P1.6 STRATIFORM PRECIPITATION OBSERVED BY AIRBORNE RADAR AT 94 AND 10 GHZ

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1. INTRODUCTION

The Cloud Radar System (CRS) operated at 94 GHz(3 mm wavelength) on board of NASA's high altitude aircraft flew for the first time along with ER2 Doppler radar (EDOP) operated at 10 GHz (3.2 cm-wavelength) during the CRYSTAL-FACE experiment in the southern Florida. The radar over flew convective, stratiform, and cirrus regions and provided a unique opportunity for the study of the microphysics of clouds and precipitation with dual-wavelength radar. The high sensitivity of 94 GHz radar allows detection of high cloud such as cirrus, which is often missed by 10 GHz radar. However, the significant attenuation at 94 GHz in deep stratus and cumulus clouds possibly reaching the precipitation stage limits its use for rain observation. In the region of light rain the attenuation on the reflectivity is significant at 94 GHz but negligible at 10 GHz, and does not affect the Doppler velocity unless the reflectivity is attenuated below the noise level. Meneghini et.al (2003) shows the feasibility of estimating drop size distribution using Doppler velocities from EDOP operated at frequencies of 9.1 and 10 GHz. This paper shows the potential of using reflectivity and Doppler velocity observed by CRS and EDOP to estimate the drop size distribution in light rain.

A stratiform cloud with light rain occurred on July 11, 2002 near Key West, Florida. High cloud with more detailed vertical structures is observed at 94 GHz but not at 10 GHz as shown by the reflectivity observed by EDOP (Fig. 1a) and CRS (Fig. 1b). Distinctive bright bands with maximum reflectivity of 30-35 dBZ and 10-15 dBZ appears at 10 and 94 GHz, respectively. There is a 6 dB increase in the reflectivity at 94 GHz when the melting starts. A noticeable difference between the reflectivities at the two frequencies is a well defined radar reflectivity minimum ("dark band") at 94 GHz just above the melting level. Attenuation at 94 GHz is shown by the decrease of the reflectivity toward the surface. At the horizontal distance of about 180 km, the signal is completely attenuated in relatively heavy precipitation. In the light rain region, the CRS detects the surface with significant one-way attenuation up to 15 dB while the attenuation at 10 GHz is negligible. The Doppler velocity at vertical incidence at 10 GHz (Fig. 1c) is larger than that at 94 GHz (Fig. 1d) in rain and about the same as that in the ice region. Unlike the reflectivity, the Doppler velocity is not affected by the attenuation.

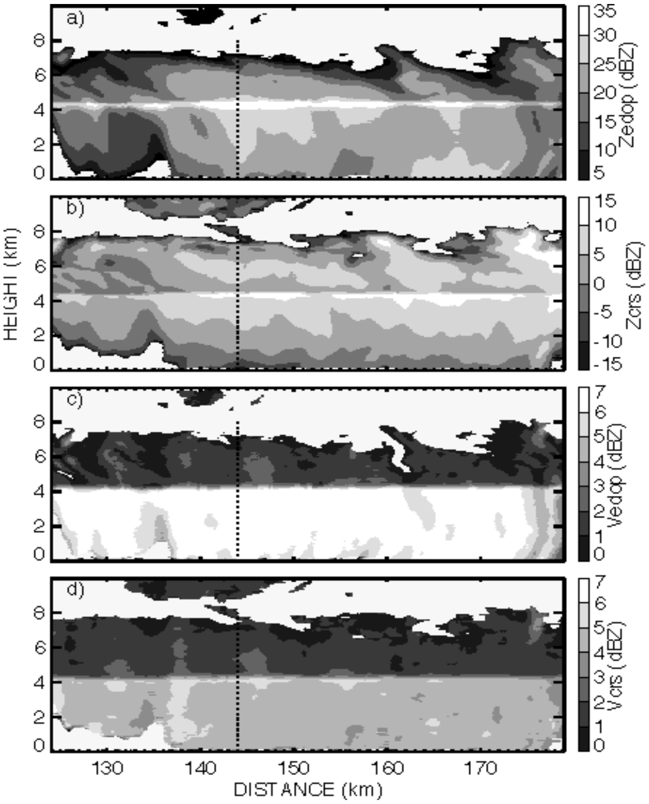

Fig. 1. Observed a) reflectivity from EDOP and b) CRS; Doppler velocity from c) EDOP and d) CRS.

2. RESULTS

For exponential drop size distribution, $N = N_0 \exp(-\Lambda D)$, the reflectivity at 10 GHz, and Doppler velocity at 10 or 94 GHz are given by

$$Z_{10}(N_0, \Lambda) = N_0 \int_{D_{\min}}^{D_{\max}} e^{-\Lambda D} \sigma_{b10} dD$$

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$$V_{10/94} = \frac{\int_{D_{\min}}^{D_{\max}} e^{-\Lambda D}\sigma_{b10/94} V_t(D,z)\,dD}{\int_{D_{\min}}^{D_{\max}} e^{-\Lambda D}\sigma_{b10/94}\,dD} - w$$

where w is the updraft. $\sigma_{b10/94}$ stands for the back-scattering cross section of the particles at 10 or 94 GHz. Vt(D,z) is the fall speed of drops corrected for air density. The Doppler velocity depends on the slope, Λ, and vertical air motion. But the difference of mean Doppler velocity between 10 and 94 GHz at the observation level z, $\Delta V(\Lambda, z) = V_{10} - V_{94}$, is a function of Λ only (Fig. 2); using ΔV eliminates the effect of vertical air motion.

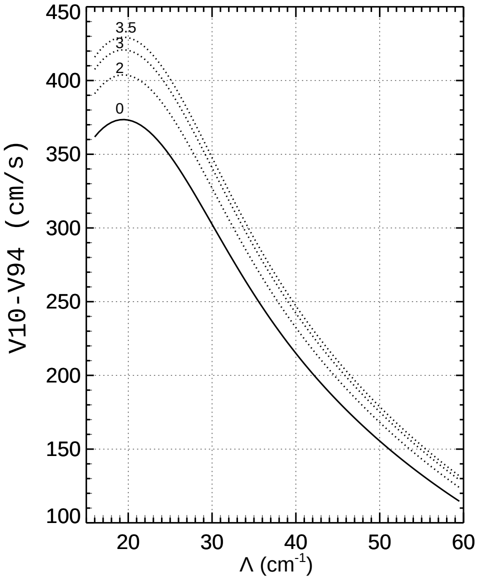

Figure 2. The difference of the Doppler velocity between 10 (V10) and 94 GHz (V94), $\Delta V = V_{10} - V_{94}$ calculated for Λ=16-60 cm^{-1} at height of 0, 2, 3 and 3.5 km. The difference of the Doppler velocity between the two frequency, ΔV, increases for $\Lambda < 20$ cm^{-1} and decreases for $\Lambda > 20$ cm^{-1} as Λ increases (D_0 decreases).

The following analysis focuses on the region below the bright band. Λ is estimated by locating ΔV closest to the difference of the observed Doppler velocity between EDOP and CRS. Observed reflectivity from EDOP is then used to calculate N_0. Once the drop size distribution is obtained, the Doppler velocity at the two frequencies can be calculated and compared with the actual data to ensure they are consistent.

Figure 3 shows a profile at the horizontal distance of 144 km. As height increases, Λ and N_0 increase and reaches a maximum at the height of 1 km and then decreases. Such change of DSD may be associated with the precipitation trail; The drops are falling along the trail not the vertical. There is good agreement between the Doppler velocity observed and that calculated from the retrieved N_0 and Λ. The difference is less than 0.5 m/s, which may be attributed to vertical air motions or the non-exponential drop sized distributions. Further study will be conducted to determine the cause of the difference.

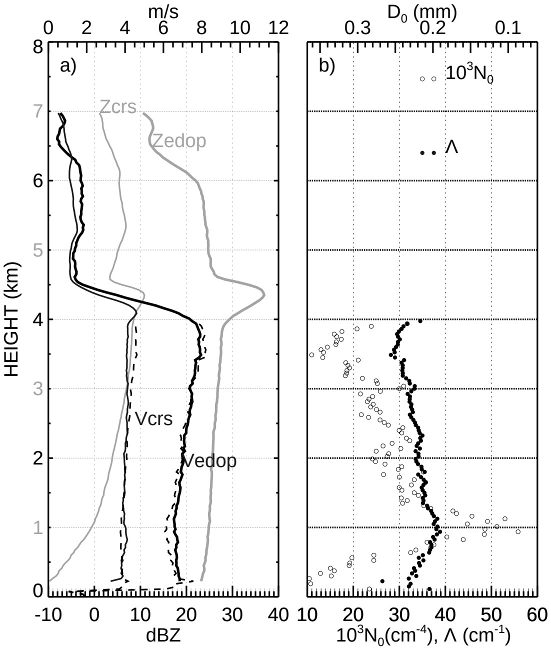

Figure 3: a) Observed profiles of reflectivity (gray lines) and Doppler velocity (black solid lines) from EDOP and CRS. The dash lines are the Doppler velocity calculated from the retrieved N_0 and Λ assuming w = 0. b) Profile of the retrieved Λ and N_0.

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References

Meneghini, R., S. W. Bidwell, R. Rincon, G. M. Heymsfield, and L. Liao, 2003: Differential-frequency Doppler weather radar: Theory and experiment. Radio Sci. 38, 1-10.