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W-band ARM Cloud Radar Handbook

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1. General Overview

The W-band Atmospheric Radiation Measurement (ARM) Program Cloud Radar (WACR) systems are zenith pointing Doppler radars that probe the extent and composition of clouds at 95.04 GHz. The main purpose of this radar is to determine cloud boundaries (e.g., cloud bottoms and tops). This radar reports estimates for the first three spectra moments for each range gate up to 15 km. The 0^{th} moment is reflectivity, the 1^{st} moment is radial velocity, and the 2^{nd} moment is spectral width. Also available are the raw spectra files. Unlike the millimeter wavelength cloud radar (MMCR), the WACR does not use pulse coding and operates in only copolarization and cross-polarization modes.

2. Contacts

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3. Deployment Locations and History

Table 1 displays the locations and status of each WACR.

Table 1. WACR Deployment Locations and Dates

Location	Date Installed	Date Removed	Status
SGP/C1	07/01/2005		Operational
AMF/M1	03/16/2006		Operational

The first WACR was installed at the Southern Great Plains (SGP) site in the same shelter as the 35-GHz MMCR in July 2005. In early August, it was removed from operation due to a problem with the transmitter. Reinstallation occurred in December 2005. From late January until mid-March 2006, the unit was redeployed to the ARM Mobile Facility (AMF) site. A new WACR was installed at the SGP site in late March 2006. The AMF WACR was first installed at Niamey in mid-March 2006.

4. Near-Real-Time Data Plots

Near-real-time WACR data plots are available from the ARM DQHandS Plot Browser, at http://dq.arm.gov/plotbowser/.

5. Data Description and Examples

WACR moments data are available from the ARM Climate Research Facility (ACRF) Data Archive in data stream "wacr."

Table 2 indicates which data streams are available at each site and time period:

Table 2. WACR Data Stream Availability

Site	Data Stream	Date Range
SGP	sgpwacrC1.b1	2005.07.01 – 2005.07.19 2005.12.13– 2006.01.26 2006.03.24 - Present
NIM	nimwacrM1.b1	2006.03.16 - Present

WACR spectra data are also collected continuously at each site. Approximately 15 GB of raw spectra files are generated per day. Due to the large volume of data collected, the disks containing spectra files are mailed to the archive every few weeks so there is a delay in their availability.

WACR spectra data are not in stored in NetCDF format, but rather in binary data files. They consist of a header block, with general information such as pulse repetition frequency, number of range gates, number of fast Fourier transformation (FFT) points, etc. followed by data values collected at each time. At each time, there are system temperature measurements followed by the measured spectrum stored as an m X n array, where m is the number of range gates and n is the number of FFT points. Detailed information on reading the binary spectra data format is available by emailing Karen Johnson at kjohnson@bnl.gov.

5.1 Data File Contents

5.1.1 Primary Variables and Expected Uncertainty

Table 3 shows the primary quantities measured by the WACR for the wacr data stream.

Table 3. Primary Variables		
	wacr Data Stream	
Variable	**Description**	**Uncertainty**
Reflectivity	WACR Reflectivity (time, height), in dBZ	0.5dB
MeanDopplerVelocity	WACR Mean Doppler Velocity (time, height), in m/s	0.1 m/s
SpectralWidth	WACR Spectral Width (time, height), in m/s	0.1 m/s

The overall uncertainties for the primary quantities measured are as follows:

- Measurement accuracy: 0.5 dB over receiver dynamic range
- Doppler resolution: less than 0.1 m/s.

5.1.1.1 Definition of Uncertainty

We define uncertainty as the range of probable maximum deviation of a measured value from the true value within a 95% confidence interval. Given a bias (mean) error B and uncorrelated random errors characterized by a variance σ^2, the root-mean-square error (RMSE) is defined as the vector sum of these,

$$RMSE = \left(B^2 + \sigma^2\right)^{1/2}.$$

(B may be generalized to be the sum of the various contributors to the bias and σ^2 the sum of the variances of the contributors to the random errors). To determine the 95% confidence interval we use the Student's t distribution: $t_{n;0.025} \approx 2$, assuming the RMSE was computed for a reasonably large ensemble. Then the *uncertainty* is calculated as twice the RMSE.

5.1.2 Secondary/Underlying Variables

Table 4 presents the secondary variables measured by the WACR.

Table 4. Secondary Variables	
wacr Data Stream	
Variable	**Description**
Polarization	0=copol / 1=crosspol

5.1.3 Diagnostic Variables

Table 5 presents the diagnostic variables measured by the WACR.

Table 5. Diagnostic Variables

wacr Data Stream	
Variable	**Description**
PowerAmbientLoad	Ambient load power in dBm
Power HotLoad	Hot load power in dBm
PowerTransmitDriver	Transmit driver power sampled by receiver in dBm
txpower	Detected pulse (Watts)
wacr_status	Status flag
Temp_ambient	Ambient temperature of radar front end components (deg. C)
Temp_LNA	Low noise amplifier temperature (deg. C)
Temp_Hot	Hot load physical temperature (deg. C)
Temp_EIKA	Extended Interaction Klystron Amplifier temperature (deg. C)
Temp_modulator	Modulator temperature (deg. C)
Temp_Chiller	Chiller reservoir temperature (deg. C) (SGP only)
Temp_Antenna_Top	Antenna top temperature (deg. C), (AMF only)
Temp_Antenna_Bottom	Antenna bottom temperature (deg. C) (AMF only)
Temp_Modulator_Control	Modulator control temperature (deg. C) (AMF only)
Temp_Future	For future use
Temp_Outside	Outside temperature (deg. C) (AMF only)
Temp_Computer_Enclosure	Computer enclosure temperature (deg. C) (AMF only)
Temp_Chiller_Supply	Chiller supply temperature (deg. C) (AMF only)
Temp_Chiller_Return	Chiller return temperature (deg. C) (AMF only)
Noise	Calculated noise (dB)

5.1.4 Data Quality Flags

There are three data quality flags in the wacr data stream:

qc_time: Contains the results of quality checks on sample time. This field has a value at each sample time. The qc_time values are calculated by comparing each sample time with the previous time. In the table below, Delta_time = t[n] – t[n-1].

qc_time:

1 = Delta_time is within expected interval
2 = Delta_time is zero: Duplicate sample times
4 = Delta_time is greater than expected
8 = Delta_time is less than expected.

qc_Reflectivity: Contains the results of quality checks on Reflectivity. This field has a value at each sample time and height. The qc_Reflectivity values are calculated by comparing Reflectivity values to reasonable maximum and minimum values. The value '0' indicates acceptable Reflectivity values.

qc_MeanDopplerVelocity: Contains the results of quality checks on MeanDopplerVelocity. This field has a value at each sample time and height. The qc_MeanDopplerVelocity values are calculated by comparing MeanDopplerVelocity values to reasonable maximum and minimum values. The value '0' indicates acceptable MeanDopplerVelocity values.

QC flag values for the above two flags can be interpreted as follows:

0 = Value is within the valid range
1 = value is missing
2 = value is less than the valid minimum
4 = value is greater than the valid maximum
8 = value failed the valid delta check, relative to previous value.

5.1.5 Dimension Variables

Table 6. Dimension Variables

wacr Data Stream	
Variable	**Description**
alt	Altitude, meters above mean sea level, of ground instrument is sited on
base_time	Base time for file, in seconds since 1/1/1970 00:00:00 GMT
heights	Range heights in meters above mean sea level of data collection (center of radar sample volume)
lat	North latitude in degrees
lon	East longitude in degrees
time	Time offset in seconds from midnight on file's collection date
time_offset	Time offset in seconds from base_time

Annotated Examples

Below are example plots of copolarization moments (reflectivity, mean Doppler velocity, and spectral width) from the SGP WACR followed by plots of cross-polarization moments, both for 20060411.

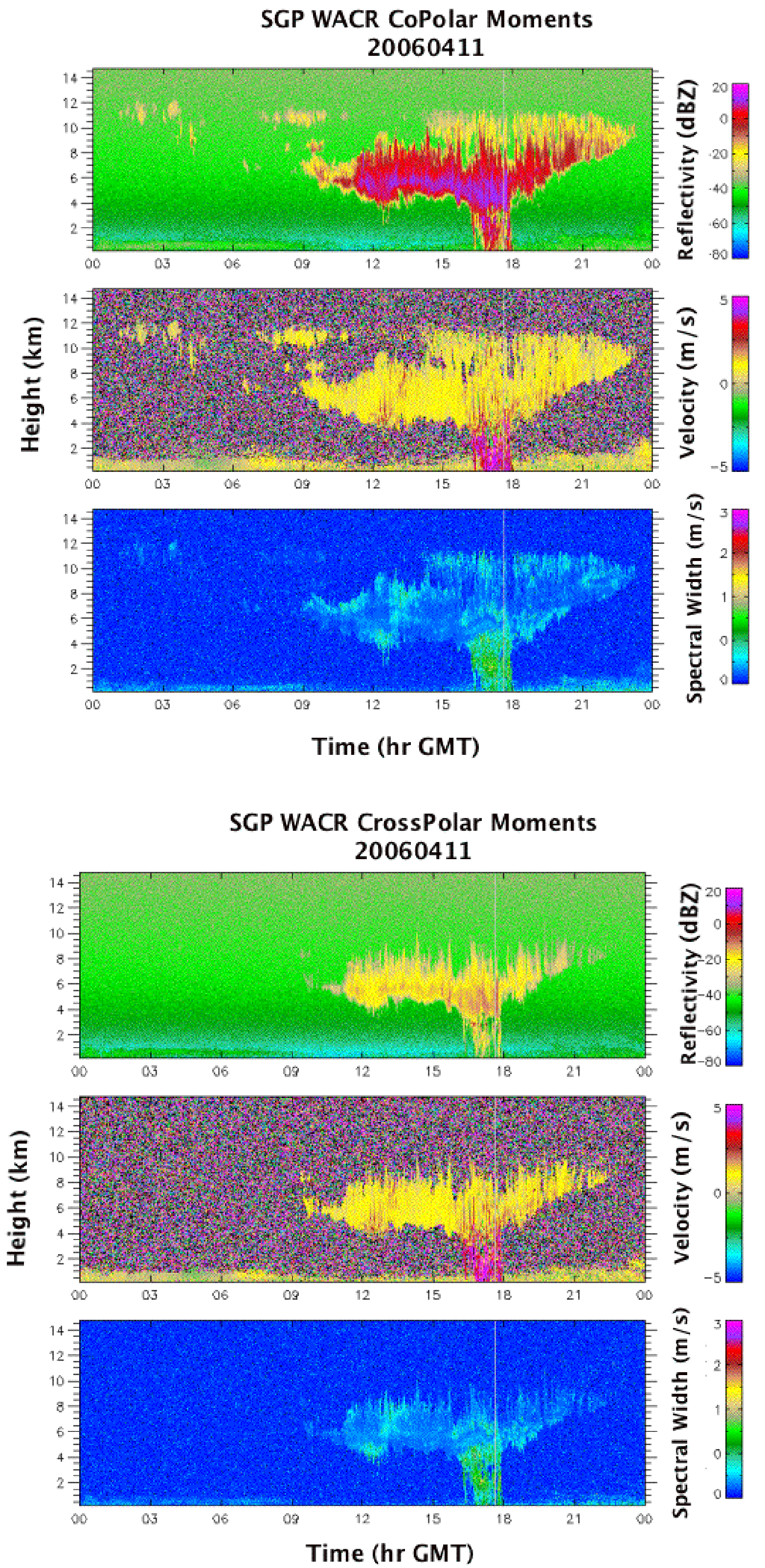

Figure 1. Plots of copolarization (top) and cross-polarization (bottom) moments, both for the SGP WACR.

Next are plots from the AMF WACR at Niamey, first copolarization moments followed by cross-polarization moments for 2006402:

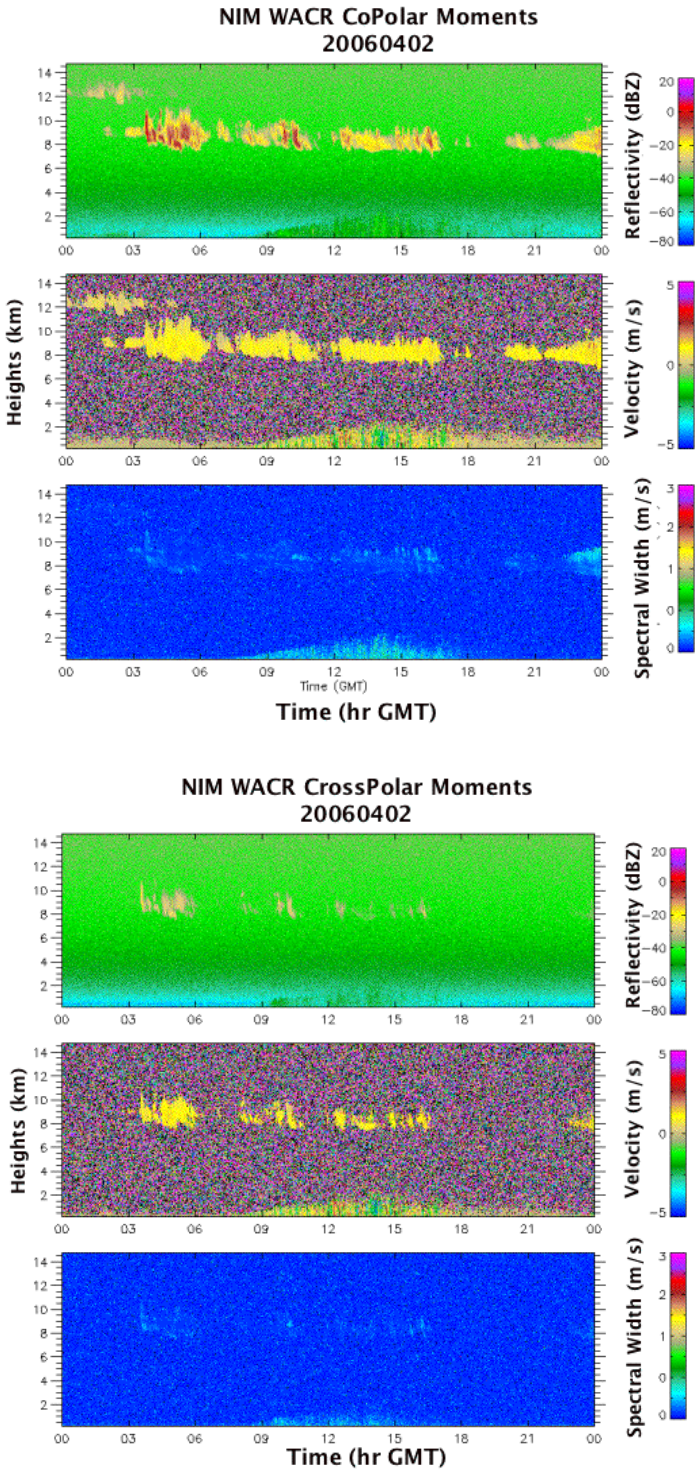

Figure 2. Plots of copolarization (top) and cross-polarization (bottom) moments from the AMF WACR at Niamey.

5.2 User Notes and Known Problems

N/A

5.3 Frequently Asked Questions

What index of refraction for water is used to computer reflectivity (Kw) at 95 GHz?

0.84 at 95 GHz vs. 0.93 for 35 GHz

6. Data Quality

6.1 Data Quality Health and Status

The Data Quality Office website has links to several tools for inspecting and assessing WACR data quality:

- DQ HandS (Data Quality Health and Status)
- DQ HandS Plot Browser
- NCVweb: Interactive web-based tool for viewing ARM data.

Plots of reflectivity, Doppler radial velocity, and Doppler spectral width provide a good indicator of whether the system is operational or not.

6.2 Data Reviews by Instrument Mentor

Data reviews are done weekly. Monthly assessments will be provided here in the future.

6.3 Data Assessments by Site Scientist/Data Quality Office

All Data Quality Office and most Site Scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

6.4 Value-Added Products and Quality Measurement Experiments

At present, no Value-Added Products or Quality Measurement Experiment exist for the WACR.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

The following is a list of components for the WACR:

- CPI Extended Interaction Amplifier (EIKA)
- Pulse Technology modulator
- Antenna
- Radio Frequency Section
- Radar controller
- Radar computer
- Chiller
- Uninterruptible Power Supply.

7.1.2 System Configuration and Measurement Methods

The WACR system consists of the radar, data acquisition/control subsystem, enclosures, cables, and accessories so that it will be operable in a semi-autonomous mode. For the purposes of this specification, semi-autonomous operation is defined as a mode wherein an operator is required only to power up and power down the system. Once powered up, the WACR will automatically enter a standby mode ready to begin taking data.

7.1.3 Specifications

Radar specifications are as follows:

Frequency	95 GHz (Wavelength 3.16 mm, W band)
Peak Transmitted Power	1500 W
Maximum Duty Cycle	0.1%
Antenna Diameter	SGP: 2 ft
	AMF: 4 ft
Antenna Gain	see table under Calibration History
Beam Width (full-width, half-maximum)	see table under Calibration History
PRF (max)	20 kHz

WACR Mode Sequence and Characteristics

The WACR alternates between copolarization and cross-polarization modes continuously. Table 7 gives operating characteristics at each site.

Table 7. WACR Operation Parameters

Radar Parameter	Site	
	SGP	**AMF NIM**
Pulse Repetition Frequency (Hz)	10000	10000
Pulse Width (microsec)	0.3	0.3
Gate Spacing (microsec)	0.143	0.143
Number of Gates	348	348
Spectral Averages	160	160
FFT Length	256	256
Obs. / Processing Time	2.14	2.14
Nyquist Velocity (m/s)	7.885	7.885

7.2 Theory of Operation

The WACR works by transmitting a pulse of millimeter-wave energy from its transmitter through the antenna. The energy propogates through the atmosphere until it intercepts objects that reflect some of the energy back to the WACR. These objects can be clouds, precipitation, insects, spider webs, man-made objects, etc. The same antenna is used to receive the return signal. The received signal is downconverted into an intermediate frequency that is then fed to a digital receiver. A digital receiver processes the signal and ultimately provides the radar spectra. From the radar spectra, power, Doppler velocity, and spectral width are calculated. The power measurement is processed by knowing the WACR's calibration coefficient to provide the radar reflectivity.

Looking at the meteorological radar range equation gives insight as to how the WACR works and what parameters affect its sensitivity. Any radar's sensitivity is proportional to the transmit power, the square of the antenna gain, and the square of the radar's wavelength. The sensitivity is inversely proportional to the square of the range from the radar to the target.

7.3 Calibration

7.3.1 Theory

Several systems within the radar require calibration at regular intervals. The values obtained from these calibrations are stored as constants, polynomials, or curves in the calibration files or programs. These are used by the software to convert raw radar moment files to range-corrected power (dBm) and reflectivity (dBZ) data in netCDF format and sent to the site data system.

7.3.2 Procedures

N/A

7.3.3 History

N/A

7.4 Operation and Maintenance

N/A

7.4.1 User Manual

N/A

7.4.2 Routine and Corrective Maintenance Documentation

N/A

7.4.3 Software Documentation

N/A

7.4.4 Additional Documentation

N/A

7.5 Glossary

See the ARM Glossary.

7.6 Acronyms

AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement (Program)
EIKA	Extended Interaction Klystron Amplifier
FFT	fast Fourier transformation
Lidar	Light Detection and Ranging
MMCR	millimeter wave cloud radar
MMW	Millimeter wave (30GHz - 300GHz)
MPL	Micropulse LIDAR
NIM	Niamey, Niger
NOAA	National Oceanic and Atmospheric Administration
NSA	North Slope of Alaska
QC	quality control
RMSE	root-mean-square error
SGP	Southern Great Plains
TWP	Tropical Western Pacific
WACR	Wband ARM Cloud Radar

Also, see ARM Acronyms and Abbreviations.

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