

The Heavy Snow and Freezing Rain of 10 and 11 January 2011

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1. Introduction

A low pressure system moved along the Gulf coast then turned northeast along the Carolina coast from 9 to 11 January 2011, leaving in its wake a blanket of snow across much of the WFO Greenville-Spartanburg (GSP) County Warning Area (CWA). Light freezing rain and freezing drizzle were observed at many locations, especially outside the mountains during the latter part of the event, but snow was the dominant precipitation type. Snowfall totals ranged from around one inch in the northeastern corner of the CWA to twelve inches in parts of the North Carolina mountains (Fig. 1).

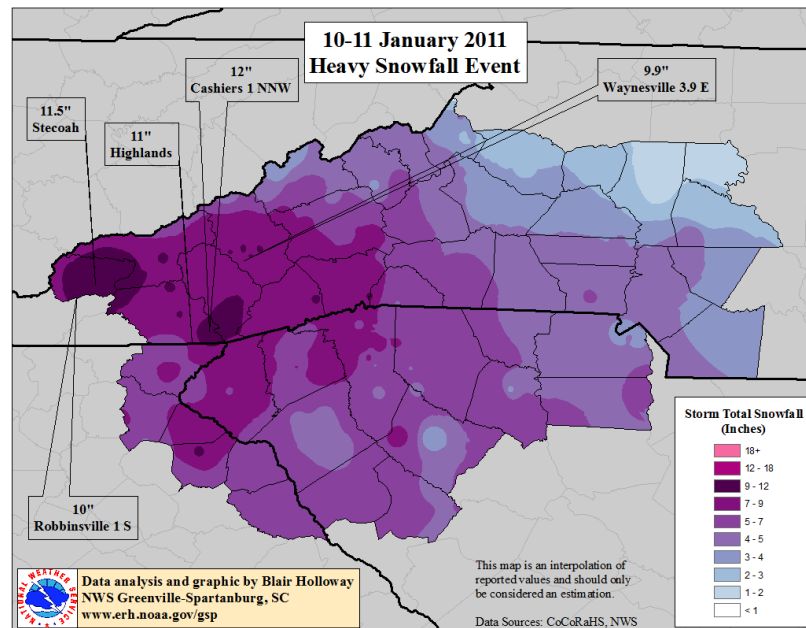


Fig. 1. Storm total snowfall 10-11 January 2011

2. Surface and Upper Air Features

The NCEP/HPC surface analyses from 1200 UTC on 9 January 2011 to 0000 UTC on 12 January (Fig. 2) showed the primary surface weather features during the event. A large high pressure system centered over central Canada and the Midwestern states extended southeast into the Carolinas and Georgia. The air mass was cold with daytime surface temperatures on 9 January in the lower and mid 30s ($^{\circ}$ F) with 20s in the mountains. A surface low pressure system that was near the Texas coast at 1200 UTC 9 January moved eastward reaching north Florida by 0000 UTC on 11 January. Thereafter, the track of the low curved to the north just off the

Georgia and Carolina coast. The center of low pressure moved north away from the Outer Banks after 0000 UTC on 12 January.

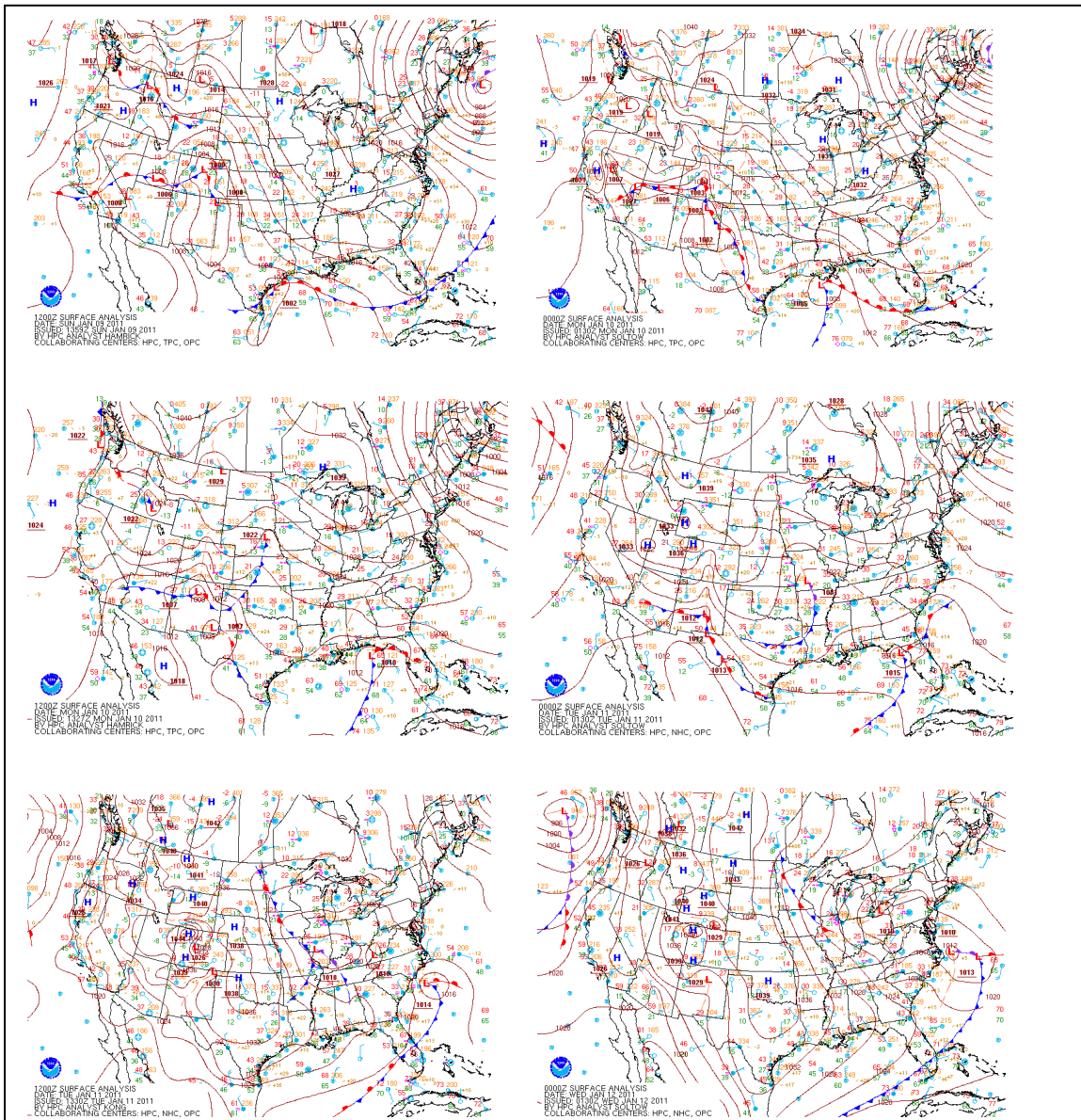


Fig. 2. NCEP/HPC Surface analyses. Top row: 1200 UTC 9 January 2011 and 0000 UTC 10 January 2011. Middle row: 1200 UTC 10 January 2011 and 0000 UTC 11 January 2011. Bottom row: 1200 UTC 11 January 2011 and 0000 UTC 12 January 2011.

When the surface low pressure center was near the Louisiana coast at 0000 UTC on 10 January, the associated upper-level trough was moving from the lower Mississippi River valley into the southeastern United States (Fig. 3). The 300 mb short wave trough extended from Arkansas to Louisiana, and a broad region of 700 mb upward motion was located just east of the trough axis. The 300 mb jet structure featured a 120 kt wind maximum over southwest Mississippi. The two upward motion maxima over Arkansas and near the Louisiana coast approximated the

classical pattern of upward motion in the front left and right rear quadrant of a linear wind maximum.

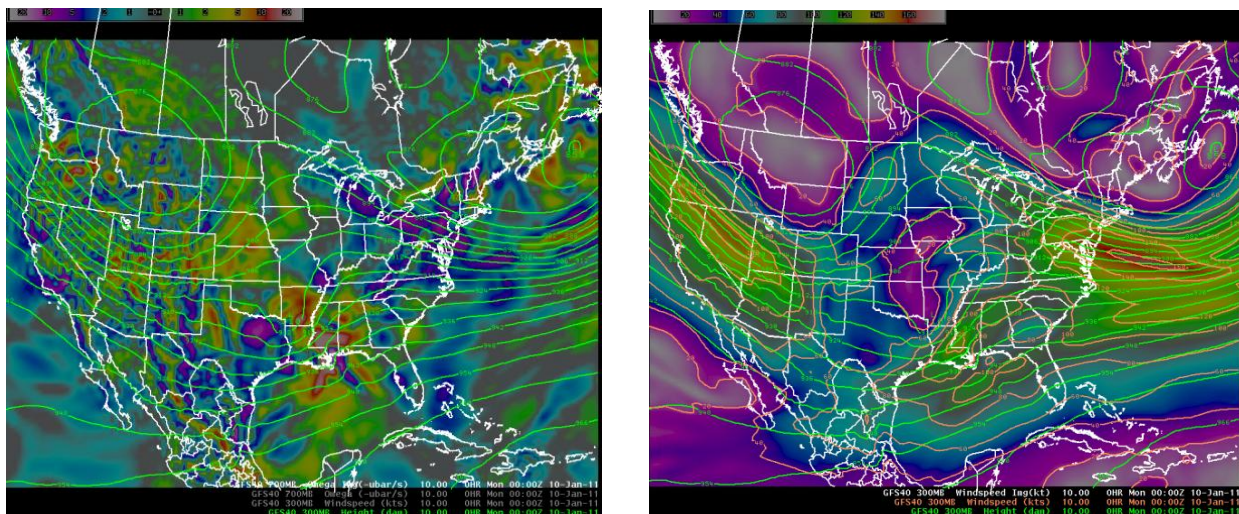


Fig. 3. 0000 UTC 10 January 2011 (Global Forecast System; GFS) analyses. Left panel: 300 mb height contours and 700 mb vertical motion (yellow and orange shades upward). Right panel: 300 mb height contours and 300 mb wind speed (brown contours and shades; higher speeds yellow and orange).

Prominent characteristics of the synoptic scale flow at 0000 UTC on 10 January were identified by examining several low- and mid-level quasigeostrophic (QG) diagnostic charts¹ (Fig. 4; Thaler and Nutter 2009).

A large area of precipitation (Fig. 5) was occurring at 0000 UTC in the region of upward motion and falling heights evident east of the trough on the diagnostic charts. The leading edge of the radar-detected precipitation was over the western portion of the GSP CWA, but much of the initial precipitation evaporated and sublimated in the dry air. After the lower atmosphere became moist allowing the hydrometeors to reach the ground, surface observations carried precipitation. The surface temperatures across the WFO GSP CWA were sufficiently cold to support freezing or frozen precipitation as the precipitation spread eastward (Fig. 6).

Even though surface temperatures were freezing or below, a key factor in determining precipitation type was the thermal structure of the layer between the precipitation-bearing clouds and the ground. Numerical model (Global Forecast System; GFS) analyses of the 0000 UTC 10 January vertical temperature profile at several locations (Anderson, Greenville-Spartanburg, Asheville, Charlotte, and Hickory) across the CWA provided a more detailed assessment of conditions as the precipitation approached (Fig. 7).

¹ The QG diagnostic charts allow one to focus on the large scale atmospheric features that force vertical motion while discounting smaller scale features that are either real (but nonetheless often important) or artifacts of the approximations and computational methods employed in numerical weather prediction models.

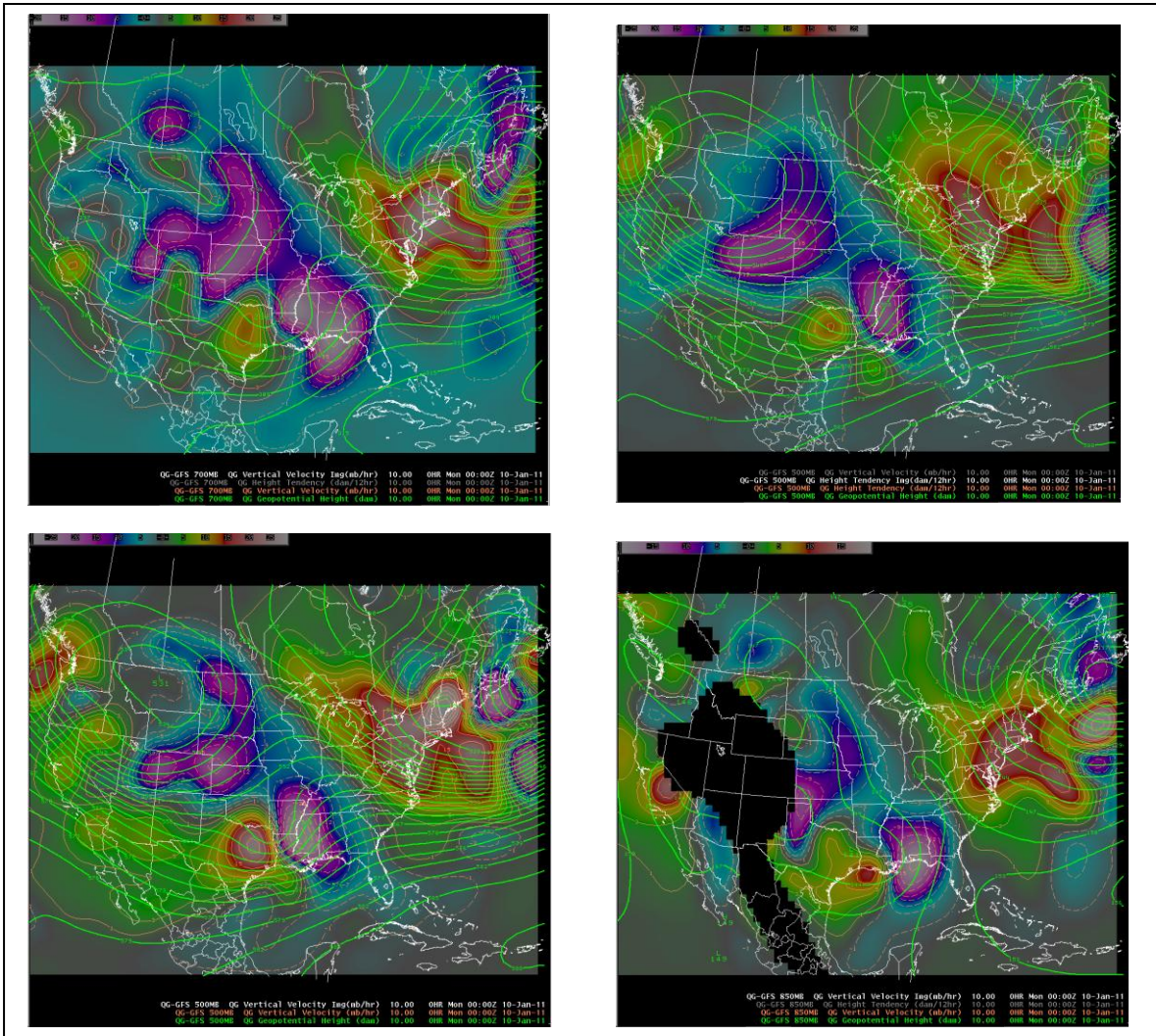


Fig. 4. Clockwise from upper left, 0000 UTC 10 January 2011 QG-GFS 700 mb height contours and vertical velocity, 500 mb height contours and height tendency, 850 mb height contours and vertical velocity, and 500 mb height contours and vertical velocity. Blue and purple shades denote upward motion on vertical velocity charts and height falls on the height tendency chart.

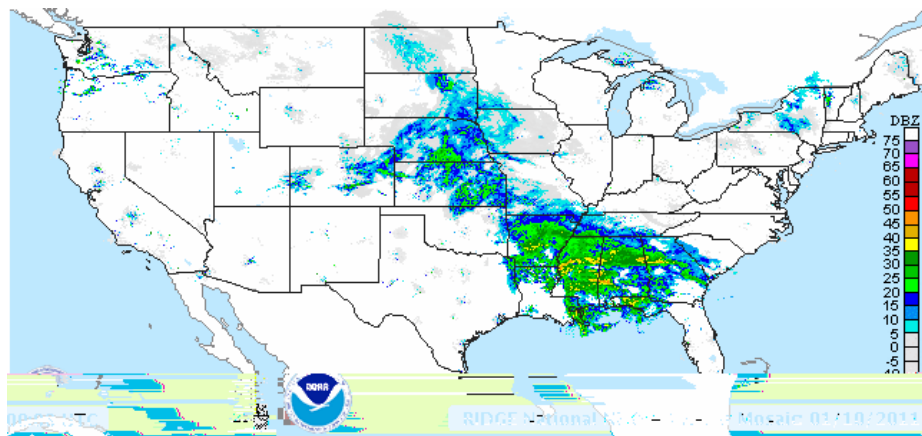


Fig. 5. National radar reflectivity mosaic at 0008 UTC on 10 January 2011 (NCDC).

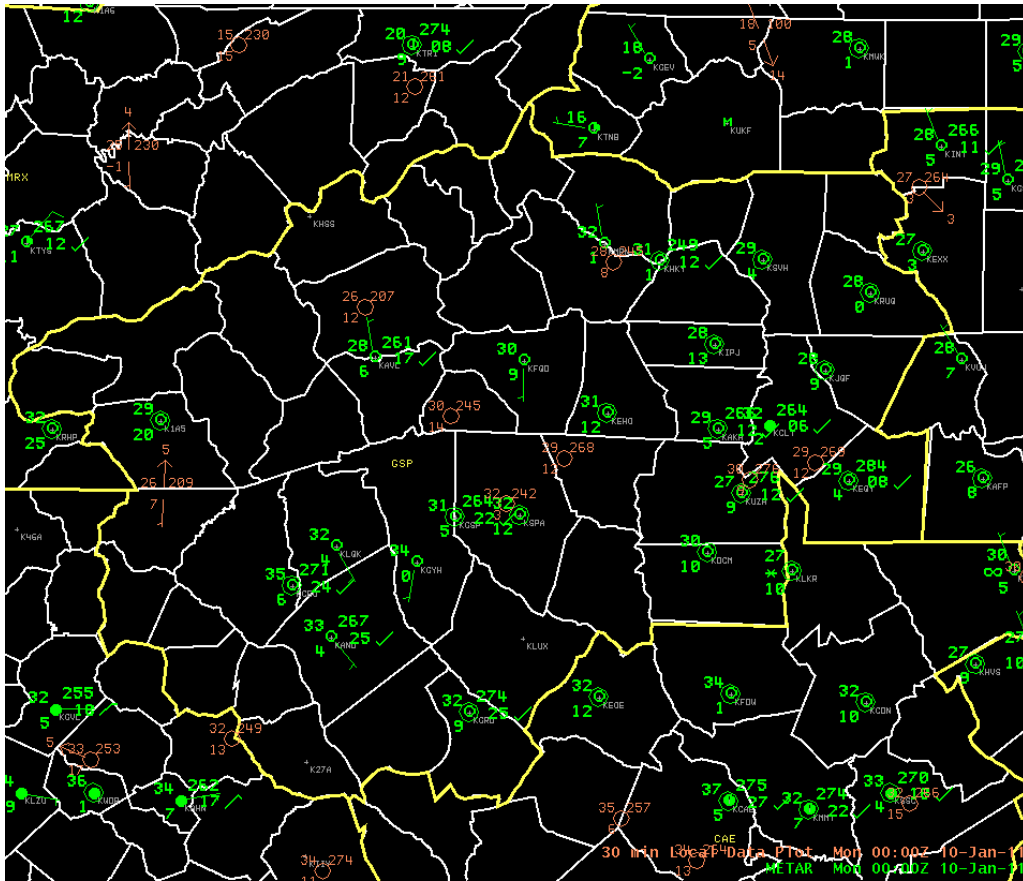


Fig. 6. Surface weather observations at 0000 UTC, 10 January 2011. Temperature is the upper left-hand number in each station plot. The WFO GSP CWA boundary is highlighted in yellow.

At each location, both the temperature and wet bulb temperature were 0°C or lower at the surface and aloft. The near-surface air was still relatively dry at 0000 UTC which would allow the temperature to lower to the wet bulb temperature unless warming due to a process such as advection occurred.

Significant warming in the lower levels of the atmosphere did not occur as the precipitation moved into the WFO GSP CWA. The upper-level ridge in the northern stream over the Midwest (Fig. 3) contributed to the strength of the surface high pressure system over the north central states which, in turn, held cold air in place from the Midwest into the mid-Atlantic states.

The temperature gradient between the cold air over the Carolinas and the warm air flowing northward east of the developing low pressure system created a strong frontal boundary. The surface manifestation of the boundary was the northern Gulf of Mexico warm front analyzed in Fig. 2. The front sloped upward toward the northeast providing a zone along which the west and southwest wind flow ascended. A vertical cross section from south of Louisiana to western Maryland depicted the frontogenetical forcing along the sloping front at 0600 UTC (Fig. 8).

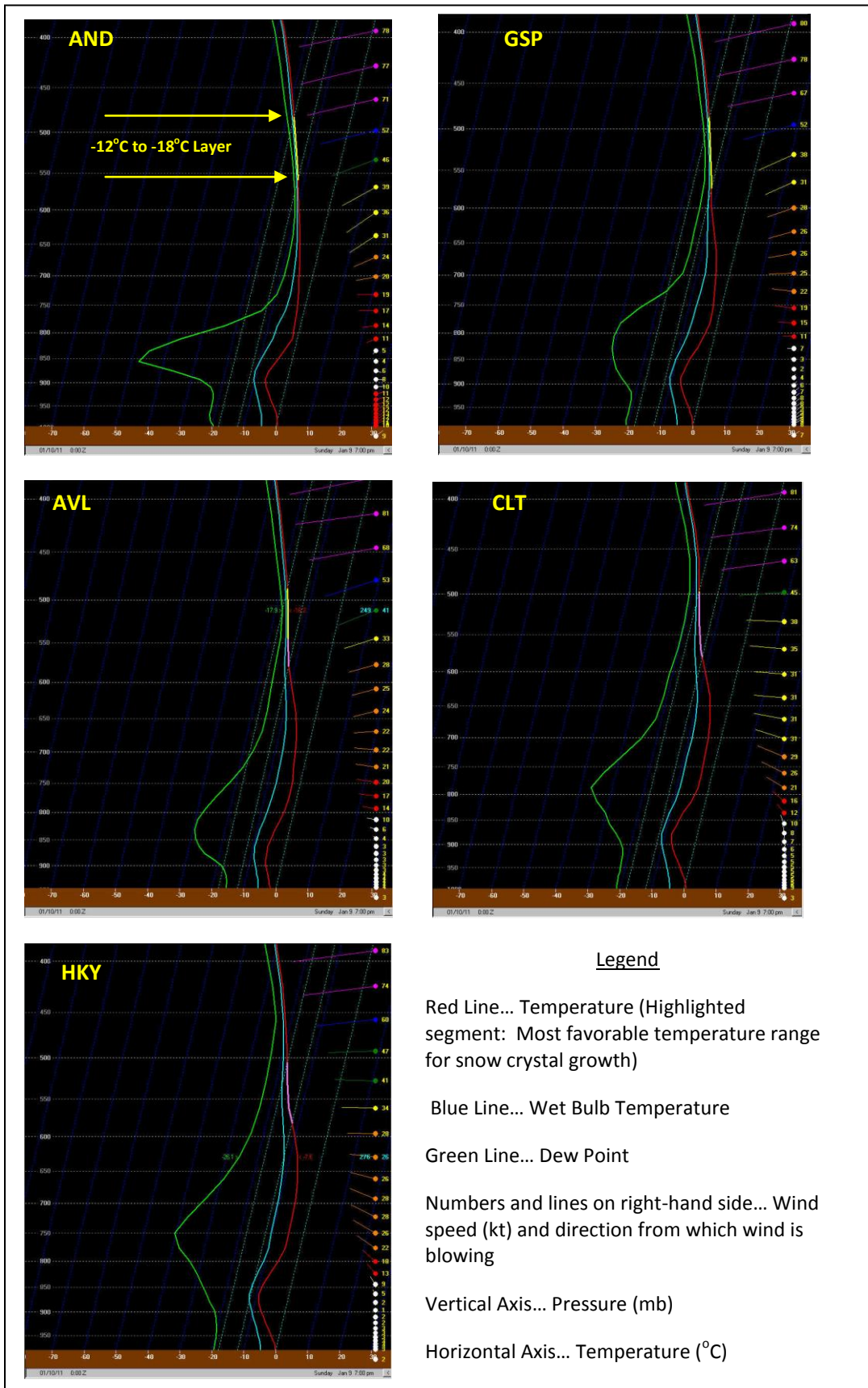


Fig. 7. GFS vertical temperature, moisture, and wind profiles for Anderson (AND), Greenville-Spartanburg (GSP), Asheville (AVL), Charlotte (CLT), and Hickory (HKY) at 0000 UTC, 10 January 2011.

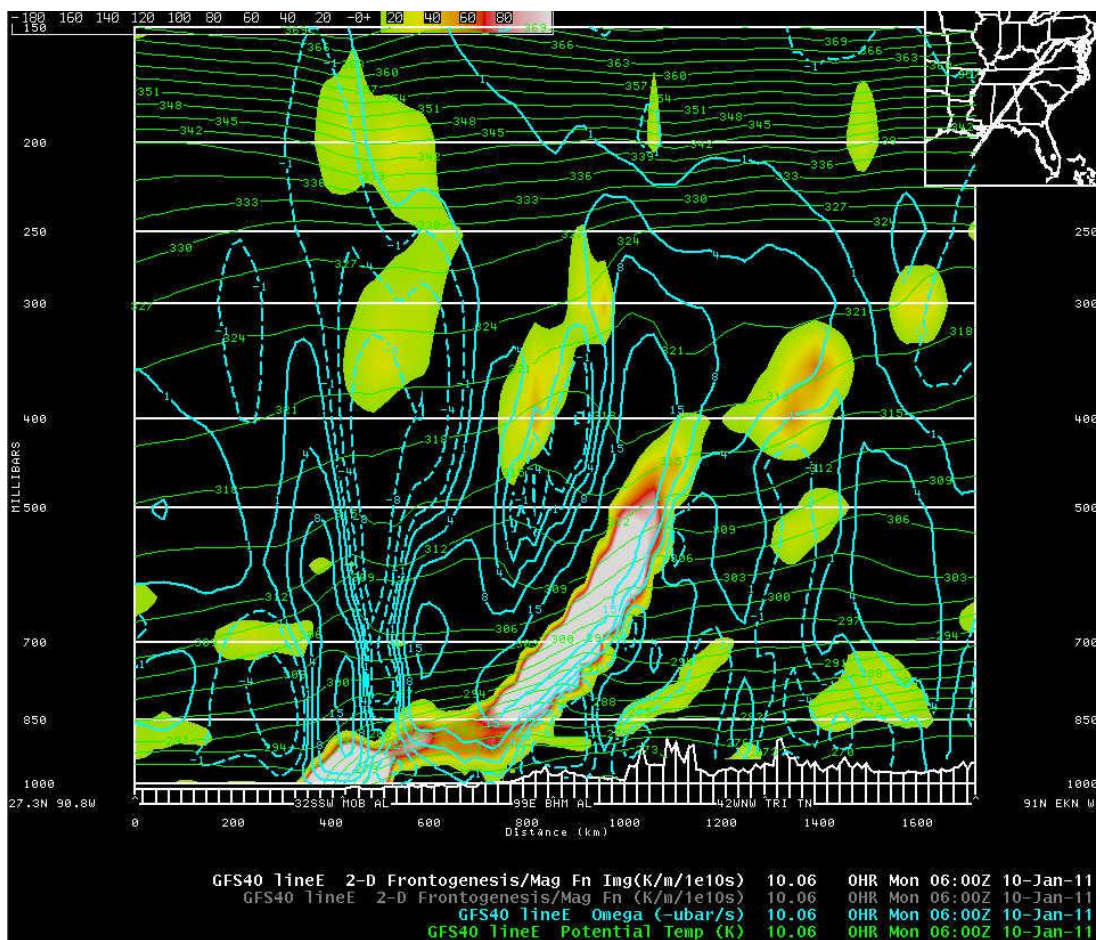


Fig. 8. GFS vertical cross section from south of Louisiana (left) to western Maryland (right) at 0600 UTC on 10 January 2011. Potential temperature (green contours), vertical motion (blue contours; solid lines upward), and frontogenetical forcing (color shades). Vertical axis: pressure in millibars. Horizontal axis: distance in kilometers.

The precipitation that moved into the extreme southwest portion of the CWA just before 0300 UTC on 10 January displayed radar characteristics frequently observed with strong frontogenetical forcing. The southeast to northwest oriented band of precipitation (Fig. 9) was aligned with the lower tropospheric thermal gradient, and it was in the zone of strong upward motion along the frontal boundary seen in the cross section (Fig. 8). The narrow, highly reflective bands over north Georgia probably owed their existence to the vertical motion maximum and highly reflective wet snowflakes and mixed precipitation.

As the low pressure system traveled across the Gulf Coast during the day causing the ascending warm, moist air to spread over the surface-based cold air, the precipitation expanded in areal coverage. The band of frontogenetically enhanced precipitation remained identifiable, but it gradually weakened with time. The more cellular precipitation elements that moved from Georgia into the Carolinas by the end of the event indicated the air mass was characterized by buoyant instability that promoted small-scale vertical motions (updrafts and downdrafts).

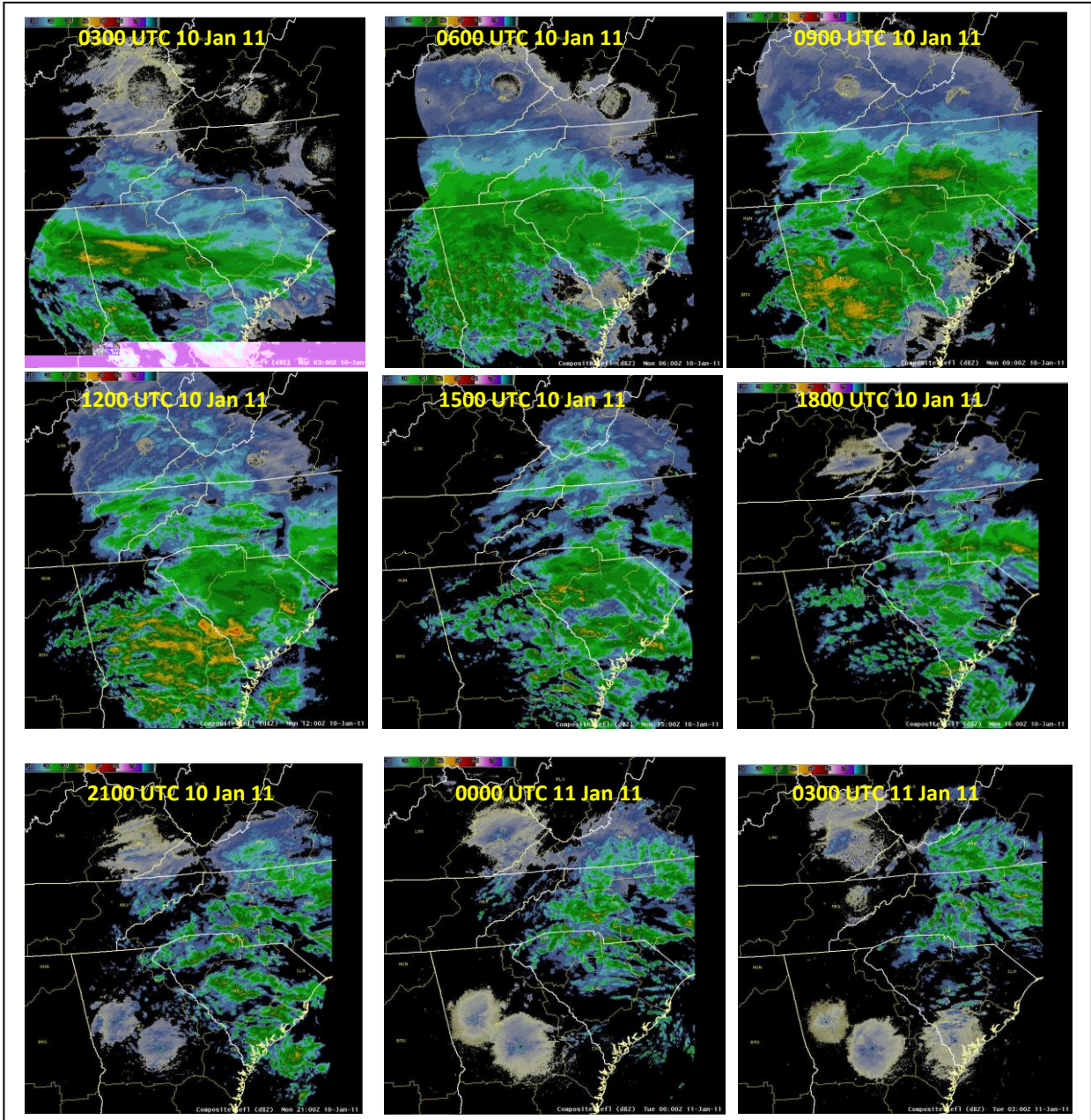


Fig. 9. Radar composite reflectivity mosaics from 0300 UTC 10 January 2011 to 0300 UTC 11 January 2011.

3. Precipitation

Snow began at approximately 0245 UTC on 10 January in the extreme southwest portion of the CWA. By 0700 UTC, the snow reached Anderson, Greenville-Spartanburg, and Asheville. The precipitation continued developing northward so that by 1100 UTC the snow covered virtually the entire area. The tables below provide a summary of hourly precipitation types at several observation sites.

Precipitation Type – 10-11 January 2011																
UTC	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
AND	OVC	-SN	-SN	-SN	-SN	SN	-SN	-SN	-SN	-SN	-SN	UP	-FZ RA	UP	UP	UP
GSP	OVC	OVC	-SN	+SN	SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN
AVL	OVC	OVC	-SN	SN	SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	BR	BR
CLT	OVC	OVC	OVC	OVC	-SN	SN	-SN	-SN	OVC	-SN	-SN	-SN	-SN	-SN	-SN	-SN
HKY	OVC	OVC	OVC	OVC	SN	SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN	-SN

OVC = Overcast -SN = Light Snow SN = Moderate Snow +SN = Heavy Snow -FZRA = Light Freezing Rain
-FZDZ = Light Freezing Drizzle UP = Unknown Precipitation BR = Mist

Precipitation Type – 10-11 January 2011													
UTC	21	22	23	00	01	02	03	04	05	06	>>>>	16	
AND	-SN	-FZRA	-FZRA	-FZRA	-FZRA	-FZRA	-FZRA	OVC	OVC	OVC	OVC	OVC	
GSP	-FZRA	FZRA	FZRA	FZ RA	FZRA	-FZ RA	-FZRA	-FZRA	-FZRA	OVC	OVC	OVC	
AVL	-SN	-SN	-SN	-SN	BR	-SN	OVC	OVC	OVC	OVC	OVC	OVC	
CLT	OVC	OVC	-FZRA	-FZDZ	-FZRA	-SN	-FZDZ	-FZDZ	-FZDZ	-FZDZ	-FZDZ	-FZDZ	
HKY	-SN	-SN	-FZRA	-FZRA	-SN	-SN	BR	BR	-FZRA	OVC	OVC	OVC	

OVC = Overcast -SN = Light Snow SN = Moderate Snow +SN = Heavy Snow -FZRA = Light Freezing Rain
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The heaviest precipitation occurred early in the event in conjunction with the passage of the frontogenetically forced band of enhanced precipitation. As the forcing weakened and the zone of heavy precipitation moved northward, the precipitation rates decreased and the coverage became less expansive.

The precipitation during the latter portion of the event changed to freezing rain except at Asheville where light snow persisted. Numerical model (GFS) vertical temperature and moisture profiles from Charlotte and Greenville-Spartanburg revealed a likely reason for the transition from snow to freezing precipitation (Fig. 10).

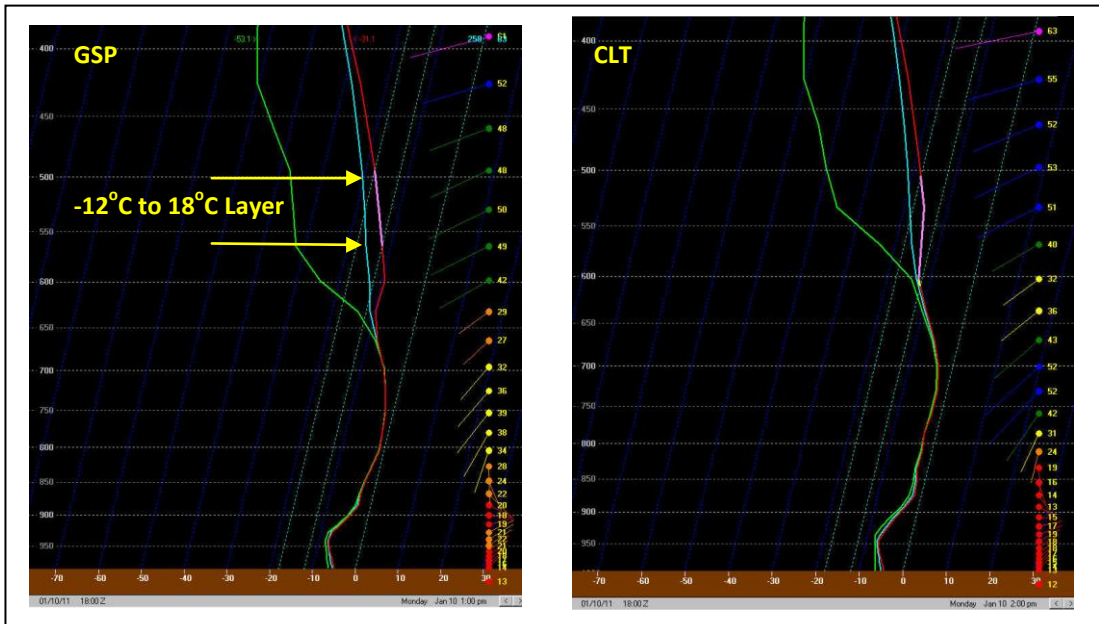


Fig. 10. Greenville-Spartanburg (GSP) and Charlotte (CLT) 1800 UTC 10 January 2011 GFS temperature, moisture, and wind profiles. Refer to the legend in Fig. 7.

Both the 1800 UTC 10 January 2011 GSP and CLT profiles showed nearly saturated air supporting the existence of precipitation below 600 to 650 mb (approximately 12,000 to 14,000 ft MSL). However, the atmosphere above that height dried significantly. Of particular importance was the drying in the layer containing the -12° to -18°C temperature range (the purple segment on the temperature profile in each panel of Fig. 10). That temperature range is the most favorable one for the formation of large dendritic ice crystals that become snowflakes. The sub 0°C , deep moist layer most likely could produce only light freezing rain and freezing drizzle because ice crystals were not introduced at the top.

A comparison of infrared satellite imagery and the depth of the moist layer as depicted by a numerical model (GFS) offered another perspective on the drying that occurred in the layer of the atmosphere where snowflake growth is most efficient (Fig. 11).

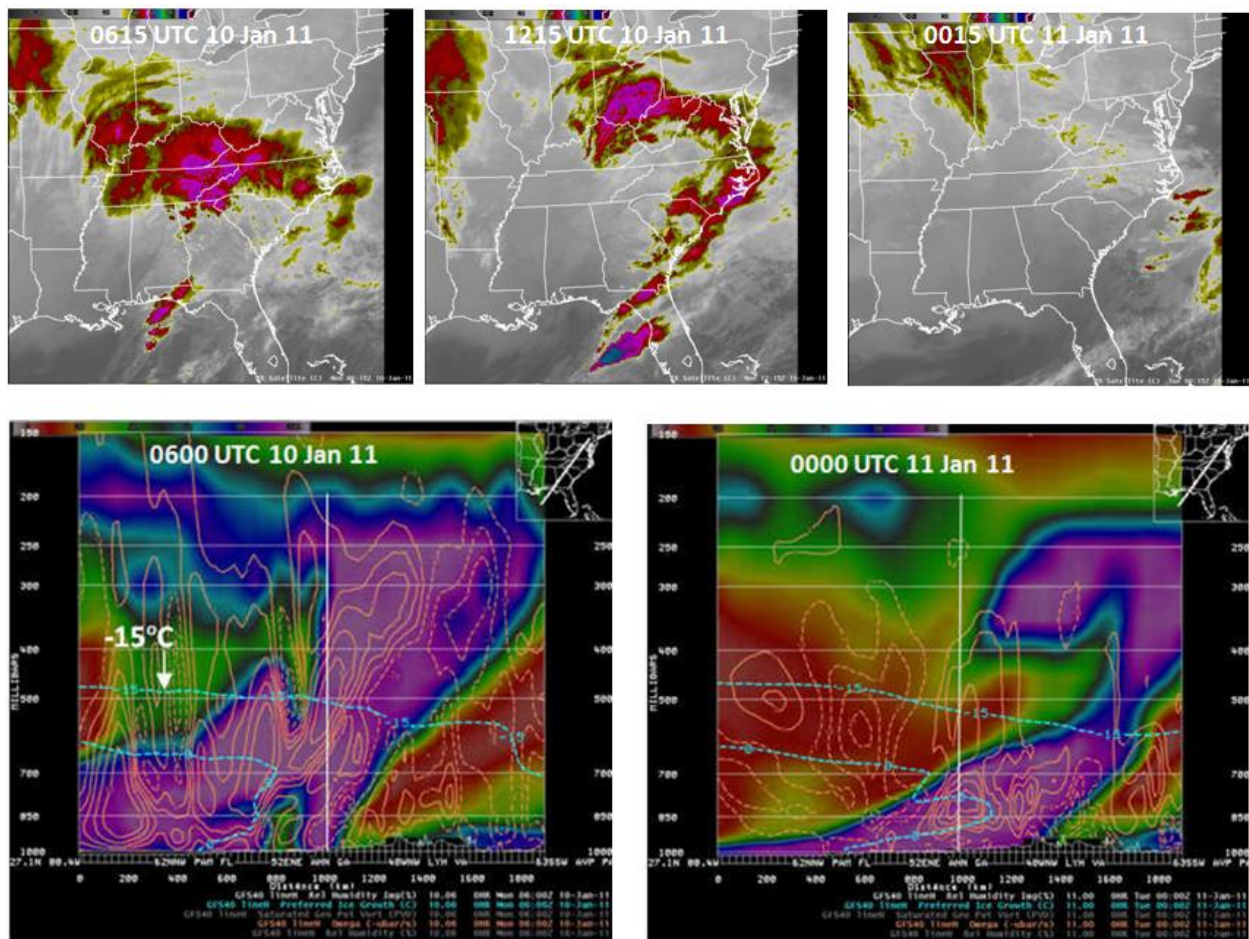


Fig. 11 Top row: IR satellite imagery at 0615 and 1215 UTC on 10 January 2011 and 0015 UTC on 11 January 2011. Gray to purple shades depict increasingly cold temperatures. Bottom row: GFS initial hour cross sections from northeastern Gulf of Mexico to Pennsylvania. Shades from red through yellow to purple represent increasingly high relative humidity. Orange contours are vertical motion (solid line is upward). Dashed blue contours are 0°C (lower) and -15°C (upper) isotherms. Vertical white line approximates the middle of the cross section in the WFO GSP CWA.

The three satellite images in Fig. 11 show the rapid warming in cloud top temperatures that occurred during the period. The dissipation of the comma cloud pattern and the loss of infrared cold enhancement were clear indications of a weakening system and lowering of cloud tops into the warmer lower troposphere. Initially, the deep moist layer with cold cloud tops was over the western Carolinas and northeast Georgia. During this time, snow developed across the CWA. The 0600 UTC cross section showed strong vertical motion in the moist layer extending into the -12°C to -18°C layer where dendritic ice crystal formation and growth are favored. By 0000 UTC on 11 January, the cross section indicated significant drying in the -12°C to -18°C layer. The satellite image at the same time showed relatively warm cloud tops. Without the introduction of ice crystals, the vertical motion in the relatively shallow moist layer was able to produce only liquid hydrometeors. Another factor inhibiting the production of frozen precipitation was the warm layer just above the surface spreading into the Carolinas from the southwest. The 0°C isotherm in the cross section panels of Fig. 11 identified the warm layer.

Even though freezing rain and freezing drizzle fell for a number of hours at many locations, widespread power outages did not occur because ice accumulations were not heavy enough to significantly affect trees and transmission lines. However, the freezing precipitation resulted in slippery roads and sidewalks thus compounding an already difficult travel situation caused by the snowfall.

4. Summary

A low pressure system traveled along the Gulf coast then curved northward along the Atlantic coast on 10 and 11 January 2011. Cold air existed over the Carolinas and extreme northeast Georgia thanks to a large high pressure system extending into the area from the north central United States. A large area of precipitation spread across the WFO GSP CWA as the low pressure system tracked south then east of the southern Appalachians. Snow was the dominant form of precipitation across the area, but drying aloft during the latter portion of the event resulted in a transition of precipitation types to light freezing rain and freezing drizzle. Snow accumulations ranged from six to twelve inches in the mountains and foothills and from one to six inches over the Piedmont.

Acknowledgments

Blair Holloway prepared the snowfall accumulation map using ArcView GIS. The surface analyses were provided by the NOAA/NCEP/Hydrometeorological Prediction Center. The national radar reflectivity mosaic was obtained from the NOAA/National Climatic Data Center.

REFERENCES

Thaler, E., and P. Nutter, 2009: Moving quasigeostrophic theory into the 21st century. Preprints, 23rd Conf. on Weather Analysis and Forecasting/19th Conf. on Numerical Weather Prediction, Omaha, NE, Amer. Meteor. Soc., 8B.3. [Available online at http://ams.confex.com/ams/23WAF19NWP/techprogram/paper_154276.htm]