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An ensemble of WRF and MM5 configurations for winter weather forecasting

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1. INTRODUCTION

In 1999 the Federal Highways Administration (FHWA) initiated a 5-year program to explore the applicability of technologies developed at national research laboratories to the problem of winter road maintenance. The first specific goal was to develop an automated decision support system to generate snow plowing and pavement chemical application guidance for use by state departments of transportation. The project, and the system, were named the Maintenance Decision Support System (Mahoney and Myers 2003).

A block diagram of MDSS is shown in Figure 1. The gridded outputs from an ensemble of mesoscale model forecasts generated by the NOAA Forecast Systems Laboratory (FSL) are transmitted in real time to the National Center for Atmospheric Research Research Applications Laboratory. There, the FSL models are ingested along with the models produced by the National Weather Service's National Center for Environmental Prediction (NCEP), namely the Eta and Aviation (AVN) models, into the Road Weather Forecast System (RWFS). RWFS uses dynamic model output statistics (DMOS) techniques to optimize forecasts of temperature, wind, humidity, insolation, and precipitation for several dozen prediction points along targeted roadways. Most of these prediction points correspond to the locations of Road Weather Information Systems (RWIS) of automated sensors that provide verification for the RWFS forecasts. The point forecasts generated by RWFS are used to inform pavement temperature and chemical concentration modules developed by the Cold Regions Research and Engineering Laboratory (CRREL). The pavement condition predictions are used with encoded rules of practice, developed by the Massachusetts Institute of Technology Lincoln Laboratories (MIT/LL), to suggest plowing and chemical applications strategies (e.g., "plow Highway 10 three times between midnight and 6 AM and spread 150 lbs of salt per lane mile"). Finally, the weather and guidance information is transmitted to a graphical user interface running on personal computers in the offices of snowplow garage supervisors.

2. THE 2002-2003 DEMONSTRATION

For the 2002-2003 MDSS demonstration the FSL model ensemble consisted of three different mesoscale models: MM5 (Grell et al. 1995), WRF (Michelakes et al. 2001), and RAMS (Pielke et al. 1992), configured with nearly identical grids and projections. Lateral boundaries were provided by two different large-scale models (Eta and AVN, as provided by the NWS National Center for Environmental Prediction), for a total of six members. The mesoscale models runs were started following receipt of the NCEP model grids, which at the time were provided four times daily. Each ensemble member was initialized using the LAPS hot-start method of diabatic initialization (McGinley and Smart 2001; Schultz and Albers 2001; Shaw et al. 2001) at 0300, 0900, 1500, and 2100 UTC (3 AM, 9 AM, 3 PM, and 9 PM CST). The models were run out to 27 hours, to provide a 24-hr forecast service.

The deviations between configurations that are different only in the lateral bound models are very small compared to deviations among configurations with different mesoscale models. This conclusion is somewhat disappointing from the perspective of building a robust ensemble, because it is likely that such model pairs are making the same errors and thus add little dispersion to the ensemble. Figure 2 shows six 27-hour run-total precipitation accumulation images for the same case. The top row contains MM5 results, the middle row is WRF, and the bottom row is RAMS. The left column contains results from models that used Eta lateral boundary conditions, the right column is AVN. Clearly, each model run from a given mesoscale model is quite similar to its counterpart with other lateral boundaries. The variety of "opinions" coming from the various mesoscale models is the dispersion we seek for a well-designed ensemble modeling system; the lack of variety contributed by different LBC

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models is the reason we changed the ensemble for the next MDSS demonstration.

3. THE 2003-2004 DEMONSTRATION

Changes to the ensemble modeling system were made prior to the 2003-2004 demonstration in response to verification statistics and practical experience during the prior 2002-2003 demonstration. The verification effort suggested that the RAMS model runs added less value to the ensemble than the MM5 and WRF model runs, and that lateral boundary conditions were adding little diversity. Field experience with the forecasting services suggested that the local models' were adding value mainly in the first 12 hours of the forecast, and the users were displeased with the fact that sometimes the system predictions made large changes when a new set of model runs were provided, which occurred every six hours. Thus, the reconfigured ensemble used two models (MM5 and WRF), both using the same model (Eta, mostly because its grids were available almost an hour earlier than AVN) for lateral boundary conditions, both models reinitialized every hour and run out to 15 hours. The Eta lateral boundaries were time-interpolated for mesoscale model runs not coincident with Eta model runs. QPF verification skill statistics are presented in Figure 3.

This ensemble configuration takes advantage of frequently-updated radar and satellite data, which are the most important inputs for diabatic initialization because of their impact on the specification of cloud parameters. The previous configuration took much less advantage of initialization-related dispersion, since new initializations were performed only every six hours. The current configuration also allows for reduced latency in forecast updates, since fresh information is provided every hour. Whereas, in the previous configuration, forecast information could be as much as seven hours old during certain times of the day, in the current configuration new forecasts arrive each hour, and the complete forecast runs are never more than two hours old. The current configuration also allows for the application of time-lagged ensembling techniques (e.g., Brankovic et al. 1990), in which the production of, say, a four-hour ensemble prediction uses the current four-hour forecast, the previous five-hour forecast, and the six-hour forecast from the cycle before that, etc. This would seem to violate the requirement that all ensemble members are equally skillful, since forecast decreases with lead time, but the earlier forecasts do add value to the final result, and the ensemble forecasts benefit from temporal consistency resulting from hour-to-hour (weighted) averaging of the ensemble members. Figure 4 shows how 1-h QPF skill scores for the 0.01" threshold fall off with lead time.

4. REFERENCES

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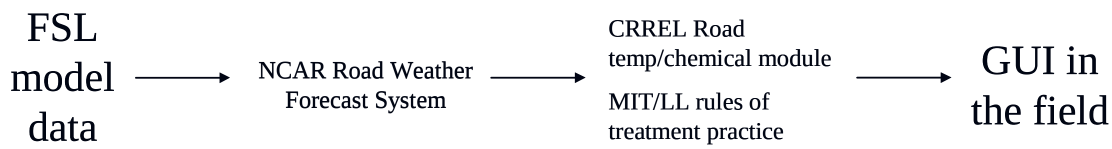

Figure 1. The components of MDSS, and the laboratories that contributed them.

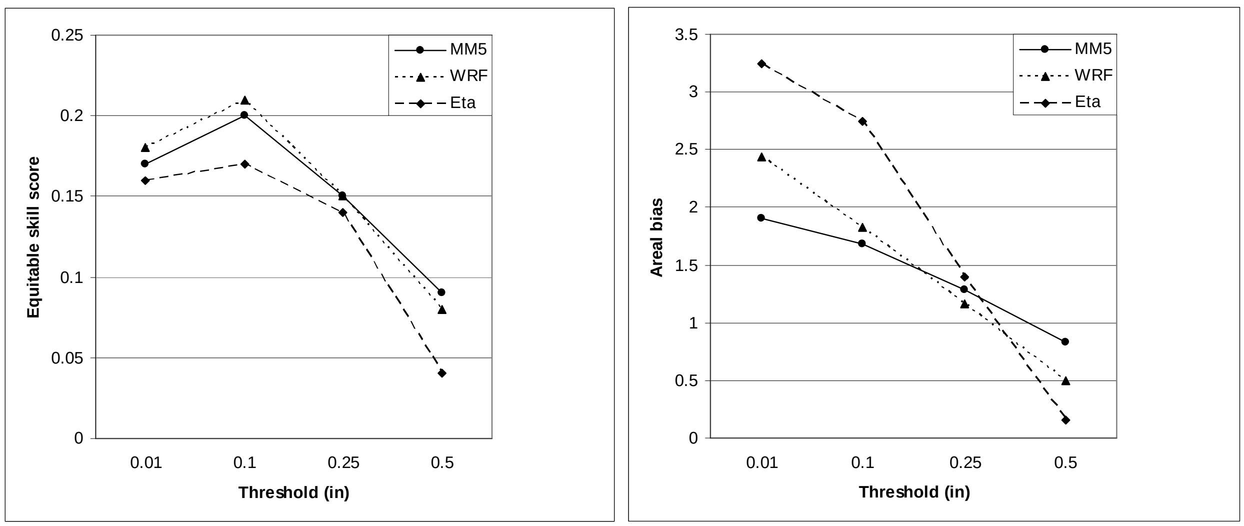

Figure 3. Verification statistics for 3-h precipitation forecasts from the 2002-2003 MDSS ensemble. Equitable skill scores (left) and areal bias (right).

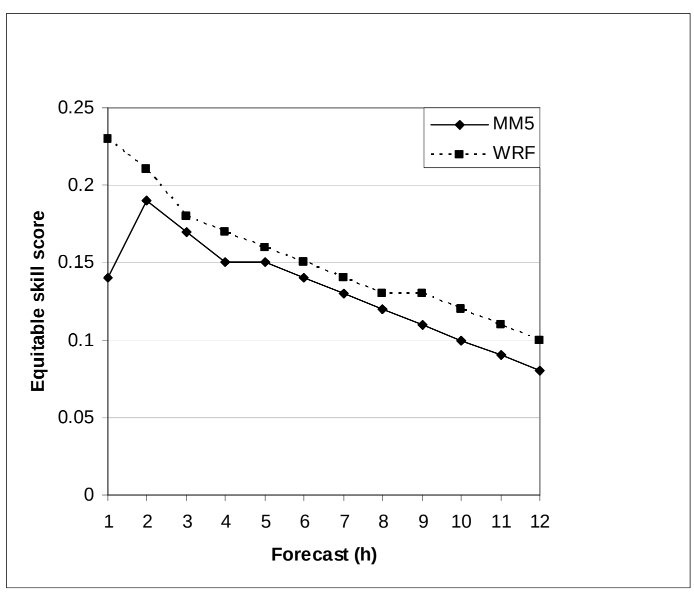

Figure 4. 1-hr QPF=.01" equitable skill scores during the 2003-2004 MDSS demonstration. The curve for the WRF model indicates that QPF "spin-up" is addressed by the LAPS hot-start method for diabatic initialization. There was an error in the initialization processing that led to the low ESS value in the 1-h MM5 QPF; verification from other experiments (not shown) indicate success similar to the WRF results in the first hour of QPF forecasting by MM5.

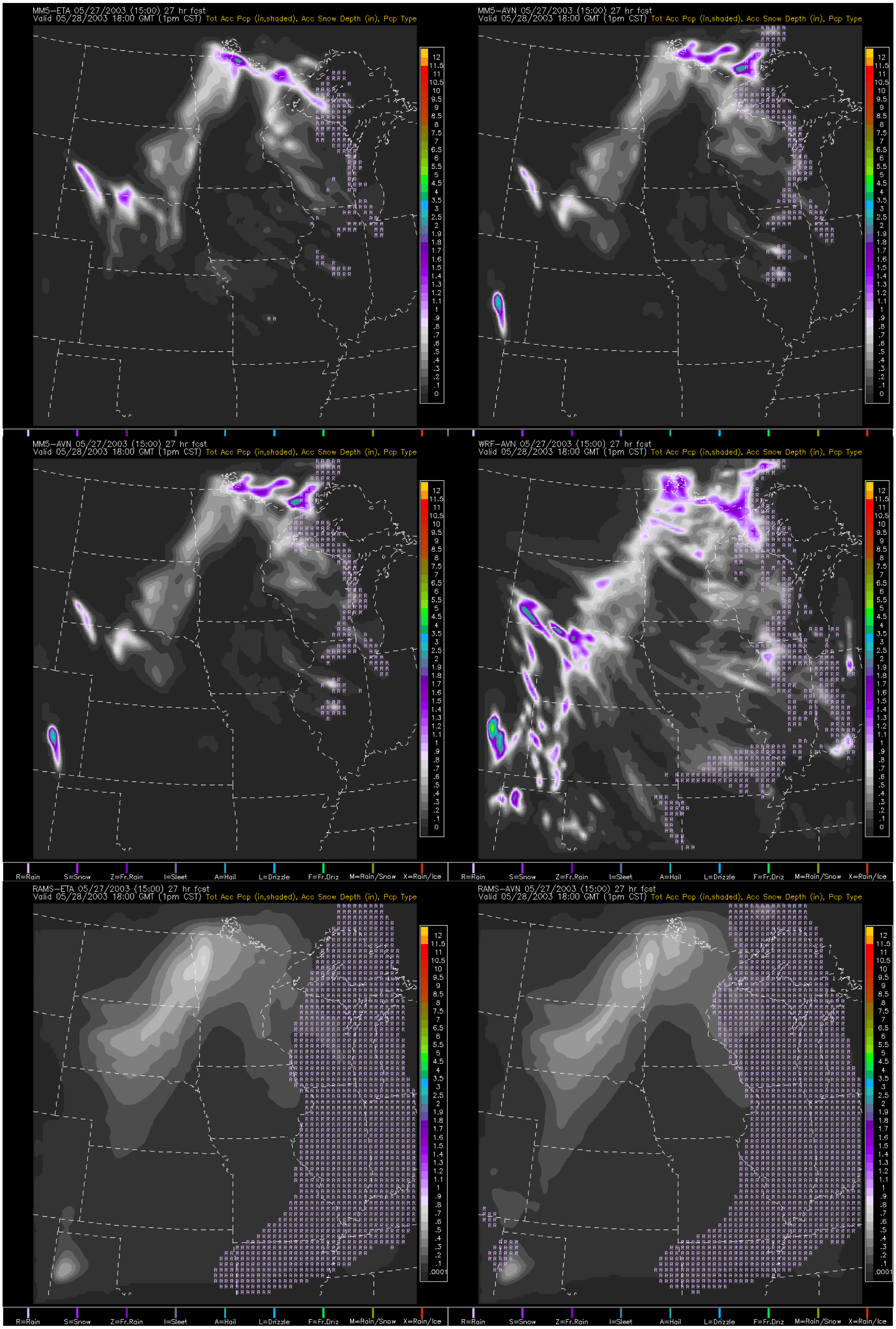

Figure 2. 27-h precipitation accumulation forecasts, all valid at the same time, from three different models (MM5 top row, WRF middle row, and RAMS bottom row) using two different models for lateral boundary conditions (Eta left column, AVN right column). The contour images are accumulated precipitation; text icons are plotted at grid points with precipitation occuring at the valid time.