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IMPACT OF IMPROVED INITIALIZATION OF MESOSCALE FEATURES ON CONVECTIVE SYSTEM QPF 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. The forecasts are difficult because: (i) the convection occurs on scales too small to be adequately resolved by even the higher-resolution operational models used today, (ii) convective parameterizations must be used, and no one scheme works best in all situations, (iii) sensitivity of QPF to convective scheme is large (e.g., Gallus 1999), and (iv) much of the convection is forced by mesoscale features also 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 heavy warm season 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

Roughly 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 at least 50 mm of rainfall within usually a 6-12 hour period, and several of the events were associated with extreme rainfalls over 150 mm and severe flooding. Eta simulations have been performed for these cases, using 10 km horizontal resolution, over limited domains of roughly 1000 × 1000 km.

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 40 km GRIB Eta files, three 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 another 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. In a third approach, we adjust moisture to ensure relative humidity exceeding 80% in the lower and middle troposphere (when warmer than -10°C) where radar echo is present. These initialization modifications in conjunction with the different convective schemes, and variations in parameters related to the convective schemes can be used to create an ensemble of 10 km runs. The 16-member ensemble data can be 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 single deterministic 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, although 6-hr periods will be emphasized. Work is ongoing to examine phase shift approaches in model validation.

The average ETSs (Table 1) for 16 events (40 6-hour periods of interest) were generally slightly higher for the runs using the BMJ scheme than for the KF runs for all precipitation thresholds except the heaviest one (1.0 inch). Skill scores for amounts of

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0.5 inch or greater were very low. The average scores show no improvement from the cold pool scheme in the BMJ runs, with limited improvement for light thresholds in the KF runs. It should be noted that the cold pool results shown here do not include the onion adjustment to humidity above the cold pool layer. When the onion adjustment was used, cold pool skill scores decline, reflecting the adverse affect of the removal of moisture in that layer.

	Precipitation Threshold (inches)				
Run	.01	.10	.25	.50	1.0
BMJ	.180	.172	.101	.050	.007
BMJ-cp	.181	.169	.100	.046	.005
BMJ-mo	.188	.178	.115	.063	.017
BMJ-rh	.197	.189	.123	.061	.020
KF	.172	.150	.082	.043	.020
KF-cp	.177	.154	.082	.043	.020
KF-mo	.169	.147	.093	.055	.026
KF-rh	.195	.173	.102	.061	.027
BMJ-KF	.198	.186	.094	.046	.011
NONE	.122	.099	.060	.026	.005

Table 1. ETSs averaged for 40 forecasts of 6-hr accumulated precipitation for Betts-Miller-Janjic (BMJ) and Kain-Fritsch (KF) runs, with cold pool scheme (cp), mesoscale observations (mo) and increased relative humidity (rh). Alternating of BMJ and KF schemes (BMJ-KF), and use of neither (NONE) also shown.

The addition of mesonet observations results in a somewhat greater improvement in skill scores, particularly for the BMJ runs where all thresholds show increased scores. Scores increase the most for the heavier precipitation thresholds. For most cases examined, the mesonet surface observations depict warmer, more moist conditions than the standard initialization.

These initialization modifications resulted in only modest improvement in ETSs, possibly because the heavy rainfall events in the upper Midwest normally occur late at night or early in the morning, from elevated convection. Any modification primarily impacting only the near-surface layer may have limited ability to improve forecasts of elevated convection. A third modification was performed, to consider adjustments over a deep layer. In this approach, relative humidities at all points where radar echo was present at the initialization time were assumed to be at least 80%, as described earlier. In some ways, this simple adjustment resembles the approach of Rogers et al. (2000) where the convective schemes were forced to activate at points where radar echo was present. The relative humidity adjustment did produce the greatest improvement in ETSs. Additional runs were performed in which the relative humidity adjustment technique was combined with the addition of mesoscale surface observations. This combination tended to improve the BMJ results only slightly more than with the relative humidity adjustment alone, with mixed impact when the KF scheme was used.

Two other tests were performed to investigate additional impacts of the convective schemes. In one test, both convective schemes were alternated, and ETSs tended to be higher for most lighter thresholds than either scheme acting alone, but the skill scores for heavier thresholds tended to reflect more of an average of the two schemes. In the other test, no convective scheme was used. On average, ETSs were much worse, although for some individual cases, the skill scores might actually be better than with convective schemes.

It should be noted that great variability occurred in the ETSs among the cases. For some cases, the BMJ scheme performed much better than the KF scheme, and vice-versa. In some cases, all variations of the model resulted in high ETSs, while in others, all versions had low ETSs. There were individual cases where the cold pool adjustment resulted in more significant improvements in the skill scores, but in many cases, the skill scores declined slightly. An example of the impact of the relative humidity adjustment for a case in which skill scores improved greatly is shown in Fig. 1. In this event, from July 10, 2000, the original BMJ 0-6 hr forecast significantly underestimated rainfall in the region where it was observed. The relative humidity adjustment caused rainfall in this region to increase significantly, with peak amounts accurately reflecting the observed ones. The impact with the KF scheme (not shown) was similar.

Bias scores from the 6-hour periods (Table 2) show that the BMJ runs typically have a high bias for all but the 1.0 inch threshold, while the KF runs have a bias closer to 1 for light or moderate rainfalls, but a high bias for the heavier thresholds. In general, the cold pool scheme lowers the bias. When the onion adjustment was used, the bias values decreased even more strongly. The other adjustments which resulted in larger improvements in ETSs also result in higher bias scores. In most cases, these adjustments cause the bias scores to differ more from the ideal value of 1. Mason (1989) noted that higher skill scores generally occurred with higher biases. Bias scores when no convective scheme is used to tend to be very low (roughly .5) for lighter thresholds, but become very high for heavier amounts (over 3 for 1.0 inch). Thus, the KF runs show trends in the bias that reflect that present when no convective scheme is used. Interestingly, the BMJ trends are nearly opposite.

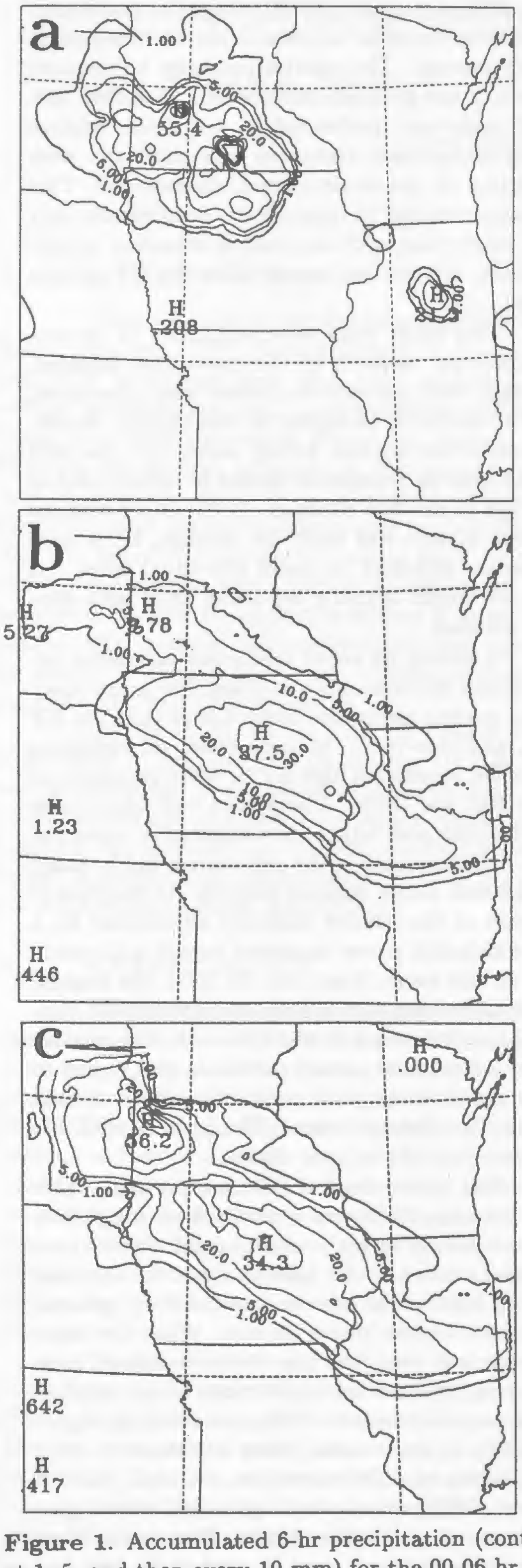

Figure 1. Accumulated 6-hr precipitation (contours at 1, 5, and then every 10 mm) for the 00-06 hr forecast period valid from 00-06 UTC July 10, 2000 from a) observations, b) control BMJ run, and c) BMJ run with humidity adjustment.

In general, none of the methods tested to improve the initialization of mesoscale features consistently changed the control forecast to a large degree. Other tests showed that these adjustments did not change the forecasts much more than what would occur, for instance, when changing a tunable parameter such as the convective time step. Particularly discouraging for forecasting extreme rainfall events was the exceptionally low ETSs for 1.0 inch rainfalls. Even when a 24-hr verification period was used, removing some of the penalty for timing errors, the ETS for 1.0 inch rainfall was generally around .05. The three most extreme events in the sample, with unofficial point rainfalls of 300 mm or more in 24 hours, tended to have skill scores at or below the average for 1.0 inch. The 10 km version of the model generally only underestimated the peak observed rainfall (averaged on to the 10 km grid) by 20-30%, although a great amount of variability was present. The more serious errors are thus likely to involve timing or location of the extreme rainfall.

	Precipitation Threshold (inches)				
Run	.01	.10	.25	.50	1.0
BMJ	1.276	1.392	1.372	1.196	0.5[illegible]
BMJ-cp	1.294	1.443	1.332	1.084	0.568
BMJ-mo	1.313	1.488	1.480	1.485	0.904
BMJ-rh	1.357	1.532	1.496	1.443	1.096
KF	0.922	0.976	1.078	1.294	1.884
KF-cp	0.903	0.949	0.981	1.144	1.615
KF-mo	0.948	1.004	1.142	1.396	2.124
KF-rh	0.960	1.026	1.121	1.291	1.905
BMJ-KF	1.324	1.451	1.283	1.042	.507
NONE	0.529	0.535	0.768	1.251	3.368

Table 2. As in Table 1, but for bias scores.

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 variance in skill scores for the cases examined is generally rather small for the initialization modifications, and is much larger when the convective schemes are switched are not used at all. 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).

A lack of dispersiveness in our ensemble can be inferred by the fact that for many cases, a high probability of rainfall exceeding a certain threshold is computed for some regions, without any rain being observed there. In addition, in some areas where rainfall does occur, none of the 16 variations of the Eta model predict rainfall. This result suggests that even greater variations in the physical parameterizations used might be necessary for more useful ensemble guidance. In addition, it suggests that larger-scale features may be incorrectly depicted in the initialization, and the impact of variations in the larger-scale variables should be investigated.

5. DISCUSSION

Preliminary results suggest that no single technique consistently improves the QPF for these heavy rain events. The addition of mesoscale surface observations seems to have a bigger positive impact than the use of the cold pool scheme, but both techniques generally don't offer as much improvement as that obtained by simply increasing the low and mid-level relative humidity in the vicinity of observed radar echo at initialization time. A surprising amount of variability is present among the cases examined. Further research is underway to determine if specific mesoscale modifications may perform better under a specific subset of larger-scale conditions. In addition, the impact of these adjustments as a function of forecast time is being investigated. 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.

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.

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