Christmas Day 2010 Snowfall

Laurence G. Lee and Patrick D. Moore
NOAA/National Weather Service
Greer, SC

1. Introduction

Measurable snow fell across much of the western Carolinas and extreme northeast Georgia on the 25th and 26th of December 2010 (Fig. 1). Snowfall totals ranged from an inch or less in southern portions of the WFO Greenville-Spartanburg (GSP) County Warning Area (CWA) to six inches or more across the northern half of the CWA. Isolated accumulations greater than twelve inches occurred in the mountains. The weather feature that produced the snow was an area of low pressure that moved across the southeastern United States then strengthened significantly off the coast before moving northeast.[1]

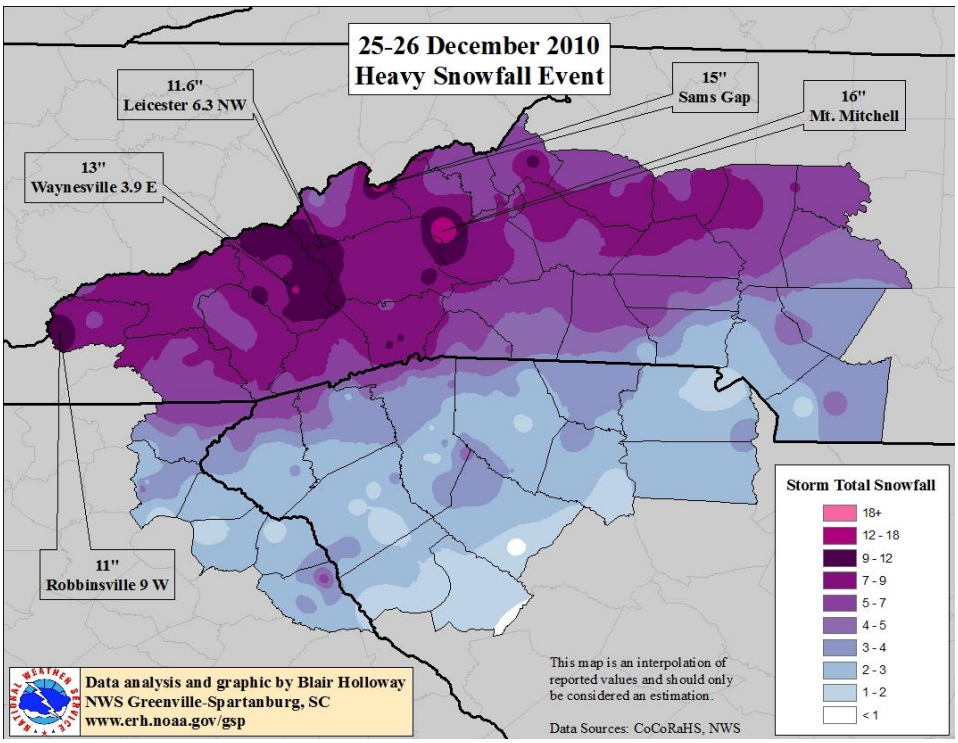


Fig. 1. Snowfall 25-26 December 2010.

2. Synoptic Scale Evolution

At 1200 UTC on 25 December 2010, a weak low pressure system was near the mouth of the Mississippi River with a cold front trailing southwestward over the Gulf of Mexico (Fig. 2). A trough of low pressure extended northeast to a small low over the western Carolinas. A high

[1] In a later section, this report briefly address the northwest flow snow (Perry 2006; Keighton et al. 2009) that occurred on 26 and 27 December 2010 following the passage of the primary low pressure system.

pressure system was centered over south central Canada, and a ridge of high pressure stretched south through the Great Plains to Texas.

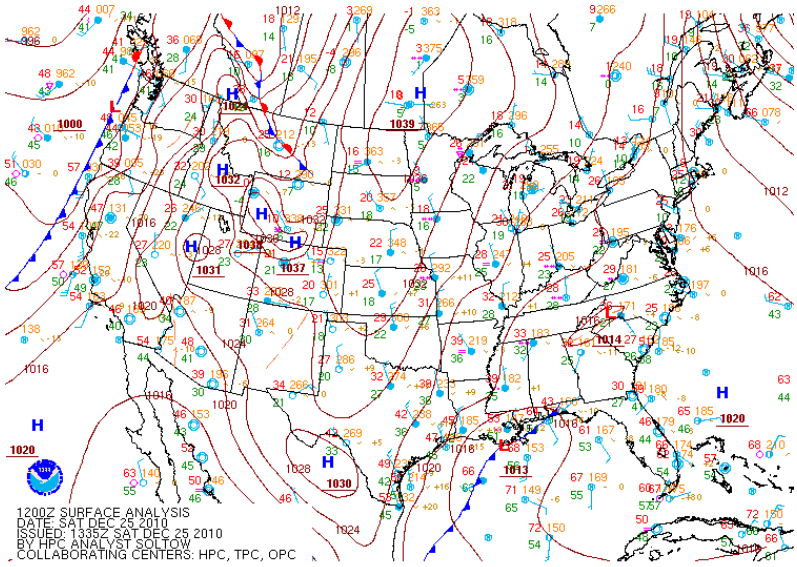


Fig. 2. NCEP/HPC surface analysis at 1200 UTC, 25 December 2010.

The synoptic scale 500 mb pattern across the United States featured a high amplitude ridge over the west and a broad trough containing several short wave troughs over the north central states (Fig. 3). A short wave trough over Louisiana was associated with the low pressure system in the Gulf of Mexico was.

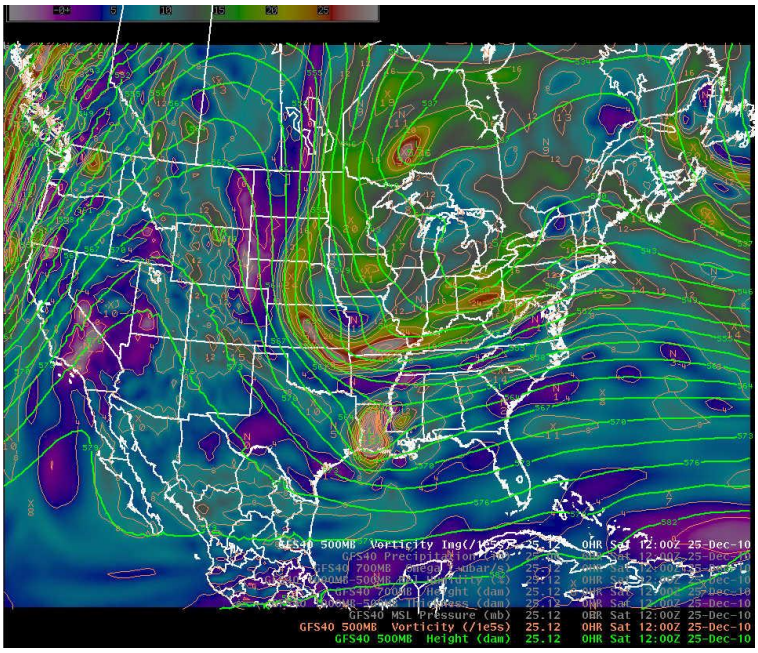


Fig. 3. GFS40 500 mb height (green contours) and vorticity (shades) analysis 1200 UTC, 25 December 2010.

At 1200 UTC, precipitation caused by the Gulf of Mexico low pressure system extended from Louisiana north into Mississippi and Alabama then northeast to the southern Appalachians (Fig. 4). The precipitation was occurring in the ascending air east of the 500 mb trough.

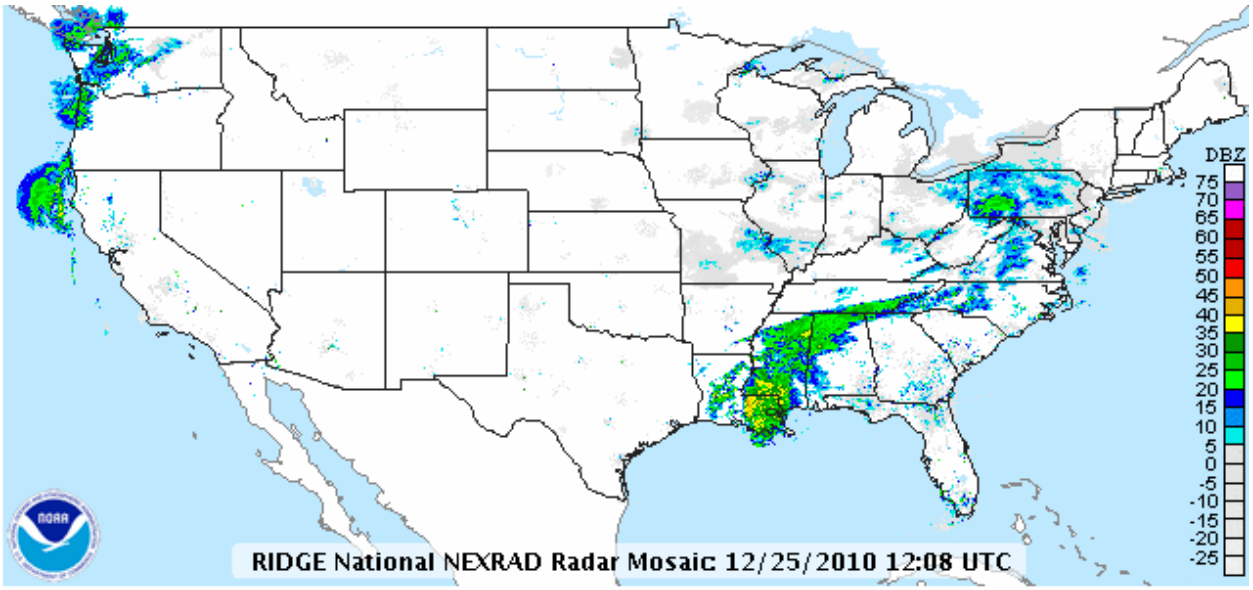


Fig. 4. Radar reflectivity mosaic at 1208 UTC, 25 December 2010.

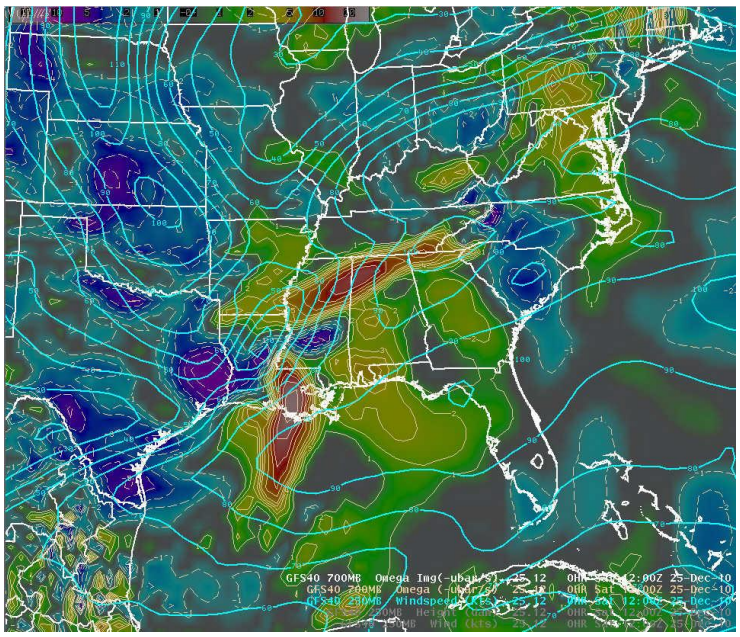


Fig. 5. GFS40 250 mb isotach analysis (blue contours) and 700 mb omega (upward motion yellow and orange shades) at 1200 UTC, 25 December 2010.

The 1200 UTC 250 mb isotach (wind speed) and 700 mb omega (vertical velocity) analysis in Fig. 5 depicted two primary areas of upward motion: One just ahead of the Louisiana 500 mb trough, and the other extending from northern Mississippi to north Georgia. The forcing that produced the vertical motion across the northern Gulf Coast states was due to frontogenesis that was clearly evident in the 850-700 mb layer (Fig. 6).

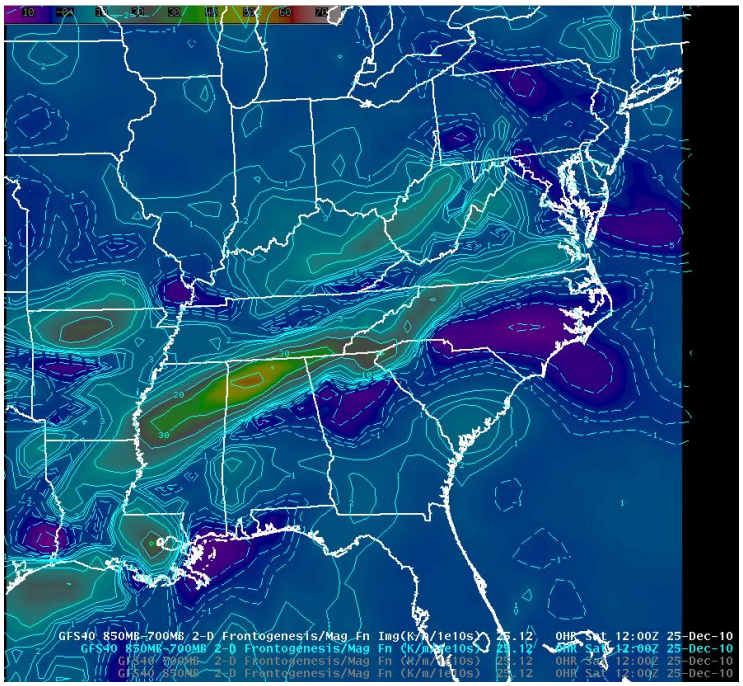


Fig. 6. GFS40 850-700 mb layer frontogenetical forcing at 1200 UTC, 25 December 2010.

The relationship between the frontogenesis and vertical motion was seen in the cross section extending from the Florida panhandle to southern Illinois (Fig. 7). The upward motion was centered almost directly over the maximum frontogenetical forcing. The ascending air on the warm (south) side of the region of frontogenesis was part of the direct circulation typically found in the entrance region of a wind maximum aloft.

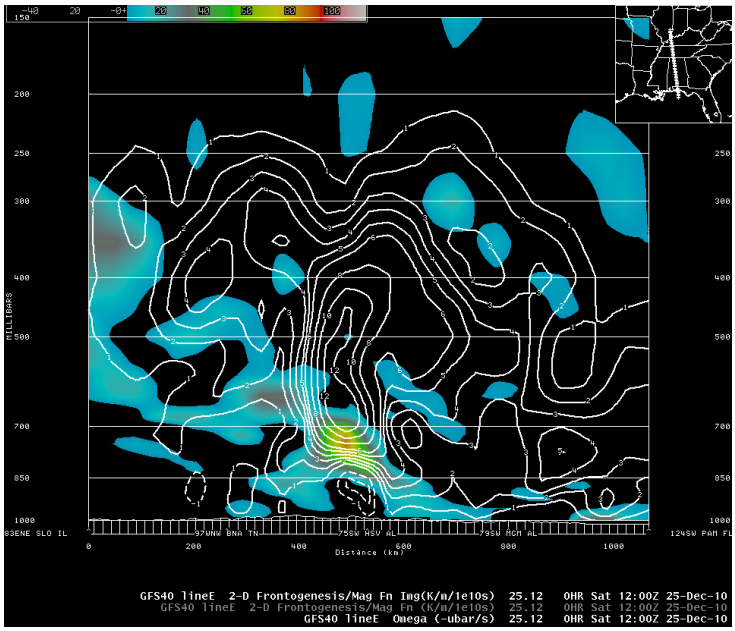


Fig. 7. GFS40 Vertical cross-section from southern Illinois (left) to the Florida panhandle (right) at 1200 UTC, 25 December 2010. Frontogenetical forcing (positive, blue to orange shades) and vertical motion (upward, solid white contours).

By 1800 UTC, the surface low had moved to a position just south of the western tip of the Florida panhandle (Fig 8). The 500 mb short wave trough had moved into southern Mississippi, and the stronger short wave trough diving into the long wave trough position was over southern Arkansas and Oklahoma (Fig. 9). The 1800 UTC 700 mb height and vertical motion analyses showed the two areas of upward motion persisting as they translated eastward. The precipitation in the region of frontogenetical forcing spread rapidly across north Georgia into the western Carolinas (Fig. 10). The coverage of precipitation detected by radar at 1800 UTC corresponded closely to the 850-700 mb frontogenetical forcing seen in Fig. 11.

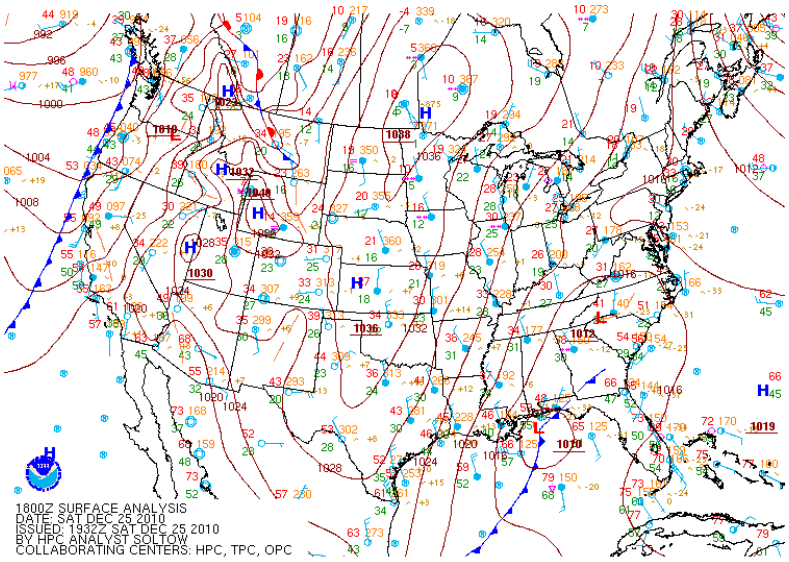


Fig. 8. NCEP/HPC surface analysis at 1800 UTC, 25 December 2010.

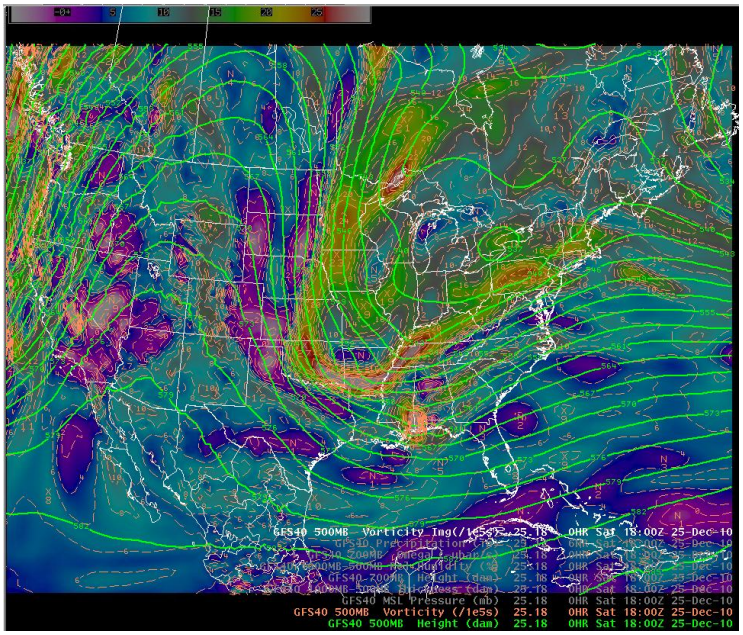


Fig. 9. GFS40 500 mb height (green contours) and vorticity (shades) analysis 1800 UTC, 25 December 2010.

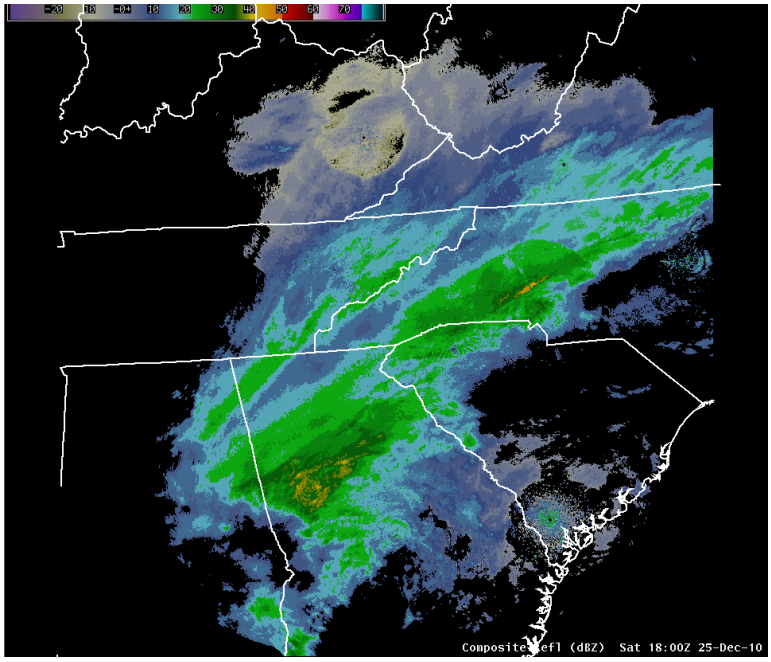


Fig. 10. Composite reflectivity mosaic 1800 UTC, 25 December 2010.

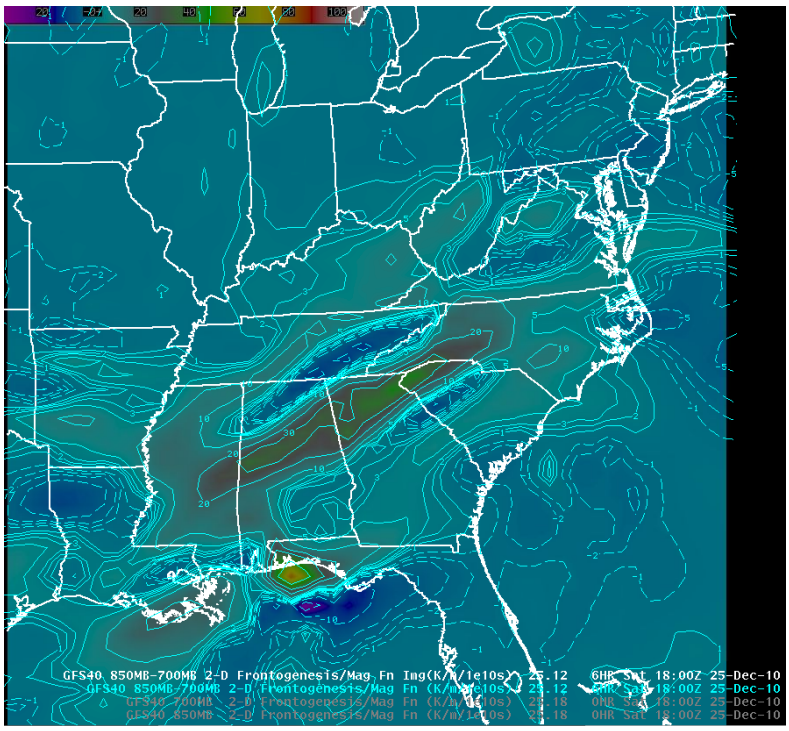


Fig. 11. 850-700 mb frontogenesis 1800 UTC, 25 December 2010. Forcing for upward motion in dark gray to green shades.

The low pressure system moved into the extreme northeastern Gulf of Mexico by 0000 UTC on 26 December (Fig. 12). The 500 mb pattern was dominated by the deepening long wave trough over the eastern U.S. (Fig. 13). The short wave trough that was moving across the Gulf Coast continued to weaken and was barely discernable along the South Carolina coast. The

surface low strengthened in response to the deepening long wave trough that induced divergence aloft from the eastern Gulf Coast toward the mid-Atlantic states. Precipitation continued over the WFO GSP CWA between 1800 UTC and 0000 UTC while developing southward and eastward to cover the entire area (Fig. 14).

The large scale setting favorable for ascent across the CWA is depicted by the 400 mb **Q**-vector[2] convergence that increased over north Georgia and the Carolinas as the upper-level trough approached (Fig. 15). Lower level forcing for upward motion (frontogenesis) shifted eastward toward the coast (Fig. 16). Upward motion through a deep layer over the western Carolinas continued at 0000 UTC on 26 December as can be seen in the omega maximum near 450 mb mb just above the zone of frontogenetical forcing sloping upward from the coast (Fig. 17).

Between 0000 UTC and 1200 UTC on 26 December, the low pressure system and associated front along the Carolina coast strengthened (Fig. 18). Precipitation continued, but the heavier amounts gradually developed across the central and eastern Carolinas closer to the best low-level frontogenetical forcing. The Greenville-Spartanburg WSR-88D showed the main band of frontogenetically forced precipitation as it was moving out of the CWA at 0805 UTC (Fig. 19).

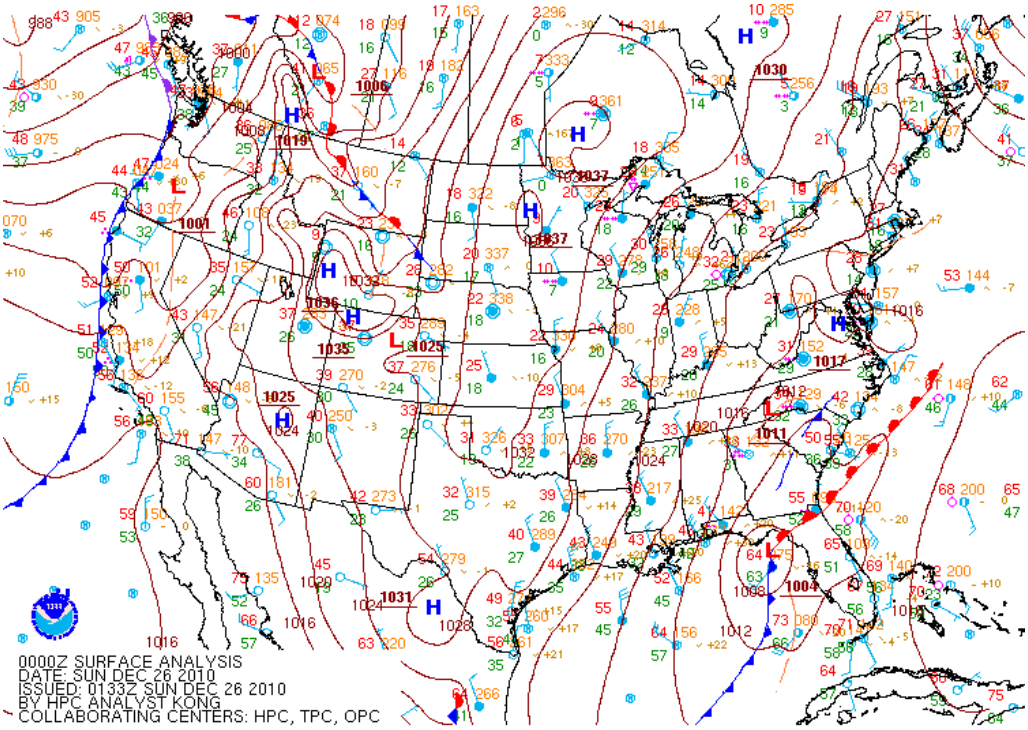


Fig. 12 NCEP/HPC surface analysis at 0000 UTC, 26 December 2010.

[2] The **Q**-vector (Hoskins et al., 1978) is a horizontal vector found on the right-hand side of the quasigeostrophic omega equation. The quantity, **Q**, embodies the forcing for vertical motion due to the individual terms in the more complex, traditional form of the equation. In areas where **Q**-vectors converge, the forcing promotes ascent. In areas where **Q**-vectors diverge, the forcing promotes descent.

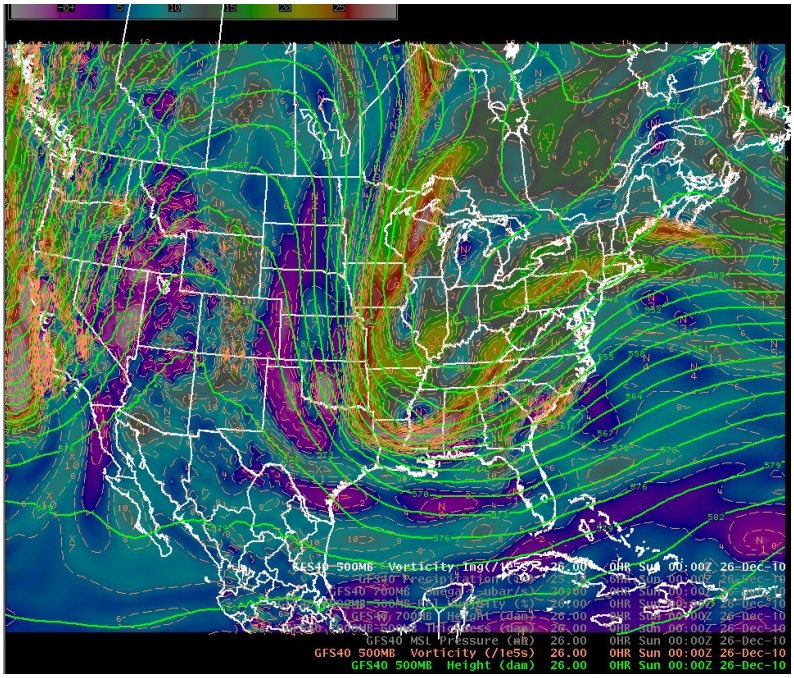


Fig. 13. GFS40 500 mb height (green contours) and vorticity (shades) analysis 0000 UTC, 26 December 2010.

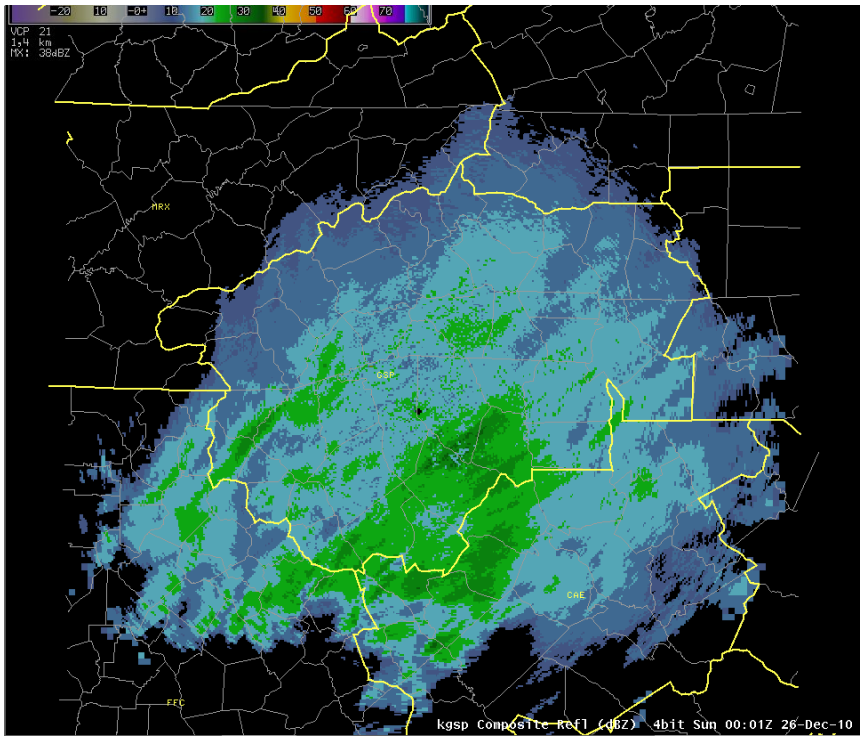


Fig. 14. KGSP WSR-88D composite reflectivity at 0001 UTC, 26 December 2010.

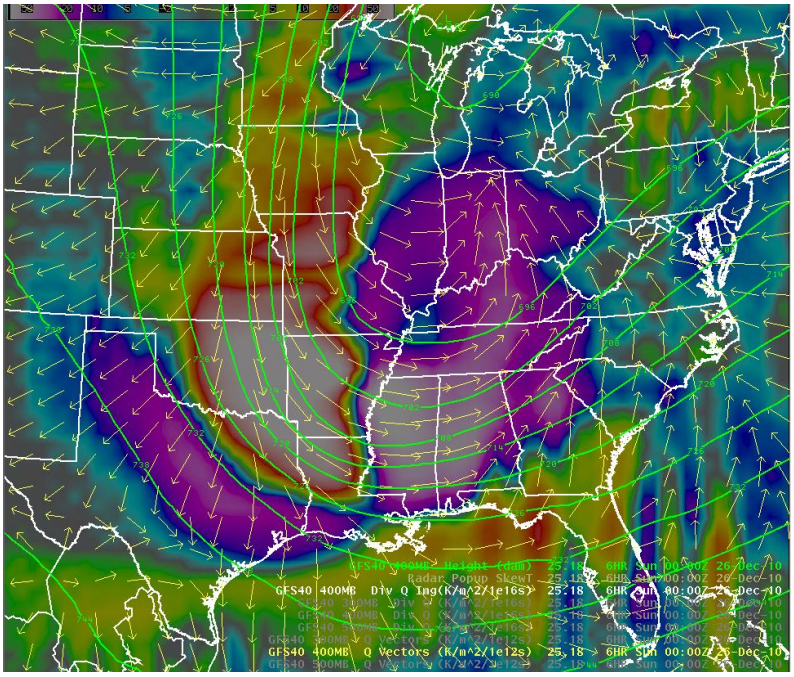


Fig.15. GFS40 400 mb height (green contours), **Q**-vectors (arrows), and **Q**-vector convergence (purple shades) and divergence (orange and red shades) six-hour forecast valid 0000 UTC, 26 December 2010.

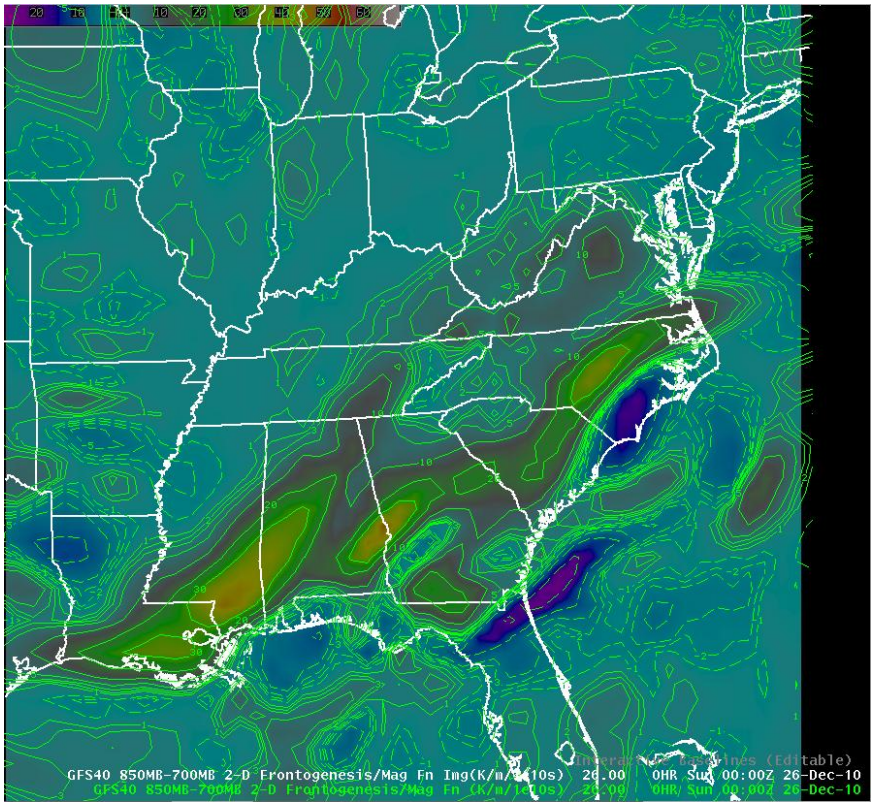


Fig. 16. 850-700 mb frontogenesis 0000 UTC, 26 December 2010. Forcing for upward motion in green and yellow shades.

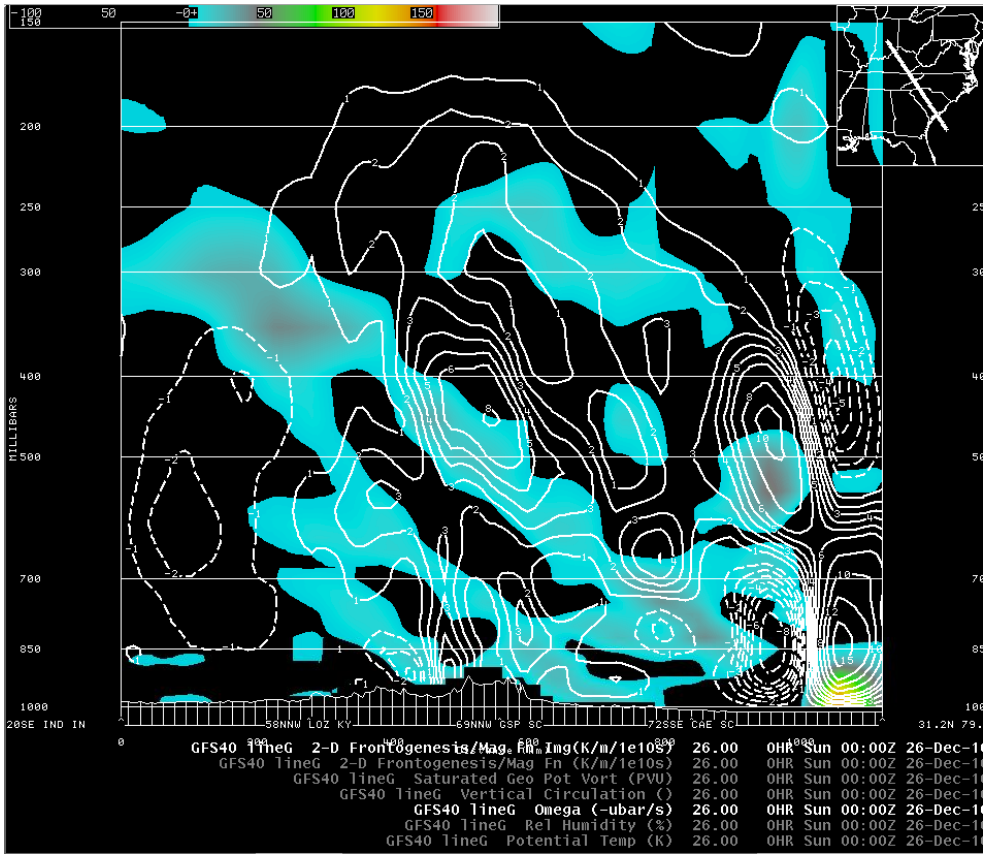


Fig. 17. GFS40 Vertical cross-section from southeast Indiana (left) to an offshore point east of Savannah, Georgia (right) at 0000 UTC, 26 December 2010. Frontogenetical forcing (positive, blue to orange shades) and vertical motion (upward, solid white contours).

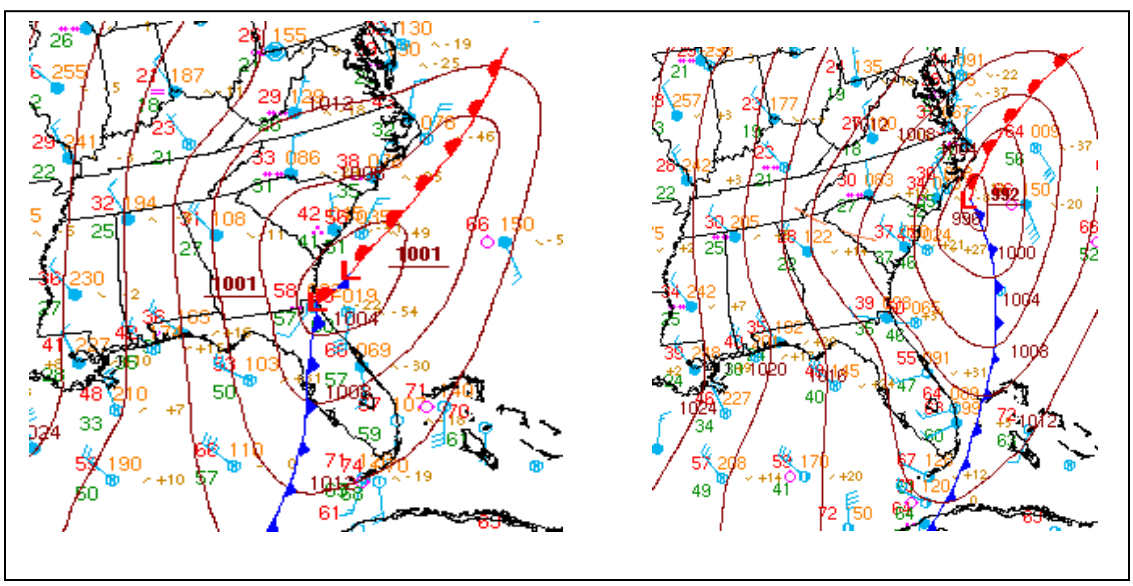


Fig. 18. NCEP/HPC surface analysis at 0600 UTC (left) and 1200 UTC (right), 26 December 2010.

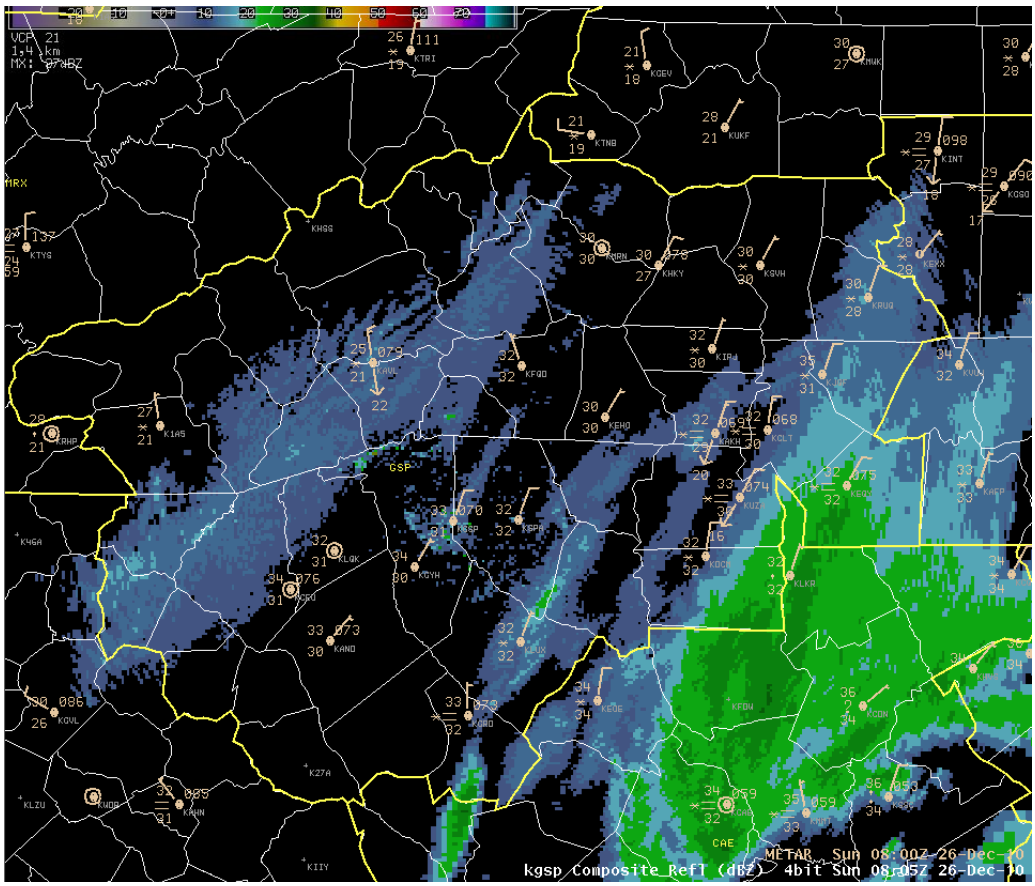


Fig. 19. KGSP WSR-88D composite reflectivity at 0805 UTC, 26 December 2010.

3. Precipitation

The precipitation that moved into the WFO GSP CWA on Christmas Day began as snow in the mountains. The temperature of the near-surface air across the Piedmont was just above freezing, so snow falling into the warmer air melted and produced rain as the initial precipitation type. The temperature, dew point, and wind profile for Greenville-Spartanburg at the approximate precipitation onset time was representative of lower atmospheric thermal conditions across the entire Piedmont portion of the CWA (Fig. 20). The temperature profile was moist in the temperature range favorable for dendritic ice crystal formation (approximately -12°C to -18°C), and was colder than 0°C except at the surface. Shortly after the precipitation began, cooling caused by evaporation and melting lowered the temperature enough to allow snow to reach the ground.

Light rain began at Greenville-Spartanburg at 1942 UTC then changed to light snow at 2014 UTC. The snow continued until 0653 UTC on 26 December. During most of the time during which snow was falling, the surface temperature varied from 32°F to 34°F. After a precipitation-free period of about three hours, light snow returned at 0925 UTC and continued until 1553 UTC. The second period of light snow occurred with the passage of the upper-level cyclonic circulation. The heaviest precipitation at 1158 UTC was along the

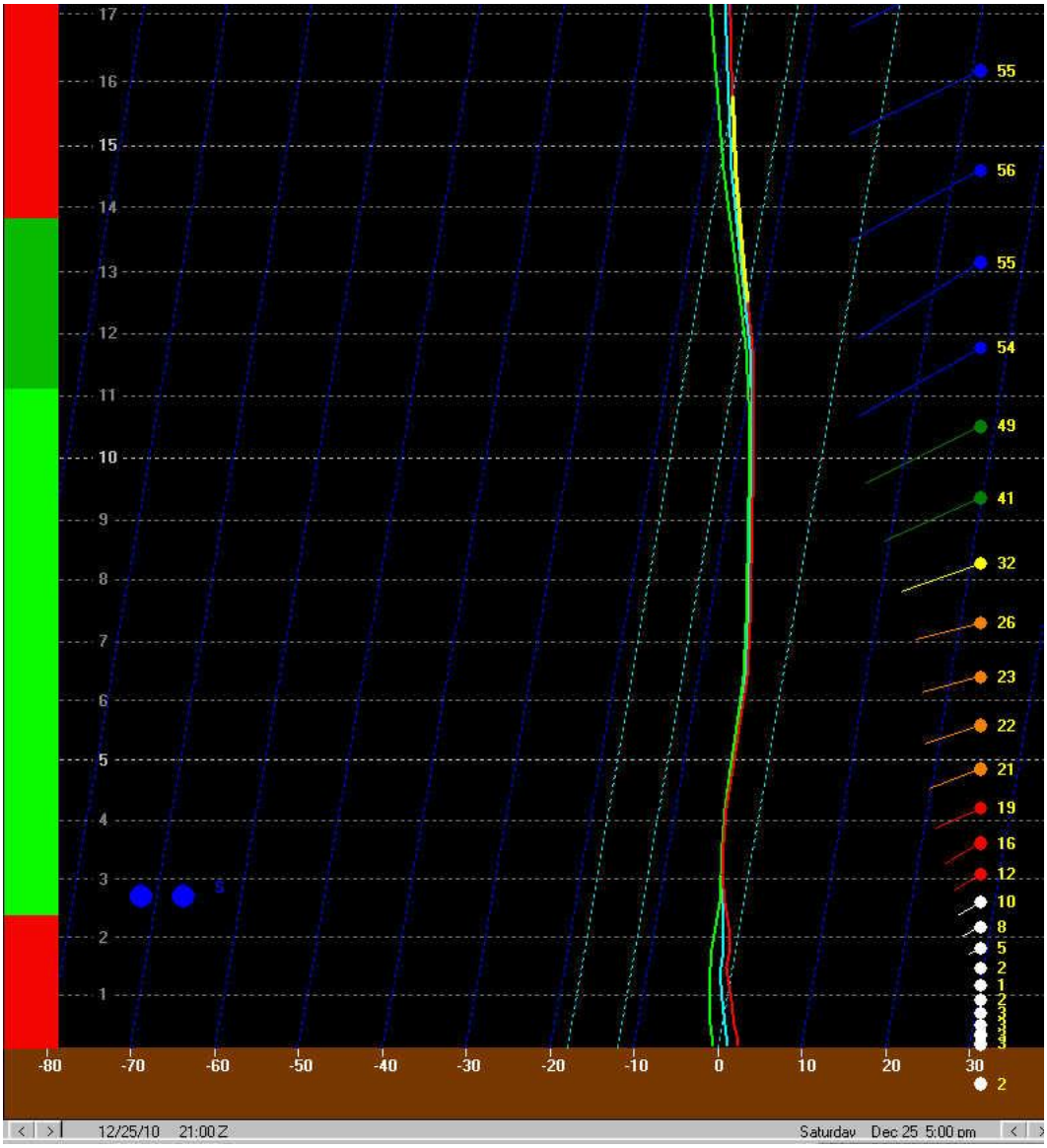


Fig. 20. GFS40 Bufkit three-hour forecast of WFO GSP temperature (red), wet bulb temperature (blue), and dew point (green) profiles valid at 2100 UTC, 25 December 2010. Wind speed (kt) and direction (stick pointing into the wind) on the right and relative humidity (red ≥ 70% to < 90%; green ≥ 90%) on the left. The blue circles denote the model forecast of snow at that hour.

coast near the strongest frontogenetical forcing (Fig 21a). A separate area of light precipitation was over the western Carolinas and northeast Georgia. The light precipitation was near the 500 mb low and in a region of upward motion forced by the **Q**-vector convergence evident in the 700-500 mb layer (Fig. 21b). The snowfall at Greenville-Spartanburg totaled 2.3 inches (1.6 inch on the 25th; 0.7 inch on the 26th).

A similar sequence of events occurred at Charlotte. Light rain started at 2052 UTC and changed to light snow at 2345 UTC on 25 December. Snow continued, without a break, until 1752 UTC on the 25th. Total accumulation at Charlotte was 2.0 inches (0.4 inch on the 25th; 1.6 inch on the 27th).

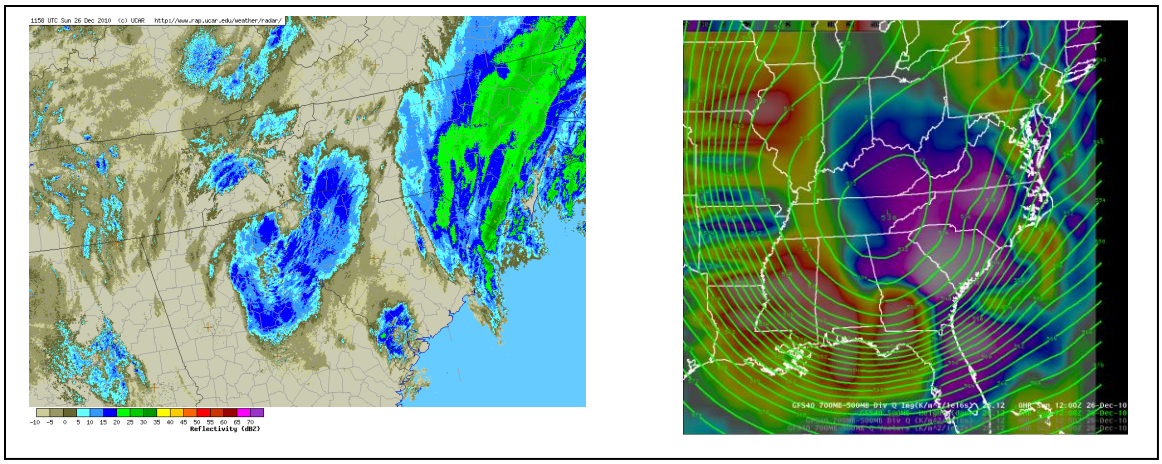


Fig. 21. (Left) WSR-88D reflectivity mosaic at 1158 UTC, 26 December 2010, and (Right) 1200 UTC 500 mb height (decamaters; green contours) and 700-500 mb **Q**-vector divergence (forcing for upward motion in blue and purple shades).

The snowfall at Asheville Regional Airport lasted from 1302 UTC on 25 December until 1537 UTC on the 26th of December. After the center of surface low pressure reached the mid-Atlantic coast and the upper-level cyclonic circulation moved east of the mountains, a period of northwest flow snow developed. The small area of light snow detected by radar along the Tennessee and North Carolina border in Fig. 22a was a persistent feature between approximately 1200 UTC on the 26th and 1200 UTC on the 27th. The 850 wind direction was nearly perpendicular to the spine of the Appalachians with a pool of moisture in the upslope flow across eastern Kentucky and East Tennessee (Fig. 22).

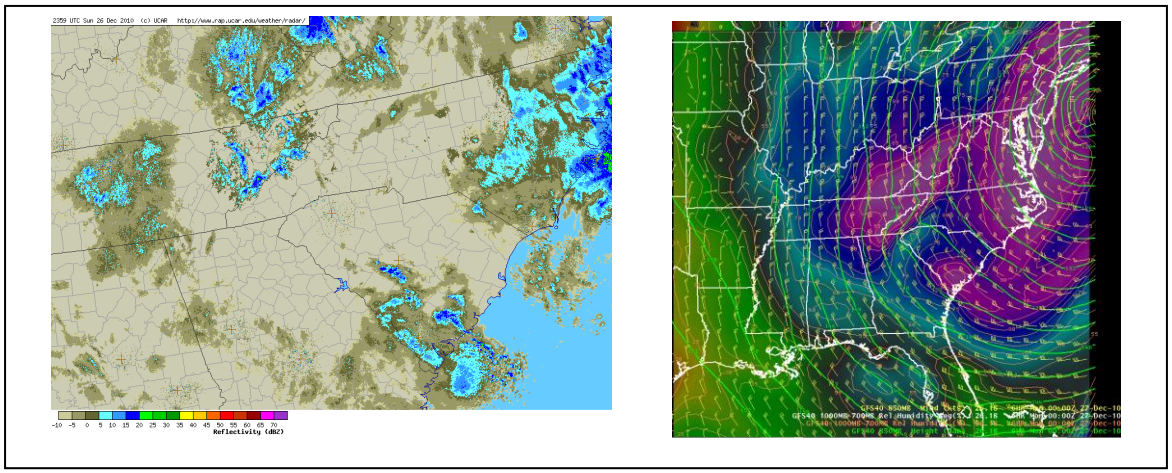


Fig. 22 (Left) WSR-88D reflectivity mosaic at 2359 UTC on 26 December 2010, and (Right) GFS 850 mb height (decameters; green countours), 850 mb wind (yellow barbs), and 100-700 mb mean relative humidity (greater than 85% in purple shade) at 0000 UTC on 27 December 2010.

Most of the accumulating northwest flow snow was confined to the Tennessee border counties, but the Asheville Regional Airport experienced periods of light snow from 1830 UTC 26 December until 1403 UTC on 27 December. The total snowfall was 7.0 inches (6.5 inches on the 25th; 0.5 inch on the 26th; Trace on the 27th).

During the northwest flow snow phase of the event, several locations near the Tennessee border had accumulations greater than 12 inches (Fig. 23). The total snowfall – including precipitation attributed to the coastal low pressure center and the northwest flow – resulted in accumulations exceeding 20 inches in the North Carolina counties along the Tennessee border (Fig. 24).

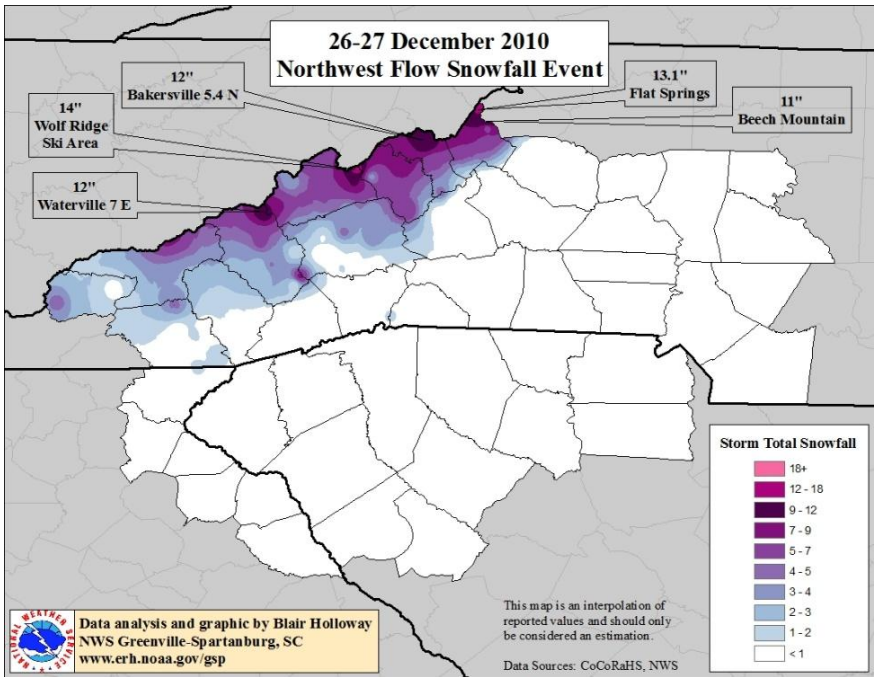


Fig. 23. Snowfall totals (inches) during the northwest flow phase of the event (approximately 1200 UTC, 26 December 2010 until 1800 UTC, 27 December 2010).

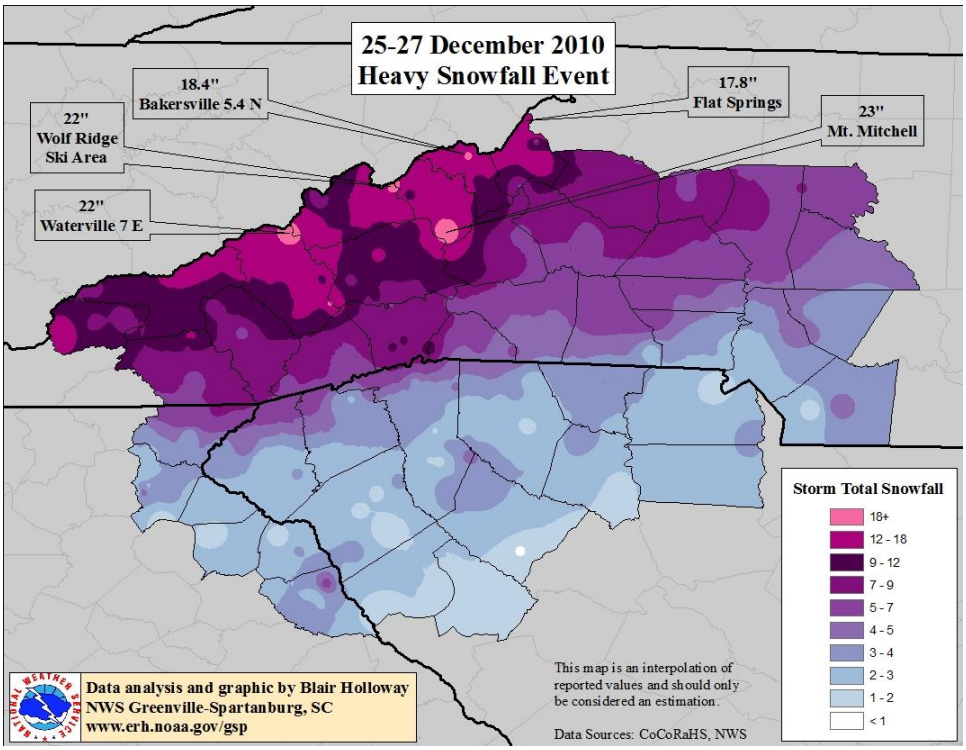


Fig. 24. Total snowfall (inches) 25-27 December 2010.

The appendix contains graphical time summaries (meteograms) of the weather at Asheville, Greenville-Spartanburg, and Charlotte on 25 and 26 December 2010. Several weather elements are plotted in the graphs that extend from 0000 UTC to 2300 UTC on both days.[3]

A Terra MODIS satellite image from midday on 27 December 2010 captured the regional snow cover two days after Christmas (Fig. 25), although clouds obscured the ground in some areas. One feature of note was the lack of significant snow cover in western portions of Upstate South Carolina and a neighboring portion of extreme northeast Georgia. Snow accumulations were less in this area than across most of the WFO GSP CWA, plus some melting had occurred by this time.

A GOES East satellite view of the eastern United States from the Carolinas northward at 1650 UTC on 27 December 2010 (Fig. 26) showed the snow cover extended from the WFO GSP CWA eastward across the Piedmont and Coastal Plain then northward along the coast to southern New England. The spiral cloud pattern associated with the low pressure center is just south of Nova Scotia.

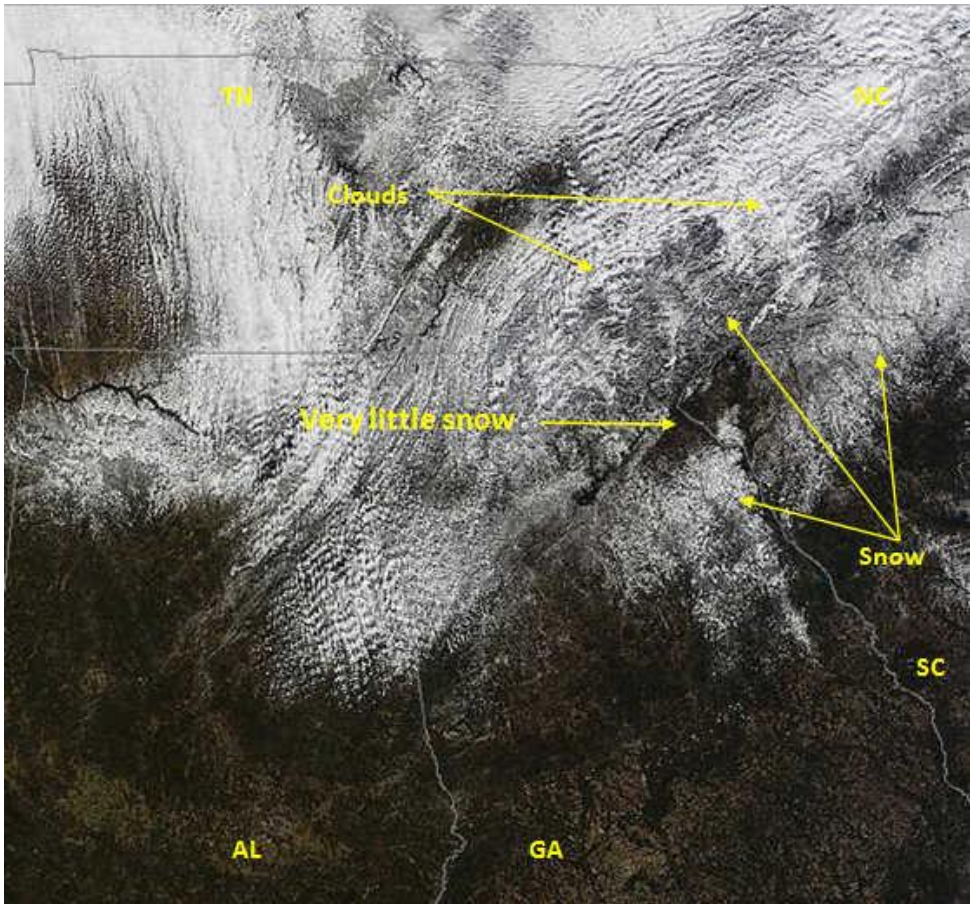


Fig. 25. Terra MODIS satellite image at approximately 1640 UTC, 27 December 2010 (University of Wisconsin-Madison, Space Science and Engineering Center).

[3] For assistance interpreting the graphs, please refer to http://vortex.plymouth.edu/meteogram_info.html

Fig. 26. GOES East satellite image at 1650 UTC, 28 December 2010 (NOAA Environmental Visualization Laboratory).

4. Summary

A late December 2010 low pressure center that traveled along the Gulf Coast then north along the eastern seaboard produced a large area of snowfall in the eastern United States. Significant accumulations occurred in the southern Appalachians. In the WFO GSP CWA, the snow began on Christmas Day and ended as a northwest flow snow event in the North Carolina mountains on the 27th. On the 25th and 26th of December, one to three inches of snow fell in northeast Georgia, upstate South Carolina, and the southern Piedmont of North Carolina. Four to eight inches accumulated in the North Carolina foothills and portions of the northwest Piedmont of North Carolina. A wide range of snow totals was observed in the mountains. Seven to ten inches of snow was common, but more than 20 inches of snow was reported from the Tennessee border counties.

A preliminary assessment of the impact of the snowstorm (Fig. 27) was prepared by the National Climatic Data Center (NCDC). Application of the Northeast Snowfall Impact Scale (NESIS; Kocin and Uccellini, 2004) to this event classifies it as “major” (a category 3 on a scale from 1 to 5). NESIS takes into account snow accumulation, area affected by the storm, and population along the storm’s path. Information regarding the calculation of NESIS scores at NCDC is available in Squires and Lawrimore (2006).

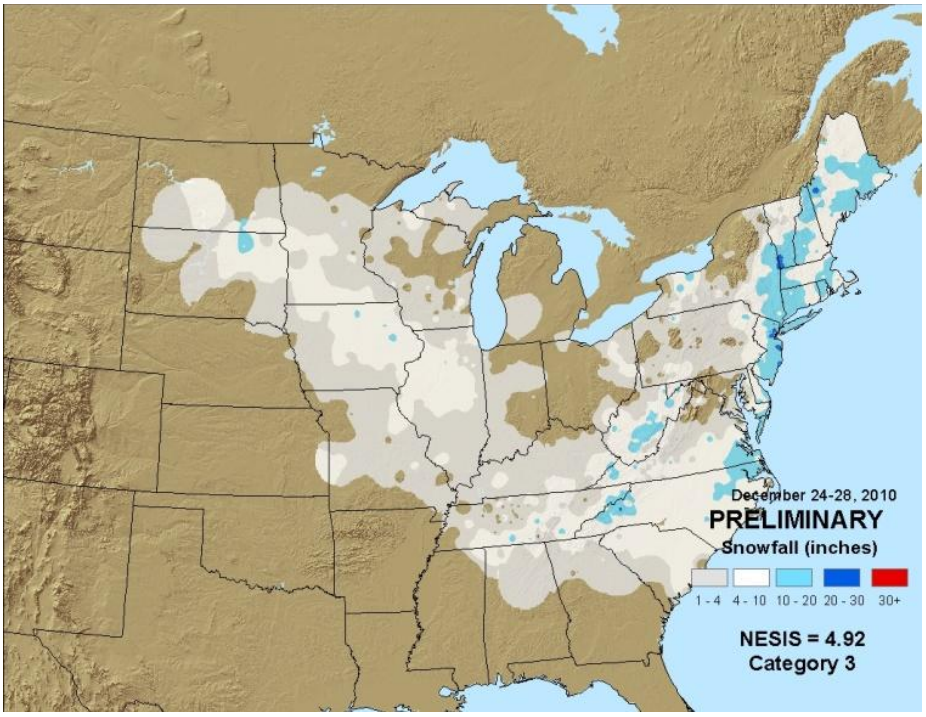
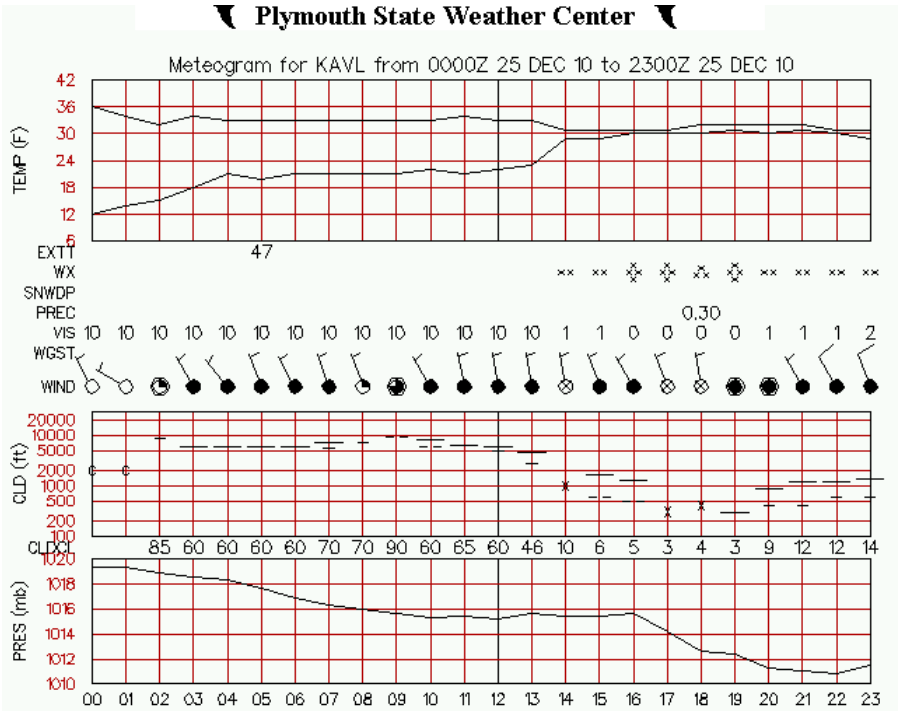
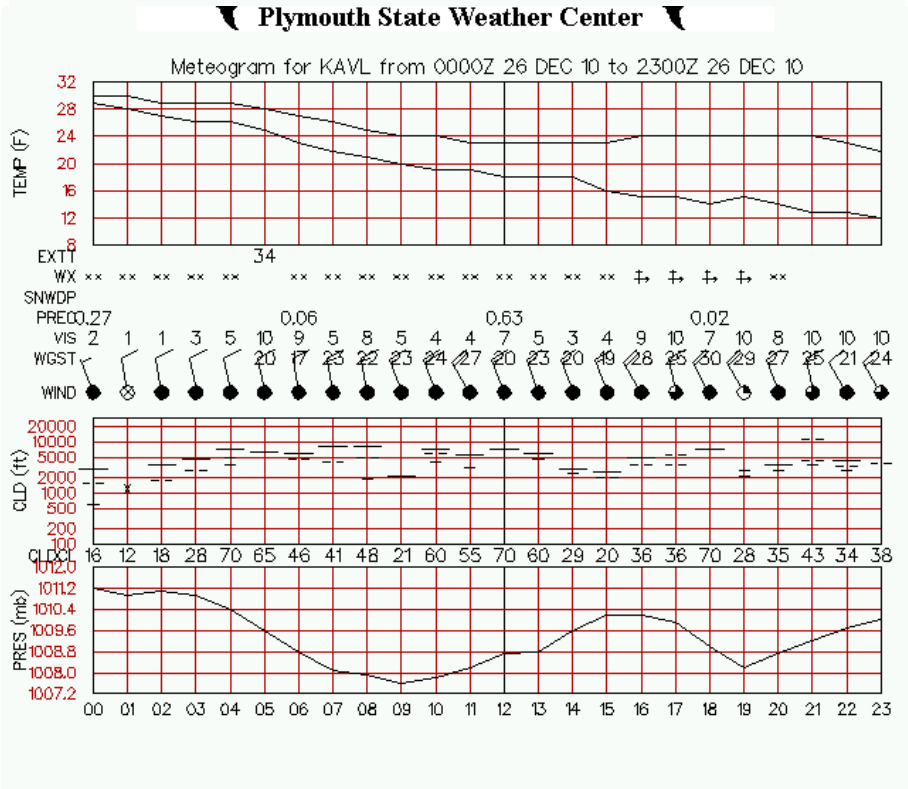


Fig. 27. Preliminary Northeast Snowfall Impact Scale analysis of the 24-28 December 2010 storm. (National Climatic Data Center).

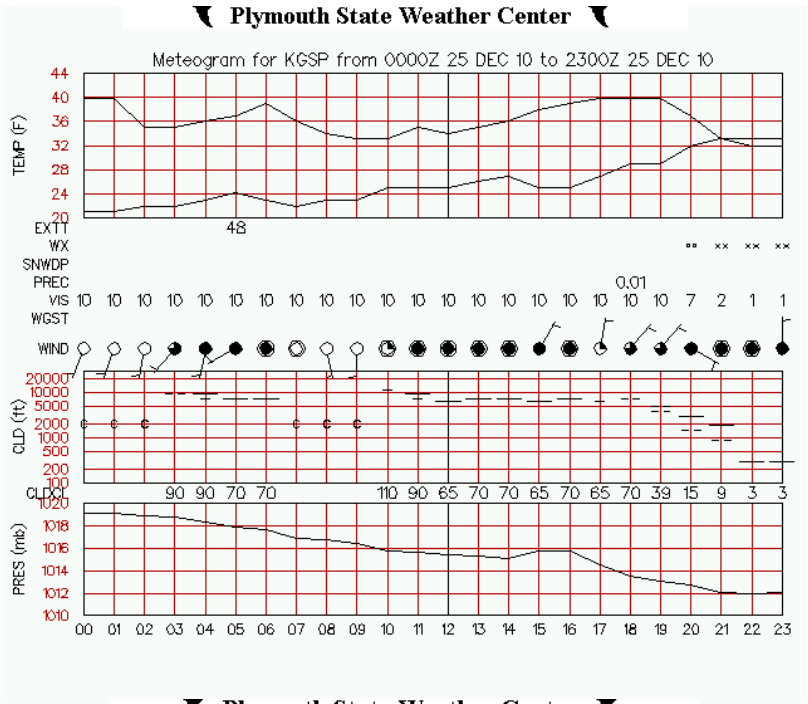
Acknowledgments. Surface analyses were prepared by the NCEP/Hydrometeorological Prediction Center. The Terra MODIS imagery was obtained from the Space Science and Engineering Center at the University of Wisconsin-Madison. The GOES East image was created by the NOAA Environmental Visualization Laboratory. The graphical time summaries of weather observations at Asheville, Greenville-Spartanburg, and Charlotte were obtained from Plymouth State University. The National Climatic Data Center produced the NESIS image.

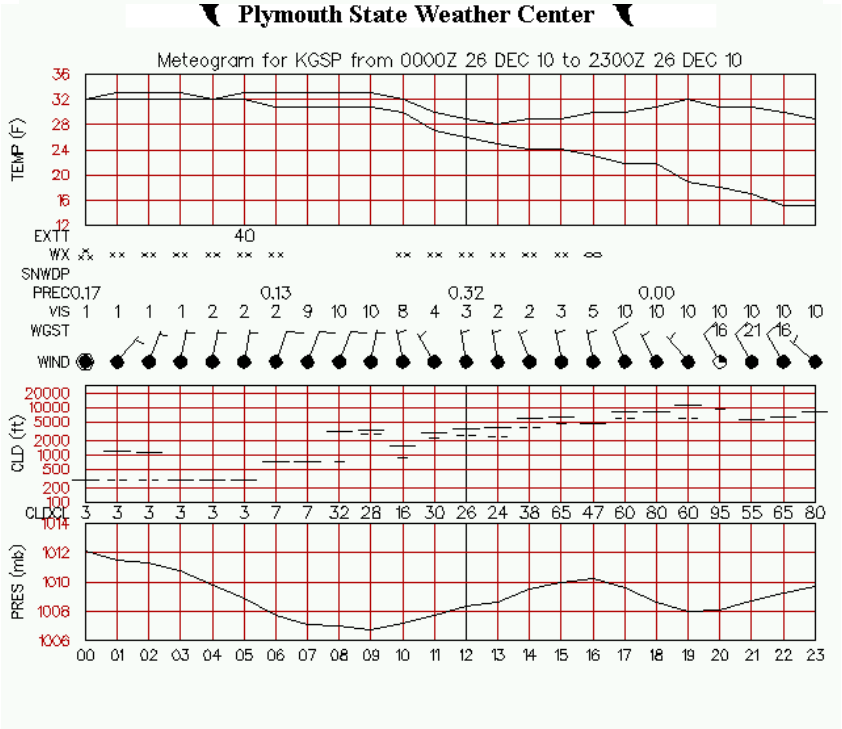
Appendix



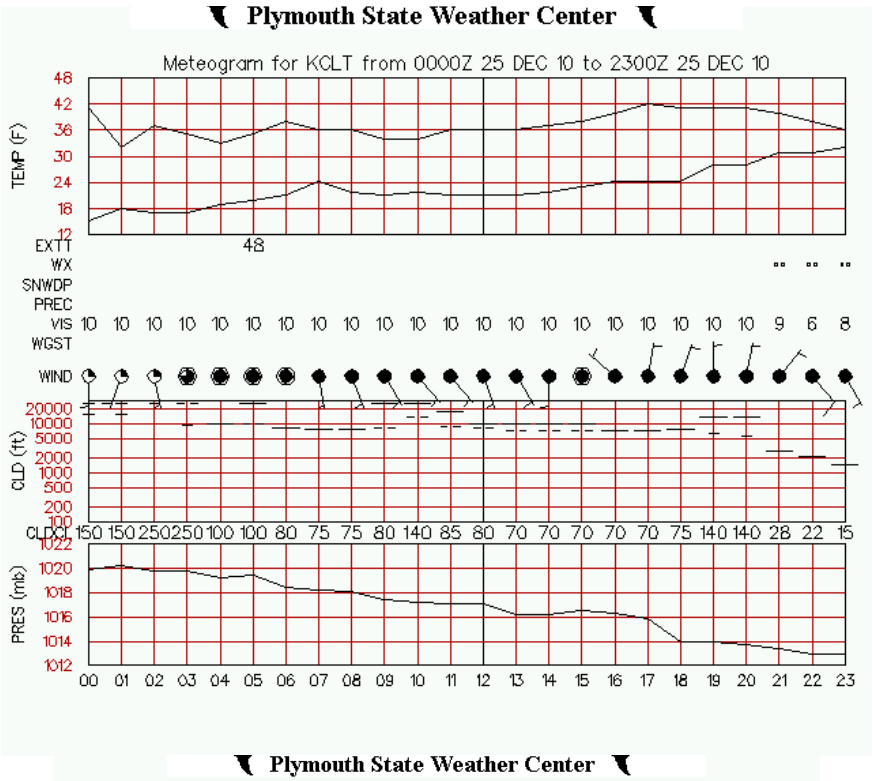


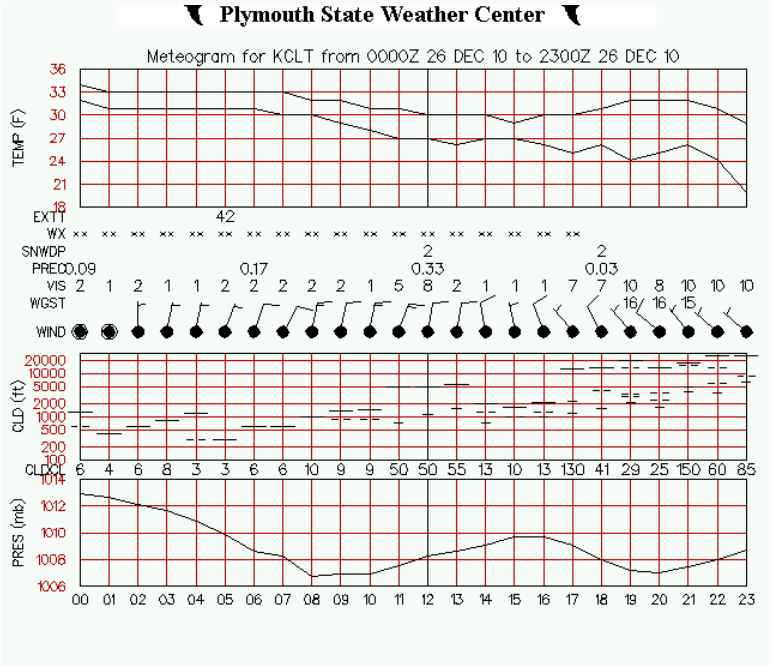
Asheville meteogram 25 (top) and 26 (bottom) December 2010





Greenville-Spartanburg meteogram 25 (top) and 26 (bottom) December 2010





Charlotte meteogram 25 (top) and 26 (bottom) December 2010

REFERENCES

Hoskins, B.J., I. Draghici, and H.C. Davies, 1978: A new look at the omega-equation. *Quart. J. Roy. Met. Soc.*, **104**, 31-38.

Keighton, S., and Coauthors, 2009: A collaborative approach to study northwest flow snow in the southern Appalachians. *Bull. Amer. Meteor. Soc.*, **90**, 979-991.

Kocin, P. J., and L. W. Uccellini, 2004: A snowfall impact scale derived from northeast storm snowfall distributions. *Bull. Amer. Meteor. Soc.*, **85**, 177-194.

Perry, L.B., 2006: Synoptic climatology of northwest flow snowfall in the southern Appalachians. Ph.D. dissertation, University of North Carolina at Chapel Hill, 176 pp.

Squires, M. F., and J. H. Lawrimore, 2006: Development of an operational northeast snowfall impact scale. Extended Abstract, *22nd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology*, Amer. Meteor. Soc., Atlanta, GA., 5.9.