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

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EXECUTIVE SUMMARY

The objectives of this study are to better understand how global changes in climate and emissions will affect pollution in the United States, focusing on particulate matter and ozone, to project their future trends, and to quantify key source attributions. We are using a state-of-the-science dynamic prediction system that couples a global climate–chemical transport model with regional climate-air quality models over North America to determine individual and combined impacts of global climate and emissions changes on air quality, with uncertainty estimate, from the present to 2050 under multiple scenarios. We are doing the long-term global climate chemistry runs using Community Earth System Model CESM1.2.2 with fully coupled chemistry using CAM5-chem at 0.9° x 1.25° horizontal resolution, then comparing the results with observational data to evaluate the model simulation.

RESEARCH CHALLENGE

Our goal is 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, quantifing pollution sources and assigning their attribution—natural vs. anthropogenic emissions, national vs. international agents, natural variations vs. climate changes—with associated probability and uncertainty. We are developing a timeline for the global change factors to become significant such that effective actions can be taken. The level of significance is defined following the cross-state air pollution rule as one percent of nonattainment areas with the goal of bringing all areas into attainment for the National Ambient Air Quality Standards. Our hypothesis is that the integration of the most advanced modeling system, most updated emissions treatment, multiscale processes representation, and a multi-climate–emission scenarios assessment will improve the predictive capability and result in more reliable projection of future changes in particulate matter, ozone, and related pollutants as well as their global and regional sources.

This research presents 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. RCAQ incorporates more complete physical representation (surface, precipitation, convection, cloud, aerosol, and radiation); comprehensive chemical mechanisms (e.g., secondary organic aerosols or SOAs); and detailed emissions treatment. Hence, it more realistically simulates interactions between surface and atmospheric processes at regional–local scales that in turn affect local air quality. This nested GCCT/RCAQ dynamic prediction system is being evaluated against observations, and subject to process-level understanding and source attribution of U.S. air quality episodes under present and future conditions.

METHODS & CODES

We are conducting three primary experiments using the dynamic prediction system: (1) historical simulations for period 1994–2013 to establish the credibility of the system and refine process-level understanding of U.S. regional air quality; (2) projections for the period 2041–2060 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.

We are also conducting a series of 20-year runs using CESM1.2 (CAM-chem5). We have completed short-term global CAM-chem simulations driven by NASA Modern-Era Retrospective analysis for Research and Applications (MERRA) reanalysis data at 0.9° x 1.25° horizontal. We used the FSTARTMAM7 component set, which uses seven modes to model aerosols, prescribed ocean and ice, and CAM5 physics with carbon and nitrogen in the Community Land Model (CLM). CAM5-chem has 160 species with 427 reactions, and has strict enforcement of the conservation of total (organic and inorganic) chlorine and total bromine under advection. The heterogeneous chemistry module has also been upgraded to reflect the underestimation of supercooled ternary solution and surface area density, in addition to an improved aerosol treatment and inclusion of aerosol–cloud interactions, with extensive tropospheric and stratospheric chemistry. It has 30 vertical levels with model top at about 40 km. The dust emission is calibrated in the model so that global dust aerosol optical depth is between 0.025 and 0.030, and the system couples tropospheric aerosol to chemistry through heterogeneous chemistry. In this run, we used CESM1.2 default emissions, which represent surface emissions of approximately 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].

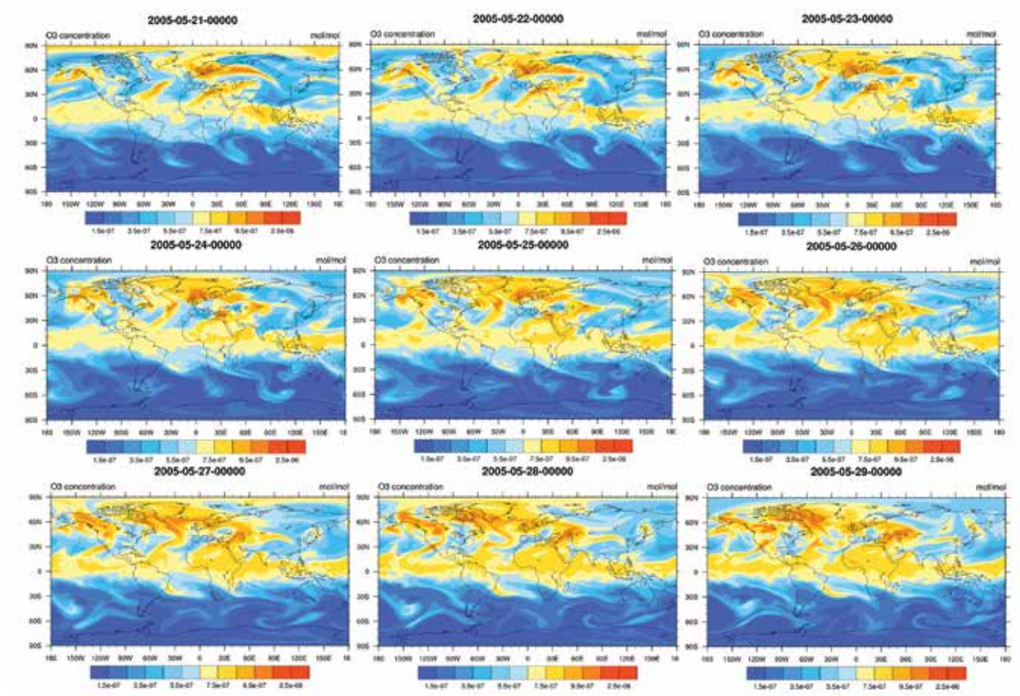

Figure 1: Evolution of daily ozone concentration for six consecutive days in May 2005 from Cam5-chem global simulation.

RESULTS & IMPACT

We did short-term global CAM-chem simulations driven by MERRA reanalysis data at 0.9° x 1.25° horizontal resolution and FSTRATMAM7 component set. Fig. 1 shows the global O_3 concentration for May 2005. We will be doing a variety of additional modeling simulations and comparing the results. Previous studies have shown that trans-Pacific dust and aerosols contribute significantly to North American aerosol inflow [2], while export-related Chinese pollutants contributed 3–10% of annual mean sulfate concentration, 0.5-1.5% of ozone, and one or more day of noncompliance of ozone standards over many U.S. regions in 2006 [3]. We are in the process of investigating the long-range transport of pollutants from China to the United States.

WHY BLUE WATERS

The computational demand of the high-resolution climate model used in this project is extensive. We are using the fully coupled model of the Earth's climate system with chemistry, which is computationally expensive. Blue Waters, with its petascale computational facility, large number of nodes, storage capability for the output from the high-resolution model simulation, is essential for our project. Blue Waters staff have been critical in 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.