2A.7 INVESTIGATING THE DENSITY OF ICE PARTICLES USING DUAL-WAVELENGTH DOPPLER RADAR

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1 INTRODUCTION

Global models used for forecasting climate and weather carry IWC as a prognostic variable. An empirical relation between IWC and ice fall speed is used which is crucial in determining ice cloud lifetime. The variation of ice particle density with size $\rho(D)$ is important in interpreting values of Z in terms of ice water content and also in determining the terminal velocity of ice particles as a function of IWC.

For cirrus clouds, Brown and Francis (1995) have used aircraft measurements from Total Water Probe and 2D probes to get values of the mass and the maximum dimension of the ice particles. Assuming the maximum dimension as the diameter of a spherical particle equivalent in mass, they found that:

$$\rho(D) = 0.07D^{-1.1} \tag{1}$$

where D is the diameter of the equivalent spherical particle in millimeter. Using the same dataset, Francis (1998) later derived an alternative formula by expressing the diameter in terms of a circle of area equal to the observed cross-section area rather then considering the maximum diameter and he suggested that:

$$\rho(D) = 0.175D^{-0.66} \tag{2}$$

But, the choice between these two density functions remains unclear and raises large uncertainties in the estimation of IWC and terminal fall velocity.

In this paper we describe how dual frequency measurements at 35 and 94 GHz of reflectivity and mean Doppler velocity in ice clouds can be used to infer the variation of ice particle density with size.

2 REFLECTIVITY-WEIGHTED TERMINAL VELOCITY OF ICE PARTICLES

The Doppler velocity measured by a vertically pointing radar V_D is the sum of the reflectivity-weighted particle vertical velocity V_Z and the vertical air velocity V_a:

$$V_D = V_a + V_Z. \tag{3}$$

For a distribution $N(D)$ of particles, V_Z the reflectivity-weighted terminal velocity is given by :

$$V_Z = \frac{\int v_t(D)D^6 f(D,\lambda)N(D)dD}{\int D^6 f(D,\lambda)N(D)dD}, \tag{4}$$

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where v_t is the terminal velocity of an individual particle and $f(D,\lambda)$ is the ratio of the Mie scattering to an assumed Rayleigh scattering for a given valiue of λ. D is usually given as the maximum particle dimension. Since in the following developments we assume that particles are spherical then D is the diameter. A basic equation to estimate the terminal velocity of ice particles is (Mitchell, 1996):

$$v_t = a\left(\frac{2g}{\rho_a}\right)^b \nu^{1-2b} D^{2b-1}\left(\frac{m}{A}\right)^b, \tag{5}$$

where g is the gravitational acceleration; ρ_a is the air density; ν is the kinematic viscosity; m is the particle mass; A is the particle cross-section area; and a and b coefficients are derived from the drag law. Considering the spherical assumtion and a density relationship $\rho(D)$ for the ice particles, $A = \frac{\pi}{4}D^2$ and $m = \frac{\pi}{6}\rho(D)D^3$ then from (5):

$$v_t = a\left(\frac{4g\rho(D)}{3\rho_a}\right)^b \nu^{1-2b} D^{2b}. \tag{6}$$

In deep ice clouds, with large ice particles Mie scattering will occur for mm wave radar and $f(D,\lambda)$ fall below unity. The size distribution may be well represented by a simple exponential distribution $N(D) = N_0\exp(-\Lambda D)$ where Λ is related to the median volume diameter by $D_0 = 3.67/\Lambda$. Then using (4) and (6):

$$V_Z = a\left(\frac{4g}{3\rho_a}\right)^b \nu^{1-2b} \frac{\int_0^\infty \rho(D)^b D^{6+2b} f(D,\lambda) e^{\frac{-3.67}{D_0}} dD}{\int_0^\infty D^6 f(D,\lambda) e^{\frac{-3.67}{D_0}} dD}. \tag{7}$$

3 SENSITIVITY OF DUAL-WAVELENGTH DOPPLER VELOCITY DIFFERENCE TO THE DENSITY FUNCTION

When ice particles are big enough in the cirrus cloud, simultaneous Doppler velocity measurements performed at different frequencies on a same sample of cloud give different values of V_D and a dual-wavelength Doppler velocity difference ΔV_D can be measured.

The ΔV_D obtained using (3) and (7) for a given pair of wavelengths and a given density relationship is independent of the vertical air motion and a function of D_0 only. Figure 1 shows the variations of ΔV_D with D_0 for the wavelength pair (Ka,W) and (X,Ka) for the two density relationships.

An equivalent relation between the dual wavelength reflectivity ratio DWR as a function of D_0 for two density

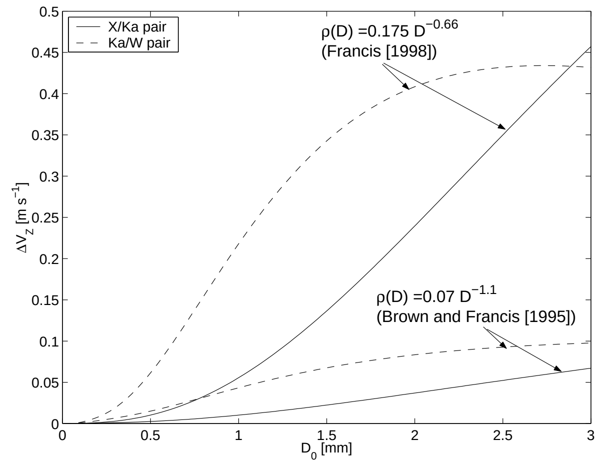

Figure 1: ΔV_D as a function of mean volume diameter for the wavelength pair (Ka,W) and (X,Ka) and two density relationships

relations is shown in Figure 2 has been used by (Sekelsky *et al.*, 1998) or (Hogan *et al.*, 2000) to infer particles size in cirrus.

The information in figures 1 and 2 is combined in figure 3 where ΔV_D is plotted against the DWR for each wavelength pair. The two density functions lead to two distinct curves.

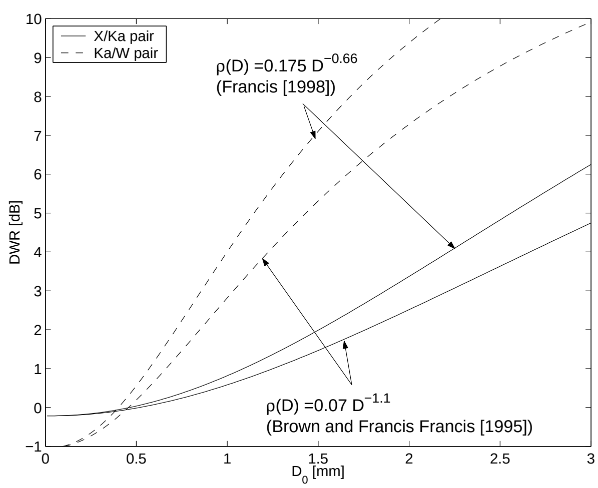

Figure 2: DWR as a function of mean volume diameter for the wavelength pair (Ka,W) and (X,Ka) and two density relationships

4 OBSERVATIONS

In March 2000, a long series of cirrus cloud observations was performed by the CPRS (UMASS) during the cloud IOP campaign. The CPRS is a dual-wavelength Doppler radar built on a single feed and single lens antenna, the single aperture eliminates antenna pointing errors which are rapidly significant otherwise. The overall low noise of the system allows particularly good simultaneous observations at 33 and 95 GHz. Figure 4 displays in the two first panels the reflectivity factor distribution and mean Doppler velocity distribution observed by the 33 GHz channel on the 12 March 2000 in 4 km deep ice

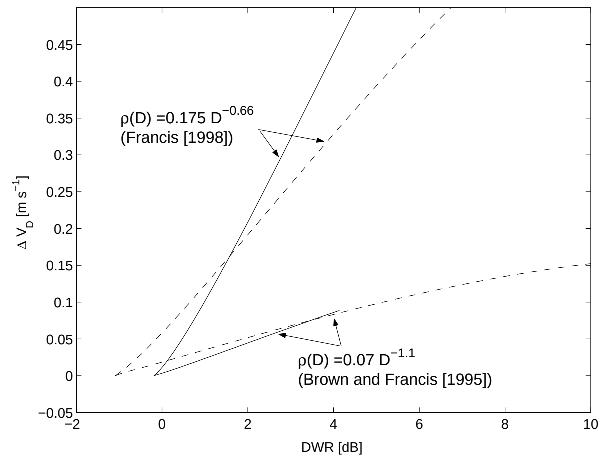

Figure 3: ΔV_D as function of DWR for the wavelength pair (Ka,W) and (X,Ka) and two density relationships

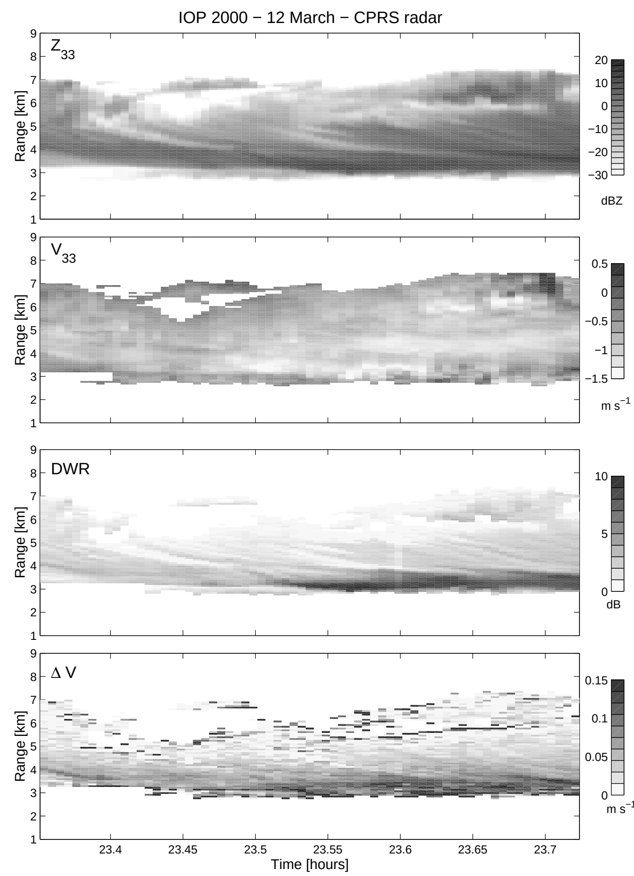

Figure 4: Top two panels: Reflectivity factor measured and Doppler velocity measured by the CPRS at 33 GHz ; Bottom two panels : DWR and ΔV_D deduced from dual wavelength measurements at 33 and 95 GHz.

cloud. The reflectivity field structure is dominated by fall streaks slanted by the wind shear whereas the Doppler velocity field structure is dominated by up and down convective processes at the top and the bottom of the cloud. It is difficult to find any kind of correlation between these two fields. In contrast the differential parameters DWR

and ΔV_D shown in the two panels underneath are very well correlated, the similar increases in both DWR and ΔV_D are corresponding to growing values of D_O related to aggregation processes. As expected, the DWR and ΔV_D seem to be linearly related.

In order to compare the theoretical results to the measurements, we have plotted figure (5) ΔV_D as a function of DWR from co-located measurements. On top of the scatter plot, are the theoretical curves from (3), for the Ka/W pair and for the two density functions. It can

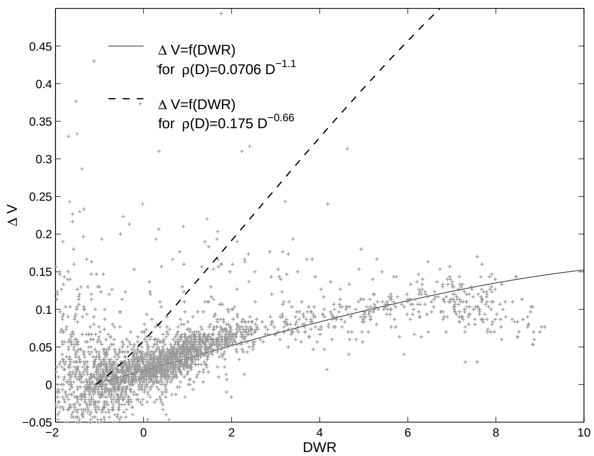

Figure 5: ΔV_D as function of DWR for both theoretical calculations and measurements

be seen without ambiguity from figure (5) that the scatter plot of data match the theoretical calculations only if the Brown and Francis density relationship is considered.

CONCLUSIONS AND FUTURE WORK

In this paper, dual wavelength measurements of Doppler velocities are used to characterize the density of ice particles as a function of size. A theoretical relation between the dual-wavelength reflectivity ratio and the dual-wavelength Doppler velocity difference is presented for two density functions. Comparison between observation and theoretical calculations agreed without ambiguity when Brown and Francis density function is used.

Particles are assumed to be spherical, in the future, a similar analysis will be done considering spheroids of different axis ratio.

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