Heavy Rainfall Event from the Mississippi River Valley to the Southeast
By: Sean Ryan, HPC Meteorologist

<u>Overview:</u> An historic heavy rain and severe weather occurred from the Mississippi River Valley eastward into the Southeast United States from May 1-5, 2010. The heavy rains in this event were particularly devastating for Tennessee, where over a foot of rain fell over the span of two days. Elsewhere across the affected region rainfall amounts of 5 to 10 inches were common. Figure 1 (panels a-d) show the observed 24 hour RFC Stage IV rainfall amounts ending at 8 AM (EDT) on May 2, 3, 4, and 5, respectively.

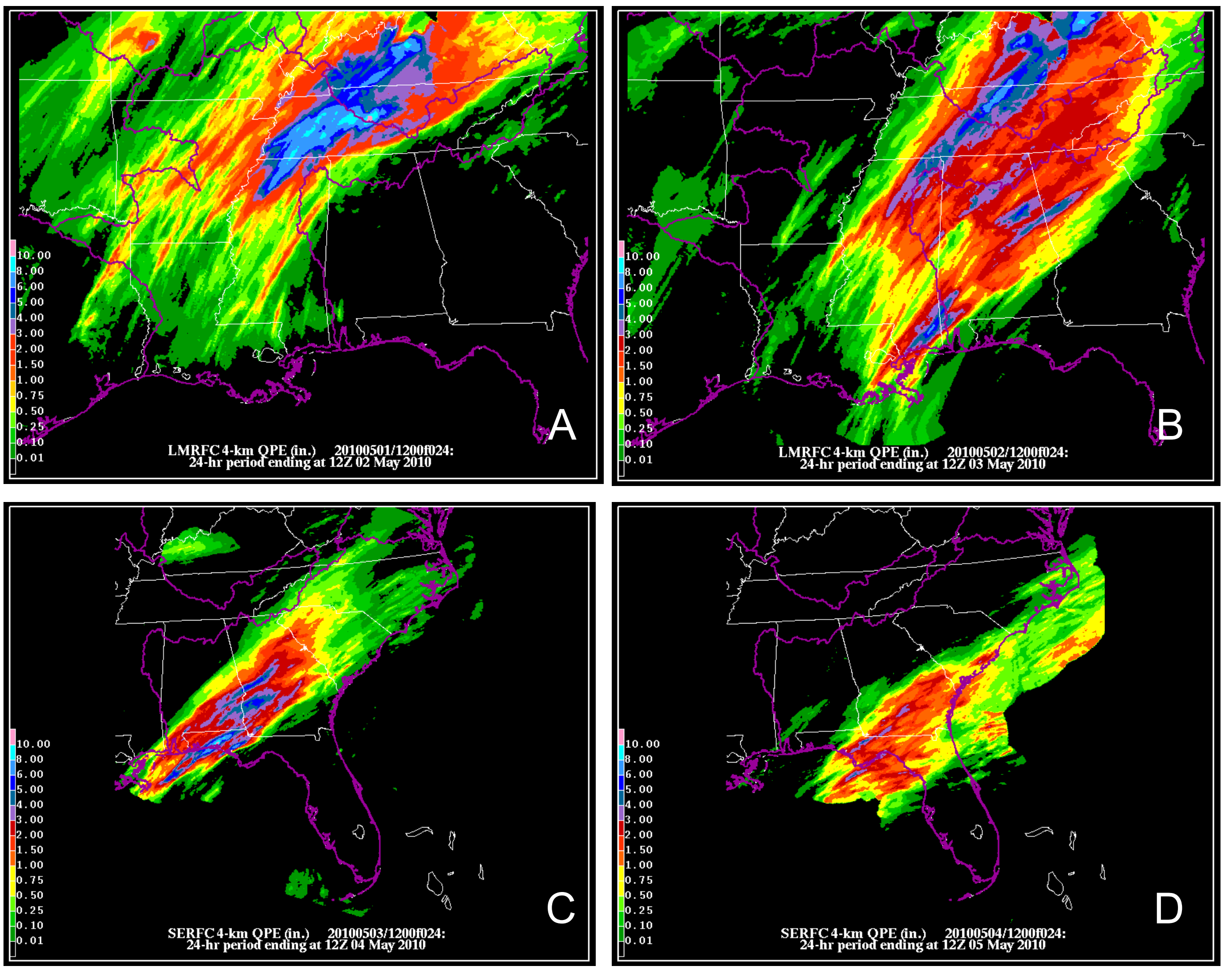

Figure 1: Total accumulated rainfall across lower MS River Valley from 8am (EDT) May 1 to 8am May 2, 2010 (A), May 2-3 (B), May 3-4 (C), and May 4-5 (D).

Figures 1A and B show that Tennessee received the heaviest rainfall on both May 1 and 2; the heaviest rainfall shifted southeastward to towards the coast on May 3-4. Rainfall records in the Tennessee Valley were shattered. A 24-hour rainfall record of 6.68 inches at Nashville was broken when 9.09 inches of rain fell in 24 hours. A two-day rainfall record at Nashville was also broken when 13.57 inches fell in two days (previous record was 6.68 inches). According to National Weather Service Storm Data, a total of 25 fatalities were reported in Tennessee, Kentucky, and Mississippi as a direct result of the flooding.

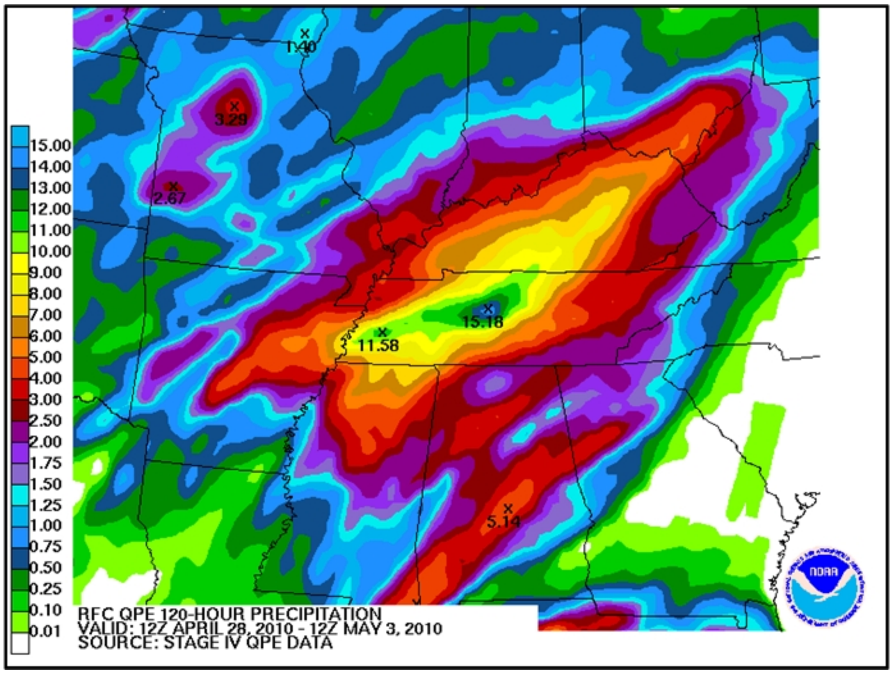

Figure 2: Total rainfall from 12 UTC on 28 April through 12 UTC on 3 May, 2010.

Figure 2 shows the total rainfall across this region from 28 April – 3 May. Maximum areal averaged rainfall amounts in excess of 15 inches occurred near Nashville during this time, with more widespread rainfall amounts of 8-11 inches across much of Tennessee and Kentucky. The highest observed rainfall at a point was 19.41 inches near Camden, TN. The Cumberland River near Clarksville, TN reached a record crest of 62.58 feet (flood stage is 46 feet). According to WFO Nashville, the amounts of rainfall that fell during a two-day period across much of Tennessee have recurrence intervals of greater than 1000 years.

In addition to the historic flooding, widespread severe weather, including tornadoes, was present during most of the event. Figure 3 shows the substantial number of tornadoes that occurred on May 1 (12 UTC 1 May to 12 UTC 2 May) in the same geographic area as the flooding.

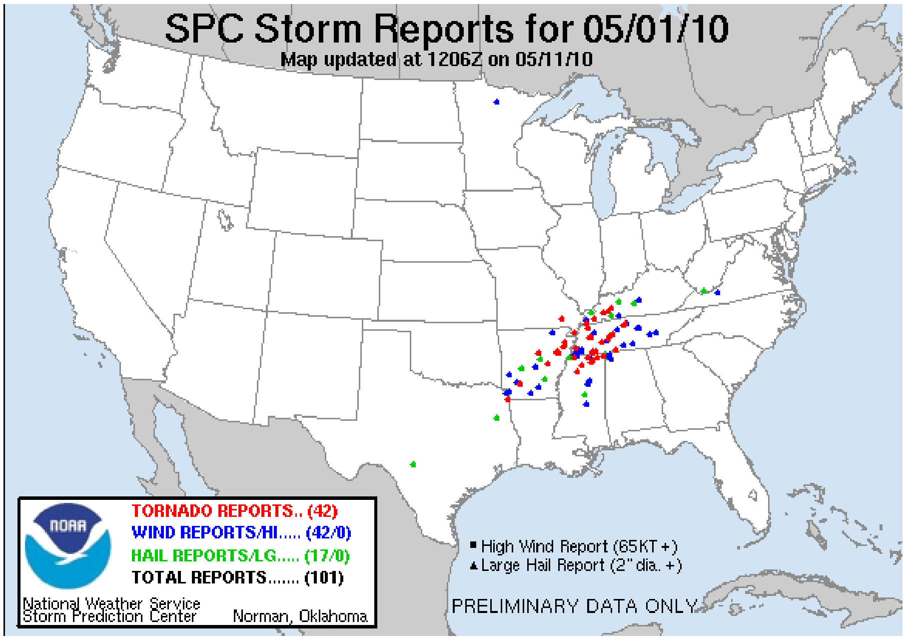

Figure 3: Preliminary severe weather reports showing tornado, hail, and damaging wind reports for 1 May, 2010. (SPC)

Synoptic Pattern: The 500 hPa analysis from 12 UTC on 1 May (Fig. 4) depicts a large long wave trough across the western half of the U.S, with a closed low near the Canadian border with North Dakota. Diffluent flow is evident across the Tennessee River Valley, aiding in the potential for upward motion across the region.

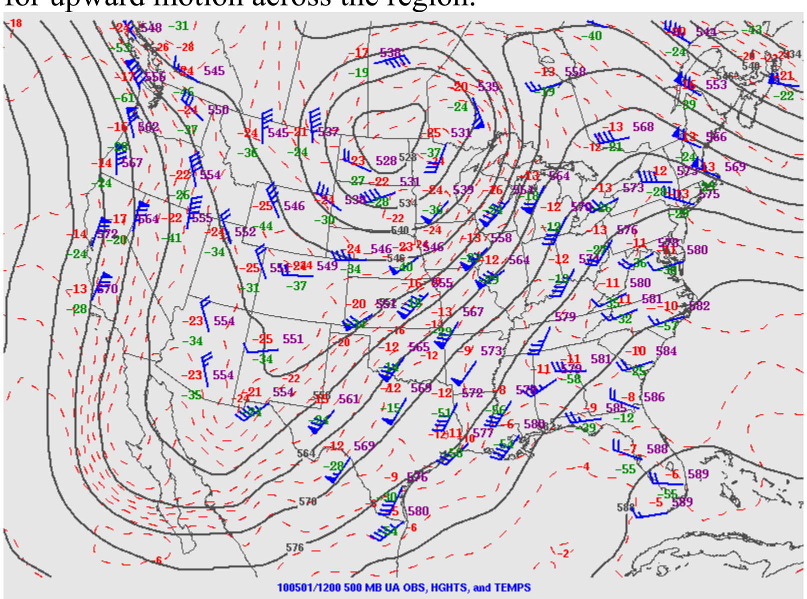

Figure 4: 500 hPa analysis from 12 UTC on 1 May, 2010 (SPC).

The 850 hPa analysis from the same time (Fig. 5) reveals a strong springtime low pressure system centered across southern Manitoba with a plume of tropical moisture being pulled northward from the Gulf of Mexico into the Deep South and Tennessee River Valley by 40 knot winds. Widespread dewpoints in the 14-17 ºC range across the same region indicate ample moisture was available for heavy precipitation. A low-level jet is also evident at 850 hPa (note the 40-45kt southerly winds in the lower Mississippi River Valley). The presence of a low-level jet resulted in strong warm air advection at this level, providing the upward motion necessary for precipitation development.

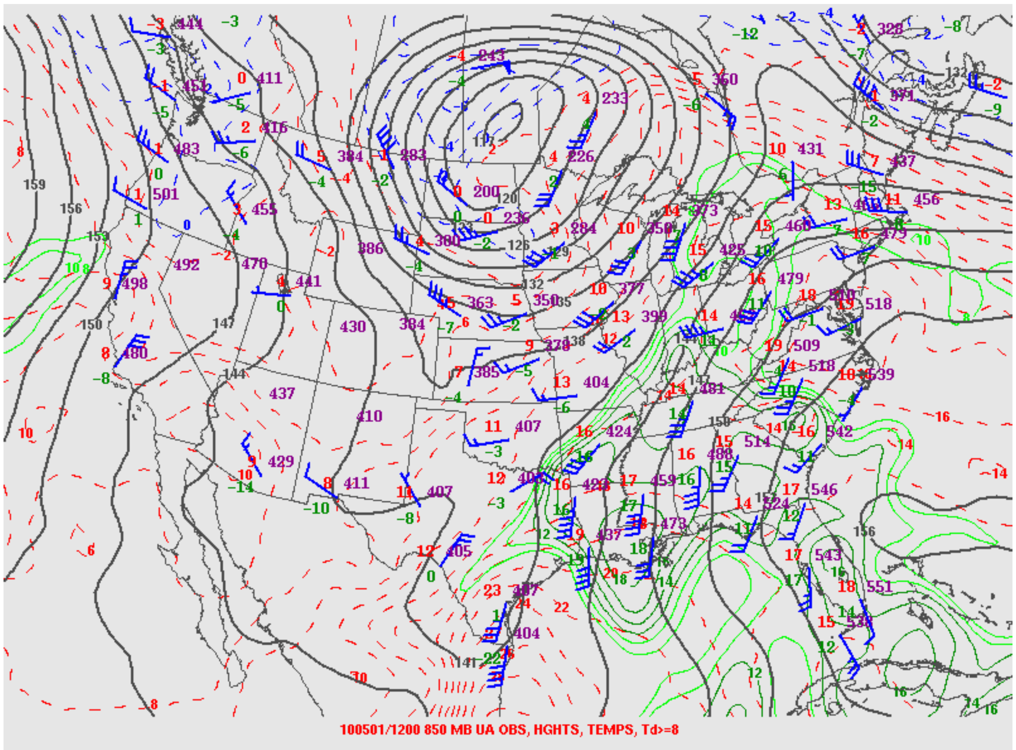

Figure 5: 850 hPa analysis from 12 UTC on 1 May, 2010 (SPC).

The surface analysis from 12 UTC on 1 May (Fig. 6) depicts the strong surface low across the northern plains, with a trailing frontal boundary extending southward through the western Great Lakes into the Mississippi River Valley. At this time, the frontal boundary was quasi-stationary, which given the ample moisture available, is an ideal pattern for long duration heavy rainfall events as multiple convective complexes can move across the same areas repeatedly. The pattern present in this case resembles the classic Maddox 'Synoptic' type heavy rain event (Maddox et al. 1979), in which a quasi-stationary north-south oriented frontal boundary is present ahead of a relatively strong upper-level shortwave. By 12 UTC on 2 May, the frontal boundary had begun to drift slowly to the east (Fig. 7), although at this time the southern portion of the front was still west of the Mississippi River. As a result, portions of the lower Mississippi, Tennessee, and Ohio River Valleys received repeated episodes of very heavy rainfall for two days.

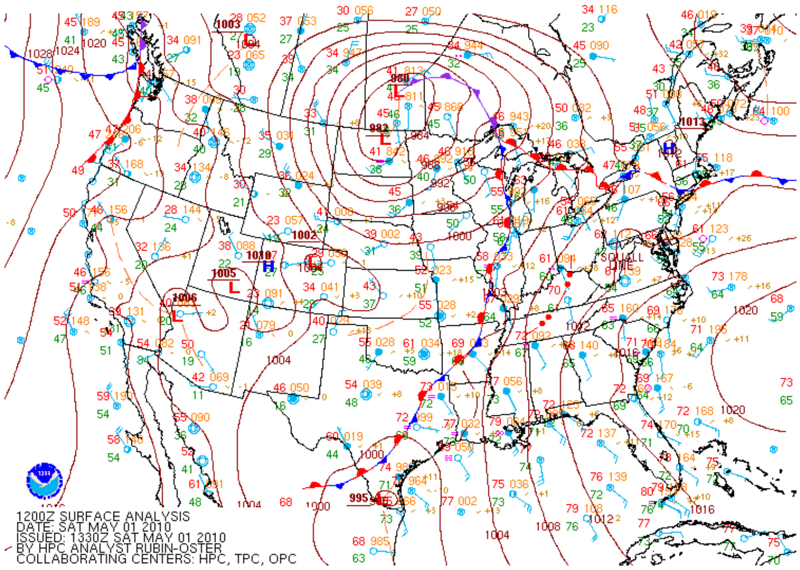

Figure 6: Surface analysis from 12 UTC on 1 May, 2010 (HPC).

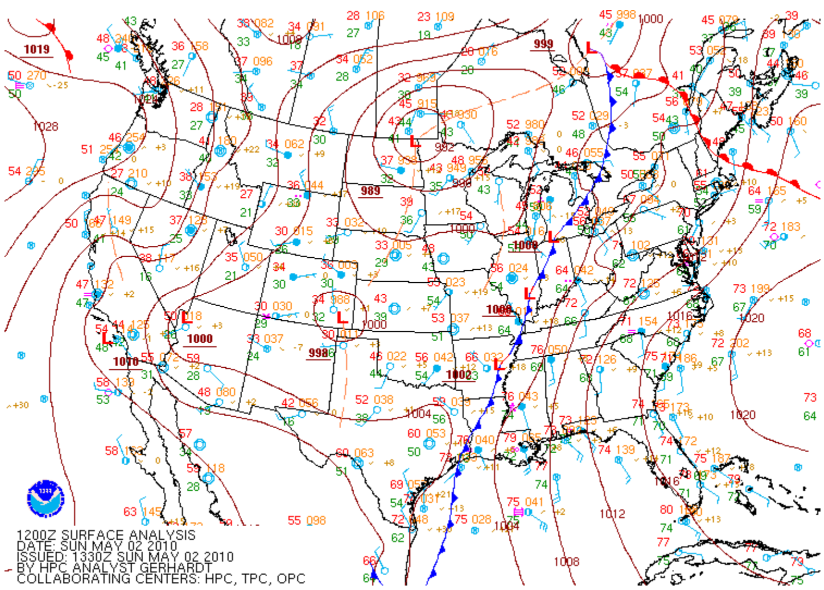

Figure 7: Surface analysis from 12 UTC on 2 May, 2010 (HPC).

One of the most significant synoptic scale contributors to the significance of this heavy rain event was a plume of deep tropical moisture (known as an 'atmospheric river') extending from the southern Gulf of Mexico/Caribbean northward into the Tennessee River Valley. This plume of moisture is best visible in the total precipitable water (TPW) field (Fig 8). The TPW image clearly shows an atmospheric river extending from the Gulf of Mexico and western Caribbean northward into the lower Mississippi River Valley.

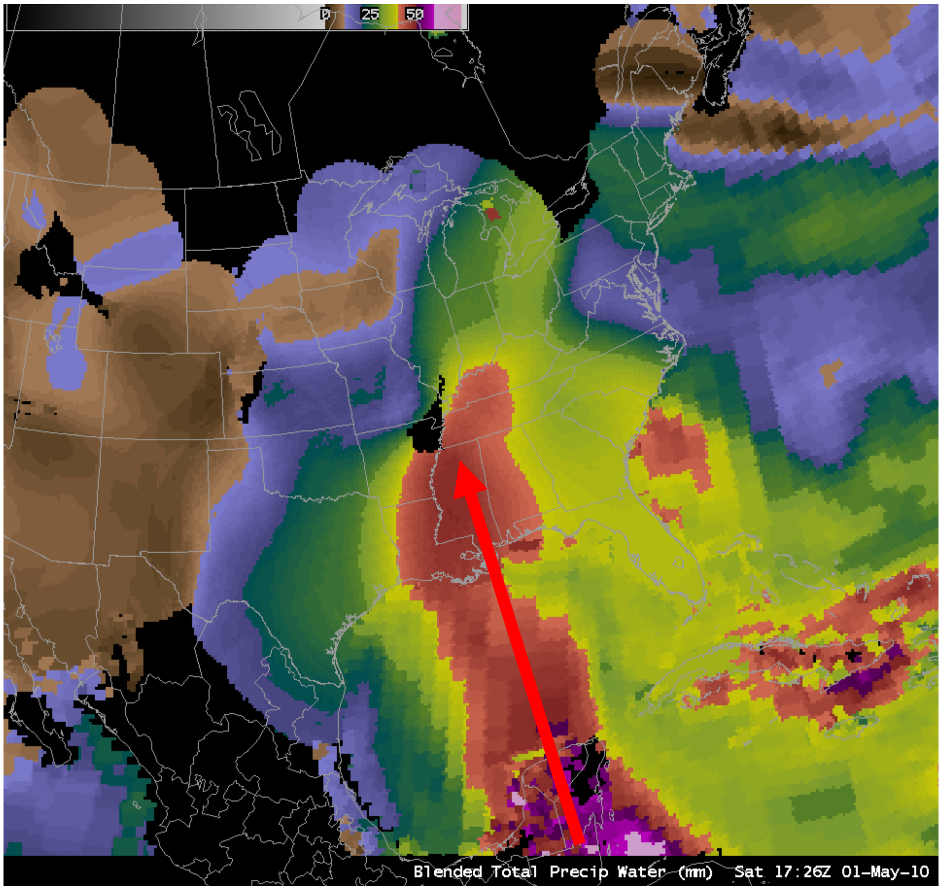

Figure 8: Total precipitable water (TPW) product for 17:26 UTC on 1 May, 2010. Arrow indicates direction of most significant water vapor flux.

Mesoscale Pattern: While the synoptic-scale quasi-stationary frontal boundary played a role in this event, the truly anomalous nature of the event appears to have occurred at the mesoscale. Backward propagation of convection as well as stationary mesoscale boundaries played a role in focusing the heaviest rainfall over specific areas for relatively long durations.

On 1 May, the low-level jet was aligned relatively parallel to the mid and upper-level winds, creating relatively unidirectional flow throughout the cloud-bearing layer. Following the method of Corfidi et al. (1996), the backward propagation of a mesoscale convective complex can be approximated by the vector equal in magnitude but opposite in direction of the low-level jet. Therefore, a situation in which a strong low-level jet is aligned parallel with the mean wind in the cloud-bearing layer, the potential exists for significant backward propagation of convection, and very slow net motion of convective systems. Figure 9 shows the wind speed and direction for 700 hPa at 12 UTC on 1 May. In this case, 700 hPa was assumed to approximate the mean wind in the cloud-bearing layer. Figure 10 shows the wind speed and direction at the same time for 900 hPa, assumed to represent the low-level jet.

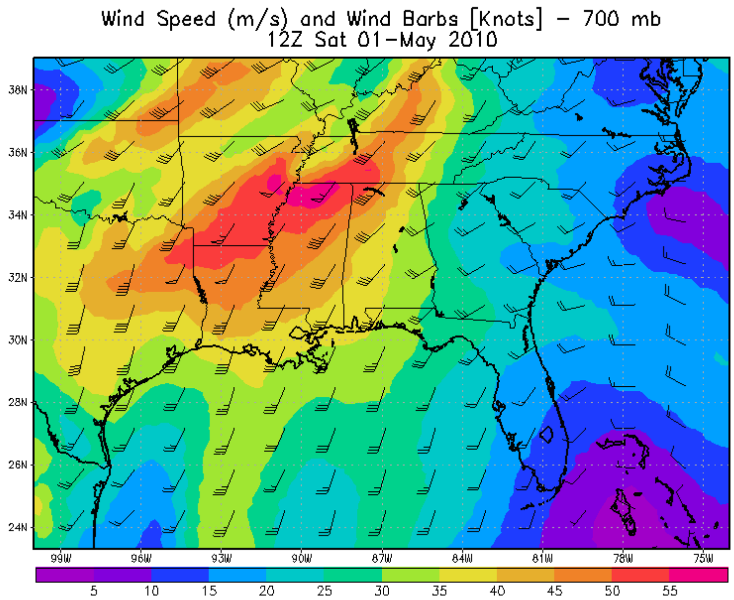

Figure 9: 700 hPa wind speed (m/s) and direction for 12 UTC on 1 May, 2010.

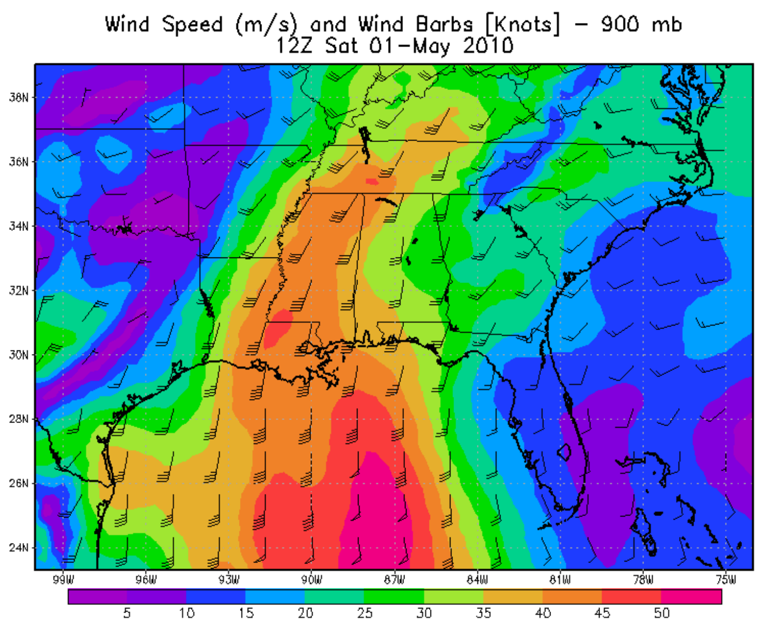

Figure 10: 900 hPa wind speed (m/s) and direction for 12 UTC on 1 May, 2010.

If one were to calculate a net motion vector for central Tennessee based on the winds in figures 9 and 10, the net motion would only be towards the ESE at 5 m/s (10 knots). Radar imagery from 1 May indicate that significant backward propagation was indeed occurring across Tennessee (Fig. 11).

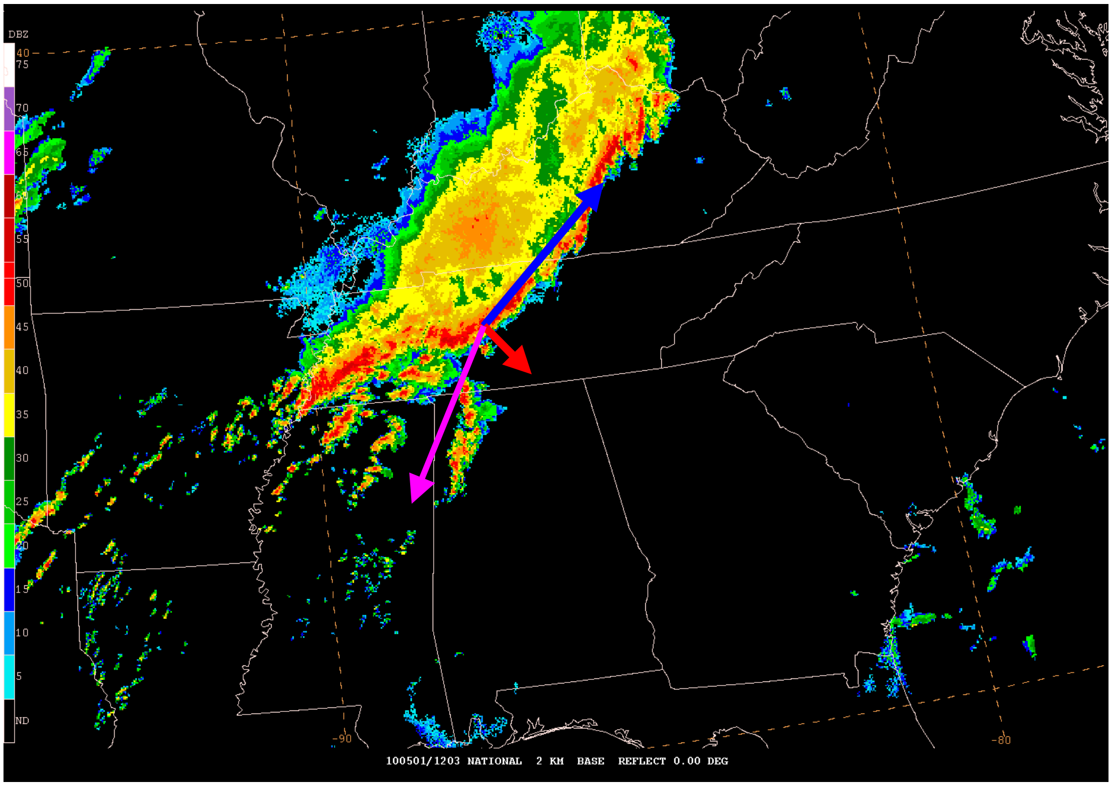

Figure 11: Regional radar image from 12 UTC on 1 May. Blue arrow indicates individual cell motion vector; the purple vector indicates the direction of propagation of convection; the red arrow indicates net system motion vector.

As mentioned previously, in addition to significant backward propagation due to an intense low-level jet aligned with the mean layer flow, a mesoscale boundary set up across portions of central Tennessee and remained stationary throughout the day on 1 May. As the intense low-level jet pulled warm, moist air from the Gulf of Mexico northward, it was lifted over this stationary boundary, resulting in constant formation of new convection over the same area. This boundary is easily visible in a base velocity image from the Nashville WSR-88D (Fig. 12) as a line of convergence over south central Tennessee. This boundary was likely the result of a cold pool from the mesoscale convective system (MCS) that traversed the area earlier in the day. Even after the MCS that spawned the cold pool diminished, this outflow boundary at the periphery of the cold pool remained a focus for convection throughout the day. Rainfall rates from the convection in central Tennessee on 1 May averaged 1 inch per hour, but rates were as high as 2-3 inches per hour in the heaviest convection. Therefore, areas that were constantly subjected to new convective development received relatively long periods of rainfall rates as high as 2-3 inches per hour.

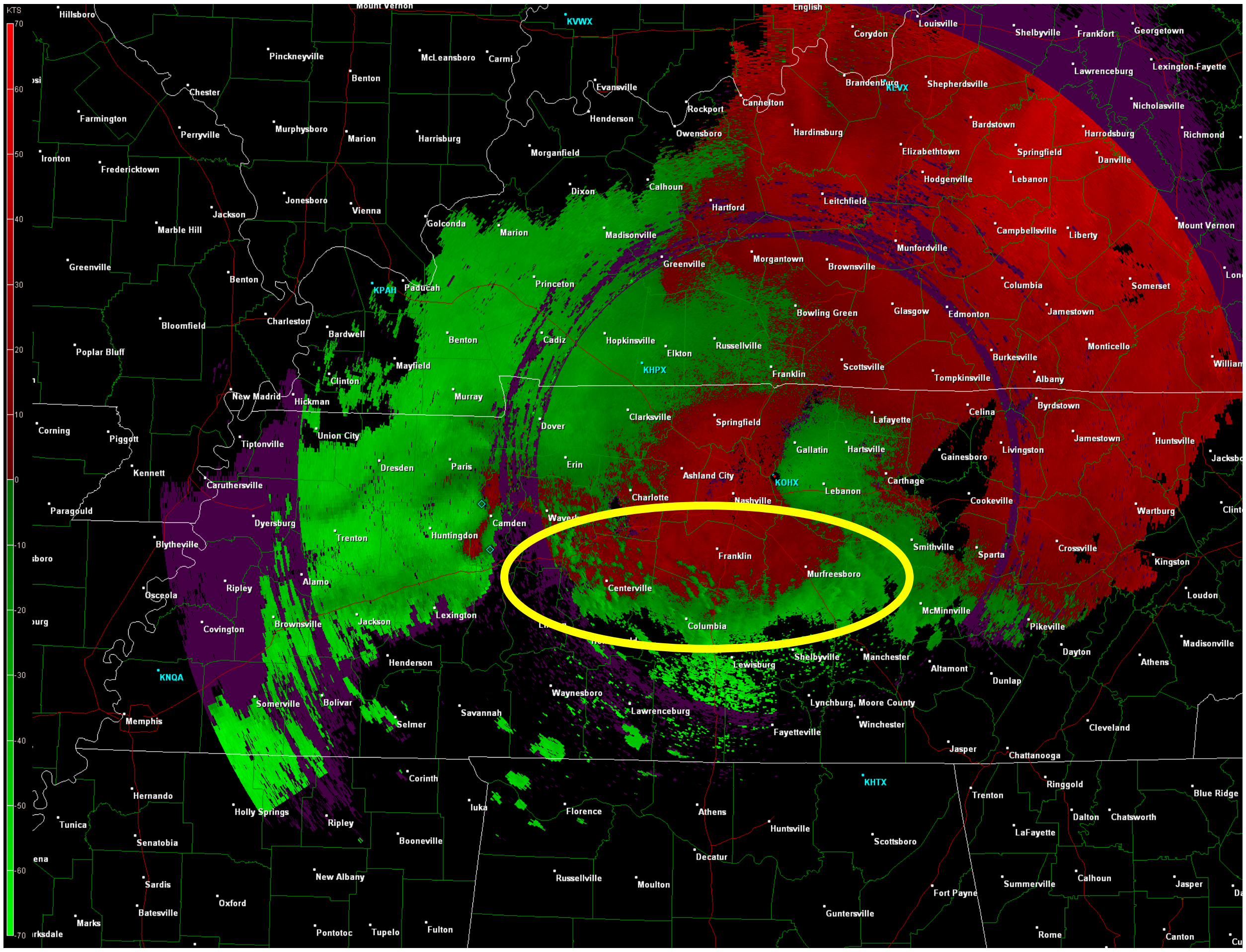

Figure 12: Base velocity image from KOHX (Nashville, TN) for 16 UTC on 1 May, 2010. Yellow outline denotes the mesoscale boundary that remained stationary through most the day, serving as a constant focus for the development of new convection.

Conclusion: The flooding in the Tennessee River Valley from May 1-5, 2010 was the result of several rounds of heavy rainfall over the course of 2-3 days at most locations. The flooding that resulted from heavy rains on May 1-2 across Tennessee and portions of Kentucky was of historic proportion. The synoptic setup that resulted in this event was a classic Maddox 'Synoptic' setup for heavy rainfall events. A large, slow-moving trough was present at the upper-levels with a slow-moving, and at times quasi-stationary frontal boundary extending in a north-south direction across Mississippi River Valley. A deep plume of tropical moisture known as an 'atmospheric river' was being advected into the region from the Gulf of Mexico and western Caribbean by a strong low-level jet. Warm air advection in association with the low-level jet, as well as the presence of a mesoscale boundary leftover from previous convection provided the necessary lift for convection with very heavy rainfall to develop repeatedly over the same areas of Tennessee on 1 May. These factors combined with backward propagation of convection resulted in devastating rainfall amounts across much of the Tennessee River Valley.

References:

Corfidi, S.F., J.H. Merritt, J.M. Fritsch, 1996: Predicting the movement of mesoscale convective complexes. *Wea. Forecasting*, **11**, 41-46.

Maddox, R.A., C.F. Chappell, L.R. Hoxit, 1979: Synoptic and meso-α scale aspects of flash flood events. *Bul. American Met. Soc.*, **60,** 115-123.