Simple, effective Earth-system modeling

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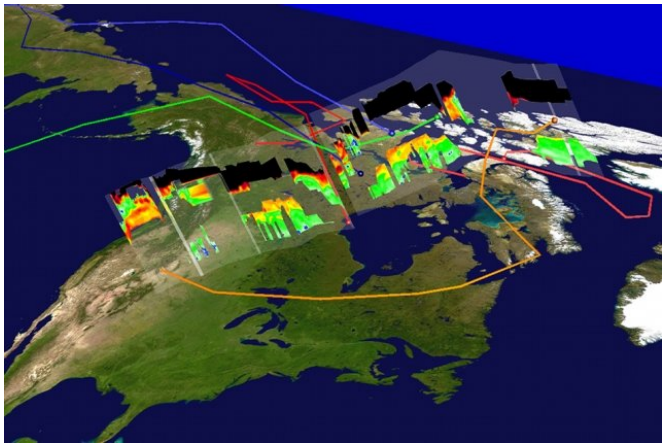

This graphic shows NASA studies of high springtime ozone levels over Canada and the Arctic. Credit: Kurt Severance/NASA Langley Research Center

To assess long-range risks to food, water, energy and other critical natural resources, decision-makers often rely on Earth-system models capable of producing reliable projections of regional and global environmental changes spanning decades.

A key component of such models is the representation of atmospheric chemistry. Atmospheric simulations utilizing state-of-the-art complex chemical mechanisms promise the most accurate simulations of atmospheric chemistry. Unfortunately their size, complexity, and computational requirements have tended to limit such simulations to short time periods and a small number of scenarios to account for uncertainty.

Now a team of researchers led by the MIT Joint Program on the Science and Policy of Global Change has devised a strategy to incorporate simplified chemical mechanisms in atmospheric simulations that can match the results produced by more complex mechanisms for most regions and time periods. If implemented in a three-dimensional Earth-system model, the new modeling strategy could enable scientists and decision-makers to perform low-cost, rapid atmospheric chemistry simulations that cover long time periods under a wide range of scenarios. This new capability could both improve scientists' understanding of atmospheric chemistry and provide decision-makers with a powerful risk assessment tool.

In a new study appearing in the European Geosciences Union journal Geoscientific Model Development, the research team conducted three 25-year simulations of tropospheric ozone chemistry using chemical mechanisms of different levels of complexity within the widely used CESM CAM-chem modeling framework, and compared their results to observations. They investigated conditions under which these simplified mechanisms matched the output of the most complex mechanism, as well as when they diverged. The researchers showed that, for most regions and time periods, differences in simulated ozone chemistry between these three mechanisms is smaller than the model-observation differences themselves. They found similar results for simulations of carbon monoxide and nitrous oxide.

"The most simplified mechanism that we tested, called Super-Fast, ran three times as fast as the most complex (MOZART-4) while largely producing the same results," says Benjamin Brown-Steiner, the study's lead author and a former postdoc at the MIT Joint Program and Department of Earth, Atmospheric and Planetary Sciences (EAPS). "This level of efficiency could, for instance, enable scientists to study an aspect of atmospheric chemistry over the course of the 21st century, running the simplified model for 100 years, and verifying its accuracy by running the complex model at the beginning, middle and end of the century."

Brown-Steiner and his collaborators also explored how the concurrent utilization of chemical mechanisms of different complexities can further our understanding of atmospheric chemistry at various scales. They determined that scientists could streamline atmospheric chemistry investigations by developing simulations that

include both complex and simplified chemical mechanisms. In such simulations, complex mechanisms would provide a more complete representation of complex atmospheric chemistry, and simple mechanisms would efficiently simulate longer time periods to better understand the roles of meteorological variability and other sources of uncertainty.

"By noting where results produced by simple and complex mechanisms diverge in particular regions, seasons or time periods, you can determine where and when simulations require more complex chemistry, and ramp up the modeling complexity as needed," Brown-Steiner says.

It's a modeling strategy that promises to enhance both scientists' understanding of the Earth's atmosphere and decision-makers' capability to assess environmental policies, the researchers say.

"Our study shows that more complex models are not always more useful for decision-making," says Noelle Selin, a co-author of the study, associate professor within MIT's Institute for Data, Systems and Society and EAPS, and Joint Program faculty affiliate. "Researchers need to think critically about whether simple and efficient approaches like this one can be equally informative at lower cost."

Finally, the study could lead to the inclusion of simplified atmospheric chemistry mechanisms in three-dimensional Earth-system modeling frameworks. This capability would help enable scientists and decision-makers to run long-term, large-ensemble (covering multiple scenarios to represent a range of uncertainty in key modeling parameters) 3-D simulations of the Earth's atmosphere within a reasonable period of clock-time.

"We currently represent ozone, sulfate aerosols, and other key contributors to radiative forcing in the Earth system in two-dimensional models that do not provide the level of accuracy we want," says Ronald Prinn, EAPS professor and Joint Program co-director, who is a co-author of the study.

"To that end we'd like to represent these in three-dimensional models and run ensembles [multiple scenarios], but once we put in a full 3-D chemical package, computer time becomes unaffordable," Prinn adds. "This study shows that for radiative forcing calculations, incorporating a fast chemical package in a modeling system can get credible agreement among simple and complex chemical mechanisms and observations."

More information: Benjamin Brown-Steiner et al. Evaluating Simplified Chemical Mechanisms within CESM Version 1.2 CAM-chem (CAM4): MOZART-4 vs. Reduced Hydrocarbon vs. Super-Fast Chemistry, *Geoscientific Model Development Discussions* (2018). DOI: 10.5194/gmd-2018-16