In Situ Comparisons with the Cloud Radar Retrievals of Stratus Cloud Effective Radius

A. S. Frisch and G. Feingold
Cooperative Institute for Research in the Atmosphere
National Oceanic and Atmospheric Administration
Environmental Technology Laboratory
Boulder, Colorado

M. D Shupe and I. Djalalova
Science Technology Corporation
National Oceanic and Atmospheric Administration
Environmental Technology Laboratory
Boulder, Colorado

M. R. Poellot
Department of Atmospheric Sciences
University of North Dakota
Grand Forks, North Dakota

Abstract

In situ sampling of cloud droplets by aircraft in Oklahoma in 1997, Surface Heat Budget of the Arctic Ocean (SHEBA) - First ISCCP Regional Experiment Aerosol Characterization Experiment (FIRE ACE) in 1998, and a collection of droplet spectra measured from various locations around the world are used to evaluate the potential for a ground-based remote-sensing technique for retrieving profiles of cloud droplet effective radius (r_e). The technique uses vertically pointing measurements from high-sensitivity millimeter-wavelength radar to obtain height-resolved estimates of the r_e in clouds.

Introduction

Approaches for retrieving cloud radar reflectivity and ice and liquid water content were suggested by Liao and Sassen (1994), which was expanded on and validated by Sassen et al. 1999. Other retrieval for stratocumulus cloud properties using solar radiation, Microwave Radiometer (MWR), and millimeter cloud radar were developed by Mace and Sassen (2000). Retrievals for marine boundary layer clouds were done by Dong et al. (1997) and Frisch et al. (1995). Gossard et al. (1997) approached the problem by using radar measurements of the full spectrum of measured Doppler vertical velocities with deconvolution adjustments for the effects of atmospheric turbulence. Further work using spectra, has been done by Babb et al. (1999). In this study, we use in situ comparisons with the r_e retrieval of Frisch et al. (1995) along with the use of radar reflectivity alone for determining the r_e.

Methods

If we assume that the cloud droplet distribution can be approximated by a log normal distribution, we can show that the r_e can be related to the radar reflectivity by

$$r_e = \frac{1}{2}\left(\frac{Z}{N}\right)^{1/6} \exp - 0.5\sigma_x^2 \qquad (1)$$

where σ_x is the logarithmic spread of the distribution and N is the droplet concentration Fox and Illingworth (1997) noted a relationship between r_e and the reflectivity factor Z from aircraft measurements of marine stratus. From (1), we can see that if we have an estimate of the droplet concentration and the droplet spread, r_e can be retrieved from Z. If simultaneous MWR measurements are available for estimating the integrated liquid water, then constraining N and σ_x to be constant with height, we can use the method of Frisch et al. 1995, and solve for the re.

$$r_e(h) = \frac{Z^{1/6}(h)}{2Q^{1/3}}\left(\frac{\pi\rho}{6}\right)^{1/3}\left(\sum_{i=1}^{i=m} Z^{1/2}(h_i)\Delta h\right)^{1/3} \exp(-2\sigma_x^2) \qquad (2)$$

where h_i is height in the cloud, i = 1 and i = m represent the radar range gate at the cloud base and cloud top, respectively, Δh is the radar range gate thickness, and Q is the MWR-derived integrated liquid water through the depth of the cloud. This additional measurement eliminates the need to know N; however, we still need an estimate of σ_x.

Measurements

To determine the range of values in the parameters needed for the two retrievals and for comparisons with in situ measurements, we used measurements made during an April 1997 Intensive Operational Period (IOP) at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site near Ponca City, Oklahoma. The droplet size distributions were measured with a Forward Scattering Spectrometer Probe (FSSP). This FSSP was installed on the University of North Dakota Citation. To get good statistics, the in situ data were only considered when the liquid particle concentrations were > 10 cm^{-3}. The FSSP droplet spectra were used to calculate the r_e radar reflectivity, the droplet concentration, and the logarithmic spread of the radii distribution.

The first retrieval Eq. (1) is based on the assumption that we know approximately what the droplet concentration is for marine and continental stratus clouds. These measurements gave us the mean and standard deviation of the quantities that were necessary to help evaluate this r_e retrieval. For example, Frisch et al. (1995) used a value of 0.35 for σ_x. The ARM IOP had a value σ_x of 0.32 ±0.09. The droplet concentration N varied from a low of 25 to a maximum of about 400 with a few measurements of much higher concentrations. The average was 212 cm^{-3}, with a standard deviation of 107 cm^{-3}. We used about 5000 1-second spectra in these calculations. These were an average of measurements taken over several days during the IOP (Frisch et al. 1998).

Comparisons with In Situ Measurements

We compared radar and radar-radiometer-retrieved r_e with the in situ FSSP measurements of re. We also used two-dimensional precipitation (2DP) to tell the number of events where we had particles that were large enough to cause large errors in our radar reflectivity measurements. Because of the height error in the aircraft and the sharp vertical gradients in the radar reflectivity measurements of the clouds, we had to adjust the aircraft height explained in Frisch et al. 2000. We set an arbitrary horizontal circle of 1.5 km around the radar for our comparisons. If the aircraft were within this circle, then we would do a comparison between the FSSP and radar-MWR retrieval. These comparisons were made on April 9, 1997, from 15:33 to 17:31 local time.

Figure 1 shows a time series plot of the aircraft FSSP calculated reflectivity factor along with the radar measured reflectivity factor for measurements within a 1.5 km horizontal distance from the radar. The measurements track very well until about 16.4 hours Universal Time (UT) when the radar reflectivity becomes much lower relative to the FSSP reflectivity calculated reflectivity. This is the time when the cloud was rapidly dissipating and probably becoming less horizontally homogenous and not suitable for a comparison. Figure 2 shows the radar-radiometer r_e retrieval compared with the FSSP for the times before 16.4 UT, and Figure 3 shows a similar comparison for the radar reflectivity r_e retrieval comparison with the FSSP. In both cases, we used σ_x =0.32 and for the second retrieval, N = 212 cm^{-3}. This shows that the retrieval without the liquid water gives the least difference between the in situ measurements.

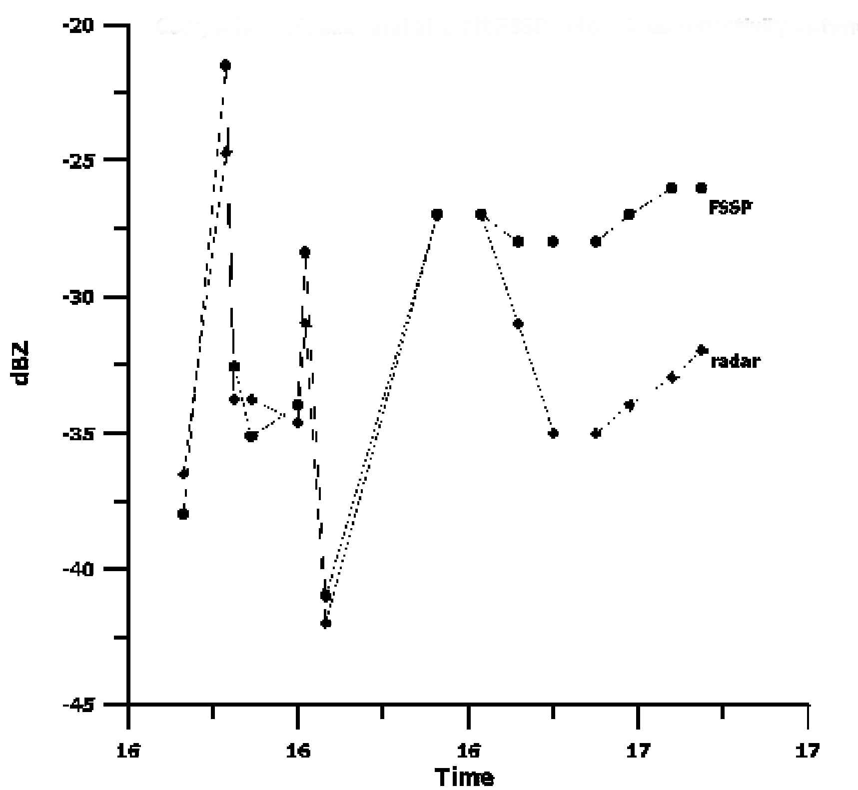

Figure 1. Comparison of radar and aircraft FSSP determined reflectivity versus time.

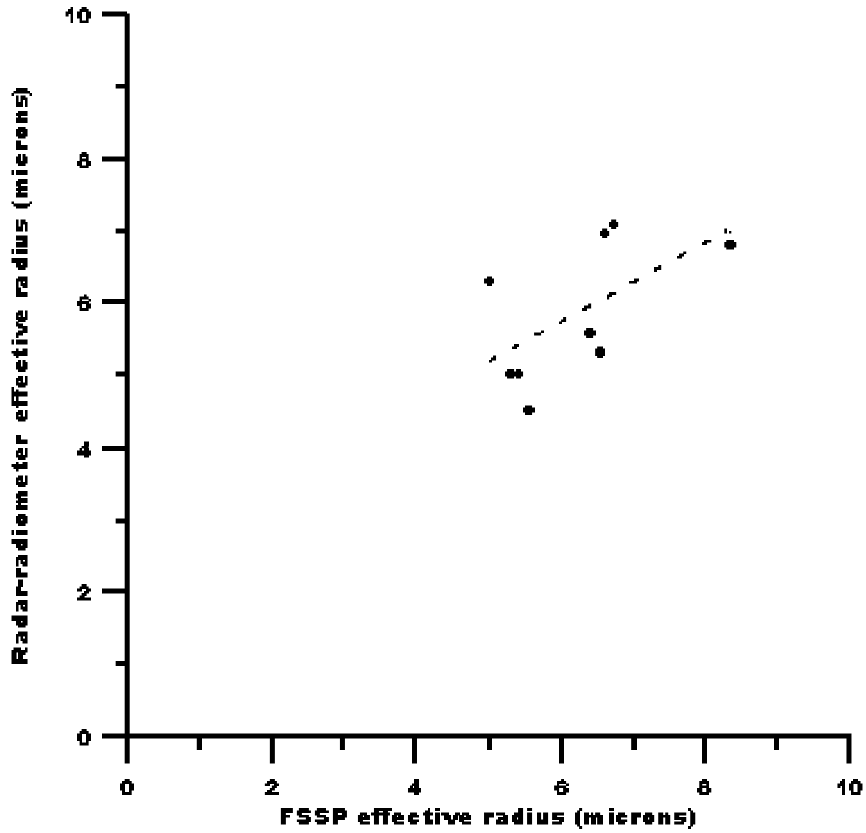

Figure 2. Radar-radiometer retrieval versus FSSP.

A potential problem with either of these retrievals is that occasional large droplets occur in the cloud at low reflectivities. We examined 2DP measurements for large particles and found about 20 events when large particles were present. The total aircraft flight time was about 90 minutes, and the sampling rate was 1 sample per second. During this time, there were more than 5000 samples, so the 20 or so events appear to be negligible for the continental stratus case.

Discussion and Conclusion

We have shown an analysis of two methods for determining the re. The first method uses only the reflectivity factor; the second is based on a method of Frisch et al. 1990, which uses the reflectivity factor and a measurement on the integrated liquid water. In both methods, an estimate of the logarithmic spread of the cloud droplets is required; however, large changes in this spread contribute small changes in the r_e retrieval using the reflectivity alone. In the technique using the radar alone, an estimate of the droplet concentration is required, although large changes in the concentration give small changes in the re. Our results show that the reflectivity alone method produces the best results.

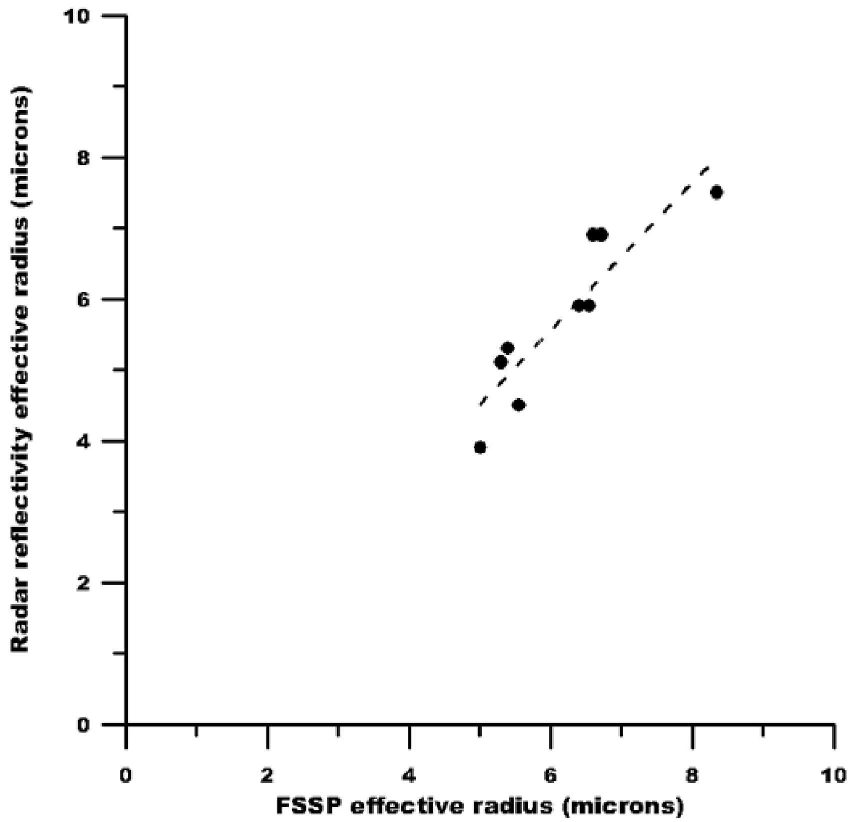

Figure 3. Radar only retrieval versus FSSP.

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Corresponding Author

A. S. Frisch, sfrisch@etl.noaa.gov, (303) 497-6209

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