Between a cloud and a hot place

Low climate sensitivity has been ruled out, but the door remains open for alarmingly high estimates. Improved understanding of cloud feedbacks is vital for better constraining the upper limit of future warming.

Credit: Petra Schramböhmer

Ever since it was discovered that carbon dioxide generated by human activities could warm the Earth, there has been one obvious question — by how much? This has proven remarkably difficult to answer. In 1979, a group of scientists led by Jule Charney estimated that doubling atmospheric carbon dioxide would raise the global temperature by 1.5 °C to 4.5 °C before a new equilibrium is reached[1]. This quantity became known as the equilibrium climate sensitivity (ECS), and tightening its range has become one of the most enduring challenges in climate science. In particular, understanding the plausibility of higher-end ECS estimates is crucial, as they could make achieving global targets on limiting future warming extremely challenging[2]. A study in this issue of *Nature Geoscience* suggests that a worryingly high sensitivity is plausible due to the nonlinear response of clouds. Better understanding of how clouds may evolve with warming is therefore crucial for determining the extent of future temperature change.

The difficulty in estimating climate sensitivity arises from the uncertain ways in which different components of the climate system respond to warming, which result in feedbacks that act to amplify or dampen the overall temperature change. Uncertainties in climate feedbacks have consistently hampered efforts to quantify ECS. As a result, the wide range outlined in the Charney report has persisted unchanged right up to the most recent assessment by the Intergovernmental Panel on Climate Change in 2013[3]. But, through combining evidence from modern observations, global climate models, and insights from the distant past, recent work has finally narrowed the range, suggesting there is a 66% chance that ECS lies between 2.6 °C and 4.1 °C (ref. [4]).

It has become clear that a climate sensitivity below 2 °C is extremely unlikely based on observations of how much warming has already occurred since pre-industrial times[4]. This is further supported by our current understanding of individual feedback mechanisms, such as changes in atmospheric water vapour and surface albedo, which act to amplify warming[5]. High-end estimates of climate sensitivity are less well constrained. Though ECS is likely to be below 4.1 °C, substantially higher values are still plausible. Many of the latest global climate models exhibit high climate sensitivities, with 10 out of 27 models having an ECS over 4.5 °C (ref. [6]). Uncertainty therefore persists regarding the plausible upper limit.

Cloud processes are responsible for much of the remaining uncertainty. Clouds occur in every shape and size, each with their own intricacies, and all affect the Earth's radiative balance. Their formation is influenced by processes spanning the microphysical to the climate scale, making precise modelling a huge challenge. Cloud properties, such as brightness, are expected to change with warming, driving radiative feedbacks that can amplify or dampen the temperature response[7]. Radiative feedbacks associated with clouds are the most poorly constrained, but satellite observations and global climate models suggest they are unlikely to have a net cooling effect[8]. Current cloud feedbacks may also change significantly in a future warmer climate, which further exacerbates the associated uncertainty.

Storelvmo et al. suggest that when a certain temperature is reached, clouds will no longer contain ice, and this affects feedbacks associated with cloud optical properties. As a result, the net global cloud feedback is enhanced in a warmer world, and climate sensitivity increases. Evolving patterns of warming over the oceans are also likely to alter the strength of cloud feedbacks[9]. Uncertainty over the extent to which cloud feedbacks may change with warming is currently the main limiting factor in providing a more confident upper bound on ECS.

Tightening the constraints on climate sensitivity is crucial for designing and implementing effective mitigation and adaptation strategies. To narrow the range, we must quantify the extent to which nonlinear cloud feedbacks could amplify the global temperature response to carbon dioxide. Long-awaited progress in reducing ECS uncertainty is now being made, but there is still work to be done while the magnitude of future warming remains hidden by the clouds. ❐

Published online: 29 October 2020
https://doi.org/10.1038/s41561-020-00658-0

References

1. Charney, J. G. et al. *Carbon Dioxide and Climate: A Scientific Assessment* (National Academy of Sciences, 1979); https://www.bnl.gov/envsci/schwartz/charney_report1979.pdf.
2. Schneider, T. et al. *Nat. Clim. Change* **7**, 3–5 (2017).
3. IPCC *Climate Change 2013 – The Physical Science Basis* (eds Stocker, T. F. et al.) (Cambridge Univ. Press, 2014).
4. Sherwood, S. C. et al. *Rev. Geophys.* **58**, e2019RG000678 (2020).
5. Dessler, A. E. *J. Clim.* **26**, 333–342 (2013).
6. Zelinka, M. D. et al. *Geophys. Res. Lett.* **47**, e2019GL085782 (2020).
7. Zelinka, M. D., Zhou, C. & Klein, S. A. *Geophys. Res. Lett.* **43**, 9259–9269 (2016).
8. Dessler, A. E. *Science* **330**, 1523–1527 (2010).
9. Zhou, C., Zelinka, M. D. & Klein, S. A. *Nat. Geosci.* **9**, 871–874 (2016).