REGIONAL PHOTOCHEMICAL MODELING FOR THE KANSAS CITY CLEAN AIR ACTION PLAN: WHAT IT TELLS US ABOUT THE CHALLENGES AHEAD FOR 8-HR OZONE NONATTAINMENT AREAS

Neil Wheeler*, Lyle Chinkin, and Steve Reid
Sonoma Technology, Inc., Petaluma, CA, USA

Tom Gross, Andy Hawkins, and Doug Watson
Kansas Department of Health and Environment, Topeka, KS, USA

Wendy Vit and Refaat Mefrakis
Missouri Department of Natural Resources, Jefferson City, MO, USA

James Joerke
Mid-America Regional Council, Kansas City, MO, USA

1. INTRODUCTION

At the end of 2003, violations of the 8-hr ozone standard in the Kansas City (KC) area appeared imminent and the Mid-America Regional Council (MARC) Air Quality Forum created an Air Quality Working Group (AQWG) to oversee the development of a Clean Air Action Plan (CAAP) for the KC region. Because nonattainment areas must use photochemical models to understand their area's ozone problem and develop and evaluate ozone response to control scenarios, the AQWG sought to use a photochemical model in developing the CAAP.

Development of photochemical model applications for the KC region had already begun in the late 1990s to address 1-hr ozone issues. Three ozone episodes had been modeled but resource constraints and model performance issues delayed the completion of the project. The CAAP provided an impetus to accelerate the completion of the modeling. The Kansas Department of Health and Environment had been improving the modeling for an episode in August 1998 that was believed to represent a worst-case scenario. Improvements to the episode were completed in this study to support the CAAP.

The modeling system included the Penn State/NCAR Mesoscale Model (MM5) (Grell et al., 1994), the Sparse Matrix Operator Kernel Emissions model (SMOKE) (Coats, 1996; Houyoux and Vukovich, 1999; Houyoux and Adelman, 2001), and the Comprehensive Air quality Model with extensions (CAMx) (ENVIRON International Corporation, 2002). A base case simulation for August 15-21, 1998 was prepared and evaluated. Observed 8-hr ozone concentrations during this period reached 103 ppb and five of six sites in the KC area exceeded 85 ppb. A year 2010 emission inventory was prepared and used to predict future ozone concentrations. Control measures were identified and quantified, and their impact on ozone concentrations assessed.

2. MODELING APPROACH

Meteorological modeling was performed with MM5 using Four-Dimensional Data Assimilation (FDDA) on three nested domains (36-km, 12-km, and 4-km). Initial and boundary conditions for MM5 were derived from routine NCEP analyses.

Emissions were based on the 1996 National Emissions Trends (NET) inventory projected to 1998 with state-specific updates to point sources in Kansas and Missouri. Onroad mobile source emissions were estimated with the MOBILE6 model using county emissions except in KC and St. Louis where link-based vehicle miles traveled (VMT) data were used. Offroad mobile source emissions were estimated with the NONROAD model. Biogenic emissions were estimated using SMOKE BEIS3. SMOKE Version 2 was used to spatially, temporally, and chemically allocate emissions and prepare CAMx-ready emission files.

Photochemical modeling was performed with CAMx Version 3.10 using the Carbon Bond IV chemical mechanism on three nested domains shown in Figure 1. Initial and top boundary condition were set at the “clean air” values used in the Ozone Transport Assessment Group (OTAG) modeling (Ozone Transport Assessment Group, 1996). Because the eastern boundary of the CAMx domain was further west than in OTAG, ozone concentrations on horizontal boundaries were set at 51 ppb.

*Corresponding author: Neil Wheeler, Sonoma Technology, Inc., 1360 Redwood Way, Suite C, Petaluma, CA 94954-1169; e-mail: neil@sonomatech.com

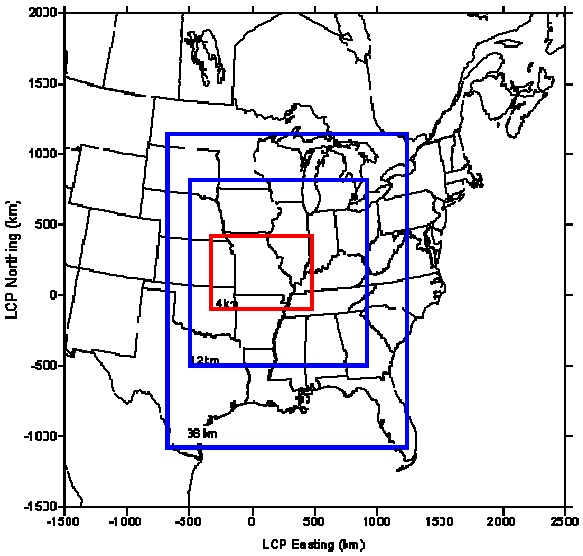

Fig. 1. CAMx modeling domains.

3. MODEL PERFORMANCE

Comparisons of model-predicted ozone levels were made with ambient air quality data to determine how closely ozone concentrations predicted by the model correspond to observed concentrations. Current monitoring sites in the KC area are shown in Figure 2. Only six of these sites were operational in 1998 and the Leavenworth, Rocky Creek, and Trimble sites were added later to monitor ozone concentrations further downwind of KC.

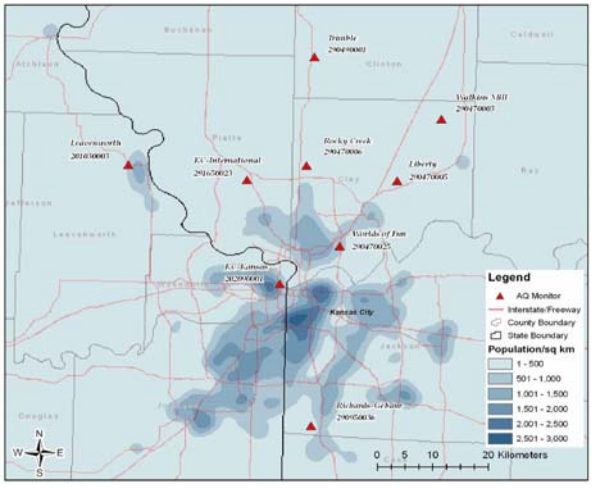

Fig. 2. Monitoring sites in the KC area.

Time-series plots of predicted and observed ozone concentrations for each hour of the day over the entire ozone episode are shown in Figure 3. The model predicts ozone quite well at all sites and for most hours of the day with a few minor exceptions (the model tends to underpredict ozone levels at night in the urban core area). The deviations however, do not reach a level of concern and the overall model performance statistics (bars) meet historical U.S. Environmental Protection Agency (EPA) performance criteria (U.S. Environmental Protection Agency, 1991) as shown in Figure 4.

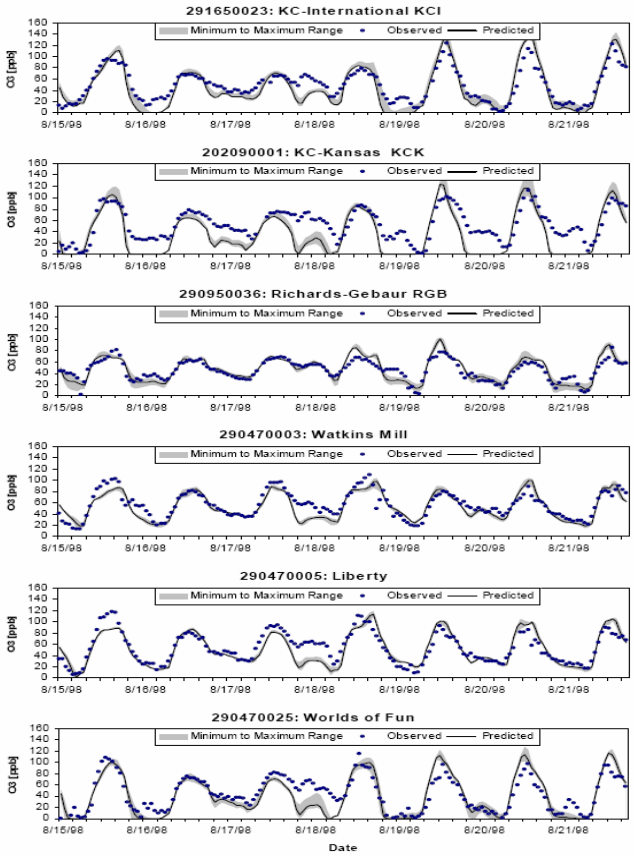

Fig. 3. Comparison of observed and predicted ozone concentrations.

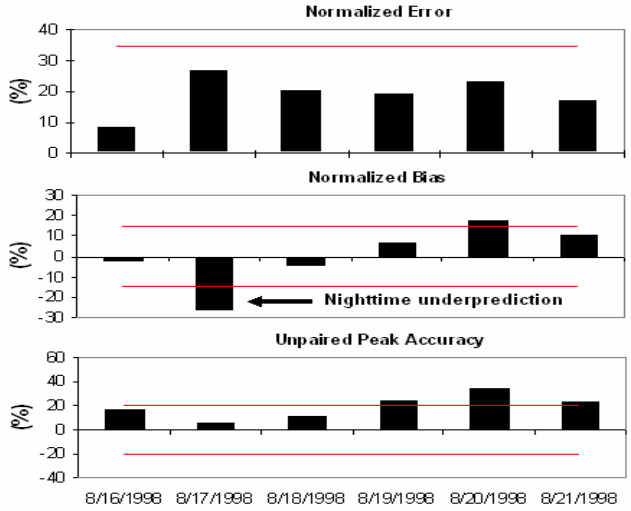

Fig. 4. Model performance evaluation statistics.

4. FUTURE-YEAR SIMULATIONS

Future-year area source emissions were developed by projecting the EPA's 1999 National Emission Inventory (NEI) to 2010 using growth factors from EPA's Economic Growth Analysis System (EGAS). For some source categories, such as locomotives and commercial marine vessels, alternative growth factors were chosen in keeping with federal regulatory support documents. Also, control factors were applied to some sources, such as locomotives and consumer/commercial solvent use, to represent existing federal control measures.

Non-road mobile sources emissions from non-road mobile sources other than locomotives, commercial marine vessels, and aircraft were estimated using the EPA's NONROAD model[1]. Emissions from on-road mobile sources were estimated using VMT data and emission factors from EPA's MOBILE6 model. For all areas outside KC, 1998 VMT were grown to 2010 levels using EGAS projection factors. For the KC area, 2010 link-based VMT data were developed by MARC.

For all states except Kansas and Missouri, emissions for electric generating unit (EGU) point sources were derived from runs of the Integrated Planning Model (IPM)[2]. For Missouri and Kansas, 2010 EGU emissions were estimated from surveys of specific facilities. For non-EGU point sources, 1999 NEI point source data were projected to 2010 using EGAS growth factors, and control factors were also applied to represent existing control measures. Table 1 summarizes the 2010 emissions for the KC area.

Table 1. KC area emissions by source type for 2010.

Source Type	2010 Emissions (tons/day)	
	VOC	NO_x
Area Sources	111	29
Nonroad Mobile Sources	32	78
Onroad Mobile Sources	52	72
Point Sources	32	226
Total	227	404

Using the future-year emission inventory, a series of across-the-board local (i.e., the KC area only) emission reduction simulations were performed and isopleth diagrams were prepared to show peak predicted 8-hr ozone concentration response to emission reductions. The concentrations in these diagrams were bias and design-day adjusted. Figure 5 shows that on August 21, peak 8-hr ozone concentrations in the KC area are responsive to both volatile organic compound (VOC) and oxides of nitrogen (NO_x) reductions but NO_x reductions are more effective. However, removing all emissions in the KC area reduced the peak ozone concentration by only 25 ppb. Figure 6 shows the ozone isopleth diagram for August 19, a day when substantial amounts of ozone were being transported into the KC area. On this day we see a similar response to emission reductions but there is no response when NO_x reductions are greater than 70%. This response is consistent with the near 70 ppb of ozone observed (and modeled) at the Richards-Gebaur monitor, which is located upwind of KC. Removing all KC area emissions reduced the peak ozone concentration by 15 ppb.

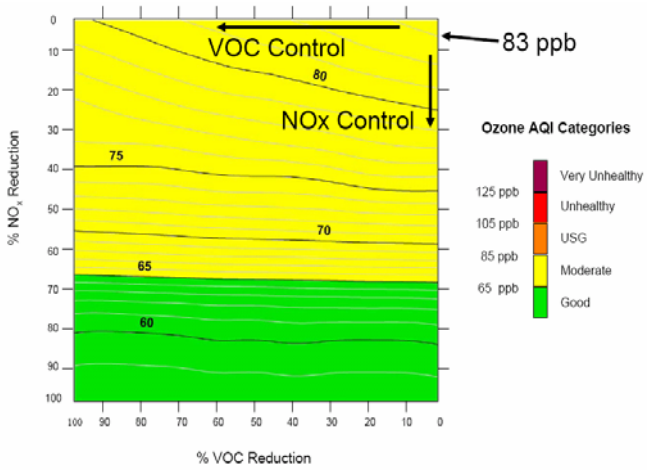

Fig. 5. KC area peak 8-hr ozone isopleth diagram for August 21, 2010.

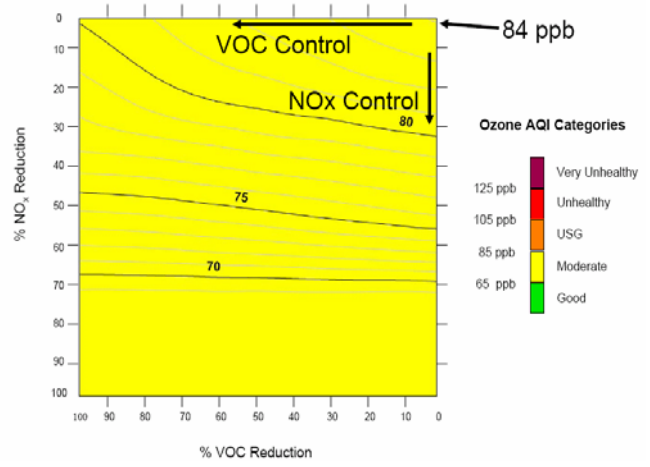

Fig. 6. KC area peak 8-hr ozone isopleth diagram for August 19, 2010.

[1] NONROAD was run by EPA Region 7.

[2] Runs of IPM for 2010 were prepared by EPA for modeling of the Clear Skies Initiative.

Five specific emission control scenarios were also modeled. The types of controls, associated emission reductions, and the changes in peak 8-hr ozone concentrations within the KC area are summarized in Table 2. Emission reductions for these scenarios were generally small except for scenarios that included voluntary controls on power plant emissions (C02 and C03). Even with a 79 ton/day reduction obtained under scenario C03 (20% of the 2010 NO_x emission in the KC area), the reduction in peak ozone was less than 2 ppb, which is consistent with the response seen in the across-the-board emission reduction simulations.

Table 2. Emission control scenarios modeled.

Control Scenario		Emission Reduction (tons/day)		Largest decrease in peak 8-hr ozone (ppb)
#	Description	VOC	NO_x	
C01	All Voluntary Measures (Conservative)	0.6	0.9	0.07
C02	All Voluntary Measures (Aggressive)	-0.5	73.6	1.50
C03	All Regulatory and Voluntary Measures; Aggressive Voluntary; Maximum Expected Reductions	5.0	79.1	1.98
C04	All Regulatory Measures	5.7	5.7	0.48
C05	Voluntary Measures (Aggressive) without Power Plant Reductions	1.5	2.6	0.63

5. DISCUSSION

The modeling was performed for only one episode period, which may not be representative of all periods when the 8-hr ozone standard may be exceeded in the KC area. However, under the conditions modeled, peak 8-hr ozone concentrations in the KC area appear to be dominated by regional ozone production because eliminating all emissions in the KC area only reduced the peak 8-hr ozone concentrations by 18 to 30%. If a global ozone background concentration of 35 ppb is assumed, the model response to local emission reductions implies that, on average, approximately 24% of the peak 8-hr ozone concentrations in 2010 will be attributable to local emissions while global background and regional transport will contribute 41% and 35%, respectively.

The modeling shows that while required federal and state emissions controls going into effect between 1998 and 2010 will reduce the peak 8-hr ozone concentration in the KC area by 9.4%, moderate additional local emission controls will only reduce peak 8-hr ozone concentrations by at most another 2%. It is important to note that impacts of emission reductions on predicted ozone levels vary by location in the KC area. The greatest reductions in ozone concentrations are predicted to occur in areas that do not typically measure the highest ozone concentrations (e.g., Johnson County) and in those areas the peak 8-hr ozone concentrations can be reduced by as much as 5 ppb with scenarios CO2 and C03.

The modeling also indicates that peak ozone concentrations will be further downwind of KC than historically observed. This prediction is consistent with KC having implemented VOC controls in the past, which reduced ozone concentrations nearer to the city, and now the highest ozone concentrations are observed at new monitoring sites further north of KC.

In reviewing both the 1998 and 2010 simulations results it was noted that those regions in the modeling domain between major cities often had ozone concentrations similar to those upwind of KC. Because so many of newly designated 8-hr ozone nonattainment areas (see Figure 7) are located in these regions, we suspect that those areas will also see a similar ozone response to local emission controls.

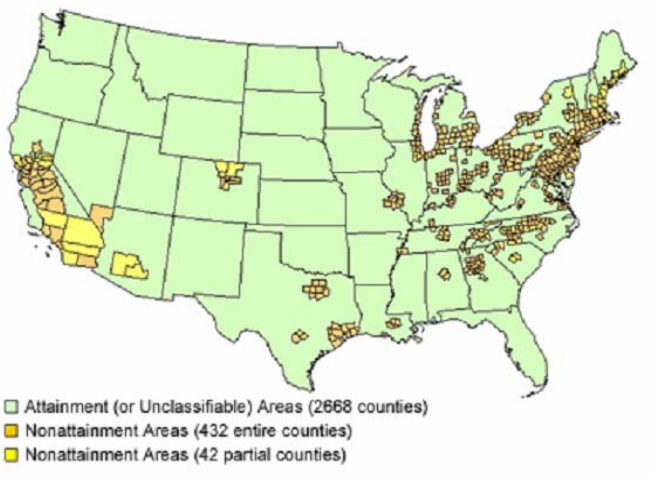

Fig. 7. 8-hr ozone nonattainment areas (Source: www.epa.gov/ozonedesignations/nonattaingreen.htm).

While the effects of regional emissions controls were not investigated as a part of this study, 50% across-the-board reductions of VOC and NO_x were performed as a part of the NARSTO Model Inter-comparison (NMI) study (Lurmann, 1998; Wheeler and Roney, 2001). While the NMI study involved

several organizations and models, the results of EPA's Community Multiscale Air Quality (CMAQ) model simulations of the July 7-18, 1995, period are representative of the simulations performed. Figure 8 shows the percent change in peak 8-hr ozone concentrations on July 13, 1995, with a 50% VOC reduction while Figure 9 shows the change with a 50% NO_x reduction. The 50% VOC reductions result in 8-hr peak ozone being reduced by less than 5% except in areas immediately downwind of large metropolitan areas. However, the 50% NO_x reductions result in some increases in ozone near major cities but 20 to 30% reductions in peak 8-hr ozone in many of the areas now classified as nonattainment for 8-hr ozone.

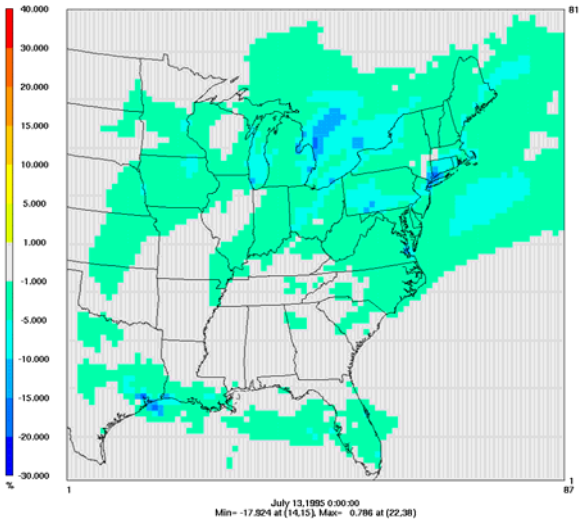

Fig. 8. CMAQ predicted percent change in peak 8-hr ozone concentrations with a 50% VOC reduction.

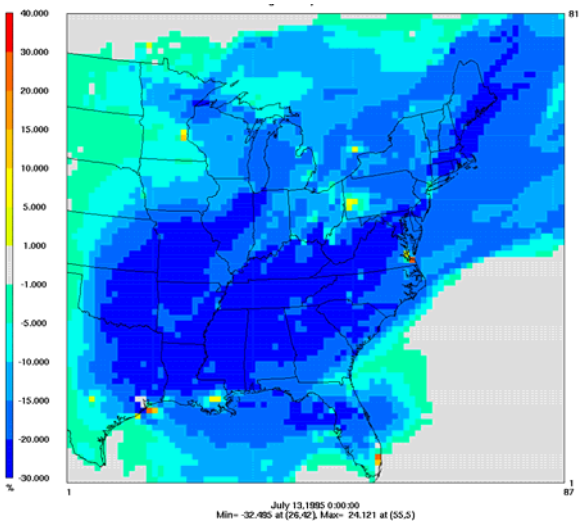

Fig. 9. CMAQ predicted percent change in peak 8-hr ozone concentrations with a 50% NO_x reduction.

6. SUMMARY AND CONCLUSIONS

While modeling was performed for only one episode in developing the KC CAAP, the simulation results indicate that the KC area will be barely in attainment of the 8-hr ozone standard in 2010. Additional local controls, most of which would be voluntary, may provide a buffer against meteorological conditions that could lead to high ozone events and result in the KC area being declared nonattainment for 8-hr ozone. In addition to the ozone benefits of these local controls, they have a potential to reduce ambient concentrations of particulate matter, greenhouse gases, and hazardous air pollutants.

While the KC area appears to have some ability to maintain their attainment status through local controls, many of the new nonattainment areas in the central and eastern United States may have difficulty in demonstrating attainment with local controls alone. As states begin to develop their State Implementation Plans for 8-hr ozone, the role of controlling regional ozone needs to be revisited.

7. REFERENCES

Coats, C. J., 1996: High performance algorithms in the sparse matrix operator kernel emissions modeling system. *Ninth Joint Conference on Applications of Air Pollution Meteorology of the American Meteorological Society and the Air and Waste Management Association, Atlanta, GA*.

ENVIRON International Corporation, 2002: User's Guide - Comprehensive Air Quality Model with Extensions (CAMx). Version 3.10, By ENVIRON International Corporation, Novato, CA.

Grell, G. A., J. Dudhia, and D. R. Stauffer, 1994: A description of the fifth-generation Penn State/NCAR mesoscale model (MM5), NCAR Technical Note-398 Prepared by National Center for Atmospheric Research, Boulder, CO.

Houyoux, M. R. and J. M. Vukovich, 1999: Updates to the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system and integration with Models-3. *Air & Waste Management Association's The Emission Inventory: Regional Strategies for the Future, Raleigh, NC, October 26-28*.

Houyoux, M. R. and Z. Adelman, 2001: Quality Assurance Enhancements to the SMOKE Modeling System. *U.S. Environmental Protection Agency's International Emission Inventory Conference: One Atmosphere, One Inventory, Many Challenges, Denver, CO, May 1-3*.

Lurmann, F. W., 1998: NARSTO model intercomparison workshop summary. Draft report, STI-998300-1819-DFR by Sonoma Technology, Inc., Petaluma, CA.

Ozone Transport Assessment Group, 1996: Modeling protocol, version 3.0. Report, prepared by the Regional and Urban-Scale Modeling Workgroup, Lake Michigan Air Directors Consortium and the EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC.

U.S. Environmental Protection Agency, 1991: Guideline for regulatory application of the Urban Airshed Model (UAM). Report, EPA-450/4-91-013 prepared by U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

Wheeler, N. J. M. and J. Roney, 2001: NARSTO model inter-comparison (NMI) study. Report, STI-900560-2111-DD by Sonoma Technology, Inc., Petaluma, CA.