Heat waves, like one in Australia in January, will get worse in a warming world.

GLOBAL WARMING

New climate models forecast a warming surge

Scientists question whether stronger predicted response to greenhouse gases is realistic

By **Paul Voosen**

For nearly 40 years, the massive computer models used to simulate global climate have delivered a fairly consistent picture of how fast human carbon emissions might warm the world. But a host of global climate models developed for the United Nations's next major assessment of global warming, due in 2021, are now showing a puzzling but undeniable trend. They are running hotter than they have in the past. Soon the world could be, too.

In earlier models, doubling atmospheric carbon dioxide (CO_2) over preindustrial levels led models to predict somewhere between 2°C and 4.5°C of warming once the planet came into balance. But in at least eight of the next-generation models, produced by leading centers in the United States, the United Kingdom, Canada, and France, that "equilibrium climate sensitivity" has come in at 5°C or warmer. Modelers are struggling to identify which of their refinements explain this heightened sensitivity before the next assessment from the United Nations's Intergovernmental Panel on Climate Change (IPCC). But the trend "is definitely real. There's no question," says Reto Knutti, a climate scientist at ETH Zurich in Switzerland. "Is that realistic or not? At this point, we don't know."

That's an urgent question: If the results are to be believed, the world has even less time than was thought to limit warming to 1.5°C or 2°C above preindustrial levels—a threshold many see as too dangerous to cross. With atmospheric CO_2 already at 408 parts per million (ppm) and rising, up from preindustrial levels of 280 ppm, even previous scenarios suggested the world could warm 2°C within the next few decades. The new simulations are only now being discussed at meetings, and not all the numbers are in, so "it's a bit too early to get wound up," says John Fyfe, a climate scientist at the Canadian Centre for Climate Modelling and Analysis in Victoria, whose model is among those running much hotter than in the past. "But maybe we have to face a reality in the future that's more pessimistic than it was in the past."

Many scientists are skeptical, pointing out that past climate changes recorded in ice cores and elsewhere don't support the high climate sensitivity—nor does the pace of modern warming. The results so far are "not sufficient to convince me," says Kate Marvel, a climate scientist at NASA's Goddard Institute for Space Studies in New York City. In the effort to account for atmospheric components that are too small to directly simulate, like clouds, the new models could easily have strayed from reality, she says. "That's always going to be a bumpy road."

Builders of the new models agree. Scientists at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey—the birthplace of climate modeling—incorporated a host of improvements in their next-generation model. It mimics the ocean in fine enough detail to directly simulate eddies, honing its representation of heat-carrying currents like the Gulf Stream. Its rendering of the El Niño cycle, the periodic warming of the equatorial Pacific Ocean, looks "dead on," says Michael Winton, a GFDL oceanographer who helped lead the model's development. But for some reason, the world warms up faster with these improvements. Why? "We're kind of mystified," Winton says. Right now, he says, the model's equilibrium sensitivity looks to be 5°C.

Developers of another next-generation model, from the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, wonder whether their new rendering of clouds and aerosols might explain why it, too, is running hot, with a sensitivity in the low fives. The NCAR team, like other modelers, has had persistent problems in simulating the supercooled water found in clouds that form above the Southern Ocean around Antarctica. The clouds weren't reflective enough, allowing the region to absorb too much sunlight. The new version fixes that problem.

Late in the model's development cycle, however, the NCAR group incorporated an updated data set on emissions of aerosols, fine particles from industry and natural processes that can both reflect sunlight or goose the development of clouds. The aerosol data threw everything off—when the model simu-

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lated the climate of the 20th century, it now showed hardly any warming. "It took us about a year to work that out," says NCAR's Andrew Gettelman, who helped lead the development of the model. But the aerosols may play a role in the higher sensitivity that the modelers now see, perhaps by affecting the thickness and extent of low ocean clouds. "We're trying to understand if other [model developers] went through the same process," Gettelman says.

Answers may come from an ongoing exercise called the Coupled Model Intercomparison Project (CMIP), a precursor to each IPCC round. In it, modelers run a standard set of simulations, such as modeling the preindustrial climate and the effect of an abrupt quadrupling of atmospheric CO_2 levels, and compare notes. The sixth CMIP is now at least a year late. The first draft of the next IPCC report was due in early April, yet only a handful of teams had uploaded modeling runs of future projections, says Fyfe, an author of the report's projections chapter. "It's maddening, because it feels like writing a sci-fi story as the first-order draft."

The ambitious scope of this CMIP is one reason for the delay. Beyond running the standard five simulations, centers can perform 23 additional modeling experiments, targeting specific science questions, such as cloud feedbacks or short-term prediction. The CMIP teams have also been asked to document their computer code more rigorously than in the past, and to make their models compatible with new evaluation tools, says Veronika Eyring, a climate modeler at the German Aerospace Center in Wessling who is co-leading this CMIP round.

Such comparisons may help the modelers respond to the IPCC authors, who are peppering them with questions about the higher sensitivity, Gettelman says. "They're asking us, what's going on?" he says. "They're pushing people. They've got about a year to figure this out."

In assessing how fast climate may change, the next IPCC report probably won't lean as heavily on models as past reports did, says Thorsten Mauritsen, a climate scientist at Stockholm University and an IPCC author. It will look to other evidence as well, in particular a large study in preparation that will use ancient climates and observations of recent climate change to constrain sensitivity. IPCC is also not likely to give projections from all the models equal weight, Fyfe adds, instead weighing results by each model's credibility.

Even so, the model results remain disconcerting, Gettelman says. The planet is already warming faster than humans can cope with, after all. "The scary part is these models might be right," he says. "Because that would be pretty devastating." ■