ARM

CLIMATE RESEARCH FACILITY

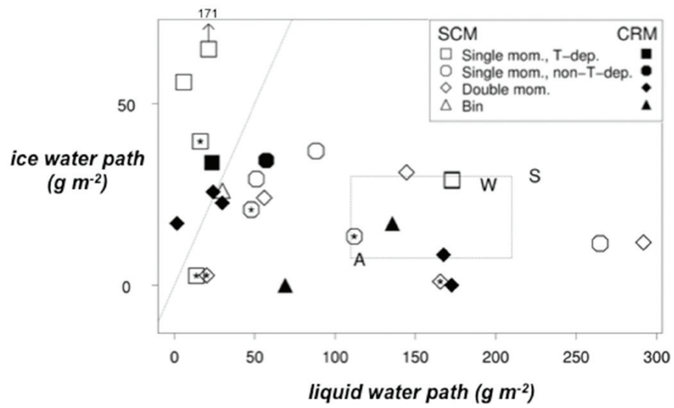
Research Highlights from the ARM Climate Research Facility

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 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.



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."

(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.

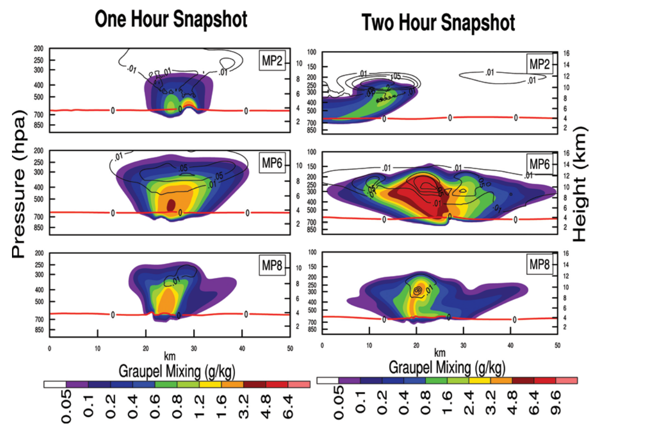
Morrison H, RB McCoy, SA Klein, S Xie, Y Luo, A Avramov, M Chen, JN Cole, M Falk, MJ Foster, AD Del Genio, JY Harrington, C Hoose, MF Khrairoutdinov, VE Larson, X Liu, GM McFarquhar, MR Poellot, K von Salzen, BJ Shipway, MD Shupe, YC Sud, DD Turner, DE Veron, GK Walker, Z Wang, AB Wolf, KM Xu, F Yang, 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.)

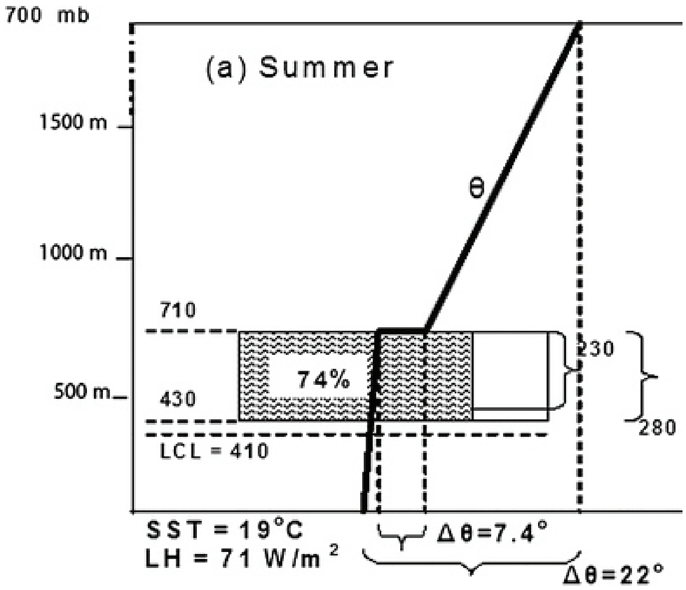


These one-hour and two-hour snapshots of mixing ratios for graupel (shades) and cloud ice (contours) from idealized thunderstorm experiments illustrate the wide discrepancy of the "ice-phase" cloud microphysics. The melting line is marked as a thicker, red line.

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



Marine boundary-layer clouds during summer off the California coast. Cloud amounts are shown in the shaded box, cloud-top and cloud-base heights and lifting condensation level (LCL) to the left, and cloud thickness and adiabatic liquid water thickness to the right of the cloud box.

were more homogeneous and associated with lower surface latent heat flux than those in the winter. Variations of low-cloud properties from summer to winter resembled the downstream stratocumulus-to-cumulus transition of MBL clouds in terms of depth, cloud-top and cloud-base heights, inversion strength, and spatial homogeneity. The observed variation of low clouds from summer to winter was attributed to the much larger seasonal cooling of the free-tropospheric air temperature than that of the sea surface temperature. These results provide a test case to understand and simulate MBL clouds in climate models.

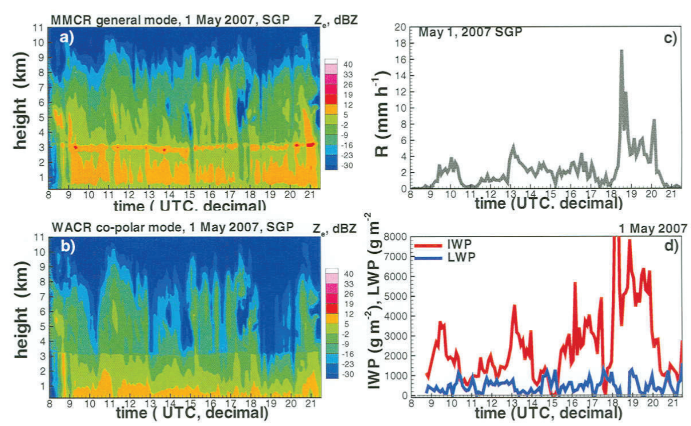
(Reference: Lin W, M Zhang, and NG Loeb. 2009. "Seasonal variation of the physical properties of marine boundary layer clouds off the California coast." *J CLIMATE*, 22(10), doi:10.1175/2008JCLI2478.1.)

Estimating Cloud and Rainfall Parameters in a Vertical Column

Comprehensive characterization both of ice and water particles, or hydrometeors, in an atmospheric column is crucial for model parameterization and validation purposes. Simultaneous retrievals of cloud systems producing significant rainfall are challenging because optical instruments do not penetrate far into precipitation and radar measurements are dominated by precipitation. This study demonstrated a non-traditional attenuation-based approach using the vertically pointing ARM 8-millimeter wavelength cloud radar (MMCR) and the 3-millimeter W-band ARM cloud radar (WACR). The two frequencies allow separation of the liquid cloud and rainfall components from the same volume. This approach was based on the wavelength differences of 8-millimeter and 3-millimeter radiation attenuations due to small and large drops.

Measurements of ice particles were retrieved based on the absolute MMCR measurements. These measurements were corrected for the combined attenuation effects in the liquid and mixed hydrometer layers using constraint measurements from the weather surface scanning precipitation radars operating at non-attenuating or weakly attenuating frequencies. Time series of the cloud liquid water path, ice water path, and the mean rainfall rate were retrieved for the vertical column above the ARM Southern Great Plains site's Central Facility. Rainfall estimates from the impact Joss-Waldvogel disdrometer, which is collocated with the ARM radars, were used to constrain retrievals and reduce the retrieval variability due to assumptions about drop-size distributions. These results will help researchers to better understand precipitation formation processes and provide data sets for model verifications.

(Reference: Matrosov SY. 2009. "A method to estimate vertically integrated amount of cloud ice and liquid and mean rain rate in stratiform precipitation from radar and auxiliary data." *J APPL METEOROL CLIMATOL*, 48, 1398-1410.)

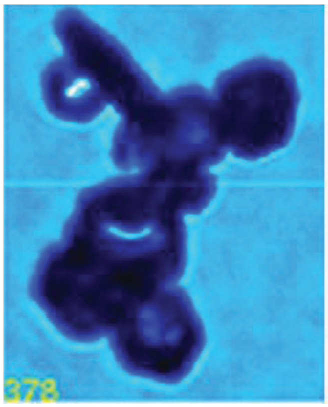


Panels (a) and (b) show measurements of a stratiform precipitating event by the MMCR and WACR, respectively, and the corresponding estimates of mean rain rate (c) and cloud ice water path and liquid water path (d).

Simulating Cirrus Sparkle

Clouds reflect sunlight away from the earth, which tends to cool the earth, but they also absorb energy from the ground, which has a warming effect. Determining how the reflection and absorption properties of clouds change in a warming climate is important for predicting future temperature increases. Understanding the role of cirrus clouds in this interplay has been limited by the inability of computer models to simulate the complex crystals of which they are made. Unlike the roughly spherical water droplets in other cloud types, cirrus clouds are composed of ice crystals that occur in five predominant shapes: bullet rosettes, columns, plates, aggregates, and irregular. As the crystals fall, they collide and combine, creating even more-complex aggregations of crystals. The complex crystal shapes scatter sunlight in many directions, affecting how much light ultimately strikes the ground or is reflected away. Models already exist for how the simpler shapes impact the light; climate scientists needed a model for the aggregates.

During the Tropical Warm Pool International Cloud Experiment in 2006, researchers used a high-flying aircraft to sample ice crystals from cirrus clouds, recording crystal images from which the different types and fractions of each type were identified. Then they created computer models of the aggregate crystals to more accurately calculate the scattering properties of ice clouds. Results indicated that aggregate ice crystals scatter less light in the forward direction and more to the sides or backward than the component crystals. Aggregates of plates make up a large portion of the ice crystals in the freshly generated outflows from convection. Because bulk scattering properties of cirrus are averaged over the shape and size distributions of the crystals, accounting for these differences will have a noticeable effect on models of cirrus clouds and the climate models that incorporate them. Researchers may also need to adjust their methods to take into account the variation of aggregation indices with geographic location and meteorological conditions.



On the left is an image from the aircraft observation of an ice crystal made of a collection of plates; on the right is a similar crystal as modeled by Um and McFarquhar (2009).

(Reference: Um J and GM McFarquhar. 2009. "Single-scattering properties of aggregates of plates." *Q J ROY METEOR SOC*, 135: 291-304.)

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