JP1.29 EFFECTIVE USE OF REGIONAL ENSEMBLE DATA IN FORECASTING

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1. Introduction

During the winters of 1999-2000 and 2000-2001, several storms affected the East Coast of the United States. Many of these storms were not well forecast in one or more of the major metropolitan areas from Raleigh, NC to Boston, MA. One potential reason for the poor forecasts may have been the reliance on a single deterministic model to determine the outcome of the event. Realizing that some locations were well forecast while others were poorly forecast poses a serious challenge to weather forecasters on how to improve the forecast process and perception of these forecasts. It will be shown that the 3 December 2000 East Coast snowstorm was a good example why forecasters should not rely exclusively on any single deterministic forecast.

The use of multiple models in arriving at a forecast can overcome the limitations that any single model may have. However, diagnosis of model forecasts has been reduced to ***a model of the day concept*** where forecasters attempt to evaluate and determine which model might perform better for a specific event. With all the uncertainty in weather forecasting, picking a model of the day is a difficult task. Fritsch et al. (2000) showed that a consensus of the Nested Grid (NGM), stepped terrain (ETA), and aviation run of the global spectral (AVN) models was typically better than any single model when compared to surrounding rawinsondes. Furthermore, the Eta and AVN showed about equal chances of being the correct model on any single day. Therefore**, synthesizing *rather than excluding various models is preferred*.**

A better way to overcome the uncertainty in weather forecasts is to use an ensemble of models (Toth 1998). Ideally, the ensemble would consist of models of equal skill but with differing model physics with additional runs of each ensemble member based on different initial conditions. The ensemble could then be used to quantify the *uncertainty or certainty* in the forecasts.

For short-term forecast problems (0-2 days), NCEP has developed a Short-Range Ensemble Forecasting System (SREF: Du and Tracton 2001; Tracton and Du 2001). The current SREF has two models, including the Eta and the regional spectral model (RSM). Five model runs were available for each model including a control run and 4 perturbed runs. NCEP plans to add more members to its SREF system in 2002.

In this paper, forecasts from the winter storm of 3 December 2000 are presented showing how the two operational NCEP models performed and how the SREF data could have been used to improve the forecast process. The goals of this paper include methods to display ensemble data for operational use; how to use ensembles effectively in the forecast process; and why it's imperative to consider ensemble data relative to a single deterministic solution in all weather forecasts. Proper use of ensembles could lead to better forecasts of major winter storms.

2. Method

2.1 Data

SREF Ensemble data were made available to the authors from NCEP after the event. These data were available in near real-time at NCEP but were not accessible to non-NCEP users. The SREF data in this study include output from 1200 UTC 1 December through 12 UTC 2 December 2000. Only examples from 0000 UTC 2 December are shown here. A full set of Eta and RSM members were available for each forecast time. The 10-member SREF suite used included 5 Eta and 5 RSM members. For each model, there was a control run and 2 positively and 2 negatively perturbed members (Toth and Kalnay 1997).

2.2 Ensemble displays

Ensemble data display techniques used in this paper include the traditional spaghetti plots (Sivillo et al. 1997), probabilistic displays, and consensus or

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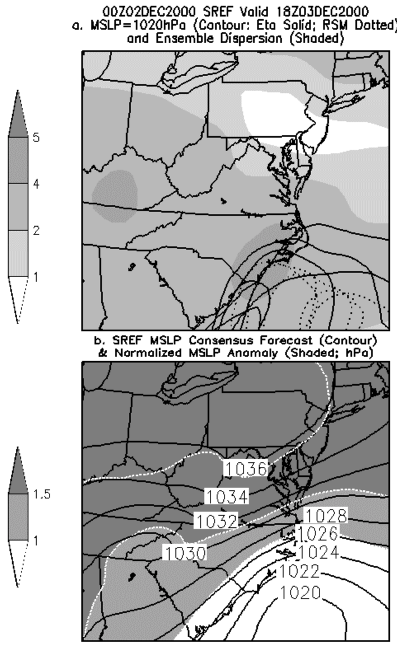

Figure 1. SREF forecasts initialized at 0000 UTC 2 December 2000 valid at 1800 UTC 3 December 2000. Data shown in upper panel include the individual Eta (solid) and RSM (dotted) position of the 1020 hPa isobar and dispersion about the mean (shaded). Lower panel includes the consensus MSLP forecast (hPa) contoured every 2 hPa and the departure of this field from the 30-year Climatological means. Departures are standard deviations from normal. Shaded values are as depicted by the color bars to the left of each panel.

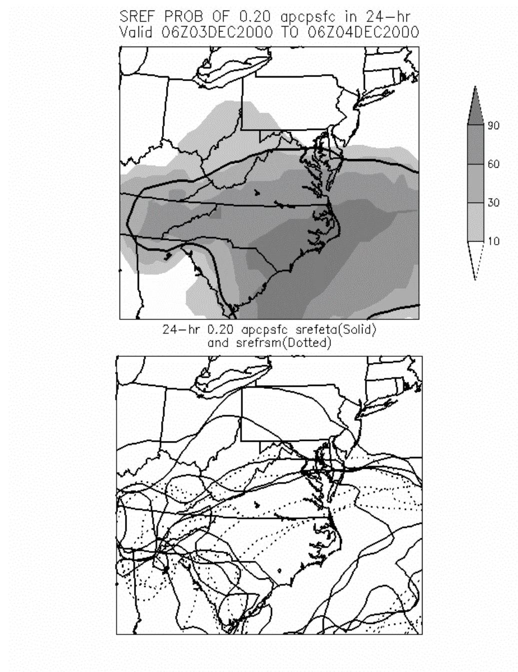

Figure 2. SREF forecasts initialized 0000 UTC 2 December 20000 of 5 mm of QPF for the 24-hour period from 0600 UTC 3 December through 0600 UTC 4 December 2000. Upper panel shows the probability of occurrence (shaded) and the consensus position of the 5 mm contour. Lower panel is the spaghetti plot from each ensemble member.

ensemble means forecasts. Each display technique has its own individual strengths and limitations. Therefore, combinations of techniques are used to present a clearer picture of the potential outcome.

Probabilistic forecasts were computed for accumulated precipitation thresholds and subfreezing 850 hPa temperatures. These data were displayed using shading to show the simple percentage of the time the SREF member met or exceeded the specified value. For example, if 7 of 10 SREF members predict 12.5 mm of rainfall or greater at a point, that point would be displayed as 70%.

3. Results

3.1 Case overview

A large anticyclone and unseasonably cold air covered the eastern United States during most of the first week of December 2000. A short wave moving over this cold air was forecast to produce a storm along the East Coast on 3 and 4 December. The developing storm and the large anticyclone to the north produced ideal conditions for an early season snowfall. Locally heavy snow was observed (not shown) in eastern North Carolina and extreme southeastern Virginia. Areas of both central Virginia and North Carolina received no significant snowfall, despite heavy snowfall forecasts in the ***operational*** Eta and AVN models.

3.2 SREF displays

The forecast of the MSLP from the 0000 UTC 02 December 2000 SREF's valid at 1800 UTC 3 December are shown in Figure 1. Similar to forecasts from 1 December (not shown), the SREF mean forecast showed a surface cyclone off the North Carolina coast. However, in this run, the surface cyclone position had shifted noticeably farther to the south than the forecasts from 12 hours earlier. There was a marked decrease in the overall area of 4-8 hPa of dispersion in the pressure field, consistent with the variability in the forecast cyclone location and intensity. The error was focused near the region of concern, in eastern North Carolina.

The probability of 5-mm (0.2 inches) of QPF valid for the 24-hour period from 0600 UTC 3 to 0600 UTC 4 December 2000 is shown in Figure 2. The 5 mm contour was chosen since it represents winter weather advisory category for snow over most of the region in question when using a 10:1 liquid equivalent snow ratio. Figure 2 reveals several interesting aspects of the event. First, the Eta and RSM solutions were divergent, with the Eta solutions producing more QPF to the north of the RSM QPF field. Second, the 90% probability contour was confined to extreme eastern North Carolina. Finally, the consensus forecast, normally considered to be the most skillful forecast (Fritsch et al 2000), followed the relatively low confidence 30 percent probability contour.

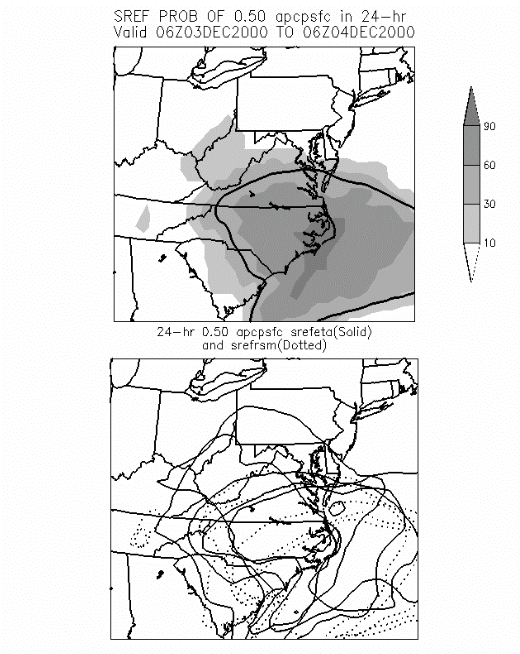

Figure 3. As in Fig. 2 except forecasts of 12.5 mm of QPF for the 24-hour period from 0600 UTC 3 December through 0600 UTC 4 December 2000

The probability of 12.5-mm (0.5 inches) of QPF valid at 0600 UTC 4 December 2000 is shown in Figure 3. Using a 10:1 liquid to snow ratio, this would represent the winter storm criteria for heavy snow throughout most of the region shown. Once again the Eta members tended to produce QPF farther to the north than the RSM members. One Eta member forecast 12.5 mm of QPF well into Pennsylvania. The high probability 60 percent contour was confined to southern Virginia and North Carolina. The very high probability 90 percent contour was confined to coastal regions of North Carolina.

Similar to the 5 mm consensus QPF, the consensus 12.5 mm QPF contour closely followed the 40 percent probability. In both instances, the consensus QPF seemed to offer a lower probability outcome. An examination of the 17.5 and 25.2 consensus plots (not shown) revealed a similar trend where the consensus QPF tended to follow the 30-50 percent probability contours.

Determining whether the precipitation would fall as rain or snow was equally as important as determining QPF amounts. The rain/snow line can be roughly approximated by the 850 hPa zero line. The probability of the 850-hPa temperatures being at or below 0^{o}C is shown in Figure 4. These data are valid at 1800 UTC 3 December, near the time of the warmest intrusion into the region and during a time when precipitation was forecast to be occurring. These data show that the area of heaviest QPF had about only a 50% chance of being at or below 0^{o}C. However, the consensus forecast showed that the mean position of the 0^{o}C isotherm was well into North Carolina. The consensus position of the 0^{o}C isotherm was located mainly in the 30-60 percent probability range except inland, where it closely followed the 60 percent probability contour. The wide divergence in solutions, mainly between Eta and RSM runs, creates a large zone of uncertainty relative to precipitation type over eastern Virginia and North Carolina.

4. **Conclusions**

In this paper, an East Coast snowstorm that was poorly forecast by the operational Eta model was examined. Using the NCEP SREF data, it was clear that the ensembles offered better clues to the potential for a snowstorm farther south than the individual Eta forecasts. Although the NCEP AVN appeared to provide a better forecast than the Eta (not shown), this information would not have been available operationally during the event. The ensemble average (consensus) was also misleading since uncertainty within the ensemble members was visually hidden. Therefore, ensemble forecast techniques appear to offer a method to improve forecasting of these and other weather events.

The NCEP SREF data, with 10 members, was able to show the most likely outcome and assign probabilities to some of these outcomes. For example, ensemble consensus forecast of fields such as the 850 hPa 0^{o}C isotherm, surface cyclone, and QPF thresholds showed the blended solution or consensus forecast. These forecasts are often more accurate then forecasts of any single model (Fritsch et al 2000). Additionally, the spaghetti and dispersion plots of specific fields showed areas of large disagreement and uncertainty in the forecasts.

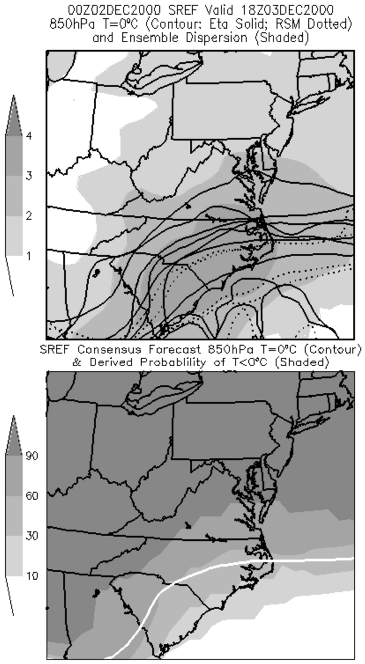

Figure 4. SREF forecasts initialized 0000 UTC 2 December 2000 of the 0°C isotherm (upper) and the probability of being at or below at 1800 UTC 3 December 2000. The consensus position of the 0°C is the white contour in the lower panel.

The probabilistic data showed percentages of occurrence of specific parameters; such as the 5 and 12.5 mm QPF contours. High confidence outcomes can clearly be assigned to areas of high probability of occurrence. Interestingly, the consensus contour of the specific QPF limits tended to follow low confidence probabilities. In this case, the winter weather advisory category QPF contour for snow (assuming all the QPF fell as snow) was a 30 percent probability outcome. Similarly, the heavy snow contour followed the 40 percent probability outcome contour. This implies that the consensus QPF forecasts may not offer the single best forecast. In this case, the consensus QPF was a low probability outcome and would have produced a forecast with a large false alarm rate.

Although not shown, the 60 percent contour would have provided a good area for the winter weather warnings and advisories. The unexpected result of the poor performance of the QPF thresholds, where consensus followed the 30 percent contour, suggests the need to use higher confidence QPF contours from SREF forecasts when considering winter weather advisories and warnings. Finally to predict the snowfall also required knowledge of what areas would receive most of the QPF in the form of snow. Clearly, consensus QPF and consensus subzero 850 hPa temperatures would not have provided the best forecast.

Integrating ensemble data into operations will be a steady transition. These data will allow forecasters to deal with uncertainties in initial conditions and model physics. Forecasters will have to be trained to use these new data and new data display concepts. This will require less reliance on model diagnostics, and using a single model; and better use of spaghetti plots, consensus forecasts, and more probabilistic ensemble output. The increased use of these latter products should lead to more accurate watches, advisories, and warnings.

5. Acknowledgements

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6. References

Fritsch, J. M., J. Hilliker, J. Ross, R. L. Vislocky, 2000: Model Consensus. *Wea. Forecasting* **15**, 571–582.

Du, J., and M. S. Tracton, 2001: Implementation of a real-time short-range ensemble forecasting system at NCEP: an update. Preprints, *9th Conference on Mesoscale Processes*, Ft. Lauderdale, Florida, Amer. Meteor. Soc., 355-356

Sivillo, S.K,J.E. Ahlquist, and Z. Toth, 1997: An ensemble forecasting primer. *Wea. Forecasting*.,**12**, 809-818.

Toth, Z., and Kalnay, E., 1997: Ensemble forecasting at NCEP and the breeding method. Mon. Wea. Rev., 125, 3297-3319.

------, Y. Zhu, T.Marchok, M.S. Tracton, and E. Kalnay, 1998: Verification of the NCEP ensemble forecasts. Preprints, *12th Conf. On Numerical Weather Prediction*, Phoenix, AZ, Amer. Meteor. Soc., 286-289.

Tracton M. S., J. Du,, 2001: Application of the NCEP/EMC short-range ensemble forecast system (SREF) to predicting extreme precipitation events. Preprints, *Symposium on Precipitation Extremes: Prediction, Impacts, and Responses,* Albuqerque, New Mexico, Amer. Meteor. Soc., 64-65.