

5.1 THE UNIVERSITY OF ALABAMA HUNTSVILLE THOR CENTER INSTRUMENTATION: RESEARCH AND OPERATIONAL COLLABORATION

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1. INTRODUCTION

The UAH Tornado and Hazardous weather Observations and Research Center (THOR) located at the National Space Science and Technology Center (NSSTC) in Huntsville, Alabama was created in 2006 in order to focus hydrometeorological research activities on severe and hazardous weather phenomena in the southeastern U.S. Specific topics of research include: (a) tornadoes and damaging winds within supercell storms, quasi-linear convective systems and landfalling tropical cyclones, (b) relationships between total lightning and severe weather, (c) nowcasting of convective initiation and lightning initiation, and (d) quantitative precipitation estimation using a combined sensor approach. These activities make use of THOR infrastructure assets including the C-band ARMOR and mobile X-band MAX dual-polarization radars, a mobile integrated wind profiling system (MIPS), northern Alabama Lightning Mapping Array (LMA), Parsivel laser disdrometers, and rain gauge networks (Fig. 1).

Importantly, the THOR Center participates as a southeastern/sub-tropical focus of the NOAA Hazardous Weather Testbed (HWT) activity in collaboration with the National Severe Storms Laboratory (NSSL), the Storm Prediction Center (SPC), and the collocated NASA Short term Prediction and Research Transition to Operations (SPoRT) Center and National Weather Service (NWS) Weather Forecast Office, Huntsville (WFO-HUN). In addition to its severe weather and HWT activities, the THOR Center infrastructure is also funded to do research for the NASA Precipitation Measurement Mission (PMM), Tennessee Valley Authority (TVA) River Forecast Operations, and the National Weather Service (NWS) COMET program. Further, through joint development of a C-band dual-polarimetric radar platform (the UAH ARMOR radar; Petersen et al., 2005), the THOR center interacts directly with private sector operational broadcast meteorologists located at WHNT-TV in Huntsville. The last three activities (TVA, NWS, WHNT-TV) constitute a direct application and transfer of research technology/methodology to operational decision support activities (note that these transfer activities are, of course, already key components of the NSSL, SPC and NASA-SPoRT operations).

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2. THOR CENTER INFRASTRUCTURE

The primary instrument complement of THOR includes two dual-polarimetric radars (the ARMOR C-band, and the MAX mobile X-band), the NWS KHTX WSR-88D radar, two Parsivel disdrometers, a mobile integrated profiling system (915 MHz plus SODAR; and profiling radiometer, collectively called MIPS), a 10-station VHF lightning mapping array (LMA; operated by NASA-MSFC) and numerous rain gauges and surface meteorological sensors (Fig. 1).

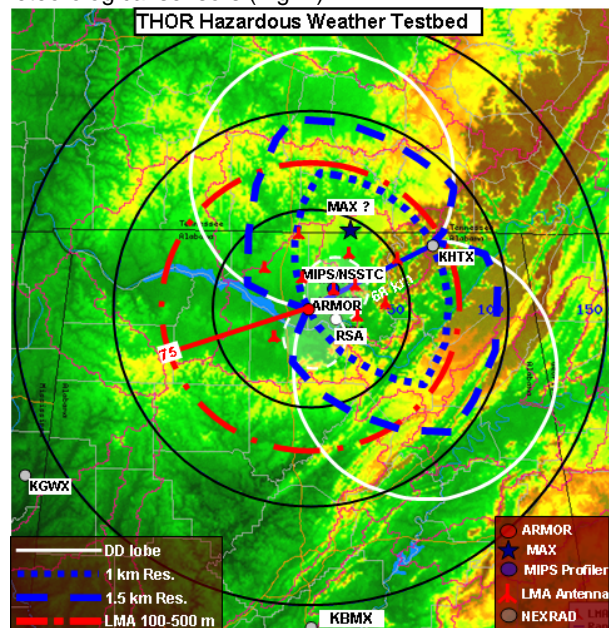


Figure 1. THOR instrumentation centered on Huntsville, Alabama. Dual-Doppler lobes of different resolution between KHTX WSR-88D and ARMOR are indicated as is the LMA range of 100-500 m 3-D location accuracy.

Radar instrumentation such as the ARMOR currently anchors the THOR observational network. ARMOR is a simultaneous H/V transmitting dual-polarimetric Doppler radar with the following characteristics:

Transmitter:	5625 MHz, 350 kW, magnetron
Pulse width/PRF:	0.4 - 2.0 μ s @ 250-2000s ⁻¹
Ant. Diam./beam width	3.7 m (CF Parabolic) / 1.07°
First side-lobe:	-28 dB
Maximum rotation rate:	36° 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

The MAX radar (operational August 1, 2007) is a truck-mounted system that uses approximately the same type of polarimetric hardware configuration as ARMOR, but transmits at a frequency of 9425 MHz and a peak power of 250 kW. The MAX antenna also provides a 1° beam width but uses an 8 ft. parabolic dish with an offset feed.

The MIPS (Knupp et al., 2006) is a mobile profiling radar system that consists of the following components: a UHF (915 MHz) 5-beam Doppler profiling radar, 2 kHz Doppler sodar, a vertically pointing X-band radar (to be completed August 2007); Radio Acoustic Sounding System (RASS), Radiometrics 12-channel microwave profiling radiometer (MPR), surface instrumentation including standard meteorological variables (1-5 Hz) and rainfall rate from two tipping bucket rain gages (0.254 and 0.1 mm resolution) and a Vaisala WXT-510 integrated compact measurement system. The MIPS profiler and RASS combined with the radiometer data provide a source of constant wind and thermodynamic information to forecasters at the WFO-HUN.

The northern Alabama LMA (Koshak et al., 2004) consists of 10 VHF antennas which detect and measure the time of arrival of electromagnetic pulses associated with VHF emissions that occur during lightning flash propagation.

Two deployable Parsivel laser disdrometers are operated by the THOR center for real-time precipitation measurement and post-event QPE research. These systems measure precipitation rate, type, particle diameters and fall speed, over ranges of .001 mm/hr to 1200 mm/hr, 0.2 to 25 mm, and 0.2 to 20 ms-1 respectively in 32 logarithmically-spaced size/velocity bins. This particular disdrometer type was chosen for the HWT due to durability and its ability to provide robust measurements of the PSD in field comparisons with both JW and 2DVD disdrometers (personal communication, Dr. Ali Tokay, UMBC/NASA-WFF). The data are used to calibrate the reflectivity of the MIPS profiler and to provide samples of surface PSD for comparison to MAX and ARMOR polarimetric data.

2.1 Real time data distribution

THOR data are transferred to operational users (NWS, WHNT, TVA) and indeed, the public, in several ways. At the most basic level, MIPS and collocated surface meteorological data at the NSSTC building (including disdrometer rain rates and PSDs) are provided in real time over a web server: <http://vortex.nsstc.uah.edu/mips/data/current/surface/index.html>. From this web site one can also reach the real-time ARMOR radar products web page at <http://www.nsstc.uah.edu/ARMOR/webimage>. LMA data are accessible at <http://branch.nsstc.nasa.gov>. In the near future the TVA River Operations Center located in Knoxville Tennessee will receive real time hourly rainfall accumulations computed from the ARMOR radar over a web-link; however, this project is in its initial stages and the web-link is not currently available.

Data are also more directly transferred to operational users via the THOR Center. For example, the ARMOR dual-polarimetric radar data including the raw variables, hydrometeor identification (HID) and precipitation products etc. are processed and distributed as shown in Fig. 2. Here it is important to note that the raw C-band products are corrected in real time for attenuation, differential attenuation etc. *external* to the RVP8 processor (cf. Bringi et al., 2001). Hence two streams of data exist; the raw real time stream (which also includes a version of the Vaisala Hydrometeor Class output; HCL) and a slightly delayed "processed" product stream. The real time raw data are currently transferred directly from the radar to both UAH (at NSSTC) and WHNT-TV. WHNT maintains a direct link to the radar and receives real time sweep data from the radar over it's own T-1 line. The NWS receives its data via IRIS/Display export from UAH at NSSTC. Both WHNT and NWS receive products over the internet and/or IRIS/Display export from UAH after the data are processed. All raw data and derived products from all platforms are archived in house at NSSTC.

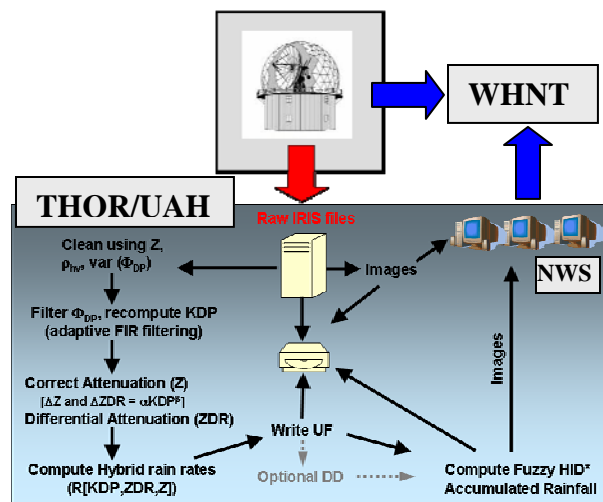


Figure 2. Data flow and processing of ARMOR radar data. In the end, image products are currently passed from THOR/UAH to operational users such as WFO-HUN.

2.2 Improving real time use of THOR radar data

WFO-HUN Forecasters use the ARMOR data combined with other THOR platforms like the MIPS to provide supplemental and important warning decision support via improved coverage and proximity to many of the most densely populated portions of the warning area. Most often, this data assists forecasters in detection and evaluation of severe convection, and other mesoscale phenomenon including lake breezes, outflow boundaries, and even wildfire smoke plumes. ARMOR radar algorithms including the HID and HCL have assisted forecasters in identifying hail cores, adding a crucial tool for severe hail identification in the warning process.

While the distribution of data over the internet to several workstations located in the NWS-HUN office and/or WHNT is helpful and expedient, the data are not always used as efficiently as they could be in warning situations. For example, in rapidly evolving warning situations WFO-HUN forecasters use AWIPS workstations to keep track of incoming analyses, satellite, and WSR-88D radar data while simultaneously preparing warnings, statements and forecasts for public dissemination. Experience suggests that it is a distraction for forecasters to have to move to separate workstations running different platform-dependent software to view raw and/or processed ARMOR polarimetric products.

The concomitant desire of WFO-HUN forecasters to more efficiently use ARMOR dual-polarimetric radar data as an augmentation to KHTX WSR-88D data in warning situations has motivated new efforts (supported by COMET) to ingest ARMOR RAW (SIGMET IRIS format) and product (netCDF HID, rainrates etc.) data streams directly into AWIPS. This way forecasters will be able to more efficiently use the data in complimentary modes via combined 3-D overlays of ARMOR products on AWIPS data sets (including N. Alabama LMA data, already ingested into AWIPS).

Analogously, beyond showing real-time sweep data broadcast meteorologists at WHNT-TV do not generally use the “noisy” raw IRIS products or polarimetric data on air, do not run research algorithms to generate polarimetric products (e.g. HID) on their machines, and do not use the current SIGMET IRIS/display or other radar editing software used by researchers at THOR. Hence, processed ARMOR products not output by the WHNT on-air display system (Baron Fastrac, VIPIR etc.) such as HID or level II-formatted volumetric data are currently constructed at UAH and placed at web locations where WHNT presentation software is pointed to retrieve the data. At this stage, the broadcast meteorologists have successfully used the ARMOR raw polarimetric variables (ZDR in particular) and derived products to support their interpretation of on-air displays of moment data and to pinpoint for the public where different phenomena exist in the radar data (e.g., hail in a high reflectivity core or snow in a winter situation).

3. OPERATIONS IN SEVERE WEATHER EVENTS

The majority of THOR instrumentation (e.g., profiler, disdrometers, gauges. LMA) runs in a semi-autonomous mode, requiring little or no interaction or modification of sampling by researchers or operational meteorologists during use. However, the situation is different for the flexibly-scanning ARMOR radar.

For ARMOR, scanning logistics are coordinated between THOR researchers and meteorologists at WHNT-TV (and by proxy, WFO-HUN since they are generally interested in the same storms) through the development of automated task schedules. During periods of no severe weather, the radar operates

continuously in alternating three-tilt polarimetric rain scans (RAIN1) and single H-polarized surveillance (SUR) scans. For periods with no TV broadcast (the overwhelming majority of the day) and/or weather concerns, the “default” operation mode is currently a cycle of one RAIN1 and one SUR scan every 5 minutes (scan types offset 2.5 minutes). In the event that severe or otherwise significant weather of interest occurs, 2-5 minute polarimetric sector volume scans and/or RHIs are collected by THOR researchers interleaved with RAIN1 and SUR scans. The more frequent scan cycle of the low level wind and precipitation fields provided by the ARMOR (and the backup provided when the KHTX WSR-88D goes down) has in several instances facilitated improved warning capabilities on behalf of both the NWS-HUN office and WHNT.

Coordination of scanning with WHNT is maintained via both telephone and instant messenger software. In at least one instance where a tornado outbreak was expected, a UAH/THOR graduate student was detailed to WHNT to act as an operations “liaison” between the radar scientist located at NSSTC and the meteorologists located at WHNT. This provided for smooth operations and also educated the graduate student in the operational practices of broadcast meteorology. Coincidental to coordinating with WHNT, WFO-HUN forecasters are updated on ARMOR operations via instant messenger software (a convenient and expedient means for THOR researchers to provide input to operational forecasters regarding radar data interpretation).

3. CASE: RESEARCH DATA COLLECTION AND OPERATIONAL UTILITY ON APRIL 4, 2007

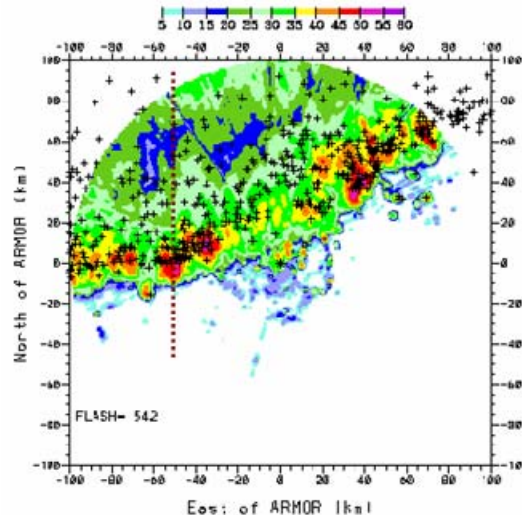


Figure 3. CAPPI of ARMOR reflectivity (shaded) at 0350 UTC at a height of 1 km for the severe, and electrically active squall-line that occurred on April 4, 2007. LMA-detected lightning flashes are indicated by the “+”. A total of 542 flashes occurred in the 5 minute period centered on 0350 UTC. The cell for which a tornado warning was issued is located at approximately $x = 4$ $y = 25$. The dashed line indicates the orientation of the cross section taken in Fig. 6.

During the late night/early morning hours of April 3-4 2007, a severe wind, frequent lightning-producing squall-line (max winds recorded in excess of 75 mph) with one reported northern Alabama tornado passed over the Huntsville area (Figs. 3-6). Well prior to storm passage, THOR students and researchers began to collect sector volume scans on the mature squall line as it propagated to the southeast through west-central Tennessee. As the system moved southeastward severe thunderstorm warnings were issued in northern Alabama and southern Tennessee for damaging winds and large hail. At 0340 UTC a tornado warning was issued for Madison County, Alabama for the specific area of Hazel Green (approximately 30 km northeast of the ARMOR radar; see Fig. 5).

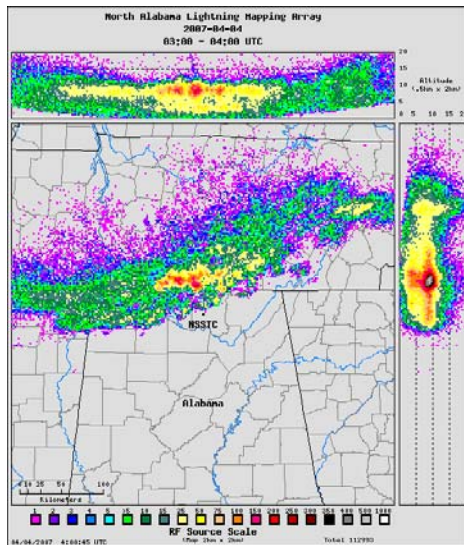


Figure 4. N. Alabama LMA 3-D view of total lightning sources detected in the severe squall line of Fig. 3 between 0300-0400 UTC on 4 April 2007. Center panel is a plan view while the upper and side panels represent composites of activity in the X-Z and Y-Z planes respectively.

For this particular event THOR researchers were interested in the 3-D mesoscale structure of the linear system (Fig. 3), QPE, and lightning characteristics as related to updraft structure (e.g., Figs. 4 and 6). Hence 2-3 minute sector volumes followed later by full-volumes, were used to sample the storm as it moved through the dual-Doppler lobes of the THOR network. As the system passed over the radar, it rapidly dissipated into a stratiform rain system- providing an excellent opportunity for collection of vertically pointing ZDR calibration scans.

Because this system produced nearly continuous manifestations of severe weather during its lifetime (primarily severe winds and hail), NWS severe thunderstorm warnings were issued in advance of the system in a very timely fashion (i.e., the severe weather was no surprise). However, in addition to the primary threat of strong straight-line winds and hail (periodically indicated in the advancing line by ARMOR) there were many transient flow perturbations that formed along and

in advance of some of the lower levels of stronger cells in the convective line (Fig. 5), resulting in concerns of potential tornadic activity. Indeed, a short-lived hook echo appeared in ARMOR data at 0335 UTC with attendant azimuthal shear (albeit in a folded velocity pattern) and even a tiny ρ_{hv} minimum in the center of the hook (Fig. 5). In this instance the proximity and higher sampling resolution of the ARMOR radar relative to the KHTX NEXRAD provided NWS forecasters added information for issuance of a brief tornado warning.

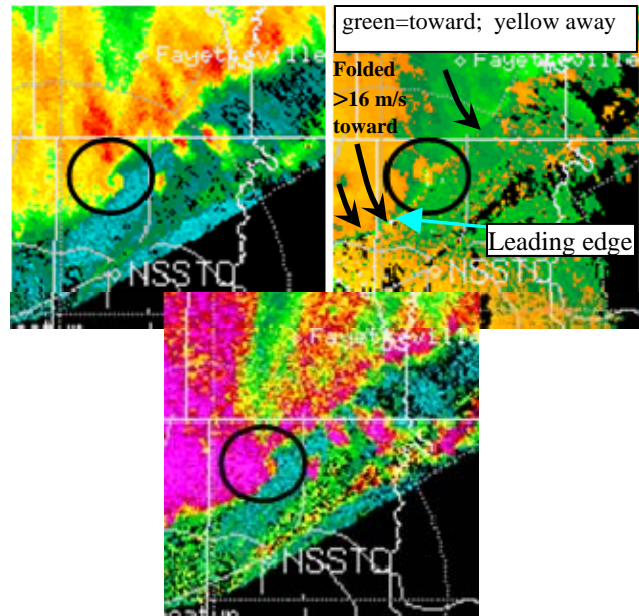


Figure 5. The real-time display of a rotation signature on the leading edge of the severe squall line of Fig. 3. Upper left real-time uncorrected ARMOR radar reflectivity; right panel, radial velocity [folded above a Nyquist of 16.2 m/s, but azimuthal shear is quite evident], bottom ρ_{hv} showing pixel of minimal values (< 0.8) surrounded by values > 0.98 in the reflectivity hook. Also note the strong attenuation through the circled cell (evident in dBZ and ρ_{hv}).

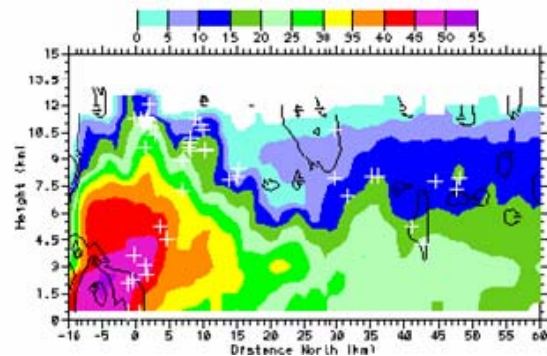


Figure 6. ARMOR cross-section of radar reflectivity, lightning flash locations ("+") and ZDR (contoured every 1 dB) taken along the dashed line of Fig. 3. Note that the flash locations are bimodally distributed, occurring in ice at upper levels and descending larger precipitation ice (low ZDR) and mixed phase at lower levels (a ZDR column in updraft is evident and leading edge).

The operational use of the UAH ARMOR radar products for the 4 April 2007 event is but one of many previous examples. From an applied research perspective this particular case will serve multiple THOR/HWT research foci, including: 1) study of both mesoscale dynamics and tornadogenesis in a quasi-linear convective system; 2) studies of severe storm electrification- facilitated by dual-Doppler and dual-polarimetric data collection under the coverage of the LMA (e.g., Figs. 4 and 6); 3) comparisons between THOR observations and the NOAA-SPC HWT 4 km WRF simulations- run for this case in real time (the end result hopefully being validation/improvement of WRF physics). Through THOR Center collaboration, meteorologists at the WFO-HUN will use ARMOR data for this case to verify forecasts, and to create their own training database studies of severe local storms.

Through continued interactive data collection and case study analysis involving THOR and HWT researchers, UAH students, and operational meteorologists (government and broadcast alike) progress should be made in our understanding of Southeastern U.S. severe weather, and in our ability to nowcast its occurrence. Finally, as part of these activities particular emphasis will be placed on developing the most *useful* products for forecasters in particular warning situations.

4. SUMMARY

The UAH THOR Center radar and ancillary instrumentation assets are used in both operational and research capacity in northern Alabama. UAH researchers and graduate students are able to collect and use real-time and archived dual-polarimetric radar, wind profiler and lightning datasets for studies of evolving southeastern U.S. convective phenomena as related to associated hazards such as lightning, 3-D winds, hail, flash flooding (e.g., polarimetric QPE) and tornadic activity. Concomitantly operational meteorologists at the NWS Forecast Office in Huntsville and WHNT-TV are able to use the same combined datasets in real-time for improved warning decision support, post-event performance analysis, and forecast verification. In a new project, the river forecast operations group of the TVA will use ARMOR-produced QPE products to support their river hydrologic/hydropower operations and forecasting.

Several successful examples of THOR infrastructure use have been documented in both the government and private operational meteorology sectors. Notably, via its collaboration with UAH, in December, 2004 WHNT-TV in Huntsville was the first television broadcast network in the U.S. to use polarimetric radar data, on-air, (in this case, ARMOR ZDRs) to warn the public of impending hail damage. Also, though not discussed in this paper (and relatively infrequent over the Huntsville domain), the use of ARMOR hydrometeor identification products by WHNT for nowcasting snow has also been successful in at least one circumstance.

Similar successes have also been achieved by the NWS Forecast Office in Huntsville for the issuance of severe thunderstorm, wind (e.g., April 4, 2007 case) and tornado warnings relying on a combination of NEXRAD and THOR (radar, MIPS etc.) datasets.

UAH THOR Center research and educational activities combined with forecast operations in northern Alabama have resulted in 1) the collection of robust, detailed atmospheric data sets well suited to atmospheric research; 2) improved awareness of operational remote sensing customer needs for UAH researchers and graduate students; 3) a new source of decision support tools for operational partners that compliments ongoing activities such as those of the NASA SPoRT Center; 4) conduits for providing improved understanding of meteorological research problems and the promise of new technology to operational customers; and 5) through the unique involvement of local broadcast meteorologists at WHNT-TV, a means to directly educate and engage the public on new and cutting edge meteorological technologies as applied to their daily activities via use of those tools in the local daily television weather broadcast.

5. REFERENCES

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