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POTENTIAL APPLICATION OF MOBILE X-BAND RADAR FOR CATCHMENT HYDROLOGY

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1. INTRODUCTION

The estimation of precipitation is complicated by temporal and spatial variability, caused in part by synoptic, mesoscale, and storm-scale forcings. This variability affects our capability to measure rainfall in-situ and through radar remote sensing. The lack of continuous observations in space and time requires a merging of information obtained from various point and remote sources at differing resolution and accuracy.

One key issue is how much of the observed variance between radar estimates and point rain gauge observations can be attributed to sensor resolution differences. To answer this question detailed observations of rainfall in space and time were carried out over the small 21.4 km^2 Goodwin Creek research watershed (Fig. 1) in northern Mississippi (Alonso 1996; Steiner et al. 1999, 2002). Instrumentation at the site includes more than 40 rain gauges of varying design, a Joss-Waldvogel (1967) raindrop disdrometer, four anemometers mounted at different heights above ground to observe the wind profile, and a SURFRAD (Hicks et al. 1996) network station in the center of the catchment (latitude 34° 15' 16" N, longitude 89° 52' 26" W) (Fig. 2).

High-resolution radar reflectivity factor and Doppler velocity observations (50 m by 1 deg in space, tens of seconds in time) were made using the mobile X-band (3 cm wavelength) Doppler-on-Wheels (DOW) radar (Wurman et al. 1997) (Fig. 3) for several storms passing over the Goodwin Creek area. The watershed is under coverage from four Weather Surveillance Radar – 1988 Doppler (WSR-88D) S-band (10 cm) radars (Heiss et al. 1990), measuring at 1 km by 1 deg in space and several minutes in time, the closest located near Memphis, Tennessee, approximately 120 km to the north of the Goodwin Creek catchment.

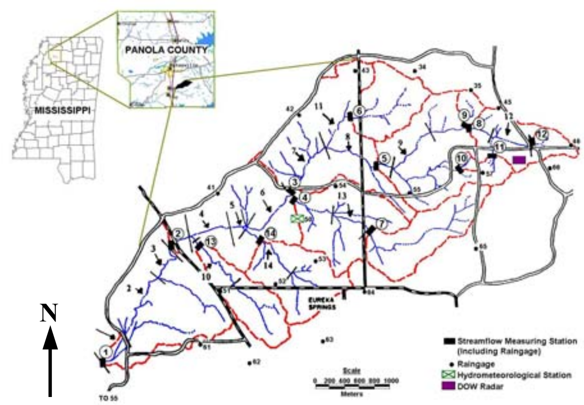

Figure 1. Geographical location and outline of the Agricultural Research Service (ARS) Goodwin Creek watershed in northern Mississippi.

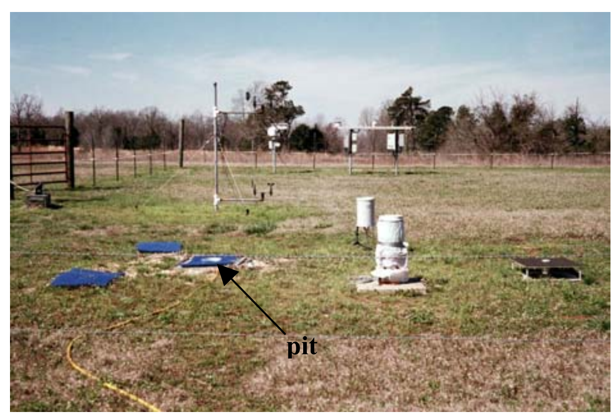

Figure 2. Climatological station (station 50) in the catchment center includes above-ground and buried rain gauges, a disdrometer, wind profile measurements, and a SURFRAD station.

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The data quality control, in particular the calibration of the radar reflectivity values and correction of the observations for signal loss due to attenuation at X-band, poses major challenges before the data may be used for analysis of the space-time variability of rainfall. Hereafter, we illustrate some of the difficulties of obtaining accurate ground-truth measurements and discuss the viability of using X-Band Doppler radar for hydrologic applications.

Figure 3. Doppler-on-Wheels (DOW) radar of the University of Oklahoma (deployment site marked by rectangle at upper end of catchment in Fig. 1).

2. STORM ANALYSIS

Data collected for a storm that passed over the Goodwin Creek watershed on 23-24 April 2001 are used to highlight some of the uncertainties involved in measuring rainfall in-situ and through radar remote sensing. The storm that crossed Goodwin Creek was well organized, with an intense line of convection (squall line) followed by some widespread (stratiform) rainfall, and part of a major storm system that extended from southern Texas to Canada (Fig. 4).

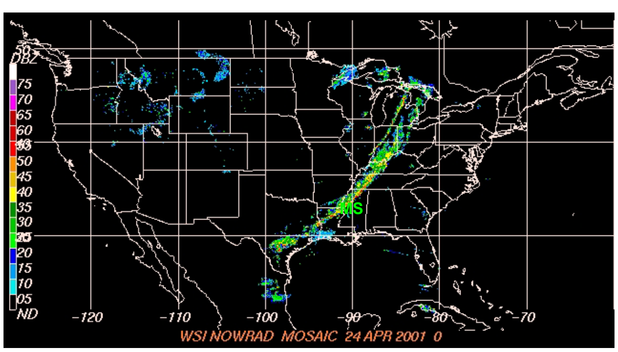

Figure 4. WSI radar reflectivity mosaic of storm on 23-24 April 2001 at 0000 UTC as it passes over Northern Mississippi.

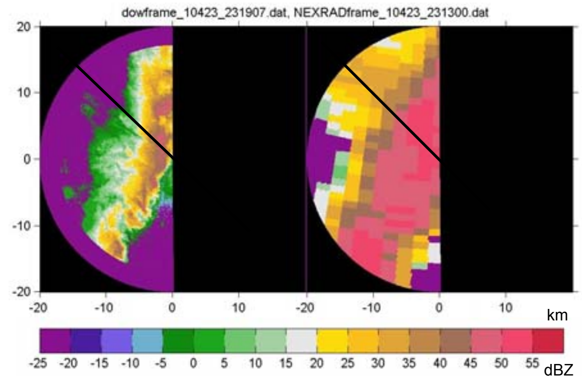

Figure 5. Horizontal cross-section of storm reflectivity as seen by the DOW at 2319 UTC (left) and the KNQA at 2313 UTC (right) radar on 23 April 2001.

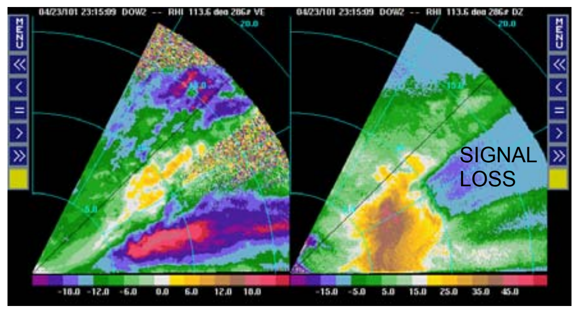

Figure 6. Vertical cross-section of radar radial Doppler velocity (left panel) and reflectivity (right panel) as observed by the DOW radar on 23 April 2001 at 2315 UTC. The resolution is 50 m in the radial direction and 1 deg in azimuth. Range rings are shown at 5 km intervals.

Figure 5 shows a snapshot of the storm on 23 April 2001 at 2319 UTC as seen by the DOW (left panel), deployed at the eastern end of the watershed (see Fig. 1), and the Memphis WSR-88D (KNQA) (right panel) radars. The KNQA reflectivity is shown only for the sector covered by the DOW, and the KNQA data have been adjusted in time by minimizing the DOW and KNQA reflectivity RMS difference near the DOW. The DOW provides an order of magnitude increase in spatial resolution over the KNQA radar. At this finer resolution, significant small-scale structures within the convective line can be seen that are not resolved by the KNQA. Moreover, the vertical profile of the storm recorded by the DOW (Fig. 6) illustrates how air is lifted along the frontal boundary and precipitation is formed. The vertical cross-section, however, demonstrates the severe limitation of the shorter wavelength radar – a complete loss of signal in the radial direction behind the intense convective cell. Comparing the DOW and KNQA reflectivities in Fig. 5, this attenuation effect can also be seen in the horizontal depiction of this storm.

Figure 7 shows a comparison of the raindrop spectra-based reflectivity time series at the center of the Goodwin Creek catchment with the closest reflectivity pixels observed by the DOW and KNQA, respectively. Considering the space and time differences in sampling volume and sampling frequency, the radar-based traces reflect the observed rainfall at the surface well. However, the DOW observations suffer from an attenuation problem that is particularly severe during the passage of the most intense part of the storm (after 2300 UTC) when the rain rates reach 150 mm/h. Interestingly, during the first rainfall burst (2200 – 2230 UTC) the DOW signal appears not as badly attenuated even though the rain rates were also high. The difference in attenuation may be explained by the fact that the second and more intense rainfall period was associated with significant lightning, indicating that this part of the storm included high-density ice particles such as graupel or small hail.

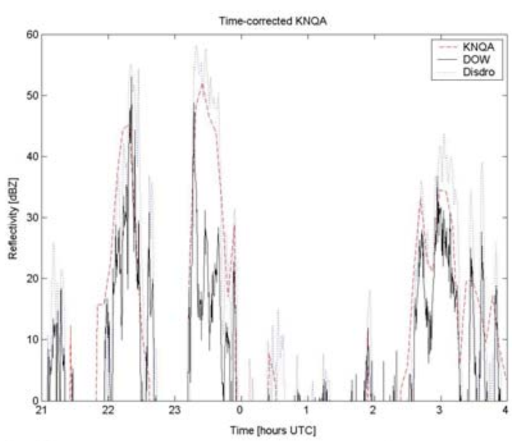

Figure 7. Reflectivity based on disdrometer observations at station 50 and closest pixel of DOW and KNQA radar.

Comparing the DOW and KNQA reflectivity along a common path, and assuming that the KNQA observations are not attenuated, the loss of DOW signal can be estimated with respect to KNQA. Figure 8 shows such a comparison along the DOW azimuth 315° (see Fig. 5), highlighting not only the rapid decrease of DOW signal with distance from the radar but also the significant variability with time. DOW signals within 2 km of the radar were not considered because of a questionable close-range correction. Attempts to quantify the loss of DOW signal in this manner are complicated by the spatial and temporal resolution differences between the KNQA and the DOW – there are approximately 400 DOW pixels that correspond to a single KNQA pixel at any given location and there are more than 20 DOW sweeps for each KNQA radar sweep. Iterative attenuation corrections, constrained by the KNQA and raindrop spectra-derived reflectivities, have not been successful for the most intense part of the storm, possibly because of the added complexity of high-density ice particles contained in the DOW radar sampling volume. Moreover, this correction procedure depends on the radar calibration. To achieve a reasonable calibration, the KNQA and DOW radar reflectivities have been compared to the raindrop spectra based values for weak-moderate rainfall, where the X-band attenuation for the DOW observations should be small.

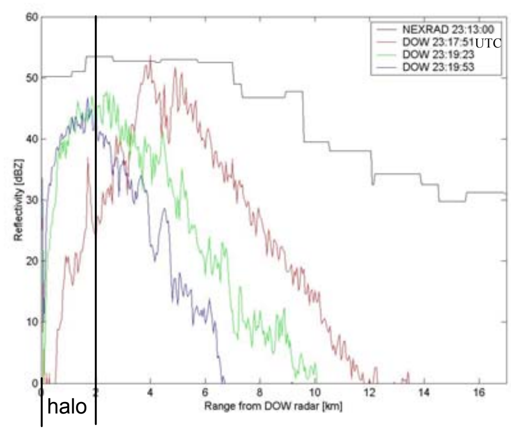

Figure 8. Reflectivity vs. distance from the DOW for both the time corrected KNQA and DOW radar.

The ultimate test of successful data quality control and correction is to compare the radar-estimated rainfall amounts to the raingauge-based surface measurements. The Goodwin Creek rain gauge network consists of several different types of instruments including Belfort weighing gauges (BEL), Texas Instruments tipping bucket gauges (TXI), USDA Agricultural Research Service tipping bucket gauges (ARS), Australian Hydrologic Service tipping bucket gauges (TB3), and simple buried/pit collectors (COL) (with rim at ground surface, see Fig. 2). At least one of each type of gauge was operated at the climatological station in the center of the catchment during this storm. Also, one tipping bucket gauge was mounted above ground (sARS) while another of the same manufacturer was buried (bARS).

The rainfall accumulations recorded in the center of the watershed are shown in Fig. 9. All gauges in the watershed were calibrated in the field. (Differences in catch between uncalibrated and calibrated rain gauges may amount to 10% or more.) Despite that, there is a significant variation in accumulated rainfall among the various rain gauges, the disdrometer, and the two radars (based on closest pixel and using $Z = 300R^{1.4}$ to convert radar reflectivity to rain rate). The 20% variability of accumulated rainfall among the gauges and the disdrometer reflect differences in collection mechanisms and wind effects that are difficult to quantify and correct. Figure 9 also demonstrates the effect signal attenuation has on accumulated rainfall estimated using the DOW radar. The DOW rainfall estimates amount to less than 20% of the total rain that reached the surface during this storm.

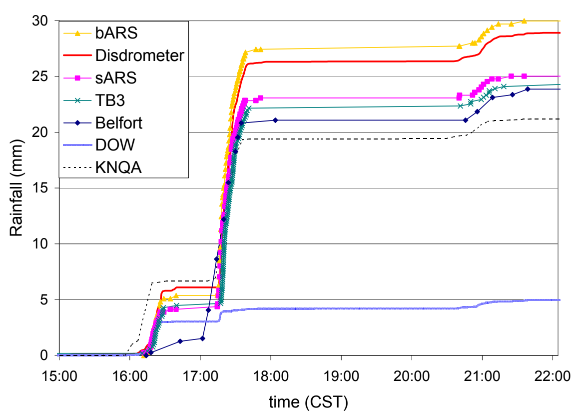

Figure 9. Accumulated rainfall in the center of catchment (station 50).

3. CONCLUSIONS

Detailed observations of a major storm system that passed over the small, but well instrumented Goodwin Creek research watershed in northern Mississippi were used to highlight the range of uncertainty encountered measuring rainfall from an in-situ to remote sensing perspective. These uncertainties are related to the rain gauge measurements (i.e., calibration, wind effect), radar rainfall estimation (calibration, attenuation, Z-R conversion), and the merging of information from various sources (space and time differences in sampling and coverage).

Mobile short-wavelength radar have become more widely used for rainfall monitoring over urbanizing areas and small catchments. Our study, however, demonstrates that the problem of signal attenuation may seriously limit the quantitative use of such radar for rainfall estimation, especially for situations of intense rainfall that bear a potential for flooding. Attenuation correction proves difficult even when additional information is available to constrain an iterative correction procedure.

Analyses of several storms observed in a similar fashion over Goodwin Creek will provide a broader basis for providing guidance and limitations to the use of short-wavelength radar for quantitative rainfall estimation.

Acknowledgments. This work is supported by NSF Grants EAR-9909696 and EAR-9909597. The assistance provided by staff of the National Sedimentation Laboratory in Oxford and the University of Oklahoma is greatly appreciated.

4. REFERENCES

Alonso, C. V., 1996: Hydrologic research on the USDA Goodwin Creek Experimental Watershed, northern Mississippi. *Proc. 16th Annual AGU Hydrology Days Conference*, Fort Collins, Colorado, Amer. Geophys. Union, 25-36.

Heiss, W. H., D. L. McGrew, and D. Sirmans, 1990: NEXRAD: Next Generation Weather Radar (WSR-88D). *Microwave J.*, **33**, 79-98.

Joss, J., and A. Waldvogel, 1967: Ein Spektrograph fuer Niederschlagstropfen mit automatischer Auswertung. *Pure Applied Geophys.*, **68**, 240-246.

Steiner, M., J. A. Smith, S. J. Burges, C. V. Alonso, and R. W. Darden, 1999: Effect of bias adjustment and rain gauge data quality control on radar rainfall estimation. *Water Resour. Res.*, **35**, 2487-2503.

Steiner, M., J. A. Smith, L. C. Sieck, S. J. Burges, and C. V. Alonso. 2002. How much rain reaches the surface? Lessons learned from very high-resolution observations in the Goodwin Creek watershed. *Preprints, 16th Conference on Hydrology*, Orlando, Florida, American Meteorological Society, 61-65.

Wurman, J., J. Straka, E. Rasmussen, M. Randall, and A. Zahrai, 1997: Design and deployment of a portable, pencil-beam, pulsed, 3-cm Doppler radar. *J. Atmos. Oceanic Technol.*, **14**, 1502-1512.