Dual-Wavelength Millimeter-Wave Radar Measurements of Cirrus Clouds

S. M. Sekelsky, J. M. Firda, and R. E. McIntosh
Microwave Remote Sensing Laboratory
University of Massachusetts
Amherst, Massachusetts

Introduction

In April 1994, the University of Massachusetts' 33-GHz/95-GHz Cloud Profiling Radar System (CPRS) participated in the multi-sensor Remote Cloud Sensing (RCS) Intensive Operation Period (IOP), which was conducted at the Southern Great Plains Cloud and Radiation Testbed (CART). During the 3-week experiment, CPRS measured a variety of cloud types and severe weather. In the context of global warming, the most significant measurements are dual-frequency observations of cirrus clouds, which may eventually be used to estimate ice crystal size and shape. Much of the cirrus data collected with CPRS show differences between 33-GHz and 95-GHz reflectivity measurements that are correlated with Doppler estimates of fall velocity. Because of the small range of reflectivity differences, a precise calibration of the radar is required and differential attenuation must also be removed from the data. Depolarization, which is an indicator of crystal shape, was also observed in several clouds (Matrosov 1991; Tang and Aydin 1995). In this abstract we present examples of Mie scattering from cirrus and estimates of differential attenuation due to water vapor and oxygen that were derived from CART radiosonde measurements.

Cirrus Observations

Figures 1a and 1b plot models of the difference between 33-GHz and 95-GHz reflectivity and the mean velocity in cirrus clouds. The quantity used to describe differences in 33-GHz and 95-GHz reflectivity is referred to as the dual wavelength ratio (DWR) and is defined as

$$DWR = dBZe_{33} - dbZe_{95}.$$

DWR is generated in two ways. The first source of DWR is backscatter from larger particles that fall into the Mie region at either 95 GHz or at both frequencies used. DWR is a function of particle shape, size, and orientation (Matrosov 1991, 1995). The second source of DWR is frequency dependent attenuation by the atmosphere and clouds.

Although external calibrations of the radar were made with a trihedral corner reflector, differential attenuation, both

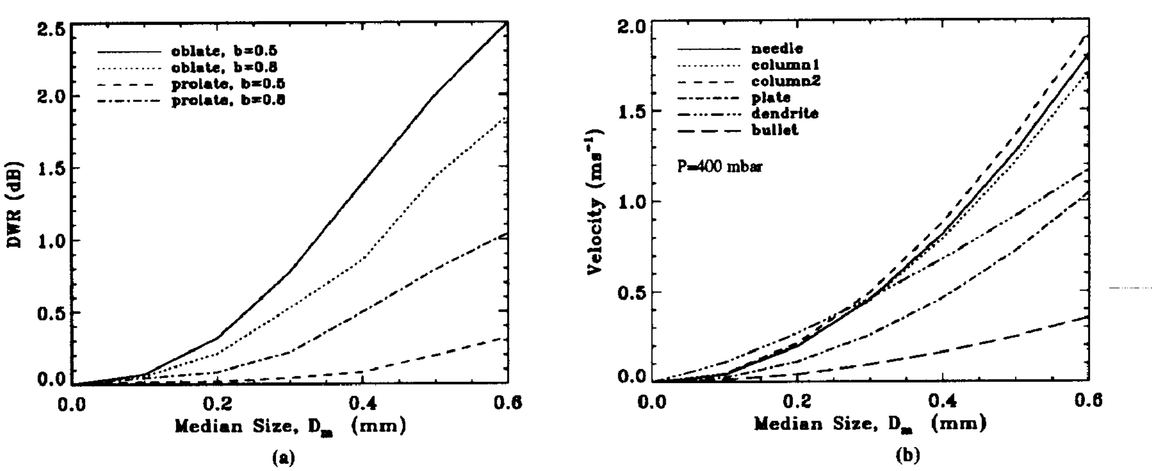


Figure 1. (a) Dual-wavelength ratio (DWR) models for gamma distributions of spheroid (adapted from Matrosov 1995) and (b) Mean velocity at 400 mbar for gamma distributions of spheroids.

from intervening clouds and from the moist atmosphere itself, contributes a substantial bias to DWR measurements and must be taken into consideration. Because of the low values of DWR produced by Mie scattering, an important step in the analysis of DWR measurements is removal of differential extinction experienced by the radar signal in propagating between the ground and cloud base. The contribution to differential attenuation from water vapor and oxygen is plotted in Figure 2 at 1-km intervals.

Figures 3a and 3b show collocated 33-GHz and 95-GHz reflectivity measurements taken on April 15th, 1994. Gaseous extinction has been removed from these measurements, and there are no lower clouds present. Cross-sections of measurements are shown in Figure 4. Although these plots show values of DWR and velocity that lie within the range of values predicted by the models in Figures 1a and 1b, they are ambiguous because crystal shape and particle orientation are not known.

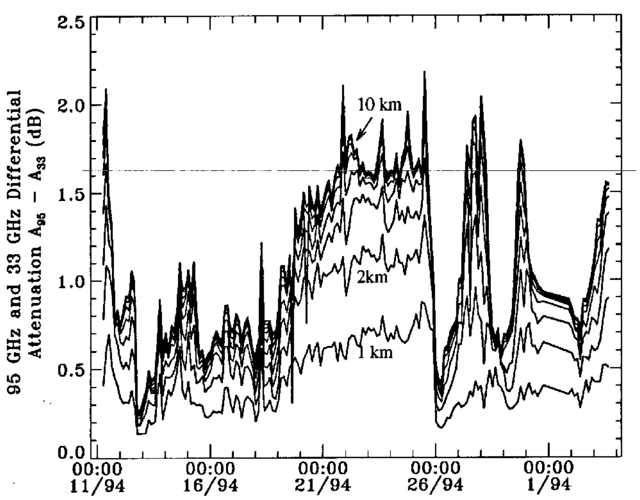


Figure 2. CART radiosonde-derived estimates of one-way differential attenuation between ground and indicated height for 1-km steps in altitude.

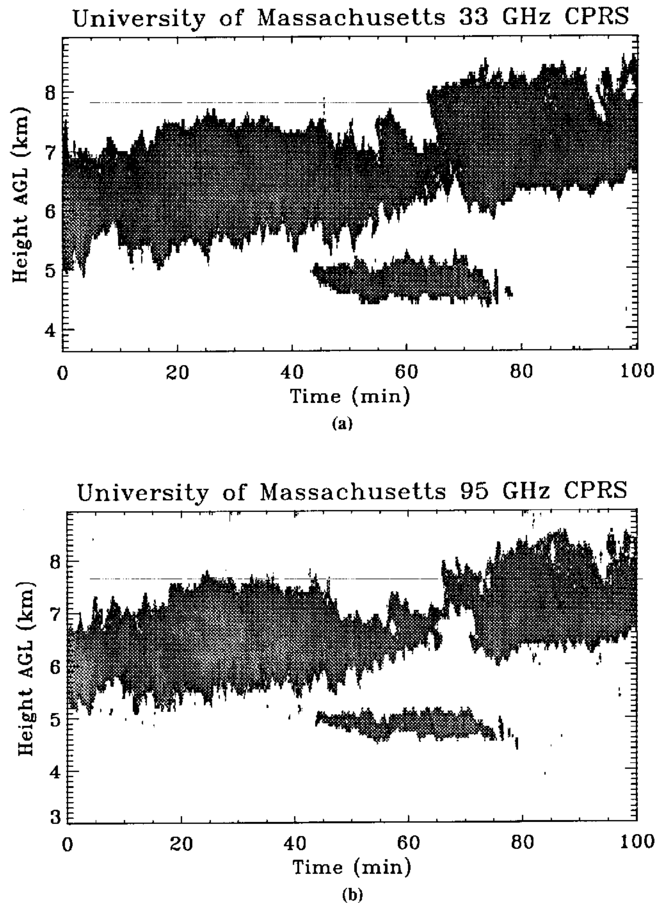
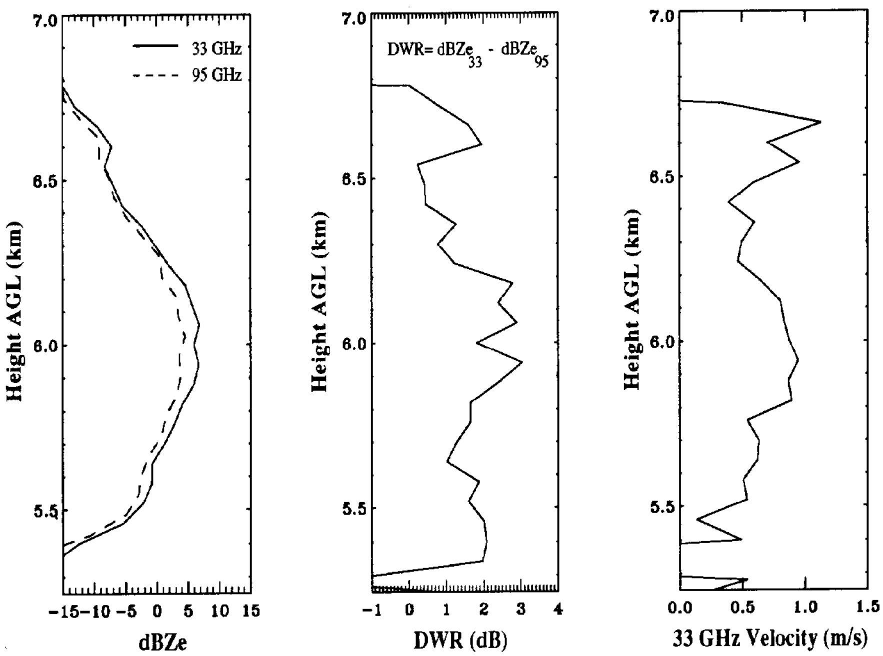


Figure 3. Collocated reflectivity measurements from April 15, 1994. dBZe values on relative scale at (a) 33 Ghz and (b) 95 GHz.



(a) (b) (c)

Figure 4. Profiles of (a) reflectivity, (b) DWR, and (c) fall velocity at 0016 GMT.

References

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