11.1 An Examination of Regional Ensemble Forecasting Techniques During Three Winter Storms

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1. Introduction

National Centers for Environmental Predictions (NCEP) Short-Range Ensemble Forecasting System (SREF: Du and Tracton 2001; Tracton and Du 2001) is examined for 3 winter storms. The first two storms were observed in December 2000, including the 3-4 December and 30-31 December East Coast snowstorms, when the SREF data were not operationally available. The third East Coast storm was observed on 6-7 January 2002, when the SREF data were operationally available and coming into wider use.

The two storms from December 2000 represent relatively successful SREF forecasts. In both cases, the SREF data performed quite well and offered useful insights into the forecast process. The 3-4 December 2000 case showed remarkable skill as to the location of the potentially heavy snow relative to the operational Eta forecasts. Similarly, during the 30-31 December 2000 event, the SREF data showed that heavy snow was a very low probability forecast in the Washington, D.C. area. Unfortunately, the operational Eta forecast a large amount of precipitation and conditions favoring snow, which lead to an erroneous forecast. Had the SREF data been employed in this case, a better forecast may have resulted.

During the 6 January 2002 East Coast snowstorm, the SREF data did not perform as well. The SREF showed that heavy snow over the mid-Atlantic region was a low probability forecast. Initially, the SREF forecasts pointed toward a widespread light snow event. It was not until 12 hours before the snow began to fall when the operational Eta forecast the heavy snowfall. The operational AVN model offered little improvement in the forecasts.

During the 6 January 2002 event, subsequent model runs, especially the AVN and Eta, showed a westward shift in the threat for heavy snow (higher QPF values). The SREF data, as late as 0900 UTC 6 January was not as optimistic with the snowfall potential, showing a high probability for only a few tenths of an inch of QPF, thus about 2-4 inches of snow, over the mid-Atlantic and southern New England.

In this paper an examination is made on the performance of the NCEP SREF's during these three East Coast snowstorms. The results are mixed, with two relative success stories and one relative failure. The initial results show great promise in using a mix of SREF and operational forecasts to create updated ensembles using a lagged average technique. The results also imply that the NCEP SREF system requires more members to fully capture the envelope of solutions.

2. Method

2.1 Data

During the winter of 2000-2001, the Eta was run at 22-km and the SREF data were available at 0000 and 1200 UTC daily. During both seasons, the 10-member SREF suite included 5 Eta and 5 Regional Spectral Model (RSM) members run at 48 km horizontal resolution. For each model, there was a control run and 2 positively and 2 negatively perturbed members (Toth and Kalnay 1997). The physics in the RSM members are not as current as those used in the operational AVN, but the RSM is run at a higher spatial resolution (48 km) than the operational AVN (80 km). The RSM is a spectral model run over a region using lateral

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boundary conditions from the global spectral model.

For the January 2002 event, the SREF, operational Eta, and operational AVN forecast data were retrieved in real-time during and prior to the event. The SREF data were available with forecasts initialized at 0900 and 2100 UTC daily. The Eta was run at 12 km and was the highest resolution model available from NCEP, compared to the coarser 48 km SREF Eta model members.

2.2 Ensemble displays

Ensemble data display techniques used in this paper include traditional spaghetti plots (Sivillo et al. 1997), derived probabilistic displays, and consensus or ensemble mean forecasts. Each display technique has its own individual strengths and limitations. Therefore, combinations of techniques are used to present a clearer and more complete picture of the potential outcome.

Probabilistic forecasts were computed for accumulated precipitation thresholds and subfreezing 850 hPa temperatures. These data were shaded to show the simple percentage of the SREF members that 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%. Operationally, models are displayed using a single color for each model run. All Eta SREF members are one color and all RSM SREF members are a different color. The operational Eta and AVN each have their own unique colors. In the QPF images, the Eta and AVN contours are made thicker to better distinguish these forecasts from the other members.

For the January 2002 case, the ensemble forecasts were updated with forecasts from the SREF's. Using lagged average forecast concepts and considering the latest forecast to likely be more accurate, the more recent operational forecasts were assigned twice the weight of any SREF member.

3. Results

3.1 3-4 December 2000

This case produced heavy snow in northeastern North Carolina and a small area in extreme

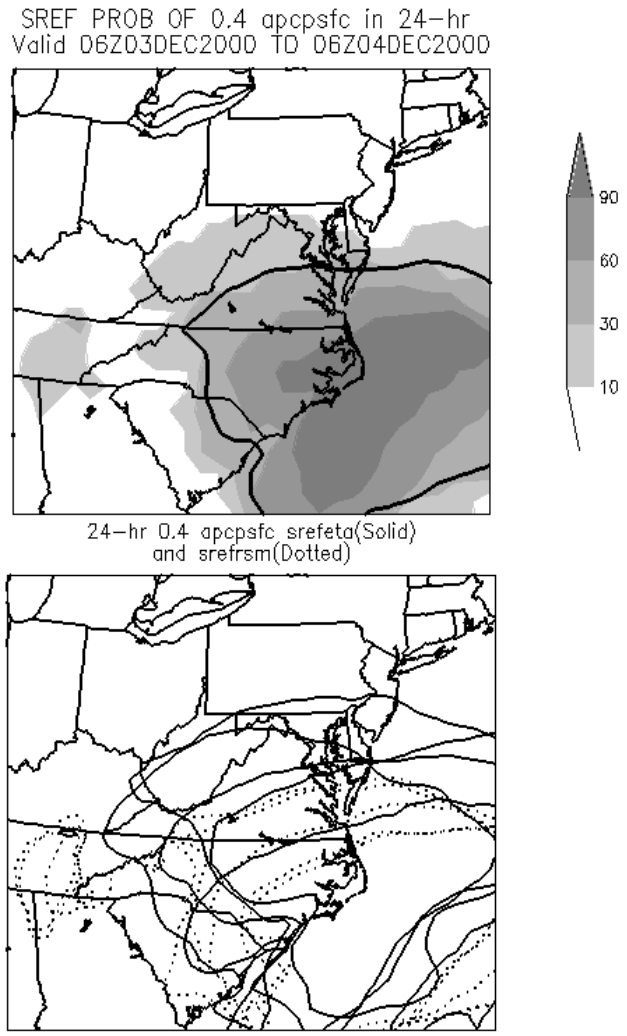

Figure 1. 24-hour accumulated QPF initialized at 1200 UTC 2 December 2000 showing a) the probability of 0.4 inches of QPF with the consensus (solid black) and b) spaghetti plots of each SREF members forecast position of the 0.4 cm contour. Eta members are solid and RSM members are dashed.

southeastern Virginia (not shown). The 24-hour QPF valid for the 24-hour period valid at 0600 UTC 4 December 2000 is shown in Figure 1. This time period encompasses the time of maximum model QPF and the observed time of the heavy precipitation. These forecasts are from the SREF cycle initialized at 1200 UTC 2 December 2000. The Eta (solid) forecast the precipitation shield farther north then the RSM members (dashed). The heaviest observed QPF was slightly north of the forecast position of the 90% confidence contour.

Surface cyclone forecasts (not shown) from the Eta members forecast the cyclone too close to

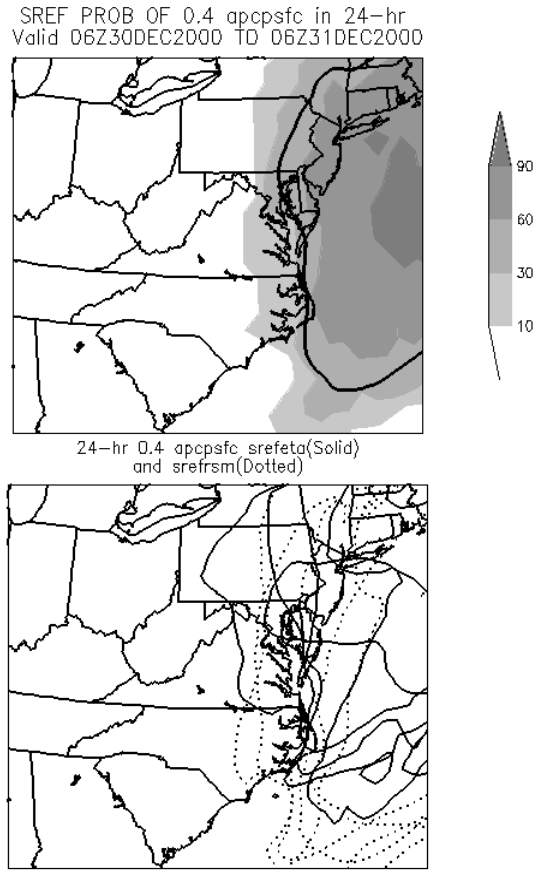

Figure 2. As in Figure 1 except forecasts from 1200 UTC 29 December 2000 valid for the 24-hour period ending 0600 UTC 31 December.

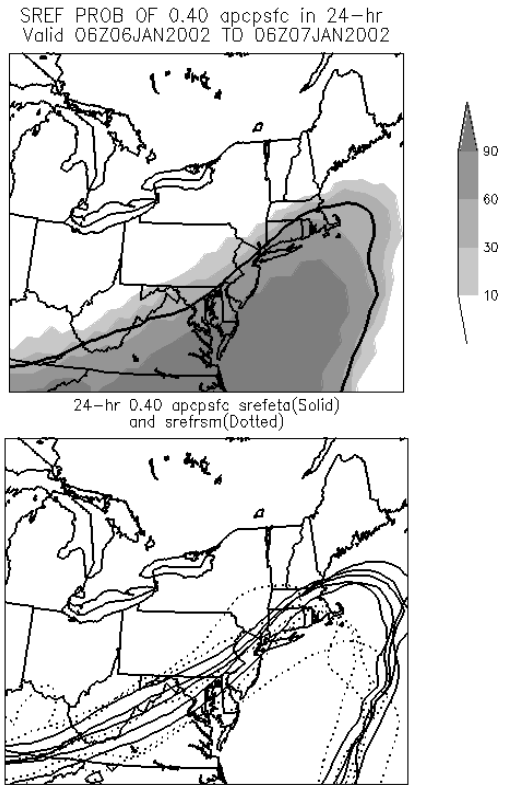

Figure 3. As in Fig. 1 except initialized with the 2100 UTC 5 January 2002 SREF and valid for the 24-hour period ending at 0600 UTC 7 January

the coast relative to the RSM members. There was a similar difference in the operational Eta and AVN model runs initialized at the same time. This more western cyclone track in the Eta and ETA SREF members implied a more westward rain-snow line. The rain-snow line was observed to the east of the Eta and Eta SREF forecast positions.

3.2 30-31 December 2001

This case produced heavy snow from near Philadelphia, PA and Wilmington, DE northward to New England. New York City recorded its heaviest December snowfall in over 40 years from this event. Over 50 cm of snow was observed in northern New Jersey and across southeastern New York and Connecticut.

The operational Eta from the 28th and 29th of December forecast heavy snow from Washington, DC to Boston. Observationally, the Washington, D.C. area was spared this storm. SREF forecasts initialized at 1200 UTC 29 December 2000 are shown in Figure 2. The consensus 10 mm contour was forecast to remain north and east of the Washington, D.C. metropolitan area. For the most part, this consensus forecast followed the 40 percent probability isoline. Most of the region, which experienced the heavy snow, New Jersey to Connecticut, was forecast to be in the 60% or greater threat region for the 10 mm contour. More important, the Washington, D.C. area was a low probability forecast (10%) for 10 cm of snow, let alone heavy snowfall.

Note that one Eta member forecast 10 cm of QPF well west of all other forecast members, with its contour reaching nearly to Pittsburgh. At least one Eta and one RSM member forecast this contour eastward toward central Pennsylvania. Unfortunately, the operational Eta (not shown) also forecast the QPF well west of the higher probability forecast region. Even in central Pennsylvania, the chance of 10 mm of QPF was generally 10 to 20 percent.

Interestingly, in this case the Eta and several SREF members clustered toward a more westward cyclone track. This may have been

related to the impact of the higher resolution models (32 and 48 km) using coarser resolution sea-surface temperatures (SST) than the operation models. The poor initial conditions related to the SST may have caused clustering toward an erroneous solution.

3.3 6-7 January 2002

This storm was initially forecast to produce only light snow over most of the mid Atlantic region and most of New York and New England. The SREF consistently forecast a very high probability of snow over the region (subfreezing 850 hPa temperatures), but the probability of more than 10 mm of QPF was very low over the region from central Pennsylvania to New York. This same region experienced in excess of 25 cm of snowfall.

The probability forecasts and spaghetti plots are shown in Fig. 3. These show that the threat for significant QPF was forecast to be south and east of the region that received the heavy snowfall. The 5 mm QPF forecasts (not shown) showed high threat from western Pennsylvania to the New Jersey coast. Both the operational Eta and AVN, initialized at 1800 UTC 5 January provided no significant clues as to the potential for more QPF to the west. The Eta runs (not shown) from both 0600 and 1200 UTC rapidly converged on the threat for significant QPF (25 mm) from central Pennsylvania into New York.

In this case, there was a tendency for the SREF members to cluster by model. The RSM members (and the AVN) produced more QPF farther west and showed the 850 hPa zero isotherm farther south then the Eta SREF members (and the operational Eta). This case clearly showed clustering by model in several forecast fields.

4. Conclusions

The SREF data show great potential in improving the forecasts of winter storms. As NCEP adds more members to the SREF system, with varied model physics, the envelope of solutions will be more accurately predicted. NCEP plans to have 15 to 20 members in the SREF system during the winter of 2002-2003 and as many as 45 members by 2005.

With the current system, comprised of the RSM and Eta, the solutions can provide some useful insights. First, forecasters must realize that the SREF system cannot represent the full uncertainty of both initialization and model biases. Approximately 10% of the time, the true solution may lie outside the forecast envelope of solutions. Furthermore, when the solutions cluster by model member (RSM and Eta members cluster), model physics may be playing a critical role in the outcome. During the 6 January case, the forecasts clustered like this. With only two models represented in the SREF system, this increases the uncertainty in the forecasts.

When there is a clustering of forecasts independent of the model (e.g., 30 December 2000), it may be a signal of the critical role the initial conditions are having on the forecast sensitivity. During these cases, the envelope of solutions may capture the forecast, but similar to the above example, the confidence in the forecasts is reduced. Future SREF members will have to include models initialized from varied four dimensional data assimilation schemes.

The results shown here, and several other cases, such as the severe weather event of 24 September 2001 and 28 April 2002, suggest that SREF system is mature enough to have useful operational value. Forecasters need to learn to use these data more effectively and further transition into the probabilistic future of forecasting. This includes considering the higher probability outcomes, without totally excluding the lower probability outcomes, which should lie with the expected envelope of solutions. As NCEP includes more members, with more varied physics and different initial conditions, this should decrease the likelihood that the verification will fall outside of the models envelope of solutions.

5. Acknowledgements

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6. References

Available upon request.