Validation of Climate Model Ice Cloud Properties

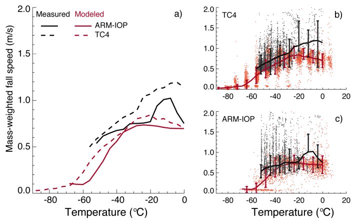
Research Highlight

General circulation models are used for understanding the past, present, and future climate. To be able to project future climate it is important that models provide a realistic depiction of the physical processes. Researchers at the National Center for Atmospheric Research (NCAR) have recently addressed how well properties of ice particles are represented in the Community Atmosphere Model Version 5 (CAM5). Ice particles in the atmosphere interact with shortwave and longwave radiation and are critical for Earth's energy balance. The concentration, sizes, and shapes of these particles are important because they impact how much radiation is scattered or absorbed. A key factor that controls the concentration of these ice particles in the atmosphere is how fast they fall from the cloud layer by gravity, which can be expressed by the terminal fall speed. The fall speed also impacts the height of ice clouds, which plays an important role in how they interact with radiation. Higher clouds trap more of the Earth's longwave radiation than lower level clouds. Thus, it is imperative to test models using observations of ice particle properties.

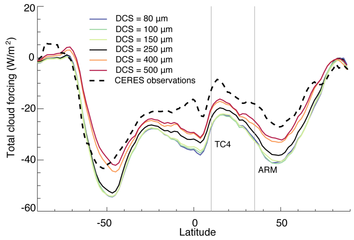
Cloud aircraft observations from two different field campaigns, the Tropical Composition, Cloud, and Climate Coupling (TC4) and Department of Energy Atmospheric Radiation Measurement Spring Cloud Intensive Operational Period in 2000 (ARM-IOP), were used to evaluate the ice particle properties in CAM5. Modeled ice cloud properties were compared with the observations by looking at the slope of the ice particle size distributions, the statistical moments of the distributions, and the mass weighed mean terminal fall speeds. Moments were obtained by integration over the size distributions, and different moments provide different pieces of information. For example, the third moment is proportional to the ice particle mass if the particles are assumed spherical (as in CAM5), while the zeroth moment is the particle number concentration. Combinations of the moments can give additional information. Focusing on several parameters is important because these quantities are closely inter-related. The unique aspect of this study was that several ice microphysical parameters were compared with the same quantities estimated from observations. This is important because it allows for an in-depth analysis of reasons for biases in key quantities like mass-weighted mean particle fall speed.

In most models, including CAM5, ice particles are grouped into two categories: cloud ice, which is smaller and denser, and snow, which is larger and less dense. In the model there is a critical size threshold—particles larger than this size are converted from the "cloud ice" to "snow" categories over a specified time scale. This is called autoconversion and represents the growth of small ice particles to larger ones through diffusion of water vapor, aggregation, and riming. However, there is not a solid physical basis for including cloud ice and snow as separate categories and the size threshold for autoconversion is not well constrained by theory or observations. Thus, a goal of the study was to test sensitivity of CAM5 to changes in this threshold size.

CAM5 generally overestimated the observed slope parameter of the size distribution for these cases, while the variation with temperature (or height) was similar. The model also overestimated the number concentration (zeroth moment of the size distribution) and underestimated higher moments, but compared well with observations for the first moment. Overall, the model showed best agreement with observations for TC4 (tropical anvil clouds) than for ARM-IOP (midlatitude frontal clouds) in regards to the moments. The mass-weighted mean terminal fall speed was lower in the model compared to observations for both ARM-IOP and TC4, which was partly due to the overestimation of the size distribution slope parameter. Interestingly, sensitivity tests with modification of the threshold size for autoconversion did not show any notable improvement in the moments, slope parameter, or mass weighed mean fall speed compared to observations. Moreover, while there was considerable sensitivity of the cloud radiative forcing to the threshold size for cloud ice to snow autoconversion, no particular value led to improvements compared to observations.



Mass weighted terminal fall speed. a) Measured and modeled Vm for ARM-IOP and TC4 for comparing fallspeeds between campaigns. b) and c) Mass weighted fall speeds for TC4 and ARM-IOP showing the individual measurements and model spread.



This figure shows the total radiative cloud forcing (longwave and shortwave) for different values of the threshold size for cloud ice to snow autoconversion (DCS). Dashed lines illustrate observed cloud radiative forcing from the NASA Clouds and the Earth's Radiant Energy System (CERES) project.

Since the autoconversion of cloud ice to snow using the threshold size has a limited physical basis, future improvements by combining cloud ice and snow into a single category and eliminating the need for autoconversion are suggested.

Reference(s)

Eidhammer T, H Morrison, A Bansemer, A Gettelman, and AJ Heymsfield. 2014. "Comparison of ice cloud properties simulated by the Community Atmosphere Model (CAM5) with in situ observations." Atmospheric Chemistry and Physics, 14(18), doi:10.5194/acp-14-10103-2014.

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Cloud Life Cycle