Ohio Valley rains of 3-4 April 2008: Using Ensemble Products-Draft

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1. INTRODUCTION

Heavy rains affected the central Mississippi and the Ohio River Valleys on 3-4 April 2008 (Fig. 1). Fortunately, this axis of heavy rains fell 100-200 km south of the axis of heavy rains which fell on 18-19 March 2008. The earlier event produced significant flooding along many streams and smaller rivers from Missouri to Ohio. Residual\(^1\) flooding was still present as of 2 April 2008 from this event.

In addition to the heavy rainfall, the cold front associated with the storm system produced severe weather from Oklahoma to North Carolina on the 3\(^{rd}\) and 4\(^{th}\) (Fig. 2). There were 136 and 150 severe weather reports on the 3\(^{rd}\) and 4\(^{th}\) respectively.

The potential for heavy rain was forecast 3-5 days in advance of the actual event. However, initial forecast by the National Centers for Environmental Predictions (NCEP) Global Ensemble Forecast System (GEFS) showed the potential for over 3 inches of precipitation too far north of the observed location. Similarly, the NCEP Short-range ensemble forecast system (SREF) also showed some issues related to the axis of heavy rainfall.

The conditions conducive to the production of severe weather were also relatively well forecast. However, the details remained elusive.

It will be shown that the GEFS forecast the patterns often associated with heavy rainfall. Heavy rainfall is as described by Junker et al. (1999) and is based on the aerial extent of the 75 mm (3 in) or greater isohyet. This event had an expansive 75 mm contour and sporadic areas which received in excess of 100 mm (4 inches) of rainfall.

Following the ingredients based forecast methodology of Doswell et al. (1996), Junker et al. (1999) determined several useful forecast tools including high precipitable water (PW), high relative humidity, and warm mid-tropospheric temperatures. It appeared that their category 3 and 4 events were often associated with higher PW and relative humidity values than lower category events. Grumm and Holmes (2007) expanded upon this by using PW anomalies to identify heavy rainfall events. GEFS forecasts of PW and \(v\)-winds will shown to identify the pattern suggesting heavy rainfall. This will serve as a proxy for identifying areas of strong low-level inflow were deemed important considerations when forecasting heavy rain identified by Junker and Schneider (1997).

In addition to forecasting the patterns associated with heavy rainfall, the EPS data can provide probabilistic quantitative precipitation forecasts (QPFs). The forecasts can highlight

\(^1\) Personal observation 1-2 April while driving across southern Indiana and Illinois. The Blue river and Wabash were out of their banks. Farm fields in Illinois and Indiana were still flood in the Wabash valley.
areas where heavy rainfall is a high probability outcome. Sivillo et al (1997) and Palmer et al. (2005) demonstrated the basic use of EPS data and representing uncertainty in forecasting. Buizza (2001) showed the potential economic value of forecasts, which require and ensemble prediction system to identify highly probable outcomes.

This paper will document the heavy rainfall event of 3-4 April 2008. The goal include, showing the pattern associated with the event, documenting that the NCEP EPSs were able to forecast the pattern, and the value of the EPS QPF probability forecasts during potential extreme events, and show some limitations of any prediction system in getting at the details with significant lead times.

2. METHODS and DATA

Data for this study include re-analysis climatological data from the NCEP/NCAR
global re-analysis project (GR: Kalnay et al 1996). The means and standard deviations were used to compute standardized anomalies, displayed in standard deviations from normal (SDs).

The 00-hour forecasts from the NCEP North American Meso-model (NAM) system and Global Forecast System (GFS) are used to provide an overview of the large scale pattern and the evolution of the rain event.

Ensemble data shown here were primarily limited to the NCEP GEFS and SREF. Displays will focus on the forecasts of the pattern conducive for heavy rain the EPS probabilities of heavy rainfall. Heavy rainfall defined as 75 mm or more rainfall in 24 hours. All data here are in inches focused on 1,2 and 3 inch probabilities (25,50 and 75 mm).

A new QPF product was developed to get at the maximum and minimum QPF at each grid point. A simple function was used to determine the highest and lowest value in any ensemble member at each grid point. A 3 panel format was used to display the mean, maximum, and minimum QPF. More robust software would facilitate a percentile approach which could then be leveraged to produce dynamic threshold amounts.

The maximum and minimum precipitation from the EPS was computed over 24 hour increments. For each time period, the maximum and minimum rainfall was computed at each grid. The maximum (minimum) value was retained from the member that had the maximum (minimum) rainfall forecast at that time period. Thus, the maximum rainfall images will show the maximum potential rainfall based on the output from every ensemble member.

The climatological data used to compute anomalies was restricted to those produced by the NCEP/NCAR GR data set (Hart and Grumm 2001). They will be presented in relation to both NAM and GEFS output.

All data was displayed using GrADS (Doty, et al 1995). Anomalies were computed as described Hart and Grumm (2001) and Grumm and Hart (2001). Shaded values show the standardized anomalies computed as:

\[
SD = \frac{F - M}{\sigma} \quad (i)
\]

Where \(F\) is the value from the reanalysis data at each grid point, \(M\) is the mean for the specified date and time at each grid point, and \(\sigma\) is the value of 1 standard deviation at each grid point.

Anomaly data were applied to GFS, NAM, SREF, and GEFS output. When anomaly data are used with EPS data it should be noted that the large anomalies are often a good indication of agreement between members. Thus, the large anomalies in the pressure and temperature fields, as well as indicating a significant event also indicated high confidence in the forecast.

For brevity times are presented in the format of 04/0000 UTC which signifies 04 April 2008 at 0000 UTC. Forecasts from both model and EPS initial and valid times are presented in this format.

The large scale rainfall estimates were derived from the unified precipitation data set (UPD: Higgins et al. 2000). These data were shown in Figure 1. It should be noted that these data often miss local maximum
rainfall. However they likely cover the larger scale pattern and may be representative of basin averaged rainfall and thus can be related to flooding and flooding potential. The hydrology of this event is not covered in this study.

3. RESULTS

i. Overview of the pattern

Figures 2-6 show the large scale pattern of 850 hPa winds, PW, and MSLP over the eastern United States from 03/1200 to 04/1200 UTC. The east-west frontal boundary was well defined in the PW field at 03/1200 UTC with positive anomalies on the warm side of the boundary from Kansas to southern Kentucky (Fig. 3). An anomalously strong surface high pressure was located to the east with +2 to +3 SD anomalies over the Mid-Atlantic region.

By 04/0000 UTC (Fig. 4) the PW anomalies were over 2SDs above normal over portions of the Mississippi and Ohio Valleys. Strong southwesterly winds, with u-wind anomalies on the order of 2 to 3SDs above normal were present in the region, east of the 850 hPa cyclone over western Missouri.

By 04/0600 UTC (Fig. 5) the PW anomalies peaked at 3 to 4 SDs above normal over southern Indiana and Kentucky. The 850 hPa winds were 1 to 2SDs above normal showing anomalous u and v-winds due to the general southwesterly flow over the region. To the

Figure 3. NAM 00-hour forecasts valid at 1200 UTC 03 April 2008 showing a) 850 hPa winds and v-wind anomalies, b) 850 hPa winds and u-wind anomalies, c) precipitable water (mm) and precipitable water anomalies, and d) mean sea level pressure (hPa) and pressure anomalies.
south, a sharp cold frontal zone was present from Illinois southwestward into Arkansas and Texas. This front was well depicted in the surface pressure field.

By 04/1200 UTC the system had accelerated with the surface low over Ohio (Fig. 6) and the trailing cold front extending to the southwest from Ohio into Arkansas. Strong southwesterly flow was present ahead of the cold front as depicted in the PW and surface fields.

The rain appeared linked to the strong southwesterly flow over the east west frontal zone from about 03/1800 to 04/0600 UTC. The severe weather was oriented (Fig. 2) to a close approximation to the cold front as indicated by the PW and MSLP fields. Strong southwesterly flow, implied shear, and high PW air ahead of the front likely contributed to the requisite instability and shear to produce the severe weather.

ii. GEFS forecasts

Figure 7 shows the GEFS forecasts initialized at 1200 UTC 30 and 31 March and 01 April 2008 showing the probability of 3.00 inches of QPF for the 36 hour period ending at 1200 UTC 4 April 2008. The forecasts initialized at 30/1200 showed this to be a low probability event. Three members had a 3 inch contour (Fig. 7 lower left) but they did not overlap and the ensemble mean QPF was 1.5 inches, mainly over Missouri into western Ohio.

The 31/1200 UTC forecasts showed 30-50% of the members had a 3 inch contour (Fig. 7-center). Compared to Figure 1, the rain shield would prove to be nearly 100 km too far north. Due to the increased rainfall and convergence of solutions, a close 2 inch contour appeared in the ensemble mean (Fig. 7 lower center).
The large scale pattern forecast by the 31/1200 UTC GEFS is shown in Figure 8. These data show some uncertainty in the location of the 25 mm PW contour, however the ensemble mean PW field showed a surge of 2 to 3 SD above normal PW air into the central Mississippi and Ohio river valleys. Combined with the strong southwesterly flow at 850 hPa, the GEFS was forecasting a pattern conducive to heavy rainfall, reinforcing the high QPF and high probability of high QPF over the same region. The 2-4 mm spread in the PW fields implied uncertainty with the location of frontal boundary associated with the heavy rainfall.

The forecasts initialized at 01/1200 UTC showed a mean 3 inch contour in the probability image as the probability increased to 50 to 60 percent that 3 inches of QPF was possible (Fig. 7-right). There area was smaller and shifted slightly to the south. A 2.5 inch contour and a 3 inch contour were present in the ensemble mean QPF field (Fig. 7-lower right).

The pattern the next day was similar as were the QPF patterns and they are not shown.

iii. SREF

The SREF forecasts of 2 inches or more QPF in 24 hours ending at 1200 UTC for select forecast cycles from 0900 and 2100 UTC 2 April and 0900 UTC 3 April 2008 are in shown in Figure 9. These data are similar to those presented by the GEFS. The probability of 2 inches in 24 hours increased with decreasing forecast length and the region of higher probabilities of heavy rainfall shifted south and east with time.
The times here were picked to be comparable to the GEFS and the verifying analysis in Figure 1. The SREF peaked its QPF for a slightly later time period with nearly 100% and 60% of the members showing areas of 2 inches or more QPF ending at 04/1500 UTC from forecasts initialized at 03/0900 and 02/2100 respectively. The SREF showed some timing issues, which based on radar (not shown) were likely realistic as the rain in Kentucky lingered past 04/1200 UTC.

As shown in Figure 10, the SREF forecast a similar pattern to that produced by the longer range GEFS. The strong southwesterly flow with both positive u and v-wind anomalies at 850 hPa with above normal PW anomalies forces over the frontal boundary were forecast by the SREF.

iv. *maximum and minimum rainfall*

Figure 11 shows the mean, maximum, and minimum QPF at each grid point for the 24 hour period ending at 1200 UTC 4 April from the 31/1200 UTC. These show the mean QPF with a 2.5 inch contour over Ohio Valley. This is in close proximity to the data shown in Figure 7 (center). The maximum QPF at any point and member was over 3 inches over the same region. The minimum QPF showed a potential for as little as 0.60 inches of QPF at some of the points in the region of heavy rainfall. The sharp cut-off and low amounts were due to the uncertainty in each members QPF fields which varied considerably (not shown) in the north-south direction.

Forecasts from 01/1200 showed a similar pattern in the rainfall (Fig. 11). The maximum rainfall, in the high probability of heavy rain, was over 3 inches. However, the minimum rainfall in the same area was around 1 inch of QPF. Thus, there was a wide range and high uncertainty in these forecasts. Though not
shown, this cycle showed higher QPF valid at the time period ending 04/1800 UTC suggesting temporal differences as well as spatial differences in the distribution of precipitation.

4. CONCLUSIONS

Heavy rains produced flooding over the central Mississippi and the Ohio River Valleys and severe weather swept across the Gulf States on 3-4 April 2008. This storm was relatively well forecast with 3-5 day lead-times by the NCEP EPS’s. However, the details as to the regions to be affected by the weather remained elusive until shorter range forecasts on the order of 6-36 hours.

The overall forecasts indicating heavy rainfall, with 3 inches or more QPF in a 36 hour period were well forecast by the GEFS 3-5 days in advance. The details as to the location of the heaviest rain remained elusive. As shown, the GEFS had the heavy rainfall area too far north. However the GEFS correctly forecast the pattern conducive for heavy rainfall and correctly produced an area of heavy rain near the correct feature.

The SREF continued to produce the same pattern predicted by the GEFS. Though it too, had the heavy rainfall slightly north of the observed axis of heavy rainfall. Perhaps these forecasts, getting the general area correct is the best we can expect from our current ensemble prediction systems in the 24-72 hour forecast periods. More accurate and more detailed forecast may reflect unrealistic expectations rather than true predictability.

Figure 7. GEFS forecasts initialized at 1200 UTC (left) 30 March, (center) 31 March and (right) 1 April 2008 showing the 36 hour QPF ending at 1200 UTC 4 April 2008, upper panels show the probability of 3 inches of QPF and solid contour shows the 3 inch ensemble mean value. Lower panels show the ensemble mean QPF (shaded) and select contours (dashed) thin colored lines show each members 3 inch contour if present.
One aspect of the probability images for QPF and the mean is the loss of information with regard to the range of outcomes. In an effort to mitigate this, a new product was developed to display the mean, maximum, and minimum values. This reduces the need to produce a wide range of probabilities and allows, in the high probability area for excessive rainfall, to visualize the maximum potential rainfall. The minimum values are difficult to use as spatial and temporal differences can often show zero values for QPF. But products to get at the maximum and minimum in critical situations is an often overlooked role of ensembles.

The new 3 panel format used to display the mean, maximum, and minimum QPF has limitations and potential. In high probability areas the maximum values may assist in providing a range of potential high end values. At the lower end, the minimum values may have some applications too. Clearly, more robust software would facilitate a percentile approach which could then be leveraged to produce dynamic threshold amounts. Thus, if at the 10 or 20th percentile 5 inches was forecast, a probability of 5 inches could be derived at based on the percentiles. Though the percentiles themselves may be of considerable value.

5. Acknowledgements

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6. REFERENCES


Palmer, T.N, G.J. Shutts, R.Hagedorn, F.J.Doblas-Reyes, T. Jung, and

Figure 9. As in Figure 7 except SREF forecasts of 2 inches of QPF in 24 hours ending at 1200 UTC 4 April 2008. Members initialized at (left) 0900 UTC 2 April 2008, (center) 2100 UTC 2 April 2008, and (right) 0900 UTC 3 April 2008.


Figure 10. As in Figure 8 except SREF initialized at 0900 UTC 3 April 2008.
Figure 11 GEFS initialized at 1200 UTC 31 March showing the 24 hour accumulated rainfall (inches) showing a) the ensemble mean, b) the maximum grid point value, and c) the minimum grid point value.

Figure 12. As in Figure 11 except initialized at 1200 UTC 1 April 2008.