6B.2 THE USE OF DUAL-POLARIMETRIC RADAR DATA TO IMPROVE RAINFALL ESTIMATION ACROSS THE TENNESSEE RIVER VALLEY

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1. Introduction

In an effort to assess the potential for significant cost reduction associated with the maintenance of a large number of rain gauges across the Tennessee River watershed, the National Space Science and Technology Center (NSSTC; UAH/NASA-MSFC) was contracted by the Tennessee Valley Authority (TVA) and the Von Braun Center for Science and Innovation (VCSI) to provide a demonstration of improved real-time distributed rainfall estimation through the use of modern dual-polarimetric radar hardware and precipitation algorithms [particularly relevant at this time given that the National Weather Service is in the process of upgrading the national radar network to dual-polarimetry].

More specifically, the goal was to demonstrate to the TVA River Operations Management that the dual-polarimetric radar estimates could:

a) Provide a quality estimate (relative to the gauges) over 1-6 hour time scales and sub-basin areas such that a significant percentage of TVA-maintained rain-gauges could be decommissioned;
b) Be provided by NSSTC to TVA in an operational mode useful to the River forecasters, and;
c) *Do so independent of rain gauge inputs [i.e., no mean field bias corrections applied etc.]*..

The prototype system developed at NSSTC utilizes multi-parameter radar measurements derived from the UAH/NSSTC dual-polarimetric Advanced Radar for Meteorological and Operational Research (ARMOR), which is located at the Huntsville International Airport in Huntsville, AL. Herein we describe the radar hardware and precipitation algorithms used, and comparisons of the outputs from the algorithm (ARMOR Rainfall Estimation System; AREPS) to current TVA estimation methods.

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2. UAH/NSSTC ARMOR Radar

The ARMOR radar is a C-band dual-polarimetric radar located at the Huntsville International Airport. The radar employs a simultaneous transmit and receive mode (STSR) to acquire standard dual-polarimetric measurements (Z, ZDR, Φ_{DP}, ρ_{hv}) in addition to conventional Doppler velocity and spectral width data (cf. Petersen et al., 2005, 2007 for a more complete description).

ARMOR is operated 24 hours per day, 7 days per week in both operational and research modes, with a current sampling strategy set to collect rain volumetric scans at a minimum of once every five minutes. These scans consist of at least three elevation angles (0.7°, 1.5°, 2.0°), collected at a gate spacing of 250 m and a PRF of 1200 s^{-1} (56 sample pairs).

Calibration of the radar is conducted via routine receiver calibrations, solar scans, post-processing checks of internal variable consistency, comparison to the Tropical Rainfall Measurement Mission (TRMM) Precipitation Radar (Morris et al., 2007), and vertically pointing scans (e.g., for calibration of ZDR). In general, radar reflectivities are maintained to within +/- 1-2 dB and the ZDR calibration remains within +/- 0.1 dB.

3. Methodology

The volumetric data are transmitted to the NSSTC in real time from the airport via T-1 line and run through a quality control process (Figure 1) which exploits internal consistencies and constraints amongst the dual-polarimetric variables to correct for attenuation and differential attenuation (Bringi et al., 2001).

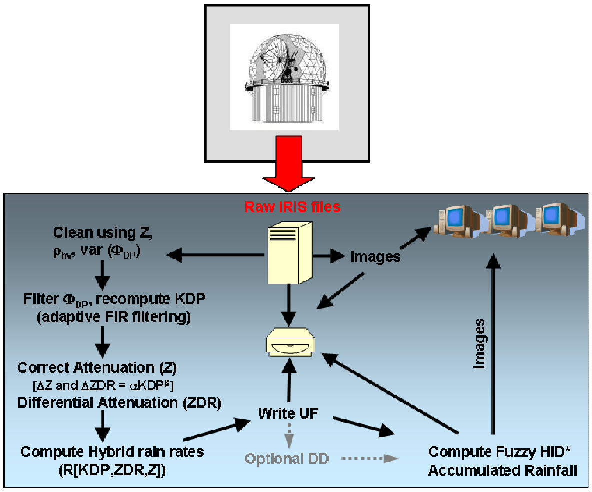

Figure 1. ARMOR processing stream.

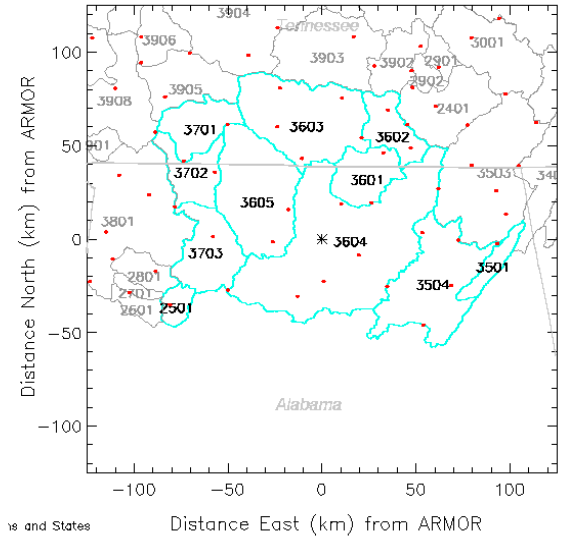

Figure 3. Map of sub-basins (bold lines) and TVA rain gauges (filled circles) relative to the ARMOR radar (asterisk). Basin identifiers are also annotated on each sub-basin.

After preprocessing, the data are checked for the presence of ice, and then a multi-parameter polarimetric rainfall estimator is applied in the radar coordinate space based on preset thresholding in Z, ZDR and KDP (Figure 2).

The rain rates computed at each 5-minute volume scan are then interpolated to a 1 km^2 grid for a 200 x 200 km^2 box centered on the ARMOR radar using REORDER and summed in order to produce a running 1-hr rainfall accumulation (i.e., a 1-hr accumulation at each 5-minute interval). Upon creation of the hourly total, updated six-hour totals are accumulated over the same grid for use by the TVA. No explicit correction for radome attenuation or non-uniform beam filling is currently attempted.

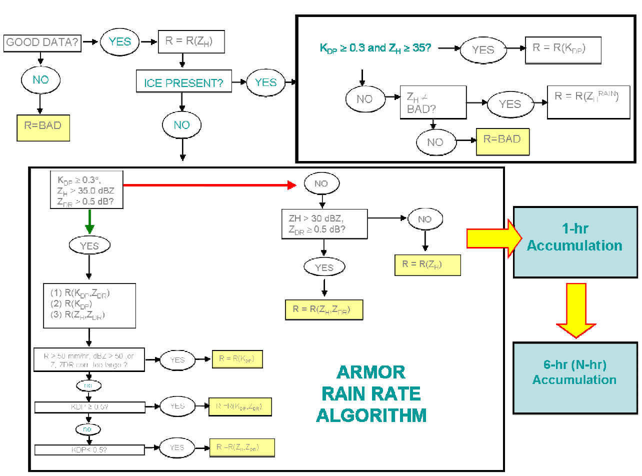

Figure 2. ARMOR hydrometeor/precipitation processing diagram.

Subsequent to quality control processing, the hourly radar rainfall estimates are computed and provided, in real-time, to TVA for each of eleven sub-basins and thirty-seven gauge locations within 100 km of ARMOR (Figure 3). The radar-derived rainfall estimates are compared to rainfall measurements from the TVA gauge network on a 6-hr timescale, which is the interval between initializations of the TVA River Operations inflow model. Using sub-basin scale rainfall, the TVA inflow model produces stream flow forecasts along the Tennessee River and its tributaries. As with most hydrologic prediction models used for water resource management, it is important to provide the most accurate rainfall estimate possible. Thus in order to improve the radar rainfall estimate, radar-gauge comparisons are conducted on both the area (i.e., sub-basin) and point (i.e., gauge location) scales.

4. Results

a. Point comparisons

A comparison of 6-hr rainfall accumulation at gauge locations has been conducted within the ARMOR domain for thirty-one rainfall events observed from 24 October 2007 to 13 July 2008. Figure 4 shows the radar versus gauge rainfall

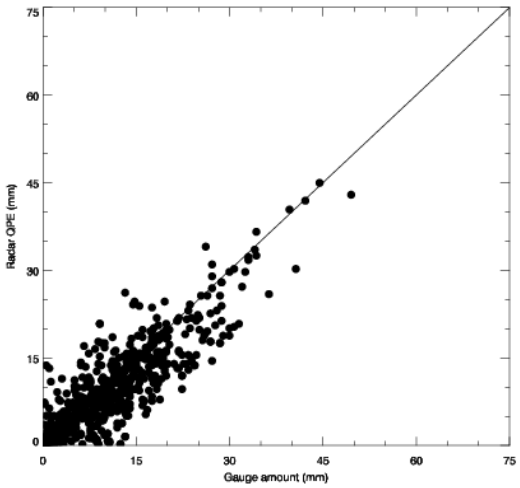

Figure 4. Comparisons of 6-hr rainfall measured by the TVA rain gauge network and estimated by ARMOR at each rain gauge.

measurements for these events. There is good agreement between the datasets, as indicated by their location relative to the 1:1 ratio line. Early radar-gauge comparisons revealed a -20% bias in the radar estimates. However, it was discovered that the receiver calibration had not been completed properly and the radar reflectivity was re-calibrated using two independent techniques: 1) dual-polarimetric self-consistency (as described in Ryzhkov et al. 2005b); and 2) direct comparisons to the NASA TRMM Precipitation Radar at levels above 6 km in altitude. The resultant bias correction resulted in a mean underestimation of the rainfall relative to the gauges by ~12%, which is about the best that can be attained with current radar technologies (e.g., May et al. 1999, Brandes et al. 2002, Ryzhkov et al. 2005). There also exists a relatively small 15% random error in the comparison of the two datasets likely due in large part to the fundamental differences that exist in sampling between radars and rain gauges (a 1 km^2 area radar sampled every 5-minutes vs. the 0.5 m^2 area of the gauge sampled nearly continuously). Importantly, inspection of the radar and gauge estimates as a function of range within 100 km of the radar revealed virtually zero range bias.

b. Sub-basin comparisons

A similar comparison was conducted on the sub-basin scale, except that twenty-seven rainfall events that occurred between 9 January 2008 and 13 July 2008 were used (winter and summer seasons). The radar rainfall estimates were averaged over each sub-basin and compared with rain gauge-derived rainfall estimates provided by TVA algorithms that employ Thiessen polygon methods to estimate area-mean rainfall over each sub-basin.

Figure 5 shows the radar versus rain gauge estimates for these events. Interestingly, there is slightly more scatter about the 1:1 ratio line compared with the point estimates in Figure 4, but the underestimation by radar remains low. On the sub-basin scale, the radar only underestimates 6-hr rainfall accumulation by 8%. The slightly larger random error (20%) can likely be attributed to the density of the TVA gauge network, which readily stands out in an examination of individual sub-basins (Table 1). The largest error in comparison of the radar and gauge estimates is associated with the sub-basin Town Creek at Geraldine (3501), which has only one rain gauge on its northwestern boundary and no rain gauges to the south or east of the basin. This can cause the rain-gauge derived Thiessen polygon to be very unrepresentative of the rainfall across the sub-basin. Smaller errors in the radar--gauge areal comparisons are found to be associated with sub-basins that contain more rain gauges (e.g., 3602, 3603 and 3604).

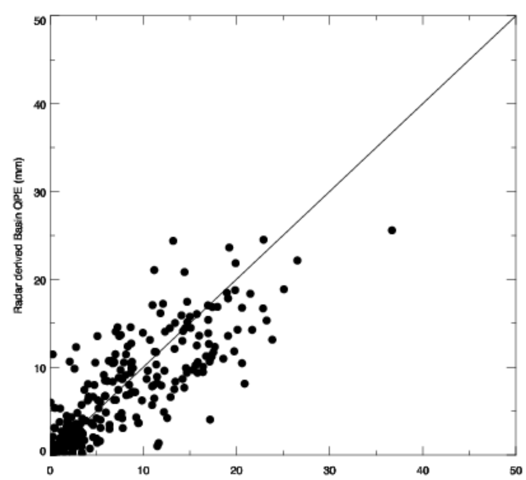

Figure 5. Same as in Figure 4, except for each sub-basin.

Other factors, such as the radar scanning strategy, likely influence the comparison between the radar and gauge-derived rainfall estimates. Some precipitation systems may move fast enough over an area containing a rain gauge such that the radar does not capture the rainfall at that gauge location. This does not only cause a discrepancy in the point-scale comparison, but can also introduce error in the areal comparison.

Table 1. Comparison of ARMOR vs TVA rain gauge network rainfall estimates for individual sub-basins.

BASIN: Sub-basin	BIAS	ERROR
2501 Upper Bear: Upper Bear Creek Local	-4.9%	20.5%
3501 Guntersville: Town Creek at Geraldine	-0.3%	25.1%
3504 Wheeler: Scottsboro to Guntersville	-2.4%	21.5%
3601 Wheeler: Flint near Chase	-9.6%	16.8%
3602 Wheeler: Tims Ford-Fayetteville	-3.3%	20.2%
3603 Wheeler: Fayetteville-Prospect	-8.4%	19.8%
3604 Wheeler: Guntersville-Decatur	-8.8%	15.7%
3605 Wheeler: Decatur-Wheeler	-9.0%	18.7%
3701 Wilson: Shoal Creek at Iron City	-12.7%	20.8%
3702 Wilson: Wilson Local North	-10.1%	22.2%
3703 Wilson: Wilson Local South	-4.4%	20.2%

c. Disadvantages of using a rain gauge network in representing basin rainfall amounts

Isolated heavy rainfall events are common in the Tennessee Valley during the sub-tropical environment of the summer months. These events can often be under sampled by coarse rain gauge networks resulting in an underrepresentation of the true basin total rainfall. Figure 6 shows one of many such examples in which the rain gauge network was to coarse to properly estimate the amount of rainfall within a sub-basin. Over a 6-hr period on 9 July 2008, the radar detected nearly 0.18 inches of rainfall, collectively, within both the Upper Bear Creek and Town Creek at Geraldine sub-basins (annotations 1 in Figure 6); however the rain narrowly missed the rain gauges which were used to determine the sub-basin rainfall. Thus the rain gauge-derived 6-hr rainfall input into the TVA inflow model was incorrect.

However, the radar may also provide an “apparent” underestimation of basin integrated rainfall when that rainfall is isolated in nature. During the 6-hr period shown in Figure 6, the rain gauge network measured 0.79 inches of rainfall within the Decatur-Wheeler sub-basin (annotation 2 in Figure 6), whereas the radar only estimated 0.25 inches of rainfall within that sub-basin. The radar underestimation was the result of a locally heavy downpour that occurred in the far eastern part of the sub-basin, in the vicinity of a rain gauge. As illustrated in Figure 6, the radar estimated 1-2 inches of rainfall in the eastern part of this sub-basin and considerably less in other parts of the sub-basin. Thus the rain gauge-derived sub-basin rainfall was much higher than that estimated by the radar for the same sub-basin. Underestimation by the radar at the gauge location is likely due to the 1 km^2 resolution and the 5-min sampling time employed within the radar rainfall

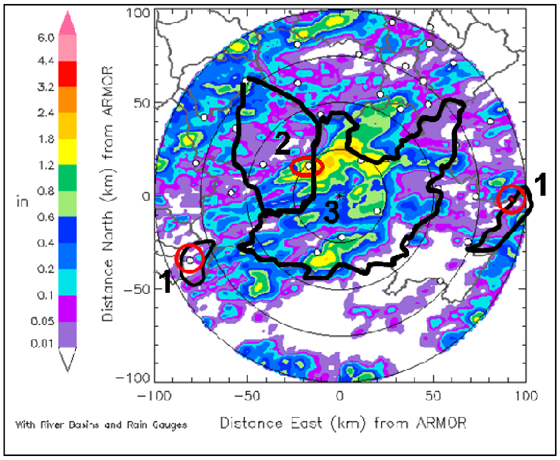

Figure 6. Rainfall accumulation estimated by ARMOR between 1700-2300 UTC on 9 July 2008 with rain gauges (filled circles) and sub-basins (bold lines).

processing, which was too coarse to capture the heavy downpour that occurred in the eastern part of the sub-basin. Conversely, Figure 6 also suggests that the radar estimate, when integrated over the basin may actually be more accurate than that derived from the coarse gauge network (and a single gauge that was located under a localized maximum in rainfall).

If the rainfall does not vary much across a sub-basin and the rain gauge network is not too coarse within the sub-basin, the ARMOR and rain gauge estimates are similar. For example, the Guntersville-Decatur sub-basin (annotation 3 in Figure 6), which had sufficient rain gauge coverage for this event, received widespread rainfall between 1700-2300 UTC on 9 July 2008. The rain gauge-derived sub-basin rainfall during this period was 0.43 inches, which compares well to the 0.46 inches estimated by the ARMOR radar.

3. Summary

A continuing validation of dual-polarimetric radar rainfall estimates across the south central Tennessee Valley has been conducted at both the gauge and sub-basin scale since October 2007 and January 2008, respectively. Comparison with the TVA rain gauge network indicates the radar underestimates 6-hr rainfall accumulation in sub-basins by roughly 8% (random error of 15%). A larger 20% random error found to exist in comparisons between radar and gauge *sub-basin* rainfall accumulations is likely attributable to the relatively sparse number of gauges used in each sub-basin as compared to the continuous spatial sampling provided by the radar. Since the maintenance of a sufficiently dense, high-quality recording rain gauge network at hourly temporal resolution or better is impractical and costly, it is believed that areal rainfall measurements can best be attained with weather radar using advanced technology (e.g., dual-polarimetry and fine-tuned traditional WSR-88D radars). Indeed, a realization of improved radar-provided distributed rainfall measurements at hourly or better time scales is likely to occur in concert with the impending dual-polarimetric upgrade of the WSR-88D radars.

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