A GCM Parameterization of Ice Particle Mean Effective Sizes for High Latitude Cirrus Clouds and It's Comparison with Mid-Latitude Parameterization

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Introduction

Single-scattering properties of ice clouds depend on both ice water content (IWC) and effective size of cloud particles (Fu 1996; Fu et al. 1998). However, only the IWC information is provided in numerical models. Stephens et al. (1990) showed that the ice cloud feedback on a CO_2 warming simulation could be either positive or negative depending on the value of the ice particle size assumed. Parameterizations of ice particle sizes for mid-latitude and tropical cirrus clouds appear in recent literatures but little is done for high latitude ice clouds. Herein we present a parameterization of ice particle mean effective sizes for high latitude ice clouds and a comparison with mid-latitude one.

Definition of Ice Particle Mean Effective Sizes

The mean effective size for ice particles in ice clouds is defined in the form (Fu 1996)

$$D_{ge} + 2(3)^{1/2}IWC/(3\rho_I A_c) \quad (1)$$

where A_C is the total cross sectional area of ice particles per unit volume, and ρ_i the density of pure ice.

The parameterization of single-scattering properties of ice clouds in terms of IWC and D_{ge} is not sensitive to ice particle shapes because both mass and projected area of ice particles in ice clouds are preserved (Fu 1996).

For the parameterization purpose, we derive D_{ge} by analyzing in situ ice microphysics aircraft measurements.

Data

Data were collected during four field projects: the Beaufort and Arctic Storm Experiment (10/94) at the Canadian Western Arctic, the First ISCCP Regional Experiment (FIRE) Arctic Cloud Experiment (4/98-7/98), the Canadian Freezing Drizzle Experiments I (3/1995) at Newfoundland, and the Canadian Freezing Drizzle Experiments III (12/97-2/98) at Ontario and Quebec. The data we used in this study are those measured by particle measuring system (PMS) forward scattering spectrometer probe (FSSP), two-dimensional cloud (2DC) and two-dimensional precipitation (2DP) optical probes, and the Nevzorov LWC/TWC probes, as well as cloud temperatures. The Nevzorov probes provide a direct measurement of IWC (Korolev et al. 1998).

IWC from 2DC and 2DP Probes

As shown in Eq. (1), we need both IWC and A, to derive D_{ge}. To obtain reliable IWC from 2DC and 2DP probes we have examined different schemes that are used to convert the particle 2D-image to the mass by comparing the derived IWCs with direct Nevzorov measurements. We considered three schemes, which relate the particle mass to the projected area (Cunningham 1978), to the maximum length (Mitchell et al. 1990), and to the mean of the maximum chord lengths (Brown and Francis 1995). Figure 1 shows the comparison of IWCs from Mitchell et al (1990) and Brown and Francis (1995) with those from Cunningham (1978). The IWCs from Mitchell et al. (1990) and Brown and Francis (1995) are more than 30% larger than those from Cunningham (1978). Since the IWCs using the Cunningham (1978) scheme have the highest correlation with direct measurement, it is recommended that the Cunningham (1978) scheme be used. Another advantage of Cunningham (1978) is that this scheme is not as sensitive to the particles shapes as other two schemes.

Contributions of Small Ice Particles

One problem in analyzing ice microphysics measurements is how to consider ice particles smaller than -100 μm, which could not be reliably measured by 2D optical probes. In this research, the small particle size distribution was assumed to be a gamma function that is constrained by the total number of small particles measured by FSSP and the size distribution measured by the 2DC at the size of 125 μm. Figure 2 shows the IWCs derived from 2DC and 2DP with and without considering small particles versus direct measurements. We can see that there is little bias in the derived mean IWCs after incorporating small particles, when compared with direct measurements, which validates the Cunningham (1978) scheme with the consideration of small ice particles. As shown in Figure 3, the mean contributions of small ice particles to the total IWC and A_c are estimated to be 20% and 43%, respectively.

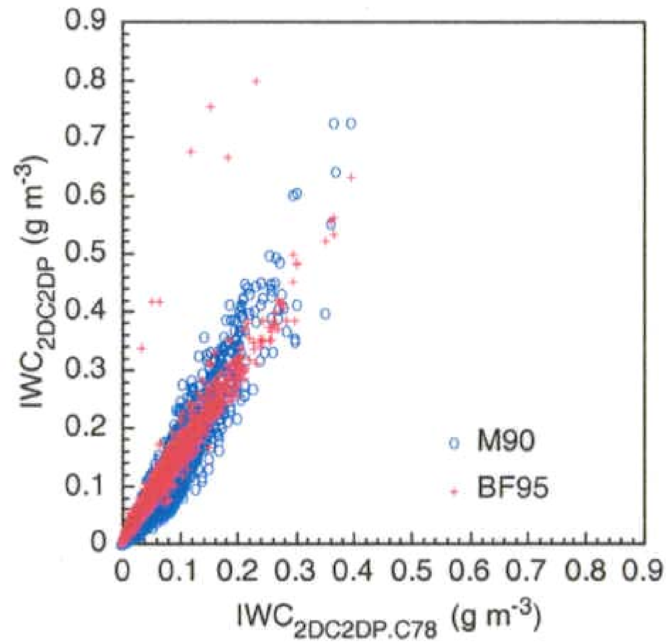

Figure 1. Comparison of IWCs using schemes of Cunningham 1978, Mitchell 1990, and Brown and Francis 1995 to convert the particle images measured by 2DC and 2DP to particle mass.

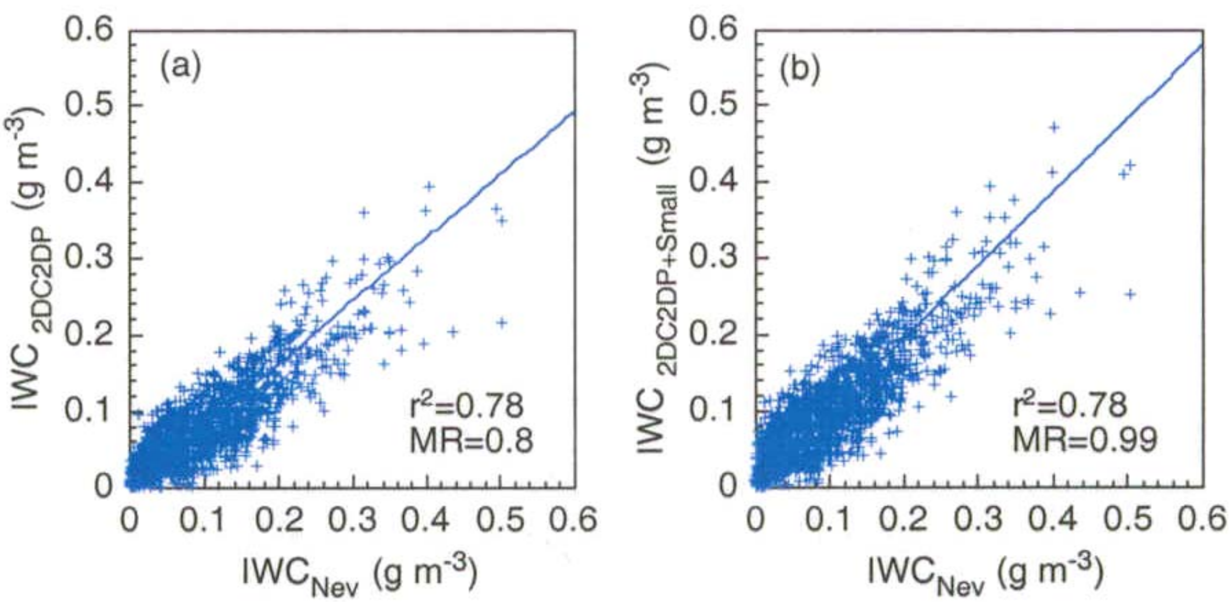

Figure 2. IWCs derived from 2DC and 2DP probes using Cunningham (1978) versus IWC directly measured from Nevzorov probe, (b) as in (a) but with the consideration of small particles.

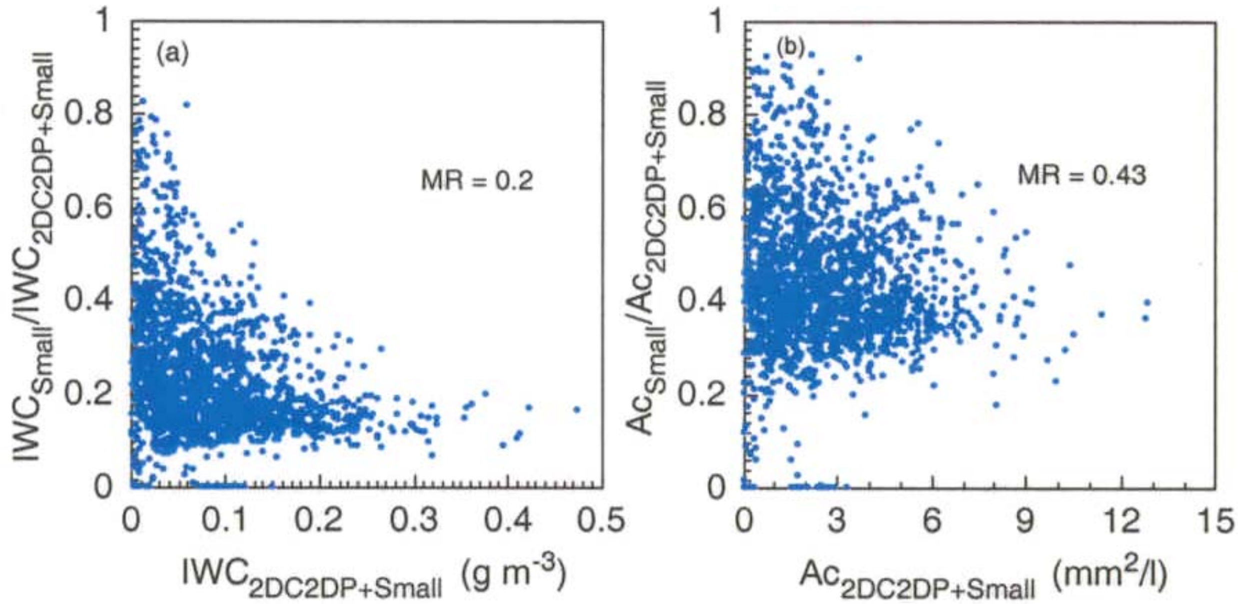

Figure 3. Relative contributions of small particles (<100 μm) to IWC and A_c versus IWC and A_c.

Parameterization of Mean Effective Sizes of Ice Particles

Figure 4 shows the mean effective size of ice particles as a function of cloud temperature. Without considering small ice particles, the mean effective size decreases with increasing cloud temperature from -40° to -20°C (Figure 4a), which is physically incorrect. The small particles act to reduce the D_{ge} from the range, 46 to 64 μm (Figure 4a), to the range 27 to 46 μm (Figure 4b). We find that the mean effective size can be parameterized as a function of cloud temperature in the form $D_{ge} = Ae^{-BT}$ with $r^2 = 0.92$ (Figure 4b), where A and B are 46.4 μm and 0.015°C^{-1}, respectively.

Comparison of Parameterizations Between Mid-Latitudes and High Latitudes

Ivanova et al. (2001) developed a parameterization of the ice particle mean effective size for mid-latitude cirrus clouds by using the ice particle size distributions measured during Atmospheric Radiation Measurement (ARM) and FIRE intensive operational periods. The IWC and A_c were derived from measured size distributions by assuming planar polycrystals to relate the ice particle size to its mass and cross section area.

Figure 5 shows the comparison of parameterizations between the mid- and high latitudes. The D_{ge} from Ivanova et al. (2001) is larger than that from the present study by 10 to 15 μm.

The difference can be due to the assumed ice particle shape in Ivanova et al. (2001), the schemes used to convert the particle geometric dimension to mass, and/or the differences between the mid-latitude and high latitude cirrus cloud systems. Further research is under way to understand the difference shown in Figure 5.

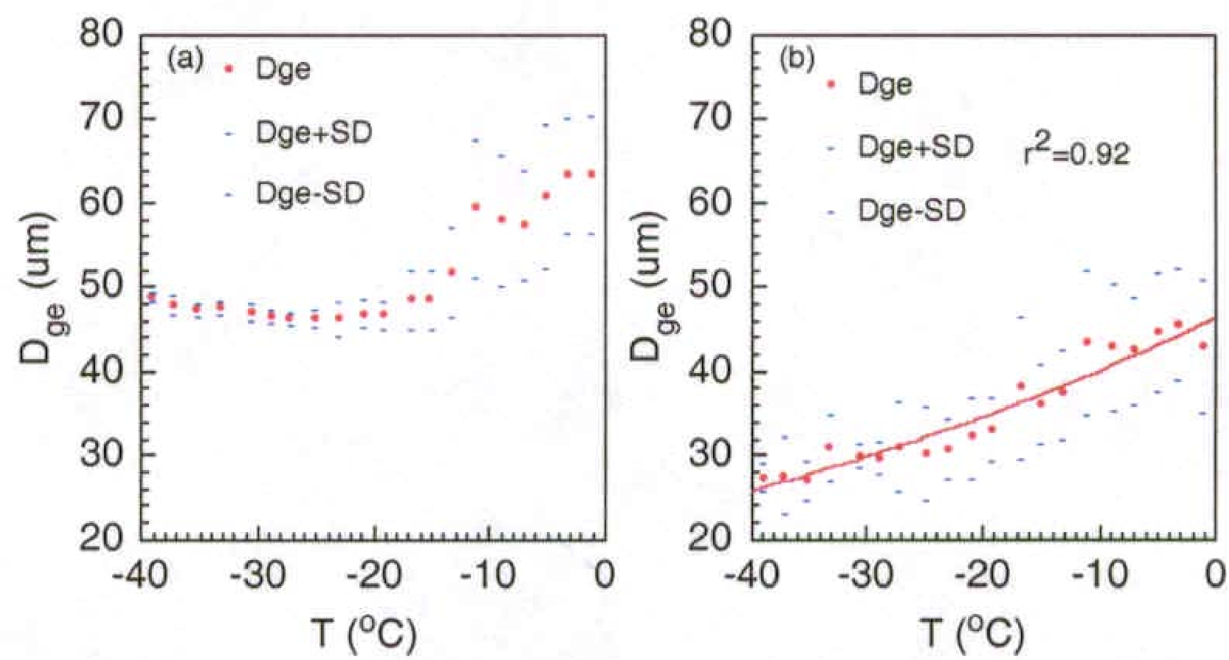

Figure 4. The mean effective size (D_{ge}) of ice particles as a function of cloud temperature. (a) D_{ge} derived from 2DC and 2DP optical probes, (b) as in (a) but with the consideration of small particles. The mean D_{ge} for every two °C cloud temperature is presented with the mean value plus and minus one standard deviation. Also shown in (b) is the fitting with r^2=0.92.

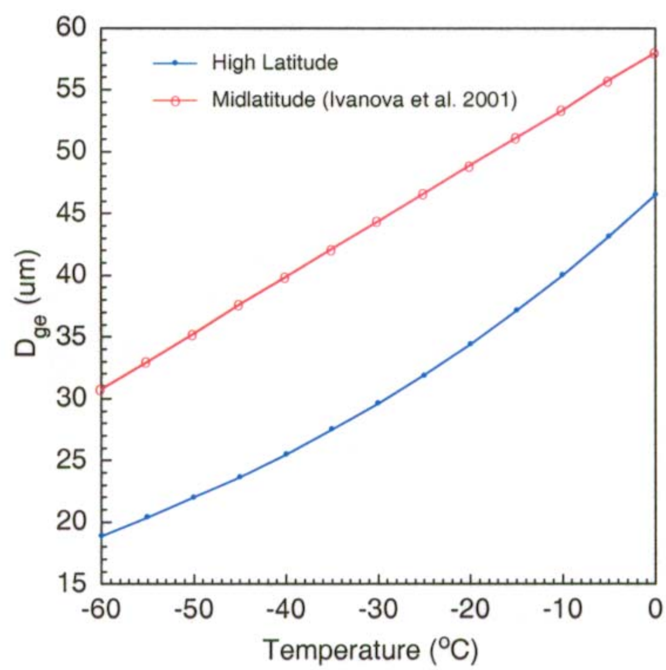

Figure 5. Comparison of parameterizations of mean effective size of ice particles between the present study for high latitude ice clouds with that for mid-latitude ice clouds from Ivanova et al. (2001).

Conclusions

We have developed a parameterization of mean effective size for high latitude ice clouds as a function of cloud temperature. The aircraft data from field campaigns at high latitudes including Surface Heat Budget of the Arctic Ocean/FIRE.ACE, Beaufort and Arctic Storms Experiment, and Canadian Freezing Drizzle Experiment I and III have been analyzed. The contributions of small particles to both IWC and total cross section area of ice particles per unit volume are considered. The scheme used to convert the ice particle image measured from 2DC/2DP probe to its mass along with the consideration of small ice particles has been validated from the direct measurement of ice water content. See more details in Boudala et al. (2001).

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