MODELING THE AIR QUALITY IMPACTS OF CLIMATE AND LAND USE CHANGE IN THE NEW YORK CITY METROPOLITAN AREA

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1. INTRODUCTION

The interaction between climate, global and regional-scale ozone (O_3) air quality has been the topic of many studies over the past years (e.g. Fiore et al., 2002; Prather and Ehhalt, 2001; Prather et al., 2003). However, little work has been performed to date to study the potential impacts of regional-scale climate change on near-surface air pollution. Another parameter affecting local and regional meteorology and air pollution is land use, and significant land use changes associated with continued urbanization are expected to occur over the same time scales as changes in regional climate.

The results presented in this paper build upon a recent study by Hogrefe et al. (2004a) who presented results of a study that simulated O_3 concentrations over the eastern United States in three future decades for a specific regional climate change scenario. In this study, we add analysis for a separate climate change scenario. Further sensitivity simulations were performed to compare the magnitude of O_3 changes due to regional climate change to those that could arise from projected anthropogenic emissions within the modeling domain and changes in chemical boundary conditions. Finally, we present the results of sensitivity simulations in which projected changes in land use were incorporated into the regional climate and air quality modeling. The analysis presented in this paper focuses on the greater New York City metropolitan area.

2. MODEL DESCRIPTION AND DATA BASE

Emissions projections for greenhouse gases and other atmospheric constituents are used as inputs to climate and air quality models to simulate possible future conditions. The Intergovernmental Panel On Climate Change (IPCC) Special Report on Emission Scenarios (SRES) describes various future emissions scenarios based on projections of population, technology change, economic growth, etc. (IPCC, 2000). In this paper, we utilize the emission projections of the SRES A2 and B2 marker scenarios. While the A2 scenario is one of the more pessimistic SRES marker scenarios and is characterized by a large increase of CO_2 emissions, the B2 scenario is relatively optimistic and is characterized by smaller increases in CO_2 emissions (IPCC, 2000).

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2.1 Emissions processing

As described in Hogrefe et al. (2004a), the county-level U.S. EPA 1996 National Emissions Trends (NET96) inventory processed by SMOKE was used as the basis for the air quality modeling presented in this study. Biogenic emissions are estimated by the Biogenic Emissions Inventory System – Version 2 (BEIS2) that takes into account the effects of temperature and solar radiation on the rates of these emissions. For sensitivity simulations assessing the relative impact of increased anthropogenic emissions, future year anthropogenic emissions are estimated by multiplying the 1996 base year emission inventory with the regional growth factors for the SRES A2 scenario for 2050 for the so-called OECD90 region that includes many industrialized countries including the U.S. Under this scenario, Emissions of the O_3 precursors NO_x/VOC increase by 125%/60% globally and 29%/8% for the OECD90 region by the 2050s (IPCC, 2000).

2.2 Land use change

In this study, we performed climate and air quality sensitivity simulations using a regional land use change scenario consistent with the 2050 A2 SRES scenario that was developed for the greater New York City metropolitan area by Solecki and Oliveri (2004). Figures 1a-b present maps of land use for the 1990s base case and the 2050s A2 scenario. It can be seen that under this land use change scenario, a large number of grid cells in the greater New York City Metropolitan area are predicted to be converted from 'forest' or 'agriculture' to 'low density urban' land use in the 2050s A2 scenario.

2.3 Global and regional climate modeling

Current and future year regional climate fields were obtained by coupling the MM5 mesoscale model (Grell et al., 1994) to the Goddard Institute for Space Studies (GISS) 4ºx5º resolution Global Atmosphere-Ocean Model (GISS-GCM) (Russell et al., 1995) in a one-way mode through initial conditions and lateral boundaries. Simulations were performed for five consecutive summer seasons (June – August) in the 1990s and three future climate scenarios, namely, 2020s A2, 2050s A2, and 2050s B2 at a horizontal resolution of 36 km over the eastern United States. Analysis presented here forcuses on the greater New York City metropolitan region. For the sensitivity simulations exploring the effects of land use changes, MM5 simulations at 4 km resolution were performed over the greater New York City metropolitan area for a 20 day period in the model-simulated summer of 2056 with both the base year and future year land use distributions displayed in Figures 1a-b. Further details on the setup of this modeling system and results of the future regional climate simulations are described in Lynn et al. (2004) and Hogrefe et al. (2004b).

2.4 Air Quality modeling

Using the processed emissions and the 36 km MM5 regional climate simulations for the five summer seasons in the 1990s, 2020s A2, 2050s A2 and 2050s B2 scenarios, air quality simulations were performed using the Community Multiscale Air Quality (CMAQ) model (Byun and Ching, 1999) at a horizontal resolution of 36 km. The CMAQ evaluation results for simulating O_3 concentrations under present-day climate conditions have been presented in Hogrefe et al. (2004b). For the simulations intended to investigate the role of regional climate change in the absence of changes in emissions and global tropospheric composition, time-invariant climatological profiles for O_3 and its precursors reflecting present day clean-air concentrations were used as boundary conditions (Byun and Ching, 1999). For the sensitivity simulations aimed at investigating the effects of changes in anthropogenic emissions, we utilized the A2-scaled emissions inventory for the 2050s as described in Section 2.1. For the sensitivity simulations aimed at estimating the role of changes in global atmospheric composition, these changes were approximated by changing the CMAQ boundary conditions according to values reported in previous studies. Details of this procedure are described in Hogrefe et al. (2004a). Finally, to investigate the effects of land use changes on CMAQ predicted ozone concentrations, we performed 4 km CMAQ simulations for a 20 day time period in 2056 using the 4 km MM5 fields with and without land use changes.

3. RESULTS AND DISCUSSION

3.1 Changes in O_3 due to Regional Climate Change

Since the U.S. National Ambient Air Quality Standard (NAAQS) for 8-hr O_3 concentrations is set at 84 ppb, model predicted exceedances of this threshold are of particular importance when assessing the effect of climate change on O_3 air quality. To analyze changes in the frequency and duration of extreme O_3 events, the number of days for which the predicted daily maximum 8-hr O_3 concentrations exceeded 84 ppb was determined over the greater New York City metropolitan area, and for each such event the number of consecutive days for which these conditions persisted was tracked. Figure 2 shows the total number of days with daily maximum 8-hr O_3 concentrations exceeding 84 ppb for the 1990s, 2020s A2, 2050s A2, and 2050s B2 simulations, grouped by the number of consecutive days on which this concentration was exceeded. Note that for these simulations, emissions, boundary conditions and land use were held constant. The total number of exceedance days increased from 584 in the 1990s to 1,302 in the A2 2020s, 1,267 in the B2 2050s, and 1,595 in the A2 2050s. Additional analysis also shows that the persistence of extreme O_3 events increases in the future climate scenarios.

To compare the effects of climate change on air quality presented above to the effects of increases in anthropogenic emissions, and the approximated effects of changes in global atmospheric composition through the specification of altered boundary conditions, sensitivity simulations were performed for the time periods from 1993-1997 and 2053-2057. To compare the contribution of the three factors to changes in summertime average daily maximum 8-hr O_3 concentrations as well as the 4^{th} highest summertime daily maximum 8-hr O_3 concentration that is of relevance to the NAAQS, these contributions were calculated and averaged over the greater New York City Metropolitan area. Figure 3 shows a bar chart of the contribution of each factor to changes in summertime average daily maximum 8-hr O_3 concentrations (light shading) and to changes in the 4^{th} highest summertime daily maximum 8-hr O_3 concentration in the 2050s A2 scenario simulation (dark shading).

Figure 3 indicates that changed boundary conditions as described in Section 2.4 are the largest contributor (5.1 ppb) to changes in summertime average daily maximum 8-hr O_3 concentration in the 2050s A2 scenario simulation from the 1990s base simulation, followed by the effects of climate change (2.1 ppb), while increased anthropogenic emissions within the modeling domain lead to a 1.4 ppb decrease of average ozone concentrations over the New York City metropolitan area, presumably through increased O_3 titration by NO_x. For the 4^{th} highest daily maximum 8-hr O_3 concentration, the effects of climate change cause an increase of 6.4 ppb, while increased boundary conditions and anthropogenic emissions account for increases of 2.6 and 0.8 ppb, respectively. In summary, while previous studies have pointed out the potentially important contribution of growing global emissions and intercontinental transport to O_3 air quality in the United States for future decades, the results presented above imply that the effects of a changing climate may be of at least equal importance when planning for the future attainment of the NAAQS.

3.2. Effects of changed land use

Figure 4a illustrates that the predicted conversion of many grid cells in the greater New York City metropolitan area to ‘low-residential urban’ for the 2050s A2 land use scenario shown in Figure 1 leads to increases in episode-maximum temperatures over many grid cells in this area, with temperature increases over 2 ºC in some areas in Connecticut. When averaged over all non-water cells shown in Figure 4a, the increase in episode-maximum temperature is 0.7 ºC, consistent with the higher heat capacity and lower moisture availability of urban grid cells compared to agricultural or forest grid cells. As Figure 4b illustrates, the impact of changes in meteorology caused by growing urbanization on episode-maximum 8-hr ozone concentrations is more variable. While most grid cells experienced an increase of ozone and the average increase over all non-water grid cells was 1 ppb, some areas experienced decreases of more than 3 ppb in episode-maximum 8-hr ozone concentrations. To investigate this effect further, future analysis will include comparisons of other meteorological variables such as wind fields and mixed layer height between the base and future land use case simulations. The preliminary results presented here suggest that changes in land use can have local impacts of comparable magnitude as the other factors considered in this study, i.e. changes in regional climate, anthropogenic emissions, and chemical boundary conditions.

4. SUMMARY

This paper described the application of a one-way coupled global/regional modeling system to simulate O_3 air quality in future decades over the eastern United States. The CMAQ simulations of O_3 concentrations utilizing the regional climate fields for the A2 and B2 emission scenario for the 2020s and 2050s show an increase in the frequency and duration of extreme O_3 events over the greater New York City metropolitan area in the absence of changes in anthropogenic emissions and boundary conditions. Through additional sensitivity simulations for the 2050s, it was determined that changes in regional climate outweigh the effects of increased boundary conditions and increased anthropogenic emissions over the greater New York City metropolitan area when changes in the 4^{th}-highest summertime daily maximum 8-hr O_3 concentration are considered. Thus, the results presented in this study imply that the effects of a changing climate may be of importance when planning for the future attainment of regional-scale air quality standards such as the U.S. NAAQS. Analysis of the effects of land use change on temperature and ozone suggests that such changes can have local impacts of comparable magnitude as the other factors considered in this study, i.e. changes in regional climate, anthropogenic emissions, and chemical boundary conditions.

5. ACKNOWLEDGMENTS

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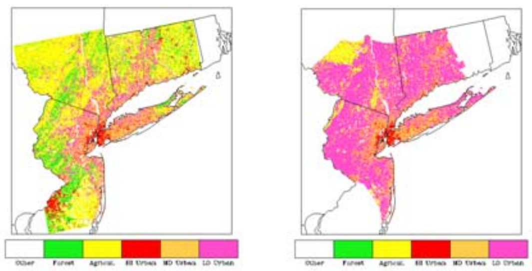

Figure 1: Land use categories in the greater New York City metropolitan area as simulated by Solecki and Oliveri (2004) for the 1990s (left) and 2050s A2 scenario (right). The land use categories shown are Forest (green), Agriculture (yellow), High Density Urban (red), Medium Density Urban (orange), Low Density Urban (pink), and Other (white).

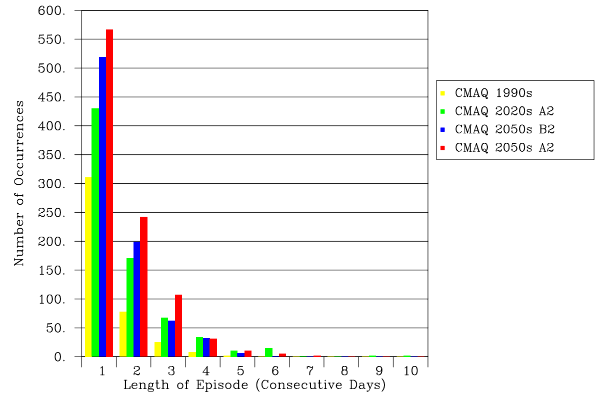

Figure 2: Number of days for which predicted daily maximum 8-hr ozone concentrations exceeded 84 ppb over the greater New York City Metropolitan area for the 1990s, 2020s A2, 2050s B2, and 2050s A2 climate scenarios, grouped by length of episode.

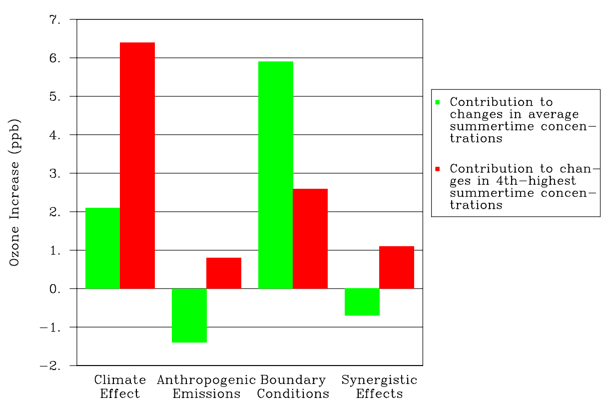

Figure 3: Contribution of changes in climate, anthropogenic emissions, and boundary conditions to changes in summertime average daily maximum 8-hr O_3 concentrations (green) and to changes in the 4^{th} highest summertime daily maximum 8-hr O_3 concentration in the 2050s A2 scenario simulation (red) over the greater New York City Metropolitan area

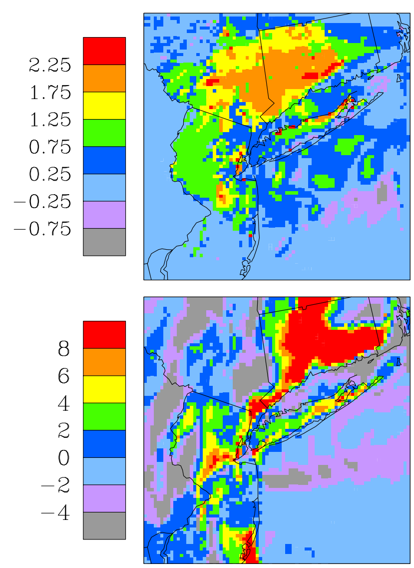

Figure 4: Changes in episode-maximum temperature (in degrees K, top) and episode-maximum 8-hr ozone concentration (in ppb, bottom) caused by incorporating the changes in land use illustrated in Figure 1 for a 20-day MM5 simulation in 2056 and subsequently using these MM5 fields to perform CMAQ simulations.