(906)

December 15, 1994

MAJOR FINDINGS AND RESULTS OF THE LAKE MICHIGAN OZONE STUDY

Introduction

To comply with the requirements of the Clean Air Act Amendments of 1990 (and the Settlement Agreement in the case of Wisconsin v. Reilly, No. 87-C-0395), the States of Illinois, Indiana, Michigan, and Wisconsin, and the United States Environmental Protection Agency (USEPA) initiated the Lake Michigan Ozone Study (LMOS). The study represents an attempt to provide a regional solution to the ambient ozone air quality problem in the Lake Michigan area. The primary objectives of LMOS are to collect information on emissions, meteorology, and air quality; develop and evaluate emissions, meteorological, and photochemical models; and deliver to the States a technically credible modeling system to use in supporting revised ozone control plans. A Memorandum of Agreement was established in 1989 to provide the framework for this cooperative technical effort.

A second Memorandum of Agreement was established in 1991 to ensure the regulatory continuation of the LMOS. This next phase of the project (referred to as the Lake Michigan Ozone Control Program or LMOP) deals with the application of the LMOS modeling system, the assessment of alternative control measures, and the development of a regional attainment strategy.

The Lake Michigan study region covers an area that is approximately 500 x 800 km centered on Lake Michigan. Included in the region are several large metropolitan areas (e.g., Chicago, Milwaukee, Grand Rapids, and Gary). Although USEPA has identified ten (10) individual nonattainment areas in the region, measured exceedances occur throughout the area indicating the regional nature of the ozone problem here. On average, exceedances of the Federal health standard for ozone occur on over 20 days per summer, with peak values on the order of 150-180 ppb.

Two special features of the ozone problem in the Lake Michigan region are worth noting. First, the Lake, which covers a significant portion of the region, strongly influences the formation and transport of ozone in the region. It is no coincidence that most of the observed exceedances occur within one or two counties of the Lake. Second, incoming ozone and ozone precursor concentrations are quite high during ozone episodes. Aloft ozone concentrations along the upwind boundary were found to be as high as 110 ppb during the 1991 field program.

Climatology of Ozone in the LMOS Region

Three general types of synoptic conditions produce elevated surface-level ozone concentrations in the Lake Michigan area: region is located on the "front-side" of high pressure system (about 10 - 15% of the exceedance days); center of high pressure system located over region (also about 10 - 15%); and region is located on the "back-side" of high pressure system (about 75%). These conditions may occur in stages during the same multi-day episode as a Canadian high moves across the region.

LMOS Episodes 1, 2, and 3 can be characterized by warm temperatures (max daily $\geq$ 33°C), light-moderate winds from the SW-SE, weak pressure gradients to the southeast/higher gradients to the northwest, and reduced visibility. These episodes are representative of the "back-side" of high conditions. LMOS Episode 4 also experienced warm temperatures, but had winds from the NE winds in the southern half of the region (i.e., "front-side" of high conditions).

Of all meteorological variables, temperature has the highest correlation with ozone concentrations ($r \sim 0.6$). Attempts to develop a reliable predictor of ozone exceedances based on temperature, wind direction, and previous day's peak ozone have been unsuccessful.

Emission Inventories

A comprehensive, regional modeling inventory was compiled from several different sources, including the four individual State inventories. This de-centralized approach to building a regional inventory (i.e., combining four State inventories into one multi-state inventory) created several problems, including extra costs, additional time, and somewhat lower quality data.

An emissions modeling system (EMS-95) was created to allow for timely, efficient management of the emissions inventory. In its present form, EMS-95 processes user-supplied point and area source emission estimates and calculates emissions for biogenic and motor vehicle sources. It also has the capability to account for projections for future year conditions.

Comparisons of ambient and emissions-based NMOC:NOx and CO:NOx ratios indicated a significant underestimation of VOC emissions, primarily from motor vehicles. Subsequent reevaluation of the modeling inventory lead to several significant revisions, including a significant net increase in VOC emissions and a net decrease in NOx emissions, changes in the spatial and temporal allocation of emissions, and modification of speciation profiles. The revised inventory was found to be in good agreement with the ambient measurements.

Instrumentation/Design for Field Studies

A comprehensive field program was conducted during the summer of 1991. The main purpose of this program was to collect air quality and meteorological data either to provide input for photochemical and meteorological models, or to evaluate the performance of these models. The 1991 field program, which cost slightly more than $6.0M, consisted of the following parts:

* land-based surface air quality and meteorological data throughout the LMOS domain and along the boundary,
* surface and aloft air quality and meteorological data from ships over the Lake,
* upper air measurements of meteorological data, and
* aloft air quality and meteorological data from aircraft over the Lake, near the shoreline of the Lake, and along the boundary of the domain.[1]

Routine surface air quality and meteorological measurements were made continuously during a 3-month period from June through August. Special intensive measurements were collected on seven days during an 8-week period from June 17 through August 9. The intensive sampling days were called by the field management contractor based on forecasts of ozone-conducive weather conditions. Airplanes, ships, volatile organic compound (VOC) and carbonyl measurements, and rawinsondes were deployed on the intensive sampling days.

Performance of Regional-Scale and Urban-Scale Air Quality Models

An enhanced version of the Urban Airshed Model (UAM-V), with two-way nested horizontal and vertical gridding, plume-in-grid treatment, and updated dry deposition was developed.

An integrated modeling system consisting of an emissions (EMS-95), prognostic meteorological (CALRAMS), regional photochemical (ROM), and mesoscale photochemical (UAM-V) models was established.

The performance of the regional photochemical model (ROM) was determined to be unacceptable because of its significant underprediction of incoming aloft ozone concentrations (i.e., bias on the order of -20 to -30 ppb). Boundary conditions for base year modeling were derived from field data.

The prognostic meteorological model (CALRAMS) was evaluated using data from the 1991 LMOS field program. Comparisons with surface measurements were generally favorable. Limited comparisons between the modeled and observed fields aloft for episodes 1 and 2 suggest that the model is also performing well aloft. Consequently, the performance of the model was judged to be acceptable.

The mesoscale photochemical model (UAM-V) was also evaluated using data from the 1991

LMOS field program. Extensive statistical and graphical analyses were performed. Several highlights of the model evaluation should be noted:

* The statistical measures comply with USEPA's performance criteria. Furthermore, the LMOS statistics are as good, if not better, than any previous evaluation using a "rich" ambient data base.

* The temporal and spatial representation of surface ozone concentrations are reasonable both region-wide and in the areas of high concentrations. The time of peak concentration is matched closely by the model and broad areas of high concentrations are reproduced successfully.

* Model performance across the full domain is consistent with performance in individual subregions. In view of the differences in the amounts of ozone precursor emissions and the source-receptor relationships throughout the region, this similarity in performance further demonstrates the credibility of the model.

* Aloft (downwind) ozone predictions compare favorably with aircraft data. Given the importance and complexity of the 3-dimensional transport in the Lake Michigan area, good model performance aloft is critical.

* Model performance for ozone precursors, especially NOx, is very good. This has been a particular short-coming in previous UAM evaluations. Being able to accurately simulate ozone precursors is an important consideration in being able to use the model to predict changes in ozone concentrations resulting from changes in precursor emissions.

On December 15, 1994, USEPA approved the use of UAM-V in the Lake Michigan region for regulatory purposes.

Factors Controlling Ozone Accumulation in the LMOS Region

A conceptual model based on field data provides a qualitative explanation for the formation and transport of ozone in the region. According to this model, early morning urban area emissions are transported off-shore and confined to a shallow conduction layer (100 - 300 m deep) which acts as an efficient reaction chamber. In the conduction layer, ozone builds to elevated concentrations in the absence of surface removal effects, any significant dilution, and subsequent, fresh NO emissions, and in the presence of high solar insolation and high humidity. As this plume moves over land, it mixes down to produce elevated ground-level ozone concentrations near the shore.

Incoming levels of ozone are on the order of 80 - 110 ppb on high ozone days. Back trajectories indicate that this polluted air mass is coming from nearby source regions such as St. Louis and the Ohio River Valley, and, possibly, as far as the Gulf Coast and the East Coast. The magnitude of these concentrations and the sensitivity of the UAM-V predictions to boundary conditions (i.e., a 1 ppb increase in ozone boundary conditions will produce almost a 1 ppb increase in the peak local ozone concentration) necessitate that modeled boundary conditions be estimated accurately.

Management of Ozone Accumulation in the LMOS Region

A series of emissions sensitivity tests were performed to examine the model's response to reductions in VOC and NOx emissions for several different basecase scenarios. The analyses found that the domain-wide peak ozone concentration, the spatial extent of concentrations greater than the ozone NAAQS, and the number of hours greater than the ozone NAAQS:

* decrease in response to VOC reductions; and
* increase in response to NOx reductions up to a certain control level (and decrease at higher control levels).

VOC and NOx emission reductions were also found to produce different impacts spatially. VOC reductions were most effective in lowering ozone concentrations in and downwind of major urban nonattainment areas. NOx reductions, on the other hand, were more effective in lowering ozone concentrations much farther downwind. Additionally, NOx reductions produced increased ozone concentrations in and downwind of the major urban nonattainment areas. (These findings were corroborated by independent analyses of the LMOS field data by the LMOS Data Analysis Contractor.) As a consequence of the local disbenefit due to NOx reductions, the Lake Michigan States petitioned USEPA on July 13, 1994 for a waiver from the NOx RACT requirements of the Clean Air Act Amendments of 1990 ("the Act"). In addition, the initial control strategies to be modeled have emphasized VOC controls.

A second series of sensitivity tests were performed to assess the relative culpability of local source regions and incoming (transported) ozone levels. These tests showed that reductions in boundary conditions were more effective in decreasing peak modeled ozone concentrations than reductions in local VOC emissions. This is not surprising given that the incoming ozone levels are generally 1/2 (or more) of the domain-wide peak ozone concentrations on episode days. Based on this finding, it is clear that the regional attainment demonstration must include substantial reductions in local VOC emissions (to meet the reasonable further progress requirements of the Act and to provide for attainment) and significant, realistic reductions in boundary conditions.

Modeling of actual control strategies is underway. The results of this modeling will be used by the Lake Michigan States to develop the regional control plan. A solid outline of this plan is expected to be available by August 1995, pursuant to the States' "Ozone Attainment Demonstration SIP Submission Schedule" (November 15, 1994).