https://doi.org/10.1038/s41561-024-01460-y

Clouds and climate

Cloud uncertainties have been a persistent problem in climate science, but innovative approaches are starting to make headway.

Clouds greatly affect the heat budget of our planet, and consequently, its climate. We regularly experience their influence first-hand, for instance when a dark cloud shields us from the Sun on a warm day. Determining precisely how a cloud impacts thermal radiation is a complex task and depends on many different cloud characteristics, including size, location, and optical depth. Quantifying the response of these characteristics to warming is currently one of the biggest obstacles to accurately constraining the sensitivity of surface temperature to greenhouse gas emissions[1]. This month's issue features three studies exploring the radiative effects of clouds using observations, storylines, machine learning, and high-resolution modelling. These studies demonstrate how innovative methods and multiple approaches are bringing long-awaited progress on the toughest questions in climate science.

As the climate warms in response to rising greenhouse gases, various aspects of the climate system respond and induce radiative feedbacks that can either amplify or dampen the overall temperature response. The cloud feedback is the least well constrained[1], with substantial uncertainties persisting despite considerable efforts. The difficulty arises from the complexity of the processes that govern cloud formation, which span from the microphysical scale to global-scale circulation. Accurate representation of clouds in climate models is challenging, with most global models lacking sufficient resolution to explicitly resolve convection — a process fundamental to the formation of many clouds. In addition, distinct physical processes are responsible for different types of cloud. Therefore, the total cloud feedback comprises many different cloud feedbacks, each requiring quantification.

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Previous work has indicated that tropical deep convective clouds — known as anvil clouds because of their shape — may have a dampening effect on warming, but the feedback remains highly uncertain[1]. An Article by McKim et al. and an Article by Sokol et al. examine the radiative feedbacks of tropical anvil clouds. McKim et al. use a storyline[2] approach whereby they construct physically consistent arguments to assess the plausibility of a particular feedback value. They use this approach to constrain the radiative effects of changes in the spatial extent of anvil clouds with warming — known as the cloud area feedback. Based on satellite observations, they show that the current radiative effects of anvil clouds are small, and therefore a very large change in cloud area would be required for the cloud area feedback to become significant. Based on these arguments, they conclude that the cloud area feedback is unlikely to have much of an effect on warming.

Another potential feedback arises from changes in the amount of ice suspended within anvil clouds, thereby altering their opacity. Sokol et al. use an ensemble of high-resolution atmospheric model simulations to show that warming drives a reduction in optically thick anvil clouds, and thus an overall reduction in the reflection of incoming solar radiation. Taken together, the work of McKim et al. and Sokol et al. suggests a dampening effect on warming from tropical anvil cloud area and opacity feedbacks is implausible. In turn, this implies a greater climate sensitivity to radiative forcing.

Constraining future warming is also hampered by large uncertainties in the interactions between clouds and atmospheric aerosols[3], which act as cloud condensation nuclei. These interactions make it hard to precisely pin down the magnitude of aerosol-induced radiative forcing over the historical period[3]. In their Article, Chen et al. tackle this problem by using a machine learning method to distinguish between volcanic aerosol effects and meteorological variability from observations of volcanic eruptions in Hawaii. They observe a strong enhancement of reflected sunlight in response to the aerosol emissions, mainly due to increased cloud cover. This suggests that total historical radiative forcing may be smaller than previously estimated, because aerosols have offset a larger portion of the radiative forcing by greenhouse gases. This provides a further indication that the sensitivity of surface temperature to radiative forcing is higher than previously thought.

Recent research, including the studies highlighted in this issue, make headway in one of the most uncertain areas of climate science. Continued progress will no doubt benefit from observations made available by new space missions, such as the European Space Agency's Earth Cloud Aerosol and Radiation Explorer (EarthCARE) satellite, which is due to launch this month, as highlighted in a session at this year's European Geosciences Union General Assembly. With valuable new observations at our fingertips, and an ever-increasing range of analytical techniques, there is great potential for making the progress in cloud science that is so crucial to accurate climate change prediction.

References

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