1.3 SUMMARY OF IN SITU OBSERVATIONS OF CIRRUS MICROPHYSICS DURING FIRE II: INSTRUMENTAL RESPONSE

W. Patrick Arnott*, Timothy. J. Ulrich, Rebecca Cole, and John Hallett
Desert Research Institute, Atmospheric Sciences Center, Reno NV 89506

Michael R. Poellot
Dept . of Atmospheric Sciences, Univ. North Dakota, Grand Forks, ND

[1]1. CIRRUS OBSERVATIONS

Winter observations of cirrus crystal content were obtained during the FIRE 2 (First ISCCP Regional Experiment) in 1991 near Coffeyville, Kansas. The instruments used were a PMS 2DC, FSSP, and the DRI formvar replicator. The 2DC data was analyzed using the 'entire in' technique as described in (Arnott, et. al., 1994). The formvar replica was analyzed using a digital image analysis system (Turner, 1996). Many detailed images of cirrus crystals from the replicator data are available at URL http://www.dri.edu/replica. This paper covers the average instrument comparison between the 2DC and replicator for some 40 time intervals of duration 10 seconds each, and represents the entire project.

Figures 1 and 2 show the average size spectra obtained with the replicator and 2DC for different temperature groupings. Note that the replicator shows considerably more crystals than the 2DC. This news is not good, and will be elaborated on in more detail below.

Figures 3 and 4 show the standard deviation normalized by the average value as a function of temperature for the 2DC and replicator. The standard deviation magnitude is due mostly the cloud to cloud variation, and partially to counting statistics related to use of a finite number of samples to form a distribution function. Note that the replicator data shows that the greatest variation in size distributions is near the small and large particle ends of the spectrum. It is likely that the small particle variation is largely driven by cloud to cloud variation, and the large particle variation by counting statistics. Small particle counts vary by up to a factor of 3.5. Replicator and 2DC variation data compare reasonably well.

Various moments of the size distributions can be obtained and used to compute the total concentration, mean diameter, solar extinction coefficient (twice the measured total projected area of all particles), and ice water content (mass dimension relations from Arnott, 1994). These quantities are shown for various temperature groupings in the panels of Fig. 5. At each temperature grouping, the lowest, average, and largest values are shown.

[1]* *Corresponding author address:* W. Patrick Arnott, Desert Research Institute, PO Box 60220, Reno, NV 89506; email: pat@dri.edu.

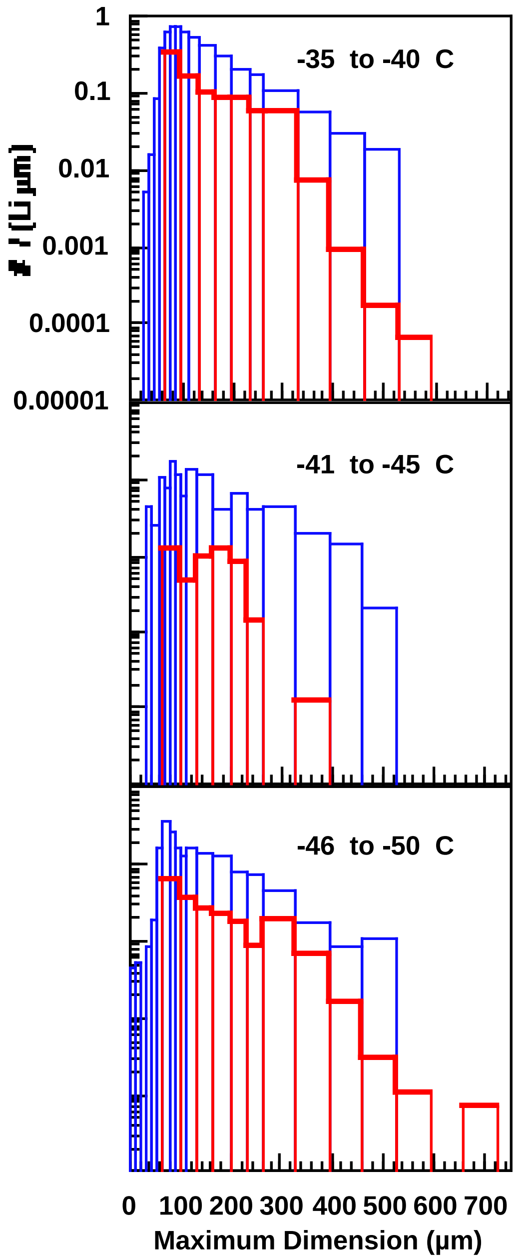

Fig. 1. Replicator and 2DC (thick lines) average size distributions for the indicated temperature ranges.

The decrease in average IWC in the -40 to -45 C range in Fig. 5 is likely due to the choice of days and time intervals and is not likely a general cirrus feature. The number of colder cirrus intervals was greatest of all; much of this data was from the volcanically-influenced cirrus case study (Sassen, et. al., 1995).

2. DISCUSSION

The discrepancy between replicator and 2DC results is unsatisfactory, and warrants further discussion. As an aid in the discussion, let us consider 10 seconds of analysis from the 11/22/91 flight starting at 3:52:06 (figs. 6, 7). Replica indicated moderate to high (5:1 to 20:1) smaller columns and larger bullet rosettes, and 179 particles were counted for a total concentration of 69.2/Li in 11.8 sec., giving a sampling rate of 0.22 Li/sec. The 2DC counted 237 particles in 8.7 sec., for a total concentration of 12.1/Li, and an average sampling rate of 2.3 Li/sec. Replicator spectra are determined by the microscope objective area of view, aircraft speed, film speed, sampling slit width, and number of particles on a given image. The 2DC algorithm was developed at DRI, with the sample

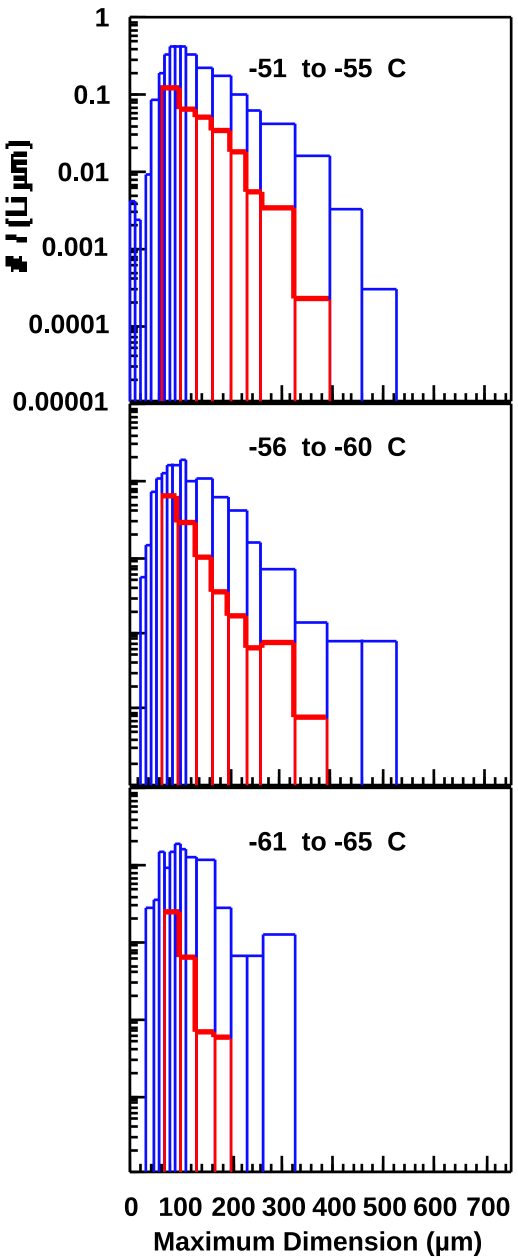

Fig. 2. Same as figure 1.

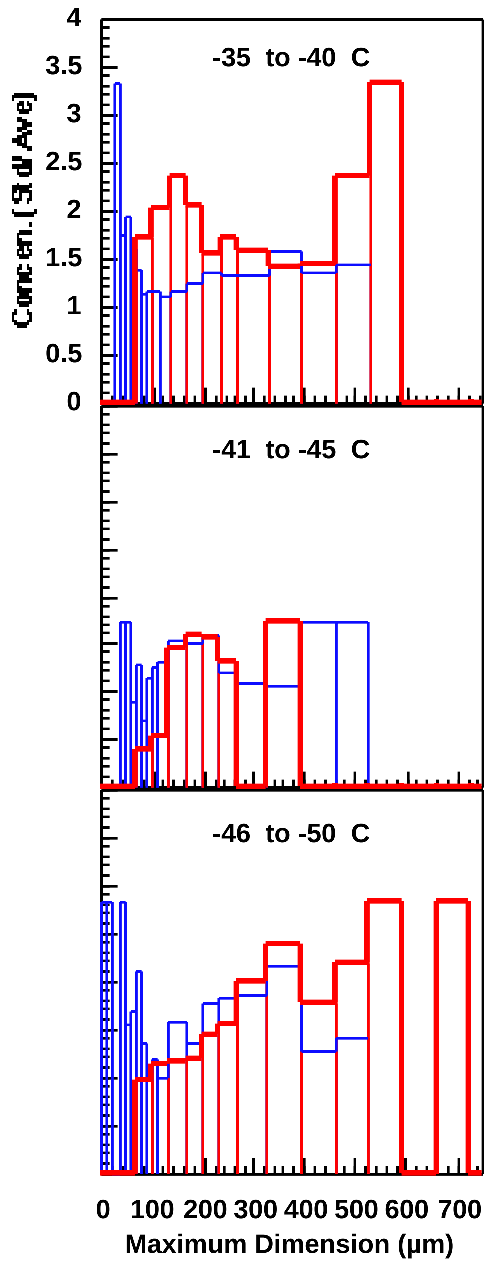

Fig. 3. Size distribution standard deviation normalized by the average distributions for replicator and 2DC (thick lines), for the indicated temperature ranges.

volume subroutine from UND so that both analysis code give the same size spectra. The replicator size spectra were computed as discussed in (Arnott, 1994; Arnott, 1995; and Turner, 1996). Many of the smaller columns observed in the replica from this case would generally not be counted by the 2DC, as their minimum dimension was less than the smallest resolvable size, 33 μm, needed to trigger the 2DC. The 2DC is known to have crystal habit dependent behavior (Baumgardner, 1997).

A curve fit of replicator number concentration to 2DC values for the data in the upper panel of Fig. 5 is

[Rep. Conc] = 2.666 [2DC Conc] + 16.44 / Li .

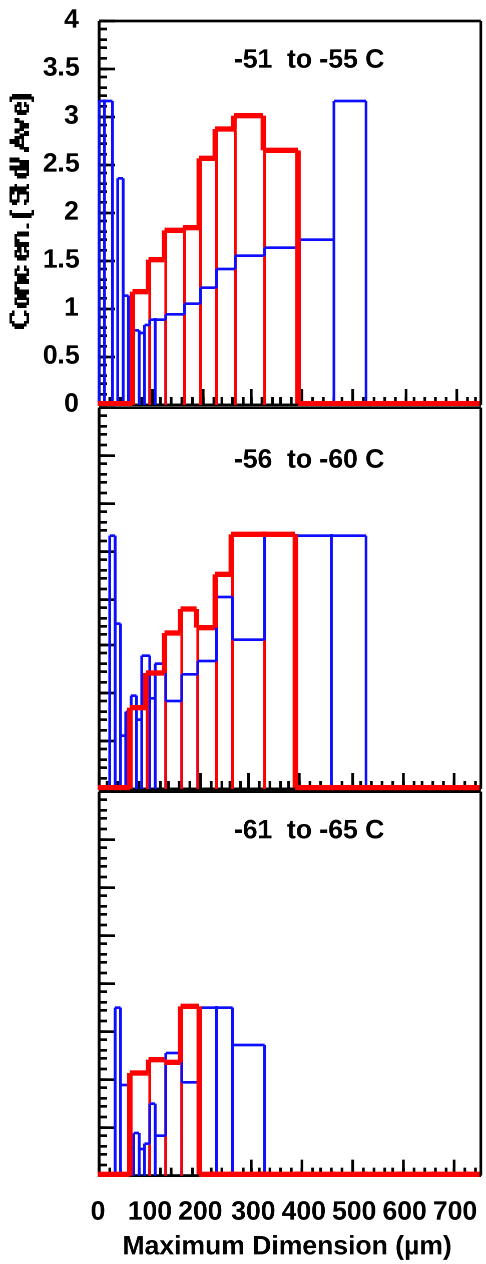

Fig. 4. Same as figure 3.

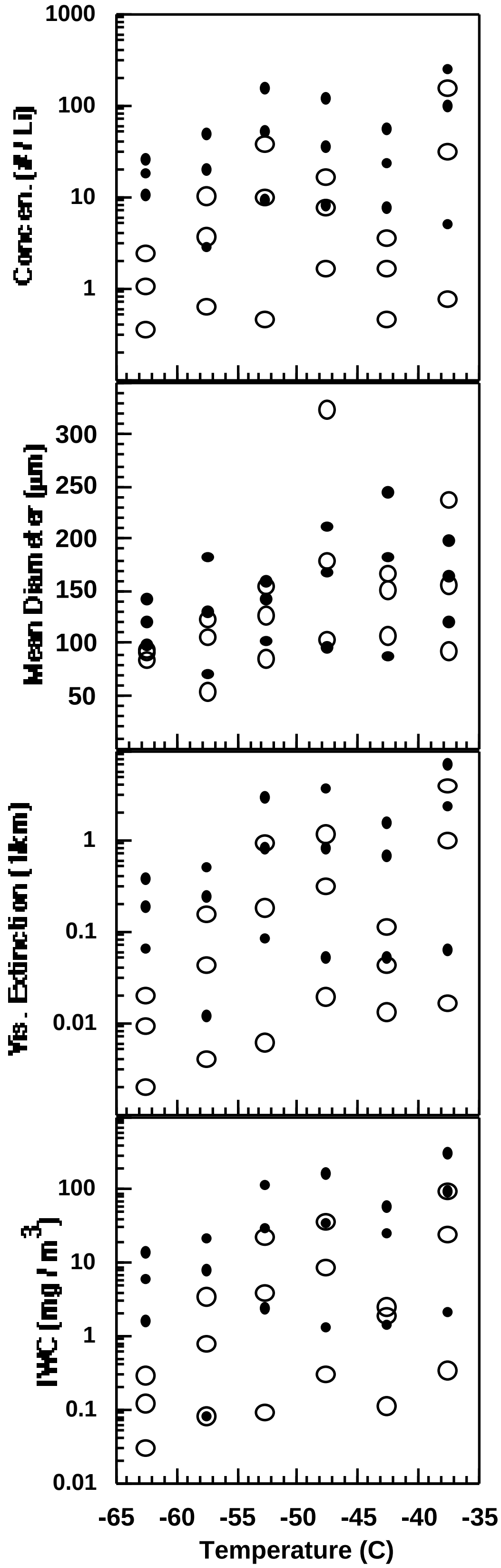

Fig. 5. Moments for replicator (dots) and 2DC (circles).

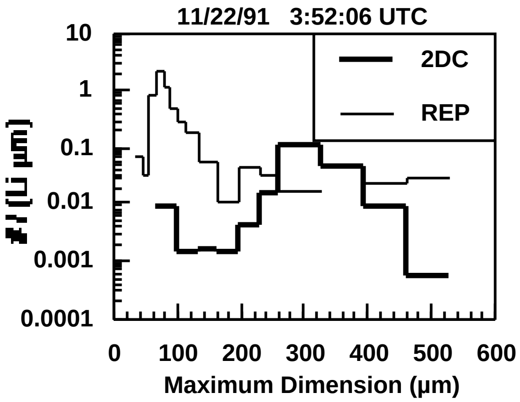

Fig. 6. Replicator and 2DC size spectra for one interval.

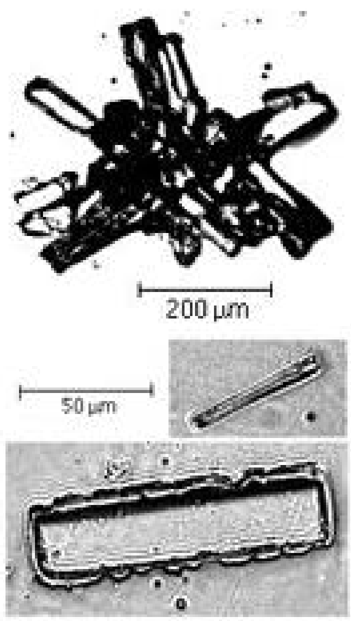

Fig. 7. Replica from the interval of Fig. 6.

This curve fit with an offset of 16.44/Li would require that we count approximately 43 artifact (not real) crystals in the replicator data for every size interval. While the replica analysis is time consuming (a human operator must point the mouse on the computer screen at every crystal that is counted), the analysis is typically conservative, where we choose not to count questionable images. However, the 2DC size bins have sampling rates varying from 1.2 Li/s for the 65-98 µm bin, 5.3 Li/s for the 164-197 µm bin, and 3.3 Li/s for the 461-527 µm bin for the 11/22/91 case study mentioned above (true air speed 118 m/s). The sample rate variation is due to depth of field correction for the smaller bins, and sample area correction for larger bins (larger particles are less likely to pass cleanly over the array, and thus have a smaller sample rate). This nonlinear sample rate for various bins compounds the prospect of a constant offset between replicator and 2DC counts. It should be noted that satisfactory agreement (to the eye) among replicator and 2DC size spectra in Figs. 1 and 2 can be obtained by dividing replicator spectra by 5.

Recent airspeed corrections for optical array probes (Baumgardner and Korolev, 1997) were developed to improve the agreement among 1DC, 2DC and FSSP instruments for water drop spectra in overlapping size bins. It is noteworthy that the 2DC corrections ranged from an increase of the size spectra at 45 µm by more than a factor of 10, to no increase in the spectra for particles larger than 200 µm (i.e. a *decrease* in the sample rate at 45 µm by a factor > 10). We have not applied any of these new corrections to our 2DC analysis.

We do not claim that the replicator size spectra is the correct value and the 2DC is incorrect, but only point out the observations we have made from the data set. Each probe has its advantage or disadvantage in terms of ease of analysis, resolution, artifact, etc, but in the end, they should all agree on size spectra. The replicator data has not been corrected for collection efficiency less than one for the smaller sizes, and so may present an unrealistically low estimate of the small crystal content of cirrus. Such collection efficiency corrections would be very habit dependent, and are not likely to be accurate enough in general for reliable spectra estimates. Cirrus observations are still imprecise, and are in need of an absolute measurement method.

Acknowledgements. DRI and Poellot acknowledge NASA support under grants NAG 1-1707 and NAG 1-1706, respectively.

3. REFERENCES

Arnott, W. P., Y. Dong, J. Hallett, and M. Poellot, 1994: Role of small ice crystals in radiative properties of cirrus: A case study, FIRE II, Nov. 22, 1991. *J. Geophys. Res.,* **99**, 1371-1381.

Arnott, W. P. and J. Hallett, 1995: Automated analysis of aircraft ice particle data. Final Report, NASA Grant NAG-1-1546.

Baumgardner, D. and A. Korolev, 1997: Airspeed corrections for optical array probe sampe volumes. *J. Atmos. Oceanic Technol.* **14**, 1224-1229.

Sassen, et. al., 1995: The 5-6 December 1991 FIRE IFO II jet stream cirrus case study: Possible influences of volcanic aerosols. *J. Atmos. Sci.* **52**, 97-123.

Turner, M., 1996: Digital image analysis of replicator ice crystal data for detection of small particles in cirrus clouds. Master Thesis, Univ. Nev. Reno, 114 pages.