Tennessee Border Snow

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1. Introduction

A cold front moved into the Carolinas and north Georgia from the west on 14 January 2013. Thereafter, the front remained nearly stationary but eventually drifted to the east during the next several days. Weak low pressure centers that developed on the front contributed to heavy rain, especially in the mountains and foothills of the western Carolinas and in extreme northeast Georgia. Cold air that remained west of the mountains finally moved east when a stronger low pressure system developed over Georgia on 17 January and subsequently moved northeast. The air was sufficiently cold to change the rain to snow, primarily in the counties along the Tennessee border. Accumulations in the County Warning Area (CWA) of the National Weather Service (NWS) Greenville-Spartanburg office ranged from a trace to nine inches (Table 1).

Table 1. Snowfall in the NWS Greenville-Spartanburg County Warning Area.

Snowfall – 17 and 18 January 2013					
Location	**Amount (in.)**	**Location**	**Amount (In.)**	**Location**	**Amount (In.)**
Beech Mtn.*	9.0	Flat Springs 1 E*	8.0	Newland	7.0
Mt. Mitchell*	6.0	Banner Elk*	6.0	Grandfather Mtn.*	4.0
Maggie Valley	3.0	Cruso	2.0	Jonas Ridge	2.0
Waynesville 1 E*	1.5	Morganton	1.0	Hot Springs*	1.0
Spring Creek 2 SW	1.0	Waterville 2*	1.0	Lenoir*	0.9
Ellendale	0.5	Mocksville*	0.5	Statesville 2 NNE*	0.5
Salisbury 9 WNW*	0.3	Concord*	0.3	Asheville (NCDC)*	T
Charlotte/Douglas Int'l. Airport*	T	Highlands*	T	Lincolnton 4 W*	T
*NWS Cooperative Observer T = Trace					

2. Synoptic Setting

A sequence of surface analyses showed the slow progression of the front across the southeastern United States from 13 to 17 January (Fig. 1), until it moved swiftly to the east on 18 January in conjunction with cyclogenesis over Georgia and the Carolinas.

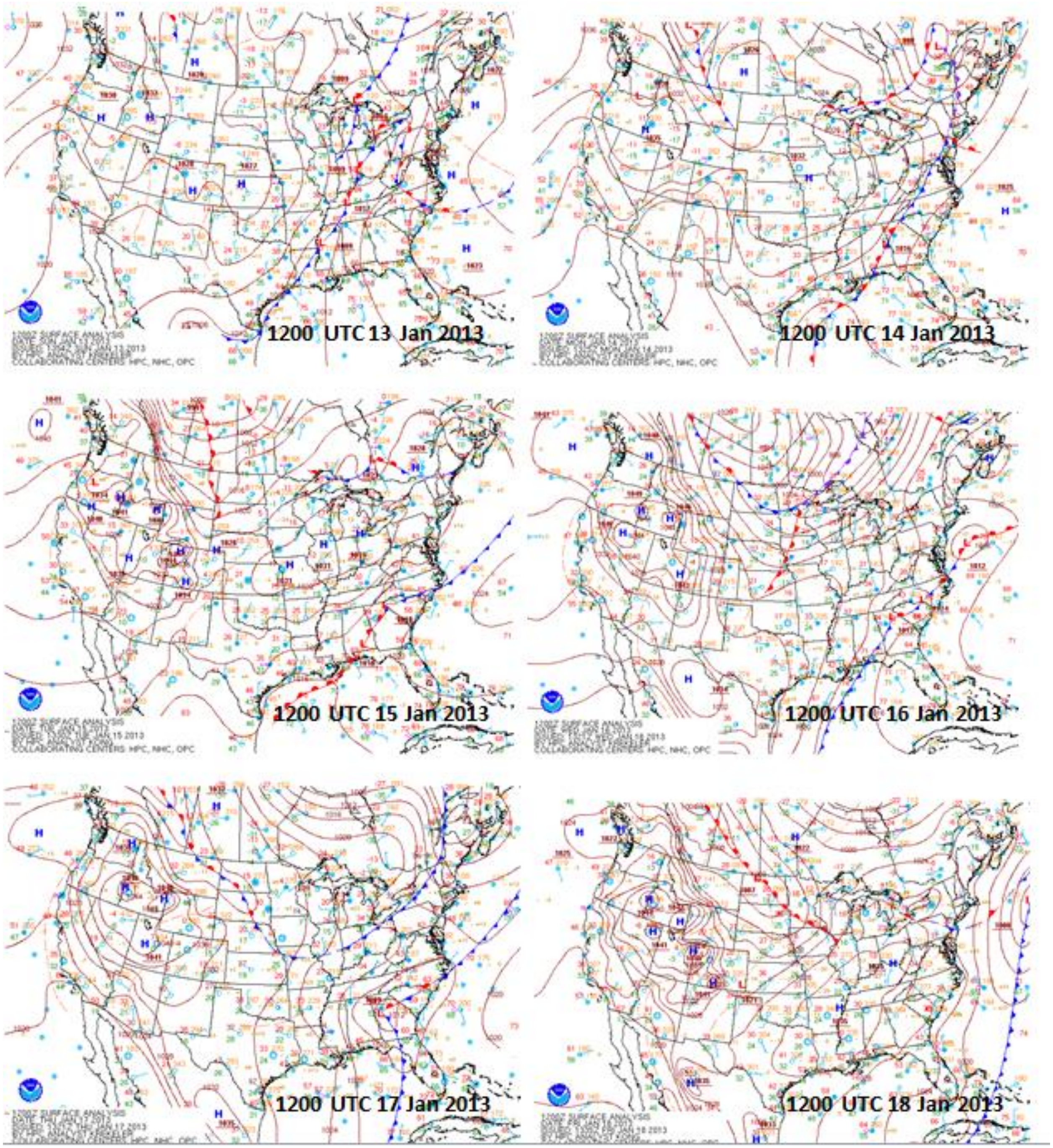

Fig. 1. NOAA/NWS/NCEP 1200 UTC surface analyses 13-18 January 2014.

The front made very little eastward progress from 14 to 17 January while it was aligned with a strong southwest flow through a deep layer of the atmosphere (Fig. 2). The primary upper level features defining the flow were a sharp trough over the central and western United States and a strong ridge over the western Atlantic. The surface reflection of the ridge aloft was a high pressure system – not unlike a summertime Bermuda high – that not only offered resistance for frontal movement, but also fed a considerable amount of warm air and low level moisture into the southern Appalachian region.

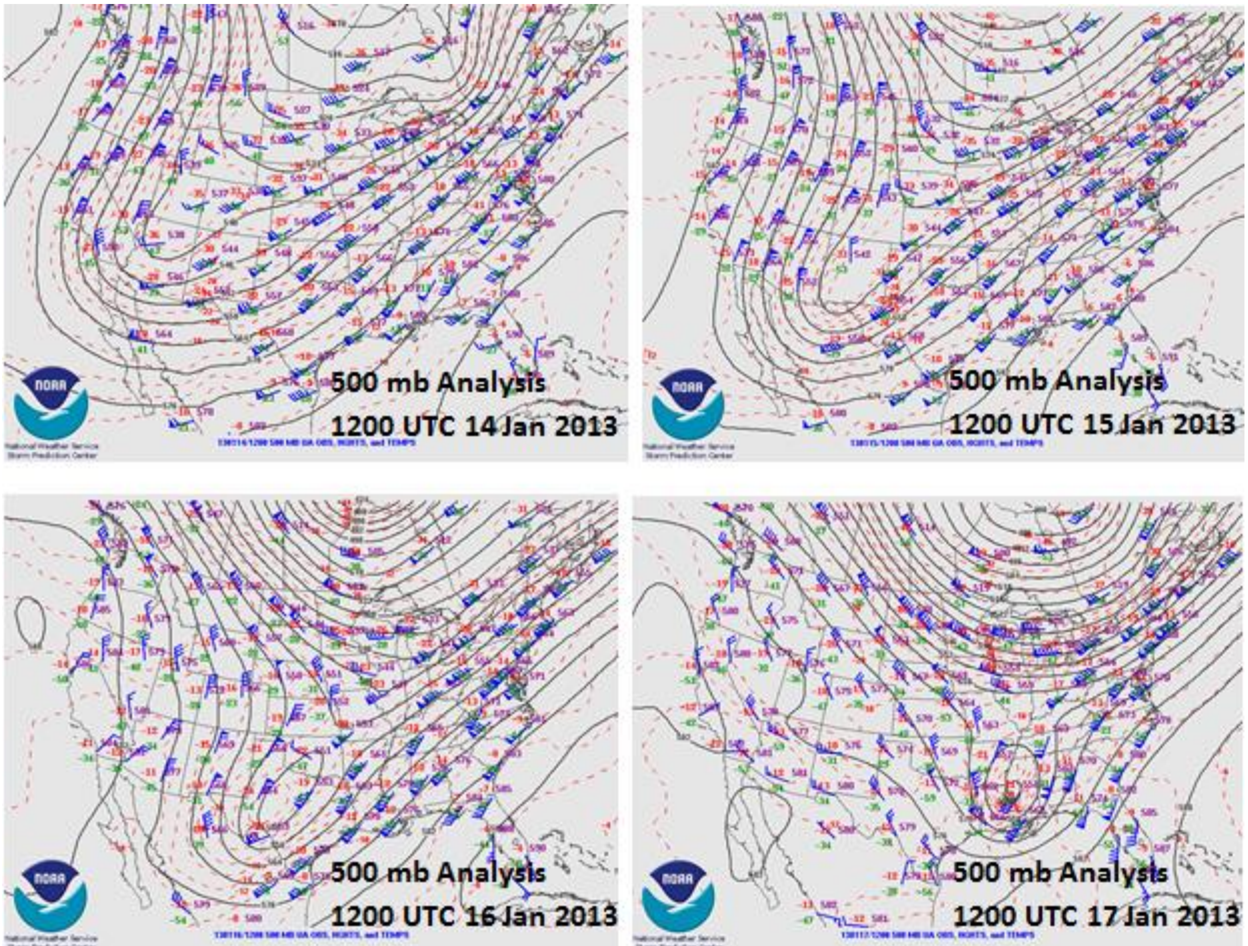

Fig. 2. NOAA/NWS/SPC 12Z 500 mb Analyses 14 – 17 January 2013.

A cutoff low developed in the southern portion of the 500 mb trough on 16 January and moved to the Gulf Coast states on 17 January. During the evolution of the cutoff low, the flow over the southern Appalachians remained southwesterly, and slight ridging was evident by 17 January. As a result, there was not a contribution from the synoptic scale to move the cold air mass across the higher elevations of the western Carolinas into the Piedmont.

The approach of the upper-level low induced the development and strengthening of the wave on the surface front across the Southeast on 17 January (Fig. 1). The 1200 UTC 850 mb analysis placed the developing low over Alabama, and it identified a well-defined southerly flow (warm conveyor belt; Carlson 1980) extending from the eastern Gulf of Mexico across the Carolinas (Fig. 3). The 850 mb temperature field showed the tight temperature gradient over and just west of the mountains. A cross-mountain 850 mb wind component at the latitude of North

Carolina did not exist to advect cold air eastward, nor was a strong high pressure system centered to the northeast to provide a cold air damming scenario.

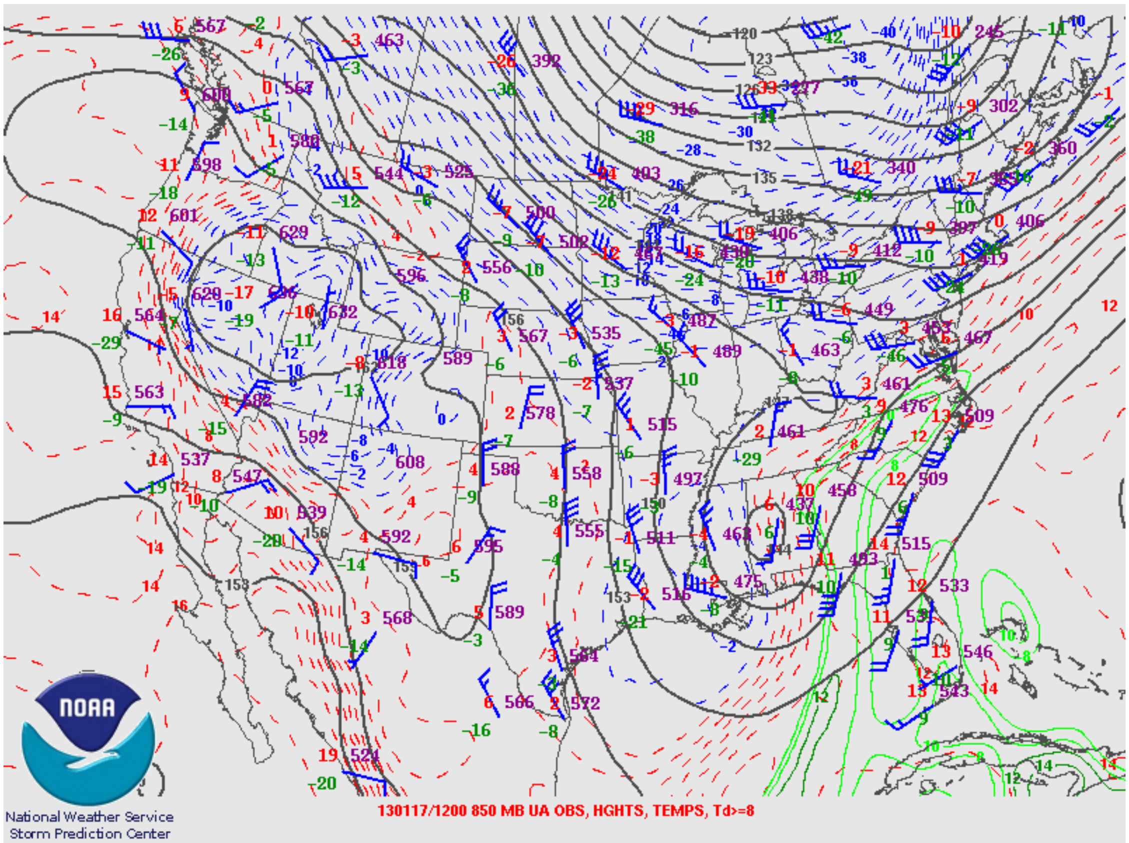

Fig. 3. NOAA/NWS/SPC 850 mb analysis 1200 UTC 17 January 2013.

3. Radar and Satellite

The upper level trough and surface low moved eastward during the daytime on 17 January. The regional WSR-88D reflectivity mosaic and the GOES-East infrared imagery provided an excellent overview of the organization and progression of the baroclinic leaf and comma head precipitation pattern as the cyclone traversed the area (Fig. 4).

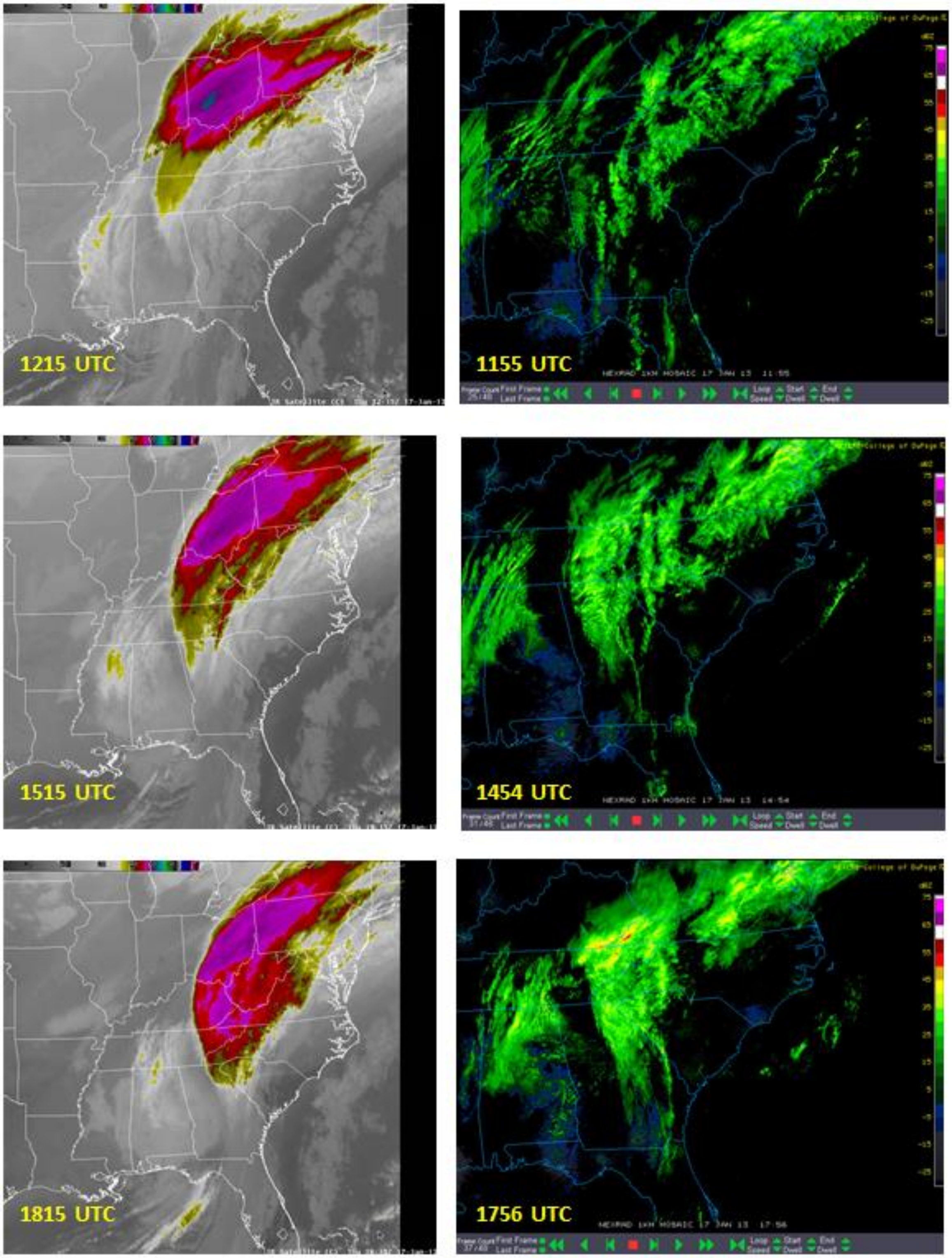

Fig. 4. Infrared satellite imagery (left) and regional WSR-88D mosaic (right) on 17 January 2013. Radar images: NEXLAB – College of DuPage.

A notable characteristic of the infrared satellite and the regional composite radar imagery was the separated cold cloud top and reflectivity signature in the developing comma head (Fig. 4). There were two distinctive features: 1) a small area of cold cloud tops over the Gulf Coast states, and 2) a baroclinic leaf over the upper Ohio Valley. Van Cleave et al. (2009) suggested a similar pattern indicated ageostrophic circulations associated with the entrance region of the northern wind maximum and the exit region of the southern wind maximum were not sufficiently close to augment one another to produce a single, coherent region of upward motion (Uccellini and Kocin, 1987). Their work offered a possible explanation for the separated comma head on 17 January, but the evidence examined in the present case was not conclusive. A detailed analysis of the interactions among the various wind maxima and the resulting three-dimensional flow awaits further research.

Several prominent upper level features were identified and mapped on infrared satellite imagery to establish essential flow characteristics during the period when the separated radar reflectivity regions were observed. The 1200 UTC 17 January Global Forecast System (GFS) 250 mb isotach analysis showed a 120 kt wind maximum over Louisiana, but the dominant wind speed maximum in the warm conveyor belt was the 200 kt maximum over Maine and Quebec (Fig. 5). An 80 kt maximum over western Arkansas and Louisiana was in the northerly flow on the west side of the trough.

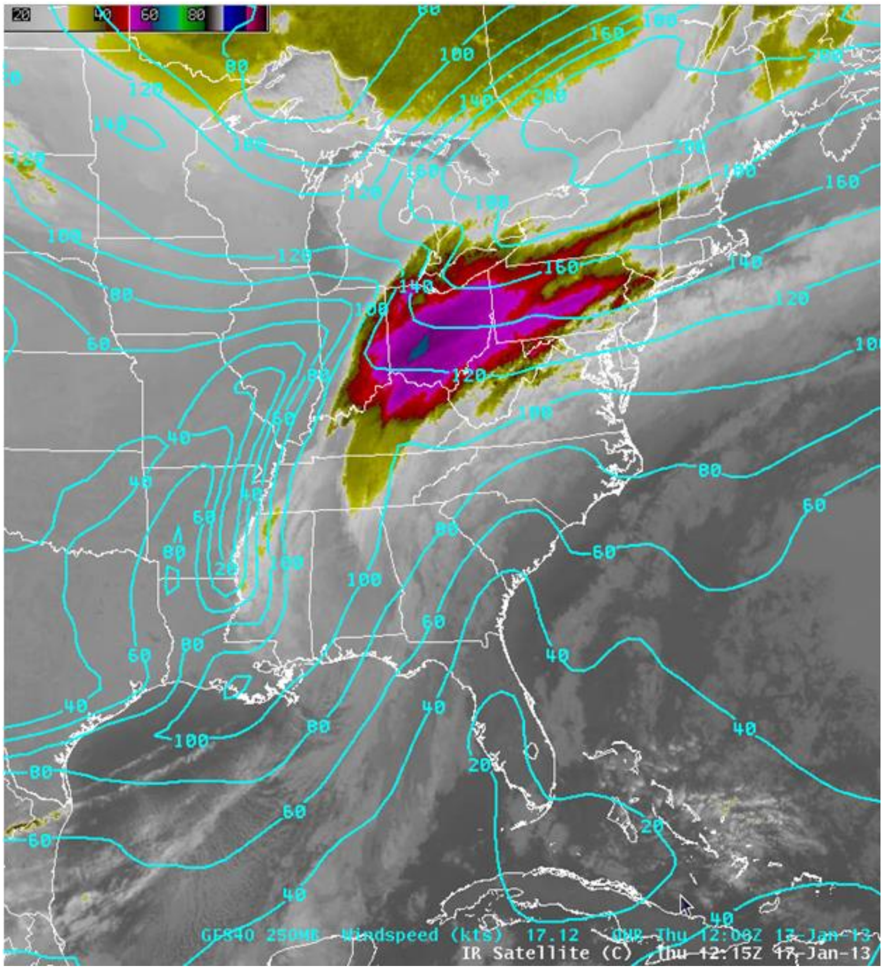

Fig. 5. 1215 UTC 17 January 2013 infrared satellite image and 1200 UTC 17 January 2013 GFS40 250 mb wind speed (kt; contours).

The GFS 250 mb divergence generally was aligned with the warm conveyor belt, but several small maxima extended from the Gulf Coast region to New York (Fig. 6). The divergence maximum over Alabama and Mississippi was coincident with the western segment of the separated comma head and precipitation.

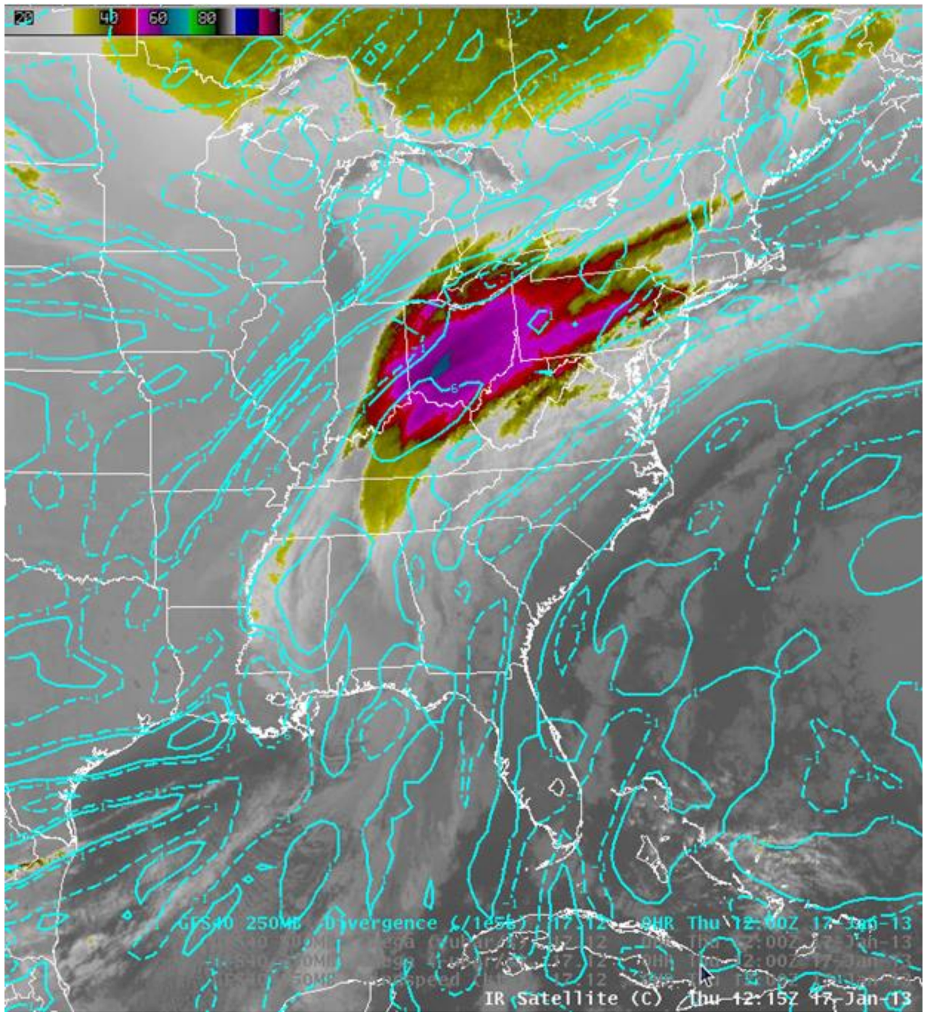

Fig. 6. Same as Fig. 5 except 250 mb divergence (sec^{-1}; contours).

The GFS mid-tropospheric vertical motion (omega) pattern at 1200 UTC was rather disorganized reflecting the complex vertical motion distribution that can exist on a single pressure level during cyclogenesis in the vicinity of strong jet stream winds (Fig. 7). Upward motion is indicated near the high, cold cloud tops and where the lower cloud maximum was associated with the 500 mb low over Louisiana. The small cloud mass over Mississippi and the western segment of the developing comma head precipitation were in the left front quadrant of the wind maximum over southern Louisiana. The cloud and radar features also coincided with a 250 mb divergence maximum.

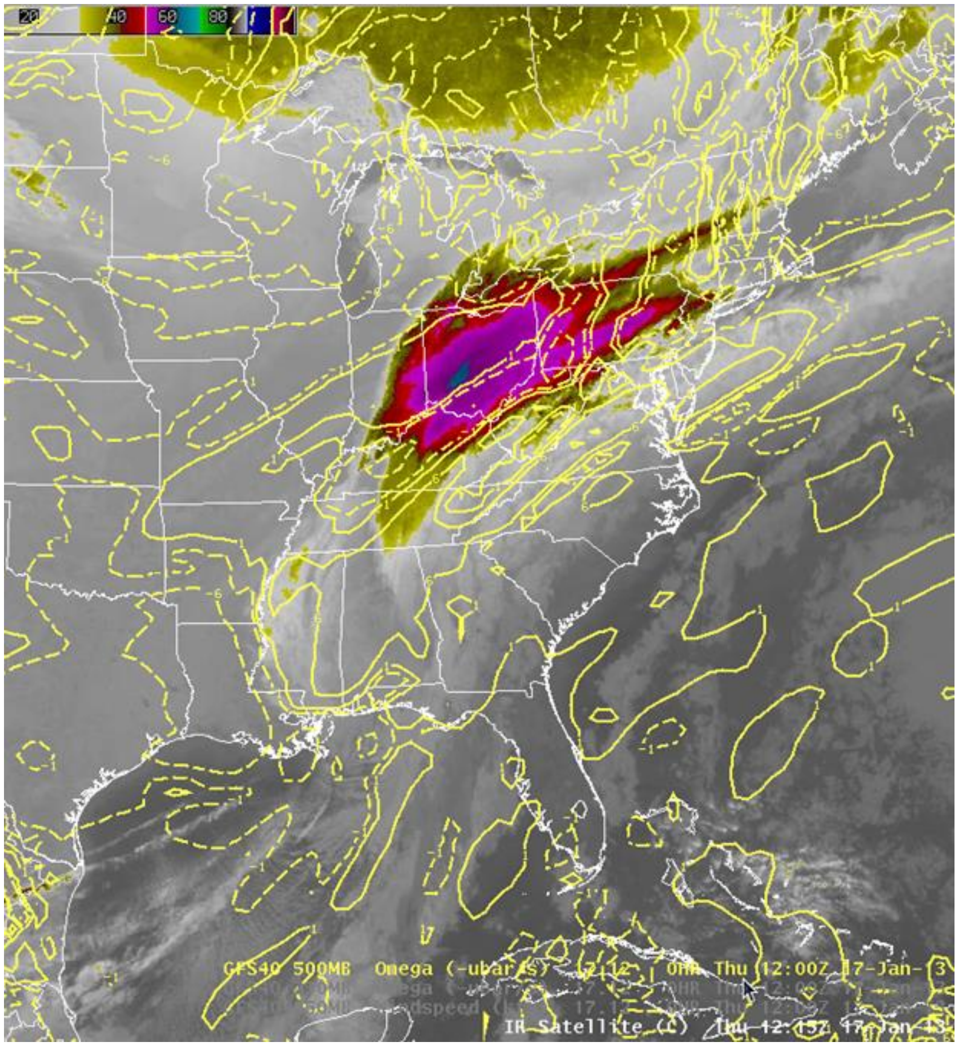

Fig. 7. Same as Fig. 5 except 500 mb omega (microbars sec^{-1}; contours).

Cloud top sampling of the Infrared satellite imagery and data from the GFS indicated a significant difference in height of the separated cloud features. At 1800 UTC, the cloud tops near the Alabama – Tennessee border had a temperature of -31°C at approximately 23,500 ft MSL. The coldest and highest cloud tops in the baroclinic leaf over the southern Appalachians had a temperature of -55°C at approximately 37,500 ft MSL (Fig. 4).

The radar reflectivity maximum over western Tennessee, Mississippi, and Alabama was in the proximity of the cutoff low propagating eastward across the southern states. The precipitation from Georgia to Kentucky then northeast to the mid-Atlantic region was associated with the warm conveyor belt and baroclinic leaf in the entrance region of the strong upper level wind maximum over northern Maine and Atlantic Canada.

4. Dry Slot and Dry Conveyor Belt

The “clear” slot separating the two areas of precipitation corresponded to the dry conveyor belt (also referred to as the “dry airstream”; Carlson 1980) wrapping around the cutoff low. A stratospheric intrusion signature (Danielsen 1968) was evident in the water vapor imagery while the 500 mb low moved across the Gulf Coast region (Fig. 9). The dry air that comprised the intrusion injected high values of potential vorticity of apparent stratospheric origin into the system and contributed to the subsequent cyclogenesis.

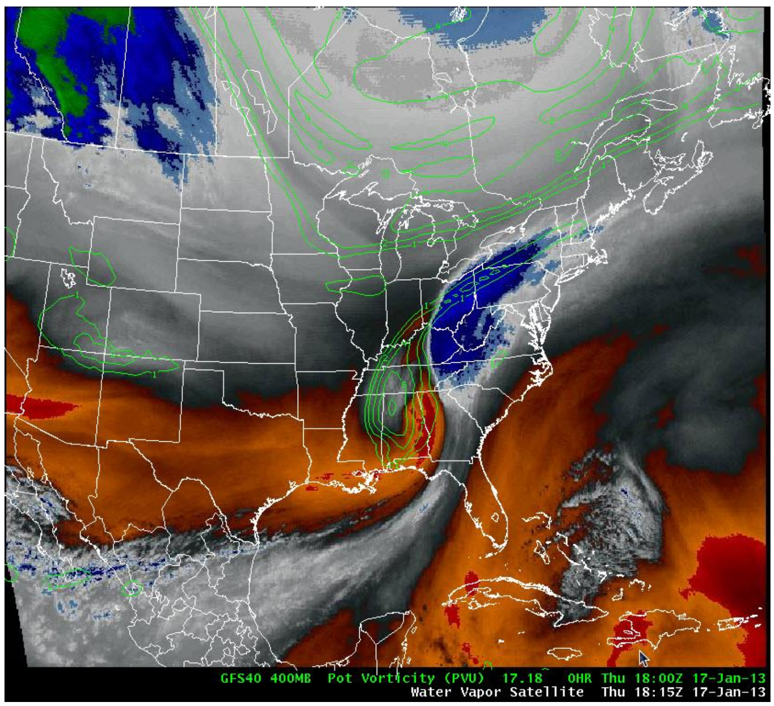

Fig. 9. GOES-East water vapor image at 1815 UTC and GFS40 potential vorticity (contours) at 1800 UTC on 17 January 2013.

A NOAA HYSPLIT (Draxler 2013; Draxler and Rolph 2013) backward trajectory analysis from three vertical points in the heart of the dry slot at 1800 UTC showed an interesting air parcel history (Fig. 10). Three parcels, at 2,000 m; 3,000 m; and 4,000 m above the same point near the Georgia and Alabama border, were moved 96 hours back in time. The two lower parcels traveled with the high potential vorticity stratospheric air associated with the 500 mb low that separated from the deep long wave trough. The highest of the three parcels traveled from the central Pacific, around the top of the western North America ridge then descended into the circulation around the 500 mb low moving from Texas into the Gulf Coast states.

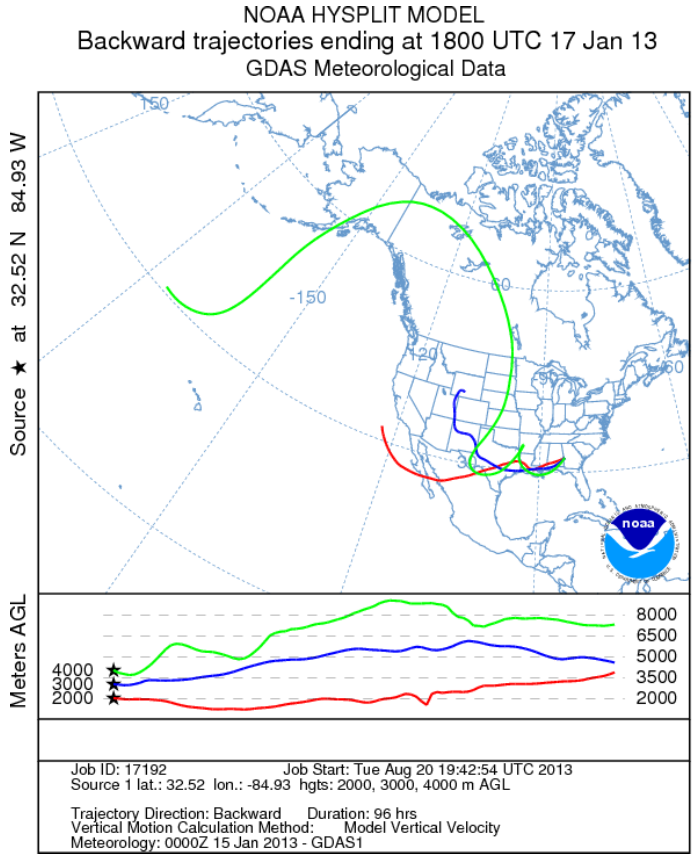

Fig. 10. 96-hour backward trajectories from 2,000 m; 3,000 m; and 4,000 m AGL in the dry slot at 1800 UTC on 17 January 2013.

A matrix of backward air parcel trajectories from points comprising the dry slot also revealed the origin of that feature (Fig. 11). The dry slot air at 4000 m AGL was a combination of air parcels that moved over the western North America ridge. Some of the parcels followed a path that took them directly into the 500 mb low over the Gulf Coast states while others went south all the way into the base of the trough before the cutoff formed. The parcels then moved northeast, but they were eventually captured by the cutoff low

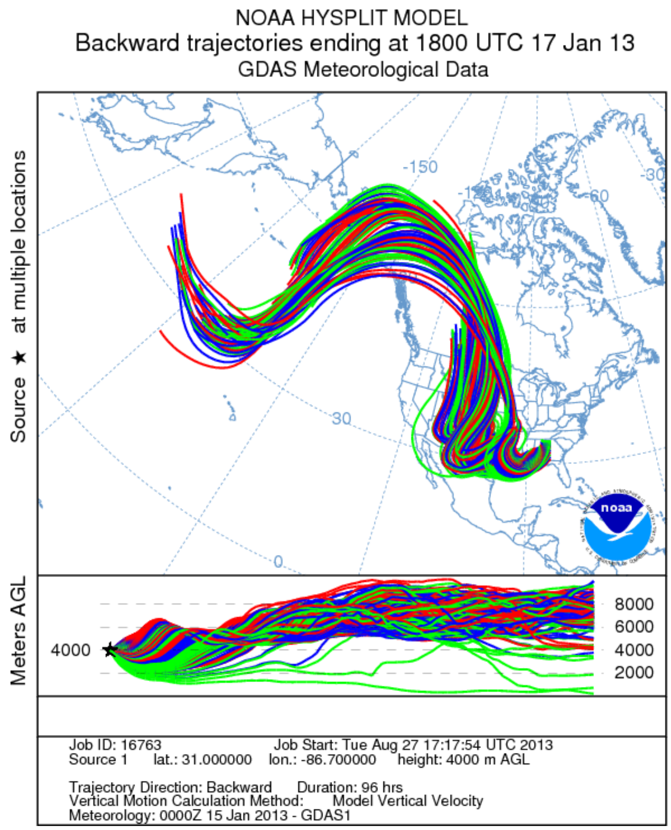

Fig. 11. Matrix of 96-hour backward trajectories from the dry slot at 4,000 m on 17 January 2013.

The boundary between the moist, ascending air of the warm conveyor belt and the dry slot air provided the sharp line of demarcation between the two flow regimes that was seen in the radar mosaics. As the dry air swept northward, it created the separation between the baroclinic leaf precipitation and the precipitation associated with the lower clouds near the cutoff low.

Visible satellite imagery also provided additional insight into the storm structure during the afternoon of 17 January (Fig. 12). The 700 mb relative humidity analysis overlaid on the image coincided with the basic cloud structure of the evolving system. The band of warm conveyor belt clouds extended northward from the eastern Gulf of Mexico to the developing comma head where the stream of warm and moist air was rising rapidly and curving anticyclonically into the fast westerly flow aloft. The smaller, separate cloud mass over Alabama was moving eastward with the 500 mb cutoff low. An area of lower clouds "bridging the gap" between the two cloud masses was evident across middle Tennessee. This area of cloud had much lower cloud tops (relatively warm in the IR imagery), and it displayed a texture indicative of weak convection. The slot of relatively low 700 mb relative humidity extending from the Florida Panhandle northward across Georgia was due to the intrusion of dry, high potential vorticity air. A curved cross section along the axis of the developing system (Fig. 13) also identified several atmospheric features related to the cloud pattern: Deep moisture at the head of the warm conveyor belt, dry air probably of stratospheric origin atop the lower clouds across Tennessee, and relatively shallow moisture in the cloud mass associated with the 500 mb low.

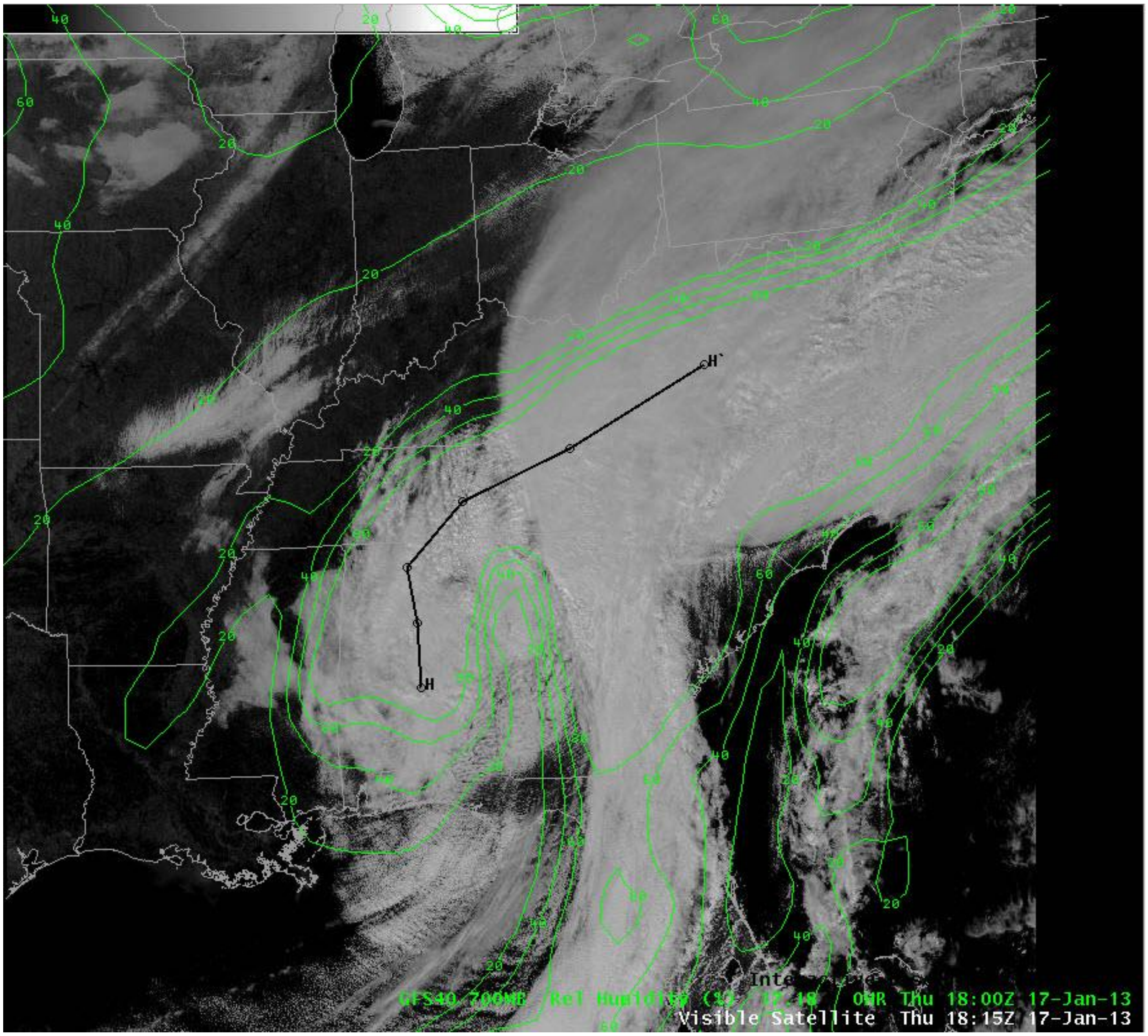

Fig. 12. GOES-East visible image at 1815 UTC and GFS40 700 mb relative humidity (percent; contours) at 1800 UTC on 17 January 2013. Black line marks the cross section in Fig. 13.

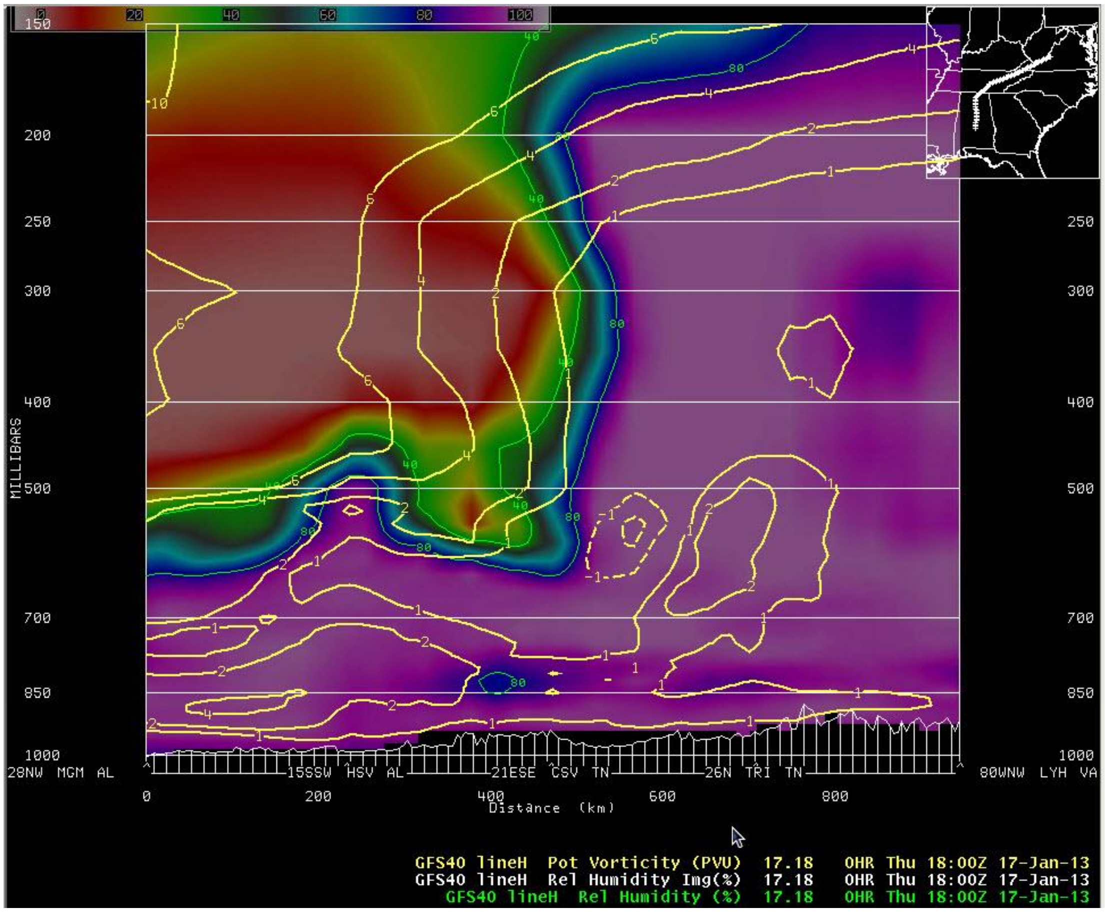

Fig. 13. Vertical cross-section at 1800 UTC on 17 January 2013 identified in upper right-hand corner and in Fig. 12. Thin green contours and image are relative humidity (percent; purple to red denotes high to low). Thick yellow contours represent potential vorticity (PVU; potential vorticity units).

During the afternoon of 17 January, the cutoff low moved to the northeast across the Carolinas, but the feature was losing definition as it was absorbed by the baroclinic system associated with the strong wind maximum to the north. Surface cyclogenesis progressed steadily and the satellite and radar imagery showed the separation between the two cloud and precipitation features disappeared. As the system matured, the cloud pattern originally associated with the cutoff low appeared to become part of the cold conveyor belt (Carlson 1980; Schultz 2001) that emerged from beneath the western portion of the baroclinic leaf comma head. The lower clouds bridging the gap between the separate cloud masses (Fig. 12) were probably in the maturing cold conveyor belt. The IR imagery subsequently detected lowering cloud-top temperatures in the cold conveyor belt signaling increased vertical motion and precipitation development. Thus, the radar depiction of the cyclogenesis gradually assumed the more traditional comma head shape similar to the satellite signature (Fig. 14).

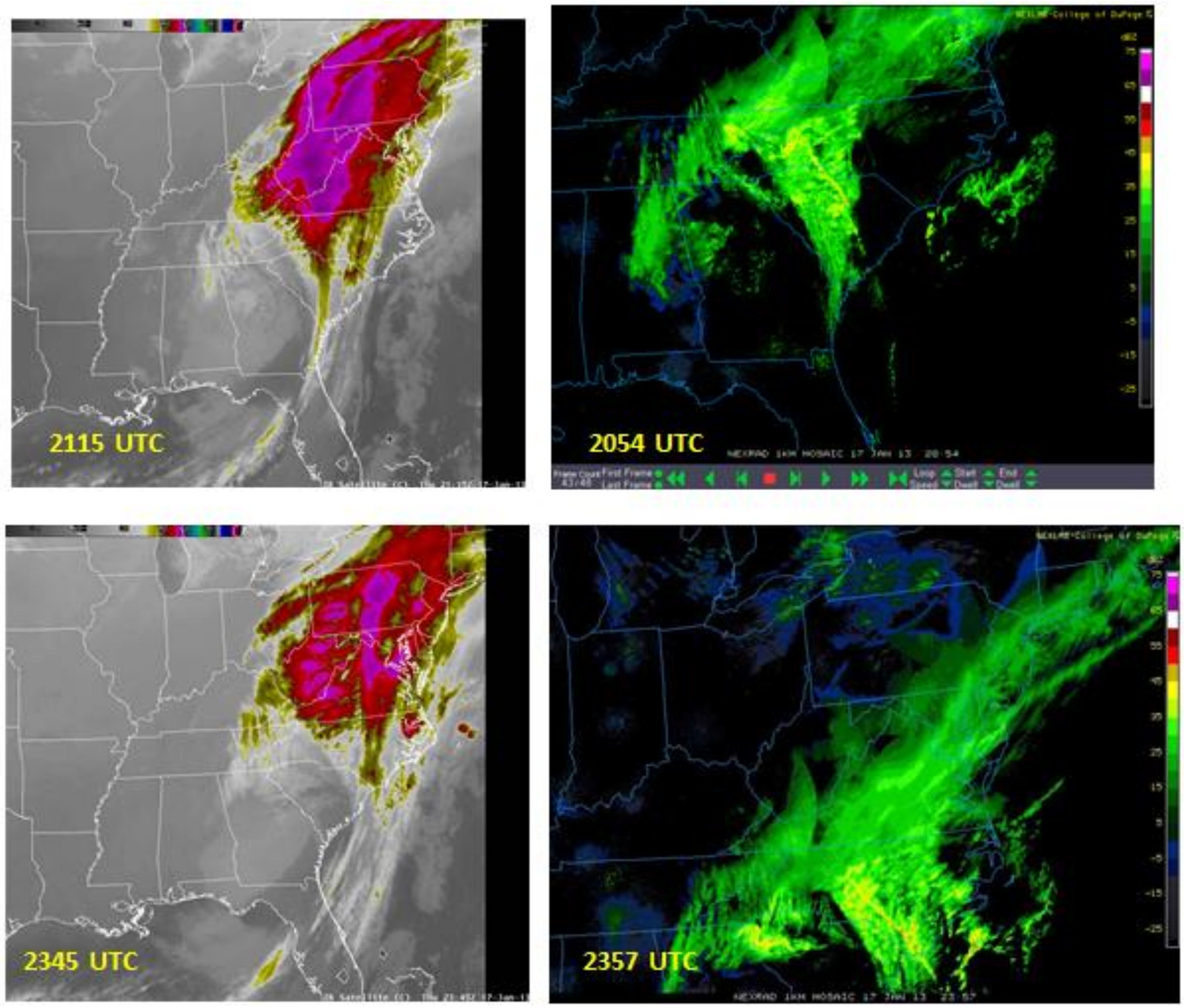

Fig. 14. Infrared satellite imagery (left) and regional WSR-88D mosaic (right) on 17 January 2013. Radar images: NEXLAB – College of DuPage.

5. Surface Development and Cold Air Advection

The developing surface low pressure system moved across the eastern Carolinas toward the Atlantic coast at 0000 UTC on 18 January. The low level convergence and upper level divergence were aligned to maximize upward motion over the southern Appalachians (Fig. 15). Indeed, precipitation was widespread per the radar imagery, but the cold air along the western side of the mountains still was not able to quickly infiltrate the valleys and cross the high ridges to change rain to snow until the bulk of the precipitation moved east. Most of the accumulating snow fell at elevations above 3500 ft MSL in the counties near the Tennessee border. The 0000 UTC 925 mb analysis (Fig. 16) showed a nose of warm air extended from South Carolina into the mountains of North Carolina even though the 850 mb analysis showed the temperature was subfreezing over the western Carolinas (Fig. 17).

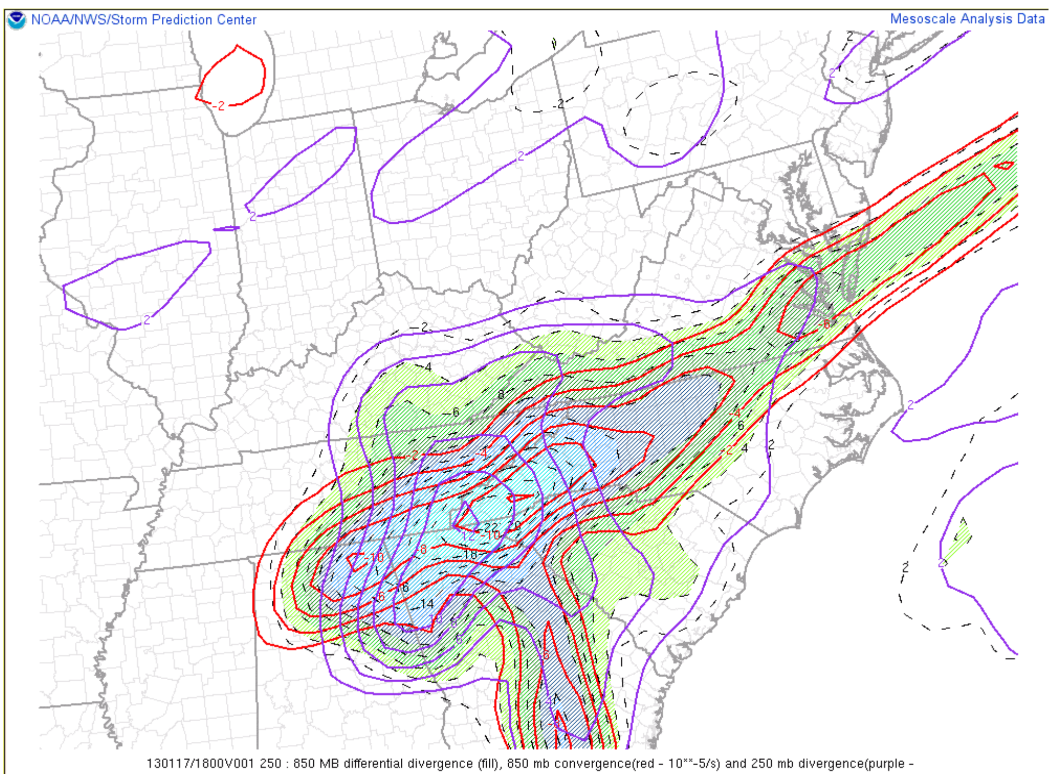

Fig. 15. NOAA/NWS/SPC mesoanalysis 250-850 mb differential divergence (fill), 850 mb convergence (red contours), and 250 mb divergence (purple contours) at 1800 UTC, 17 January 2013.

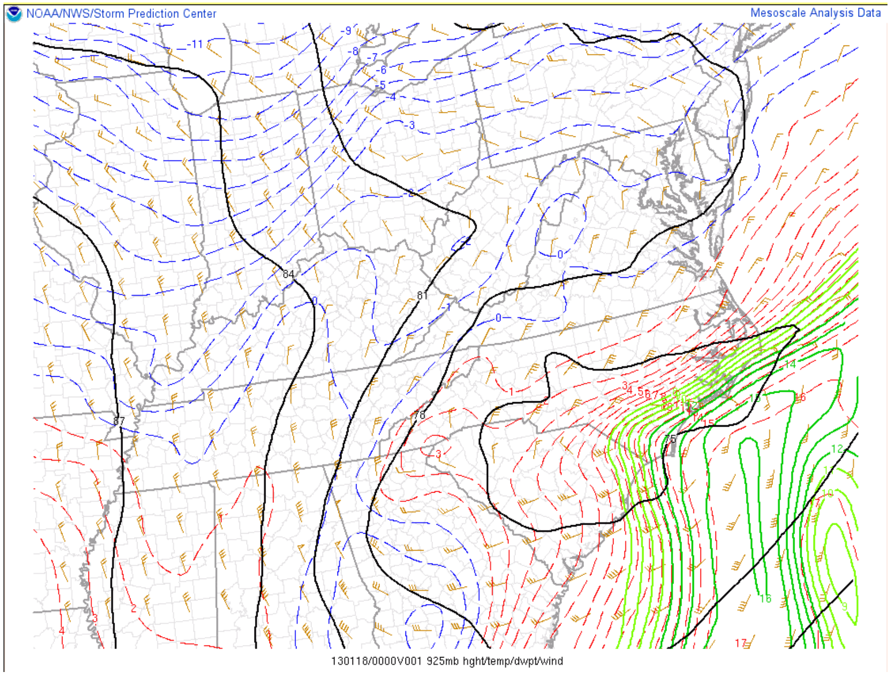

Fig. 16. NOAA/NCEP/SPC mesoanalysis 925 mb height (black contours), temperature (dashed contours), dew point (green contours), and wind (barbs) at 0000 UTC, 18 January 2013.

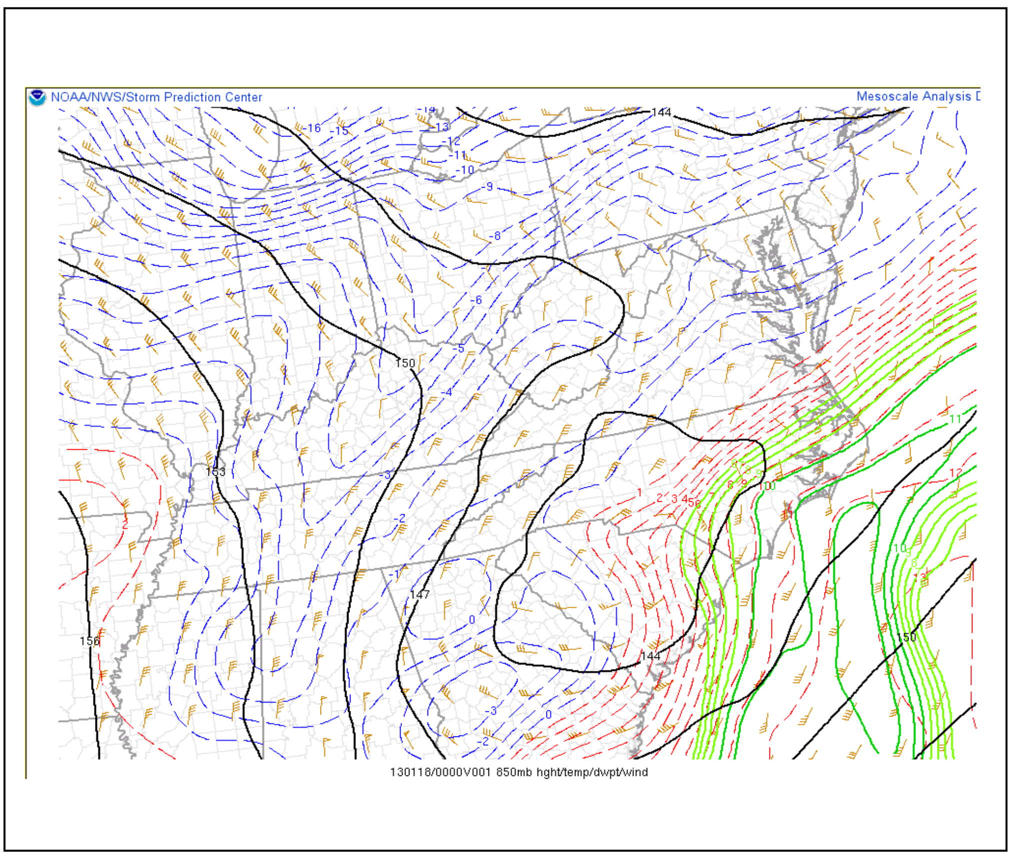

Fig. 17. Same as Fig. 16 except 850 mb.

When the surface low pressure system approached the coast, cold air advection east of the mountains contributed to a changeover of rain to snow across some of the Piedmont counties in the WFO Greenville-Spartanburg County Warning Area. The precipitation transition east of the mountains occurred on the western edge of the departing precipitation so accumulations generally were insignificant (Table 1).

The gradual progression of cold air into the mountains was evident in the North American Mesoscale (NAM) model vertical temperature profile at Asheville (Fig. 18). The early afternoon (1800 UTC) temperature was above 0°C from the surface to 652 mb (approximately 8,500 ft AGL). The evening (0000 UTC) temperature profile had lowered to the extent that the entire column was subfreezing except for the bottom several hundred feet. By this time, the snow level was approaching the valley floor, but the precipitation was nearing an end. Snow was mixed with rain on the campus of UNC-Asheville at 0000 UTC.

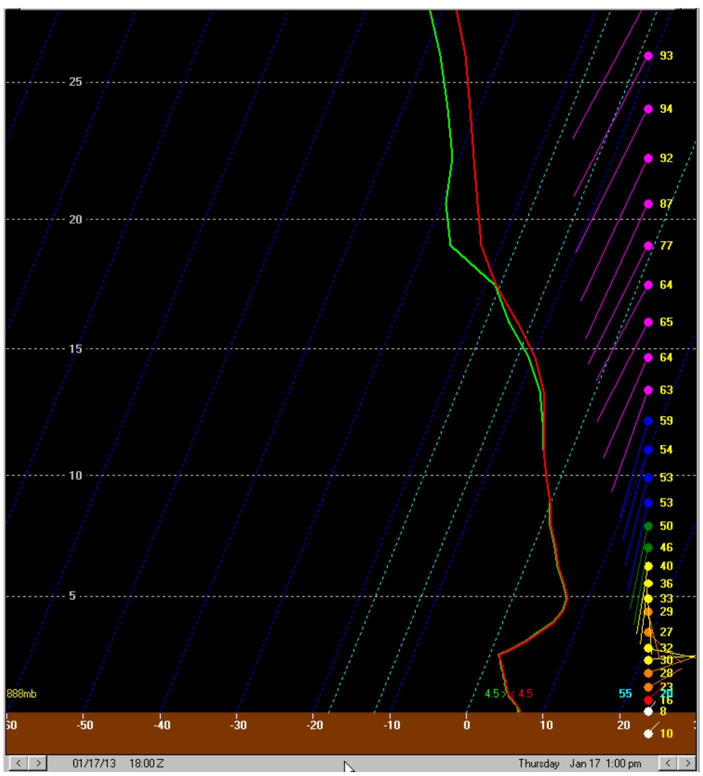

Fig. 18. NAM 1800 UTC, 17 January 2013 temperature (°C; red) and dew point (°C; green) profiles at Asheville Regional Airport. Wind speed (kt) and direction on right. Vertical scale on left in thousands of feet.

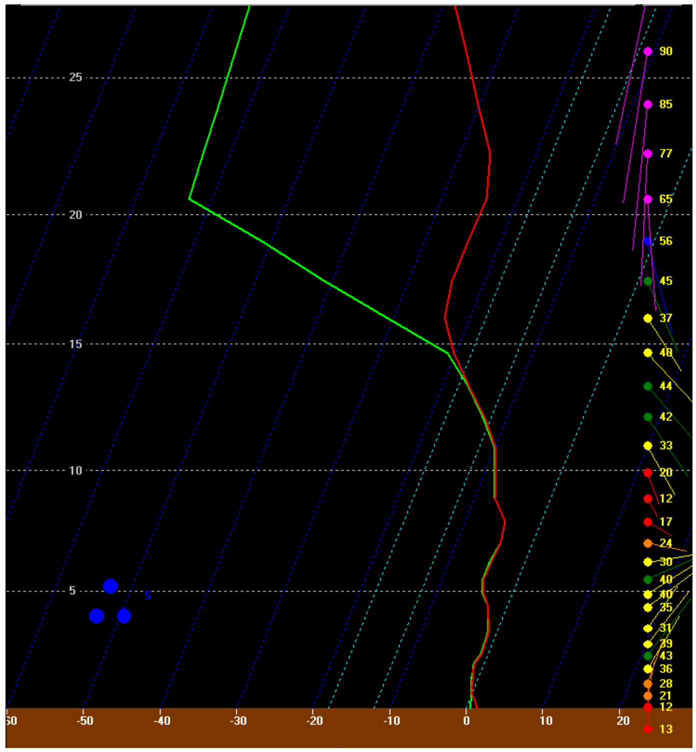

Fig. 19. Same as Fig. 18 except 0000 UTC, 18 January 2013.

6. Summary

A nearly stationary front and subsequent cyclogenesis produced a broad area of precipitation over the southeastern United States on 17 January 2013. The surface low strengthened over north Georgia on 17 January then moved across South Carolina and eastern North Carolina to a position off the mid-Atlantic coast on 18 January. The southwest wind through a deep layer on the east side of a deep trough aloft prevented cold air from crossing the southern Appalachians until the precipitation was exiting the area. Therefore, most of the precipitation in the WFO GSP CWA was in the form of rain. Snow accumulated in a limited area primarily near the Tennessee border on the fringe of the cold air mass. As the low pressure system developed, satellite and radar imagery detected a separation of cloud and radar features that subsequently evolved into a classical comma head pattern associated with maturing extratropical cyclones. The separate cloud and radar features early in the event were related to the interaction of the warm, cold, and dry conveyor belts.

Acknowledgements. Regional composite radar imagery was obtained from the College of DuPage Next Generation Weather Lab. Some of the sounding data used, but not appearing, in this review were obtained from the Sounding-based Experiment on Mixed Precipitation Events at the University of North Carolina at Asheville.

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