The Qualla Boundary Flash Flood of 14 and 15 July 2011

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1. Introduction

During the late night and early morning hours of 14 and 15 July 2011, a flash flood occurred along Straight Fork Creek in the Qualla Boundary in western North Carolina, home of the Eastern Band of Cherokee Indians. Fortunately, no injuries or deaths were reported, but considerable damage occurred at the Cherokee Tribal Fish Hatchery (Fig. 1). Hatchery officials said that a wall of water 8 to 10 feet high raced through the complex leaving behind thousands of pounds of dead fish and damaging screens, gates, and fences. Damage estimates ranged from $30,000 to $50,000[1]. A person living in the area said that rain did not fall at the hatchery.

The flood was caused by a small convective system that remained nearly stationary along the Balsam Mountain ridge that marks the Haywood County and Swain County border in the Great Smoky Mountains National Park. A substantial portion of the precipitation fell in northwest Haywood County, but heavy rain also occurred in the northeast corner of Swain County (Fig. 2). In Haywood County, the heavy rain fell in the Big Creek basin, but no flooding was reported. In Swain County, the precipitation fell in the headwaters of Straight Fork Creek. The water flowed rapidly downhill toward the creek's confluence with Raven Fork Creek beyond the hatchery. The rainfall in the Straight Fork Creek headwaters lasted approximately five hours from 2338 UTC until 0430 UTC, but the heaviest rain occurred between 0000 and 0300 UTC based on radar observations. The flood waters affected the hatchery at approximately 0400 UTC. No one was present to observe the flood event, but a nearby resident heard rocks tumbling down the mountain near midnight (Johnson 2011).

Flooding without warning in the Qualla Boundary has occurred in the past due to heavy rain falling in the headwaters of Raven Fork and Straight Fork creeks in the northeastern portion of Swain County. Straight Fork Creek empties into Raven Fork Creek just inside the Boundary. The town of Cherokee, a busy tourist and camping area, is further downstream on the Oconaluftee River.

[1] News article posted on WLOS-TV web site on 15 July 2011 at 2236 UTC.

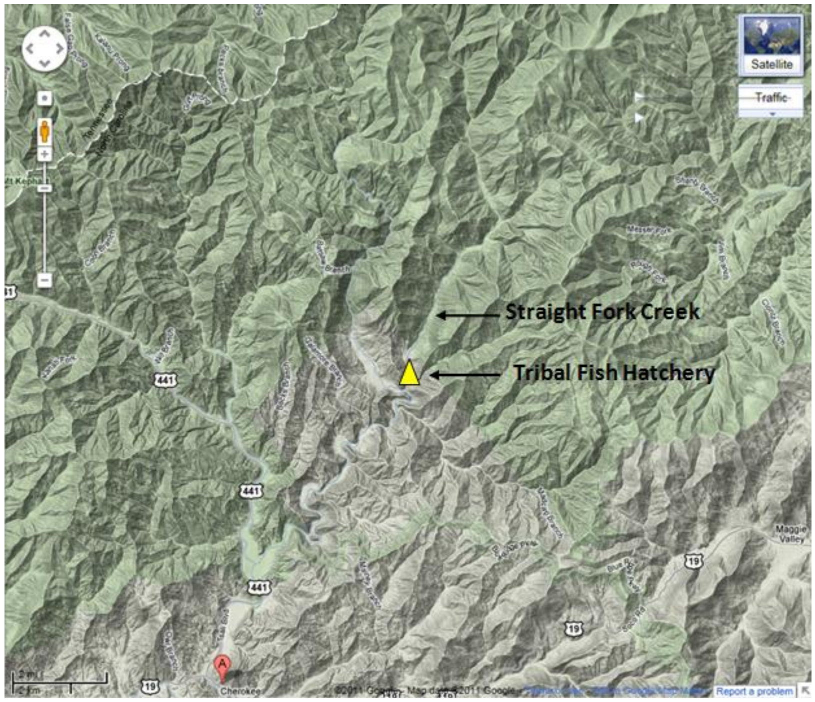

Fig. 1. Tribal Fish Hatchery denoted by yellow triangle. Marker at bottom of image shows location of Cherokee, NC. White dashed line in upper left is the Tennessee-North Carolina border. (Google Maps)

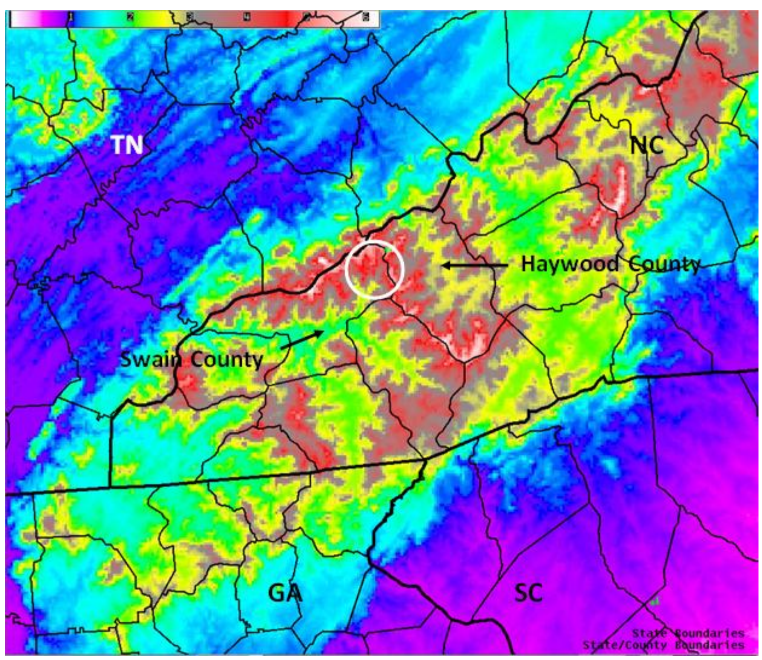

Fig. 2. Image of topography in western North Carolina and neighboring states. White circle encompasses the region of heaviest rain and flash flooding. Red and white denote highest elevations.

2. Meteorological Setting

The 0000 UTC 15 July 2011 surface analysis (Fig. 3) featured high pressure centers over the Great Lakes and the mid-Atlantic coast. A stationary front extended from northeast Alabama across Georgia to the Atlantic. A weak trough of low pressure was west of the Appalachians.

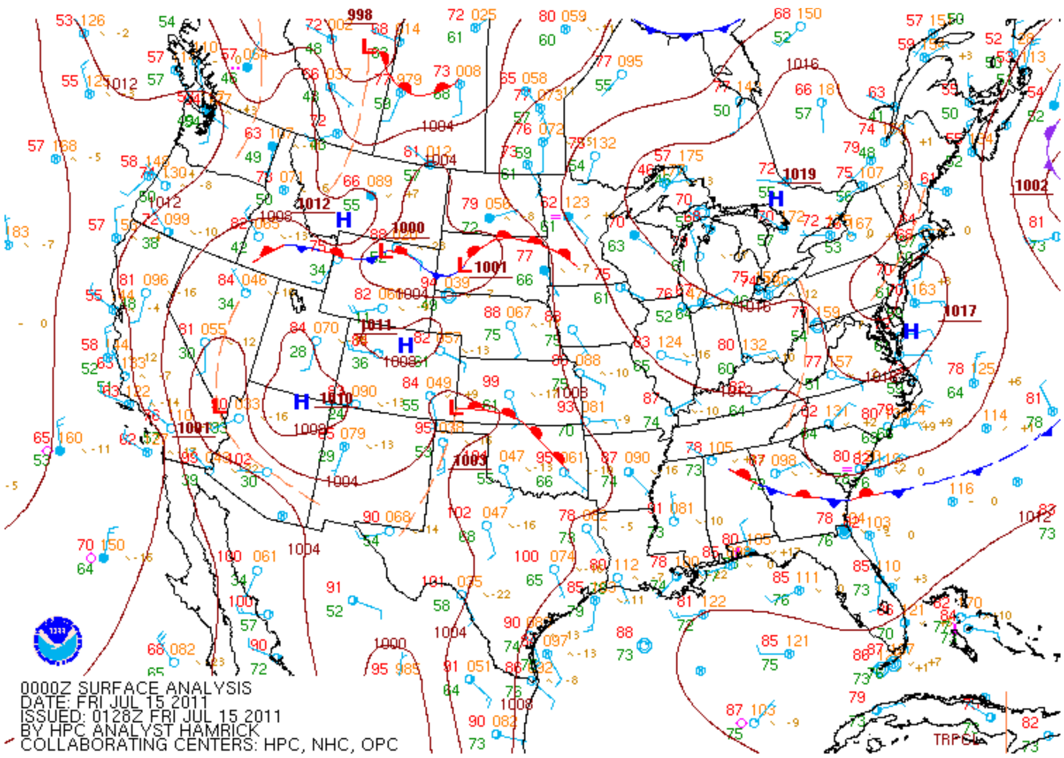

Fig. 3. 0000 UTC 15 July 2011 NCEP/HPC surface analysis.

The front over the southeastern U.S. represented the surface transition between the air mass associated with the mid-Atlantic high and the warm, moist air mass covering the Gulf Coast region. The 0000 UTC RUC (Rapid Update Cycle) surface dewpoint analysis (Fig. 4) showed relatively dry air over Virginia and northeastern North Carolina, but very moist air over the mountains of North Carolina. The 0000 UTC surface observation at the Asheville Regional Airport (KAVL; approximately 45 miles southeast of the heavy rain) indicated the temperature was 76^{o}F, and the dewpoint was 65^{o}F. The sky was overcast at 4100 feet AGL, and the wind was calm. KAVL was the ASOS observation closest to the heavy rain and flood locations.

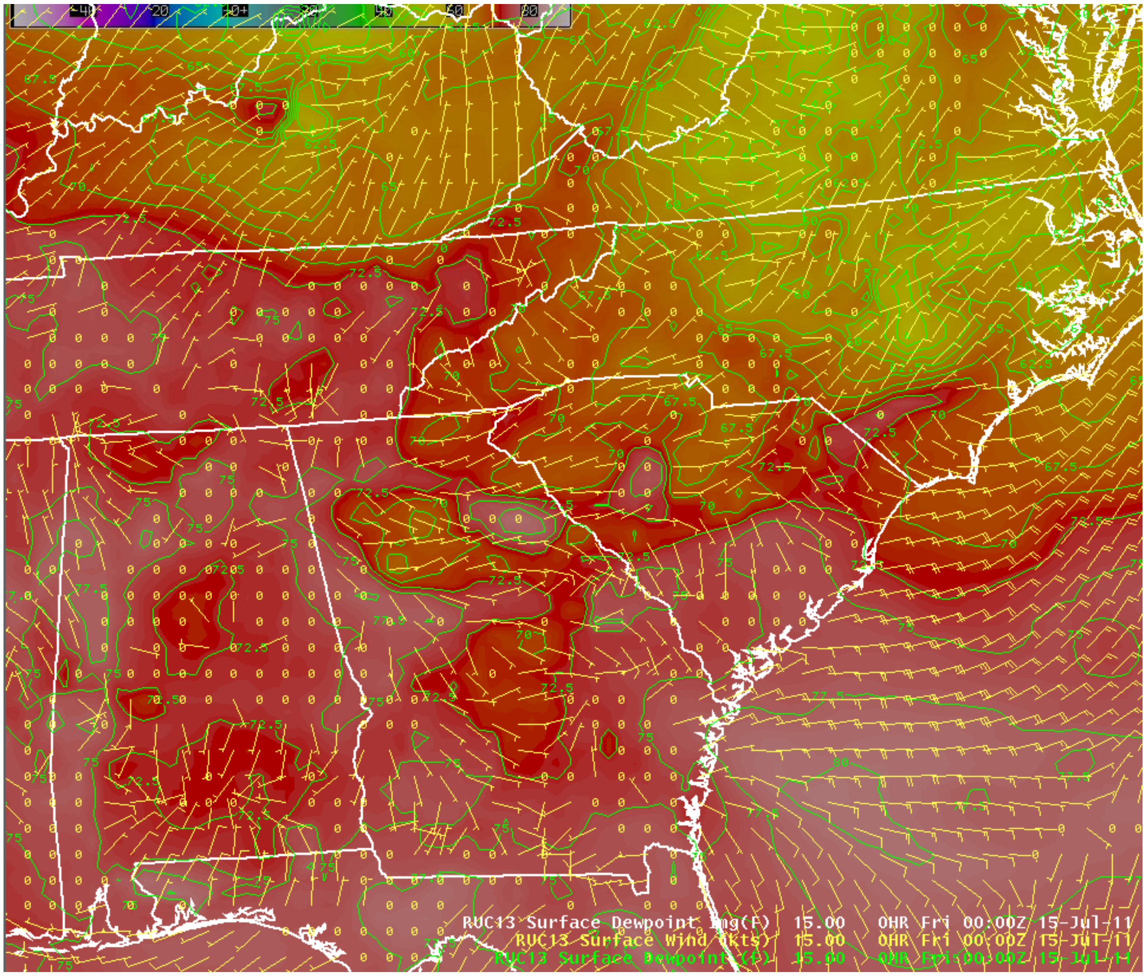

Fig. 4. 0000 UTC 15 July 2011 RUC surface dewpoint and wind (barbs) analysis. Red shades over the southern Appalachians indicate dewpoints ranging from 68° to 71°F. Yellow shades in eastern North Carolina represent dewpoints between 55° and 60°F.

The 0000 UTC RUC 850 mb height, wind, and relative humidity analysis (Fig. 5) also showed dry air over the mid-Atlantic coast while central and western North Carolina remained moist (surface dewpoints 65° to 70°F). The surface and 850 mb analyses indicated the frontal boundary separating the two air masses was just the low level representation of what actually was a very broad, but nonetheless significant, zone of transition. Abundant low-level moisture remained across the southern Appalachians even though the surface front had moved far south of the area. In addition, the winds at both the surface and 850 mb had significant easterly components resulting in upslope flow along the higher terrain oriented generally north-south.

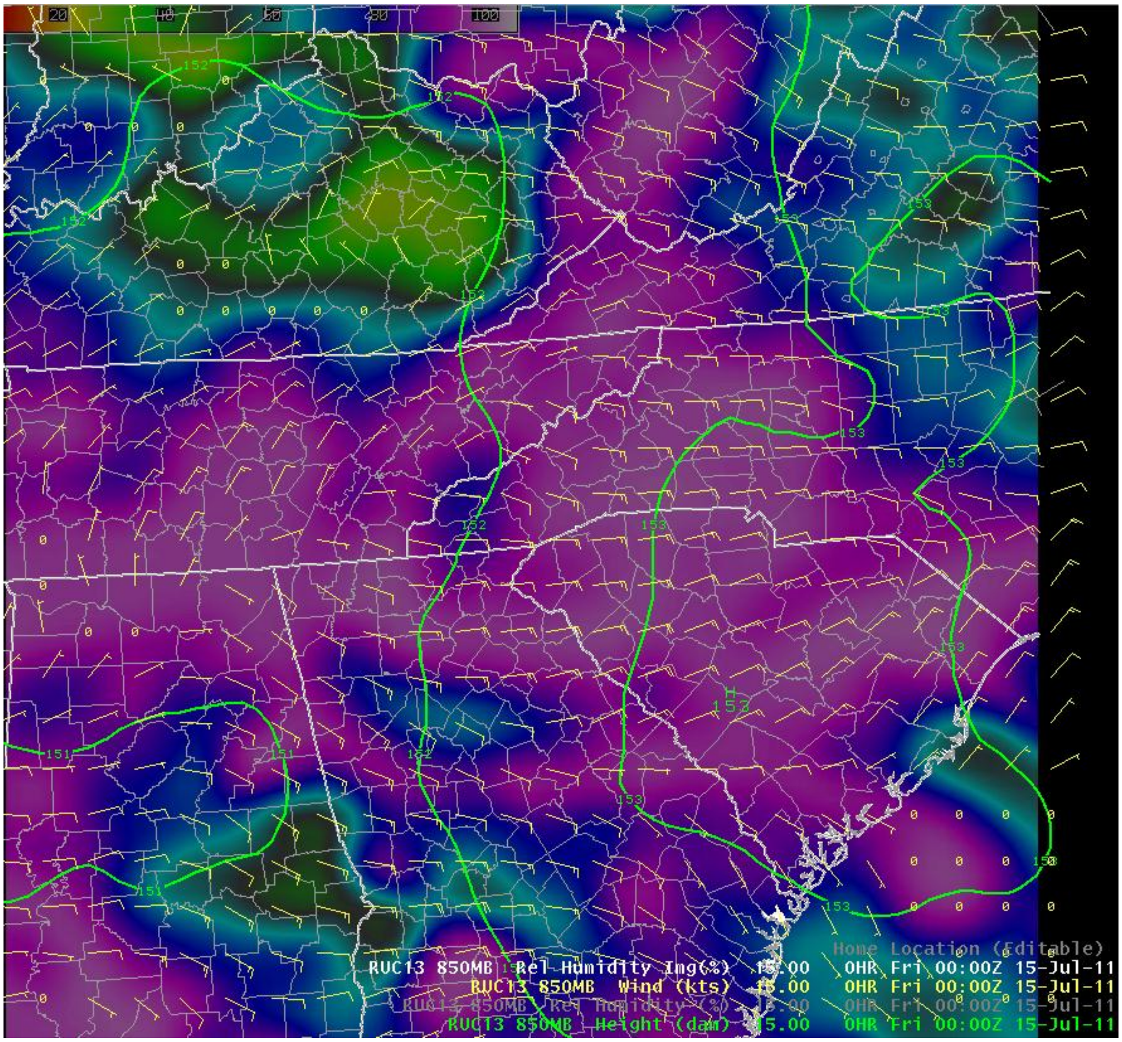

Fig. 5. 0000 UTC 15 July 2011 RUC 850 mb height (green contours) and wind (barbs) analysis. Purple shades denote relative humidity greater than 80 percent.

The primary features that defined the mid and upper level flow pattern at 0000 UTC across the southern Appalachians were a cyclonic circulation center east of New England and an anticyclonic circulation center over the southern Great Plains. North Carolina was under the southern edge of the well-defined 500 mb northwest wind flow across the mid-Atlantic states. A short wave trough over central North Carolina was moving toward the southeast away from the Appalachian mountains. Embedded within the very weak 500 mb northwest flow over east Tennessee were a weak short wave trough and several small vorticity maxima (Fig. 6).

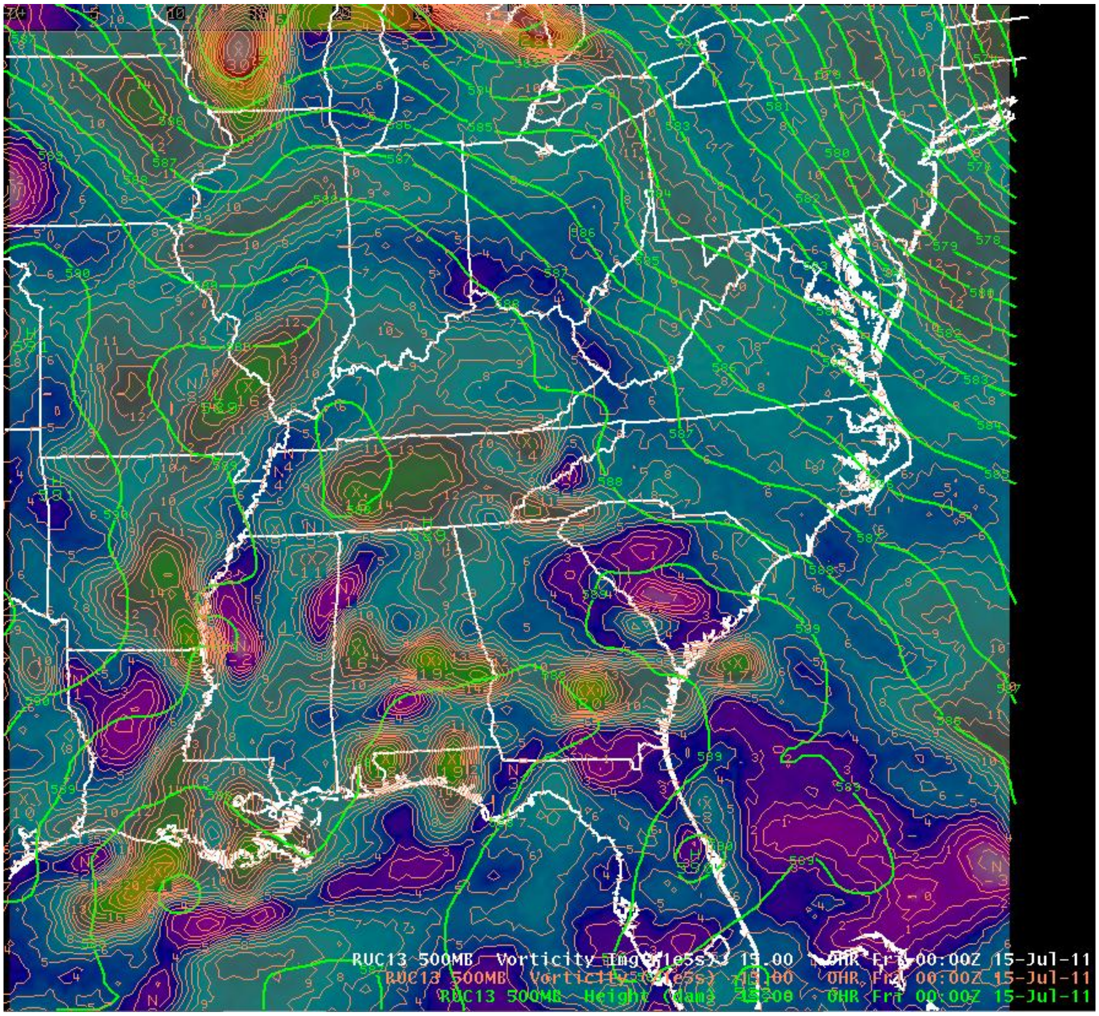

Fig. 5. 0000 UTC 15 July 2011 RUC 500 mb height (green contours) and vorticity (thin orange lines) analysis. Vorticity maxima are indicated by yellow and orange shades.

The air mass transition and a general sense of the atmosphere's ability to support convection were evident in the two 0000 UTC RUC analyses in Fig. 6. The K index[2] depicted the west to east transition from moist to dry air. It also showed that K index values were sufficiently high (approximately 35) to indicate an environment capable of supporting thunderstorm development. The Convective Available Potential Energy (CAPE) analysis clearly showed that the mountains of North Carolina were on the northeastern edge of the air mass containing energy that could be released if upward motion allowed air parcels to reach the level of free convection. CAPE across the area where the convective storms developed ranged from 1800 to 2200 J kg^{-1}.

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[2] Stability index that is a measure of thunderstorm potential based on temperature lapse rate, moisture content of the lower troposphere, and the vertical extent of the moist layer. (http://amsglossary.allenpress.com/glossary)

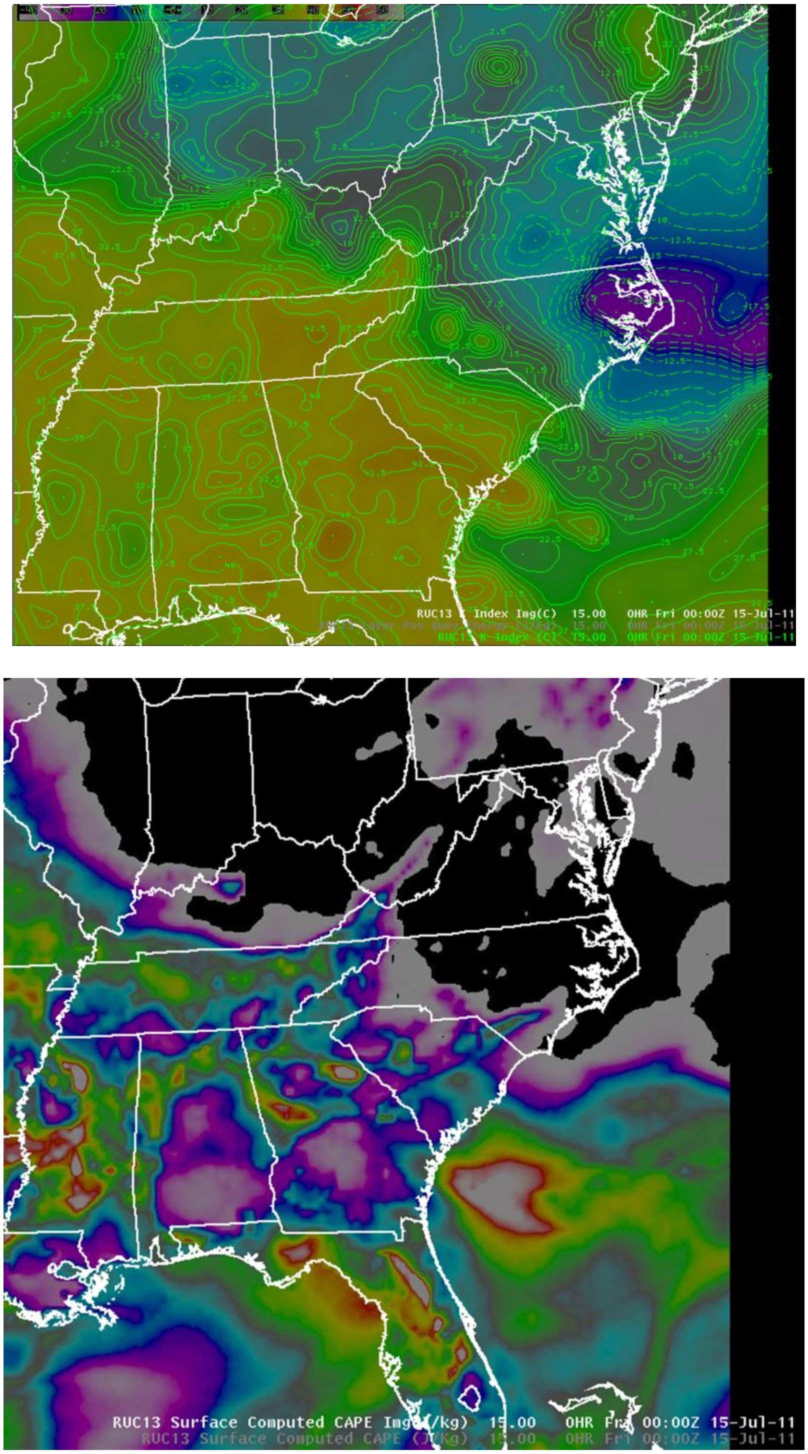

Fig. 6. 0000 UTC 15 July 2011 RUC K index (top) and CAPE (bottom). K index was approximately 35 and CAPE was approximately 1900 J kg^{-1} in the area where the heavy rain occurred.

The weak height and temperature gradients in combination with light winds through a significant depth of the atmosphere resulted in very weak forcing for upward motion. The vorticity and thermal advection patterns that determine a major portion of synoptic scale forcing at any one time were ill-defined. Nonetheless, the summertime environment provided sufficient instability that allowed the weak forcing to create a noticeable response (viz. upward motion) over western North Carolina, as seen in the RUC initial analysis of vertical velocity at 0000 UTC along a cross-section from western Tennessee to eastern North Carolina Fig. 7).

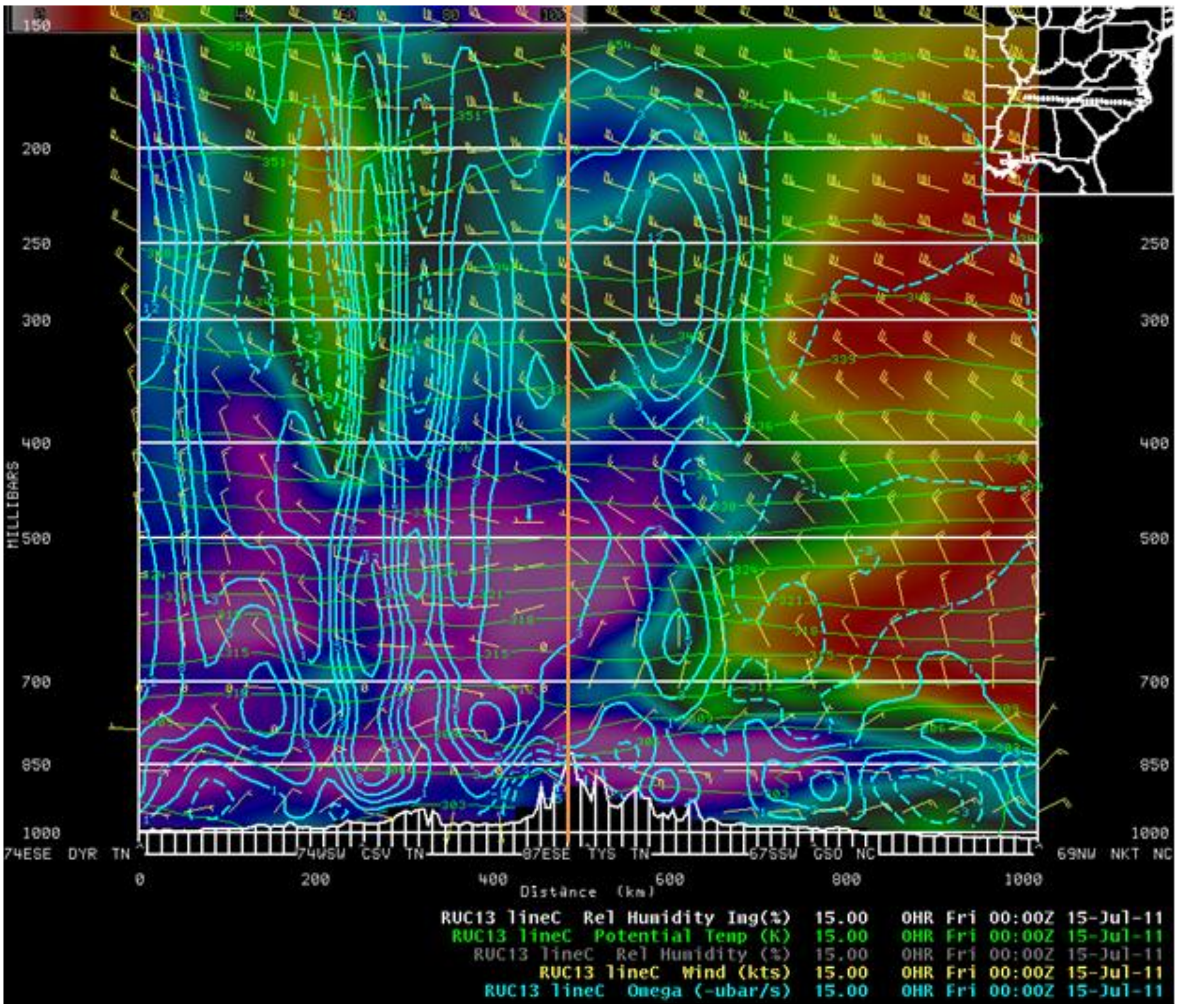

Fig. 7. 0000 UTC 15 July 2011 vertical cross-section from west Tennessee (left) to the North Carolina coast (right). Purple to orange shades denote decreasing relative humidity from west to east. Solid blue contours identify areas of upward motion. Thin green contours are potential temperature.   Vertical orange line near center of image identifies the approximate location of the heavy rain producing thunderstorms.

A more localized view of the RUC atmosphere's characteristics was available in a 0000 UTC model profile of temperature, dewpoint, and wind near the location of the heavy rain (Fig. 8). The temperature data point just above the model surface appeared to be spurious. Discounting the bad data[3], the essential features of the model profile were the availability of moisture and the relatively light winds through a deep layer. An easterly component (upslope along the Balsam Mountain ridge) was evident in the winds from the surface to approximately 600 mb. Even though some slightly drier mid-level air was present, the precipitable water value of 1.77 inch approached the 99th percentile of July precipitable water in the North Carolina mountains (Fig. 9). Also, the freezing level was relatively high (15,600 feet; 580 mb). The deep, warm air that provided the environment for the convective storms helped optimize the collision-coalescence process that produced the precipitation. Radar imagery (Figs. 10 and 11) showed the strongest updrafts were probably protected from entraining drier air because lower reflectivity (lighter rain) surrounded the updraft cores.

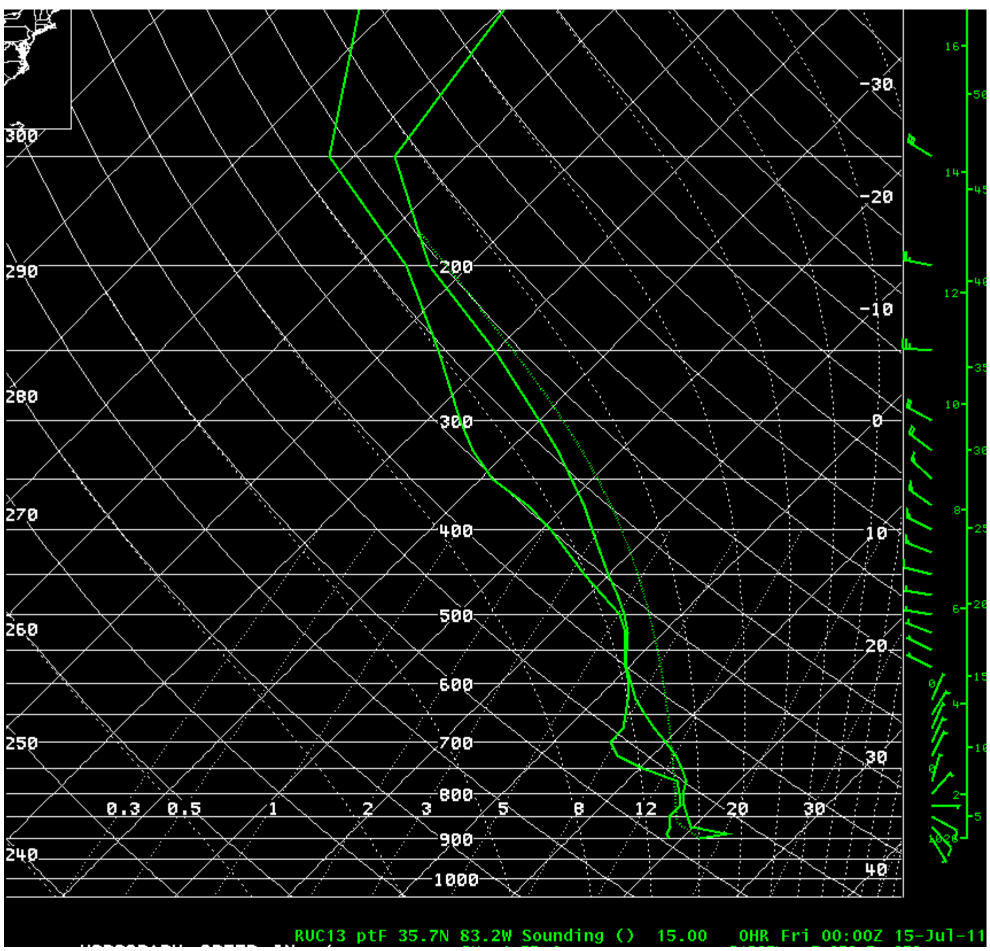

Fig. 8. 0000 UTC 15 July 2011 RUC temperature, dewpoint, and wind profile near the location of heavy rain in the Straight Fork Creek headwaters.

[3] The bad data point (3661 feet MSL) in the RUC model profile was actually below the elevation of the terrain along the ridge (approx. 5000 to 6000 feet MSL) where the convection developed.

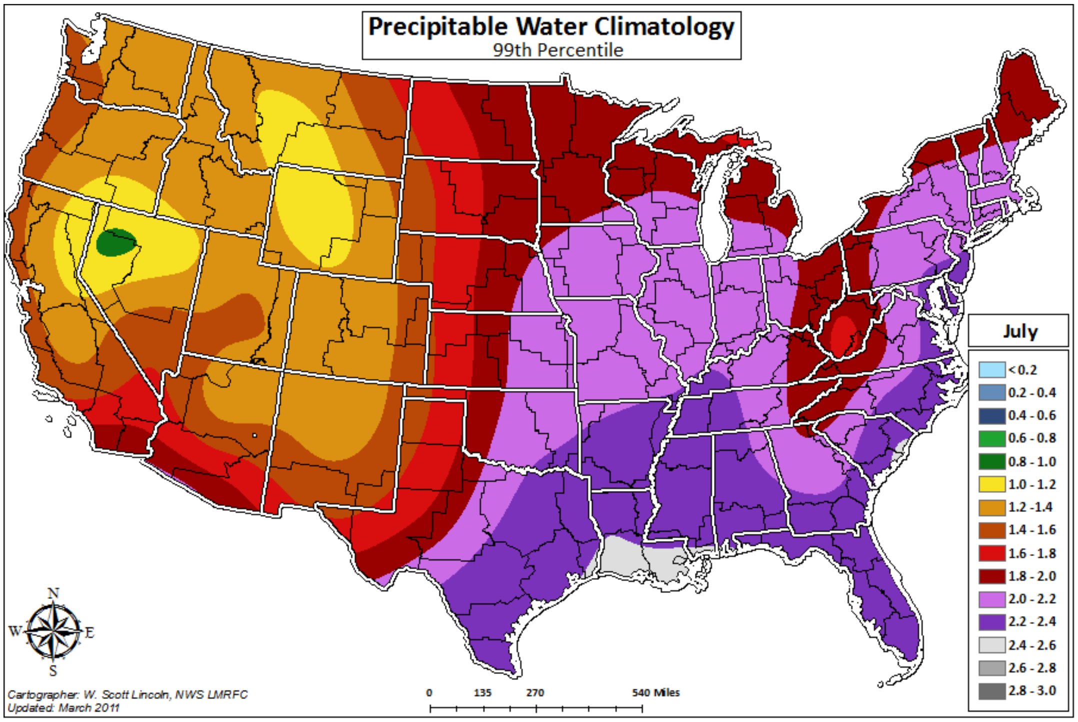

Fig. 9. July Precipitable Water Climatology 99th Percentile (inches). Courtesy: WFO Rapid City; http://www.crh.noaa.gov/unr/?n=pw

3. Radar Observations

The first radar echo detected by the KGSP (WFO Greenville-Spartanburg; 77 miles southwest) WSR-88D in the vicinity of the flash flood appeared at 2338 UTC on 14 July 2011. Thereafter, the precipitation developed and expanded along the ridge defining the border between Swain and Haywood counties (Figs. 10 and 11). The easterly wind component below 580 mb (southeast near the surface backing to northeast above) more than likely produced the weak upslope flow along the ridge providing the vertical motion that served as the trigger for thunderstorm development. The 0000 UTC RUC CAPE (approximately 2000 J kg^{-1}) indicated sufficient energy was available to sustain the convection.

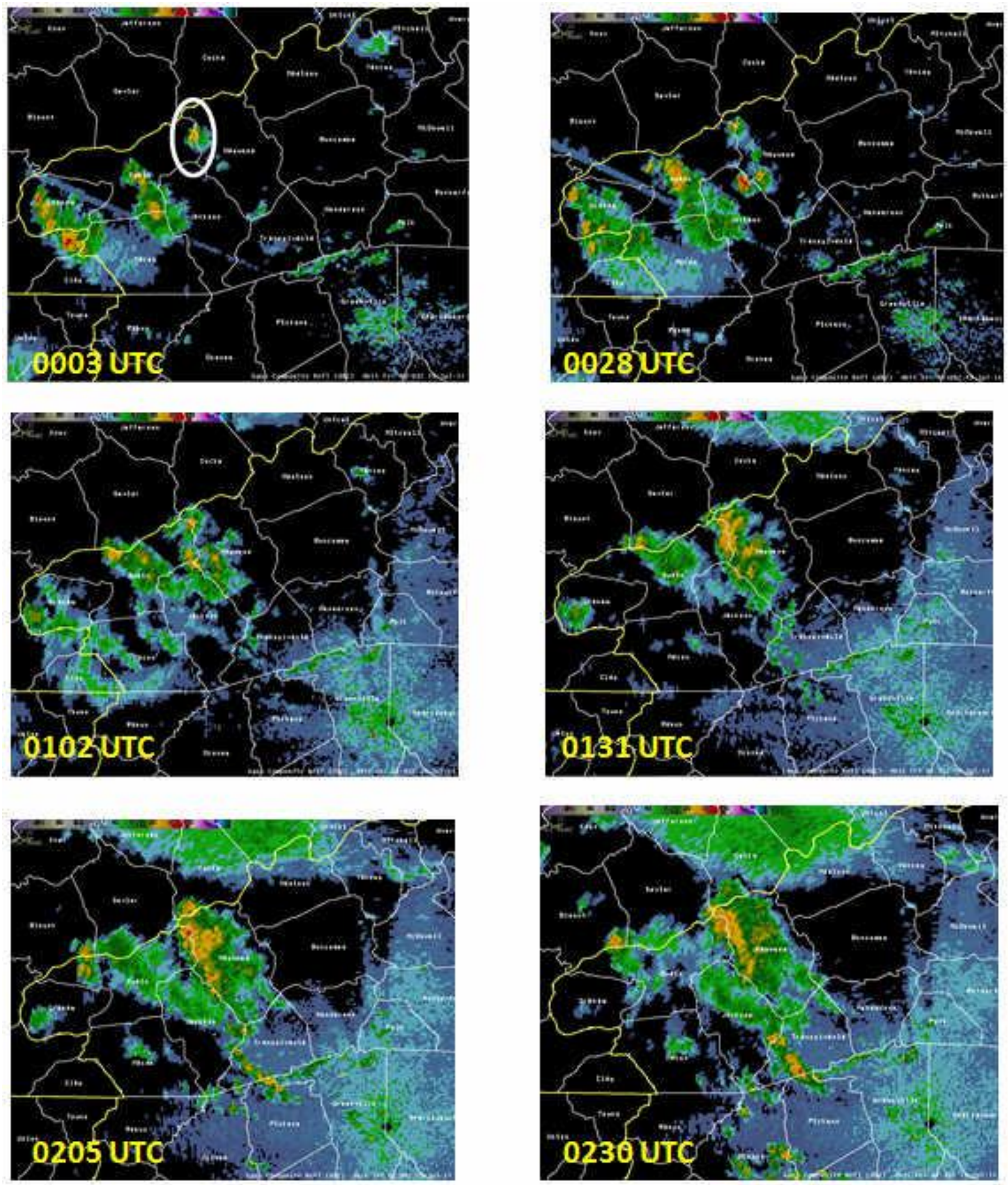

Fig. 10. KGSP WSR-88D composite reflectivity radar images from 0003 to 0230 UTC 15 July 2011. Oval in upper left panel highlights area of interest

As the convective storms developed, they extended above 580 mb where the wind direction was from the northwest. Wind speeds through the depth of the storms were relatively light, ranging from approximately 5 kt below 450 mb to approximately 30 kt near the storm tops between 200 and 160 mb. The northwest flow aloft was not sufficiently strong to disrupt the updrafts nor was it able to transport the updrafts away from their source of low level moisture and vertical motion. The faster flow aloft near the storm top might have assisted in evacuating air from the top of the updraft thus contributing to storm longevity. The RUC indicated weak 250 mb divergence across western North Carolina at 0000 UTC diminished significantly after 0300 UTC (not shown).

The precipitation continued along the border of Swain and Haywood counties through 0400 UTC (Fig. 11). However the rainfall rates and the area covered by the heavier rain decreased significantly after 0300 UTC.

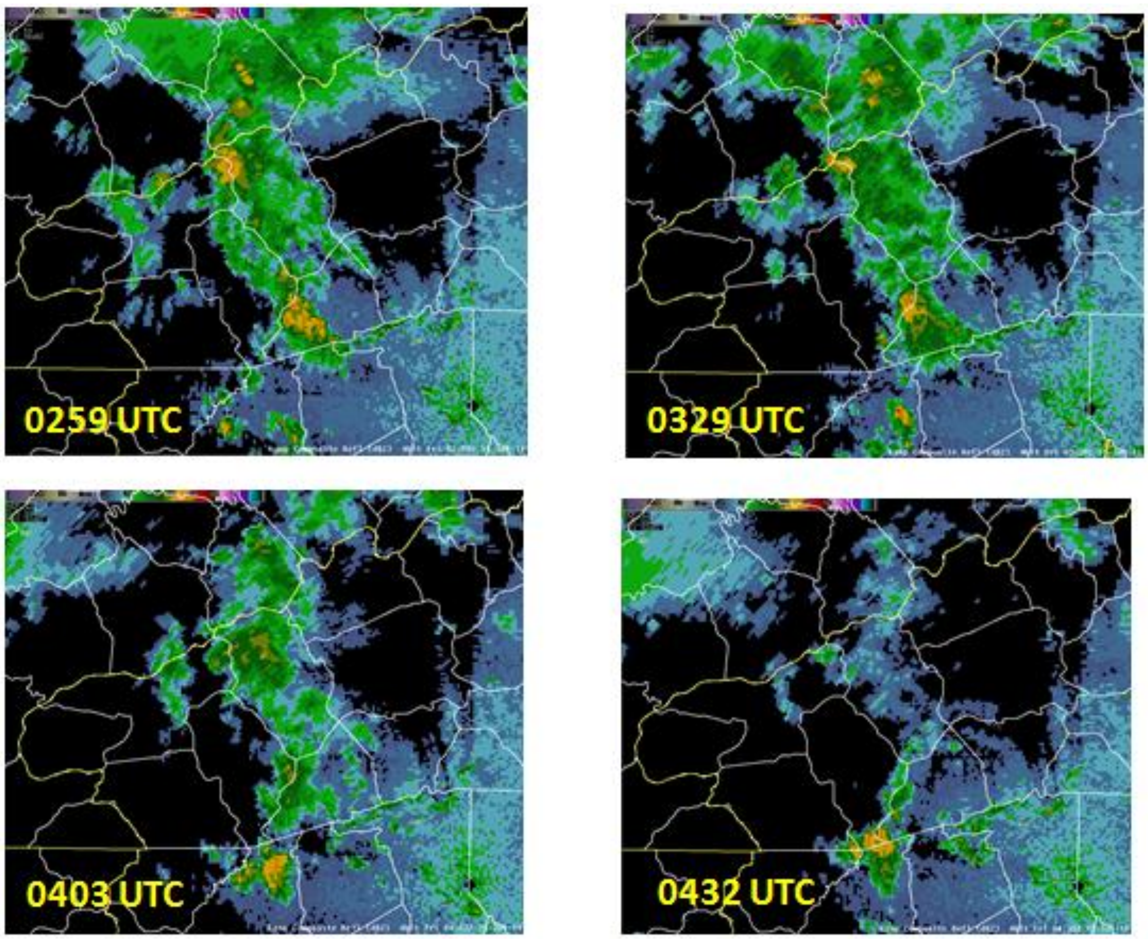

Fig. 11. KGSP WSR-88D composite reflectivity images from 0259 to 0432 UTC 15 July 2011.

A substantial portion of the rainfall occurred between 0000 UTC and 0300 UTC. A scan-by-scan examination of the radar imagery at four minute intervals (not shown) indicated the highest radar reflectivity[4] in the headwaters of Straight Fork Creek occurred between 0200 and 0215 UTC, but significant rainfall rates accompanied lower

[4] Highest radar reflectivity in the Straight Fork Creek headwaters was approximately 50 to 55 dbz. These reflectivity values, derived from the WSR-88D default Z-R relation ($Z = 300R^{1.4}$; where Z is reflectivity and R is rainfall rate), are associated with rainfall rates that range from 2.50 to 5.68 inches per hour. A detailed examination of the location of the greatest radar rainfall estimates with respect to the small drainage basins supplying Straight Fork Creek is beyond the scope of this report.

reflectivity values at other times. The flash flood was reported to have occurred near 0400 UTC.

The KGSP WSR-88D estimated the maximum rainfall from 0000 to 0300 UTC was approximately 3.00 inches (Fig. 12). The greatest precipitation totals occurred just inside Swain County in the high terrain of the basins that drained into Straight Fork Creek. The storm total precipitation estimated by the KGSP WSR-88D was 3.60 inches in a small area straddling the Swain and Haywood county border (Fig. 13). The KMRX WSR-88D (WFO Morristown, TN; 36 miles north-northwest) storm total maximum precipitation estimate was 4.16 inches (not shown).

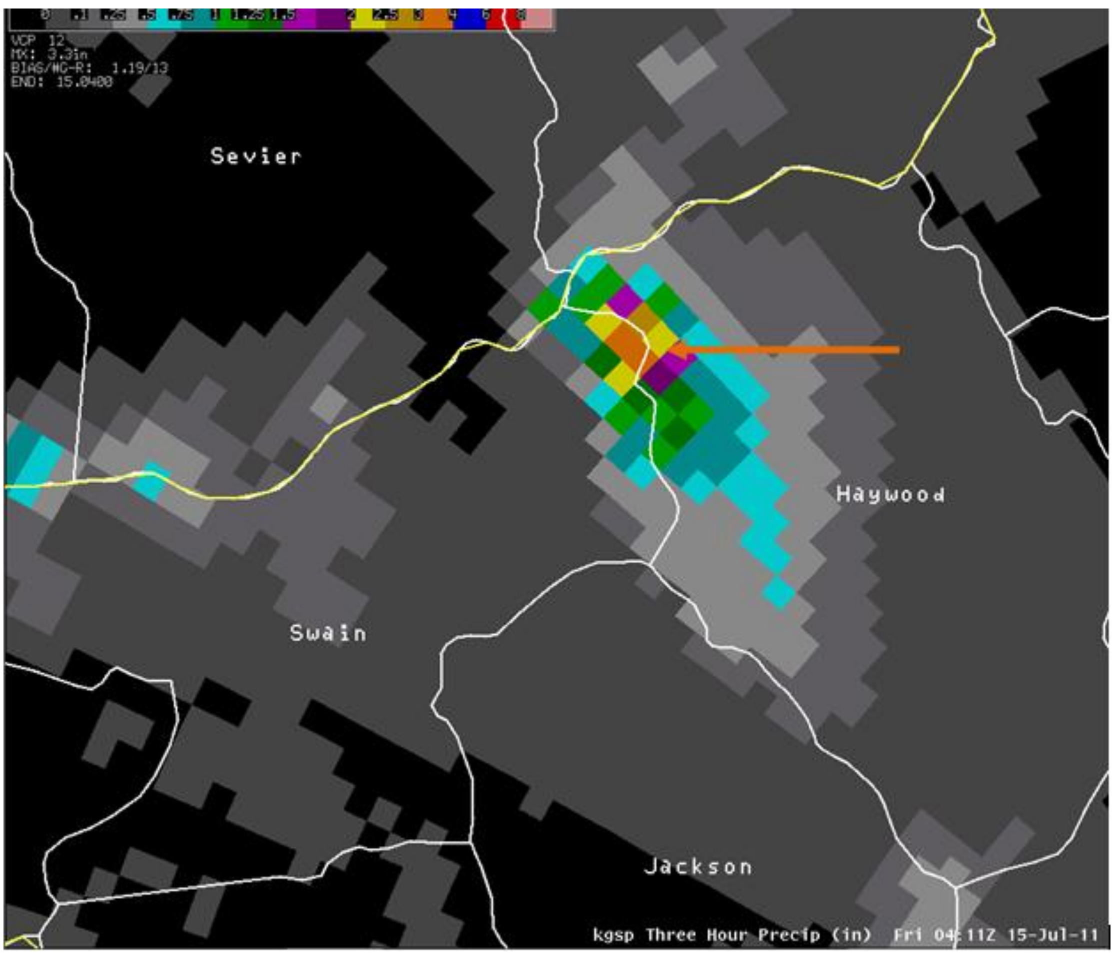

Fig. 12. KGSP WSR-88D three-hour rainfall estimates from 0000 to 0300 UTC 15 July 2011. The arrow points toward location of largest precipitation totals (2.50 to 3.00 inches).

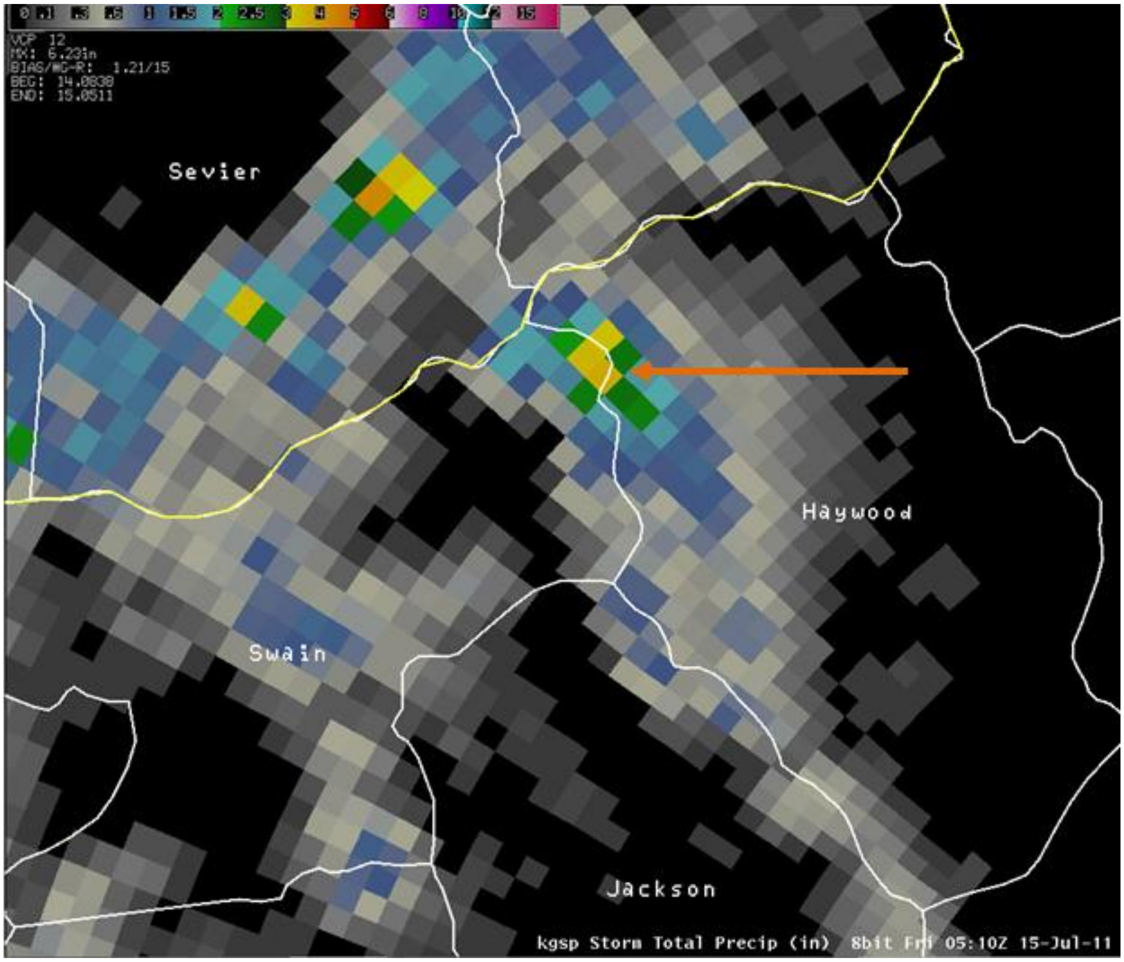

Fig. 13. KGSP WSR-88D storm total rainfall estimate between approximately 2330 UTC on 14 July 2011 until 0430 UTC on 15 July 2011. Arrow points toward precipitation maximum (3.60 inches).

The storm total radar rainfall estimate from the KGSP WSR-88D was overlaid with a drainage basin map to show where the precipitation fell in relation to the streams that were the source of the water for the flood event (Fig. 14). A small creek, Balsam Corner Creek, originated in the area where the radar detected the greatest rainfall totals. The precipitation that drained into Balsam Corner Creek and its tributaries (especially Laurel Gap Branch) flowed a short distance downhill where it joined with additional runoff from the short upstream reach of Straight Fork Creek and its tributaries (especially Miller Branch, Manse Branch, and an unnamed stream).

The distribution of radar estimated rainfall indicated that very little precipitation fell downstream of the confluence of Balsam Corner and Straight Fork creeks (Fig. 15). It appears that the major portion of the water contributing to the flash flood at the Tribal Hatchery originated in a very limited area. Heavy precipitation over small drainage basins combined with rapid runoff in steep terrain (3,000 to 4,000 feet descent) focused a considerable amount of water into a stream that could not effectively contain the flow.

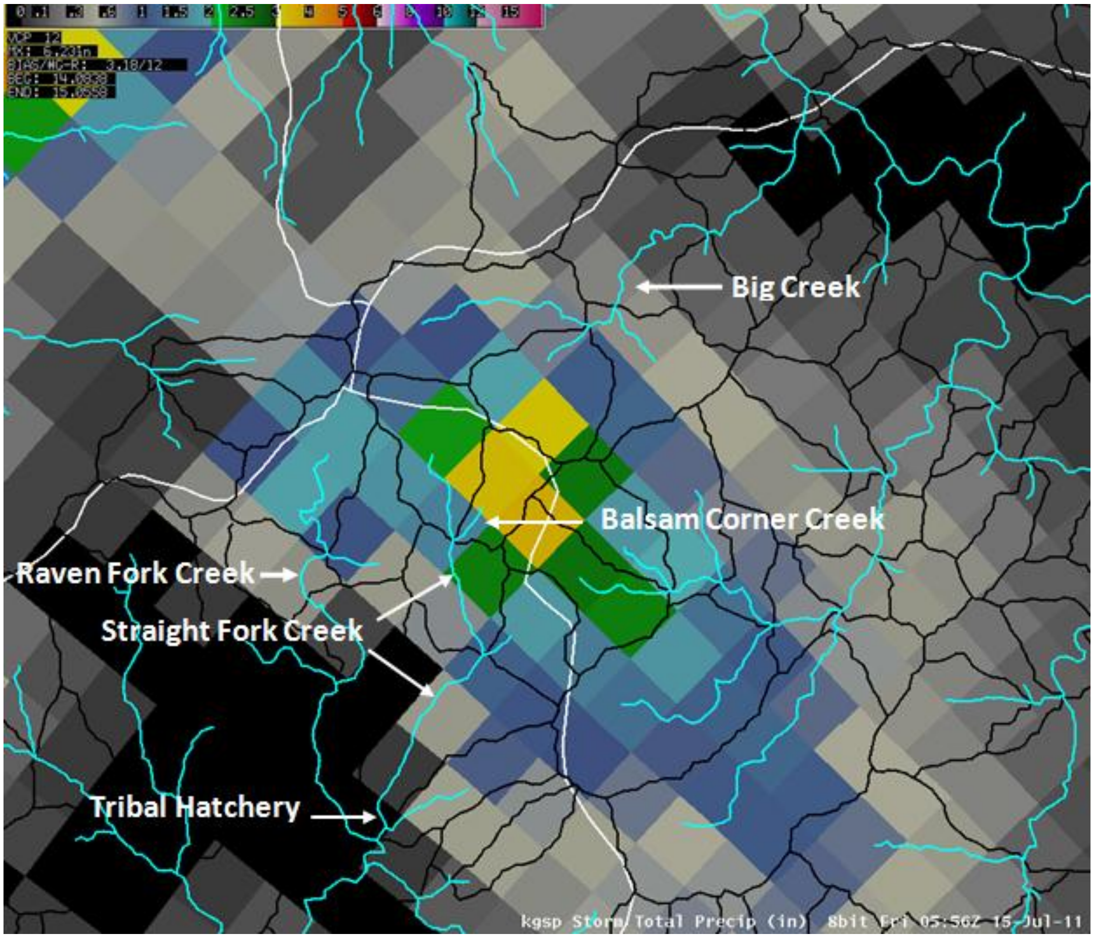

Fig. 14. KGSP Storm Total Precipitation (image) from 0838 UTC 14 July 2011 until 0516 UTC 15 July 2011. Sub-basins defined by black lines, and streams identified by blue lines.

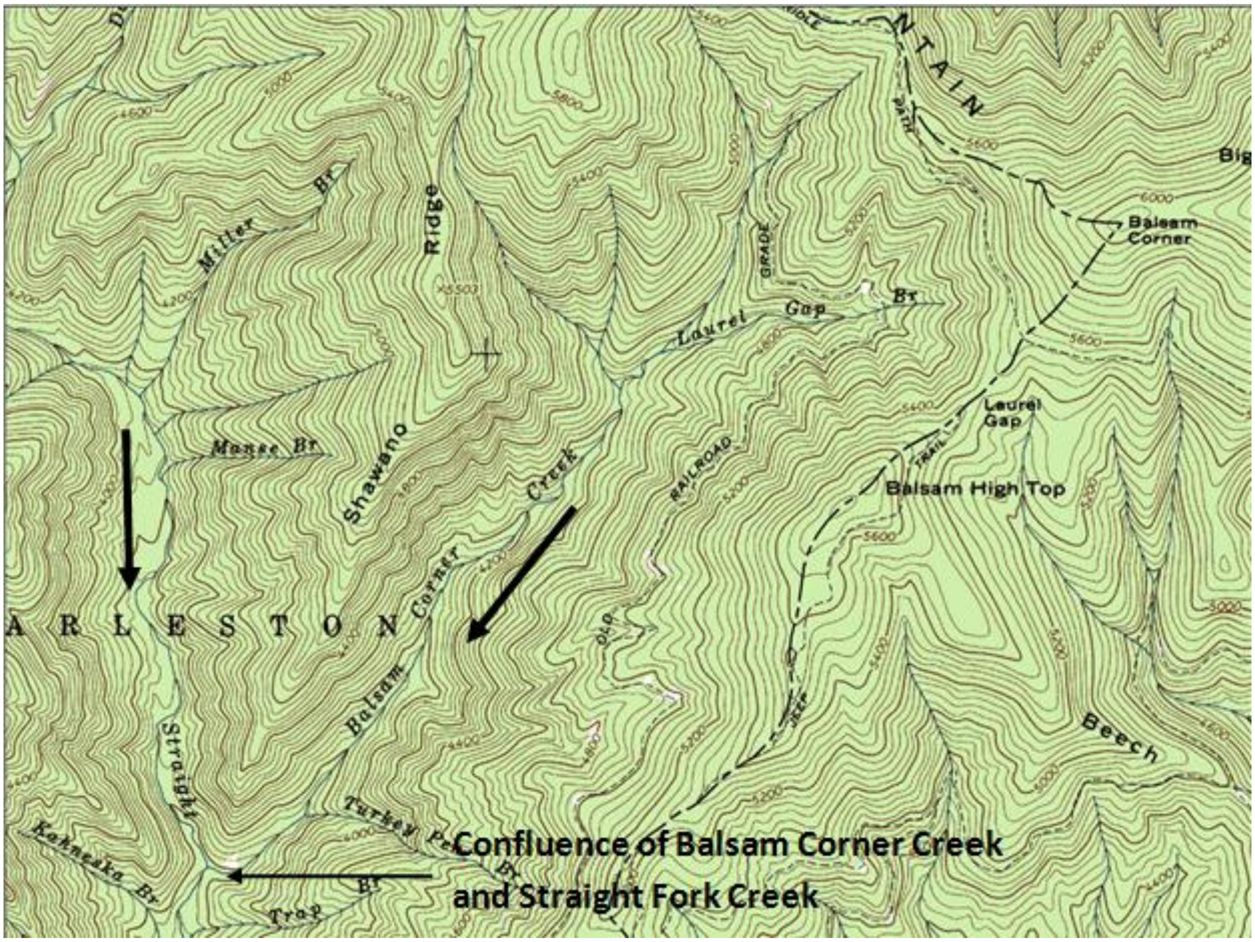

Fig. 15. USGS topographic map of the drainage basins in the headwaters of Straight Fork Creek. The thick arrows depict the general direction of flow down Balsam Corner Creek (arrow on right) and upper portion of Straight Fork Creek (arrow on left).

4. Satellite Observations

Even though the first detectable radar return in the vicinity of Straight Fork Creek at 2338 UTC was followed by a rapid increase in reflectivity and areal extent, infrared satellite imagery did not provide a clear indication of cold cloud top growth until approximately 0200 UTC (Figs. 16 and 17). The cold cloud top expansion coincides with the detection of 50 to 55 dbz radar reflectivity between 0200 and 0215 UTC. It is assumed that the expansion of cold cloud tops was related to an increase in updraft strength and precipitation enhancement.

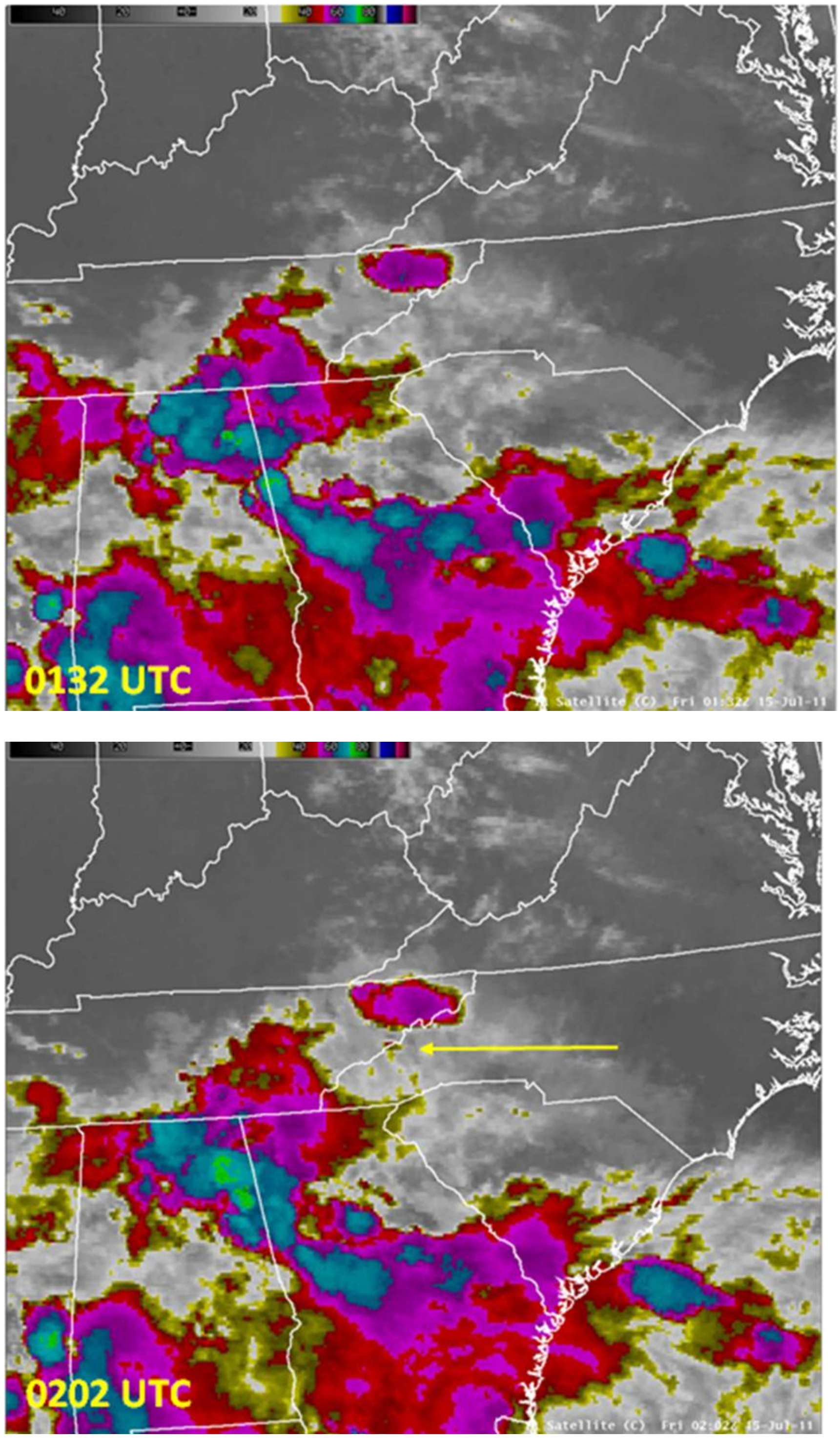

Fig. 16. Infrared satellite imagery at 0132 (top) and 0202 (bottom) UTC. Coldest cloud tops are in purple and blue shades. Arrow in bottom panel points toward expanding cold cloud top (-46^{o}C) in the vicinity of Straight Fork Creek headwaters. The GOES-East viewing angle results in cloud features being offset slightly northward from their actual position relative to the earth.

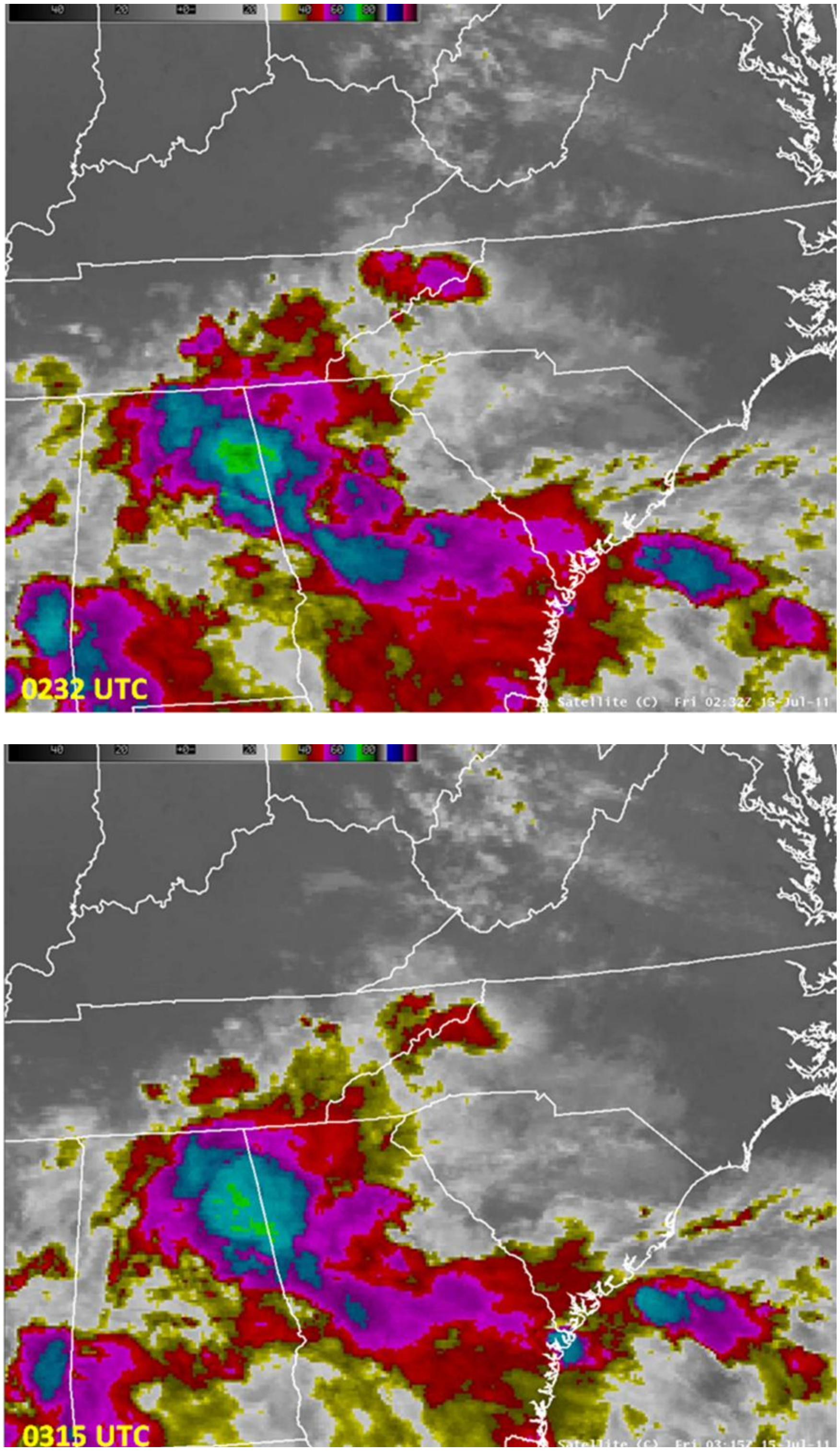

Fig. 17. Same as Fig. 16 except at 0232 and 0315 UTC. Cloud tops over the Straight Fork Creek headwaters were warming (-32^{o}C) by 0315 UTC.

5. Hydrologic Observations

The National Weather Service had very limited access to real-time and post-event rain or river gauge data in the vicinity of the heavy rain and flash flood. There was one operational Integrated Flood Observing and Warning System river gauge in northeast Swain County on Raven Fork Creek when the flash flood occurred. The gauge, situated just to the west of the heaviest precipitation, measured only a small rise because the basin did not receive excessive rainfall. Between 0630 and 0645 UTC, a 2.39 feet rise was measured on the Oconaluftee River at Birdtown. This increase in river stage indicated a considerable amount of water had traveled down Straight Fork Creek into Raven Fork Creek then eventually into the Oconaluftee River.

A U.S. Forest Service rain gauge at Round Bottom campground (Fig. 18) recorded 1.99 inch between 0100 and 0400 UTC (1.12 inch between 0100 and 0200 UTC; 0.70 inch between 0200 and 0300 UTC; 0.17 inch between 0300 and 0400 UTC). The heaviest rain was north of this gauge.

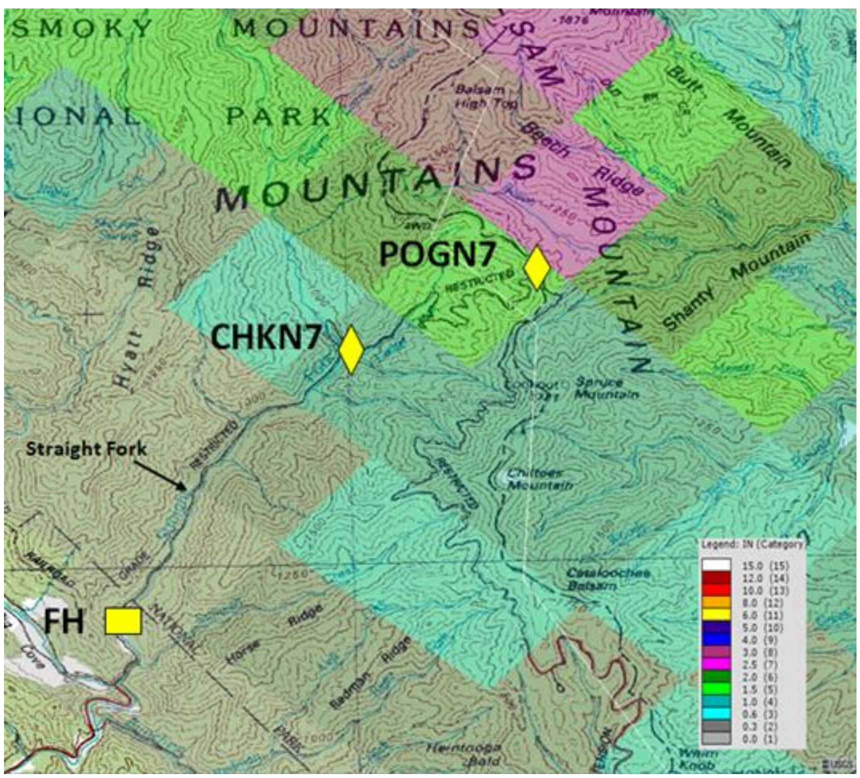

Fig. 18. Topographic map with an overlay of KGSP WSR-88D storm total radar rainfall estimates. Heaviest rain occurred in pixels of brown and purple shades near top edge of image. Round Bottom campground rain gauge (CHKN7) and an inoperative rain gauge at Pin Oak Gap (POGN7) are denoted by yellow diamonds. Yellow rectangle identifies location of Tribal Fish Hatchery.

6. Summary

On 15 July 2011 at approximately 0400 UTC, a flash flood occurred along Straight Fork Creek in the Qualla Boundary. The flood caused major damage to the Cherokee Tribal Fish Hatchery, but no one was injured. Apparently, rain did not fall at the hatchery. The flood was caused by a nearly stationary, orographically induced system of heavy rain showers and thunderstorms that developed along the ridge separating Haywood County and Swain County in a remote section of the Great Smoky Mountains National Park. The precipitation fell into the upper portion of the Straight Fork Creek basin and flowed rapidly downhill where it inundated the hatchery. Radar rainfall estimates indicated that approximately 4.00 inches of rain occurred in the observation-sparse headwaters of the basin. Key environmental factors contributing to the convective system development included a moist and unstable air mass with easterly, upslope flow in the low levels and light wind through the entire layer containing the storm.

The event documented in this review brings to mind other notable mountain flash floods. A number of floods have been identified that were related to excessive rainfall in terrain that focused rapid runoff into small drainage basins (e.g., Maddox et al. 1978; Caracena et al. 1979; Lee and Goodge 1984; Pontrelli et al. 1999; Johnstone and Burrus 1998). Additional documentation and study of similar events will lead to more accurate and more timely forecasting of mountain flash floods. Forecasters must remain alert to the subtle meteorological, hydrological, and terrain features that combine to create these situations in the face of the reality that numerical weather prediction models have shortcomings, remote sensing technologies have limitations, and surface observations are few and far between. In addition, people using recreational areas such as the Great Smoky Mountains National Park must have an awareness of flood susceptibility when hiking and camping near creeks and streams. Flash floods, such as the one described in this document, sometimes occur when rain is not observed at the flood site, and they can happen at night.

Acknowledgments
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