

# Increased warming in latest generation of climate models likely caused by clouds

June 24 2020

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As scientists work to determine why some of the latest climate models suggest the future could be warmer than previously thought, a new study indicates the reason is likely related to challenges simulating the formation and evolution of clouds.

The new research, published in *Science Advances*, gives an overview of 39 updated models that are part of a major international climate endeavor, the sixth phase of the Coupled Model Intercomparison Project (CMIP6). The models will also be analyzed for the upcoming sixth

assessment report of the Intergovernmental Panel on Climate Change (IPCC).

Compared with older models, a subset of these updated models has shown a higher sensitivity to carbon dioxide—that is, more warming for a given concentration of the greenhouse gas—though a few showed lower sensitivity as well. The end result is a greater range of model responses than any preceding generation of models, dating back to the early 1990s. If the models on the high end are correct and Earth is truly more sensitive to carbon dioxide than scientists had thought, the future could also be much warmer than previously projected. But it's also possible that the updates made to the models between the last intercomparison project and this one are causing or exposing errors in their results.

In the new paper, the authors sought to systematically compare the CMIP6 models with previous generations and to catalog the likely reasons for the expanded range of sensitivity.

"Many research groups have already published papers analyzing possible reasons why the climate sensitivity of their models changed when they were updated," said Gerald Meehl, a senior scientist at the National Center for Atmospheric Research (NCAR) and lead author of the new study. "Our goal was to look for any themes that were emerging, especially with the high-sensitivity models. The thing that came up again and again is that cloud feedbacks in general, and the interaction between clouds and tiny particles called aerosols in particular, seem to be contributing to higher sensitivity."

The research was funded in part by the National Science Foundation, which is NCAR's sponsor. Other supporters include the U.S. Department of Energy, the Helmholtz Society, and Deutsches Klima Rechen Zentrum (Germany's climate computing center).

## Evaluating model sensitivity

Researchers have traditionally evaluated climate model sensitivity using two different metrics. The first, which has been in use since the late 1970s, is called equilibrium climate sensitivity (ECS). It measures the [temperature increase](#) after atmospheric carbon dioxide is instantaneously doubled from preindustrial levels and the model is allowed to run until the climate stabilizes.

Through the decades, the range of ECS values has stayed remarkably consistent—somewhere around 1.5 to 4.5 degrees Celsius (2.7 to 8.1 degrees Fahrenheit) - even as models have become significantly more complex. For example, the models included in the previous phase of CMIP last decade, known as CMIP5, had ECS values ranging from 2.1 to 4.7 C (3.6 to 8.5 F).

The CMIP6 models, however, have a range from 1.8 to 5.6 C (3.2 to 10 F), widening the spread from CMIP5 on both the low and high ends. The NCAR-based Community Earth System Model, version 2 (CESM2) is one of the higher-sensitivity models, with an ECS value of 5.2 C.

Model developers have been busy picking their models apart during the last year to understand why ECS has changed. For many groups, the answers appear to come down to clouds and aerosols. Cloud processes unfold on very fine scales, which has made them challenging to accurately simulate in global-scale models in the past. In CMIP6, however, many modeling groups added more complex representations of these processes.

The new cloud capabilities in some models have produced better simulations in certain ways. The clouds in CESM2, for example, look more realistic when compared to observations. But clouds have a complicated relationship with climate warming—certain types of clouds

in some locations reflect more sunlight, cooling the surface, while others can have the opposite effect, trapping heat.

Aerosols, which can be emitted naturally from volcanoes and other sources as well as by human activity, also reflect sunlight and have a cooling effect. But they interact with clouds too, changing their formation and brightness and, therefore, their ability to heat or cool the surface.

Many modeling groups have determined that adding this new complexity into the latest version of their models is having an impact on ECS. Meehl said this isn't surprising.

"When you put more detail into the models, there are more degrees of freedom and more possible different outcomes," he said. "Earth system models today are quite complex, with many components interacting in ways that are sometimes unanticipated. When you run these models, you're going to get behaviors you wouldn't see in more simplified models."

## **An unmeasurable quantity**

ECS is meant to tell scientists something about how Earth will respond to increasing atmospheric carbon dioxide. The result, however, cannot be checked against the real world.

"ECS is an unmeasurable quantity," Meehl said. "It's a rudimentary metric, created when models were much simpler. It's still useful, but it isn't the only way to understand how much rising greenhouse gases will affect the climate."

One reason scientists continue to use ECS is because it allows them to compare current models to the earliest climate models. But researchers

have come up with other metrics for looking at climate sensitivity along the way, including a model's transient climate response (TCR). To measure that, modelers increase carbon dioxide by 1% a year, compounded, until [carbon dioxide](#) is doubled. While this measure is also idealized, it may give a more realistic view of temperature response, at least on the shorter-term horizon of the next several decades.

In the new paper, Meehl and his colleagues also compared how TCR has changed over time since its first use in the 1990s. The CMIP5 models had a TCR range of 1.1 to 2.5 C, while the range of the CMIP6 models only increased slightly, from 1.3 to 3.0 C. Overall, the change in average TCR warming was nearly imperceptible, from 1.8 to 2.0 C (3.2 to 3.6 F).

The change in TCR range is more modest than with ECS, which could mean that the CMIP6 models may not perform that differently from CMIP5 models when simulating temperature over the next several decades.

But even with the larger range of ECS, the average value of that metric "did not increase a huge amount," Meehl said, only rising from 3.2 to 3.7 C.

"The high end is higher but the low end is lower, so the average values haven't shifted too significantly," he said.

Meehl also noted that the increased range of ECS could have a positive effect on science by spurring more research into cloud processes and cloud-aerosol interactions, including field campaigns to collect better observations of how these interactions play out in the real world.

"Cloud-aerosol interactions are on the bleeding edge of our comprehension of how the [climate](#) system works, and it's a challenge to [model](#) what we don't understand," Meehl said. "These modelers are

pushing the boundaries of human understanding, and I am hopeful that this uncertainty will motivate new science."

**More information:** Context for interpreting equilibrium climate sensitivity and transient climate response from the CMIP6 Earth system models. *Science Advances* (2020). [DOI: 10.1126/sciadv.aba1981](https://doi.org/10.1126/sciadv.aba1981)

Provided by National Center for Atmospheric Research

Citation: Increased warming in latest generation of climate models likely caused by clouds (2020, June 24) retrieved 2 May 2024 from <https://phys.org/news/2020-06-latest-climate-clouds.html>

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