Forthcoming Upgrades to the ARM MMCRs: Improved Radar Processor and Dual-Polarization

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Background

The Atmospheric Radiation Measurement (ARM) Millimeter Wavelength Cloud Radars (MMCRs) are vertically pointing ground-based Doppler systems, designed for long-term, unattended operations. In spite of very low transmitted power, they achieve excellent sensitivity, sufficient for detecting most visible clouds overhead, through their short wavelength and the use of a large antenna, long sampling duration (~1 sec), and signal processing and pulse compression techniques. Table 1 summarizes some of the radar's basic characteristics. Since the original design in the early 1990s, various minor improvements have been made to the radar system. National Oceanic and Atmospheric Administration/ Environmental Technology Laboratory (NOAA/ETL) is now in the process of implementing two major upgrades: (1) replacing the radar's original data system with a more powerful processor, and (2) adding a dual-polarization measurement capability.

Table 1. Characteristics of the MMCR.

Transmitter	TWTA, 100-W peak power
Duty Cycle	up to 25%
Antenna	6-ft or 10-ft diameter
Beam Width	0.3 and 0.2 deg.
Height Coverage	0.1 to 20 km
Height Resolution	45 m and 90 m, typically
Time Resolution	9 sec/mode, typical
Sensitivity	As good as -50 dBZ at 5 km
Operating Modes	programmable, typically cycles through 4 modes
Wavelength	8.6 mm

New Processor

The present MMCR processor can be programmed to optimize the radar's performance for a variety of cloud types. The radar's sensitivity to a particular cloud observation is governed by variables such as transmitted pulse width, number of coherent pulse averages, pulse repetition frequency, number of incoherent spectral averages, and the number of code bits used in pulse compression processing. These variables, in turn, influence the desired measurements such as maximum unambiguous velocity, range resolution, maximum range, range sidelobe artifacts, and observation time. Numerous tradeoffs are possible and the radar routinely cycles through four independent modes designed to observe particular clouds types encountered at individual radar sites (Moran et al. 1998). Table 2 shows some of the operating characteristics of the four modes for the MMCR located at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site near Lamont, Oklahoma.

Table 2. Characteristics for the MMCRs four operating modes.

Cloud Type	Stratus	Cirrus	General	Convective
Inter-pulse Period (μs)	68	126	106	106
Number of Coherent Avgs	10	6	6	1
Number of Spectral Averages	64	21	60	29
Number of Code Bits	8	32	not coded	not coded
Dwell Time (s)	2.8	1.0	2.4	0.4
Unambiguous Velocity (ms^{-1})	±3.2	±2.8	±3.4	±20.3
Unambiguous Range (km)	10.2	18.9	15.9	15.9
Range Resolution (m)	45	90	90	90
Processor Efficiency (%)	31	12	29	4
Est. Sensitivity (dBZ at 5 km)	-47	-54	-42	-38

The operating characteristics of the radar were designed so that each mode has nearly the same observation time of 9 seconds (time required to collect and process the measurements). Because the hardware and software overhead in the radar's signal processor varies with each mode, not all of the data that are available can be processed. The dwell time is that portion of the 9 seconds that is actually used in the cloud measurements and the processor efficiency represents that as a percentage. For the cirrus and convective modes, the processor efficiency is low enough to have an impact on the performance of the radar.

The radar processor in the MMCR is based on the design of wind profiler radars, which exhibit many of the same operating characteristics as the cloud-profiling radar. Observation times for wind profilers, however, are on the order of minutes and the processor's performance doesn't become a factor. Cloud researchers, however, are often interested in observing the dynamics of cloud systems on as short a time scale as feasible. The narrow beamwidths of cloud radars means that short observation times of a few seconds present an opportunity to observe many independent samples of the cloud structure. Poor processor performance impedes the ability of the radar to shorten the observation time without affecting the sensitivity of the measurements. Alternatively, the improved efficiency could be used without changing observation times to improve the sensitivity of each mode or to reduce range sidelobe contamination by reducing the number of code bits used in the pulse-compressed modes.

A block diagram of the present and new MMCR radar processor is shown in Figure 1. The present architecture uses a specialized hardware pulse averager and a programmable digital signal processor (DSP) to implement the processing. As part of the radar upgrade, a new radar processor architecture has been adopted that uses 5 programmable DSPs, as shown. The advantages of the new design are the use of higher clock frequencies and multiple DSPs working in parallel to accelerate the radar's processing power. The hardware runs under a new radar control software program, LAP®-XM, which will replace the present (POP4) software. LAP®-XM was developed out of the need for a versatile radar control software environment that is easily programmed for new processing algorithms and operates under Windows NT.

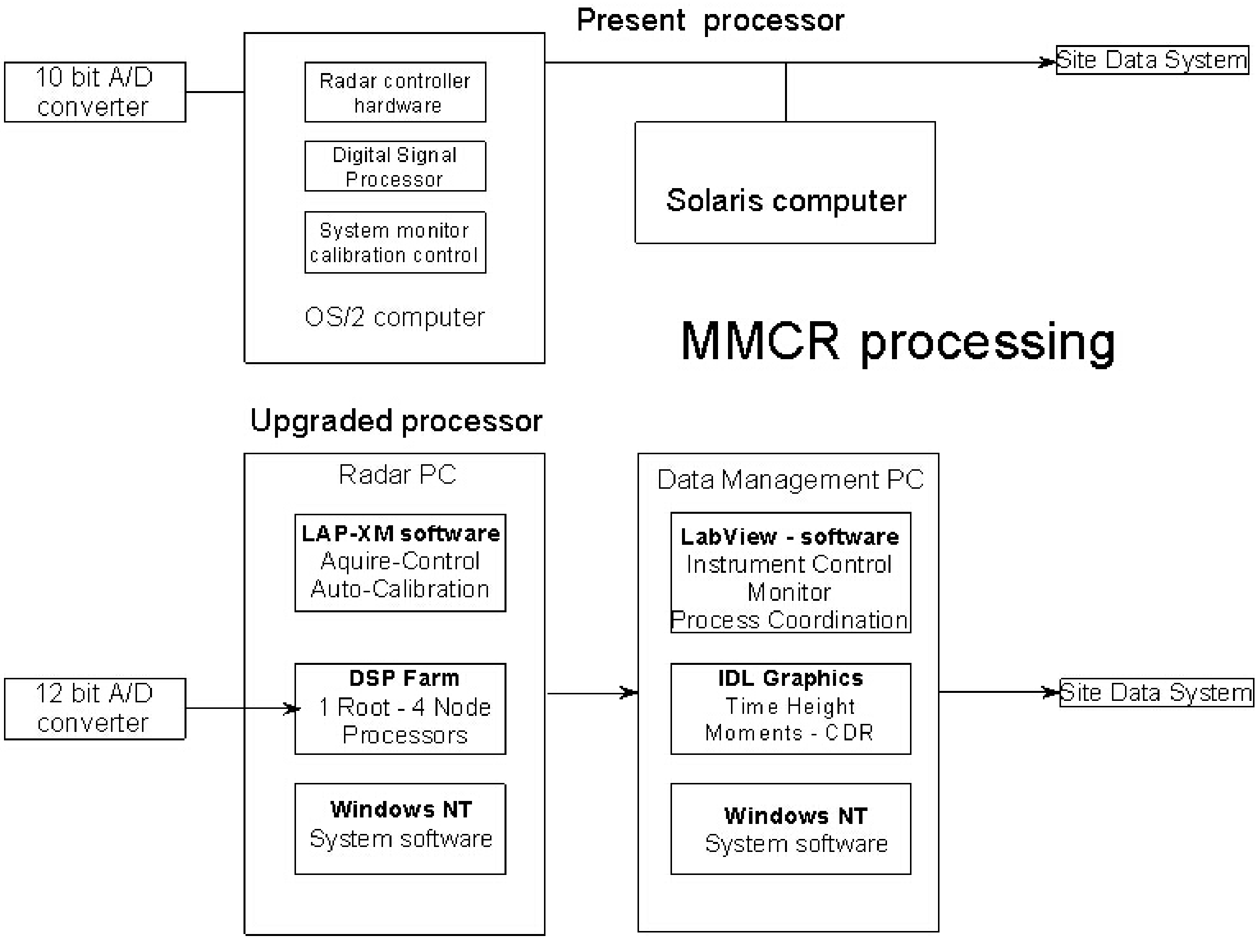


Figure 1. Block diagram of the MMCRs present and upgraded processors.

The improvements in the processing speed will mean the temporal resolution for each mode will approach the dwell time without affecting the radar's sensitivity. Each mode may not reach the optimum dwell time, depending on the implementation. However, there are numerous other tradeoffs that can be used to take advantage of faster processing. Table 3 shows the results of a recent laboratory test of the new processor, operating the current modes used on the SGP radar. The sensitivity of each mode is improved by increasing the number of spectral averages and leaving the observation time the same. An improvement in sensitivity also provides an opportunity to reduce the number of code bits used, which reduces the range sidelobe artifacts in modes that use pulse compression. As an example, the cirrus mode on the upgraded processor could use 16 code bits instead of the original 32 (3 dB sensitivity loss) and still improve this mode's sensitivity by 0.7 dB. Using fewer code bits would also improve the modes' minimum height for useable data and would reduce range sidelobe contamination problems. The convective mode was designed to observe clouds with the fewest ambiguities imposed by the processing. The upgraded processor improves the sensitivity by nearly 5 dB, which would put it in the same sensitivity range as the old general mode, perhaps eliminating the need for one of the modes, leaving room for a new mode in its place.

Table 3. Performance characteristics of the MMCRs upgraded processor.

Mode	1 (Stratus)	2 (Cirrus)	3 (General)	4 (Convective)
Dwell (sampling) Time in Seconds				
Old	2.8	1.0	2.4	0.4
New	6.7	5.6	6.9	3.7
Observation time(s)				
Old	9.0	8.6	8.4	9.0
New	9.0	9.0	9.0	9.0
Proc. Efficiency (%)				
Old	31	12	29	4
New	74	62	77	41
Sensitivity Improvement (dB)	1.9	3.7	2.3	4.8

Dual-Polarization

As is the case with other high-sensitivity radars, the MMCR readily detects non-hydrometeor targets suspended in the air in addition to cloud droplets and ice crystals. Based on the currently available reflectivity and velocity measurements alone, it is usually not possible to distinguish between these two kinds of targets. This represents a major problem for ARM, where the goal is to determine the characteristics of clouds overhead in an automated fashion. The problem is particularly bothersome in the afternoon at continental locations in spring, summer, and fall, when insects and bits of vegetation are commonly suspended aloft in the convective boundary layer.

One approach to solving this problem is to add dual-polarization capability to the radar and use the resulting depolarization ratio measurements to provide information about the target shapes. This will allow the radar users to distinguish between the spherical droplets of stratus clouds and the comparatively non-spherical insects. Dual polarization may also be useful for distinguishing between various cloud hydrometeor types (such as droplets, column crystals and plate crystals), but the insect problem is the motivation for ARM to upgrade some of its radars to include dual-polarization measurements. Martner and Moran (2001) describe how ARM may implement this new capability into its automated cloud-mask algorithms to identify the stratus cloud regions and distinguish them from non-hydrometeor targets in the CART data stream.

The MMCR currently transmits linear polarization. Figure 2 is a block diagram showing the configuration for the dual-polar upgrade. In the upgrade the hardware is altered with the addition of an ortho-mode transducer (OMT), which separates the received signal into co-polarized and cross-polarized components. An additional electronic switch (#3 in the block diagram) is added to the receiver chain to allow the radar's single receiver to measure the co- and cross-polar signals on alternate pulses. Other switches protect the low-noise pre-amp while transmitting. A spare channel mode in the processor software is used for processing and recording the new cross-polar data. Dwell time is evenly divided between the two polarizations, thus sensitivity is reduced by 3 dB. The logarithmic ratio of the two nearly simultaneous signals is computed to determine the linear depolarization ratio (LDR), which is a function of the target particles' shapes and orientations. With some additional hardware changes, the radar could transmit circular polarization and measure circular depolarization ratio (CDR), which would reduce or eliminate the sensitivity to particle orientations. Figure 3 shows an example of vertical profiles of (a) co-polarized and (b) cross-polarized returned power spectra for tests of the dual-polar MMCR in Colorado. The co-polar plot reveals three echo layers. The new cross-polar plot shows that

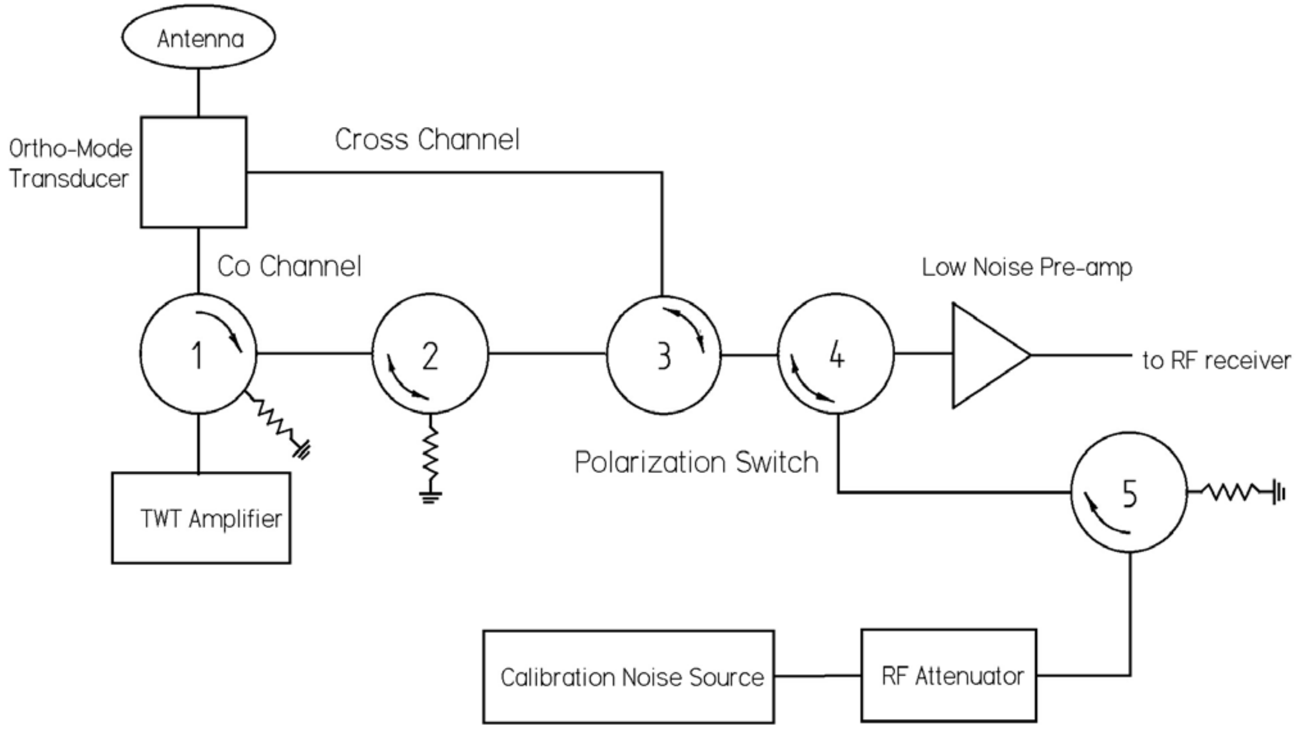
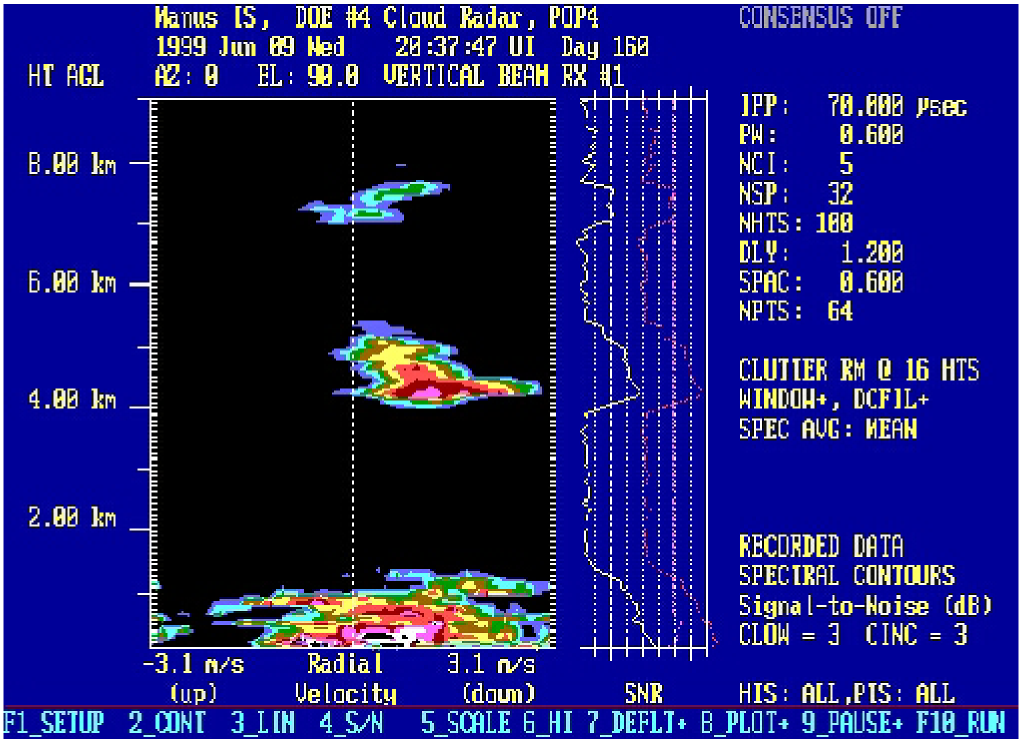


Figure 2. Dual-polarization block diagram.

(a)



Manus IS, DOE #4 Cloud Radar, POP4
CONSENSUS OFF
1999 Jun 09 Wed 20:37:47 UT Day 160
AZ: 0 EL: 90.0 VERTICAL BEAM RX #1

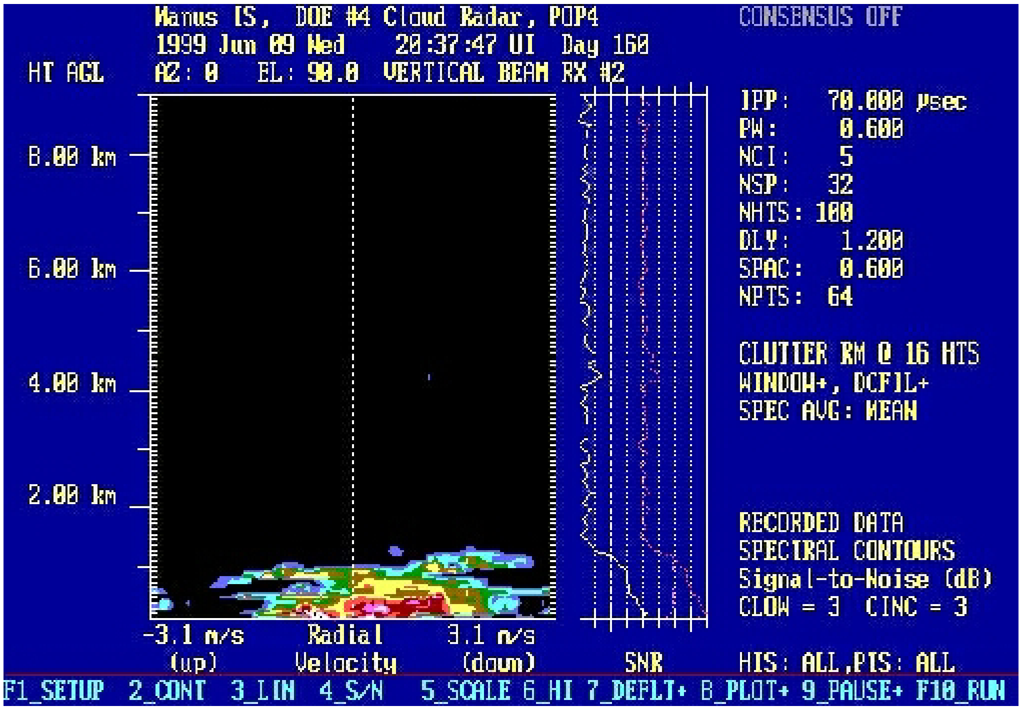
IPP: 70.000 µsec
PW: 0.600
NCI: 5
NSP: 32
NHTS: 100
DLY: 1.200
SPAC: 0.600
NPTS: 64

CLUTTER RM @ 16 HTS
WINDOW+, DCFIL+
SPEC AVG: MEAN

RECORDED DATA
SPECTRAL CONTOURS
Signal-to-Noise (dB)
CLOW = 3 CINC = 3

HIS: ALL, PIS: ALL

(b)



Manus IS, DOE #4 Cloud Radar, POP4
CONSENSUS OFF
1999 Jun 09 Wed 20:37:47 UT Day 160
AZ: 0 EL: 90.0 VERTICAL BEAM RX #2

IPP: 70.000 µsec
PW: 0.600
NCI: 5
NSP: 32
NHTS: 100
DLY: 1.200
SPAC: 0.600
NPTS: 64

CLUTTER RM @ 16 HTS
WINDOW+, DCFIL+
SPEC AVG: MEAN

RECORDED DATA
SPECTRAL CONTOURS
Signal-to-Noise (dB)
CLOW = 3 CINC = 3

HIS: ALL, PIS: ALL

Figure 3. Vertical profiles of (a) co-polarized and (b) cross-polarized echoes aloft observed during tests of the MMCR in Colorado.

the radar detected significant depolarization only in the lowest layer. This means that the lower layer definitely contained non-spherical particles, most likely insects. The significant amount of cross-polar signal could not have been caused by cloud droplets. This illustrates the basic idea for identifying the presence of insects in the MMCR data.

Summary

The MMCR is a high-sensitivity Doppler cloud radar, which has already logged several years of detailed cloud observations at a number of locations. Upgrades to the system, now in progress, include replacing the processor with a multiple-DSP system, adaption of the LAP®-XM operating software and adding a dual-polarization measurement capability. These upgrades will provide improved observing/processing efficiency and flexibility and the ability to identify non-droplet particles, such as insects, which often contaminate the cloud data sets collected by the radars.

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References

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