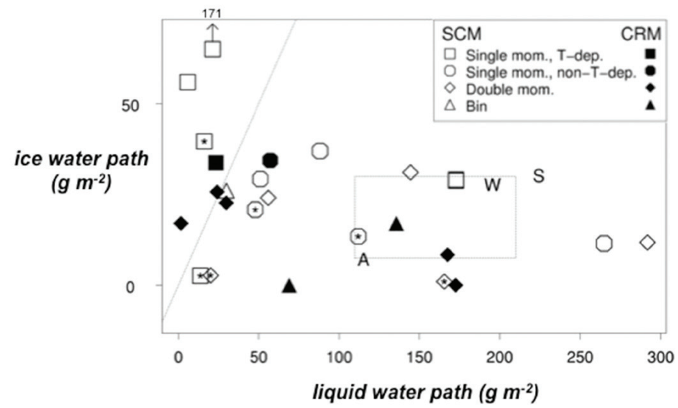
Research Highlights from the ARM Climate Research Facility

Scientists around the world use data from the ARM Climate Research Facility for their research. The following pages feature a selection of research highlights from 2009.

Challenges in Modeling Arctic Mixed-Phase Clouds

Clouds that contain both super-cooled liquid and ice are called mixed-phase clouds. Mixed-phase clouds are particularly common in the Arctic, which is undergoing rapid climate change. Therefore, it is important for climate models to simulate mixed-phase clouds well. Using observations from the Mixed-Phase Arctic Cloud Experiment (M-PACE), which was conducted at the ARM North Slope of Alaska site in 2004, researchers tested the ability of 17 single-column models and 9 cloud-resolving models to simulate Arctic mixed-phase clouds. This collection of models—one of the widest ever assembled for this type of study—included single-column models of the world's leading climate and weather prediction modeling centers. Simulation results varied widely, 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 on the surface energy budget. Conversely, the models generally overestimated the amount of liquid but underestimated the amount of ice in multi-layer clouds. 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 models have difficulty correctly simulating cloud fraction, which is an important variable for determining the correct impact of clouds on the surface energy budget. Models that do a credible job of simulating the relative amounts of liquid and ice as well as other characteristics of these clouds tend to have more detailed representation of cloud microphysics, suggesting that improved representations



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 M-PACE. Aircraft observations are depicted by the letter "A," whereas the ground-based radar-lidar retrievals are depicted by "S" and "W."

of cloud microphysics can lead to improved simulations. The high-quality observations and broad participation of the modeling community in this study points to the importance of Arctic mixed-phase clouds as a key target for climate modeling centers to improve with future cloud parameterization developments.

(References: Klein SA, RB McCoy, H Morrison, AS Ackerman, A Avramov, G de Boer, M Chen, JN Cole, AD Del Genio, M Falk, MJ Foster, A Fridlind, JC Golaz, T Hashino, JY Harrington, C Hoose, MF Khairoutdinov, VE Larson, X Liu, Y Luo, GM McFarquhar, S Menon, RA Neggers, S Park, MR Poellot, JM Schmidt, I Sednev, BJ Shipway, MD Shupe, DA Spangenberg, YC Sud, DD Turner, DE Veron, K von Salzen, GK Walker, Z Wang, AB Wolf, S Xie, KM Xu, F Yang, and G Zhang. 2009. "Intercomparison of model simulations of mixed-phase clouds observed during the ARM Mixed-Phase Arctic Cloud Experiment. Part I: Single layer cloud." *Q J ROY METEOR SOC*, 135(641): 979-1002, doi:10.1002/qj.416.

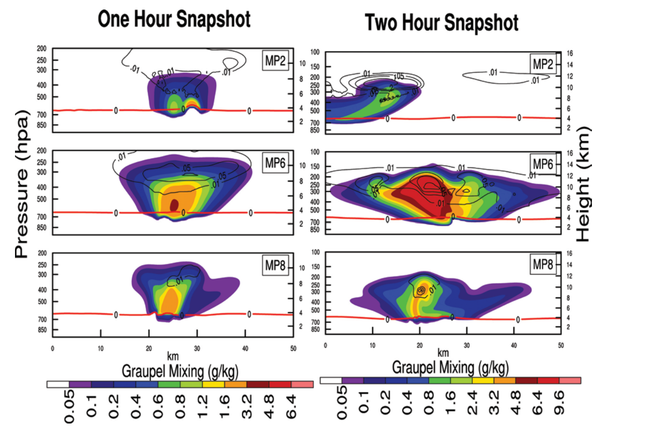
Morrison H, RB McCoy, SA Klein, S Xie, Y Luo, A Avramov, M Chen, JN Cole, M Falk, MJ Foster, AD Del Genio, JY Harrington, C Hoose, MF Khrairoutdinov, VE Larson, X Liu, GM McFarquhar, MR Poellot, K von Salzen, BJ Shipway, MD Shupe, YC Sud, DD Turner, DE Veron, GK Walker, Z Wang, AB Wolf, KM Xu, F Yang, and G Zhang. 2009. "Intercomparison of model simulations of mixed-phase clouds observed during the ARM Mixed-Phase Arctic Cloud Experiment, Part II: Multi-layered cloud." *Q J ROY METEOR SOC*, 135(641): 1003-1019, doi: 10.1002/qj.415.)

Implications for Ice-Phase Cloud Microphysics for Next-Generation Climate Models

As high-performance computing resources and technology advance, the next generation of climate models will run at much finer "cloud-permitting" resolutions. At such high spatial and temporal resolutions, the information gained from traditional single-column model performance may be invalid. Based on observations gathered during the Tropical Warm Pool International Cloud Experiment (TWP-ICE), conducted in Darwin, Australia, in 2006, this study conducted a suite of cloud-permitting evaluations for three sophisticated six-class, bulk cloud microphysics using the Weather Research and Forecasting (WRF) model. The systematical evaluation under this uniform platform of code and initial and lateral boundary conditions ensured that discrepancies in results were caused only by the different cloud parameterization and interactions with other physical parameterizations.

Preliminary evaluations using a simulated 2D idealized thunderstorm illustrated the wide discrepancy of the "ice-phase" cloud microphysics. The TWP-ICE simulations confirmed that the "ice-phase" parameterization of cloud microphysics contributes most to the wide discrepancy between models and observations. A set of model evaluations in which the interactions between cloud and radiation parameterizations were "turned off" further illustrated the potential influence of the cloud-radiation feedback. The findings highlight the importance of ice-phase cloud parameterization, while the interactions between cloud and radiation play a secondary role in contributing to the wide discrepancy. The study also illustrates that evaluations of cloud microphysical parameterizations are vitally important to the success of the next generation of climate models.

(Reference: Wang Y, CN Long, LR Leung, J Dudhia, SA McFarlane, JH Mather, SJ Ghan, and X Liu. 2009. "Evaluating regional cloud-permitting simulations of the WRF model for the Tropical Warm Pool International Cloud Experiment (TWP-ICE, Darwin, 2006)." *J GEOPHYS RES-ATMOS*, 114, D21203, doi:10.1029/2009JD012729.)



These one-hour and two-hour snapshots of mixing ratios for graupel (shades) and cloud ice (contours) from idealized thunderstorm experiments illustrate the wide discrepancy of the "ice-phase" cloud microphysics. The melting line is marked as a thicker, red line.

Seasonal Variation of the Physical Properties of Marine Boundary-Layer Clouds

Marine boundary-layer (MBL) clouds can significantly regulate the sensitivity of climate models, yet they are poorly simulated in current models. Using measurements from the ARM Mobile Facility while deployed at Point Reyes, California, in 2005, reanalysis products, and several independent satellite data sets, this study aimed to characterize the seasonal variations of physical properties of these clouds and their associated processes. Cloud properties included the MBL cloud-top and cloud-base heights, cloud thickness, the degree of decoupling between clouds and MBL, and inversion strength off the California coast. Data from the Point Reyes deployment were used to validate an algorithm for deriving cloud-top and inversion height from satellite measurements off the California coast.

The study showed that MBL clouds over the northeast subtropical Pacific were more prevalent and associated with a larger in-cloud water path in the summer than in winter; also, cloud-top and cloud-base heights were lower in the summer than in the winter. Although the lower-tropospheric stability of the atmosphere was higher in the summer, the MBL inversion strength was only slightly stronger in the summer because of a negative feedback from the cloud-top altitude. Summertime MBL clouds