DIRECT AND EMISSION-INDUCED IMPACTS OF CLIMATE CHANGE ON OZONE AND FINE PARTICULATE MATTER: PRELIMINARY RESULTS

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1. INTRODUCTION

Climate change can be induced by the emissions of gases and particulate matter, land use modifications, and other human activities. Of recent interest is how climate change might potentially impact regional air quality, e.g., ozone and particulate matter levels. Given the large uncertainties in predicting future climate, there can be large uncertainties in how such changes will impact air quality. A second question, which may be of less uncertainty, is how climate change will impact the response of air quality to emissions controls. This question is as important, since it bears directly on ability to formulate long term strategies to improve air quality in a fashion that will remain effective in spite of climate modification of weather patterns.

Preliminary modeling has been conducted to assess how climate change affects ozone and fine particulate matter (here, sulfate aerosol) throughout the U.S. during summertime. This was investigated by uniformly increasing mean temperatures in the meteorological fields in the MM5/SMOKE/SMOKE system (CMAS, 2004). The direct effects are those caused by change in meteorology alone whereas the emission-induced (i.e. indirect) effects consider associated changes in temperature-dependent emission rates. Results from the quantification of responses (including first- and second-order sensitivities) are given and discussed.

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2. METHODOLOGY

A 147x111 grid domain was used for study, which includes the entire U.S. and parts of Canada and Mexico, with a 36-km resolution horizontally and 9 layers vertically. The mapping of the domain was based on Lambert conformal projection. Meteorological fields were generated using MM5 modeling with four-dimensional data assimilation (FDDA). Emissions data were processed by SMOKE to generate CMAQ-ready emissions fields. This study followed Park and Russell (2003) for the physical specifications used in MM5 and the emissions inventory for SMOKE. In CMAQ simulation, SAPRC-99, RADM, AERO3, and AERO_DEPV2 modules/sub-models were used, and default initial and boundary conditions in CMAQ were adopted. A five-day episode of July 1–5, 2001 was representatively chosen for investigation.

To determine the direct effects, temperature values in a meteorological field obtained from a base-case simulation are uniformly increased by 3 K (Kelvin) over the entire domain, and this meteorological field is then incorporated into CMAQ simulation directly. For the emission-induced effects, a similar procedure is used, except that the meteorological field with a uniform 3-K increase is also used to drive SMOKE simulation. Fig. 1 shows an example of a base-case temperature field. Since the rates of various emissions in the modeling are temperature-dependent, such as biogenic and mobile emissions, an increase in temperature results in their higher rates. Fig. 2 displays an example of change from base case in biogenic VOC emission rate due to increased temperatures.

To estimate the first- and second-order sensitivities of a species' concentration to an emission, brute force method was employed

based on a 3-point differencing scheme with ±10% perturbations from the original emission, i.e.

$$S_1(i, j) = [C(i, j+1) - C(i, j-1)] / 2\,\Delta\varepsilon(j), \text{ and}$$
$$S_2(i, j) = [C(i, j+1) - 2\,C(i, j) + C(i, j-1)] / \Delta\varepsilon^2(j), \quad (1)$$

where $S_1(i, j)$ and $S_2(i, j)$ are the first- and second-order sensitivities of species i's concentration to emission j, respectively, C(i, j) and C(i, j±1) are the concentrations of species i from the original (i.e. unperturbed) case and positively/negatively perturbed cases on emission j, respectively, and $\Delta\varepsilon(j)$ is the magnitude of perturbation on emission j (here, set to 0.1). $\Delta\varepsilon(j)$ has no unit due to being semi-normalized by its original value. S(i, j) and $S_2(i, j)$ are the approximate local slope and local curvature of the species-emission relationship, respectively.

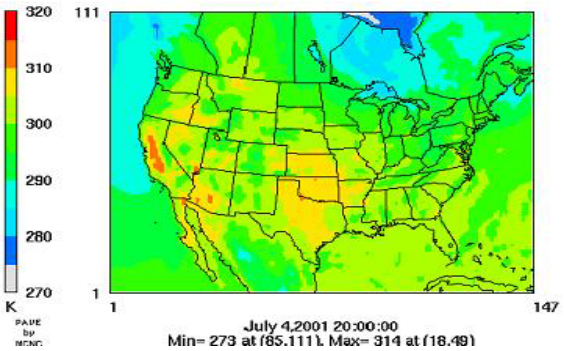


Fig. 1 Base-case temperature (K) at UTC Hour 20 (i.e. 1pm EST), Jul. 4, 2001.

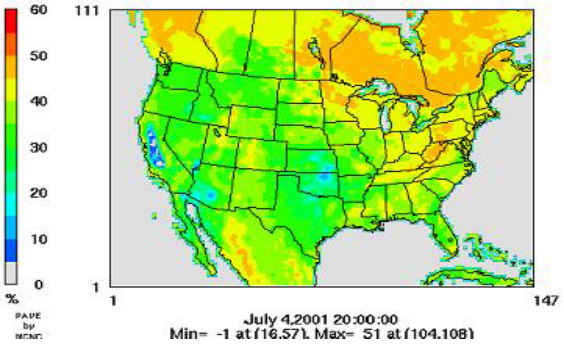
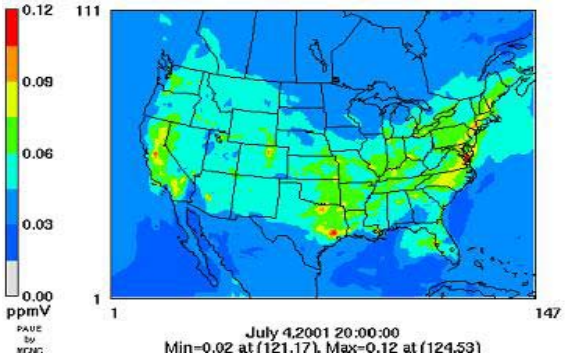


Fig. 2 Percent of change in biogenic VOC emission rate in base case at Hr. 20, Jul. 4 due to a uniform 3-K increase in temperature.

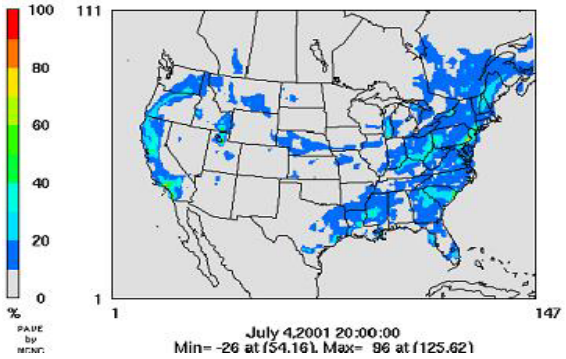
3. RESULTS AND DISCUSSION

An example of hourly-averaged O_3 and ASO4 concentration levels in base case are shown in Figs. 3a and 4a, respectively. Figs. 3b-c and 4b-c show changes (from base case) in direct and emission-induced cases. ASO4 denotes sulfate aerosol that is here the sum of ASO4I (Aiken mode) and ASO4J (accumulation mode). For O_3, the concentration changes in direct and emission-induced cases share a similar spatial pattern, and O_3 level increases by +10 to +40% from base case

a) Base case, concentration



b) Direct case, relative change



c) Emission-induced case, relative change

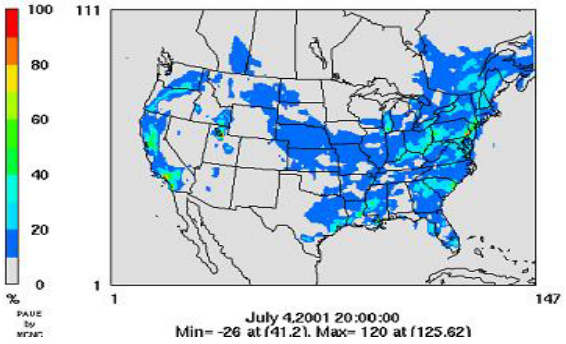
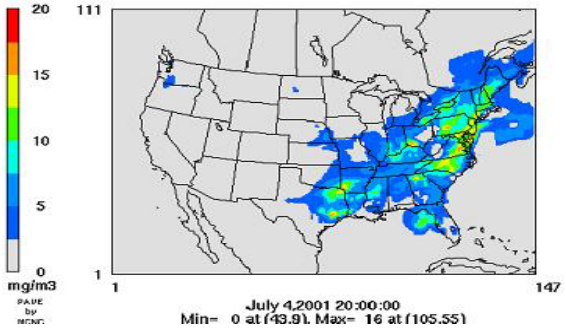
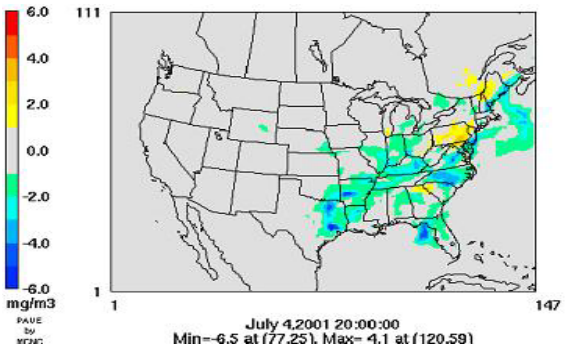


Fig. 3 O_3 at Hr. 20, Jul. 4: a) Concentration in base case, b) Percent of change (from base case) in direct case, c) Percent of change (from base case) in emission-induced case.

a) Base case, concentration



b) Direct case, absolute change



c) Emission-induced case, absolute change

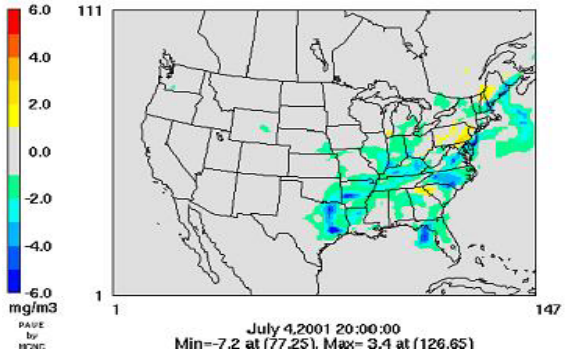
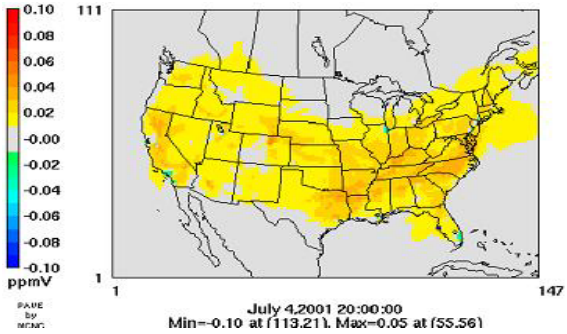


Fig. 4 ASO4 at Hr. 20, Jul. 4: a) Concentration (mg/m^3) in base case, b) Absolute change (from base case) in direct case, c) Absolute change (from base case) in emission-induced case.

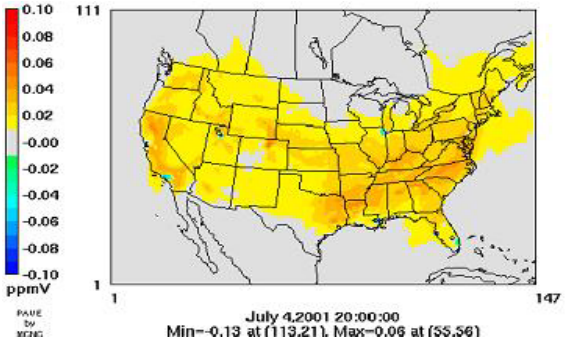
For ASO4, its concentration changes from base case range from -6 to +3 mg/m^3 but there is no significant change from base case in both direct and emission-induced cases for most of the western region.

The first-order sensitivity of O_3 to NO_x emissions in each case is given and compared in Fig. 5. It is seen that sensitivity is positive (around +10 to +40 ppb) for most of the domain. The magnitude of sensitivity also appears relatively large in emission-induced case. For the first-order sensitivity of O_3 to VOC emissions, there is no

a) Base case



b) Direct case



c) Emission-induced case

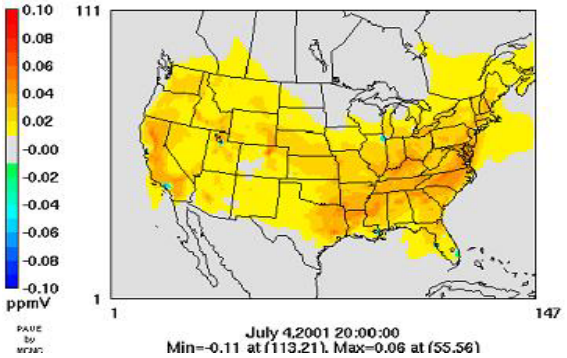
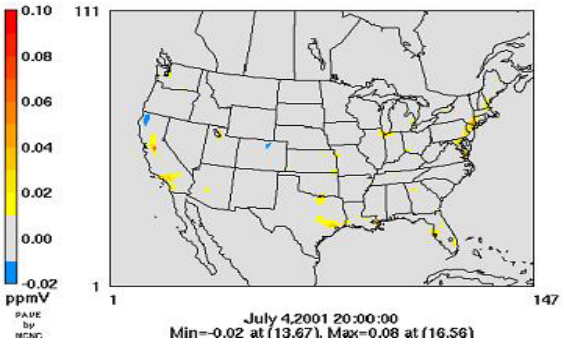


Fig. 5 First-order sensitivity of O_3 to NO_x emissions (ppmv) at Hr. 20, Jul. 4: a) Base case, b) Direct case, c) Emission-induced case.

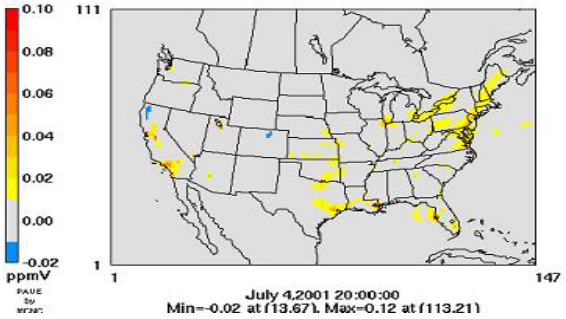
significant sensitivity for most of the western region, except for some specific areas where sensitivity is around +10 to +40 ppb, as seen in Fig. 6. In Fig. 7, the time series of the first- and second-order sensitivities of O_3 to NO_x emissions at the grid cell corresponding to the city of Atlanta (GA) are given. The first-order sensitivity is relatively large in emission-induced case, and the trend of second-order sensitivity in each case does not show a significant difference from one another.

The results from this preliminary study suggest

a) Base case



b) Direct case



c) Emission-induced case

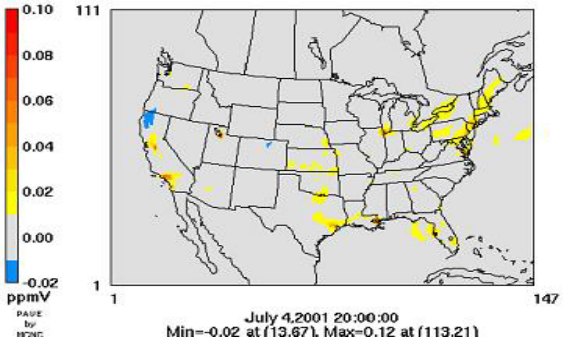
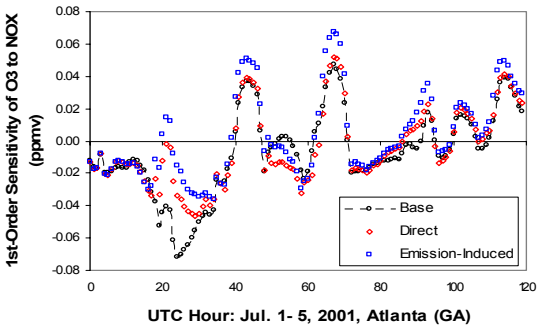


Fig. 6 First-order sensitivity of O_3 to VOC emissions (ppmv) at Hr. 20, Jul. 4: a) Base case, b) Direct case, c) Emission-induced case.

that warmer temperatures directly affect emission rates and O_3 and ASO4 levels to some extent in both direct and emission-induced cases. Sensitivities of O_3 and ASO4 to emissions are also affected by warmer temperatures, indicating the importance of the uncertainty in meteorology due to climate change that may affect the uncertainty of air quality.

For future work, it is planned to use meteorological data forecast by a global climate model and downscaled for a regional scale to drive regional air quality simulation, to update the current emissions inventory, and to implement direct decoupled method (Yang et al., 1997) for sensitivity calculation.

a) First-order sensitivity



b) Second-order sensitivity

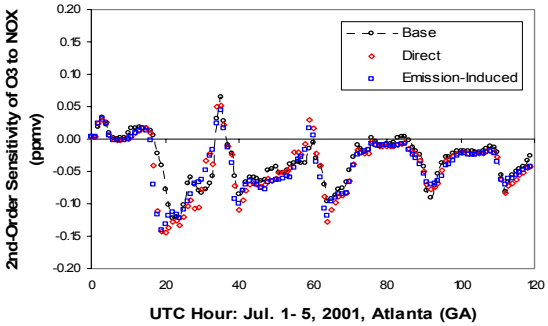


Fig. 7 Time series of first and second-order sensitivities of O_3 to NO_x emissions for Atlanta (GA) at Hr. 20, Jul. 4.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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