ENVIRON

MEMORANDUM

To: The EPA Source Attribution Workshop Peer Review Panel

From: Greg Yarwood and Ralph Morris

Date: June 27, 1997

Subject: Description of the CAMx Source Attribution Algorithms

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This memorandum describes the source attribution algorithms developed by ENVIRON and implemented in the Comprehensive Air Quality Model with extensions, or CAMx.
These materials have been developed for the EPA Source Attribution Workshop to be held in RTP on July 16-18, 1997. The invitation to participate in the workshop (letter from Dr. Robert J. Wayland of June 4, 1997) raised 14 issues for participants to consider. We have addressed all of these issues in this memorandum. To present information in an orderly and logical manner, the memorandum is organized the under the following headings:

1. Overview of Methods
2. Scientific Basis, Assumptions and Limitations
3. Requirements For Using CAMx
4. Availability
5. Relationship to Other Methods
6. Recommendations for Further Work
7. References

In addition, the following supplemental materials are referenced in the memorandum and are attached:

1. User's Guide to the Ozone Tool
2. User's Guide to the CAMx
3. Peer-Review of ENVIRON's Ozone Source Apportionment Technology and the CAMx Air Quality Model
4. Cinergy Report -"Ozone Source Apportionment Modeling Using the July 1991 OTAG Episode for the Northeast Corridor and Lake Michigan Regions".
5. Ohio EPA Report - "Description of the CAMx and Ozone and PM Source Apportionment".
6. Review of Potential Technical Approaches to Ozone Source Apportionment
7. Methodology for a PM Source Apportionment Technology (PSAT)

There is some redundancy in some of the supplemental materials and we apologize to the reviewers for any inconvenience this causes. However, each supplemental report contains unique specific information on the ozone source allocation schemes that we felt would aid the reviewers in fully understanding our approaches.

1. OVERVIEW OF THE METHOD

Objectives

Photochemical grid models, such as CAMx, are used to design control strategies for reducing emissions of VOCs and NO_X to achieve ozone air quality standards. Developing an effective ozone attainment strategy involves many cycles of changing the emission inventory and then re-running the photochemical grid model to determine which geographical source areas, source categories, and pollutant types (i.e., VOC and NO_X) should be controlled to effectively reduce ozone. The difficulty in carrying out this task has been illustrated recently in the OTAG process. For OTAG, several modeling centers performed many hundreds of model runs over a period of more than a year to develop sufficient information to design regional control strategies. The same modeling challenges faced by OTAG will soon be faced by many States (and regional groupings of States and/or stakeholders) in developing regional/sub-regional/urban scale control strategies for ozone and other pollutants. Similarly, powerful modeling and/or ambient data analyses are needed to help define appropriate geographical areas over which control strategy development activities should be coordinated (i.e., performing area of influence/area of violation, or AOI/AOV, analyses). In this context, the need is clear for new methodologies that will improve the efficiency, clarity and effectiveness of such planning activities.

The type of modeling analyses performed by OTAG may be thought of as laboriously mapping out the relationships between ozone and groups of emission sources by means of a long series of sensitivity tests. Because photochemical grid model simulations are computionally demanding, not all permutations of controls can be analyzed by this approach and the potential exists for controlling sources that contribute little to the high ozone concentrations or, conversely, not controlling sources that do contribute significantly. The Ozone Source Apportionment Technology (OSAT) was developed by ENVIRON to address this issue by providing modelers with a means of estimating the contributions of many different source areas/categories/types to ozone formation in a *single model run*. OSAT is a diagnostic tool that extracts much more information from the host model without in any way changing the underlying simulation. Since the cost-effectiveness of control strategies might be enhanced in some cases by temporally targeting control measures, OSAT also includes a methodology for diagnosing the temporal relationships between ozone and emissions from groups of sources. OSAT is directly applicable to model performance evaluation, culpability assessments, AOI/AOV analyses, and control strategy design.

OSAT was first implemented in the UAM-IV (see the attached User's Guide to the Ozone Tool) and then in the CAMx (see the attached User's Guide to the CAMx). As described further below, there are now several variations to the OSAT methodology available in CAMx.

The ozone source attribution methods described here were developed to provide estimates of source culpability so that grid models can be used more effectively as a planning tool. They do not provide a "true source apportionment" of grid model ozone concentrations: We believe that because ozone formation is a non-linear process involving multiple precursors there is no single, unique ozone source apportionment to be had. This caveat applies in some form to all ozone source attribution analyses, including the current methodology of performing multiple sensitivity analyses. However, the fact that relationships between ozone and precursors are non-linear does not negate the many advantages of having powerful diagnostic tools such as OSAT to help understand the factors driving ozone formation in grid models.

Technical Approach

The OSAT uses multiple tracer species to track the fate of ozone precursor emissions (VOC and NO_X) and the ozone formation caused by these emissions within a CAMx simulation. The tracers operate as spectators to the normal CAMx calculations so that the underlying CAMx predicted relationships between emission groups (sources) and ozone concentrations at specific locations (receptors) are not perturbed. Tracers of this type are conventionally referred to as "passive tracers," however it is important to realize that the tracers in the OSAT track the effects of chemical reaction, transport, diffusion, emissions and deposition within the CAMx. In recognition of this, they are described here as *"ozone reaction tracers."* The ozone reaction tracers allow ozone formation from multiple "source groupings" to be tracked simultaneously within a single simulation. A source grouping can be defined in terms of geographical area and/or emission category. Figure 1 provides an example of the way that a CAMx domain (this figure shows TNRCC's regional modeling application) can be sub-divided into multiple source areas -- 10 in this example. Also, the emission inventory could be sub-divided into several source categories -- four emission categories over 10 source regions would produce 40 separate source groupings. So that all sources of ozone precursors are accounted, the boundary conditions (BCs) and initial conditions (Ics) are always tracked as separate source groupings (BCs can be optionally configured as one group covering all boundaries, or five separate groups for the N, S, E, W and top boundaries). The methodology is designed so that all ozone and precursor concentrations are attributed among the selected source groupings at all times. Thus, for all receptor locations and times, the ozone, VOC and NO_X concentrations predicted by the UAM are attributed among the source groupings selected for the OSAT run. The methodology also estimates the fractions of ozone arriving at the receptor that were formed en-route under VOC- or NO_X-limited conditions. This information indicates whether ozone concentrations at the receptor will respond more to reductions in VOC or NO_X precursor emissions.

In addition to using ozone reaction tracers to apportion ozone formation, the OSAT has the capability to use separate families of *"timing tracers"* to allow source-receptor transport times to be estimated. Unique timing tracers are released from each geographical area selected for ozone source apportionment. Thus, if the ozone formation tracers show that emissions from a given source area contributed to ozone, VOC or NO_X at any receptor of interest, the timing tracers can then be used to estimate the time at which the emissions were released. This provides a way of investigating temporal features of the source-receptor relationships for ozone and ozone precursors.

The formulation of OSAT is described above because it was first methodology implemented by ENVIRON and is the most widely used to date. Several variations on OSAT are now available that differ in using different algorithms to attribute ozone contributions. One advantage of the coding framework for OSAT is that it allows for easy modification of the source attribution algorithm by modifying a single subroutine. The methods currently available in CAMx are described below (other options are possible).

OSAT stands for Ozone Source Apportionment Technology, and as described above, OSAT attempts to track ozone formation based on how groups of ozone precursors contributed to ozone formation. Thus, OSAT decides whether ozone formation is NOx or VOC limited in each grid cell at each time step, and bases ozone attributions on the relative amounts of the limiting precursor from different sources that are present in that grid cell at that time step. These incremental ozone attributions are integrated throughout the model run

GOAT stands for Geographic Ozone Assessment Technology. GOAT does not attempt to trace ozone production back to the source of the precursors, but rather ozone formation is tracked based on the geographic location where it occurred. Thus ozone formation in a grid cell over “Area A” would be attributed to Area A even if the culpable emissions originated upwind in Area B. The disadvantage of GOAT is its simplistic assumption regarding the basis for ozone culpability. The advantages of GOAT are its freedom from assumptions about whether ozone formation is NOx or VOC limited, and that its results may be more directly comparable to other emerging source attribution methodologies (e.g., trajectories, tracers and possibly the spatial analysis component of process analysis)

OPPAT stands for Ozone Precursor Participation Assessment Technology, and differs from OSAT in that ozone formation is always tracked back to both the VOCs and NOx that participated. This sacrifices obtaining information on whether VOCs or NOx are limiting ozone formation (and therefore which pollutant would be a more effective control path), but always tells you how both the NOx and VOCs from each emission group are participating in ozone formation. OPPAT is useful to obtain a complete picture of how emissions from different groups are interacting to form ozone.

APCA stands for Anthropogenic Precursor Culpability Assessment, and differs from OSAT in recognizing that certain emission groups are not controllable (e.g., biogenic emissions) and that apportioning ozone production to these groups does not provide control strategy relevant information. To address this, in situations where OSAT would attribute ozone production to non-controllable (i.e., biogenic) emissions, APCA re-allocates that ozone production to the pre-cursors that participated in ozone formation along with the non-controllable precursor. So in the case when biogenic emissions are the uncontrollabel source category, APCA would only attribute ozone production to biogenic emissions when ozone formation is due to the interaction of biogenic VOC with biogenic NOx. When ozone formation is due to biogenic VOC and anthropogenic NOx under VOC-limited conditions so that OSAT would attribute ozone production to biogenic VOC's, APCA would re-direct that attribution to the anthropogenic NOx precursors present. The result of using APCA instead of OSAT would be more ozone formation attributed to anthropogenic NOx sources and less ozone formation attributed to biogenic sources. APCA is not really a "source apportionment" technique because it expresses biases as to which sources should be implicated (i.e., those that are controllable), hence it is referred to as a "culpability assessment."

Example Applications

Here we describe results for several CAMx applications to illustrate the applicability of OSAT to:

- model performance evaluation
- culpability assessments
- control strategy design
- AOI/AOV analyses

TNRCC Regional Modeling. In recent work for the State of Texas, ENVIRON used OSAT in CAMx to identify the contribution of emissions from different geographic areas to ozone concentrations at the boundaries of the COAST domain (Yocke et al., 1996). Some of these results are briefly reviewed here. For the source apportionment of the TNRCC regional modeling of August 16 - September 9, 1993, the domain was divided into 10 geographic areas as shown in Figure 1. OSAT was used to track the contributions of emissions in each of these areas to ozone, VOCs and NOx. An illustration of geographic ozone source apportionment is shown in Figures 2-4 for 2 pm on August 26, 1993. This hour is selected because it coincides with the time at which the model showed a significant area of elevated ozone concentrations moving on-shore near Victoria, to the southwest of Houston. This area can be seen in Figure 2 which shows the hourly ozone for 2 pm on August 26, 1993 -- it is in the center of the dashed box which marks the COAST domain boundary. OSAT was used to identify which geographic areas contributed to this area of high ozone. Figures 3 and 4 show the area of influence on ozone concentrations of emissions from regions 1 and 9 (the COAST domain and the eastern Gulf Coast, respectively, as shown in Figure 1). Figures 3 and 4 show that this ozone is associated with emissions from the eastern Gulf Coast as well as local (COAST domain) emissions.

Figures 3 and 4 present a "*source-oriented*" view of ozone source-receptor relationships; an alternate "*receptor oriented*" view of this same information is shown in Figure 5 for a receptor placed at Victoria one hour later (3 pm on August 26). The pie chart at top right shows the relative contributions of different geographic areas plus boundary and initial concentrations to the 90 ppb of ozone at the receptor, and areas 1 and 9 (COAST domain and the eastern Gulf Coast, respectively) are the major contributors. (The 18% contribution of BCs in Figure 6 corresponds to about 16 ppb, showing the extent to which the 40+ ppb BCs for the regional domain have been attenuated by the time they reach Victoria).

Information such as that shown in Figure 5 for a single hour also can be shown as a time-series for the duration of an ozone episode. This is illustrated in Figures 6 and 7 which are for a "receptor" defined as a "wall of cells" along the northern boundary of the COAST domain (i.e., the receptor is an average of all grid cells in all layers along the north boundary of the COAST domain). The contribution of all 10 geographic areas plus boundary and initial concentrations to this receptor are shown for August 16-21 in Figure 6, and September 6-11 in Figure 7. Differences in meteorology between these two time periods lead to quite different geographic contributions to ozone at this receptor: during the August period winds were from the south and the north boundary receptor is influenced by outflow from the COAST domain and regional domain BCs (almost certainly from the south boundary of the regional domain, although this could be verified by turning on the OSAT "stratify by boundary" source apportionment option). During the September period, contributions from areas to the north of the COAST domain are seen through most of the period, switching to contributions from the COAST domain at the end of the period shortly after prevailing winds reverse from Northerly to Southerly.

Ozone Culpability Assessment and Control Strategy Development. The ozone allocation schemes that have been developed (GOAT, OSAT, OPPAT, and APCA) have been used to assess different regions and source categories contribution (culpability) to elevated ozone concentrations in key nonattainment regions. Such information is useful to guide the development of optimally effective control strategies. In fact, the original development of the OSAT was for the South Coast Air Quality Management District (SCAQMD) to aid in developing ozone control plans for the Los Angeles region. As part of the OTAG process, the CAMx with several of the different ozone allocation schemes has been applied to assess the contributions of different regions (e.g., "states") to elevated ozone concentrations. Attached with this write up is a document prepared for the Ohio EPA (Attachment 5) which discusses one such ozone culpability assessment using the CAMx OSAT and the July 1991 OTAG episode. Figure 8 below shows an example of the ozone culpability of different source regions to the peak ozone concentration in Baltimore on July 18, 1991. The OSAT results suggest that over 50 percent of the ozone peak on this day is due to anthropogenic emissions from the Northeast Corridor and that such ozone is formed mainly under NOx-limited conditions. Thus, the OSAT results suggest that controlling NOx emissions in the Northeast Corridor would be the most effective strategy for reducing the peak ozone concentration in Baltimore on this day. More details of this application of the OSAT are provided in the Attachment prepared for the Ohio EPA, including the integrated assessment of the contributions of different geographic regions to elevated ozone concentrations across the episode.

OTAG Area of Influence Analysis. The CAMx OSAT has also been used to perform Area of Influence (AOI) analysis of the contribution of emissions to ozone exceedances in key ozone nonattainment areas as a function of distance from the ozone nonattainment area. The attached report “Ozone Source Apportionment Modeling using the July 1991 OTAG Episode for the Northeast Corridor and Lake Michigan Regions” prepared for Cinergy Corporation provides details of the CAMx AOI analysis for the Northeast Corridor and Lake Michigan nonattainment areas (abbreviated discussion of some of these results are also contained in the Ohio EPA Attachment). AOI modeling analysis was also performed for the Atlanta nonattainment area for Southern Company Services (SCS). In the CAMx AOI analysis, the OSAT was used with geographic source regions that were a function of distance from the ozone nonattainment area under study. Starting with the nonattainment region as the first geographic source region, concentric rings of source regions were added around the nonattainment area whose thickness started at 50 km and got larger the further away from the nonattainment area the rings were. Spokes were added to the concentric rings to add directionality of transport in the AOI assessment (e.g., assess transport to the Northeast from the Midwest versus from the South). Figure 9 displays one of the results from the CAMx OSAT AOI analysis, the scale of influence of anthropogenic emission contributions to ozone greater than 100 ppb in three key nonattainment regions: Northeast Corridor, Lake Michigan, and Atlanta. This figure clearly illustrates that the AOI of emissions to elevated ozone concentrations varies by geographic region. The Atlanta area has the shortest AOI with 90 percent of the elevated ozone produced by anthropogenic emissions (SCALE90) coming from emissions within approximately 300 km of the nonattainment area. Lake Michigan has the largest AOI with 90 percent of the elevated ozone concentrations in the Lake Michigan nonattainment area coming from emissions within approximately 650 km. The Northeast Corridor AOI falls between the two with a SCALE90 AOI value of a little under 400 km.

Applicability to Workshop Issues: Ozone and PM

As demonstrated above, ENVIRON’s Ozone Source Apportionment Technology (OSAT) implemented in CAMx is directly applicable to many workshop issues as they relate to ozone, including:

- model performance evaluation
- culpability assessments
- AOI/AOV analyses
- control strategy design

The methodologies used in OSAT are also applicable to Particulate Matter (PM) modeling and the related issues of visibility and acid deposition. The same approaches used in OSAT to track secondary pollutant formation from primary emissions within a grid model framework can be used with the emerging generation of advanced PM grid models. The methodology for performing this task, called PSAT (PM Source Apportionment Technology), is described in the attached document *"Methodology for a PM Source Apportionment Technology (PSAT)."*

State of the science PM grid models (such as the UAM-AERO and GATOR, which employ a size-section approach to resolve PM size distributions and have a detailed PM chemistry module) are extremely computationally intensive to run. Thus, a source apportionment methodology such a PSAT that can leverage extra information from the expensive PM model calculations will be greatly enhance the feasibility of using such models, indeed it may be essential.

The existing OSAT methodology can be used for source apportionment of inert pollutants, and we have already used OSAT for geographic source apportionment of CO in a UAM-IV simulation using the Ozone Tool (the Ozone Tool is OSAT implemented in UAM-IV).

2. SCIENTIFIC BASIS, ASSUMPTIONS AND LIMITATIONS

A detailed description of the technical formulation of the OSAT (i.e., its scientific basis) is provided in the Ozone Tool User's Guide (Yarwood et al., 1996a) attached to this memorandum.

Peer-Review

Sonoma Technology (STI) recently completed an independent peer-review for the Ohio EPA of the OSAT and CAMx formulations with the goal of reviewing the "technical formulation of the ozone source apportionment technology that is implemented in the CAMx." STI's review is included as an attachment. The main conclusions of the review were that the "review of the OSAT and its underlying assumptions did not reveal any assumptions that are inconsistent with the current scientific understanding of the relevant processes. The OSAT apportionment model is technically sound, although its results are approximate and are not unique." We agree that OSAT is only an approximation, but would add that all other approaches to ozone source apportionment (including the current de-facto approach of running multiple sensitivity simulations) must also be approximations since, we believe, there is no unique ozone source apportionment.

Assumptions and Limitations

Since OSAT (and the related methods GOAT, OPPAT and APCA) are based on a photochemical grid model, OSAT inherits all of the assumptions of a modern photochemical grid model, such as CAMx. Since the goal of OSAT is to aid in the effective use of photochemical grid models, this is not necessarily a limitation.

The major assumptions in OSAT are related to tracing the sources contributing to ozone formation back to precursor sources, i.e., making the link between ozone tracers and precursor tracers. These assumptions are related to apportioning culpability between VOCs and NOx, and accounting for the reactivity of VOCs from different source groups. Other methods that attempt to track ozone culpability back to precursor sources will face these same issues.

GOAT is unique among the methods described above in that it avoids making any assumptions about how ozone is related to precursor sources since ozone attributions are based only on where the ozone was formed. In this regard, GOAT appears to be more comparable than OSAT to several other ozone source attribution methods currently being considered. GOAT may be an adequate tool for coarse resolution geographical analysis of regional scale domains, but GOAT does not get to the heart of the ozone source attribution problem, namely, identifying which precursors are culpable. Because of its simplicity and freedom from assumptions, GOAT may be useful for evaluating other methods.

In OSAT and APCA, the apportionment of culpability between VOCs and NOx is based on whether the ozone formation process is locally NOx or VOC limited for that grid cell and time step. VOC versus NOx limitation is distinguished by looking at the relative production rates of nitric acid and hydrogen peroxide which are sensitive to the fate of radicals. In their peer-review of the OSAT, STI performed an extensive series of tests which confirmed that this method is sound, but suggested changing the threshold from P_{H2O2}/P_{HNO3} from 0.35 to a value between 0.05 and 0.2. STI's analyses and recommendations seem reasonable, however the effect of making such a change appears likely to be fairly small -- a small shift (5 to 10%) in ozone formed under VOC-limited conditions to ozone formed under NOx-limited conditions.

STI also reviewed the OSAT methodology for tracking the contributions of VOCs from different source groups using a single reactivity weighted tracer. This assumption allows OSAT to efficiently track many separate source groups, but it may not distinguish reactivity differences very well depending upon how source groupings are defined. For this reason, OSAT is generally applied with biogenic emissions treated as a separate source grouping because they have much higher specific reactivity than most other emissions.

3. REQUIREMENTS FOR USING CAMx

Additional Data

To use OSAT in CAMx you need a photochemical modeling database that is compatible with CAMx, such as the OTAG database. Beyond this, the input file requirements for OSAT are minimal. There are three types of additional data needed to use OSAT:

Source area mapping. OSAT can apportion ozone and ozone precursor concentrations among several geographic regions within the modeling domain, as shown in Figure 1. The "source area mapping" file identifies which region each surface grid cell is a member of. The format of the file is an ASCII array of integer number (i3) specifying which cells are members of each geographic region. An example file is shown in section 4 of the attached Ozone Tool User's Guide.

Extra emission files. OSAT can apportion ozone and ozone precursor concentrations among multiple emission categories. Emission categories are defined by supplying extra emissions files in the standard emission file format. The usual way emission inventories are processed is as separate components which are then merged. Thus, the following emission categories can generally be resolved with no additional emissions processing effort: biogenics, elevated points, motor vehicles and other anthropogenic emissions. With special emissions processing, source apportionment could be carried down to individual sources.

Receptor definition. OSAT tracer concentrations for selected receptor locations are output to an ASCII file every hour. This ASCII file is processed by a post-processor (implemented in Microsoft Excel) to produce graphics like that shown in Figure 5. The receptors for each model run are defined in an ASCII "Receptor definition" input file. An example file is shown in section 4 of the attached Ozone Tool User's Guide.

Portability to Different Computer Platforms

CAMx is coded in Fortran using modern structured coding practice. As such, it is easily adaptable to any modern computer platform. To date, CAMx has been run on UNIX workstations including SGI, DEC, IBM and Sun.

One issue that has been encountered by UAM users with DEC Alpha workstations is an incompatibility in binary file formats compared to other UNIX workstations. CAMx has been coded so that DEC Alpha users can read and write binary files in the same format as most other UNIX workstations. Thus, CAMx is completely portable to DEC workstations.

Level of Expertise Required

The level of expertise required to use OSAT is the same as required to use any modern photochemical grid model, such as CAMx. In terms of computer experience, the additional input files needed to configure OSAT (described above) are easily prepared using standard workstation tools as simple as a text editor. CAMx output can be post-processed using the same tools as are used to visualize the standard CAMx outputs (e.g., PAVE). In terms of photochemical modeling experience, users should be familiar with grid modeling concepts. However, since OSAT helps with the interpretation of model results by providing easily comprehended diagnostic information, it probably is easier to interpret CAMx results with OSAT than without.

Computational Requirements

The computational requirements for running OSAT are comparable to those for running a modern, efficient photochemical grid model such as CAMx:

- A UNIX workstation is ideal.
- A fast PC is adequate for an urban scale application.
- Super-computers are not required.

As an example, for the CAMx application to the OTAG regional domain, the core model without OSAT requires about 100 MB of memory (RAM) and a couple of hours of CPU time per simulated day on our UNIX workstation. Adding OSAT with 19 geographic areas and 3 emission categories (i.e, 59 separate groups, remembering to count ICs and BCs) increases memory requirement to about 500 MB and CPU time to about 10 hours per simulated day. Considering that in this case OSAT provides about 120 times more information about ozone (i.e., ozone attributed to VOC and NOx from each of 59 groups) than the standard CAMx run in about 5 times the run rime, OSAT is providing a "*leverage*" of about 20 (where leverage is increase in information divided by increase in run time). In considering the CPU times and memory requirements given here for OTAG runs, remember that OTAG is a large, nested regional domain: computer requirements will be proportionately less for smaller domains.

Software Requirements

The software requirements are the same as for running CAMx. At a minimum, a Fortran compiler. Microsoft Excel is needed to use the OSAT receptor file post-processor that prepares graphics like Figure 5.

4. AVAILABILITY

Code Availability

CAMx (including OSAT) is available under license to *any* interested party. We understand that license agreements are a contentious issue in the photochemical modeling community right now. Our intention in using a license agreement is not to restrict the availability of CAMx, on the contrary, we would like to see CAMx widely used, so long as our investment in developing CAMx is not abused. The main points in the CAMx license agreement are summarized below:

What you can do with CAMx:

- You can use CAMx for any model application that you are interested in; you do not need to modify your license for each new application.

- You can modify the CAMx source code for your own internal purposes.

What you can not do with CAMx:

- You can not distribute the CAMx source code to third parties in either original or modified form. Third parties can obtain CAMx directly from ENVIRON.

The license agreement allows you to modify CAMx for your own purposes, but not to distribute that modified code. However, if you develop a modification to CAMx that you are interested in distributing, ENVIRON would be happy to develop a cooperative distribution arrangement that protects both your and our intellectual property. To make CAMx widely available, license fees have been set at a low level that covers distribution costs only (if we can send you CAMx over the Internet, the fee is zero).

Documentation and Reports

The User's Guides describing CAMx and OSAT are freely available from ENVIRON in electronic format as Adobe Acrobat portable documents (.pdf files). In a few weeks they should be available for download from the CAMx web page at *www.camx.com* -- coming soon.

The AWMA paper describing OSAT (Yarwood et al., 1996) is available from AWMA or ENVIRON.

The STI "Peer-Review of ENVIRON'S Ozone Source Apportionment Technology and the CAMx Air Quality Model" is available from the Ohio EPA.

The reports describing applications of CAMx and/or OSAT referred to here are available from the sponsoring agencies, as indicated in the reference list below.

5. RELATIONSHIP TO OTHER METHODS

It is difficult for us to comment specifically on any potential relationships between our approach and some of the other approaches being presented at the workshop in advance of learning the details of those approaches at the workshop. However, when OSAT was first developed we evaluated several potential approaches to source attribution of ozone concentrations, and this evaluation was included in our report on the development of the method (Yarwood et al., 1996b).

This review is included here as the attachment "*Review of Potential Technical Approaches to Ozone Source Apportionment.*"

Process Analysis

We would like to comment on the relationship between our methodology and Harvey Jeffries "Process Analysis." We believe that these two methods are complementary and show great potential for application together. Harvey has described our methodology as a "forward method" and his as a "backward method," meaning that ours runs forward in time within the host model and his runs backward in time by post-processing information output from the model: This seems to us like a useful distinction. A consequence of the forward methodology of OSAT is that source apportionment information is provided simultaneously for the whole grid system. Thus, many receptors can be examined in a single run, and any locations that were not identified as a receptor before the run was performed can be added in later by post-processing the gridded output files. Because of this flexibility, OSAT is a powerful tool for surveying the whole model to identify key receptor and source locations. Once locations have been identified for study, Process Analysis provides a powerful tool for investigating processes impacting ozone at those receptors in detail, including looking into the chemistry in detail. Thus, using OSAT to help select target analysis regions is one area in which we see great synergistic potential for the OSAT and Process Analysis techniques.

Since some of the capabilities of OSAT and Process Analysis seem to be quite similar, another potential synergy between the techniques is method evaluation and the development of new enhanced methods. It seems certain that there is much to be learned from a side-by-side application of OSAT and Process Analysis.

6. RECOMMENDATIONS FOR FURTHER WORK

We can suggest two areas where further work would be beneficial, further development and evaluation of ENVIRON's methods and inter-comparisons with other methods.

Further Developments of ENVIRON's Methods

- Inter-comparisons of results from the different algorithms currently available in CAMx for ozone source attribution: GOAT, OSAT, APCA.

- Further evaluation of CAMx ozone source apportionment results against grid model targeted control strategies.

- Sensitivity evaluation of OSAT to different assumptions for distinguishing VOC from NOx limitation, and alternate schemes for tracking VOC reactivity.

- Implementation of the proposed source apportionment method for PM (PSAT).

Methods Inter-comparison

- Development of standard problems that can be used for evaluation and inter-comparison of different methods.

- Side-by-side application of methods with comparable abilities, e.g., OSAT and Process Analysis

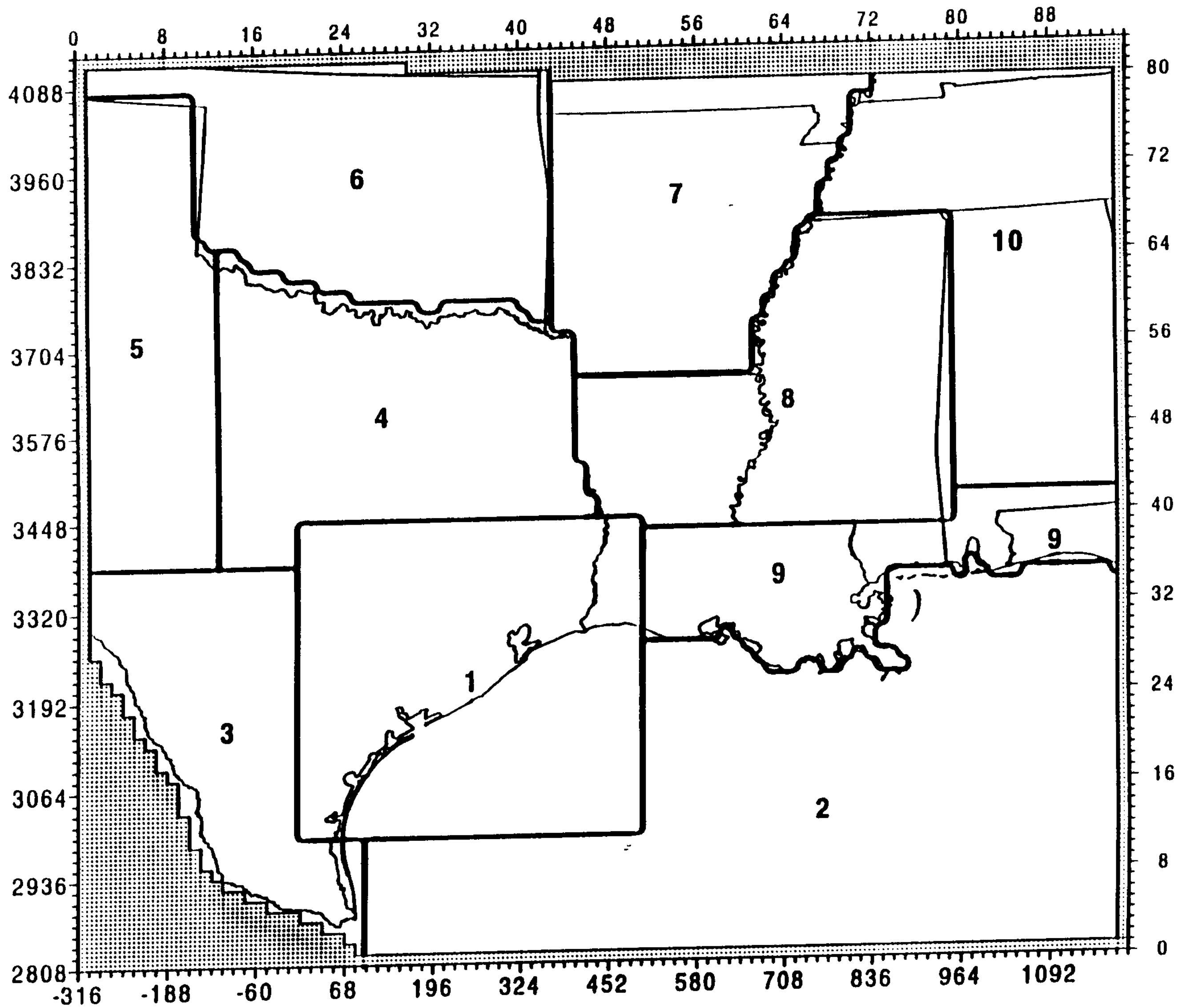


Figure 1. Map of the TNRCC Regional Domain Showing Geographical Source Areas used for CAMx Source Apportionment.

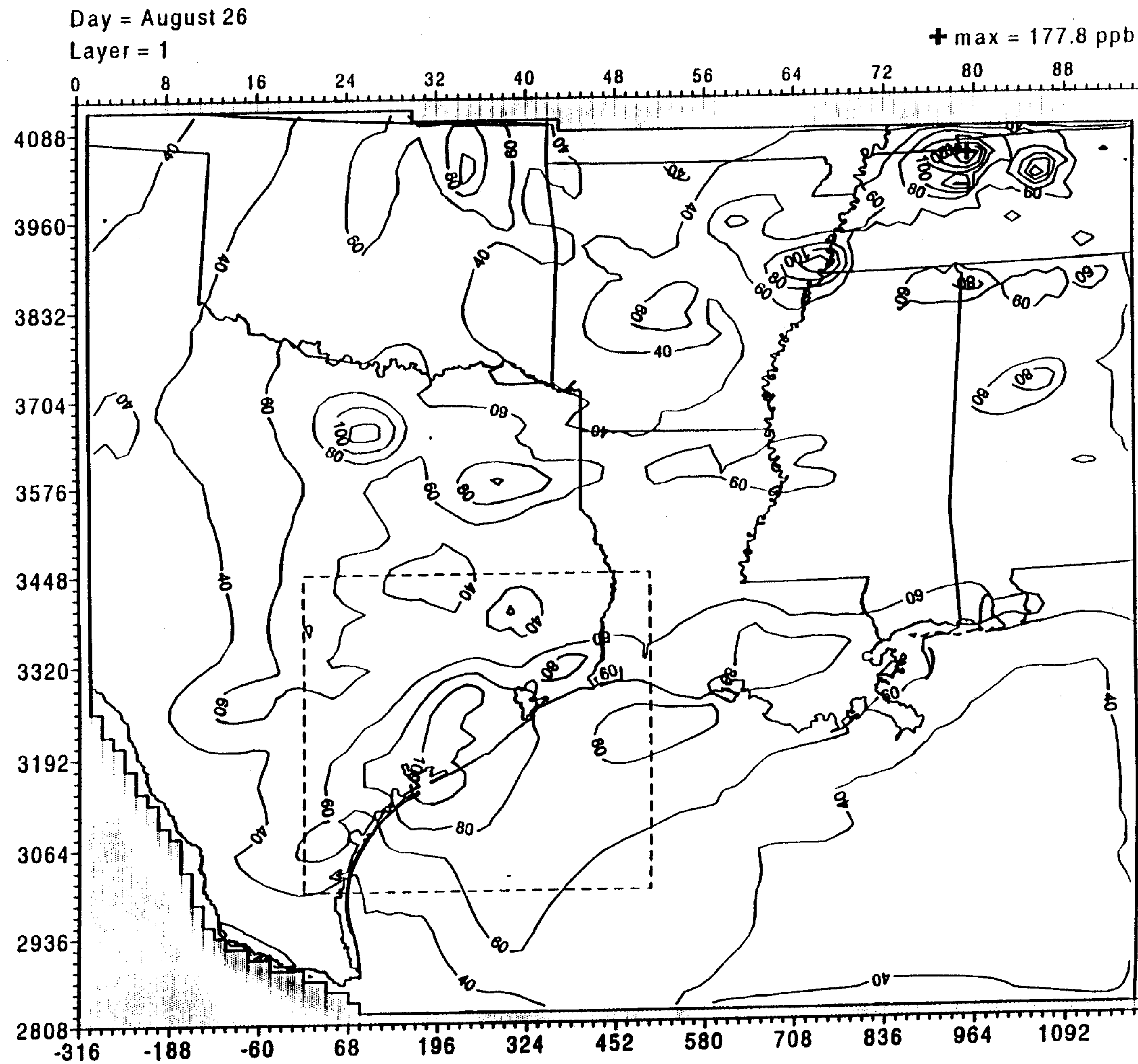


Figure 2. Hourly average ozone concentrations (ppb) for 2pm on August 26, 1993. CAMx OSAT base case.

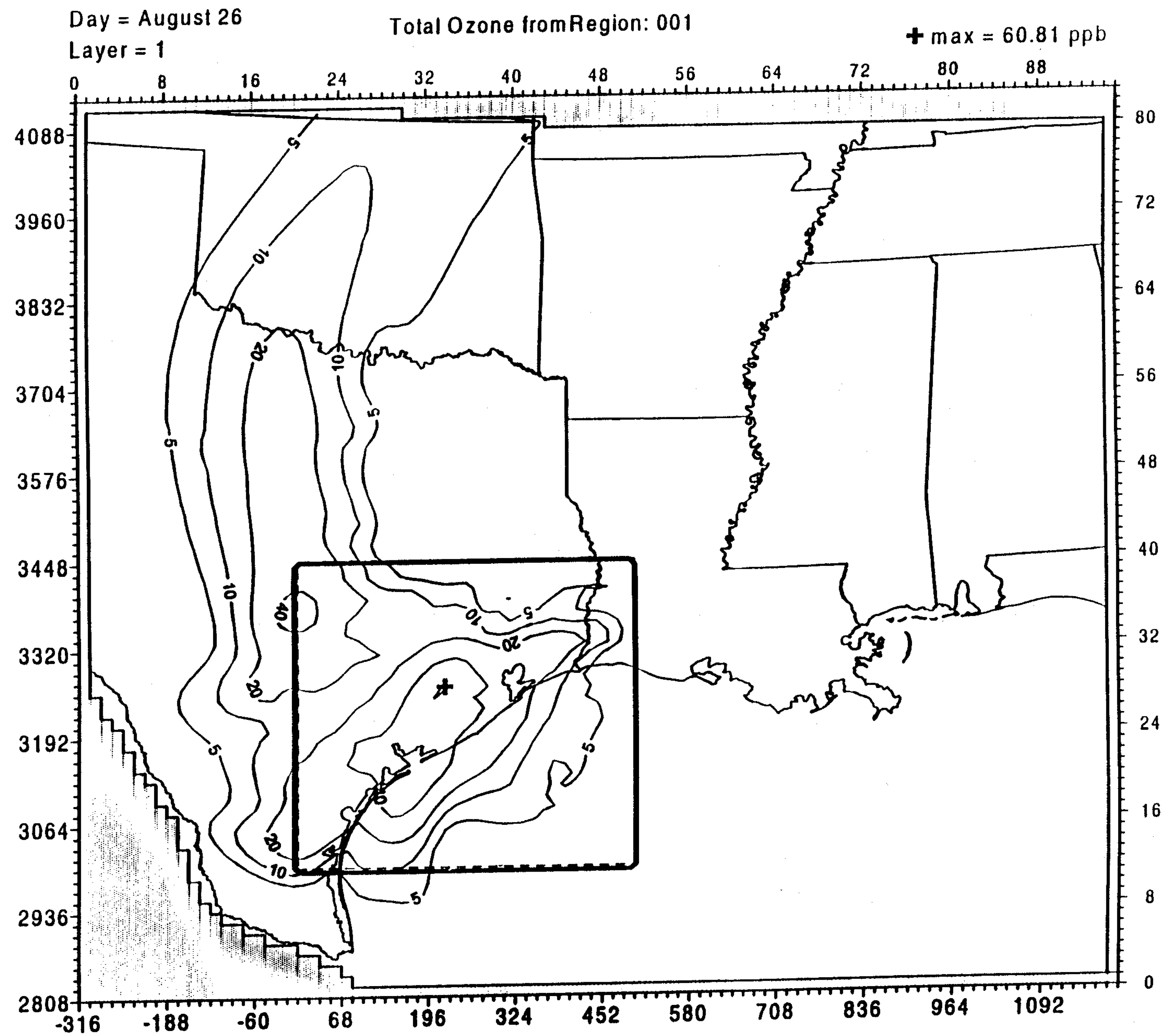


Figure 3. Contribution of source region 1 (COAST domain) to hourly average ozone concentrations at 2pm on August 26, 1993. CAMx OSAT base case.

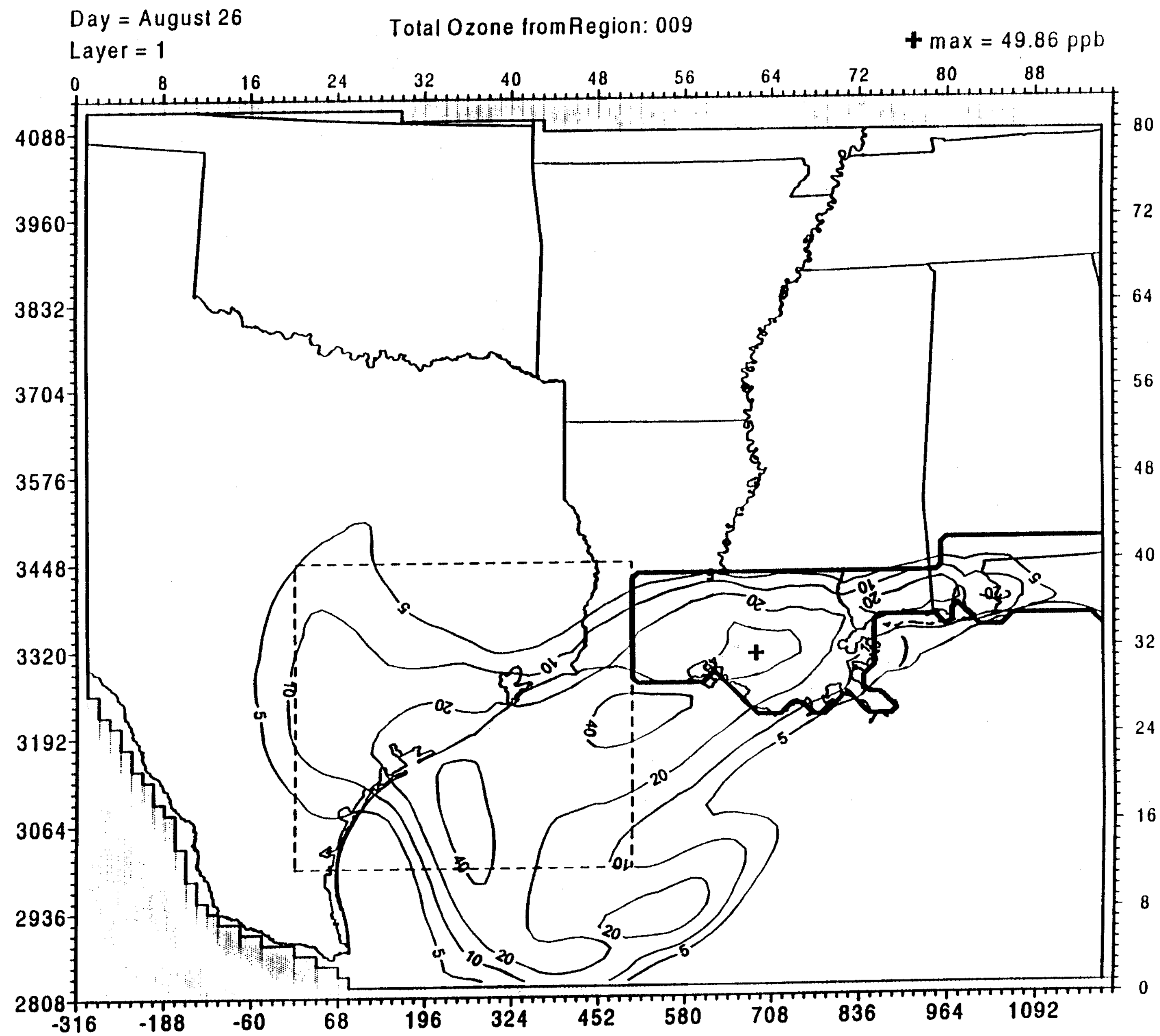
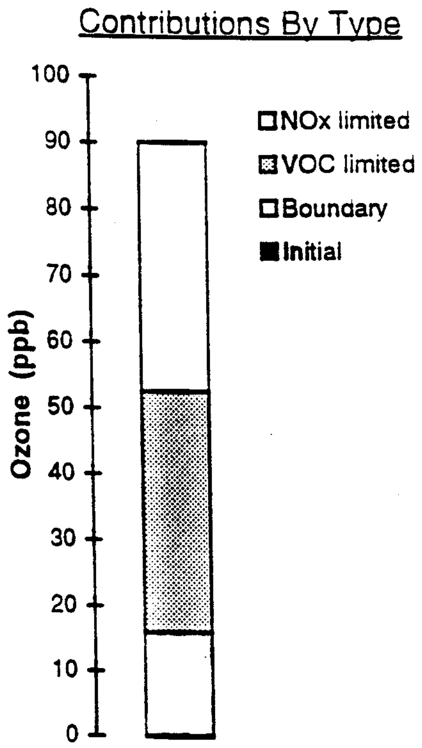
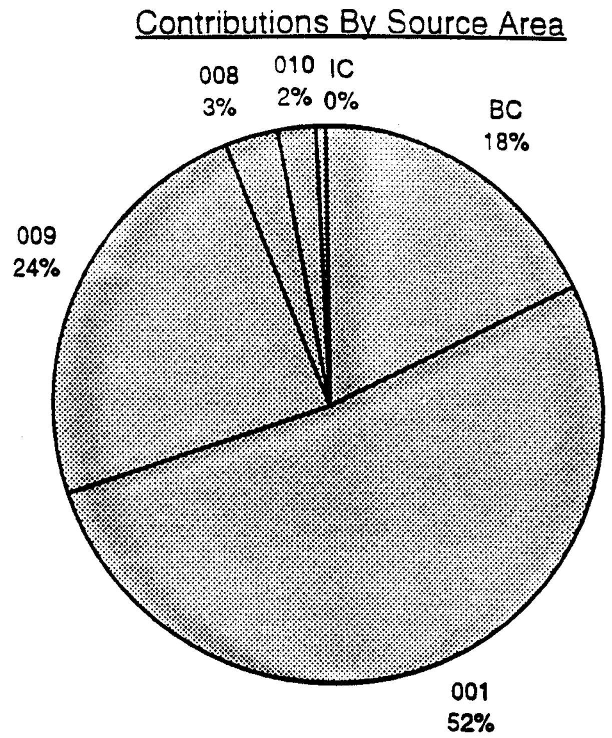


Figure 4. Contribution of source region 9 (eastern Gulf Coast) to hourly average ozone concentrations at 2pm on August 26, 1993. CAMx OSAT base case.





Receptor	**=**	**Victoria**		
Time	**=**	**15**	**To**	**16**
Date	**=**	**8/26/93**		
Scenario	**=**	**REGIONAL Base Case: 1 16 km Grid**		
Total Ozone	**=**	**90**		

Source Area	*Source Group*	*Percent Ozone from NOx*	*VOC*	*Total*	*Time Emitted*	*Recirculation Likely*
IC				0%		
BC				18%		
001	000	26%	27%	52%		
009	000	13%	11%	24%		
008	000	2%	2%	3%		
010	000	1%	1%	2%		
002	000	0%	0%	1%		
All Others				0%		

Figure 5. Sample display of CAMx source apportionment results for the Victoria receptor for 15:00 to 16:00 on August 26.

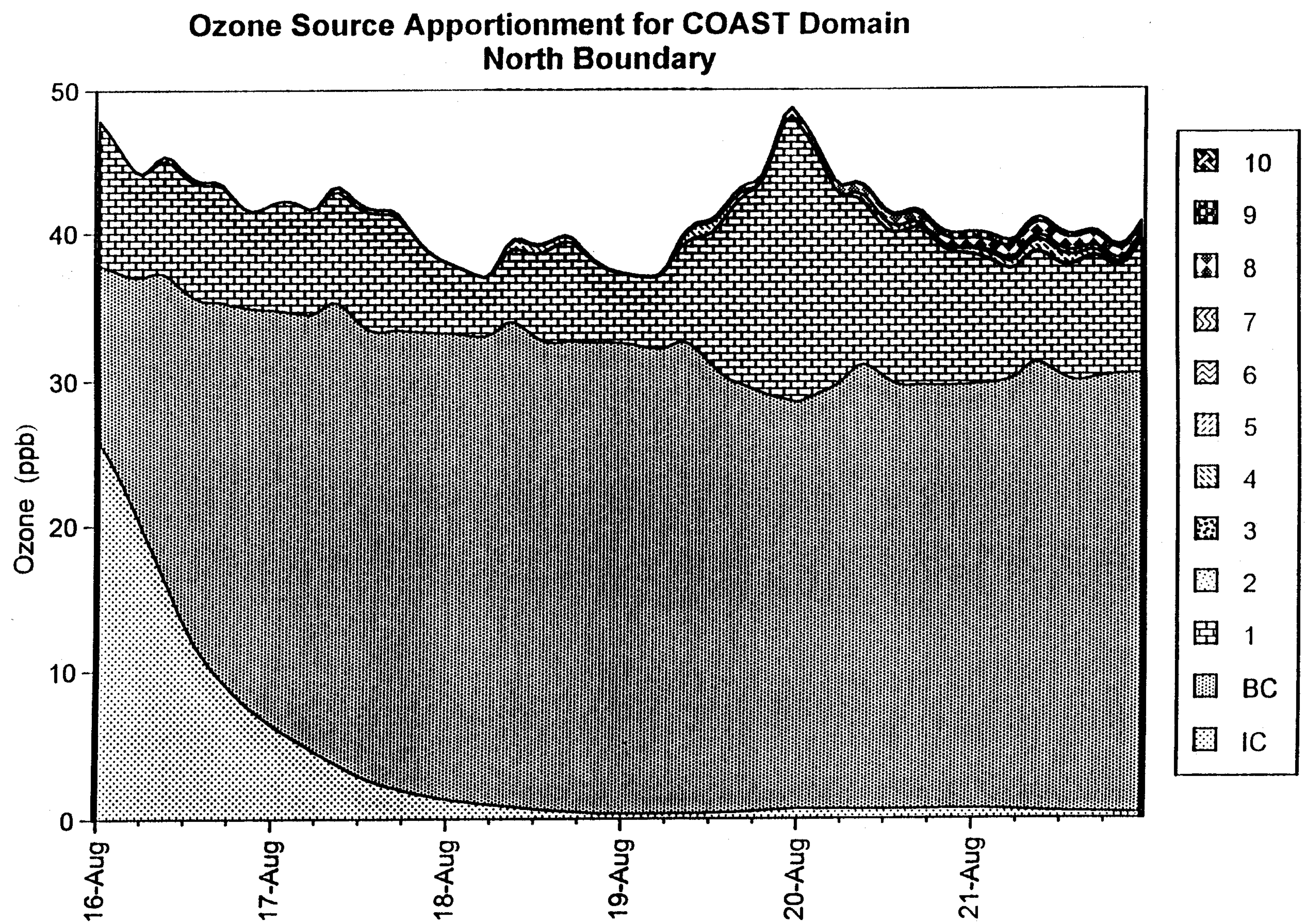


Figure 6. Ozone source apportionment for the COAST domain north boundary among the geographic areas shown in Figure 1 for August 16-21. CAMx OSAT base case.

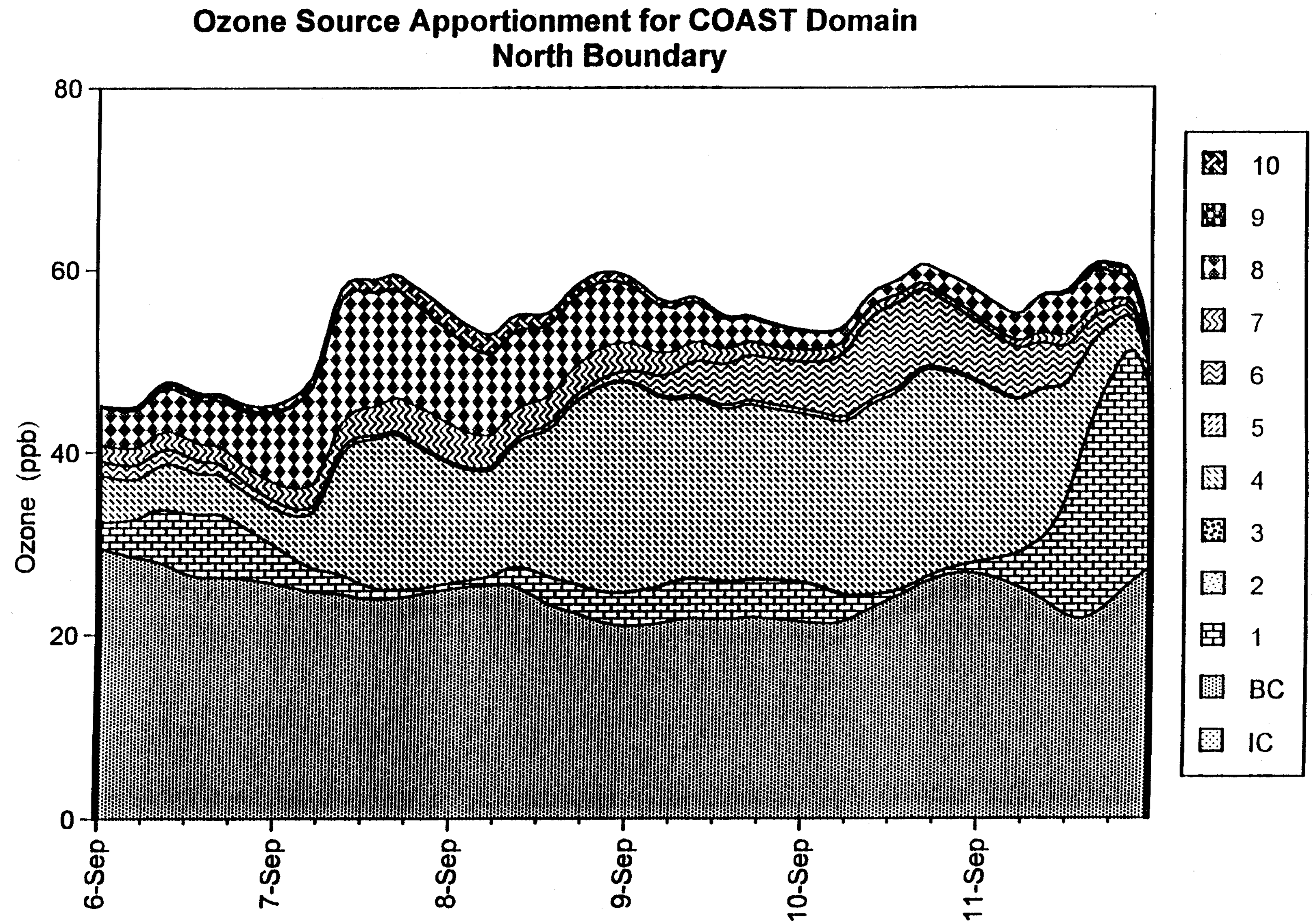
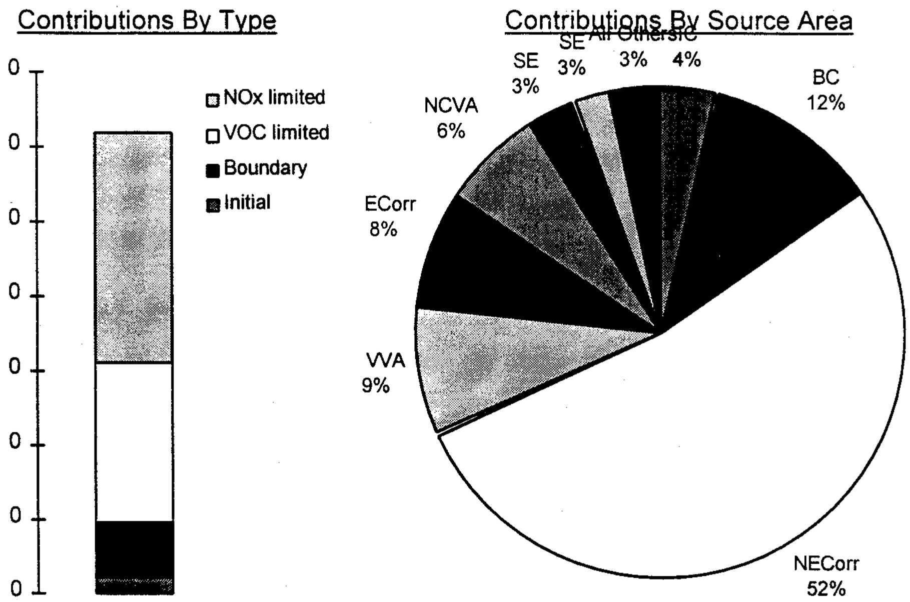


Figure 7. Ozone source apportionment for the COAST domain north boundary among the geographic areas shown in Figure 1 for September 6-11. CAMx OSAT base case.



Receptor	=	**Baltimore**		
Time	=	**14**	**To**	**15**
Date	=	**7/18/91**		
Scenario	=	**Ohio July 18**		
Total Ozone	=	**124**	**ppb**	

Source Area	*Source Group*	*Percent Ozone from NOx*	*VOC*	*Total*	*Time Emitted*	*Recirculation Likely*
IC				4%		
BC				12%		
NECorr	Anthro	37%	16%	53%		
WVVA	Anthro	3%	5%	9%		
NECorr	Bio	1%	7%	8%		
NCVA	Anthro	5%	2%	6%		
SE	Anthro	3%	0%	3%		
SE	Bio	0%	2%	3%		
All Others				3%		

Figure 8. Contribution of anthropogenic and biogenic emission s from different geographic source regions to the daily maximum ozone concentration in Baltimore, Maryland on July 18, 1991 calculated using the CAMx OSAT for the July 1991 OTAG basecase scenario.

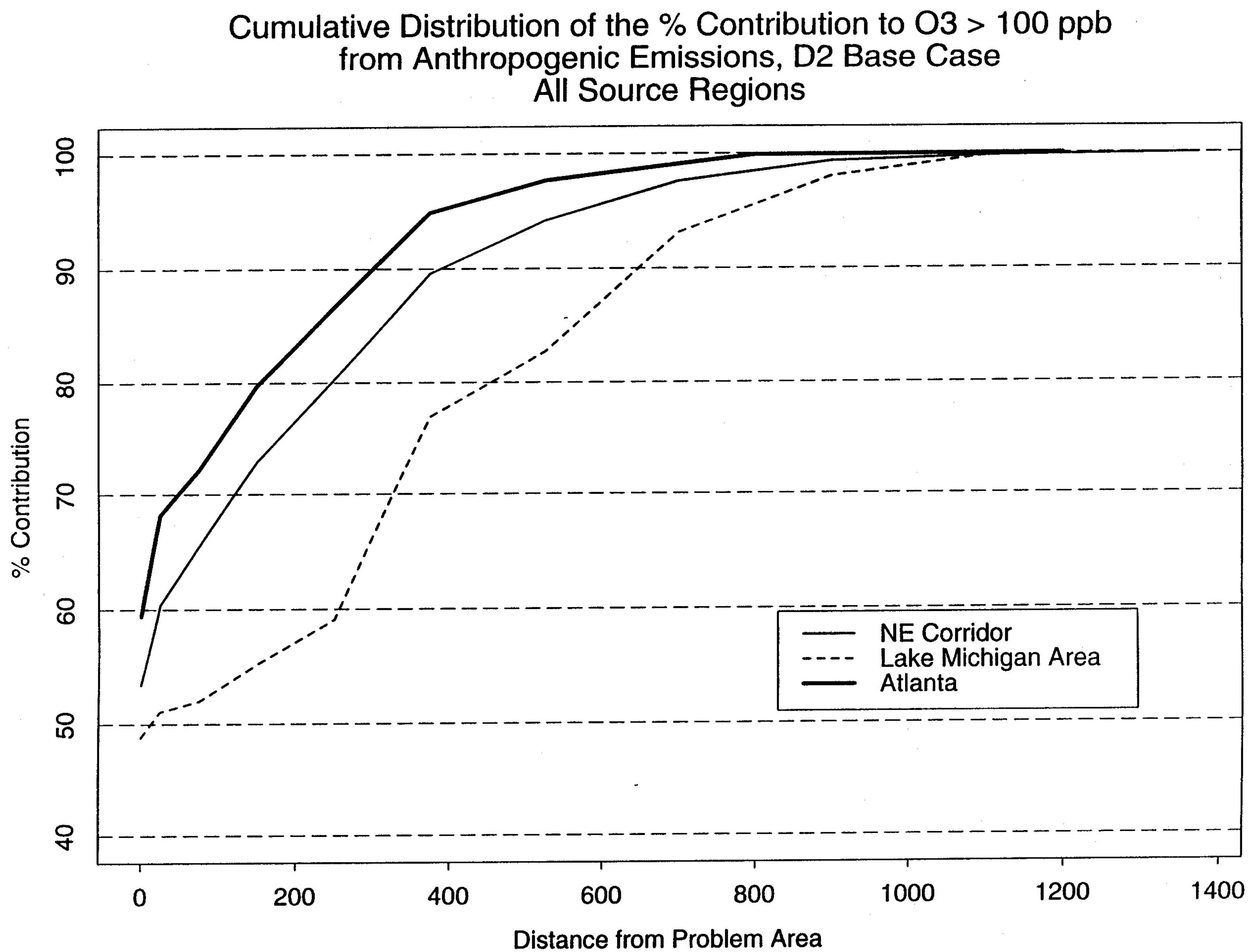


Figure 9. Scales of area of influence (AOI) for ozone around the Northeast Corridor, Lake Michigan and Atlanta problem areas determined by CAMx OSAT.

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