

**SUMMARY OF CAM_x
SOURCE APPORTIONMENT MODELING
RESULTS USING THE OTAG DATABASE**

Prepared for

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DESCRIPTION OF THE CAMx AND OZONE AND PM SOURCE APPORTIONMENT

Overview of the CAMx Technical Formulation

The Comprehensive Air-quality Model with extensions is a current, advanced three-dimensional photochemical grid model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect pollutant concentrations. CAMx is based on the so-called atmospheric continuity or continuity equation. This balance equation relates pollutant concentrations all of the relevant emissions, physical, chemical, and removal processes and is expressed mathematically below:

$$\begin{aligned} \frac{\partial c_l}{\partial t} = & -(\nabla_H \cdot \vec{V}_H c_l) + \left[\frac{\partial(c_l \eta)}{\partial z} - c_l \frac{\partial(\eta + w)}{\partial z} \right] + (\nabla \cdot K \nabla c_l) \\ & + \left. \frac{\partial c_l}{\partial t} \right|_{Chemistry} + \left. \frac{\partial c_l}{\partial t} \right|_{Emission} + \left. \frac{\partial c_l}{\partial t} \right|_{Removal} \end{aligned}$$

where c_l is the three-dimensional concentration of pollutant species l at time t , V_H is the horizontal wind vector, w is the vertical velocity, and K is the turbulent diffusion coefficient (given separately for horizontal and vertical coordinates). The first term on the right-hand side represents horizontal advection, while the second term represents vertical transport. As the vertical grid structure is defined via external inputs, layer heights may be specified as a any arbitrary function of time and/or space. Total vertical transport is therefore the net effect of vertical advection, mass exchange between layers due to entrainment, and concentration change due to dilution. The local entrainment rate η is a combination of vertical velocity and the total (Lagrangian) time rate of change of the layer interface heights h :

$$\eta = \frac{\partial h}{\partial t} + (\vec{V}_H \cdot \nabla_H h) - w$$

The continuity equation is solved using the method of fractional steps (or time-splitting) in which each major process (advection, diffusion, chemistry) is solved in independent sequence. The model is integrated forward in time using a driving time step that ensures numerical stability of the coarse grid horizontal advection and diffusion. Therefore, the maximum time step is a function of the coarse grid size, wind speed, and horizontal diffusion coefficient. Typical time steps for grid spacing of 10-50 km are 10-30 minutes, whereas time steps for grid spacing of 1-2 km are several minutes or less. Therefore, multiple advective time steps per driving step are required for the finer nested grids depending on their size relative to coarse grid spacing. Multiple chemistry time steps per driving step are usually needed as well to ensure stable solutions of the often very stiff chemical reaction equations.

In addition to the features it shares with most grid models, the most notable new features of the initial version of CAMx are described below:

Source Apportionment -- A novel technique was recently developed by ENVIRON to allow CAMx (and one version of UAM-IV) to track source region or source category contributions to predicted grid cell ozone concentration. Thus, for any selected receptor point and time, the model gives a clear picture of what concentrations of various ozone precursors are likely present and what emission sources categories or regions contributed to predicted ozone. An indication is also provided of whether the ozone at the selected time and location would more likely respond to upwind NO_x or VOC controls. Its new advanced technology is described in more detail below.

A single CAMx run, with its ozone source apportionment option enabled, yields complete source apportionment information that would literally require hundreds of runs with other models. The source apportionments determined in the single grid model run have much more internal consistency than source apportionments derived from multiple model runs. Now, for the first time, a grid model, CAMx, can be used in a cost-effective fashion for ozone source apportionment, replacing less technically capable models used previously. The method is easily extendable to other primary and secondary pollutant species, either gaseous or aerosol, such as : SO₂; NO; NO₂; CO; TSP; PM₁₀, sulfate, secondary organic, and ammonium nitrate aerosol concentrations

Nested Grid Structure -- This feature allows CAMx to be run with coarse grid spacing over a wide regional domain in which high spatial resolution is not particularly needed, while within the same run, applying fine grid nests in areas where it is needed. Any number of fine grid nests can be used, and multiple grid spacings can be employed within a single run. Vertical layer structures can vary from one grid nest to another. The entire grid structure is two-way nested, meaning the information propagates into and out of all fine grid nests. The nested grid capability of CAMx allows it to be cost-effectively applied to large regions in which regional transport occurs, yet at the same time provide fine resolution sufficient to address small-scale impacts.

Fast Plume-in-Grid Module -- Even with nested-grids there is a lower limit on the grid size. Practical and theoretical considerations suggest 500-1000 meters as a lower limit. However, in the case of point source plumes finer resolution may sometimes be needed. To deal

with subgrid scale impacts, CAMx incorporates a plume-in-grid (PiG) feature. This allow CAMx to track individual plume segments, accounting for plume dispersion and chemical evolution, until such time as they can be adequately represented within the grid model framework. CAMx contains a new PiG method called GREASD (Greatly Reduce Execution Time and Simplified Dynamics) PiG which is many times faster than earlier PiG versions developed by ENVIRON staff or others. Further, GREASD PiG allows calculation of ground-level impacts of plume segments prior to their release into the grid.

Fast Numerical Chemical Kinetics Solver -- In photochemical grid models, typically 80 percent of the CPU time is spent numerically integrating (solving) the time evolution of the chemistry. To desire to increase the complexity of photochemical mechanisms will tend to push this figure higher. ENVIRON developed a highly efficient chemistry solver that is based on an “adaptive-hybrid” approach. Relative to the standard chemistry solvers, our approach results in about a ten-fold speedup in chemistry solution and a speedup in overall grid model run times of 3 to 4 times. Model performance with our fast solver is nearly identical to the standard chemical solvers. ENVIRON’s fast chemical solver can be applied to either Carbon Bond IV or SAPRC chemical mechanisms.

Chemical Mechanism Compiler -- CAMx contains a chemical mechanism compiler (CMC) which will directly compile any user defined chemical kinetics mechanism into source code for ENVIRON’s fast chemistry solver. Chemistry updates using the CMC can be performed in a matter of hours compared to the weeks or months required for other photochemical grid models.

Description of the Ozone Source Apportionment Technology (OSAT)

The Ozone Source Apportionment Technology (OSAT) has been added to the urban-scale UAM and the regional/urban-scale CAMx. For the Los Angeles region, a comprehensive evaluation of OSAT was performed comparing its results against those of conventual targeted emission reduction scenarios and was proven to be an effective methodology for developing optimally effective emissions control strategies for reducing ozone concentrations. Qualitative comparison of the OSAT technology for the Cincinnati urban-scale and the Texas and OTAG regional-scale scenarios have also shown that it can reliable estimate the effects targeted control strategies would have and, in fact, in one simulation can obtain as much information of 10s to 100s of conventional emission reductions scenarios. The basic formulation of the OSAT is described next.

Four tracers are added to the grid model simulation for each source group requested by the user (a source group as a geographic region/emission category combination). There are two emission tracers (for NO_x and VOC) that track the emission, transport, deposition and chemical destruction of ozone precursors from each source group, and two ozone reaction tracers (O3N and O3V) that track the ozone formation attributed to NO_x and VOC precursor emissions from each source group, respectively. The attribution of ozone production to precursor emissions is performed at each time step in each grid cell throughout the model run and the ozone reaction

tracers accumulate ozone contributions as they happen. The decision on whether to attribute ozone formation at each time step to NO_x or VOC is based on whether the ozone formation process is NO_x or VOC limited in that grid cell at that time step. The tracer methodology does not perturb the regular grid model calculations or predictions in any way. Boundary conditions and initial conditions are always tracked as separate source groups so that the sum of the ozone tracers from all source groups always equals the ozone predicted by the regular grid model. Displaying the ozone tracers from an individual source group (i.e., the O3V plus O3N tracers for that group) shows clearly where and how much ozone is being formed by a particular source group. Examining the ratio of O3V/O3N tracers for a particular source group shows whether ozone formation from that group is more VOC or NO_x limited.

CAMx ozone source apportionment has tremendous potential for revealing what processes are contributing to simulated ozone concentrations. This has direct application to the identification of source-receptor relationships for ozone, diagnosis of model performance problems, and design of optimally effective ozone control strategies. A single UAM or CAMx run with source apportionment provides detailed insight that would require literally hundreds of sensitivity simulations without source apportionment. We acknowledge that the ozone source apportionment method we have implemented can only estimate source contributions. However, evaluations have shown that the source apportionment model results are consistent with the results of conventional UAM sensitivity simulations both in terms of area of impacts and magnitude of impacts.

PM Source Apportionment Technology (PSAT)

As advanced photochemical grid models such as CAMx are developed for particulate matter (PM) modeling, they will be used to develop emissions control strategies for PM and related issues such as visibility and acid deposition. The development of a PM control strategy will involve iteration through many photochemical grid model scenarios to identify the source regions and source categories that contribute to high PM levels. Because not all permutations of controls can be analyzed, and because photochemical grid model simulations for PM are computationally very demanding, there is potential for implementing controls on sources that contribute little to high PM levels or, conversely, not controlling sources that do contribute.

A situation similar to that described above also exists for ozone modeling, although the problem is less severe because ozone grid models are less demanding than PM grid models and because the modeling community has more experience with ozone models. For ozone modeling, ENVIRON developed a technique for determining the contribution of emissions from specified source categories, source regions and pollutant (i.e., VOC vs. NO_x) to ozone concentrations estimated by CAMx. This software is called OSAT, standing for Ozone Source Apportionment Technology. CAMx-OSAT has wide applicability to the development of effective ozone control strategies. In addition, the detailed knowledge of the contributions to modeled ozone provides a powerful tool for diagnosing and improving model performance. CAMx-OSAT utilizes multiple tracer species to access information on ozone and precursor production/destruction to track the amount of ozone formed due to emissions from separate source groups. The term “source group”

is used to describe a unique geographic area/source category combination that has been selected for source apportionment with CAMx-OSAT.

The same source apportionment methods that have been successfully applied in CAMx for ozone can be extended to source apportion PM and its precursors between separate source groups: CAMx-PSAT will be able to identify the specific geographic areas and source categories contributing to high PM concentrations, visibility impairment and acid deposition. This capability will allow users to develop (and justify) intelligent, targeted, PM control strategies. The PSAT and OSAT features can be used together in the same CAMx simulation.

The PSAT software accesses normal internal UAM information such as PM production and precursor destruction rates for use in tracer calculations that are performed in parallel with the standard CAMx calculations. This approach ensures that the PSAT does not perturb or alter the standard CAMx estimates of PM and precursor concentrations. The formulation of the tracers used to track PM formation is described below.

PSAT Tracer Species

For each user specified source group (I), a distinct set of thirteen tracer species is added to the simulation. The thirteen tracer species are:

Primary PM tracers

PS _i -	Primary sulfate tracer for source group I
PEC _i -	Primary elemental carbon tracer for source group I
POC _i -	Primary organic carbon tracer for source group I
PO _i -	Primary other PM (excluding sulfate, elemental carbon and organic carbon) tracer for source group I

PM precursor tracers

N _i -	NO _x tracer for source group I (also used by OSAT)
S _i -	SO ₂ tracer for source group I
SOAP _i -	Secondary Organic Aerosol Precursor tracer for source group I
A _i -	NH ₃ tracer for source group I
NA _i -	Tracer accumulating nitric acid attributable to source group I

Secondary PM tracers

SS _i -	Tracer accumulating secondary sulfate aerosol attributable to source group I
SOA _i -	Tracer accumulating secondary organic aerosol attributable to source group I
SA _i -	Tracer for ammonium attributable to source group I in secondary ammonium nitrate

SN_i - Tracer for nitrate attributable to source group I in secondary ammonium nitrate

The primary PM tracers (PS_i, PEC_i, POC_i, PO_i) enter the model via emissions and have emission rates and geographic distributions characteristic of source group I. These species are chemically inert within the model and are transported, dispersed and removed (deposited, rained out) by the standard CAMx algorithms for those processes. Source apportionment for these chemically inert species is straightforward, being simply a form of weighted tracer simulation. These primary PM components are tracked separately because of their different impacts on acid deposition and light extinction.

The secondary PM precursor tracers N_i, S_i, A_i, and SOAP_i also enter the model via emissions, but are not chemically inert. The N, S and A tracers decay chemically according to the local CAMx predicted NO_x, SO₂ and NH₃ decay rates weighted by the fractions N_i/N_t, S_i/S_t and A_i/A_t respectively (where the subscript T denotes the sum of tracer concentrations over all source groups I). The SOAP species are used in addition to the normal CB4 speciation for VOCs because CB4 speciation was developed to reflect the ozone formation potentials of various types of organic compounds and these potentials are not particularly relevant to secondary organic aerosol formation potentials. For example, terpenes and butane are both lumped primarily into the CB4 PAR category, but have radically different secondary organic aerosol production potentials. In the case of the SOAP tracers, the reactivity of each SOAP tracer (kOH_i and kO₃_i) is calculated in advance by averaging the OH and O₃ rate constants of the speciated VOC emissions for its respective source group. At each CAMx grid cell/time step, the SOAP tracers decay at a rate calculated as the product of their concentrations, the local OH and O₃ concentrations and the weighted OH and O₃ reaction rate constants.

The secondary PM tracers SSA and SOA accumulate a portion of the aerosol production activity that occurs in each CAMx grid cell at each chemistry time step. Nitric acid production is similarly apportioned to NA_i tracers. The process of apportioning secondary sulfate and organic aerosols and nitric acid production to the various tracer groups occurs as follows:

Attribute the secondary sulfate aerosol produced to the SS tracer for each source group I (SS_i) by the formula:

$$(SSA_i)_{new} = (SS_i)_{old} + (\Delta\text{sulfate} \times (S_i/S_t)),$$

where Δsulfate is the CAMx predicted sulfate production for a time step. CAMx predicted sulfate production rates are the sum of gas- and aqueous-phase sulfur oxidation.

Attribute the secondary organic aerosol produced to the SOA tracer for each source group I (SOA_i) by the formula:

$$\begin{aligned} (SOA_i)_{new} = & (SOA_i)_{old} + [((SOAP_i)_{old} \times \text{local OH} \times kOH_i)] \\ & + [((SOAP_i)_{old} \times \text{local O}_3 \times kO3_i)] \end{aligned}$$

where kOH_i and $kO3_i$ are, respectively, the species-weighted average OH and ozone reaction rate constant for SOAP source group I.

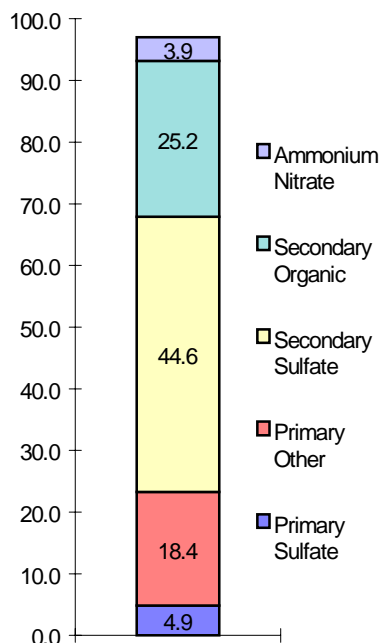
Attribute the nitric acid produced to the local NA tracer for each source group I (NA_i) by the formula:

$$(NA_i)_{new} = (NA_i)_{old} + (\Delta \text{nitric acid} \times (NA_i/NA_t))$$

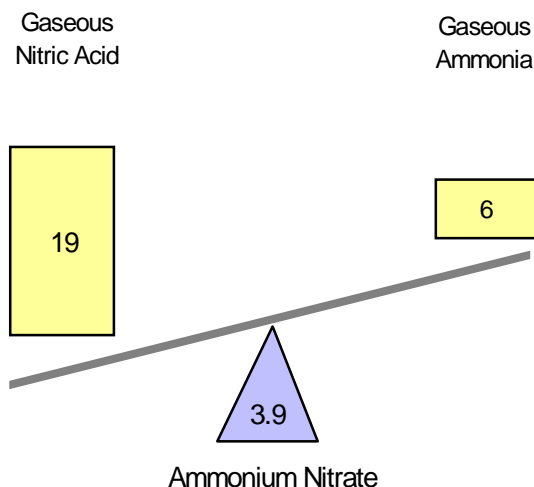
where $\Delta \text{nitric acid}$ is the UAM predicted nitric acid production for a time step.

This approach to apportioning the CAMx production of secondary aerosols (and nitric acid) ensures that the sum of source contributions for all source groups stays “in register” with the concentration of the corresponding CAMx species. For example, in any grid cell at any time step

Total PM (ug/m3)



Ammonium Nitrate Equilibrium



Receptor = Hypothetical
 Date = 6/31/1995
 Scenario = Hypothetical
 Total PM = 97 ug/m3

Source Apportionment

Source Group	Primary		Secondary			
	Sulfate	Other	Sulfate	Organic	Ammonium Nitrate	
1	30	10	30	20	40	0
2	20	0	40	5	15	0
3	0	0	0	0	0	80
4	0	30	0	0	0	0
5	0	0	0	25	5	10
6	40	40	20	40	30	5
IC/BC	10	20	10	10	10	5
Total	100	100	100	100	100	100

component. Note that the IC/BC contributions are also tracked in the PSAT. The seesaw diagram at top right shows the equilibrium distribution between nitric acid, ammonia, and ammonium nitrate and indicates whether ammonia or nitric acid is in excess which could potentially help guide the development of effective control strategies (in this case, nitric acid is in excess).

Figure D-1. Example display of PM Source Apportionment information from CAMx-PSAT

Example of CAMx Ozone Source Apportionment For Culpability Assessment

We have performed several CAMx ozone source apportionment simulations using the OTAG regional modeling databases with different source apportionment geographic regions and source sectors (source groupings). One such simulation used 15 geographic regions and separated the emissions inventory into anthropogenic and biogenic emissions (2 source sectors). The 15 geographic source regions roughly followed state boundaries as shown in Figure D-2.

The simulation was performed for the July 1991 OTAG base case scenario, the results for July 18, 1991 are briefly discussed followed by an approach for obtaining source contribution rankings to elevated ozone concentrations across the entire episode.

Summary of July 18, 1991 Ozone Source Apportionment Modeling Results

Figure D-3 displays the source contributions to the daily maximum ozone concentration in Cincinnati Ohio on July 18, 1991. The largest source contributor to daily maximum ozone concentration in Cincinnati (22%) is anthropogenic emissions from the Kentucky/Tennessee (KYTN) source region (Figure D-2) of which most ozone was formed during NO_x-limited conditions (18%). Biogenic VOC emissions from Ohio (OH) contributed the second most (17%) to the daily maximum ozone concentration in Cincinnati, followed by biogenic emissions from KYTN (16%) and anthropogenic emissions from OH (9%).

The largest emissions group contributing to the daily maximum ozone concentration in Pittsburgh on July 18, 1991 (Figure D-4) is anthropogenic emissions from Pennsylvania (20%), of which it is estimated that controlling VOC emissions (13%) would be approximately twice as effective as controlling NO_x emissions (7%). Emissions from Ohio contribute the next most to the daily maximum ozone concentration in Pittsburgh with ozone formed from OH biogenic emissions (18%) contributing more than ozone formed from OH anthropogenic emissions (14%). Anthropogenic emissions from West Virginia/Virginia (WVVA) and KYTN also contribute to the peak ozone concentration in Pittsburgh on this day (6% and 4%, respectively).

For both the southern (Baltimore, Figure D-5) and northern (Southern Maine, Figure D-6) receptors in the Northeast Corridor, anthropogenic emissions from the Northeast Corridor contribute over 50% to the daily maximum ozone concentration on July 18, 1991. For the Baltimore receptor, the next most important region whose anthropogenic emissions contribute to the daily peak ozone is the WVVA region which contributes over five times less (9%) than the Northeast Corridor (53%). Up at the Southern Maine receptor (Figure D-6), the second most important anthropogenic emissions source group to anthropogenic emissions from the Northeast Corridor is anthropogenic emissions from the Lake Michigan region (Lake MI), who contribute over ten times less (4%) than anthropogenic emissions from the NE Corridor (51%). Anthropogenic emissions from MENH, OH, and PA are also minor contributors (2%) to the daily maximum ozone concentrations at Southern Maine. For Southern Maine there is a fairly significant contribution (13%) from “All Other” source groupings, which means that a large number of areas have very small contributions (~1%).

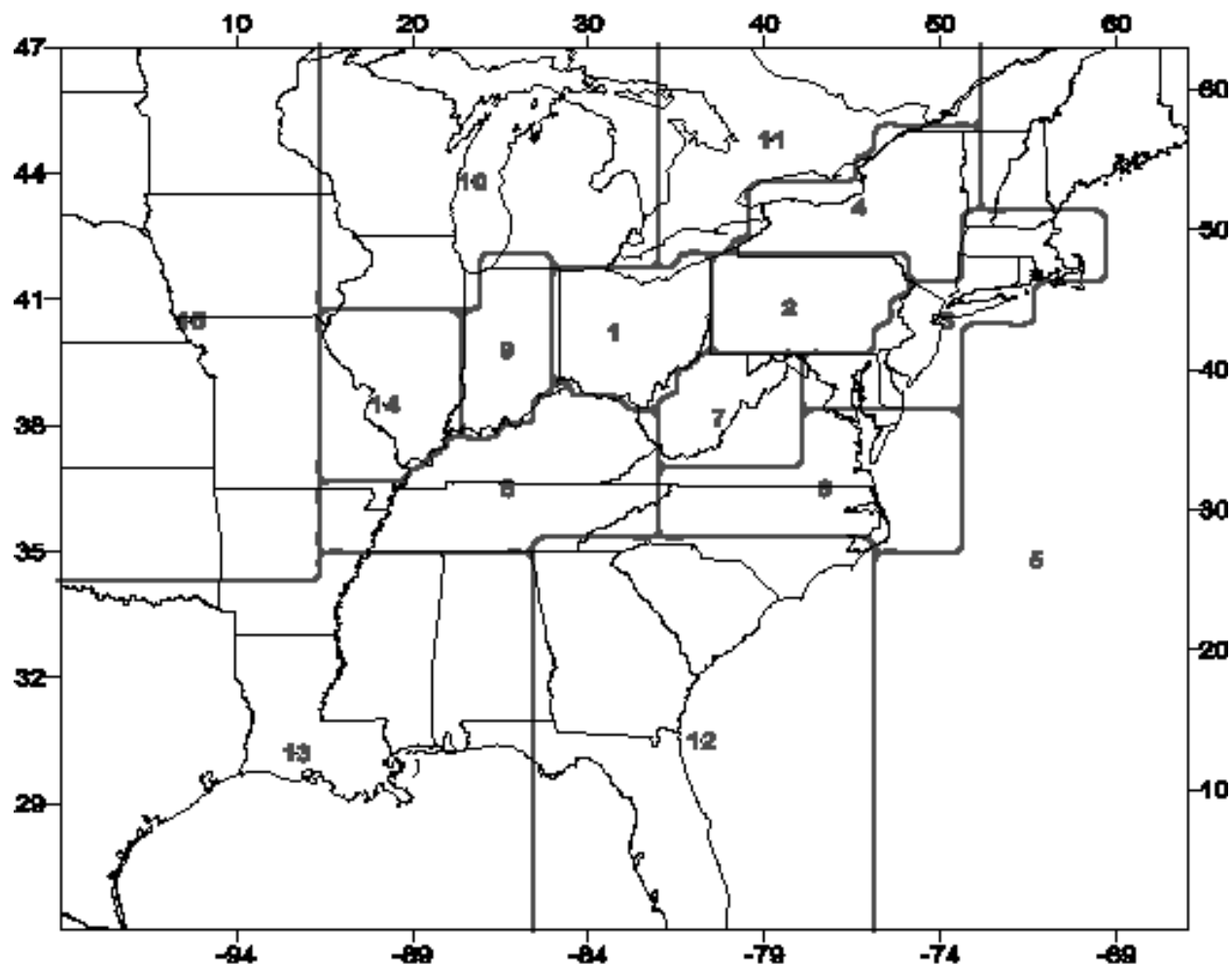


Figure D-2. Geographic source region definitions used in the CAMx ozone source apportionment culpability assessment using the OTAG July 1991 base case database.

Integration of Results for Designing Effective Control Strategies

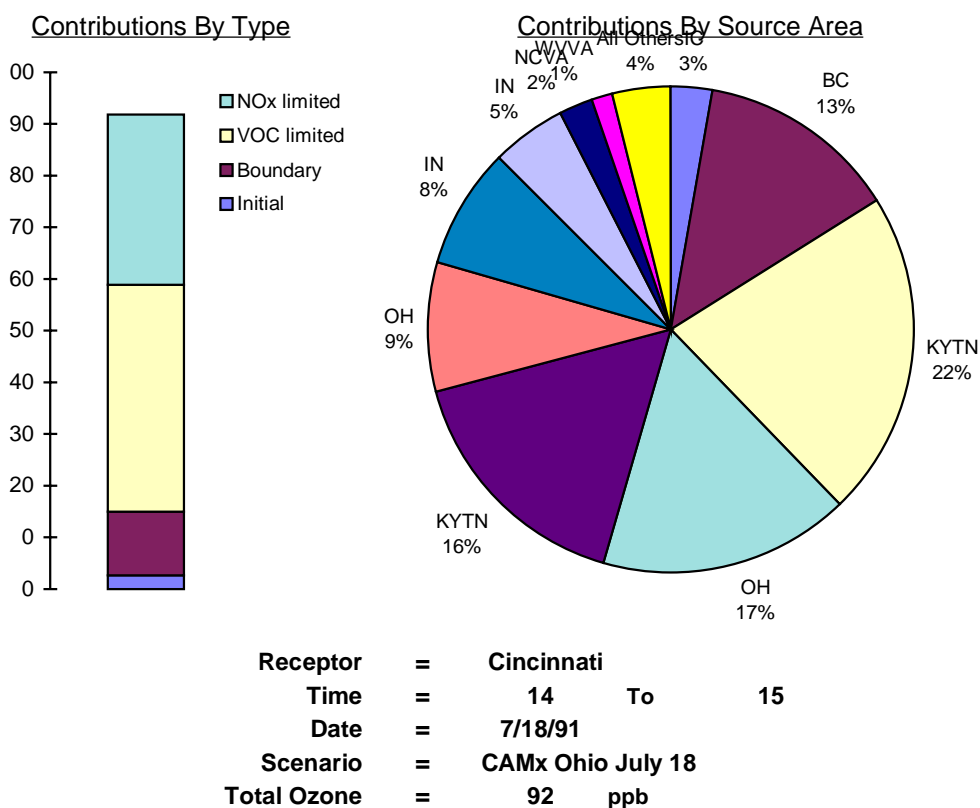
The ozone source apportionment modeling tool provides vast information on the contribution of different source regions, emissions groups, and pollutants to ozone concentrations at each hour in each grid cell of the photochemical grid model. Essentially, the information contained in the receptor pie chart/bar chart/tabular shown in Figures D-3 through D-6 is available for each grid cell and hour for the entire episode. Although the graphical displays are illuminating for examining source culpability to ozone for one hour and one location, the integration of all of the source apportionment data into a concise summary form is needed for developing effective control strategies.

Thus, we developed a postprocessor to the source apportionment modeling output that summarizes the contribution of different source regions to high ozone concentrations in a receptor area. In this example we use the Eastern OTR (including the Northeast Corridor Problem Area) as an example receptor region where we demonstrate a summative assessment of

he contribution of different source regions to elevated ozone concentrations. The percent contribution of each source region to ozone concentrations in each receptor area when ozone concentrations were greater than a threshold value (i.e., > 100 ppb) was calculated and averaged over all hours in the entire 9-day episode period (July 13-21, 1991). The percent average contribution of each source grouping to high ozone were then ranked to determine which source regions, source categories (anthro or bio), and pollutant (VOC or NO_x) are contributing the most to high ozone concentrations in the receptor areas.

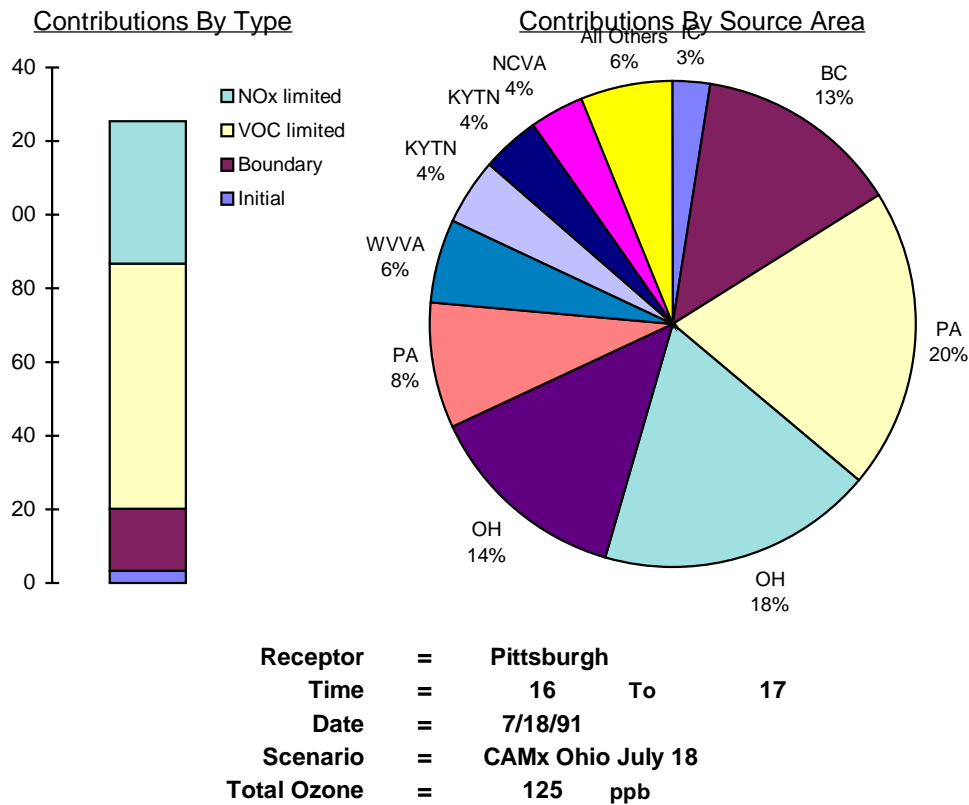
Table D-1 rank the source regions (Figure D-2), emissions group (anthropogenic or biogenic) and pollutant (VOC or NO_x) contribution to ozone concentrations in excess of 100 ppb in the eastern OTR receptor area, respectively. By far the highest contributor to ozone concentrations in excess of 100 ppb in the eastern OTR is NO_x emissions from the Northeast Corridor source region (35%). VOC emissions from the Northeast Corridor, whether biogenic (14%) or anthropogenic (10%) are also significant contributors. Ozone due to boundary conditions (BC), whether primary ozone entering on the lateral or aloft boundaries of the OTAG domain or ozone formed from boundary condition (BC) VOC and NO_x, also contribute a significant amount (15%) to ozone concentrations in excess of 100 ppb in the eastern OTR. The next most important source region to the Northeast Corridor is PA whose anthropogenic NO_x and VOC emissions contribute 4% and 3%, respectively (7% total). Anthropogenic emissions (VOC and NO_x) from WVVA and NCVA source regions each contribute approximately 4% and anthropogenic emissions from OH, KYTN, and SE each contribute approximately 3%, 2%, and 2%, respectively.

These results suggest that by far the most effective strategy for reducing elevated ozone concentrations in the eastern OTR would be controlling NO_x emissions in the Northeast Corridor followed by controlling VOC emissions in the Northeast Corridor. The next most important source group would be NO_x emissions in (non-Corridor) Pennsylvania, however controlling PA NO_x would be a little under ten times less effective at reducing elevated ozone concentrations in the eastern OTR than controlling NO_x emissions in the Northeast Corridor. Similarly, controlling NO_x emissions in the NCVA, OH, and WVVA source regions would be over ten times less effective than controlling Northeast Corridor NO_x emissions.



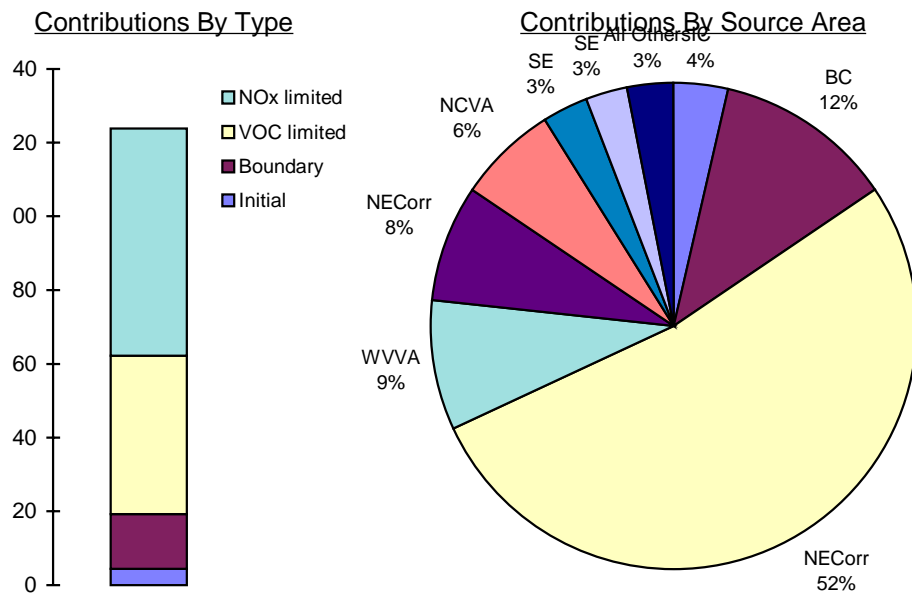
Source Area	Source Group	Percent Ozone from			Time Emitted	Recirculation Likely
		NOx	VOC	Total		
IC				3%		
BC				13%		
KYTN	Anthro	18%	3%	22%		
OH	Bio	1%	16%	17%		
KYTN	Bio	1%	16%	16%		
OH	Anthro	7%	2%	9%		
IN	Bio	0%	8%	8%		
IN	Anthro	5%	0%	5%		
NCVA	Anthro	1%	1%	2%		
WVVA	Anthro	1%	1%	1%		
All Others				4%		

Figure D-3. Contribution of anthropogenic and biogenic emissions from different geographic source regions to the daily maximum ozone concentration in Cincinnati, Ohio on July 18, 1991 calculated using the CAMx OSAT for the July 1991 OTAG basecase scenario.



Source Area	Source Group	Percent Ozone from			Time Emitted	Recirculation Likely
		NOx	VOC	Total		
IC				3%		
BC				13%		
PA	Anthro	7%	13%	20%		
OH	Bio	1%	17%	18%		
OH	Anthro	12%	2%	14%		
PA	Bio	1%	7%	8%		
WVVA	Anthro	4%	2%	6%		
KYTN	Bio	0%	4%	4%		
KYTN	Anthro	2%	2%	4%		
NCVA	Anthro	2%	2%	4%		
All Others				6%		

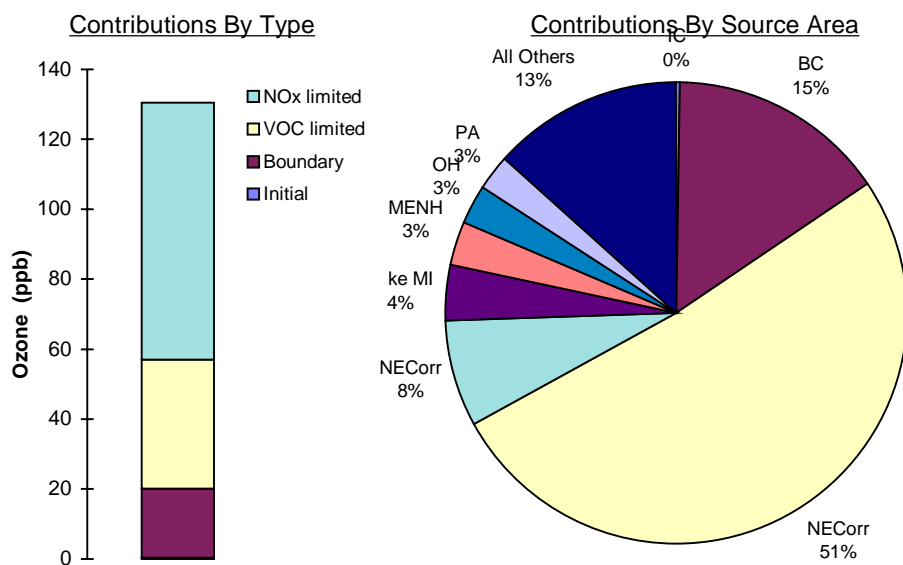
Figure D-4. Contribution of anthropogenic and biogenic emissions from different geographic source regions to the daily maximum ozone concentration in Pittsburgh, Pennsylvania on July 18, 1991 calculated using the CAMx OSAT for the July 1991 OTAG basecase scenario.



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

Source Area	Source Group	Percent Ozone from			Time Emitted	Recirculation Likely
		NOx	VOC	Total		
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 D-5. Contribution of anthropogenic and biogenic emissions 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.



Receptor = **Southern Maine**
Time = **23** To **24**
Date = **7/18/91**
Scenario = **CAMx Ohio July 18**
Total Ozone = **130 ppb**

Source Area	Source Group	Percent Ozone from			Time Emitted	Recirculation Likely
		NOx	VOC	Total		
IC				0%		
BC				15%		
NECCorr	Anthro	41%	10%	51%		
NECCorr	Bio	2%	5%	8%		
Lake MI	Anthro	2%	2%	4%		
MENH	Anthro	3%	0%	3%		
OH	Anthro	1%	1%	3%		
PA	Anthro	1%	2%	3%		
All Others				13%		

Figure D-6. Contribution of anthropogenic and biogenic emissions from different geographic source regions to the daily maximum ozone concentration in Southern Maine (near Acadia Park) on July 18, 1991 calculated using the CAMx OSAT for the July 1991 OTAG basecase scenario.

Table D-1. Average and maximum percent contribution of 15 source regions, two source categories (anthropogenic and biogenic emissions), two pollutants (VOC and NOx), boundary conditions, and initial concentrations to hourly ozone concentrations greater than 124 ppb in the eastern Ozone Transport Region (OTR) (i.e., Northeast Corridor)during the July 13-21, 1991 using the OTAG 1991 B2 base case modeling database.

Northeast Corridor
Ozone > 124 ppb
Percent Contributions of Source Groupings

Source Group	Source Region	Pollutant	Average Contribution	Maximum Contribution	Minimum Contribution
Anthro	NE Cor	NOx	43.58	86.18	0.00
Bio	NE Cor	VOC	18.94	59.33	0.00
Anthro	NE Cor	VOC	12.76	44.30	0.00
000	BC	VOC	7.94	14.03	0.00
000	BC	NOx	7.13	13.48	0.00
Anthro	PA	VOC	4.31	18.30	0.00
Anthro	PA	NOx	4.22	17.14	0.00
Bio	PA	VOC	4.00	17.61	0.00
Bio	NE Cor	NOx	3.29	8.99	0.00
Anthro	OH	NOx	2.78	10.33	0.00
Anthro	WVVA	VOC	2.47	20.78	0.00
Bio	OH	VOC	2.33	9.08	0.00
Anthro	WVVA	NOx	2.09	17.95	0.00
Anthro	NCVA	NOx	2.02	12.09	0.00
Bio	WVVA	VOC	1.73	22.19	0.00
Anthro	KYTN	NOx	1.28	11.16	0.00
Bio	PA	NOx	1.25	4.29	0.00
Bio	KYTN	VOC	1.23	9.10	0.00
Anthro	Up NY	NOx	1.04	15.07	0.00
Anthro	NCVA	VOC	0.95	9.23	0.00
Anthro	OH	VOC	0.81	4.10	0.00
Bio	OH	NOx	0.69	2.77	0.00
Anthro	SE	NOx	0.67	4.79	0.00
Bio	IN	VOC	0.66	3.72	0.00
Bio	SE	VOC	0.65	4.99	0.00
Anthro	IN	NOx	0.60	3.28	0.00
Anthro	KYTN	VOC	0.59	5.06	0.00
Bio	NCVA	VOC	0.57	6.45	0.00
Anthro	Up NY	VOC	0.54	6.68	0.00
Bio	Up NY	VOC	0.53	7.87	0.00
000	IC	NOx	0.48	2.54	0.00
000	IC	VOC	0.48	2.48	0.00
Anthro	Lake M	NOx	0.48	4.21	0.00
Anthro	MENH	NOx	0.47	16.77	0.00
Bio	Canada	VOC	0.34	5.00	0.00
Anthro	Lake M	VOC	0.33	3.92	0.00
Bio	Lake M	VOC	0.30	2.21	0.00
Bio	WVVA	NOx	0.28	3.81	0.00
Bio	Up NY	NOx	0.25	2.05	0.00
Anthro	IN	VOC	0.25	1.14	0.00
Anthro	Canada	NOx	0.23	1.90	0.00
Bio	ILMO	VOC	0.16	2.68	0.00

Example of Using CAMx Source Apportionment for Area of Influence Analysis

One of the critical issues in the OTAG study, which is also critically important as EPA is developing new definitions of ozone nonattainment regions, is the range of influence of the contribution of emissions to ozone exceedances at a particular receptor as a function of distance from that receptor. We have performed such area of influence (AOI) analysis for three Problem Areas in the eastern U.S.: Northeast Corridor, Lake Michigan, and Atlanta, using the CAMx OSAT technique and the July 1991 OTAG database.

Definition of Analysis

An objective scheme was used to define the AOI geographic regions around the Problem Areas (PA) based solely on distance from the PA. The objective procedures we used in defining our geographic regions are as follows:

1. The Problem Area is defined as all grid cells (based on 36 km mother coarse grid cells) that encompass the serious or worse ozone nonattainment counties of the region in question (e.g., Northeast Corridor).
2. The AOI source regions were defined as concentric “circles” around the Problem Areas whose widths are: 50 km, 50 km, 100 km, 100 km, 150 km, 150 km, 200 km, 250 km, etc.
3. Canada was defined as a separate geographic source region group as it is not part of the OTAG process.
5. For the Northeast Corridor PA, the upwind states (VT-NH-ME) were also made a separate source region; and
6. Radial spokes were added so that we can assess the directionality of transport (e.g., for the Northeast Corridor we can distinguish transport from the West (Midwest) versus from the South (Southeast)).

Figure D-7 displays the AOI geographic regions used for the Northeast Corridor Problem Area using the objective procedure described above.

Several air quality metrics were analyzed in the AOI analysis. The three that are presented here are:

Percent Contribution to ozone > 100 ppb in the Problem Area (Northeast Corridor) as a function of distance due to: (1) emissions from all sources (i.e., combining the contributions from the different radial spoke regions and from anthropogenic and biogenic emissions); (2) anthropogenic and biogenic emissions within different radial directions (i.e., from Midwest and Southeast for Northeast Corridor PA and from West and East for Lake Michigan PA); and (3) due to anthropogenic emissions only for all geographic regions, and focusing on the different radial directions.

Normalized Percent Contribution to ozone > 100 ppb in the Problem Area (Northeast Corridor) which examines the contribution of emissions from different geographic regions to ozone > 100 ppb and 120 ppb in the PA as a function of distance from the PA normalized by the emissions within the geographic region. This metric is also displayed for anthropogenic and biogenic emissions combined, anthropogenic emissions only, and for all source regions and the different radial directions.

Cumulative contribution of emissions from source regions to ozone > 100 ppb in the Problem Area as a function of distance is similar to the percent contribution metric above but allows for defining the distance where 50%, 75%, 95% of ozone in a Problem Area is accounted for by the emissions.

The first air quality metric provides an absolute measure (in percent) of the contribution of emissions at a given distance from a PA has to elevated ozone in the PA. The second air quality metric is designed to evaluate how effective emissions contribute to elevated ozone concentrations in a PA as a function of distance from the PA by providing the contribution to elevated ozone in the PA per ton of emissions (i.e., CHI/Q).

AOI Modeling Results

Figure D-8 displays the average percent contribution to ozone > 100 ppb in the Northeast Corridor as a function of distance due to All Emissions (anthropogenic and biogenic) and All Source Regions. The Northeast Corridor region is the largest contributor to its own high ozone concentrations on average (41%), with regions contributing 7-8% of the high ozone in the Northeast Corridor out to approximately 400 km where the contribution drops to < 5%. Note that boundary conditions (BC) are also a significant contributor (10%). These absolute average percent contribution displays do not account for the fact that the different concentric rings contain larger areas as they go out and contain different amounts of emissions. Thus we normalized the percent contribution by the emissions within each ring to obtain an “effectiveness” plot (Figure D-9). These normalized contributions allow one to gauge the relative contributions of emissions at different distances from the Northeast Corridor to elevated ozone in the Northeast Corridor in terms of contributions per unit emissions. Here we see a steady fall off in the emissions contribution to ozone as a function of distance.

The next two figures (Figures D-10 and D-11) present the same air quality metrics in a Box Plot format, which contains much more information about the distribution of contributions to elevated ozone concentrations. Note that the symbol in the Box Plot (mean) corresponds to the bars in the Bar Charts discussed previously.

The final display of the AOI analysis is the average cumulative contribution of ozone concentrations > 100 ppb and > 120 ppb in the Northeast Corridor as a function of distance due to anthropogenic emissions normalized by the total anthropogenic emissions contribution (Figure D-12). This figure clearly shows that 60% of the ozone due to anthropogenic during high ozone periods in the Northeast Corridor are emitted within 50 km of the Northeast Corridor. Similarly, 80% of the anthropogenic contribution comes from anthropogenic sources within 200 km and 90% of the contribution are from anthropogenic emissions within 375 km.

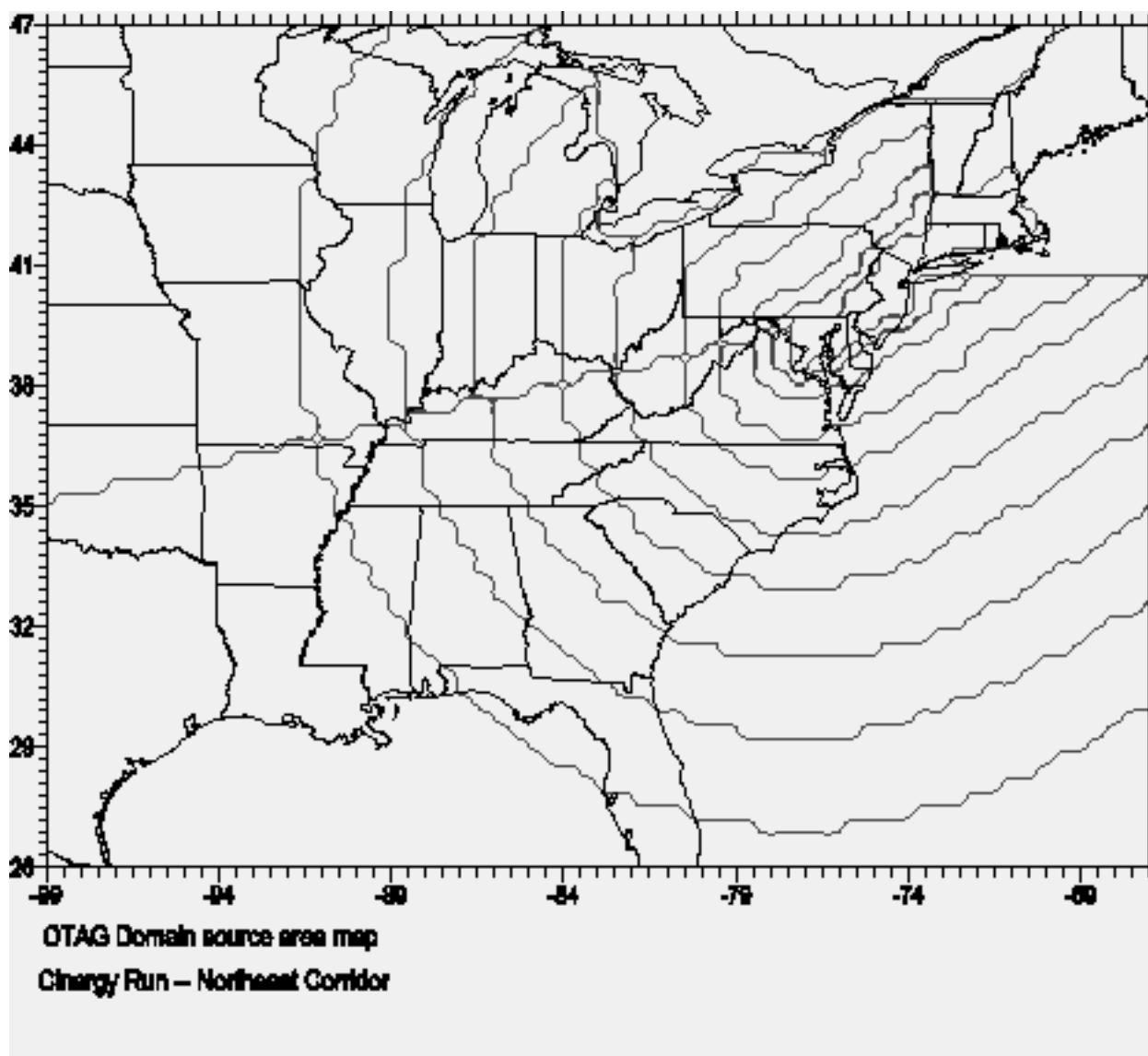


Figure D-7. Geographic regions used for Area of Influence (AOI) CAMx ozone source apportionment modeling for the Northeast Corridor.

Average % Contribution to O₃ > 100 ppb in the NE Corridor
from All Emissions for the 1991 D2 Base Case and
July 1991 Episode (All Source Regions)

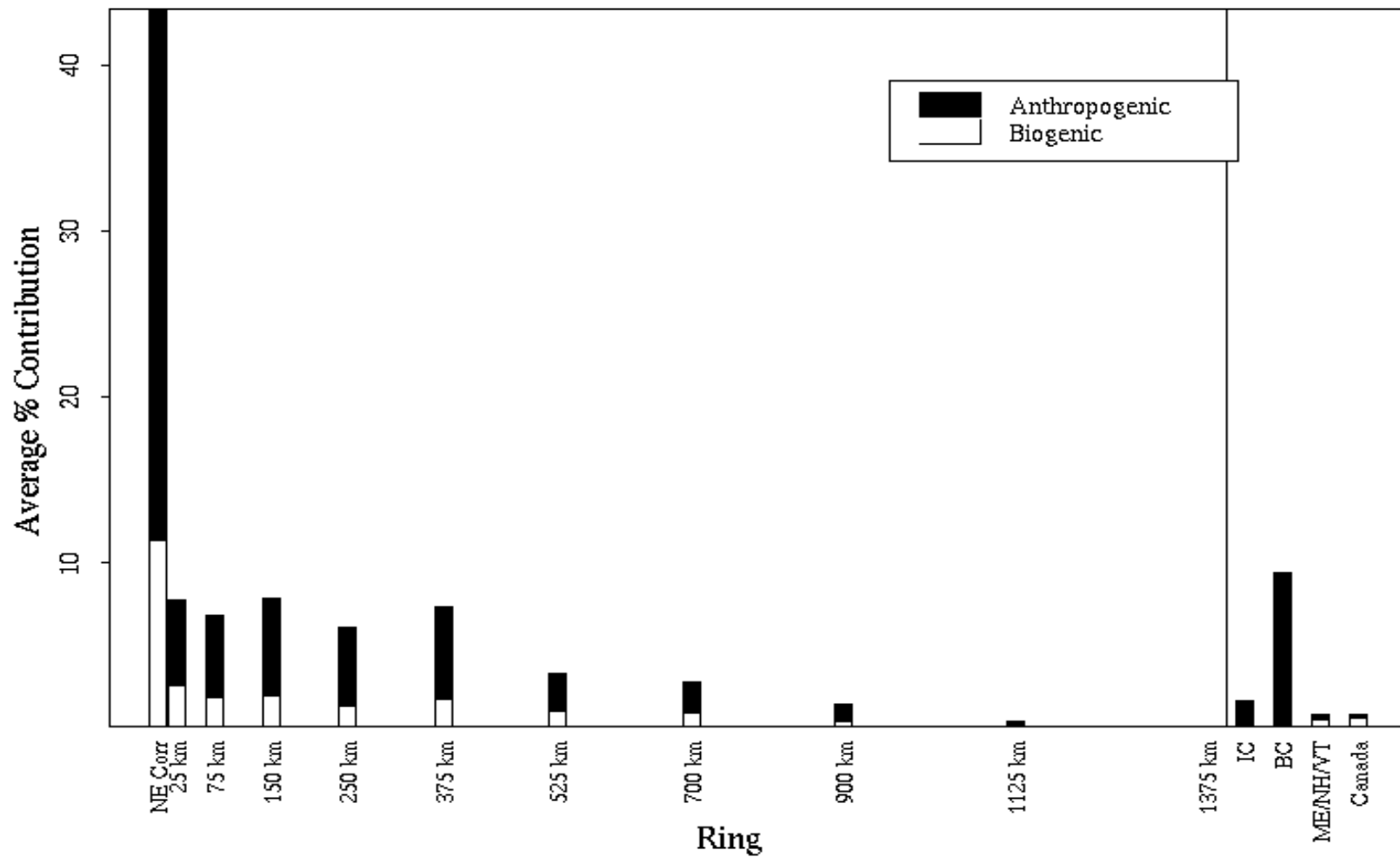


Figure D-8

Normalized Average % Contribution to O₃ > 100 ppb in the NE Corridor
from All Emissions for the 1991 D2 Base Case and
July 1991 Episode (All Source Regions)

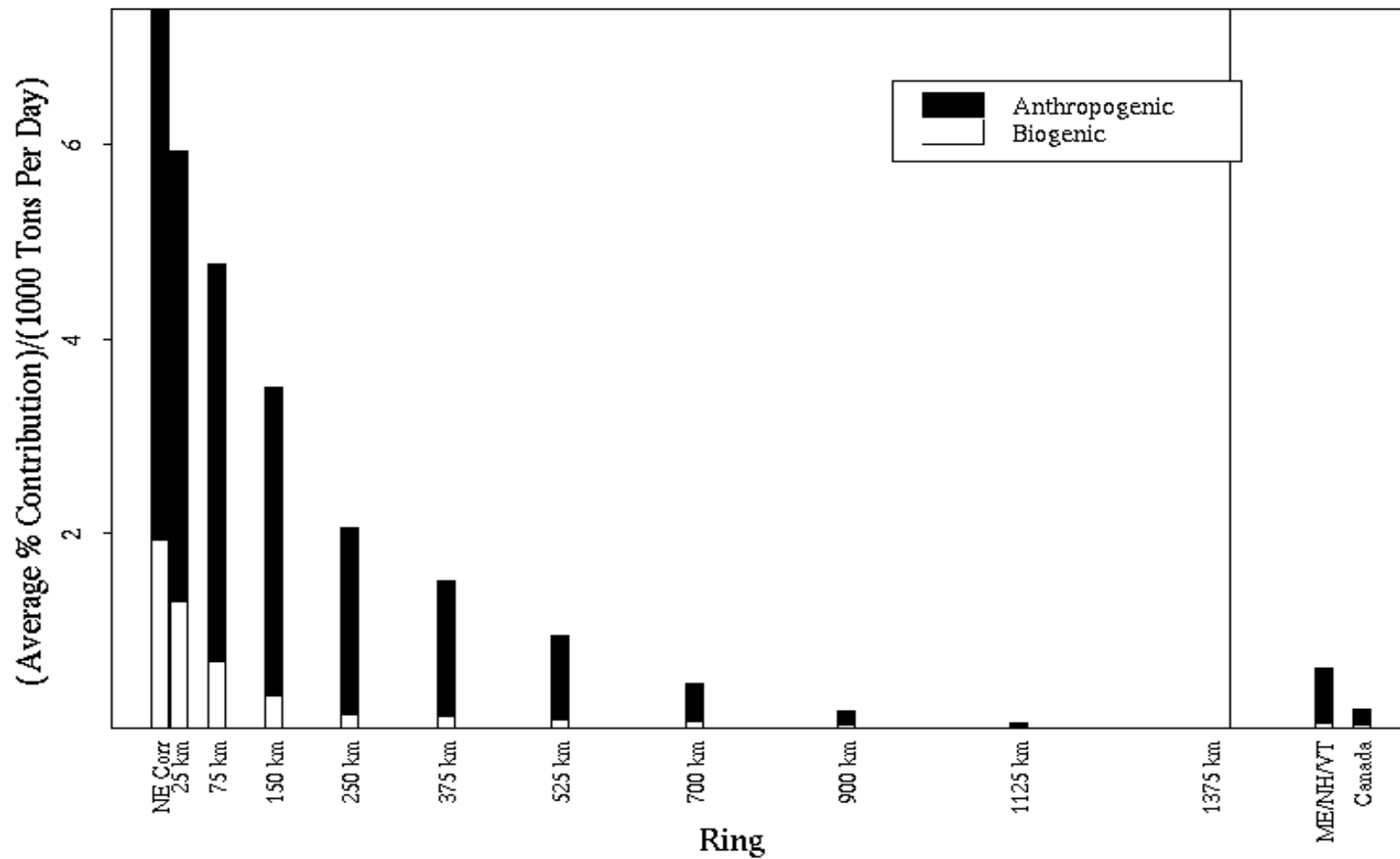


Figure D-9

**% Contribution to O₃ > 100 ppb in the NE Corridor from
Anthropogenic + Biogenic Emissions for the 1991 D2 Base Case and
July 1991 Episode (All Source Regions), N = 10994**

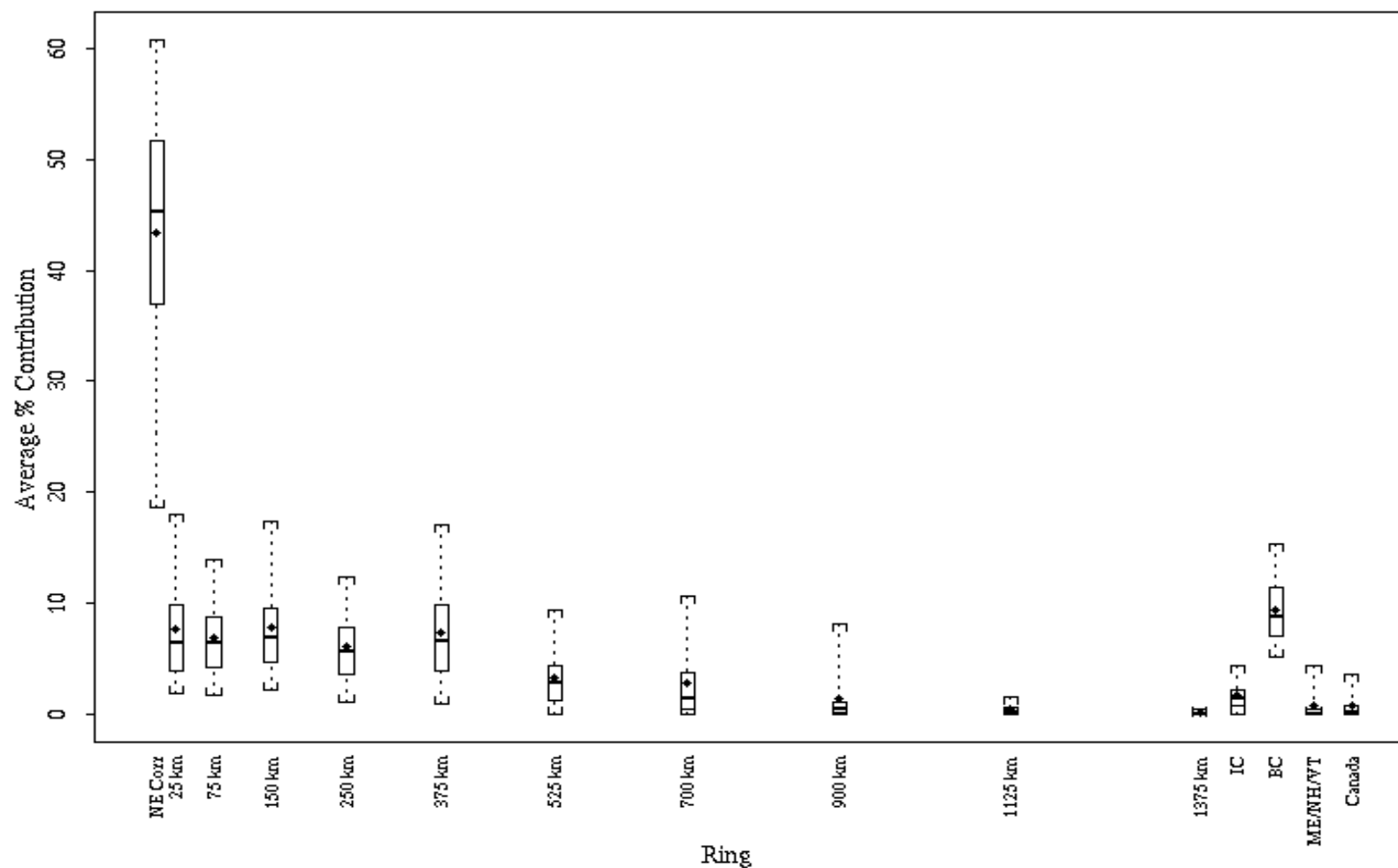


Figure D-10

Normalized % Contribution to O₃ > 100 ppb in the NE Corridor from
Anthropogenic + Biogenic Emissions for the 1991 D2 Base Case and
July 1991 Episode (All Source Regions), N = 10994

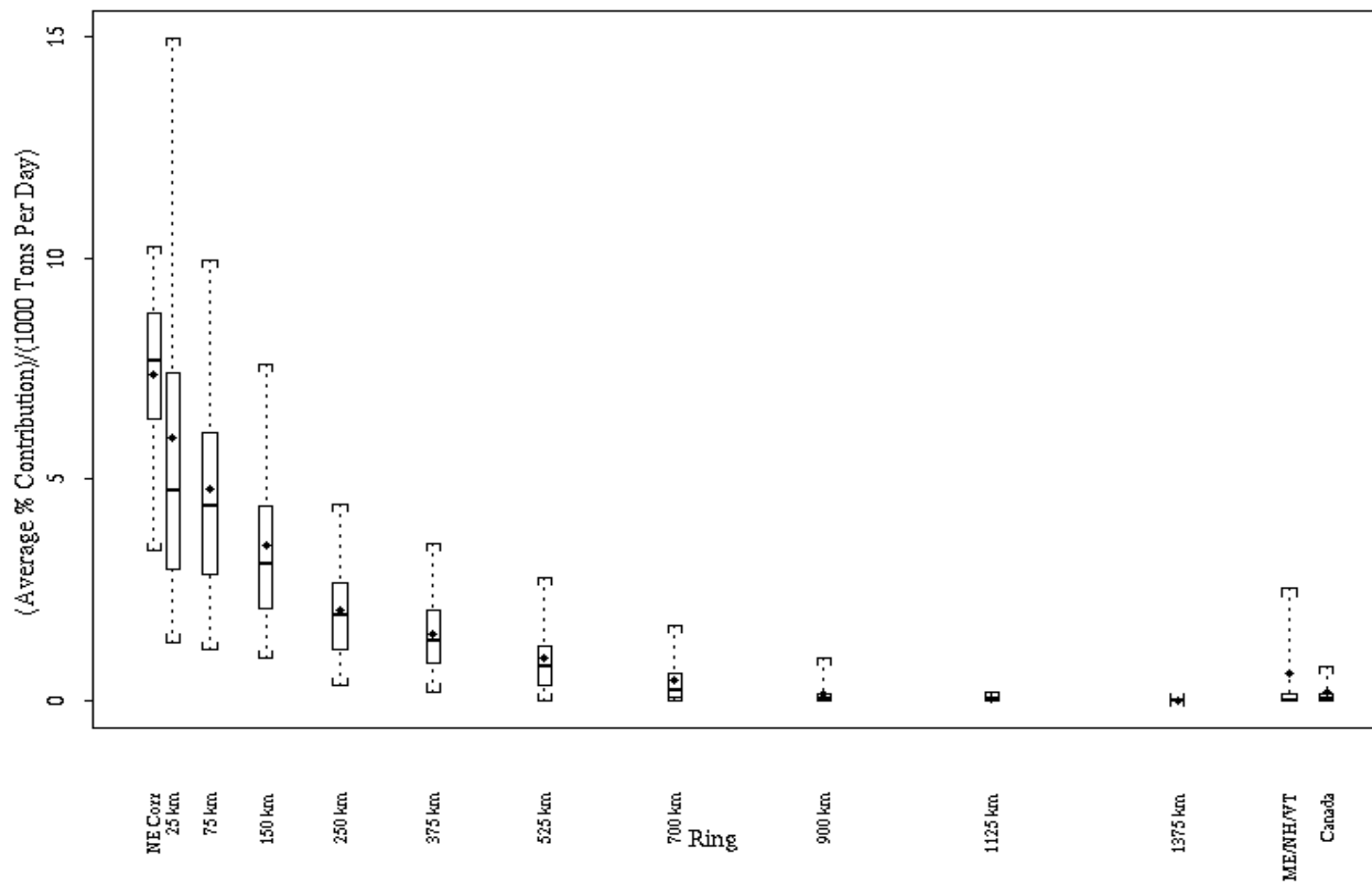


Figure D-11

Cumulative Distribution of the % Contribution to O₃ from
 Anthropogenic Emissions, 1991 D2 Base Case and July 1991 Episode
 All Source Regions, NE Corridor Area

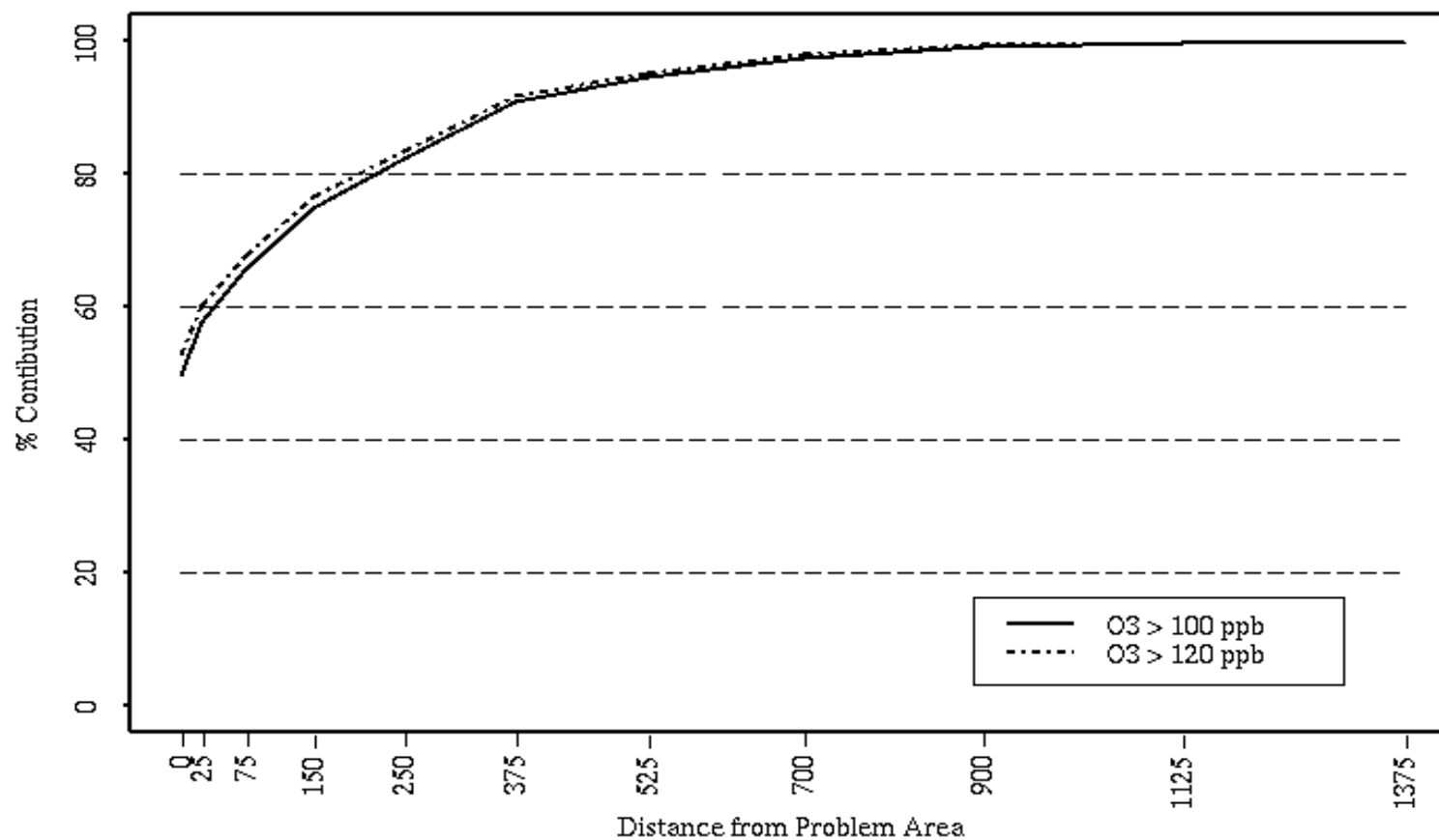


Figure D-12