Ground-based atmospheric research radar systems at the University of Massachusetts

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1. Introduction

Over the past two decades, the Microwave Remote Sensing Laboratory (MIRSL) at the University of Massachusetts has developed several specialized radar systems for a variety of atmospheric research applications spanning UHF to W-band frequencies. Presently, the laboratory operates four ground-based research radar systems, with others in development. These systems are designed, constructed, and operated almost exclusively by electrical engineering graduate students of the MIRSL laboratory, often in cooperation with researchers in meteorology or the atmospheric sciences from other universities or organizations. These mobile radar systems are available to the atmospheric research community through collaborative proposals or subcontracts and in some instances through lease agreements. Interested parties should contact the authors. The radar systems are summarized below.

2. W-band Mobile Doppler "Tornado" Radar

The W-band mobile Doppler radar (Pazmany et al. 1999) is a fully polarimetric radar operating at 95 GHz with a peak transmit power of 1 kW. Using a 1.2 m high-gain Cassegrain antenna, the radar achieves a $0.12°$ beamwidth with range resolution typically 30 m. The radar is integrated on an azimuth-over-elevation pedestal on a modified Ford F350 pickup truck. Data acquisition and control electronics are housed in a rack inside the trucks crew-cab with seating for three. AC power is provided by a 3 kW inverter system attached to a pair of high capacity marine batteries which are recharged by the trucks alternator when enroute. Battery power is sufficient for approximately 3 hours of operation with the truck engine off. Bore-sighted video is used to monitor beam pointing and is recorded for post experiment interpretation.

Figure 1: W-band radar performing a clear-air VAD scan during Vortex2.

Originally designed as a bistatic (two-antenna) radar, this W-band radar was adapted in the early 1990s for severe storm research performed in collaboration with the University of Oklahoma School of Meteorology. It was rebuilt in 2004. It currently employs a single antenna with a network of latching circulators serving as a transmit/receive and polarization switch. The transceiver employs two multiplied frequency sources and a double down-conversion receiver with intermediate frequencies at 1.2 GHz and 120 MHz. A digital receiver samples the final IF signal, producing baseband in-phase and quadrature samples.

Due to the 3 mm wavelength of the radar, the unambiguous velocity interval for W-band radars is very narrow. A dual-PRT scheme is employed with a ratio of 1.1 providing unambiguous velocity measurements up to 40 m/s. The pulsing scheme of the radar is selectable: single or alternating polarizations on transmission, with simultaneous reception of both polarizations.

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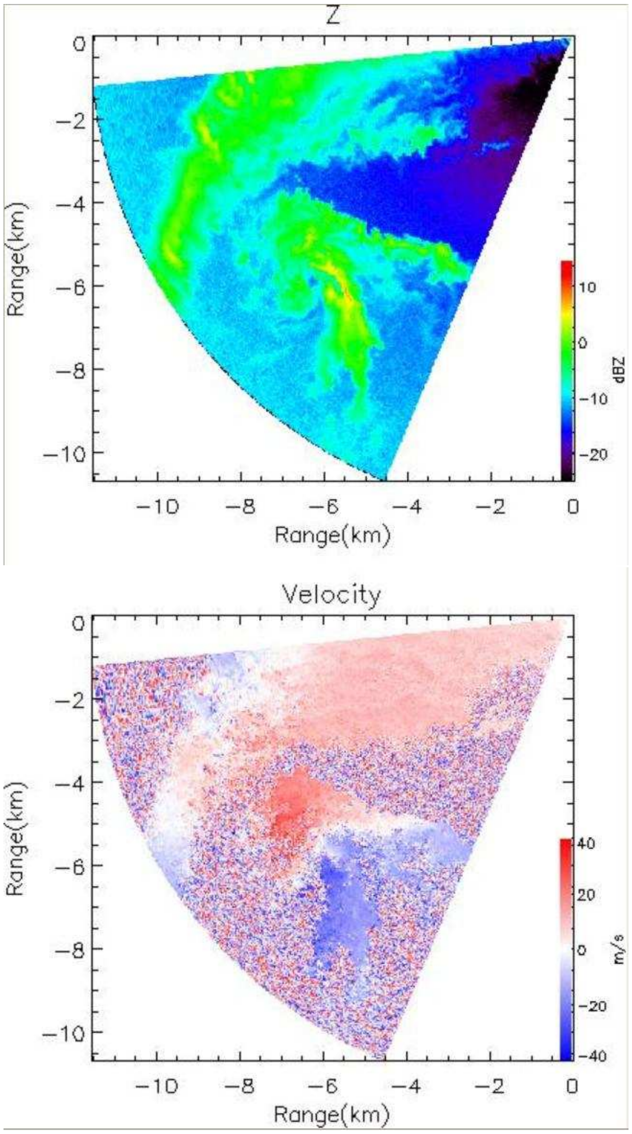

Figure 2: W-band radar PPI reflecivity (top) and dual-PRT Doppler velocity (bottom) of a rain-wrapped weak echo eye from a convective storm near Dighton, KS on 23 May 2008.

Table 1: W-Band Radar Specifications

Transmitter	Klystron
Frequency	95.04 GHz
Peak Power (duty cycle)	1 kW (< 1 %)
Pulse Width	200 ns (typ) - 1 us
Pulse Rate	< 10 kHz
Antenna	1.2 m Cassegrain
Beamwidth (Gain)	0.18° (59 dBi)
Polarization	Tx: H or V, Rx: H & V
Sensitivity (1 pulse)	-26 dBZ at 1 km

Figure 3: The X-Pol mobile radar deployed for refractivity measurements in Colorado, July 2005.

3. X-Pol dual-polarized mobile doppler radar

The X-Pol mobile Doppler radar (Junyent-Lopez 2003; Venkatesh et al. 2008) is a dual-polarized X-band radar operating at 9.4 GHz with a peak transmit power of 6.25 kW per polarization channel provided by a modified marine navigation radar transmitter. Often used in tandem with the W-band radar, it is deployed on a nearly identical truck platform. X-Pol employs the hybrid polarization technique of simultaneous transmission and reception of both H and V polarizations and a dual-PRT waveform to obtain unambiguous velocities up to 40 m/s. It employs a refurbished Army Signal Corps SCR-584 type scanning pedestal common to many mobile weather radars. Similar to the W-band radar, the power system employs an inverter supplied from marine batteries that are recharged by the truck's alternator.

X-Pol is presently undergoing a conversion to a pulse-compression design employing an 80 W solid-state power amplifier in place of the magnetron currently used. In the new design, an intermediate-frequency digital transceiver both produces the chirp waveform(s) and demodulates the received echoes. This is a first step in ultimately migrating to a solid-state active phased-array architecture, currently in development by the CASA Engineering Research Center.

4. S-band FMCW Radar

The S-band FMCW radar profiler (Ince et al. 2003) is a very high-resolution vertical profiler resolving fine structure in the atmospheric boundary layer. It operates at 2.9 GHz with a continuous transmit power of 250 W and employs a pair of 2.4 m parabolic dish antennas. Range

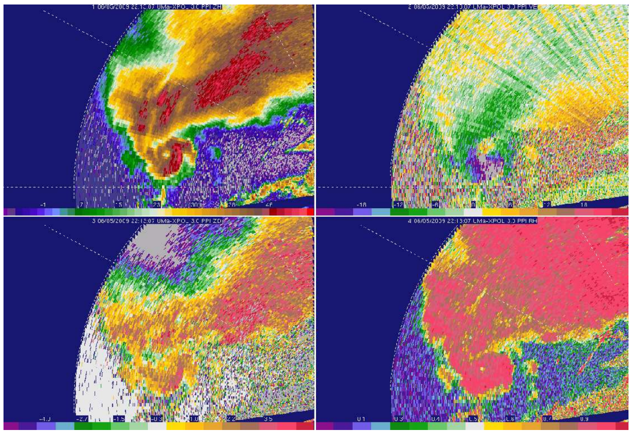

Figure 4: Preliminary X-Pol radar observations of the June 5, 2009 tornado near Chugwater, WY. Panels are (clockwise from upper left) Z_H, Velocity, ρ_{HV}, and Z_{DR}

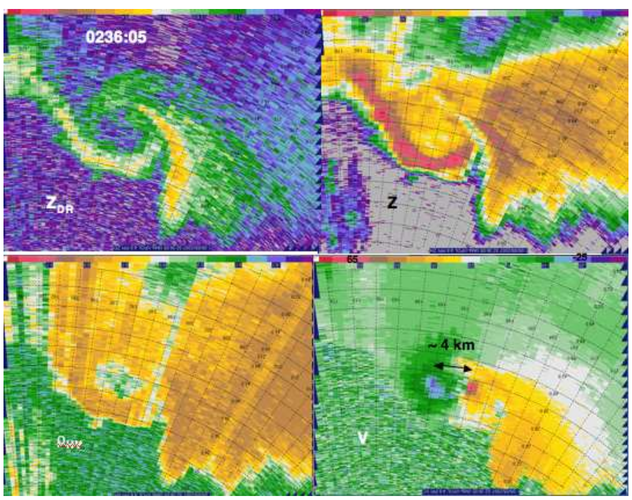

Figure 5: X-Pol observations of the May 4, 2007 Greensburg, KS tornado at at 21:36 CDT. Panels are (clockwise from upper left) Z_{DR}, Z_H, Velocity, and ρ_{HV}.

Table 2: X-Pol Radar Specifications

Transmitter	Magnetron
Frequency	9.41 GHz
Peak Power (duty cycle)	12 kW (< 0.1 %)
Pulse Width	1 us
Pulse Rate	.51/1.6/2.4 kHz
Antenna	1.8 m parabola
Beamwidth (Gain)	1.2 deg (41 dBi)
Polarization	simultaneous H & V

Figure 6: S-band FMCW radar deployed at Boulder Atmospheric Observatory, Aug 2007.

Table 3: FMCW Radar Specifications

Transmitter	TWTA
Frequency	2.94 GHz
Peak Power (Duty Cycle)	250 W (< 100 %)
Bandwidth	< 60 MHz
Range Resolution	> 2.5 m
Antennas	2.4 m parabolas
Beamwidth (Gain)	3° (34 dBi)
Polarization	single,linear

resolution is as fine as 2.5 m and beamwidth is 3 degrees. The radar can measure vertical velocity structure with temporal resolution of 0.2 s. The FMCW radar is deployed on a 20' flatbed truck with and integrated power system (5 kVA generator).

The primary scattering sources for this radar are refractive index turbulence and insects. This radar is noteworthy for its very fine spatial and temporal resolution, which often allows it to resolve individual insects, which appear as dot-echoes in radar imagery. Depending upon the desired application, range resolution or height covereage may be traded for a given Nyquist velocity interval. Recent measurements at the Boulder Atmospheric Observatory confirmed that velocity turbulence spectra could be observed up to a limiting frequency of 0.5 Hz (Frasier et al. 2008).

A 915 MHz analog of this instrument employing spaced-antenna wind retrieval methods is currently in development.

5. Advanced Multi-Frequency Radar

The Advanced Multifrequency Radar (AMFR), is a three-frequency system (Ku-, Ka- and W-band) cloud and pre-

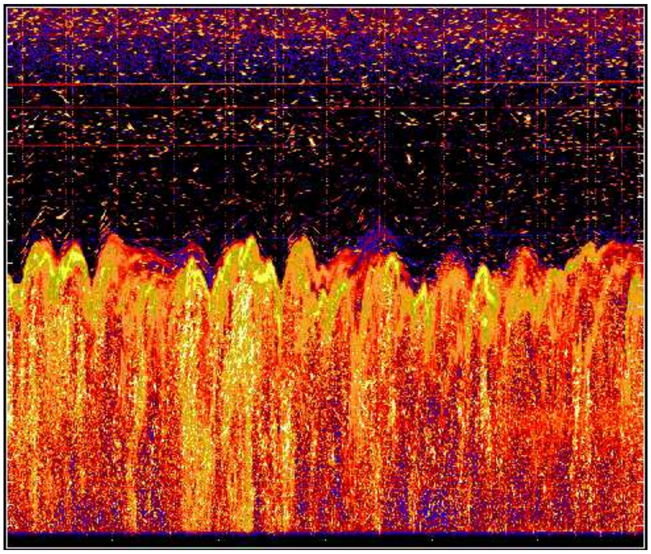

Figure 7: Time-height cross-section of S-band reflectivity from a convective boundary layer shows both Bragg scattering from refractive index turbulence and Rayleigh scattering from insects.

cipitation radar with peak transmit powers exceeding 1.5 kW, provided by three powerful Extended Interaction Klystrons. Three matched beam (0.75 degrees) antenna systems are mounted on an elevation over azimuth positioner. Pulse compression enables 30 m range resolutions, with Doppler and polarimetric variables measured simultaneously at the three frequencies as shown in Fig 8. AMFR is housed on a custom truck with mobile laboratory space and a 10 kVA generator system.

AMFR participated in the Canadian Cloud-SAT/CALIPSO validation Project (C3VP) located in south central Ontario during January 2007. Despite difficulty with hardware due to the extreme environments experienced during the experiment (some temperatures as low as -27 C), AMFR observed both precipitating and non-precipitating clouds at Ku- and Ka-band (Fig 10), and calibrations compared favorably with that of a nearby C-band weather radar. From these data particle size distributions were derived from the dual-wavelength ratio for falling snow that have been verified with concurrent ground validation measurements as shown in Fig 11 (McLinden 2009).

6. Acknowledgments

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Figure 8: AMFR : The large antenna at left is for Ku-band, at the lower right is Ka-band and two W-band antennas at the upper part of the platform, can be pointed in both azimuth and elevation.

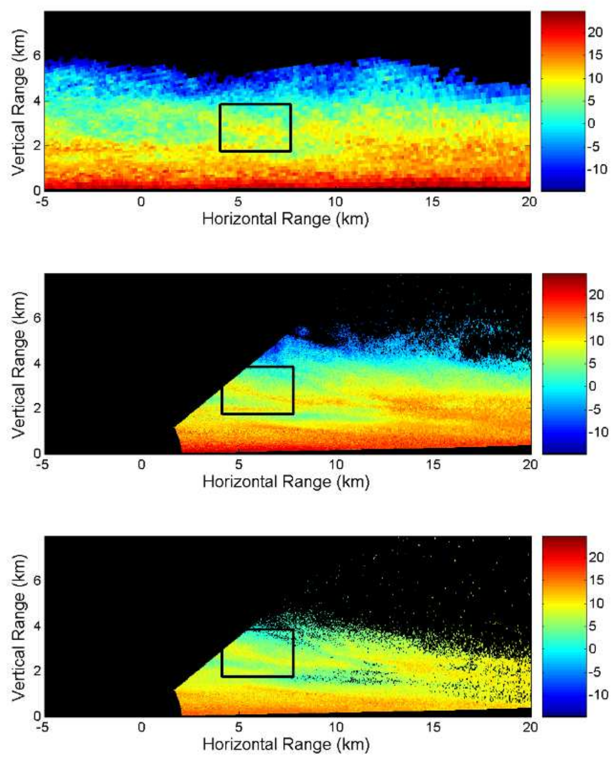

Figure 9: A comparison between the King City C-band radar (top) with 125 m resolution, Ku-band AMFR reflectivity (middle) and Ka-band AMFR reflectivity (bottom) with 30 m resolution, during a 2007 winter storm in Canada. Simultaneous observations compared to within 1.5 dBZ.

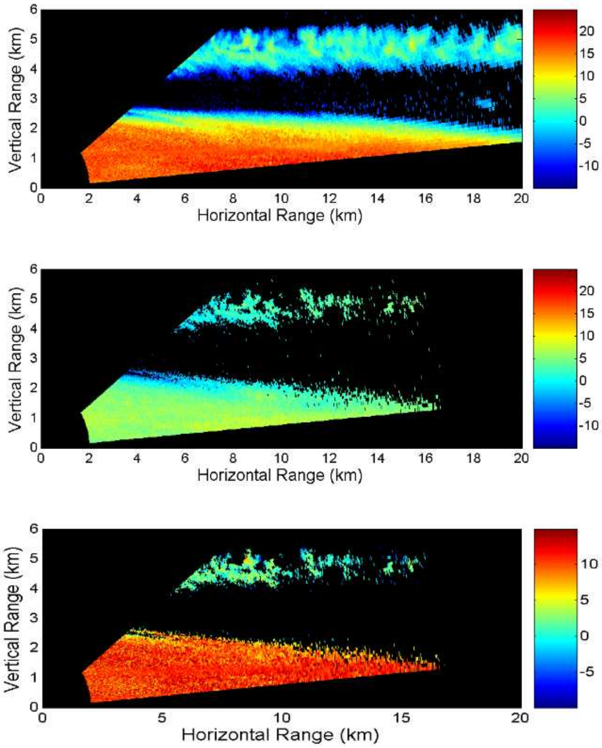

Figure 10: AMFR equivalent reflecitivity imagery a.) Ku-band, b.) Ka-band, and c.) dual-wavelength ratio, Ku/Ka refectivity (in dB) during a 2007 winter storm in Canada. Clearly visible are two cloud layers, one which is precipitating. The dual-wavelength ratio in the lower plot clearly distinguishes between the smaller cloud particles of the higher cloud, from the precipitating components of the lower cloud.

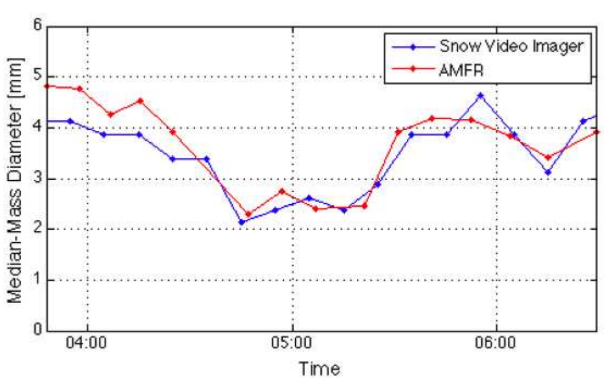

Figure 11: A snow size distribution retrieval comparison created from AMFR and from Snow Video Imager data collected during a winter storm on 22 January, 2007. The AMFR and the Snow Video Imager were separated by approximately 300m (McLinden, 2009).

Table 4: AMFR Radar Specifications

Transmitters	Klystron
Frequencies	13.4, 35.6, 94.92 GHz
Peak Power	5, 1.5, 2 kW
Range Resolution	30-150 m
Antennas	parabola, Cassegrain, GOLA
Beamwidth (Gain)	0.7° (48 dBi)
Polarization	Tx: H or V, Rx: H & V

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