

LAKE MICHIGAN OZONE STUDY LAKE MICHIGAN OZONE CONTROL PROGRAM

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Since 1990, the States of Illinois, Indiana, Michigan, and Wisconsin, along with the federal government, have been engaged in a comprehensive study of the ozone air quality problem in the Lake Michigan region (see Figure 1) and of potential control measures designed to improve the regional air quality. These efforts -- the Lake Michigan Ozone Study (LMOS) and the Lake Michigan Ozone Control Program (LMOP) -- have led to a greater understanding of the regional ozone problem and of the measures necessary to bring the region into compliance with the National Ambient Air Quality Standard (NAAQS) for ozone.

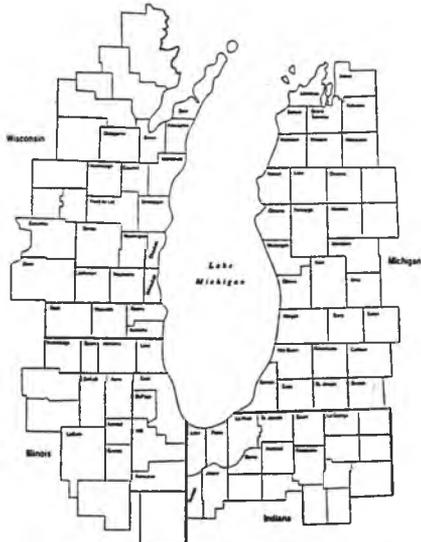


Figure 1. Lake Michigan Study Region

Local emission reduction measures have improved air quality in the region and will continue to do so. The study found, however, that transported ozone and ozone precursors from outside the Lake Michigan region have a major impact on the local air quality. The Ozone Transport Assessment Group (OTAG) was formed to address ozone transport in the eastern half of the U.S.. The results of the OTAG study will be considered in the development of an attainment plan for the Lake Michigan area. The Lake Michigan States will also continue progress in lowering ozone levels, with the ultimate goal to attain the ozone NAAQS in the region by or before the year 2007, as mandated by the Clean Air Act Amendments of 1990 (CAAA).

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Background

Currently, the Lake Michigan region experiences exceedances of the ozone NAAQS on the average of about 10 - 20 days per summer. Exceedances occur throughout the region in portions of all four States (see Figure 2). These exceedances occur during the afternoon and early evening, when the amount of outdoor activity is high. Thus, exposure to unhealthy air is a frequent occurrence in this region during the summer.

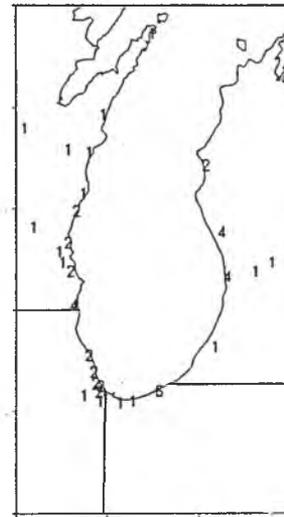


Figure 2. Ozone Exceedance Days During 1995

Lake Michigan itself provides favorable conditions for ozone formation and transport. Morning "rush hour" emissions in major cities, such as Chicago, Gary, and Milwaukee, are carried off-shore by the prevailing winds (or by an early morning land breeze), where they concentrate in a shallow layer and react in the presence of sunlight to form ozone. While these reactions are taking place, the polluted air mass is blown downwind to the north or northeast by the prevailing southerly or southwesterly winds. As a result, the highest ozone levels occur not in the major source regions, but farther downwind in eastern Wisconsin and western Michigan.

Elevated ozone concentrations in the Lake Michigan region are generally associated with high pressure systems; most commonly when the region is located on their "back-side" as they progress eastward. Under these conditions, southerly or southwesterly winds bring warm, moist air into the region. This incoming air mass is generally quite polluted due to the accumulation of emissions from many upwind cities and source regions.

Past ozone control efforts focused on each State developing individual plans for their own nonattainment areas. While local air quality improved, the ozone NAAQS were not met. This may be due to the failure to look at the region as a whole, and to account for the transport of ozone and ozone precursors into and within the region. The States began to work together in 1988 on what was increasingly felt to be a common air quality problem.

Prior to this collaborative effort, the United States Environmental Protection Agency (USEPA) and the States of Illinois and Wisconsin were engaged in litigation concerning ozone control in the Chicago area. This lawsuit stemmed from Wisconsin's concerns about transport of pollution from the Chicago area into southeastern Wisconsin (Wisconsin vs. Reilly, No. 87-C-0395). The lawsuit was resolved with a settlement agreement which called for a regional study of the ozone problem, and the development of a more sophisticated air quality model. To support the more sophisticated model, the LMOS was established pursuant to a Memorandum of Agreement (MOA) signed by the USEPA and the four Lake Michigan States in September 1989.

In 1991, a second MOA was signed by the States to establish the LMOP, which represents the regulatory continuation of LMOS. This next phase of the study dealt with the application of the LMOS modeling system, the assessment of alternative control measures, and the development of a regional attainment plan. The goal of LMOP is to develop an effective regional control strategy, and to implement it in order to achieve the ozone NAAQS in the region and satisfy the CAAA attainment deadlines.

Elements of the LMOS/LMOP Study

Field Program

The LMOS included an intensive field program, the compilation of a regional emissions inventory, and the development of regional-scale emissions, meteorological, and photochemical computer models.

The States and various contractors conducted the field program during the summer of 1991. The purpose of the field program was to collect air quality and meteorological data to be used as inputs for the models, and to evaluate the performance of the models. The 1991 field program, which cost approximately \$6 million, consisted of:

- * land-based surface air quality and meteorological measurements throughout the Lake Michigan area and along the boundary;
- * surface and aloft air quality and meteorological measurements from ships on the Lake;

- * upper-air meteorological measurements; and
- * aloft air quality and meteorological measurements from aircraft over the Lake, near the shoreline of the Lake, and along the boundary of the Lake Michigan area.

Routine surface air quality and meteorological measurements were made continuously from June through August. Special intensive measurements (i.e., aircraft, vessel, and volatile organic compound (VOC)/carbonyl sampling) were made on seven days during an 8-week period from June 17 through August 9. Intensive sampling days were called based on forecasts of ozone-conducive weather conditions.

Incoming levels of ozone along the upwind boundary of the Lake Michigan area were measured to be 70-110 parts per billion (ppb) on high ozone days in the Lake Michigan region. (Note, in comparison, the ozone NAAQS is 120 ppb.) Consequently, transport into the region was determined to be a major contributor to the local ozone problem. Back trajectories indicate that the incoming air mass passed through many upwind cities and source regions.

Emissions Inventory

A comprehensive regional emissions inventory was developed by combining the inventories from the four States. Certain improvements were made to these emission estimates based on new information, including comparisons with ambient field data. An emissions model (EMS-95) was developed to allow for timely, efficient management of the regional inventory. The emissions model processes user-supplied point and area source emission estimates, calculates emissions for biogenic (plant-generated) and mobile sources, and accounts for growth and control to derive future year emissions.

Development and Evaluation of Modeling System

An integrated modeling system consisting of emissions, meteorological, and photochemical models was established for the Lake Michigan region. The "heart" of this modeling system is the UAM-V photochemical model, which provides predictions of ozone and ozone precursor concentrations. UAM-V is an enhanced version of USEPA's Urban Airshed Model, with two-way nested horizontal and vertical gridding, a plume-in-grid treatment, and improved meteorological fields.

The key inputs for the photochemical model are emissions, meteorology, and boundary conditions. Emissions inputs were generated by the EMS-95 emissions model, as discussed above. Meteorological inputs were generated by a prognostic meteorological model (CALRAMS). The CALRAMS meteorological fields were compared to the ambient field data and were determined to be reliable. Boundary conditions were derived from the ambient field data.

The UAM-V photochemical model was also evaluated using the ambient field data. Numerous statistical and graphical performance measures were examined. Overall, model performance was found to be very good:

- * statistical measures were in compliance with USEPA's performance criteria;
- * spatial and temporal ground-level ozone concentration patterns were reproduced successfully;
- * aloft (downwind) ozone predictions compare favorably with aircraft data; and
- * predicted ozone precursor concentrations were generally consistent with the ambient field data.

Based on the performance evaluation, USEPA approved the use of the UAM-V model for regulatory purposes in the Lake Michigan region.

Initial Modeling and Data Analysis

The UAM-V model was first used to perform a series of emissions sensitivity tests to examine the model's response to reductions in local ozone precursor emissions (VOC and oxides of nitrogen [NO_x]). The sensitivity tests found that:

- * domain-wide peak ozone concentrations decreased in response to VOC reductions and increased in response to NO_x reductions;
- * in and downwind of the major urban areas, VOC reductions resulted in significantly lower ozone concentrations, while NO_x reductions resulted in higher ozone concentrations; and
- * farther downwind (in areas with no modeled exceedances), NO_x reductions resulted in slightly lower ozone concentrations.

These findings were confirmed by independent analyses of the ambient field data.

The sensitivity tests also showed that the amount of VOC emissions reduction needed to provide for attainment is probably unachievable -- as much as 90% for some days. If reductions in boundary conditions are also considered, then the VOC reduction target is still very high, on the order of 50 - 60% depending on the assumed boundary conditions, but may be more achievable.

Strategy Modeling and Implementation

The UAM-V model was then used to assess the effectiveness of future control strategies. Four ozone episodes that occurred during the 1991 LMOS field program were used as the basis to model strategies. The weather conditions during these episodes are typical of those associated with most historical ozone episodes. Episodes 1, 2, and 3 are characterized by warm temperatures (maximum daily temperature greater than 90°F), light-moderate winds from the south-southwest, and reduced visibility. Episode 4 also had warm temperatures, but the winds were from the northeast. (These conditions are associated with a lesser, yet significant, number of historical ozone episodes.)

Three different control strategies, which are packages of emission control measures, were modeled to assess their effectiveness in improving ozone concentrations. The following measures were included:

- * national measures required by the CAAA, such as emission standards for new cars;
- * specific measures required of nonattainment areas, such as gasoline pump vapor recovery; and
- * state-discretionary measures needed for 15% Reasonable Further Progress (RFP) Plans and to meet Rate of Progress (ROP) requirements.

Strategy 1 consisted of all emission reduction measures expected to be in effect in 1996 (i.e., mandatory CAAA national measures, plus the States' 15% RFP Plans).

Strategy 2 consisted of these same measures grown out to the year 2007, plus additional mandatory CAAA national measures expected to be in effect by then.

Strategy 4 consisted of all Strategy 2 measures, plus a few additional measures for point, area, and mobile sources.

(Strategy 3, which consisted of all Strategy 2 measures, plus additional NO_x control measures, was not pursued due to the finding that extra NO_x control will actually increase domain-wide peak ozone concentrations. This finding led the Lake Michigan States to petition USEPA for a waiver from these control requirements, as allowed by the CAAA. Even with the NO_x waiver, there will be a net reduction in NO_x emissions in the region, due to other CAAA requirements - e.g., Title II motor vehicle controls and Title IV acid deposition controls. If selective NO_x reductions within the region are found to be necessary as a result of the OTAG study, then the Lake Michigan States expect to revise their State Implementation Plans (SIPs) to require such reductions.)

The modeling results show that the control strategies will produce improved (lower) ozone concentrations. The magnitude, as well as the frequency and spatial extent, of elevated ozone concentrations are all less for future year conditions than for base year conditions. A demonstration of attainment of the ozone NAAQS is dependent upon of the level of assumed future year boundary conditions.

Unless there is a major change in federal ozone policy, measures included in Strategy 2 will come into effect incrementally over the next 12 years. Specific additional national, regional, and local measures which may be needed for attainment will be identified as an outcome of the OTAG study. Strategy 4 identifies some measures which may be implemented as a result of this process.

Summary of Study Conclusions

Ozone is a "superregional" problem:

A surprising and significant result of the study is that there are high levels of ozone and ozone precursors entering the Lake Michigan region (see Figure 3). These high 'boundary conditions', which have been measured to be on the order of 70-110 ppb on some hot summer days, contribute significantly to ozone exceedances in the region. Elevated ozone levels were found to extend well upwind of the Lake Michigan region on these days, covering large areas of the eastern United States. Reducing this incoming pollution is critical. Otherwise, an unrealistically large level of local emission reduction will be required to achieve attainment.

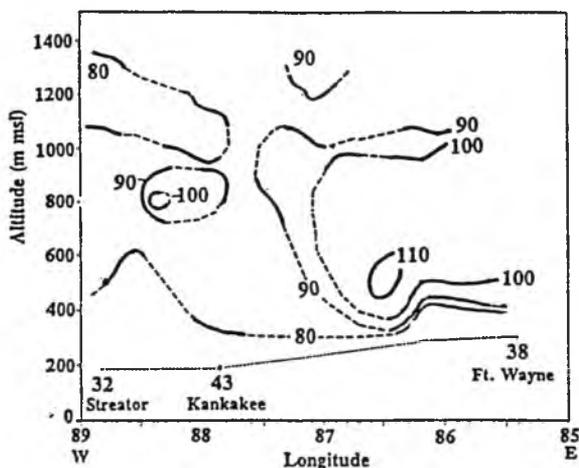


Figure 3. Ozone Upwind of Lake Michigan Region

Ozone levels can be reduced successfully:

The model shows that it is possible for the Lake Michigan region to meet the ozone NAAQS by the statutory attainment year. Attainment is possible if there are local

VOC emission reductions in the region and if there are also reductions of ozone and ozone precursor concentrations entering the region. For example, the effect of Strategy 2 controls plus lower boundary conditions are presented in Figure 4.

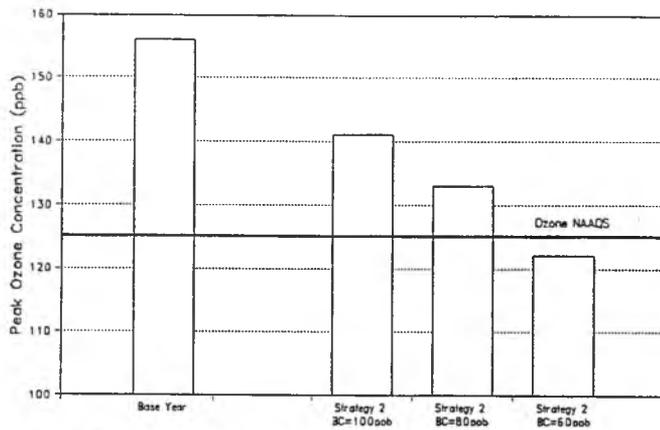


Figure 4. Peak Ozone Concentrations

Local emission reductions from existing national and nonattainment area controls have already resulted in cleaner air. While exceedances of the ozone NAAQS still occur, there are less exceedances than expected given the number of hot summer days. As seen in Figure 5, the number of exceedance days compared to the number of "hot" days (i.e., days above 90°F) has declined considerably since the late 1980s.

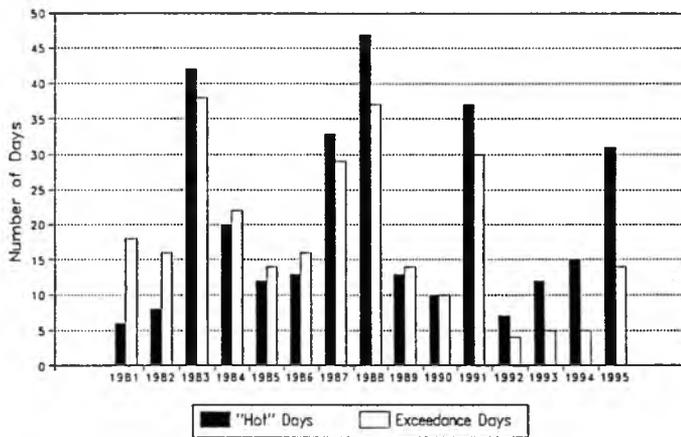


Figure 5. Ozone Exceedance Days v. "Hot" Days

Local VOC emission reductions are more important than local NOx reductions:

Modeling and data analyses show that local VOC emission reductions decrease the magnitude, spatial extent, and duration of high ozone levels.

VOC emissions come from diverse sources, with sizable contributions from motor vehicles, off-highway mobile sources, industrial point and area sources, and

residential/commercial area sources (see Figure 6). This diversity necessitates the application of control measures across all major source sectors.

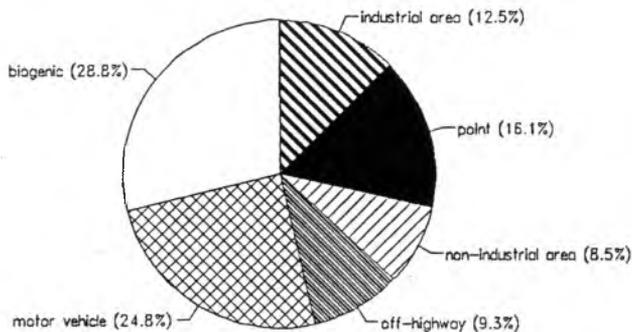


Figure 6. VOC Emission Sources in the Lake Michigan Region (Total Emissions = 3825 TPD)

Although biogenic emissions comprise over one-fourth of the total regional VOC emissions, most of these emissions occur in the northern portion of the study region (i.e., downwind of the highest ozone concentrations). As such, they do not contribute to the high local ozone concentrations.

The modeling and data analyses also show that local NOx emission reductions will have a negative effect. The air in major urban areas is typically VOC-limited due to the large amount of NOx emitted from motor vehicles and industrial point sources. The high NOx emissions actually "scavenge" local ozone concentrations. Thus, reductions in these local NOx emissions mean less scavenging (i.e., result in higher ozone concentrations). Farther downwind, the air becomes NOx-limited and NOx reductions will have a positive effect (i.e., result in lower ozone concentrations).

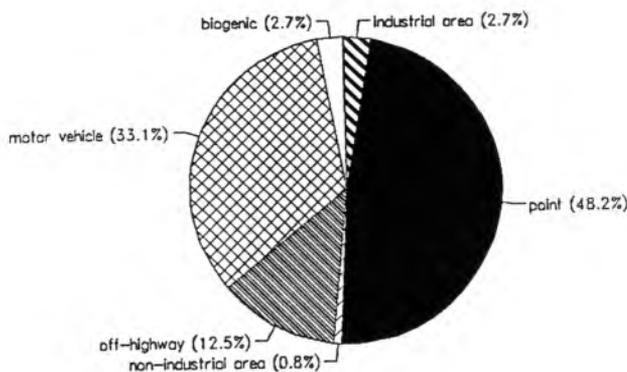


Figure 7. NOx Emission Sources in the Lake Michigan Region (Total Emissions = 2950 TPD)

NOx emissions come mostly from motor vehicles and power plants (see Figure 7). Motor vehicle emissions are released near ground level, while power plant emissions are released from elevated stacks. This difference in release height results in different spatial impacts from these two major source categories.

Future Study and Control Efforts

The LMOS/LMOP study has revealed that the transport of pollution into the Lake Michigan region has a major impact on local ozone air quality levels. Without significant reductions in this transport, the region will not be able to attain the ozone NAAQS. Other areas in the eastern United States have reached this same conclusion. To deal with this transport problem, USEPA adopted a new policy on March 2, 1995, regarding ozone attainment demonstrations. This policy established a two-phase process for states to develop approvable SIPs.

Phase I requires states to complete pre-November 1994 SIP requirements, such as the 15% RFP Plans and other CAAA requirements; to submit regulations sufficient to meet the initial ROP requirements; and to submit modeled attainment demonstrations based on assumed reductions of future year transported ozone levels. The modeling demonstration prepared by the Lake Michigan States shows that attainment is achievable if incoming ozone and ozone precursor concentrations are reduced by about 30%, and local VOC emissions are reduced by about 50 - 60%.

Phase II calls for a two-year consultative process to assess national and regional strategies to reduce ozone transport in the eastern United States. OTAG was formed for this purpose. The results of the OTAG study will be considered in the development of an attainment plan for the Lake Michigan area. The Lake Michigan States will continue efforts to improve local ozone air quality, with the ultimate goal to attain the ozone NAAQS in the region by or before the year 2007.

OTAG MODELING RESULTS

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1. INTRODUCTION

On some hot summer days, high ozone concentrations occur over a large portion of the eastern U.S. (NRC, 1991; Sigma, 1995; and SOS, 1995). These high regional (transported) concentrations make it difficult for many urban areas to demonstrate attainment of the ozone standard. In recognition of the transport problem, the Environmental Council of the States, in conjunction with the U.S. Environmental Protection Agency (USEPA), established the Ozone Transport Assessment Group (OTAG) in 1995 (OTAG, 1997a).

Air quality models were run as part of OTAG's study of ozone in the eastern U.S. The purpose of the modeling was to assess the transport of ozone and ozone precursors, and to determine the air quality benefits from national or regional control strategies. The modeling effort was one of the largest air quality assessment projects ever conducted.

2. OVERVIEW OF MODELING

Key elements of the OTAG modeling included:

- * Establishment of four Modeling Centers to conduct the modeling: Northeast Modeling and Analysis Center, Southeast Modeling Center, Midwest Modeling Center, and USEPA Modeling Center.
- * Development of a new national emissions inventory based on data for 37 states, the District of Columbia, Canada, and off-shore (Gulf of Mexico).
- * Application of state-of-the-science emissions (EMS-95), meteorological (RAMS and SAIMM), and photochemical (UAM-V) models. The modeling domain covered most of the eastern half of the U.S. (i.e., from Texas to the Dakotas to Maine to Florida) - see Figure 1. Model grid resolution (12 km in the inner, fine grid, 36 km in the outer, coarse grid) was adequate to provide a reasonable representation of regional ozone concentrations, and the change in regional ozone concentrations due to changes in ozone precursor emissions.

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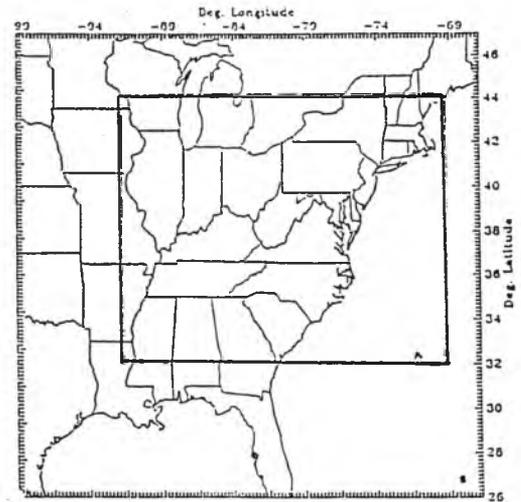


Figure 1. OTAG Modeling Domain

- * Examination of four multi-day periods of high ozone concentrations (i.e., ozone episodes). These episodes occurred in July 1988, July 1991, July 1993, and July 1995. During each episode, there were high ozone concentrations across a broad multi-state region in the eastern U.S.
- * Establishment of a data clearinghouse to provide greater access to the modeling data. The web site address for the clearinghouse is "<http://www.iceis.mcnc.org>".

Basecase modeling began in March 1996. (Preparation of key model inputs, such as emissions and meteorology, began a few months before then.) After several months of analyses, an acceptable basecase was identified. Improvements made as part of this process included use of the most recent biogenic emission estimates (BEIS2), updating the chemistry in the model (to accommodate the BEIS2 emissions), and correcting to the anthropogenic emissions inventory.

Sensitivity modeling, which was performed during July - October 1996, consisted of emissions and geographic sensitivity runs. This modeling provided general information to guide the development of control strategies.

Strategy modeling, which was performed during October 1996 - March 1997, consisted of three rounds of modeling runs: Round 1 (evaluate possible emission reductions), Round 2 (refine emission reduction level for OTAG strategies), and Round 3 (evaluate geographic applicability of OTAG strategies).

3. EXPECTATIONS

The expectations of those using the OTAG modeling results should be consistent with the following points:

- * The modeling was designed to provide an assessment of regional-scale concentrations. As such, the results should not be used to address local regulatory issues, such as urban area attainment demonstrations.
- * The modeling also provides boundary conditions for these four episodes for future year (2007) conditions. To support subsequent urban modeling analyses, boundary conditions will be needed for other episodes and other future years.
- * The limited number of episodes which were modeled may not represent all possible transport patterns or all possible nonattainment conditions.
- * Models are tools for helping decision makers understand air quality problems and evaluate potential control strategies. Models are most reliable for directional and relative assessments.
- * The decision to apply the models for this study was an attempt to take advantage of their capabilities at their current state of development. Evolution and improvement of the models and the underlying data bases in the future should be expected.

4. KEY FINDINGS

Key strategy-relevant findings of the modeling are as follows (OTAG, 1997b):

- * Basecase modeling showed reasonably good agreement between simulated and observed surface ozone concentrations, with no large positive or negative biases. Based on limited aircraft measurements, however, the model underestimated observed ozone concentrations aloft, which suggests that the model may be underestimating transport.
- * NO_x emission reductions are more effective than VOC emission reductions in lowering regional ozone concentrations; NO_x reductions decrease ozone domainwide, while VOC reductions decrease ozone only in urban areas
- * Both elevated and low-level NO_x emission reductions are both effective in lowering regional ozone concentrations

- * More emission reduction results in more ozone benefit
- * Regional NO_x emission reductions due to Clean Air Act mandatory controls, as well as possible OTAG controls, will reduce transported ozone and ozone precursors, but may not be sufficient to provide for attainment of the 1-hour ozone standard throughout the eastern U.S.
- * Ozone reductions in a given region are most influenced by emission reductions in that same region, but are also influenced by emission reductions in upwind regions
- * The magnitude and spatial extent of 8-hour concentration differences are similar to 1-hour concentration differences. This suggests that a regional strategy designed to help meet the current 1-hour standard will also help meet an 8-hour standard.

5. SUMMARY

The OTAG modeling provided information on ozone and ozone precursor concentrations in the eastern U.S., and the relative effectiveness of controls (on both a pollutant and geographic basis) in reducing transported ozone and ozone precursor concentrations on a regional scale. The study is unique in its attempt to both bring together the numerous stakeholders and employ state-of-the-art models and up-to-date data bases, which enhanced the political and technical acceptability of the modeling results.

6. REFERENCES

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