

## New Tools for Quantifying Cloud Response to Varying Climate States

Clouds play a central role in Earth's climate because they regulate both the amount of sunlight reaching the Earth and the amount of infrared radiation the Earth emits to space. But the climatic effect of clouds is an aggregate effect over a bewildering variety of cloud types, structures, and sizes. In principle the aggregated effect can be calculated on a cloud-by-cloud basis, by simulating all clouds in detail and then adding up their individual contributions. But such simulations are simply not feasible on a global scale, and in any case would not guarantee an improved understanding of cloud processes. An alternative approach is to look for ways in which the fine-scale properties of clouds are determined, at least approximately, by the bulk properties of the large-scale atmosphere. This approach has the advantage of focusing on cloud properties which are likely to be influenced by climate change and which may act to amplify or suppress the amount of warming caused by greenhouse gas increases.

The PIs (Tim Garrett and Steve Krueger) recently developed a theory in which the stratification of the large-scale atmosphere exerts a thermodynamic constraint on the fine-scale complexity of tropical convective clouds. The theory implies a relationship between the length of cloud perimeters and the stability of the atmosphere to overturning motions. The theory further implies that the number of clouds with a given perimeter length is inversely proportional to that perimeter length. The theory can be used to show that clouds of high convective potential energy are rarer than clouds of lower potential energy

Research under this award will test the theory's predictions regarding the perimeter and energy dependence of cloud occurrence using satellite observations and model simulations. Further research will address the extent to which the theory can be used to infer the number of clouds with a given horizontal area; this is important because cloud area has a direct connection to the climatic effects of clouds. Finally, the implications of the theory for changes in tropical convective clouds in response to climate change will be explored. Atmospheric stability is expected to increase in a warmer climate, and the relationship between stability and perimeter length suggests that warming will increase cloud number and total perimeter.

The project has societal relevance given concerns regarding the severity of climate change and its impacts on people and the environment. Clouds are perhaps the greatest source of uncertainty in efforts to determine the amount of warming produced by increases in greenhouse gas concentrations, and the relationships between fine-scale cloud properties and large-scale atmospheric conditions to be examined could help to reduce this uncertainty.