14.3 IMPACT OF IMPROVED INITIALIZATION OF MESOSCALE BOUNDARIES ON HEAVY RAINFALL FORECASTS IN 10 KM ETA SIMULATIONS

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1. INTRODUCTION

Although skill scores for quantitative precipitation forecasts (QPF) have generally improved over the years as models have used finer resolution and refined parameterizations, these scores are still especially poor for warm-season convective rainfall. Because flash flooding is currently the convective storm-related event producing the most fatalities annually in the United States, these poor warm-season forecasts are troubling.

Several factors combine to complicate warm-season numerical model rainfall forecasts. Much warm season rainfall is convective in nature, and therefore too small to be resolved well by even the higher-resolution operational models used today. Convective parameterizations must be used, and it appears that no one scheme works best in all situations. The sensitivity of QPF to convective scheme is large (e.g., Gallus 1999). In addition, much of the convection is forced by mesoscale features which are themselves poorly resolved in the models (Stensrud and Fritsch 1994).

In this study, we use a 10 km version of the Eta model to examine the impact on QPF of better initialization of mesoscale boundaries that play an important role in precipitation events in the Midwest. In addition, we investigate the use of high-resolution ensembles to provide guidance for warm-season rainfall forecasting.

2. METHODOLOGY

Approximately 30 events have been identified from the warm seasons of 1998-2000 in which mesoscale boundaries such as thunderstorm outflows were present in the Iowa/Minnesota region at either 12 or 00 UTC. In general, subsequent convection in these events resulted in a maximum of at least 50 mm of rainfall within a 24 hour period, and several of the events were associated with over 150 mm and severe flooding. The IA/MN region was chosen due to the presence of rather dense mesonetworks of surface data in these states. Eta simulations have been performed for these cases, using 10 km horizontal resolution, over limited domains of roughly 1000 × 1000 km.

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In the simulations, both the Kain-Fritsch (KF; Kain and Fritsch 1993) and Betts-Miller-Janjic (BMJ; Janjic 1994) convective schemes are used. In addition to standard initializations using NCEP GRIB Eta files, two modification techniques have been used to better represent mesoscale boundaries. The first is a cold pool initialization technique (Stensrud et al. 1999b) which modifies low level temperatures and moisture based on positive mesoscale pressure perturbations found by performing objective analyses of surface data. In regions with "mesohighs", temperatures are cooled at low-levels to hydrostatically account for the pressure increase. An additional modification can be made to the vertical moisture profile to allow for an onion type structure like those observed in many stratiform regions.

In the second technique, mesoscale observations of temperature and moisture are added to the initialization using the model's own vertical diffusion to link these observations with higher levels in the model. In general, a diffusion time period of three hours has been found to work well. These initialization modifications in conjunction with the different convective schemes, and variations in parameters related to the convective schemes are used to create an ensemble of 10 km runs. The ensemble data are used to compute probability forecasts for specific thresholds of rainfall.

3. IMPACT OF CHANGES IN INITIALIZATION AND MODEL PHYSICS

One goal of the work was to determine if a standard adjustment to account for mesoscale boundaries would consistently improve the forecasts, and to see if any one model configuration worked best in these events. Simulations were verified using the NCEP Stage IV 4km precipitation data averaged on to the model grid. Bias and equitable threat scores (ETSs) were calculated, as has been used at NCEP traditionally. Serious questions remain about the best way to quantify model skill objectively for high-resolution simulations. For the cases examined here, skill scores were computed for both 6-hour time periods and 24-hour periods. Some of the problems inherent in traditional techniques are especially apparent in the 6-hour computations, where small time errors can result in exceptionally poor skill scores. Work is ongoing to examine phase shift approaches in model validation, and some of these results may be presented at the conference.

The average ETSs for 9 events studied at this point (16 6-hour periods of interest) were generally similar for both BMJ and KF runs (Fig. 1). The KF scheme tended to have somewhat better ETS scores compared to the BMJ scheme for 24-hr periods (not shown), particularly for some heavier thresholds such as .5 inch, where the KF score was 50% better than the BMJ score. At the higher thresholds, however, the scores themselves were low (< .15). The difference in performance between 6-hr periods and 24-hr periods may indicate persistent timing errors. In some individual cases, the ETSs could differ substantially among the schemes (for example, ETSs of ~ .3 for many thresholds with KF and .12 with BMJ for the July 18, 1999 event, where over 150 mm was observed in northeastern Iowa). Some events appeared to be inherently more predictable with both schemes performing well; for others, both did poorly. Events could be found in which the BMJ scheme performed much better than the KF, and vice-versa.

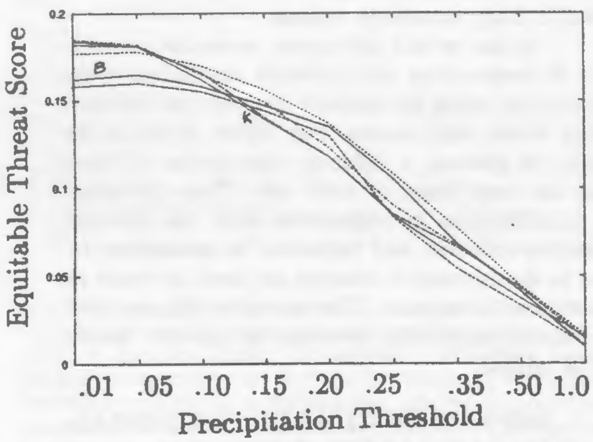

Figure 1. ETSs averaged for 16 forecasts of 6-hr accumulated precipitation for BMJ and KF runs using unadjusted (dark solid line labeled B, light solid line labeled K), cold pool (short dash, long dash lines), and mesoscale observation (dotted, dash-dotted lines) initializations.

Bias scores from the 6-hour periods (Fig. 2) showed that the BMJ runs generally had a high bias for most thresholds and a low bias for the heaviest amounts, while the KF runs were consistently close to 1, with a small low bias.

Although both of the initialization modifications did result in model surface fields generally agreeing better with observations at the initialization times, the impact of the adjustments on traditional skill scores was minor when averaged over all cases. The inclusion of mesoscale observations did result in improvements for all thresholds in the BMJ runs, with the largest magnitudes of improvement for the light thresholds. Smaller improvements occurred at most thresholds in the KF runs. The cold pool scheme did not improve results when the BMJ scheme was used, but did on average improve several thresholds when the KF scheme was used, although the amount of improvement was small (less than 5%). The larger impact of the cold pool scheme in KF runs compared to BMJ runs was also found in Stensrud et al. (1999b). The impact of the mesoscale initialization techniques on the scores was generally much less than the differences that occurred when different convective schemes were used. However the impacts were more similar to those that occurred in tests where tunable parameters were adjusted within the convective schemes.

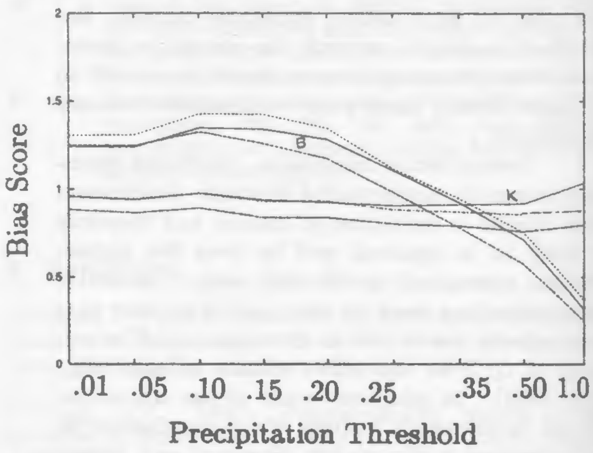

Figure 2. As in Fig. 1 except for bias scores.

The impact of the mesoscale initialization techniques on bias scores was generally more noticeable. The cold pool scheme tended to reduce the bias scores in BMJ runs by 10-20% for thresholds above .1 inch. The mesoscale observation adjustment raised the bias scores, particularly for light amounts. With the KF scheme, the cold pool adjustment again lowered the bias scores, which were already a little low. The mesoscale observations had little impact on bias scores for low thresholds, and did decrease the bias scores for higher thresholds, but only by about half as much as the cold pool scheme.

The model skill scores tended to be higher than the average for 24-hour periods for a subset of the three cases with heaviest rainfall (July 18, July 20, Aug. 6, 1999). Again the ETS values did not differ significantly between the two convective schemes. When the BMJ scheme was used, significant improvement (~ 10%) in the ETS scores occurred at many thresholds from the inclusion of mesonetwork observations, but the cold pool adjustment worsened results. With the KF scheme, both adjustments resulted in some improvement in ETSs, with the cold pool scheme resulting in an improvement of over 10% for thresholds between .25 and .50 inch.

4. ENSEMBLE OUTPUT

The large variability among the cases, and lack of significant consistent improvement from choice of convective scheme or improved initialization suggests that ensemble guidance may be of more value to forecasts of heavy rainfall than attempts to achieve one outstanding deterministic forecast. The limited impact of the initialization adjustments on the skill scores described above suggests that a more dispersive ensemble will be obtained from physical variations in the model than initialization perturbations, similar to the findings of Stensrud et al. (1999a).

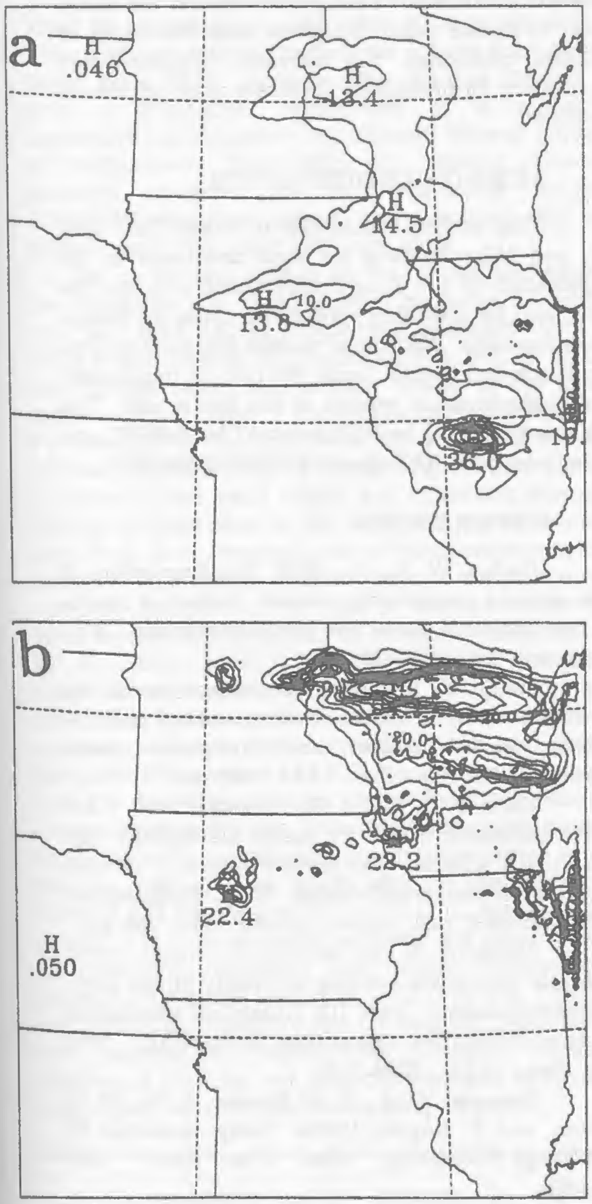

Figure 3. Accumulated 6-hr precipitation (contour interval of 5 mm) for the 18-24 hr forecast period valid from 06-12 UTC July 19, 1999 for Eta runs with a) BMJ and b) KF convective parameterizations.

As an example of the difficulties facing forecasters using numerical guidance for Midwestern heavy rain events, model forecasted 6-hr precipitation during the 18-24 hour forecast period from the Eta with the BMJ scheme and the KF scheme is shown in Fig. 3. These model runs were initialized at 12 UTC July 18, 1999, and the valid time of the forecast is 06-12 UTC July 19, 1999. Observed precipitation during this period (Fig. 4) was as large as 100 mm in portions of northeastern Iowa (with 24-hr totals nearing 200 mm) resulting in severe flooding. This heavy rain event was followed within 48 hours by a similar event, over nearly the same area, resulting in record river crests in this portion of Iowa. Neither version of the model was able to accurately simulate the magnitude of rains that fell, with the BMJ run peak rainfall around 36 mm, and the KF run peak around 54 mm. In a study of the impact of horizontal resolution on QPF in 5 excessive rain events, Gallus (1999) also found that the Eta generally underestimated peak amounts when 12 km resolution was used, and that the BMJ scheme often led to a more significant underestimate.

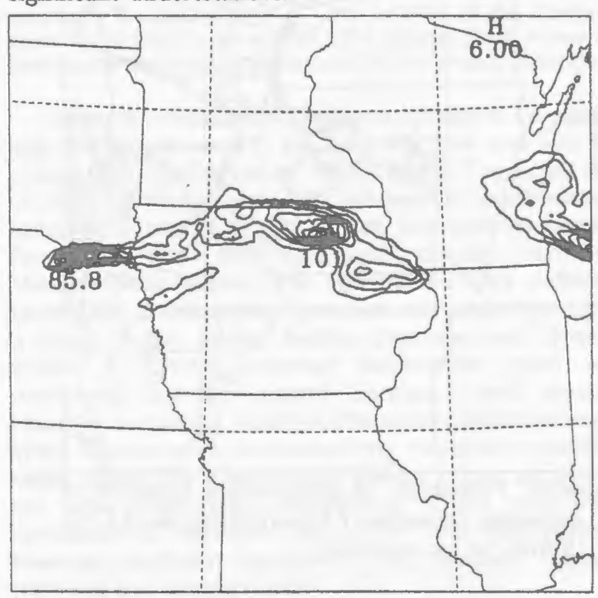

Figure 4. Observed 6-hr precipitation (contour interval of 10 mm) from 06-12 UTC July 19, 1999.

Both schemes in this case also failed to depict the primary region of intense rainfall. The BMJ run had generally small amounts of precipitation over a large area in eastern Iowa, western Wisconsin and northern Illinois, with an isolated region of heavier rainfall in central Illinois. The KF run had most of its precipitation in Wisconsin, with isolated small regions of rainfall in northern Iowa, and almost no rainfall in Illinois. It is difficult to discern if the primary discrepancies were mainly due to a shift in the location of predicted rainfall, or to more serious problems in simulating the forcing mechanisms for the convection. Skill scores for this period favored the KF runs, likely due as much to less overestimate of areal coverage compared to the BMJ runs as to better depiction of the heavy rainfall band.

When ensembles of short-range simulations are performed, probability forecasts for thresholds of rainfall can be computed easily. Fig. 5 depicts a probability forecast for rainfall exceeding .25 inches (7.5 mm) during this 6 hour period, using an 8-member ensemble. It can be seen that a lack of dispersiveness in the ensemble, primarily due to the minimal impacts of the initialization adjustments, and poor skill among all ensemble members result in a rather poor probability forecast. The highest probabilities for over .25 inches of rain are found in northwestern (100%) and southwestern Wisconsin (over 80%) where little or no rain occurred. In much of the region experiencing heavy rain, probabilities were under 20%. A narrow zone of higher probabilities (40-80%) across northern Iowa did coincide with the heavy rainfall band.

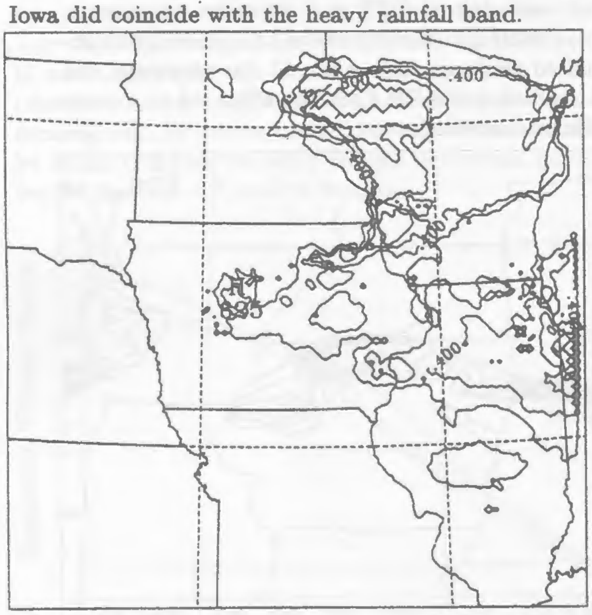

Figure 5. Probability of precipitation (contours of 20%) exceeding .25 inches (7.5 mm) during 06-12 UTC July 19 from 10 km ensemble.

5. DISCUSSION

Preliminary results suggest that no single technique consistently improves the QPF for these heavy rain events. Both techniques, however, do improve the forecasts over some time periods within some cases. Further research is underway to determine if the mesoscale modifications have a greater ability to improve the forecast when low-level flow is relatively weak. The cold pool adjustment may offer the greatest benefit when the Kain-Fritsch scheme is used, since that scheme includes a convective downdraft which can sustain the cold pool over a longer period in the simulation. As the number of simulated cases increases, some attempt will be made to determine why some events are generally well-forecasted by all versions of the model, and others by none. In addition, if certain larger-scale patterns consistently favor one convective scheme over another, it may be advantageous to allow the model to choose the scheme to use. Preliminary tests allowing each scheme to be used within one model run, alternating on each convective time step, resulted in skill scores that generally fell between the extremes of each individual scheme, and occasionally exceeded both.

The mixed results obtained with the various initialization improvements suggest that ensemble guidance may be of more value to forecasters in these situations. Variations in the physics within the model appear to create more dispersion than variations in the initial conditions. The increased dispersion may be necessary for probability forecasts to be of value to forecasters.

6. ACKNOWLEDGEMENTS

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