimore/Washington, DC	Greater Connecticut
Boston	Greater New York City
Charleston, WV	Philadelphia and vicinity
Detroit	Pittsburgh

An assessment of the impact of uncertainty in biogenics is presented in terms of (1) episode maximum 1-hour concentrations, (2) grid-hours $\geq$ 125 ppb, and (3) population exposure to 1-hour levels $\geq$ 125 ppb.

Discussion of Results

Episode Maximum Predicted Ozone

1985 Base Case

The spatial distribution of predicted episode maximum ozone with "best" estimate biogenics is shown in Figure 5-31. Ozone levels > 200 ppb are predicted over the New York City area and over Lake Ontario. Levels > 140 ppb are indicated over Pittsburgh, Cleveland, Baltimore/Washington DC and much of the Northeast Corridor. In the "low" biogenics scenario (see Figure 5-31), ozone levels > 200 ppb are predicted over New York City. Levels > 140 ppb are indicated near Pittsburgh and for a portion of the Northeast Corridor.

In contrast, with the "high" biogenics (see Figure 5-32) ozone levels > 200 ppb are predicted over New York City, Lake Ontario, Washington ,DC, and off the coast of Delaware. Levels > 140 ppb are indicated over Detroit, Pittsburgh, Cleveland, portions of West Virginia, much of Maryland, and most of the Northeast Corridor.

It should be noted that the ozone levels predicted with the "best" estimate biogenic emissions most closely replicated the observed ozone levels.

Control Scenarios

Figure 5-33 illustrates the episode maximum ozone levels predicted for each of the eight urban areas listed above. In all cases, the impact of the "high" estimate biogenic emissions is greater than the impact of the "low" estimate biogenic emissions (impact is defined as the change in predicted concentration from the "best" estimate biogenics). This result is anticipated, because the threefold increase in biogenic emissions contributes a greater proportional increase in VOC mass in relation to the proportional

decrease in total VOC mass with a threefold reduction in biogenic emissions, since anthropogenic emissions are constant for a given scenario. Thus, the relative impact in each area is a function of the relative abundance of anthropogenic VOC to biogenic VOC emissions, and the availability of NO_x emissions to react with the VOC emissions to form ozone.

CS19, which used "best" estimate biogenic emissions, reduced episode maximum ozone levels in the US portion of the domain to below 125 ppb. When "high" estimate biogenic emissions were simulated, five of the areas in Figure 5-40 would exceed 125 ppb. In the Baltimore/Washington DC area, levels are predicted to exceed 200 ppb. When "low" estimate biogenic emissions are modeled with CS19, the episode maximum ozone levels are reduced to approximately 100 to 105 ppb.

Grid-Hours ≥ 125 ppb

An alternative method of assessing control strategy effectiveness is to determine the number of grid-hours exceeding 125 ppb. This particular parameter is extremely sensitive to the uncertainty in biogenic emissions, especially in the base case. For example, in the Baltimore/Washington, DC area for the 1985 Base Case, 285 grid-hours exceeded 125 ppb when the "best" estimate biogenics were simulated (Figure 5-34). The number increased to 863 grid-hours in the "high" estimate scenario, and decreased to 42 grid-hours > 125 ppb for the "low" estimate scenario. A similar sensitivity is observed in each of the other seven areas shown in Figure 5-34.

This sensitivity to biogenic emissions is diminished as controls are applied, especially NO_x controls. Ozone levels in CS19 with "best" estimate biogenics are below 125 ppb in the US portion of the domain. For five of the eight areas, "high" estimate biogenics results in an increase of grid-hours ≥ 125 ppb. The total increase for these five areas with "high" estimate biogenics is 837 grid-hours.

Population Exposure to 1-Hour Ozone Levels ≥ 125 ppb

Population exposure of 1-hour levels ≥ 125 ppb show trends similar to the grid-hours ≥ 125 ppb. The 1985 Base Case values are extremely sensitive to biogenic VOC emission rates, but the sensitivity decreases as controls are applied (Figure 5-35). For example, the Baltimore/Washington, DC area is predicted to have over 75 million person-hours ≥ 125 ppb with "high" estimate biogenics, but only 7 million person-hours ≥ 125 ppb with "low" estimate biogenics. This range reduces to 22 million person-hours for "high" estimate biogenics and 0 person-hours for "low" estimate biogenics when CS19 is simulated.

Findings

The following are the key findings for Issue #5:

How does the large uncertainty in biogenic emissions alter conclusions regarding the effectiveness of control measures?

- ROM simulations with "best estimate" biogenic emissions yield predicted ozone concentrations closer to observed values than biogenic emissions at either end of the uncertainty range ($\pm$ a factor of three), which provides some added confidence to the emissions rates used in ROM strategy simulations.

- The sensitivity of ozone levels and population exposure to biogenic uncertainty varies considerably from city to city. In general, there is a greater sensitivity with increasing biogenics at the high end of the uncertainty range than at the lower end.

- Grid-hours $\geq$ 125 ppb are much more sensitive to an increase in biogenic emissions than the other metrics.

- If biogenics were at the "low" end of the range, predicted ozone in Pittsburgh and Detroit would fall below 125 ppb with the controls in CS05; all other cities would still be above this level (note that ozone in Charleston, WV was already below 125 ppb with "best estimate" biogenics).

- With the application of stringent controls that reduced peak ozone to below 125 ppb with "best estimate" biogenics (CS19), ozone levels rise well above this level in the "high" biogenics scenario in all cities except Pittsburgh and Charleston. Thus, if biogenics are actually near the high end of the uncertainty range, then additional controls offering reductions in emissions beyond those in CS19 will be needed in many of the Northeast cities.

5.4 SUMMARY OF MAJOR FINDINGS TO KEY STRATEGY ISSUES

ISSUE #1:

What are the relative benefits of VOC versus NOx controls in reducing ozone levels across the region?

- NO_x controls are more effective than VOC controls (beyond existing programs) in many areas of the Northeast.
- The efficacy of NO_x versus VOC control varies from city to city and from day to day in some cities.
- Unlike VOC control, NO_x control can be counterproductive in some cities.

ISSUE #2:

What is the impact of reducing regional transport on Northeast Corridor ozone levels?

- The impact of controls outside the Corridor on ozone levels inside the Corridor is minor, given current control programs and planned pre-Clean Air Act control measures.
- Following the application of stringent controls in the Corridor, upwind controls may determine whether or not the NAAQS is met throughout the Corridor.

ISSUE #3:

What levels of VOC and/or NO_x emissions reductions are necessary to reduce predicted ozone concentrations in the Northeast to below 125 ppb?

- Reducing ozone to < 125 ppb appears to be possible in the Northeast with the application of stringent control measures.
- The magnitude of emissions reductions required varies by city.
- The greatest amount of emissions reductions are needed in the New York City urban area, with a VOC reduction of 91 percent from present (1985 base) emissions levels, maximum technology mobile-source NO_x tailpipe standards, and reactivity reduction measures.

ISSUE #4:

How effective are potential reactivity-based strategies in reducing regional ozone levels?

- Reactivity-based measures appear to be most effective in areas where VOC controls produce the largest reductions in ozone levels. However, maximum technology VOC controls are more effective than the reactivity-reduction measures.
- In such areas, the most benefit appears to occur close-in to the city where population is greatest, with diminishing benefits evident further downwind.

ISSUE #5:

How does the large uncertainty in biogenic emissions alter conclusions regarding the effectiveness of control measures?

- The uncertainty in biogenic emissions is large, but model predictions are closest to observed values with "best estimate" biogenic emissions rates.
- If biogenic emissions were near the high end of the uncertainty range, then most of the Northeast Corridor would require emissions reductions beyond the stringent measures required to reduce peak ozone to below 125 ppb with "best estimate" biogenics.
- If biogenic emissons were actually near the low end of the uncertainty range, measures in the 1989 proposed Clean Air Act legislation would still be insufficient to reduce ozone to < 125 ppb throughout the Corridor.

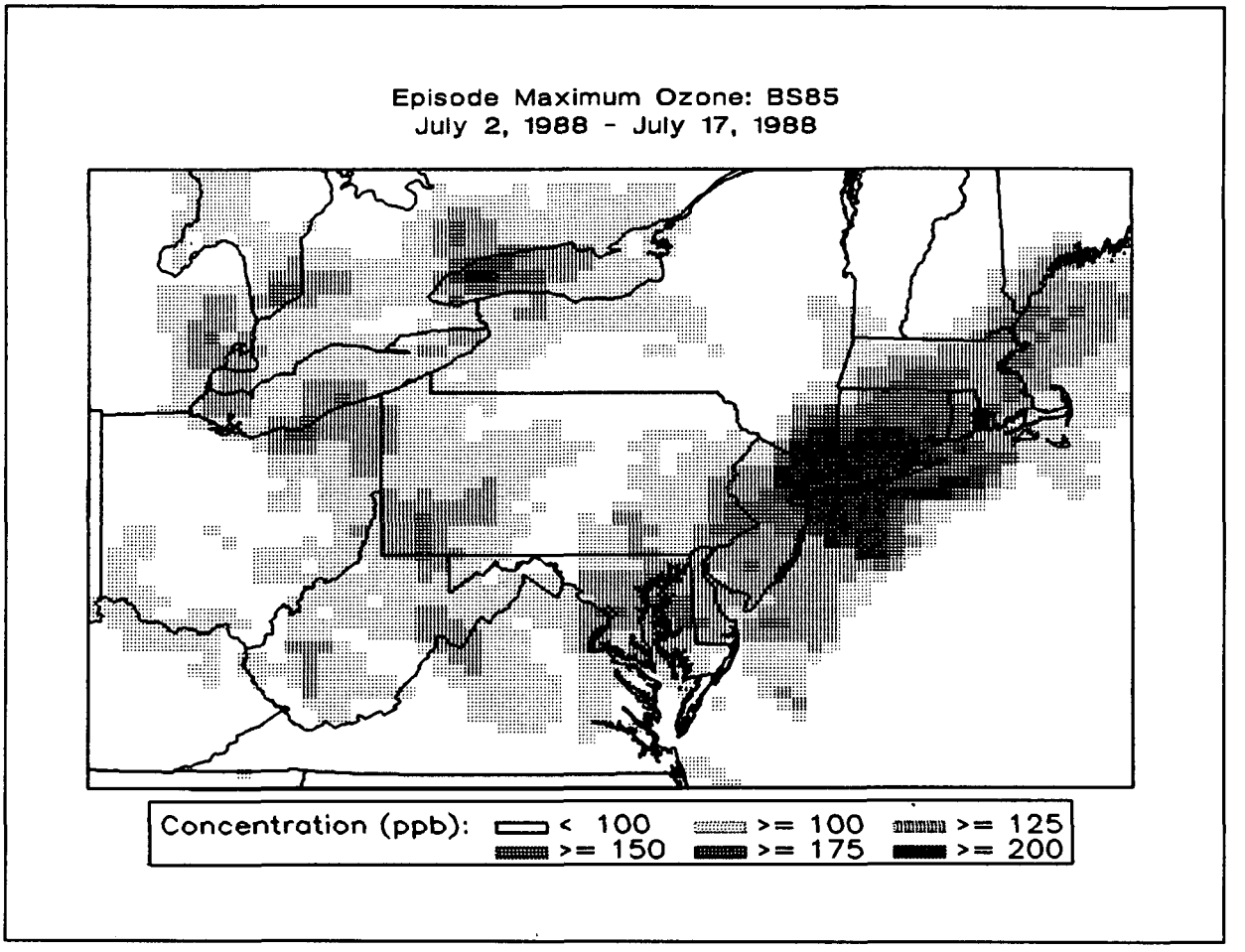


Figure 5-1. Predicted 1985 base case episode maximum 1-hour ozone concentrations (ppb) for the July 1988 episode.

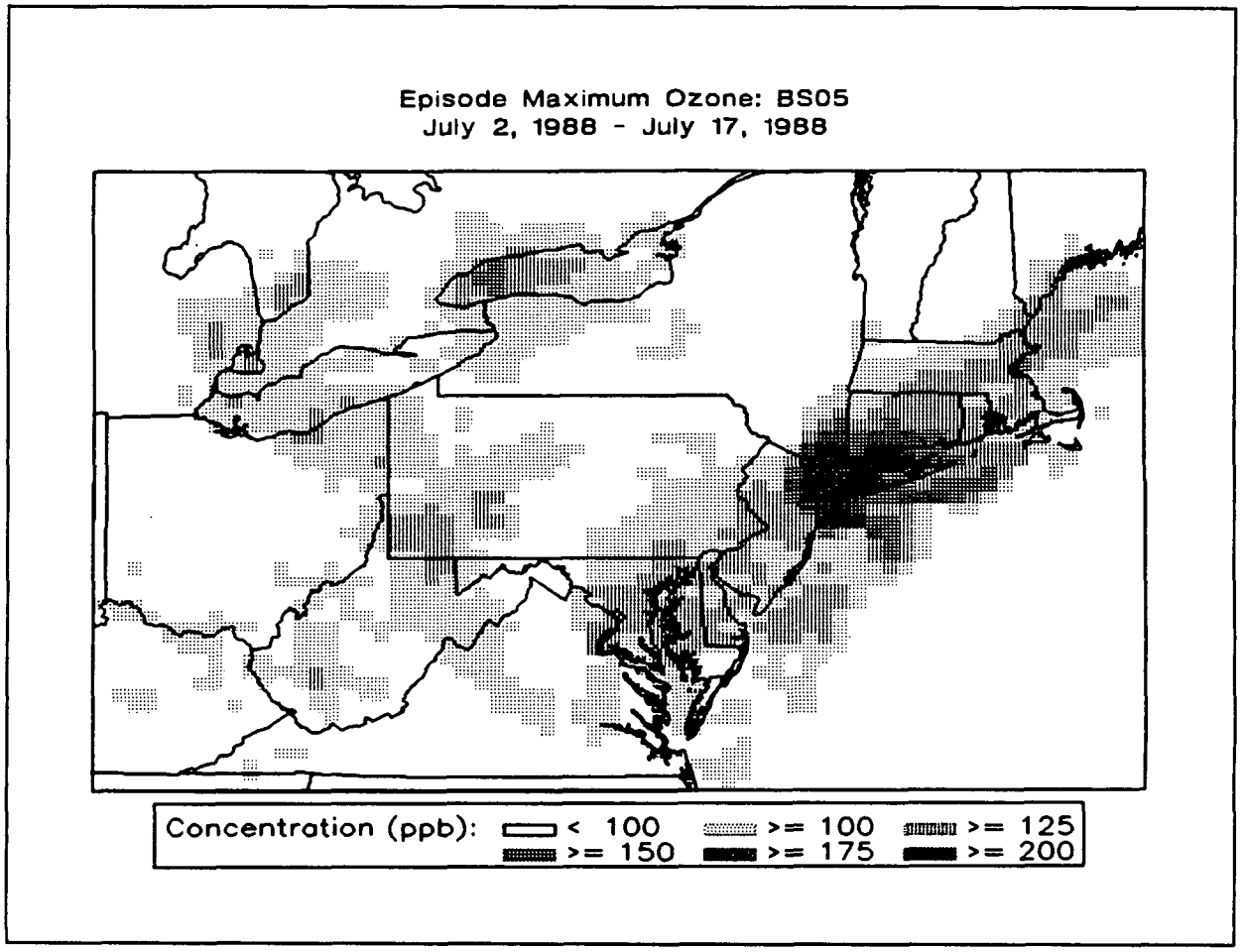


Figure 5-2. Predicted 2005 baseline episode maximum 1-hour ozone concentrations (ppb) for the July 1988 episode.

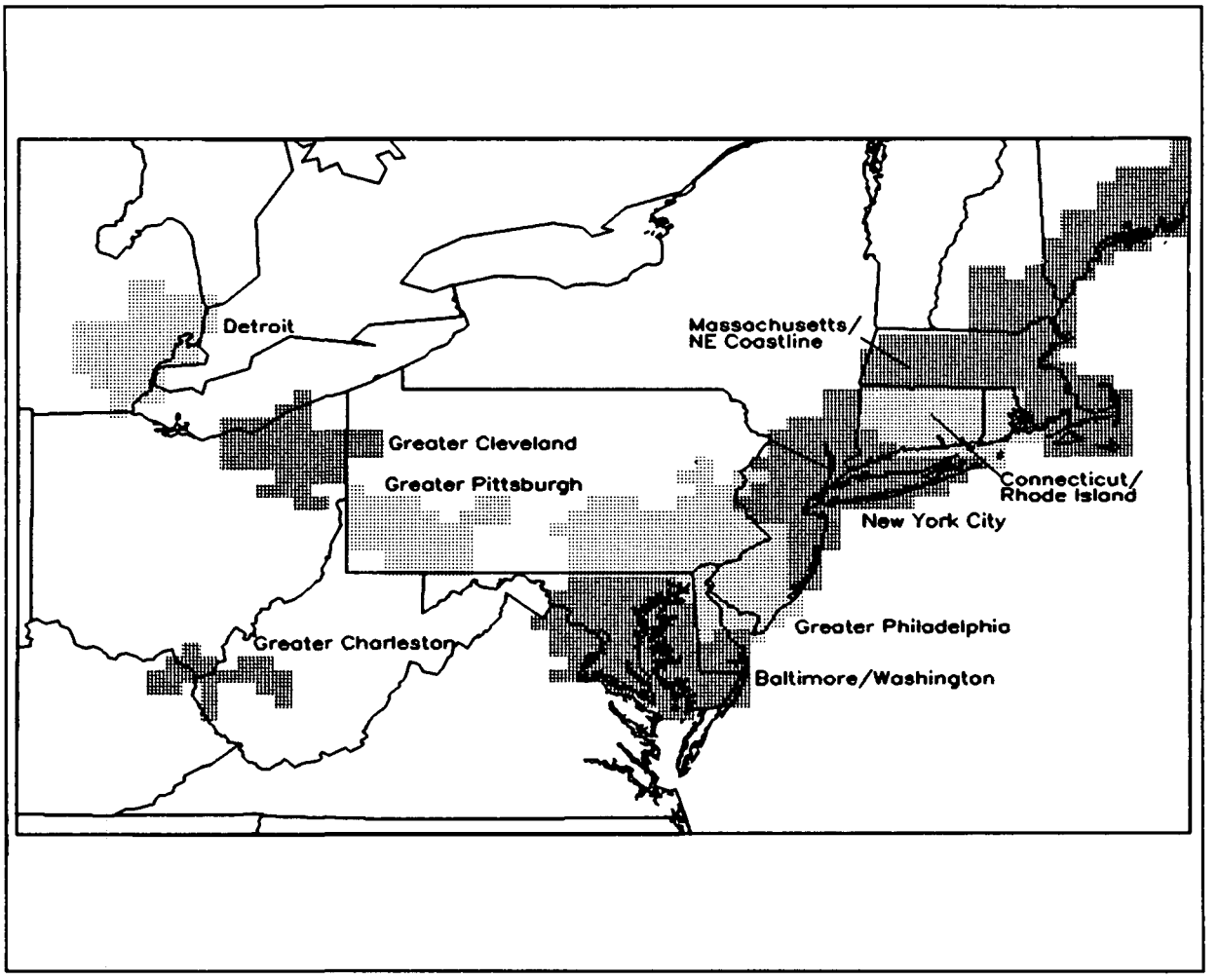


Figure 5-3. Areas in the ROMNET domain used in calculating selected metrics.

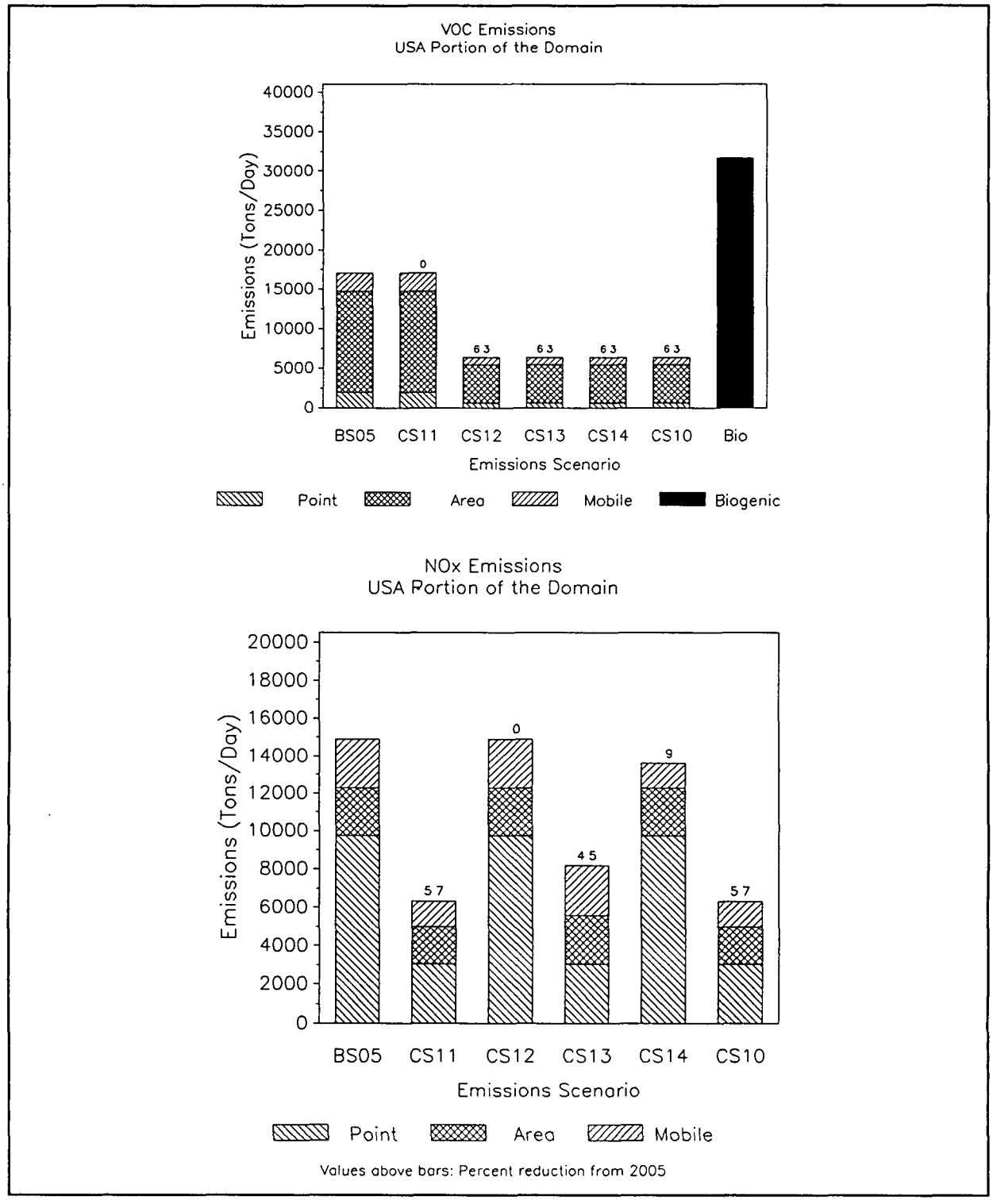


Figure 5-4. Anthropogenic VOC emissions and NO_x emissions for the US portion of the ROMNET region.

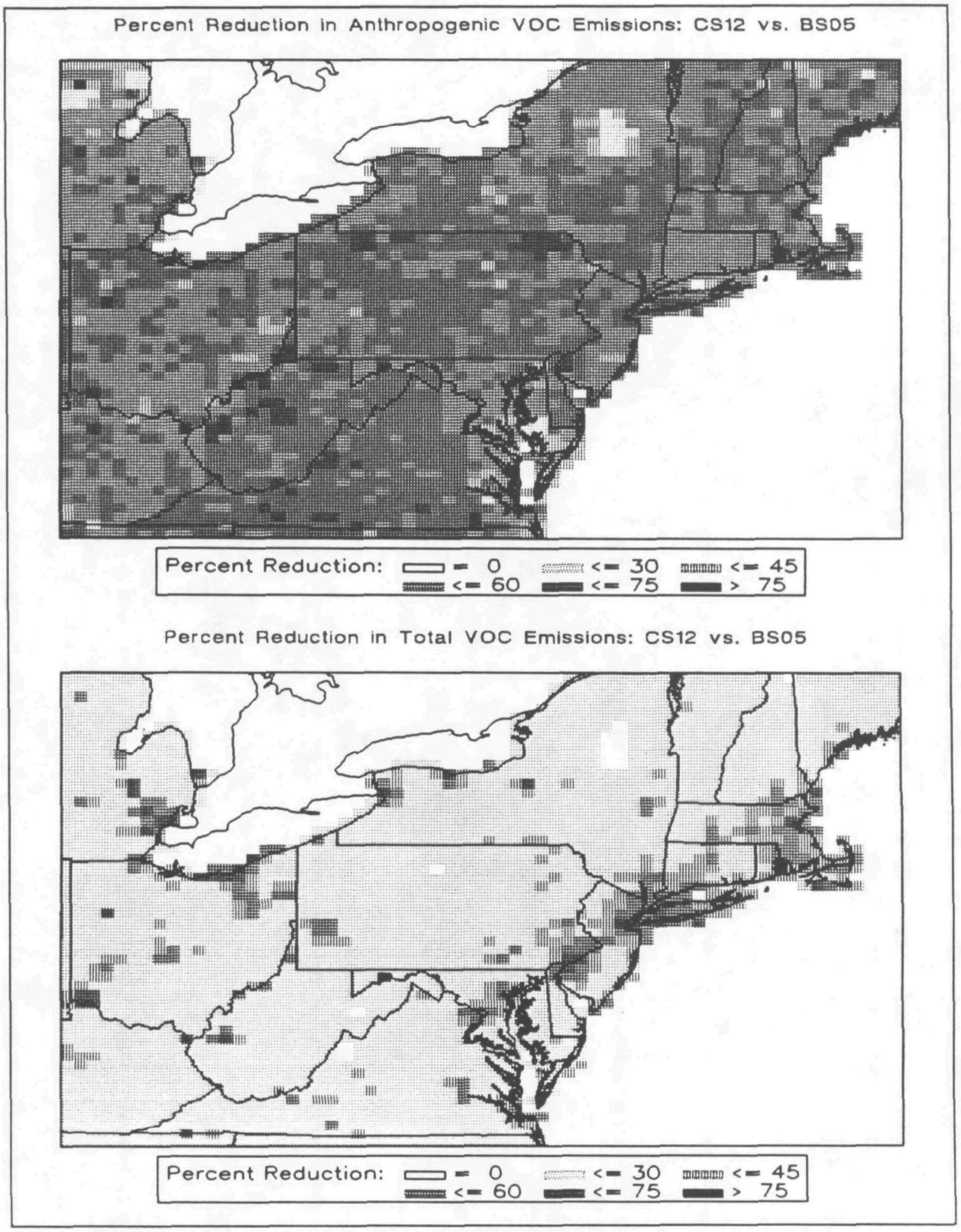


Figure 5-5. Percent reduction in VOC emissions between CS12 and the 2005 baseline for anthropogenic emissions only and anthropogenic plus biogenic emissions.

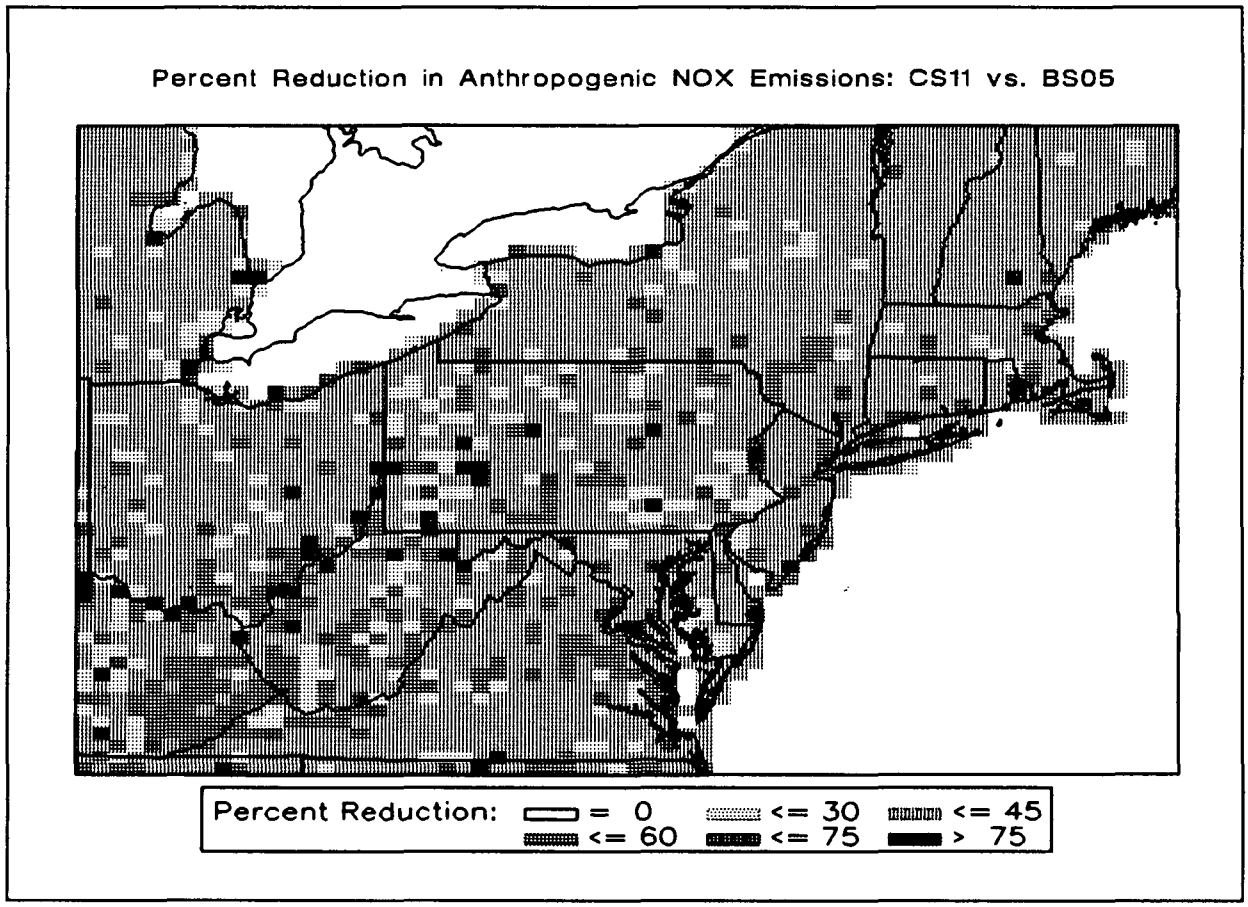


Figure 5-6. Percent reduction in NO_x emissions between CS11 and the 2005 baseline.

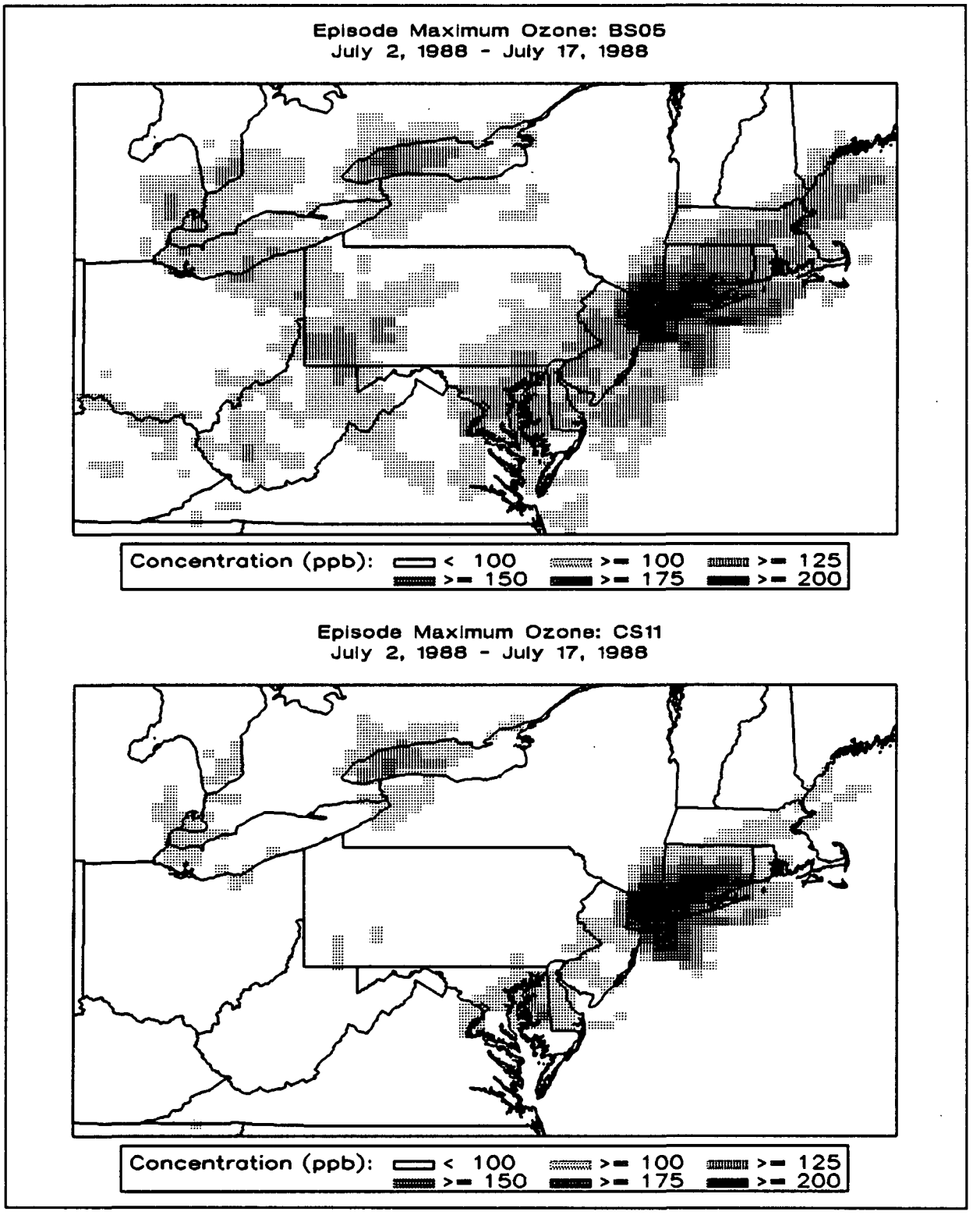


Figure 5-7. Predicted episode maximum 1-hour ozone concentrations (ppb) for the July 1988 episode: 2005 baseline and CS11.

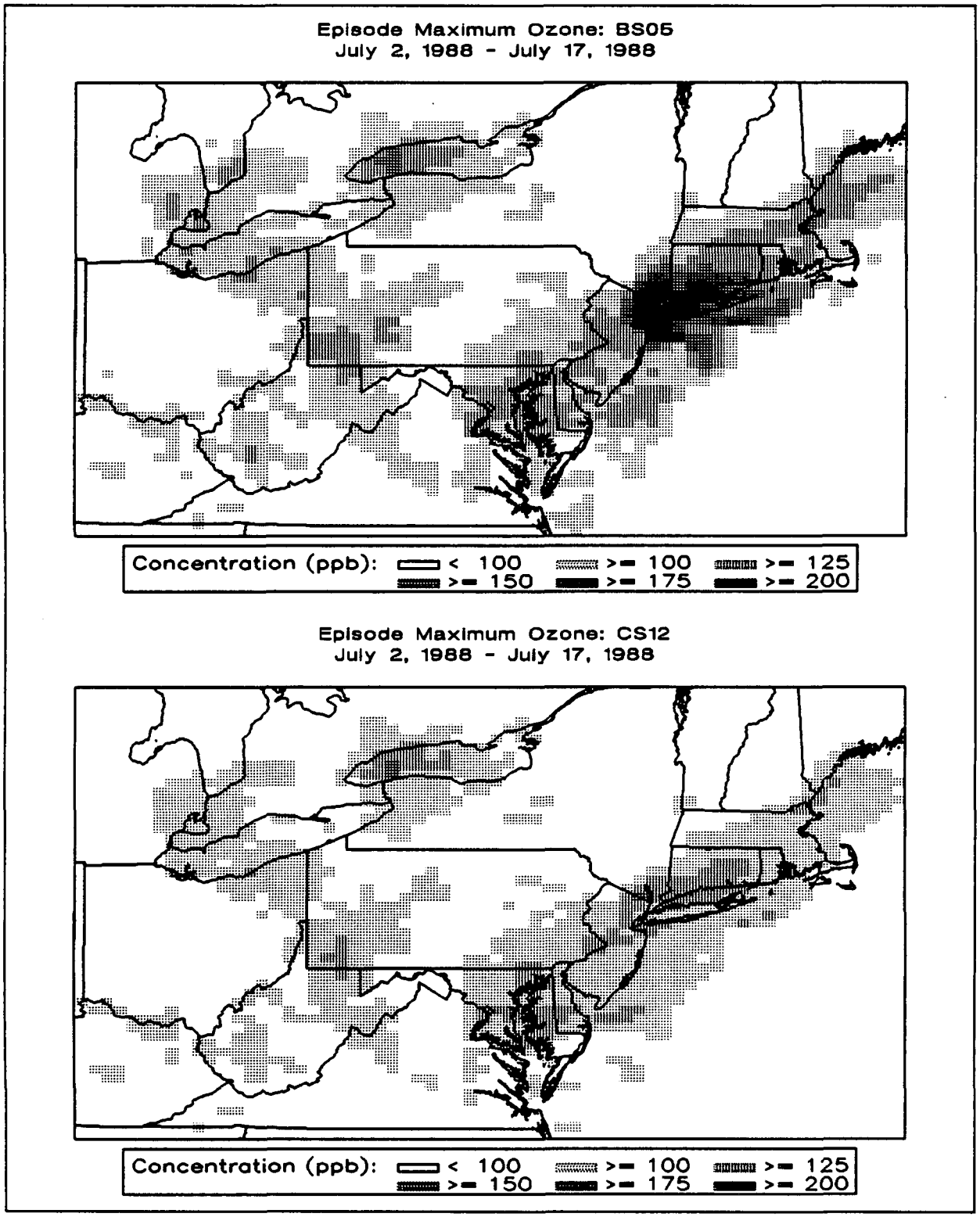


Figure 5-8. Predicted episode maximum 1-hour ozone concentrations (ppb) for the July 1988 episode: 2005 baseline and CS12.

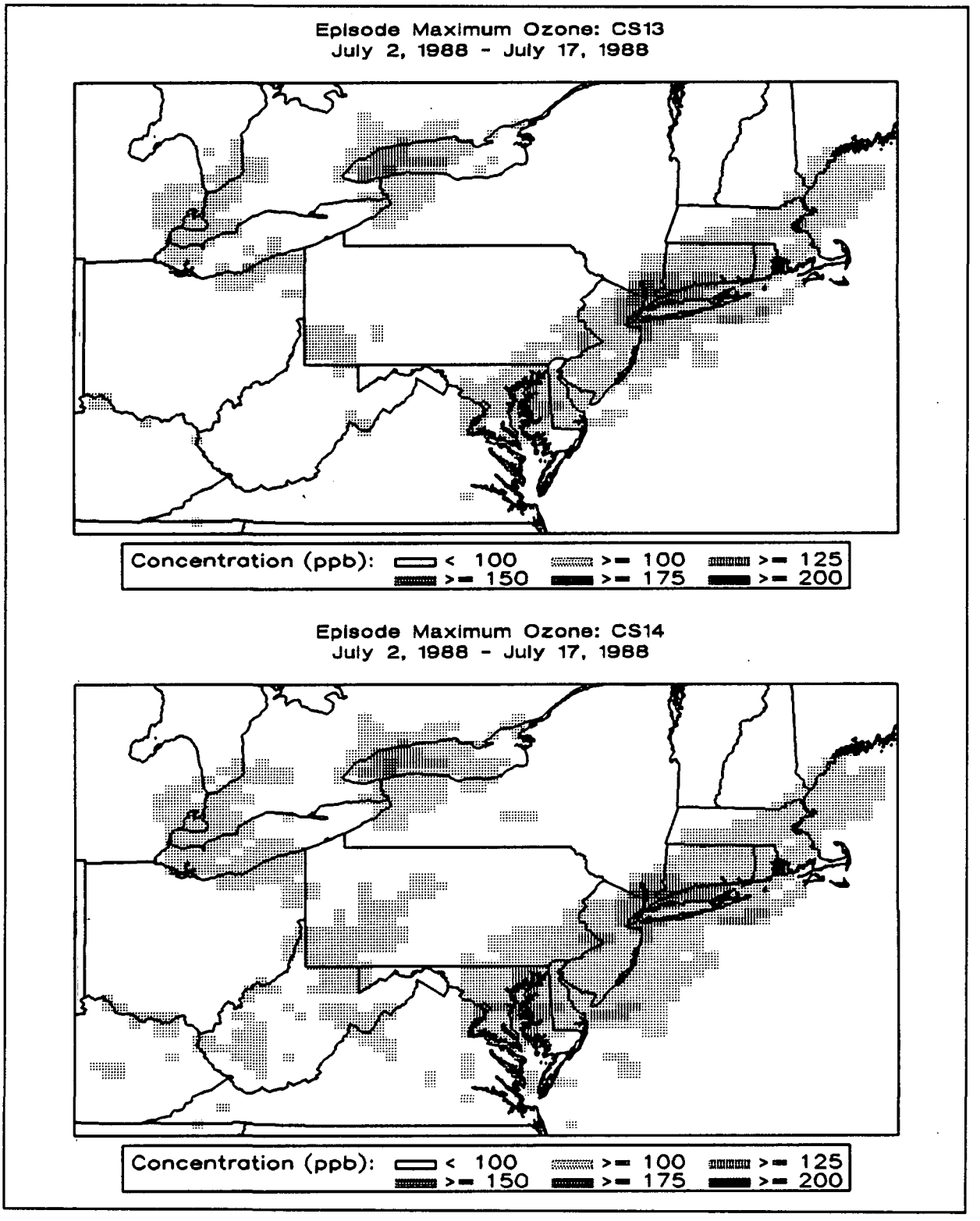


Figure 5-9. Predicted episode maximum 1-hour ozone concentrations (ppb) for the July 1988 episode: CS13, CS14, and CS10. (Page 1 of 2)

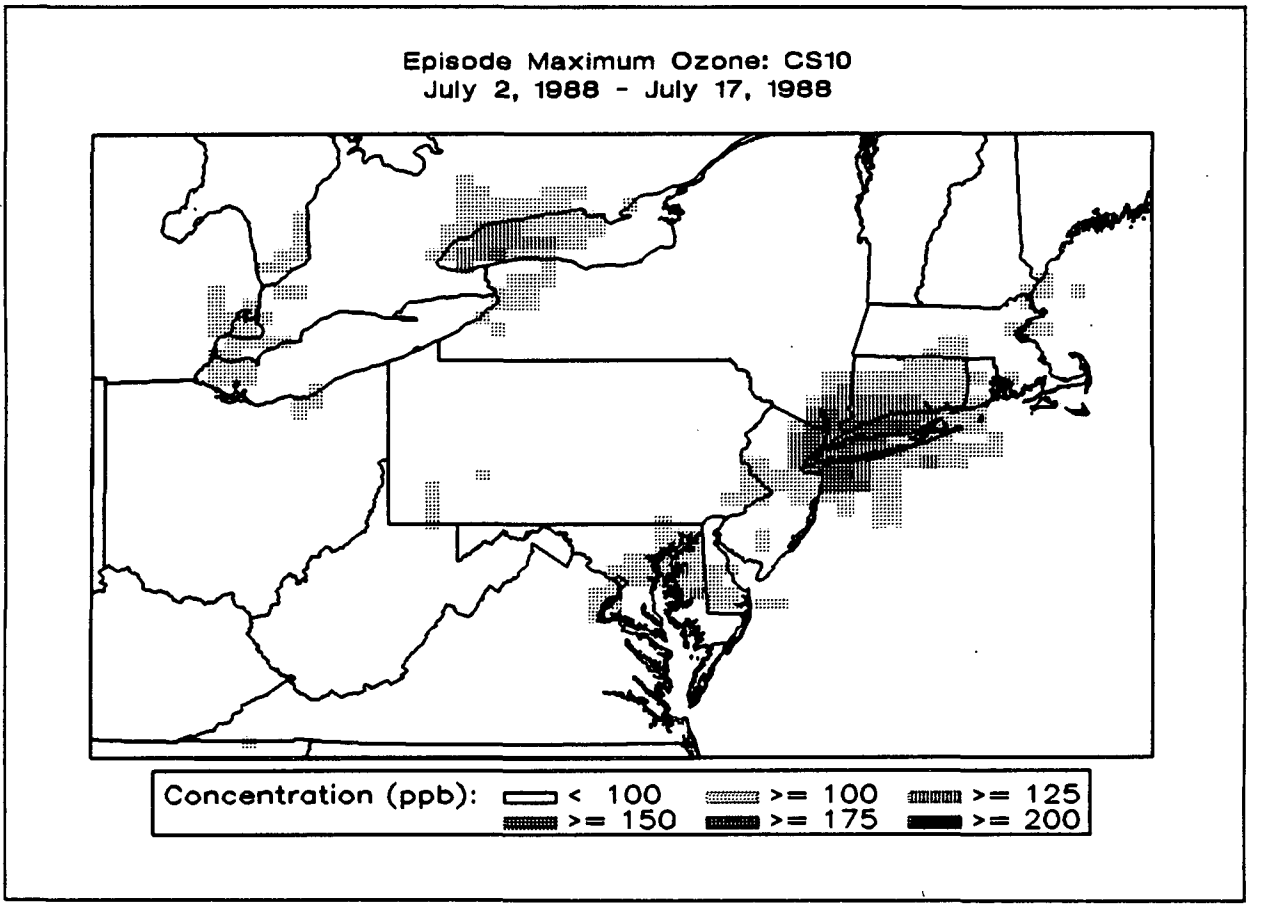


Figure 5-9 (Page 2 of 2)

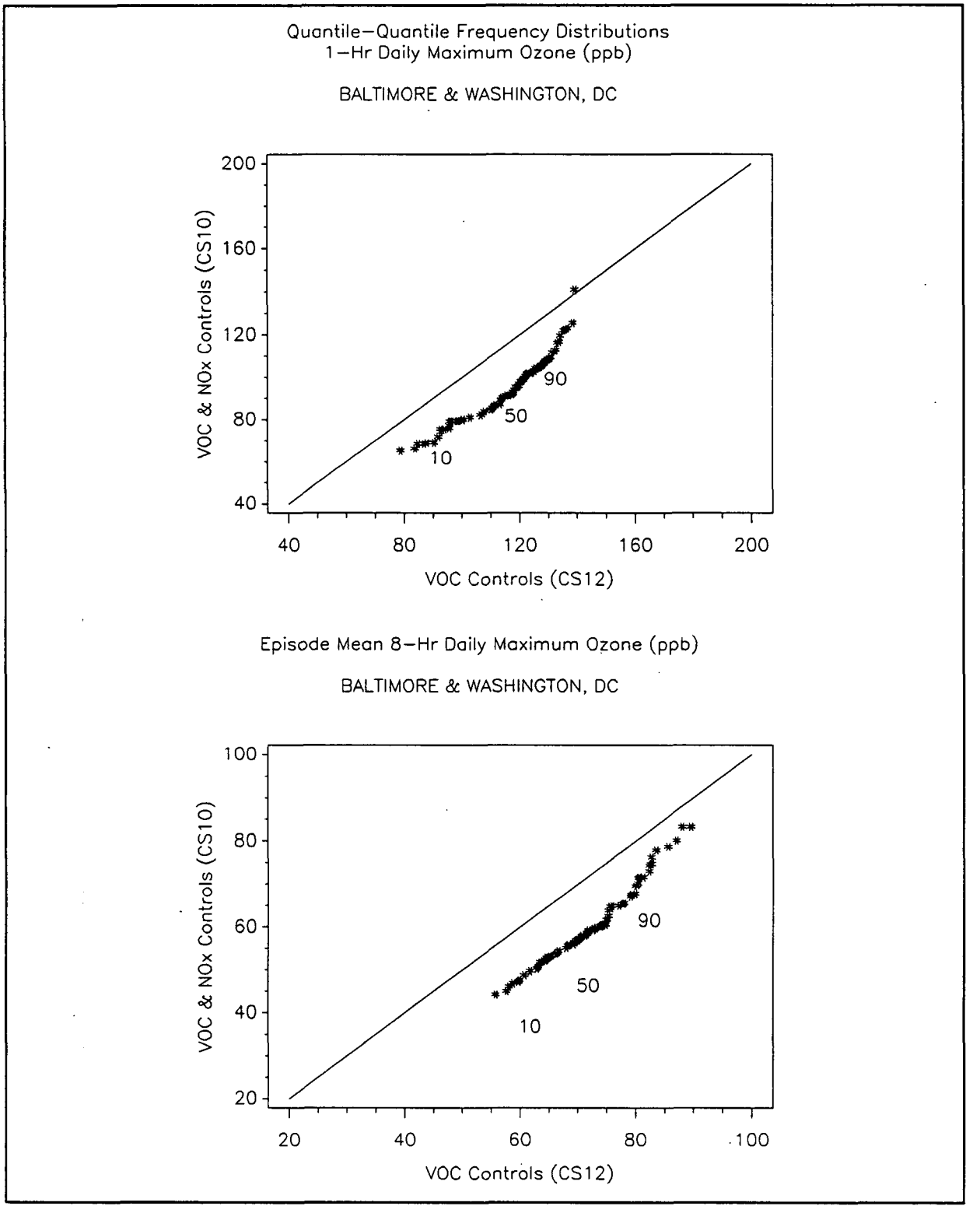


Figure 5-10. Quantile-quantile frequency distributions of 1-hour daily maximum ozone and episode mean 8-hour daily maximum ozone for Baltimore/Washington, DC and vicinity.

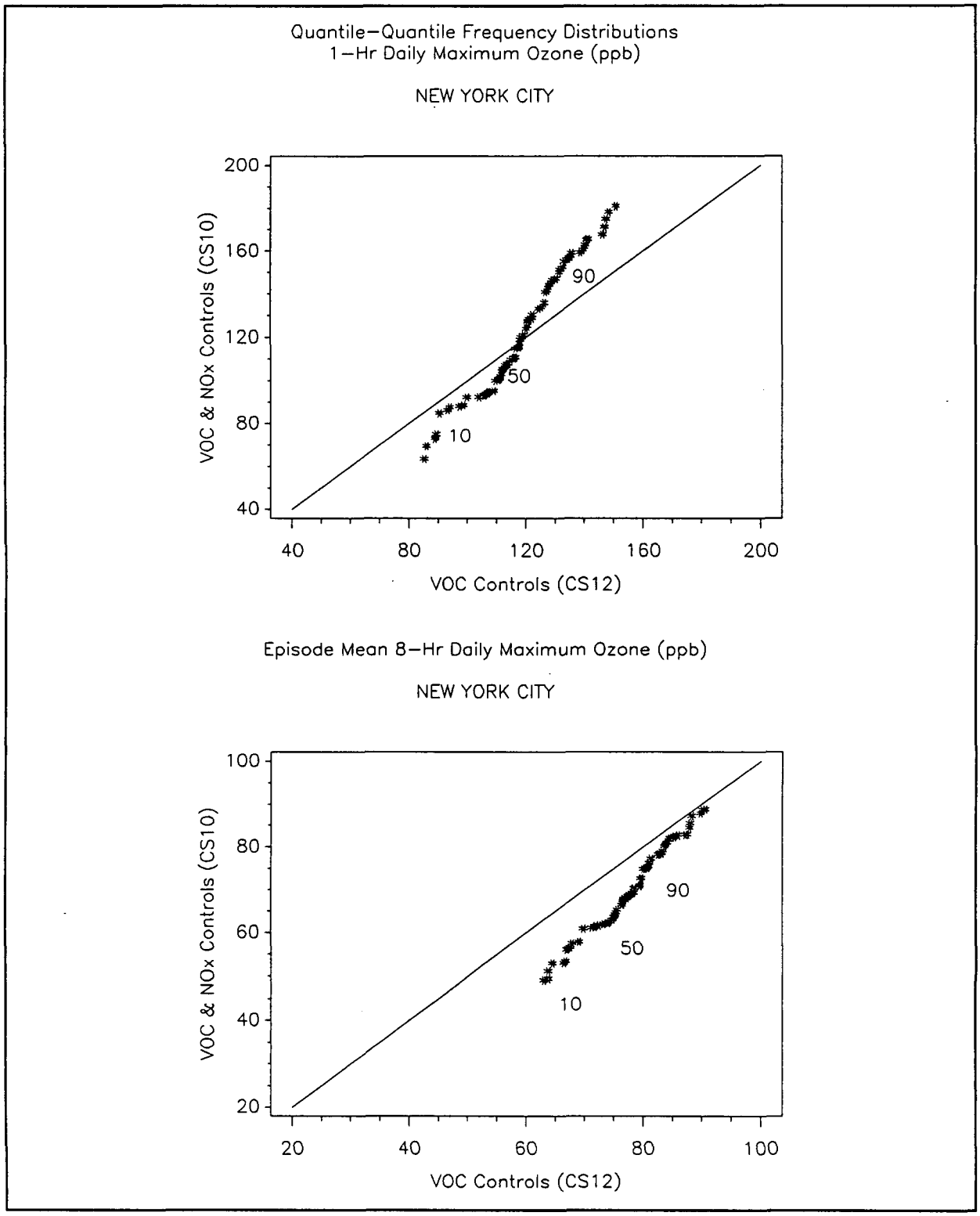


Figure 5-11. Quantile-quantile frequency distributions of 1-hour daily maximum ozone and episode mean 8-hour daily maximum ozone for New York City.

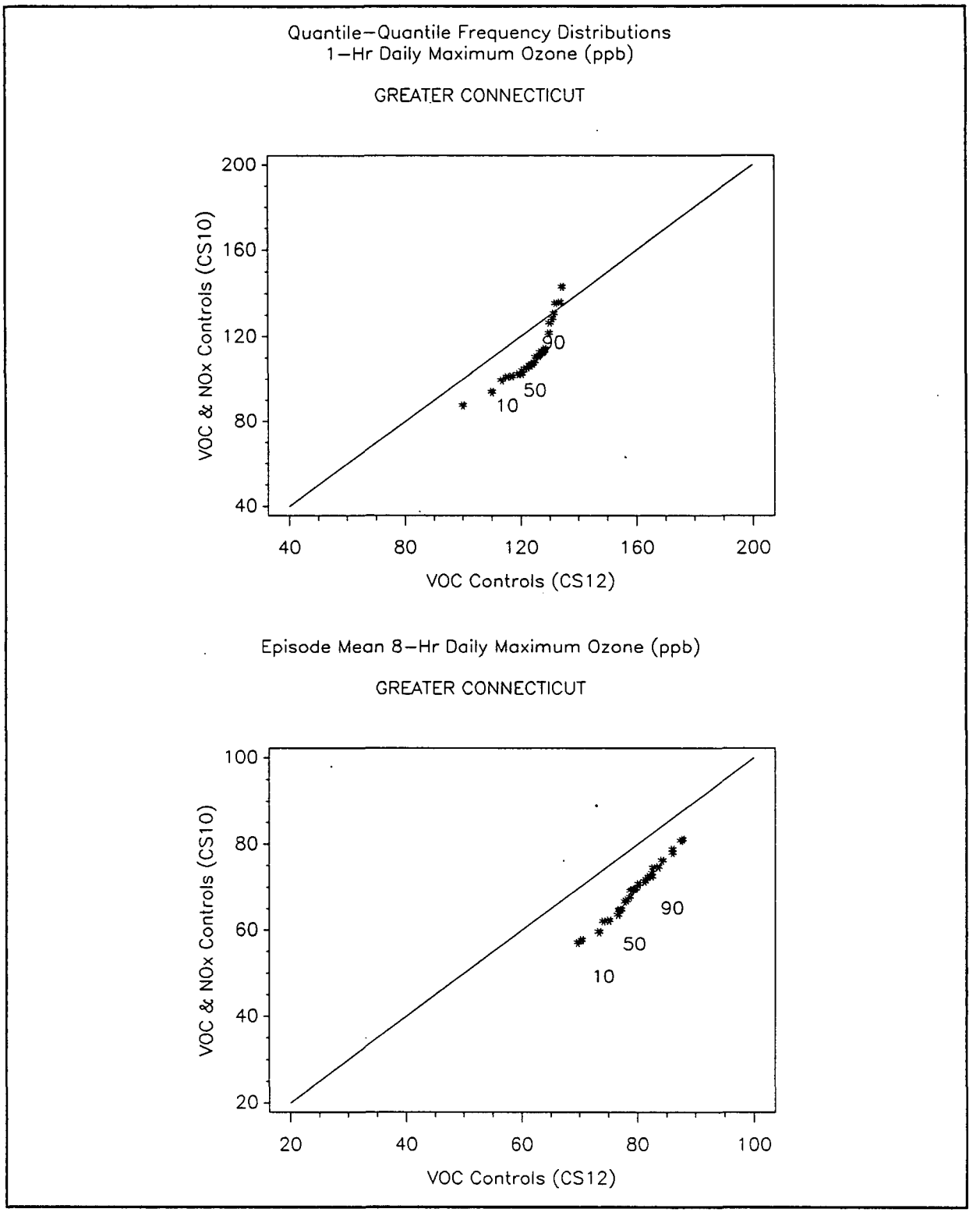


Figure 5-12. Quantile-quantile frequency distributions of 1-hour daily maximum ozone and episode mean 8-hour daily maximum ozone for Greater Connecticut.

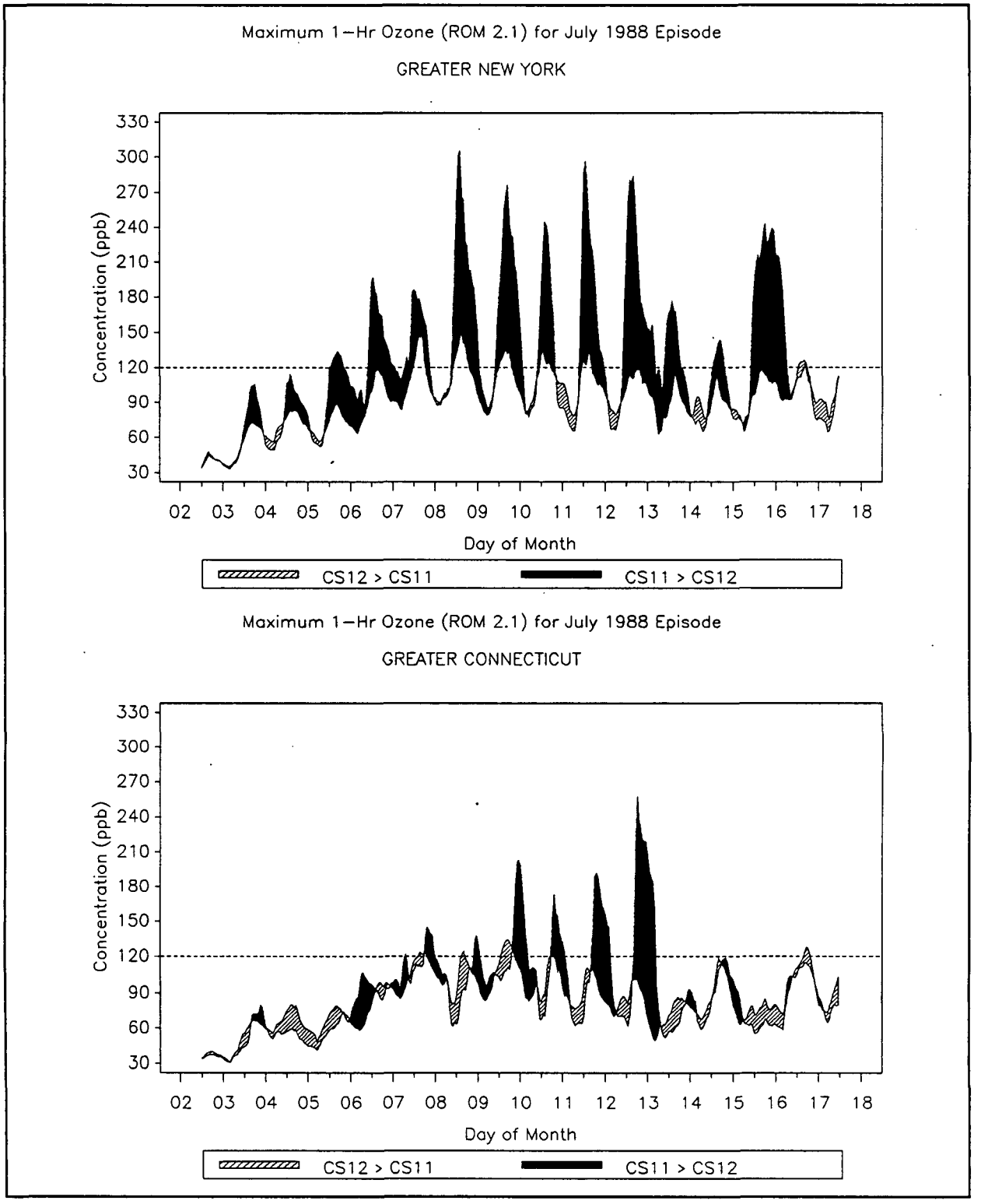


Figure 5-13. Diurnal time series of maximum hourly ozone concentrations in New York City and Greater Connecticut for CS11 and CS12.

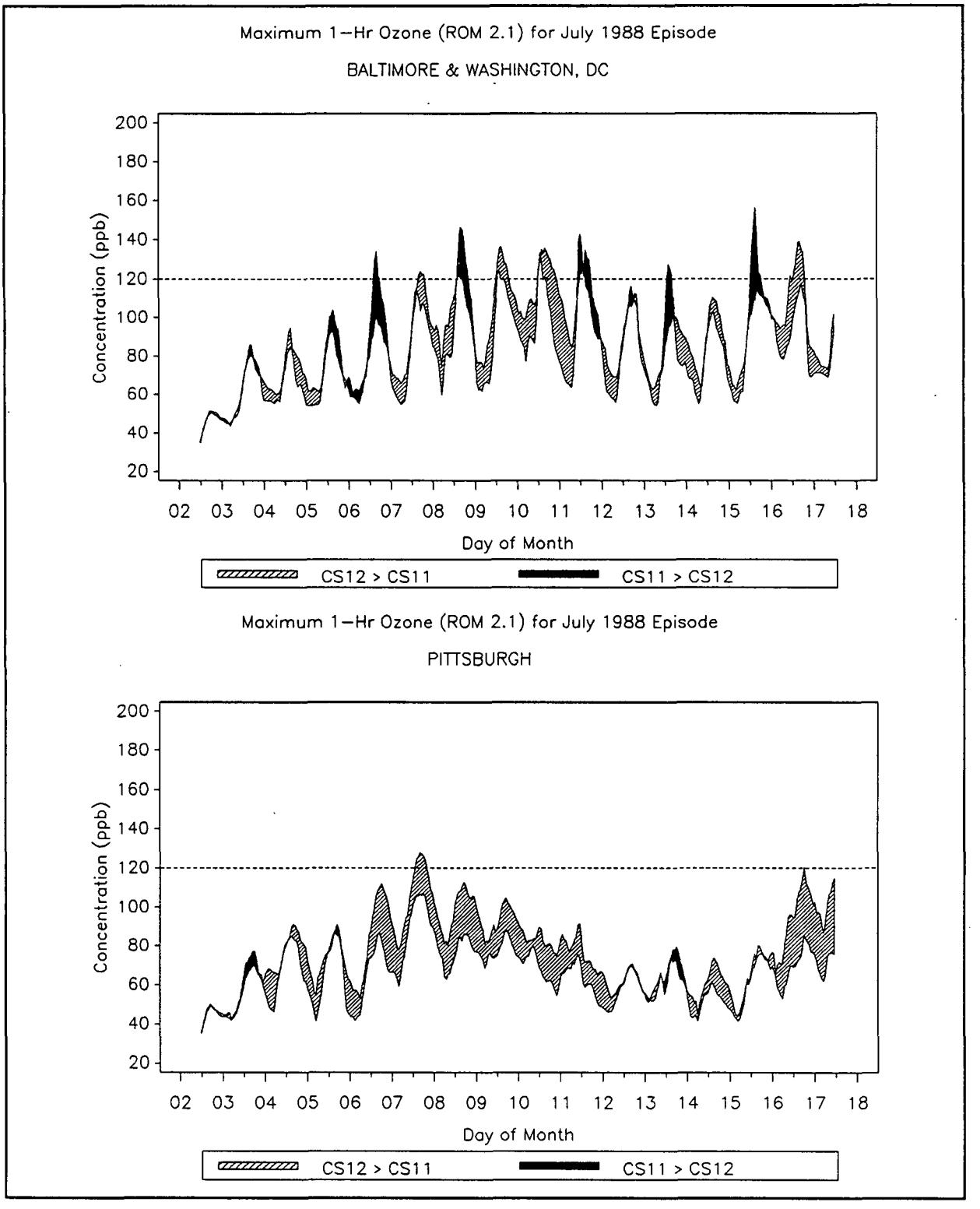


Figure 5-14. Diurnal time series of maximum hourly ozone concentrations in Baltimore/Washington, DC and vicinity and Pittsburgh and vicinity for CS11 and CS12.

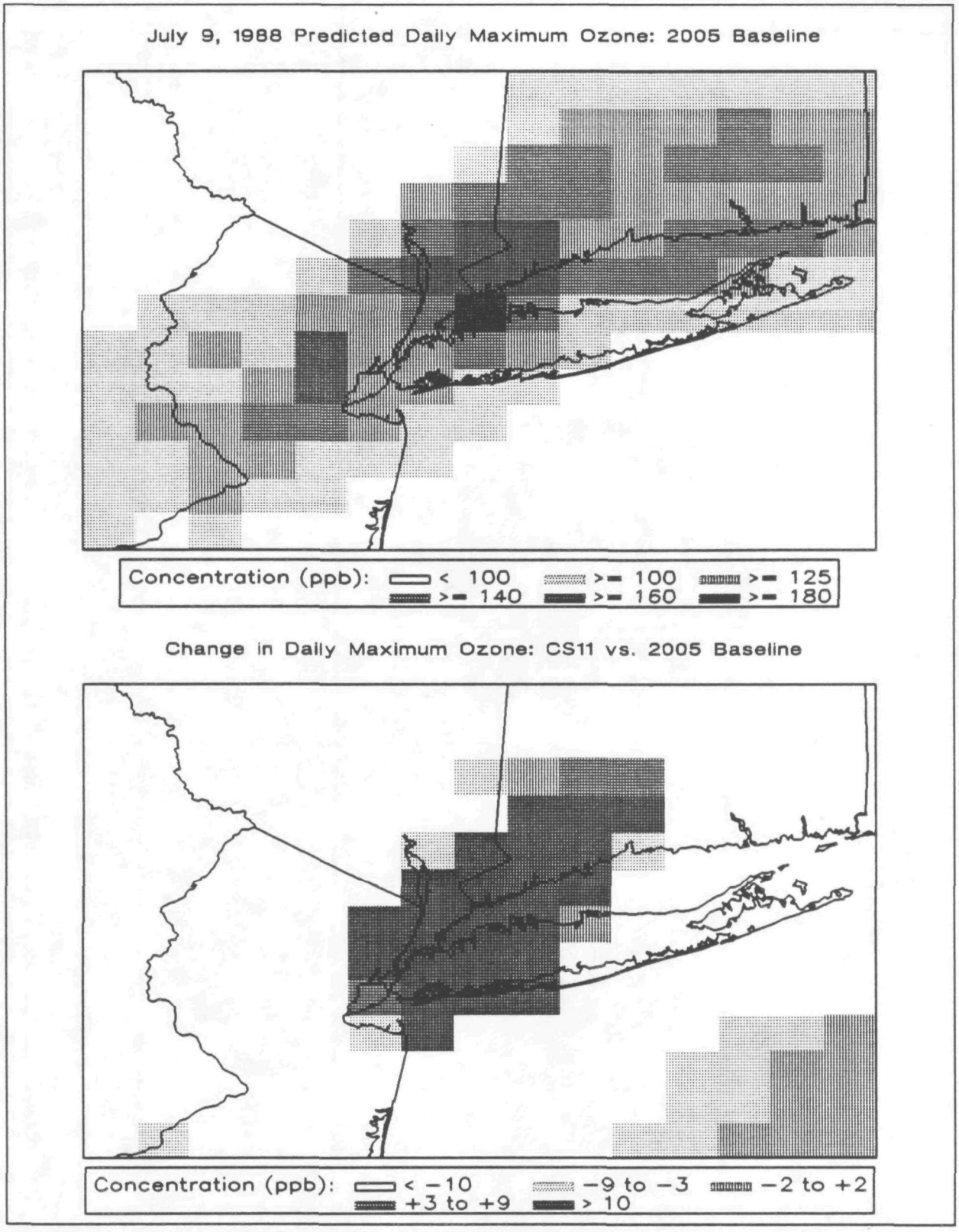


Figure 5-15. Predicted daily maximum ozone concentrations across the New York City area for July 9, 1988: 2005 baseline and the change in ozone following the application of NO_x controls in CS11.

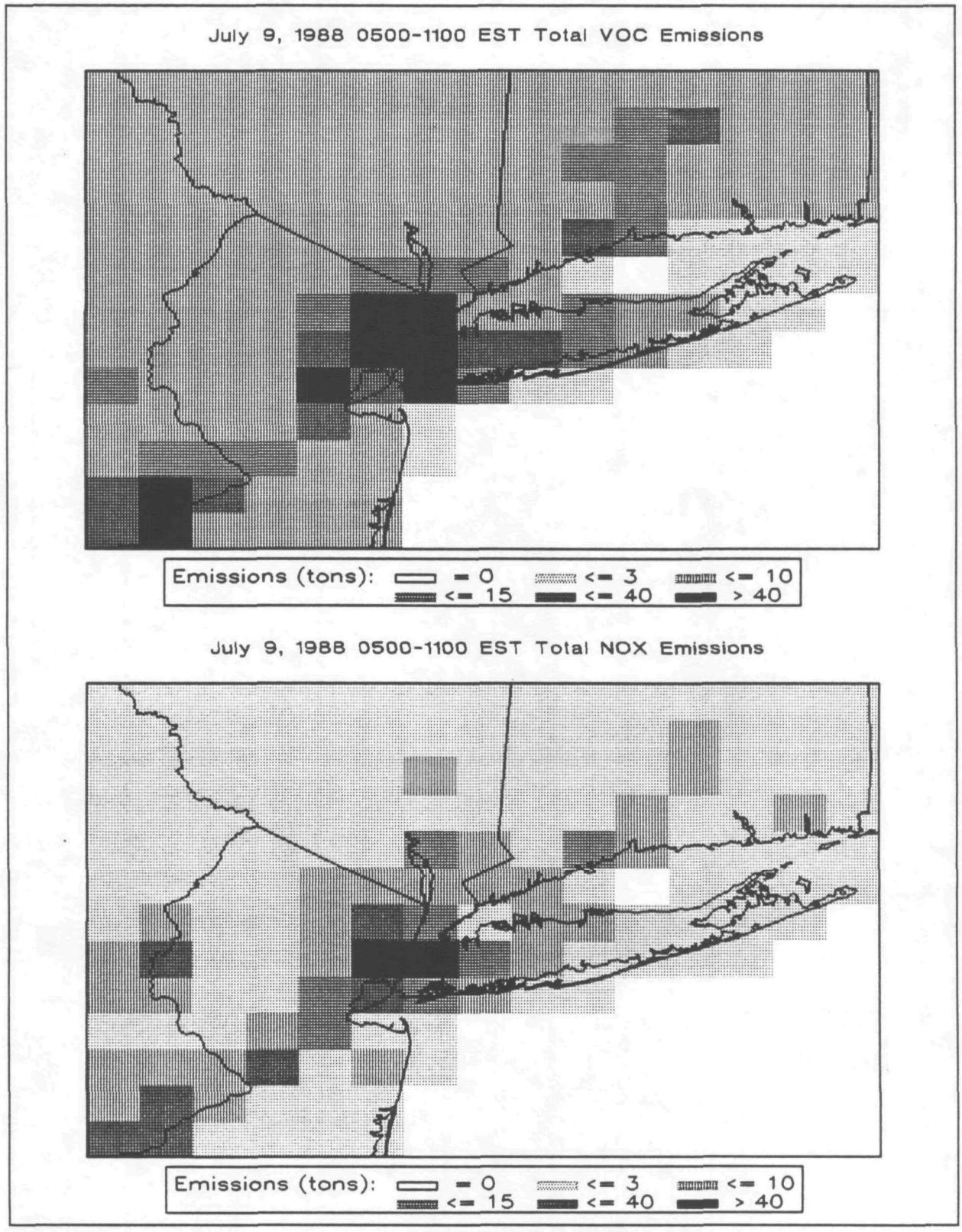


Figure 5-16. Morning (0500 - 1100 EST) total VOC emissions and NO_x emissions (tons) on July 9, 1988 in the vicinity of New York City.

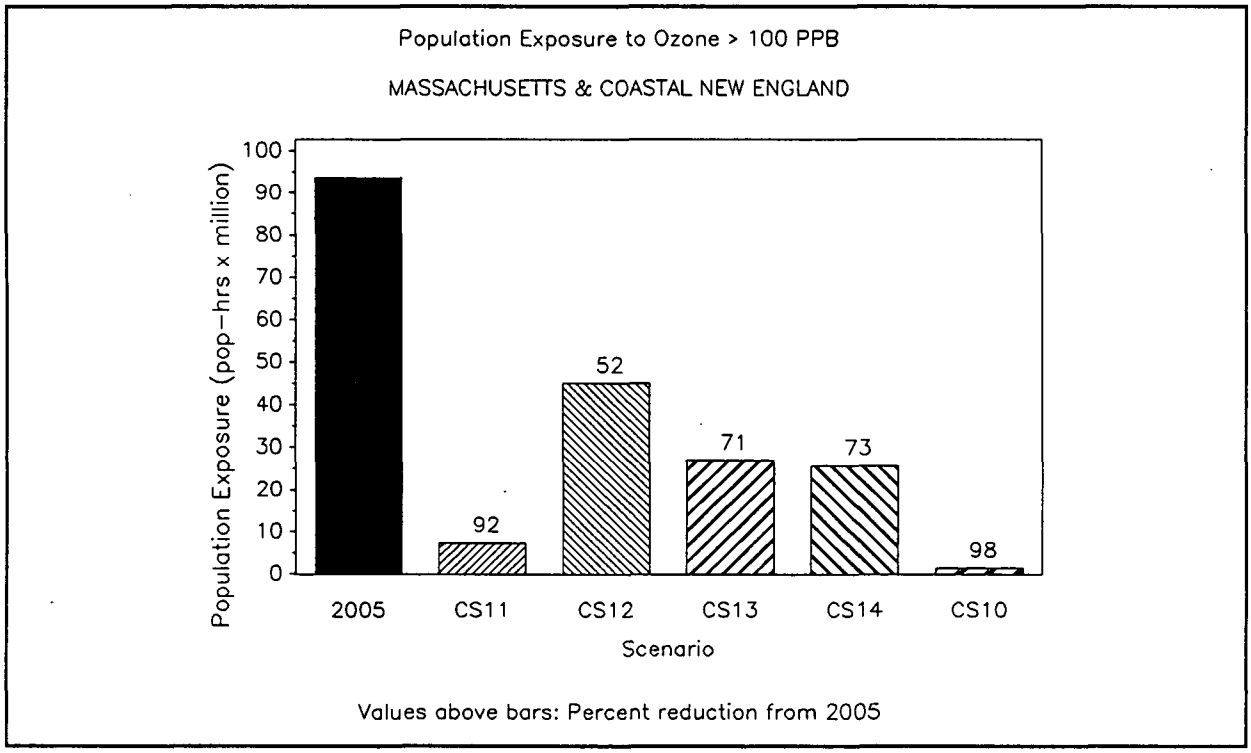


Figure 5-17. Population exposure to 1-hour ozone > 100 ppb in Massachusetts and coastal New England for selected scenarios.

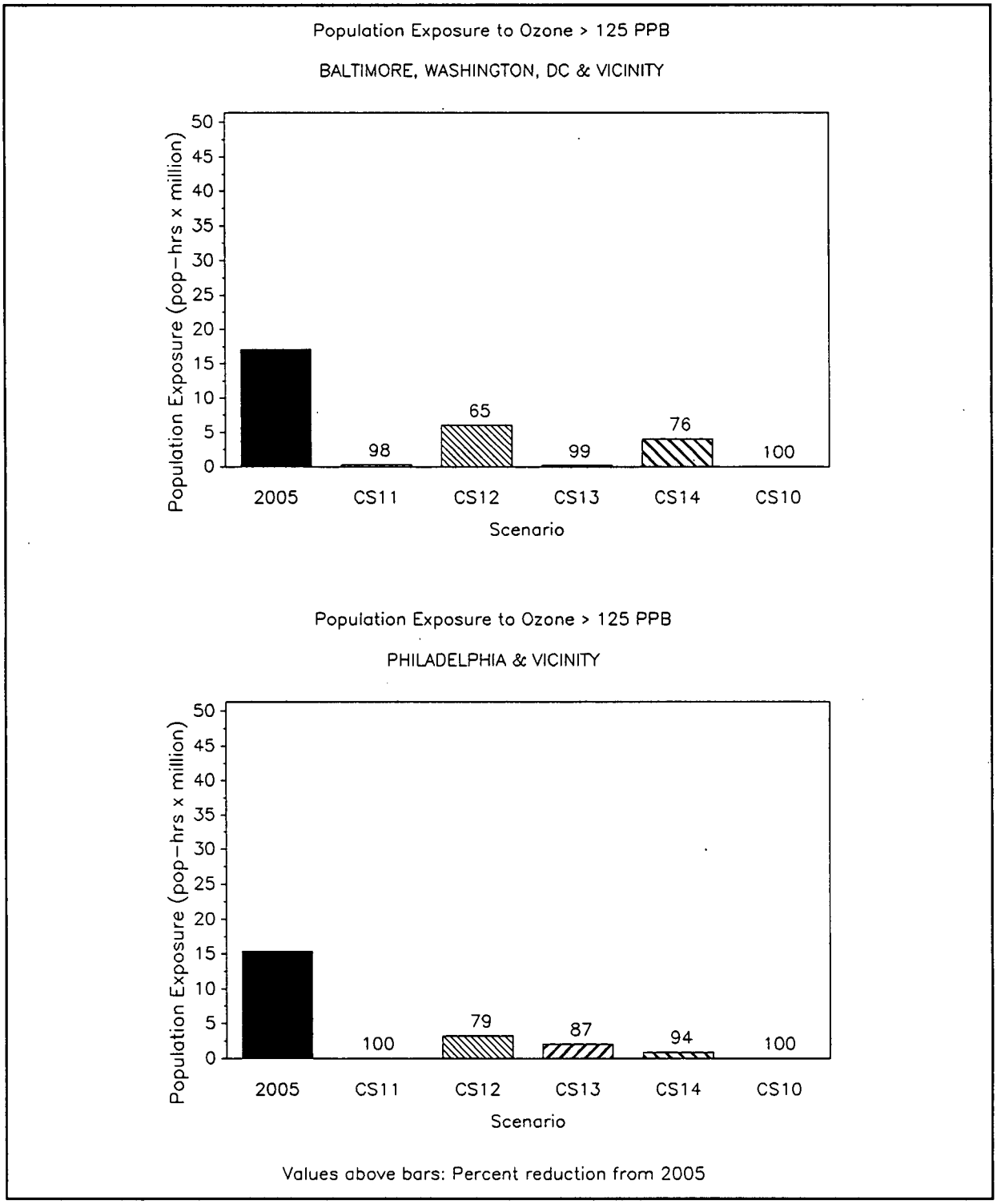


Figure 5-18. Population exposure to 1-hour ozone > 125 ppb in Baltimore/Washington, DC and Philadelphia for selected scenarios.

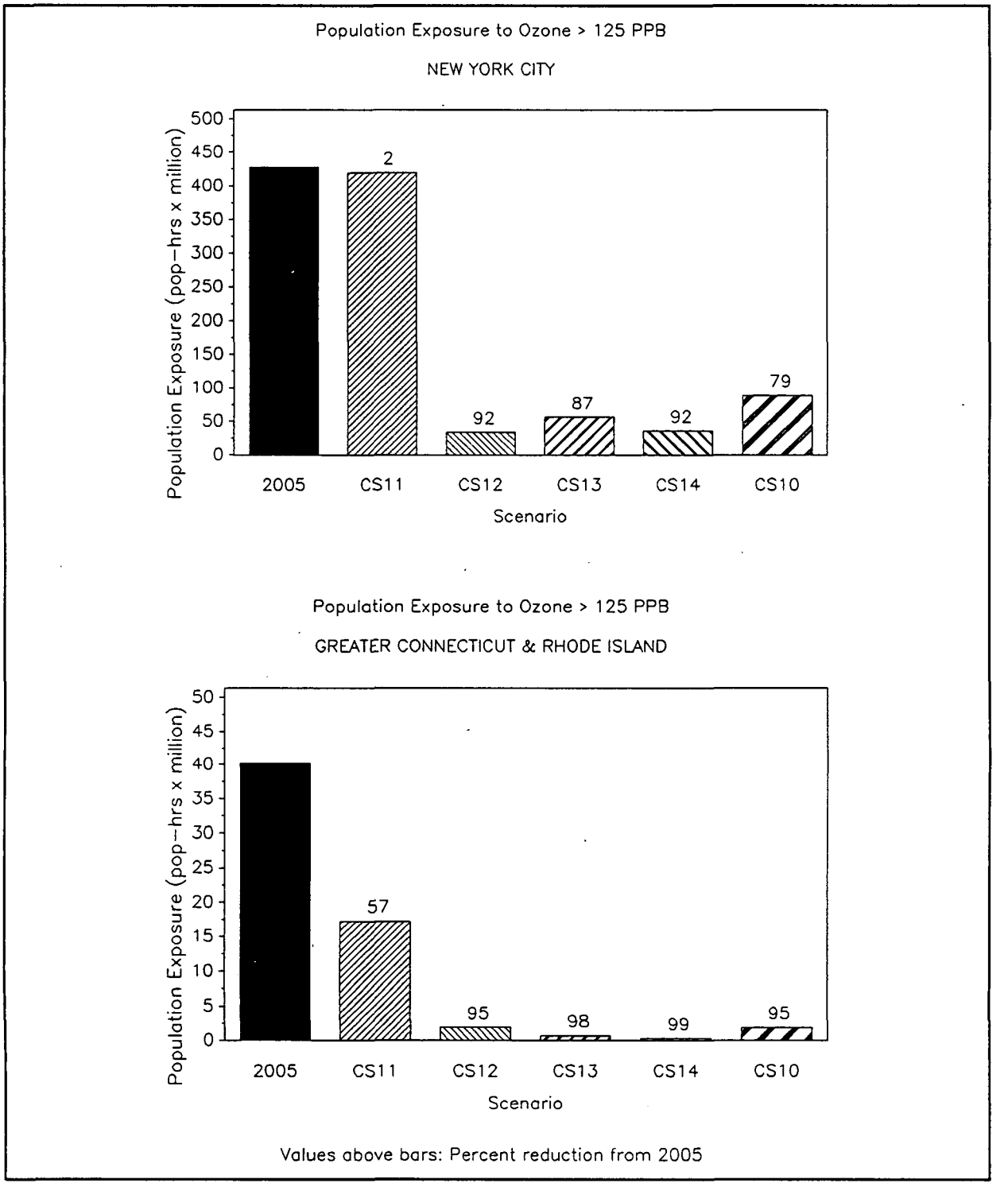


Figure 5-19. Population exposure to 1-hour ozone > 125 ppb in New York City and Greater Connecticut/Rhode Island for selected scenarios.

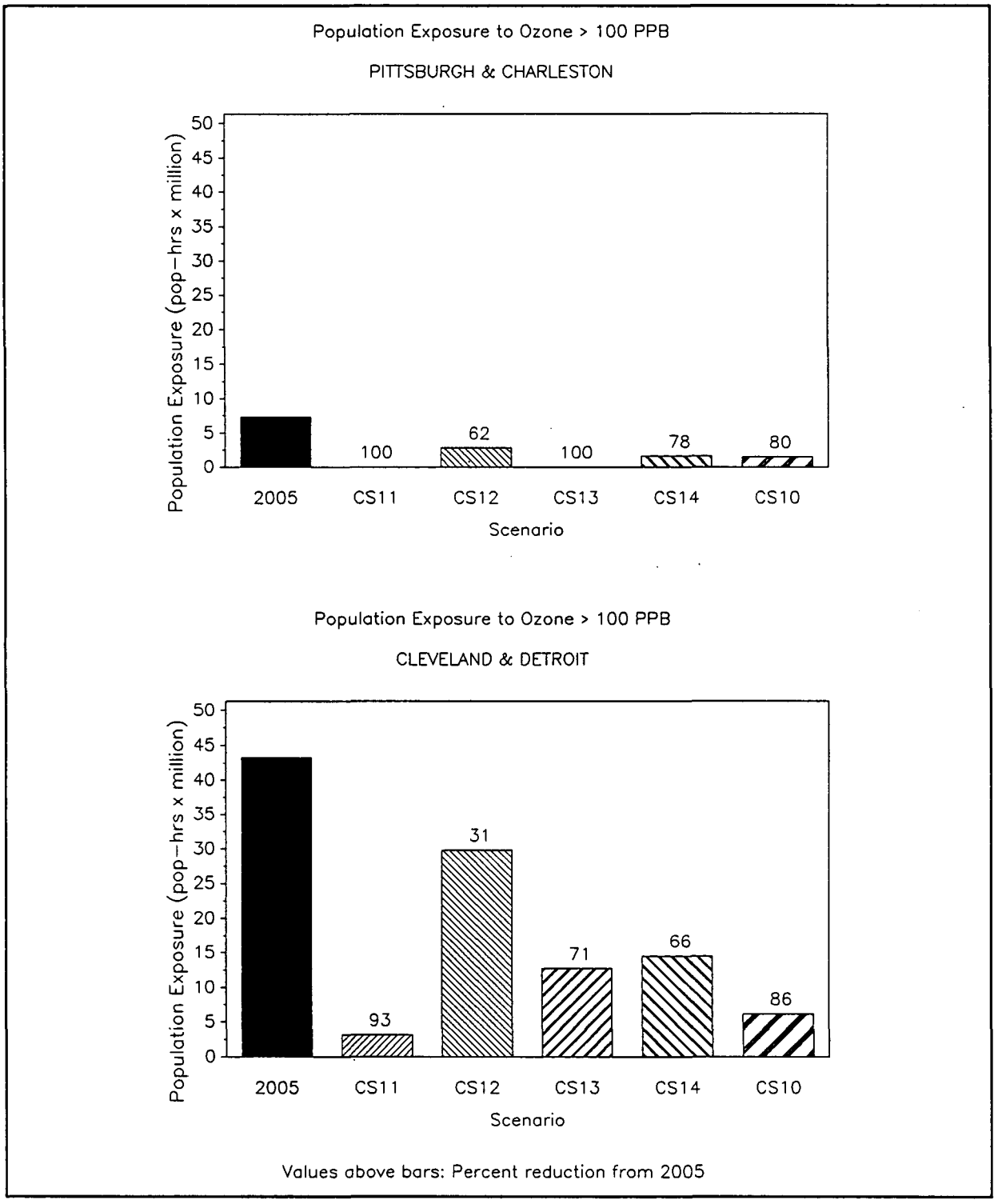


Figure 5-20. Population exposure to 1-hour ozone > 125 ppb in Cleveland and Detroit (combined) and Pittsburgh and Charleston, WV (combined) for selected scenarios.

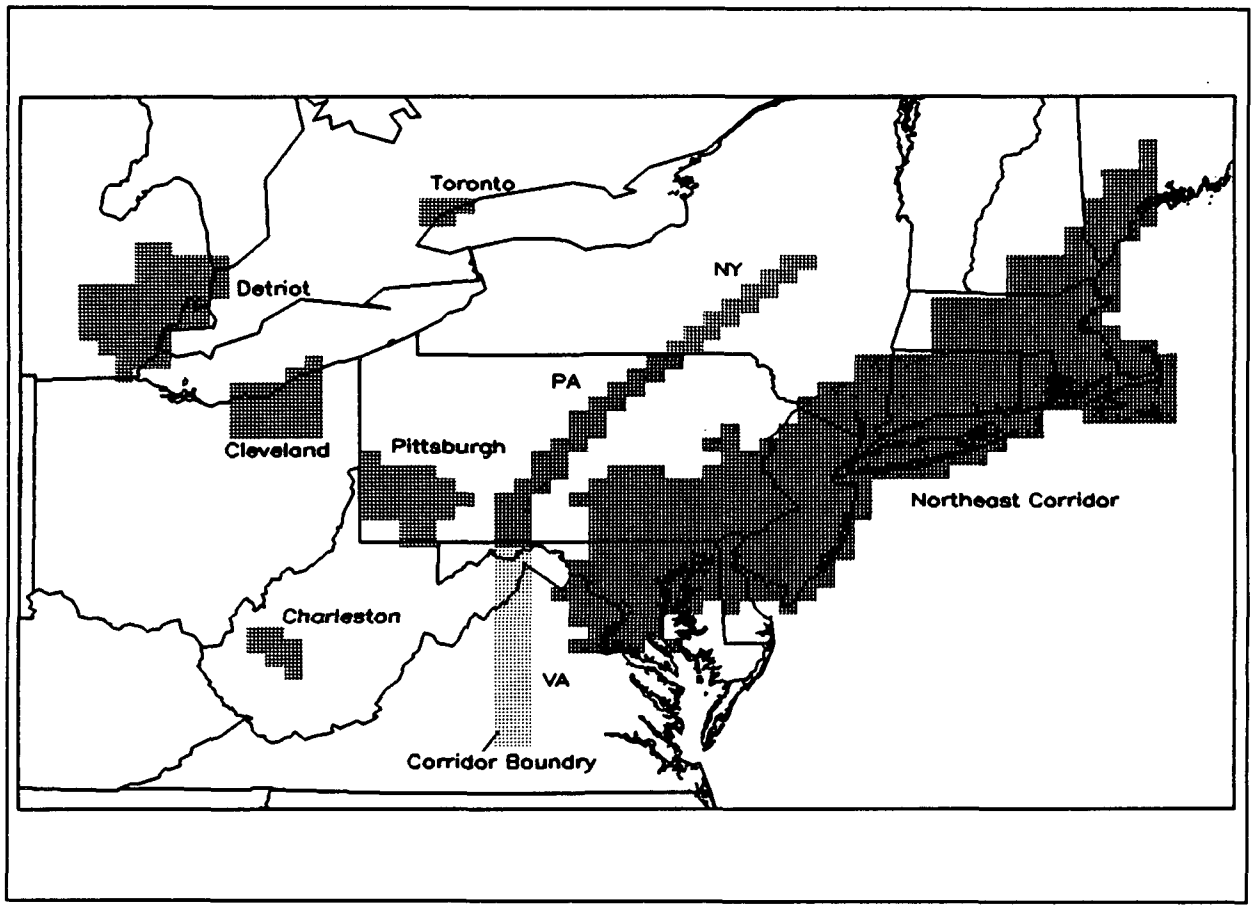


Figure 5-21. Location of the boundary to the Northeast Corridor used in quantifying incoming ozone transport.

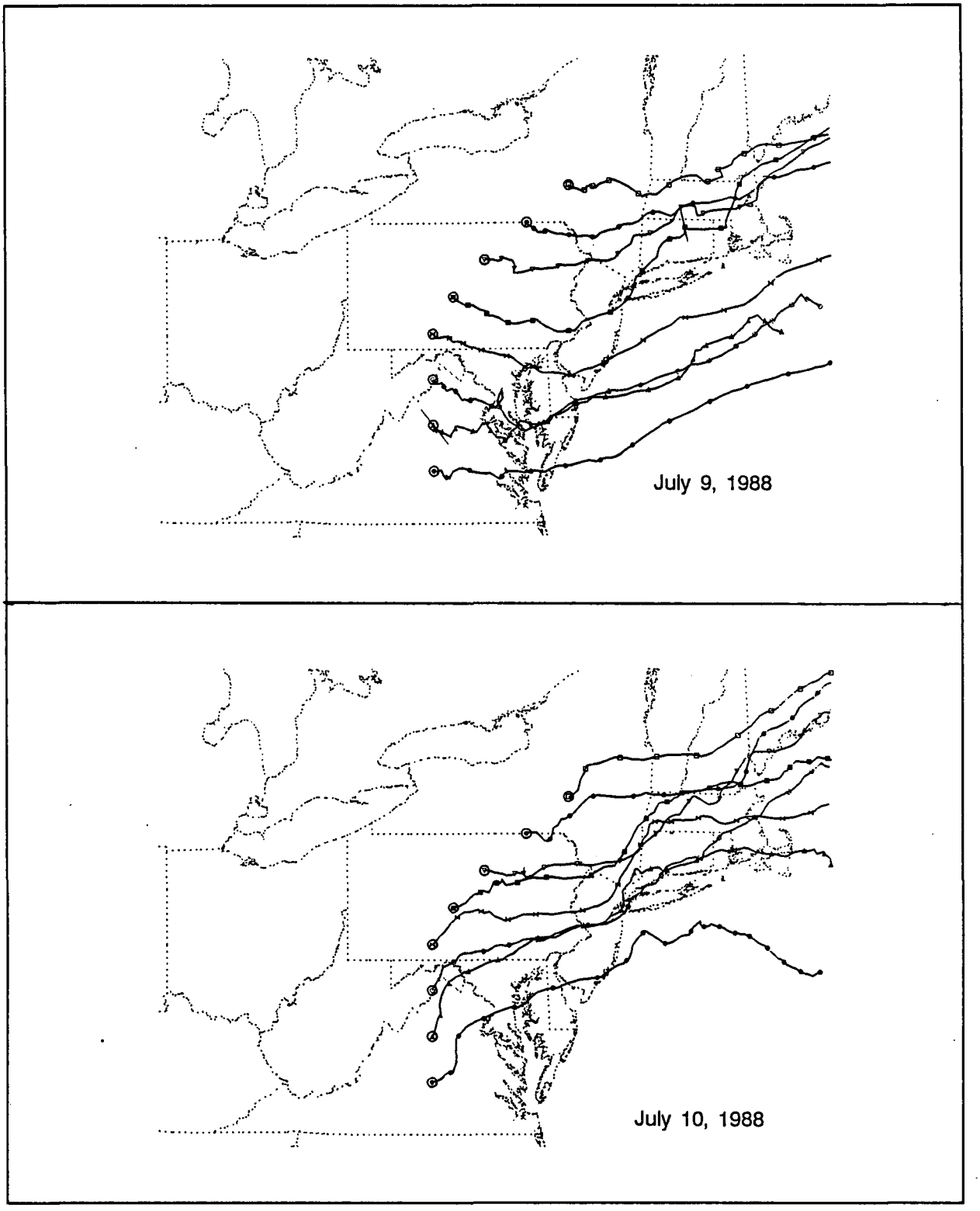


Figure 5-22. Layer 2 forward trajectories starting at 1500 EST from locations along the boundary to the Northeast Corridor for July 9, 1988 and July 10, 1988. Trajectory markers are at 4-h intervals.

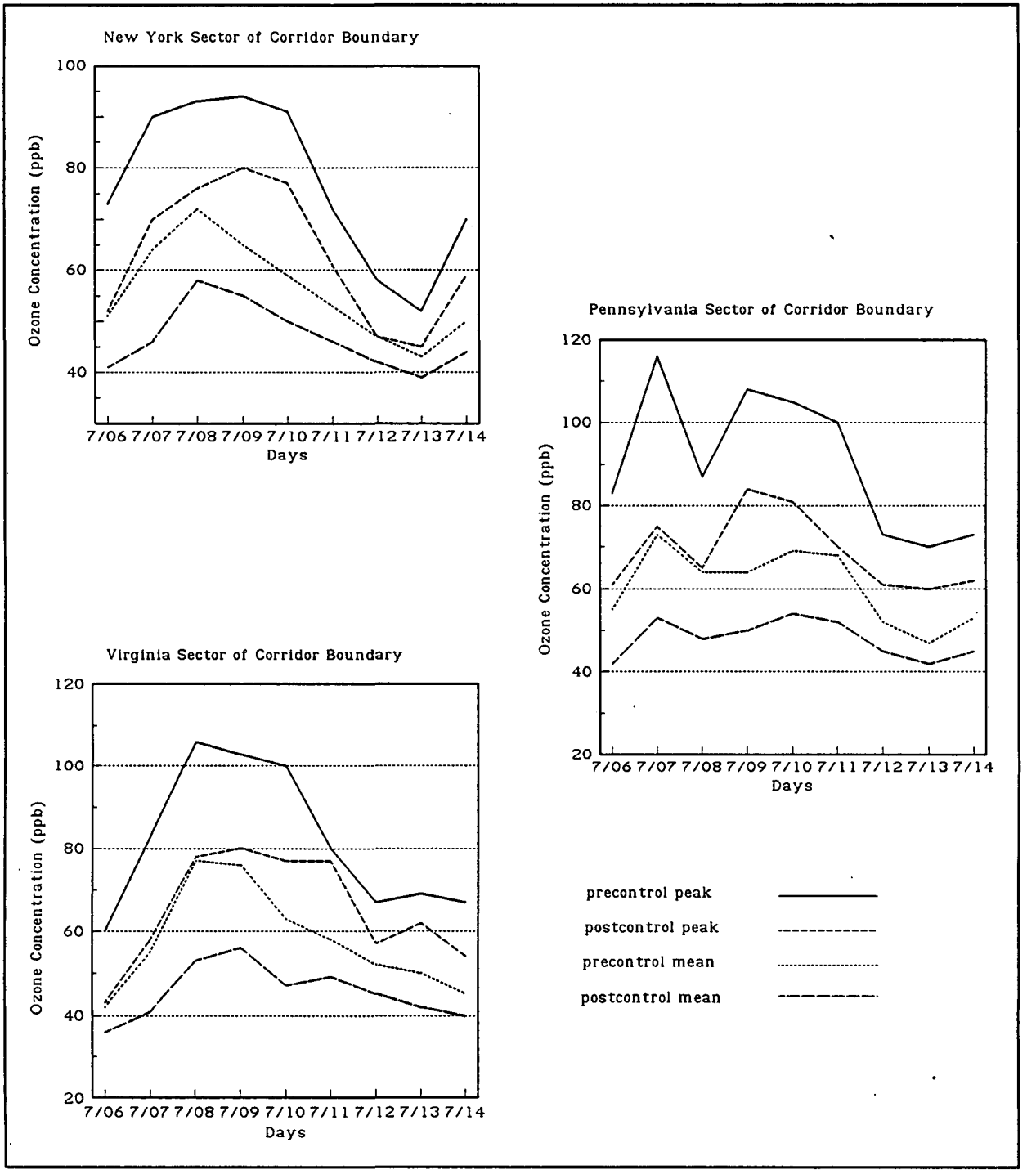


Figure 5-23. Peak and mean ozone concentrations by day within the three Northeast Corridor boundary segments.

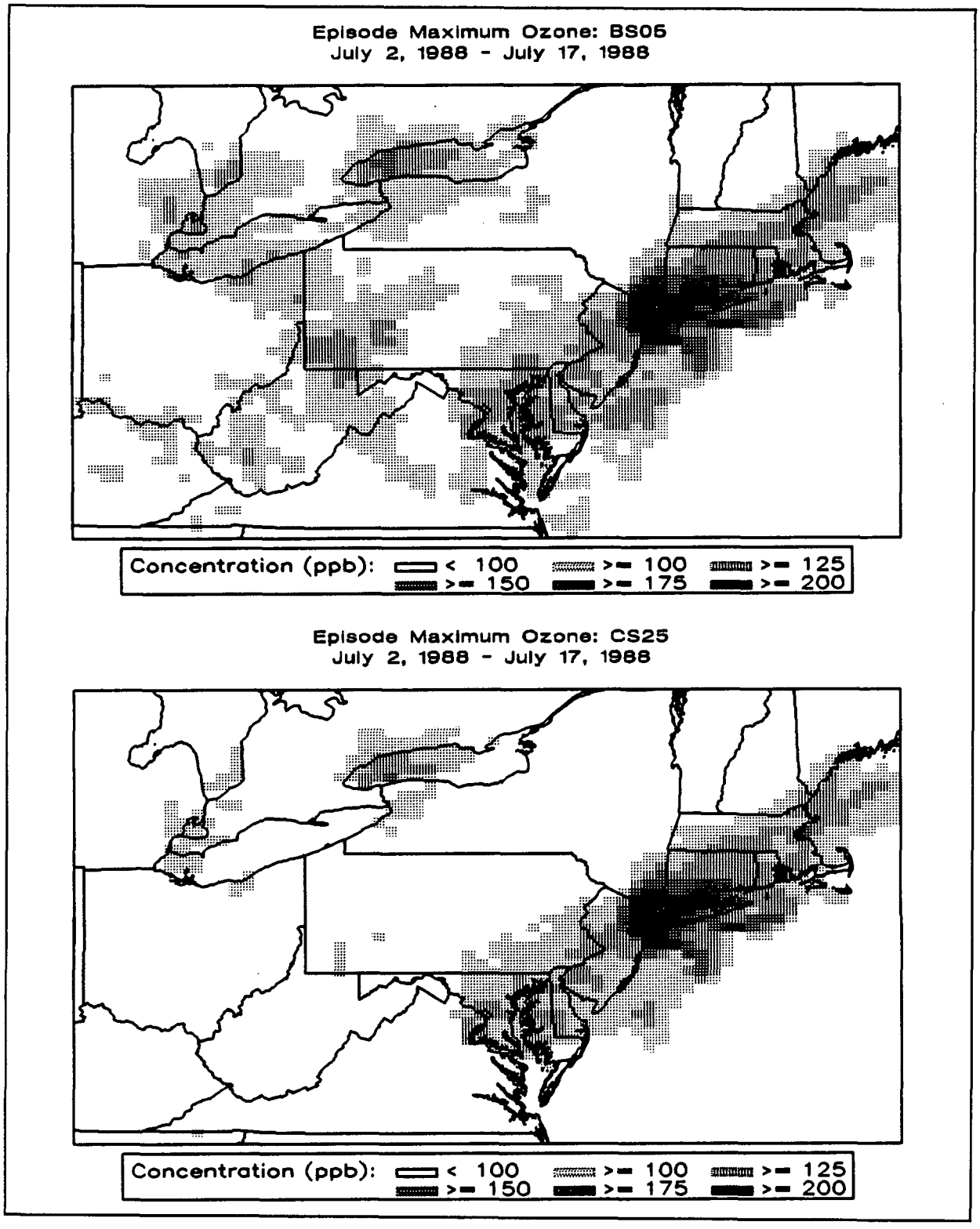


Figure 5-24. Predicted episode maximum 1-hour ozone concentrations for the July 1988 episode: 2005 baseline and CS25.

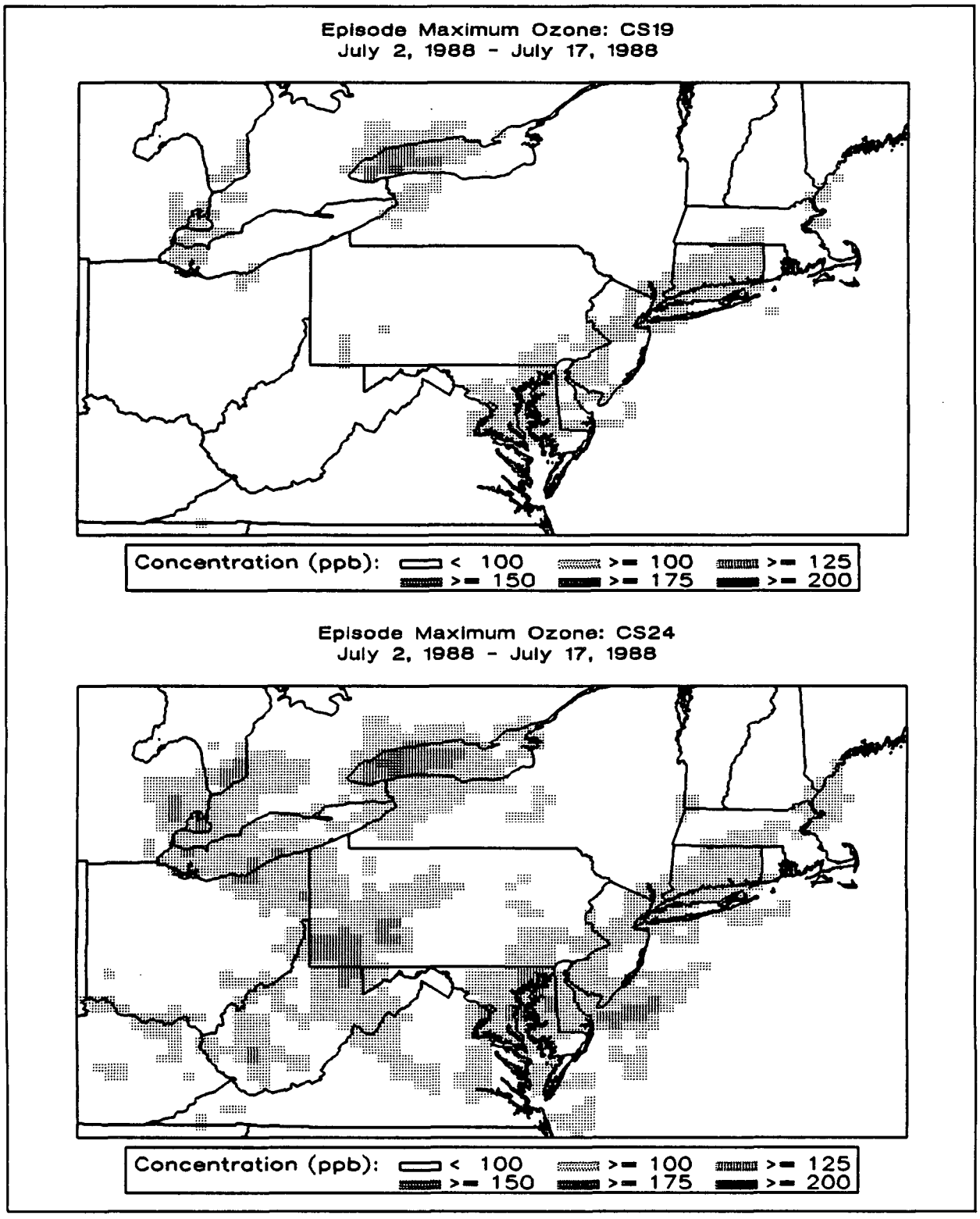


Figure 5-25. Predicted episode maximum 1-hour ozone concentrations for the July 1988 episode: CS19 and CS24.

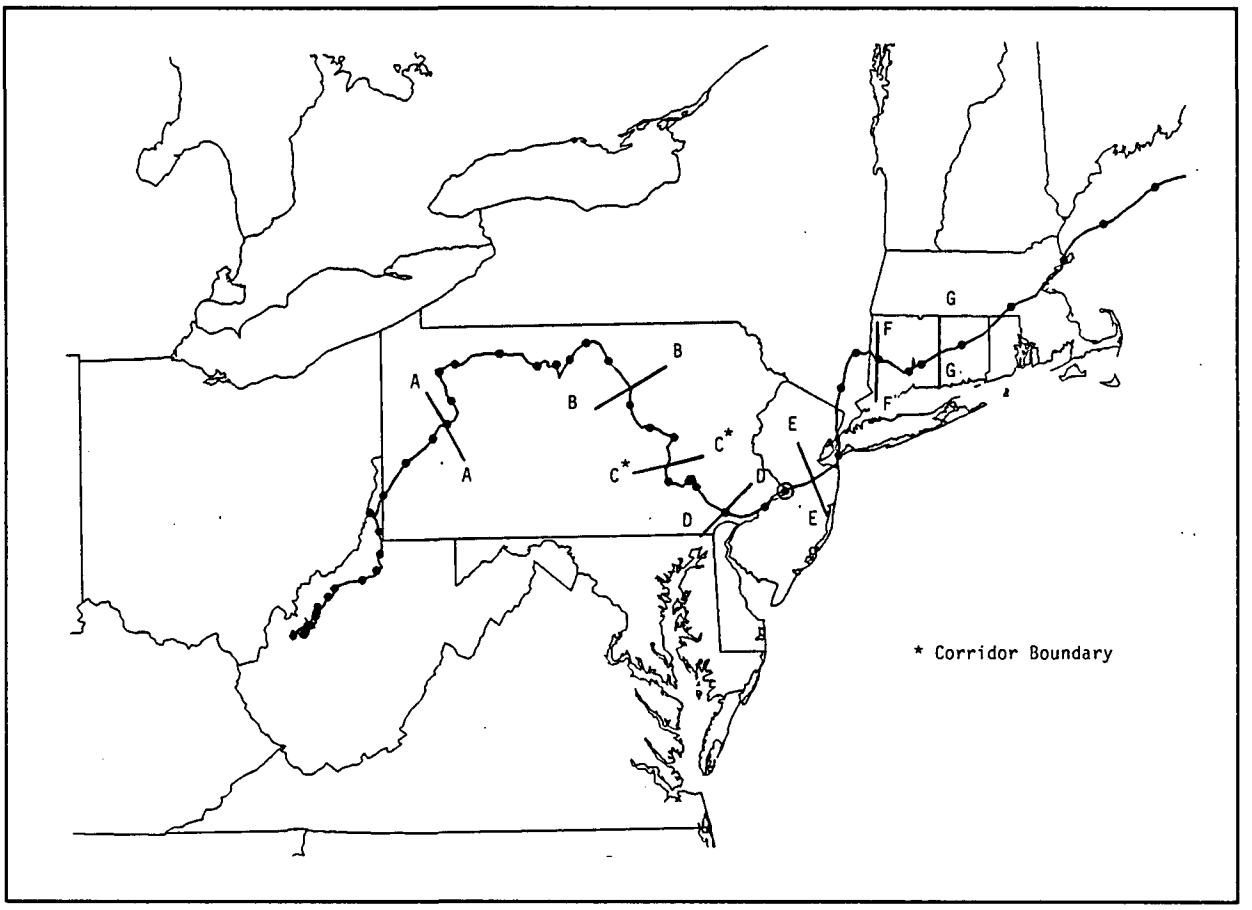


Figure 5-26. ROM layer 2 trajectory for the transport case study (trajectory markers are at 4-h intervals).

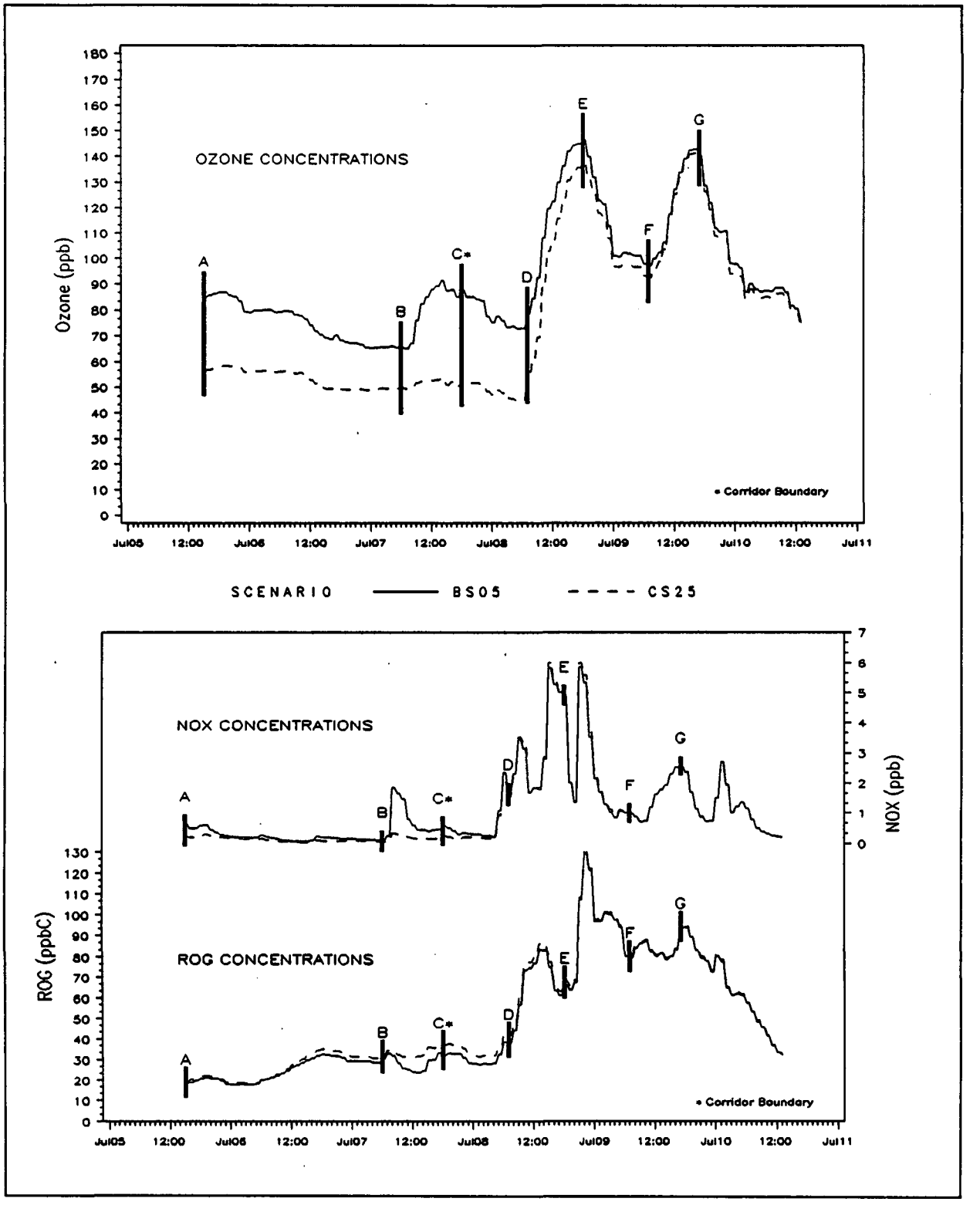


Figure 5-27. Time history of layer 2 ozone, NO_X, and ROG concentrations: 2005 baseline and CS25.

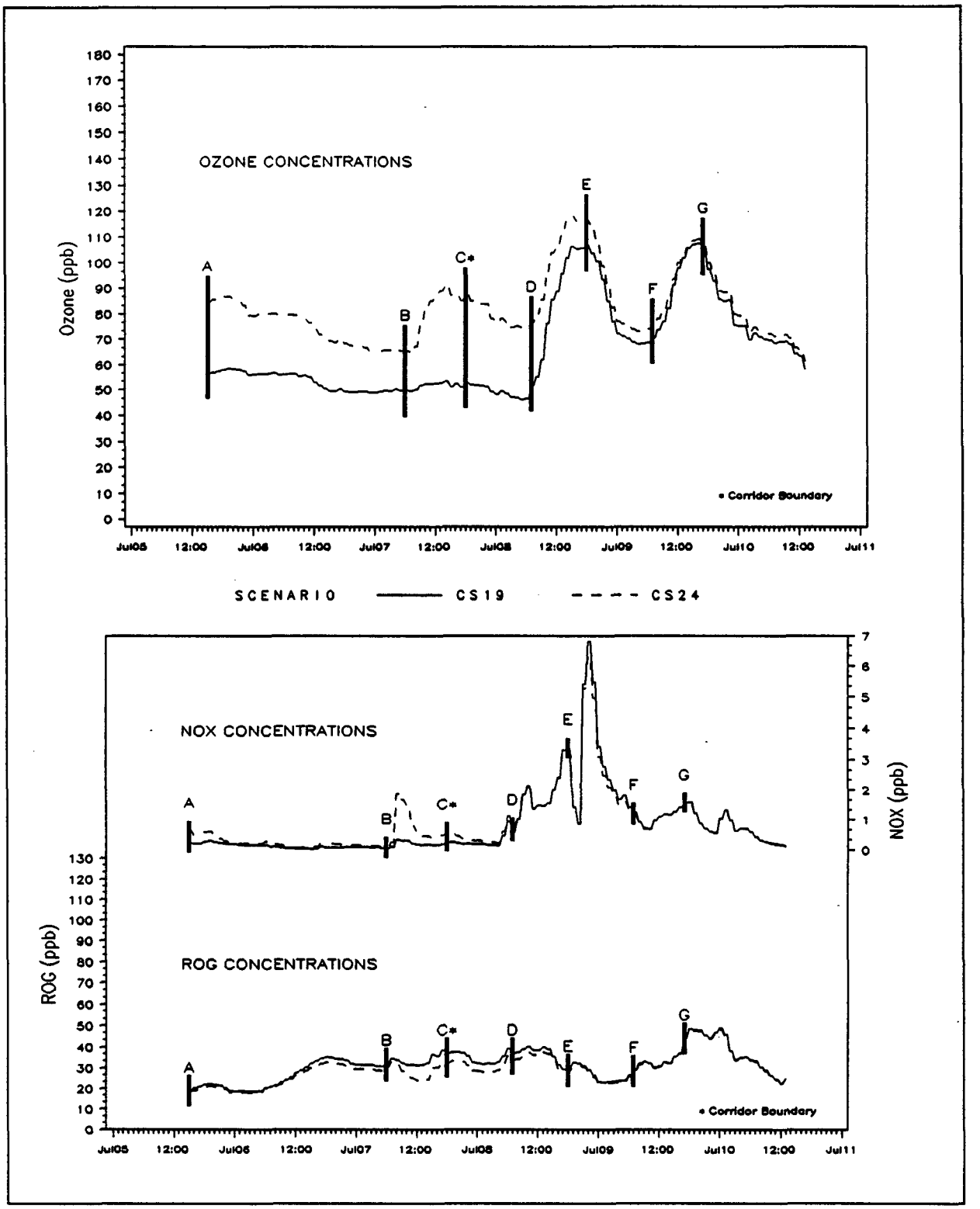


Figure 5-28. Time history of layer 2 ozone, NO_x, and ROG concentrations: CS19 and CS24.

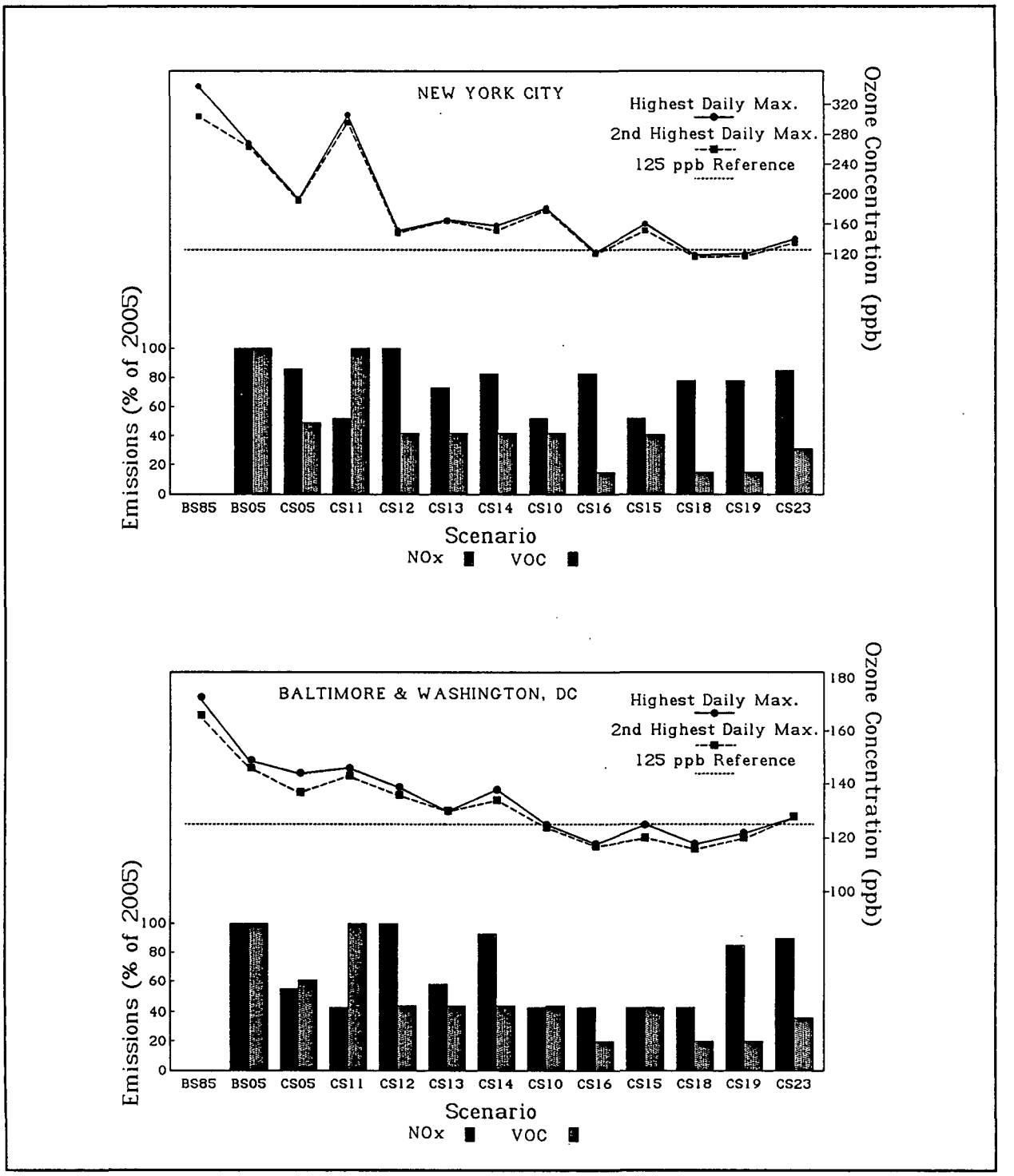
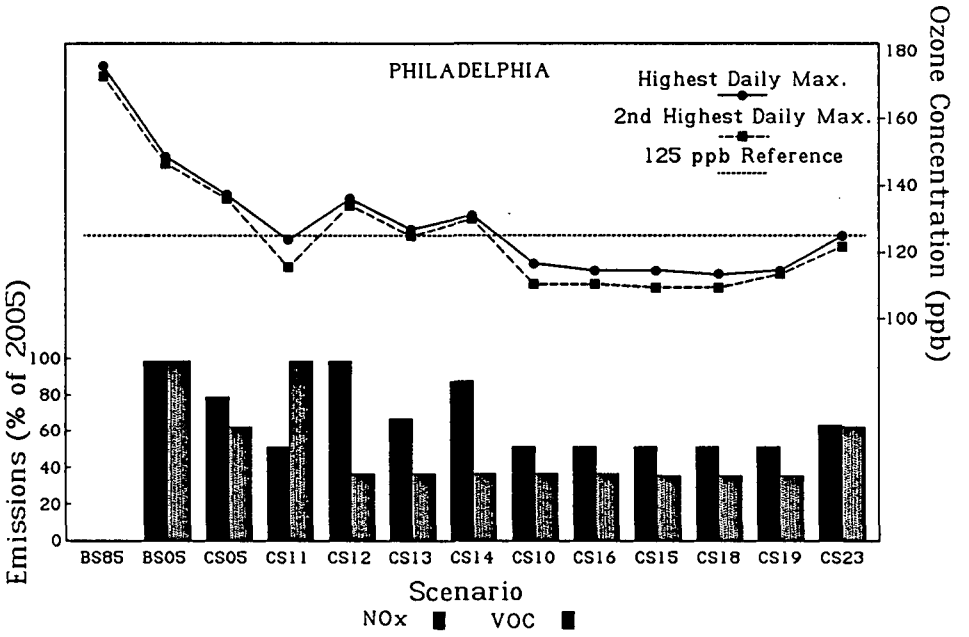


Figure 5-29. Emissions for Phase II scenarios, and predicted highest and second-highest daily maximum ozone concentrations (ppb) for selected urban areas. (Page 1 of 4)



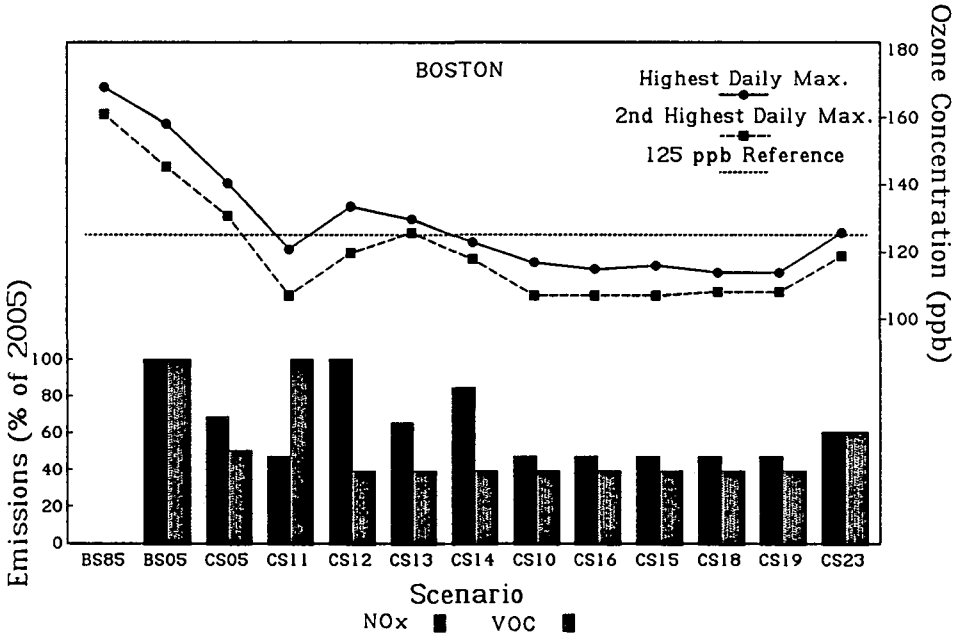


Figure 5-29 (page 2 of 4)

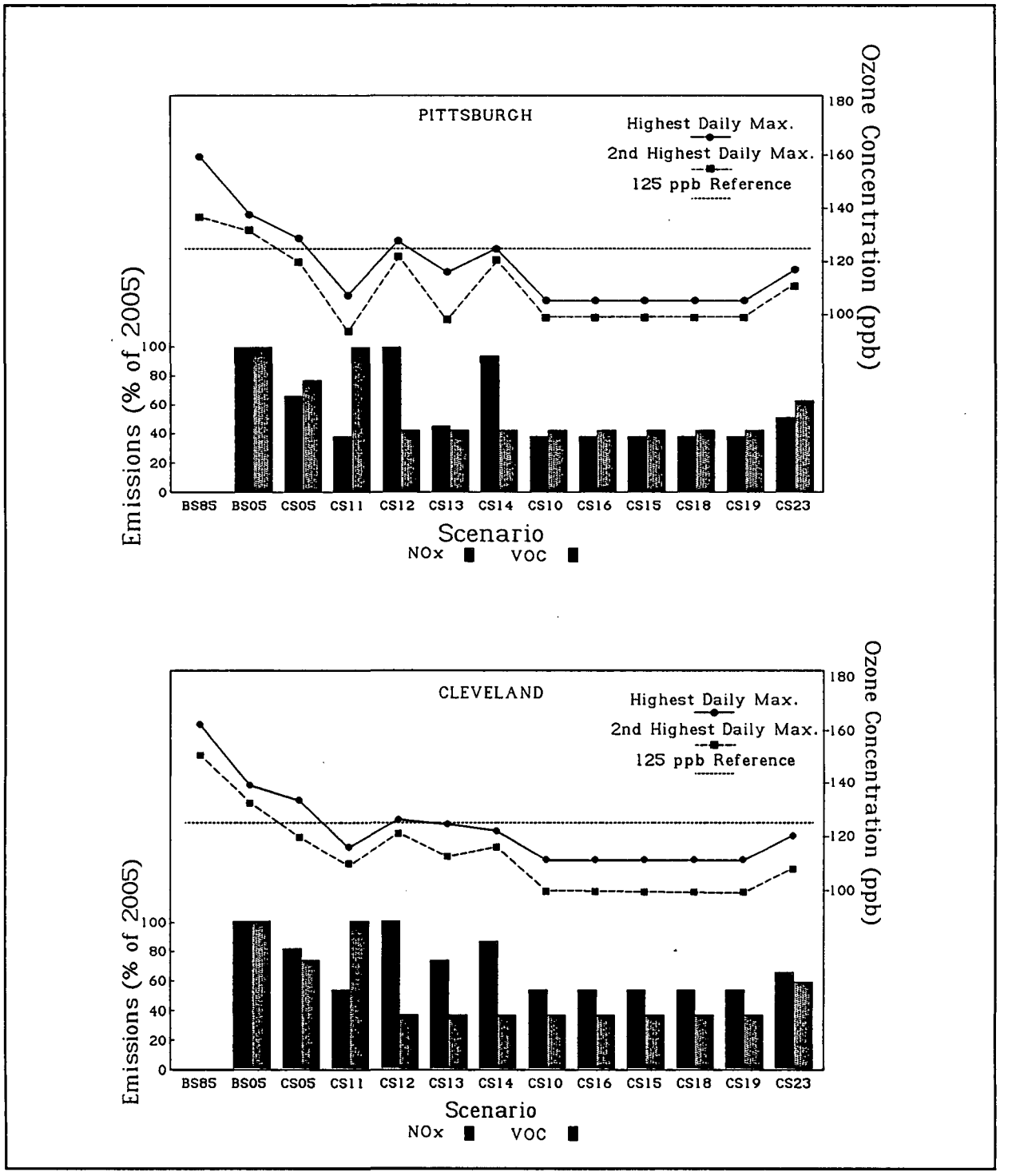
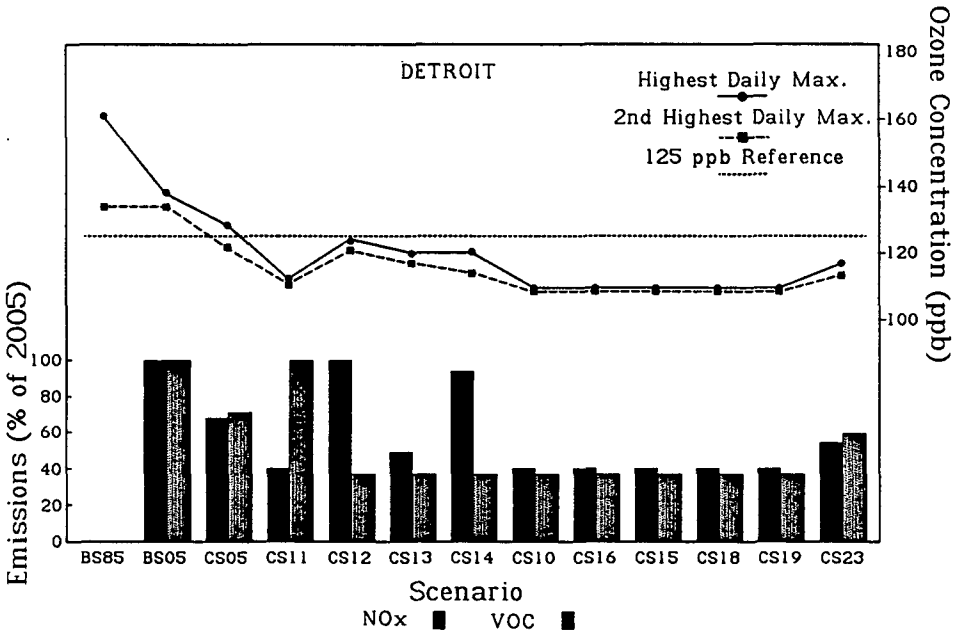


Figure 5-29 (page 3 of 4)



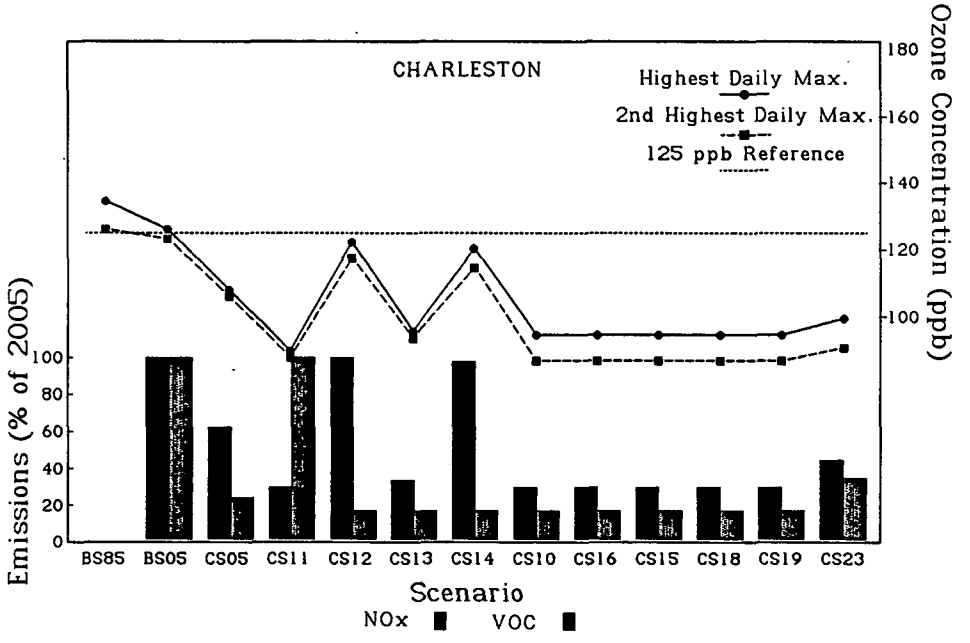


Figure 5-29 (page 4 of 4)

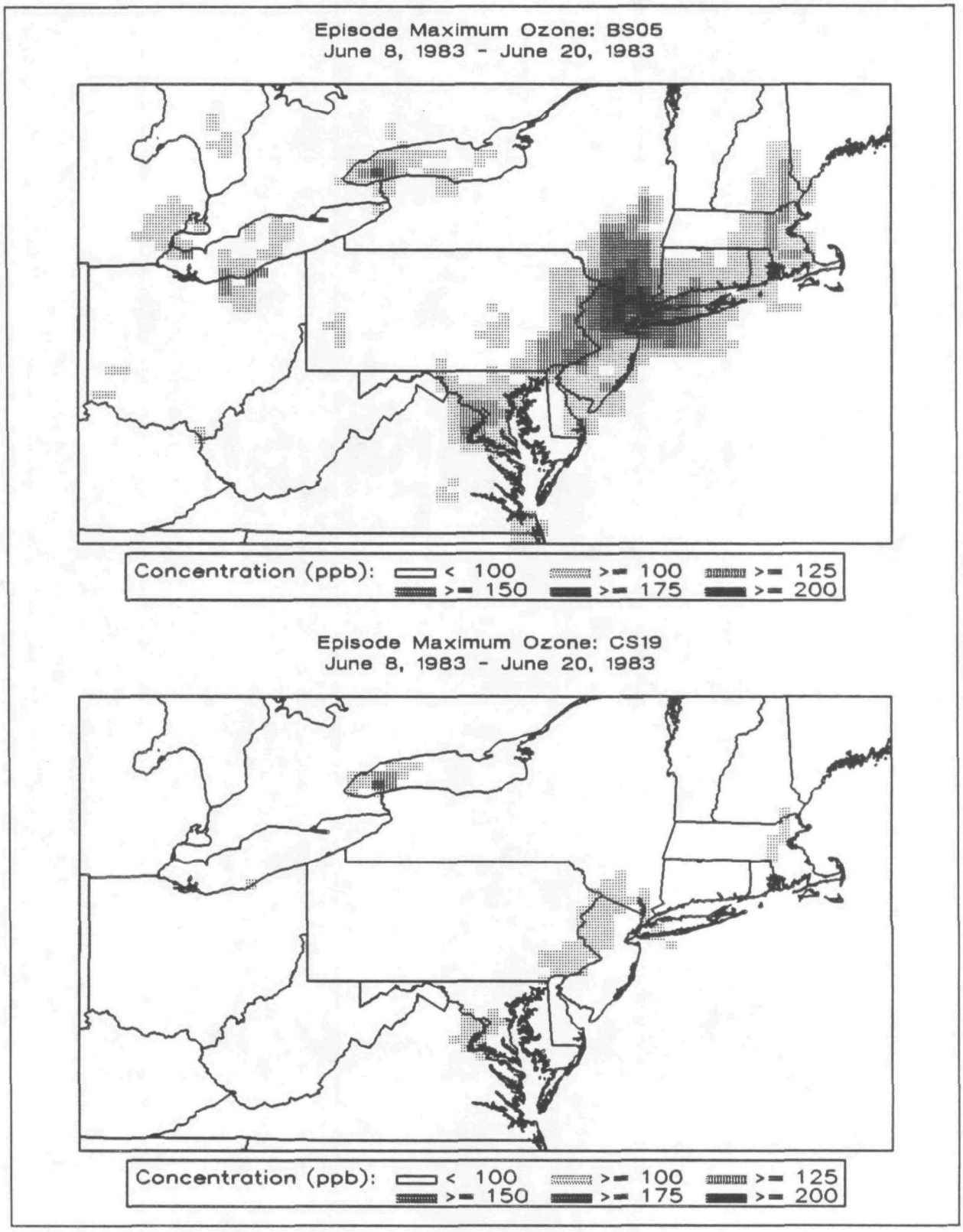


Figure 5-30. Predicted episode maximum 1-hour ozone concentrations (ppb) for the June 1983 episode: 2005 baseline and CS19.

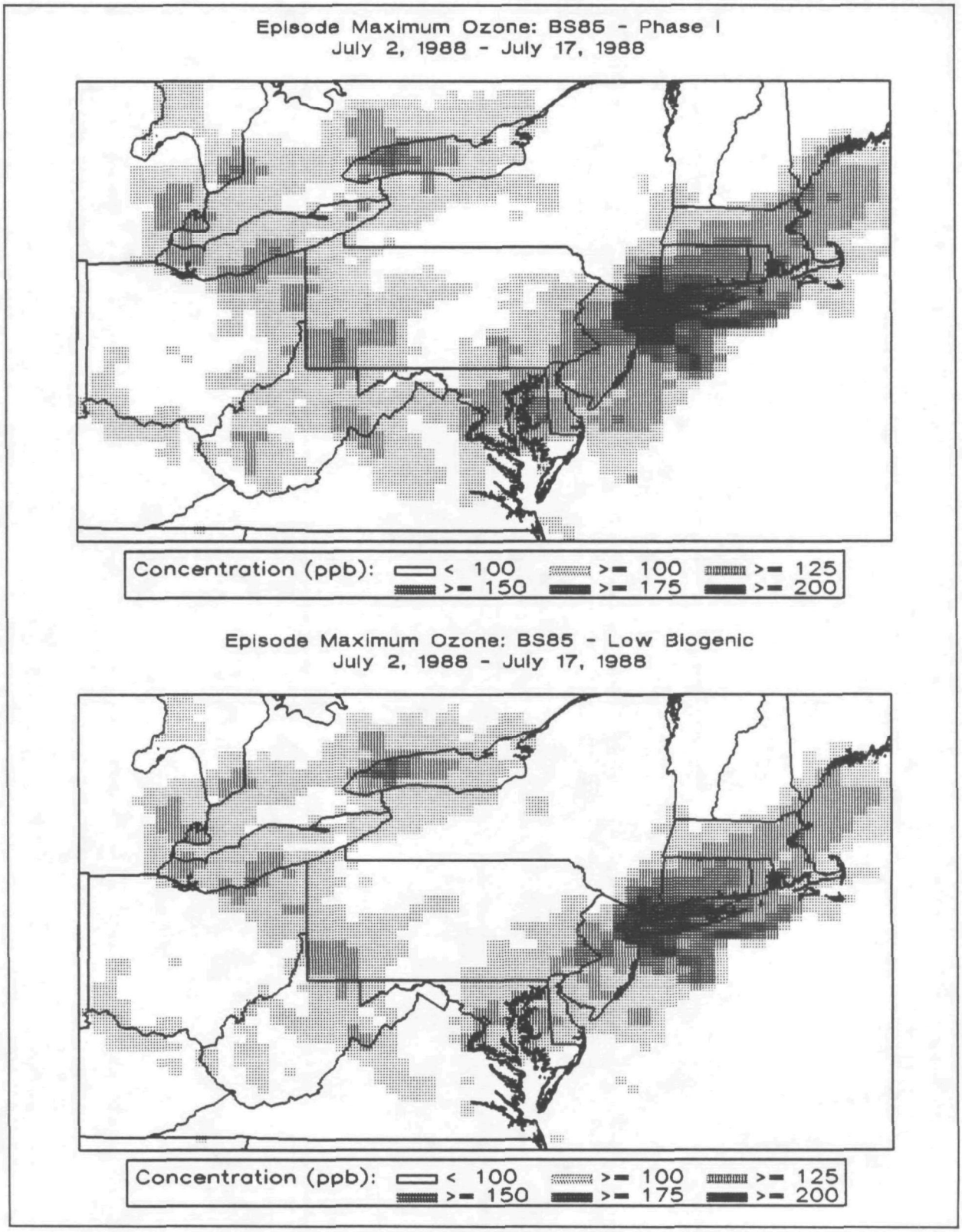


Figure 5-31. Predicted episode maximum 1-hour ozone concentrations (ppb) for the July 1988 episode: Phase I 1985 base case with "best estimate" biogenics and 1985 base case with "low" biogenics.

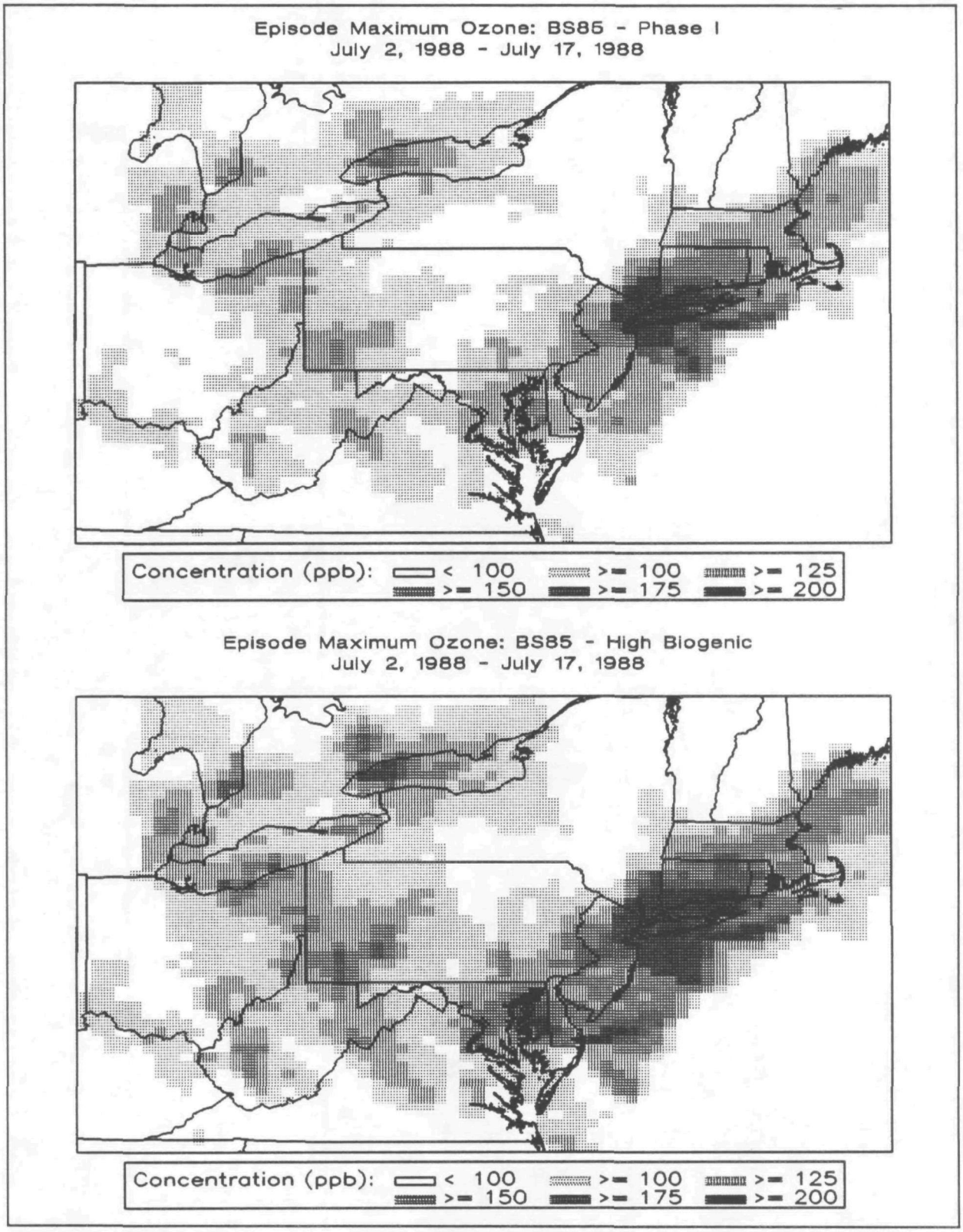


Figure 5-32. Predicted episode maximum 1-hour ozone concentrations (ppb) for the July 1988 episode: Phase I 1985 base case with "best estimate" biogenics and 1985 base case with "high" biogenics.

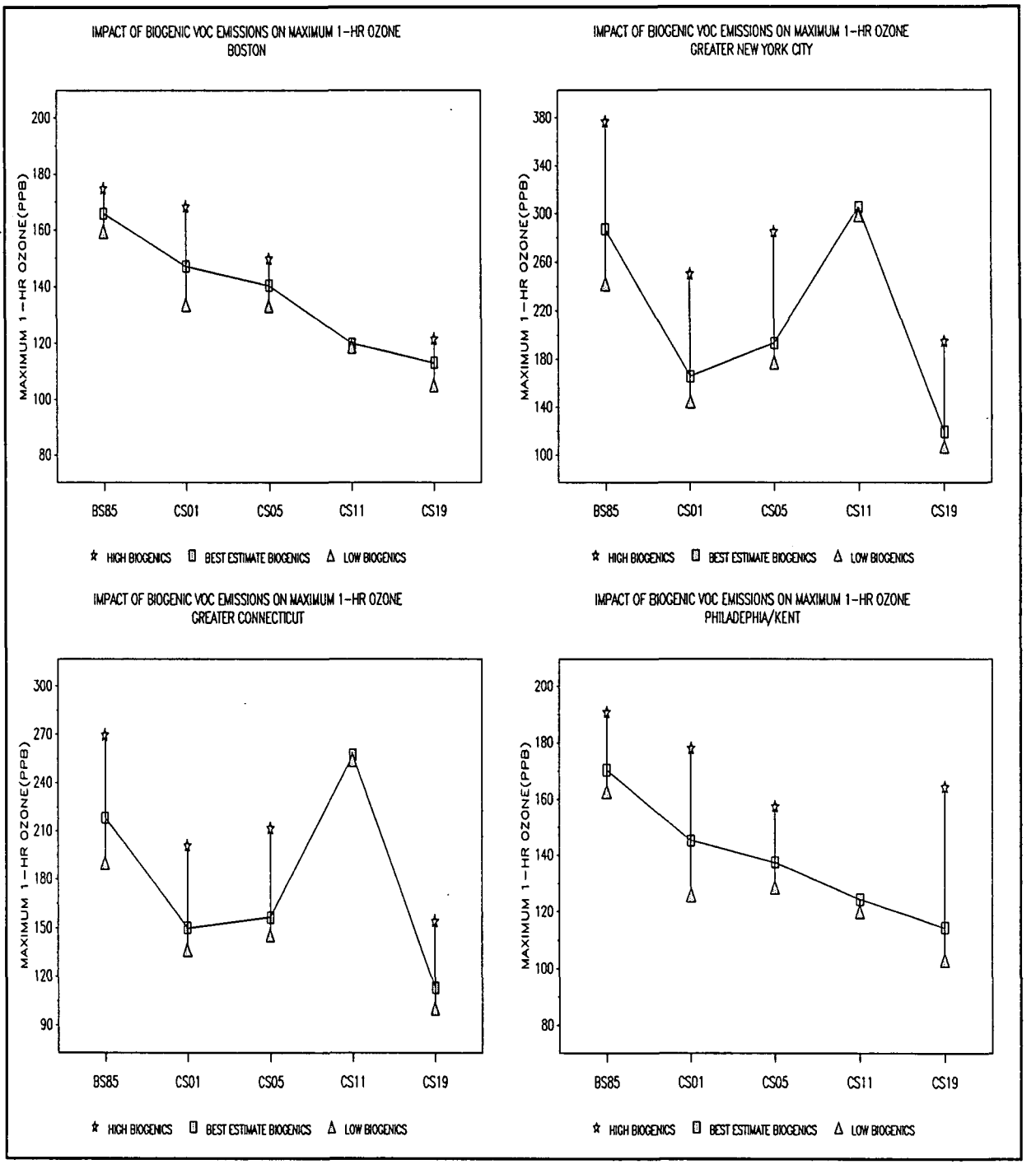


Figure 5-33. Predicted episode maximum 1-hour ozone concentrations for biogenic sensitivity scenarios for selected urban areas. (Page 1 of 2)

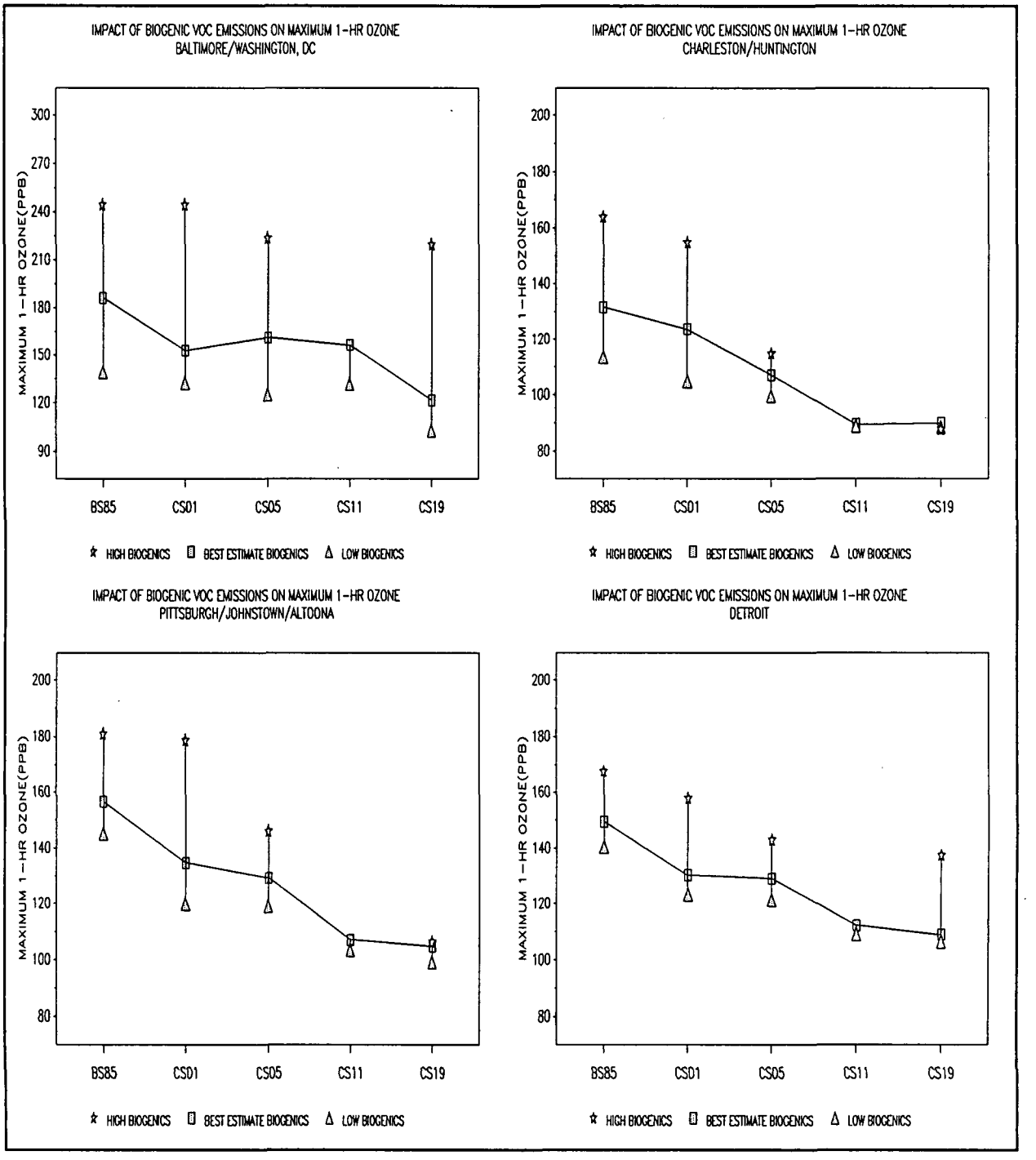


Figure 5-33 (Page 2 of 2)

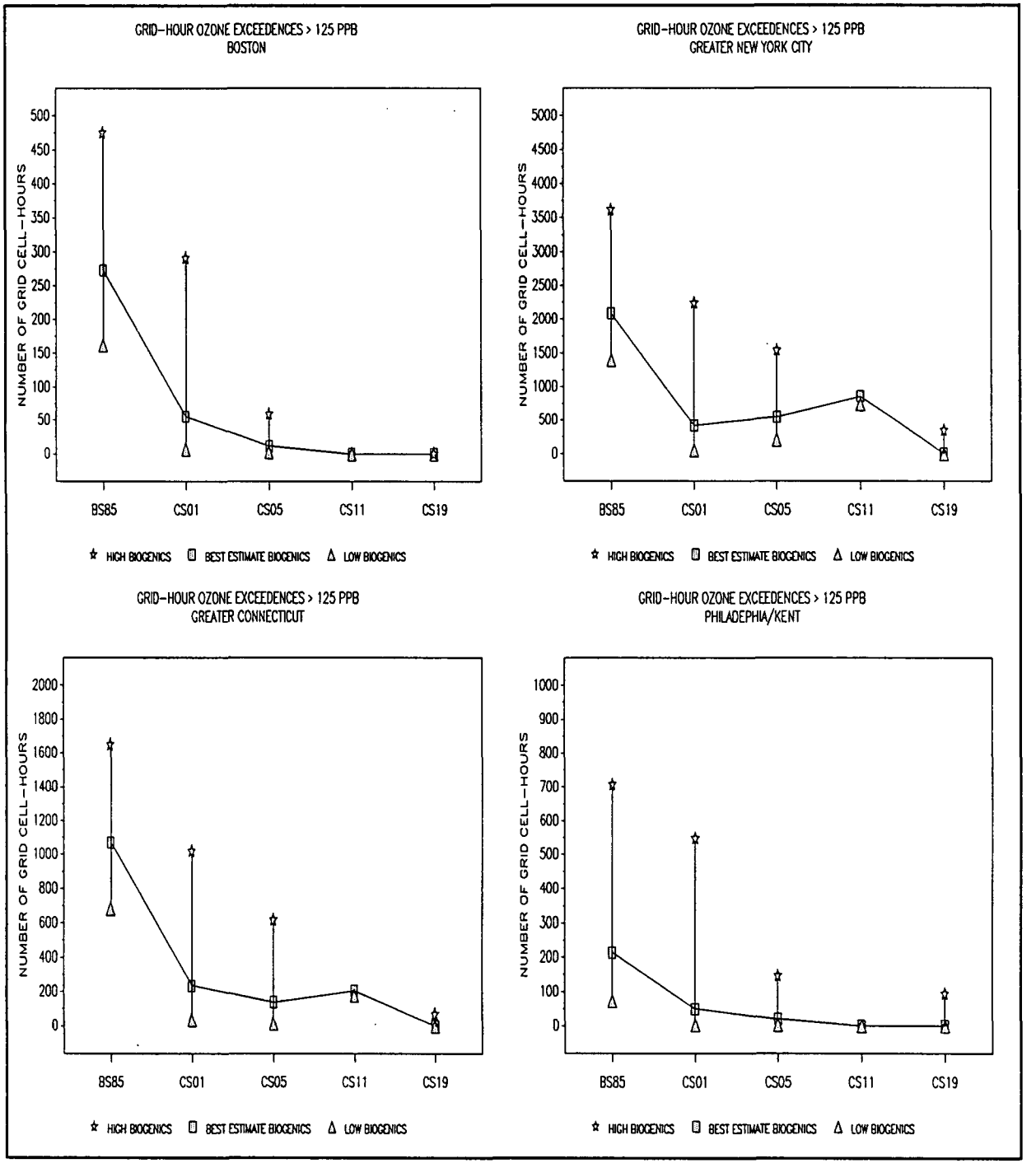


Figure 5-34. Predicted grid-hours exceeding 125 ppb for biogenic sensitivity scenarios for selected urban areas. (Page 1 of 2)

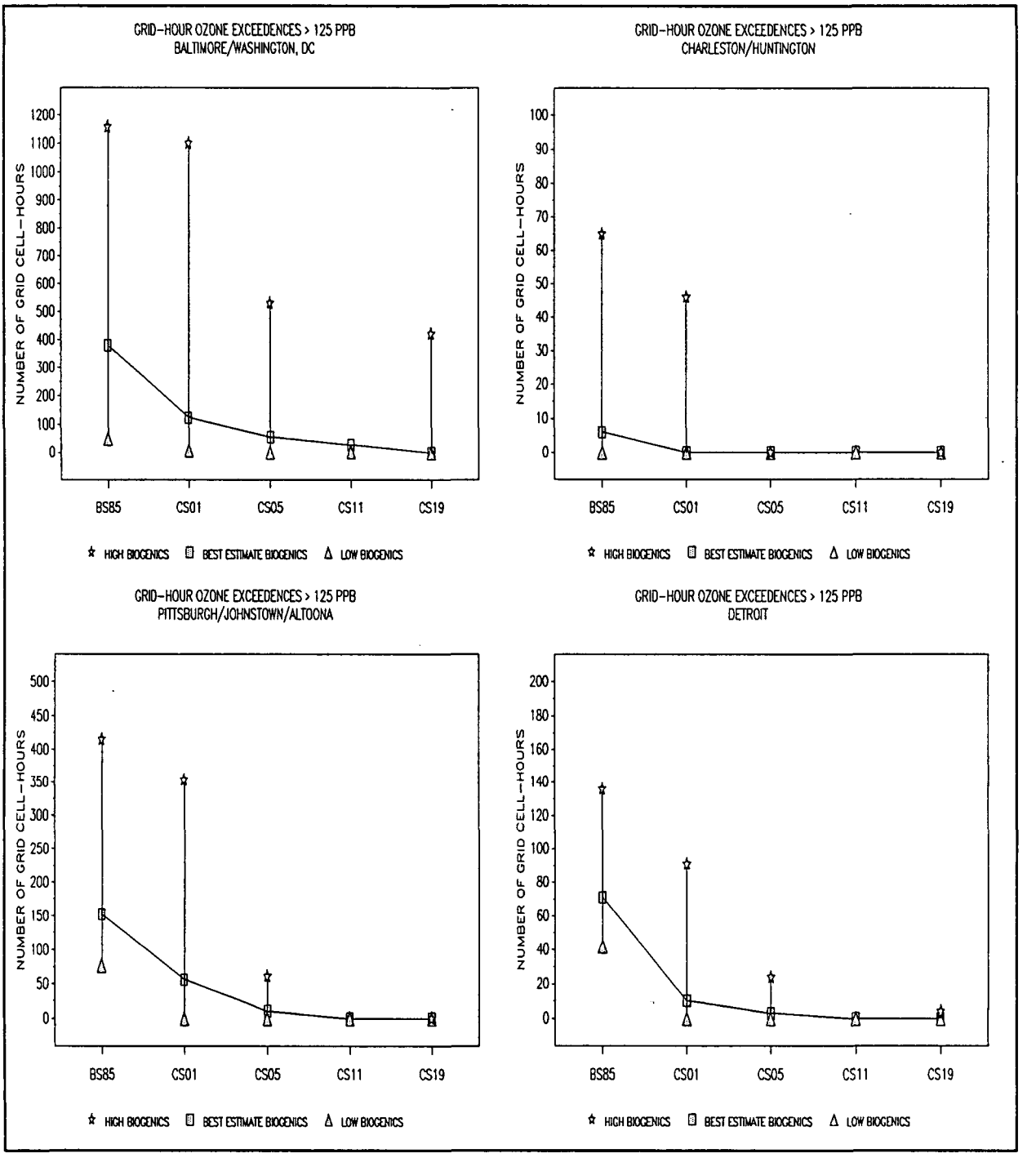


Figure 5-34 (Page 2 of 2)

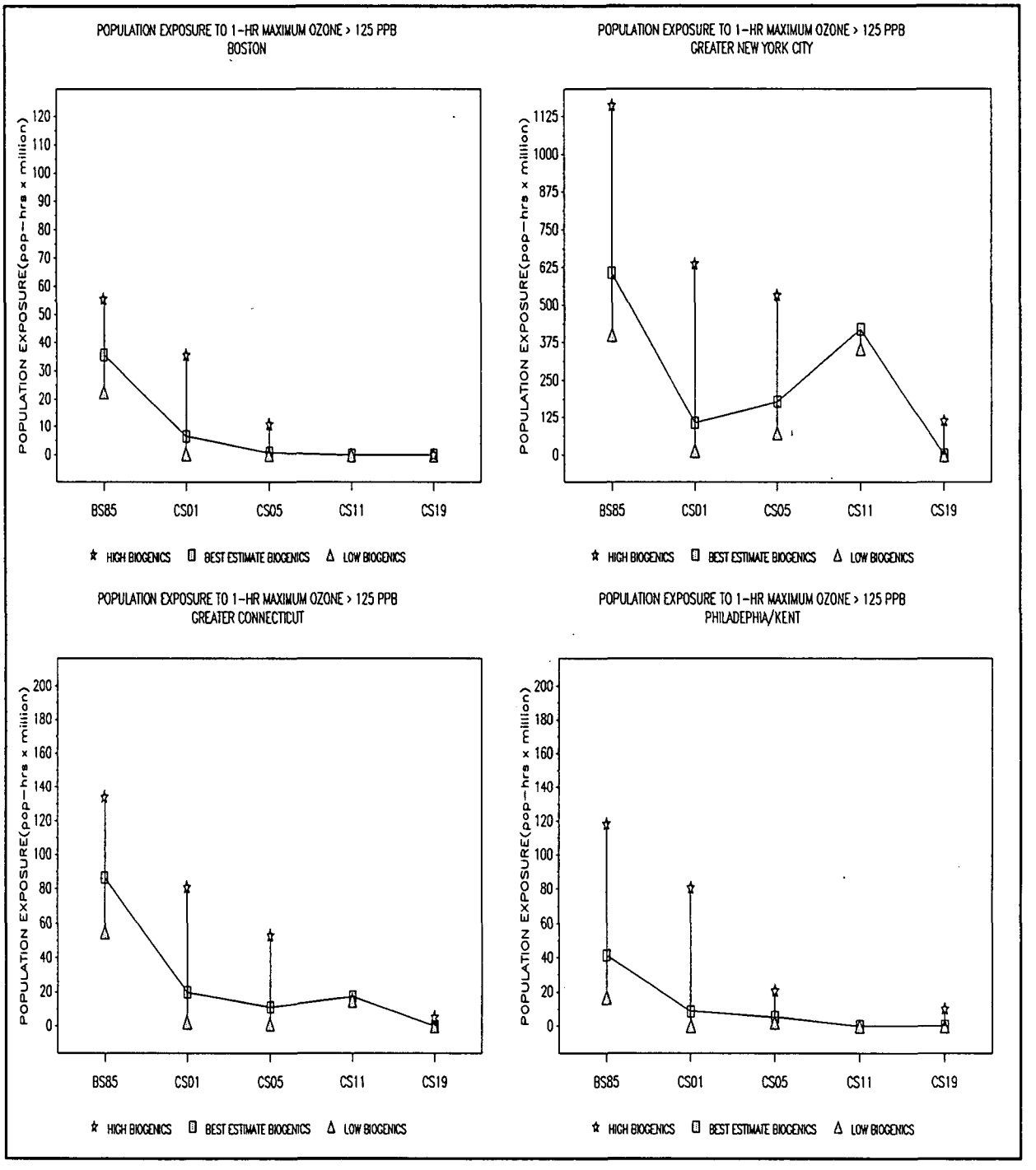


Figure 5-35. Predicted population exposure to ozone exceeding 125 ppb for biogenic sensitivity scenarios for selected urban areas. (Page 1 of 2)

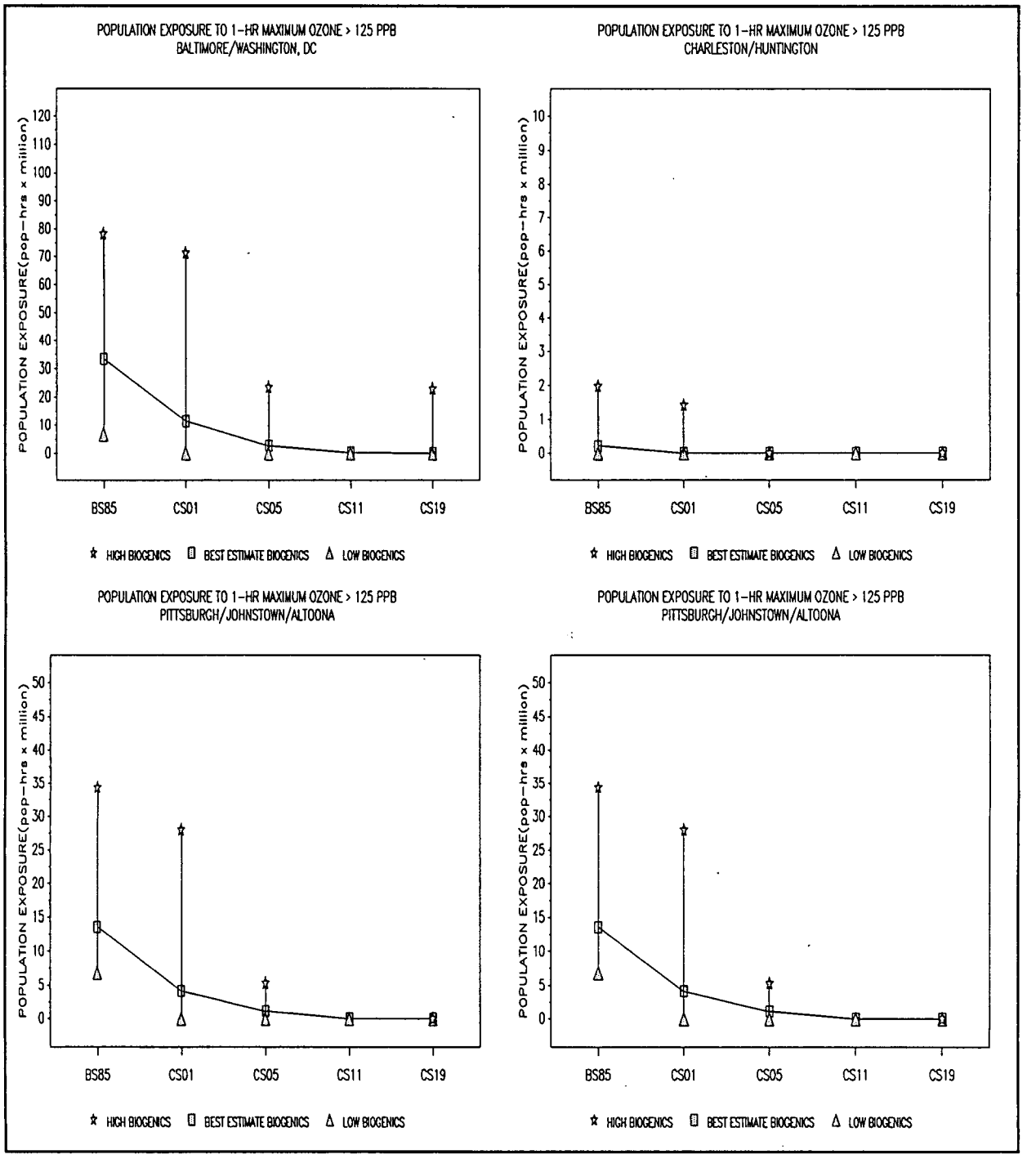


Figure 5-35 (Page 2 of 2)

TABLE 5-1. PROCEDURES USED FOR CALCULATING POPULATION EXPOSURE

$$\mathrm{Exp}_A = \sum_{t=1}^{T} \sum_{i=1}^{n} \mathrm{Pop}_i \cdot O_{ti}(\chi)$$

where

Exp_A	population exposure to ozone exceeding concentration χ within area A for the entire episode; units are in population-hours
Pop_i	population in grid i in area A
n	n total grids in area A
t	hour
T	total hours in episode = (24 hours × number of days)
O_{ti}	= 1 if $\chi_{ti} > c$, = 0 otherwise; occurrence of ozone exceeding concentration χ in grid i for hour t
c	ozone concentration cutoff (i.e., 125 ppb)

TABLE 5-2. SUMMARY OF EMISSIONS REDUCTIONS THAT REDUCED PREDICTED OZONE TO < 125 PPB

	PEAK OZONE		EMISSIONS REDUCTIONS BEYOND 2005 BASELINE		
	2005	POSTCONTROL			
NORTHEAST CORRIDOR CITIES					
			VOC	NO_x	CO
Philadelphia	148 ppb	117 ppb	63%	48%	16%
Boston	158 ppb	116 ppb	60%	52%	18%
Balt./Wash., DC	149 ppb	118 ppb	80%	15%	17%
New York City	268 ppb	119 ppb	85%	22%	21%
CITIES OUTSIDE THE NORTHEAST CORRIDOR					
Pittsburgh	138 ppb	116 ppb	46%	30%	NC
Cleveland	139 ppb	115 ppb	NC	47%	NC
Detroit	140 ppb	117 ppb	NC	60%	NC
Charleston, WV	128 ppb	109 ppb	77%	38%	7%

NC = no change

TABLE 5-3. COMPARISON OF THE JULY 1988 AND JUNE 1983 EPISODE MAXIMUM 1-HOUR CONCENTRATIONS (ppb) FOR THE 2005 BASELINE AND CS19

	June 83		July 88	
	2005	CS19	2005	CS19
New York City	242	110	268	120
Baltimore/Washington, DC	160	124	149	122
Philadelphia	162	118	148	115
Boston	143	108	158	113
Pittsburgh	117	95	138	105
Cleveland	148	104	139	112
Detroit	135	99	140	109
Charleston, WV	95	69	128	95

TABLE 5-4. SUMMARY OF OZONE METRICS USED TO ASSESS THE IMPACTS OF REACTIVITY-BASED STRATEGIES

Average change in daily maximum ozone (ppb) for days ≥ 125 ppb

	2005 *vs.* CS20	2005 *vs.* CS12	CS10 *vs.* CS15
New York City	69	80	36
Greater Connecticut	37	46	13
Rhode Island	22	28	5
Group 1 *	8	16	1
Group 2 *	5	12	<1
Group 3 *	2	10	<1

Number of days with ozone ≥ 125 ppb

	2005	CS20	CS12	CS10	CS15
New York City	12	8	6	10	8
Greater Connecticut	9	6	3	4	1
Rhode Island	7	1	0	0	0
Group 1 *	6	4	3	0	0
Group 2 *	2	2	0	0	0
Group 3 *	2	2	0	0	0

Percent reduction in population exposure to ozone ≥ 125 ppb

	2005 *vs.* CS20	2005 *vs.* CS12	2005 *vs.* CS10	2005 *vs.* CS15
New York City	75	92	79	93
Greater Connecticut	69	95	95	99
Rhode Island	90	100	100	100
Group 1 *	46	79	100	100
Group 2 *	33	82	100	100
Group 3 *	28	92	100	100

* Average for group

TABLE 5-5. CASES TESTED WITH VARYING BIOGENIC EMISSIONS

Case	Description
Base 1985:	Base Case 1985 emissions; "best" estimate biogenics
Base 1985L:	Base Case 1985 emissions; "low" estimate biogenics
Base 1985H:	Base Case 1985 emissions; "high" estimate biogenics
CS01:	Strategy 1 - maximum technology VOC controls applied regionwide; "best" estimate biogenics
CS07:	Strategy 1 with "low" estimate biogenics
CS09:	Strategy 1 with "high" estimate biogenics
CS05:	Strategy 5 - Clean Air Act legislation controls; "best" estimate biogenics
CS06:	Strategy 5 with "low" estimate biogenics
CS08:	Strategy 5 with "high" estimate biogenics
CS11:	Maximum NO_x controls from Strategy 10, VOC at 2005 Base Levels; "best" estimate biogenics
CS17:	Strategy 11 with "low" estimate biogenics
CS19:	Maximum technology, reduced reactivity, across the board reductions and modified NO_x controls in Baltimore/Washington DC; "best" estimate biogenics
CS21:	Strategy 19 with "low" estimate biogenics
CS20:	Strategy 19 with "high" estimate biogenics

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SECTION 6

STATE ACCESS AND USE OF ROM DATABASES

by

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6.1 INTRODUCTION

As noted in Section 2, performance of the ROM indicated that the model predicts observed regional ozone levels reasonably well. Use of the model to estimate effects of regional control strategies on ozone predictions was demonstrated in Section 5. There are a number of reasons why the ROM would be advantageous in the development of required NAAQS attainment demonstrations. First, it provides a means for ensuring consistency in the way States derive and use transport assumptions in their design of urban strategies. Second, it provides a means of simulating the combined effects of many urban strategies. Third, it provides the most technically-defensible way to estimate transport to urban areas of future-year ozone/precursor concentrations. Finally, it can provide data for use in State Implementation Plans (SIP's) that may be difficult and/or expensive to otherwise obtain.

For reasons discussed in Sections 2 and 5, it is inappropriate to use the ROM by itself to demonstrate attainment of the ozone NAAQS in the vicinity of cities. The Urban Airshed Model (UAM) has been designated as the preferred approach for attainment demonstrations. Thus, the ROM is best used by "nesting" the UAM within a ROM domain, and extracting data generated by the ROM for use as inputs to the UAM.

Although the concept of nesting is simple, its implementation is not. For example, in using results from the ROM to provide inputs for urban attainment demonstrations, States are likely to be interested in only a small subset of these data. Episodes considered in attainment demonstrations will typically focus on a one- to two-day period and concentrate on only a small portion of the ROM domain. Thus, a manageable way is needed for States to retrieve data from applications of the ROM to support SIP development.

A second problem arises from the fact that, like the ROM, the UAM is also a three-dimensional photochemical grid model - and it is just as complex as the ROM. In addition, the UAM's grids are a different size than those in the ROM, and there are more vertical layers in the UAM. Further, the UAM and its numerous preprocessor programs require input data that is somewhat differently structured than the data generated by the ROM.

Therefore, one of the goals of ROMNET was to provide the ROM predictions and ancillary input data sets to States for use in urban modeling, along with methods and guidance on how to use these data for incorporating pollutant transport into the development of ozone SIPs. Two computer systems were developed as part of ROMNET to meet these objectives: the Gridded Model Information Support System (GMISS) and the ROM/UAM Interface Program System.

GMISS is a database management system that provides an archive for ROM system databases and access to these data by EPA and States. Databases associated with the ROMNET base case, future baseline, and control strategy scenarios have been archived in GMISS. This system resides on the EPA National Computer Center IBM 3090.

The ROM/UAM Interface Program System is a series of integrated Fortran programs that contain the methodologies for using ROM system data to prescribe various inputs for the Urban Airshed Model (UAM). Among the UAM inputs provided are boundary conditions of pollutant concentrations for the urban domain. Using ROM predictions to specify urban boundary conditions via the Interface System will enable States to explicitly consider the effects of regional pollutant transport in urban scale model applications.

This section of the report describes GMISS (Section 6.2) and the ROM/UAM Interface Program System (Section 6.3). More information can be found in the user's guides for these systems as provided by Dessent (1990) and Tang *et al.* (1990), respectively.

6.2 THE GRIDDED MODEL INFORMATION SUPPORT SYSTEM (GMISS)

6.2.1 Overview of GMISS

As indicated above, the GMISS was designed to store and provide access to ROM system databases needed to derive UAM inputs using the ROM/UAM Interface. The main functional components of GMISS are contained in the UAM Subsystem. This subsystem includes loading ROM data into GMISS and retrieval of these data by the user. Data loading functions are performed by an EPA designated Database Administrator (DBA). Retrievals are made by the user through an interactive series of menus. Access to these menus is documented in the GMISS User's Guide, (Dessent, 1990).

The next three sections provide additional information on the key user-oriented aspects of GMISS. The contents and structure of the GMISS databases are described first, followed by the functional processes of the UAM Subsystem. Finally, the user protocol for retrieving data is provided.

6.2.2 GMISS Databases

Concentration Data

As described in Section 2, the ROM generates concentrations of 35 chemical species at half-hour intervals in three vertical layers for each grid cell of the modeling domain. GMISS reads ROM Concentration Files created on the IBM-3090 mainframe computer and stores the data in GMISS database files. In this process the half-hourly values are averaged to obtain hourly values and the data are time-shifted from ROM's end-of-hour convention to start-of-hour (i.e., the first hour of a day, beginning at midnight, is hour 00; the last hour of a day, beginning at 11:00 pm, is hour 23). Each database file holds up to one month's data for a particular species, layer, and scenario (e.g., base case, strategy, etc). Each record in a database file has 24 hourly values for a particular date and grid cell (row and column of the ROM grid). A separate Model Data Index File keeps track of the species, layer, model scenario, episode dates, and names of each database file.

The Concentration Output File, which is produced by a user-initiated retrieval, always contains data in whole-day units. There may be one or more (successive) days in the file, and data for all 24 hours of each day and all three ROM layers are included. As described in Section 6.3, only 17 of the 35 chemical species computed by ROM are required by the ROM/UAM Interface System. Thus, only the species listed below are contained in the Concentration Output File.

ALD2	Aldehydes (high molecular weight)	NO	Nitric Oxide
CO	Carbon Monoxide	NO2	Nitrogen Dioxide
ETH	Ethene	O3	Ozone
FORM	Formaldehyde	OLE	Olefins
H2O2	Hydrogen Peroxide	PAN	Peroxyacetyl Nitrate
HNO2	Nitrous Acid (HONO)	PAR	Paraffins
HNO3	Nitric Acid	TOL	Toluene
ISOP	Isoprene	XYL	Xylene
MTHL	Methanol (MEOH)		

In the Concentration Output File the hourly values are temporally "smoothed" as required by the ROM/UAM Interface System. Specifically, 3-hour moving averages are created for each hour by computing the arithmetic means of the values for that hour, the preceding hour, and the following hour. (There is no spatial smoothing; averages are computed separately for each grid cell in each layer.)

ROM Processor Data

As described in Section 6.3, various ROM input databases are also handled by the ROM/UAM Interface. These inputs, as listed below, are contained in the ROM processor files described in Section 2.2:

Observed upper-air vertical profiles	Layer 1 wind fields
Surface effective roughness	Sky coverage (cloudiness)
Land use (ten categories)	Biogenic emissions
Terrain elevation	Elevation of the boundary between layer 1 and layer 2
Surface meteorological data	Elevation of the boundary between layer 2 and layer 3
Layer 2 wind fields	Layer 1 water vapor concentration.

As with the ROM concentration file, the UAM Subsystem reads these files and stores the data in the database. User-requested processor data are provided in up to twelve retrieval files structured to be compatible with the ROM/UAM Interface System. No time-smoothing is required for the ROM processor data.

The UAM Subsystem keeps track of data in the database by using two index files, a model data index file and a retrieval index file. The model data index file is used to establish the correspondence between the ROM concentration data and processor data. This index is updated when model concentration data or ROM processor data are loaded into the database. The retrieval index file keeps track of data available for retrieval in the UAM Subsystem.

6.2.3 System Functional Description

There are three main processes in the UAM Subsystem: Data Load, Approval, and Retrieval. The Load process has an interactive component and a batch component. The GMISS Database Administrator (DBA) uses interactive menus to initiate the Load process and specify the data to be entered into the database. In the batch environment, the Load program reads each file of ROM processor or concentration data specified by the DBA, loads the data into database files, and records the presence of the data in Index files. Each file loaded is described in a Log file, and a report is printed confirming and summarizing the transaction. The Index file serves as a directory to keep track of all data loaded into GMISS. The Log file is designed to provide a traceable path of the transactions in each Load process.

Before the ROM concentration data can be released for public use, they must be reviewed by data quality analysts. In the approval process the concentration data are assigned a "restricted" status when they are initially loaded into GMISS. After the quality assurance review, the DBA changes the status to "public," and the data become available for UAM Subsystem users. ROM processor data, on the other hand, are reviewed extensively before they are used in ROM simulations. Therefore, the ROM processor data are assigned a "public" status when they are loaded, automatically making them available for retrieval.

Retrieval is the last of the three main processes of the UAM Subsystem. Through interactive menus, users initiate the process and specify the data to retrieve. A batch job submitted during the interactive session performs most of the "work" of retrieving data. The batch job determines which database files contain the requested ROM System data (concentration data and/or ROM processor data), extracts the data, computes 3-hour moving averages of concentration data, and writes one or more retrieval files in which the data are properly organized and formatted for input to the Interface. In addition, the batch job prints a report summarizing the data retrieved, and creates an entry in the Retrieval Log file. This log provides a record of users accessing the system, the types of data retrieved, names of output files, and the date and time of the retrieval. This information is used to assist in resolving any user-access problems.

6.2.4 User Protocol for Data Retrieval

For UAM Subsystem data retrievals, users specify the selection criteria for ROM concentration data, and GMISS automatically selects the associated ROM processor data.

Users choose the data to be retrieved by specifying the ROM domain (e.g., ROMNET), study (e.g., ROMNET), scenario (e.g., 1985 Base Case), and begin date and end date (e.g., Jul 10-Jul 15, 1988). Users also specify the subregion, or spatial "window" of the ROM domain, that corresponds to the UAM domain of interest. If a user enters valid and appropriate values for all of these fields, the UAM Subsystem has sufficient information to retrieve the data from the database. However, a user may not know exactly what values to specify for each field. Two kinds of menus allow users to inquire what values are possible and choose among them. They are the List-of-Values menu and the Final Data Selection menu.

GMISS displays a List-of-Values menu when a user enters a question mark ("?") in the domain, study, or scenario field. The question mark tells GMISS to display another menu that lists valid values for the field. When a List-of-Values menu is displayed, a user may select one of the values on the menu. If the user enters question marks in more than one field on the initial data selection menu, GMISS displays a List-of-Values menu for each field.

The Final Data Selection menu finishes the data selection process. It is analogous to a List-of-Values menu; however, it presents a scrollable list of the types of data in the database that match the specifications for the domain, study, scenario, and date, and which are available for retrieval. Users select the particular data desired from the list of available data on the Final Data Selection menu. The data retrieved through the UAM Subsystem must represent a single domain, study, and scenario of ROM data, and must be for successive days. In any one retrieval file, multiple scenarios, studies, domains, or gaps in the time sequence of the data are not allowed.

By default, the UAM Subsystem generates a complete set of data for input to the UAM: a retrieval file of ROM concentration data and 12 retrieval files of ROM processor data. Since a single set (scenario) of ROM processor data may be used to compute species concentrations for many different emissions scenarios, users may not need to retrieve ROM processor data every time ROM concentration data are retrieved. To facilitate this selective retrieval, the UAM Subsystem defines the five data categories below. ROM concentration data is one such category; groups of the twelve ROM processor files comprise the other four categories. The files in each category are likely to be used together by the UAM.

CONC	Hourly gridded ROM concentration data for the 17 chemical species UAM requires, in each of the three ROM layers;
RAWIN	Hourly non-gridded upper-air vertical profiles (observed data);
GEO	Time-invariant gridded geographic data (surface roughness, land use, and terrain elevation);
BIOGEN	Hourly gridded biogenic emissions;
MET	Hourly gridded meteorology data (surface meteorology, layer 2 wind fields, layer 1 wind fields, cloudiness, height of layer 1, height of layer 2, and layer 1 water vapor concentration).

The data type selection menu allows users to choose the categories of data for which the UAM Subsystem will create retrieval files. The default is that all five categories are selected. Users must choose at least one category.

The geographic extent of the ROM data available for retrieval is much larger than the typical domain used for urban modeling with the UAM. As indicated previously, GMISS users retrieving any category of gridded data for use with UAM can choose a smaller rectangular array of ROM grid cells that covers only the geographic area to be modeled by the UAM. This geographic "windowing" is based on user-entered longitude and latitude coordinates of opposite corners of the desired UAM domain.

For selecting observed upper-air data, the UAM Subsystem provides a menu list of available stations based upon the selection criteria specified in the initial data selection menus. The user selects the station or stations from this menu. At least one station must be selected.

Execution of the UAM Subsystem results in the creation of up to 13 ROM System files (1 ROM output concentration file and 12 ROM processor input data files). These are the files required to drive the ROM/UAM Interface Program System. At this point, users may move these files to the desired computer and set up the ROM/UAM Interface Program System for execution.

6.3 THE REGIONAL OXIDANT MODEL - URBAN AIRSHED MODEL INTERFACE PROGRAM SYSTEM

6.3.1 Introduction

One of the major objectives of ROMNET was to provide procedures for using ROM predictions to specify boundary conditions for urban-scale models. In the process of developing such procedures, it became evident that additional urban model inputs could be derived from ROM system data sets. Thus, the scope of the task was expanded accordingly. It was felt that the additional information would reduce the burden on States of gathering input data from other sources. Also, it would ensure greater consistency between urban and regional modeling as well as between State Implementation Plans (SIPs) from States that rely on the ROM data sets.

The Urban Airshed Model (UAM) was selected as the urban-scale model to interface with ROM, because the UAM is the preferred modeling approach for urban ozone modeling (EPA, 1986). Although both the ROM and the UAM are grid models using a common chemical mechanism, interfacing these two models is not straightforward. A detailed discussion of the methodologies and assumptions used in the interface is contained in Appendix N.

A set of computer programs was developed to enable the UAM system to be driven by ROM system input and output data sets. The computer program package has been designated the ROM-UAM Interface Program System. Since both the ROM and UAM are independent models with their own separate processor systems, the interface programs serve as external links between particular ROM files and components of the UAM system. The principal functions of the interface are to interpolate specific gridded parameters from the ROM system, and to generate data files in compatible formats for input to the UAM preprocessors or the UAM program. In particular, the interface programs have been designed for use with the ROM 2.1 system files and the UAM Carbon Bond IV [UAM (CB-IV)] system.

Like the ROM, the UAM is a grid-based photochemical oxidant model that mathematically treats the relevant physical and chemical processes important to ozone production, destruction, and removal, albeit on a smaller spatial scale. Both models require extensive input data including concentrations for initial and boundary conditions, and meteorological and emissions data. In all, 13 different ROM data files are applied in the interface programs, which include gridded fields of pollutant concentrations, various meteorological parameters (e.g., winds, temperature, water vapor, etc.), land use information, and biogenic emissions.

The ROM-UAM interface system actually consists of seven main programs. Each interface program provides a link between certain ROM data files and a particular UAM preprocessor or the model program. Specifically, an output file generated by an interface is in a compatible format for direct input to either a UAM preprocessor or the model.

The remainder of this section provides an overview of the interface package, including a summary of some of the salient features and important limitations when applying the interface programs, and an overview of the interface package and its programs. A detailed technical description of the methods and procedures employed to derive the time dependent and spatially-varying gridded data fields for the UAM system from the ROM data sets is given in Appendix N. The detailed format specifications of the input/output files for each interface and instructions for their execution are given elsewhere (Tang *et al.*, 1990).

6.3.2 Features and Limitations of the Interface

The principal features of the ROM/UAM Interface are enumerated below:

- Interfaces link only components of the UAM (CB-IV) model system and certain outputs of the ROM 2.1 system, and not earlier versions of these two models.
- Four interfaces provide formatted input files for the UAM preprocessors and three interfaces generate binary files directly for use in executing the UAM model.
- Thirteen different ROM output files are applied in executing the various interface programs. Users must create these spatially "windowed" data files for their particular UAM domain and simulation period by accessing the ROM database through a data retrieval program developed for the Gridded Model Information Support System (GMISS) on the EPA NCC-IBM 3090 computer system.
- Interface programs have been generalized to allow the user to input specifications about the particular UAM domain and grid (i.e., origin, number of grid cells, and grid cell size) and the vertical configuration of the UAM (i.e., number of lower and upper levels).
- Interfacing for initial, lateral and top boundary conditions is performed for 17 of the 23 pollutant species that must be specified in the UAM (CB-IV) model. Default values are defined for the remaining six species.

- Lateral and top boundary concentrations are resolved hourly and spatially at each UAM grid cell.

- Options have been built into two interface programs to allow the user to apply non-ROM input data files (i.e., concentrations, winds).

- Quality-assured data may be incorporated into formatted packet files through an on-line editor at a terminal.

- A utility program included with the interface package converts any binary file into an equivalent ASCII formatted data file so that its contents may be examined prior to use in model execution.

- Horizontal wind fields generated by the wind interface are determined by matching the ROM gridded wind components from layers 1 and 2 into the vertical levels of the UAM. The methodologies employed in the wind interface are those applied in the UAM Diagnostic Wind Model system described in Volume III of the UAM User's Guide (Douglas et al. 1990).

Certain limitations also exist with this version of the interface:

- No interfacing is performed for the diffusion break height needed by the UAM. The user must apply a method recommended for deriving hourly values of this parameter as described in Volume II of the UAM User's Guide (Morris *et al.* 1990b). As part of the interface package, a processor program (PDFSNBK) produces a formatted packet file for the UAM diffusion break preprocessor program (DFSNBK) using a user-supplied data file of diffusion break values. The interface programs handle only a spatially-invariant diffusion break for each hour (note that diffusion breaks can vary from hour to hour).

- No interfacing of anthropogenic area, mobile, or point source emissions is performed. The UAM point source preprocessor (PTSRCE) and the Emissions Processor System (EPS) already exist for creating emissions for these source types (Volume IV, Causley *et al.* 1990). A biogenics interface is limited to combining an existing binary anthropogenic area emissions inventory file and the ROM gridded biogenic emissions of certain hydrocarbon and NO_x species.

- No interfacing is performed for the UAM preprocessors, CPREP or SPREP, the chemical parameters and the simulation control programs, respectively.

6.3.3 Description of the Interface System

A general framework showing how the interface program package fits into the overall UAM model system is depicted in Figure 6-1. The interface programs are executed before exercising any UAM preprocessor program. The important first step to be performed in the interfacing process is the creation of a set of formatted data files that are needed as inputs to the interface programs. This step is performed using GMISS, as described in Section 6.2.

Since the retrieved data files will be formatted, the user may decide to transfer them to another computer system where the actual execution of the interface programs, and the UAM preprocessor and model simulations will be conducted.

The set of interface programs produce either formatted "packet" files that are in a compatible format for direct input to particular UAM preprocessors or binary files that are ready for direct input to the UAM model. For the latter, certain UAM preprocessors are bypassed with no execution required. Therefore, although the interface programs reside on the IBM 3090 computer, these codes are easily adaptable to other computer systems after minor revisions Tang *et al.*, 1990). The user has the ability to examine the contents of "packet" files generated by most interface programs with an on-line editor. Furthermore, at this stage the user may wish to supplement these files with additional quality-assured observed data before proceeding with the execution of a UAM preprocessor. For the interface programs that generate binary files ready for the model, an optional feature has been built into the codes that allow the user the flexibility of supplying an alternate data set.

In this instance, it must be noted that the user would be undertaking an additional effort to generate an alternate data file for an interface program. A utility program is also part of the interface package for converting a binary file into a formatted ASCII file version so that it can be examined before model execution.

The UAM model code requires 13 binary input files in any modeling application. Table 6-1 gives a complete list of the UAM preprocessor names and the binary output file generated by each program. The UAM preprocessor programs have been grouped into categories to indicate which binary data files are required for initial and boundary (lateral and top) concentrations, various meteorological parameters (e.g., winds, etc) and surface features, emissions, and finally, control information about the chemical species and reactions, and the model run parameters.

A comprehensive approach was taken in interfacing the two model systems in order to take advantage of the extensive variety of data sets available from the ROM model and processor network for use as inputs to as many UAM preprocessors as possible. A complete list of the data files and their contents that are used in the interface is provided in Table 6-2. The file names listed are those designated within the ROM system and these file names will be imbedded within the extended file name of the retrieved files generated by the user. One or more of these files are needed to exercise each interface program. With the exception of the temperature profile data file, all of the retrieved files contain gridded fields of the ROM processor or model results.

An overview of the complete ROM-UAM interface program package is provided in Table 6-3. It shows the retrieved ROM files needed for each interface program. There are seven actual interface programs. The designated name for an interface program begins with the letter "I" and the remainder of its name is given by the UAM preprocessor program name. In addition, a processor program (PDFSNBK) that reformats hourly diffusion break data (DBDATA), supplied by the user, is part of the interface program package. The outputs from the other interface programs are formatted "packet" files (e.g., RTPACK, etc.) for use as inputs to the appropriate UAM preprocessor. Since these files are formatted, the user has the capability to examine their contents and also can insert additional data before exercising the UAM preprocessors. The interface programs for generating winds (IWIND) and for initial and boundary concentrations (ICONC) produce binary files for use in UAM execution. Consequently, the diagnostic wind model (DWM) system and the concentration preprocessors (i.e., AIRQUL, BNDARY, TPCONC) are not exercised when these interface programs are applied. A combined area emissions file is created by the IBIOG interface program from a user-supplied anthropogenic file and a ROM biogenic emissions file. The output emissions file of IBIOG is also binary and ready for input in UAM simulations. However, interfacing of anthropogenic point or area emissions is not performed. A detailed description of the interface method for each UAM processor is given in Appendix N.

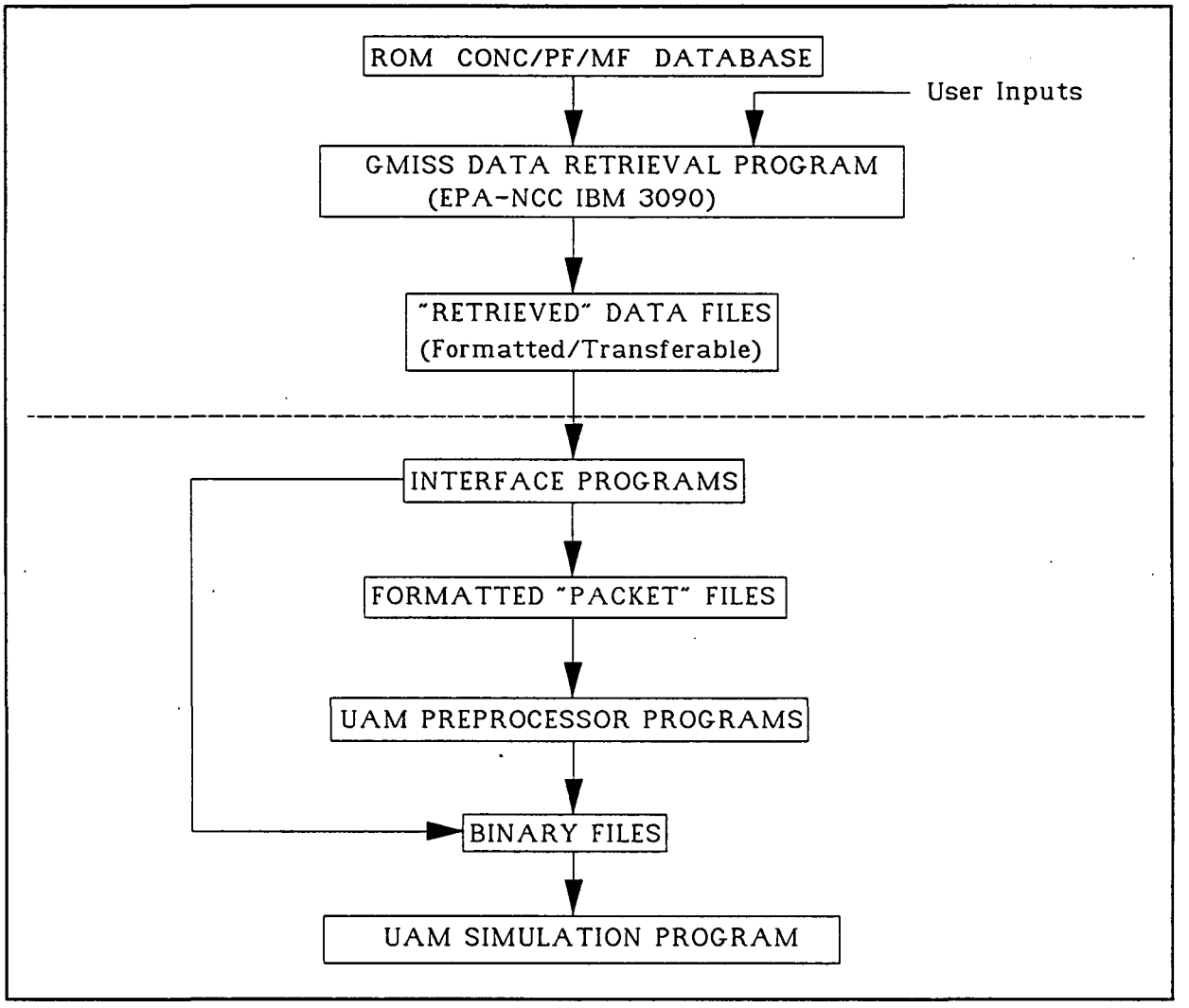

Figure 6-1. Flow diagram showing the data retrieval and interface processing steps performed to generate data files for the UAM preprocessors and model.

TABLE 6-1. SUMMARY OF THE UAM PREPROCESSOR PROGRAMS

Name	Internal name in binary file	Contents
		CONCENTRATIONS
AIRQUL	AIRQUALITY	Initial concentration fields
BNDARY	BOUNDARY	Lateral boundary concentrations
TPCONC	TOPCONC	Top boundary concentrations
		METEOROLOGY AND SURFACE CHARACTERISTICS
DFSNBK	DIFFBREAK	Diffusion break heights
REGNTP	REGIONTOP	Model region top heights
METSCL	METSCALARS	Five meteorological parameters and photolysis rate
TMPRTR	TEMPERATURE	Surface temperature field
DWM[1]	WIND	Horizontal wind component fields
CRETER	TERRAIN	Surface roughness and vegetation fraction factor
		EMISSIONS
EPS[2]	EMISSIONS	Anthropogenic area emissions
PTSRCE	PTSOURCE	Major point source emissions
		CONTROL DATA
CPREP	CHEMPARAM	Species reaction rate information
SPREP	SIMCONTROL	Model simulation input information

1. DWM = Diagnostic Wind Model
2. EPS = Emissions Preprocessor System

TABLE 6-2. RETRIEVED ROM FILES USED BY INTERFACE PROGRAMS

ROM system file name	Description of file contents
ROM21	Hourly predicted concentrations of 17 species from layer 1, 2, and 3
MF165	Hourly gridded heights of layer 1
MF166	Hourly gridded heights of layer 2
MF174	Hourly gridded water vapor concentration in layer 1
PF102	Hourly vertical-interpolated temperature profiles
PF103	Hourly gridded surface air temperature
PF108	Gridded surface roughness length
PF114	Hourly gridded layer 2 horizontal wind components
PF115	Hourly gridded layer 1 horizontal wind components
PF117	Hourly gridded total sky cover fraction
PF118	Gridded fractions of eleven land use categories
PF119	Gridded terrain elevation
PF144	Hourly gridded biogenic emissions of six species

TABLE 6-3. OVERVIEW OF THE ROM-UAM INTERFACE PROGRAMS AND INPUT/OUTPUT FILES

ROM or other input files	Interface programs	'PACKET' file	UAM preprocessor	Binary file
User DBDATA	PDFSNBK ——>	DBPACK	DFSNBK	DBBIN
DBDATA MF166 PF119	IREGNTP ——>	RTPACK	REGNTP	RTBIN
	└——> RTDATA			
MF174 PF102 PF117 PF119 RTDATA DBDATA	IMETSCL ——>	MSPACK User data (optional)	METSCL	MSBIN
PF103	ITMPRTR ——>	TPPACK User data (optional)	TMPRTR	TPBIN
MF165 PF114 PF115 PF119 DBDATA RTDATA	IWIND ——>			WDBIN
PF108 PF118	ICRETER ——>			CRBIN
ROM21 MF165 PF119 DBDATA	ICONC ——>			AQBIN BCBIN TCBIN
PF144 User	IBIOG ——>			EMBIN
	EMISSIONS*			
	└——> BIOASC (optional)			

* Anthropogenic area emissions file

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REFERENCES AND BIBLIOGRAPHY

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Alliance Technologies Corp., 1989. *Regional Ozone Modeling For Northeast Transport -- Development of a Base Year Anthropogenic Emissions Inventory.* EPA-450/4-89-008. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

Alliance Technologies Corp., 1990. *Regional Ozone Modeling for Northeast Transport -- Projection Year and Control strategy Emissions Inventories.* Draft Report, U.S. Environmental Protection Agency, Technical Support Division, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711.

Arnts, A. and S. Meeks, 1981. Biogenic hydrocarbon contribution to the ambient air in selected areas. *Atmos. Environ.* (**15**) 9: 1643.

Baldocchi, D., D. Matt, B. Hutchinson *et al.,* 1984. Solar radiation within an oak-hickory forest: an evaluation of the extinction coefficients for several radiation components during fully-leafed and leafless periods. *Agricultural and Forest Meteorology* (**32**): 307.

Battye, W., M. Smith and M. Deese, 1987. *Cost Assessment of Alternative National Ambient Air Quality Standards for Ozone* (Draft Report for External Review). Alliance Technologies Corporation. Prepared for Ambient Standards Branch, U.S. Environmental Protection Agency, Research Triangle Park, NC.

BEA, 1986. *1985 OBERS BEA Regional Projections, Volume 1: Methodology, Concept, and State Data.* U.S. Department of Commerce, Bureau of Economic Analysis.

Causley, M.C., J.L. Fieber, M. Jimenez, and L. Gardner, 1990. *User's Guide for the Urban Airshed Model. Volume IV: User's Guide for the Emissions Processor System.* EPA-450/4-90-007D. Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Chameides, W., R. Lindsay, J. Richardson *et al.,* 1988. The role of biogenic hydrocarbons in urban photochemical smog: Atlanta as a case study. *Science* (**241**): 1473.

Chun, K. C, 1988. *Uncertainty Database for Emissions Estimation Parameters: Area Source Supplement to Interim Report.* ANL/EES-TM-353, Argonne National Laboratory, Argonne, Illinois.

Computer Sciences Corporation (CSC), 1990. *Gridded Model Information Support System (GMISS): UAM subsystem design.* EPA Office of Air Quality Planning and Standards, Source Receptor Analysis Branch, Research Triangle Park, NC.

Demerjian, K.L., K.L. Schere, and J.T. Peterson, 1980. Theoretical estimates of actinic (spherically integrated) flux and photolytic rate constants of atmospheric species in the lower troposphere. In: *Advances in Environmental Science and Technology*, Vol. 10, J. Pitts and R. Metcalf, Eds., Wiley Publ., New York. pp. 369-459.

Dessent, T., 1990. *The GMISS UAM Subsystem User's Guide.* In preparation. Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Dodge, M.C., 1989. A comparison of three photochemical oxidant mechanisms. *J. Geophys. Res.* 94:5121-5136.

Douglas, S.G., R.C. Kessler, and E.L. Carr, 1990. *User's Guide for the Urban Airshed Model. Volume III: User's Manual for the Diagnostic Wind Model (Version 1.1).* EPA-450/4-90-007C. Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Ellison, W., 1988. *Assessment of SO_2 and NO_x Emission Control Technology in Europe.* EPA-600/2-88-013, U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA, 1986. *Guideline on Air Quality Models (Revised).* EPA-450/2-78-027R. U.S. Environmental Protection Agency. Research Triangle Park, NC.

EPA, 1989. *User's Guide to MOBILE4.* EPA-AA-TEB-89-01, U.S. Environmental Protection Agency, Office of Mobile Sources, Ann Arbor, MI.

Faucett, J. and Associates, 1988. *The Faucett VMT Forecasting Model* (Draft Final Report). Office of Policy Administration, Federal Highway Administration, U.S. Department of Transportation.

Fehsenfeld, F., 1990. National Oceanic and Atmospheric Administration, Boulder, CO, personal communication.

Gates, D. and L. Papian, 1971. *Atlas of Energy Budgets on Plant Leaves,* Academic Press, New York, pp. 1-16.

Gay, D., 1987. *A National Inventory of Biogenic Hydrocarbon Emissions Based Upon a Simple Forest Canopy Model.* M.S. Thesis, Washington State University, 73 p.

Gery, M.W., G.Z. Whitten, and J.P. Killus, 1988. *Development and testing of the CBM-IV for urban and regional modeling.* EPA-600/3-88/012, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Gery, M.W., G.Z. Whitten, J.P. Killus, and M.C. Dodge, 1989. A photochemical kinetics mechanism for urban and regional scale computer models. *J. Geophys. Res.* **94**:D10, 12295-12956.

Godowitch, J.M., J.K.S. Ching, and J.F. Clarke, 1987. Spatial Variation of the Evolution and Structure of the Urban Boundary Layer. *Bound. Layer-Meteorol.*, **38**: 249-272.

Johnson, K., 1988. *Industrial Boiler Low-NO_x Combustion Retrofit Cost Algorithm.* EPA-600/8-88-091, National Acid Precipitation Assegsment Program, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Killus, J.P, and G.Z. Whitten, 1984. *Technical Discussion Relating to the Use of the Carbon Bond Mechanism in OZIPM/EKMA.* EPA-450/4-84/009, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lamb, B., A. Guenther, D. Gay, *et al.*, 1987. National inventory of biogenic hydrocarbon emissions. *Atmos. Environ.* (**21**) 8: 1695.

Lamb, R.G., 1983. *A regional scale (1000 km) model of photochemical air pollution. Part I - Theoretical formulation.* EPA-600/3-83/035, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lamb, R.G., 1984a. *A regional scale (1000 km) model of photochemical air pollution. Part II - Input processor network design.* EPA-600/3-84/085, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lamb, R.G., 1984b. Air pollution models as descriptors of cause-effect relationships. *Atmos. Environ.* 18(3):591-606.

Lamb, R.G., 1985. *Application of the first generation Regional Oxidant Model to an assessment of the effects of proposed 1987 emissions reductions on episodic ozone levels in the northeastern United States.* Internal Report, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lamb, R.G., 1986. *Numerical simulations of photochemical air pollution in the northeastern United States: ROM 1.0 Applications.* EPA-600/3-86/038, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lamb, R.G., 1987. *Design and applications of the Regional Oxidant Model (ROM).* In: Conference Proceedings of the North American Oxidant Symposium, February 25-27 1987, Quebec, Canada. Environment Canada, pp. 153-189.

Lamb, R.G., 1988. *Simulated effects of hydrocarbon emissions controls on seasonal ozone levels in the northeastern United States: A preliminary study.* EPA-600/3-88/017, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lamb, R.G., and G.F. Laniak, 1985. *A regional scale (1000 km) model of photochemical air pollution. Part III - Tests of the numerical algorithms.* EPA-600/3-85/037, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Lamb, R.G., and S.K. Hati, 1987. The representation of atmospheric motion in models of regional-scale air pollution. *J. Clim. Appl. Meteorol.* 26(7):837-846.

Langstaff, J. and T. Young, 1990. *User's Manual for Regional Emissions Growth and Control Strategy Software* (Draft). Alliance Technologies Corporation. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC.

Logan, J., 1983. Nitrogen oxides in the troposphere: global and regional budgets. *Journal of Geophysical Research* (**88**): 10,785.

Milich, L., Boehm, T., Coats, C., Eichinger, J., Fudge, S., Jordan, D., Maxwell, C., Olerud, D., Tang, R., Van Meter, A., Wayland, R., and Young, J., 1990. *The Regional Oxidant Model (ROM) User's Guide.* In preparation, U.S. Environmental Protection Agency, Research Triangle Park, NC. J. Novak, Technical Monitor.

Modica, L., D. Dulleba, R. Walters, and J. Langstaff, 1988. *Flexible Regional Emissions Data System (FREDS) Documentation for the 1985 NAPAP Emissions Inventory.* Prepared by Alliance Technologies Corporation for the U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

Morris, R.E., T.C. Myers, and J.L. Haney, 1990a. *User's Guide for the Urban Airshed Model. Volume I: User's Manual for the UAM(CB-IV).* EPA-450/4-90-007A. Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Morris, R.E., T.C. Myers, E.L. Carr, M.C. Causley, S.G. Douglas, and J.L. Haney, 1990b. *User's Guide for the Urban Airshed Model. Volume II: User's Manual for the UAM(CB-IV) Modeling System (Preprocessors).* EPA-450/4-90-007B. Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Novak, J.H., and J.A. Reagan, 1986. *A comparison of natural and man-made hydrocarbon emission inventories necessary for regional acid deposition and oxidant modeling*, paper 86-30. In: Proceedings of the 79th Annual APCA Meeting. APCA, Pittsburgh, PA.

Olson, R., C. Emerson, and M. Nunsgesser, 1980. *GEOECOLOGY: A County-Level Environmental Data Base for the Conterminous United States,* ORNL/TM-7351, Oak Ridge National Laboratory, Oak Ridge, TN, 54 p.

Pagnotti, V. 1987. A meso-meteorological feature associated with high ozone concentrations in the northeastern United States. *Journal of the Air Pollution Control Association*, **37**(6): 720-722.

Pechan, E.H. and Associates, 1989. *ERCAM-VOC: Description and Applications.* Prepared for the U.S. Environmental Protection Agency Office of Policy, Planning and Evaluation (EPA Contract No. 68-01-7047, Work Assignment No. 126).

Peterson, E. and D. Tingey, 1980. An estimate of the possible contributions of biogenic sources to airborne hydrocarbon concentrations. *Atmos. Environ.* **(14)** 1: 79.

Pierce, T.E., and K.L. Schere, 1988. *Regional ozone modeling: An investigation of hydrocarbon emissions from treatment, storage, and disposal facilities on ambient levels of ozone.* Internal Report, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Pierce, T., B. Lamb, and A. Van Meter, 1990. Development of a biogenic emissions inventory system for regional scale air pollution models. In: *Proceedings of the 83rd Air Waste Management Association Annual Meeting*, Pittsburgh, PA, June 24 - 29, 1990; 16 p.

Pierce, T.E., K.L. Schere, D.C. Doll, and W.E. Heilman, 1990. *Evaluation of the Regional Oxidant Model (Version 2.1) using ambient and diagnostic simulations.* Draft Report, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Possiel, N.C., J.A. Tikvart, J.H. Novak, K.L. Schere, and E.L. Meyer, 1989. *Evaluation of ozone control strategies in the northeastern region of the United States.* In: Proceedings of the Third U.S.-Dutch International Symposium on Atmospheric Ozone Research and Its Policy Implications, May 9-13 1988, Nijmegen, The Netherlands. Elsevier, The Netherlands, pp. 623-632.

Rao, S.T., G. Sistla, J.Y. Ku, R. Twaddell, R. Whitby, V. Pagnotti, E. Davis, N. Possiel, J. Pearson, K. Schere, and R. Dennis, 1987. Examination of the Urvan Airshed model performance in the New York metropolitan area. *Proceedings*, 80th Annual A.P.C.A. Meeting, New York, NY, 22 - 26 June, 1987. Paper no. 87-71.8, Air Pollution Control Association, Pittsburgh, PA.

Rasmussen, R., 1972. What do the hydrocarbons from trees contribute to air pollution? *Journal Air Pollution Control Association* **(22)** 7: 537.

Roselle S. and K. Schere, 1990. Sensitivity of the EPA Regional Oxidant Model to biogenic hydrocarbon emissions. In: *Proceedings of the 83rd Air Waste Management Association Annual Meeting*, Pittsburgh, PA, 1990, 20 p.

Saeger, M., J. Langstaff, R. Walters, L. Modica, D. Zimmerman, D. Fratt, D. Dulleba, R. Ryan, J. Demmy, W. Tax, D. Sprague, D. Mudgett, A. Werner, 1989. The NAPAP Emissions Inventory (Version 2): Development of the Annual Data and Modeler's Tapes. EPA-600/7-89-012a, U.S. Environmental Protection Agency, Research Triangle Park, NC.

SAS Institute Inc. 1985. *SAS User's Guide:* Basics, Version 5 Edition. SAS Institute Inc., Cary, NC.

Schere, K.L., 1986. *EPA Regional Oxidant Model: ROM 1.0 evaluation for 3-4 August 1979.* EPA-600/3-86/032, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Schere, K.L., 1986. *Evaluating O_3 predictions from a test application of the EPA Regional Oxidant Model.* In: Proceedings of the Fifth Joint Conference on Applications of Air Pollution Meteorology, November 18-21 1986, Chapel Hill, NC. AMS, Boston, MA, pp. 61-64.

Schere, K.L., and A.J. Fabrick, 1985. *EPA Regional Oxidant Model: Description and evaluation plan.* EPA-600/3-85/067, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Schere, K.L., and J.H. Novak, 1986. *Regional oxidant modeling of the northeast U.S.* In: C. DeWispelaere *et al.*, eds. Air Pollution Modeling and Its Application, V - Vol. 10. Plenum Press, NY, pp. 45-59.

Schere, K.L., and N.P. Possiel, 1984. *U.S. EPA Regional Oxidant Model - Background and overview,* paper no. 84-47.2. In: Proceedings of the 77th Annual APCA Meeting, June 25-29 1984, San Francisco, CA. APCA, Pittsburgh, PA.

Schere, K.L., and R.A. Wayland, 1989. *Development and evaluation of the Regional Oxidant Model for the northeastern United States.* In: Proceedings of the Third U.S.-Dutch International Symposium on Atmospheric Ozone Research and Its Policy Implications, May 9-13 1988, Nijmegen, The Netherlands. Elsevier, The Netherlands, pp. 613-622.

Schere, K.L., and R.A. Wayland, 1989. *EPA Regional Oxidant Model (ROM 2.0): Evaluation on 1980 NEROS databases.* EPA-600/3-89/057, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Tang, R.T., S.C. Gerry, J.S. Newsom, A.R. Van Meter, R.A. Wayland, J.M. Godowitch, and K.L. Schere, 1990. *User's Guide for the Urban Airshed Model. Volume V: Description and Operation of the ROM-UAM Interface Program System.* EPA-450/4-90-007E. Prepared for the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Tingey, D., M. Manning, L. Grothaus *et al.,* 1980. Influence of light and temperature on monoterpene emission rates from slash pine. *Plant Physiol.* (**65**): 797.

Tingey, D., 1981. *Atmospheric Biogenic Hydrocarbons.* J. Bufalini and R. Arnts, eds., Ann Arbor Science Publications, Ann Arbor, MI, pp. 53-79.

Tingey, D., R. Evans, and M. Gumpertz, 1981. Effects of environmental conditions on isoprene emissions from live oak. *Planta* (**152**): 565.

Trainer, M., E. William, D. Parrish *et al.,* 1987. Models and observations of the impact of natural hydrocarbons on rural ozone. *Nature* (**329**): 705.

Wagner, J., R. Walters, L. Maiocco, and D. Neal, 1986. *Development of the 1980 NAPAP Emissions Inventory.* EPA-600/7-86-057a, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711.

Walters, R., L. Modica, and D. Fratt, 1988. *1985 NAPAP Emissions Inventory Allocation Factors.* Prepared by Alliance Technologies Corporation for the U.S. Environmental Protection Agency, Research Triangle Park, NC 27711

Whitten, G.Z., and M.W. Gery, 1986. *Development of CBM-X mechanisms for urban and regional AQSMs.* EPA-600/3-86/012, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Young, J.O., M. Aissa, T.L. Boehm, C.J. Coats, J.R. Eichinger, S.J. Roselle, A.R. Van Meter, R.A. Wayland, and T.E. Pierce, 1989. *Development of the Regional Oxidant Model, Version 2.1.* EPA/600/3-89/044. (NTIS PB89-194252). Atmospheric Research and Exposure Assessment Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Zimmerman, P., 1979. *Determination of Emission Rates of Hydrocarbons from Indigenous Species of Vegetation in the Tampa Bay/Petersburg, Florida area,* EPA-904/9-77-028. U.S. Enviromental Protection Agency, Atlanta, GA, 173 p.