P2.64 ASSESSING RADAR REFLECTIVITY RETRIEVAL METHODS WITH IN-SITU OBSERVATIONS OF CLOUD HYDROMETEOR SPECTRA.

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1. INTRODUCTION

Ground and satellite radar measurements are used to infer cloud properties. Retrieval methods assume a relationship of radar reflectivity to the distributions of hydrometeor particle size and shape. In-situ aircraft measurements of cloud particle properties provide a means for validating and improving retrieval methods. Radar reflectivity is proportional to a power of the instrumentally determined particle size. Effective values of this power, ranging between 3.8 and 4.8 for ice clouds, are described in the literature (Locatelli and Hobbs, 1974, Cunningham, 1978, Heymsfield and Parrish, 1978). This implies that a few large particles can dominate the radar reflectivity. It is therefore very important to accurately characterize this part of the spectrum and to determine possible contributions from large particles beyond the instrument measuring limits. It appears that more than 50% of the reflectivity calculated from in-situ measurements of ice crystal spectra comes from particles with sizes between 6.4mm and 12.8 mm (Figure 1). The PMS-2DP 200-6400 micron probe is the standard instrument used for measuring particle sizes in this range. Because large particles greater than 6.4 mm cannot be completely imaged, and many smaller particles are only partially imaged, in order to determine the sizes of large particles some approximations need to be made, such as assuming circular geometry of the particles.

The goals of this study were to 1) examine in-situ measurements of particle size spectra to determine how often radar reflectivity is contributed by large particles >12.8 mm, and then 2) estimate the actual contribution to reflectivity from large particles with sizes above the instrument measuring limits by fitting gamma distributions to the spectra and extrapolating beyond the largest measured particle size.

2. DATA

Data from 97 research flights collected by Environment Canada during four field projects were examined. Flights were in stratiform winter clouds. The projects are: CFDE1 (maritime environment), CFDE3 (continental environment), FIRE.ACE (arctic environment) and AIRS1 (continental environment) (see Isaac et al., 2001; Gultepe and Isaac, 2002). The data set represents 34,000 km of in-cloud data collected at temperatures <= 0^{o}C. Particle concentrations and dimensions were measured with three PMS 2D probes: a 2D-C 25-800 micron probe, a 2D-Grey 25-1600 micron probe and a 2D-P 200-6400 micron probe. Data were averaged over both 30 second and 300 second intervals and assessed as liquid, mixed or glaciated phase (Cober et al., 2001). Particle images were tested using the Cober et al., (2001) rejection criteria and processed following the center-in technique (Heymsfield and Parrish, 1978). Circular symmetry is assumed to locate the particle center and size. Only particles with their center in the diode array are processed. Particle concentration spectra up to 12.8 mm were extracted and the corresponding reflectivity spectrum for glaciated phase was calculated using the method of Locatelli and Hobbs, (1974).

3. PREVIOUS EVIDENCE FOR MISSED REFLECTIVITY

A simple indicator for determining whether any reflectivity has been missed is the slope of the reflectivity spectrum at 12800 microns. (Bailey et al., 2005). The percent of reflectivity spectra rising

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at 12.8 mm was determined for 30 and 300 second averages and two temperature ranges (0 to -13°C and 0 to -50°C) for each project. The results (Table 1) indicate that 4% to 17% of records measured with the 2DP instrument may be underestimating *some* reflectivity because of the presence of particles too large to be accurately recorded (the largest values are for warm temperatures and long averaging times). However, these results say nothing about *how much* reflectivity (in dBZ) is being missed.

4. PREDICTING MISSED REFLECTIVITY WITH A GAMMA DISTRIBUTION MODEL

A gamma distribution.

$$y = c\, d^{(a-1)} \;\; \exp(-d/b)$$

was fitted to each 30 or 300 second concentration spectrum for each project, where *d* is the instrument-measured particle size and the parameters *a*, *b* and *c* are the shape, scaling and normalization factors of the fit. A single gamma distribution would not fit the entire range of measured concentration data from the combined 2DC and 2DP instruments and also provide a good fit to the tail end of the spectra at high diameters. Since it was important to represent the spectra well at the high diameters, it was decided, after some experimentation, to fit the spectra between 2800 microns and the instrument cutoff of 12.8 mm (the "fitting range"). Figure 2 gives an example of a measured spectrum and the three gamma distributions fitted to it. Scatter plots of modeled and observed concentration and reflectivity (Figure 4) show the effectiveness of the fitting method.

The resulting fitted gamma distributions were used to extrapolate the concentration spectra from 12.8 mm out to 50 mm (greater than the largest expected particle size) and the amounts of missed reflectivity at sizes greater than 12.8 mm were calculated (Figure 3)

A large fraction of spectra (often 50% for some flights) had either no particles or very few that were large enough to lie within the fitting range. These could not be satisfactorily fitted, and were discarded. However, these spectra also presumably have no particles in the extrapolation range, and discarding them does not miss any radar reflectivity.

5. RESULTS

The estimated missing reflectivies (the difference between the modeled reflectivities to 5cm and the observed reflectivities) are plotted in cumulative histograms in Figure 5 for each project, for two temperature intervals and two averaging periods. The results are summarized in Table 2. It is clear that up to 15% of spectra are underestimating at least a small amount of reflectivity (> 0.1 dBZ) and that the effect is stronger for warmer temperatures. A correlation with averaging interval is not clear. These trends are not evident for the higher values of missed reflectivity. Only 1% to 2% (15 to 26) spectra for each project have missing reflectivity greater than 1dBZ. Each project has a few spectra (< 10) that are missing a large amount of reflectivity (for example > 10dBZ for project CDFE3)

6. DISCUSSION AND CONCLUSIONS

A good gamma fit to the large-particle tail of 2DP-derived spectra was possible. The resultant estimates of the frequency of missing reflectivity agree in general with earlier estimates. From 5% to 15% of spectra are missing some reflectivity at the 0.1 dBZ level or greater, but typically only 1% to 2% of spectra (15 to 26 per project) are missing more than 1 dBZ.

The frequency and amount of missed reflectivity is greater when a warm temperature range is considered. A few spectra (< 10 per project) are missing a large amount (>5dBZ) of reflectivity. A case study of these individual spectra and their particular conditions might allow us to determine if and when they are important.

In general, it appears that detection of particle sizes up to 12.8 mm is sufficient in almost all cases to detect all but 1 or 2 dBZ of the radar reflectivity due to glaciated phase hydrometeors. The counting accuracy of hardware and software at high diameters has yet to be quantified; the associated errors in determining the particle size could produce larger uncertainties in the reflectivity than 1 to 2 dBZ.

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REFERENCES

Bailey M.E., G.A. Isaac, S.G.Cober, A.V. Korolev, and J.W. Strapp, 2005: The Contribution of Large Particles to Radar Reflectivity. IAMAS 2005, August 2-11, Beijing, China.

Cober, S.G., G.A. Isaac, A.V. Korolev, and J.W. Strapp, 2001: Assessing cloud-phase conditions. J. Appl. Meteor., 40, 1967-1983.

Cunningham, R.M., 1978: Analysis of particle spectra from optical array (PMS) 1D and 2D sensors. Amer. Meteor. Soc., 4th Symposium Meteorol. Obs. Instrument., Denver, USA, 10-14 April 1978, 345-350.

Gultepe, I. and G.A. Isaac, 2002: The effects of air-mass origin on Arctic cloud microphysical parameters during FIRE.ACE. *J. Geophy. Res., 107,* (C10), SHE 4-1 to 4-12.

Heymsfield, A.J. and J.L. Parrish, 1978: A computational technique for increasing the effective sampling volume of the PMS two-dimensional particle size spectrometer. J. Appl. Meteor., 17, 1566-1572.

Isaac, G.A., S.G. Cober, J.W. Strapp, A.V. Korolev, A. Tremblay, and D.L. Marcotte, 2001: Recent Canadian research on aircraft in-flight icing. Canadian Aeronautics and Space Journal, 47-3, 213-221.

Locatelli, J.D. and P.V. Hobbs, 1974: Fall speeds and masses of solid precipitation particles. J. Geophys. Res., 79, 2185-2197.

	300-s 0>T>-50ºC	300-s 0>T>-13ºC	30-s 0>T>-50ºC	30-s 0>T>-13ºC
AIRS	4%	**7%**	4%	6%
CFDE3	11%	**17%**	6%	9%
CFDE1	9%	**12%**	7%	9%

Table 1: The percent of reflectivity spectra with positive slope at 12.8 mm. The largest values (in bold) are for warm temperatures and long averaging times. (IAMAS 2005)

PROJECT	***t_{AV} (SEC)***	***T (°C)***	***Z_{MISSED} >0.1 dBZ***	***Z_{MISSED} >1 dBZ***	***Z_{MISSED} dBZ_{MAX}***	***N_{TOT}***	***N_{FITTED}***
CFDE-I	30	0 to -13:0	**11 %**	2 %	~3.4	895	760
CFDE-I	30	0 to -30:0	7 %	1.5 %	~3.4	1167	781
CFDE-III	30	0 to -13:0	**11 %**	2 %	> 10	1292	924
CFDE-III	30	0 to -30:0	8 %	2 %	> 5	2099	1075
AIRS	30	0 to -13:0	**10 %**	1 %	>3	1060	250
AIRS	30	0 to -30:0	5 %	2 %	> 3	2577	1327
CFDE-I	300	0 to -13:0	**15 %**	1 %	~ 1.2	89	84
CFDE-I	300	0 to -30:0	11 %	1 %	~1.2	118	97
CFDE-III	300	0 to -13:0	**12 %**	1 %	~ 1	98	88
CFDE-III	300	0 to -30:0	12 %	4 %	>10	173	117
AIRS	300	0 to -13:0	**7%**	1%	>3	113	99
AIRS	300	0 to -30:0	5%	2%	>3	241	149

Table 2: Statistics of estimated missed radar reflectivity, tabulated by project, record averaging time, and temperature range. Percentage of fitted spectra which gave missed radar reflectivity in excess of 0.1 and1 dBZ respectively and largest dBZ observed. N_{TOT} and N_{FITTED} are the total number of spectra examined and the number fitted. Largest values are in bold.

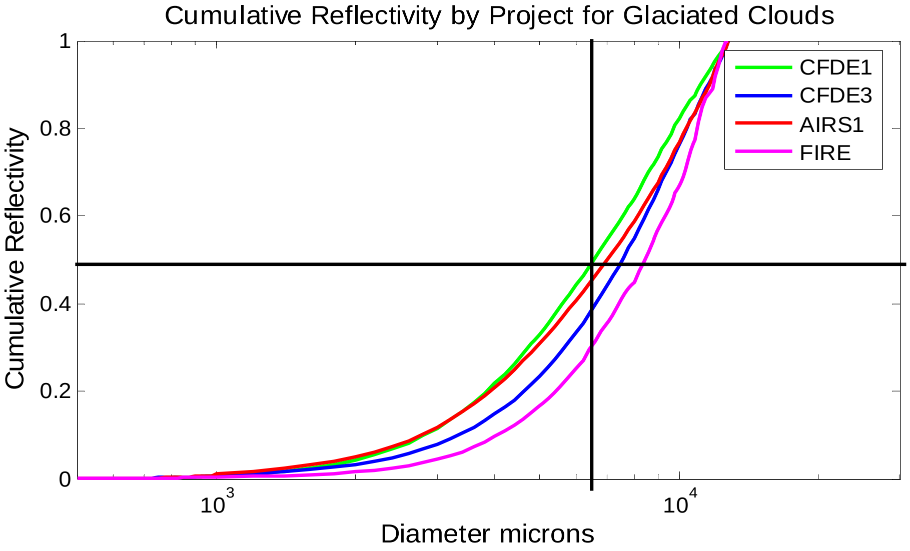

Figure 1: Average normalized Cumulative reflectivity for four projects. 50% of the reflectivity calculated from project average spectra for ice clouds comes from particles with sizes between 6.4 and 12.8 mm

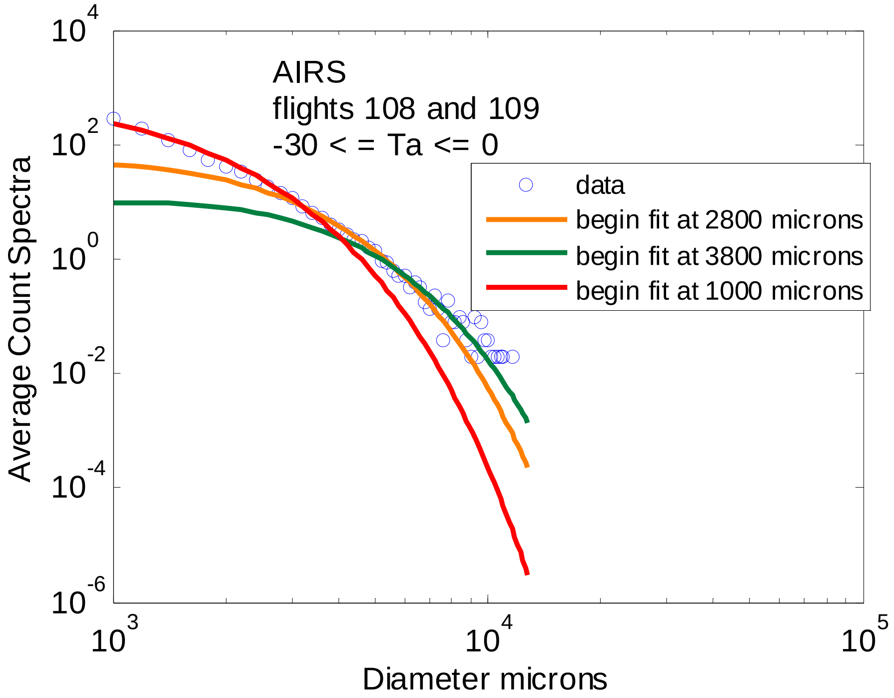

Figure 2: Comparison of gamma fits over different size ranges to the average count spectra for two flights from the AIRS project. The starting diameters for the fits are 1000, 2800 and 3800 microns.

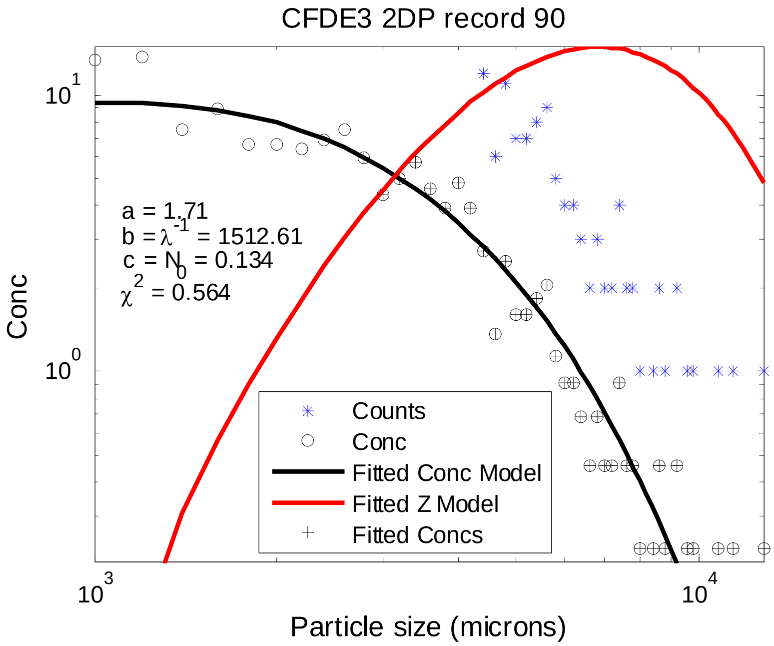

Figure 3: Example of a gamma distribution fit to a single 30 second concentration spectrum (black symbols) for project CFDE3. The gamma function is fitted to the concentration spectrum between 2800 microns and the last non zero data point (black + symbols). The modeled concentration is extrapolated back to 1000 microns and forward to 5cm (black curve). The modeled reflectivity (red curve) is calculated from the modeled concentration. Note that there are typically fewer than 10 particle counts (blue stars) in each size bin in the model fitting range. Gamma fit parameters are shown on the plot. The Y axis is absolute for concentration and counts, but relative for Z.

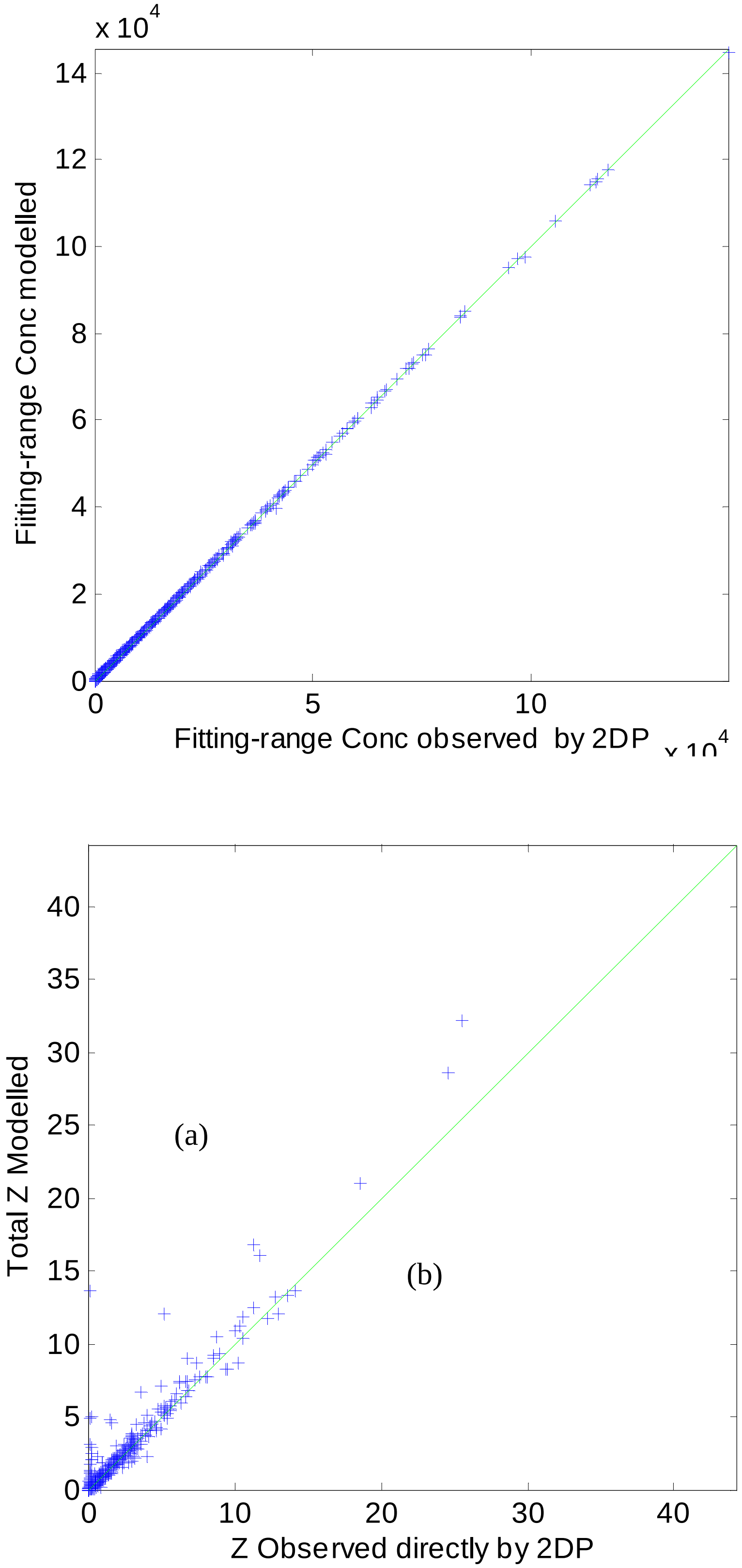

Figure 4: (a) A comparison of modeled to measured concentration in the instrument measuring range for 1075 ice spectra for project CFDE3 shows the effectiveness of the fitting method. (b) A similar comparison for reflectivity.

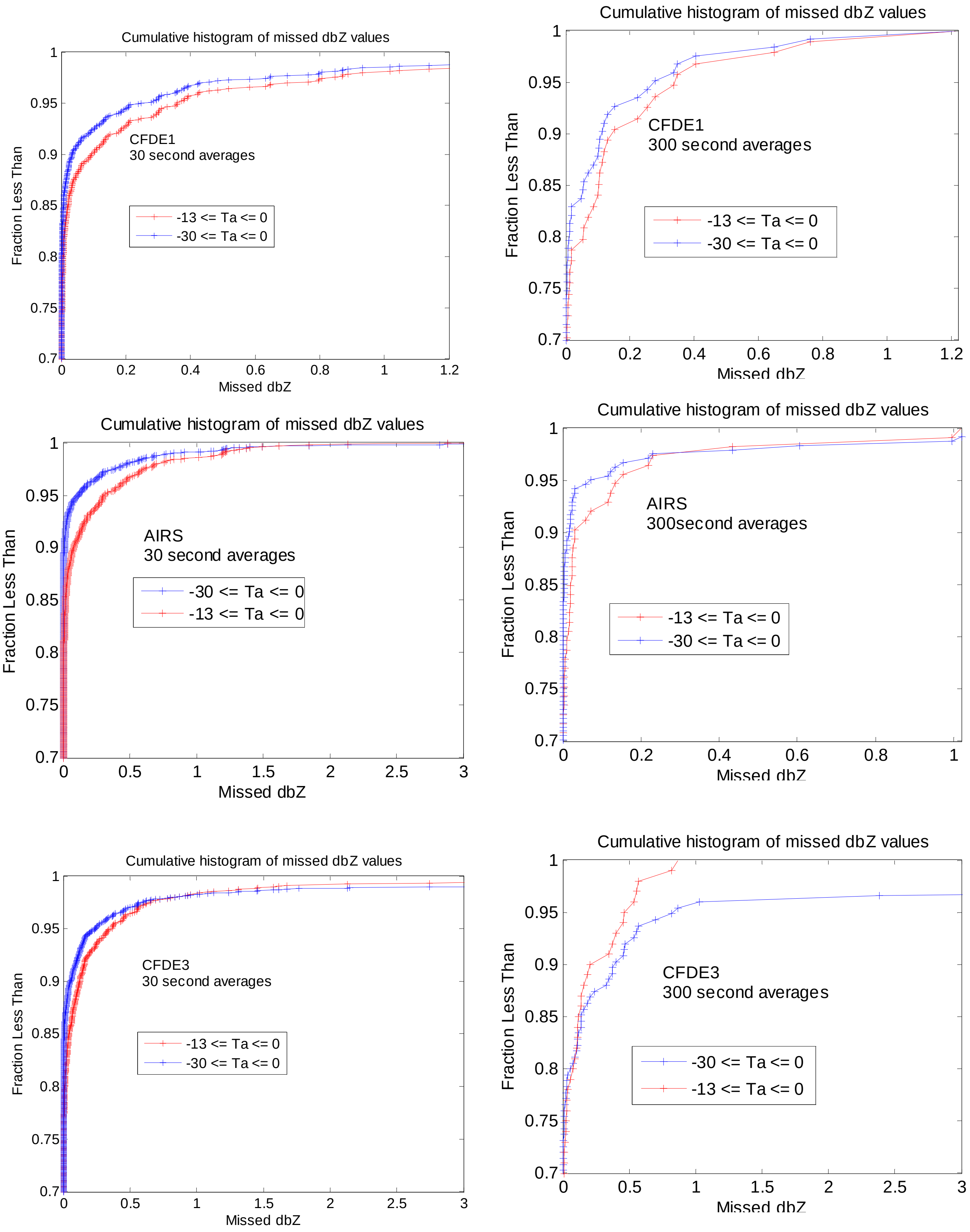

Figure 5: Cumulative histograms of the missed reflectivity (modeled reflectivity to 5cm – observed reflectivity) for each project. Results are shown for data averaged over 30 seconds and 300 seconds and for temperature intervals -30ºC to 0ºC and -13ºC to 0ºC