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Global warming

Homing in on a key factor of climate change

The sensitivity of Earth's climate to atmospheric carbon dioxide levels is a big unknown in predicting future global warming. A compelling analysis suggests that we can rule out high estimates of this sensitivity. See Letter p.XXX

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The quantity known as equilibrium climate sensitivity is crucial for understanding Earth's future temperature[1] and ongoing uncertainty about its value elevates the risks of long-term climate change[2]. This key parameter enumerates the increase of Earth's average surface temperature that would occur if atmospheric carbon dioxide levels were doubled and the *climate* system was given enough time to reach an equilibrium state. More than 150 estimates of equilibrium climate sensitivity have been published[3], many of which suggest worryingly high sensitivities are possible — including one that was published in *Nature* just a few weeks ago[4]. On page XXX, Cox *et al.*[5] use an ingenious approach to rule out high estimates. If correct, this would improve the chances of achieving internationally agreed targets for minimizing global warming.

The measurements of many different properties, such as the height of Everest or the speed of light, have often been refined. This has helped bring certainty to science and thereby driven progress. But equilibrium climate sensitivity (ECS) has not capitulated to these scientific norms and remains stubbornly uncertain. It has also become something of a focus for those who doubt the robustness of climate science. Despite the huge progress in our understanding *of climate science* over the past 40 years, the Intergovernmental Panel on Climate Change (IPCC) concluded in 2013 that there is a 66% likelihood of ECS being between 1.5°C and 4.5°C (ref. 1) — little different from the range first postulated[6] by the meteorologist Jule Charney in 1979.

Cox and colleagues' estimate is exciting because it develops an underexplored line of evidence: the natural variability of global temperature. The authors also provide the first convincing evidence that we are not living in a world in which ECS is greater than the range of values thought likely by the IPCC. This point is important, because estimates of ECS based on the historical temperature record have largely been unable to exclude high values that would invariably result in world-devastating warming of 4°C or more by 2100.

Past research that seemingly constrained the top end of ECS estimates to lower values often excluded major uncertainties, and/or worked from a prior estimate of ECS that was skewed to low values. The published ranges therefore depended on the researchers' assumptions about ECS, rather than the evidence. In contrast, Cox *et al.* started from climate-model values that are at the upper end of the IPCC range, and they used evidence to effectively rule out catastrophically high values: they estimate a 66% likelihood range of 2.2 to 3.4 °C, with only a 1% chance of ECS being larger than 4.5 °C.

The idea underpinning this work is so enviably simple to climate scientists that it will make them ask, "Why didn't I think of that?" The authors examined the variability of surface temperature in terms of its variance and autocorrelation — the 'memory' of a previous year’s surface temperature that is retained in measurements taken the following year. They developed a theoretically-derived metric of surface-temperature variability and evaluated this metric in historical simulations from 22 different Earth-system models, and ultimately found that the metric is a good predictor of the inherent ECS of each of the models.

Cox *et al*. then used this metric relationship found in models as a constraint on real-world ECS, finding that only climate models that produce relatively small values of ECS match the variability seen in the historic temperature record. It turns out that climate models generally have quite a lot of memory in their climate systems, so if one year is abnormally hot, for example, then the next year is also likely to be hot. The historic temperature record, however, does not seem to have as much system memory as most models. This means that some models have both autocorrelations and ECS values that look too high.

These new findings must be interpreted carefully. ECS is arguably the main factor that governs uncertainty in projected temperatures, but not the only factor. For example, Earth-system feedbacks such as the effects of permafrost melting are expected to increase warming. Climate models often exclude these feedbacks, reducing the amount of projected warming. In models that that have an ECS that is too high, such exclusions could potentially compensate for the effects of the inflated ECS value.

It is also crucial to examine other lines of evidence when assessing ECS. The best estimates of ECS that have been made by analysing Earth’s energy budget (the balance of the energy received by Earth from the Sun and that radiated back to space) are relatively low, at around 2 °C (ref. 7). But recent work[8] is helping us to understand why ECS inferred from energy budget changes over the last century are likely low, and shows that a higher value is more applicable when projecting future change. Applying such a correction to the original estimates brings their values very much in line with Cox and co-workers' estimate[9].

In contrast, analyses of present climate conditions produced by the models, particularly their cloud properties, show that models that best represent today's climate have ECS values greater than 3 °C. Indeed, one of the most recent of these analyses[3] showed that models with an ECS of around 4 °C were best at capturing today's climate across nine emergent constraints. In my view, Cox and colleagues' estimate and the estimates produced by analysing the historic energy budget carry the most weight, because they are based on simpler physical theories of *climate* forcing and response, and do not directly require the use of a climate model that correctly represents cloud. To resolve which estimates are most accurate, more research is needed to compare the different lines of evidence and to improve the representation of clouds in models.

I hope that a far more refined estimate of ECS can be made from the different lines of evidence by the time of the next IPCC assessment in 2021. If the upper limit of ECS can truly be constrained to a lower value than is currently thought, then the risk of very high surface-temperature changes occurring in the future decreases. This in turn would increase the chances of keeping the temperature increase well below 2°C, the target of the Paris Agreement under the United Nations Framework Convention on Climate Change. So, rather than be jealous, I should thank Cox and colleagues for helping me sleep a little easier in my bed at night.

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