CLIMATE CHANGE IMPACTS ON US AIR QUALITY: EXAMINATION OF OZONE AND FINE PARTICULATE MATTER CONCENTRATIONS AND THEIR SENSITIVITY TO EMISSION CHANGES

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1. INTRODUCTION

Climate change over the next century is predicted to have a direct impact on meteorology (IPCC, 1996). Changes in surface air temperature and downward solar radiation, precipitation frequency, stagnation events and ventilation are predicted over the US, based on future climate simulations (e.g., Leung and Gustafson, 2005). These changes have the potential to affect regional air quality. The objective of this study is to assess the impacts of global climate change on O_3 and $PM_{2.5}$ (PM with an aerodynamic diameter less than 2.5 μm) and their sensitivities to emission changes. Here, O_3 and $PM_{2.5}$ concentrations in 2050 are compared to 2001 levels

2. METHODS

Air quality modeling was conducted using CMAQ (http://www.cmascenter.org) and downscaled meteorology from the GISS global climate model (Rind et al., 1999) (Figure 1). Future-year emissions forecast for North America are developed by forecasting activity growth and application of emission controls.

2.1 Emissions

The 2001 Clean Air Interstate Rule (CAIR) emission inventory (EI) (http://www.epa.gov/cair/technical.html) is used as the U.S. emission inventory for the historic period (i.e., 2001), as well as the basis for projected emissions up to 2020. For Canada, the US Environmental Protection Agency (EPA) 1996 Canadian inventory has been updated with the combination of Environment Canada emissions (http://www.epa.gov/ttn/chief/net/ canada.html) and New York States Department of Environmental Conservation point source inventory. For Mexico, the US EPA's 1999 BRAVO inventory has been updated with the Mexico NEI (http://www.epa.gov/ttn/chief/net/mexico.html).

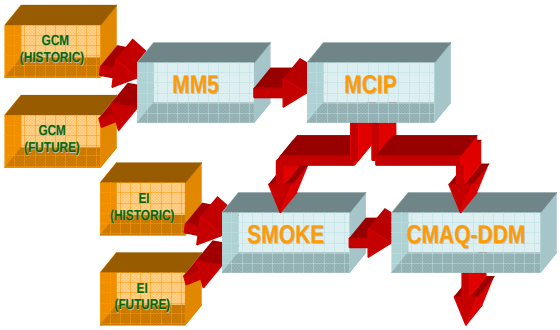

Figure 1: Modeling approach

Projection of emissions is done in two steps: i) for near future (2001 – 2020) projection, the 2020 CAIR EI of the US EPA is grown by using the Economic Growth Analysis System (EGAS) (http://www.epa.gov/ttn/ecas/egas5.htm); ii) far future (2020 – 2050) projection is carried out based on the results suggested by the Netherlands Environmental Assessment Agency's IMAGE model (http://www.mnp.nl/image). IMAGE uses widely accepted scenarios (i.e. Intergovernmental Panel on climate Change (IPCC) Special Report on Emissions Scenarios (SRES)) (IPCC, 2000) which are consistent with the scenario SRES-A1B and the climate/meteorological modeling used here.

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2.2 Meteorology

Meteorological fields are derived from the Goddard Institute of Space Studies (GISS) Global Climate Model (GCM) (Rind et al., 1999), which was applied at a horizontal resolution of 4° latitude by 5° longitude to simulate current and future climate at global scale. The simulation followed the SRES-A1B emission scenario (IPCC, 2000) for greenhouse gases. Leung and Gustafson, (2005) downscaled GISS outputs using the Penn State/NCAR Mesoscale Model (MM5) (Grell et al., 1994) to the regional scale (Figure 2).

Figure 2: Modeling domain and regions examined

2.3 Air Quality Modeling

CMAQ (Byun, 1999) with SAPRC-99 (Carter, 2000) and DDM-3D, are used to quantify the concentrations and sensitivities of historic and future ozone and $PM_{2.5}$ concentrations to specific sets of emissions: anthropogenic and biogenic VOCs and NOx, total NH_3 and SO_2, over a domain of 111x147, each 36 by 36 km, horizontal grid cells (Figure 2). DDM-3D (Dunker, 1981; 1984; Dunker, et al., 2002; Yang, et al., 1997) directly calculates the sensitivities of both gas phase and particle phase pollutants to precursor emissions. The seminormalized sensitivity (Si,j) of pollutant concentration i (Ci) to emissions source term parameter j (Ej) is given as:

$$S_{i,j} = E_j \frac{\partial C_i}{\partial E_j}$$

The seminormalized sensitivities are composed of two terms, emission (Ej) and fractional concentration yield from per unit emission ($\partial C_i / \partial E_j$). Thus the sensitivities presented here have the same units pollutant concentrations.

3. RESULTS AND DISCUSSION

3.1 Emissions

Emissions changes between future (2050) and historic (2001) years show large decreases in SO_2 (-50%) and NOx (-50%) when climate change, growth in human activities and emission controls are simulated (Figure 3). These reductions are due to control strategies applied to anthropogenic US and Canadian sources while the growth of the industrial sector gives higher emissions in Mexico. Emission reductions in anthropogenic VOC's combined with the higher biogenic emissions in the warmer climate results in a small change in VOCs emissions (+2%). Description of the regional emissions is detailed in Woo et al. (2006).

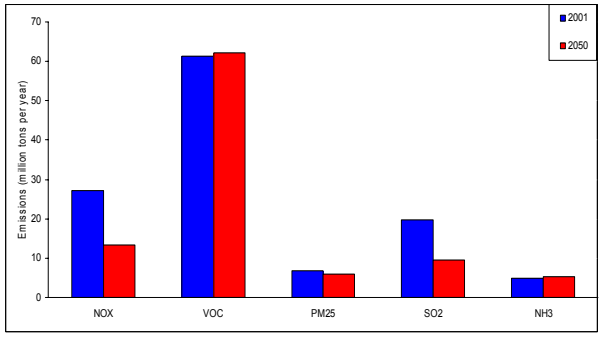

Figure 3: Annual emissions for 2001and 2050

3.2 Meteorology

2050 yearly average temperature compared to 2001 is expected to be 1.7 K warmer in US, with slight variability by region (± 0.5K) (Table1). Maximum warming will happen during fall months with simulated average temperature changes up to 4.8 degrees in the West.

Table 1: Regional mean annual temperature for historic (2001) and future (2050) years

Region	T_{2001} (K)	T_{2050} (K)	ΔT
West	281.9	284.1	2.3
Plains	282.8	284.2	1.4
Midwest	281.7	283.2	1.5
Northeast	280.8	282.8	2.0
Southeast	289.5	290.8	1.3
US	283.2	284.9	1.7

3.3 Air Quality

Impacts of climate change, growth activity and emissions controls are more pronounced for regional $PM_{2.5}$ concentrations than $M8hO_3$ (Figure 4).

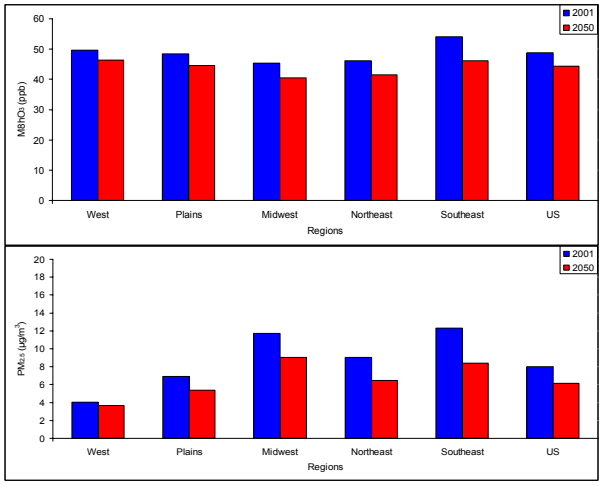

Figure 4: Mean annual maximum eight (8) hour O_3 ($M8hO_3$) and $PM_{2.5}$ concentrations for historic and future periods

US annual average concentrations for $PM_{2.5}$ and $M8hO_3$ are predicted to be 23% and 9% lower, respectively in 2050 compared to 2001. Significant reductions are predicted for sulfate (-31%), nitrate (-48%), and ammonium (-32%) fractions, while a smaller reduction is predicted for organic carbon (-6%) (Table 2). Control programs for NMVOC for area and point sources that are less stringent than for SO_2 and NOx combined with the higher VOCs emissions from biogenic sources expected in a warmer future climate are the primary factors. A slight increase in organic carbon in the West is noted due to increases in both primary and secondary organic carbon.

Sensitivities of ozone formation to domain-wide emissions of anthropogenic NOx, biogenic VOCs and anthropogenic VOCs are examined for the grid cells presenting the highest 8-hour average ozone concentrations in each region (Figure 5).

Reductions in future anthropogenic NOx emissions decrease ozone formation. The contributions of anthropogenic NOx to ground-level ozone formation are more important than anthropogenic and biogenic VOCs in the current and future episodes.

Table 2: Annual average change (percentage) in pollutant concentration for 2050 compared to 2001

	$M8hO_3$	$PM_{2.5}$	SO_4^+	NO_3^-	NH_4^+	OC
West	-6.5	-9.2	-20.2	-41.4	-24.9	4.0
Plains	-7.8	-22.0	-29.2	-45.3	-31.7	-3.4
Mid-West	-10.6	-22.7	-22.2	-48.5	-28.7	-9.3
North-East	-10.1	-28.5	-37.4	-45.6	-32.6	-13.0
South-East	-14.8	-31.4	-41.5	-54.9	-37.0	-14.9
US	-9.2	-23.4	-30.8	-47.8	-31.6	-6.4

Sensitivities of sulfate $PM_{2.5}$ formation to total SO_2 emissions (SO_4_SO_2_total) and nitrate $PM_{2.5}$ formation to anthropogenic NOx emissions (NO_3_NOx_anthr.) are predicted to decrease due to the controls of anthropogenic SO_2 and NOx emissions in the future.

Sensitivities of sulfate PM formation to ammonia (SO_4 to NH_3_total) are predicted to increase although significant reductions of SO_2 emissions are projected (Figure 6). Increases are due to projected increased ammonia emissions (which are mainly biogenic emissions) in the future. Higher ammonia/ammonium concentrations tend to neutralize cloud water, allowing more SO_2 oxidation by ozone. On the other hand, lower NOx emissions decrease ammonium nitrate formation in the nitrate-limited environment and reduce sensitivity of nitrate PM to NH_3 emissions.

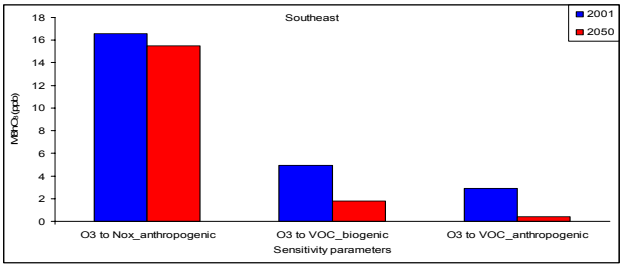

Figure 5: Sensitivities of ozone formation to emissions of anthropogenic NOx, biogenic VOCs and anthropogenic VOCs for the grid cell presenting the highest 8-hr ozone concentrations in Southeast region for both historic (2001) and future (2050) years

SO_2 and NOx emissions tradeoffs are complicated. Reductions in SO_2 emissions decrease sulfate but increase nitrate aerosol formation while lower NOx emissions decrease nitrate aerosol but slightly increase sulfate. In both cases, the indirect impact is small comparatively.

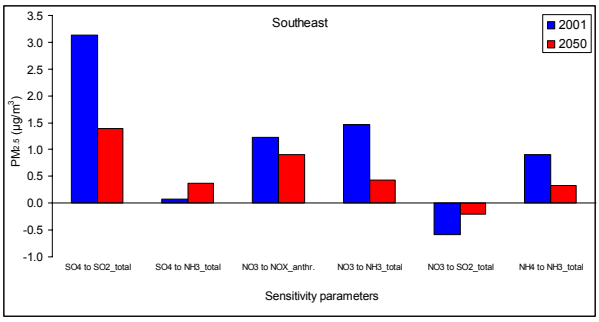

Figure 6: Sensitivities of specied $PM_{2.5}$ formation to domain-wide emissions of PM precursors for the grid cell presenting the highest $PM_{2.5}$ concentrations in the Southeast region for both historic (2001) and future (2050) years

4. CONCLUSIONS

Regional O_3 and $PM_{2.5}$ concentrations for a future period (2050) are simulated to be lower compared to the historic period (2001), given the planned controls on precursor emissions, though global warming, alone, does lead to an increase in biogenic emissions. Future levels of sulfate, nitrate and ammonium are simulated to be significantly lower compared to organic carbon, leaving organic carbon as the likely major constituent of fine particulate matter in the future.

The impact of emission controls has a significant effect on ozone and $PM_{2.5}$. SO_2, NH_3, anthropogenic NOx and biogenic VOCs are found to continue as important precursors to $PM_{2.5}$ formation in the future while anthropogenic NOx emissions are dominant for ozone formation. The results suggest that the planned controls of SO_2 and NOx will continue to be effective in reducing mainly $PM_{2.5}$ concentrations in the future.

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