

# How Hot Will The Greenhouse World Be



Scientists know that the world has warmed lately, and they believe humankind is behind most of that warming. But how far might we push the planet in coming decades and centuries? That depends on just how sensitively the climate system—air, oceans, ice, land, and life—responds to the greenhouse gases we're pumping into the atmosphere. For a quarter-century, expert opinion was vague about climate sensitivity. Experts allowed that climate might be quite touchy, warming sharply when shoved by one climate driver or another, such as the carbon dioxide from fossil fuel burning, volcanic debris, or dimming of the sun. On the other hand, the same experts conceded that climate might be relatively unresponsive, warming only modestly despite a hard push toward the warm side.

The problem with climate sensitivity is that you can't just go out and directly measure it. Sooner or later a climate model must enter the picture. Every model has its own sensitivity, but each is subject to all the uncertainties inherent in building a hugely simplified facsimile of the real-world climate system. As a result, climate scientists have long quoted the same vague range for sensitivity: A doubling of the greenhouse gas carbon dioxide, which is expected to occur this century, would eventually warm the world between a modest 1.5°C and a whopping 4.5°C. This range—based on just



**A harbinger?** Coffins being lined up during the record-breaking 2003 heat wave in Europe.

two early climate models—first appeared in 1979 and has been quoted by every major climate assessment since.

Researchers are finally beginning to tighten up the range of possible sensitivities, at least at one end. For one, the sensitivities of the available models (5% to 95% confidence range) are now falling within the canonical range of 1.5°C to 4.5°C; some had gone considerably beyond the high end. And the first try at a new approach—running a single model while varying a number of model parameters such as cloud behavior—has produced a sensitivity range of 2.4°C to 5.4°C with a most probable value of 3.2°C.

Models are only models, however. How much better if nature ran the experiment? Enter paleoclimatologists, who sort out how climate drivers such as greenhouse gases have

varied naturally in the distant past and how the climate system of the time responded. Nature, of course, has never run the perfect analog for the coming greenhouse warming. And estimating how much carbon dioxide concentrations fell during the depths of the last ice age or how much sunlight debris from the eruption of Mount Pinatubo in the Philippines blocked will always have lingering uncertainties. But paleoclimate estimates of climate sensitivity generally fall in the canonical range, with a best estimate in the region of 3°C.

The lower end of at least of likely climate sensitivity does seem to be firming up; it's not likely below 1.5°C, say researchers. That would rule out the negligible warmings proposed by some greenhouse contrarians. But climate sensitivity calculations still put a fuzzy boundary on the high end. Studies drawing on the past century's observed climate change plus estimates of natural and anthropogenic climate drivers yield up to 30% probabilities of sensitivities above 4.5°C, ranging as high as 9°C. The latest study that varies model parameters allows sensitivities up to 11°C, with the authors contending that they can't yet say what the chances of such extremes are. Others are pointing to times of extreme warmth in the geologic past that climate models fail to replicate, suggesting that there's a dangerous element to the climate system that the models do not yet contain.

Climate researchers have their work cut out for them. They must inject a better understanding of clouds and aerosols—the biggest sources of uncertainty—into their modeling. Ten or 15 years ago, scientists said that would take 10 or 15 years; there's no sign of it happening anytime soon. They must increase the fidelity of models, a realistic goal given the continued acceleration of affordable computing power. And they must retrieve more and better records of past climate changes and their drivers. Meanwhile, unless a rapid shift away from fossil fuel use occurs worldwide, a doubling of carbon dioxide—and more—will be inevitable.

—RICHARD A. KERR

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