LONG RANGE TRANSPORT OF OZONE IN NORTH EASTERN NORTH AMERICA

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1. INTRODUCTION

Tropospheric ozone presents a serious risk for health (Ontario Medical Association, 2001) and agricultural crops (Linzon et al., 1984) in Southern Ontario. The atmospheric generation of ozone is complicated because it involves multiple sources of different precursor emissions in different geographical locations. These sources have been classified broadly as (Yap et al, 1988):

? Natural or 'background' tropospheric O_3
? Local anthropogenic emissions
? Long-range transport and accumulation
? Vehicle-related urban plumes
? Stratospheric injections

The importance of long range transport has been noted by numerous authors (e.g., Fiore et al, 2003; Brankov et al, 2003; Yap et al, 1988) but its magnitude depends heavily on the relative locations of the source and receptor regions and the meteorology connecting them.

This study will focus on ozone transported to Southern Ontario, which is a region with a population of approximately 11 million inhabitants (Ontario Ministry of Finance, 2004). The objectives are to assess the ability of the MODELS-3/CMAQ system (Byun and Ching, 1999) to simulate this process, and to quantify its influence on the air quality of Southern Ontario.

2. METHODS DESCRIPTION

The CMAQ and MM5 horizontal grid sizes were set to 36 km and 15 sigma layers were used. The domain size was 42x50 grid cells, located in the Northeastern part of the U.S. and Southeastern Canada (see Figure 1). CMAQ version 4.3 and the Carbon Bond I V mechanism (CB-IV) (Gery et al., 1989) was used to perform gas phase chemistry simulations. Time-invariant climatological profiles for ozone and its precursors were used as boundary conditions.

Version 3 of MM5 (Grell et al, 1994) and version 2.0 of the SMOKE emissions modeling System (Carolina Environmental Programs, 2003) were used to generate, respectively, the meteorological inputs and the gridded, hourly, speciated emissions for CMAQ. The 1996 EPA National Emissions Trends (NET96) U.S. criteria inventory and the 1995 Canadian emissions inventory were used for this study.

Observational data were obtained for the U.S. from 514 sites of the Aerometric Information Retrieval System (AIRS) and from 53 Canadian sides (33 located in Southern Ontario) of the National Air Pollution Surveillance (NAPS). In order to get a comprehensive description of summertime ozone transport, the study covered the period from June 1st to July 31, 2001.

3.0. RESULTS AND DISCUSSIONS

3.1. Model evaluation

Figure 1 shows a map of observed and predicted daily 8-h maximum ozone concentration averaged over all days from June 4 to July 31, 2001 (we neglect the first 3 days for model spin-up). Both show bands of high average ozone along the Ohio River valley, over Lakes Michigan and Erie, and along the Eastern seaboard, with a gradual decrease towards the north part of the domain. Differences between observed and predicted daily average rarely exceed 15 ppb, with the prediction tending to have a small positive bias around Ohio River valley and slightly under-predicting the ozone concentration in Southern Ontario.

Figure 2 gives the temporal pattern of observed and predicted 8-h daily maximum ozone concentrations in Southern Ontario during the study period. The ozone concentration is predicted rather well, except for under-predictions on June 19 and the five-day period from June 26 to 30, and

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over-predictions on the five days from July 20 to 24 (day 50 to 54).

All these dates coincided with official smog advisories, reported in the annual Air Quality Report (Ontario Ministry of the Environment, 2001). Despite these small discrepancies, the ozone variations are predicted quite well by CMAQ. The correlation coefficient for the observed and predicted 8-h daily maximum ozone concentration averaged at the 33 stations is 0.76. The bias is 2 ppb, the slope is 0.99 and the standard error of the estimate is 8 ppb

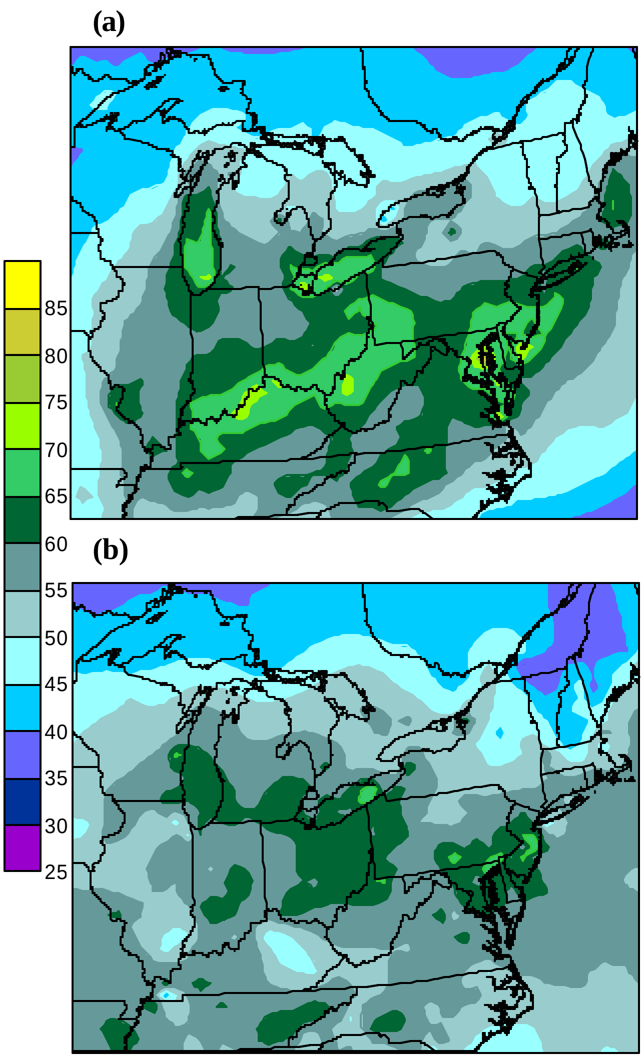

Fig. 1. CMAQ-predicted (a) and observed (b) 8-h daily maximum ozone concentrations, averaged over all summer days from June 4 to July 31, 2001. The contour levels in the map (b) were calculated using Kriging over 567 monitoring stations.

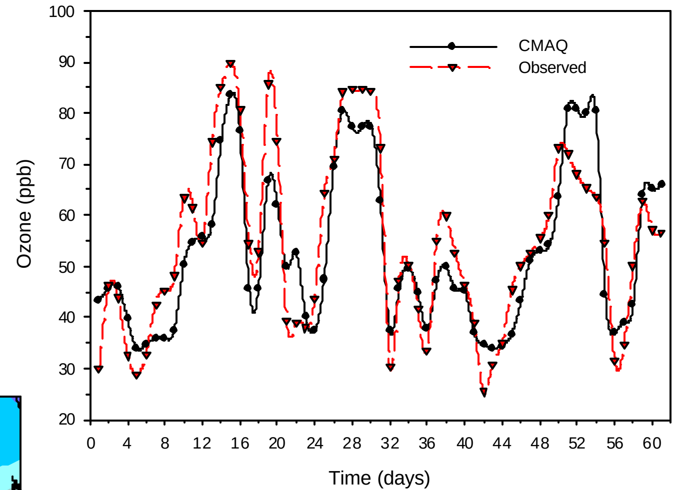

Fig. 2. Observed and CMAQ-predicted 8-h daily maximum ozone concentrations from June 1 to July 31, 2001 averaged over Southern Ontario. Observed data were averaged over 33 monitoring stations.

3.2. 'Background' Ozone evaluation

Essentially, if we don't consider the injection from the stratosphere into the troposphere, the 'background' tropospheric ozone come both in situ formation in the free troposphere, and production involving natural hydrocarbons (Yap, 1988). For this study, we ignored injections of stratospheric ozone, but considered the contribution from natural hydrocarbons. We considered two scenarios that differed from the base case in the following ways:

1) 'Zero': No anthropogenic or biogenic emissions.
2) 'Bio': No anthropogenic emissions but normal biogenic emissions.

The ozone concentration for Southern Ontario predicted for these scenarios (and others to be described below) is illustrated in Figure 3. Even though small differences appear in high ozone episodes, the ozone concentrations from scenarios 'Zero' and 'Bio' are almost identical, indicating that the contribution from the biogenic emissions is not significant for the 'background' ozone concentration calculated by CMAQ. This result agrees qualitatively with the modeling study of Lurmann et al. (1984), who estimated the contribution from biogenic emissions to be only 2-9% of the predicted maximum ozone concentration in urban areas. The 8-h daily maximum ozone concentration averaged over the entire period for scenarios 'Zero' and 'Bio' is 31 ppb for both cases, while it is 53 ppb for the 'base case'. This result corresponds to the study of Yap et al (1988), who estimates the local 'background' ozone level for the Southern Ontario in approximately 20-30 ppb.

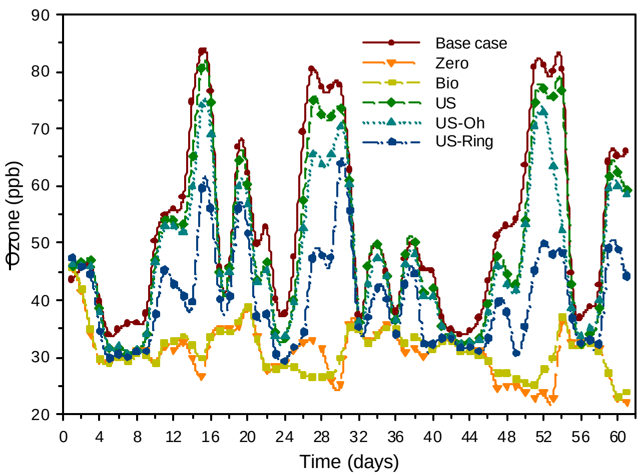

Fig. 3. CMAQ-predicted 8-h daily maximum ozone concentration averaged over Southern Ontario from June 1 to July 31, 2001.

3.3. Contributions from selected emissions

This part of the study involved the following scenarios:

3) 'US': No anthropogenic emissions over the Canadian part of the model domain.
4) 'US-OH': Scenario 3 plus no anthropogenic emissions from Ohio.
5) 'US-Ring': Scenario 4 plus no anthropogenic emissions over Michigan, Pennsylvania and New York.

The ozone concentration averaged over Southern Ontario for these scenarios is illustrated in Figure 3. The most significant effects appear when the ozone concentration is high (the smog episodes); otherwise the differences are small with the tropospheric 'background' being the major contributor to the predicted ozone.

There is only a small reduction in the ozone concentration when the Canadian emissions are turned off (scenario 3). Figure 4a shows that the 8-h maximum average ozone concentration calculated for scenario 3 is more than 90 % of the ozone concentration calculated for the 'base case'. Figure 4b shows that this percentage reduction does not change substantially when days inside smog episodes are isolated. Also, when the anthropogenic emissions for Ohio are turned off (scenario 4), the ozone decrease is approximately 10 % for the smog episodes compared to scenario 3 (Figure 4b).

The most important reduction in the ozone concentration is caused by scenario 5, which predicts reductions of 25 % to 35 % in smog episodes. After separating the contribution of the ozone 'background', turning off the anthropogenic emissions from Canada and the closest US states implies a reduction of more than 60 % in the anthropogenic ozone. This reduction is approximately 15 ppb in the 8-h maximum average ozone concentration over the entire study period and as high as 27 ppb in the days with 8-h maximum ozone is > 65 ppb

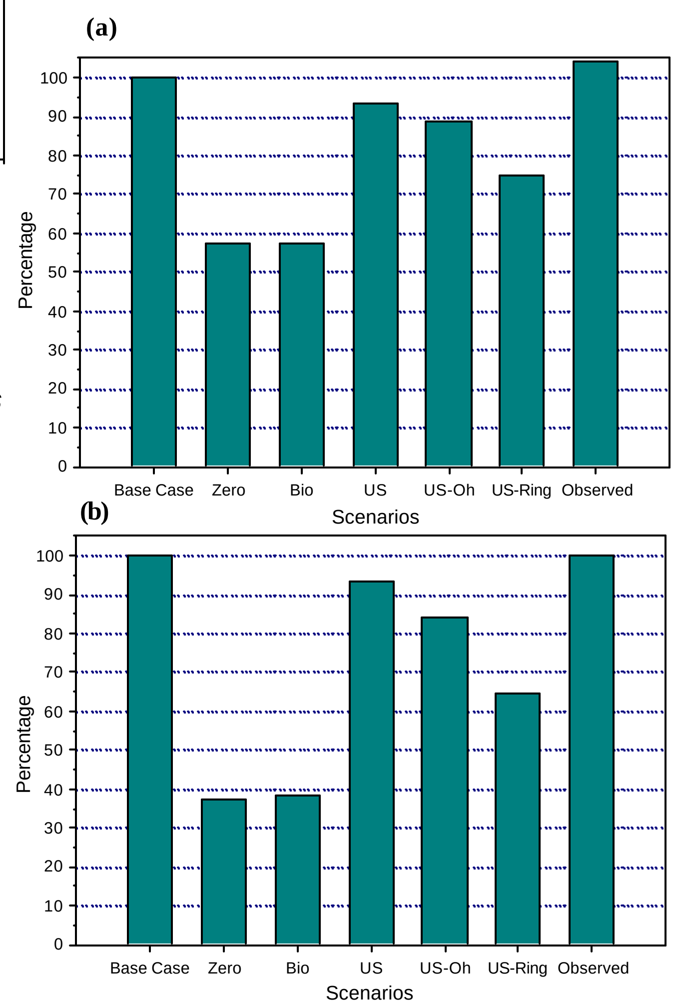

Fig. 4. Percentage of 8-h daily maximum ozone concentration averaged over Southern Ontario for selected scenarios from 'base case' (a) all days from June 4 to July 31 in 2001 and (b) only for days with 8-h daily maximum ozone concentration is more than 65 ppb.

4. SUMMARY

The average ‘background’ ozone concentration for Southern Ontario is found to be 31 ppb, which agrees with results of other authors. Biogenic emissions do not make a significant contribution to this tropospheric ‘background’.

Local emissions are not significant for the Southern Ontario ozone concentration, but reductions of more than 60 % are observed if selected U.S. anthropogenic emissions are eliminated.

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