Further Estimates of the Error in the Retrieval of Cloud Radar Effective Radius

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Introduction

We use aircraft Forward Scattering Spectrometer Probe (FSSP) data taken near the Southern Great Plains (SGP) site and during the ISCCP (First International Satellite Cloud Climatology Project) Regional Experiment-Arctic Cloud Experiment (FIRE-ACE) program in the Arctic to estimate a radar reflectivity retrieval of a stratus cloud effective radius (r_e) in the non-drizzling part of the cloud.

Method

The retrieval uses a lognormal distribution for the representation of the cloud droplet distribution. For this distribution, the moments of the droplet radius can be written as

$$< r^k >= r_0^k \exp\left(\frac{k2}{2}\sigma_x^2\right)$$

where r_0 is the median radius, and σ_x is the logarithmic spread of the distribution (Frisch et al.1995).

The r_e is defined as

$$r_e \equiv \frac{< r^3 >}{< r^2 >} = r_0 \ \exp\left(-\frac{5}{2}\sigma_x^2\right)$$

The radar reflectivity is given as

$$Z = 2^6 \ N < r^6 >= 2^6 \ Nr_e^6 \exp 18\sigma_x^2$$

Solving for r_e

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

Notice that even if N and σ_x vary by a large amount, since N enters in as the one-sixth power and σ_x varies as exp $(-0.5\,\sigma_x^2)$, the effect of these variations on r_e will be much smaller than the variations themselves. If we have approximate values of N and σ_x, we can do a reasonable retrieval of r_e with this equation.

Results

We used the measured cloud droplet size distributions to compute both radar reflectivity and particle r_e size. We plotted the r_e versus the calculated radar reflectivity for the FIRE-ACE Arctic measurements (Figure 1a), and for the SGP intensive operational period (IOP) measurements (Figure 1b). The curves represent (5) for different values of N with a value of $\sigma_x = 0.32$. The measurements from FIRE-ACE show that most of the droplets fall between 10 and 200 cm^{-3}, while results from the ARM SGP IOP show higher droplet concentrations, with most values between 100 and 400 cm^{-3}.

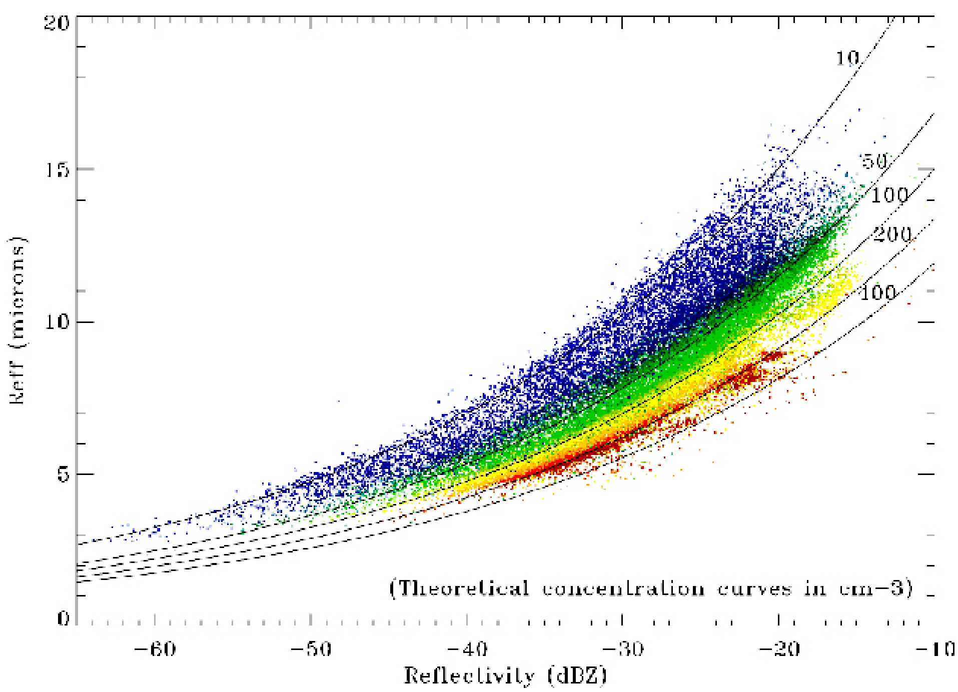

Figure 1a. FSSP-derived r_e versus FSSP-derived reflectivity for the SGP-IOP data. Color scale indicates droplet concentration range from 10 cm^{-3} (blue) to about 400 cm^{-3} (red).

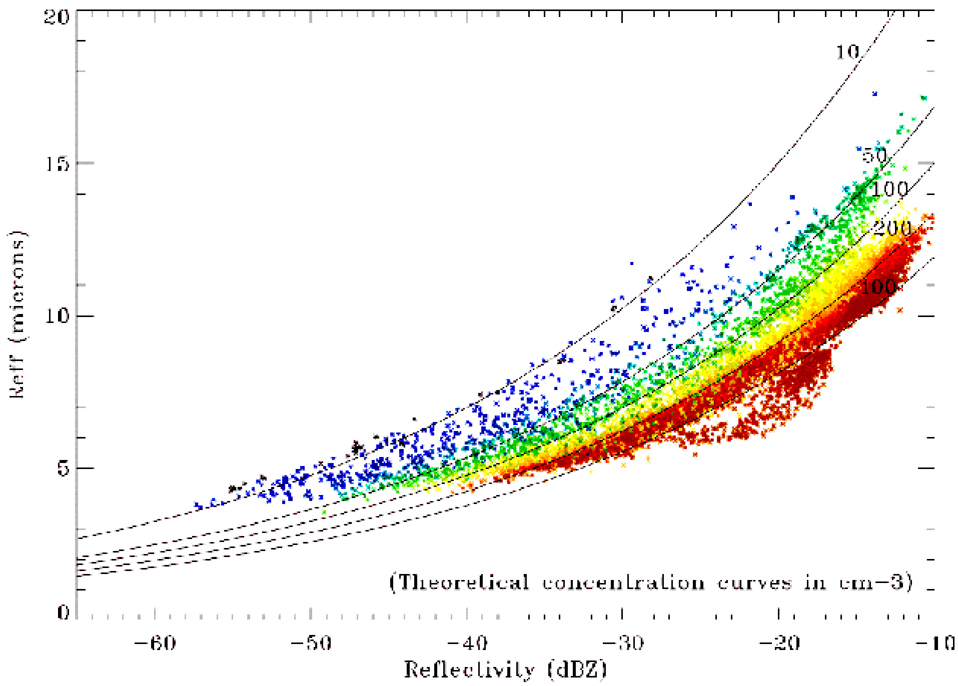

Figure 1b. FSSP-derived r_e versus FSSP-derived reflectivity for the FIRE-ACE data. Color scale indicates droplet concentration range from 10 cm^{-3} (blue) to about 400 cm^{-3} (red).

Figure 2 shows the measured values of σ_x for both continental and marine stratus clouds verses calculated values of radar reflectivity. There is a spread in σ_x from about 0.1 to 0.7, similar to the results of Miles et al. (2000); however, most of the values lie in a much smaller band. To test the retrieval, we used the marine and continental aircraft FSSP data to compute reflectivities for use in the retrieval. The plot of retrieved cloud droplet r_e versus FSSP measured r_e is shown in Figure 3. We used a droplet concentration of N=200 for the continental retrievals and N=100 for the marine droplet retrievals. Values of $\sigma_x = 0.32$ and $\sigma_x = 0.34$ were used for the continental and marine stratus retrievals, respectively. The standard deviation between retrieved cloud droplet r_e and measured r_e is about 12% for continental stratus, while the marine standard deviation is about 16%.

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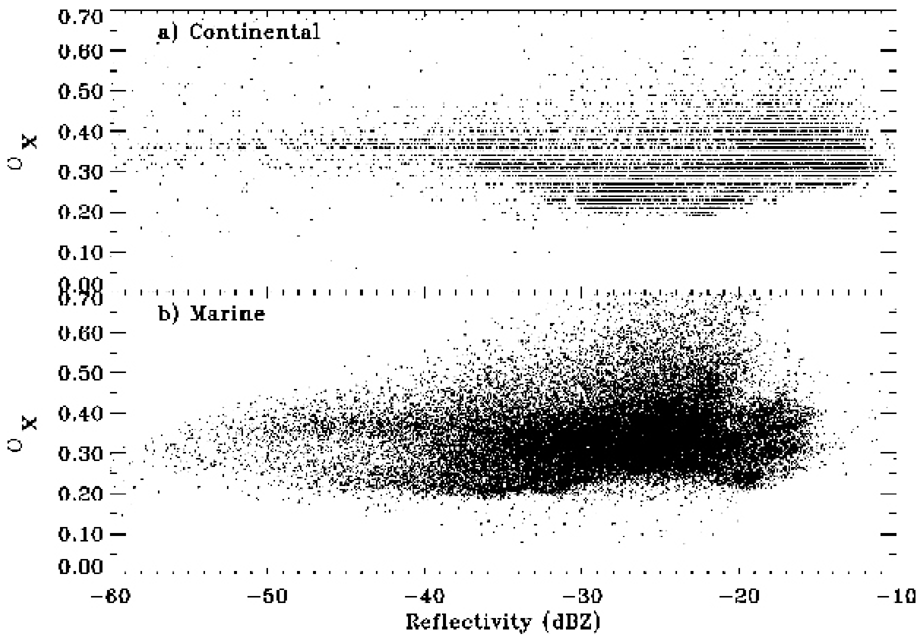

Figure 2. Logarithmic standard deviation (F_x) of stratus cloud droplets versus calculated radar reflectivity from aircraft measurements with an FSSP. Top is for continental cloud droplets; bottom is for marine stratus cloud droplets. The blank horizontal stripes in the bottom are due to roundoff in the calculations of F_x, which isn't present in the top F_x calculation.

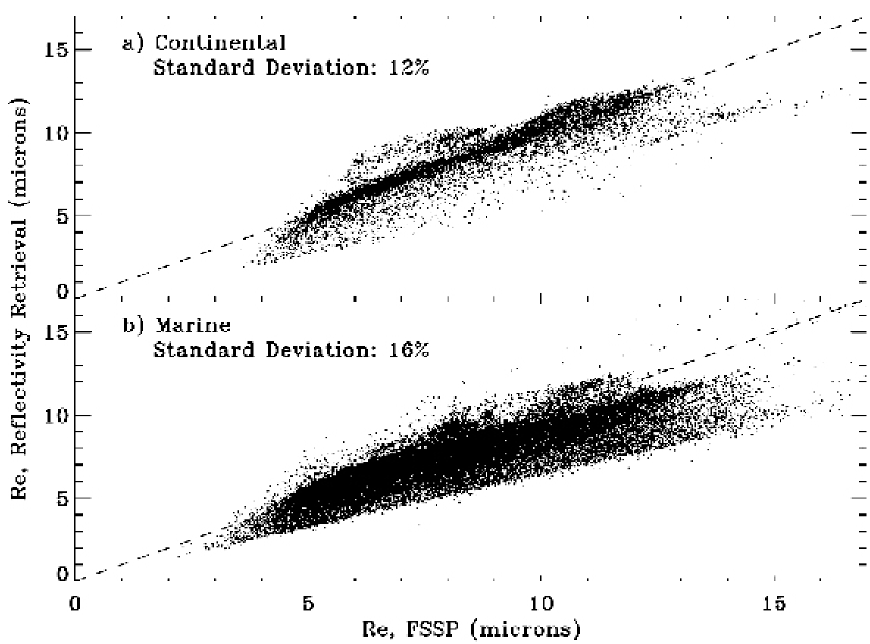

Figure 3. Retrieved cloud droplet r_e values versus calculated radar reflectivity from equation 5 using Aircraft FSSP measurements. Top is from continental stratus; bottom is from marine stratus. We used F_x = 0.32 and an N = 200 cm^{-3} for the continental and F_x = 0.34 and N = 100 cm^{-3} for the marine stratus clouds.

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