Beijing flood of 21 July 2012

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1. Overview

Flow about a strong mid-level anticyclone (Fig. 1) pushed tropical moisture into eastern China on 20-21 July 2012 resulting in one of the heaviest rain events in Beijing in the past 60 years (NY Times 2012). The 150 mm (6 inches) of rain collapsed roofs and produced flooding. The flooding claimed 37 lives and forced the evacuation of 50,000 people. The town of Fanshan reported in excess of 450 mm (18.10 inches) of rain. The precipitable water (PW) values peaked near 70mm near Beijing (Fig. 2c) which was about +3σ above normal. The PW field showed a tight gradient and a surge of drier air moving in from the west (Figs. 2d-f) implying a frontal system and mid-tropospheric disturbance moving into the region contributed to the lift the resulting record rainfall (Fig. 3).

Satellite estimated rainfall for 21 July 2012 (Fig. 3) suggests most of the rain fell over Hebei province and over the cities of Beijing and Tianjin and along the coast of the Yellow Sea. The satellite rainfall showed an expansive area of over 150 mm and areas of in excess of 200 mm of rainfall. This is in reasonable agreement with the limited observations but does not show the 450 mm over Fanshan which is in a valley west of Beijing.

The deep PW plume (Fig. 2) is a signature often associated with heavy rainfall (Junker et. al. 2008). The use of standardized anomalies to identify high impact weather events has been demonstrated by Hart and Grumm (2001), Grumm and Hart (2001), and Graham and Grumm (2010). Many high impact weather events, including flood events often contain useful signals to aid in identifying many high impact events. Grumm (2011) showed the value of standardized anomalies in identifying the extreme and enduring Russian heat wave of July-August 2010. The flow about this anticyclone and the deep cyclone beneath was associated with the extreme flooding in Pakistan in July 2010 (Galarneau et al. 2012; Grumm 2011). Many mid-latitude heavy rainfall events are associated with a plume of deep moisture on the western flanks of strong downstream anticyclones (Junker et. al. 2009);

This paper will document flooding in Beijing and the surrounding regions. The focus is on the pattern and anomalies which produced the heavy rainfall. NCEP model and ensemble guidance are presented to address the predictability of this event.

2. Data and Methods

GFS 00-hour forecasts were used to diagnose the pattern over China and the adjacent oceans. The NCEP/NCAR re-analysis data were used to compute the standardized anomalies of these fields. The focus was on fields often associated with heavy rainfall.

The GFS, GEFS, and EC model data were used to examine the forecasts of the pattern (not shown) and the potential quantitative precipitation forecasts. The NCEP models were...
retrieved and archived in real-time. The other models used, including the EC models and ensembles were retrieved from the European Center for Medium-Range Weather Forecasts (ECMWF) TIGGE site.

Satellite data were taken from the Climate Prediction Center (CPC) CMORPH site. The 24-hourly version of the CMORPH data were used to get an estimate of the heavy rainfall and the 3-hourly data were used along with Chinese Meteorological Agency (CMA) reports to narrow down the time window of the rainfall.

All model and CMORPH data were displayed using GrADS.

3. The large scale pattern associated with the flood

The large scale pattern (Fig. 1) showed the 500 hPa field and anomalies. These data showed the large ridge over northeasternmost China at 18/1200 UTC. The 500 hPa heights were 3σ above normal. The ridge began to weaken and slide to the south (Fig. 1b-e). Part of the erosion of the northern extent of the ridge was due to an approaching 500 hPa trough which lowered the heights over much of eastern China and Korea. A tropical storm, well away from the rain in Hebei was present by 22/1200 and 23/1200 UTC.

As with many large ridges, a plume of deep moisture and above normal PW surge poleward on the western flanks of the ridge (Fig. 4). The moisture plume was well defined by 21/1200 UTC with a significant tropical connection. The regional view of the PW (Fig. 2) and PW anomalies showed the surge of high PW air over Hebei and the region about Beijing. The PW values were over 60 mm from 21/0600 through 21/1800 UTC (Fig. 2c-e) and then began to fall rapidly as drier air moved in from the west. The PW values peaked at over 70 mm (Fig. 2d-e) with +4 to +5σ PW anomalies over Hebei Province. Experience and recent research shows that many high end rainfall events are associated with +2 to +4σ PW anomalies. This event had anomalies approaching 5σ above normal.

The deep moisture and strong winds ahead of the frontal boundary (Fig. 6) produced large values of 850 hPa moisture flux (Fig. 7) with moisture flux anomalies in excess of 6σ above normal from 21/1200 UTC though 22/0600 UTC. Fortunately, the region of extreme moisture flux did not persist at any location and the strong implied forcing kept moving to the east. Though a good pattern for heavy rainfall, this was not an enduring event. The best forcing over Beijing (blue dot in Fig. 7) was from 21/0600 UTC through 21/1200 UTC. After which the higher winds (Fig. 6) and high values of moisture flux (Fig. 7d) had moved to the east.

4. Satellite data

MTSAT and FY2D geostationary imagery was available and made into loops to evaluate the evolution of the event. Due to navigation issues the focus here is on MTSAT data. The MTSAT imagery showed a north-south band of enhanced clouds west and southwest of Hebei at 21/0101 UTC (not shown). Initial enhanced convective elements were apparent by 21/0514 UTC.
By 21/1001 UTC there was enhanced convection over Hebei Province west of Beijing which developed rapidly and appeared to back-build (Fig. 8) through at least 21/1401 UTC (Fig. 8). The back-building process resulted in a massive mesoscale convective complex (MCC) which extended from the Yellow Sea westward over most of Hebei Province. The strong low-level southerly flow at 850 hPa (Fig. 6) supported back-building as the source of warm moist air was from the south.

The cold cloud top area began to shrink and move to the northeast from 21/1400 to 21/1600 UTC before undergoing a second surge of back-building around 21/1700 UTC (Fig. 9) resulting in an expansive cold cloud shield by 21/1900 UTC. This process continued through 22/0000 UTC, however the area of enhanced convection and inflow had moved well to the south and east of Hebei Province and Beijing.

The FY2D imagery showed the evolution from a better angle and captured the initial surge of back-building elements at 21/1546, 21/1616 until the merger with the larger MCS (Maddox 1980) at 21/1716 UTC (Fig. 10). The arrow in Figure 10 shows the merger of the new elements and the track of the new convection.

5. **Quantitative Precipitation forecasts**

The larger scale pattern for this event was relatively well predicted by the NCEP models and ensemble forecasts systems with about a 4 day lead-time. Prior to 16/1800 UTC (Fig. 11a) the NCEP GFS had difficulty with the location and potential for heavy rainfall over Hebei Province. As the strength of the frontal boundary and moisture plume increased in the model (not shown) the QPF forecasts rapidly began to produce heavy rainfall in the correct region (Fig. 11b). The QPF amounts began to exceed 100mm on and after 17/0000 UTC (Fig. 11b) and the area covered by the potential for in excess of 100mm rapidly expanded over the next 2 successive 24 hour forecast cycles (Fig. 11c-d). Intervening 6 and 12 hour GFS QPF showed similar patterns and trends (not shown).

Shorter range NCEP GFS forecasts showed a continued trend of increased predictability of the pattern (not shown) and the corresponding continued forecasts of heavy rain over Hebei Province (Fig. 12). The 19/1200 UTC GFS had over 200 mm of QPF (Fig. 12b) likely indicating the convective parameterization scheme was responding to significant and persistent instability. In a general sense, the GFS was predicting the potential for 100 to 150 mm over Hebei Province and near Beijing. The location and QPF amounts showed considerable run-to-run variability but the area of concern was consistent.

Forecasts from most GFS cycles showed the surge of high PW air into the region to include the strong low-level jet, high PW, with PW values over 70mm and the strong moisture flux. The pattern from the 20/0000 UTC GFS valid at 21/1200 UTC is shown (Fig. 13) as an example of the correctly predicted large scale pattern which produced the heavy rainfall event and allowed the GFS to predict over 100mm of rainfall in the correct relative region.
The NCEP GEFS forecasts of the QPF showing 50mm and 100mm in the critical 12 hour period are shown in Figures 14 & 15 respectively. The probability of 50mm or more QPF were well predicted at least 3 days in advance in the correct general region of eastern China. Additionally, the 100 mm QPFs (Fig. 15)

6. Summary

The GFS 00-hour forecasts and the standardized anomalies depicted a nearly textbook example of a Maddox Synoptic heavy rainfall event. The deep plume of above normal PW and the 3-5σ above normal PW anomalies (Fig. 2) were aligned in a general south to north pattern in a region of strong 850 hPa winds (Fig. 6). These strong winds and anomalous PW values produced high values of 850 hPa moisture flux (Fig. 7) and periods when the moisture flux exceed 6σ above normal. The Pakistani Floods of July 2010 and the January 2011 flood in Australia are the type of high-end flood events which have been associated with moisture flux anomalies in excess of 5σ. This event shared many of the key characteristics often associated with high-end and relatively predictable heavy rainfall and flood events. The pattern for heavy rainfall was one of the more common patterns found about the world.

Satellite imagery showed the development of an MCC (Maddox 1980) over Hebei province after 21/0500 UTC. The MCC underwent back-building, the back building scenario and potential was indicated by the strong low-level southerly flow and the inflow of high PW into the region from the south. The pattern favored a general north-south axis if heavy rain and the plume of deep moisture on strong southerly low-level favored the potential for new convective elements developing on the southern flank of the convection (Corfidi 2003:Fig. 6). The strong low-level southerly winds and plume of anomalous PW into the region implied this back-building event in a classic Maddox-Synoptic type pattern (Maddox et. al 1979) had the potential to be a record event.

The GFS QPF forecasts suggest that in terms of the potential for a significant QPF event over Hebei Province and in the vicinity of Beijing were relatively predictable with at least 4 days lead-time. The high predictability is likely related to the strong signal in the synoptic pattern. Though not shown, the GFS was able to produce the large scale pattern with similar anomalies to those shown in the overview section related to the large scale and regional pattern. The GFS was able to correctly bring a plume of above normal PW and strong low-level flow into the region. The Maddox Synoptic heavy rainfall pattern is fortunately a pattern that is relatively quite predictable by both regional and global scale models. The details of where the QPF falls relative to verification are subject to considerable uncertainty. The key is for forecasters to recognize the pattern and use the QPF and probabilities of extreme QPF values to aid in decisions to planners for potential high impact weather events.

The NCEP GEFS forecast of 50 and 100 mm of QPF (Figs. 14 &15) suggest that the relatively coarse global ensemble, at 55km resolution was able to predict the potential for heavy
rainfall in the correct region. This implies that the larger scale pattern which produced the heavy rainfall was relatively predictable, despite the overall convective nature of the event. Clearly, both the 55km GEFS and 27km GFS were able to predict this potential high impact heavy rainfall event. Rather unique in this event is the ability of a global model and ensemble forecast system to predict over 100 mm of QPF in a 12 hour period. The internal model climatology of 100mm in this region of the world must be quite low and knowing the internal model climate may have added value. Knowing when the prediction system is predicting a record event is important, if not critical forecast information.

No high resolution models were run against these data. But it is likely that higher QPFs would have been provided by higher resolution guidance. Based on news reports, forecasters were able to predict this event quite successfully and provided some advanced warning. This implies good pattern recognition skills and good forecast guidance was well employed by the forecasters.

7. Acknowledgements
Kito Holliday provided initial news stories on the Beijing flood event. The Albany MAP provided insights and links to data and stories on the event too. Lance Bosart of the Albany map provided a summary of the event. Scott Lindstrom of SSEC at the University of Wisconsin provided all the satellite imagery. Jun Du of NCEP for input on news stories and forecast aspects of the event.

8. References
Corfidi, S. F. 2003: Cold Pools and MCS propagation: Forecasting the motion of Downwind-developing MCSs. WAF, 18,997-1017.


Figure 1. GFS 00-hour forecasts of 500 hPa heights (m) and height anomalies (standard deviations) in 24 hour increments from a) 1200 UTC 18 July 2012 through f) 1200 UTC 23 July 2012. Return to text.
Figure 2. As in Figure 1 except for precipitable water (mm) and precipitable water anomalies in 6-hour increments from a) 0000 UTC 21 July 2012 through f) 0600 UTC 2012.  

*Return to text.*
Figure 3. Satellite estimated rainfall (mm) for 21 July 2012 from the CMORPH satellite data set.
Figure 4. As in Figure 2 except in 24 hour increments from a) 1200 UTC through f) 1200 UTC 23 July 2012. Return to text.
Figure 5. As in Figure 2 except for 850 hPa winds and wind anomalies. The blue dot is the approximate location of Beijing. Return to text.
Figure 6. As in Figure 5 except for 850 hPa moisture flux. Return to text.
Figure 7. MTSAT 10.8 micron channel showing imagery over China at 0514 UTC and 1010 UTC. All satellite imagery courtesy of Scott Lindstrom of SSEC. Return to text.
Figure 8. As in Figure 7 except for 1100 and 1401 UTC. Return to text.
Figure 9. As in Figure 7 except for 1701 and 1901 UTC. Return to text.
Figure 10. As in Figure 7 except the FY2D satellite imagery, without navigation. The yellow line shows the track of feeder elements into the larger MCC. Return to text.
Figure 11. NCEP GFS quantitative precipitation forecasts (mm) over eastern China showing total accumulated precipitation for the 12 hour period of 0600-1800 UTC 21 July 2012 from the GFS initialized at a) 1800 UTC 16 July, b) 0000 UTC 17 July, c) 0000 UTC 18 July and d) 0000 UTC 19 July 2012. Shading as in the color bar to the right of each image and contours are 25,50,100, 150 and 200 mm. Return to text.
Figure 12. As in Figure 11 except for GFS forecasts initialized at a) 1800 UTC 18 July, b) 12Z 19 July, c) 0000 UTC 20 July, and d) 1200 UTC 20 July 2012.
Return to text.
Figure 13. The large scale pattern as predicted by the 0000 UTC 21 July 2012 NCEP GFS valid at 1200 UTC 21 July 2012 showing a) 250 hPa winds and wind anomalies, b) 850 hPa moisture flux and anomalies, c) 850 hPa winds and wind anomalies, and d) precipitable water and precipitable water anomalies. Return to text.
Figure 14. NCEP GEFS forecasts of 50mm or more QPF valid for the 12-hour period from 0600-1800 UTC 21 July 2012 from the NCEP GEFS initialized at a&d) 0000 UTC 18 July, b&e) 0000 UTC 19 July, and c&f) 0000 UTC 21 July 2012. Upper panels for each ensemble forecast cycle show the probability of 50 mm or more QPF and the ensemble mean 50mm contour. Lower panels show the ensembles mean QPF (mm) and each members 50 mm contour and the ensemble mean 50 mm contour. Return to text.
Figure 15. As in Figure 14 except for 100 mm of QPF. Return to text.
Appendix: MAP of Provinces and adjacent Seas.