1. INTRODUCTION

A synoptic scale front moved through the Mid-Atlantic region on 25-26 October 2008 producing widespread rainfall across the region (Fig. 1). A few locations in northeastern Pennsylvania received 75 to 100 mm of rainfall and a large portion of Pennsylvania and New York State received over 50 mm of rainfall. During month that had been unseasonably dry across Pennsylvania, the rainfall moved many locations back toward their normal monthly rainfall.

The rain fell over a relatively short period of time. The 6-hourly data indicated most of the rainfall was observed between 0600 UTC 25 October through 0000 UTC 27 October 2008. The event was classified as a Maddox Synoptic type (Maddox et al. 1979). A sharp north-south frontal boundary and a strong low-level southerly jet accompanied were associated with the rainfall. This event type often produces heavy rainfall over a short period of time.

Figure 2 shows the distribution of heavy rainfall events producing 140 mm or more rainfall by month. The data were extracted from the unified precipitation data set (Higgins et al. 1996). The late summer and autumn are the period of maximum occurrence of these events. Most of these events were Synoptic Events or Synoptic events which interacted with an approaching tropical cyclone. The event of 25-26 October did not produce enough rainfall to add to the values in Figure 2. Figure 2 illustrates that heavy rainfall is quite common in the later summer though mid-autumn.

This paper will serve to document the event of 25-26 October 2008. NAM and SREF data are used to illustrate the pattern and forecast issues associated with this rainfall event.

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) is 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.

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:

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

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.

For brevity times are presented in the format of 25/1200 UTC which signifies 25 October 2008 at 1200 UTC. Forecasts from both model and EPS initial and valid times are presented in this format.

The 4km precipitation data was obtained from the multi-sensor State-IV data (Seo 1998 and Seo et al. 1999). The summed data was shown in Figure 1, over the eastern United States. The 6-hourly data were used to make the totals. These data is available in 1, 6, and 24-hour increments.

3. RESULTS

i. NAM analysis

The NAM 00-hour analysis of the surface and low-level winds are shown in Figs 3-7. Typical of many eastern US events, the initial rainfall came with east to south easterly flow (Fig. 3). The 925 hPa winds showed the southeasterly flow with -4 u-wind and +2 SD v-wind anomalies. The strongest winds were over the Carolinas.
The retreating anticyclone (Fig. 3c) had +1 to +1.5SD pressure anomalies. The PW anomalies were near normal in the Mid-Atlantic region with +1 to +3SD above normal values moving into the Carolinas.

By 25/0600 UTC the wind maximum and moved northward (Fig. 5). PW and low-level wind anomalies had surged northward. Some above normal PW values were present ahead of the thermal front (not shown) in eastern Ohio and western Pennsylvania.

By 25/1200 UTC the PW anomalies had risen to 1 to 1.5SDs above normal as the low-level wind anomalies increased over the Mid-Atlantic region. The u-wind anomalies (negative) were focused over northern Pennsylvania and south-central New York State (Fig. 5b).

The low-level u-wind anomalies pushed farther northward and PW anomalies peaked at 2-3SDs above normal over Pennsylvania by 25/1800 UTC (Figs 6b & 6d). The v-winds over the coastal plain had increased to +4.5SDs above normal ahead for the frontal system, implied in the MSLP and PW fields. The rain had ended over western Pennsylvania but lingered in central and eastern sections.

By 26/0000 UTC the surface-frontal trough had reached the coastal plain and the strong southerly winds were evident along and ahead of this feature (Figs. 7c & 7a). The u-wind anomalies were over New England. The PW anomalies were normal behind the front in central Pennsylvania and New York. Above normal PW values and rainfall were along the coastal plain. The World Series in Philadelphia was rain
delayed as the front slowly shifted eastward.

In addition to the strong low-level features, there was a strong upper-level jet stream present over the region (Fig. 8). The wind vectors at 25/1200 and 25/1800 UTC showed a strong south-southwesterly jet over the eastern United States. The v-winds were 2-3SDs above normal in the core of this jet streak. The u-wind anomalies implied an imbedded exit region over the Mid-Atlantic region. Plotted as vectors, the relative upper-level divergence was evident to the eye over Pennsylvania, New York and New England.

\textit{ii. Rainfall forecasts}

Figure 9 shows the rainfall over Pennsylvania in 6-hourly increments for the periods ending 25/0600, 25/1200, 25/1800 and 25/0000 UTC. These data show the light rain ahead of the front ending at 25/0600 UTC over eastern Ohio and western Pennsylvania. By 25/1200 UTC the rain was over central Pennsylvania and western New York and had ended over Ohio. This likely allowed the field to dry for the Big Ten football game between The Ohio State University and the Pennsylvania State University.

The periods of heaviest rain over New York were the 6-hour periods ending at 25/1800 and 26/0000 UTC. It was during this time that the low-level winds and anomalies had peaked and when the highest PW anomalies had moved over the region.

\textit{iii. Forecasts}

There are many forecast aspects about this event which could be discussed. The focus here is on the pattern and probabilities with an emphasis on brevity. It should be noted...
that the potential for 1-2 inches of rainfall on 25-26 October 2008 was indicated in the GEFS as many as 6 days in advance, though the emphasis was on a more easterly wind driven event type.

Figure 10 shows the pattern as predicted by the successive 0900 UTC SREF runs initialized at 22, 23 and 24 October 2008. Each forecast cycle showed the surge of high PW air into the region in a south to north orientation. Clearly, the longer range forecasts showed more uncertainty which likely created the lower anomalies. Note that forecasts from 22/0900 showed only 1 to 1.5SD PW anomalies while shorter forecasts showed 2 to 3 SD PW anomalies. This can be attributed to a convergence of forecasts. The key point is that the surge of high PW air and the frontal system were similar in these forecasts. Later forecasts, in the mean fields were faster slower than older forecasts and observations (Fig. 6).

The SREF 850 hPa winds for the same times are shown in Figure 11. These data show the strong southerly 850 hPa jet over the region. The same pattern of generally stronger anomalies, showing more agreement and less uncertainty is evident in these data. The data in Figures 9 & 10 show the classic Maddox Synoptic type of heavy rainfall pattern. The sharp frontal boundary and the strong southerly flow into the region in the observational data (Figs. 3-7) and these forecasts facilitate identification of the event type.

The SREF precipitation forecasts are shown in Figure 12. Note that the 22 October data is from the 1500 UTC cycle due to missing QPF grids in the 0900 UTC cycle. It is clear all three runs indicated a widespread 1 inch or greater event. Due to timing and location issues, each forecast had a different region where over 1 inch of QPF was a highly likely event. The details with QPF often remain an elusive as heavy rainfall often is driven by mesoscale processes.

For comparison purposed, the GEFS 1.00 inch QPFS on a larger projection are shown in Figure 13. The GEFS showed a similar threat but with a higher probability of 1 inch or more of QPF over Pennsylvania and New York than the SREF. Similar to the SREF, the GEFS also showed timing issues with the forecasts from 22/1200 UTC being slower and the forecasts from 24/1200 UTC being faster with the arrival and ending of heavy rainfall.

The value of the higher resolution deterministic models can not be understated, thus NAM and GFS QPF’s are shown in Figure 14. These data show that both models forecast heavy rainfall over Pennsylvania and New York State. Due to resolution differences, the high resolution NAM at 12km and the lower resolution GFS at 40km, the NAM show mesoscale details not evident in the coarser GFS. The 40 mm contours in the GFS indicated it over forecast the rainfall over a broad region. Compared to a verifying field (Figure 15) both models failed to move the rainfall area eastward as fast as it progressed.

4. CONCLUSIONS

A fast moving frontal system brought a short-lived period of moderate to heavy rainfall to the Mid-Atlantic region on 25-26 October 2008. The north-south frontal orientation and the strong low-level southerly winds identified this event as a Maddox Synoptic type event (Figs. 3-7). Overall rainfall was between 25 and 75 mm (1-3 inches) with a few areas in eastern Pennsylvania and south-central New York
State where 100 mm (4 inches) of rainfall were observed.

The SREF forecasts showed that the SREF correctly predicted the pattern associated with a Maddox Synoptic type event at least 3 days prior to the onset of the rainfall (Figure 9). Though not shown, the GEFS was equally successful at predicting the pattern. When the GEFS, with a current horizontal of about 100 km, is improved to 70 km in December 2008 it should improve on its ability to predict these mesoscale event types.

The PW and wind anomalies in the SREF showed that as the uncertainty decreased, as a function of forecast length, the value of the anomalies increased. Thus, the anomalies are a gage of the uncertainty in the forecasts. Though not shown, the NAM and GFS forecasts showed the potential for 2-3 SD PW anomalies several days in advance as they were unencumbered by uncertainty issues.

Both the GEFS and SREF did reasonable job showing the potential for 25 mm (1 inch) or more QPF. Due to timing and other uncertainty issues, the details remained quite elusive. This fact was also evident in the QPFs produced by each model (Fig. 14) which showed in 12 hour increments that the NAM and GFS showed differences, between forecasts cycles, in the location and amounts of rainfall which would accumulate. Note the 12 mm difference between the 24/0000 and 24/1200 UTC NAM QPF over Pennsylvania. Additionally, compared to Figure 15, this heavy rainfall was forecast too far west relative to observations.

The GFS QPFs showed similar variations and differences in the details of the QPF values and locations. The large area covered by the 48 mm contours from the 24/0000 UTC GFS was narrower and more focused in the 24/1200 UTC forecasts. Additionally, he forecasts from 24/1200 showed a narrow area of 72mm and greater rainfall in central Pennsylvania. Clearly, the GFS had too much rainfall too far west in the forecasts from 24/1200 UTC with the 24mm contour extending well westward into Ohio. The NAM showed a slight tendency toward the same error.

The overall similarity in the QPFs between the SREF (Fig. 12) and GEFS (Fig. 13) indicated both EPSs had similar forecasts of the larger scale pattern (not shown though examined and verified). Thus, they predicted a similar outcome and general evolution. These similar solutions were, perhaps an indication of a predictable event. The high resolution models also indicated a similar outcome. Thus, the details were not clear, the overall pattern and area of rainfall was relatively well predicted.

Getting the timing and location of the QPF, in terms of location, start and end times is important for a wide range of reasons. During this event, the fast moving rainfall allowed for improving conditions and fair weather for the PSU-OSU football game in Columbus, Ohio. However, the east, the slow exit of the rainfall delayed the onset of the World Series in Philadelphia.

5. Acknowledgements

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6. References

ingredients based approach.


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Figure 6. As in Figure 3 except valid at 1800 UTC 25 October 2008.
Figure 7. As in Figure 3 except valid at 0000 UTC 26 October 2008.
Figure 8. NAM 00-hour forecasts valid at (left) 1200 UTC and (right) 1800 UTC 25 October 2008 showing in upper panels a) wind vectors and u-wind anomalies (shaded) and b) wind vectors and v-wind anomalies.
Figure 9. As in Figure 1 except showing 6-hour rainfall for the periods ending at a) 0000 UTC, b) 1200 UTC, and 1800 UTC 25 October 2008 and d) 0000 UTC 26 October 2008.
Figure 10. SREF forecasts of PW initialized at 0900 UTC (left) 22 October, (center) 23 October and (right) 24 October 2008. Upper panels show each members 25, 12.5 and 6.25 contours and the spread about the mean (shaded) lower panels show the ensemble mean and the anomaly of this field compared to the climatology.

Figure 11. As in Figure 9 except showing 850 hPa winds with u wind anomalies in the upper and v-wind anomalies in the lower panels.
Figure 12. As in Figure 9 except showing SREF probability of 1.00 inches of rainfall in 24 hours ending at 0000 UTC 26 October. Lower panels show each members 1 inch contour and the ensemble mean precipitation. Note the far left panel is from the 1500 UTC 22 October cycle due to missing data in the 0900 UTC cycle.

Figure 13. As in Figure 12 except GEFS QPF from forecasts initialized at 1200 UTC 22, 23 and 24 October 2008.
Figure 14. NAM (left side) and GFS (right side) forecasts of accumulated QPF ending at 0000 UTC 26 October from forecasts initialized at 0000 and 1200 UTC 24 October 2008. Values in mm as indicated by the color bar at the bottom of each image.
Figure 15. As in Figure 1 except 24 hour Stage-IV rainfall data ending at 0000 UTC 26 October 2008.