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THE NSSTC ARMOR C-BAND DUAL-POLARIMETRIC DOPPLER RADAR: A TOOL FOR INTEGRATED REMOTE SENSING

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ABSTRACT

The University of Alabama-Huntsville (UAH) and National Space Science and Technology Center (NSSTC) C-band Doppler weather radar was recently upgraded to dual-polarimetric capabilities. The upgraded radar is called ARMOR (Advanced Radar for Meteorological and Operational Research) and operates within the UAH/NSSTC STORMnet (Severe Thunderstorm Observations and Research Meteorological network). ARMOR multi-parameter radar data are collected on a 24/7 basis and can be processed in real-time to provide an integrated view of atmospheric wind flow and precipitation fields. For meteorological purposes, polarimetrically-diagnosed cloud dynamic and microphysical information is easily combined to provide detailed displays of regional cloud development and storm intensity. This type of information is critical to cloud physics research, weather warning decision support, and the physical validation of atmospheric models. For atmospheric transport and diffusion modeling, near real-time low-level multi-Doppler wind retrievals gridded at 1-2 km and temporal resolutions O[5-10 min.] can be assimilated into air pollution transport and dispersion models to improve forecasts of pollutant concentrations; the potential application to problems in areas ranging from environmental protection to homeland security being obvious. Similarly, these winds can be used to study the interaction of convective initiation and boundary layer circulations at relatively high resolution. From a hydrological perspective, dual-polarimetric radar-derived rainfall estimates provide one of the most accurate means to measure precipitation over large areas at relatively high spatial and temporal resolution. The ARMOR radar (and radars like it) can provide gap filling information to simulation activities the dynamic state of the atmosphere and land-surface.

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1. INTRODUCTION

Figure 1. ARMOR radar at Huntsville International Airport.

The University of Alabama Huntsville/National Space Science and Technology Center (UAH/NSSTC) C-band WSR-74C Doppler radar (Fig. 1) was recently upgraded to dual-polarimetric capability. The upgraded radar, named ARMOR (Advanced Radar for Meteorological and Operational Research), is located at Huntsville International Airport under the coverage umbrella of the NASA N. Alabama Lightning Mapping Array (LMA) and within the northern Alabama Severe Thunderstorm Observations and Research Meteorological network (STORMnet; Fig. 2).

In addition to serving as an education and research tool at NSSTC/UAH, ARMOR is the only operational dual-polarimetric radar in the world to be used concurrently by operational meteorologists at WHNT-TV (partner in upgrade) and the Huntsville National Weather Service (NWS) Forecast Office. Radar data and derived products are provided to WHNT and NWS for warning decision support and training purposes.

2. ARMOR SPECIFICATIONS, DATA AND OPERATIONS

Location :	Huntsville Intl. Airport
Transmit frequency:	5625 MHz
Peak Power:	350 kW
Pulse width:	0.4, 0.8, 1.2, 2.0 μs
Maximum PRF:	250-2000 s-1
Antenna Diameter	3.7 m (CF Parabolic)
Antenna Beam width:	1°
First side-lobe:	-23 dB
Maximum rotation rate:	18° s^{-1}
Transmit/RX polarization:	Simultaneous H and V, or H
Sig. Processor:	SIGMET RVP/8
Variables:	Z, V, W, ZDR, Φ_{DP}, KDP, ρ_{hv}, LDR

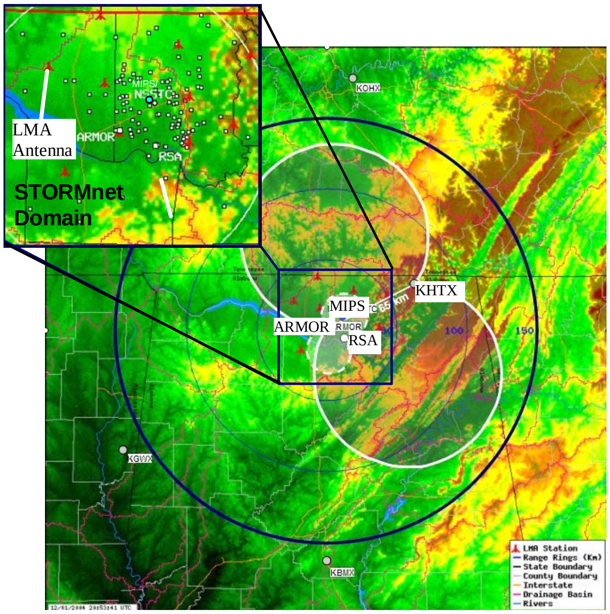

Figure 2. STORMnet: Location of ARMOR, KHTX and RSA Radars together with MIPS (nominally located at NSSTC), LMA antennas and CHARM rain guage sites (upper left).

Major hardware upgrades to ARMOR include a SIGMET Antenna Mounted Receiver (AMR) with a dual-polarimetric option, a new 350 kW solid state transmitter (magnetron), RCP-8/RVP-8 radar controller and signal processor, AMR wave-guide assembly, a new dual-polarimetric feed and 18 ft. sandwich foam-core radome coated with a state of the art resilient hydrophobic paint. The existing 3.7 meter EEC antenna and pedestal (both in good condition) are currently being used for operations with a planned upgrade in FY06 contingent on funding.

The AMR hardware/software enable both single linear polarization transmit, with co- and cross-pol receive, and simultaneous linear transmit and receive (STAR) modes. In both modes, the standard weather radar variables of total power (T), reflectivity (Z), radial velocity (VR) and spectral width (W) are collected. In STAR mode three additional dual- polarimetric variables are collected including: differential reflectivity (ZDR), differential propagation phase (Φ_{DP}), and the correlation coefficient (ρ_{hv},). In addition to Φ_{DP}, the RVP-8 automatically computes specific differential phase (KDP) using a linear least squares algorithm (cf. Bringi and Chandrasekar, 2001).

In parallel to the RVP8 processing, real-time dual-polarimetric data processing at NSSTC employs locally-modified software originally developed by V. N. Bringi; Colorado State University, to compute differential back scatter phase and KDP using a FIR/adaptive spatial filter approach.. The software also corrects Z and ZDR for attenuation and differential attenuation respectively (e.g., Fig. 3), and then computes polarimetric estimates of rainfall.

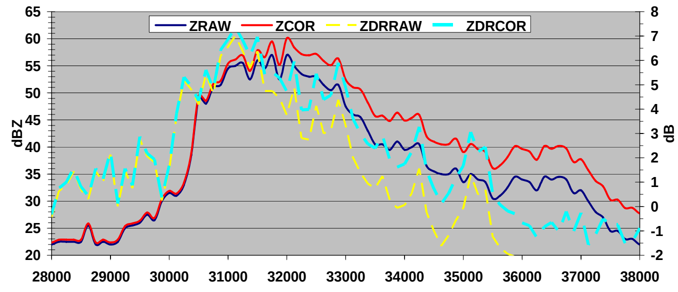

Figure 3. Example of raw Z (navy blue) and ZDR (yellow dash), and corrected Z (red) and ZDR (light blue dash) collected on 4/7/05 along a propagation path consisting of mixed large hail and rain.

Operation in STAR mode (64 sample pairs; 125 m gate spacing) enables more efficient scanning of evolving boundary layer flows and convective situations while facilitating collection of variables fundamental to advanced rainfall and hydrometeor identification (HID) algorithms (Z, ZDR, KDP, ρ_{hv}; Straka et al., 2000, Liu and Chandrasekar, 2000; Zrnic et al., 2001; Schuur et al., 2003; Ryzhkov et al., 2003; Baldini et al., 2005). Note that real time sampling of the wind flow, clear air and/or precipitation properties on scales of 1-2 km also provides a database for assimilation into coupled numerical weather prediction, hydrological, and transport and diffusion models.

When not in STAR mode, surveillance (SUR) data collection in the single polarization mode is often used for high temporal resolution (single sweep, 0.8°) sampling of both clear air and convection. For research purposes, these scans are used for convective initiation and boundary layer studies (e.g., Fig. 4). WHNT-TV and WFO Huntsville also use the SUR data to fill time gaps when NWS NEXRAD radar data are not available.

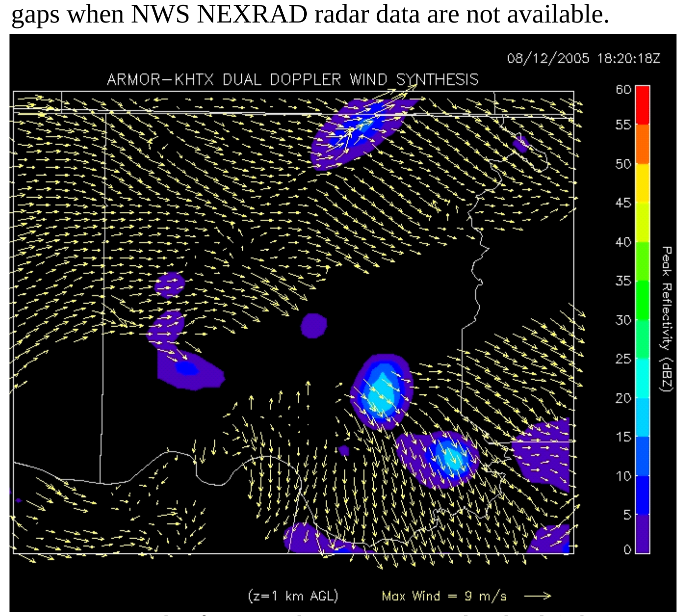

Figure 4. Example of automated ARMOR-KHTX low level (1 km) dual-Doppler wind synthesis output in relatively clear air.

To satisfy both operational and research considerations ARMOR is operated 24 hours per day, seven days a week in either SUR (non-polarimetric), RAIN1 (Doppler, polarimetric, rainfall/hydrology scan) or sector volume scans (Doppler/polarimetric). Radar control, display, data ingest, and archive are managed at NSSTC, with another radar control and real time data display node located at WHNT-TV in Huntsville.

3. SCANNING

Scanning logistics are well coordinated through the use of semi-autonomous task schedules. For periods of little or no weather concern, the "default" operation mode is currently a cycle of one 3-tilt RAIN1 sequence and one SUR scan every 5 minutes with scan types offset 2.5 minutes. In the event that severe or otherwise significant weather of research interest occurs, either RAIN1 and SUR scans are run back to back, or 2-5 minute polarimetric sector volume scans (18 tilts; full 3-D sampling of atmosphere) are collected and interleaved with RAIN1 and SUR scans taken at approximately 5 minute intervals.

4. SCIENCE AND APPLICATION

The ARMOR and STORMnet instrumentation (Fig. 2) are located in a region of locally complex terrain in an environment of oscillating "tropical" and "mid-latitude" climates. This combination of surface and meteorological heterogeneities greatly facilitates the study of complex variety of boundary layer, precipitation, cloud, and hydrological processes. The atmosphere in each of these "regimes" can be systematically interrogated and studied via fusion of ARMOR radar data with data collected by other STORMnet resources (Fig. 5) including: Doppler radars (Hytop NWS NEXRAD radar; Redstone Arsenal S-band Doppler radar); the UAH Mobile Integrated Profiling System (MIPS; comprised of a 915 MHz wind profiler, Doppler SODAR, multi-spectral scanning radiometer, laser ceilometer, and surface meteorological instrumentation); NASA Northern Alabama VHF 3-D Lightning Mapping Array; and surface mesonet data consisting of automated rain gauge networks such as CHARM (Cooperative Huntsville Area Rainfall Measurements).

To facilitate more complete studies of atmospheric flow as it relates to convective initiation, cloud system dynamics and microphysics (Fig. 5; ARMOR observations of the 3-D kinematics and microphysics of a severe hail storm), we have recently teamed with colleagues from the Colorado State University CHILL radar to run real time dual-Doppler wind retrievals at NSSTC. These retrievals are performed by using a combined/coincident collection of Doppler radial velocities from the ARMOR and NWS Hytop NEXRAD radars. After velocity dealiasing and clutter removal, the radial winds are gridded to a common coordinate system (1 x 1 x 0.5 km) and a 2-D wind field

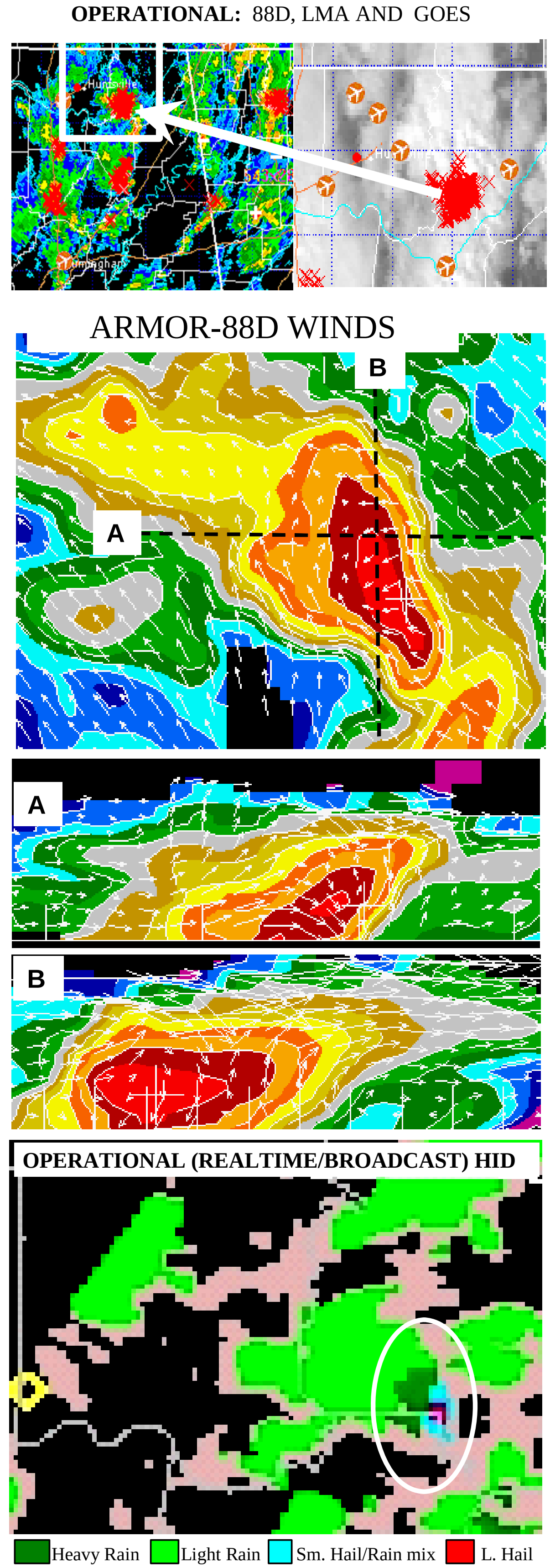

Figure 5. Examples of STORMnet and ARMOR products collected for hail producing convection on 4/7/05. Top: Left, 88D dBZ and NASA LMA total lightning source locations, GOES and LMA for outlined box. Middle, plan and views of storm radar reflectivity X-Z and Y-Z cross-sections A and B in outlined box with 3-D winds overlaid. Bottom: Real-time operational table-based version of hydrometeor identification retrieval.

synthesis is performed in the horizontal plane. This synthesis is then repeated for each 500 m vertical level from the surface to the highest level of sampling. If the full atmosphere is sampled (e.g., 18-tilt volume scans are conducted), subsequent integration of the mass-continuity equation permits a retrieval of the vertical component of the wind at each grid point in the column. Subsequent to the wind retrieval, the combined hydrometeor identification and 3-D wind products can then be combined in near real time with LMA total lightning flash rates to develop real-time metrics and efficient displays of storm intensity and growth (Fig. 5).

Importantly, even when the weather is relatively suppressed, the planetary boundary layer can be very active. This is often manifested as wide-spread "clear-air" echo (Fig. 6), the result of scattering via gradients in refractive index and the presence of biological entities (bugs or birds etc.). In this instance retrieved low-level dual-Doppler winds are exploited to study boundary layer flow structure and dynamics as related to terrain forcing and convective initiation (Fig. 6). Current plans at NSSTC call for use of the retrieved wind fields in data assimilation experiments designed to ascertain the degree to which such information can be used for improving the predictive capabilities of dispersion and transport models.

Another important application of polarimetric weather radar is in hydrological modeling. One of the most important upper boundary conditions supplied to any hydrological model is the rain rate. Conventional radar estimates of rain rate rely primarily on a non-linear conversion of returned power in the form of radar reflectivity, to rain rate. While the area coverage and spatial/temporal resolution of such estimates are good (order of 10^4 km^2 and 2 x 2 km/5-10 minutes), the accuracy of the rain rate estimates is often fair to poor (50-100% errors in integrated rain totals are common). Because polarimetric radars sample more properties of the precipitation in a given pulse volume (e.g., phase, size and shape information), estimates of rainfall made using polarimetric algorithms are typically much more robust (errors < 25%; Bringi and Chandrasekar, 2001). Hence the more accurate rain rates computed from ARMOR polarimetric data should be of use in coupled

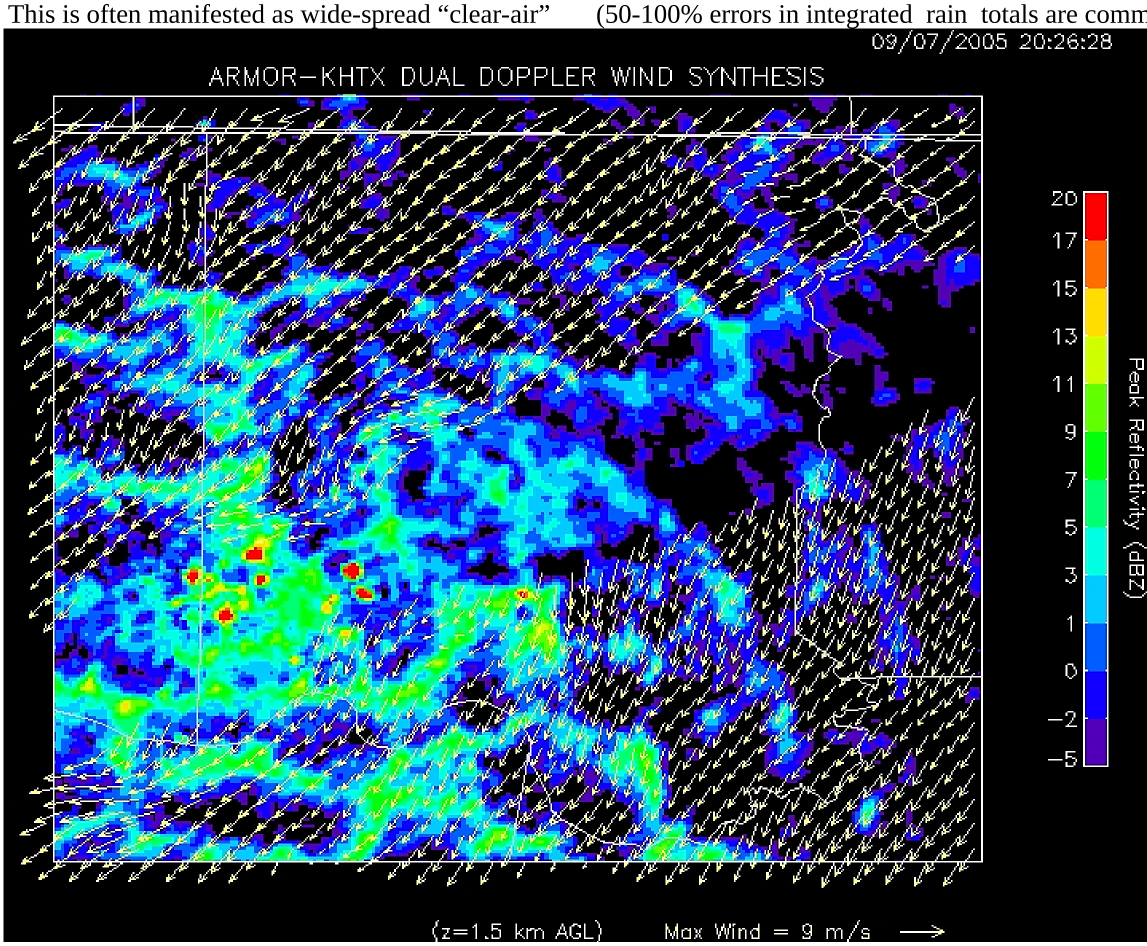

Figure 6. Boundary layer clear-air cellular convection and wind flow as indicated by clusters of low radar reflectivity (colors) "fine lines". Dual-Doppler wind vectors retrieved for the top of the mixed layer at 1.5 km are indicated. Diffluent flow near the center of the plot may be related to the location of significant local topography. The SW-NE oriented area of missing wind vectors occurs along the dual-Doppler baseline where wind retrieval is not possible.

land-surface atmospheric models that rely on observational data assimilation.

It is anticipated that the planned continuous daily operation of ARMOR within the STORMnet infrastructure at NSSTC will facilitate an end-to-end sampling of the atmosphere from boundary layer-forced flows, to mature convective system precipitation and electrification processes, and finally to surface rainwater fluxes. The resolution of the aforementioned data collection lends itself readily to coupled atmospheric land-surface modeling as it fills an "observations" gap for data assimilation.

5. SUMMARY

The UAH/NSSTC ARMOR C-band Doppler radar controlling hardware, and data systems have been upgraded to full dual-polarimetric capabilities. The ARMOR polarimetric and Doppler data are used for applied research and education at NSSTC, and for operational warning and decision making at the NWS and WHNT-TV. Near real-time retrieval and gridding of high resolution wind flow fields, rainfall, and hydrometeor/scatterer types in both a clear and cloudy atmosphere, provide a potential gap-filling data set for assimilation into regional coupled land-surface and atmospheric models, and/or atmospheric transport and dispersion models.

Note: Real time ARMOR data can be viewed at:
http://www.nsstc.uah.edu/ARMOR

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