The 8-mm Cloud Profiling Radar for the Southern Great Plains Cloud and Radiation Testbed Site: the First 1000 Hours

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Introduction

The National Oceanic and Atmospheric Administration's (NOAA's) Environmental Technology Laboratory (ETL) is developing a series of unattended 8-mm wavelength Doppler cloud profiling radars for the Atmospheric Radiation Measurement (ARM) Program (Moran et al. 1996). The primary purpose of the radar is to provide high-resolution, high-sensitivity, continuous observations of clouds above the ARM Cloud and Radiation Testbed (CART) sites. The radar provides calibrated estimates of the backscattered power, reflectivity, mean vertical velocity, velocity variance, and noise level.

The development of the millimeter cloud radar (MMCR) program was undertaken after the results from several of the ARM Program's field campaigns showed the ability of millimeter wave radars, such as ETL's NOAA/K research radar (e.g., Martner and Kropfli 1993; Kropfli and Kelly 1996) to provide a very sensitive, high-resolution (~50 m) look at the internal structure of nonprecipitating and weakly precipitating clouds.

The radar's measurements of the clouds' macro-physical parameters, such as cloud base and depth, can be combined with measurements of cloud properties from other instruments, such as microwave radiometers, to provide estimates of clouds' micro-physical properties (e.g., Frish et al. 1995; Intrieri et al. 1995; Matrosov et al. 1994).

Many of the radars used in the field programs were one-of-a-kind research systems designed to be operated by a dedicated scientist or engineer. These radars run continuously for field campaigns lasting only about 1 month, and some use sophisticated scanning and polarization diversity to measure cloud properties. The goal of the MMCR design was to provide a less complex, but more robust system that would require minimal routine maintenance while operating continuously and unattended. The radar could be controlled remotely over a standard communications network link and would provide near real-time time-height images of measured quantities. The sensitivity of the MMCR design was anticipated to be better than many of the research cloud radars used in previous ARM studies, but the design would omit the scanning and polarization capabilities.

The first of five radars destined for use in the ARM Program was installed at the Southern Great Plains (SGP) CART site and started routine data collection on November 8, 1996. Through December 1996, more than 1000 hours of continuous observations were collected. We describe the design features and the operating characteristics of this prototype vertically pointing radar.

Design Features

The MMCR is housed in a environmentally controlled sea container similar to the one used for the Atmospheric Radiation and Cloud Station (ARCS) deployed in the Tropical Western Pacific (Figure 1). A high gain (57 dB) Casegrain-fed parabolic dish antenna is mounted on the roof. The vertically pointed antenna surface is protected from the environment by a low loss (less than 0.2 dB, one way) fiberglass cloth radome. The radome is supported with a shroud attached to the dish's rim that elevates it above the sub-reflector spars and provides a tilted surface (~5°) to allow for moisture run off. The antenna is attached to the sea container with a rugged adjustable mount that is used to align the electromagnetic axis vertically.

Figure 1. The MMCR as it is sited at the Southern Great Plains field site.

The electronics fit into two small equipment racks (see Figure 2). The radar transmitter is a high duty cycle (25%) traveling wave tube amplifier (TWTA) supported in a ceiling-mounted rack. The entire 34.86-GHz Radio Frequency (RF) section of the radar uses standard WR-28 waveguide components to reduce transmission losses. Having the TWTA mounted at ceiling height minimizes the length of the waveguide run to the antenna and reduces the transmitter and receiver path loss. The waveguide run to the antenna feed horn and back to the receiver input is pressurized to 5 psi with dry air to prevent moisture from being drawn into the waveguide.

The Intermediate Frequency (IF) and RF electronics use phase-locked oscillators in the up-and-down conversion chain, thus providing a simple coherent signal source. A low-noise amplifier (LNA) is used in the first down conversion stage, and the receiver achieves a better than 4-dB noise figure. The LNA is easily damaged with small RF levels, and a series of RF switching circulators is used to shunt any unwanted RF during the transmit pulse. The switches can also be set to inject a calibrated noise signal into the receiver. An IF signal source with an offset frequency equivalent to a Doppler velocity shift of 1 ms^{-1} is used to measure the receiver response curve.

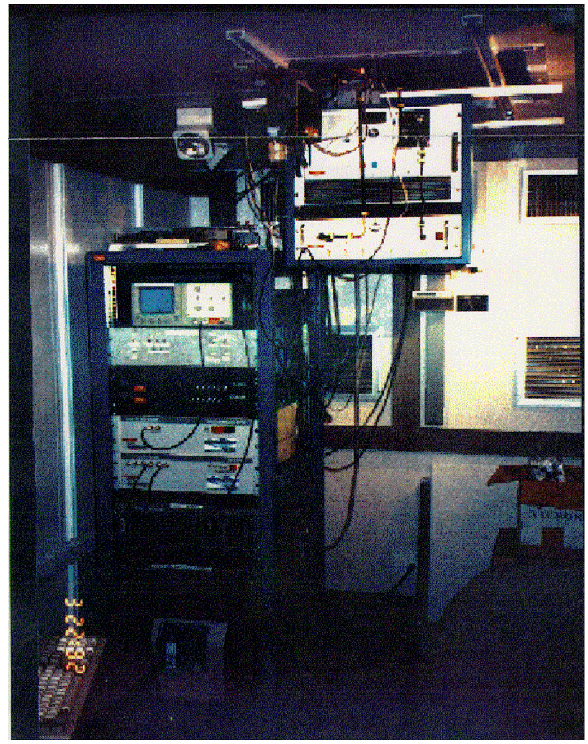

Figure 2. The configuration of the electronics and equipment racks for the SGP millimeter cloud radar.

Two personal computer (PC) technology processors linked over the local SGP site network provide 1) radar control and data collection (OS/2 operating software) and 2) system data management (Solaris operating software). The radar data collection and Doppler signal processing software is similar to the software used in commercially available wind profilers. The two processors share a single display and keyboard. An uninterruptible power source (UPS) provides 20 minutes of AC power to the computers and all the electronics except the TWTA. The entire radar is monitored at regular intervals; each hour a health message is sent, along with radar data sets. The computers and electronics require about 500 watts of power, while the TWTA consumes about 400 watts.

Operating Characteristics

The radar's data collection cycle sequences between four operating modes, as summarized in Table 1. These modes were instituted in the spring of 1997 after earlier experimentation with slightly different operating modes. Collectively, the four modes optimize several measurement capabilities for a wide range of anticipated cloud conditions. Most operating parameters are selectable. The radar currently uses two range resolutions (45 m and 90 m); and the processor can provide height coverage of 220 vertically spaced range gates. The low range modes (1 and 4), with height coverage from 0.1 to 10 km; AGL; and 45-m range resolution provide the best spacial coverage in the lower atmosphere. The high modes (2 and 3), with height coverage from 0.1 to 15 km, use 90-m height resolution, and can be extended to 20-km range when needed. Two of the operating modes use pulse-coded transmit waveforms (1 and 2), but maintain the same vertical height resolution and range as the uncoded modes. The pulse-coded modes provide about 15 dB more sensitivity than the uncoded modes, and it is estimated that they can detect cloud targets as weak as -50 dBZ at 5-km height. This sensitivity is sufficient for the radar to reveal almost all visible clouds overhead. However, the coded modes are subject to range sidelobe artifacts, when observing strong reflectivity gradients and large Doppler velocities.

Table 1. MMCR operating parameters for the Southern Great Plains field site.

SGP operating mode	1	2	3	4
Inter-pulse Period (μs)	82	126	106	72
Pulse Width (ns)	300	600	600	300
Number of Coherent Avgs.	8	6	6	4
Number of Spectral Avgs.	16	21	60	37
Number of Range Gates	220	167	167	220
Fast Fourier Transform Length	64	64	64	64
Number of Code Bits	32	32	0	0
Duty cycle (%)	11.7	15.2	0.6	0.4
Dwell Time (s)	0.7	1.0	2.4	0.7
Observation Time (approx., s)	9	9	9	9
Range Resolution (m)	45	90	90	45
Height Coverage (km)	0.1 - 10	0.1 - 15	0.1 - 15	0.1 - 10
Unambiguous Velocity (ms^{-1})	3.3	2.8	3.4	7.5
Unambiguous Range (km)	10.8	16.0	15.7	10.7

Each altitude range has an uncoded pulse mode and a coded pulse mode, providing a low- and high-sensitivity look at the same region. This sequencing provides a convenient method for comparing modes and using the higher sensitivity of the pulse-coded modes to fill in missing regions on the uncoded data. ETL is working on ways to edit the range sidelobe artifacts from the coded data. Until then, scientists can use the uncoded modes with confidence. They are free of contamination from artifacts; however, because they are less sensitive, they may fail to detect the weakest clouds. Conversely, the coded modes can be used to view very weak clouds, but the user must be alert for the presence of range sidelobe artifacts.

During the first 1000 hours of operation, many different types of clouds were observed over the CART site. The operating modes were chosen to optimize the performance for observing nonprecipitating clouds, which often go undetected by conventional Doppler weather radars. The MMCR operated nearly continuously, except for short power outages, and recorded the clouds' structure with great detail. The radar recorded reflectivity, Doppler velocity, and the width of the velocity spectrum for each range. Figure 3 shows a time height display of the backscattered signal from multi-level clouds observed in January 1997. Note the ability of the radar to penetrate the low-altitude cloud and reveal the multiple cloud layers above that frequently go undetected from ground- and satellite-based optical sensors.

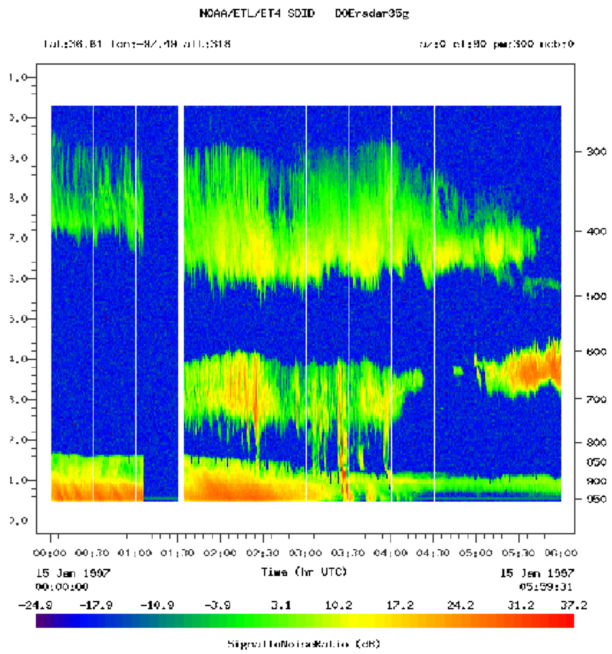

Figure 3. A time height plot of backscattered power from multilayer clouds as measured by the MMCR from its low altitude (0.1 - 10 km) operating mode 4 (see Table 1).

Summary

The first unattended continuously operating millimeter cloud radar (MMCR) has been installed at the SGP CART site and has collected data for the first 1000 hours. The radar provides detailed highly sensitive measurements of the nonprecipitating and weakly precipitating clouds over the site. Data collected by the radar will provide the first records of cloud heights, thicknesses, and layering under most atmospheric conditions. These data sets will provide the foundation for studies leading to a better understanding of the radiative processes in the atmosphere.

Data from the radar may be viewed on the World-Wide-Web at **http://www4.etl.noaa.gov/ cloudrdr.html** (reflectivity, velocity and spectral width last 24 hrs) and **http://research1.sgp.arm.gov/quicklook/mmcr/ display_mmcr.html** (reflectivity lasts 7 days)

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