ARM CLIMATE RESEARCH FACILITY

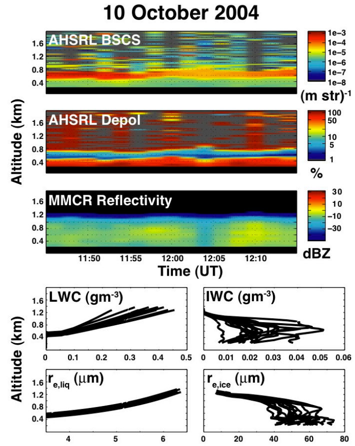
Mixed-Phase Cloud Radiative Properties from M-PACE Microphysical Retrievals

Research Highlight

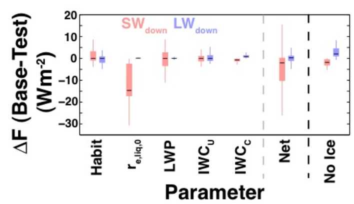
Mixed-phase stratiform clouds have been demonstrated to be a major contributor to the surface radiative budget of the Arctic. Measurements of these clouds and the associated surface radiative flux densities are expanding. In this work, we utilize a variety of cloud and atmospheric measurements to derive the macro- and microphysical properties of mixed-phase clouds observed during the 2004 Mixed-Phase Arctic Clouds Experiment (M-PACE) at the ARM North Slope of Alaska site. These cloud properties are assembled to drive a column radiative transfer model in order to calculate the influence of these clouds on the surface radiative budget. In addition, a sensitivity study is performed to evaluate the impact of various aspects of the implemented retrievals on the performance of these calculations. Cloud radiative forcing and its relationship to various cloud properties is derived for the M-PACE mixed-phase clouds.

A variety of mixed-phase clouds were observed, with mean liquid water paths ranging from 11 to 352 gm-2. The radiative flux densities calculated using the Global version of the Rapid Radiative Transfer Model (RRTMG) are compared to values derived from the quality controlled radiation products (QCRAD) for the North Slope of Alaska produced by ARM. These comparisons reveal general agreement between the modeled and observed flux densities, with most errors falling below 10 Wm-2. In order to assess the sensitivity of these estimates to retrieval error and missing measurements, 56 sensitivity experiments were completed. Retrievals were re-calculated modifying a series of different quantities, including the ice crystal habit assumed, the liquid droplet effective size at cloud base, the MWR-retrieved LWP, and the radar-derived IWC. With the exception of sensitivity associated with the liquid droplet effective radius, variability is generally less than 15 Wm-2 for individual parameters. Changes in assumed ice crystal habit appear to impact shortwave flux density estimates at a level comparable to changes in cloud LWP. Liquid droplet size has a larger impact, particularly on shortwave flux densities. In addition to these shortwave sensitivities, there are also some minimal impacts on longwave downwelling radiation. IWC has the smallest impact on the surface flux densities. Sensitivity to the leading coefficients (IWCC) previously presented in the literature for Z-IWC relationships (0.04 and 0.07) has minimal impact on the surface radiation. A more thorough retrieval uncertainty number of 75 % (IWCU) causes slightly larger deviations, but even those are small compared to those resulting from liquid water property uncertainties. Cloud radiative forcing for these clouds ranged between 0 and -50 Wm-2 in the shortwave and 59 to 86 Wm#2 in the longwave.

Surface radiative properties were estimated for mixed-phase cloud conditions observed during M-PACE using a combination of modern cloud remote sensors, current cloud measurements and retrievals, and an advanced radiative transfer model. Using profiles of cloud properties such as liquid and ice water paths, cloud heights, effective particle sizes, and temperature profiles to drive the radiative transfer model, a total of 16 mixed-phase cloud periods were evaluated, resulting in 154 two-minute mixed-phase cloud observations. This technique was demonstrated to generally agree well with surface radiometric estimates, with the magnitude of most errors falling below 10Wm-2. The information presented here is relevant to understanding the impact of clouds on a changing surface state. The radiative impacts of specific cloud types on the freezing and melting of sea ice, permafrost, and glaciers, for example, are just beginning to be explored. Results presented provide guidance on use of this technique for expanding our knowledge of mixed-phase cloud forcing at observational sites that have cloud remote sensors but lack or have limited radiometric instrumentation. Future work will focus on application of this method to larger data sets and exploration of the radiative impact of mixed-phase stratiform clouds on surface ice melting rates.



Measured and retrieved cloud properties on 10 October 2004. Included are (top to bottom) AHSRL bacscatter cross-section, AHSRL depolarization ratio, MMCR reflectivity, and profiles of liquid water content (LWC), ice water content (IWC), and liquid (r_{e,liq}) and ice (r$_{e,ice}$) effective particle sizes.



Distributions of differences between derived downwelling shortwave (red) and longwave (blue) flux densities from the sensitivity study. IWC_U represents the sensitivity to IWC retrieval uncertainty, while IWC_C (not included in net) represents the sensitivity to the coefficient used in the empirical relationship. The mean value is indicated by the black line in each distribution, the box indicates the IQR, and the whiskers represent 1.5xIQR beyond the 25th and 75th percentiles.

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Reference(s)

de Boer G, WD Collins, S Menon, and CN Long. 2011. "Using surface remote sensors to derive radiative characteristics of mixed-phase clouds: An example from M-PACE." Atmospheric Chemistry and Physics, 11, doi: 10.5194/acp-11-11937-2011.

Contributors

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Working Group(s)

Cloud Life Cycle