Mid Atlantic Heavy rainfall event

With an inertial gravity wave?

By

Richard H. Grumm
National Weather Service, State College, PA 16803
Contributions from the Albany MAP

1. Overview

An unseasonably strong 500-hPa upper-level wave (Fig. 1) moved into the eastern United States on 5 May 2017. The 500 hPa heights were -3 to -4σ below normal. In the implied deep southerly flow on the east side of the 500 hPa trough there was a surge of deep moisture. The precipitable water (PWS: Fig. 2) was +2 to +3σ along the Mid-Atlantic and southern New England coastal zone. The deep moist flow produced a significant rainfall event as shown in Figure 3. Broad areas of central Pennsylvania had 25 to 50 mm of rainfall and over 50 mm of rainfall was observed over New Jersey.

The subtle streak of 24 to 48 mm of rainfall in the Susquehanna Valley into southern New York will be addressed later in the paper. This feature, in addition to producing a brief period of heavy rainfall, was associated with rapid pressure fall and rise couplet of 5-7 hPa (Fig. 4). From the mid-Susquehanna Valley and into southern New York close to the time of the pressure fall there were strong and damaging winds. Behind the wave as the pressure rose, the precipitation ceased (Fig. 4) to the south.

The feature which moved through Pennsylvania and New York had 5-minute pressure traces which showed sharp 5-7 hPa pressure falls then similar rises as the wave moved to the north-northeast. These values are in line with the gravity wave diagnosed by Bosart and Seimon (MWR 1988) and Bosart et al. (1998). The event also occurred on the cool side of a surface boundary (Fig. 3 Bosart and Seimon 1988) between the downstream trough and the upstream ridge. The synoptic settings for gravity wave evolution are summarized in Uccellini and Koch (1987: See their Fig. 1).

This short paper will summarize the Mid-Atlantic heavy rainfall event of 5 May 2017. The focus is on the pattern and the feature which contributed to local QPE maximum and the focused area of high wind and wind damage.

2. Methods and Data

The NCEP 3 km HRRR and the climate forecast system reanalysis version II (CFSR) were used to diagnose and reconstruct the meteorological setting for the event. Traces of the pressure trends were retrieved from Weather Underground and ASOS sites.

The rainfall was retrieved using the NCEP CCPA QPE analysis. As of this time the Stage-IV feed had not updated since 2 May 2017.

Radar data from KCCX and the MRMS radar products were used to show the evolution and estimate the speed of the wave. Most estimates using the AWIPS-II tracking tools were on the order of 50 to 50kts.

3. Pattern

The 500 hPa pattern (Fig. 5) shows the deep trough in 6-hour increments from 0000 UTC 5 to 0600 UTC 6 May 2017. The region between the trough and the 500 hPa ridge is an area which...
favors the potential development of gravity waves (Uccellini and Koch 1987: Fig. 1). At the surface, a deepening cyclone moved from the Tennessee Valley into the Mid-Atlantic region between 0000 UTC 5 May through 0600 UTC 6 May 2017. The time of the high winds and enhanced rainfall occurred between 1500 and 1800 UTC (Fig. 6c-d).

The 850 hPa isotherms (Fig. 7) show the quasi east-west boundary in the Mid-Atlantic region implying cool and stable air north of the boundary from Pennsylvania into New York. The PW field (Fig. 2) showed the surge of deep moisture and above normal PW mainly along the coastal plain with some deeper moisture moving over the implied frontal boundary. The 850 hPa winds (Fig. 8) showed a surge of strong southerly flow over the frontal boundary. The winds were 27 to 33 ms-1 over Pennsylvania and New York between 12 and 1800 UTC (Figs. 8c-d).

The NCEP 12km NAM was used to produce soundings at points near Harrisburg (KMDT) and Selinsgrove (KSEG) are shown in Figure 9. The 1500 UTC sounding at KSEG showed a stable boundary layer with and inversion near 880 hPa. Above the inversion the winds veered rapidly and were generally greater than 50 kts. The KSEG was conditionally unstable above the inversion to about 300 hPa. The 1200 UTC sounding at KMDT lacked the pronounced low-level inversion that was present in the KSEG sounding. It did show the same veering profile and strong winds in the 900 to 300 hPa layer.

The 3km HRRR 1 hour pressure change and 1 hPa analysis from 1500 to 1700 UTC is shown in Figure 10. At 1600 UTC the pressure wave was located in the central Susquehanna valley in close proximity to where the high wind and damage was reported. The feature appeared to amplify as shown in the 1700 UTC image.

4. Impacts

The 3-hour QPE during the period the wave moved through Pennsylvania is shown in Figure 11. The heavier rainfall clearly fell along the coastal plain in the deep moisture plume. However as shown in Figure 11f there was a locally enhanced stripe of heavier rain which moved up into the Susquehanna Valley. And after the wave passed through the region there was little additional significant precipitation in the region.

The total QPE (Fig. 12) for the event shows the enhanced axis of heavy rainfall likely associated with feature of interest.

Several METAR sites experienced wind gusts as the wave moved through the region. However the main impact was strong winds snapping and uprooting trees. This lead to a surge in power outages (Fig. 13) mainly in central Pennsylvania to the New York border (not shown). Wind damage reports are shown in Figure 14.

It should be noted that the first call from a 911 center came in at 1616 UTC. It was a report of an ongoing tornado. With more information the center called back around 1630 UTC. More reports followed between 1630 and 1700 UTC. A false funnel cloud picture was also reported. The salient point is that the damage was reported too late to provide useful warning information. One 911 Centre reported as many as 200 reports in their county.

1 Based on surface observations and personal weather stations, the temperatures were mainly the upper 40s to lower 50s in Pennsylvania during the heavy rainfall.
received about 10 reports of wind damage. But overall the number of known potential reports was on the order of 200\(^2\) despite the fact that over 20,000 customers lost power.

5. Pressure traces

The HRRR was used to show the larger scale evolution of the pressure perturbation. Individual METAR locations were examined. Several had the highest wind gusts near the time of lowest pressure and the winds were from the east. This matched well with damage reports which as one reported stated “Almost all were trees laid out in an East to West configuration”

The station pressure trace from KSEG is shown in Figure 15. The lowest pressure occurred at 1530 UTC (1130 AM EDST) with an east wind at 30 with a gust to 47 kts. There was a sharp pressure rise from 1530 through 1610 UTC when the larger scale pressure trend reflected the approaching surface cyclone (Fig. 6). The pressure fall and rise were timed at KCXY (1500 UTC) and KMDT (1605 UTC) and KBGM (1720 UTC). The plot of the pressure at KBGM is shown in the upper right panel of Figure 16.

Many personal weather stations are accessible online and the plot from Watsontown, PA was retrieved (Fig. 17). These data too show passage of the pressure trough and rise and they imply multiple sources to track potential similar events in real-time.

6. Radar

The MRMS composite radar data were used here as they captured the feature better than a single radar. It should be noted that the high winds, and the pressure traces of the rise-fall couplets were on the extreme western edge of the reflectivity. And no lightning was observed in the echoes.

At 1254 UTC the radar data showed several north-south enhanced band in Maryland with a more general weak area of reflectivity and rainfall in Pennsylvania (Fig. 18 upper). By 1414 there were still some band including one in south-central Pennsylvania. The feature of interest is highlight by the red arrow and it was over northern Maryland at this time.

By 1540 UTC (Fig 19), within the time window of many of the wind damage reports, the feature was over central Pennsylvania. By 1656 UTC the feature developed a unique appendage over northeastern Pennsylvania as it continued northward into southern New York State.

Velocity data was examined using KCCX radar (not shown). Winds on western edge of the feature were at times in the 40 to 58kt range. Most of these high winds were 6 to 8kft above the surface.

7. Forecast data

The 00-hour HRRR “analyses” were used to show the pressure trough and the rise fall couplets associated the theorized IGW. An examination of HRRR forecasts showed that the HRRR forecast and intense area of rainfall and rapid moving simulated echoes to zip across Pennsylvania from 1200 UTC to 1700 UTC on 5 May 2017. Timing these features suggested the

---

\(^2\) One 911 center said they had received about 200 calls. Most had one or two reports. Most citizens never call 911 centers.
HRRR speeds were in the 35kts range. Examples of the HRRR radar from the 1400 UTC HRRR is presented in Figure 20.

Figure 21 shows the HRRR QPF from the same forecast cycle. The upper panel shows the total QPE ending at 1800 UTC and the lower panel shows the QPF for the 1 hour period ending at 1800 UTC. The key point of the lower panel is that behind the wave the HRRR rapidly decreased the QPF similar to how the QPE and radar in the observed atmosphere ceased. The 6-hour QPF field showed the higher QPF amounts in New Jersey but similar to the CCPA data it too showed a secondary streak of higher QPF in central Pennsylvania.

Though not shown, shorter range HRRR QPFs showed even lower QPF amounts behind the wave.

8. Summary

An unseasonably strong 500-hPa upper-level wave (Fig.1) pushed warm moist air into the Mid-Atlantic region producing a widespread moderate to heavy rainfall event on 5 May 2017. Shallow cold air with a conditionally unstable layer above the cold air may have combined to allow an IGW to propagate northward across central Pennsylvania into New York State. This wave as I moved across Pennsylvania and into New York produced strong easterly wind gusts at several METAR sites and produced a swath of damaging winds which downed trees and power lines.

Pressure traces at several METAR sites showed the classic rapid pressure fall then sudden rise the pressure began to fall again in response to the approaching surface low pressure system. The wave produced pressure falls of 4 to 7 hPa and comparable rises as the wave passed. At all the examined sites the pressure began to slowly fall again as the low approached. Model soundings showed shallow cold layer with an inversion below 800 hPa and deep conditionally unstable layer to about 300 hPa. Winds in this layer were over 50 kts.

Radar data was used to show the feature along its path. These data showed stronger but not convective looking echoes head of the wave and a relative dearth of intense echoes and rain behind the wave. The passage of the wave was accompanied by strong easterly winds and heavy rainfall. The winds and rain abated behind it.

The NCEP HRRR was used to show the pressure perturbation and the rise-fall couplets as the system moved across Pennsylvania. The HRRR forecasts of the radar and QPF suggest that the HRRR was clearly able to simulate this feature, move it rapidly across Pennsylvania into New York and it was able to produce the narrow area of enhanced precipitation which was observed during the event. Clearly, the HRRR has the ability to simulate these fast moving intense systems.

9. Acknowledgements

Thanks to Charles Ross for processing and plotting 5-minute ASOS data in Excel. The Albany MAP provided more information as to the extent of the wave and the impacts into New York and Vermont. Information on gravity waves and details related to gravity waves was provided by Lance Bosart, Anton Seimon, and Louis Uccellini as a thread off the Albany MAP.

10. References


Figure 1. CFSR 500 hPa heights and height anomalies in 24-hour increments from a) 0000 UTC 22 May through f) 0000 UTC 07 May 2017. Contours every 60m shading in standard deviations from normal. Black dot is the location of Raleigh, NC. Return to text.
Figure 2. As in Figure 1 except for the precipitable water (mm) and PW anomalies from a) 0000 UTC 5 May through f) 0600 UTC 6 May 2017. Return to text.
Figure 3. Stage-IV QPE in 12 hour increments from a) 0000 UTC 05 May 2017 b) 1200 UTC c) 1200 UTC 5 May 2017 and d) total QPE for the 36 hour period. [Return to text]
Figure 4. Upper panel shows the 3km HRRR 1 hour pressure falls (hPa; shaded) and the mean sea-level pressure (hPa) in 1 hPa intervals. The lower panel shows the 3-hour QPE as estimated by the CCPA ending at 1800 UTC. Return to text.
Figure 5. As in Figure 1 except zoomed in over the eastern United States and for every 6 hours from a) 0000 UTC 5 May through f) 0600 UTC 6 May 2017. Return to text.
Figure 6. As in Figure 5 except for CFSR mean-sea level pressure (hPa). Return to text.
Figure 7. As in Figure 6 except for 850 hPa temperatures and temperature anomalies. Return to text.
Figure 8. As in Figure 7 except for 850 hPa wind in ms$^{-1}$. Return to text.
Figure 9. KSEG (top) and KMDT (bottom) soundings from the NCEP 12km NAM. The KSEG sounding is a 3-hour forecast valid at 1500 UTC and the KMDT sounding is a 00-hour forecast valid at 1200 UTC. Return to text.
Figure 10. NCEP HRRR pressure analysis (hPa) at every 1 hPa and the 3-hour pressure change (hPa: shaded). The red arrow depicts the general pressure trough and the associated trough.  

Reference: [Return to text](#).
Figure 11. The CCPA 3-hour total QPE in 3-hour increments for the periods ending at e) 1200 UTC, f) 1500, and g) 1800 UTC 5 May. Values in millimeters as in the color bar. The white arrow shows the enhanced rainfall maximum with the wave and is drawn to the right as not to obfuscate the data. Return to text.
Figure 12. As in Figure 11 except for the event total estimated QPE. Return to text.
Figure 13. DOE site reported power outages in Pennsylvania by hour from 5 to 6 May 2017. Return to text.
Figure 14. Locations of tree and power line damage received from 911 Centers on 5 May 2017. Times reflect estimates from 911 Centers and are unlikely to represent the actual time of the damage. The Blue Star shows a point that may have had damage about 1 hour prior to all other reports represented by red stars. 

Return to text.
Figure 15. Trace of 5 minute station pressure at the Selinsgrove METAR site. Data on 5 May 2017 and are in local time. Values were converted to millibars and plotted in Excel. The peak wind and direction is shown. It should be noted there were gusty east winds as the pressure trough approached. Return to text.

Data were retrieved in text format from

Figure 16. Trace of parameters on 5 May at Binghamton, NY. The wind and wind gusts with the pressure traces is in the upper right panel. The timing in the text was based on the METAR text data. Return to text.
Figure 17. Pressure trace from Watsontown, PA from the Weather Underground. The large fall and rise couplet occurred short before 1200 PM (1600 UTC). Return to text.
Figure 18. MRMS composite reflectivity valid at 1254 (top) and 1414 UTC 5 May 2017. The red arrow shows the feature of interest and the red curve outlines this feature. Return to text.
Figure 19. As in Figure 18 except showing the AWIPS-II timing tool and data valid at 1540 UTC and 1656 UTC. The yellow lines track near the path of the pressure traces and wind damage. Return to text.
Figure 20. The 3km NCEP HRRR forecasts initialized at 1200 UTC 5 May showing the evolution of the synthetic radar in 2-hour intervals from 1400 to 1800 UTC 5 May.

Return to text.
Figure 21. As in Figure 20 except for the upper panels showing the total QPF for the 6-hour period ending at 1800 UTC 5 May. The lower panel shows the QPF for the 1 hour period ending at 1800 UTC 5 May 2017. Please note each forecast has a different color bar for the QPF (inches). The lower panel also has the isobars (2 hPa interval). Return to text.