1A.1 VERTICALLY PROFILES OF RAIN DROP SIZE DISTRIBUTIONS ESTIMATED WITH S-BAND AND W-BAND PROFILERS

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1. INTRODUCTION

Vertically pointing profilers are useful tools in studying the vertical structure of precipitating cloud systems when they advect over the profiler site. Profilers operating at different frequencies provide different information about the precipitating cloud systems. Profilers operating near 3 GHz (near a wavelength of 10 cm) are in the S-band frequency range and detect Rayleigh scattering processes from the raindrops. And profilers operating near 94 GHz (near a wavelength of 3.2 mm) are in the W-band frequency range and detect Rayleigh scattering from small raindrops and Mie scattering from larger raindrops.

In previous studies, the vertical profile of air motion and rain drop size distributions (DSDs) were estimated from either the S-band (Williams, 2002) or the W-band (Kollias et al., 2002, 2003) observations. In this study, the observations from collocated S-band and W-band profilers are combined to estimate the profile of air motion and DSDs.

2. OBSERVATIONS

The NOAA Aeronomy Laboratory deployed a 2.835 GHz vertically pointing profiler (S-band profiler) at the Tamiami-Kendall Airport in support of the NASA CRYSTAL-FACE campaign. The University of Miami deployed a 94 GHz vertically pointing profiler (W-band profiler) at the same site enabling collocated observations for the month of July 2002.

The vertically pointing S-band profiler operated at 2.835 GHz and is sensitive to the particles larger than about 0.5 mm in precipitating cloud systems that passed overhead (Carter et al. 1995, Ecklund et al. 1999). The S-band profiler operated in two different modes. Both modes had a vertical resolution of 60 meters (pulse length and distance between range gates) and a dwell time of about 10 seconds. One mode had a dynamic range of about 10 to 60 dBZ_e at 10 km and the other mode used a 10-bit pulse code to increase the sensitivity by about 10 dBZ_e. Three profiles of each mode were collected in succession so that 30 second dwell spectra could be constructed in the post analysis.

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The vertically pointing W-band profiler operated at 94 GHz and is sensitive to the cirrus cloud particles and to the particles in precipitating cloud systems (Kollias et al., 2003). The W-band operated in a single mode with 30 meter resolution (pulse length and distance between range gates) and a dwell time of about 1 second. The dynamic range was about -40 to 10 dBZe at 10 km.

3. ESTIMATING THE VERTICAL AIR MOTION

The vertical air motion can be estimated by analyzing the Mie oscillations in the W-band profiler spectra. Figure 1 shows the backscattering cross section σ_b versus diameter for both the W-band and S-band frequencies at 20ºC. The scattering process remains in the Rayleigh regime for the S-band profiler for all raindrop sizes. And the W-band enters the Mie scattering regime at diameters greater than approximately 1 mm.

Mie theory describes the rain drop diameters that correspond to the minima and maxima of the Mie oscillations shown in Figure 1. The first minima occurs for a raindrop diameter of 1.7 mm. The vertical air motion is estimated by calculating the difference in terminal fall speed of a raindrop with a diameter of 1.7 mm with the observed Doppler velocity of the first minima. Lhermitte (1988) first introduced this technique for stratiform rain and Firda et al. (1999) and Kollias et al. (1999, 2001) used this technique in stratiform and light convective rain.

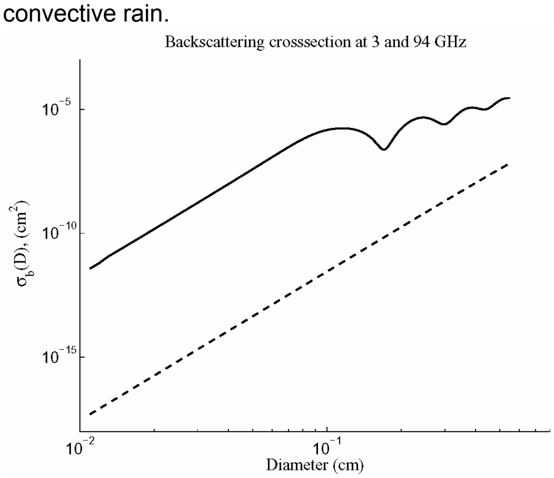

Figure 1. Backscattering cross section at 3 GHZ (S-band) (Dashed line) and 94 GHz (W-band) (Solid line). Oscillations in W-band backscattering are due to Mie scattering.

4. ESTIMATING THE DSD

While the first minimum in the Mie backscattering cross section can be used to estimate the air motion, a combination of other characteristics in the observed reflectivity Doppler velocity spectra can be used to determine the shape of the DSD. Assuming that the DSD is represented by an exponential function of the form

$$N(D) = N_o \exp[-\Lambda D], \quad (1)$$

the reflectivity Doppler velocity spectra is express as

$$S(D) = \sigma_b(D) N_o \exp[-\Lambda D] dD / dV \ . \quad (2)$$

The first and second $\sigma_b(D)$ peaks at 94-GHz occur at D_1 = 1.15 mm and D_2 = 2.46 mm correspondingly. If we assume N(D) constant for all sizes, $10\log_{10}(S_C(V_1)/S_C(V_2))$ is equal to -7.65 dB. For an exponential DSD, the relative intensity of the first and second peak depends on the parameter Λ of the Marshall-Palmer DSD:

$$\Lambda = \frac{dB\left(\frac{S_{OBS}(V_1)}{S_{OBS}(V_2)}\right) - dB\left(\frac{S_C(V_1)}{S_C(V_2)}\right)}{4.343(D_2 - D_1)} \quad (3)$$

where $S_{OBS}(V)$ are the observed 94-GHz Doppler spectra power density at the first two peaks. This simple formula can be used to retrieve the slope Λ of the assumed DSD. Using the backscattering cross section for W-band and an exponential DSD the reflectivity Doppler velocity spectra S(V) can be calculated for different values of the slope parameter Λ and are shown in Figure 2. The asterisks indicate the location of the first and second maxima and the squares indicate the location of the first minimum. The distance between the location of the first and second maximum of the S(V) changes very little with Λ.

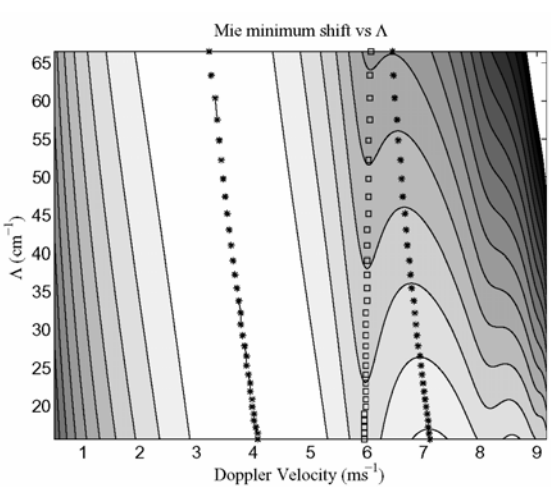

Figure 2. Normalized reflectivity Doppler velocity spectra as a function of slope parameter Λ. The asterisks indicate the first and second maxima and the squares indicate the first minimum.

Furthermore, the vertical profile of reflectivity from the S-band profiler is not affected by attenuation of water vapor or particle scattering and can be used to scale the retrieved DSD exponential shape by estimating the scale parameter N_o using the following formula

$$Z = N_o \int_{D=0}^{D=\infty} D^6 \exp[-\Lambda D] dD \quad (4)$$

After the slope parameter has been estimated by analyzing the W-band spectra, the scale parameter can be estimated using the S-band reflectivity and rearranging (4) to solve for N_o .

5. OBSERVATIONS IN STRATIFORM RAIN

Figure 3 shows an example of simultaneous vertical profiles of reflectivity Doppler velocity spectra (spectrograms) during stratiform rain on 11 July 2002 as observed by the S-band and W-band profilers. The S-band Doppler spectra have a Gaussian shape that results from an exponentially decreasing number concentration in the DSD and a D^6 dependence of the backscattering cross section. The W-band Doppler spectra have a multi modal shape due to the modulating affect of the Mie scattering.

The dashed line in Figure 3 indicates the location of the 1st Mie minimum. The 1st backscattering minimum is visible from near the surface (200 m) to the base of the melting layer (4000 m). Using the location of the first minimum in the Doppler spectrum and correcting for the air density change with altitude, a profile of the vertical air motion is retrieved (Kollias et al., 2002; 2003). The technique is applicable from near the surface to the base of the melting layer where the technique is not applicable due to the suppression (collapse) of the terminal fall velocities of the hydrometeors (see Figure 3).

5. CONCLUDING REMARKS

The collocation of vertically pointing S-band and W-band profilers provides the opportunity to use the scattering features inherent with these two instruments to simultaneously estimate the vertical air motion and raindrop size distribution in precipitating cloud systems. The Mie scattering characteristics resolved in the W-band reflectivity Doppler velocity spectra are used to estimate the vertical air motion and the slope parameter of the assumed exponential shaped DSD. And the unattenuated S-band reflectivities are used to estimate the scale parameter of the exponential DSD.

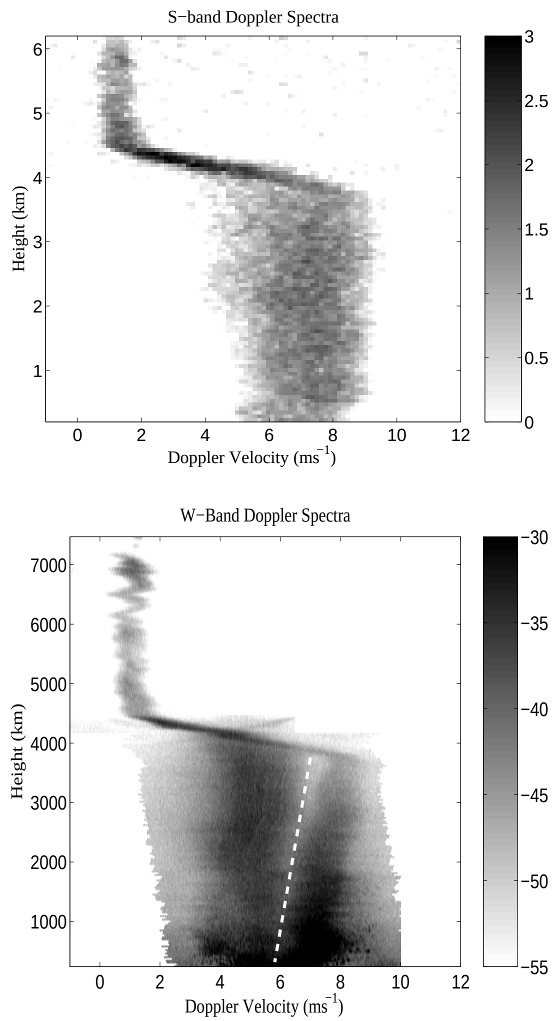

Figure 3. Example of reflectivity Doppler velocity spectra as a function of altitude from stratiform rain observed on 11 July 2002. NOAA/AL S-band profiler (top) and the University of Miami 94-GHz profiler (bottom).

6. ACKNOWLEDGMENTS

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