4.8 WATER CYCLE VARIABILITY OVER A SMALL WATERSHED: A ONE-MONTH COMPARISON OF MEASURED AND MODELED PRECIPITATION OVER THE SOUTHERN GREAT PLAINS

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1. INTRODUCTION

There are many studies of the water budget of individual watersheds using various forecast and climate models (Roads et al., 1994; Betts et al., 1998; Roads and Betts, 1999; Betts et al., 1999; Roads et al., 2002). To date, these model studies are the most useful method for analyzing the contributions of various processes to the total water budget over a given watershed. In most cases, observations over the modeled watershed are sparse, typically consisting of precipitation and runoff measurements. A common element of these models is that they typically use nudging procedures in soil moisture to achieve budget closure, so they do not conserve water. This nudging term can exceed 20-30%, suggesting that there are 20-30% uncertainties in some or all of the modeled components of the budget. This uncertainty stems from a basic lack of understanding of many of the physical processes that are modulating the water fluxes. Despite the useful information obtained from these model studies, failure to achieve budget closure illustrates a serious flaw in our knowledge of the mechanics of the water cycle over a given river basin.

The modeling studies listed above consider the water budget of large river basins, which limits the possibility of thorough, domain-wide observational evaluation of the model projections. Many of the physical processes that contribute to the hydrology of these large river basins operate at local to regional watershed scales. These local watersheds, which may be <2500 km^2 in area, are more amenable to detailed observation networks than large river basins. Given this small area, coupled hydrology models of the water cycle in these small watersheds must use mesoscale models capable of resolving precipitation, evaporation, and land-surface gradients across the watershed.

There have been relatively few systematic attempts to evaluate the precipitation forecasts of mesoscale models on scales of only a few kilometers, or to evaluate the scale dependence of these forecasts. A principal goal of the Department of Energy's (DOE) Water Cycle Pilot Study (WCPS) is to balance the water budget in a small watershed (the Walnut River) in the Southern Great Plains using observations of as many water cycle components as possible. Another goal is to evaluate various model components, both atmospheric and hydrologic, that could be joined to form an analysis and forecast system of the water cycle and its variability in this watershed.

We evaluate the precipitation simulated by the MM5 mesoscale model over the Southern Great Plains (SGP) Atmospheric Radiation Measurement (ARM) Cloud and Radiation Test-bed (CART) site during March 2000, as well as for the Walnut River Watershed, which is a small area in the northern portion of the CART site (Figure 1). The evaluation data are rain-gauge-corrected rainfall estimates from the National Weather Service WSR-88D radars in the region, which are produced and disseminated by the National Weather Service's Arkansas Red River Forecast Center. These radar-based rainfall estimates were evaluated independently using a high-resolution network of rain gauges (Figure 2) situated in the Walnut River Watershed as part of the DOE Atmospheric Boundary Layer Experiment (ABLE). Modeled and measured precipitation was compared using MM5 simulations at three resolutions, 8-km, 12-km, and 4-km, to determine the impact of scale on the models ability to predict precipitation.

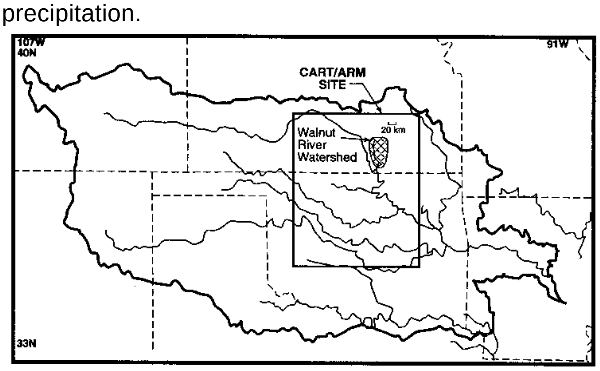

Figure 1. Map of ARM CART and Walnut River Watershed

2. EXPERIMENT DESCRIPTION

Hourly accumulation of rainfall from rain-gauge-adjusted radar rainfall estimates from the

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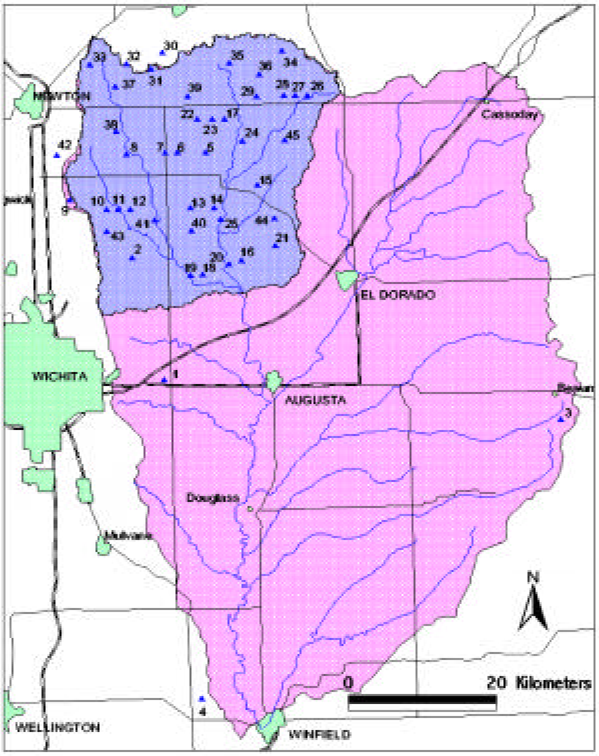

Figure 2. Map of the Walnut River Watershed showing the locations of ABLE rain gauges (triangles).

Arkansas Red River Forecast is provided in HRAP (Hydrologic Rainfall Analysis Project) coordinates on an approximately 4-km by 4-km rectilinear grid. The HRAP coordinates are based on a polar stereographic grid so the geometric distribution of rainfall estimates over the CART site and the Walnut River Watershed is not completely symmetric, although this asymmetry does not introduce a significant bias in our results. Rain gauge data from ABLE were compared to the Arkansas Red River radar-based estimates using a weighted nearest-neighbor approach (i.e. the rain gauge data are matched with the distance-weighted average of the four nearest radar estimates). Results show generally good agreement between these two independent rainfall estimates over the Walnut River Watershed using the HRAP 4-km data (Figure 3a). For the month, the difference in the total accumulated precipitation for the radar and rain gauge estimates was on the order of 26 mm (Figure 3b), although there were two days during the month when the radar significantly overestimated the amount of rainfall (Figure 3a). Given the overall quality of these results, the radar-based estimates for the entire CART site are assumed to be of equally high quality.

The accumulated MM5 precipitation for the 6-hour period after the model initialization was reported every six hours for March 2000 for the three different model resolutions listed above. For the 12-km and 48-km MM5 simulations, the radar-based rainfall estimates that were contained within a given MM5 grid cell were averaged to produce a rainfall estimate that could be compared with the simulated rainfall. The radar-based rainfall estimates had a typical resolution of 4-6 km over the CART site and approximately 5-km over the Walnut River Watershed.

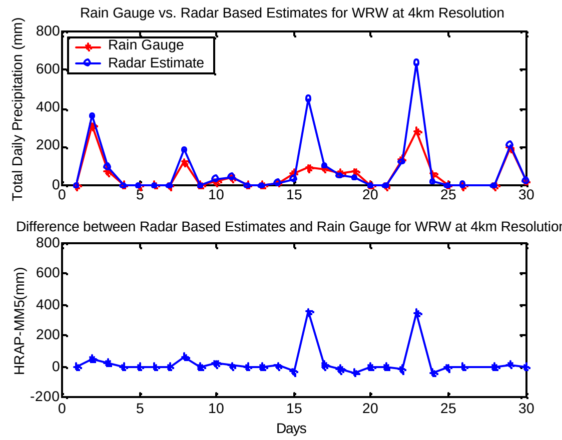

Figure 3. Independent rain gauge versus ABLE rain gauge estimates of rainfall within the Walnut River Watershed.

3. RESULTS

The month of March 2000 was characterized by a series of synoptic disturbances that typically affected the ARM CART site for less than 24-hours. Upper level flow was generally zonal, so disturbances were fast moving. The MM5 six-hour rainfall estimates over the Walnut River Watershed using 4-km resolution show reasonable agreement with the radar-based precipitation estimates for the month, although MM5 tends to underestimate precipitation (Figure 4a). Although one event (day 3) seems to show a phase lag between onset of precipitation in MM5 and that which was actually observed, in general, the timing of precipitation events seems to be well represented by the model when it is run at 4-km resolution. The model has good skill at predicting the occurrence of precipitation, though it has less skill predicting the amount of precipitation that is actually observed. When the 4-km MM5 results are compared to radar precipitation over the entire ARM CART site (Figure 4b), much better general agreement is observed between the model and measured precipitation, especially during events that showed relatively poor agreement when the analysis was restricted to the Walnut River Watershed. This suggests that the model may be underestimating the precipitation in the Walnut River Watershed, but overestimating it in other areas. The larger area of the ARM CART site allows the possibility of compensating errors, while the fairly restricted area of the Walnut River Watershed is less forgiving.

A summary of the results of these experiments (Table 1) shows that the agreement between modeled

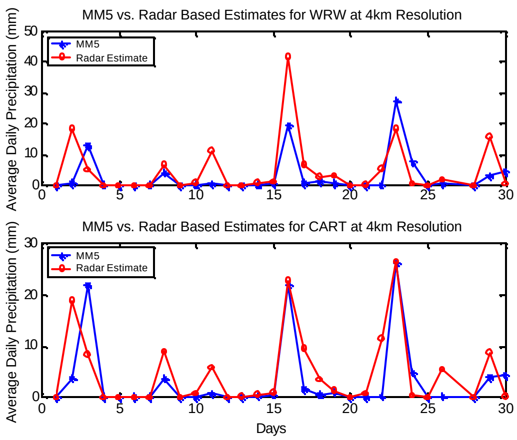

Figure 4. Comparisons of MM5 and rain gauge adjusted rainfall over the Walnut River Watershed and the ARM CART site.

and measured precipitation is scale dependent for March 2000. The MM5 6-hour forecast tends to underestimate the amount of precipitation that was actually observed when it is run with 4-km resolution, regardless of the size of the domain used in the comparison. At 12-km resolution, the MM5 model has remarkable skill at forecasting the total amount of precipitation that was observed. At 48-km, the size of the comparison domain becomes an important issue; the precipitation in the Walnut River Watershed is significantly underestimated, while that over the entire ARM CART site is faithfully represented. While the MM5 underestimates the amount of precipitation at 4-km, it faithfully represents the observed variability in precipitation from point-to-point. At 12-km resolution, the model, particularly in the Walnut River Watershed, overestimates variability in observed precipitation.

The MM5's convective parameterization is rarely invoked during Mach 2000, so most of the precipitation produced by the model is of the non-convective variety. The non-convective precipitation scheme evidently struggles when the resolution is 4-km. It performs better at 12-km, but significantly overestimates variability. These results suggest that the MM5 model may be used during non-convective situations to predict the amount of precipitation over small watersheds (tens of kilometers) in the Southern Great Plains of the United States during early spring as long as the resolution is 12-km. Attempts to resolve local scale precipitation features with the MM5 model are likely to be biased toward underestimation of precipitation amount.

Table 1. Ratios of means and standard deviations between radar-measured and modeled precipitation over the Walnut River Watershed (WRW) and the entire ARM SGP CART site.

	μ (Radar)/ μ (MM5) [σ(Radar)/ σ(MM5)]		
	4-km	12-km	48-km
WRW	1.68 [1.10]	1.07 [0.68]	1.32 [0.92]
CART	1.41 [1.14]	1.11 [0.84]	1.01 [0.83]

4. REFERENCES

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