The 12–14 March 1993 Superstorm: Performance of the NMC Global Medium-Range Model

Abstract

The performance of the NMC Global Medium-Range Model in forecasting the March 1993 “superstorm” at various lead times is assessed. The forecasts of mean sea level pressure, 1000–500-mb thickness, 500-mb geopotential height and vorticity, 850-mb wind and streamfunction, and precipitation are described. Forecasts of storm track and intensity are shown, and comparisons with the European Centre for Medium-Range Weather Forecasts and the U.K. Meteorological Office forecasts are made. It is shown that the main features of the storm and the planetary-scale developments leading up to it were accurately predicted as much as five days in advance, especially north of its track, but that there were significant underestimates of the early stages of its development in the Gulf of Mexico.

1. Introduction

One of the most remarkable aspects of the forecasts of the March 1993 “superstorm” was the ability of many operational medium-range models to provide notice of the intensity, timing, and location of the event at least five days in advance. While the high level of skill shown by these forecasts may not be typical, advances in modeling, data assimilation, and analysis have in fact increased the frequency of cases in which accurate prediction of major cyclogenesis is provided three to five days in advance. This paper will focus on the predictions by the National Meteorological Center (NMC) Global Medium-Range Forecast Model (MRF) of the intensity and path of the March 1993 storm and the hemispheric-scale systems in which it was embedded, and the degree to which successive runs of the MRF (and the models of other centers) were able to provide consistent guidance for weather forecasts during the storm period. The MRF is described in Kanamitsu (1989) and Kalnay et al. (1990). For a detailed description of the history and effects of this storm, see the companion paper by Kocin et al. (1995).

2. Mean sea level pressure

The first warning of a possible intense East Coast storm was provided by the six-day forecast initialized at 0000 UTC 8 March, verifying at 0000 UTC 14 March. The evolution of the MSLP and 1000–500-hPa thickness fields through 10 successive forecasts by the MRF for the eastern United States can be seen in Fig. 1. Here, the histories of all MRF forecasts verifying at four critical times (1200 UTC 12 March; 0000 and 1200 UTC 13 March; and 0000 UTC 14 March) are shown, each in a separate column. Each row depicts a successively later initialization time, from 0000 UTC 8 March through 1200 UTC 13 March. For the forecast from 1200 UTC 10 March, the final frame is blank because 1200 UTC forecasts were available only to hour 72.

All the forecasts verifying at 1200 UTC 12 March placed a weak trough in the western Gulf of Mexico (detailed analyses actually showed that a strong center had already developed) and the 540-dam thickness line near the latitude of South Carolina. At the next verification time, 0000 UTC 13 March, although all MRF model runs developed a large cyclone in the Gulf (Fig. 1, second column), they were all too weak and placed it too far to the south. The 8 March run (the earliest shown) predicted a double cyclone structure throughout and attempted to develop a primary low too soon over Georgia. The thermal field predictions for all but this first run were fairly consistent and accurate, as can be seen by scanning down the columns in Fig. 1 and comparing the forecast thickness contours with the analyzed contours at the bottom of each column.

During the next 12 h, the observed storm moved northeastward to eastern Georgia and intensified by about 14 hPa (from 996 to 982), an unusual rate for this latitude (see Sanders and Gyakum 1980). It is important to note that the central pressures referred to here are estimated from model analyses and tend to be higher than those reported in Kocin et al. (1995), which are based on special mesoscale analyses. With the

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Fig. 1. MRF forecasts of mean sea level pressure (solid) and 1000–500-hPa thickness (dashed), with contour intervals of 4 hPa and 120 dam, respectively, with 546 dam shown bold. All forecasts in a column verify at the same time, with the verifying analysis at the bottom of the column. All forecasts along a row originate at the same time. Forecast lead time decreases downward row by row, in steps of 24 h.

In the help of Fig. 2, which shows time histories of central pressure predictions, it can be seen that the MRF, especially in the 0000 UTC run from 11 March, consistently underestimated the rate of deepening that occurred during this period (0000 to 1200 UTC 13 March) when the storm center was intensifying over the Gulf. However, all runs tended to be accurate and consistent in placing the 540-dam thickness line along the hurricane track.
southern Appalachians and through southern Virginia, close to the axis of heaviest precipitation rate. During the final 12-h period shown in Fig. 1, the storm intensified by yet another 15 hPa (to 967), a rate anticipated by almost all of the MRF runs and overestimated by some. The right-hand column (0000 UTC March 14) in the figure shows once again that, with only small variation from run to run, the storm’s position and intensity at this time were well predicted from all forecasts from 9 March onward.
FIG. 2. Time history of eight MRF forecasts of central pressure (hPa), verifying 0000 UTC 12 March through 0000 UTC 15 March. The pressure value for each verifying analysis is marked with a circle.

For this last verification time, Fig. 3 compares forecasts of four models at different lead times. Six days prior to 14 March, both the European Centre for Medium-Range Weather Forecasts (ECMWF) model (initialized 1200 UTC 8 March and verifying at 1200 UTC 14 March) and the U.K. Meteorological Office (UKMO) model (initialized 0000 UTC 8 March) were predicting a central pressure of approximately 980 mb. Although at this time the MRF operational model initialized at 0000 UTC 8 March forecast a low of only 995 mb, an experimental T62 (triangular truncation, 62 waves) version of the model also predicted a 980-hPa low, but at this stage there was still a lot of variability in the pressure tendencies. With shorter lead times, all four models continued to predict a major cyclone, especially the ECMWF model, which at 4 and 3 days’ lead predicted central pressures some 20 mb lower than the other models. This difference was partly the result of poor initial conditions over the Gulf of Mexico that went into the forecasts (MRF and UKMO models) from 0000 UTC 11 March, and perhaps partly due to the tendency of the ECMWF model occasionally to overintensify strong cyclones. Every MRF forecast in Fig. 2 indicated a period of intense development during the 12 h beginning at 1200 UTC 13 March. There was a corresponding consistency in the MRF predictions of storm position (Fig. 4) from initial conditions at 0000 UTC on seven consecutive days, beginning with 8 March. The scatter of the MRF, ECMWF, and UKMO model forecasts of the storm center position about the observed position for different initial times and verifying near the time of maximum intensity is shown in Fig. 5. For purposes of comparison, it should be noted that for the lower half of the figure, which shows two sets of forecasts verifying at 1200 UTC, the 6-, 5-, and 4-day MRF forecasts, which originate at 0000, have lead times that are 12 h longer than the ECMWF model, whose forecasts originate at 1200 UTC. The MRF positions were especially useful as guidance to forecasters.

FIG. 3. Forecasts for lead times of up to six days for central pressure (hPa) verifying at 0000 UTC 14 March from four models: the full-resolution MRF (thin crosses), the UKMO (circles), the T62 version of the MRF (thick crosses), and the ECMWF (triangles). The ECMWF begins and ends at 1200 UTC.

FIG. 4. MRF storm track predictions with positions at 12-h intervals; analyzed storm track given by rectangles. Tracks are from seven successive runs—0000 UTC 8 March through 0000 UTC 14 March.
because of their relatively small scatter normal to the storm's track, as discussed in another companion paper by Uccellini et al. (1995).

The above comparison of numerical weather forecasts that verify at the same time but are generated from different models and different initial times amounts to a limited exercise in ensemble prediction. A more complete and objective system of ensemble prediction that uses mostly T62 resolution (Tracton and Kalnay 1993) had already been in place at NMC since 7 December 1992. The daily operational ensemble produced on any given day D consists of 14 independent MRF predictions, some of which were initialized as early as day D2. The ensemble is analyzed to determine clusters of forecast results that are objectively found to be similar to one another. In this case there emerged a clearly dominant cluster encompassing 10 of the 14 forecasts from an ensemble available at 0000 UTC 10 March, verifying at 0000 UTC 14 March. The average of these 10 forecasts, shown in Fig. 6 (from Tracton and Kalnay 1993, Fig. 8), clearly points to the likely development of a major East Coast storm.

Fig. 5. Scatter of forecasts for 14 March about analyzed position for lead times of 1–6 days. Upper half shows forecasts from UKMO and MRF valid at 0000 UTC; lower half shows forecasts from MRF and ECMWF valid at 1200 UTC. All forecasts in the lower half origin-ate at 1200 except the earliest three MRF forecasts, which originate at 0000 and thus have a half-day longer lead time.
3. Middle troposphere

The success shown by the medium-range forecasts of MSLP can in large part be explained by the model’s ability to predict the large-scale changes in the hemispheric circulation pattern that took place during the period 9–14 March, shown for the 500-hPa geopotential field in Fig. 7. As the flow evolved, a low-amplitude pattern with mostly weak disturbances gave way to a high-amplitude pattern characterized by powerful jets, prominent ridges, and intense troughs over western Asia, the western Pacific, and the eastern United States, transporting cold air to low latitudes. Another view of the rapid global change accompanying this storm is provided by the Hovmöller diagram in Fig. 8. The relatively undisturbed geopotential field at 500 hPa on 9 March in the 30°–40°N latitude belt evolved quickly to the active pattern of 14 March. The major low-latitude troughs (longitude–time trajectory shown by dashed lines) that developed, one over the U.S. East Coast and the other over the western Pacific, can be clearly seen to be part of two trains of downstream amplification (dotted lines), propagating at about 25°–30° of longitude (2400–2900 km) per day. The stronger of these troughs carried the 540-dam geopotential contour to the Gulf Coast by 0000 UTC March 14 as the storm under discussion was reaching its maximum intensity (and another intense surface low was developing rapidly off the coast of Japan).

Fig. 6 (at left). Composite four-day forecast representing the dominant cluster from an ensemble of 14 members, valid at 0000 UTC 14 March. Contours are 1000-hPa geopotential (solid) and 1000–500-hPa thickness. Contour intervals are 30 m and 6 dam, respectively. Central sea level pressure is about 992 hPa. (From Tracton and Kalnay 1993, Fig. 8.)
Along with the observed evolution of the 500-hPa geopotential field shown in Fig. 7 is the forecast from 9 March (Fig. 9). The overall change in the circulation pattern is well predicted, as is the formation of the intense trough in the eastern United States. In this and later runs, however, the speed of the trough and its rate of intensification were underestimated and the interaction of two short-wave troughs over the southern United States was not resolved. This can best be appreciated by a look at the shorter waves, for which the success of early MRF predictions was somewhat limited. This can be seen in Fig. 10, which shows two successive forecasts of the 500-hPa geopotential and relative vorticity fields and the verifying analysis for 0000 UTC 13 March. The analysis shows phasing about to take place between two strong short waves near the axis of the developing high-amplitude long-wave trough described above. The four-day forecast from 9 March shows only a suggestion of a dual structure, and the three-day forecast from 10 March is slow with the major short wave and fails to reveal any double structure, although it does an excellent job with the short waves and ridge upstream of the major trough. Although both model runs substantially underestimated the rate of development in the Gulf, they each managed by 14 March to produce a respectable surface cyclone (983 hPa for the 10 March run and 987 hPa for the 11 March run) located quite close to the observed position along the East Coast (see Fig. 1, second and third row, far right).
An estimate of the skill of the forecasts verifying on 14 March is given for the 500-hPa Northern Hemisphere (20°–80°N) geopotential forecasts by the anomaly correlation (defined as the correlation between forecast and verifying analysis after climatology has been removed from each). The MRF, ECMWF, and UKMO models, plus the Japanese model (JMAS), seemed to produce unusually skillful forecasts (Table 1), showing values of day 5 anomaly correlation that were well above their average for the month—by over one standard deviation in some cases. These good scores are partly due to the large magnitude of the anomaly itself (defined here as the root-mean-square difference between the analysis and the forecast). These forecasts have been removed from each).

**Table 1.** Statistics for 5-day forecasts, 1000- and 500-hPa geopotential for 20°–80°N for five models. Shown are anomaly correlation (AC) for this case, the 30-day average AC and its standard deviation, and the normalized departure (z) of this case from the average.

<table>
<thead>
<tr>
<th>Center</th>
<th>1000 hPa</th>
<th>500 hPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AC</td>
<td>AC(avg, sd)</td>
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<tr>
<td>MRF</td>
<td>0.778</td>
<td>0.686, 0.142</td>
</tr>
<tr>
<td>UKMO</td>
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<td>0.659, 0.118</td>
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<tr>
<td>JMAS</td>
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<td>EC</td>
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<tr>
<td>Persist</td>
<td>0.258</td>
<td>0.172, 0.194</td>
</tr>
</tbody>
</table>
FIG. 11. (a) The 72-h forecast from 1200 UTC 10 March, (b) 60-h forecast from 0000 UTC 11 March, (c) 48-h forecast from 1200 UTC 11 March, and (d) verifying analysis, 1200 UTC 13 March. Contours are 850-hPa streamfunction, with an interval of $0.2 \times 10^7$ m$^2$ s$^{-1}$.

lyzed 500-hPa geopotential and that of climatology), which, during the period 9–15 March, rose from a value of 86.1 m, the lowest for the month, to 149 m, the highest in the eight years for which these statistics are available. As pointed out in Van den Dool and Toth (1991), the anomaly correlation tends to vary directly with the anomaly. However, for most models the rms error (not shown)—even though it usually increases with the anomaly—was well below its monthly mean, also indicating very good forecasts.

FIG. 12. Forecast times as in Fig. 11 but contours are wind speed, with a contour interval of 5 m s$^{-1}$ with wind barbs overlaid (long barbs are 10 kt). Winds exceeding 15 m s$^{-1}$ are stippled. Shading patterns change at 25, 35, and 45 m s$^{-1}$.
4. MRF wind forecasts over Florida and the Caribbean

While the main features of the storm were well predicted along the northern portion of the storm track, all model forecasts underestimated the intensity and forward speed of important features of the storm as it was intensifying in the Gulf of Mexico on 12 March, even at relatively short lead times (see companion papers). For example, a powerful cold front moved through the area, accompanied and followed by unusually strong sustained winds, creating a damaging storm surge on the west coast of Florida and the northwest coast of Cuba, including Havana. Three successive MRF forecasts (72, 60, and 48 h) of 850-hPa streamfunction, all valid at 1200 UTC 13 March, are shown in Fig. 11, along with the verifying analysis. All three forecasts produced a center that was too weak, with a frontal trough that was too slow—by approximately 1000 km in the case of the 72-h forecast. Another problem can be seen in the 850-hPa wind forecasts in Fig. 12, which did not capture
the extensive region of 25–30 m s⁻¹ northwesterly winds sweeping a large portion of the eastern Gulf and an area of 35–40 m s⁻¹ southwest winds east of Florida.

5. Precipitation

The MRF forecasts of precipitation (Fig. 13) provided early warning of a major event, as in the case of MSL pressure, with large areas covered with over 20 mm (0.79 in.) in the 24-h period ending 0000 UTC 14 March. There was reasonable continuity from forecast to forecast, with the exception of the forecast from 0000 UTC 11 March whose problems were alluded to above. The northeast–southwest axis of heaviest precipitation amounts was systematically moved a little northward with each successive forecast, finally extending along a line from Long Island through southern Pennsylvania into eastern West Virginia. As mentioned above, the thickness forecasts in the area of heavy precipitation were consistent, thus enabling accurate forecasts of the rain/snow line to be issued well in advance, as discussed in Uccellini et al. (1995).

Three of the shorter-range MRF forecasts for the 24-h period beginning at 1200 UTC 13 March, when the storm was most intense, are shown in Fig. 14. The lead times are 48–72 h, 24–48 h, and 0–24 h, reading from left to right. A rough comparison with observations showed that the large area enclosed by the 50-mm (2 in.) contour seemed to verify in location but somewhat underestimated the true areal extent of the heaviest precipitation. The precipitation observations are not shown here because, as mentioned by Kocin et al. (1995), there may have been gross underestimates in areas where heavy snow occurred with high winds, which indicates that the model underestimated amounts in the Appalachian Mountains and just to the east.

6. Conclusions

The NMC Global Medium-Range Model produced accurate forecasts of the large-scale features of pressure, temperature, and precipitation fields at least five days in advance of the 12–14 March 1993 superstorm, especially along and to the north of the storm track. The consistency of the model simulations from run to run gave forecasters enough confidence to issue forecasts of severe weather over a very large area well in advance of the developing storm. Smaller-scale features connected with the timing and intensity of development in the Gulf of Mexico and the passage of a wind shift line and storm surge were not well forecast, even at fairly short range.

The ability of the MRF (and other medium-range global models) to provide warning so far in advance is a consequence of the steadily improving skill of modern global data assimilation and forecast systems to model accurately the planetary scale of the atmo-

Fig. 14. As in Fig. 13 but for the 24-h period ending 1200 UTC 14 March. Lead times are (a) 48–72 h, (b) 24–48 h, and (c) 0–24 h. Contours are 1, 5, 10, 15, 20, ... mm, and shading pattern changes at 5, 15, 25, ... mm.
spheric developments of which this storm was a part. These in fact played such a dominant role in this storm that the inability of the models to phase correctly several energetic short waves embedded in the larger-scale flow did not seem to detract much from the accuracy of the forecast over the bulk of the area affected by the storm. The model’s problems south of the storm track—especially the underestimation of the rapid cyclogenesis in the Gulf of Mexico—will likely provide ample material for many research studies.

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References