East Coast Winter Storm of 6 January 2002:
The role of and limits of SREF forecasts
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1. Introduction

On Sunday 6 January 2002, a fast moving storm moved out of the Gulf of Mexico and tracked over the Delmarva Peninsula. The resulting storm produced heavy rain in coastal areas, a mixed precipitation event over many inland areas and heavy snow north and west of the surface cyclone track.

This storm was not well forecast by the NCE short-range Ensemble Forecasting System (SREF: Du and Tracton 2001; Tracton and Du 2001). This despite the fact that SREF’s were designed specifically to address short-term (0-2 days) forecast problems. The current SREF has two models, including the Eta and the regional spectral model (RSM). The models driving both the Eta and RSM are not the current versions of the operational Eta or AVN, each contain slightly older physics packages in addition to the coarser resolution of the Eta-SREF (personal conversation, Jun Du-NCEP). Five model runs were available for each model including a control run and 4 perturbed runs. The National Weather Service in State College produces forecast graphics from the SREF and updates these with output from the operational Eta and AVN.

The QPF forecasts from the SREF’s kept the Winter Storm criteria snowfall well East of the State College Forecast area (CTP-CWA). The SREF’s forecasts on Saturday did imply some advisory category snowfall was possible over the southern third of the CTP-CWA. The 1200 UTC 5 January AVN did show advisory category snowfall potential over a larger area.

Subsequent model runs, especially the AVN and Eta showed a westward shift into the CTP-CWA for heavy snow QPF values. The SREF data, as late as 0900 UTC 6 January was not as optimistic with the snowfall potential. Based on experience with ensembles and poor performance with the Eta during the winter of 2000-2001, the Eta was probably not as heavily weighted in the forecast decision making process.

Significant things about this event included the cyclone track and intensity; and the formation of a strong CSI band between 1930 and 0000 UTC 6 January. This CSI band produced 2-3 inch per hour snowfall rates over central Pennsylvania. The deep cyclone showed an anomalous 850 hPa low-level easterly jet of 3-4 standard deviations (SDs) below normal

In this paper an examination is made of the 6 January 2002 storm as it affected central Pennsylvania. The SREF data and updated SREF data are examined to see how a better forecast could have been made. Using the SREF consensus (Fritsch et al. 2000) was not the best forecast. It appears as the time of the event draws closer, model diagnostics, of more skillful model members, are important considerations in the forecast process. model on any single day.

2. Method

2.1 Data

SREF Ensemble and operational Eta and AVN forecast data were retrieved in real-time during and prior to the event. The Eta is run at 12 km and is the highest resolution model available from NCEP compared to the coarser 48-km SREF model members. 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). The physics in the RSM are not as current as those used in the even coarser operational AVN. The RSM is a spectral model run over a region using lateral boundary conditions from the global spectral model.

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 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

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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%. Models are displayed using a single color for each model run. All Eta SREF members are a single color and all RSM SREF members are a single color. The operational Eta and AVN each have their own color. In the QPF images, the Eta and AVN contours are made thicker to better distinguish these forecasts from the other members.

3. Results

3.1 Case overview

At 1200 UTC the surface cyclone, with a central pressure of 1002 hPa was located just south of Atlanta, Georgia. By 1800 UTC, a new cyclone had formed over southern North Carolina and the primary low had weakened over northwestern North Carolina. The 995 hPa cyclone along the coastal plain had become the primary cyclone. At about this time steady precipitation had developed over Pennsylvania and by 1900 UTC, a CSI band would be clearly evident on radar. By 0000 UTC 07 January, a 985 hPa surface cyclone was located near Salisbury, Maryland. Historically, deep cyclones tracking over Delmarva Peninsula are often associated with heavy snow over central Pennsylvania. This storm followed a nearly ideal track. (Fig 1. Not scanned yet).

In addition to the ideal storm track, an anomalous surface cyclone and low-level easterly jet set up over along the Mid-Atlantic regions as shown in Figures 2 and 3. Note the -2.6 SD surface cyclone along the New Jersey coast, slightly northeast of the manually analyzed position at this time, and the -4.6 SD easterly jet over New Jersey extending into eastern Pennsylvania. Grumm and Hart (2001) showed how large QPF and climatologically significant events in the eastern United States are often associated with strongly anomalous low-level easterly jets.

3.2 SREF displays

The SREF forecasts from 0900 UTC 4 January 2002 (not shown) showed complete model divergence with the solution to several parameters associated with the event. Over Pennsylvania, the 5 ETA-SREF members forecast the 0°C 850 hPa isotherm west of the consensus forecast and all 5 RSM-SREF members forecast the 0°C 850 hPa isotherm east of the consensus forecast. Perhaps the model divergence signature was a measure of uncertainty and to give more weight to lower-probability outcomes.
An example of this model divergence can be seen in the 0°C 850 hPa isotherm and spaghetti plots from 05./2100 UTC SREF forecasts valid at 06/2100 UTC (Fig. 4). The black spaghetti contours show the SREF-ETA and the blue lines the SREF-AVN. The RSM forecasts showed a colder solution favoring snow relative to the Eta members. The consensus forecast was 50% outcome based on the divergence between the two model types used in the SREFs.

The corresponding MSLP forecasts are shown in Figure 5. The consensus was for a cyclone of -2.54 SD's from normal to be over the North Carolina coast. The Eta members forecast a deeper cyclone, farther west, then the RSM members. Due to model divergence, the 850 hPa wind anomalies were only on the order of -2 SD's from normal with the maximum located offshore (not shown).

The QPF forecasts at this time suggested that even advisory category snowfall (using a 10:1 ratio) was a low probability forecast over most of the CTP-CWA (Fig. 6). Several RSM members placed the QPF farther west of the mean and most Eta members.

Figure 7 shows the combined forecasts from the SREF and the operational models. Note how much farther west the operational AVN forecast advisory category snow, using a 10:1 ratio, back to State College, well west of the operational Eta and most SREF members. However, weighted as 1/12 it had little impact on the probabilistic forecasts. In retrospect, the operational AVN was suggesting a surge of precipitation well west of the majority of SREF members. But it still did not forecast any 0.60 or greater QPF in the CTP-CWA. Although not shown, by this time, both the AVN and Eta were showing a signal for a very anomalous surface cyclone and associated easterly jet. The SREFs, due to model divergence failed to show how anomalous these features would be.

The comparable MSLP forecasts are shown in Figure 8. These data show a stronger cyclone in the Eta. At 12-km resolution, this might be expected. However,
the AVN was also showing a deeper cyclone than most of the SREF members.

The updated SREF and operational Eta and AVN ensemble forecasts of 0.40 and 0.60 QPFs are shown in Figure 9. At this time, the ETA jumped its 0.40 forecast contour well west of the SREF members and the AVN forecasts. Additionally, the Eta 0.60 contour had shifted about 200 km west to a position that now covered about 80% of the CTP-CWA. The AVN was not as aggressive with the QPF, however part of this problem was a timing error and the forecasts valid 6 hours later showed at least advisory category snow across the entire CTP-CWA and a large area of warning criteria QPF over the eastern sections.

4. Conclusions

During this event, the SREF guidance under predicted the probability of heavy snow over most of eastern and central Pennsylvania. In fact, no SREF run ever showed any significant potential for heavy snow over central Pennsylvania. The operational Eta began to show clear signals for heavy snow from forecasts initialized after 0000 UTC 6 January 2002.

The AVN run from 1200 UTC 5 January also forecast a large area of advisory category snow for eastern and east-central Pennsylvania.

The fact that most of central Pennsylvania received heavy snow suggests there were problems with the models and in the current SREF system. The Eta forecast initialized at 1200 UTC 7 January 2002 forecast in excess of 1.2 inches of QPF over central Pennsylvania. Preliminary snow ratios suggest between a 10:1 and 12:1 ratios were observed during this event. The 13 inches of snow in State College was associated with around 1.2 inches of precipitation, very close to the Eta forecast.

Unfortunately, the Eta forecasts were made available only a few hours prior to the onset of heavy snow. A reliance on the SREF-ensembles was also quite problematic. The SREF’s never forecast the QPF and therefore the snow. This case clearly shows the limits of the current SREF system, when the outcome is the very low probability forecast. Several clues were available, including the tendency of the operational models to lean toward the SREF outliers, with a more western QPF shield.

Other considerations included the highly anomalous surface pressure and low-level jet forecasts in the AVN and Eta. These data need to be used in conjunction with SREF data. The SREF’s had difficulty showing how anomalous these features would be due to the divergence of solutions, which in itself was information. In this case, the warmer and more westward QPF shield in the Eta solutions was more correct than the RSM solutions.

This case also suggests that at shorter time scales, the higher resolution and better physics models, the Eta and AVN respectively, should be given considerably more weight than any SREF member. The RSM currently does not have all the physics that the operational AVN has, hence the RSM is not as skillful a model as the AVN. NCEP is working to make the RSM physics package comparable to the operational AVN. Similarly, the Eta, at 12-km resolution is typically more skillful than any single ETA-SREF member. The operational 12-km Eta has more advanced physics than the Eta used in the SREF system. NCEP plans to upgrade the Eta forecast portion of the SREF system with the current Eta model in mid January 2002 (personal communication, Steve Tracton). Therefore, the operational AVN and Eta are to be considered the most skillful models and need to be given higher weights when considering forecasts.
A final issue on SREF’s and ensembles in general. First, the consensus forecast washes out large and significant features. Thus anomalous features such as deep cyclones and anomalous easterly jets, which characterized this event are under forecast by a consensus forecast. The larger the model divergence the more these features will be washed out. A control single model should be used to determine how potentially anomalous a system might be. This is specifically true of QPF fields. An examination of 3 winter storms from the winter of 2000-2001 revealed that the consensus QPF maximum can be 1/3 of any single models maximum beyond about 48-hours and about 60% at 24 hours. The consensus will rarely show the higher amounts and the higher amounts (typically above 0.7 inches) will be low probability forecasts due model differences. There appears to be great skill at low QPF amounts (0.01 to about 0.20 inches). Its often difficult to get a consensus 1 inch QPF contour, hence 1 inch QPF amounts are generally low probability forecasts. Finally, ensembles do not and are not intended to produce a binary YES or NO forecast. Instead, they should be used to see a range of possibilities (personal conversation Jun Du, NCEP) and the most likely outcome.

Another issue is CSI and the conditions required to produce it. During this event, the KCCX radar showed distinct bands which produced 2-3 inch snowfall rates per hour. Diagnosis of EPV and low-level frontogenesis, on a single deterministic model are important considerations. On 30 December 2000 the Eta produced too much frontogenesis resulting in it over forecasting of the potential for heavy snow well west of where it was observed. However, the Eta has been improved since the SST error impacted its forecasts last winter. Second, at short time scales, of 12-24 hours before an event, these forcing mechanisms can help the forecaster consider solutions that the SREF may be playing down. The risk of course is doing diagnostics on the wrong model. That is, the forecast that turns out to be incorrect, which is not known prior to the event.

Finally, an examination of the Eta and AVN anomaly fields showed an anomalous cyclone moving over the Delmarva Peninsula. The resulting easterly flow suggested the potential for an extraordinary QPF event, which in fact verified. Forecast experience in central Pennsylvania has revealed a high correlation with heavy snow in central Pennsylvania and storms which remain in the coastal plain rather then offshore. The Delmarva track is an ideal heavy snow-producing track for central Pennsylvania. In hindsight we now know that a very anomalous surface cyclone crossed the Delmarva at 0000 UTC 7 January producing one of the largest snowfalls over wide area of central Pennsylvania since 6-7 January 1996.

5. Acknowledgements

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6. References


Figure 7: 2100 UTC 5 January 2002 SREF and operational Eta (BLUE) and AVN (RED) initialized at 0000 UTC 6 January 2002. Forecast show probability and consensus and spaghetti plots.

Figure 9. As in Figure 7 except 0900 UTC SREF and 1200 UTC 6 January 2002 operational Eta and AVN forecasts of 0.40 and 0.60 inches of QPF for the 24-hour period ending 09Z 07 January 2002. Note Eta is blue and AVN is red.
Figure 10. Preliminary snowfall map of the 6-7 January 2002 Winter Storm. Data provided courtesy of the Weather Communications Group and the State Climatologists office of the Pennsylvania State University.