B03

The Lake Michigan Ozone Study—Summer 1991 Field Measurements

by: Norman E. Bowne
Senior Program Manager, ENSR Consulting and Engineering
Michael Koerber
Technical Director, Lake Michigan Air Directors Consortium

AUTHORS' NOTE: "An Overview of the Lake Michigan Ozone Study" was included in the Winter 1991 edition of *E²m*. The following article, which presents the results of the 1991 field measurement program, is the second in a series of three on the Lake Michigan Ozone Study (LMOS). The field data are currently being used to evaluate the performance of a mathematical model which will support the development of a regional control strategy for the Lake Michigan area. The results of the modeling will be discussed in a future article.

ABSTRACT

Measurements of air quality and meteorology were made in the Lake Michigan area during the summer of 1991. These data will be used to evaluate the performance of a mathematical model which makes predictions of ambient ozone concentrations. The ultimate use of the model will be to support the development of a regional control strategy for the Lake Michigan area. Routine air quality observations were obtained hourly from the existing state networks in WI, IL, IN and MI, and from several dozen additional monitoring stations installed for the project. Special measurements were made from boats and aircraft. The measurement program is described and preliminary results are discussed.

INTRODUCTION

The States of Illinois, Indiana, Michigan, and Wisconsin and the United States Environmental Protection Agency (USEPA) have joined together to study ambient air quality levels of ozone in the Lake Michigan area. The study stems both from the mutual recognition of the need for a regional solution to the regional ozone problem and a Court Order which requires the expeditious development and application of a photochemical grid model for this area. The four Lake Michigan States and USEPA entered into a Memorandum of Agreement (MOA) to establish a cooperative interstate and Federal effort (referred to as the Lake Michigan Ozone Study or LMOS) to support the photochemical grid modeling.

The LMOS will involve the collection of data bases, the development and evaluation of a photochemical grid model, and the establishment of a technically credible modeling system for the Lake Michigan area. Air quality and meteorological data were gathered during two field studies: a preliminary study during 1990, and a comprehensive field program during 1991. This paper reviews the measurement program and preliminary results for the 1991 field program.

DESIGN PROCESS

Regulatory and Court-mandated deadlines necessitated an accelerated

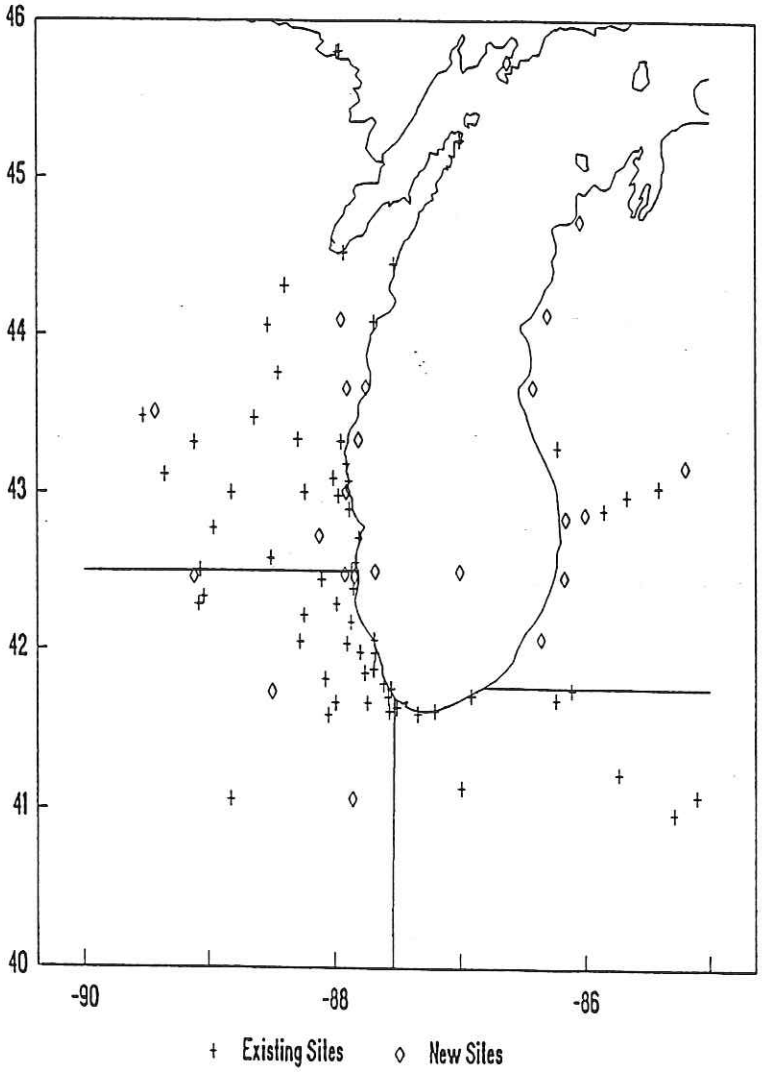

Figure 1. Ozone Monitoring Sites

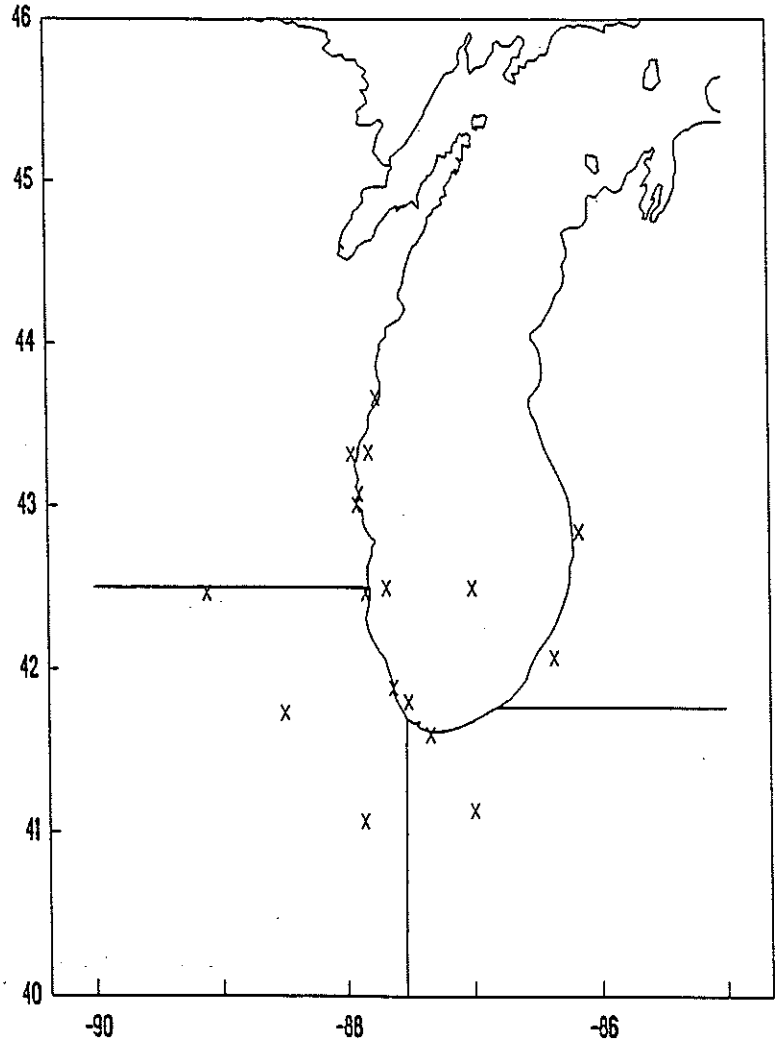

Figure 2. VOC Monitoring Sites

planning schedule. Planning for the LMOS was conducted by the States, USEPA, and several contractors over a two-year period. The planning began in 1989 with a scoping study commissioned by the States.[1] The purpose of the scoping study was to improve the understanding of the existing ozone problem, to identify an effective photochemical modeling tool, and to identify data collection activities needed to support the application of a photochemical model.

Guided by the recommendations of the scoping study, the States and USEPA developed a plan for a preliminary program to be conducted during the summer of 1990. In addition to providing data and experience needed to plan and perform the more extensive field program in 1991, the 1990 measurement program was designed to improve understanding of the complex meteorological condition in the Lake Michigan area and the transport of ozone and ozone precursors into the area.

Serious planning for the 1991 field program began with the preparation of a Conceptual Design Document by the project management contractor in November 1990.[2] The Conceptual Design Document examined the data requirements for the models, and provided a detailed outline of the operations plan for the 1991 field program. Using this document as a strawman, a series of monthly, multi-day planning sessions were held under the direction of the project management contractor between December 1990 and April 1991. During these sessions, the design of the field program was modified and refined to reflect data priorities and the integration of the various measurements. The purpose of each measurement was identified and justified. In addition, sufficient redundant sampling was incorporated to provide back-up measurements for certain key variables and to serve as a quality assurance function. The planning culminated in a final operations plan prepared by the project management contractor in May 1991.[3]

To ensure the integrity of the program, a comprehensive quality assurance plan was prepared by the project management contractor and approved by USEPA. This plan outlined the quality control procedures to be followed by the field contractors and States in collecting and processing ambient data. System audits (review of operational and quality control procedures to assess whether they are adequate to assure valid data which meet desired levels of accuracy and precision) and performance audits (establishment of whether predetermined specifications for accuracy are being achieved in practice) were conducted prior to and during the field program by an independent quality assurance contractor.

MEASUREMENT PROGRAM

The 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 success of the data collection effort depended on the adequacy of the planning, the performance of the data collection teams, and the occurrence of ozone-conducive weather conditions. Fortunately, all three of these conditions were met during the 1991 field program.

The 1991 field program, which cost slightly more than $6 million, consisted of the following parts:

1. Land-based surface air quality and meteorological data throughout the LMOS domain and along the boundary,
2. Surface and aloft air quality and meteorological data from ships over the Lake,
3. Upper air measurements of meteorological data, and
4. Aloft air quality and meteorological data from aircraft over the Lake, near the shoreline of the Lake, and along the boundary of the domain.

Routine, surface measurements were made continuously during a three-month period from June through August. Special, intensive measurements were collected on seven days during an eight-week period from June 17 through August

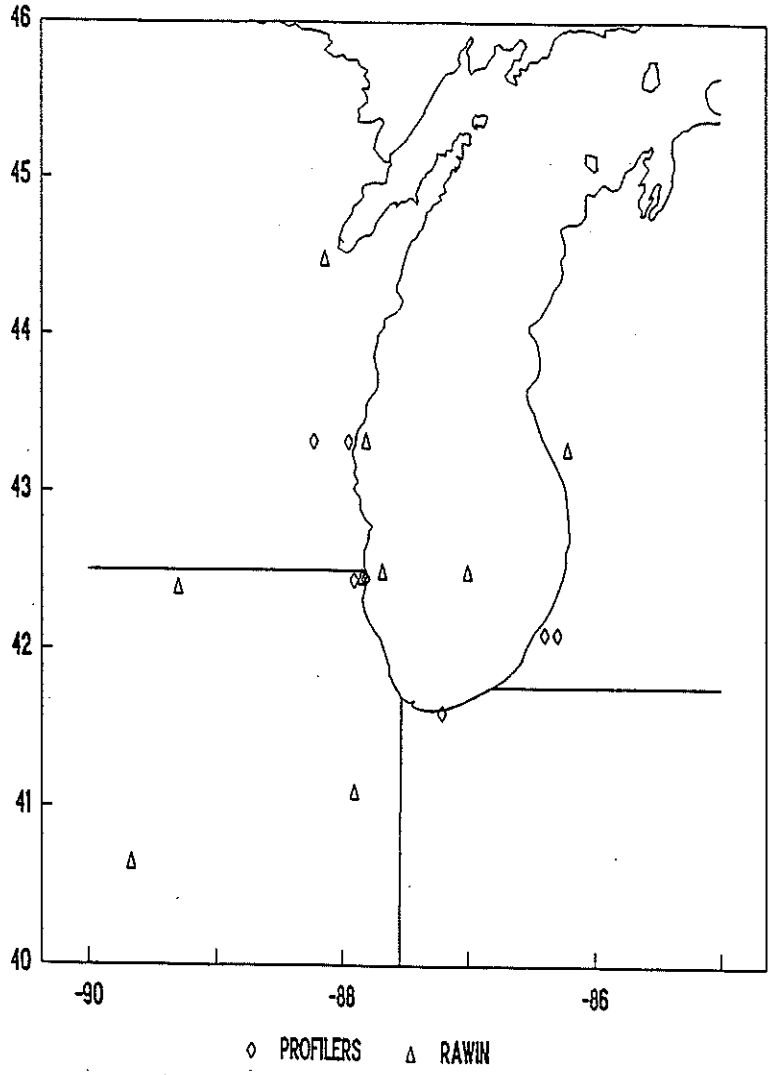

Figure 3. Upper Air Sites

9. A week of set-up and practice for procedures was scheduled for June 10 to 16 with June 12 being an "Operational Shakedown Day" during which all systems operated as if it were a regularly scheduled, although short, intensive measurement day. The intensive sampling days were selected by the field management contractor based on forecasts of ozone-conducive weather conditions. The special monitoring platforms which were deployed on intensive sampling days included aircraft, ships, volatile organic compound (VOC) and carbonyl sampling, and rawinsonde measurements. All systems made around the clock observations during intensive study days as weather conditions permitted.

The study domain and surface ozone measurement sites are illustrated in Figure 1. This monitoring network was designed to document the region wide ozone distribution for the primary wind directions of interest (i.e., southerly to westerly).

The surface-level air quality sampling included continuous measurements for ozone at over 85 stations, oxides of nitrogen (NOx) at over 30 sites, and carbon monoxide at about 20 stations.

In addition, peroxyacetyl nitrate (PAN) was measured continuously at three sites, and VOC and carbonyl were measured on intensive study days at 13 stations (see Figure 2). The AIRTRAK monitoringsystems (which provide measurements of reactive organic compounds, the reaction rate coefficient for smog formation, and concentrations of nitric oxide, NOx and ozone) were operated at four sites. The surface-level meteorological sampling included continuous measurements at over 70 State and private (industrial) sites, and several dozen National Weather Service/Federal Aviation Administration stations.

Four vessels were deployed over Lake Michigan. The three main vessels collected continuous measurements of air quality and meteorology on intensive sampling days, as well as serving as a platform for launching rawinsondes. The fourth vessel travelled in a NW-SE direction about 2-3 km off-shore from the Chicago-Gary area collecting a spatially integrated VOC and carbonyl sample.

Upper air meteorological data were collected at 14 stations: (1) seven stations (four over land and three over the Lake) with rawinsondes launched every three hours on the intensive sampling days, and (2) seven stations with radar wind profilers (and, at two stations, a radio acoustic sounding system)providing continuous measurements throughout the study period. These sites are identified in Figure 3.

Five planes collected air quality (VOC, carbonyl, ozone, and NOx) and meteorological data in three main areas: (1) along key flux planes (e.g., east- west planes extending across the Lake located between Chicago and Milwaukee, and north of Milwaukee), (2) over the Chicago metropolitan area, and (3) along the boundary of the study domain (see Figure 4). In addition, a separate plane was instrumented with a UV-DIAL by SRI, International to provide vertical x-z profiles of ozone between the ground up to about 5,000 feet, with resolution of about 150 m in the vertical and 2900 m in the horizontal.

Finally, it should be noted that while the focus of the field program was on air quality and meteorological data, several emissions-related measurements were made. Three separate analyses are planned based on these measurements: (1) analysis of various ambient ratios, (2) receptor modeling, and (3) analysis of the reactive organic compound concentrations from the AIRTRAK monitors. (Although plans were made to conduct a mass balance study in the Milwaukee area, these measurements were not taken because the proper meteorological conditions did not occur.) In addition, the State agencies worked with over 200 of the largest emitters of ozone precursor emissions to compile a day-specific inventory. This information provides a more accurate representation of the actual operating and emission levels for the study days of interest, and will allow the model to be

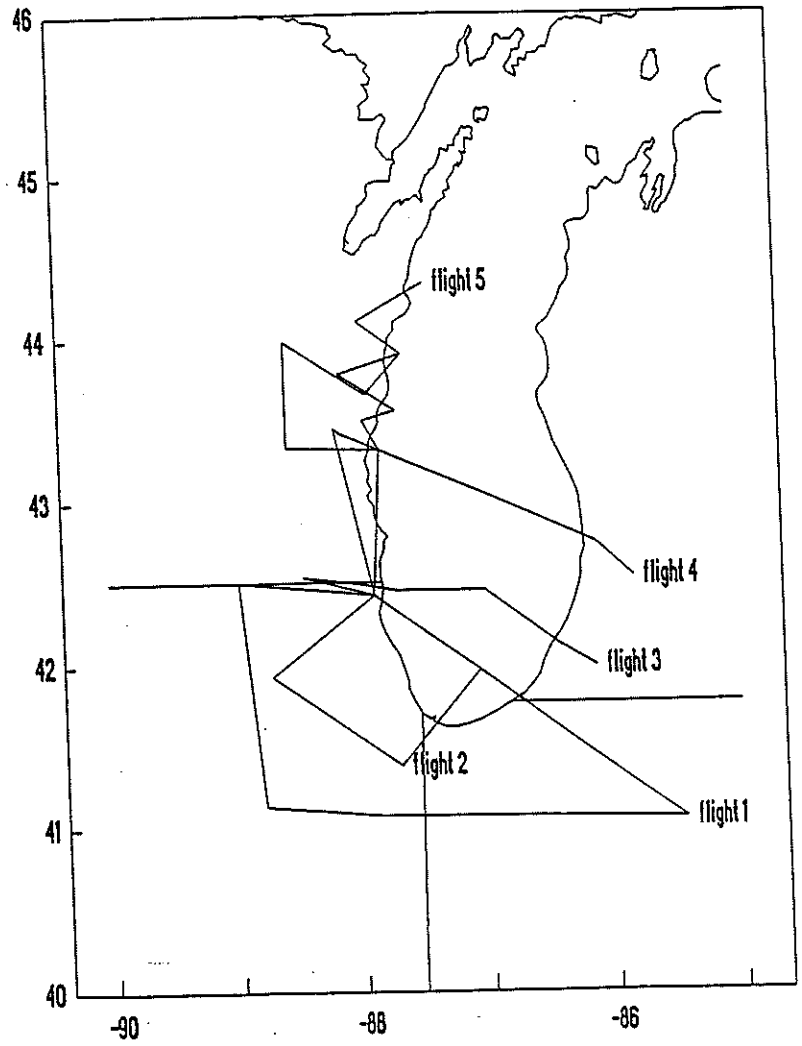

Figure 4. Aircraft Flight Patterns

evaluated with concurrent air quality, meteorological, and emissions data.

RESULTS

There were several periods of elevated ozone levels occurred during the field program.[4] The first event occurred during the period from June 18 to 21. Ozone concentrations above the ambient air quality standard occurred in Illinois and Indiana. Wind directions were east to northeast. An intensive measurement day was not called during this period because the sampling network was designed to accommodate south to west winds. Certain supplemental monitoring was, however, conducted (e.g., radar wind profilers, AIRTRAK, and expanded surface air quality and meteorological samplers). This episode was subsequently selected for modeling given the unique set of meteorological conditions.

The next event occurred during the period from June 25 (Tuesday) to June 29 (Saturday). Intensive measurements were taken during this episode. Tuesday had southerly winds with building ozone levels showing peaks near 100 ppb. On Wednesday, the winds remained southerly at 10 to 15 miles per hour and peak ozone levels over 150 ppb were observed in Wisconsin from Milwaukee to Manitowoc. Values near 120 ppb were observed in western Michigan (see Figure 5). Thursday had winds more from the southwest at 10 to 15 miles per hour and the highest ozone concentrations were just over 110 ppb in Michigan. Friday had similar weather conditions and the highest values were just over 120 ppb in Michigan. Saturday was the last day of the episode, although the boats and aircraft were removed from service so the crews could be rested, and ozone levels reached near 130 ppb in Michigan. Because the meteorological conditions which occurred during this episode were typical of those associated with historical episodes in the region, this period has been selected for modeling.

A third, brief episode occurred on July 6 (Saturday) and 7 (Sunday). Due to the unavailability of certain key measurement platforms and the concern with being able to reproduce, for modeling purposes, the emissions for a holiday weekend, no intensive measurement days were called. Peak hourly concentrations were near 150 ppb at Milwaukee and Manistee, MI on Saturday. Peak levels were only 120 ppb at the Illinois-Wisconsin state line on Sunday. The synoptic weather pattern for this episode was quite similar to that for the late June episode noted above and the mid-July episode noted below.

The fourth episode occurred from July 16 (Tuesday) to July 20 (Saturday). Intensive measurements were taken during this episode. Winds were from the south on Tuesday, but became southwesterly on Wednesday and remained from the southwest until Saturday. Speeds were 10 to 15 miles per hour. Highest concentrations on Tuesday were near 120 ppb at the Illinois - Wisconsin state line, near Manistee, MI and in Door County, WI. High concentrations on Wednesday were near 130 ppb at Benton Harbor and South Haven, MI. Concentrations exceeded 150 ppb in Michigan on Thursday, but were generally below 100 ppb on the west side of the Lake. The intensive measurements by the boats and aircraft ended on Thursday.

High concentrations of ozone continued to be observed in Michigan on Friday with peaks over 150 ppb between Mears and Frankfort (see Figure 6). Saturday was the last day of the episode with peak concentrations just over 130 ppb in Wisconsin and near 100 ppb in Michigan. Because the meteorological conditions which occurred during this episode were typical of those associated with historical episodes in the region, this period has been selected for modeling.

A final summer episode occurred after August 9; from August 24 (Saturday) through August 29 (Thursday). Although the intensive measurement platforms were not available, the enhanced surface network was still in place. Winds started out from the southeast, and remained primarily from the south throughout this period,

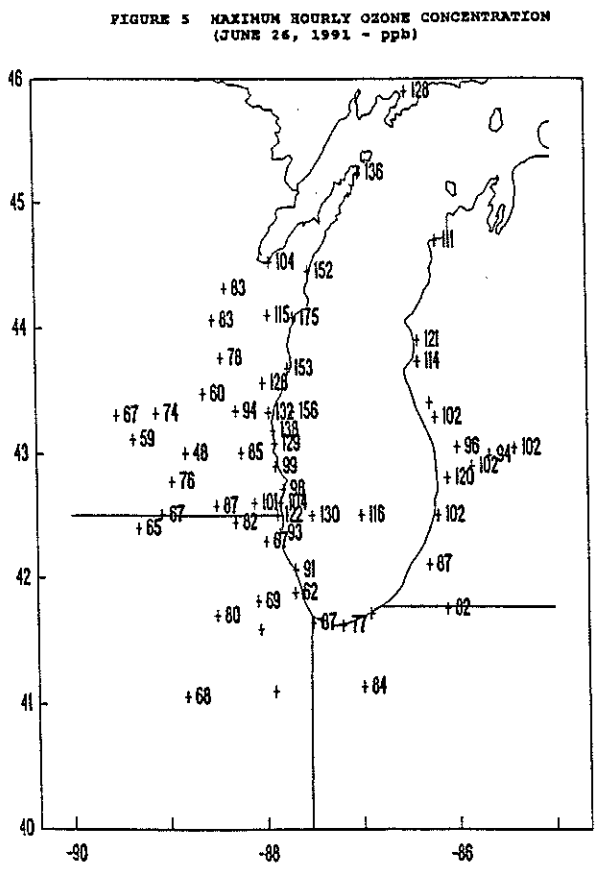

Figure 5. Maximum Hourly Ozone Concentration (June 26, 1991 - ppb)

with somewhat lighter speeds than the late June and mid July episodes. On Saturday, ozone levels began to build across the region, reaching 100 ppb. Nine sites in eastern Wisconsin and two in northeastern Illinois recorded exceedances on Sunday, with a peak concentration of 148 ppb near Milwaukee, WI. On Monday, 15 stations in eastern Wisconsin, two in northeastern Illinois, and one in northern Michigan recorded exceedances, with a peak concentration of 189 ppb near Milwaukee, WI. During the next three days of the episode, the magnitude and spatial extent of the elevated ozone levels declined. Because the meteorological conditions which occurred during this episode were typical of those associated with historical episodes in the region, this period has been selected for modeling.

It should be noted that many of the historical high ozone episodes in the region, especially in Wisconsin, have been associated with lake breeze wind circulations driven by the temperature (and pressure) contrast between the land and the Lake. Special tracer experiments were planned during 1991 to study the depth and penetration of the lake breeze. A lake breeze established on the first day of each of the two intensive measurement periods, but the vertical extent and depth of inland penetration, as indicated by the tracer data, was small. In general, it was found that lake breezes were not much of a factor throughout the summer due to the early warming of the Lake in the spring; thus, reducing the land-lake temperature differential.

RESULTS IN MICHIGAN

During the 1991 ozone monitoring season, exceedances were measured on 12 different days in western Michigan. In addition to the exceedances noted above during four of the five summer episodes, exceedances occurred on May 28, June 9, and July 22. The peak 1-hour concentration was 170 ppb measured on July 18 at Borculo and on July 19 at Sleeping Bear Dunes National Lakeshore. The most number of exceedances at an individual site (i.e., five) occurred at Holland and Muskegon. Surprisingly, exceedances occurred as far north as the Garden Peninsula in the Upper Peninsula (two exceedance days), and Sleeping Bear Dunes National Lakeshore (three exceedance days).

These two relatively remote locations are over 250 miles away from the major ozone precursor source areas of northeast Illinois, northwest Indiana, and southeast Wisconsin. The occurrence of exceedances, as well as the magnitude of these exceedances, this far downwind was not anticipated.

On seven of the 12 exceedance days, more than one county experienced ozone levels above the ambient standard. Dur-

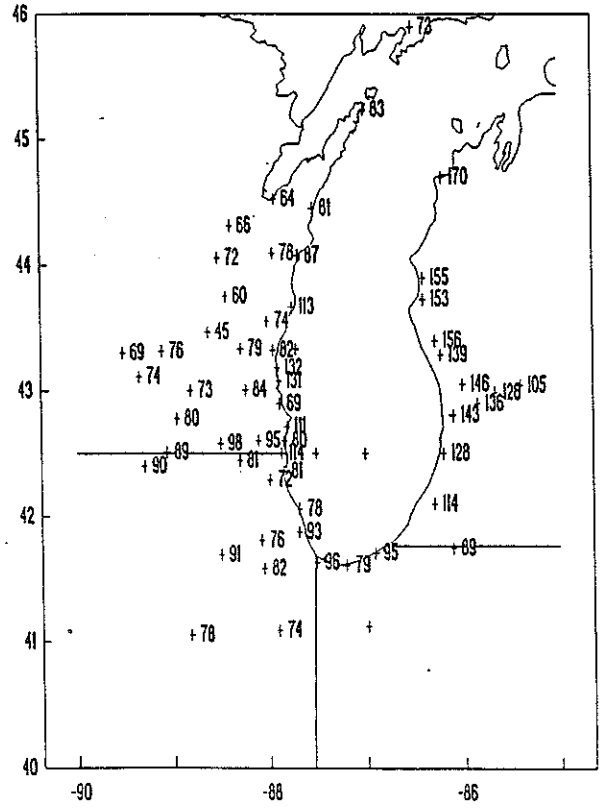

Figure 6. Maximum Hourly Ozone Concenration (July 19, 1991 - ppb)

ing the mid July episode, for example, the stations located along the entire west coast of the State measured exceedances. The large spatial extent of the observed exceedances demonstrates that the ozone problem here is not limited to the urban areas such as Muskegon, but is actually a western Michigan problem.

NEXT STEPS

The field data have been submitted to the data management contractor. Data validation is being performed in various levels. The field contractors were responsible for performing Level 1 validation (i.e., verifying computer files against data sheets, flagging suspect values, eliminating invalid values, and replacing or adjusting values, as necessary). The data management and data analysis contractors are performing Level 2 validation (i.e., apply consistency checks based on known physical relationships between variables in the data base). A third level of validation will occur as part of the data interpretation and modeling.

The modeling effort is underway. The four 1991 episodes selected for modeling are being simulated by the LMOS modeling contractors. Ozone predictions will be made with an enhanced version of the Urban Airshed Model (UAM). Emission inputs will be supplied by the emissions contractor, based on State-supplied emissions inventories processed with an Emissions Modeling System. Meteorological inputs will be supplied by the meteorological modeling contractor, based on the prognostic CALRAMS model. Boundary conditions will be supplied by the USEPA, based on the ROM model. (Other model inputs will be derived from the field measurements.) The UAM evaluation is expected to be completed in early 1993. The Lake Michigan States will then have a technically credible planning tool to use in assessing alternative control strategies.

A second MOA has been prepared by the Lake Michigan States which provides for the cooperative development of interstate ozone control strategies. This MOA will continue in effect until a consensus has been reached on appropriate control strategies, those strategies are approved by USEPA, and those strategies are implemented by their respective States.

REFERENCES

1. Haney, J.L., S.G. Douglas, L.R. Chinkin, D.R. Souten, C.S. Burton and P.T. Roberts, 1989: Ozone Air Quality Scoping Study for the Lower Lake Michigan Air Quality Region, Systems Applications, Inc., San Rafael, California.

2. Bowne, N.E., P.M. Roth, S.D. Reynolds, C.L. Blanchard, and D.L. Shearer, 1990: Lake Michigan Ozone Study: Conceptual Design Plan, ENSR Consulting & Engineering, Glastonbury, Connecticut.

3. ENSR Consulting and Engineering, 1991: Lake Michigan Ozone Study: Field Program Operations Plan for the 1991 Summer Measurements, Glastonbury, Connecticut.

4. Bowne, N.E. and D.L. Shearer, 1991, Summary of LMOS 1991 Field Measurements Program, ENSR Consulting & Engineering, Glastonbury, Connecticut.