What if the 1-4 May 2010 Historic Nashville, Tennessee Flood Occurred East Tennessee?

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The paper will take a detailed look at the synoptic and mesoscale weather conditions that resulted in the historic flood that occurred across Nashville, Tennessee area on 1-4 May 2010. River model contingency forecasts from the NWS Lower Mississippi River Forecast Center were used to perform a “What if?” scenario should a similar rainfall event occur across East Tennessee, extreme southwest Virginia and southwest North Carolina. The model contingency river forecasts showed that historic river flood levels would occur, and average river levels would be between 15 and 20 feet above flood stage. In addition to such historical river flooding, the mountainous terrain and local urban effects would produce extremely dangerous flash flood emergency situations.

The objectives of this study were to use this “What if?” scenario to more accurately define and effectively share this information with emergency management and media partners to mitigate the loss of life and property. This unprecedented flood scenario will also serve as a preparedness initiative to better educate the public concerning what could happen if maximum rainfall values of 15 inches in a few days were to occur across this portion of the southern Appalachians.

1. INTRODUCTION

Multiple synoptic and mesoscale features combined to produce the Nashville Flood. Review of the environment suggests the synoptic features were the dominant forces of the event. The meteorological conditions present during the Nashville Flood categorize the event under the synoptic type heavy rainfall events classified by Maddox et al. (1979 and 1980). The synoptic set-up ultimately led to the high rainfall totals. Rainfall totals of over ten inches were common for the event. The highest observer reported total was 19.41" at Camden 4.5NE, Tennessee. The meteorological portion will be broken into two main sections, the synoptic and mesoscale.

2. SYNOPTIC PRE-EVENT

On April 28th, 2010 at 00UTC, three and a half days prior to the event, signs of a building ridge were evident across the Great Plains and can be seen in Fig 1. and Fig 2. (SPC)

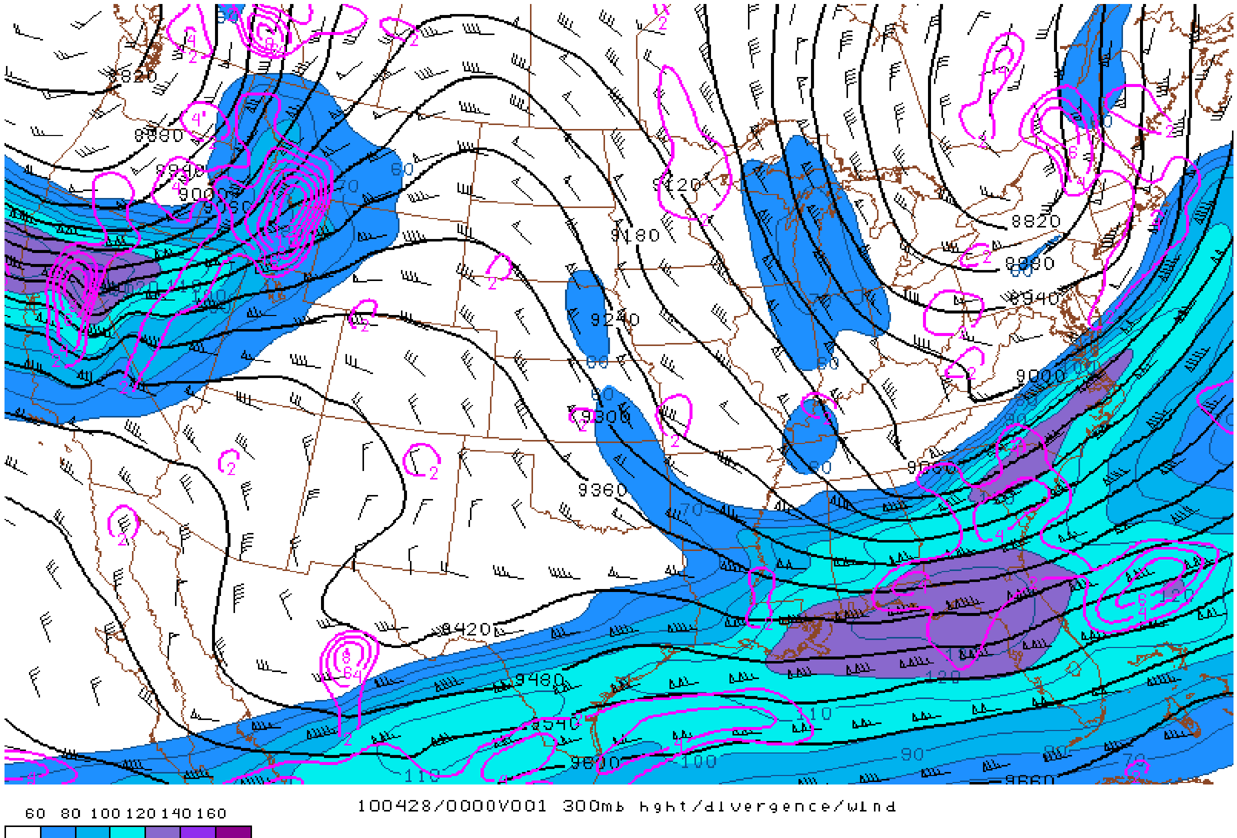


Fig. 1: 300mb heights, wind and divergence (in purple) at 00UTC on April 28th, 2010.

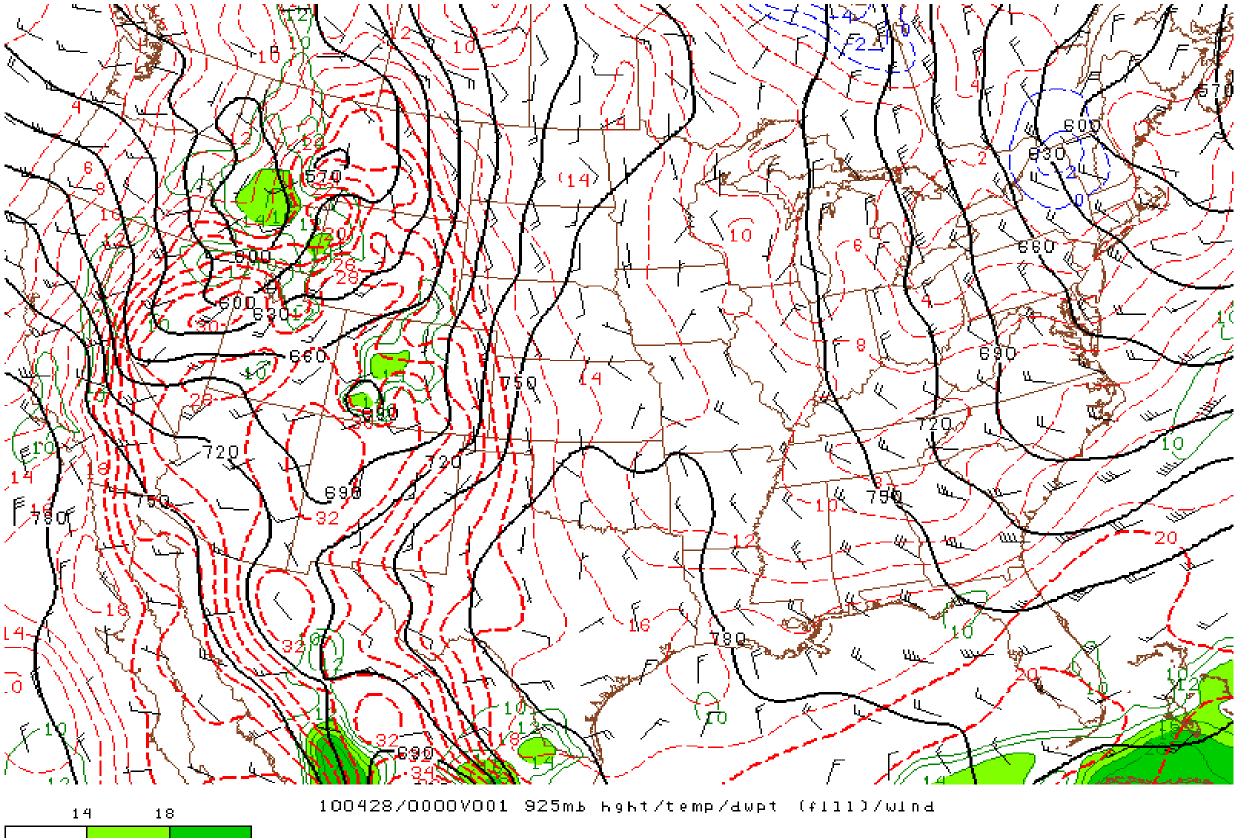


Fig. 2: 925mb heights, temperatures, dewpoints and wind at 00UTC on April 28th, 2010.

The ridge is present at 300mb down to the surface at 925mb and was due to a developing center of high pressure located over Eastern Texas extending into the Gulf of Mexico. Also, there was a deep neutral positioned upper level 300mb trough centered over western New York that stretched south along the spine of the Appalachians. While to the west of the ridge, a new trough had entered the Pacific Northwest.

On April 29th at 00UTC, a building ridge was slowly sliding east and continued to expand well into the Canadian provinces of Manitoba and Ontario as seen in Fig 3. and Fig 4. (SPC)

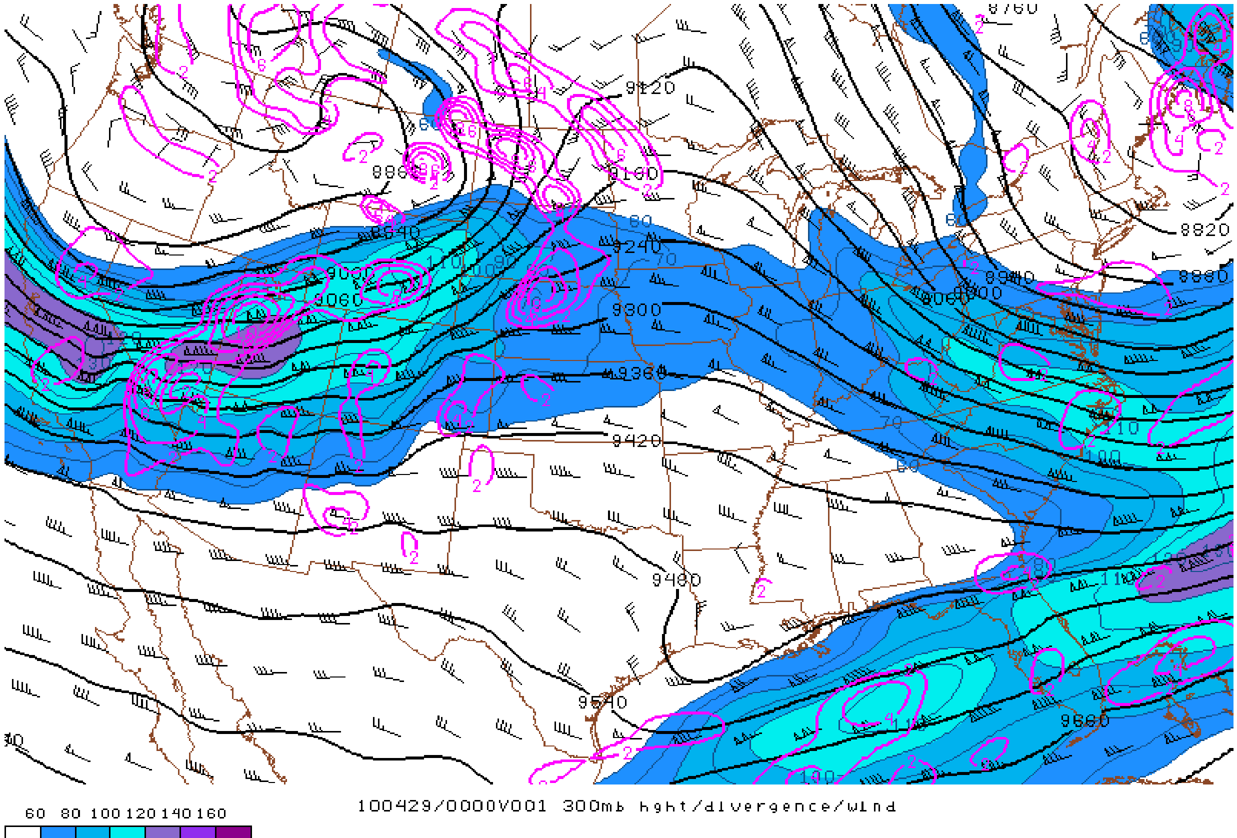


Fig. 3: 300mb heights, wind and divergence (in purple) at 00UTC on April 29th, 2010.

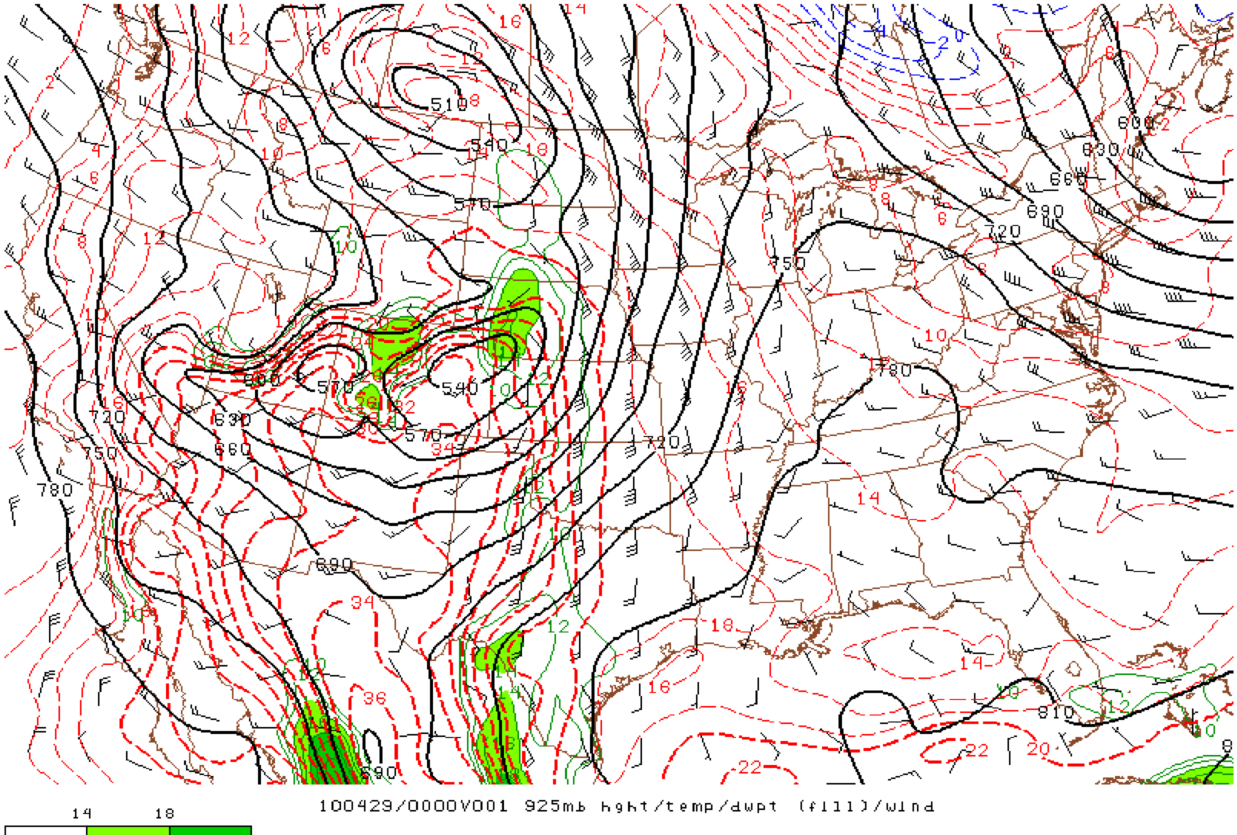


Fig. 4: 925mb heights, temperatures, dewpoints and wind at 00UTC on April 29th, 2010.

The once neutral trough became centered over New England and negatively tilted. The trough that entered the Pacific Northwest was now in the beginning stages of deep amplification. This was due to the intensification of the ridge located over the Midwest as well as a developing ridge located over the Pacific Ocean shown in Fig. 8 (Unisys)

April 30th at 00UTC, Fig. 5 and Fig. 6 (SPC) show the movement of the Midwest ridge and its new location over the Eastern United States. The ridge now reached up into parts of Northern Ontario and Northwestern Quebec.

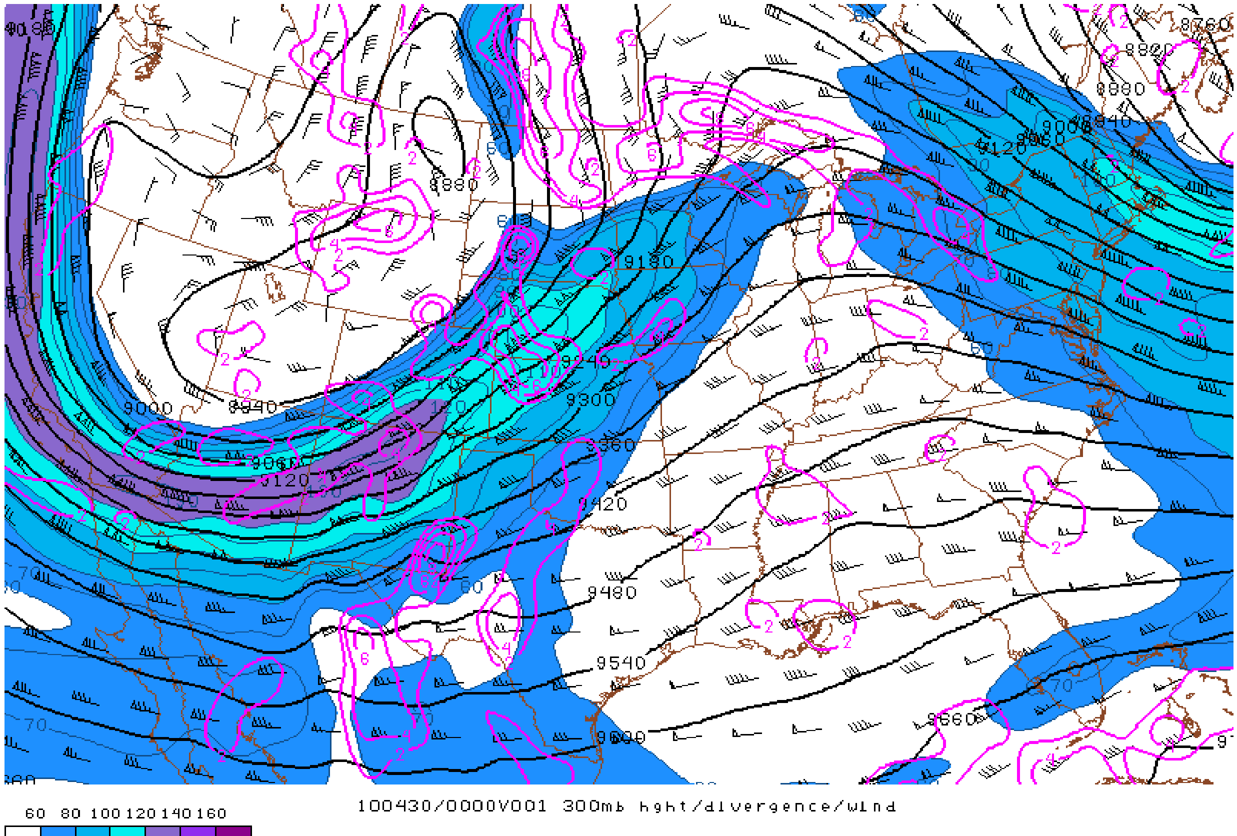


Fig. 5: 300mb heights, wind and divergence (in purple) at 00UTC on April 30th, 2010.

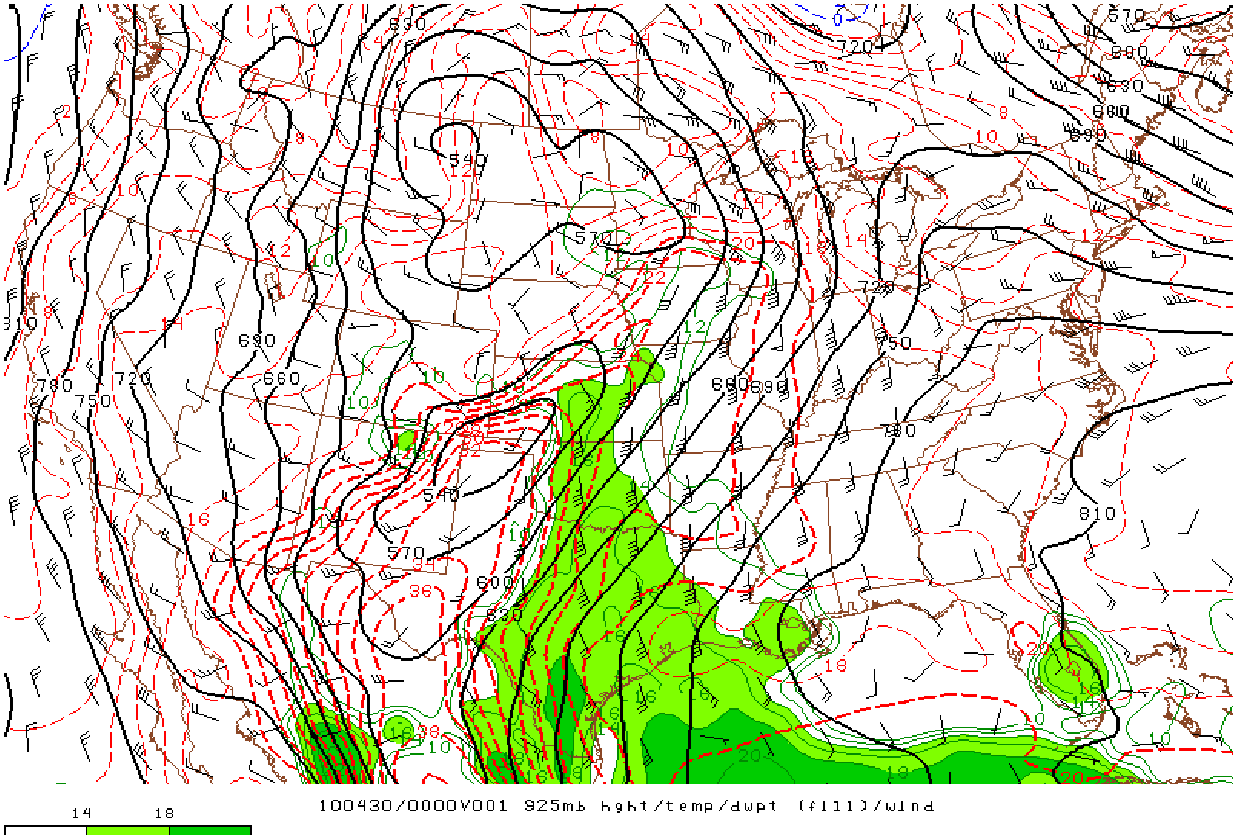


Fig. 6: 925mb heights, temperatures, dewpoints and wind at 00UTC on April 30th, 2010.

The trough over New England was now centered just off the coast to the east with minimal advancement of its position. The Pacific Northwestern trough now encompassed the entire Western United states and was centered west of the Four Corners states. The digging Western trough was very broad and reached south down into Northern Mexico. The troughs deepening amplitude is again attributed to the strengthening Pacific high and eastern high that had now set-up off the east coast of Florida.

3. SYNOPTIC-EVENT

The development of multiple synoptic features from April 28th to May 1st, 2010 helped to set up a modified version of an Omega Block. The blocking pattern that developed during the

Nashville, Tennessee flood was not an idealized Omega block but did possess similar traits of a traditional Omega type block shown in Fig. 7. The Omega Block proved to be one of the primary factors in producing the Nashville, Tennessee flood.

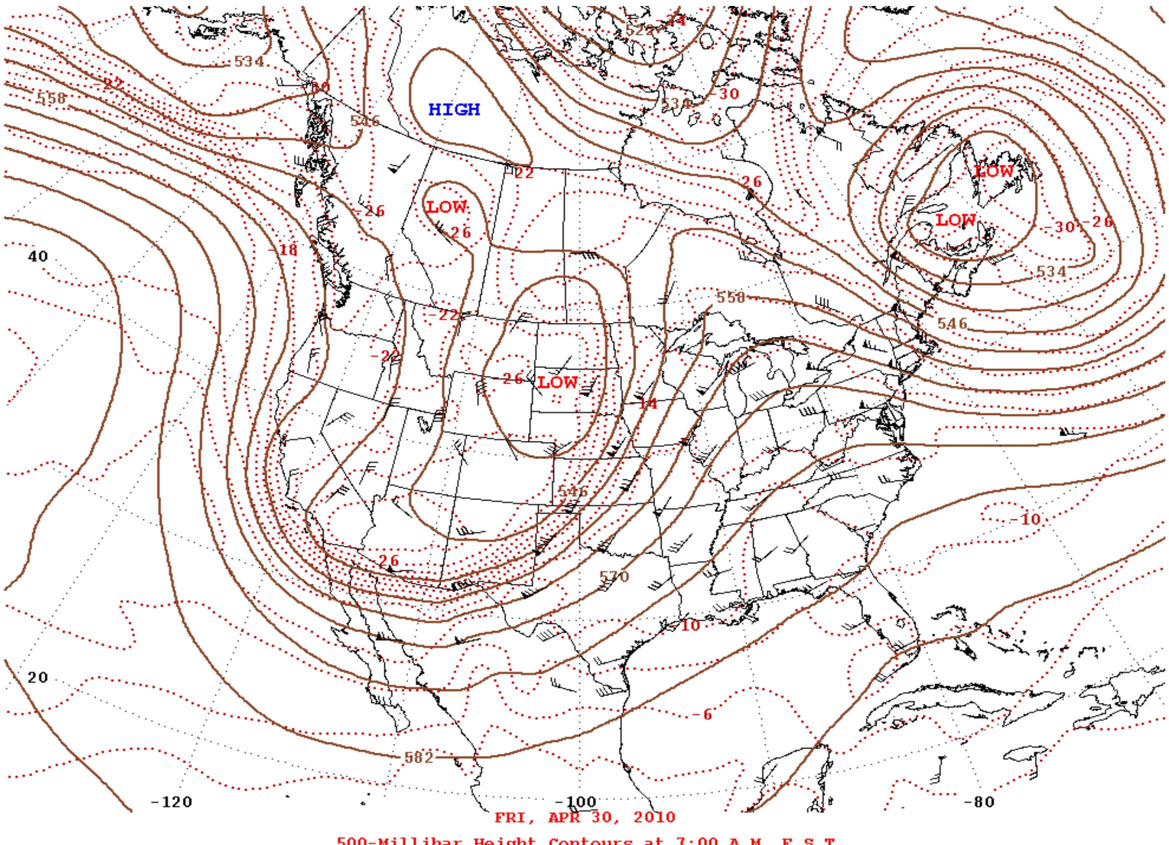


Fig. 7: 500mb heights contours and winds at 11UTC on April 30th, 2010.

In Fig. 8 (Unisys) the infrared satellite imagery shows another view of the Omega Block that set up just before May 1st.

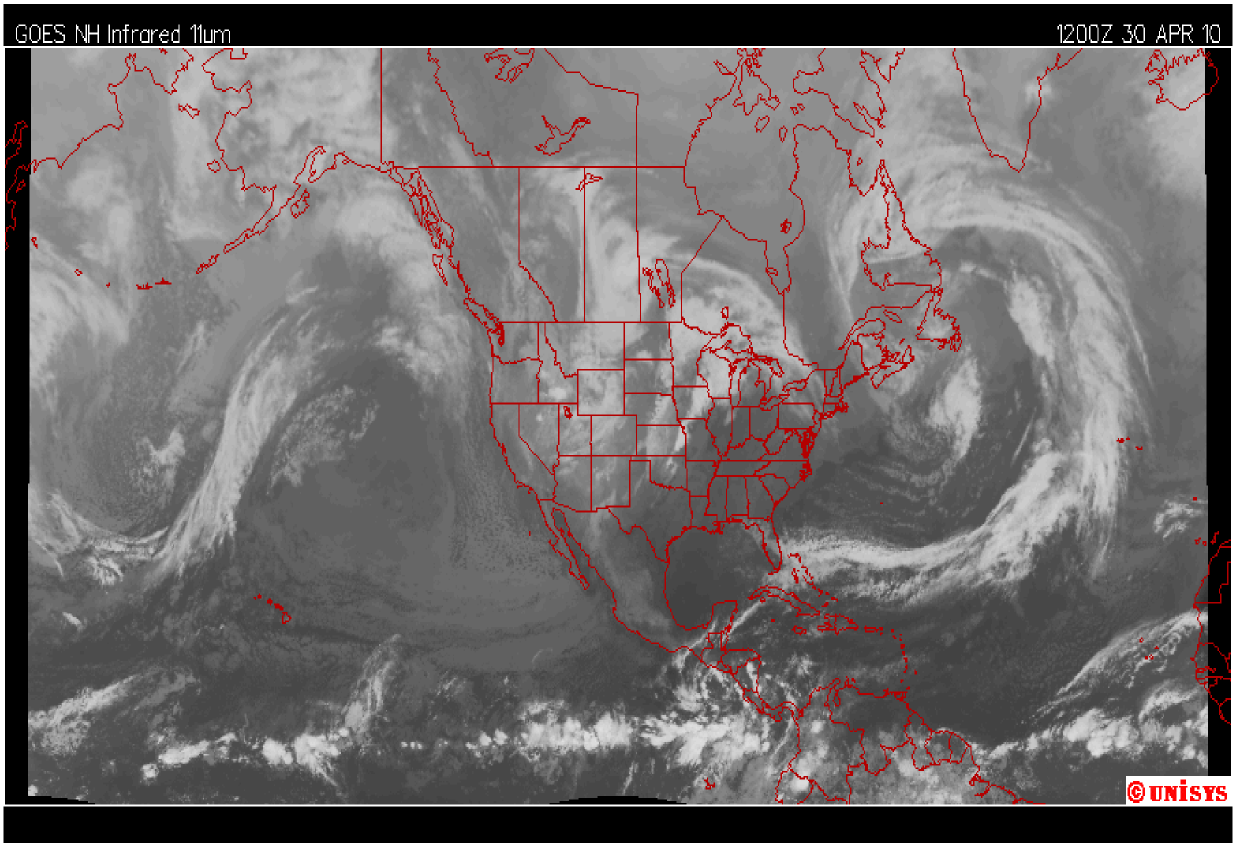


Fig. 8: GOES Northern Hemisphere Infrared Satellite Imagery at 12UTC April 30th, 2010.

The onset of precipitation began approximately at 12 UTC on May 1st, 2010 and ended roughly at 07 UTC on May 3rd. On May 1st at 16 UTC Fig. 9 (SPC) below shows the western trough now had an extreme amplification and gained a positive tilt with the leading edge west of Middle Tennessee. The trough was centered roughly over the four corners states with a base that now reached across the Baja Peninsula and into Central Mexico.

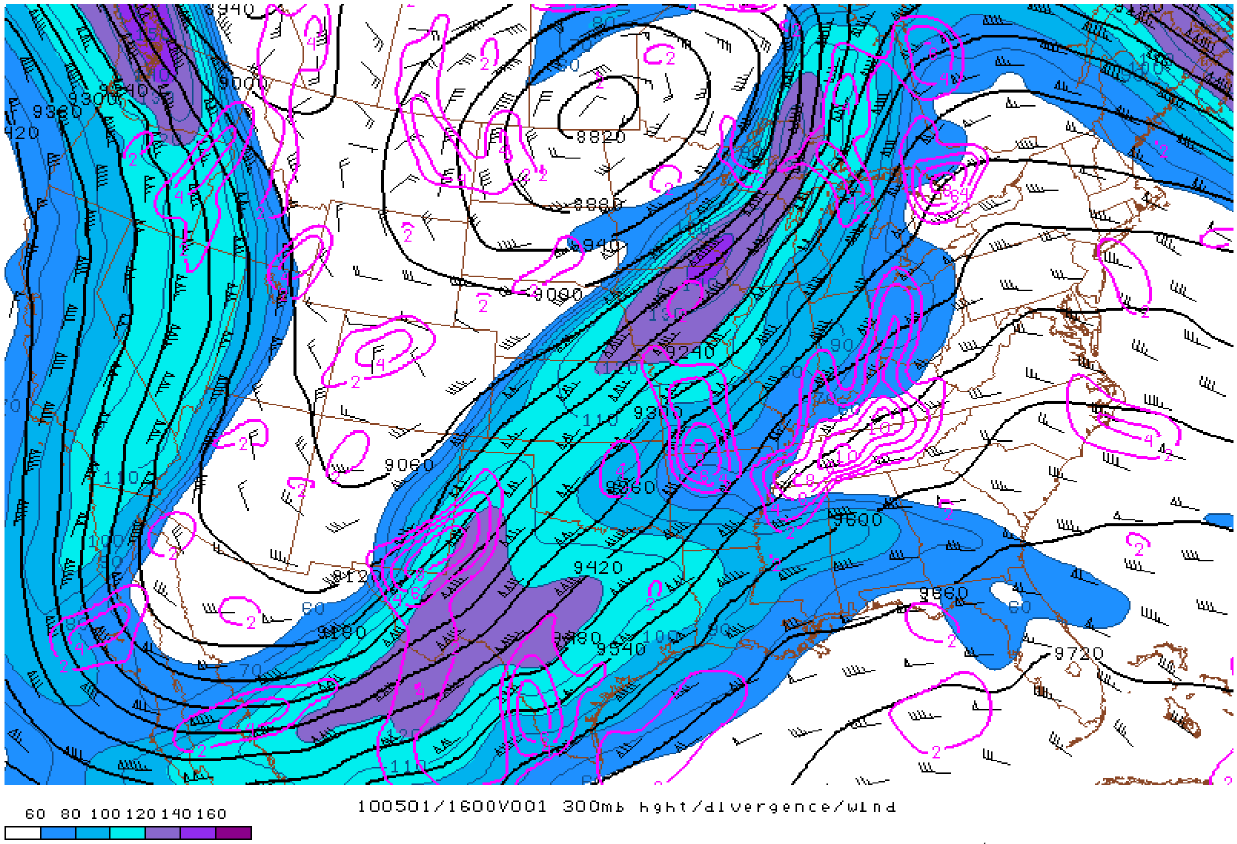


Fig. 9: 300mb heights, wind and divergence (in purple) at 16UTC on May 1st, 2010.

Due to the trough's deep amplification, the leading edge kept the polar jet in near north to south vertical orientation. This allowed the mean flow to be roughly parallel with the frontal boundary. The positioning of the trough also allowed several strong northern jet impulses to track over middle Tennessee which provided synoptic lift throughout the event. The vertical orientation of the polar jet, combined with the influx of deep tropical moisture, enabled training to occur over the Nashville, Tennessee area.

As the surface low made its way across the northern Plains, the leading edge of the trough eventually interacted with the tilted sub-tropical jet. At 09 UTC May 1st, 2010 synoptic forcing favorable for lift had begun edging its way into middle Tennessee. The forcing produced strong and widespread upper level divergence over middle Tennessee and persisted throughout the duration of the event. The direct circulation associated with the right entrance region of the jet further enhanced the lift over the area. Large-scale vertical motions normally do not provide the amount of lift necessary to initiate convection. However, Doswell, et. al. (1996) indicates there is an unmistakable connection between synoptic-scale weather systems and deep, moist convection. Doswell (1987) noted that the connection pertains to the moistening and destabilization created by the moderate but persistent synoptic-scale vertical ascent ahead of short-wave troughs.

4. DIAGNOSIS

Further diagnosis suggests the positioning of the Omega Block greatly slowed the progression of the advancing cyclone with the mean flow aligned with the frontal boundary. The jet orientation provided a transport mechanism to permit a vast amount of deep tropical moisture to continually stream into the region. In addition to the 300mb sub-tropical jet; the moisture flow was aided by a strong low level jet of 60 to 70 knots at 850mb, as well as the cyclonic flow around the advancing low pressure system across the northern Plains and the anti-cyclonic flow around the high off the coast of Florida. These combined features helped to efficiently transport a plume of deep tropical from the Inter-Tropical Convergence Zone (ITCZ) into the southeastern United States shown in Fig 10.

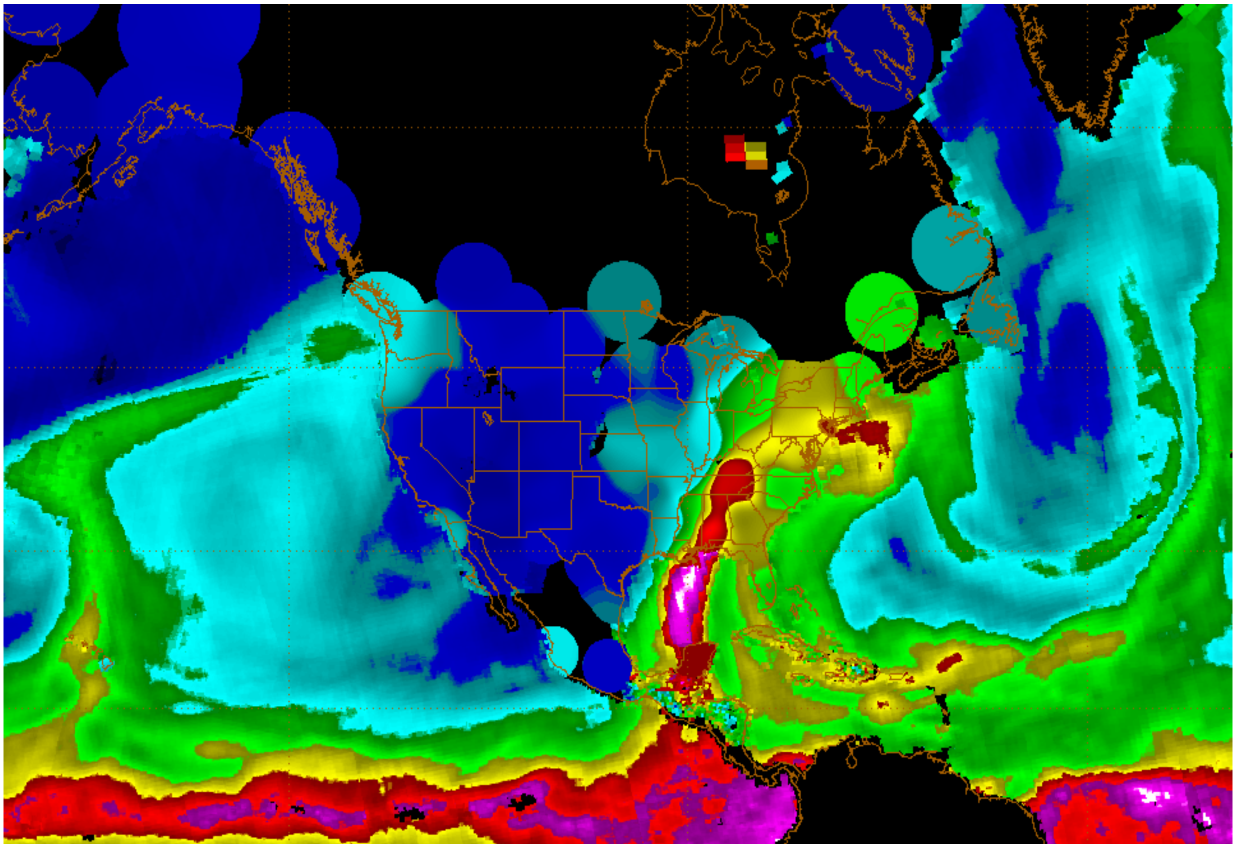
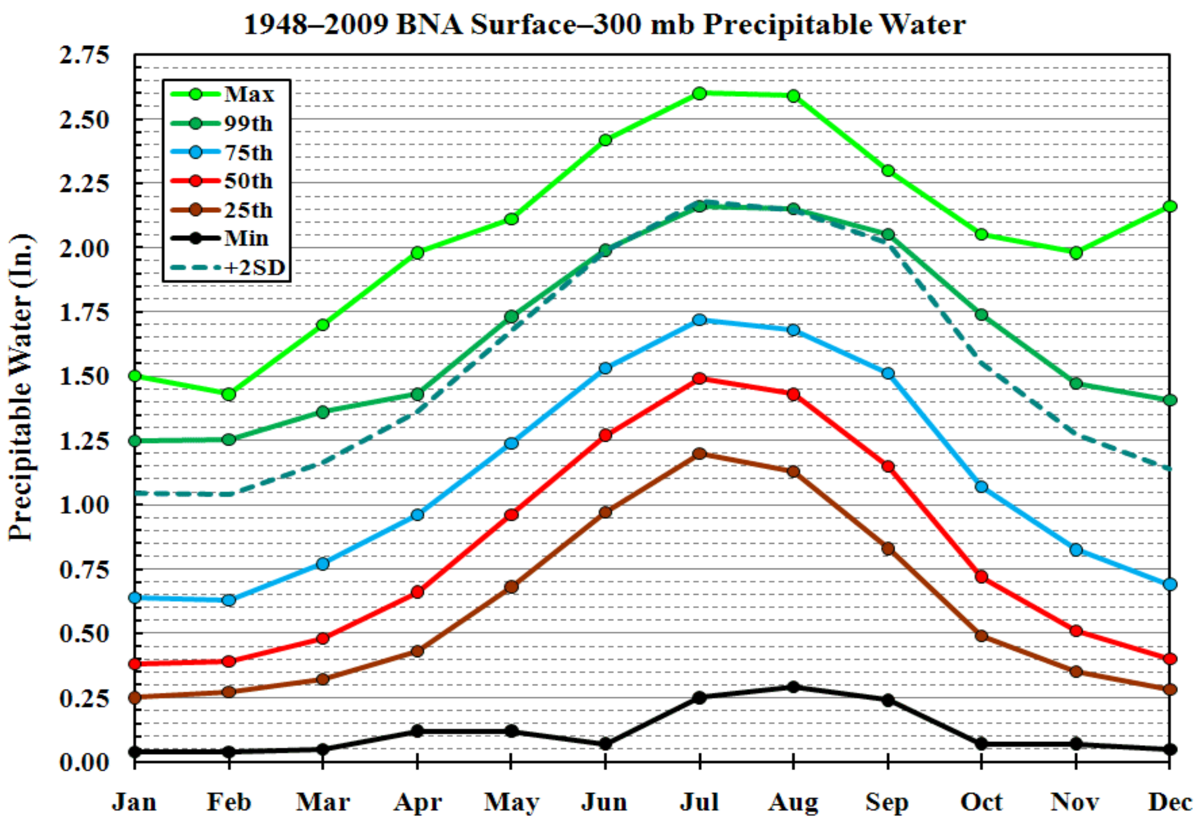


Fig. 10: Total Precipitable Water (TPW) at 18UTC May 2nd,2010. TPW shows deep moisture plume or atmospheric river streaming into the southern United States.

This event had similar characteristics to “Maya Express” type events as found by Dirmeyer. Dirmeyer uses this term in correlation with Midwest heavy rainfall events. During these events a long fetch of moisture originating in the deep western Gulf of Mexico eventually links up with the Great Plains Low Level Jet (LLJ). It is believed the “Maya Express” is related to the strengthening or displacement of the Atlantic subtropical ridge. Though in a different region, the conditions present at Nashville, Tennessee displayed similar characteristics of the “Maya Express” type events. Dirmeyer and Kinter go on to mention that heavy rainfall events over the eastern United States are associated with an above-average Caribbean moisture supply. (Dirmeyer and Kinter 2009).

Due to the source region of the moisture, precipitable water values over Nashville were close to reaching the maximum value ever recorded for early May and are shown in Graph 1. (NWS)



Graph 1. Climatology of Precipitable Water (PW) at Nashville, Tennessee from 1948-2009.

Graph 1. shows the surface to 300mb climatology of precipitable Water (PW) at Nashville, Tennessee from 1948 though 2009. The observed and forecasted PW for Nashville, Tennessee was near 2.1 inches, which is well over the 99th percentile for early May. While the maximum value ever recorded for this date is roughly 2.13 inches. This illustrates the abundance of available moisture during the event and further reveals that the moisture was another major component in the Nashville flooding. It is believed that without the blocking in place, the same amount and depth of moisture would not have been available for this event. Under normal atmospheric flow, most synoptic features move too fast to be able to pull an extreme amount of moisture from the gulf as seen with the Nashville Flood. The duration of the block wasn't the only factor; the actual positioning of the Omega Block was critical in the placement of the available moisture.

Upon review of the synoptic conditions, one of the patterns recognized was the Synoptic type classified by Maddox et al. (1979) The Synoptic type event is usually associated with a strong 500mb trough moving slowly eastward or northeastward and fronts that are oriented southwest to northeast. The heavy rain usually occurs in the warm sector or near an old frontal boundary. Most of the time the front is slow moving and aligned parallel to the mean flow. This alignment promotes training of cells. The excessive rainfall event that occurred across middle and west Tennessee was likely a Synoptic type event.

5. PRECIPITATION EFFIENCY

As discussed, several synoptic factors were in place to produce the Nashville flood. The synoptic setup was likely the dominant player, but certain thermodynamic features likely enhanced rainfall efficiency. These features include CAPE orientation, CIN, and LCL heights. The highest values of Mixed Layer CAPE (MLCAPE) existed to the southwest of Nashville across northern Mississippi from 06 UTC through 12 UTC on May 2nd 2010. The instability was focused along the boundary from northern Mississippi to western Tennessee. Fig.11 (SPC) below shows this image.

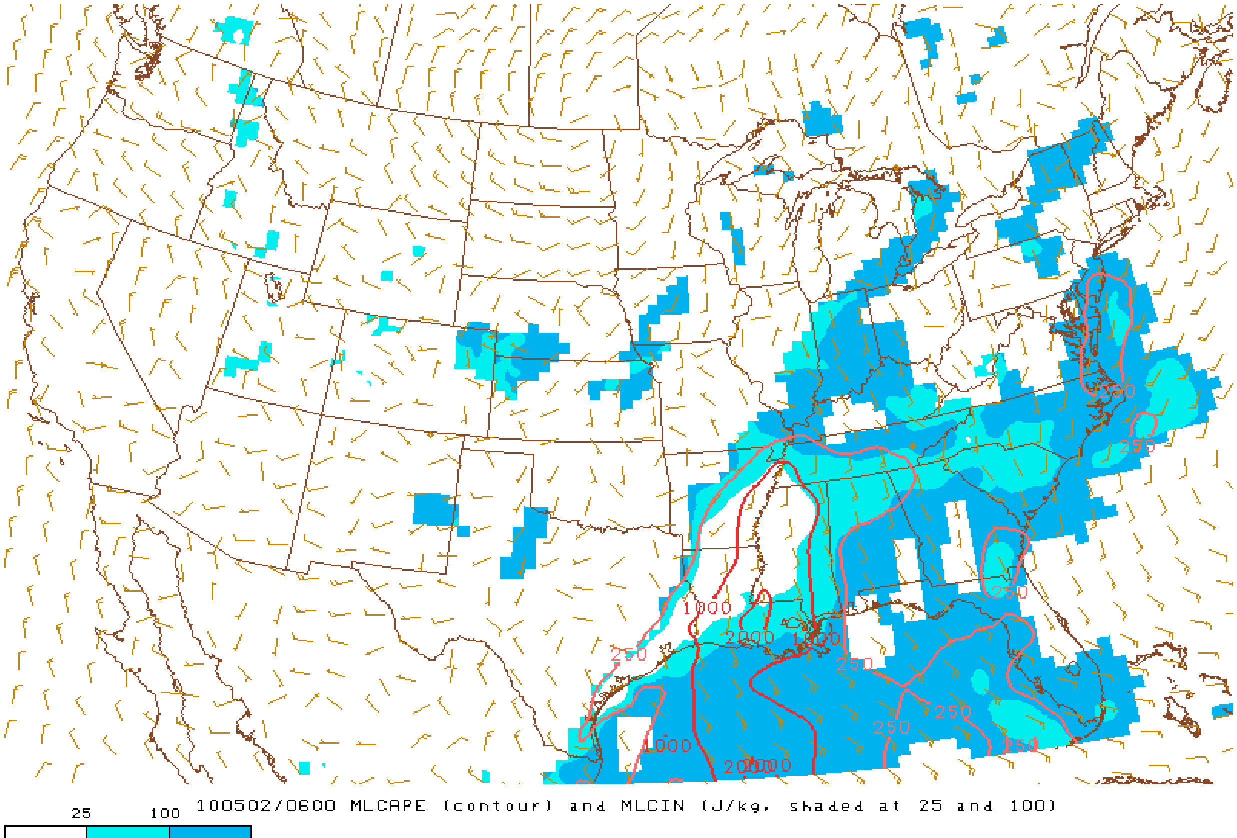


Fig. 11: Mixed Layer Cape (MLCape) at 06UTC on May 2nd, 2010

The likelihood that convective cells will live long enough to form into an organized convective system increases with decreasing CIN. Fig. 12 (SPC) shows weakening convective inhibition at 18 UTC, May 2nd, 2010.

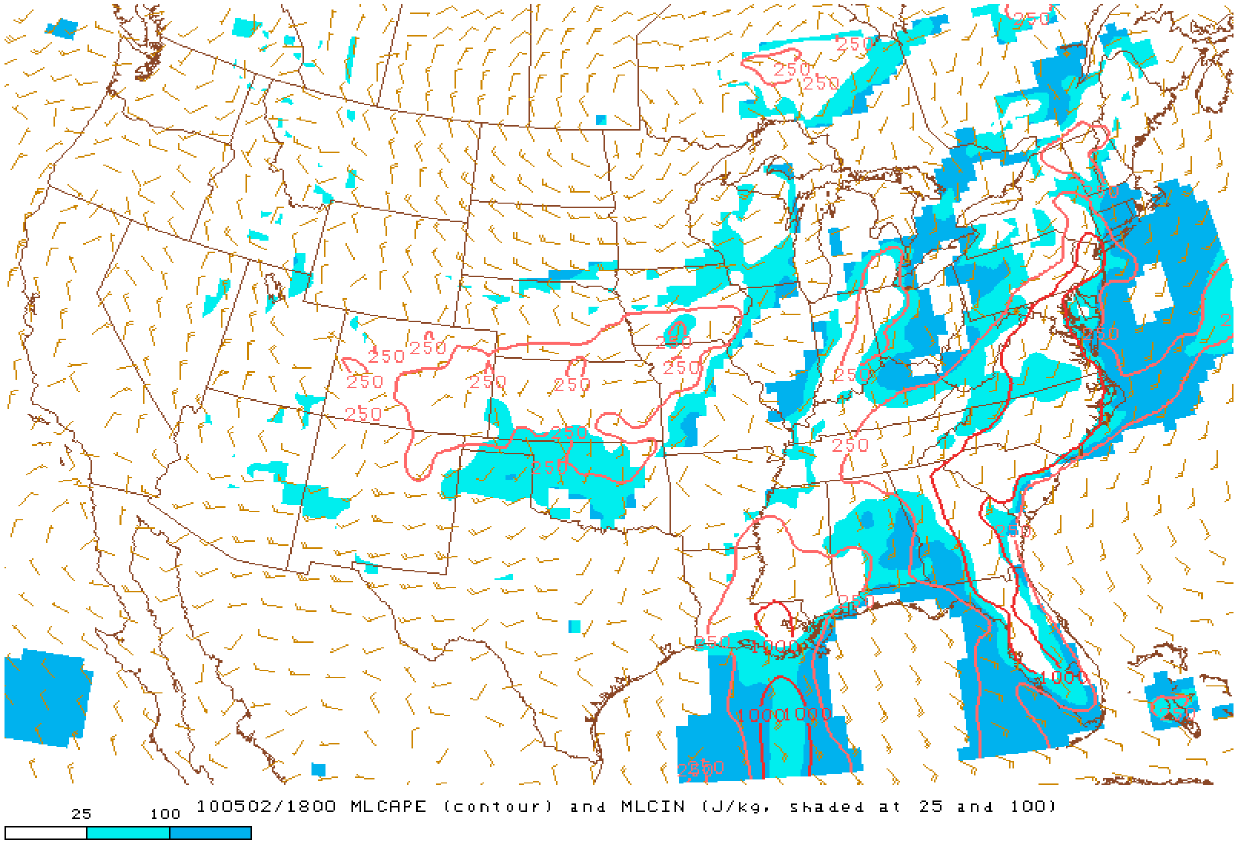


Fig. 12: Convective Inhibition (CIN) at 18UTC on May 2nd, 2010

The scale of the mesoscale precipitation system affects the Precipitation Efficiency (PE) as small isolated convective systems are more likely to have dry air entrained into their core than larger systems as noted by Doswell et al. (1996). This is because the environment surrounding a cloud within a larger scale system is much more saturated than that found near the perimeter of a single convective cell. This also might explain the negative correlation between Convective Inhibition (CIN) and PE found by Market and Allen (2003). The inverse correlation of decreasing CIN to increasing PE suggests that a stronger cap may lead to fewer, more isolated cells that will be more vulnerable to the effects of entrainment, thus reducing the likelihood that convective cells will live long enough to form into an organized convective system. The weakening CIN across Middle Tennessee, shown in Fig. 12 allowed for a better organized convective system to develop.

Lifted Condensation Level (LCL) heights are also important for determining precipitation efficiency. Work by Market and Allen (2003) and Fankhauser (1988) suggested that Precipitation Efficiency (PE) is higher with low cloud base height or low LCL heights. The higher cloud base or LCL heights suggests that precipitation will be falling through a deeper unsaturated layer causing greater evaporation. As the sub-cloud base relative humidity increases or lower LCL heights, PE increases because of limited evaporation below the cloud base. Low LCL heights were present during most of the Nashville flooding event. At 06 UTC May 1st, LCL heights of 500 meters were present over middle Tennessee. The low LCL heights persisted through 07 UTC on May 3rd, shown in Fig. 13. (SPC)

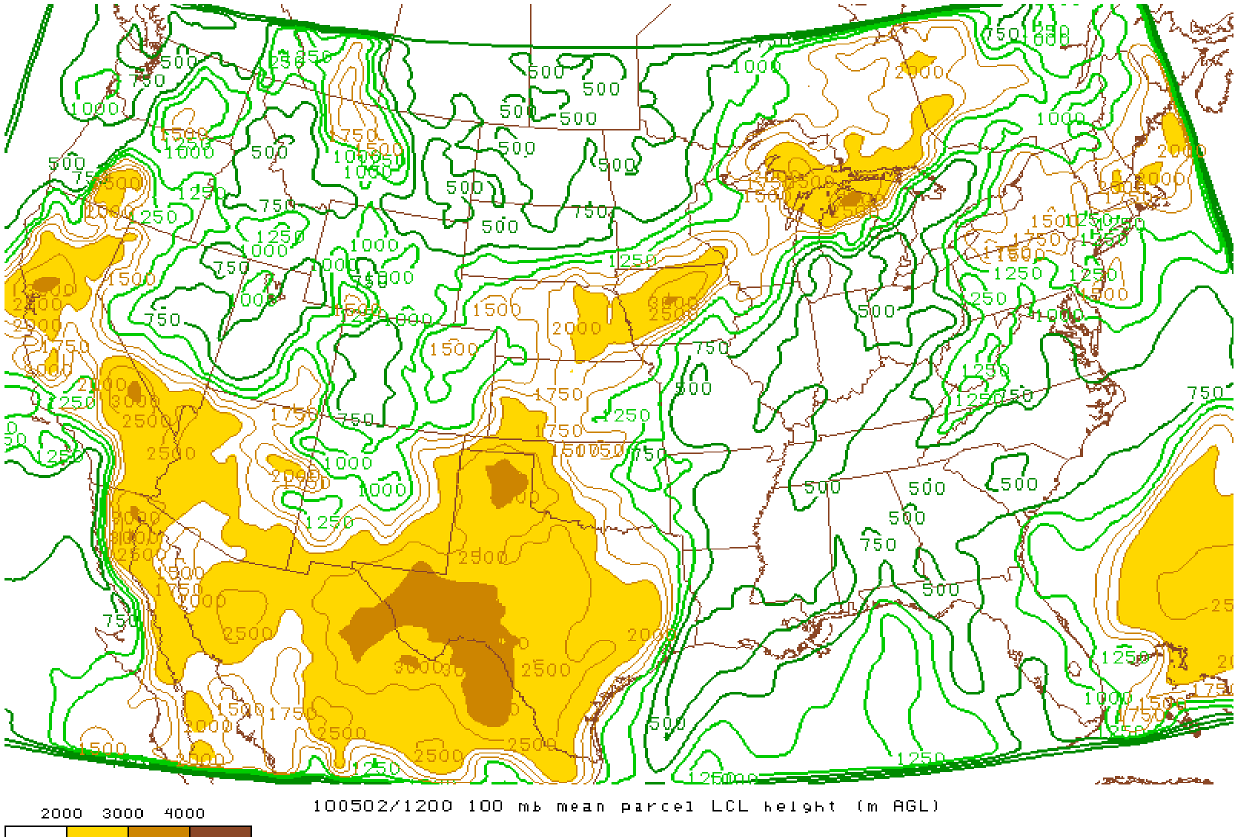


Fig. 13: LCL height at 12 UTC on May 2nd, 2010 (m above ground level)

The RUC sounding at Nashville, Tennessee for 16 UTC, May 2nd, 2010 reveals a sounding favorable for heavy rainfall. The sounding shows deep moisture, high Precipitable Water (PW), and moderate skinny CAPE. While the environmental lapse rate must be conditionally unstable for free convection to occur, large CAPE values do not necessarily favor high PE. Convection associated with extremely high CAPE produce intense updrafts, but some of the moisture will be ejected out of the top of the cell reducing precipitation efficiency. The long “skinny” positive area would have slower updraft acceleration and a taller thunderstorm. The thunderstorm associated with the skinnier sounding would also have less precipitation carried into the higher portions of the thunderstorm and would therefore lose less mass (ice crystals) from the top. In turn, a skinnier sounding would likely be more efficient.

6. TOPOGRAPHY

Flooding is either exacerbated or mitigated by the topography and land use characteristics on which the precipitation falls. The terrain of middle Tennessee is hilly to rolling, interspersed with low lying areas, generally along watercourses. The floods occurred in the most urbanized area in the region. This contributed to the catastrophic nature of the flooding in certain locations, while others were spared.

East Tennessee, extreme southwest Virginia, and the westernmost tip of North Carolina are generally hilly to mountainous, although large relatively flat areas occur along the Tennessee River mainstem and a few of its larger tributaries. There are also isolated locations where the flood plain along a particular stream will suddenly widen and flatten out immediately after the water exits a narrow valley or canyon. In addition, the three large metropolitan areas of East Tennessee, Chattanooga, Knoxville, and the Tri-Cities of Johnson City/Kingsport/Bristol, pose unique problems of their own. Chattanooga sits in the flat floodplain of the Tennessee River and the South Chickamauga Creek/West Chickamauga Creek system; Knoxville is the most heavily urbanized area and sits on complex karst landforms; the Tri-Cities each lie relatively close downstream from hilly to mountainous terrain and can be affected by headwater and, to some degree, snowmelt flooding as shown in Fig 14.

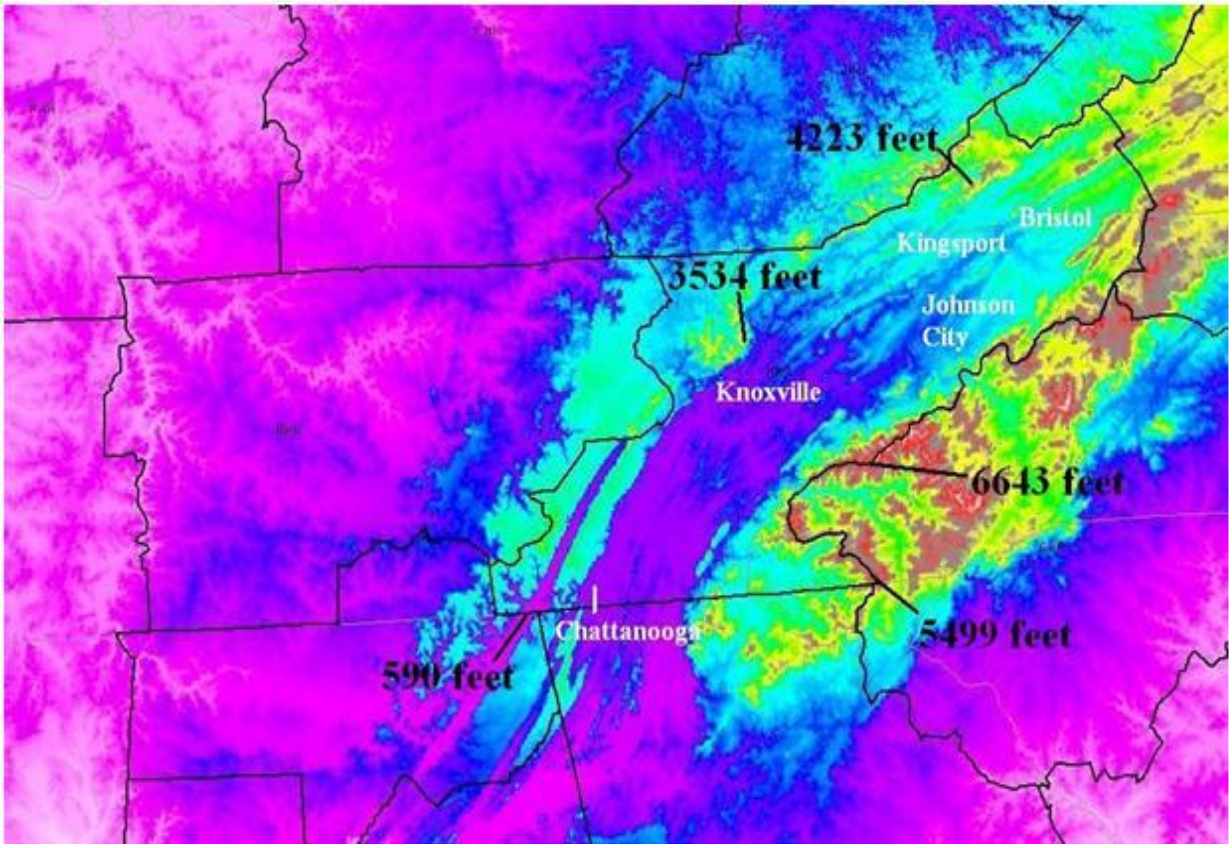


Fig. 14: Topography of southern Appalachia. Black lines delineate National Weather Service County Warning Areas (CWA's). White words are cities. Black numbers indicate selected elevations above Mean Sea Level (MSL).

The lowest elevation in this tri-state region lies along the Tennessee River in Marion County, Tennessee at approximately 590 feet MSL. The highest is at Clingman's Dome in the Great Smoky Mountains National Park along the North Carolina border at 6,643 feet. The overall terrain in the entire region is complex and rugged, often with quite high local relief. The distance from the top of Clingman's Dome to the Tennessee River in downtown Knoxville is about 36 miles, with an elevation drop of about 5,800 feet. By comparison, the distance from the headwaters of the Big Thompson River to Loveland, Colorado is 32 miles with an elevation drop of around 6,000 feet. Many places along the western slopes of the southern Appalachians have elevations changes comparable to the Front Range of the Rocky Mountains. Local elevations changes of over 1500 feet in less than one mile are common. Contrarily, the elevation change of the South Chickamauga Creek flowing through Chattanooga is only 500 feet in nearly 30 miles. Elevation changes of around one foot per mile are fairly common in the Tennessee River valley of southeast Tennessee, but many areas are known for nearly vertical drops. Indeed, waterfalls or cascades occur in nearly every county in the region, from 50 to 450 feet in height.

7. BASIC HYDROGRAPHY OF THE REGION

A very basic map of the larger rivers and lakes in the region is shown is Fig. 15. Large blue areas represent controlled lakes of the Tennessee Valley Authority (TVA), each of which lies behind a dam of considerable size. The blue lines represent a selection of primary, secondary, and tertiary tributaries of the Tennessee River, with the exception of a small portion in the northwest and far north of WFO Morristown, Tennessee County Warning Area (CWA) in which streamflow is into the Ohio River system.

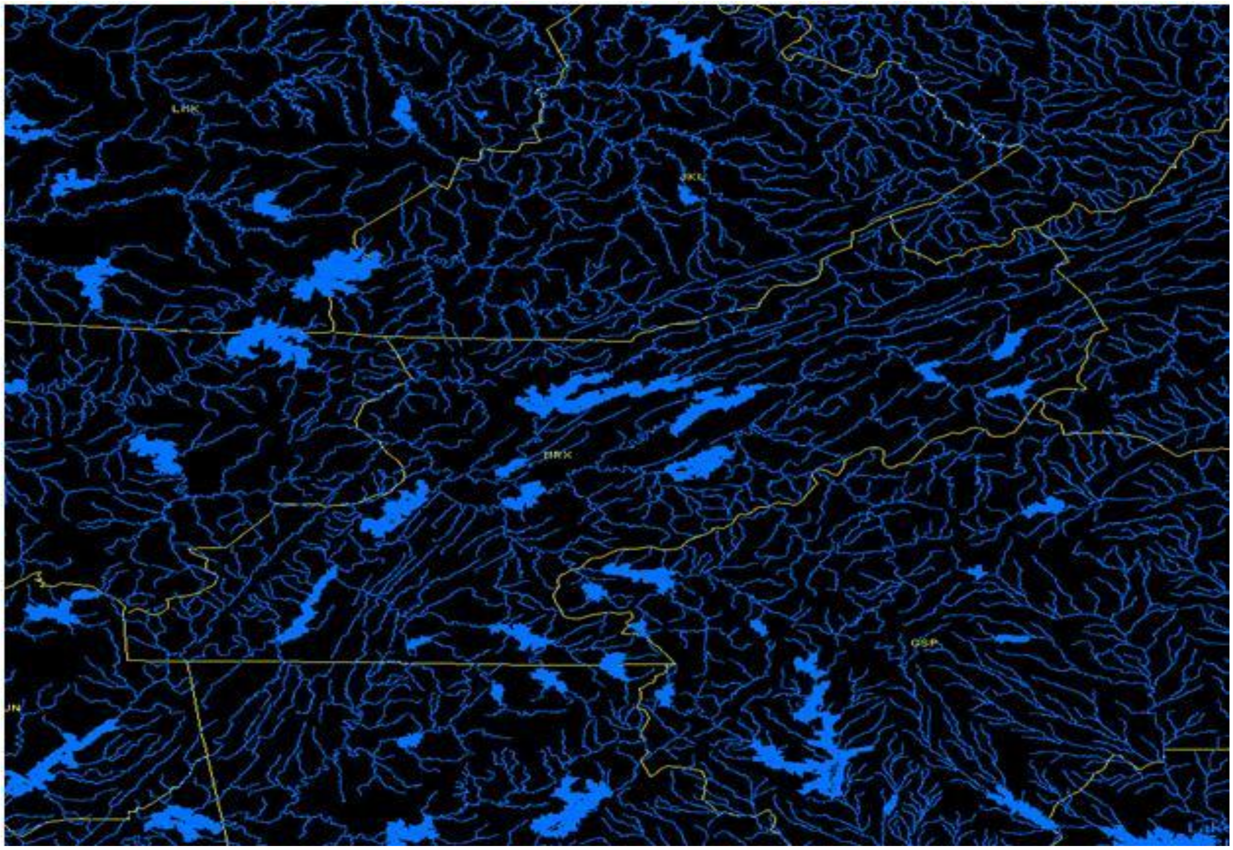


Fig. 15: Basic hydrography of WFO Morristown's CWA. Yellow lines delineate NWS CWAs. Blue areas are Tennessee Valley Authority (TVA) lakes. Blue lines are major streams.

The Tennessee River is the central feature of the region. Technically it occupies the valley of the same name, although the word "valley" is a bit misleading. The upper Tennessee River drainage is about 130 miles wide at its widest point, extending from the South Carolina border to the Kentucky-Virginia line. Yet, the "valley" contains several of the highest peaks in the eastern half of North America. This complex terrain is interspersed with limestone underpinnings and some of the most notorious karst (sinkhole) topography in the world. The complex terrain creates an extreme dendritic pattern to the streams in the region.

In addition, normal annual rainfall is quite high, with the driest part of Tennessee, the Tri-Cities Airport, receiving 41.3 inches annually. The rainiest part of the state lies in the southern mountains along the North Carolina border receiving upwards of 90 inches. Portions of southwest North Carolina, just outside the Morristown CWA, receive over 100 inches annually. Highland locations in extreme southwest Virginia receive nearly 70 inches annually. Precipitation falling in these area flows into the Tennessee River mainstem through a series of highly dendritic tributaries. Notable tropical systems such as Ivan tracked just east of Tennessee and produced relatively lighter rain in the Morristown CWA, yet created near record to record flooding.

The extreme dendritic nature of the stream system and topography, coupled with very high precipitation, combine to form a flood prone region second to few other places. One of the reasons the Tennessee Valley Authority was formed in the 1930s was to bring a sense of control to the Tennessee River and its larger tributaries which heretofore had been wildly destructive and deadly.

The general flow pattern into the central Tennessee Valley of East Tennessee is quite complex as depicted in Fig. 16. Streams descending from the mountains along the Tennessee-North Carolina border, the highlands of southwest Virginia and north Georgia, and off Cumberland Escarpment all make their way into the Tennessee River. Many of the headwater areas are also fan shaped, which further creates flood prone outlet streams.

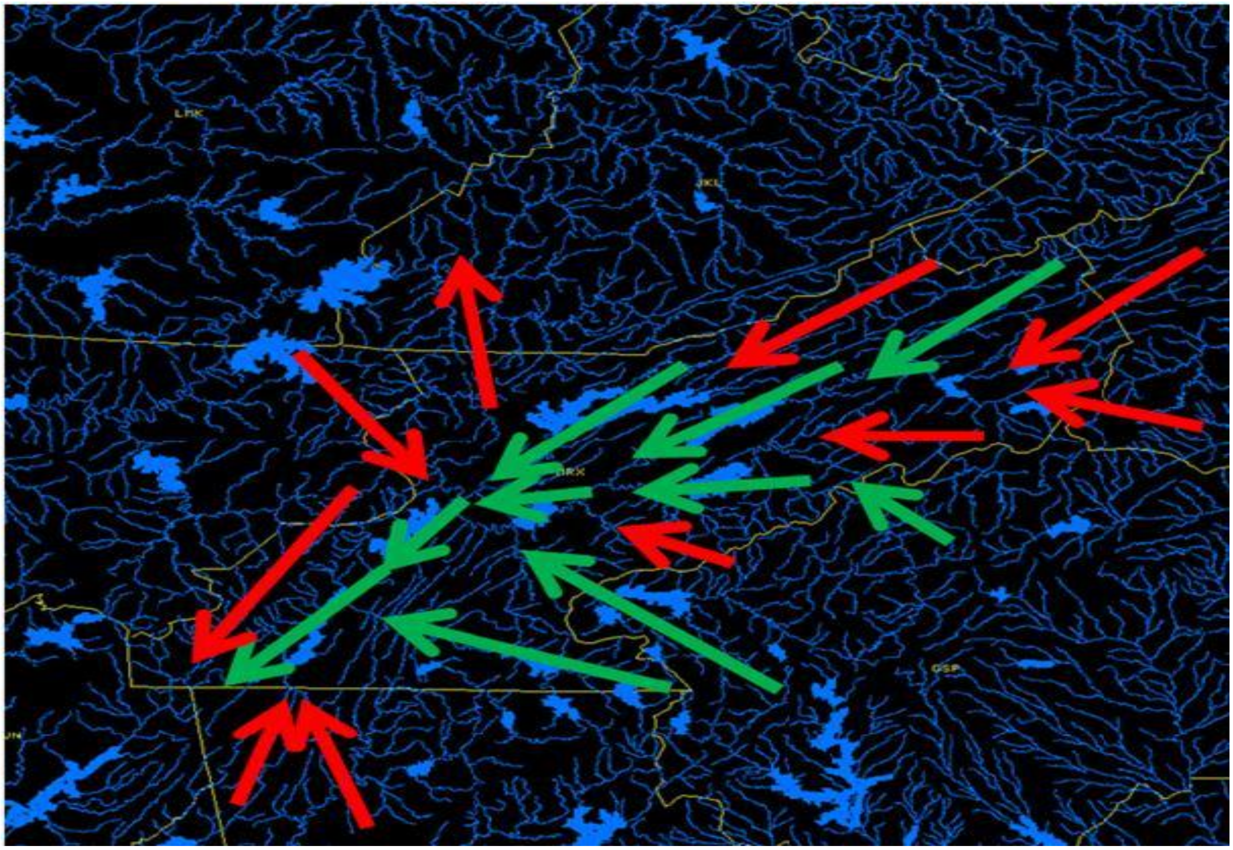


Fig. 16: Basic streamflow directions of the upper Tennessee Valley. Yellow lines delineate NWS CWA's. Blue areas are TVA lakes. Blue lines are major streams. Green arrows indicate the Tennessee River and its major tributaries. Red arrows show smaller tributaries or non-tributaries.

8. INITIAL CONDITIONS OF THE "WHAT IF" SCENARIO

Since the middle Tennessee flood occurred in early May under essentially normal streamflow conditions, it was deemed more accurate to run a contingency model run for the Morristown CWA rivers under similar conditions. Streamflows in early May 2010 in East Tennessee, extreme southwest Virginia, and the westernmost tip of North Carolina were near to just under the median levels for that week of the year. Hence, resultant crest forecasts are on the conservative (low) side. If soil moisture content had been higher the river forecasts would certainly have been higher. If snow pack had been present in the higher terrain, the crests would have been much higher. Some of the most devastating and deadly floods in the region have been in winter and early spring when rain falls on ample snow pack. The largest assumption was in using a uniform 15 inch mean areal precipitation (MAP) value for the entire region. It is not realistic to assume that 15 inches of rain will fall on every single place in the area, but this number was used for each river gage modeled, which is line with the maximum MAP for certain gages in the middle Tennessee flood. Also, the rain was assumed to have fallen uniformly temporally over a four day period.

9. THE "WHAT IF" SCENARIO

A map showing the locations and NWS id's for the thirteen river gages for which the Lower Mississippi River Forecast Center (LMRFC) in Slidell, LA ran its simulation using the National Weather Service River Forecast System (NWSRFS) model is shown in Fig. 17.

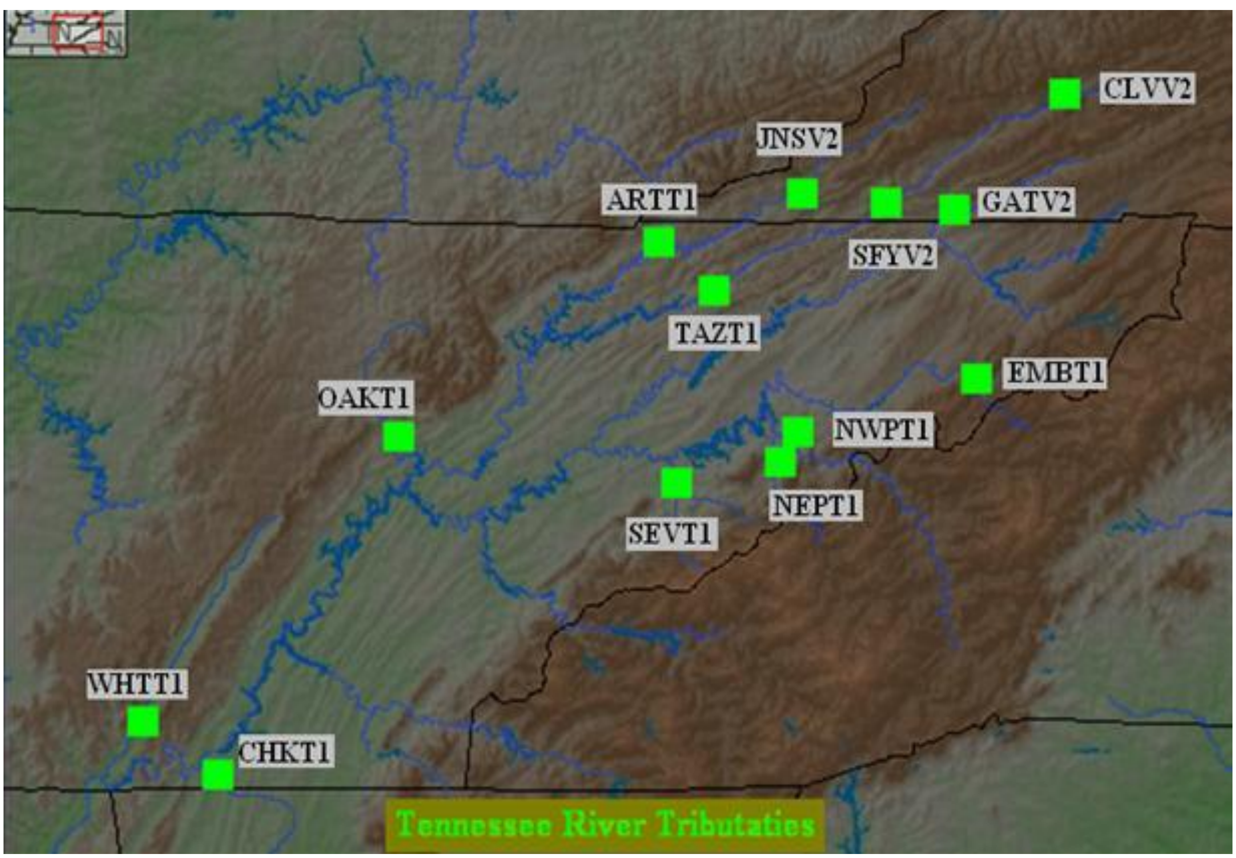


Fig. 17: Locations of LMRFC forecast points in the Morristown CWA.

The table below (Table 1) shows partial results of the forecast from the NWSRFS model run for the 15" MAP "What if" scenario. The column "Site" corresponds to the gages shown in Fig. 17.

SITE	NAME	Flood stage	Forecast crest	Flood severity	Flood of record
WHTT1	Sequatchie River nr Whitwell, TN	14.0	17.5	Minor - 6th highest	19.00
CHKT1	South Chickamauga Creek nr Chickamauga, TN	18.0	32.0	**New record**	29.29
OAKT1	Emory River at Oakdale, TN	27.0	28.5	Moderate - 19th highest	42.30
SEVT1	Little Pigeon River at Sevierville, TN	11.0	21.5	**New record**	18.00
NEPT1	Pigeon River at Newport, TN	8.0	18.5	Major - 3rd highest	23.40
NWPT1	French Broad River nr Newport, TN	10.0	23.0	Major - tie for 2nd highest	24.00
EMBT1	Nolichucky River at Embreeville, TN	12.0	15.0	Minor - 5th highest	24.00
GATV2	North Fork Holston River nr Gate City, VA	12.0	24.5	**New record**	22.50
ARTT1	Powell River nr Arthur, TN	17.0	38.0	Major - 2nd highest by <1'	38.96
JNSV2	Power River n Jonesville, VA	18.0	30.5	Moderate - 6th highest	44.32
TAZT1	Clinch River abv Tazewell, TN	12.0	32.5	**New record**	29.32
SFYV2	Clinch River abv Speers Ferry, VA	18.0	38.0	**New record**	36.69
CLVV2	Clinch River at Cleveland, VA	14.0	30.0	**New record**	26.40

Table 1: Partial results of the NWSRFS model forecast

It is evident from the table that this would, with few exceptions, be a catastrophic flood event. To illustrate the devastation of the flooding, we will use Chattanooga as an example. The flood of May 2003 caused the South Chickamauga Creek to reach its flood of record at 29.29 feet. The creek is normally about 30-50 feet wide near the gage. During the crest, its width increased to over one half mile, as shown in Photograph 1. Its largest tributary, West Chickamauga Creek, was nearly one mile wide in places. Both of these rivers are fairly slow moving. The contingency forecast results (not shown) imply that the speed of movement of the flood crest during the "what if" scenario would be between one and two miles per hour from headwaters to mouth. (In contrast, the speed of the Clinch River crest would be around 10 mph, due to a much steeper channel.)


Photograph 1: South Chickamauga Creek in the city of Chattanooga, TN, during the flood of record in May 2003. The river is approximately a half mile wide.

In Photograph 2 the gage for the South Chickamauga Creek is labeled at the bottom right with US Highway 11 (Lee Highway) partially inundated, and Lovell Field (Chattanooga's regional airport) essentially an island. If the "What if" scenario were to occur and a new flood of record established at nearly three feet higher, the river would come near the edge of the runways, and only the tops of buildings and trees and a few cars would be visible. It is estimated that the river would exceed one mile in width in places.

Photograph 2: Aerial view of the South Chickamauga flood in May 2003. The gage is just off the view to right bottom. The Chattanooga airport is at top left. US Highway 11 runs through the middle of the view.

In the flood of May 2003, approximately $165 million in damage occurred in southeast Tennessee in a few counties. If this “what if” scenario were to occur, there are no estimates currently available to approximate the damage. More on this will be mentioned in the next section. In the middle Tennessee flood of May 2010, over $1.5 billion in damage occurred. Middle Tennessee has one major metropolitan area, while East Tennessee has three, and Chattanooga is highly susceptible to flooding from both the Tennessee River and its tributaries, and from local area flooding.

10. THE TENNESSEE RIVER MAINSTEM

The record flood on the Tennessee River at Chattanooga occurred in March 1867. This was many decades before TVA was established and during the "wild river" era of Tennessee River flooding. Photograph 3 illustrates the degree of flooding that occurred then.

Photograph 3: Two views of the Tennessee River at Chattanooga, TN, taken over a century apart.

The view on the left is from the 1867 flood, taken from the top of Lookout Mountain, looking down on Chattanooga during the crest. The river is over three miles wide at this time and completely covers the city of Chattanooga. In the right hand photograph, a more recent image shows the river in its channel and the city sprawling to the horizon.

The Tennessee Valley Authority has established the figures for the entire Tennessee River in a "what if" scenario such as we have described in this paper, but are planning to release them at a news conference and official press release in the spring of 2011. The NWS in Morristown, Tennessee has established a strong relationship with TVA and supports the release of these data at this later date. It is anticipated that TVA will release estimates of damage that would occur if TVA did not exist to mitigate the flood, and also estimates that would occur with TVA actually performing flood mitigation, resulting in substantial savings of money and lives.

11. AREAL AND FLASH FLOODING

While the estimates for river flooding are relatively easily obtained through NWSRFS or TVA model runs, estimates for areal and flash flooding are more readily established through previous experience. Rainfall totals approaching 15 inches over a few days or even several hours have occurred in isolated locations in East Tennessee, extreme southwest Virginia, and the westernmost tip of North Carolina. In several such floods in the recent past, bridges, roads, and buildings were utterly devastated. Severe mud and rock slides occurred and even top soil was wiped away. Numerous injuries and fatalities have also ensued, as well. Landslides are common in such events in the more rugged locations. Strip mined or clear cut areas are especially susceptible. In all three major urban areas, rainfall totals of less than two inches per hour in the summer are enough to cause flash flooding. In winter, as little as one inch per hour rates will cause flooding on partially frozen or saturated soils and pavement. In addition, extensive snow pack is common in the Blue Ridge chain, higher elevations of the Cumberland Plateau, and the highlands of southwest Virginia. Rapid melting of snow has resulted in several notable floods in recent years, some of which have caused millions of dollars in damage and even fatalities.

The timing of a “what if” flood event is critical to accurate forecasting and warning. If such a rain event occurred in winter or early spring on top of extensive snow pack, the results would likely be beyond the imagination of the public, emergency managers, and even professional meteorologists.

12. SUMMARY

In summary, the synoptic type heavy rainfall event classified by Maddox et.al (1979) identifies well with the Nashville Flood event. The two dominant synoptic features of this event were the modified Omega Blocking and the deep tropical moisture plume. The moisture plume or (Atmospheric River) produced near record PWs over the Nashville area. The depth of moisture combined with duration of moisture transport, produced high rainfall rates and impressive totals over the Nashville, Tennessee area. Several thermodynamic features also enhanced the rainfall totals. Such parameters include: moderate CAPE values, low convective inhibition and low LCL heights.

The extreme meteorology of such an historic event combined with the unique topographic and urban features of the region would no doubt produce a flood with few if any precedent in the United States.

The National Weather Service in Morristown, Tennessee has developed a simplified version of this scenario for use in educating the public, emergency managers, utility district managers, engineering consulting consortiums, etc, and has presented it dozens of times across the region. We anticipate continuing in this effort, and coordinating with TVA and state and county emergency management agencies to develop a table top and functional exercise. The broadcast media in the three urban markets have also been included and more activities will be undertaken with them to make the public aware of the dangers of flooding, and the efforts by local, state, and federal government to save lives and livelihoods.

References

-Bach, C., Tennessee Valley Authority, Knoxville, TN, June-August 2010: personal communications.

-Costanza, K., Smith, J., cited May 2010: National Weather Service, Lower Mississippi River Forecast Center, NWS River Forecast System model contingency forecast.

-Doswell, C.A., III, 1987: The distinction between large-scale and mesoscale contribution to severe convection: A case study example. *Wea Forecasting*, **2,** 3–16.

-Dirmeyer, P. A., and J. L. Kinter III, 2009: The Maya Express - Late spring floods in the US Midwest. *Eos – Transactions of the American Geophysical Union*, **90**, 101-102.

-Fankhauser, J.C., 1988: Estimates of Thunderstorm Precipitation Efficiency from Field measurements in CCOPE- *Mon Wea Rev,* **116,** 677-678

-Hydrometeorological Prediction Center, cited 2011: HPC Daily Weather Maps. [Available online at http://www.hpc.ncep.noaa.gov/dailywxmap/]

-Maddox, R.A., Hoxit, L.R., Chapell, C.F., 1979: Synoptic and meso-α scale aspects of flash flood events. *Bull. Amer. Meteor. Soc*., **60,** 115-123.

-Maddox, R. A., Doswell, C. A., and Brooks, H. E., 1996: Flash Flood Forecasting: An Ingredients-Based Methodology. *Wea Forecasting,* **11,** 561-563.

-Market, R. S., Kuligowski, R., and A. Gruber, P., S. Allen, 2003: Precipitation efficiency of warm-season midwestern mesoscale convective systems. *Wea. Forecasting*, **18**, 1273–1285.

-National Weather Service Rapid City, South Dakota, cited 2011: Precipitable Water Plots [Available online at http://www.crh.noaa.gov/unr/?n=pw]

-Storm Prediction Center, cited 2011: SPC Mesoanalysis Archive. [Available online at http://www.spc.ncep.noaa.gov/exper/ma_archive/]

-Unisys Weather, cited 2011: Unisys Image and Map Archive. [Available online at http://weather.unisys.com/archive/index.php]