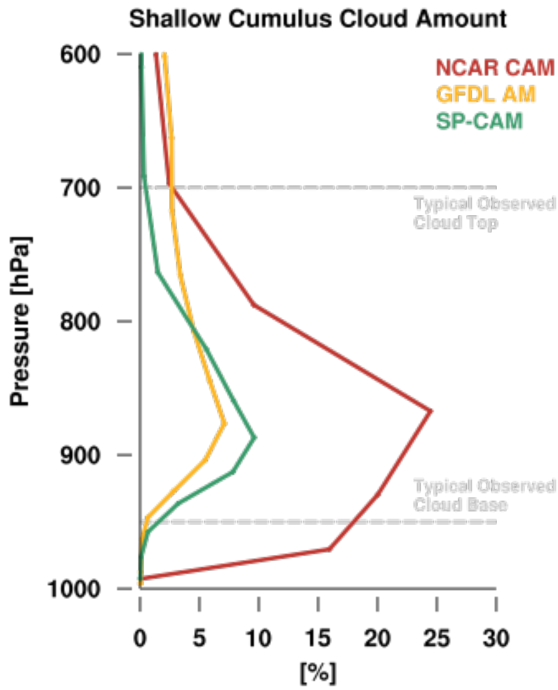
Low Clouds and Climate Change

Even when they produce the same environmental conditions, different climate models will produce different kinds of clouds. This result may help shed some light on a problem that has plagued climate modelers for the better part of three decades: that climate models produce very different changes in clouds for the same change in climate.

The basic result is not especially surprising, since the different climate models use different approaches to representing clouds. Clouds are much smaller than a typical climate model can resolve, so they have to be represented by sets of statistical rules, called parameterizations, that use the resolved environmental conditions to produce the unresolved clouds. It has long been appreciated by climate modelers that different parameterization choices can strongly impact the resulting climate, including the sensitivity of the simulated climate to changes (like increasing carbon dioxide). The Intergovernmental Panel on Climate Change has repeatedly listed cloud effects among the most pressing problems in climate projections.

Research conducted within the NSF Center for Multiscale Modeling of Atmospheric Processes (CMMAP), headquartered at Colorado State University, has shown that model estimates of climate change are particularly influenced by an innocuous sort of cloud typically found in the trade-wind regions of the tropics. These shallow cumulus clouds are quite small-- a couple kilometers in diameter and height -- but they are the dominant cloud type over much of the tropical oceans, making their cumulative impact on the modeled climate system overwhelming. Different models make more or less of these clouds, and make them in slightly different forms (with higher or lower tops, or more or less horizontally extensive), which changes their overall impact on the climate system. More importantly, though, is that when the modeled climate is forced to change, these modest differences get exaggerated through very different cloud responses. Some models show a decrease in the area covered by these clouds while others show a modest increase, and this difference plays strongly in the magnitude of the climate change.

To help understand how the cloud changes can be so different, CMMAP researchers have analyzed several climate models focusing on these clouds. Instead of searching the model data for shallow cumulus clouds, they applied a set of selection criteria to find environmental conditions where shallow cumulus clouds would be expected. In this way, observational and model data can be sampled in similar ways, potentially providing a means of model evaluation as well. The results show that all the models considered produce the environmental conditions conducive to shallow cumulus, with small differences in frequency of occurrence compared with observations. The clouds produced within these conditions, however, showed an unrealistic diversity across the models. The model that produced the most realistic depiction of the clouds was the prototype developed by CMMAP scientists at CSU that replaces traditional parameterizations with a high resolution cloud model (SP-CAM in the Figure). Even that model can not resolve such small clouds, but is able to capture more realistic structure in this regime.



The profile of cloud amount from three models (colors) through about the lowest 4 km of the atmosphere. The profiles are conditioned on environmental conditions conducive to shallow cumulus convection. The SP-CAM (green) shows the most realistic profile considering cloud base, cloud top, and the shape and size of the profile.

Credit Brian Medeiros

Since all the models produce more or less realistic conditions for these clouds to form, but the clouds themselves are different, this points to the parameterizations of clouds as the main factor leading to the different cloud statistics. Improvements in the realism of shallow cumulus clouds in climate models are a necessary step toward more confident estimates of climate change. This work was led by Brian Medeiros and Bjorn Stevens (University of California, Los Angeles) and Christopher Bretherton (University of Washington).