J8.2 Global Climate Change Impacts on Air Quality in North America

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1. INTRODUCTION

Global climate change over the next century is predicted to have a direct impact in future meteorology (e.g. temperature, downward solar radiation, precipitation frequency) over the North America which, in turn, impacts air quality (e.g., Leung and Gustafson, 2005). Moreover the emission control strategies will also affect future air quality.

The objective of this study is to assess the impacts of global climate change and emissions on regional air quality over North America. We focus on O_3 and $PM_{2.5}$ (PM with an aerodynamic diameter less than 2.5 μm) as they have suspected health effects.

2. METHODS

O_3 and $PM_{2.5}$ concentrations in three (3) month summer episodes (JJA) in both historical (i.e. 2000 – 2002) and future periods (i.e. 2049 - 2051) are compared using CMAQ (http://www.cmascenter.org). Both the direct (impact of climate change on meteorology) and indirect impacts (those caused by emission changes due to either/both controls and climate change) are evaluated using two different cases. In the first case, the impacts of changes on air quality by climate alone are examined by keeping emissions sources, activity levels and controls constant. In the second case, the future pollutant concentrations are estimated based on changes in climate and emissions using IPPC A1B emission scenarios and planned controls.

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Meteorological inputs to the CMAQ chemical transport model are developed by downscaling GISS Global Climate Model (Rind et al., 1999) outputs using MM5 (Grell et al., 1994). Future-year emissions forecast for North America are developed by forecasting activity growth and application of emission controls (Woo et al., (2006)).

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., 2000-2002), as well as the basis for projected emissions up to 2020. For Canada, the Environment Canada (EC)'s 2000 inventory has been used for area and mobile sources http://www.epa.gov/ttn/chief/net/canada.html). 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).

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. Emissions are processed by the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System (http://cf.unc.edu/cep/empd/products/smoke/index.cfm). Historic and future emission inventories include the following compounds: carbon

monoxide (CO), nitrogen oxides (NO_X), sulfur dioxide (SO_2), nonmethane volatile organic compounds (NMVOC), ammonia (NH_3), and speciated particulate matter (PM_{10} and $PM_{2.5}$). A detailed description of the method has been presented by Woo et al., (2006).

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^o latitude by 5^o 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 1). The Meteorology Chemistry Interface Processor (MCIP) (http://www.cmascenter.org) is used to provide the meteorological data from the hourly MM5 outputs needed for the emissions and air quality models that both have 147x111 horizontal grids of 36 km x 36 km, with nine (9) vertical layers up to approximately 15 km.

Figure 1: Modeling domain and regions examined

2.3 Air Quality Modeling

CMAQ (Byun, 1999) with SAPRC-99 (Carter, 2000) is used to simulate the historic (i.e. summers 2000 – 2002) and future (i.e. summers 2049 - 2051) ozone and $PM_{2.5}$ concentrations. For the future period, two different cases are examined. In the first case the same emission state, i.e., the 2001 inventory, is used for both historic and future simulations in order to estimate the impact to air quality by changes in global climate alone. Although the emission inventory is kept the same, emissions are not, since some pollutant emissions (e.g., biogenic and mobile sources) depend on meteorology. In the second case the combined impact of future emissions (based on the forecast emissions and climate) and future climate is evaluated to simulate future levels of O_3 and $PM_{2.5}$. Average regional concentrations are predicted for five continental US sub-regions, West, Plains, Midwest, Northeast and Southeast (Figure 1).

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 2). 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%). For the case where only climatic changes are considered, VOC emissions are slightly higher (+15%) in the future due to temperature effect on biogenic and mobile sources. Minor increases in NO_X (+2%) and SO_2 (+4%) are also predicted. Description of the regional emissions is detailed in Woo et al., (2006).

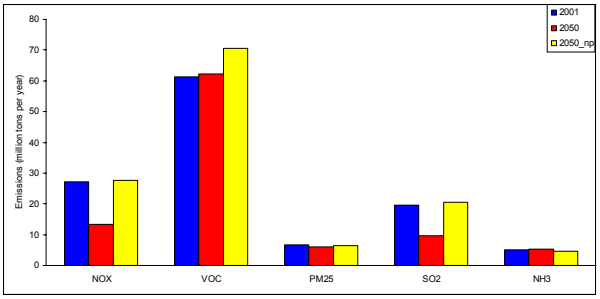

Figure 2: Annual emissions for 200, 2050 and 2050 for the "no emissions projection" scenario (2050_np)

3.2 Meteorology

Future summer temperatures (i.e., 2049-2050) compared to the historic ones (i.e., 2000-2002) are simulated to be 1.4K warmer in US (Figure 3), with small variations by region (± 0.6K). The minimum

increase is noted in the Midwest (0.8K) and the maximum in the West (2.0K). A detailed climate simulation description for the years 1995-2005 and 2045-2055 has been presented by Leung and Gustafson (2005).

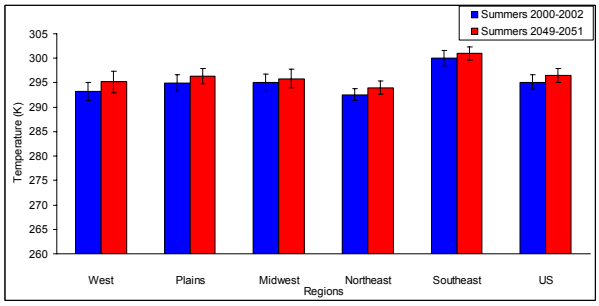

Figure 3: Regional mean summer temperatures for both future and historic periods

3.3 Air Quality

Global climate change, alone, has a small effect on future summer (i.e., 2049 – 2051) maximum 8hr ozone concentrations ($M8hO_3$) over the US (Figure 4) when compared to the historic summers (i.e., 2000-2002). The average regional changes range from -2.5% to +2.8%. Summer $PM_{2.5}$ concentrations (Figure 5) are predicted to be lower in all the US sub-regions (average about 10%) using the same emission inventory, as a result of the increased precipitation and higher temperatures. Higher temperatures lead to increased gas phase partitioning of ammonium nitrate and organics. Sulfate, nitrate, ammonium and organic carbon fractions of $PM_{2.5}$ are predicted to be lower in the US (Table 1).

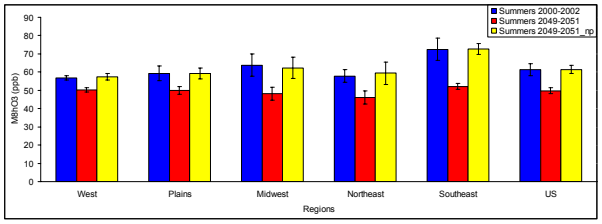

Figure 4: Mean summer maximum eight (8) hour O_3 ($M8hO_3$) concentrations for historic and future periods

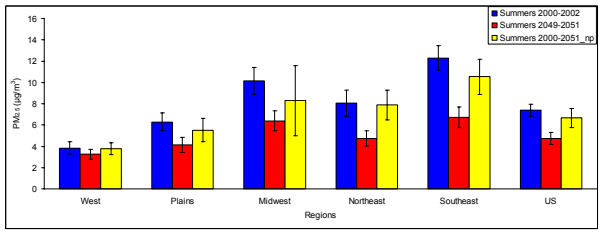

Figure 5: Mean summer $PM_{2.5}$ concentrations for historic and future periods

The impact of climate change, growth activity and emissions controls are more pronounced for the $PM_{2.5}$ concentrations than $M8hO_3$ (Figures 4, 5). The US summer average concentrations for $M8hO_3$ and $PM_{2.5}$ are predicted to be lower by about 20% and 35%, respectively. Significant reduction is predicted for sulfate, nitrate and ammonium while a smaller reduction is predicted for organic carbon (Table 1).

4. CONCLUSIONS

Regional O_3 and $PM_{2.5}$ concentrations over US for a future period (i.e., summers 2049-2051) are simulated to be lower compared to the historic period (i.e., summers 2000-2002), given the planned controls on precursor emissions, though global warming, alone, does lead to an increase in biogenic emissions. Climate change, alone, with no emissions growth or controls has a small effect on the $M8hO_3$ and $PM_{2.5}$ levels. 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 far future.

5. REFERENCES

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	M8hO$_3$ (%)		$PM_{2.5}$ (%)		SO_4 (%)		NO_3 (%)		NH_4 (%)		OC (%)	
	Summers	*Summers_np*	*Summers*	*Summers_np*	*Summers*	*Summers_np*	*Summers*	*Summers_np*	*Summers*	*Summers_np*	*Summers*	*Summers_np*
West	-11.6	0.9	-15.7	-2.0	-32.2	-3.7	-72.8	-42.8	-33.0	-6.9	-6.7	0.7
Plains	-15.8	-0.1	-34.3	-12.1	-48.7	-16.4	-46.4	-15.2	-41.8	-14.1	-16.2	-7.7
Midwest	-24.4	-2.5	-37.1	-18.4	-52.6	-22.4	-68.5	-24.1	-45.7	-21.9	-19.1	-11.7
Northeast	-20.2	2.8	-41.2	-1.7	-56.7	-2.2	-79.3	-28.8	-44.5	-0.8	-25.2	-0.4
Southeast	-27.9	0.3	-45.2	-14.3	-60.5	-16.5	-77.1	-37.1	-47.9	-13.3	-27.5	-14.8
US	-18.9	0.0	-35.9	-9.9	-52.6	-13.9	-65.6	-22.6	-43.9	-12.2	-17.2	-5.5

Table 1: Mean summer changes (percentile) in pollutants concentrations for future periods compared to historic ones

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