A Review of the 23 June 2016 West Virginia Historic Flash Floods: Use of emerging observational technologies to monitor threats

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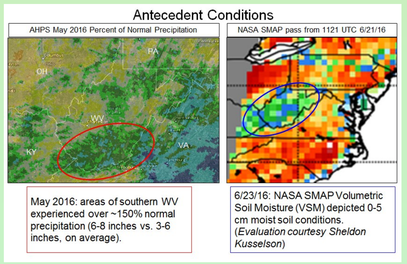
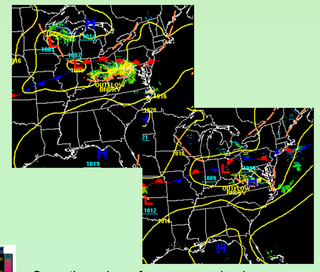
Summary of Historic Flash Flood/Flood Impacts

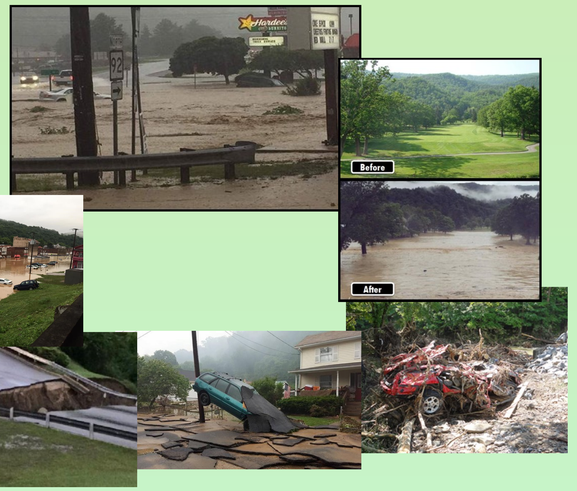
- Multiple waves of organized convection developed south of stationary front and in vicinity of outflow boundary, with high rain rates and damaging winds
- Max 24hr rainfall 8-10" (200-250mm), much of which fell in less than 12 hrs
- Multiple locations experienced record and near-record flooding on streams/rivers
- 23 fatalities (15 in Greenbrier County), well over $100 million in road/property damage with thousands of homes damaged/destroyed



Very moist soil conditions due to recent rainfall over the previous month (May), as well as much of the first half of June including just a few days before June 23. Slide courtesy of NCEP/WPC.



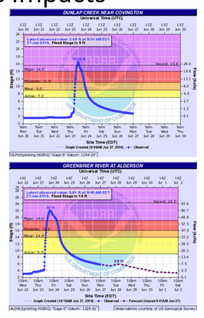
Synoptic scale surface maps and radar mosaics for 0900 UTC (left) and 1800 UTC (right) on 23 June 2016, indicating position of frontal boundaries and convective complexes. Maps created by NOAA/NCEP/WPC.



Photos of flooding and damage. Clockwise from top: White Sulphur Springs; Greenbrier Resort Golf Course before/during (PGA tournament for following weekend was cancelled, photo courtesy Greenbrier Resort), Destroyed car along Howard Creek near White Sulphur Springs; downtown White Sulphur Springs road/car damage; Elkview shopping center road washed out, stranding almost 500 people; downtown Clendenin (photo courtesy Robin Young)

Hydrologic Impacts

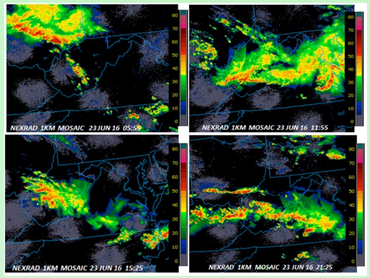
- Record flooding on Dunlap Cr. near Covington VA (16.49 ft.). Previous record was from remnants of Agnes June 1972.
- Jackson R. @Covington VA 22.33 ft. (3rd highest)
- Greenbrier R. @Alderson WV 22 ft. (3rd highest); last this high Jan 1996
- Greenbrier R. @Hilldale WV 25.45 ft. (3rd highest); last this high Jan 1996
- Gauley R. @Camden WV 39.75 ft. (record); previous record was 27.38 ft. July 1932
- Elk R. @Queen Shoals WV 33.37 ft. (record); previous record was 32.0 ft. Jan 1888!



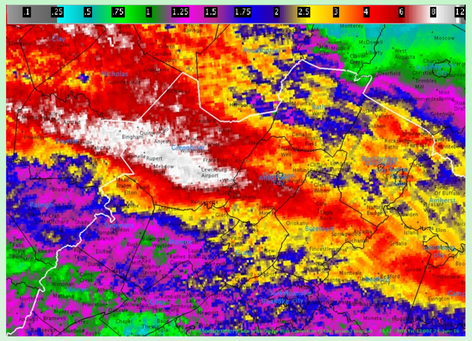
Summary of significant stream/river flooding (left) and two hydrographs (right): Dunlap Creek in Covington VA (top) and Greenbrier River at Alderson WV (bottom).

Watch/Warning Summary for NWS Charleston (RLX) and Blacksburg (RNK)

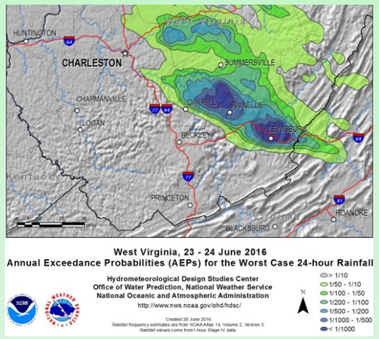
- FF Watches issued morning (RLX) and afternoon (RNK) of June 22
- FF Warnings (FFW) began early in the morning of June 23 and continued through late on the 23rd
- FF Emergencies were issued by both offices later in afternoon and evening:
  - 1623 (local time) for Town of Richwood WV
    - 1641 for all of Greenbrier Co WV
    - 1815 for Town of Clendenin
- 26 total FFWs (Avg Lead Time = 110min)
- In addition, 6 Tornado Warnings and 78 Severe Thunderstorm Warnings from late June 22 – June 23 were issued



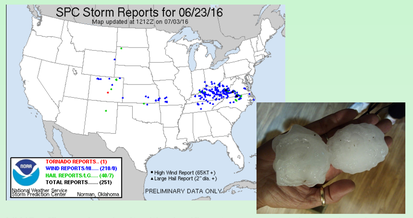
Radar reflectivity mosaic sequence for 0555 UTC 23 June 2016 (upper left), 1155 UTC (upper right), 1525 UTC (lower left), and 2125 UTC (lower right).



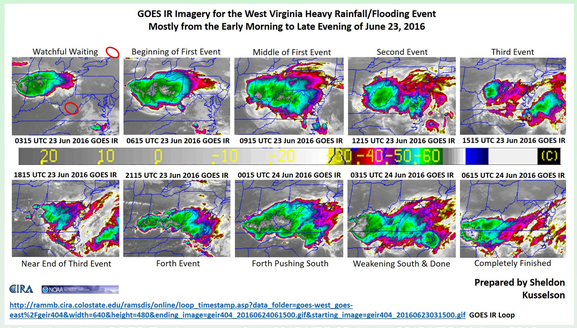
24 hr Multi-Radar Multi-Sensor (MRMS) rainfall estimates, biased-corrected with rain gauge data, ending at 1200 UTC 24 June 2016. Highest rainfall estimates are in Greenbrier County WV (8-10 in). Scale at top in inches.



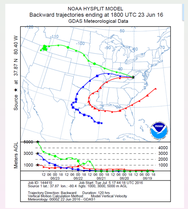
12 hr rainfall annual exceedance probabilities (AEP) for 23-24 June 2016, suggesting a probability of 1/1000 in any given year for the highest amounts in a couple of locations in WV (dark blue), and a 1/100 probability for rainfall amounts across a large area (green).



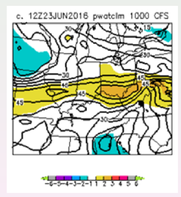
NWS offices also dealt with significant severe weather outbreak (wind damage and large hail) on 23 June 2016 from KY to NC.



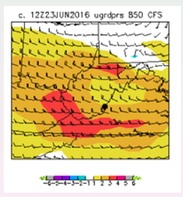
Infrared satellite (GOES-East) sequence from 0315 UTC 23 June – 0615 UTC 24 June 2016. Courtesy of WPC and prepared by Sheldon Kusselson (retired NOAA/NESDIS).



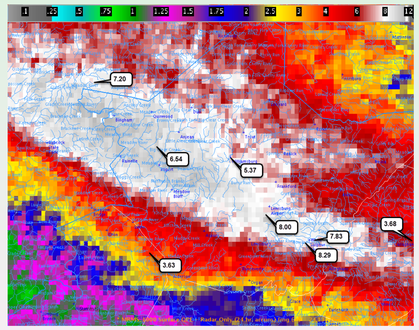
HYSPLIT trajectory analysis (based on GDAS) ending at 1800 UTC 23 June 2016, indicating low-level trajectories ultimately came from over oceans a couple days before.



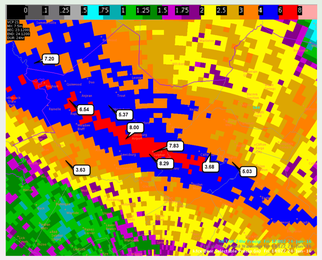
Precipitable water (mm) and anomaly (image) from CFS model, valid at 1200 UTC 23 June 2016. Black dot near location of max rainfall.



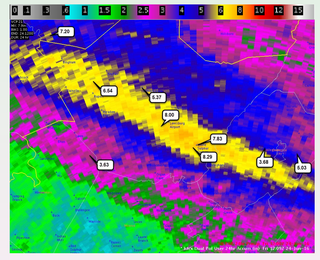
Same as on the left but 850 hPa U wind component (wind barbs and anomaly).



24 hr MRMS rainfall estimates (based on radar-only) for 24-hr period ending 1200 UTC 24 June 2016, overlaid with rain gauge reports for same period (values plotted in inches). Zoomed over Greenbrier County WV. MRMS estimates appeared to slightly over-estimate in some locations based on these gauge values, however there were a couple of unofficial reports over 10 in. in Greenbrier County. Scale at top same as gauge bias-corrected MRMS image above.



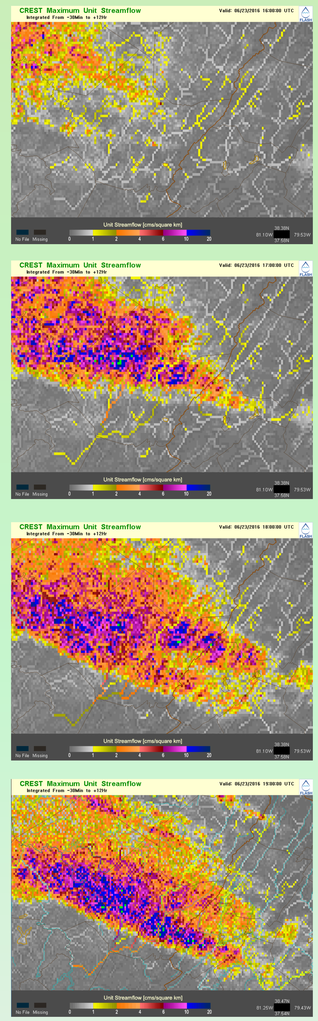
KFCX DHR (legacy) 24 hr rainfall estimates ending at 1200 UTC 24 June 2016. Rain gauge data for same period overlaid (plotted values in inches). Scale at top in inches, with blue representing 4-6", and red representing 6-8".



Same as on left but for DPR (dual-pol) 24 hr rainfall estimates and different color scale at top. Blue is roughly 4", yellow is roughly 6", and orange roughly 8". It appears the DPR estimates are similar, perhaps slightly higher, than DHR.

Flooded Locations and Simulated Hydrographs (FLASH)
(Courtesy Univ. of Oklahoma/CIMMS/NSSL, but now available real time at NWS Blacksburg and other offices)

Sequence of Max Unit Streamflow (CREST model)
1600-1900 UTC 23 June 2016



Between 1600 and 1700 UTC (3rd of the four convective waves), modeled runoff across much of Greenbrier increased dramatically. FF warnings (FFW) were already in effect except for eastern part of county, which was issued at 1720 UTC. The FF Emergency for entire county was issued at 2041 UTC. The extreme runoff values seen in these products between 1700-1900 UTC suggest potential to increase lead times on warnings and statements with strong wording.

Summary

- Historic FF event in terms of rainfall return frequency, fatalities, and stream/river flood levels
- Radar estimates, including MRMS, proved quite accurate (perhaps slightly on the high side) in areas with sparse gauge coverage and other radar limitations (range, topography of region, partial beam blockage), and were crucial for good warning decisions
- FLASH products (not viewed in real time during this event) show tremendous potential for monitoring FF and river flood threat levels, increasing lead times, and determining downstream impact locations and thus FFW polygon geography