PARTICULATE MATTER PREDICTION AND SOURCE ATTRIBUTION FOR U.S. AIR QUALITY MANAGEMENT IN A CHANGING WORLD

Allocation: Illinois/550 Knh

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EXECUTIVE SUMMARY

This project looks into the changing climate and its impact on U.S. air quality, with a special focus on fine particulate matter and ozone, projecting their trends and quantifying key source attribution. We are using a state-of-the-science dynamic prediction system that couples a global climate–chemical transport model with regional climate and air-quality models over North America, to determine individual and combined impacts of global climate and emissions changes on U.S. air quality. These include uncertainty evaluations, from the present to 2050, under multiple climate and emission scenarios. The results from the global and regional model simulations for the past are evaluated with observational data to assess the capabilities of the model simulation and impacts of emissions change, climate change, and long-range transport on future U.S. air pollution.

RESEARCH CHALLENGE

The objectives of this study are to better understand how global changes in climate and emissions will affect U.S. air quality, focusing on particulate matter and ozone, to project their future trends, and quantify key source attributions. Thus, we aim to provide actionable information for U.S. environmental planners and decision makers to design effective dynamic management strategies, including local controls, domestic regulations, and international policies, to sustain air quality improvements in a changing world. We are applying a state-of-the-science dynamic prediction system that couples global climate–chemical transport models with regional climate and air-quality models over North America to determine the individual and combined impacts of global climate and emissions changes on U.S. air quality from the present to 2050 under multiple scenarios. The aim is to quantify pollution sources and assign their attribution—natural vs. anthropogenic emissions, national versus international agents, natural variations versus climate changes—with associated probability and uncertainty.

We are conducting three primary experiments using the dynamic prediction system: (1) historical simulations for the period of 1990–2015 to establish the credibility of the system and refine process-level understanding of U.S. regional air quality; (2) projections for the period of 2030–2060 to quantify individual and combined impacts of global climate and emissions changes under multiple scenarios; and (3) sensitivity analyses to determine future changes in pollution sources and their relative contributions from anthropogenic and natural emissions, long-range pollutant transport, and climate-change effects. The advanced state of the prediction system will produce more complete scientific understanding of the challenges from global climate and emissions changes imposed on U.S. air quality management and a more reliable projection of future pollution sources and attribution changes.

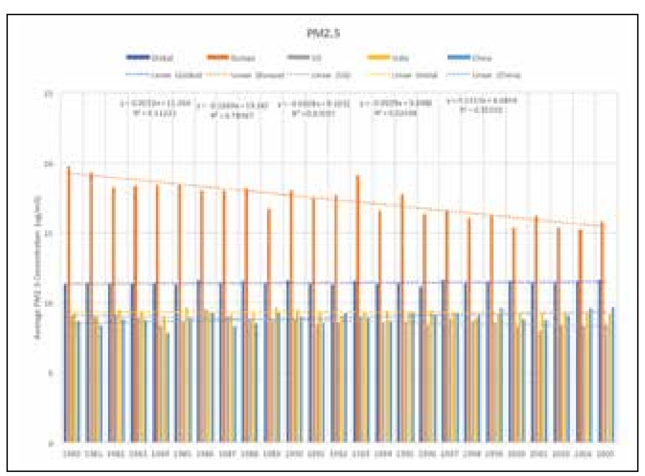

Figure 1: Annual average $PM_{2.5}$ concentration globally and in the United States, Europe, India, and China.

METHODS & CODES

The proposed research uses a state-of-the-science approach for advancing quantitative knowledge of the impacts of global changes in climate and emissions on U.S. air quality. The Global Climate Chemistry Transport model (GCCT) integrates global climate change with long-range pollutant transport that links worldwide natural and anthropogenic source emissions, while providing lateral boundary conditions that drive the Regional Climate–Air Quality model (RCAQ) for regional climate and air-quality prediction.

We used CESM1.2 (Community Earth System Model) default emissions, which represent surface emissions of ~30 species of aerosols. The surface emission of each species is composed of all possible sources of emissions, including those from biomass burning, domestic sources, transportation, waste treatment, ships, industry, fossil fuels, and biofuels, and were composed from POET, REAS, GFEDv2, and FINN emissions databases [1,2]. The results from the runs done in the current allocation have been presented in scientific conferences (e.g., Sanyal, et al., at the American Geophysical Union Annual meeting in December 2017).

The Blue Waters allocation supports the coupling and testing of the regional CWRF–CMAQ modeling system at NCSA. Historical runs (1990–2016) of U.S. air quality have been driven by the ECWMF ERI reanalysis and finished to test the model performance and the trends of U.S. air quality in the past decades. Runs for future periods are now in process.

RESULTS & IMPACT

The CESM model simulation was used to look into long-term Particulate Matter (PM) $PM_{2.5}$ concentration globally from 1980–2005. Fig. 1 shows the annual average $PM_{2.5}$ concentration, globally as well as in different regions such as the continental United States, Europe, India, and China. The $PM_{2.5}$ concentration shows a decreasing trend globally and in the continental United States, Europe, and India whereas it shows an increasing trend in China.

To evaluate the model performance at simulating the major air pollutants, especially ozone and $PM_{2.5}$, we used EPA AQS ozone measurements and $PM_{2.5}$ measurements from IMPROVE and CASTNET networks to evaluate the results (Fig. 2). The ozone comparison shows that CMAQ can capture the distribution of ozone pollution in the United States. The CWRF–CMAQ modeling system has substantial underestimations in urban and suburban areas, such as the central valley in California. For the $PM_{2.5}$ pollution, both comparisons of CMAQ simulations and IMPROVE/CASTNET measurements suggest that the CWRF–CMAQ modeling system can successfully capture the $PM_{2.5}$ pollution pattern, while some isolated sites have substantial discrepancies. This shows the capability of the dynamic CWRF–CMAQ system. We will extend the simulation period of CMAQ to 25 years (1990–2015) next year.

We hypothesize that the integration of the most advanced modeling system, most updated emissions treatment, multiscale processes representation, and various climate-emission scenarios assessment will improve the predictive capability of the model. This should result in more reliable projection of future likely changes in $PM_{2.5}$, O_3 and related pollutants as well as their global and regional sources. We will make a major contribution to a key goal of the U.S. Environmental Protection Agency's Strategic Plan to address climate change. The advanced state-of-the-prediction system will produce more complete scientific understanding of the challenges from global climate and emissions changes imposed on U.S. air quality management and a more reliable projection of future pollution sources and attribution changes. The outcome will provide actionable information for U.S. regional and state agencies to design effective strategies to meet the air-quality standards and achieve sustainability in a changing world. Climate change will affect air quality. Policymakers need to understand what these effects are so they can plan for such effects in their management of air quality. These studies will guide policymakers in how to respond to climate change as they sort out air-quality management goals for the future.

WHY BLUE WATERS

The computational demand of high-resolution climate models used in this project is very extensive. In addition, we are using a fully coupled model of the Earth's climate system with interactive chemistry, which is also computationally expensive even when not run at high resolution. Blue Waters, with its petascale computational facility, large number of nodes, and storage capability for the output from the high-resolution model simulation, is essential for our project. Blue Waters' staff have been critical at figuring out the various issues arising with the long-term fully coupled climate chemistry runs with CESM. The staff have helped figure out and resolve various issues with the CESM1.2.2 models. Blue Waters has given us the computational resource, data management, and support staff to perform our research.

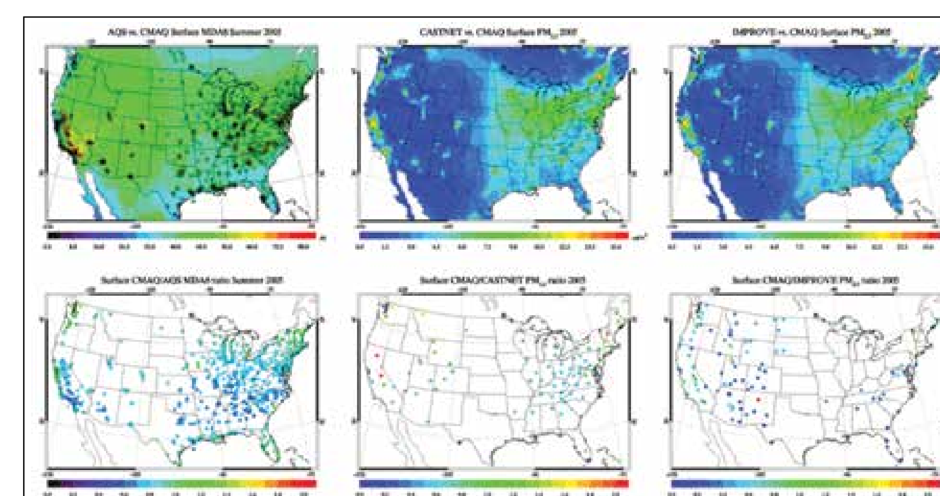

Figure 2: Comparison of EPA Air Quality Standards observations and Community Multiscale Air Quality (CMAQ) simulations. Ozone values are from summer JJA MDA8 and $PM_{2.5}$ measurements are the annual mean. Dots show AQS/CASTNET/IMPROVE observations and background shows CMAQ results (upper panel). Lower panel shows the ratio of observations to CMAQ results.