3.2 PARTICLE SPECTRA IN STRATIFORM WINTER CLOUDS

by

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1. INTRODUCTION

It is important to know the cloud particle spectra in clouds for a wide variety of reasons. First, the spectra give information on how particles are formed. Second, in order to model precipitation production, it is useful to know the spectra. Third, the remote detection of cloud microphysical parameters requires some knowledge of the particle spectra. Of course, clouds are complicated because they can be all liquid, all ice, or exist in a mixed phase environment where both liquid and ice are present.

Ever since the pioneering works of Marshall and Palmer (1948) and Gunn and Marshall (1958) there have been many studies of the size distribution of rain and snow in precipitating clouds. There have also been a number of articles on the size distribution of ice particles in cirrus and frontal clouds (e.g. Platt 1997, and Heymsfield et al. 2002).

This paper uses a large data set to examine the cloud particle spectral characteristics within all liquid and glaciated clouds. The spectra were measured in stratiform winter clouds during several field projects described in Table 1. The Canadian Freezing Drizzle Experiments (CFDE I and III) and the Alliance Icing Research Study (Isaac et al. 2001) were conducted primarily to characterize aircraft icing conditions within clouds.

2. INSTRUMENTATION AND ANALYSIS TECHNIQUES

A description of the instrumentation used for these measurements is given in Cober et al. (2001a), and Isaac et al. (2001). The basic probes used and their nominal size ranges were the PMS FSSP Standard Range (3-45 μm), the PMS FSSP Extended Range (5-95 μm), the PMS 2D-C (25-800 μm) and the PMS 2D-P (200-6400 μm). For the 2D-C probe, only the particles larger than 100 μm were counted, because of uncertainties in counting and sizing particles from 25-100 μm with this probe. This creates a sizing gap between the FSSP and 2D-C probes which is seen on many of the plots. The analysis techniques, including the phase discrimination method, have been described in detail by Cober et al. (2001b). The total water content (TWC) measurements were made using the Nevzorov probe (Korolev et al. 1998).

For this paper, only the 30-s (approximately 3 km in path length) averaged spectra in all liquid and glaciated clouds, as defined by Cober et al. (2001b), are used. Mixed phase clouds pose many challenges for determining the spectra and consequently the analysis will be considered in subsequent papers. Table 2 shows the frequency of occurrence of all liquid, mixed, and glaciated phase clouds for maritime (CFDE I) and continental clouds (CFDE III and AIRS). Further discussion regarding mixed phase clouds can be found in Cober et al. (2001b) and Korolev et al. (2002), but it can be seen from Table 2 that they occur quite frequently.

It is also a problem to specify the size distribution of small ice particles. Gultepe et al. (2001) discussed the problems associated with the FSSP and 2D probes in glaciated clouds. Although Gardiner and Hallett (1985) noted that the FSSP could over count ice particles, other authors indicate otherwise. For example, Arnott et al. (2000) and Gayet et al. (1996) suggested that FSSP measurements in glaciated conditions could be used. It was shown that FSSP spectra reasonably agreed with the spectra of the Desert Research Institute Cloud Scope Instrument when the concentration of large particles was low enough (Arnott et al. 2000). However, because of the uncertainties, and the fact that the Standard Range and Extended Range FSSPs did not agree in glaciated clouds, the measurements are not reported here.

3. SPECTRA

Average number concentration, mass and reflectivity spectra for liquid drops were determined as a function of equivalent circle diameters (D) calculated by determining the projected area (A) of each particle, and then determining the diameter of a circle having that area.

$$D = \sqrt{\frac{4A}{\pi}} \qquad (1)$$

However, for ice particles, it is more difficult to describe the particles because they have many different shapes. The ice particle number concentration spectra were calculated in a similar manner as done for the liquid

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spectra. However, for the mass and reflectivity spectra, the following methods were used. Using A, the equivalent melted diameter (D_{em}) was determined using relationships suggested by Cunningham (1978) for "aggregate plates and dendrites:"

$$D_{em} = 0.39A^{0.31} \qquad A \le 0.25 \tag{2}$$

$$D_{em} = 0.44A^{0.40} \qquad A > 0.25 \tag{3}$$

where D_{em} is in mm and A is in mm^2. It should be noted that D and D_{em} are uniquely related. The Ice Water Content (IWC) or ice mass was calculated as follows:

$$IWC = \sum \frac{\pi}{6} \rho_w N(D_{em}) D_{em}^3 \tag{4}$$

where ρ_w is the density of liquid water and N is the concentration of particles. Following Heymsfield et al. (2002), the reflectivity factor Z_e is calculated following the relationship:

$$Z_e = \sum N(D_{em}) D_{em}^6 \tag{5}$$

The results are shown in Figs. 1, 2 and 3 with equivalent circle diameter (D) used as the x-axis. Fig. 1 shows the number concentration, mass, and reflectivity factor spectra for CFDE I as a function of TWC. Fig. 2 shows the same results for CFDE III and AIRS combined. Fig. 3 shows the mass spectra as a function of static temperature. The area distributions were also determined because of their importance to radiation calculations, but space does not permit their inclusion.

The spectral shape for the maritime (CFDE I) and the continental (CFDE III and AIRS) projects are remarkably similar. Fig. 3 shows that there tends to be more mass as the temperature gets warmer. This is expected because a number of studies have shown how the TWC and/or LWC get larger with warmer temperature (Gultepe and Isaac, 1997; Cober and Isaac, 2002). The droplet concentration at small sizes is definitely lower in the maritime case, which again follows the expected trend.

4. CONCLUSIONS

When the total water content increases, the liquid spectra change shape, with there being fewer larger particles. The higher liquid water content cases probably represent "younger clouds" with shorter drop growth times. However, it is interesting to note that there are still a substantial number of large particles yielding a significant amount of reflectivity in these high total water content clouds.

As one might expect, there is a greater contribution of the larger particles to reflectivity and the small particles dominate the total number concentration. The mass distributions show a rather flat shape.

It should be mentioned that the mass curves for ice particles are actually related to particle area through Eqs. 2, 3, and 4. The reflectivity factor for ice actually depends approximately on area squared. Further studies are needed to determine the reflectivity from the linear dimensions of the particles, rather than using D_{em}.

There is evidence that the total reflectivity may not be captured by the PMS 2D-C and 2D-P probes. The larger CFDE III and AIRS I data set shows a more continuous increase in reflectivity at the larger sizes, in comparison to CFDE I. A probe which measures larger sizes is required to make sure reflectivity is adequately captured.

Since the analysis in the early stages, no relationships have been fitted to the data. However, it looks promising that a suitable parameterization can be found which would be useful to modelers and remote sensing experts.

5. ACKNOWLEDGEMENTS

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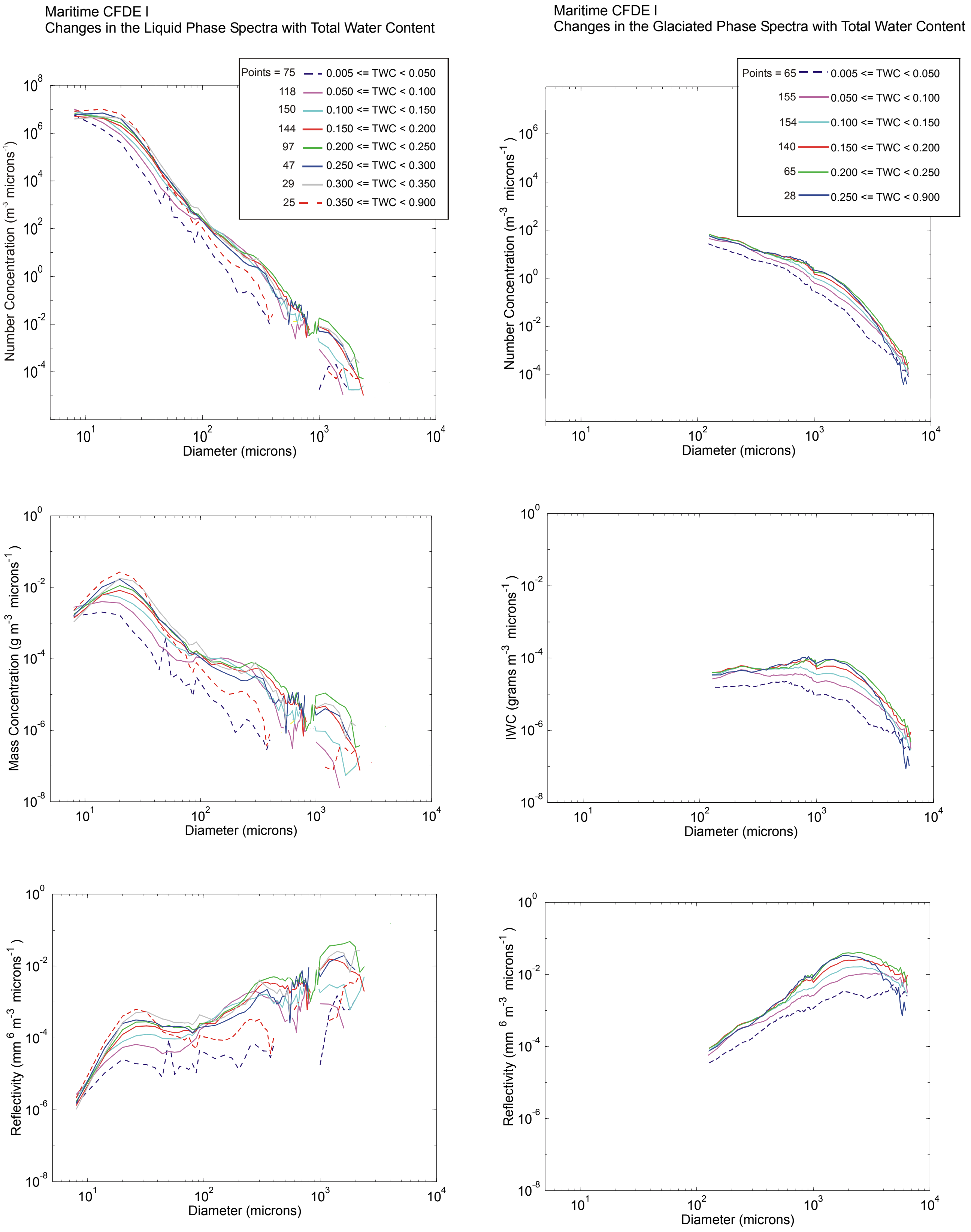
Project Name	Date	Flight Region	Number of flights	In-cloud path length (km)	Main air mass Type
CFDE I	March 1995	45°N-53°N; 54°W-63°W	12	7,848	Maritime
CFDE III	Dec. 1997-Feb. 1998	42°N-50°N; 71°W-83°W	26	15,592	Continental
AIRS	Dec. 1999-Feb. 2000	42°N-46°N; 74°W-82°W	25	9,998	Continental

Table 1: Information on the projects used for this paper. CFDE, and AIRS stand for the Canadian Freezing Drizzle Experiment, and the Alliance Icing Research Study respectively.

Phase	Total	Continental	Maritime
Liquid	27%	27%	26%
Mixed	46%	50%	21%
Glaciated	27%	23%	53%

Table 2: The frequency of occurrence of various phases for temperatures between 0 and –20°C.


Maritime CFDE I
Changes in the Liquid Phase Spectra with Total Water Content

Maritime CFDE I
Changes in the Glaciated Phase Spectra with Total Water Content

Fig. 1: Averaged spectra for CFDE I sorted by all liquid and glaciated 30-s values. The “number” of 30-s spectra used for each Total Water Content (TWC) are shown.

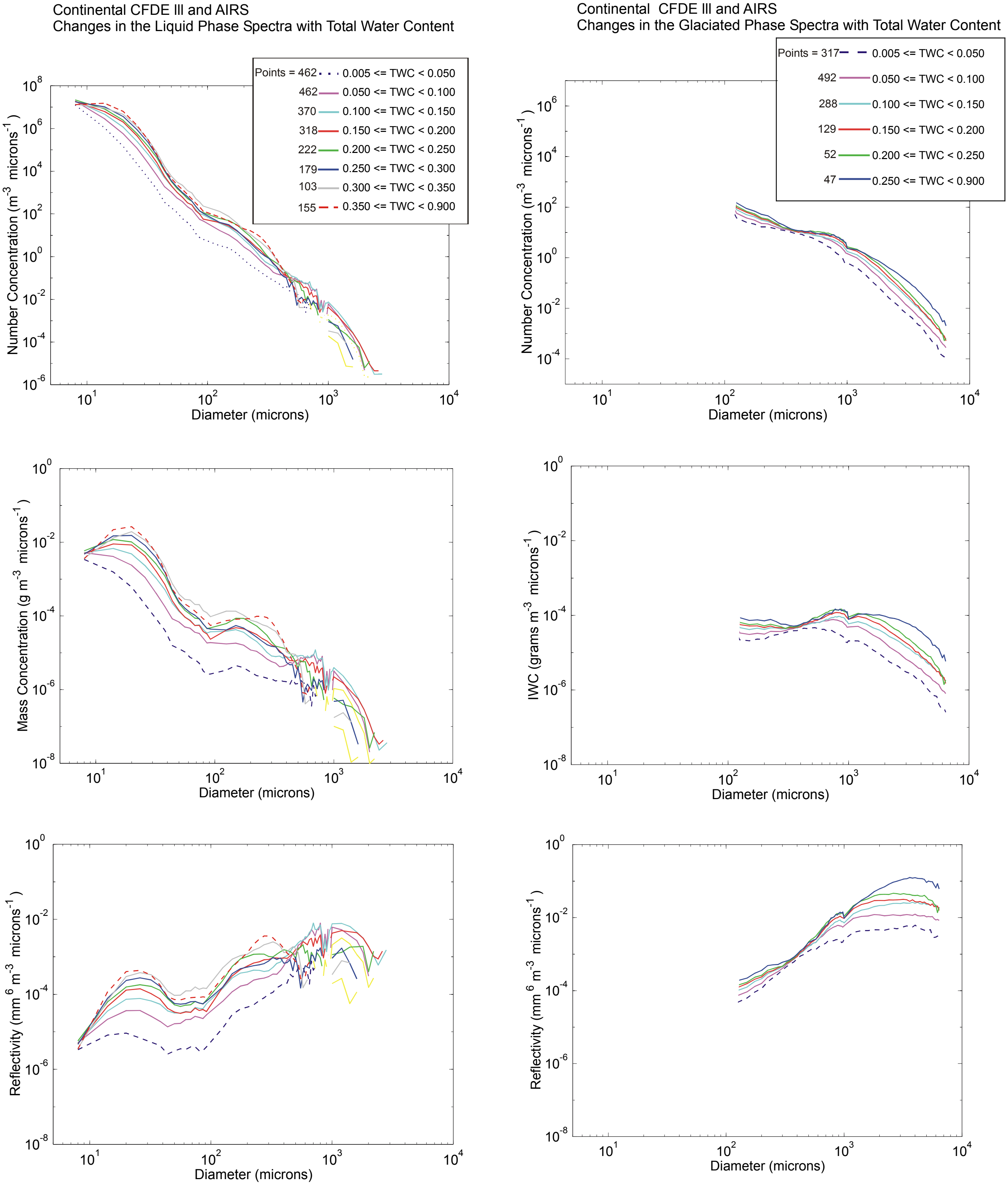


Fig. 2: Averaged spectra for CFDE III and AIRS sorted by all liquid and glaciated 30-s values. The “number” of 30-s spectra used for each Total Water Content (TWC) are shown.

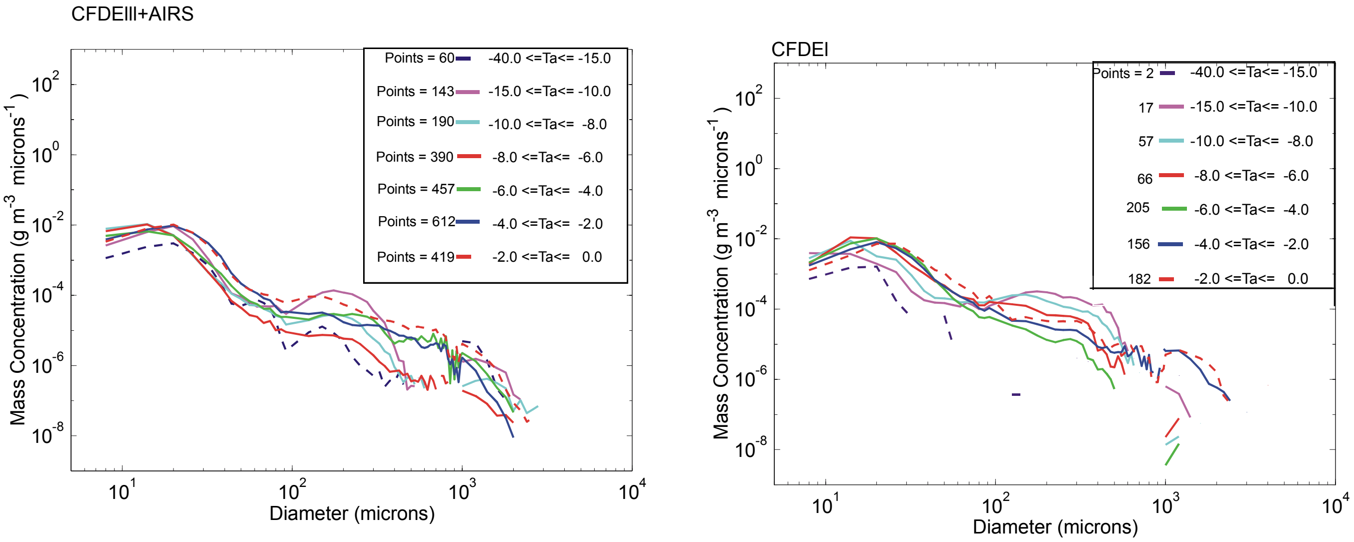


Fig. 3: Mass spectra for the continental (CFDE III and AIRS) and maritime (CFDE I) data sets as a function of temperature.