Uncertainty in CMAQ Modeling

Background

CMAQ is a state-of-the-art air quality modeling tool used to predict future ozone concentrations for use in attainment demonstrations. The University of Maryland assessed the model's performance and examined the implications for the attainment demonstration and weight of evidence. The University of Maryland's research complements the model performance evaluation conducted by the Virginia Dept. of Environmental Quality and described in Section 10.3. The University of Maryland Department of Meteorology's research is summarized below. Details of this research are in Appendix G Attachment 15.

Analysis of Model Performance

The University of Maryland found that CMAQ does an excellent job of capturing the mean distribution of surface layer ozone during the ozone season.2 However, their research identified several characteristics of the model that could impact the conclusions of the attainment modeling results. The University of Maryland analyses involved comparisons of surface and aircraft ozone measurements and CMAQ ozone simulations. As described in more detail in Appendix G, the results of these analyses indicate the following:

- CMAQ underestimates ozone concentrations in upwind areas
- CMAQ underestimates ozone concentrations aloft
- CMAQ overestimates ozone formation in urban areas
- CMAQ biases in upwind areas are larger when air quality is poor
- CMAQ underestimates the contribution of transported pollution on concentrations within the nonattainment area
- CMAQ underestimates the importance of NOx controls in upwind areas.

CMAQ Underestimates Ozone Concentrations in Upwind Areas. CMAQ exhibits its best performance in urban areas (small bias), less success in suburban areas (underestimates ozone, a larger negative bias), and its worst performance in rural areas (underestimates ozone more, larger negative bias). The model's performance is at its worst in upwind, rural areas. In particular, research indicates that the ozone in Virginia and the Ohio River Valley is under-predicted.

CMAQ may Underestimate Ozone Aloft. In comparison to aircraft observations, the base-case model run underestimates the rate of photochemical smog production above about 500 m and overestimates it below this altitude.

CMAQ Overpredicts Ozone Formation in Urban Areas. The CMAQ model tends to overestimate the rate of formation and concentration of ozone, especially in VOC-rich urban plumes. The overall chemistry may therefore be more NO_x-limited than CMAQ would suggest. It is believed that the CB4 mechanism and photochemical processor used in the version of CMAQ run for this SIP are simplified and missing reactions that were thought to be inconsequential, but are now known or in some instances suspected to play a major role. Altogether, these reactions could sequester at least 1.5 ppbv NOx.

CMAQ Biases are Larger when Air Quality is Poor. Biases between CMAQ-calculated and measured 8-hour ozone concentrations are minimal (1-2 ppbv) when averaged over the summer but there is a large negative bias in rural upwind areas (7-8 ppbv) on days when air quality is poor.

CMAQ Underestimates the Contribution of Transported Pollution on Ozone Concentrations in the Nonattainment Area. The transport of ozone into and within the State of Maryland above the nocturnal boundary layer was examined using a combination of aircraft and ground-based measurements. These aircraft observations indicate that CMAQ underestimates transport. The research indicates that when upwind pollution source regions lay over the Ohio River Valley (~59% of aircraft profiles), transport accounted for 69-82 percent of the afternoon boundary layer ozone.5 When winds were weak (~27% of aircraft profiles), transport only accounted for 58 percent of the afternoon boundary layer ozone.

The ground level ozone data obtained from MDE monitoring stations has also been examined for evidence of downward mixing. On days when the transported ozone is low, peak ozone occurs at about 15:00 EST. However when the transported ozone is large, an earlier peak occurs at about 10:00 EST, corresponding to the breakdown of the nocturnal boundary layer. The rate of increase of ozone within this peak is about four times greater than that due to pure photochemistry.

CMAQ Underestimates the Importance of Reducing Upwind NOx Emissions and Overestimates the Significance of Local Sources. Several studies suggest that CMAQ, and likely photochemical models in general, under-predict the change in ozone concentrations that result from a change in NO_x emissions, particularly those from upwind power plants (and large industrial sources). CMAQ shows that although model simulated NO_x reductions result in ozone reductions, the percentage reductions in ozone were smaller than the percentage reductions in NO_x.

Even when compared to results from within the 2002 ozone season, CMAQ under-predicts daily ozone variability, and shows important model performance issues in areas just upwind of Maryland on high ozone days, namely in the Ohio River Valley and central Virginia. A study of the 2003 Northeast Blackout [Marufu et al., 2004] shows that the blackout caused a drop of at least 7 ppbv ozone (partly attributable to decreases in power plant emissions), and likely considerably more, while a modeling study of the same event [Hu et al., 2006] used CMAQ to predict only a 2.2 ppbv change.

Analysis of ozone trends before and after the NO_x SIP Call reveals that Maryland's ozone improved significantly after the NO_x SIP Call. Ozone values were binned according to peak temperature to remove most of the effects of meteorology from the analysis, revealing a consistent 12 percent downward trend in ozone after the SIP Call. An ongoing study by EPA reveals that the NO_x SIP call likely produced double the benefit that CMAQ predicted.

Implications of CMAQ Performance on Attainment Demonstration

Demonstrated issues with CMAQ's performance, particularly with respect to extreme values and transport, imply that CMAQ predicted future ozone concentrations are overestimated for the Washington, DC-MD-VA non-attainment area. The results imply that the Washington, DC-MD-VA region may be more likely to comply with the ozone standard than the model indicates.

The transport of pollutants from areas outside the region has an extremely important impact on the attainment of the 8-hour ozone standard. The evidence from both the aircraft and the station ozone data clearly points to the importance of transport in the overall quality of the air in the Washington region.[1] Upwind power plant emission sources of NO_x and SO_2 from West Virginia, Ohio, and Pennylvania along the Ohio River Valley play a crucial role in the amount of ozone and aerosol measured in the lower troposphere in the Mid-Atlantic region. Due to the higher stack heights of power plants these emissions are more likely to be transporter large distances. The effect of the transported ozone is to add ozone early in the day and hence to expand the time interval over which the ozone levels may exceed 85 ppbv.

In some instances, emissions in the rural/suburban areas upwind of the Washington region are dominated by power-plant emissions. The analysis indicates that ozone after the NO_x SIP Call improved significantly, suggesting that future control programs similar to those implemented over this time period should be highly effective as well. This suggests that NO_x controls, and especially power plant controls are likely to be similarly effective in controlling ozone in the future.

The research also suggests that regional control programs should be more effective than predicted by CMAQ and local programs somewhat less effective. Since the bulk of the control programs in the SIP are regional (e.g. fleet turnover, heavy duty diesels, and the Clean Air Interstate Rule), greater changes in surface ozone can be expected than those predicted by CMAQ, especially given CMAQ's lack of response to changes in emissions.

[1] The study of the relative contribution of transported and local photochemistry to the ozone data for six exceedance days in August 2002 suggests that if local photochemistry were the only source of ozone, none of the 6 days examined would have exceeded the 8-hour ozone standard.