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WRF MODEL EVALUATION AT THE SPC AND NSSL

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1. INTRODUCTION

The new Weather Research and Forecasting (WRF) model is under continued development and may eventually become the primary 1-3 day operational numerical weather prediction model in this country (Skamarock et al. 2001). This model is designed for optimal configuration with grid spacing from 1 to 10 km. Thus, it has the potential to provide unprecendented mesoscale detail in its numerical forecasts. Yet, it is not clear how we might best take advantage of the potential capabilities of the WRF modeling system. At the Storm Prediction Center (SPC), National Severe Storms Laboratory (NSSL), and University of Oklahoma we have been evaluating the WRF model so that the needs of operational forecasters are considered during the course of model development and the design of model output presentation.

Forecasters at the SPC are responsible for issuing severe weather and general thunderstorm outlooks, tornado and severe thunderstorm watches, and short-term mesoscale guidance products for severe thunderstorms, heavy rain, heavy snow, and freezing precipitation. Since their forecast domain covers the entire lower 48 states, SPC forecasters must monitor and predict hazardous weather nearly every day, yet their forecast challenges are almost exclusively within the realm of mesoscale phenomena. They have exceptional insight into forecasting mesoscale and storm-scale processes and can provide valuable feedback to WRF model developers.

WRF model output has been evaluated systematically as part of the 2002 SPC/NSSL Spring Program, which was conducted in coordination with the IHOP field program. Model strengths and weaknesses have been identified and compared to other operational models (*i.e.*, Eta and RUC) within the same evaluation framework. Results from this evaluation and recommendations for continued WRF development will be presented at the conference.

For this paper, we provide a brief overview of a very successful realtime WRF forecast. In particular, we focus on a case in which WRF forecasts were considerably better than those from two different configurations of the Eta. We speculate on the reasons for this improvement and provide additional discussion.

2. OBSERVATIONS AND RESULTS

During the late afternoon of 11 June 2001 a mesoscale convective system formed along the eastern border of the Dakotas. This system developed a prominent bow echo and produced a broad swath of wind damage as it propagated into Minnesota and raced southeastward across southern Wisconsin (Fig. 1). During its mature stage, radar images revealed a prominent high-reflectivity bow structure on its leading edge and a large region of moderately high reflectively trailing to the north and northwest (Fig. 2).

Forecasters at the SPC received guidance for the prediction of this system from both the operational Eta model (Black 1994), utilizing the Betts-Miller-Janjic convective parameterization (Janjic 1994 - hereafter BMJ), and an experimental version of the Eta (hereafter EtaKF) using the Kain-Fritsch convective scheme (Kain et al. 2002a - hereafter KF), among other model guidance. Both the Eta and the EtaKF struggled in their prediction of this system. Although convective activity initiated in central Minnesota in both models, in close agreement with reality, the forecasted MCS moved southward in the Eta (Fig. 3a) and eastward in the EtaKF

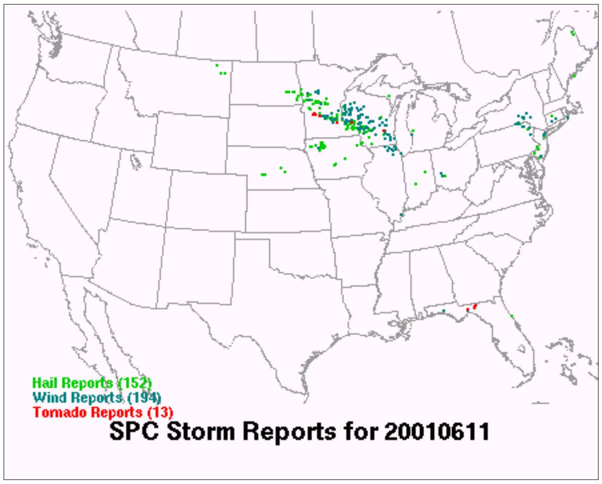

Fig. 1. Local storm reports for the 24 h period ending 1200 UTC 12 June 2001.

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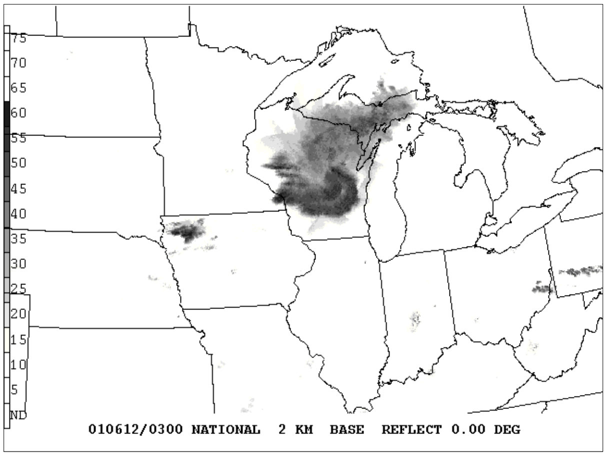

Fig. 2. Maximum base reflectivity (dBz, 0.5^{o} elevation) during the previous hour from the WSR-88D national mosaic, valid 0300 UTC 12 June 2001.

(Fig. 3b), whereas the observed system propagated to the southeast (Fig. 2).

Close examination of the two model forecasts reveals a pattern of behavior (and meteorological conditions) quite similar to that described for another warm-season bow-echo environment (Kain et al. 2001). Consider the operational Eta first. Based on our analysis of this previous case, the similarities between the two, and a preliminary diagnosis of this event, it appears that the BMJ convective parameterization creates a deep, elevated cold pocket over a mesoscale area during the formative stages of the simulated convective system (see Kain et al. 2001 for a more detailed explanation). As this cold anomaly begins to sink, divergence is induced underneath and low-level convergence is enhanced in surrounding areas, particularly in those regions where low-level inflow is already strong. This process promotes subsequent convective activity in peripheral areas where inflow is maximized. As a result, the BMJ scheme effectively induces a significant propagation of convective activity into the low-level flow. In this case, there was a pronounced southerly low-level jet and the most intense and persistent parameterized convection propagated almost due southward in the Eta (Fig. 3a). Nearly all precipitation associated with the predicted system was generated by the BMJ scheme, with very little coming from grid-scale microphysical processes.

In the EtaKF forecast, the system progressed to the east. As described in Kain et al. (2001) the KF scheme struggles to maintain convective activity in this type of environment, where instability is elevated. When and where the scheme does activate, it creates only a relatively shallow cold pool that is in contact with the ground. This cold pool appears to be relatively ineffective at enhancing convergence in the *deep* low-level inflow. Since parameterized stabilizing effects are sporadic, the environment slowly destabilizes and moistens. Eventually, saturation occurs in an unstable environment and latent heat feedbacks create a mesoscale "bulls-eye" in vertical motion and grid-resolved precipitation. This feature moves downstream (eastward) with the mid-level flow and creates a strip of heavy precipitation to the north and east (downstream) of its observed location. There is little, if any, system propagation into the low-level inflow and the heaviest precipitation is associated with strong upward motion and condensation on resolved (rather than parameterized) scales (Fig. 3b).

This system was also simulated using the WRF model with the same two convective parameterizations. Initial conditions were for these simulations came from the Eta model and grid spacing was fixed at 34 km (compared to 22 km with the Eta/EtaKF) These runs used the NCEP 3-class microphysical parameterization (Hong et al. 1998) and the MRF boundary layer parameterization (Hong and Pan 1996).

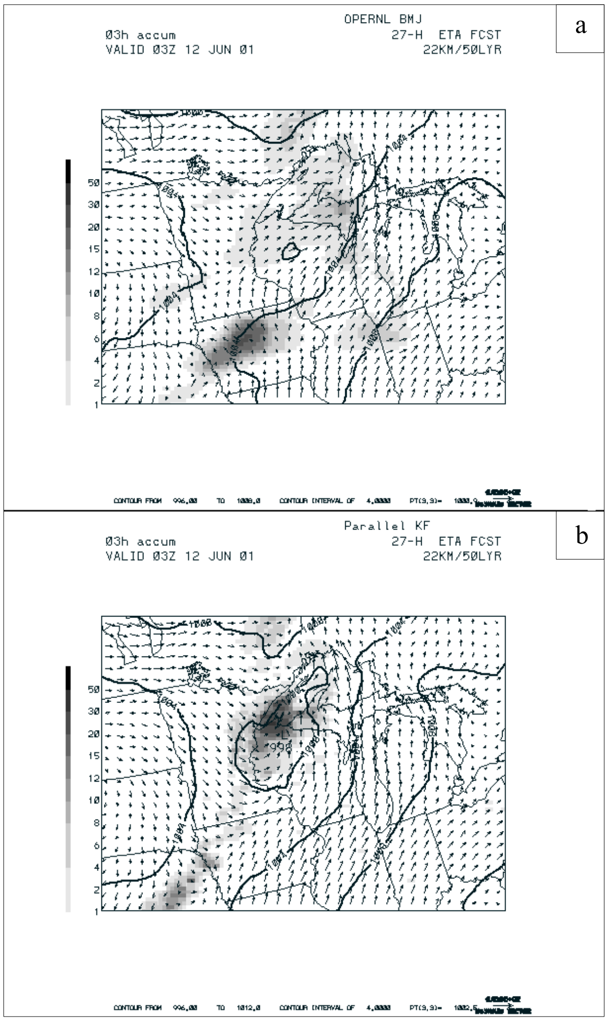

Fig. 3. Accumulated 3 h precipitation totals for the period ending 0300 UTC 12 June 2001 from the a) operational Eta model and b) EtaKF model. Both forecasts were initialized 27 h earlier, 0000 UTC 11 June 2001.

The WRF model generated a much more realistic evolution of the MCS, regardless of which convective parameterization was used. In particular, both runs produced a system with intense precipitation in a comma-like configuration that propagated through southern Wisconsin at about the right time (Figs. 4a and b). Note the strongly divergent flow in east-central Wisconsin in both simulations, as one would expect beneath the "stratiform" region in a bow echo.

The WRF-BMJ run produced a much higher fraction of grid-resolved precipitation than the operational Eta forecast, which was dominated by parameterized rainfall. On the other hand, the excessive grid-scale precipitation generated in the EtaKF forecast was moderated considerably in the WRF-KF. Thus, both WRF runs appeared to produce a more realistic partitioning between grid-resolved and parameterized precipitation than either forecast with the Eta.

A complete understanding of the differences in these forecasts will require a detailed analysis. However, we speculate that the more sophisticated microphysical parameterization used in the WRF runs is the critical difference in these simulations. The microphysical parameterization used in the Eta model at the time of this event was relatively crude. In particular, it prognosed cloud water and ice, but it contained no prognostic equations for precipitation-sized hydrometeors, such as rain, snow and graupel. In contrast, the NCEP 3-class microphysics package explicitly predicts the evolution of the three-dimensional precipitation field as rain or snow, depending on temperature. Previous studies have shown that explicit predictions of this type can be critically important for numerical prediction of convective systems (e.g., Zhang et al. 1988).

It is also noteworthy that additional WRF model simulations were carried out using the "Purdue Lin" microphysics package (http://www.mmm.ucar.edu/wrf/users/wrf_phy.html#physics_scheme) with both the BMJ and KF schemes. This is a considerably more sophisticated scheme, but its internal parameters are set for high resolution, cloud-resolving simulations, whereas the NCEP 3-class is tuned for mesoscale resolution. Interestingly, the Purdue Lin runs produced structures that more closely resembled Eta model forecasts than the NCEP 3-class runs of the WRF (not shown), confirming the extreme sensitivity to the microphysical parameterization in this case.

Obviously, these results are very preliminary and their interpretation involves considerable speculation. They provide motivation for a more detailed examination of the different behaviors of the Eta and WRF models, particularly with regard to the role of model physics in the simulation of mesoscale convective systems.

Precipitation skill scores collected over the past year suggest that the Eta model is currently outperforming the WRF on average, but it is encouraging to see that the new WRF model provides much better forecasts in some situations. The challenge for us is to develop a better understanding of the physical mechanisms that are operative in producing these differences.

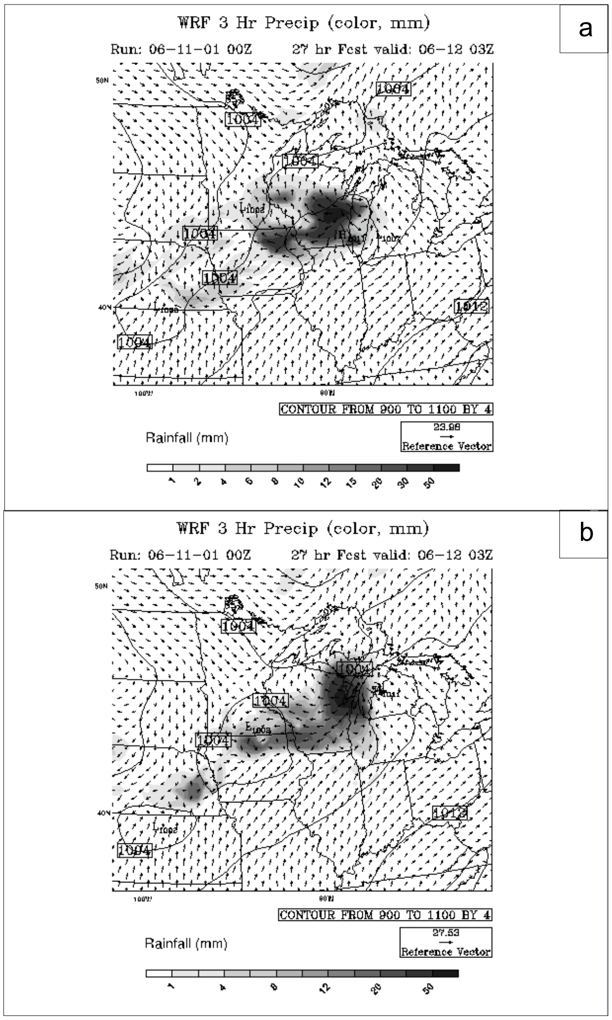

Fig. 4. As in Fig. 3, except that the WRF model is used instead of the Eta model, with the a) BMJ and b) KF convective parameterizations.

3. SUMMARY

The WRF model is under development and may eventually replace the Eta as the primary 1-3 day numerical forecast product in this country. We believe that this model will be assured a much higher probability of operational success (value to the forecasting community) if operational forecasters become involved in the WRF development at the relatively early stage. Thus, we are examining the WRF model in an operational forecasting setting at the Storm Prediction Center (SPC), where higher resolution forecasts could be particularly beneficial. Forecasters are being encouraged to provide feedback on their impressions of WRF model performance and utility so that any operational form of the model will be responsive to the needs of operational forecasters.

Preliminary comparisons with the Eta model, based on equitable threat scores compiled over the last year, give a slight advantage to the Eta. However, the WRF model significantly outperforms the Eta on some days, as demonstrated herein. Furthermore, many aspects of the WRF are still under development, inspiring optimism that model performance will continue to improve as development matures.

During a six-week period in the late spring of 2002, the WRF model was included in a systematic subjective verification of operational and experimental models that was conducted in association with IHOP (http://www.spc.noaa.gov/exper/Spring_2002/). Subjective evaluation procedures at the SPC and NSSL are designed to measure the value of model forecasts to operational forecasters. These measures are inherently different from traditional objective verification metrics and can provide key information that is lacking in objective strategies (Kain et al. 2002b - this volume). Results from this subjective verification, focusing on comparison with other operational and experimental numerical models, will be shown at the conference.

Acknowledgements

This work was supported by COMET Cooperative Project S01-32796.

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