Retrieval of Liquid Water Path and Effective Drop Size Using Radar Data and Shortwave Optical Depth

R. T. Austin and G. L. Stephens
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

Q.-L. Min
Atmospheric Sciences Research Center
State University of New York
Albany, New York

Introduction

We present a new retrieval of liquid water path (LWP), effective drop size, and liquid water content (LWC) of water clouds, based on data from the Millimeter-Wave Cloud Radar (MMCR) and shortwave optical depths retrieved from the Multifilter Rotating Shadowband Radiometer (MFRSR) (Min and Harrison 1996). This algorithm is being developed in anticipation of the 94-GHz radar and Profiling Oxygen A-band Spectrometer/Visible Imager (PABSI) data to be available from the CloudSat platform in 2003. The algorithm has been adapted to use 35-GHz reflectivities from the MMCR and optical depths from the MFRSR. In this abstract, examples of retrieved LWP are compared with independent measurements obtained by the Microwave Radiometer (MWR) at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site.

Method

We consider a cloud composed of droplets having a gamma-size distribution:

$$n(r) = N_T \frac{1}{\Gamma(\nu)} \left(\frac{r}{r_n} \right)^{\nu-1} \frac{1}{r_n} \exp\left[-\left(\frac{r}{r_n} \right) \right],$$

where N_T is the number density of drops, r_n is a characteristic radius, and ν is a width parameter. The effective radius r_{eff} is given by

$$r_{eff} = r_n \frac{\Gamma(\nu+3)}{\Gamma(\nu+2)}.$$

Using various values of r_n and N_T, we can calculate the integrated reflectivity IZ and optical depth τ of a 1-kilometer cloud column, obtaining an orthogonal relationship between LWP and r_{eff} when plotted against the corresponding IZ and τ (Figure 1). We can therefore obtain values of the column-averaged effective radius and LWP from measured values of IZ and optical depth.

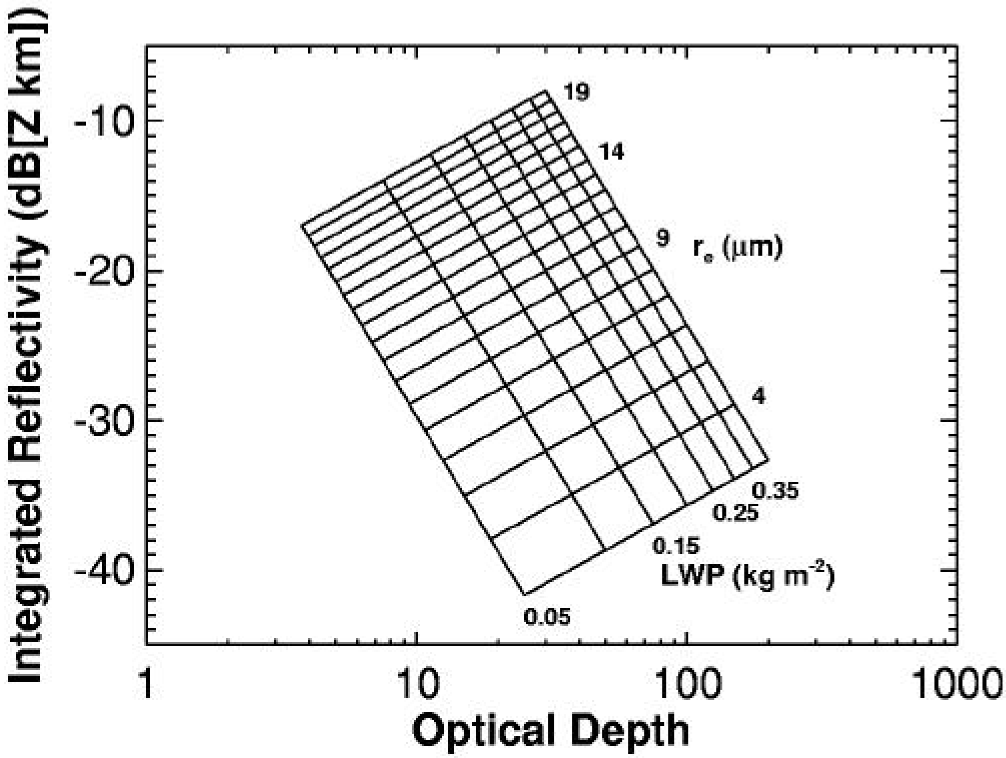

Figure 1. Integrated reflectivity and optical depth for a variety of gamma distributions, with effective radius and LWP values as parameters.

If we assume the number density to be constant with height, we can solve for the effective radius and LWC as a function of position within the cloud.

Sample Cases

The retrieval has been applied to some sample cases of stratus clouds over the SGP CART site. For December 3, 1997, the MMCR reflectivity and MFRSR-based visible optical depth are shown in Figure 2.

We first retrieve the column LWP and effective radius r_{eff}, and compare these to other retrievals in Figure 3. The LWP values are compared with LWP retrievals from the MWR and are shown to have a root mean square (rms) error of 10.9%. The effective radius values are well correlated with those retrieved by Q. Min using another method (Min and Harrison 1996).

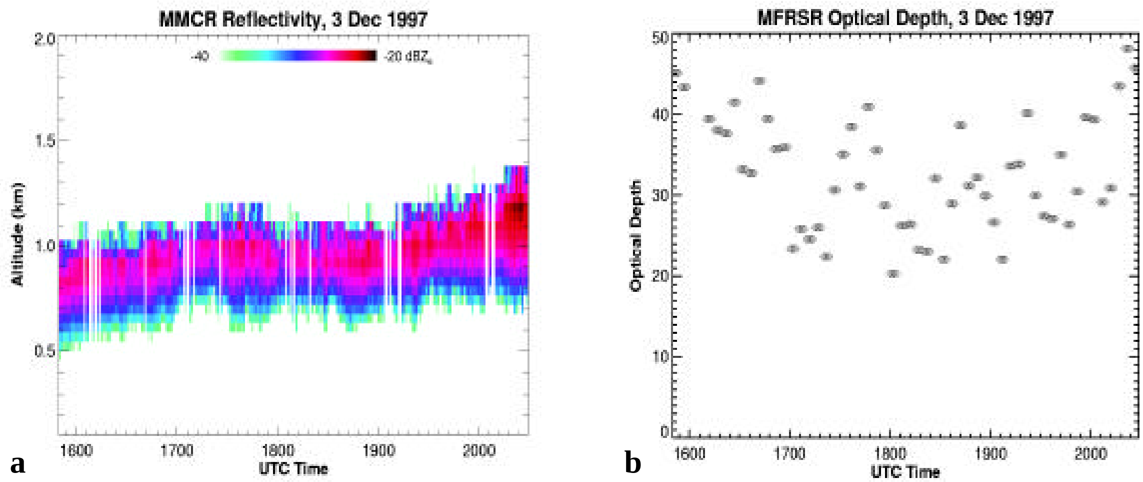

Figure 2. The case of December 3, 1997, showing (a) MMCR reflectivity and (b) optical depth retrieved from MFRSR.

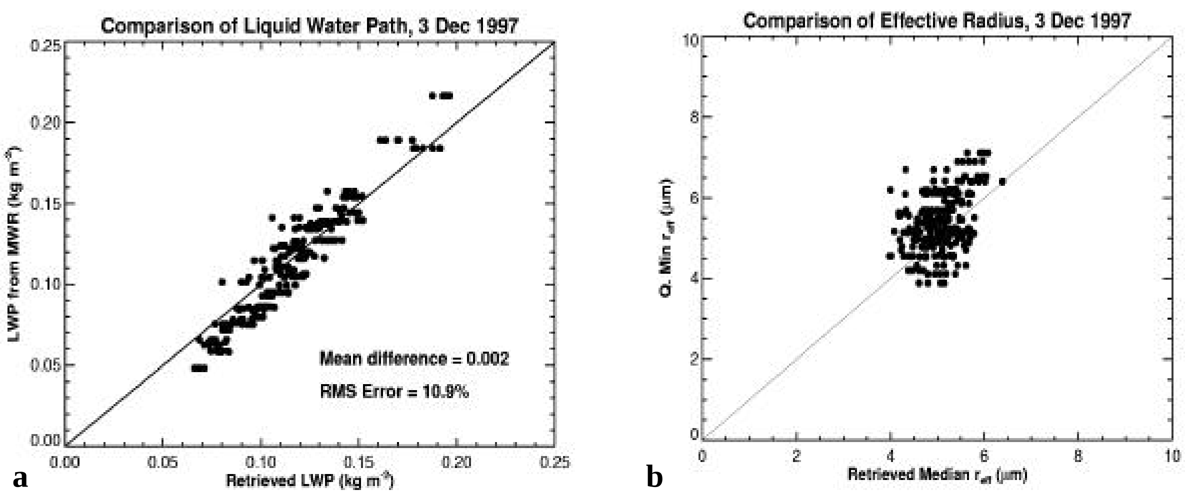

Figure 3. Comparisons of (a) LWP and (b) effective radius between this algorithm and other methods for December 3, 1997.

We may also compare the LWC and effective radius as a function of position. In Figure 4a, the retrieved LWC in the cloud is shown in a time-height diagram, while the corresponding values from a radar-radiometer retrieval (G. Mace, personal communication) are shown in Figure 4b. Similarly, the retrieved effective radius values are shown in Figure 5a, compared against those from the radar-radiometer retrieval in Figure 5b. There is qualitative agreement for both of these quantities. Detailed quantitative comparisons will be the focus of future studies.

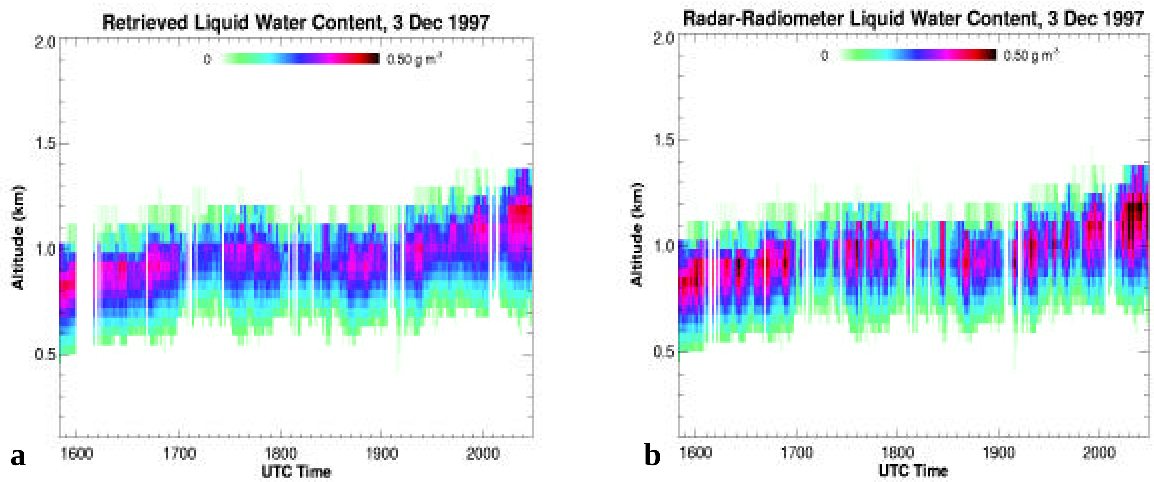

Figure 4. Retrieved LWC for December 3, 1997, from (a) this retrieval and (b) a radar-radiometer retrieval (data supplied by G. Mace).

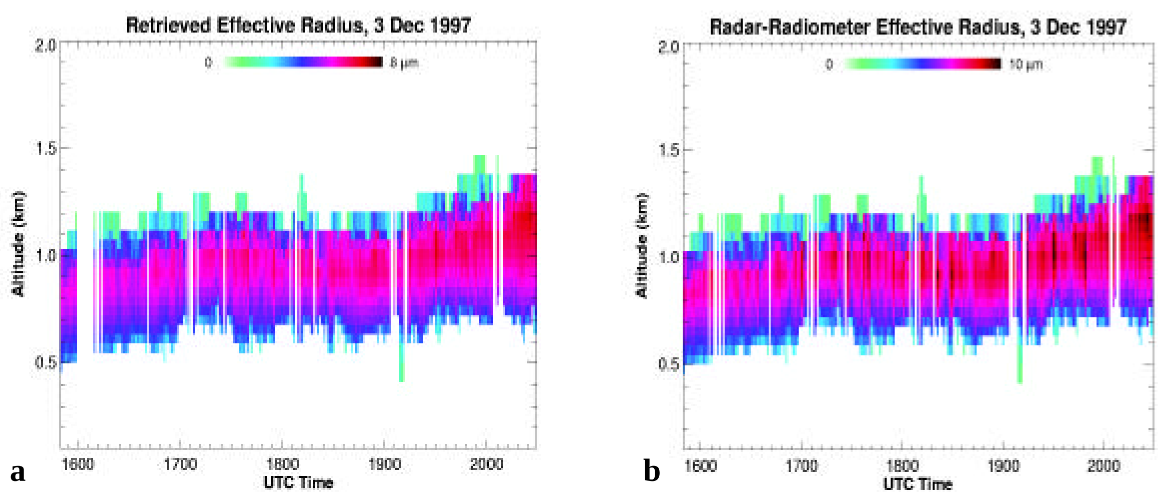

Figure 5. Retrieved effective radius for December 3, 1997, from (a) this retrieval and (b) a radar-radiometer retrieval (data supplied by G. Mace).

Similar retrievals were calculated for a stratus case on December 8, 1997, at the same site. The MMCR reflectivity and MFRSR optical depths are shown in Figure 6, and comparisons of the column quantities to those given by other retrievals is shown in Figure 7. The LWP values have a rms error of 6.8% as compared with the MWR LWP values.

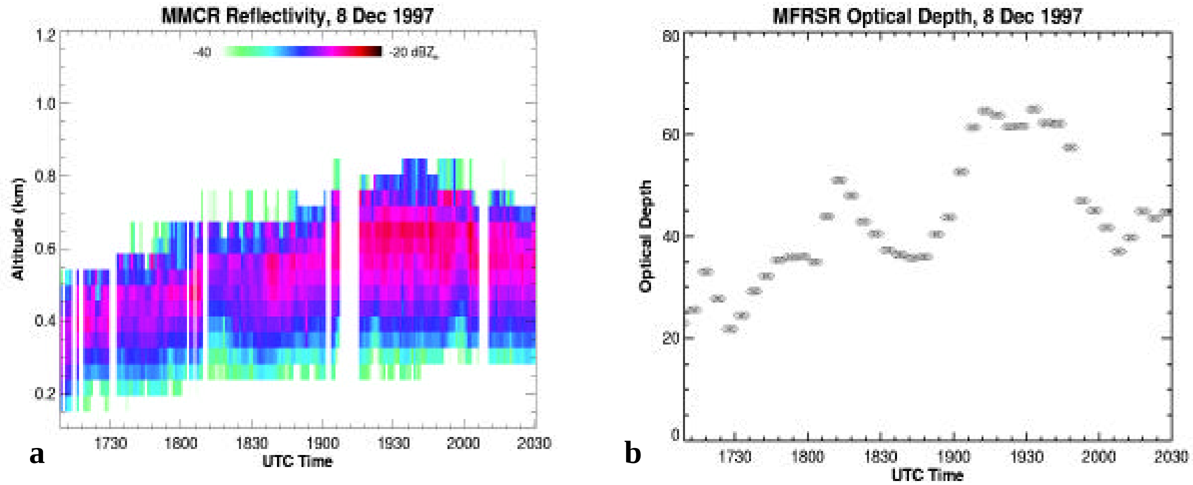

Figure 6. (a) MMCR reflectivity and (b) MFRSR optical depth for December 8, 1997.

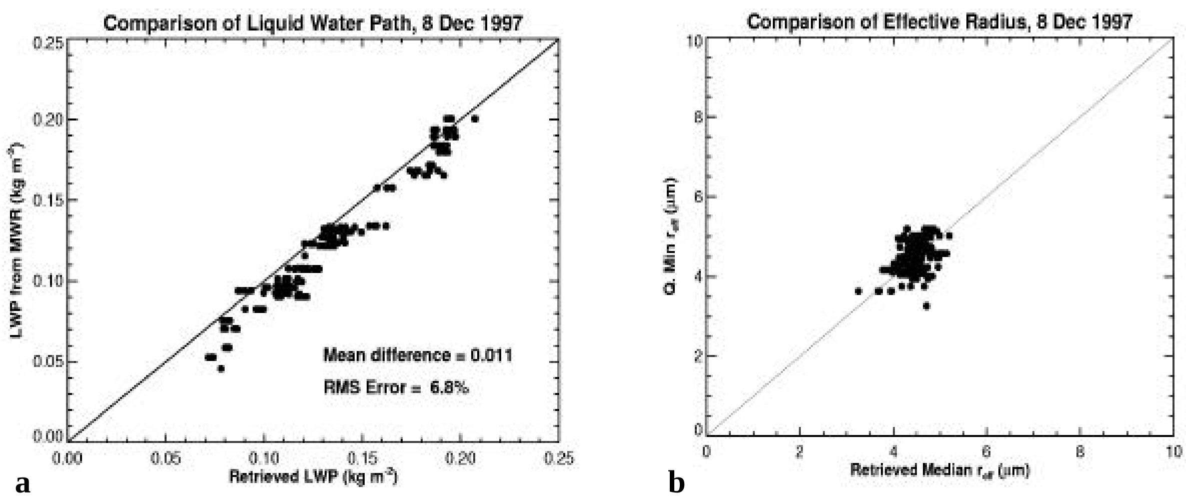

Figure 7. Comparison of (a) LWP and (b) effective radius for December 8, 1999.

Conclusion and Future Issues

The combination of millimeter radar and shortwave optical depth shows promise in the retrieval of water cloud LWC, LWP, and effective radius. The technique is applicable to the ARM CART sites, allowing validation and extension of this algorithm in anticipation of the launch of CloudSat. We are examining the sensitivity of the retrieval to various assumptions and measurement errors. The presence of drizzle within the cloud will change the retrieval relations. Adjustments to the algorithm for the drizzle case are being developed.

There is a possibility that CloudSat will orbit in formation with the Earth Observing System-afternoon sun-synchronous (EOS-PM) satellite series early in the next decade. This will allow inclusion of Advanced Microwave Scanning Radiometer data (6.925, 10.65, 18.7, 23.8, 36.5, and 89-GHz) in the retrievals and comparison against other methods (e.g., radar-radiometer methods).

Monterey Experiment

A field experiment is proposed for June/July 1999 near Monterey, California, which will attempt to verify and extend this retrieval for drizzle and non-drizzle cases. This experiment will include Atmospheric Radiation Measurement (ARM) and National Aeronautics and Space Administration (NASA) instruments on the U.S. Department of Energy (DOE) Twin Otter aircraft. It is designed to "piggy-back" on planned research sponsored by the Office of Naval Research and led by Prof. B. Albrecht, which includes surface instruments and another Twin Otter aircraft making in situ measurements inside stratus decks.

Acknowledgments

This research was supported under the DOE, Office of Health and Environmental Research, Grant DE-FG03-94ER61748.

Reference

Min, Q., and L. C. Harrison, 1996: Cloud properties derived from surface MFRSR measurements and comparison with GOES results at the ARM SGP site. *Geophys. Res. Lett.*, **23,** 1641-1644.