Convective system rainfall forecast accuracy as a function of large-scale forcing

William A. Gallus, Jr. and Isidora Jankov
Dept. of Geological and Atmospheric Science, Iowa State University, Ames, IA
email: wgallus@iastate.edu

A 10 km version of the NCEP Eta model has been run over a roughly 1000×1000 km domain centered over the U.S. upper Midwest for 20 warm season mesoscale convective system cases. Simulations were performed using both the Betts-Miller-Janjic (BMJ) and Kain-Fritsch (KF) convective schemes. In addition, both schemes were used in runs initialized with several different techniques to better represent mesoscale features. These techniques included (i) an adjustment to depict cold pools, (ii) inclusion of mesonetwork surface data coupled to a deeper layer through use of the model's own vertical diffusion over a 3 hour assimilation period, and (iii) elimination of layers where relative humidity was less than 80% if radar echo was present. For all of the runs, the rainfall forecasts were examined to determine if accuracy was related to the magnitude of larger-scale forcing and thermodynamics.

To perform the analysis, five parameters (700 mb vertical motion, 200 mb divergence, 500 mb vorticity advection, 850 mb temperature advection, and surface frontogenesis) were averaged over the area within $\sim$ 200 km of the centroid of the convective system during the first 6 hours of the simulation when organized precipitation was observed. The strongest $\sim$ 25% of all events and weakest 25% were identified in all 5 categories. A ranking of 1 was assigned to the weakest forcings and 3 to the strongest, with 2 for the middle 50%. The rankings in all 5 categories were then summed, and the top 25% of the scores were defined to be strongly-forced events, and the lowest 25% of cases weakly-forced. For these "extreme" sets of cases (5 strongly-forced and 5 weakly-forced), average equitable threat (ET) and bias scores were determined for 6-hourly rainfall. The strongly-forced cases were represented by 12 6-hour periods of active rainfall, while the weakly-forced cases were represented by 10. Adjusted ET scores were computed using the technique of Hamill (1999) to equalize bias between the sets of cases.

In both simulations using the BMJ and KF convective schemes, strongly-forced cases earned higher ET scores (Table 1) for most rainfall thresholds. It should be noted that although the bias-equalization adjustment did change most ET scores, the changes were not large enough to affect trends shown in the table. The difference in ET scores between strongly and weakly forced cases was roughly similar when both schemes were used, except at the heaviest threshold where BMJ runs had noticeably higher ET scores for strongly-forced events, but KF runs had similar ET scores regardless of the forcing. In general, weakly forced cases with both schemes had higher biases than strongly-forced events (table not shown). For BMJ runs, the bias of the strongly-forced events was close to 1.0, so that the bias errors (overprediction of rainfall area) were worse with weakly-forced events. For KF runs, strongly-forced events generally had biases less than 1.0, and the bias error was less for the weakly-forced events.

Similar comparisons were performed for upper-level dynamic forcing (represented by 500 mb vorticity advection) and lower-level forcing (represented by surface frontogenesis). ET scores did not differ much between cases with large and small amounts of 500 mb vorticity advection. A larger difference was present when comparing strong frontogenesis cases to weak ones, especially for BMJ runs (not shown). These results may suggest that processes typically resulting in smaller-scale, more intense upward motion, such as frontogenesis, play a greater role in influencing the accuracy of warm season convective rainfall forecasts than quasi-geostrophic forcing mechanisms such as 500 mb vorticity advection.

	Precipitation Threshold (mm)				
Model&Forcing	.254	2.54	6.35	12.7	25.4
BMJ-strong	.293	.276	.245	.180	.111
BMJ-weak	.206	.164	.138	.100	.015
KF-strong	.302	.285	.280	.185	.060
KF-weak	.216	.173	.148	.111	.067

Table 1: Adjusted ET scores (to equalize bias) averaged for strongly and weakly forced cases for simulations using the BMJ and KF schemes.

Forecast accuracy as a function of several thermodynamic parameters was also evaluated. In BMJ runs, ET scores did not vary much between cases with large and small (relative to initialization time average) convective available potential energy (CAPE). However, with KF, ET scores were much higher when CAPE was larger. For both schemes, cases with small convective inhibition (CIN) earned higher ET scores than those with large CIN for lighter rainfall thresholds, but differed little for heavier rainfall. ET scores did not differ much between cases with high and low 1000-500 mb relative humidity or precipitable water.

The impacts of the initialization adjustments as a function of large-scale forcing was also examined. The cold pool adjustment had little impact regardless of the forcing magnitude. The inclusion of mesoscale observations improved unadjusted ET scores, but primarily when forcing was strong. This result was disappointing since it was hoped weakly forced events would benefit more by having better representation of mesoscale details. The relative humidity-radar echo adjustment improved unadjusted ET scores for both strongly- and weakly-forced events when the BMJ scheme was used, but only for strong events when the KF scheme was used. With BMJ, improvement in the weakly-forced cases was comparable to that of the strong ones for light thresholds, suggesting that although mesoscale details are important in model initialization, the more positive impact occurs when the details are provided through a deep atmospheric layer. Boundary layer information alone may not help the rainfall forecast much.

In summary, we have found from a rather large sample of cases that model forecasts of warm season rainfall are more accurate when large-scale forcing is strong. The accuracy is more sensitive to low-level forcing mechanisms (such as surface frontogenesis) than forcing at upper levels (e.g., 500 mb vorticity advection). More accurate forecasts are also likely when CAPE is large, not small, if the KF scheme is used, but little difference occurs when the BMJ scheme is used. Small CIN values favor better accuracy than large values for lighter thresholds, but CIN does not strongly influence ET scores for heavier rainfall amounts.

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References

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