Microphysical Properties of Thin Clouds Retrieved from Ground-Based Infrared Observations

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Introduction

Both longwave and shortwave radiative fluxes are very sensitive to small changes in a cloud's integrated liquid water amount when the liquid water path (LWP) is below 100 g/m^2 (Figure 1, Turner et al. 2006). Therefore, to correctly model the radiative flux requires very accurate measurements of LWP when a cloud is optically thin. The primary ground-based instrument used by the Atmospheric Radiation Measurement (ARM) Program to provide LWP are microwave radiometers (MWRs) that observe the downwelling sky emission around the 22.2 GHz water vapor absorption line; however, the uncertainty in the retrieved LWP from these instruments is 25-30 g/m^2 (e.g., Marchand et al. 2003).

Various cloud properties, including LWP, can be retrieved from the ground-based Atmospheric Emitted Radiance Interferometer (AERI, Knuteson et al. 2004) radiance observations when the LWP is below 50 g/m^2 (Turner 2005, Turner and Holz 2005). By combining the AERI and MWR observations into an optimal estimation-based retrieval, we will demonstrate that the cloud LWP can be retrieved over the entire range of LWP and that retrievals of small LWP significantly more accurate.

Previous work has shown that the AERI-retrieved properties, for single phase (liquid-only or ice-only) are very accurate. However, when the precipitable water vapor is less than approximately 1 cm, the microphysical properties of mixed phase clouds can be retrieved from the AERI radiance observations (Turner 2005). Several cases from the ARM program's Mixed-Phase Arctic Cloud Experiment (M-PACE) are used to validate, for the first time, the AERI-retrieved optical depths of the ice and liquid phases from mixed-phase clouds.

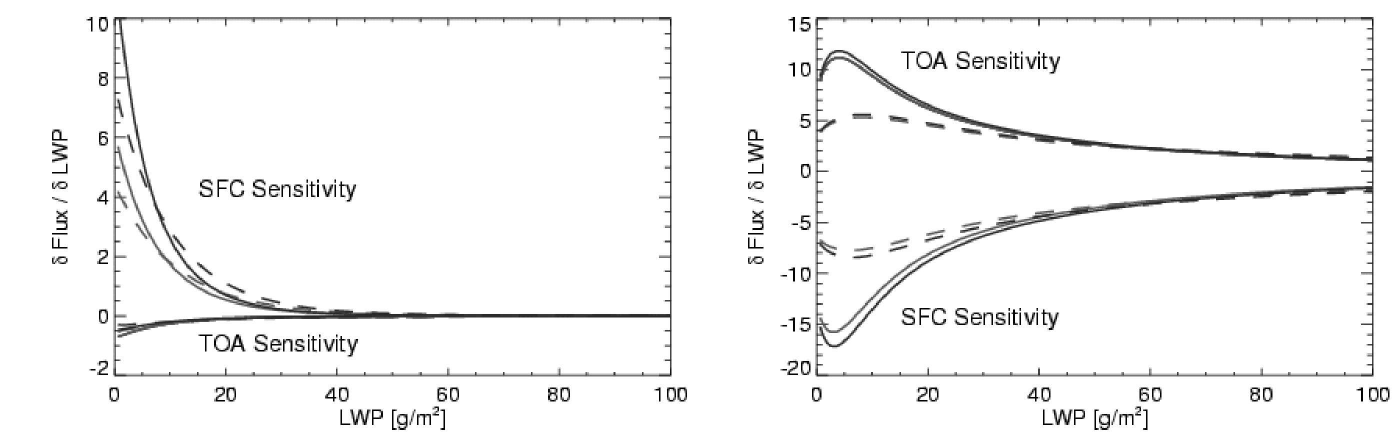

Figure 1. Sensitivity to top-of-the-atmosphere and surface longwave (left) and shortwave (right) radiative fluxes to LWP [W m^{-2}/(g m^{-2})] for different atmospheres and assumed cloud particle sizes. From Turner et al. 2006.

Combined AERI and MWR Retrievals of LWP

Infrared radiance is very sensitive to small amounts of liquid water in the atmospheric column, and thus complements the microwave observations nicely. The joint AERI + MWR retrieval uses the same infrared forward model as in Turner (2005); the microwave absorption model is the monoRTM (Clough et al. 2005). The assumed uncertainty in the MWR observations was 0.2 K. Figure 2 illustrates the differences between the AERI+MWR retrievals and the MWR-only retrievals for an overcast two-day period at Pt. Reyes, California, where the ARM Mobile Facility was deployed in the summer of 2005. The addition of the AERI data into the retrieval reduces the uncertainty in the LWP considerably. The AERI+MWR and MWR retrieved cloud properties were then used in a radiative transfer model to compute the downwelling shortwave diffuse flux; these calculations were then compared with observations from a shaded precision spectral pyranometer. The flux residuals for the AERI+MWR retrievals are much smaller than for the MWR-only retrievals, suggesting that the combined retrieval algorithm is more accurate.

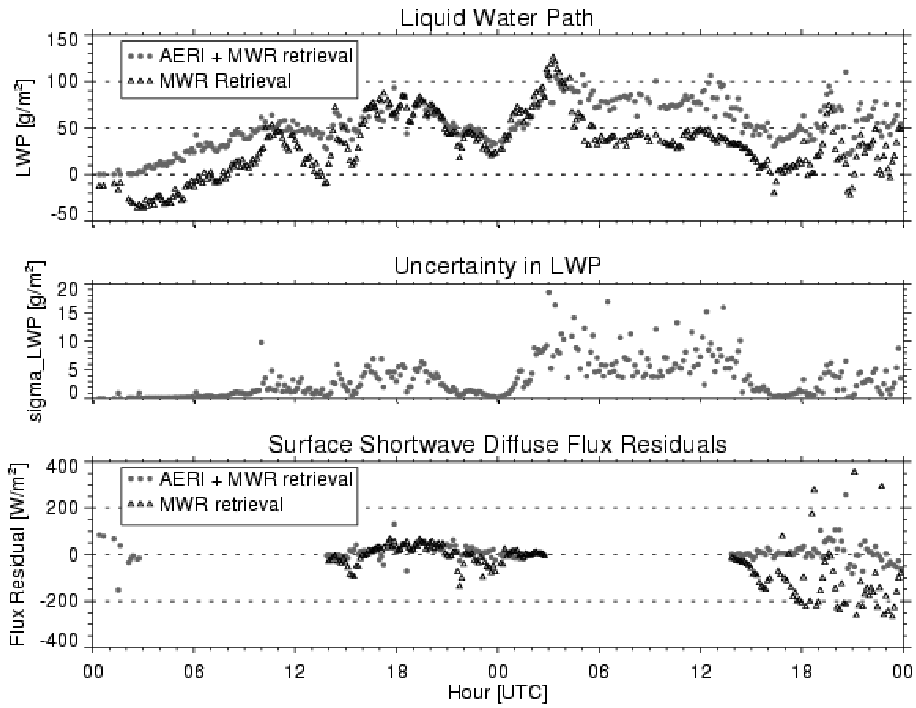

Figure 2. LWP from the AERI+MWR and MWR-only (top), the uncertainty in LWP from the AERI+MWR, and the differences in the observed minus calculated shortwave diffuse flux for 5-6 July 2005 at the Pt. Reyes site. See text for details.

Validation of AERI-Retrieved Mixed Phase Cloud Properties

The M-PACE experiment, which was conducted at the ARM North Slope of Alaska site in September and October 2004, provided an excellent opportunity to validate the mixed-phase AERI retrievals (Turner 2005). During M-PACE, the University of Wisconsin – Madison deployed its Arctic High-Spectral-Resolution Lidar (AHSRL), which provides accurate height-resolved extinction measurements in clouds. Using the depolarization ratio measured by the AHSRL, the liquid and ice optical depths mixed-phase scenes were computed, and these optical depths were compared with the independently retrieved liquid and ice optical depths from the AERI observations. An example from 1 November is provided in Figure 3. Qualitatively, the AERI-retrieved optical depths and the AHSRL measurements agree quite well. As the liquid optical depth gets larger (approaches 3), the AERI retrieval algorithm is unable to separate the two phases completely, and thus the liquid optical depth is slightly underestimated and the ice optical depth is slightly overestimated. However, the AHSRL is also reaching its maximum optical depth limit at approximately 3, which could affect the accuracy of the separation of optical depth into liquid and ice components. The AERI retrievals in this comparison did not include the MWR observations (e.g., Section 2), and thus the inclusion of these additional observations may help understand this issue.

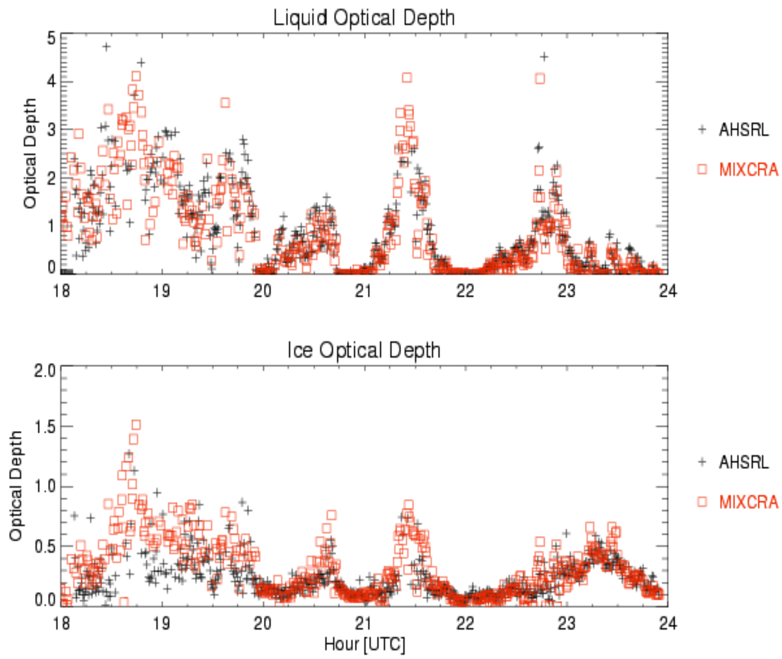

Figure 3. Comparison of the AERI-retrieved liquid optical depth (top) and ice optical depth (bottom) with the AHSRL of a mixed-phase cloud at the North Slope of Alaska site on 1 Nov 2004.

Acknowledgments

This research was funded by the U.S. Department of Energy's Office of Science as part of the ARM Program. The ARM Program collected the data used in this analysis.

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References

Clough, S.A., M.W. Shephard, E.J. Mlawer, J.S. Delamere, M.J. Iacono, K. Cady-Pereira, S. Boukabara, and P.D. Brown. 2005. "Atmospheric radiative transfer modeling: A summary of the AER codes." *Journal of Quantitative Spectroscopy and Radiative Transfer* 91:233-244.

Knuteson, R.O., N.C. Ciganovich, R.G. Dedecker, T.P. Dirkx, S.C. Ellington, W.F. Feltz, R.K. Garcia, H.B. Howell, W.L. Smith, J.F. Short, and D.C. Tobin. 2004. "Atmospheric Emitted Radiance Interferometer (AERI): Part II: Instrument Performance." *Journal of Atmospheric and Oceanic Technology* 21:1777-1789.

Marchand, R., T. Ackerman, E.R. Westwater, S.A. Clough, K. Cady-Pereira, and J.C. Liljegren. 2003. "An assessment of microwave absorption models and retrievals of cloud liquid water using clear-sky data." *Journal of Geophysical Research* 108(D24)4773.

Turner, D.D. 2005. "Arctic mixed-phase cloud properties from AERI-lidar observations: Algorithm and results from SHEBA." *Journal of Applied Meteorology* 44:427-444.

Turner, D.D., and R.E. Holz. 2005. "Retrieving cloud fraction in the field-of-view of a high-spectral-resolution infrared radiometer." *Geoscience Remote Sensing Letters* 3:287-291.

Turner, D.D. and coauthors. 2006. "Optically thin liquid water clouds: Their importance and our challenge." *Bulletin of the American Meteorological Society* submitted.