Development of a Dual-Frequency, Millimeter-Wave Cloud Profiling Radar System

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Introduction

The Microwave Remote Sensing Laboratory (MIRSL) is developing a mobile, scanning millimeter-wave radar for the Atmospheric Radiation Measurement (ARM) Program. This project is intended to fill the void for instrumentation that can remotely measure the physical boundaries and phase of cloud particles in three dimensions. At present, there is no routine method for gathering such data. Imaging lidars cannot penetrate into thick cloud cover; thus, they give limited vertical information about clouds. *In situ* measurements from aircraft can provide accurate microphysical data, but aircraft are expensive to operate and the measurements cover only a limited region of the sky. A ground-based radar is the only practical way to routinely provide three-dimensional characterizations of cloud properties on the scale and in the detail required for ARM.

In this paper, we show preliminary data, which demonstrate that polarimetric millimeter-wave radars can distinguish cloud water droplets from ice particles. We also describe the ground-based Cloud Profiling Radar System (CPRS), which will be able to simultaneously obtain three-dimensional images of the polarimetric response of clouds at 33 and 95 GHz (9 and 3.2 mm). This system should be complete and ready to participate in an intensive operation period (IOP) planned for June 1993.

Millimeter-Wave Advantages

Millimeter-wave radars offer significant practical advantages over microwave frequency radars because they are more sensitive to cloud particles and because they are more compact and portable. For spherical targets such as small liquid cloud droplets, the backscatter coefficient is proportional to λ^{-4}. Table 1 shows the relative magnitude of this backscatter at various frequencies and the antenna diameter required to achieve a 1.0 degree beamwidth. These data demonstrate why millimeter-wave radars can use smaller antennas and lower peak power transmitters.

Millimeter-wave systems can also scan fading targets more quickly than lower frequency radars. Cloud structures can change rapidly, so accurate cloud pameterization depends on the measurement speed. Since the time needed to make accurate reflectivity and Doppler measurements is proportional to the radar's wavelength, millimeter-wave systems can obtain three-dimensional images of the clouds in reasonable times.

Table 1. Comparison of microwave and millimeter-wave radars.

	S-band (2 GHz)	C-band (4 GHz)	X-band (10 GHz)	Ka-band (35 GHz)	W-band (95 GHz)
Relative Sensitivity	0.0 dB	12.0 dB	28.0 dB	49.7 dB	67.1 dB
Antenna Diameter for 1.0° beamwidth	8.6 m	4.3 m	1.7 m	0.5 m	0.18 m

Success of Polarimetry in Detecting Ice Particles

Recent experiments with 95-GHz polarimetric radars show that high polarization purity radars can discriminate cloud particle phase. Over the past three years, MIRSL has participated in joint ground- and air-based experiments with the University of Wyoming's Atmospheric Science Department. The purpose of this collaborative program is to characterize polarimetric backscatter from ice particles and to demonstrate that polarimetric millimeter-wave radars can distinguish between cloud water and ice particles.

The initial ground-based measurements were held at the University's Elk Mountain Observatory, which is equipped with a variety of ground truth equipment, including a cloud sampling wind tunnel and a two-dimensional imaging probe. The mountain, whose geometry induces lingering cap clouds in the winter, provided a variety of ice cloud types from which data were collected. The radar and ground truth data clearly related the polarimetric backscatter seen by the radar to actual particle shape and orientation.

Our collaboration with the University of Wyoming continued in a series of experiments in which a 95-GHz polarimeter was flown on the University's King Air aircraft. The radar measured two-dimensional cloud profiles and the aircraft collected air truth data. Polarimetric data from these flights, shown in Figure 1, illustrate depolarization in the melting layer of a cloud.

Development of the CPRS

The CPRS will be mounted on a mobile laboratory which can be transported to the first Cloud and Radiation Testbed (CART) site. The major components of the CPRS (depicted in Figure 2) are

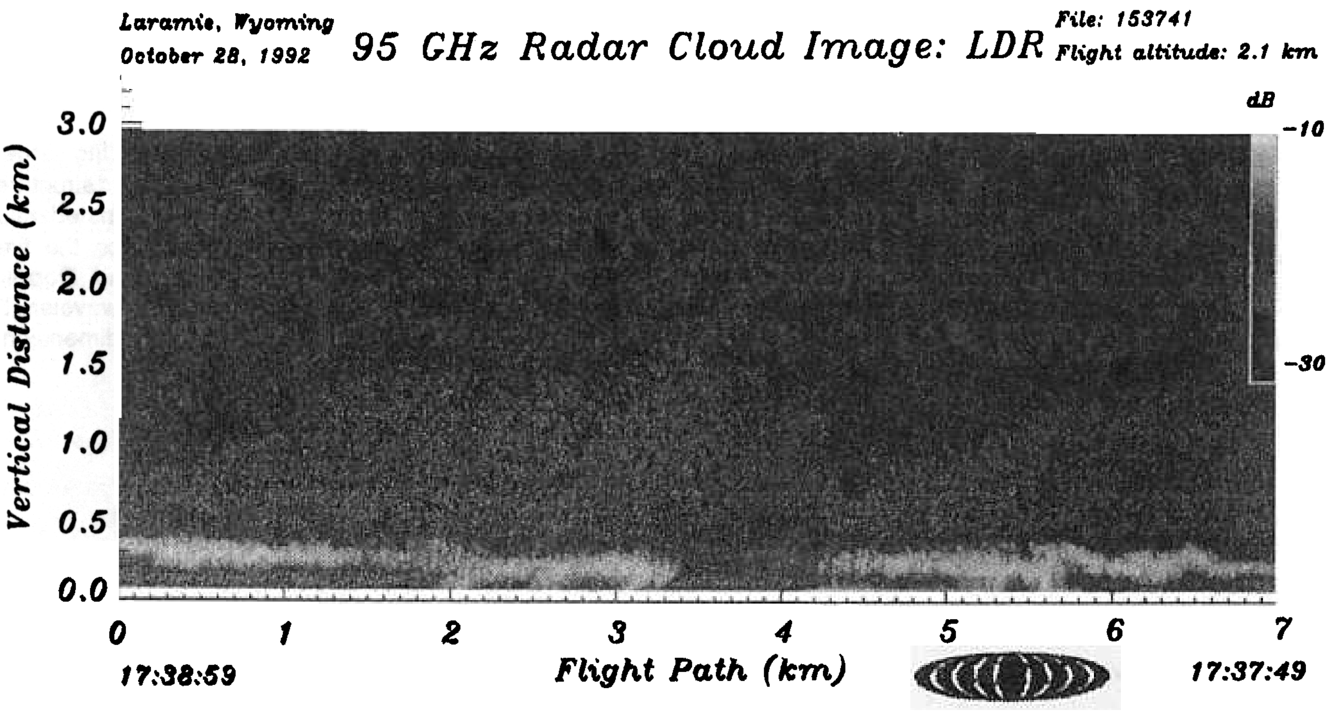

Figure 1. Recent 95-GHz image illustrating detection of the melting layer.

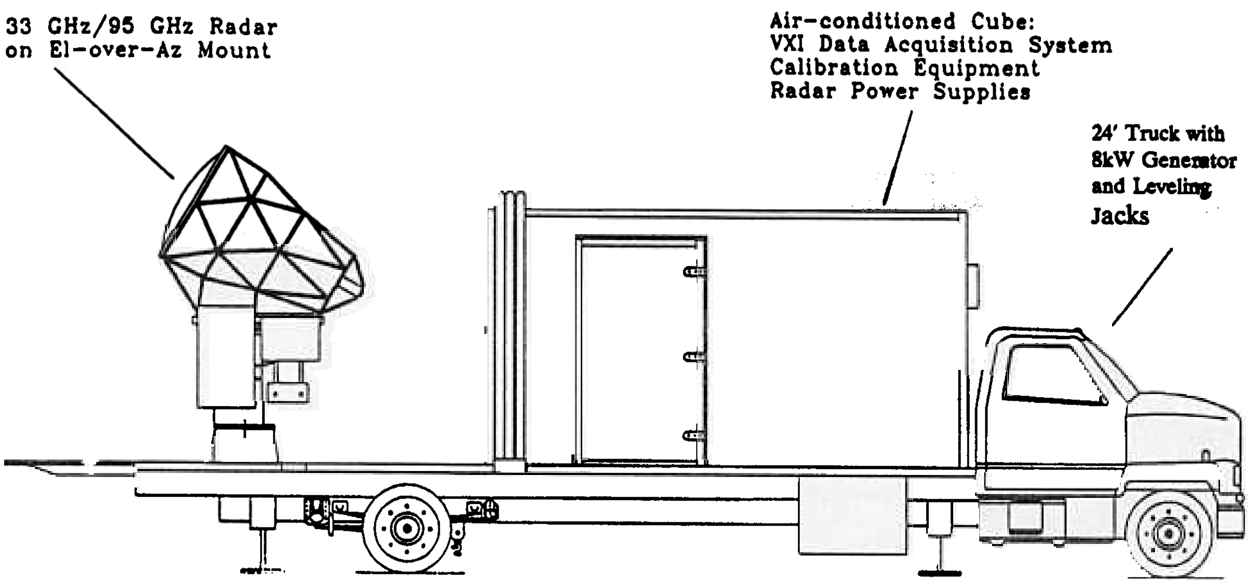

Figure 2. The Cloud Profiling Radar System.

- a polarimetric 95-GHz Doppler radar (1.5 kW peak power)
- a polarimetric 33-GHz Doppler radar (120 kW peak power)
- a 1-m diameter, low cross-polarization dielectric lens antenna
- a high-speed VXI-based data acquisition and digital signal processing (DSP) system.

The dual-frequency antenna feed and lens was designed at the University of Massachusetts' Antenna Laboratory. It produces collocated radiation patterns with a 0.5° beamwidth and a 0.18° beamwidth at 33 GHz and 95 GHz, respectively. Each radar is independently controlled and has its own data acquisition and DSP system. The CPRS can transmit V or H polarized energy simultaneously at both frequencies, switch polarizations from pulse to pulse, and simultaneously receive orthogonal V and H polarized components of backscatter.

Unique Measurement Capabilities of the CPRS

The CPRS and its mobile platform offer unique capabilities for the scientific study of clouds. The truck-mounted pedestal can scan either the entire sky or a particular sector at a maximum rate of 9°/second. Horizontal (vertical) profiles can be scanned and stacked vertically (horizontally) to form 3-D images. Images of reflectivity, radial velocity, and polarimetric parameters can be derived from the radar data. These radar observations will be compared with data from other remote *in situ* sensors to obtain empirical relationships between water and ice contents of the clouds.

Because such relationships are not yet known, we intend to operate the CPRS as often as possible to observe a wide variety of cloud types. The database formed from these measurements should improve our ability to identify cloud particle phase via remote sensing instruments.