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EVOLVING AIR QUALITY UNDER THE CHANGING CLIMATE

Allocation: Illinois/589.958 Knh
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EXECUTIVE SUMMARY

This study investigates the effects of the changing twenty-first century climate on human health by evaluating projected effects on air quality exceedance events, focusing on particulate matter ($PM_{2.5}$) and ozone (O_3). The research team employed fully coupled global climate–chemistry modeling analyses using the Blue Waters system to simulate the historical and future time periods for multiple scenarios. The focus was on the United States, India, and China. The frequency of exceedance events increased in India for both scenarios and the resulting changes in climate, but the United States and China showed improvement in the lower-emissions scenario. The researchers also examined an ideal clean energy scenario, where mid-century fossil fuel emissions are reduced to zero. By eliminating the burning of fossil fuels, both $PM_{2.5}$ and O_3 concentrations reduce by 20% to 60% in high-pollution regions, greatly reducing future health risks.

RESEARCH CHALLENGE

Many studies have shown that projected climate change could affect air quality, but there is little known about the resulting effects on health. One way to look at health effects is to consider exceedances set by environmental policy for upper limits of exposure. The objectives of this study are to better understand how global changes in climate and emissions will affect air quality, focusing on particulate matter and ozone; to project their future trends; to quantify key source attributions; and thus provide actionable information for 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. The research team applied a state-of-the-science dynamic prediction system that couples global climate–chemical transport models to determine the individual and combined impacts of global climate and emissions changes from the present to 2050 under multiple scenarios.

The team has conducted three primary experiments using the dynamic prediction system: (1) historical simulations for the period 1990–2015 to establish the credibility of the system and refine the process-level understanding of U.S. regional air quality; (2) projections for the period 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 a more complete scientific understanding of the challenges from global climate and emissions changes imposed on air quality management and a more reliable projection of future pollution sources and attribution changes.

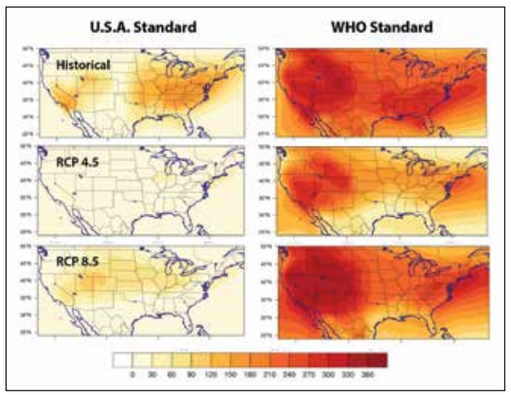

Figure 1: Total number of days annually when the 8-hour average ozone (O_3) level exceeds the U.S. standard of 70 parts per billion (ppb) (left column) and exceeds 50 ppb (WHO standard) (right column) over the continental United States. This is for 1991–2014 (first row) and for 2031–2060 with the low (second row) and the high (third row) scenarios.

METHODS & CODES

The 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 team used CESM1.2 default emissions, which represent surface emissions of approximately 30 species of speciated 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 the POET, REAS, GFEDv2, and FINN emissions databases [1,2]. The results from the runs done using the current allocation have been presented at scientific conferences.

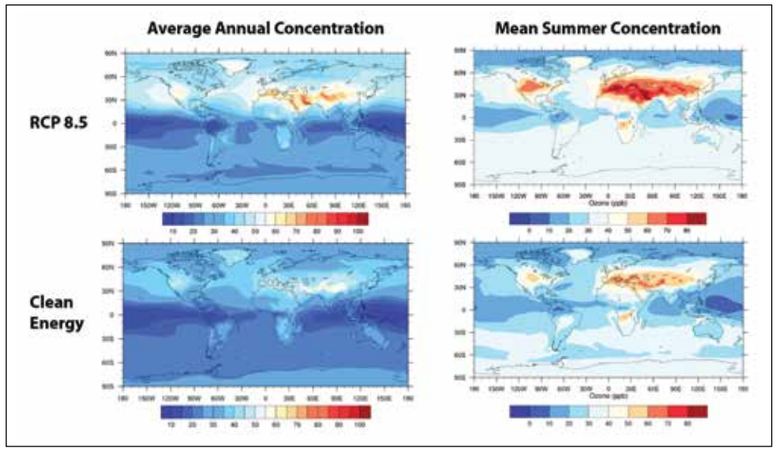

Figure 2: Annual average surface ozone concentration (2051–2060) (top panel) and summer average surface ozone concentration (bottom panel) for baseline scenario and the clean energy scenario (note the difference in the color scale).

RESULTS & IMPACT

The research team used the long-term climate chemistry runs done as a part of this project to examine exceedances for surface ozone and particulate matter concentration for two different climate projections using the lower emissions RCP4.5 and the higher emissions RCP8.5 scenarios. The results from two 30-year time periods in the future (2031–2060) were compared with the historical 25-year period (1990–2014). Cumulative distribution functions of surface ozone and particulate matter concentration and trend analysis of exceedance events annually and seasonally were analyzed over three major regions: the United States, India, and China as well as megacities within them. The results show that the frequency of exceedance events for ozone increases significantly at 90% confidence interval in India for both of the climate scenarios and in China for the high climate scenario, but decreases in the future in US especially western US and in China under RCP4.5 scenario. Along with the overall increase in ozone exceedance events, the study also showed a significant shift in seasonality of the events, with the number of episodes increasing during colder months, although ozone has primarily been considered as a summer problem. Unlike ozone, particulate matter concentration showed a significant increasing trend in all the regions in the future, with an overall increase in the number of particulate matter exceedance events annually.

As a part of the project, the research team also looked at a clean energy scenario and its impact on air quality in the mid-century. In this hypothetical scenario, emissions owing to fossil fuel are reduced to zero from 2050 in order to study the impact of a non-fossil-fuel-based energy system. The study showed a significant reduction in concentration of both ozone and particulate matter in all the current global hotspots, with a reduction of 20% to 60% in most high-pollution regions.

WHY BLUE WATERS

The computational demand of high-resolution climate models used in this project is extensive, particularly the fully coupled model of the Earth's climate system with chemistry. Blue Waters, with its petascale-class computational resources, large number of nodes, and storage capability for the output from high-resolution model simulations, was essential for the project. Blue Waters' staff have been critical in figuring out the various issues arising with the long-term, fully coupled climate chemistry runs using the Community Earth System Model (CESM). Staff members have also helped figure out and resolve various issues with the CESM1.2.2 models. In short, Blue Waters has given the team the computational resources, data management, and staff support to perform this research

PUBLICATIONS & DATA SETS

S. Sanyal, "Evolving air quality and impact of climate change," Ph.D dissertation, Dept. of Atmos. Sciences, University of Illinois at Urbana–Champaign, Urbana–Champaign, IL, U.S.A., 2019.

S. Sanyal *et al.*, "Impact of changing climate on surface ozone exceedance events," in preparation, 2019.

S. Sanyal *et al.*, "Impact of changing climate on particulate matter exceedance events," in preparation, 2019.

S. Sanyal *et al.*, "Impact of clean energy on air quality in the mid-century," in preparation, 2019.

S. Sanyal and D. J. Wuebbles, "Particulate matter and ozone prediction and source attribution for U.S. air quality management in a changing world," poster presented at the American Geophysical Union Fall 2018 Meeting; Washington, DC, U.S.A., Dec. 10–14.

S. Sanyal and D. J. Wuebbles, 'Particulate matter and ozone prediction and source attribution for U.S. air quality management in a changing world," poster presented at the Midwest Student Conference on Atmospheric Research, Urbana, IL, U.S.A., Oct. 27–28, 2018.