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Using ensembles of numerical weather forecasts for road weather prediction

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1. INTRODUCTION

The NOAA Forecast Systems Laboratory is one of six laboratories contributing to the development of the Maintenance Decision Support System (MDSS, Mahoney 2001). The MDSS uses weather observations, statistics, and numerical models to make automated point-specific weather forecasts for key points along roadways. The weather forecast information is used by road-condition algorithms, graphical displays, and other tools that help state departments of transportation decide how best to deploy snowplows and road treatments. Although the focus of the MDSS project is winter weather problems, the MDSS approach to providing tailored point weather forecasts is intended to be more broadly applicable.

FSL's role in MDSS is providing a variety of very-high-resolution forecasts from multiple locally-configured mesoscale models such as RAMS, MM5, WRF, and ARPS. The premise behind running an ensemble of models is as follows: given an imperfectly-observed predictand (the atmosphere in this case), it is in principle possible to combine multiple predictions so that the ensemble forecast is superior to any single prediction included in the ensemble. This assumes that each of the predictions is equally likely to be closest to "reality", and that the forecast errors among the models are uncorrelated, two assumptions that are typically not valid in most ensemble modeling systems. Still, there have been notable successes in ensemble weather forecasting.

Two aspects of this activity are new to the relatively young science of ensemble NWP (numerical weather prediction). First, these model forecasts are computed and provided at very high resolution, compared to previous and current ensemble modeling systems. Over the target forecast area the MDSS ensemble members will be computed and produced on 4-km grids. By comparison, the Short Range Ensemble Forecast system at NWS/EMC is running at 30-km resolution. Second, the emphasis of this modeling system is best-possible point forecasts (i.e., along roadways), whereas whole-grid verification is usually emphasized by other ensemble modeling communities. Implications of resolution and point-forecasting practices are discussed in section 3.

2. REVIEW

As stated earlier, it is difficult in practice to create an ensemble composed of totally independent forecasts. One early landmark study on ensemble modeling (Leith 1974) conceived the approach as consisting of forecasts made by slightly perturbed initial conditions for a single forecast model. Of course, this assumes that the model has no systematic errors, which is untrue for any model. Other ways have since been tested for achieving the goal of *dispersion* among the ensemble members. For example, Stensrud et al. (2000) describe experiments in which some ensemble members consisted of models using various combinations of methods for parameterizing precipitation and surface fluxes, while other ensemble members consisted of models given realistically perturbed initial conditions. Hou et al. (2001) report the results from an ensemble system composed of various continental-domain models each receiving lateral boundary updates from various global-domain models.

Obviously, ensemble forecasting requires large computing resources, so choices must be made as to the optimum number of ensemble members and what those members will be to achieve the desired dispersion. Du et al. (1997) state that for precipitation forecasting, most of the improvement

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obtainable by ensemble forecasting can be had using 8-10 members. If the key predictand of the ensemble system is cyclogenesis, Stensrud et al. (1999) suggest that variously perturbed initializations give good dispersion and ensemble forecast results. On the other hand, for precipitation forecasts, Stensrud et al. (2000) show that an ensemble consisting of various physical parameterizations gave better results than an ensemble of perturbed initializations. Thus, there are several ways of adding variety to an ensemble, any of which may be most beneficial depending on the targeted forecast problem.

For the MDSS project, precipitation and precipitation type forecasts are of great importance, so various cloud/precipitation physics parameterizations are included; i.e., Reisner et al. (1998) in WRF, Schultz (1995) in MM5, and Walko et al. (1995) in RAMS. Furthermore, since the forecast domain is small enough (approximately 400-km square) that the air in the domain will be completely replaced one or more times during the integration time (48 h), the mesoscale models are provided lateral boundaries by three different large-scale models (AVN, Eta, and RUC). For the time being, there is no competitive alternative to initializing the models with LAPS hot start (Albers et al., 1996; Shaw et al., 2001), in which clouds and precipitation processes are present in the intialization. Other approaches require several forecast hours to create useful cloud/precipitation fields, or take too much computing resources to be used in real time.

3. PRACTICAL CONSIDERATIONS

Spatial resolution vs multiple forecasts. The geometric growth of computer resources required with increasing grid resolution forces tradeoffs between the benefits of better physical representation of atmospheric processes and the benefits of ensemble modeling discussed above. For example, the compute cycles required to produce a single 6-h forecast on a 10-km grid are sufficient for eight 6-h forecasts on a 20-km grid. Higher resolution captures important terrain-related flow features and precipitation maxima, which are critical for road weather problems, but these same details are difficult to verify with traditional objective methods such as threat scores and RMSEs. For example, a snow band 25 km wide and 200 km long could be perfectly replicated but displaced by two or three gridpoints, in which case the traditional skill scores would indicate zero or even negative skill. Verification (or postprocessing) problems and the tradeoffs between spatial resolution and probabilistic resolution are two key scientific issues of the MDSS modeling component.

Point forecasts and areal forecasts. Most of the ensemble modeling studies to date, including those cited above, evaluate forecasts with equal emphasis on all grid points. For example, Stensrud et al. (1999) compute mean and RMSE of basic fields such as 500 mb geopotential height, and cyclone position errors. Thus, the forecast performance at a particular point in the domain is reduced to two statistical moments. However, some key predictands exhibit more complex behavior than can be conveyed by mean and RMSE statistics. For example, nighttime temperature minima at many low spots along roadways are distinctly bi-modal; i.e., if the winds are calm and the sky is clear the temperatures are likely to be 10 or more Celsius degrees colder than they would be in windy or cloudy conditions. For another example, although the winds in the lee of a mountain barrier are usually downslope, they can sometimes blow *upslope* in certain combinations of shear and static stability that support rotor structures, which are typically unresolved. For point forecasting applications, it is practical to save the entire joint distribution of forecasts and verifying observations, since this is a relatively small volume of data, even for hundreds of forecast points, which would allow for reasonable probabilities of important but infrequent events. This is not practical for whole-grid forecasting systems, because complete model forecasts require very large on-line storage. Exploitation of the full range of historical forecast/observation information is another key scientific issue for the MDSS project.

4. CONCLUSION

At this point (October 2001) FSL's ensemble modeling system is under construction. Two mesoscale models have been configured to run with lateral bounds from three different larger-scale models, for a total of six members. A third mesoscale model, the WRF, will probably be ready in time for presentation at the Conference. These models will run at 12-km resolution over an area roughly 1000 km on a side, centered on Minnesota, but at least two of the model runs will also have 4-km nests centered on the Minneapolis metropolitan area. This allows us to examine the benefits of both the ensemble approach and the high-resolution approach.

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