To Be or Not to Be Liquid? the Challenge of Arctic Mixed-Phase Cloud Modeling

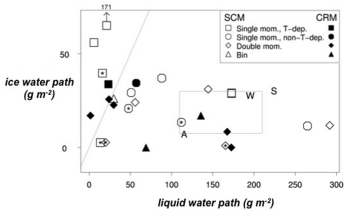
Research Highlight

Common experience is that if the temperature is lower than 0°C, then water will be in the form of ice instead of liquid. However, this is not true for the atmosphere, because many clouds with temperatures less than 0°C have super-cooled liquid in them. If these clouds also contain ice, they are called mixed-phase clouds. Because mixed-phase clouds are particularly common in the Arctic and because the Arctic is undergoing rapid climate change, it is important for climate models to be able to simulate mixed-phase clouds well, including the relative amounts of liquid and ice in them and the impact of these clouds on the surface radiation budget.

In this study, the ability of 17 single-column models and 9 cloud-resolving models to simulate Arctic mixed-phase clouds was tested using observations from the ARM 2004 Mixed-Phase Arctic Cloud Experiment (M-PACE) which was conducted at the ARM Climate Research Facility's North Slope of Alaska site. Two periods during the experiment were selected for analysis. The first period involved a single-layer boundary layer cloud formed under conditions of high pressure when the air in the atmosphere is sinking. The second involved multi-layer clouds formed under conditions of low pressure when the air in the atmosphere was rising. The models were subjected to the same observed boundary conditions and forcings allowing one to make a fair comparison of the models to the observations and each other. This collection of models is one of the widest ever assembled for this type of study and includes single-column models of the world's leading climate and weather prediction modeling centers.

Models simulated a wide variety of results with only a few models consistent with ARM observations. For the single layer cloud, models typically simulated less liquid than observed with the result that they underestimated the impact of the simulated cloud on the surface shortwave and longwave radiation budgets. Results for the multi-layer cloud tended to be opposite, with models generally overestimating the amount of liquid but underestimating the amount of ice. These contrasting results may point to the difficulties of simulating ice formation mechanisms that differ between single-layer and multi-layer clouds. The multi-layer cloud period also highlighted that cloud fraction can be a difficult variable for models to simulate correctly but is important to get the correct impact of clouds on the surface radiation budget.

A pessimist viewing these results might be discouraged by the generally poor performance of both the single-column and cloud-resolving models in simulating this case. However, an optimist would point out that there are some models that do a credible job of simulating the relative amounts of liquid and ice as well as other characteristics of these clouds. These models tend to have more detailed representation of cloud microphysics suggesting that improved representations of cloud microphysics can lead to improved simulations. Furthermore, the availability of high quality observations and broad participation of the modeling community in the intercomparison means that the simulation of Arctic mixed-phase clouds will join the list of important targets for climate modeling centers to improve with future cloud parameterization developments. It is expected that observations from the ARM 2008 Indirect and Semi-Direct Aerosol Campaign also will play a role in guiding improved climate model parameterizations of Arctic clouds.



Scatterplot of the liquid water path and ice water path from observations (letters) and model simulations (symbols) for the single boundary layer cloud observed during the 2004 ARM Mixed-Phase Arctic Cloud Experiment. The aircraft observations are depicted by the letter "A", whereas the ground-based radar-lidar retrievals of Matt Shupe with Dave Turner and Zhien Wang are depicted by the letters "S" and "W".

Reference(s)

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Working Group(s)

Cloud Modeling