On Stratus Cloud Liquid Water Profiles from a Cloud Radar and Microwave Radiometer

A. S. Frisch and G. Feingold
Cooperative Institute for Research in the Atmosphere
Colorado State University and
NOAA-Environmental Technology Laboratory
Boulder, Colorado

C. W. Fairall
NOAA-Environmental Technology Laboratory
Boulder, Colorado

J. B. Snider
Cooperative Institute for Research in the Atmosphere
Colorado State University
Boulder, Colorado

Introduction

Stratus clouds are important in boundary-layer dynamics and global climate. Most measurements of stratus clouds have been made with aircraft (Slingo et al. 1982a, Slingo et al. 1982b, Nicholls 1987). However, aircraft measurements are expensive, and cannot be used for long-term monitoring at a single location. The development of the cloud-sensing radar (Pasqualucci et al. 1983, Kropfli and Kelly 1996) gives us the opportunity to monitor the cloud reflectivity, and when the antenna is pointed vertically and the radar has Doppler capability it can also measure the vertical velocity structure of the cloud droplets. Frisch et al. (1995) showed how the cloud radar measurements of reflectivity could be combined with the integrated liquid water measurements of a microwave radiometer to retrieve cloud properties using a log-normal cloud droplet model.

We can show that for vertical liquid water profiles, a log-normal droplet distribution assumption is not necessary, which makes the earlier method of Frisch et al. (1995) more general. We can use any droplet distribution where we can relate the sixth moment to the third moment. Then, using radar reflectivity and integrated liquid water from the radiometer, we can derive the profile of liquid water. In addition, if the radar calibration is off by a constant value, then the liquid water profile retrieval is independent of this calibration offset.

Method

The liquid water is given by

$$q(z) = \frac{4}{3}\pi N(z)\rho_w < r^3(z) > \quad (1)$$

where z is the height, ρ_w is the water density, (the brackets denote the moment of the radius over an arbitrary distribution), and N is the number of droplets.

The reflectivity Z is

$$Z(z) = 10^{(dBZ(z)-180)/10} \quad (2)$$

and if the measured value of dBZ* is given by dBZ+b, where b is the calibration offset and dBZ is the measured backscattered power in mm ^{6}m^{-3} then,

$$Z(z) = 10^{b/10} Z(z)* \quad (3)$$

Now if we can relate the higher moment to the lower, i.e., if $<r^6>=k^2<r^3>^2$, then the reflectivity is

$$Z(z) = 2^6 N(z) < r^6(z) > = 2^6 N(z)k^2 < r^3 >^2 \quad (4)$$

Solving for $<r^3>$ from (4) and substituting into (1) the liquid water is

$$q(z) = \frac{0.52}{k}\rho_w N(z)^{1/2} Z(z)^{1/2} \quad (5)$$

If we replace the height z with a radar range gate index i, the total water as measured by the radiometer, Q, is the sum of q_i over all heights N. This can be expressed as

$$Q = \sum_{i=1}^{i=N} q_i dz = \frac{0.52\rho_w N^{1/2}}{k} \sum_{i=1}^{i=N} Z_i^{1/2} dz \qquad (6)$$

and we have assumed that the single layer warm cloud is completely within all of the radar range gates. The liquid water at a radar range gate, i, is

$$q_i = \frac{QZ_i^{1/2}}{\sum_{i=1}^{i=N} Z_i^{1/2} \Delta z} \qquad (7)$$

where Δz is the range gate height interval.

Note that this relationship is unchanged if we include the effect of radar calibration as in (2), and that it is independent of k.

While we have no data yet to directly check the retrieval because of bug contamination at the Southern Great Plains (SGP), we do have droplet data from a variety of warm phase liquid water clouds and at different geographical locations (Pinnick et al. 1983). We compared the square of the third moment versus the sixth moment (Figure 1). The plot of these data shows that the relationship holds over a wide range of values of the moments.

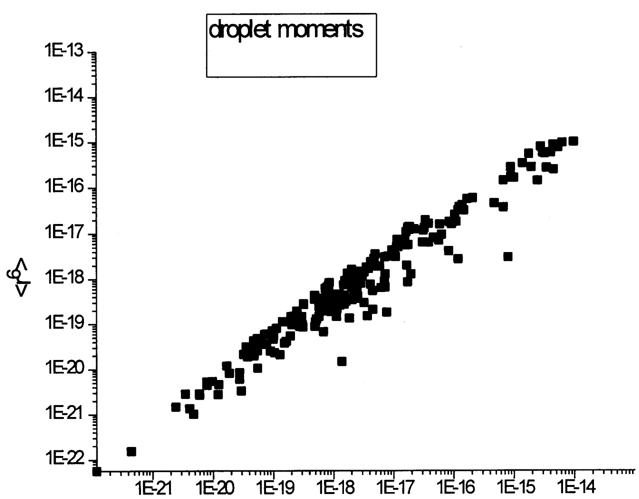

Figure 1. Plot of the droplet sixth moment vs. the square of the third moment from data of Pinnick et al. (1983).

Acknowledgments

This work was funded jointly by the National Oceanic and Atmospheric Administration's (NOAA's) Office of Global Programs and the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program.

References

Frisch, A. S., C. W. Fairall, and J. B. Snider, 1995: Measurement of stratus cloud and drizzle parameters in ASTEX with a K-band Doppler radar and microwave radiometer. *J. Atmos Sci*., **52**, 2788-2799.

Kropfli, R. A, and R. D. Kelly , 1996. Meteorological research applications of mm-wave radar. *Meteorol. Atmos Phys*. **59**, 105-121.

Nicholls, S., 1987: A model of drizzle growth in warm, turbulent, stratiform clouds. *Quart. J. Roy. Meteor. Soc.*, **113**, 1141-1170.

Pasqualucci, F. B., B. W. Bartram, R. A. Kropfli, and W. R. Moninger, 1983: A millimeter-wavelength dual-polarization Doppler radar for cloud and precipitation studies. *J. Climate Appl. Meteor*., **22**, 758-765.

Pinnick, R. G., S. G. Jennings, P. Chylek, C. Ham, and W. T. Grundy, Jr., 1983: Backscatter and extinction in water clouds. *J. Geophys. Res.*, **88**, 6787-6796.

Slingo, A. S., S. Nicholls, and J. Schnetz, 1982a: Aircraft observations of marine stratocumulus during JASIN. *Quart. J. Roy. Meteor. Soc*., **108**, 833-856.

Slingo, A., R. Brown, and C. L. Wiench, 1982b: A field study of nocturnal stratocumulus; III. High resolution radiative and microphysical observations. *Quart. J. Roy. Meteor. Soc*., **108**, 145-166.