Observations of Melting Layer from 94 GHz and 10 GHz Airborne Doppler Radars

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1.Introduction

The melting band has been a distinctive feature of the radar measurements of precipitation. It is primarily caused by the rapid increases in the dielectric constant of hydrometeors at the top of the melting layer followed by an increase of the fall velocity of melting snowflakes toward the bottom of the melting layer. The melting band in stratiform rain, originally studied at cm wavelength, is characterized by an enhancement of the radar reflectivity. However, later observations made at mm wavelength (Lhermitte 1988) often show the absence of the bright band and, in some cases, a decrease of the reflectivity in the melting layer, namely, a dark band. Such phenomena was attributed to the dominance of non-Rayleigh scattering effects at mm wavelength (Sassen et al. 2005).

During the Cirrus Regional Study of Tropical and Cirrus Layers (CRYSTAL) Florida Area Cirrus Experiment field campaign in southern Florida, light stratiform rain with rainfall rate less than 2 mm/hr were observed by 3.2 mm and 3.2 cm wavelength airborne Doppler radars. A method that uses both reflectivity and Doppler velocity to retrieve the rain rate below the melting layer has shown promising results (Tian et al. 2005). In this paper, we focus on regions in and above the melting layer. We are attempting to understand the observations in terms of particle melting processes and scattering cross-sections of melting particles at the two wavelengths. Such understanding is important for improving the rainfall retrieval with dual-wavelength Doppler radars.

2. Observations

Fig. 1 shows a flight line from July 2002. Fig. 2 is a profile from Fig. 1. The reflectivity profile at 3.2 cm wavelength is typical for the stratiform rain. That is, it increases as height decreases, an indication of growing ice particles by aggregation. It then increases as particles start melting, reaching a maximum in the melting band, and then decreases and is stabilized in rain. The corresponding profile at 3.2 mm wavelength decreases as height decreases, an indication that ice particles are no longer the Rayleigh scatters. A minimum is reached at top of the melting band, indicating the onset of the melting. The reflectivity

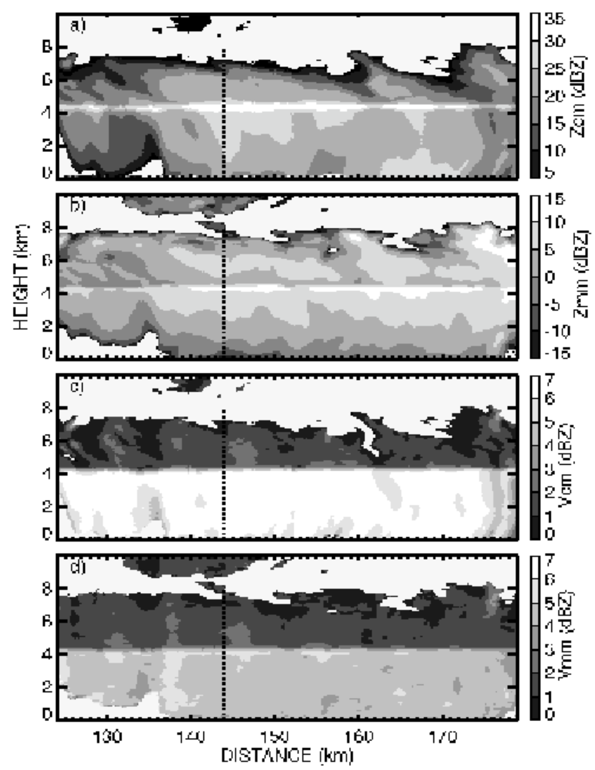

Fig. 1 Observed a) reflectivity from EDOP (Z_{cm}) and b) CRS (Z_{mm}); Doppler velocity from c) EDOP (V_{cm}) and d) CRS (V_{mm}).

then increases to a maximum in the melting layer at the same height as that of maximum reflectivity at the cm-wavelength and decreases downward. The further decrease in rain is due to the large attenuation at mm-wavelength.

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The Doppler velocities in the snow are more or less the same at both wavelengths. As melting starts, the velocities start increasing with distance downwards and stabilize in the rain region with greater velocities at the cm wavelength. The stabilization occurs earlier for the mm-wavelength. Complete melting is probably achieved where the cm wavelength velocity has stabilized to the rain value. This difference has been interpreted as the different reflectivity weighting toward the different sizes for the mm and cm wavelengths.

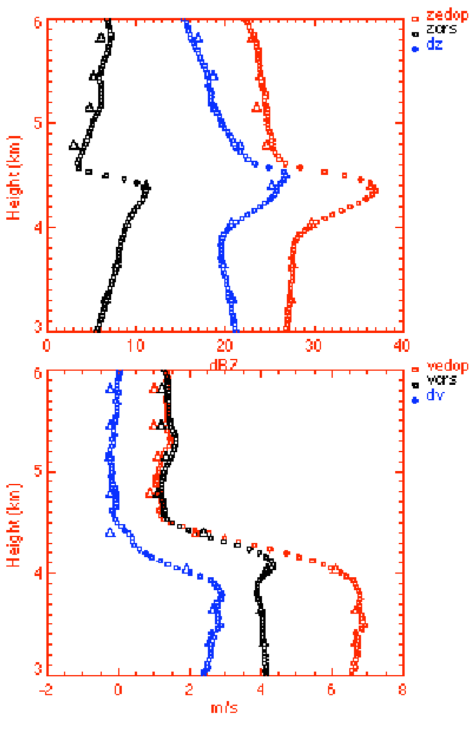

Fig. 2 Top: Reflectivity at cm (zedop) and mm (zcrs) wavelength and the difference (dz = zedop-zcrs). Bottom: Doppler velocity at cm (vedop) and mm (vcrs) wavelength and the difference (dv = vedop-vcrs).

3. Results from theoretical calculation

The back-scattering cross-section of the melting particles depends not only on the size and refractive index but also on the density of the particles. In addition, both the particle size distribution and terminal velocity are changing during the melting process. We start with a simple model with the following assumptions: a) Spherical melting snow flakes are covered with water, b) Precipitation rate is constant at any level, c) All particles are melted at the same rate, and d) Exponential particle size distribution in rain. With these assumptions, we calculated the reflectivity, Doppler velocity, and specific attenuation at both wavelengths as a function of the fraction of melting for selected ice densities (Fig. 3).

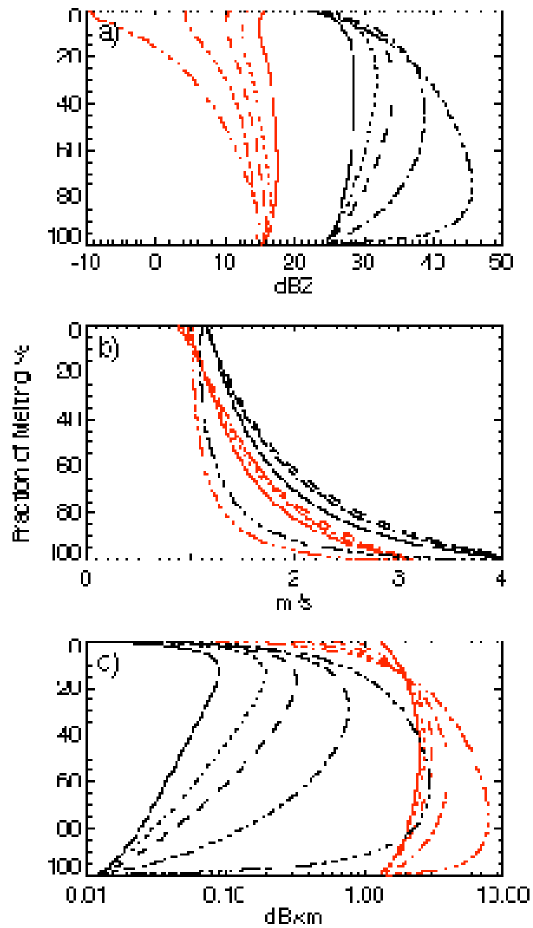

Fig. 3 a) Reflectivities, b) Doppler velocities, and specific attenuation at 3.2 cm (black) and 3.2 mm (red) wavelength for selected snow densities of 0.92 (solid line), 0.5, 0.3, 0.1, and 0.01 g cm^{3}.

This simple model captures some of the interesting observed features. Fig. 3a shows a maximum reflectivity at 3.2 cm wavelength in the melting layer, and the maximum increases as the ice density decreases. It also shows a slight decrease of the mm-wavelength reflectivity at the onset of melting, which disappears at ice density of 0.01 g cm^{-3}. Fig. 3b shows the increase of Doppler velocity as melting proceeds. Fig. 3c shows specific attenuation at both wavelengths. It is interesting to see that at mm wavelength, snow attenuation is smaller for a lower density but as the melting fraction reaches 20%, the trends reverse. Depending on the snow density, the specific attenuation at mm wavelength can be as large as 8 dB/km. Further analysis that include a melting model will be shown at the conference.

Acknowledgements

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References

Lhermitte, R., 1988: Observation of rain at vertical incidence with a 94 GHz Doppler radar: an insight on Mie scattering. *Geophys, Res. Lett.*, **15**, 1125-1128.

Sassen K., J. R. Campbell, J. Zhu, P. Kollias, M. Shupe, and C. Williams, 2005: Lidar and triple-wavelength Doppler radar measurements of the melting layer: A revised model for dark- and brightband phenomena. *J. Appl. Meteor.*, **44**, 301-312.

Tian, L., G. M. Hemsfield, Li, L., and R. C. Srivastava, 2005: Raindrop Size Distribution, Vertical Air Velocity and Water Vapor Attenuation Retrieved from Dual-Wavelength Doppler Radar Observations. *J. Appl. Meteor.*, Submitted.