P 1.7 IMPACT OF CLIMATE CHANGE ON U.S. AIR QUALITY USING MULTI-SCALE MODELING WITH THE MM5/SMOKE/CMAQ SYSTEM

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1. INTRODUCTION

Global climate change, land use changes and population growth are interrelated forces that can cause significant changes in future air quality in the US. Global warming can influence regional weather, modify boundary layer meteorology and change chemical reaction rates. Furthermore, higher temperature can lead to increased emissions from both biogenic and anthropogenic sources and faster chemical reaction rates. Climate change can also cause significant changes in land use by altering the vegetative pattern and change the distribution, composition and magnitude of regional biogenic emissions. Land use change and changes in climate patterns can also affect the occurrence of fires and the resulting gas and particulate emissions. The growth of population will expand the sizes of urban centers in US and further increase anthropogenic pollutants emissions. All of these effects of global climate change can significantly alter the chemistry of the lower troposphere and change the formation of secondary pollutants in the atmosphere.

It is difficult to determine and quantify the effects and influences of regional air quality from large scale global climate changes. In this work, we apply a numerical modeling approach to address the questions concerning future air quality stemming from global change. We hope to address, first, how global change can impact US regional air quality. We investigate air quality 50 years in the future (2045 – 2055) in the Pacific Northwest and the Northern Midwest. Second, how sensitive is predicted air quality to uncertainties in modeling future climate scenarios. Through various input scenarios we investigate how climate, landuse and emission changes impact the modeled regional air quality. This three-year large-scale modeling project has just begun. In this paper we emphasize on the overall approach that will be implemented for this study.

2. MODELING SYSTEM

The impact of global change is multi-scaled thus the modeling system is comprised of nested regional scale models with global scale models. The global models predict the general trends of climate change while regional models refine the changes and reflect the effects on regional air quality.

In this work we employ two global scale models. They are the NCAR/DOE Parallel Climate Model (PCM) (Washington et al., 2000), and the NCAR MOZART-2 (Model for OZone and Related chemical Tracers version 2) chemical transport model (Horowitz et al., 2003).

The PCM simulates the global atmospheric circulation and temperature. It is coupled with modules for land, ocean and sea ice to form an earth system model for future climate scenario projections. In this application, we use the model with standard IPCC greenhouse emission projections for "business as usual" scenario (case A2 (IPCC 2000)) to establish the global climate for current years (1990 – 2000) as a baseline, and 50 years into the future (2045 – 2055).

The MOZART-2 global chemistry model simulates the formation and transport of ozone

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and 57 other related pollutants in the global scale. It also models the long range transport of pollutants and tracers. The emissions inventory used here is based on the improved Emissions Database for Global Atmospheric Research (EDGAR: Olivier et al. 1996) and the Global Emissions Inventory Activity Data (GEIA). For future scenarios, an interpolated version of the emissions inventory is used based on suggested factors in the IPCC scenario. For meteorology, MOZART-2 uses the assimilated parameters and PCM outputs.

Both PCM and MOZART-2 models are run with the T42 horizontal resolution (2.8^o latitude by 2.8^o longitude). The PCM has 18 sigma layers and outputs every 6-hour while MOZART-2 has 34 sigma layers and outputs every 3 hours.

The MM5 / SMOKE / CMAQ regional modeling system is used to refine the global scale model outputs to regional scale air quality. MM5 is the PSU/NCAR mesoscale model (Grell et al. 1994). SMOKE is an emissions modeling system that processes anthropogenic and biogenic emissions (www.cmascenter.org). CMAQ is the EPA multi-scale regional photochemical model (Byun et al., 1999). Together they serve as a regional modeling system that predicts the formation and transport of urban air pollutants (ozone and aerosols).

To translate global climate change to effects on regional scale air quality, results from the global models are coupled with regional scale models. The PCM provides boundary condition for the MM5 regional meteorological model, while MOZART-2 provides time-dependent chemical boundary conditions for the CMAQ regional air quality model. In order to further resolve urban scale air quality changes, the regional simulations are nested down from 36 km US continental scale to 12 km and 4 km urban scales for the two areas of interest. Higher resolution is necessary to resolve the complex flow pattern of the regions and allow a more detailed analysis of the pollutant exposure levels in the areas (Figure1).

Figure 2 shows the model system flow chart of coupled global models with the regional modeling system. Output from PCM is first fed to MOZART-2 for global chemistry simulations. Results from both PCM and MOZART-2 are then post-processed before feeding into the regional models. The results provide time

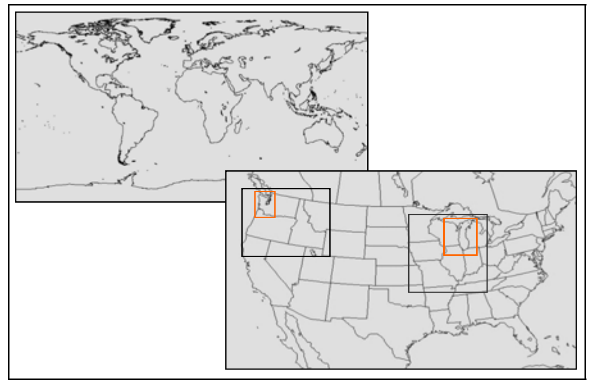

Figure 1: Top: Global model domain at T48 horizontal resolution. Bottom: Regional model domains showing the 36km parent domain and the two 12km and 4km nested domains.

stepping boundary conditions for CMAQ and MM5 at 36 km simulation. For 12 km and 4 km nested simulations, CMAQ and MM5 use results from the next larger domain to provide initial condition and boundary condition for the inner domain simulation.

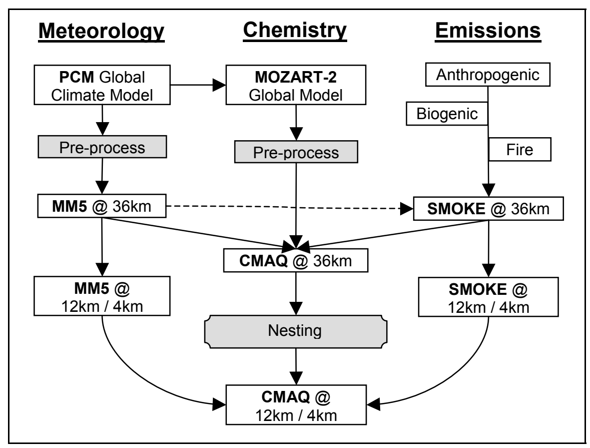

Figure 2: General model data flow chart for both base year simulation (1990 – 2000) and future year simulations (2045 – 2055).

3. EMISSIONS INVENTORY

Three emission categories are included in the regional scale simulations: anthropogenic, biogenic, and fire emissions. These inventories cover the simulation domains with the respective grid resolutions. The SMOKE model is used only to process anthropogenic emissions and to combine all emission types into one uniform file for CMAQ. Fire and biogenic emissions are processed separately outside the SMOKE model framework.

3.1 Anthropogenic Emissions

For base year simulation, the US continental anthropogenic emissions inventory is based on the National Emissions Trend 1999 (NEI99) dataset from EPA (http://www.epa.gov/air/data/neidb.html). The inventory contains area, point and mobile sources for all States. Emissions were in countywide, annual averaged values. 36 km gridding surrogates are used to allocate the emissions into each simulation domain. Additional 12 km and 4 km gridding surrogates are used to generate higher resolution gridded emissions for nested domains. Various hourly emission allocation profiles are used to create final hourly emissions.

For future year emissions, the base case emissions inventory are projected using emission growth factors from EPA's the Economic Growth Analysis System (EGAS) (http://www.epa.gov/ttn/chief/emch/projection/egas40) and combinations of IPCC and other literature projections.

3.2 Biogenic Emissions

A new biogenic emissions model called the Model of Exchange of Gases between the Atmosphere and Nature (MEGAN) will be used to estimate biogenic emissions. MEGAN is a newly formulated biogenic emissions model incorporating recent advances in biogenic emission modeling methods (Guenther et al. 1999, Guenther et al., 2000). It estimates over 50 individual emission species and has additional features important for long term biogenic emission prediction. The model has improved methods for characterizing and processing land cover type and biomass density. It also accounts for emission controlling factor by environmental stresses such as drought, nutrients, stomata conductance, and long-term changes in growth environment.

One main uncertainty for future biogenic emission is estimating the future landuse change from changes in global climate. Landuse adjustments are made from the current BELD3 landuse dataset with the NCAR Dynamic Global Vegetation Model. The model adjusts vegetation distribution and density base on predicted climatology.

3.3 Fire Emissions

Fire emission is significant for air quality in terms of aerosol and ozone chemistry. A newly developed Stochastic Fire Scenario Builder (FSB) is used to estimate prescribed and wild land fire emissions for current and future scenarios. To predict fire emissions, fire occurrences are randomly located on the landscape based on projected fire probability distribution functions. The spatial and temporal extend of the fire and its emissions depend on the probably distribution function which is based on parameters such as modeled meteorology, predicted land use types, fire management practices and historical fire records.

For future fire emission estimates, the FSB takes into account of moisture regime changes and effects of vegetation changes in the MEGAN vegetative dynamics model to estimate fuel loading parameters. Furthermore, fire emission estimates can account for effects of various land and fire management practices for creating fire emission scenarios.

4. MODELING APPROACH

The first step in executing the model system is to setup a base case for comparison with future model simulations.

In this work, the base case contemporary period is established for year 1990 – 2000. This sets up a baseline air quality representing the current air quality status. Both global climate and chemistry models simulate the entire ten year period. This extended period simulation is desirable to account for inter-annual climatic variability. However simulation duration at the regional scale is constrained by the high computational cost in running CMAQ. We plan to complete 1 to 5 year CMAQ simulations at the 36 km scale and shorter periods at the smaller scales. For finer resolution nested domains, only selected periods of interest from the 36 km result are performed. The urban scale simulation period ranges from weeks to months. In the base case the results are compared against averaged observation data to verify that the model system predicts in the correct pollutant concentration range.

Future year simulation follows the same modeling strategy as the base case contemporary period. The target future period is 2040 – 2050. The results from the future year simulation are then compared with the base case simulation.

Besides the one future year comparison, several additional simulations are performed to determine the sensitivity of predicted air quality to uncertainties in modeling future climate scenarios. These sensitivity scenarios include changes to PCM, MOZART-2 input emissions, changes in projected anthropogenic emissions, changes in future fire emission due to land management practices and changes to future biogenic emissions due to vegetation and landuse variations.

5. SUMMARY

This paper outlines a numerical modeling approach to investigate the US regional air quality from the impacts of global climate change. The method couples the global climate model (NCAR/DOE PCM) and global chemistry model (NCAR MOZART-2) with the regional air quality modeling system (MM5 / SMOKE / CMAQ). The global models predict the general trends of global climate change while regional models refine the changes and reflect the effects on local air quality. To better resolve urban scale air quality, the CMAQ model is nested down from 36 km US continental scale to 12 km and 4 km urban scale domains centered over the Pacific Northwest and the Northern Midwest.

To investigate changes in future air quality, the modeling program will simulate a base case contemporary period, 1990 – 2000, and a future year period, 2045 – 2050. Emissions for both cases include anthropogenic emissions, fie emissions and biogenic emission. All emissions are adjusted for future growth and predicted climatic change.

Additional future year sensitivity simulations contain changes in various emission input scenarios. They include PCM, MOZART-2 input adjustments, fire emission changes due to changes in fire regimes and land managements, biogenic emissions changes due to changes in landuse and vegetation distribution, and anthropogenic emissions variations.

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