The 95 GHz Airborne Cloud Radar: Hardware Modifications for Medium Altitude Flight on the DOE Twin Otter Aircraft and Results from the 2000 Cloud IOP/ARESE II

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Introduction

The Airborne Cloud Radar (ACR) is a W-band (95 GHz) polarimetric Doppler radar jointly developed by the University of Massachusetts (UMass) and National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). It was designed as a prototype airborne facility for the development of the 94 GHz Cloud Profiling Radar System (CPRS), which is the central instrument for NASA CloudSat mission. Since its completion, ACR has participated in a number of important research programs. It has flown on the NASA DC-8 research aircraft and on the U.S. Department of Energy (DOE) Twin Otter aircraft in support of the Atmospheric Radiation Measurement (ARM) Program Unmanned Aerospace Vehicle (UAV) Program. The latest flight series during the Second Atmospheric Radiation Measurements Enhanced Shortwave Experiment (ARESE II) demanded that ACR operate at altitudes as high as 6.7 km. At this altitude, however, the low ambient pressure is problematic for high-voltage and mechanical components. Critical equipment, such as the power transmitter and computer hard drives, will fail at such low pressure. Therefore, extensive ACR hardware modifications were made and system tests were performed in an environmental chamber before the ARESE II. These efforts ensured that ACR functioned reliably during ARESE II.

ACR System Overview

The ACR is a third-generation millimeter-wave cloud radar built at UMass. While adopting the well-tested techniques used by its predecessors, ACR also has a number of new features including an internal calibration loop, frequency agility, digital I and Q demodulation, digital matched filtering, and a W-band low-noise amplifier. Table 1 gives the ACR's system specifications. The radar hardware and analysis of initial datasets were described by Williams (1996) and by Sadowy (1997). Since its completion in 1996, ACR has flown on the NASA DC-8 and the DOE Twin Otter in support of six field experiments, including: (1) 1996 Summer Synthetic Apeture Radar (SAR) Experiment, (2) Pacific Rim Experiment on board the NASA DC-8 (Sadowy 1997), (3) 1998 Summer Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) DC-8 Cloud Radar Experiment (Sekelsky et al. 1999; Li et al. 2000), (4) 1999 Spring ARM-UAV Kauai Experiment (Stephens et al. 2000), (5) Summer ARM-UAV

Monterey Coastal Stratus Experiment (Stephens et al. 2000) on board the DOE Twin Otter (http://abyss.ecs.umass.edu/acr-web), and (6) 2000 Spring ARM-UAV ARESE II. The ACR will also fly in support of CloudSat during pre-launch experiments and post-launch validation.

Table 1. ACR system specifications.

Frequency (GHz)	94.905, 94.915, 94.925, 94.395
Transmit Polarization	V or H
Receive Polarization	V or H
Peak Power (kW)	1.2
PRF (Hz)	5,000-80,000
Range Resolution (m)	38, 75, 150
Noise Figure (dB)	9.5
Receiver Bandwidth (MHz)	1, 2, 4
3 dB Beamwidth (degree)	0.8
Sensitivity (dBZe, R=1 km, ΔR=75 m, 1 sec averaging	-46

Installation on DOE Twin Otter

The ACR is the first airborne cloud radar flown by the ARM-UAV Program. A major goal of the ARM-UAV Program is to use UAVs to obtain high-altitude and long-endurance cloud measurements for studying evolving cloud fields and their effect on the solar and thermal radiation balance in the atmosphere. Additionally, this program focuses on measurements to calibrate satellite radiance products and validate their associated flux retrieval algorithms. Flying remote sensors on the manned research aircraft, such as the DOE Twin Otter, is an important part of the ARM-UAV Program in terms of instrument and algorithm development. It has either augmented the UAV measurements or has substituted for the latter when the UAV platforms were unavailable for any field campaign (Stephens et al. 2000).

The ACR flights on the DOE Twin Otter aircraft have demonstrated the measurement capabilities of the 95 GHz cloud radar and collected crucial data during the ARM UAV field missions. Significant modifications to ACR were made for operation on the DOE Twin Otter aircraft. In contrast with the NASA DC-8, the DOE Twin Otter is a small twin turbine engine aircraft. Its cabin is not pressurized and has stricter limits on power consumption and space. On the other hand, a new highly reliable modulator for the ACR EIA subsystem (see Table 2 for specifications) was designed by Communication and Power Incorporation (CPI) in Beverly, Massachusetts. To reduce the physical size of the prime power filters, the new EIA subsystem uses 220 VAC instead of 110 VAC. However, the Twin Otter provides only 28 VDC and uses DC-AC converters to get 110 VAC power. A high-efficiency DC-to-AC power inverter was therefore used to convert the 28V DC power to 220 VAC for the EIA subsystem. This approach is significantly more efficient in terms of power consumption than using inefficient DC-to-AC converters already installed on the Twin Otter.

Table 2. Specifications of CPI VZB2941A1 millimeter-wave pulsed EIA transmitter subsystem (before modification for high altitude operation).

RF	Center Frequency (GHz)	94.92
	Peak Power (kW)	1.0 min
	3 dB Beam width (MHz)	100 min
	Duty Cycle	0.01 max
	PRF (Hz)	0 to 80,000
	Pulse Width (μs)	0 to 2.0
Prime Power	Voltage (VAC)	220
	Current (A)	0 to 10 rms
Cooling	Forced Air	
Environmental	Temperature Range (°C)	0 to 40 (operating)
	Altitude (m)	1,500 max (operating)

RF = radio frequency

Hardware Modifications for ARESE II

ARESE II was a multi-agency multi-sensor field campaign organized by the ARM-UAV Program. The objectives of ARESE II were to directly measure the absorption of solar radiation by the cloudy atmosphere and to place uncertainty on these measurements; to investigate the possible causes of cloudy sky absorption in excess of model predictions; and to investigate the possible causes of cloudy sky absorption in excess of clear-sky absorption (Ellingson and Tooman 1999). ARESE II was held during overlapping time periods with ARM Cloud Intensive Operational Period (IOP) 2000 in order to share the data collected by ARESE II sensors and Cloud IOP sensors to obtain maximum scientific results. Therefore, some of the ACR flights were also designated in support of Cloud IOP 2000 as well as ARESE II.

To simulate satellite field of view, the ARESE II demanded that the Twin Otter fly at 6.7 km above sea level. However, at this altitude, the atmospheric temperature and pressure decrease significantly (-30°C and 400 mbar for U.S. standard atmosphere [Cole 1965]). Critical equipment and components designed to operate at ground level, such as general purpose computer hard drives using rotating disks, will fail in an unpressurized environment at that altitude since the disk heads, which “ride” on a cushion of air, are specified for operation below 3,000 m. In addition, the EIA subsystem’s high-voltage modulator was designed for operation below 1,500 m altitude. Most of the critical components, such as the W-band EIA transmitter, radar system power supply, and local oscillators, are cooled by forced air to prevent them from overheating. However, under a low-pressure environment, cooling performance could deteriorate due to thin air.

During the preparation for ARESE II, the EIA subsystem was modified and tested by CPI in Beverly, Massachusetts, to prevent corona and arcing at low pressure. Generic computer hard drives used by ACR were replaced by high-performance, solid-state drives. Extra cooling units were added to the radar power supply and RF/IF subsystem. Moreover, the entire system was thoroughly examined for any potential component failure at low-pressure and low-temperature ambient conditions. Table 3 summarizes major ACR equipment modifications for operation at 6.7-km altitude.

Table 3. ACR equipment modification for middle-altitude operation.

Equipment	Modifications
1. Computer System Sun SPARC20 PC104	 Install solid-state SCSI disk Install solid-state flash disk
2. Power Supply	Improve cooling performance
3. EIA Transmitter	Modify potting of HV connections Subsystem test under low pressure

After the hardware modifications, ACR was tested for pressure and temperature performance in an environmental chamber at Sanders Corp., near Nashua, New Hampshire (Figure 1). During the test, thermocouples were used to measure hot spots due to thin air. The temperature and pressure inside the chamber were computer controlled and programmed to simulate the aircraft taking off and landing. The test results demonstrated that ACR hardware functions well at low pressure and low temperatures. This was later proved during the ARESE II.

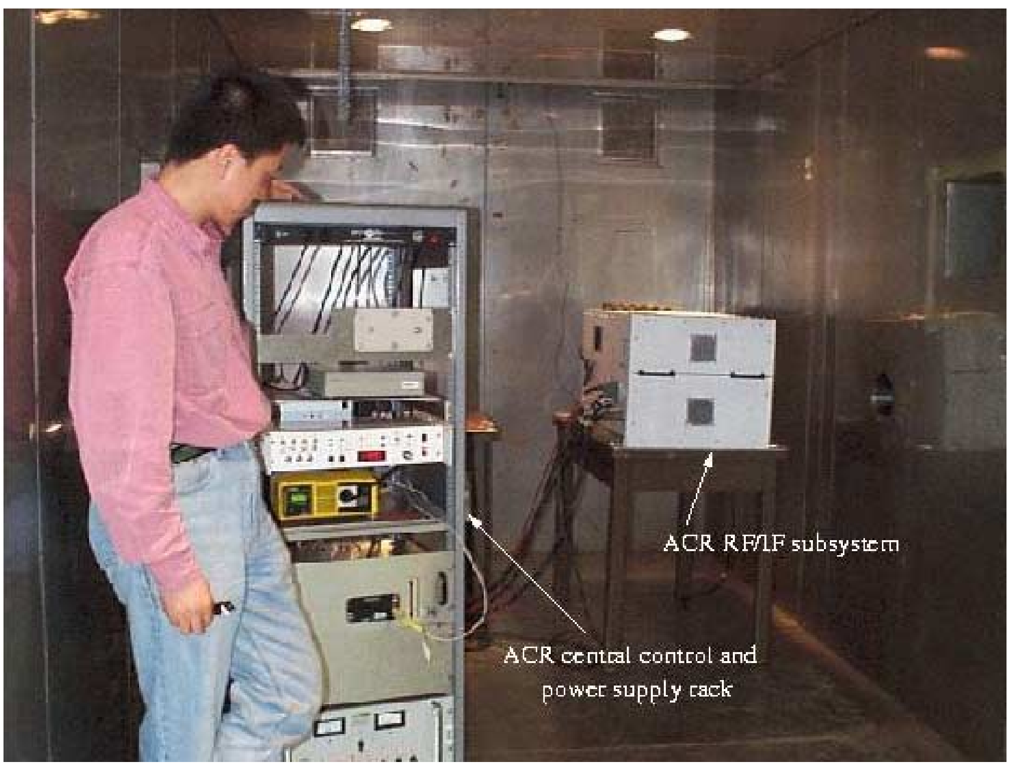

Figure 1. ACR system test in an environmental chamber at Sanders Inc., New Hampshire.

Figure 2a shows the ACR RF/IF subsystem before it was installed on the Twin Otter during the ARESE II. Inside the Twin Otter payload bay, ACR's antenna was pointed to cross track direction. A 45-degree reflector plate (see Figure 2b) was used to guide the radar beam either up for zenith-looking mode or down for nadir looking mode. Figure 3 shows ACR measurements of medium-level cirrus clouds on March 1, 2000, and low-level stratus clouds on March 18, 2000.

(a)

(b)

Figure 2. (a) ACR RF/IF subsystem before installation in the DOE Twin Otter during the ARESE II. (b) The DOE Twin Otter aircraft. A 45° reflector was used guide the radar beam up or down.

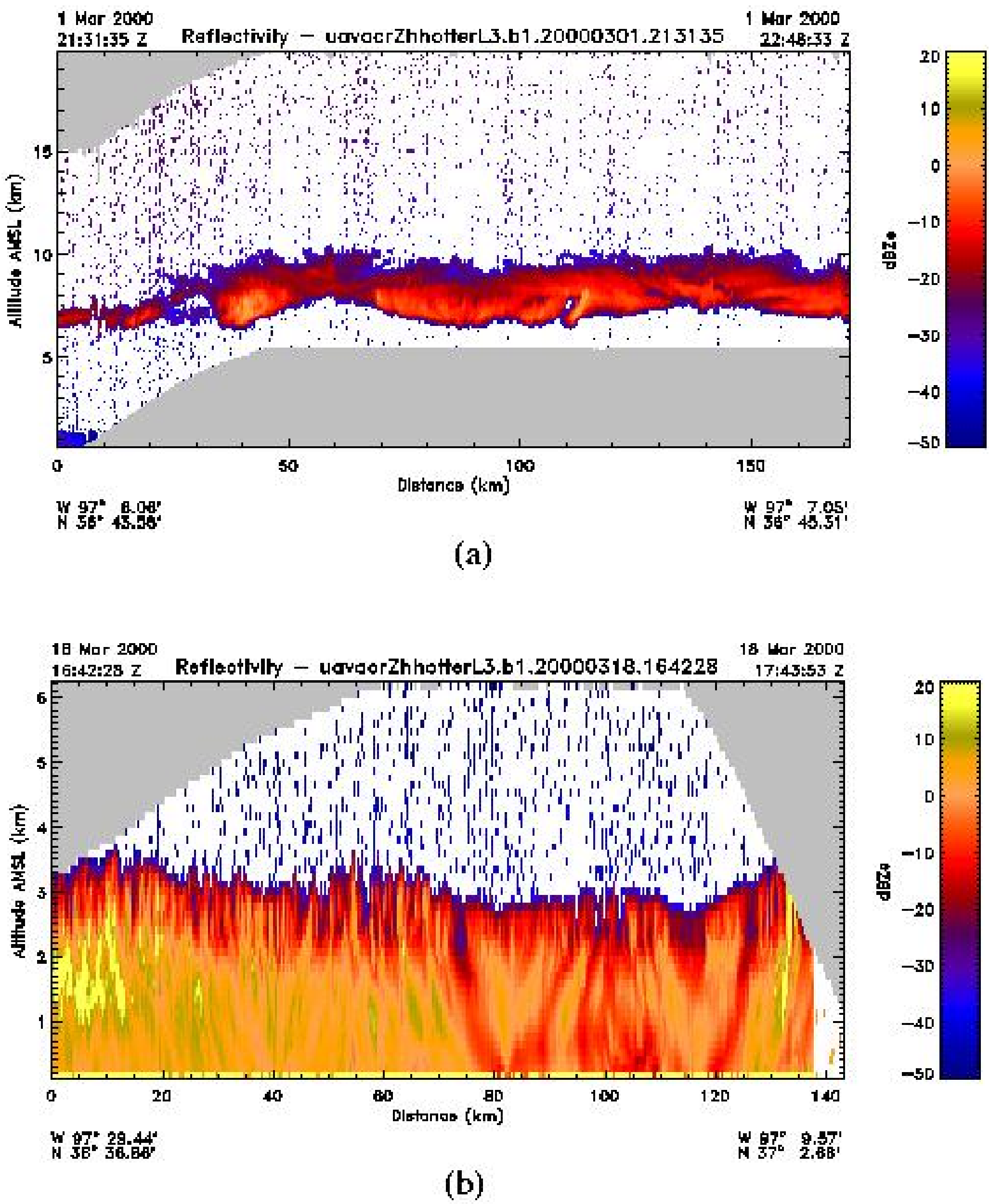

Figure 3. ACR reflectivity images from ARESE II. (a) Measurements of medium-altitude cirrus clouds. (b) Measurements of low-level stratus clouds.

Summary

In order to operate ACR at medium altitude during the Cloud IOP 2000/ARESE II, extensive hardware modifications were made. The ACR was then tested in an environmental chamber before the experiment. These efforts ensured a successful flight series.

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