ARM M-PACE Data Used to Evaluate and Improve Arctic Mixed-Phase Clouds Simulated in Climate Models

Contributors
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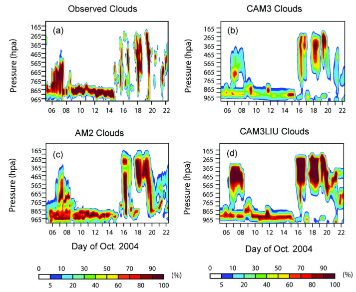
Research Highlight

Mixed-phase clouds dominate low-level Arctic clouds and have a significant impact on the surface energy budget in the Arctic through modulating radiative fluxes. However, the treatment of mixed-phase clouds in most current climate models is often oversimplified because the detailed microphysical processes involved in mixed-phase clouds are not completely understood due to the paucity of cloud observations, which is particularly true in the Arctic. To advance our understanding of the dynamical and physical processes in mixed-phase Arctic clouds, the DOE ARM Program conducted a major field campaign, the Mixed-Phase Arctic Cloud Experiment (M-PACE), in October 2004 at its North Slope of Alaska (NSA) site. Detailed in situ observations of Arctic clouds and their microphysical properties have been obtained by using various ground-based remote sensors and aircraft during M-PACE, which provides extremely valuable information to assess and improve model cloud parameterizations.

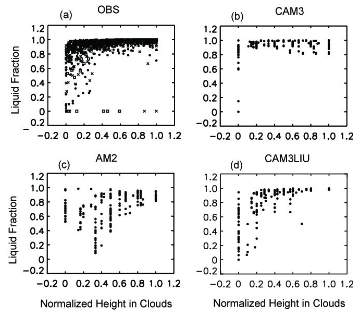
In this study, two major U.S. climate models, the National Center for Atmospheric Research (NCAR) Community Atmospheric Model version 3 (CAM3) and the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) climate model (AM2), are tested using a framework developed through a joint effort between the DOE's Climate Change Prediction Program (CCPP) and the ARM Program, called the CCPP-ARM Parameterization Testbed (CAPT), which allows running climate models in weather forecast mode so that climate models can be directly assessed using the ARM data. We attempt to reveal potential deficiencies related to the cloud and cloud microphysical schemes used in these two climate models by a direct comparison of model results with the in situ and remote sensing data from M-PACE. A new physically based cloud microphysical scheme also is tested in CAM3 to help understand how cloud microphysical processes affect the evolution and phase partitioning of the mixed-phase clouds. The sensitivity of the model results to initial data, model resolution, and cloud ice number concentration is discussed

It is shown that CAM3 significantly underestimates the observed boundary layer mixed-phase cloud fraction and cannot realistically simulate the variations of liquid water fraction with temperature and cloud height due to its oversimplified cloud microphysical scheme. In contrast, AM2 reasonably reproduces the observed boundary layer cloud fraction while its clouds contain much less cloud condensate than CAM3 and the observations. The simulation of the boundary layer mixed-phase clouds and their microphysical properties is improved considerably in CAM3 when a new physically based cloud microphysical scheme is used (CAM3LIU). The new scheme also leads to an improved simulation of the surface and top of the atmosphere longwave radiative fluxes.

Sensitivity tests show that these results are not sensitive to the analysis data used for model initialization. Increasing model horizontal resolution



Time-height cross sections of active remote sensing cloud layer (ARSCL) cloud frequency (a) and modeled cloud fraction (b) CAM3, (c) AM2, and (d) CAM3LIU at Barrow during M-PACE. The unit is %.



Liquid fraction as a function of cloud height. (a) UND citation data, (b) CAM3, (c) AM2, and (d) CAM3LIU. Different symbols in (a) represent data collected from different flights. Note that the cloud altitude in the figure is normalized from 0 at cloud base to 1 at cloud top.

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helps capture the subgrid-scale features in Arctic frontal clouds but does not help improve the simulation of the single-layer boundary layer clouds. AM2 simulated cloud fraction and liquid water path (LWP) are sensitive to the change in cloud ice number concentrations used in the Wegener-Bergeron-Findeisen process while CAM3LIU only shows moderate sensitivity in its cloud fields to this change. This paper shows that the Wegener-Bergeron-Findeisen process is important for these models to correctly simulate the observed features of mixed-phase clouds.

Reference(s)

Xie, S., J. Boyle, S. A. Klein, X. Liu, and S. Ghan (2008), Simulations of Arctic mixed-phase clouds in forecasts with CAM3 and AM2 for M-PACE, J. Geophys. Res., 113, D04211, doi:10.1029/2007JD009225.

Working Group(s)

Cloud Modeling