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THE SUITABILITY OF LOW-COST URBAN AIRSHED MODELING IN THE CHICAGO AREA

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1. INTRODUCTION

The interesting composition of the utility mix in the Chicago region and the potential for electric vehicle use in that area make it an interesting candidate for emissions sensitivity and scenario studies. However, it is difficult to apply the Urban Airshed Model (UAM) to the Chicago region because of the complex meteorology associated with Lake Michigan. The Lake Michigan Air Directors Consortium (LADCO) has developed, at considerable expense, an improved version with nested grids and embedded plumes (UAM-V) for application in the Lake Michigan Ozone Study (LMOS) (Myers et al., 1993) and for regulatory use. The complexity of the LMOS modeling system makes it costly and time-consuming to implement.

In this study, we apply UAM-IV (U.S. Environmental Protection Agency [EPA], 1990a) in its simple "PLANR (Practice for Low-cost Application in Nonattainment Regions)" mode (U.S. Environmental Protection Agency, 1990b) to the Chicago region to study various interesting scenarios in a rapid and low-cost manner. The details of the data sets, methods and results of this study are contained in Fernau et al. (1992) and Fernau et al. (1993) and are summarized here. In addition, we comment on the usefulness of this type of limited-data study as compared to more complex modeling systems and data inputs.

2. METHODS

The period simulated went from 1200 LST 5 July to 2000 LST 6 July 1988. The performance of the model was analyzed for 6 July, to allow the influence of initial conditions to diminish. Some of the highest ozone values of the year in the Chicago region were recorded on this day. UAM-IV was used with meteorological inputs from National Weather Service sites, utility meteorological towers and chemical monitoring sites. Boundary and initial chemical conditions were taken from monitoring sites and EPA-recommended default values. Grid cells were five kilometers per side. Figure 1 shows the extent and resolution of the domain as well as the major utility point sources in the domain. The domain covers most of northern Illinois in order to capture major utility point sources that are of policy interest.

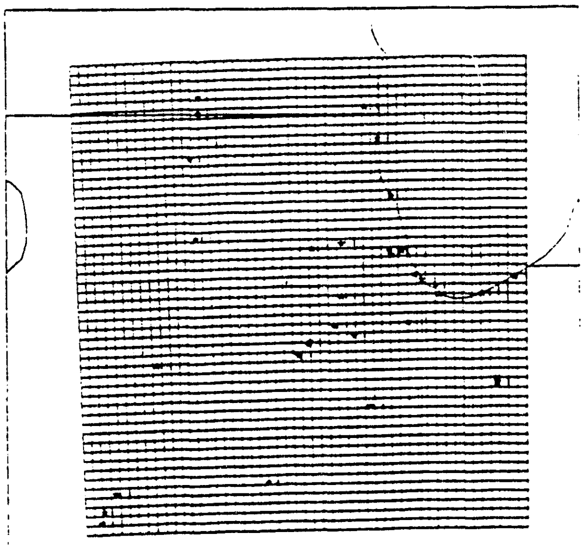

Figure 1. 250 kilometer by 250 kilometer grid used in this study, covering the Chicago area, the northern part of Illinois, and parts of Indiana and Wisconsin. Stars indicate major utility point sources.

Emissions were derived from the 1985 National Acid Precipitation Assessment Program (NAPAP)

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data set and were extended to 1988 using Argonne's Month and State Current Emissions Trends (MSCET) data base (Kohout et al., 1990). Based on NAPAP and National Energy Strategy assumptions, the emissions were projected to 2010 using the Argonne Utility Simulation Model (ARGUS) (Veselka et al., 1990) and other Argonne emissions projection models. 2010 was chosen to reflect the time frame in which Chicago must reach attainment of the National Ambient Air Quality Standard of 120 ppb for ozone.

A 1988 base case run was done to test model performance and then various sensitivity and future scenario simulations were performed to examine the impacts of various parameters and emissions sectors on model performance and ozone pollution in the area.

3. RESULTS

3.1 *Evaluation of the Base Case*

The performance of the model compared to observed ozone concentrations for the episode was examined. The model simulated well the spatial distribution of maximum ozone concentrations during the day on 6 July, with an extensive area of one-hour average ozone concentrations above 140 ppb along the western shore of Lake Michigan north of Chicago. The simulated maximum of 159 ppb is only about ten or fifteen kilometers from the location of the observed maximum of 222 ppb, and the model caught a secondary area of high ozone along the south shore of the lake in Indiana. Although the spatial pattern matches well, the absolute value of peak ozone was underpredicted by 28 percent and the average monitoring station peak was underestimated by 22 ppb or 19 percent. Review of time-series comparisons between observed and simulated ozone concentrations showed that night-time values were overpredicted by UAM.

The U.S. Environmental Protection Agency (1991) recommends various statistical measures when evaluating the performance of photochemical models. These measures include the unpaired highest prediction accuracy (UHPA), which is the difference between the observed and predicted maximums, relative to the observed maximum and unpaired in time or space; the normalized bias test (NBT), which is the difference between all hourly prediction-observation pairs at all monitors, relative to the observations; and the gross error of all pairs greater than 60 ppb (GEAP>60), which is the gross error (absolute difference), summed over all monitors, between all hourly prediction-observation pairs for which the observation is greater than 60 ppb, relative to the observed values. Predicted values were calculating by interpolation from the four grid cells nearest to the observations.

EPA-recommended ranges indicative of good performance are ± 15 to 20 percent, ± 5 to 15 percent, and 30 to 35 percent for UHPA, NBT and GEAP>60, respectively. The UHPA for the 6 July base case was an underprediction of 28 percent, somewhat higher than EPA recommendations, and the GEAP>60 was 18 percent, well within EPA recommendations. When all pairs were included, the NBT for the base case showed an overprediction of 231 percent, reflecting the large overprediction of overnight values. However, in practice, a cutoff is frequently used when presenting this statistic. When only observations greater than 40 ppb are included, the NBT drops substantially, to an overprediction of only 14 percent, within the EPA guideline. It is not clear from EPA documentation whether a cutoff is to be used; a cutoff is frequently seen in the literature when presenting this statistic and perhaps can be justified because the normalized nature of the statistic magnifies greatly small absolute errors. Allowing the prediction to be within a one or two cell radius of the grid cell in which the observation is located to account for possible spatial shifts in the ozone pattern also improves the model evaluation statistics.

3.2 *Improvements to the Base Case*

Several different changes were made to try to improve the bias in the base case. These included using a corrected VOC emissions factor from corn provided by the EPA, varying the ozone boundary conditions with time, using higher initial and boundary conditions, calculating mixing heights in a different way, and combining all of those. The combined run had a UHPA of 29 percent overprediction (about the same as the original base case), a GEAP>60 of 21 percent (slightly worse), and a NBT of 116 percent overprediction (an improvement of over 100 percent). With a 20 ppb cutoff the NBT was 18 percent overprediction and with 40 ppb cutoff it changed to an underprediction of 7 percent, which is within EPA guidelines. Again, one and two cell searches improved the statistics. Although overall bias was reduced, simulation of the highest values deteriorated slightly, and the secondary maximum at the south end of the lake was lost.

A sensitivity test in which mobile source emissions were doubled in combination with the other changes improved the statistics even more, lowering the bias somewhat and bringing the UHPA within EPA guidelines at an 18 percent underprediction.

3.3 *Sensitivity and Future Scenarios*

Since the performance of the revised base case was adequate based on statistical and graphical analysis, various emissions scenarios were examined. Runs were done in which either utility, motor vehicle or industrial emissions were removed. The transportation sector provided the largest contribution to elevated ozone concentrations. The peak ozone concentration fell from 159 ppb to 132 in this scenario, while the utility and industrial scenarios had peaks of 145 and 148 ppb, respectively. In the transport scenario, the number of grid cells above 120 ppb fell by 61 percent, while in the other two scenarios the number fell by about 37 percent.

A realistic electric vehicle penetration scenario was developed by the Argonne Center for Transportation Research. The subsequent UAM run showed that electric vehicles were effective in reducing downtown ozone relative to the amount of emissions reductions gained from them but the absolute amount of penetration achieved by 2010 is not large enough to make a large difference in air quality. The electric vehicles are relatively effective in part because the energy to recharge the vehicles is derived from excess nuclear capacity that still exists during this time period.

Various future scenarios that involve implementation of the Clean Air Act Amendments of 1990 in the utility, industrial and motor vehicle sectors did not have a large impact on ozone air quality. This result is not as robust as the sensitivity studies because of the bias that exists in the model results and the uncertainties that surround the choice of mixing heights, boundary conditions and initial conditions, and other inputs, as well as the difficulties involved in projecting emissions to a future year. The unresponsiveness of the model to emissions changes also may reflect the influence of initial conditions on the model run. Future simulations will be started earlier to allow more time for the initial conditions to be swept out of the model.

4. DISCUSSION

In this study, it was found that the model could reproduce observed conditions accurately enough to meet EPA performance guidelines, but that peak ozone concentrations were underpredicted and early morning low ozone concentrations were overpredicted. Similar behavior has been seen with the more sophisticated LMOS UAM-V system and using UAM-IV in other modeling domains (Koerber; Schulman, personal communications). The methods used to define a predicted concentration and the concentration cutoff used to define verification statistics influenced the outcome of the simulation statistics. Because of the coarseness and uneven spatial distribution of the input data and the inherent uncertainty in calculating emissions, model performance was sensitive to meteorological conditions such as wind fields and mixing heights, to air quality parameters such as initial and boundary conditions and to the input emissions fields; the resulting ozone concentrations varied with choice of parameter. This variation illustrates the importance of the detailed field studies undertaken in LMOS to develop accurate input data for UAM-V.

Although model performance probably is not good enough for regulatory application, it is adequate to allow exploration of various sensitivity and future emissions scenarios involving utilities, motor vehicles, industry and other source categories. It was found that doubling mobile source emissions gave a much better fit to observed concentrations. The mobile source sector contributed more to high ozone concentrations than did the utility or industrial sectors, based on selective removal of emissions. The utility and industrial sectors contributed equally to emissions. Attainment of the ozone NAAQS was not achieved by removal of any one sector alone. Electric vehicles can help reduce the ozone burden in the Chicago area.

Studies like this one provide a low-cost complement to the more rigorous UAM-V modeling of the Lake Michigan Ozone Study and a substitute in those areas where meteorology and emissions are relatively simple. They provide some insight into the relative importance of various emissions sectors to air qaulity and the effectiveness of future control strategies. Although the simple implementations complement and supplement the more detailed modeling exercises, the biases present in their results due to data uncertainties make their conclusions less robust and point out the importance of those comprehensive exercises for making effective policy.

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