In Situ Microphysical Measurements of Cirrus Properties During ARM 2000 IOP

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Introduction

Retrievals of cirrus properties from remote sensing instruments need a good base for proper interpretation. We will investigate some important microphysical parameters that should help towards this understanding. This includes the microphysical properties of the ice particles, most notably their masses (m), properties that have been elusive to determine in the past.

We developed a two-parameter technique, which prescribed m using both particle maximum dimension (D) and area ratio (A_r, the crystal area divided by the area of a circumscribed circle, Heymsfield et al. 2001). In the past, one-parameter techniques of the form $m = aD^b$ were used. The relationships we used are of the form $m = \rho_e (\pi/6)D^3$ ($\rho_e = k(A_r)^n$). They were developed using a combination of numerical modeling calculations, in situ data, and ice particle collections at the ground (Heymsfield and Iaquinta 2000).

The Atmospheric Radiation Measurement Program (ARM) Cloud Intensive Operational Period (IOP) in March 2000 provided an opportunity to test the approach in cirrus clouds with the hope of extracting useful information for remote sensing applications. Particle size distribution data were collected with two-dimensional (2D) probes. High-resolution particle habit information was obtained with a Cloud Particle Imager (CPI), and direct measurements of the ice water content (IWC) were obtained with a Counterflow Virtual Impactor (CVI). The data was collected from the University of North Dakota Citation aircraft during level flights and in Lagrangian spiral descents through the depths of cirrus layers.

We have focused on three IOP cirrus cases: March 9, March 12, and March 13, 2000, when bullet rosettes, arguably the dominant crystal type in synoptically-generated cirrus, predominated in both the CPI and 2D imagery (Figure 1). Our understanding of the mass relationship for rosettes is high as it

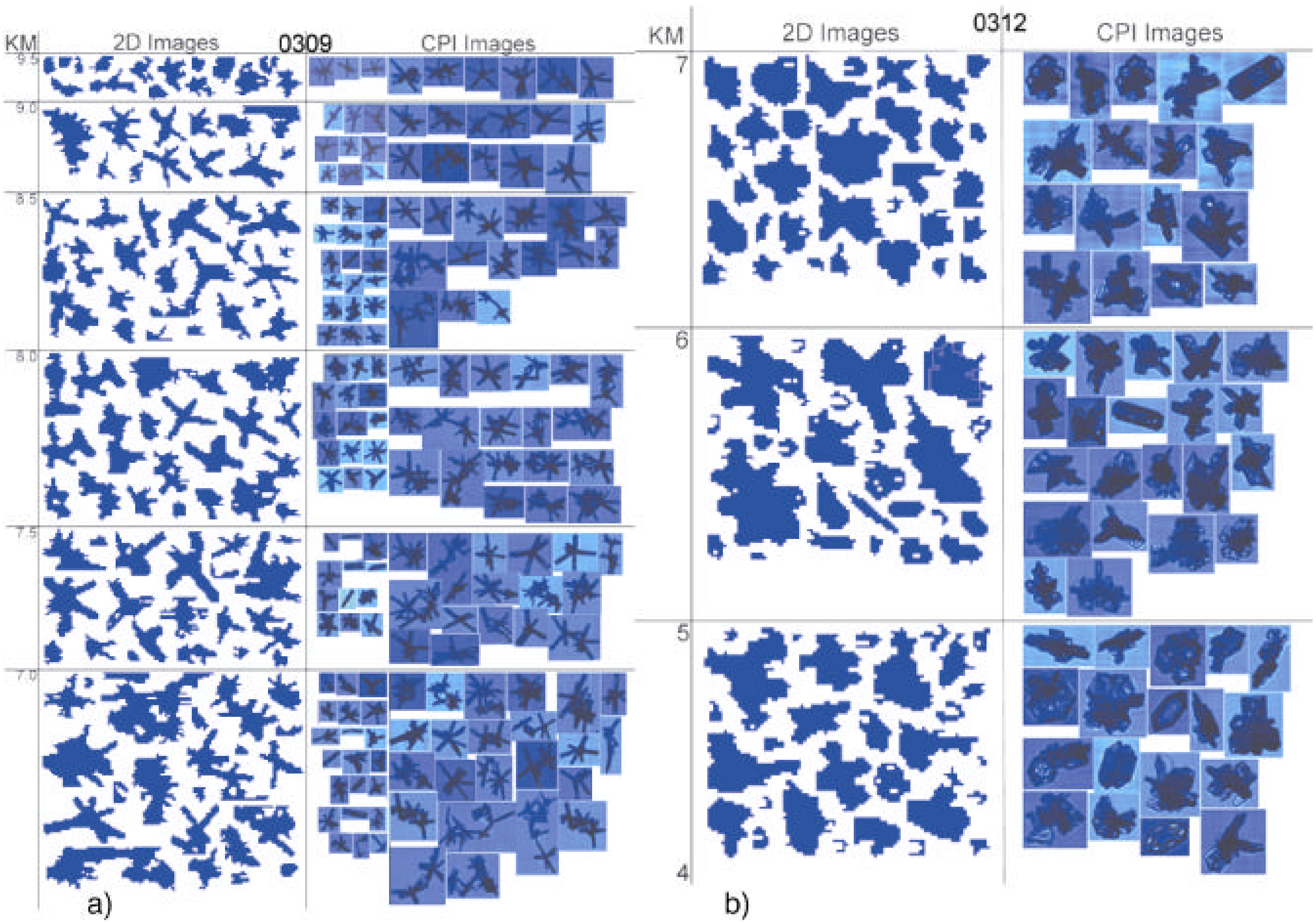

Figure 1. A partial profile of crystal images for a) March 9, 2000, and b) March 12, 2000, ARM IOP. The left-hand sides of each profile are images from the 2D particle measuring system (PMS) probe, and the right sides are images from the CPI.

derives from numerical modeling studies, which reliably simulate their three-dimensional structure. Using the size distributions from the 2DC and 2DP probes, we have calculated the IWC and compared those results to direct measurements from the CVI.

On March 9, a Lagrangian descent was made by the Citation. The IWC from the two-parameter technique compares well with the CVI (Figures 2a and 2b). A one-parameter technique, by Brown and Francis (1995), also compares favorably at first inspection (Figures 2c and 2d). Closer inspection indicates that near cloud top, the IWCs are overestimated and near base underestimated. This feature leads to a trend of the IWC with height, which is opposite in sign to that observed. The one-parameter approach of Mitchell (1996) for five-bullet-rosettes (Figures 2e and 2f) underestimates the IWCs at all times, by about a factor of two.

March 13 was also a day of bullet rosettes. The flight pattern was a series of legs at various altitudes rather than a single descent. In this way, rather than following the motion of a particle, we get a better look at the particles at a given level. The samples would be expected to show a larger diversity in size at

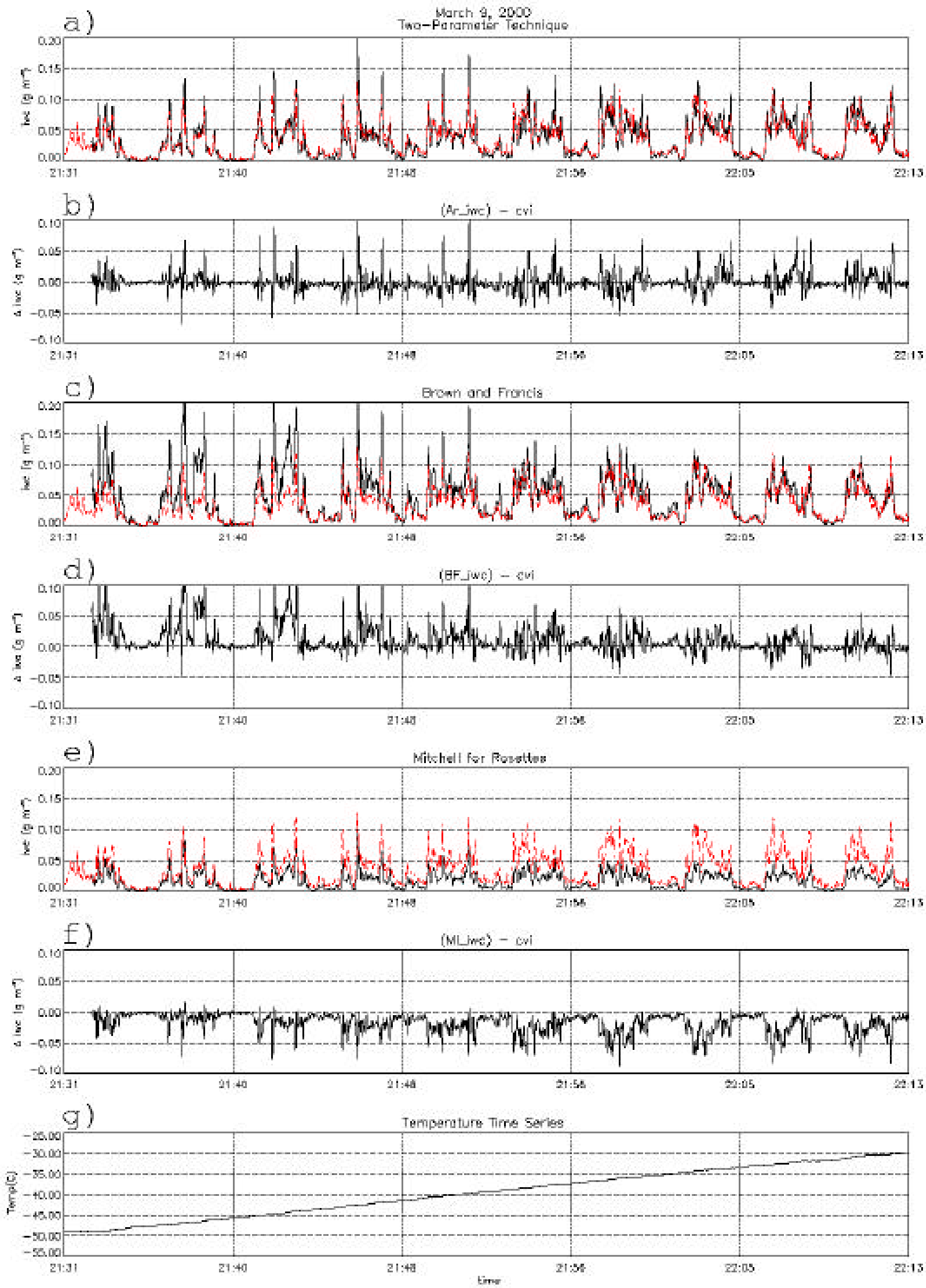

Figure 2. Time series of IWC and temperature for March 9, 2000. Panel a) Two-parameter technique in black, CVI appears in red for all the subsequent panels; Panel b) (A_r IWC) – CVI; Panel c) Brown and Francis 1994 in black; Panel d) (Brown and Francis IWC) – CVI; Panel e) Mitchell 1996 for 5 bullet rosettes in black; Panel f) (M96 IWC) – CVI; and Panel g) Temperature (C).

a particular level than the descent would. Plots similar to Figure 2 for March 13 are not shown, but the two-parameter technique shows good agreement while Brown and Francis overestimates the masses of the smaller particles and Mitchell consistently underestimates the masses.

The March 12 case was a series of level flight legs at different altitudes. There was liquid water present during the flight. (Notice the IWC scales are different from the previous figure.) At about 00:30 the aircraft flew through a region of very high IWC, which saturated the CVI device (redline in the Figures 3a, and 3c). This saturation is confirmed by the occurrence of high IWCs in the 2D data. The particle images for the March 12 case looked different from the pristine bullet rosettes on March 9 (Figure 1b versus Figure 1a). The A_{rs} were larger for given D. Outside of the time where the CVI was saturated, the two-parameter technique compared well with the CVI (Figure 3b) while Brown and Francis consistently underestimated the IWC (Figure 3d) by a larger amount than can be explained by the existence of the liquid water present (Figure 3e).

Given that the two-parameter technique appears to provide an accurate estimate of particle masses across the range of particle sizes, we are able to extract meaningful information on the crystal properties. The two-parameter technique provided us with IWC in each of 40 size bins (IWC_I) for each one second of aircraft flight time. Normalizing by the concentration N_i in each bin, we obtained values of m_i as a function of D_i. Through curve fitting, these values led to a single parameter relationship, with coefficients a and b. The distribution of the a and b mass coefficients for the 0309 and 0312 cases can be seen in Figure 4. The means calculated for each of the distributions plotted are in Table 1. Notice that the means are not the same for the a or b coefficients between the two days. The distribution plots and the difference in the means highlights the limitations of using a single a, b pair of coefficients for the mass-diameter relationship.

Z_e-IWC Relationships

The reflectivity, as measured by radar, is a function of the equivalent melted diameter (D_m) and the concentration. To determine an equivalent reflectivity from the 2D data, the following relationships are used:

$$Z = \sum n_i D_{mi}^6,$$

$$D_m^6(\mathrm{mm}) = \left(\frac{6}{\pi}\times 10^3 m\right)^2,$$

and

$$Z_e = \left(\frac{K_i}{K_w}\right)^2 \left(\frac{6}{\pi}\times 10^3 m\right)^2 \sum n_i m_i^2 .$$

The variable K is a function of the complex index of refraction of ice (i) or water (w).

The equivalent reflectivity is compared to the IWC in Figure 5. The dots are calculated values from the 2D data; the solid line is a power-law fit according to Matrosov (personal communication).

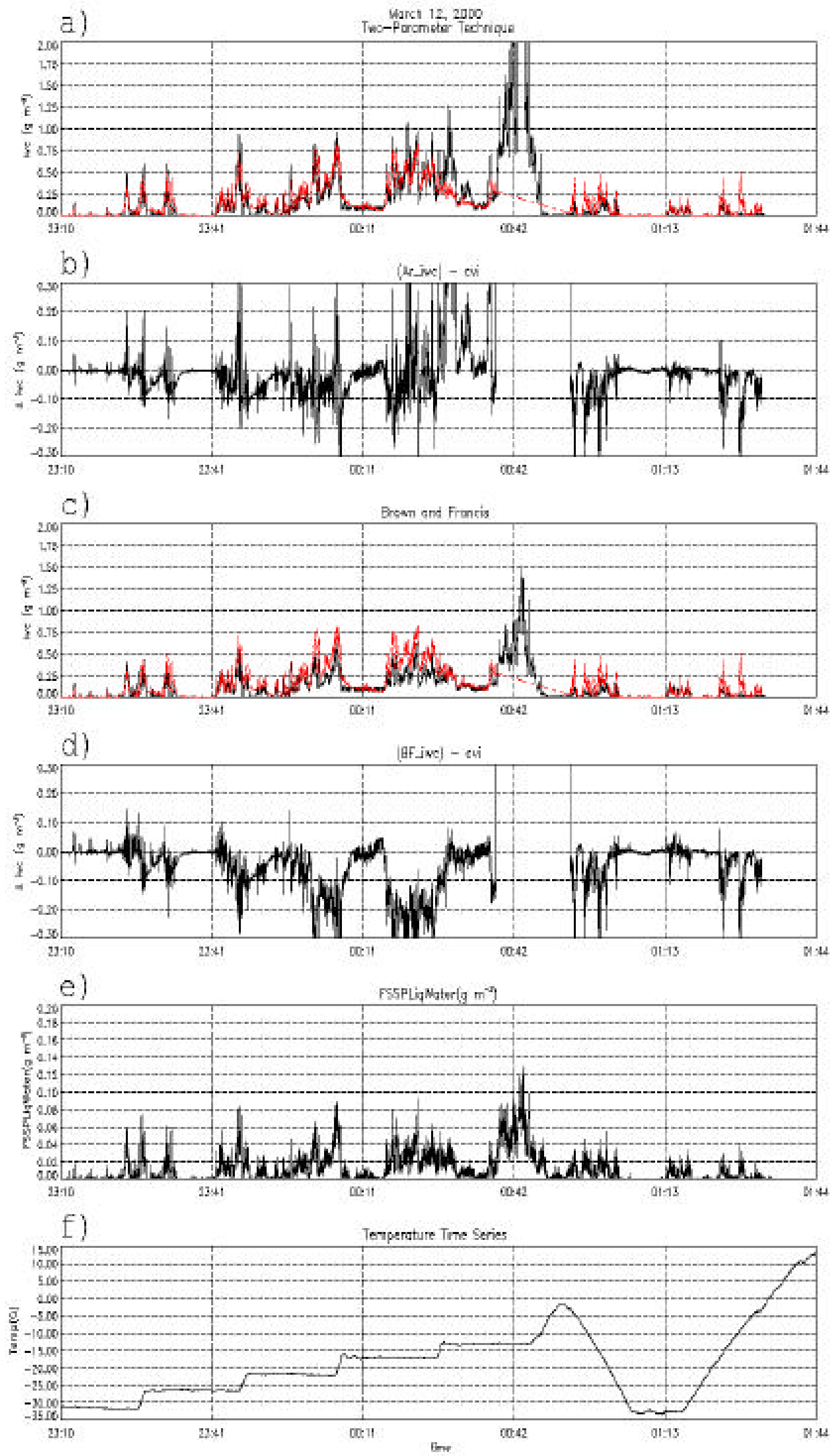

Figure 3. Time series of IWC and temperature for March 12, 2000. Panel a) Two-parameter technique in black, CVI appears in red for all the subsequent panels; Panel b) (A, IWC) – CVI; Panel c) Brown and Francis 1994 in black; Panel d) (Brown and Francis IWC) – CVI; Panel e) Liquid water content (LWC) from the Forwarding Scattering Spectrometer Probe (FSSP); and Panel f) Temperature (C).

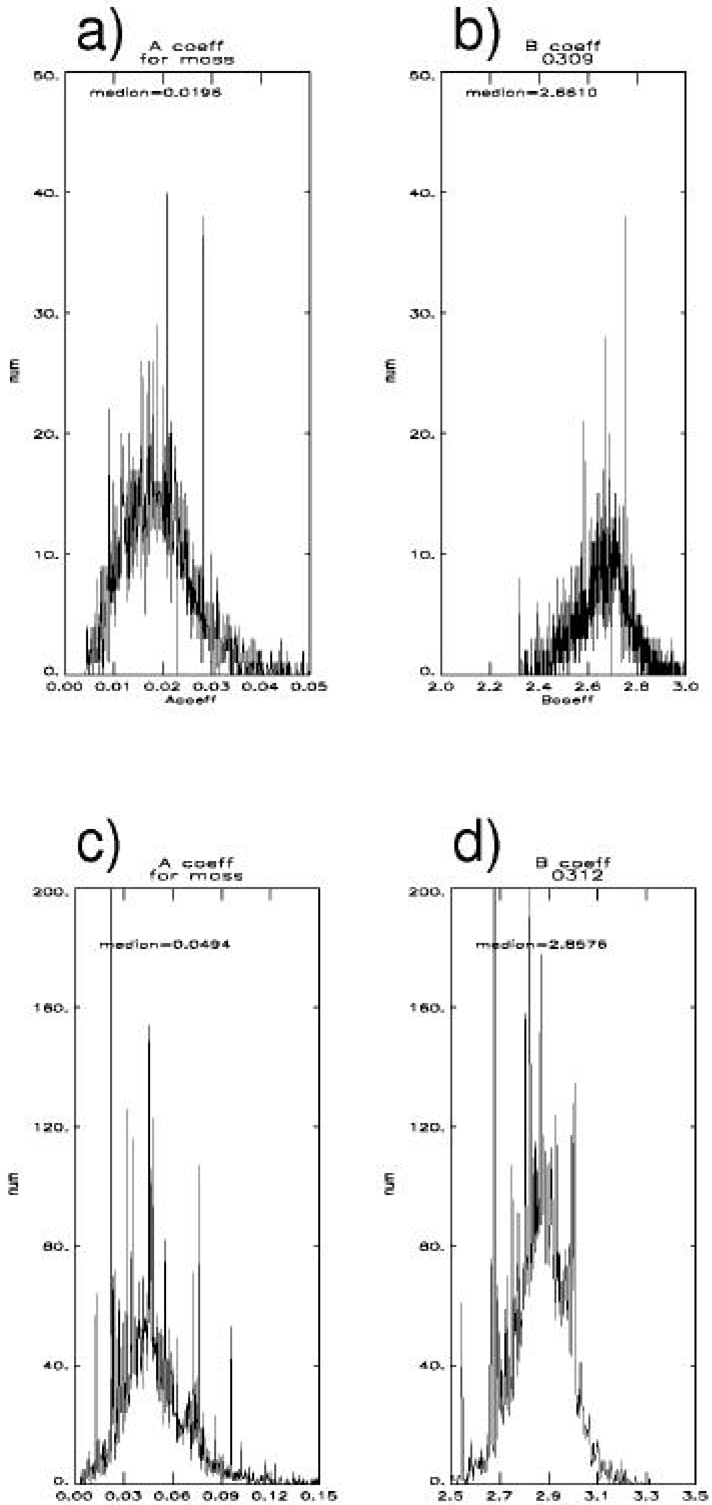

Figure 4. Distributions for mass coefficients for a) March 9, a coefficient; b) March 9, b coefficient; c) March 12, a coefficient; and d) March 12, b coefficient. (Note: The scales are not the same for each of these plots.)

Table 1. Mean values for the a and b coefficients shown in Figure 4.

Year 2000	A Coefficient	B Coefficient
March 9	0.0196	2.661
March 12	0.0494	2.8576

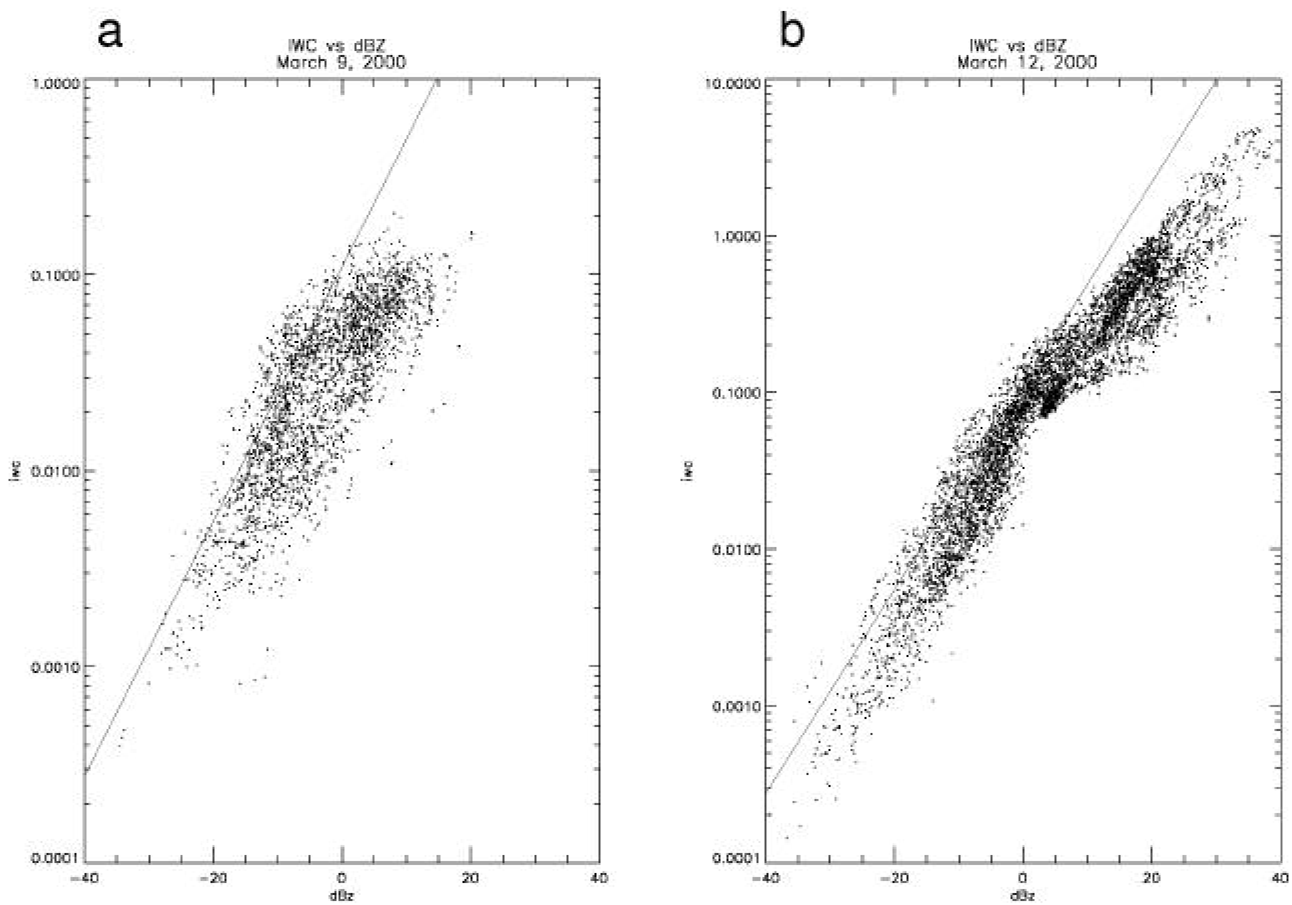

Figure 5. Plots of log IWC versus dBZ (dots) showing a power-law fit similar to that suggested by Matrosov (solid line). a) March 9, 2000, and b) March 12, 2000.

Summary

A two-parameter technique for determining the mass is applied to the 2D PMS data to determine IWC for several cases from the ARM 2000 IOP. The IWC was also determined using single-parameter approaches such as those of Brown and Francis (1994) and Mitchell (1996). The single-parameter approach of Mitchell (1996) consistently underestimates the IWC and Brown and Francis (1994) overestimates the IWC for smaller particles and underestimates it for larger particles.

We will continue to pursue the two-parameter technique for other habits. Distributions for a and b in both mass and v_t (not shown here) show that a single a, b pair is not appropriate.

References

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