P14.1 RAINFALL VARIABILITY AND ITS EFFECT ON RAINFALL MEASUREMENTS

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1. INTRODUCTION

Rainfall is highly variable in space and time, depending on synoptic, mesoscale or topographic forcing. This variability affects our capability to measure rainfall from an in-situ as well as remote-sensing perspective. In particular, the variability of rainfall within the range of sensor resolution differences appears to have a significant effect on the comparison between observations made by instruments with differing resolutions in space and time (e.g., Kitchen and Blackall 1992; Ciach and Krajewski 1999). For example, a radar and rain gauge may both measure rainfall perfectly and accurately, from an instrument and retrieval perspective, yet provide differing rainfall estimates (Austin 1987). In reality, the rainfall amounts estimated by both instruments might be burdened by measurement limitations and uncertainties. The question is thus: how much of the observed variance between radar and gauge observations can be explained by sensor resolution differences and the space-time variability of rainfall?

Thirty storms that passed in 1996 and 1997 over the highly-instrumented Goodwin Creek research watershed in Panola County, northern Mississippi, have been analyzed to find an answer to the above question (Steiner et al. 1999). These storms, each contributing at least 10 mm of storm total rainfall, accumulated approximately 785 mm of rain, which corresponds to about half the average annual rainfall for this area. Extensive quality control of the radar and rain gauge data, drop spectrometer and lightning data, storm cell tracking and sensitivity to data processing analyses have been combined to study differences in radar-estimated and gauge-measured rainfall amounts, and how these relate to storm structure and movement, and storm microphysics.

2. RADAR–GAUGE DIFFERENCES IN RAIN

The analyses of Steiner et al. (1999) were focused on the effect of data quality and processing schemes on the bias adjustment of radar rainfall estimation based on using rain gauge data from a dense network. Their results highlight the importance of high-quality rain gauge data for bias adjustment. Questionable gauge data can dramatically affect the radar-gauge merged rainfall product, as shown by Fig. 1. Malfunctioning of the tipping-bucket rain gauges was frequently caused by biological and mechanical fouling, and human interference.

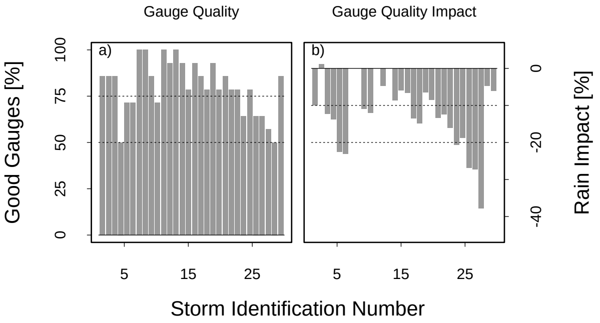

Figure 1. Effect of rain gauge quality on bias adjustment of radar-estimated storm total rainfall for 30 storms passing over Goodwin Creek. **(a)** Number of good-quality rain gauges per storm (percentage of all network gauges) and **(b)** impact of using all rain gauge data instead of quality controled data only on bias-adjusted radar rainfall estimates. (Adapted from Steiner et al. 1999).

By using high-quality gauge data and storm-based bias adjustments, Steiner et al. (1999) were able to achieve radar rainfall estimates with root-mean-square (RMS) radar-gauge rain differences of approximately 10% for storm total rainfall accumulations of 30 mm or more. Differences resulting from radar data processing schemes were small compared to the effect caused by bias adjustment and using high-quality gauge data.

Bias adjustment was implemented on a storm total rainfall basis to minimize uncertainties due to space and time mismatching of observations. However, significant changes in storm structure and microphysics (e.g., raindrop size distribution) may cause the difference between radar and gauge rainfall estimates to be time dependent.

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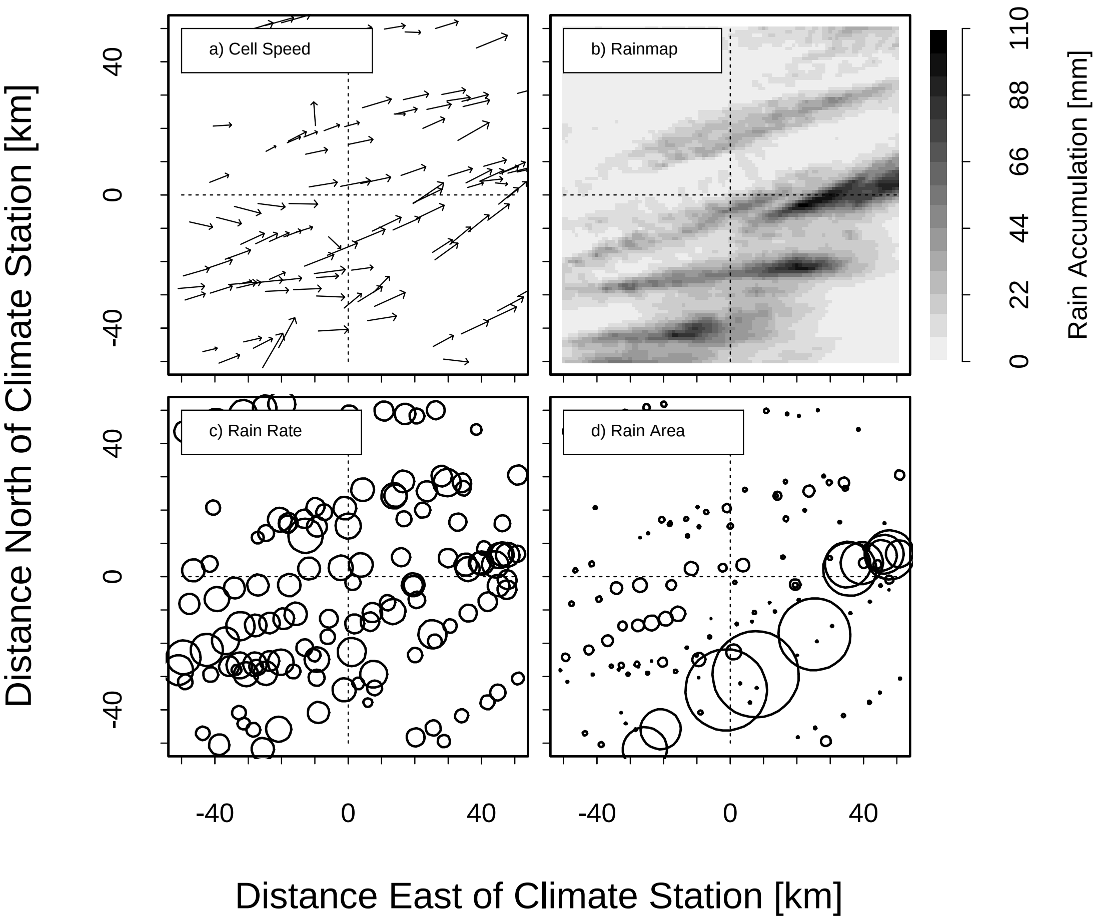

Figure 2. Storm cell tracking and rainfall analyses for storm cells passing over the 100 km by 100 km area centered on Goodwin Creek on 20 April 1996, based on Memphis WSR-88D radar data. Each arrow or circle belongs to a cell, identified at a given instant in time, centered on the location of the reflectivity centroid of that cell and scaled by the cell's speed **(a)**, average rain rate **(c)**, and rainy area **(d)**. The panel **(b)** shows the spatial distribution of the rainfall accumulation.

3. STORM CHARACTERISTICS

The study of Steiner et al. (1999) showed that the variability of storms affects the comparison between radar-estimated and gauge-accumulated rainfall: the RMS difference was found to increase with increasing spatial variability (coefficient of variation) of the storm total rainfall distribution.

The focus, therefore, shifted to a mesoscale characterization of the variability of rainfall in space and time, and how this variability may depend on the storm environment. Detailed Lagrangian analyses of storm cells (e.g., evolution and motion) have been carried out using the storm-tracking analysis software TITAN (Dixon and Wiener 1993) and related to the spatial rainfall accumulation (Fig. 2). The hypotheses are that (1) the space-time variability of rainfall can be decomposed into birth, evolution, and storm cell motion, and (2) the pattern of storm cells and resulting spatial rainfall distribution can be linked to physical properties of the storm environment (e.g., atmospheric, land surface, and topographic conditions). For example, Fig. 2 indicates that for this particular storm there was not much variation among the storm cells' speed or rain rate, and that the spatial distribution of rainfall was mainly the result of the storm cell tracks and sizes.

The radar-based storm-tracking analyses are complemented by analyses of the storm microphysics (raindrop size distributions and lightning) and characterizations of the atmospheric storm environment (based on sounding and synoptic analyses). The 30 storms discussed in Steiner et al. (1999) are used to develop a climatology of storms for northern Mississippi.

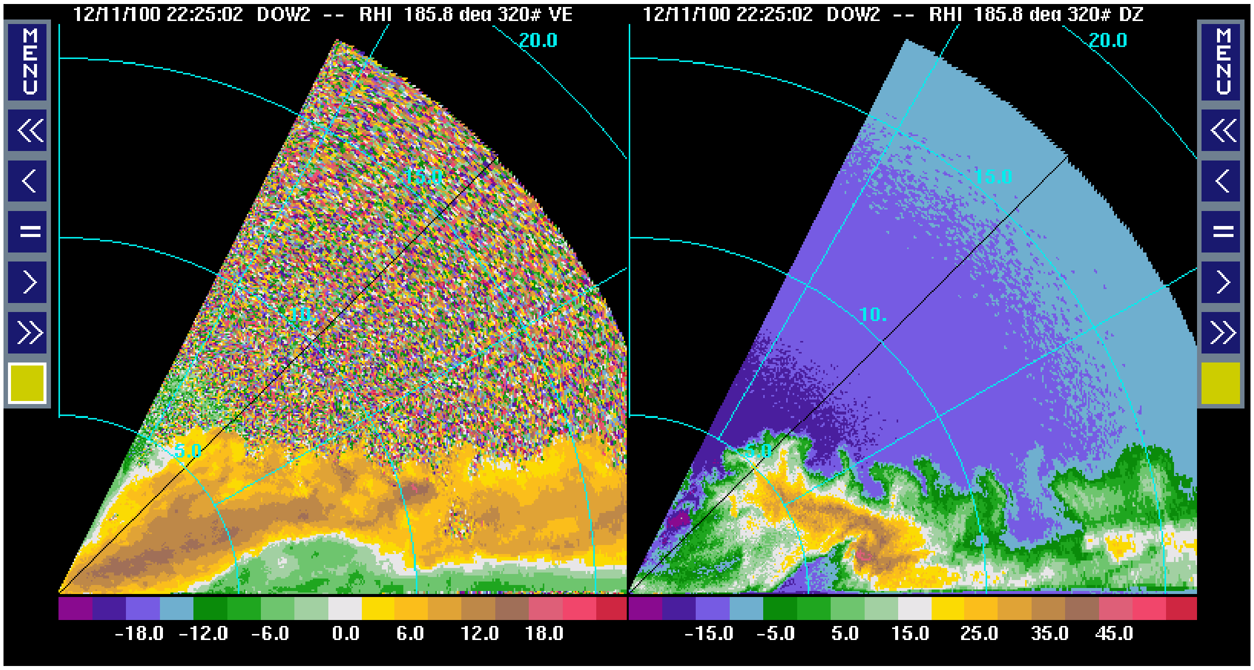

Figure 3. Vertical cross section through a frontal boundary passing over the Goodwin Creek watershed on 11 December 2000 at 22:25 UTC, as seen by the Doppler-on-Wheels radar. Radial Doppler velocity is shown in the left panel and radar reflectivity in the right panel. Range rings are at 5 km intervals.

4. SMALL-SCALE RAINFALL VARIABILITY

A mobile Doppler radar platform (Doppler-on-Wheels, Wurman et al. 1997) has been used since April 2000 to obtain very-high resolution, short-range radar observations over the Goodwin Creek watershed. For several storms, we have been collecting data at a resolution of 50 meter in range, 1 degree in azimuth, and 2-3 minutes in time. Figure 3 shows an example of a vertical cross section through a frontal boundary passing over the watershed, illustrating the rich details in velocity (wind) and reflectivity (rain) structure revealed by these high-resolution observations.

These data are used to assess how much improvement in the radar-gauge comparison of rainfall estimates can be achieved by increasing the radar resolution to better match the gauge point-measurements. This is done by stepwise aggregating the radar observations from the highest spatial resolution (50 m) to the coarser WSR-88D resolution (1 km) and evaluating how a change in resolution will affect the radar-gauge comparison of rainfall.

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REFERENCES

Austin, P.M., 1987: Relation between measured radar reflectivity and surface rainfall. *Mon. Wea. Rev.*, **115**, 1053-1070.

Ciach, G.J., and W.F. Krajewski, 1999: On the estimation of radar rainfall error variance. *Adv. Water Res.*, **22**, 585-595.

Dixon, M., and G. Wiener, 1993: TITAN: thunderstorm identification, tracking, analysis, and nowcasting—a radar-based methodology. *J. Atmos. Oceanic Technol.*, **10**, 785-797.

Kitchen, M., and R.M. Blackall, 1992: Representativeness errors in comparisons between radar and gauge measurements of rainfall. *J. Hydrol.*, **134**, 13-33.

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.

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.