The ARM Millimeter-Wavelength Cloud Radars: Proposed Operational Modes and Cloud Products

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Introduction

The Atmospheric Radiation Measurement (ARM) Program has supported the development of several millimeter-wavelength radars for the study of clouds. This effort has culminated in the development and construction of a 35-GHz radar system by the Environmental Technology Laboratory (ETL) of the National Oceanic and Atmospheric Administration (NOAA). Radar systems based on the NOAA ETL design are now operational at the U.S. Department of Energy (DOE) ARM Southern Great Plains (SGP) central facility in central Oklahoma and on the icebreaker ship that forms the heart of the Surface Heat Budget of the Arctic (SHEBA) program. Operational systems are expected to come on-line in the next 2 years at the DOE ARM Tropical Western Pacific (TWP) sites located at Manus (Papua New Guinea) and Nauru and the DOE ARM North Slope of Alaska (NSA) site near Barrow, Alaska. For the ARM 35-GHz radars to produce reliable estimates of the presence of all cloud types, they must be able to detect clouds with reflectivities that range from approximately -50 dBZ to +20 dBZ, i.e., 7 orders of magnitude in Z. Four operational modes for the ARM radars are proposed that, when considered together, satisfy the requirement of detecting hydrometers that range in reflectivity from -50 dBZ to +20 dBZ (Figure 1). The radar parameters for each mode are illustrated in Table 1 and the important relationships between them are illustrated in Table 2. The characteristics of each mode are aimed at accurately determining the reflectivities of certain kinds of hydrometeors: 1) a “robust mode” (Figure 2a) that produces accurate reflectivities at all heights all the time; 2) a “general mode” (Figure 2b) that is fairly sensitive to all cloud particles at all altitudes with no data artifacts, except during heavier precipitation; 3) a “cirrus mode” (Figure 2c) that is tuned to detecting weakly reflecting mid- and higher-level ice clouds; and 4) a “boundary layer stratus mode”

Table 1. Operational parameters for the ARM 35-GHz radars.

	SGP				TWP				NSA			
Mode	**4**	**3**	**2**	**1**	**4**	**3**	**2**	**1**	**4**	**3**	**2**	**1**
Number Range Volumes (N_{vol})	167	167	167	110	226	226	226	134	221	149	149	135
Range Volume Spacing (R_{space}, m)	90	90	90	45	90	90	90	45	45	90	90	45
Pulse Width (τ_{pw}, ns)	600	600	600	300	600	600	600	300	300	600	600	300
Interpulse Period (τ_{ipp}, μs)	106	106	126	68	142	142	160	90	90	96	115	68
Number Coded Bits (N_{bits})	0	0	32	8	0	0	32	8	0	0	32	8
Number Coherent Averages (N_{coh})	1	6	6	10	1	5	4	8	2	7	6	10
Number Spectra Averaged (N_{spec})	29	60	21	64	20	44	16	50	20	70	23	50
Number FFT Points (N_{fft})	128	64	64	64	128	64	64	64	128	64	64	64
Minimum Range (R_{min}, m)	105	105	2985	465	105	105	2985	465	105	105	2985	465
Maximum Range (R_{max}, m)	15045	15045	15045	5010	20355	20355	20355	6090	10005	13425	13425	6135
Unambiguous Range (R_u, m)	15900	15900	18900	10200	21300	21300	24000	13500	13500	14400	17250	10200
Range Volume Resolution (ΔR, m)	90	90	90	45	90	90	90	45	45	90	90	45
Unambiguous Velocity (V_u, ms^{-1})	20.28	3.38	2.84	3.16	15.14	3.03	3.36	2.99	11.94	3.20	3.12	3.16
Velocity Resolution (ΔV_u, ms^{-1})	0.32	0.11	0.09	0.10	0.24	0.09	0.11	0.09	0.19	0.10	0.10	0.10
Time Resolution (T_s, s)	9.0	8.5	8.7	9.0	9.0	8.6	9.0	8.5	9.0	9.0	9.0	9.0
Minimum Detected Signal (dBm)	-132	-135	-133	-135	-131	-134	-131	-134	-131	-136	-133	-134
Estimated Sensitivity (5 km, dBZe)	-38	-42	-54	-47	-32	-35	-48	-41	-32	-40	-51	-44

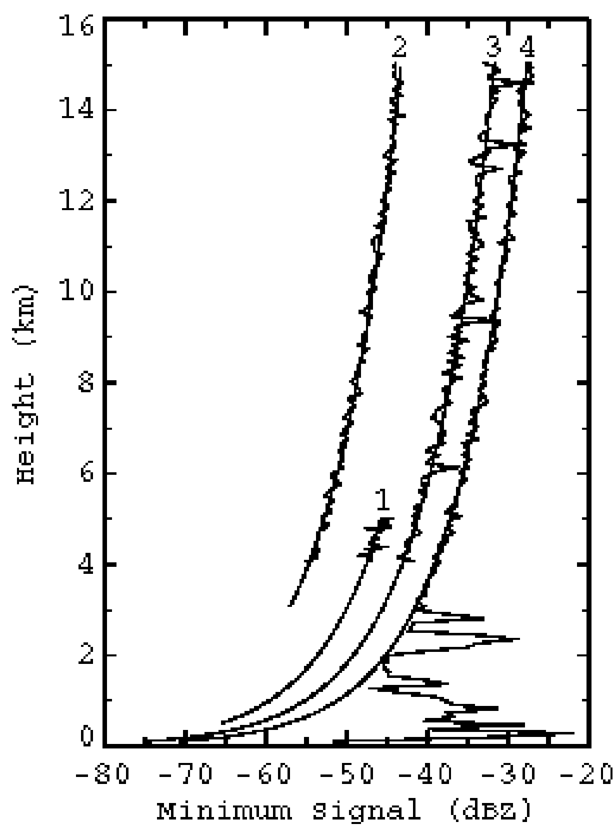

Figure 1. Minimum detectable reflectivity as a function of height for the four modes.

Table 2. Radar parameter relationships.

$R_{min} = R_{deadtime} + N_{bits}\,\Delta R$

$R_{max} = R_{deadtime} + (N_{vol} - 1)\,R_{space}$

$R_u = (c\tau_{ipp})/2$

$\Delta = (c\tau_{pw})/2$

$V_u = \lambda/(4\tau_{ipp}\,N_{coh})$

$\Delta V_u = (2V_u)/N_{fft}$

$T_s \propto N_{vol}, N_{fft}, N_{spec}$, 1/Processor Speed

Radar Sensitivity $\propto \tau_{pw}, N_{bits}$

Receiver Noise $\propto 1/N_{coh}, 1/\sqrt{N_{spec}}$

(Figure 2d) that is tuned to detecting weak reflecting lower-level liquid-droplet clouds. When considered together, these four modes appear to provide the required sensitivity while covering the full 70 dB dynamic range of reflectivities with few, if any, artifacts in the data. The modes in Table 1 for the ARM SGP site and the ARM NSA site are based on the original set of four modes developed by Moran et al. (1997, 1998) and T. Uttal (personal communication, 1998), respectively. The proposed set of modes for the ARM TWP site is a natural extension of the ARM SGP and ARM TWP sets. A detailed justification for each parameter setting can be found in Clothiaux et al. (1998a). Once all of the millimeter-wave cloud radars become operational, the ARM SGP, TWP-Manus, TWP-Nauru, and NSA sites will have a suite of operational active remote sensors that consist of a Belfort or Vaisala, laser ceilometer, a micropulse lidar, and a millimeter-wave cloud radar. We have developed an algorithm that combines the data from these active remote sensors to produce a time series of the vertical distribution

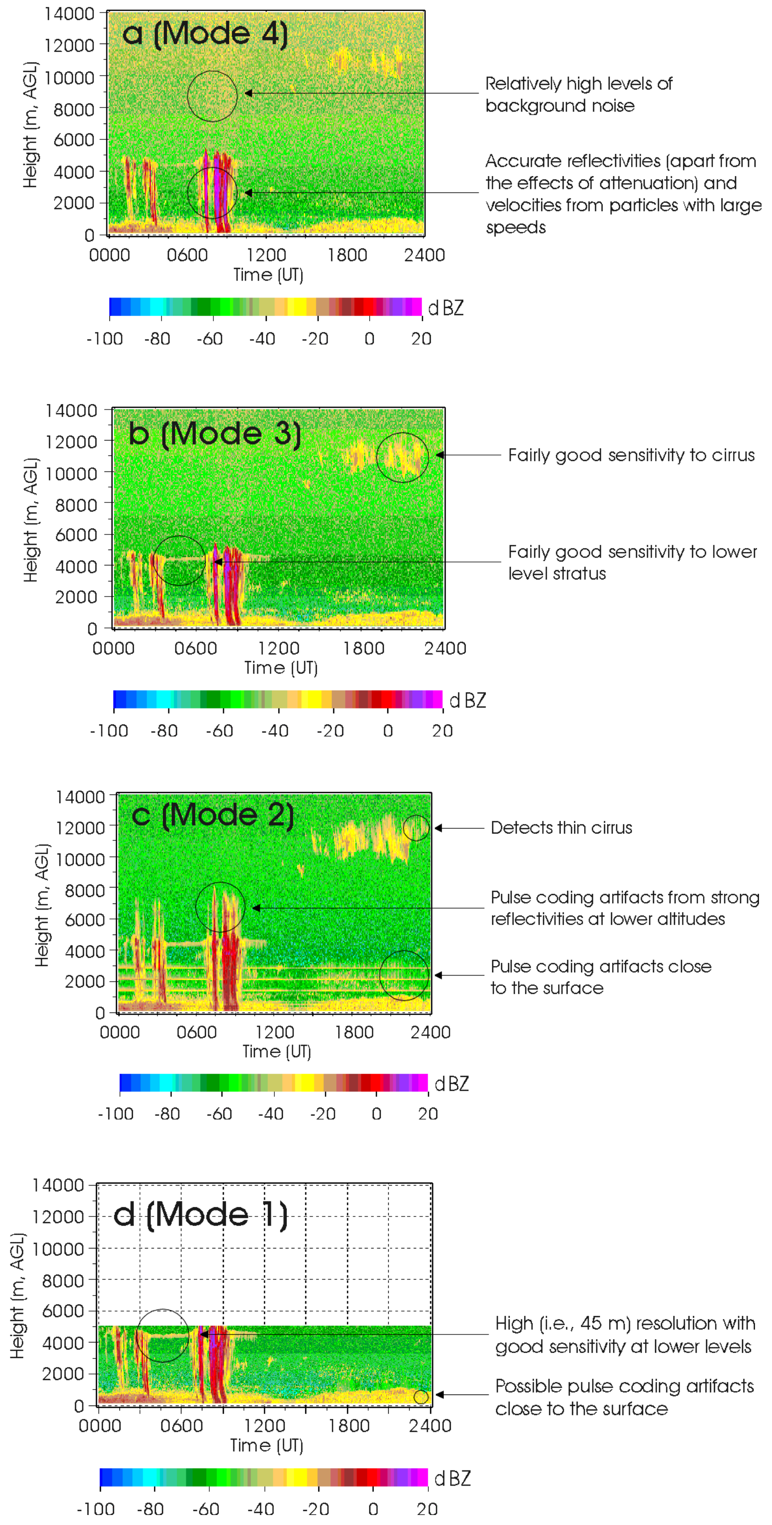

Figure 2. Example illustrations of the reflectivities from the four modes for data that occurred on September 21, 1997. (For a color version of this figure, please see *http://www.arm.gov/docs/ documents/technical/conf_9803/clothiaux-98.pdf*.)

of cloud hydrometers over the ARM sites (Clothiaux et al. 1998b). An example of the output from this algorithm for May 7 and 8, 1997, is illustrated in Figure 3. The variables illustrated in Figure 3 are given below, together with a brief synopsis of the figure that displays the variables contents:

ReflectivityNoClutter (Figure 3, K1). Radar reflectivity (0th Moment) in dBZe from all heights which our processing has indicated as containing hydrometeors ONLY. Regions which contain insects should be just about completely removed from this field if our processing has adequately down its job.

ReflectivityBestEstimate (Figure 3, K2). Radar reflectivity (0th Moment) in dBZe from all heights which our processing has indicated as containing hydrometeors. Regions which appear to contain insects, as well as hydrometeors, are contained in this field.

ModeId (Figure 3, K3). The final set of reflectivities, Doppler velocities and Doppler widths are generated from four different modes. This image flags which modes are contributing to the three fields as a function of time and height. Green (Mode 1) will not be seen much until after September 15, 1997. Light brown (Mode 2) is the cirrus mode. Muddy red (Mode 3) is the general mode and should be the predominant color in most cases. Magenta (Mode 4) occurs at times and heights where the hydrometeors have significant fall speeds and reflectivities, as might occur during precipitation.

ReflectivityClutterFlag (Figure 3, K4). Black indicates no significant power detection. Green (Flag Value 1) indicates a hydrometeor detection with no significant clutter (e.g., insect) contamination. Brown indicates that both hydrometeors and insects are potentially contributing to the significant power returns to the radar. Under these conditions, the cloud top height is uncertain; that is, the top of the brown flagged region may not be true cloud top height. However, cloud top height falls within the brown region. Magenta (Flag Value 4) indicates regions where our processing says all of the significant power returns come from insects and other clutter.

MeanDopplerVelocity (Figure 3, K5). The mean Doppler velocity (1st Moment) generated from the spectra acquired over a period of about 10 s. Velocities above 1.5 m/s are not plotted and appear as gaps in the imagery.

SpectralWidth (Figure 3, K6). The mean Doppler width (2nd Moment) generated from the spectra acquired over a period of about 10 s. Widths above 1.5 m/s are not plotted and appear as gaps in the imagery.

SignaltoNoiseRatio (Figure 3, K7). The signal-to-noise ratio in dB of the signal power returns to the radar receiver noise. As the signal-to-noise ratio increases, the Doppler moments become more reliable.

For studies on the distribution of hydrometeors as a function of time and height, we anticipate these data products to be one starting point. Current research by many investigators is attempting to build on products such as these by retrieving the microphysical characteristics of the particles that lead to the significant radar returns.

References

Moran, K. P., B. E. Martner, D. C. Welsh, D. A. Merritt, M. J. Post, T. Uttal, and R. G. Strauch, 1997: ARM's cloud profiling radar. *28th Conference on Radar Meteorology*, Austin, Texas, Am. Meteor. Soc., 296-297.

Moran, K. P., B. E. Martner, M. J. Post, R. A. Kropfli, D. C. Welsh, and K. B. Widener, 1998: An unattended cloud-profiling radar for use in climate research. *Bull. Amer. Meteor. Soc*., **79**, 443-455.

Other Publications in Progress

Clothiaux, E. E., K. P. Moran, B. E. Martner, T. P. Ackerman, G. G. Mace, T. Uttal, J. H. Mather, K. B. Widener, M. A. Miller, and D. J. Rodriguez, 1998a: The Atmospheric Radiation Measurement program cloud radars: Proposed operational modes. *J. Appl. Meteor*., submitted.

Clothiaux, E. E., T. P. Ackerman, G. G. Mace, K. P. Moran, and R. T. Marchand, 1998b: The Atmospheric Radiation Measurement program active remote sensors: Cloud location products. *J. Appl. Meteor.*, in preparation.

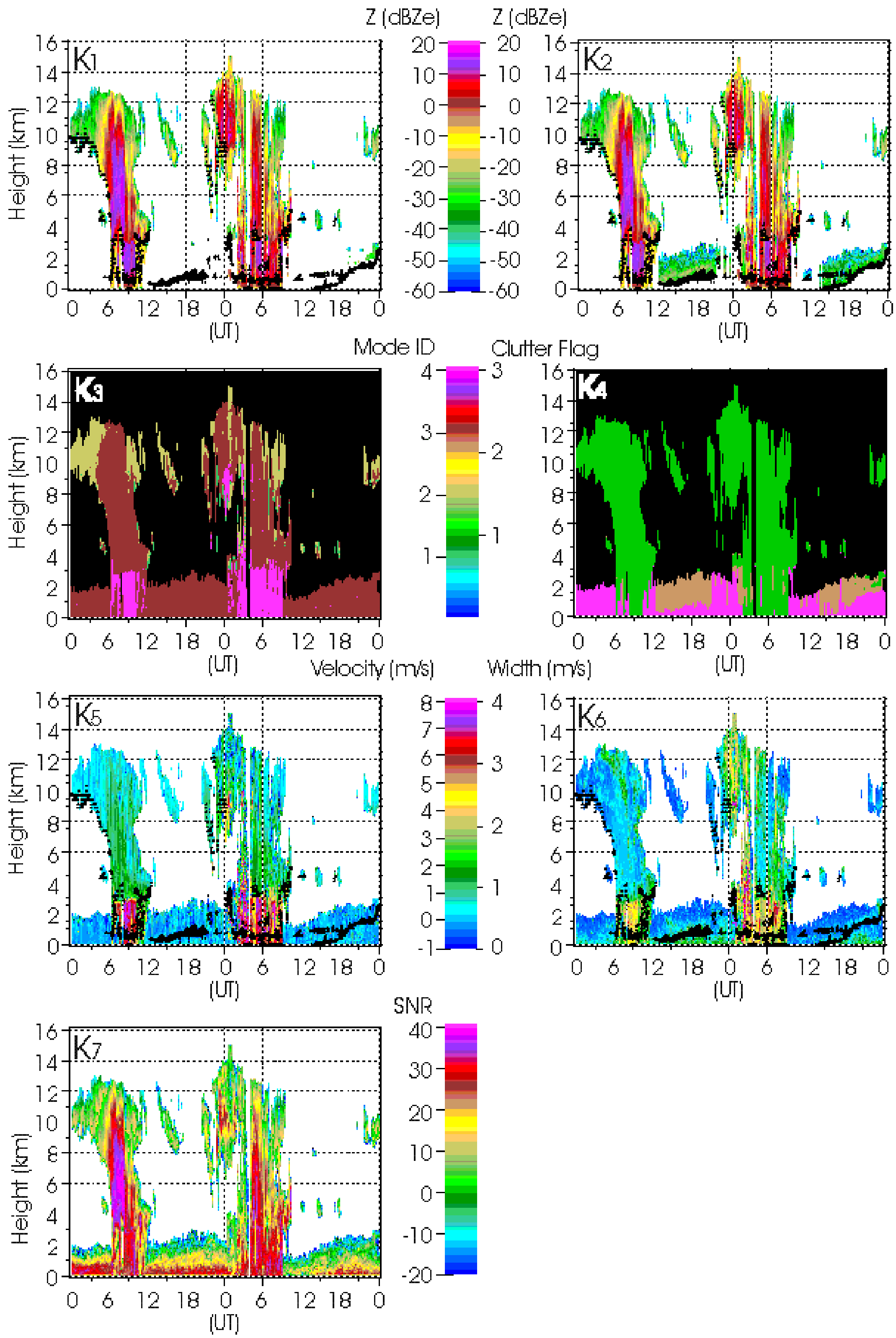

Figure 3. Example of the cloud location products for May 7 and 8, 1997. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/clothiaux-98.pdf*.)