The Pre-Frontal Snow in Western North Carolina on 12 December 2010

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1. Introduction

During the morning of Sunday, 12 December 2010, a synoptic pattern not commonly associated with snow produced accumulations of several inches in the North Carolina mountains and foothills. A prefrontal band of precipitation moved across the southern Appalachians leaving in its wake accumulations of two to four inches with a maximum of eight inches (Fig. 1). Typically, widespread accumulating snow in western North Carolina occurs during a cold air damming event in tandem with a surface low pressure system that tracks across the Gulf Coast region and southern Georgia to the Atlantic Ocean. Northwest flow snow events can result in substantial snowfall, but those accumulations are generally limited to the Tennessee border counties.

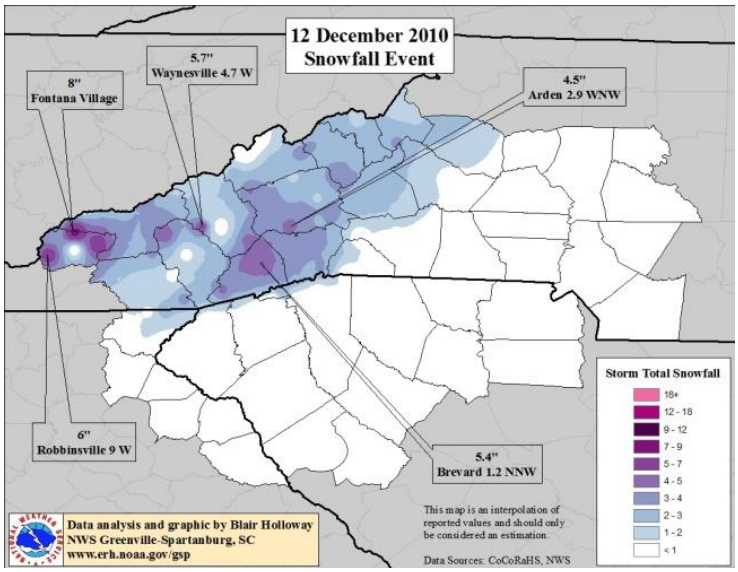

Fig. 1. Snowfall on 12 December 2010

2. Synoptic Setting

At 0000 UTC on 12 December, an occluded front was approaching the southern Appalachians from the west (Fig. 2). The front extended from a low pressure center near the Wisconsin-Illinois border south to another low over the Mississippi-Alabama border. A nearly stationary front stretched from the Mississippi-Alabama low to south Georgia. A weak low pressure system was located near Myrtle Beach, South Carolina. A band of precipitation along and ahead of the occluded front extended from Lake Michigan to eastern Kentucky then southwest through middle Tennessee into Mississippi.

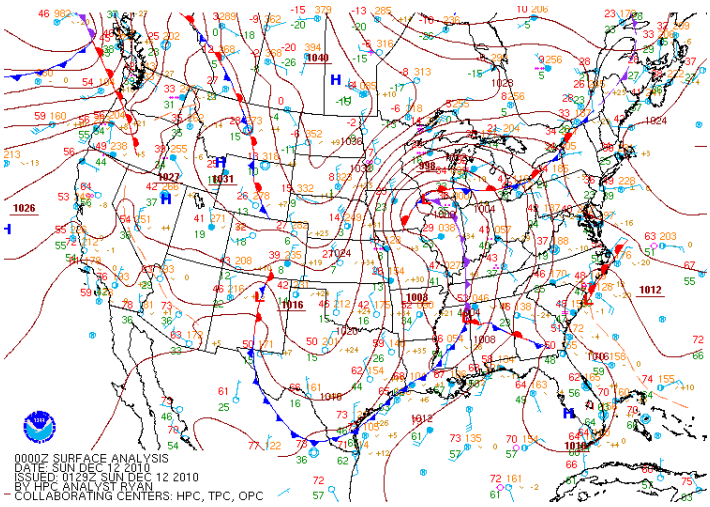

Fig. 2. NCEP/HPC surface analysis at 0000 UTC, 12 December 2010.

The 500 mb analysis at 0000 UTC featured a cutoff low over Iowa and Missouri with a trough axis south to Louisiana (Fig. 3). A broad southwest flow existed across the southern Appalachians. A 90 kt wind maximum over north Texas was approaching the base of the trough.

The 850 mb low was centered over southeast Iowa (Fig. 4). A weak trough extended from the western Carolinas to near Charleston, South Carolina. A 50 to 70 kt wind maximum stretched from Nashville, Tennessee, to Jackson, Mississippi. The wind maximum coincided with an axis of relatively warm (+6° to +10° C) air that was streaming northeastward ahead of the advancing surface front. At 850 mb, the temperature over western North Carolina was above 0° C. The 0000 UTC surface temperatures at Asheville, Morganton-Lenoir, and Hickory were 39° F, 43° F, and 44° F, respectively.

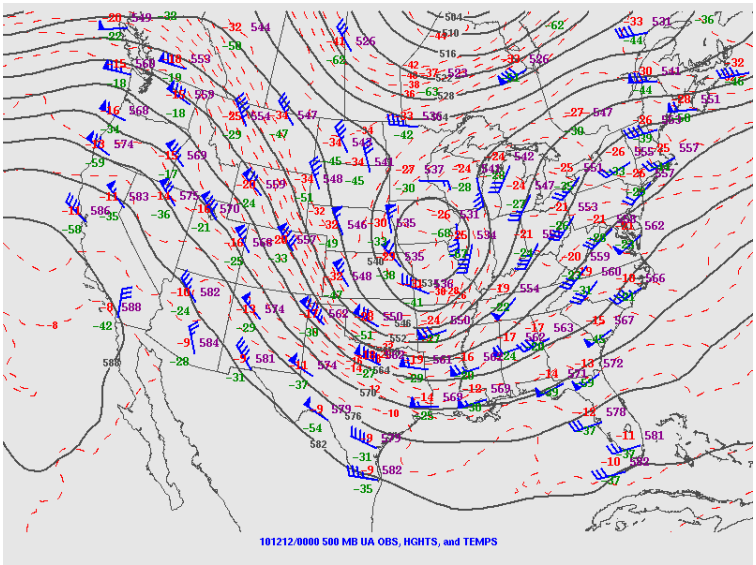

Fig. 3. NCEP/SPC 500 mb analysis at 0000 UTC, 12 December 2010

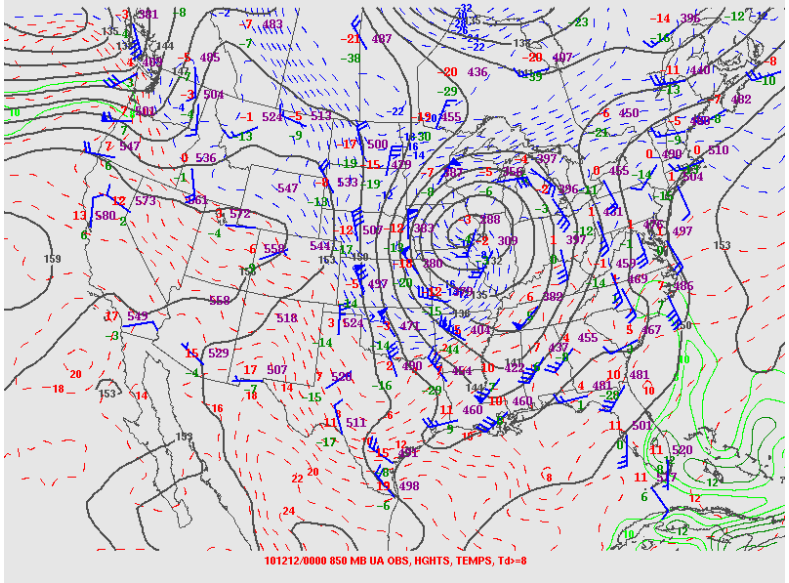

Fig. 4. NCEP/SPC 850 mb analysis at 0000 UTC, 12 December 2010

Figure 5 provided a more detailed view of the near-surface conditions just prior to the onset of precipitation in the mountains. The analysis depicted the surface pressure pattern, radar reflectivity, and surface temperatures 40° F and lower. The analysis indicated the absence of subfreezing surface temperatures in the western Carolinas. The weak low near the Carolina coast caused some precipitation from the Coastal Plain north to Chesapeake Bay, but this system did not affect the southern Appalachians. The surface pressure pattern also revealed a weak ridge of high pressure extending from the northeastern states into North Carolina, but its influence as a source of low-level cold air was minimal. The high receded and weakened as the occluded front moved east.

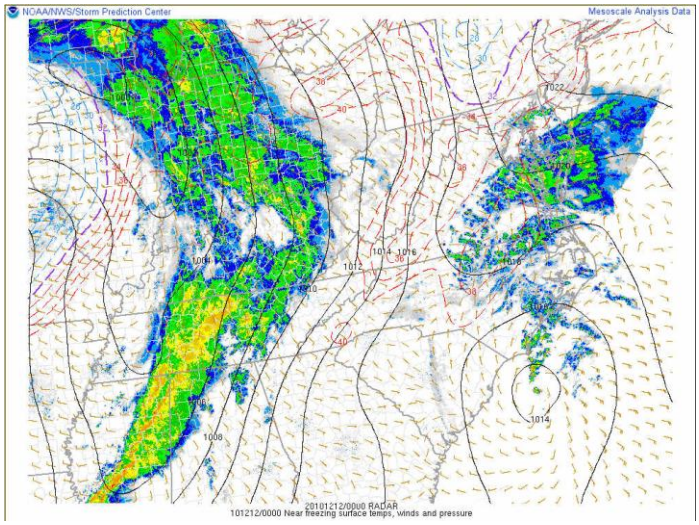

Fig. 5. NCEP/SPC 0000 UTC 12 December 2010 mesoscale analysis of surface pressure, radar reflectivity, and surface temperature 40° F and lower.

Vertical temperature profiles at 0000 UTC were representative of the conditions that existed in the mountain valleys (Asheville) and northern foothills (Hickory) prior to the arrival of the precipitation (Fig. 6). The temperature at Asheville was above freezing in the lowest 3,000 to 4,000 ft. The temperature at Hickory was above freezing in the lowest 5,000 ft. The relatively dry air at Asheville, indicated by the temperature-dew point difference of 10 to 20 degrees (C), resulted in a subfreezing wet bulb temperature profile through a relatively deep surface-based layer. The Hickory wet bulb temperature profile was near or below freezing, although the "nose" of higher dew point near 2,500 ft indicated a moist layer with the potential to minimize evaporative cooling.

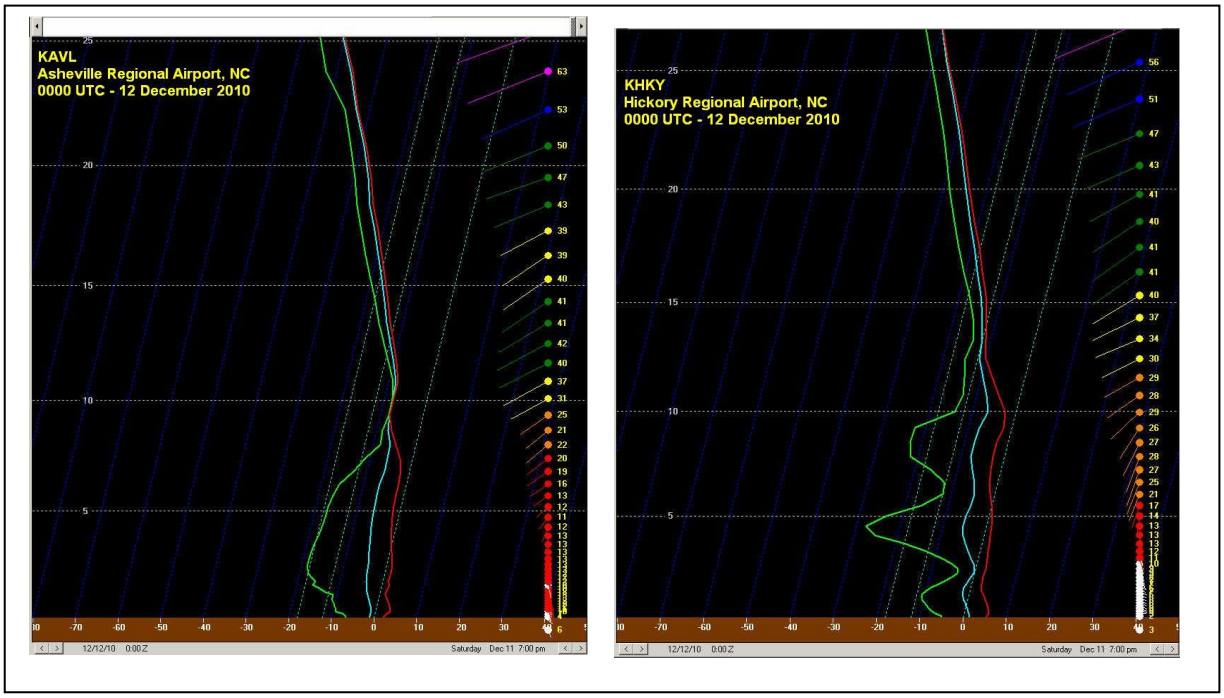

Fig. 6. NAM 0000 UTC 12 December 2010 vertical profiles of temperature (red), wet bulb temperature (blue), and dew point temperature (green) at Asheville Regional Airport (KAVL; left) and Hickory Regional Airport (KHKY; right).

The SPC 0000 UTC 850 mb mesoscale analysis (Fig. 7) provided a more detailed look at characteristics of this pressure surface than is discernible in Fig. 4. A small area of less than 0° C temperatures was over western North Carolina. The vertical profiles of temperature and dew point at both Asheville and Hickory indicated that evaporational cooling caused by the precipitation moving in from the west had the potential to lower the temperature to near or below freezing not only at 850 mb, but at nearly all levels above the surface. However, the 850 mb wind and temperature patterns indicated that warm advection could result in warming of the lower atmosphere coincident with the arrival of the precipitation.

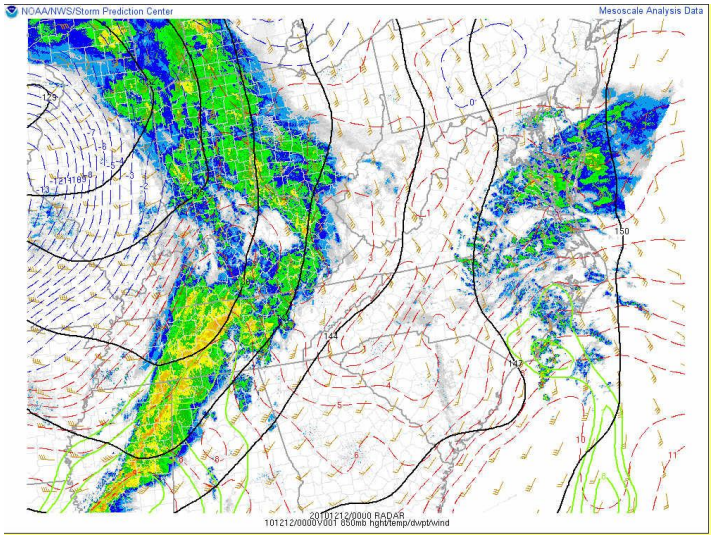

Fig. 7. NCEP/SPC 0000 UTC 12 December 2010 850 mb mesoscale analysis. Height contours (black), isotherms (dashed blue 0°C and below; dashed red above 0°C), and WSR-88D reflectivity are shown.

3. Event Overview

The prefrontal precipitation moved into far western North Carolina at approximately 0600 UTC on 12 December 2010 (Fig. 8). The precipitation progressed steadily eastward before moving out of the foothills into the Piedmont late in the morning. Snow was the predominant precipitation type in the mountains. A mixture of rain and snow was reported at a number of sites, especially in the foothills.

Fig. 8. WSR-88D reflectivity mosaic at 0602 UTC (left), 0859 UTC (middle), and 1200 UTC (right) on 12 December 2010.

The table on the next page provides a summary of weather observations at three sites in western North Carolina. The occurrence of measurable snow even though above freezing surface temperatures existed at the onset of precipitation can be explained, at least in part, by examining the vertical profiles of temperature, dew point temperature, and wet bulb temperature. The profiles in Fig. 6 (six to eight hours before precipitation began in the mountains) indicated that evaporative cooling had the potential to lower the temperature to subfreezing. The 0600 UTC Asheville and Hickory profiles in Fig. 9 showed a thermodynamic environment similar to the one six hours earlier, although the dew point temperature was increasing in advance of the approaching precipitation.

Hourly Weather Observations – 12 December 2010												
Time UTC	**Asheville** (elevation: 2165 ft)				**Morganton-Lenoir** (elevation: 1270 ft)				**Hickory** (elevation: 1190 ft)			
	T	T_d	T_{wb}	Pcpn	T	T_d	T_{wb}	Pcpn	T	T_d	T_{wb}	Pcpn
0600	37	19	30		39	27	34		39	32	36	
0700	37	19	30		39	30	35		39	33	36	
0800	35	22	30	-SN	37	32	35		38	34	36	
0900	31	29	30	-SN	37	32	35		37	34	36	BR
1000	31	30	31	SN	36	34	35	RA	37	35	36	-RA
1100	31	30	31	-SN	34	34	34	UP	37	36	37	RA
1200	31	30	31	-SN	34	34	34	-SN	37	35	36	-RA
1300	32	31	32		34	34	34	-SN	37	36	37	-RA
1400	32	32	32		34	34	34	-SN	36	35	36	
1500	35	33	34		34	34	34	-SN	34	33	34	+RA
1600	35	33	34		34	34	34		35	34	35	-RA
1700	36	33	35		34	34	34		37	36	37	
T = Temperature; T_d = Dew Point Temperature; T_{wb} = Wet Bulb Temperature; Pcpn = Precipitation Type												
-SN = Light Snow; SN = Moderate Snow; -RA = Rain; RA = Moderate Rain; +RA = Heavy Rain; UP = Unknown Precipitation Type												
Asheville and Hickory observations made by ASOS (Automated Surface Observing System)												
Morganton-Lenoir observations made by AWOS-3 (Automated Weather Observing System)												

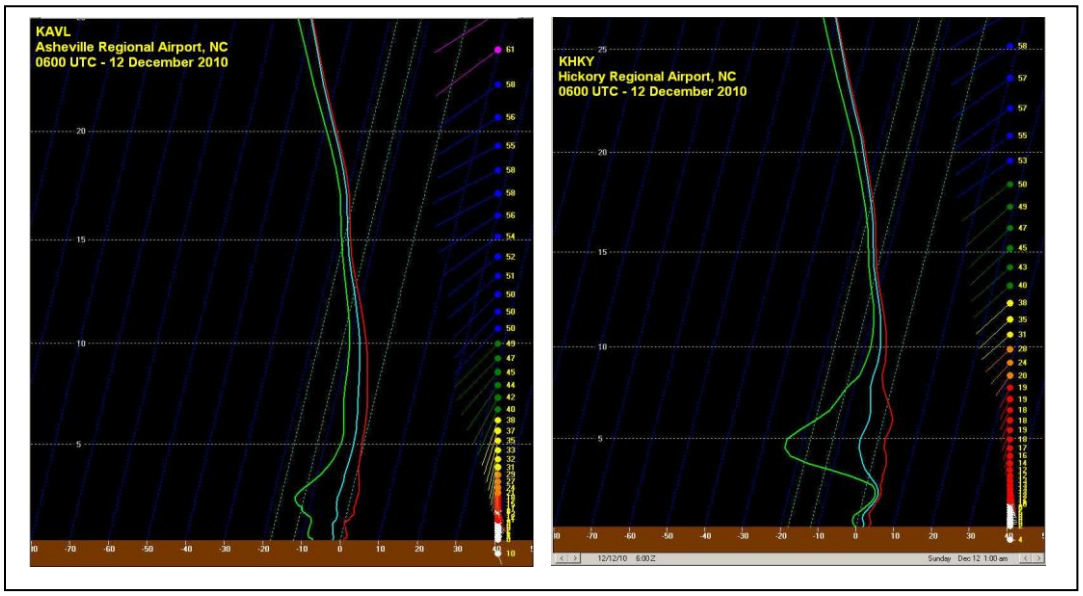

Fig 9. Same as Fig. 6 except at 0600 UTC

Even though the 0600 UTC Asheville profile detected increasing moisture, it still indicated that evaporational cooling had the potential to lower the near-surface above-freezing temperatures to values near or below freezing. Indeed, this appears to be what happened because light snow began at 0654 UTC. The surface temperature at the onset of precipitation was 35° F, but it

lowered to 32° F by 0715 UTC. The temperature at Asheville quickly lowered to the near-freezing wet bulb temperature at the onset of snow and remained nearly steady until warming slightly when the precipitation ended (Fig. 10).

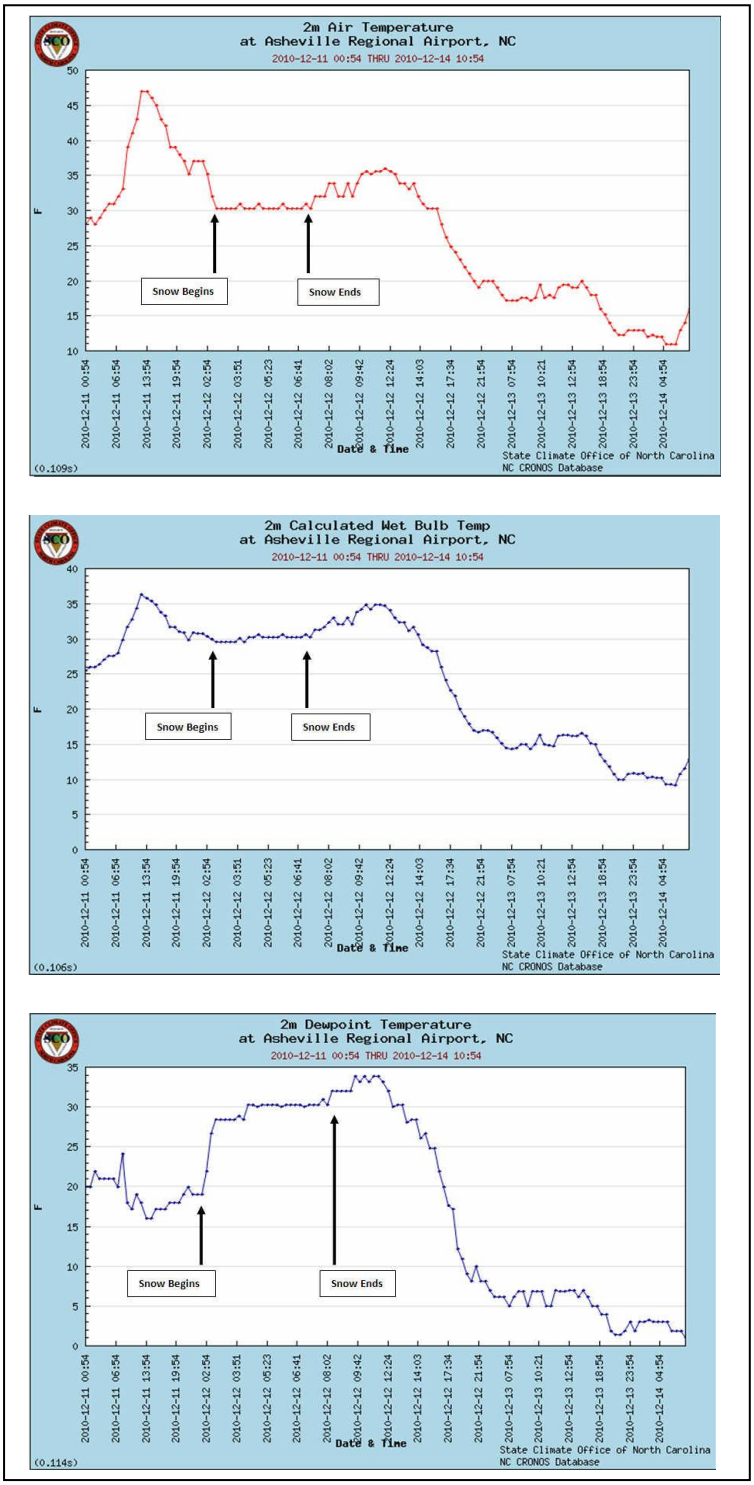

Fig. 10. Graphs of Asheville temperature (top), wet bulb temperature (middle), and dew point temperature (bottom) from 11 December 2010 to 14 December 2010. Arrows denote beginning and ending of snow. Graphs from North Carolina State Climate Office.

The Hickory profile at 0600 UTC revealed that the moist "nose" identified at 0000 UTC persisted and the moisture increased. This occurrence resulted in a wet bulb temperature several degrees above freezing 1,000 to 2,000 feet above the surface. When the precipitation reached Hickory at 0951 UTC, rain (possibly mixed with a few pellets of sleet) began and continued until the precipitation ended later in the morning. The warm layer near the surface apparently melted snow falling from the colder air above thus producing liquid precipitation at the surface. The warm layer at Morganton-Lenoir (approximately 12 nm northwest of Hickory) was not as warm nor as deep because snow was the predominant precipitation type after beginning as rain. The surface temperature at Morganton-Lenoir never dropped below 34° F. The surface-based warm layer did not contain enough heat to melt the snow.[1]

The vertically pointing RENCI[2] MicroRain Radar located at Newton, North Carolina (approximately 10 miles southeast of the Hickory Regional Airport), showed a maximum reflectivity at around 1100 UTC/0600 EST (top panel, Fig. 11). The fall velocity of precipitation particles (bottom panel, Fig. 11) showed a transition between blue shades (fall velocity of 1 to 2 m sec^{-1}, commonly associated with snow) and green, yellow, and red shades which indicated an increase in fall speed after the snow changed to rain. The melting layer near the onset of precipitation was about 5,000 ft, but it lowered quickly to approximately 2,500 ft. The lowering of the snow level was probably caused by evaporational cooling in the dry layer seen in the 0600 UTC Hickory profile (Fig. 9). The downward trend of the snow level was halted near 2,500 ft because of the relatively warm and moist layer evident at the same altitude in the 0600 UTC Hickory profile. The highly reflective precipitation coincided with the period during which the snow level was at its lowest. More than likely, melting snowflakes covered with water contributed to the high reflectivity.

4. Thermodynamic Environment

The occurrence of snow in a near-surface environment featuring above freezing temperatures at the onset of precipitation focuses attention on a fundamental, yet complex, aspect of forecasting. The various dynamic and thermodynamic components of the temperature forecast process can be summarized in the following plain language equation:

Local temperature change = Horizontal temperature advection + Temperature change due to vertical motion + Effects of non-adiabatic temperature change

Horizontal temperature advection is the change in temperature caused by the horizontal wind blowing across a horizontal temperature gradient.

Temperature change due to vertical motion is caused by the vertical wind blowing across a vertical temperature gradient.

Non-adiabatic temperature changes are caused by processes that occur when an air parcel interacts with its environment (e.g., heating caused by condensation, cooling caused by evaporation, heating by absorbing warmth from the ground). This is in contrast to adiabatic processes which are the result of work done on the air parcel (heating caused by compression, cooling caused by expansion).

[1] Surface temperatures are observed five to six feet above the ground. It is likely that melting at the actual ground surface lowered the air temperature to 32° F which allowed the snow to accumulate.
[2] Renaissance Computing Institute (http://www.renci.org/)

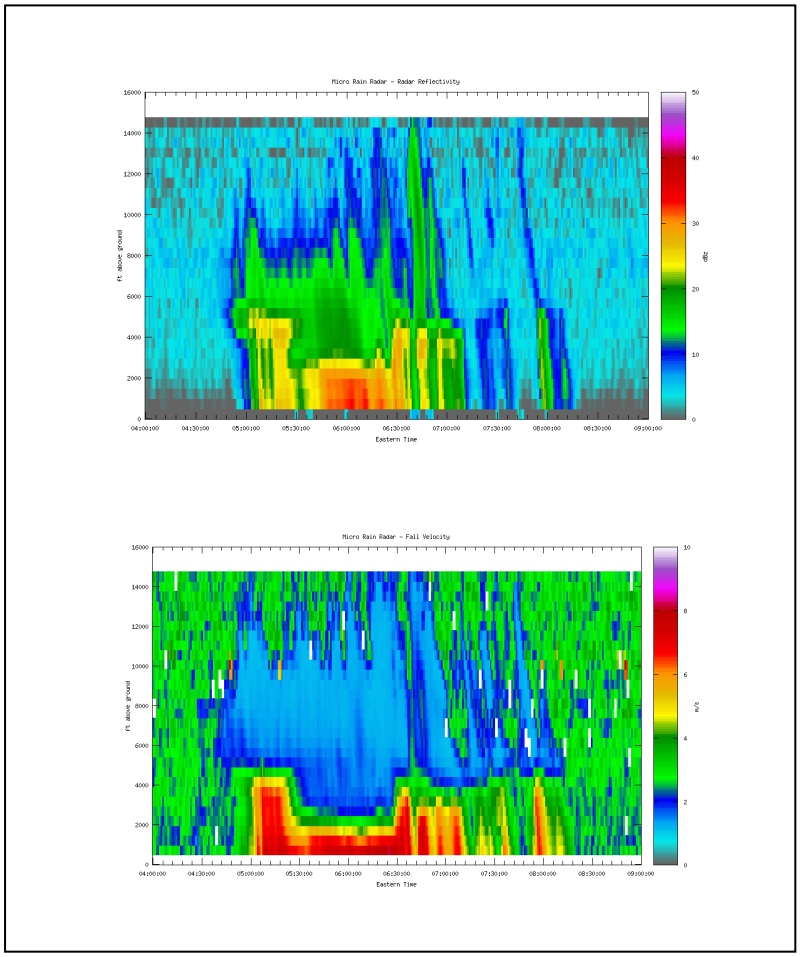

Fig. 11. RENCI MicroRain Radar reflectivity (top) and fall velocity (bottom) at Newton, NC on 12 December 2010. Time advances from left (0900 UTC/0400 EST) to right (1400 UTC/0900 EST). The vertical axis in both images is feet above ground. The reflectivity scale ranges from 0 dBZ to 50 dBZ. The fall velocity scale ranges from 0 m/sec to 10 m/sec.

The various terms in the equation have different degrees of influence and different signs (positive or negative) in each and every precipitation event. It seems likely that the third term (non-adiabatic temperature change) played a pivotal role during the western North Carolina snow event on 12 December 2010. When the precipitation moved into the mountains and precipitation fell into the drier low-level air, the dry bulb temperature lowered to the wet bulb temperature which was near or slightly below freezing. Thus, snow which formed in the colder air aloft was able to reach the surface.

The roles of horizontal temperature advection and temperature advection due to the vertical wind in this case cannot be discounted. However, a subjective evaluation of the weather pattern leads one to believe that they were not sufficiently strong to counter the effects of the third term (non-adiabatic temperature changes -- in this case, cooling caused by evaporation). The warm advection pattern evident at 850 mb (Fig. 7) and in the southwest winds in the Asheville profiles (Figs. 6 and 9) could not overcome the other factors, primarily evaporational cooling, that determined the temperature characteristics of the lower atmosphere. Certainly, a more rigorous study is justified to examine the details of the thermal environment.

5. Summary

A pre-frontal band of precipitation moved across western North Carolina during the morning of 12 December 2010. Snow was the predominant form of precipitation in the mountains and portions of the foothills. Accumulations were generally in the two to four inch range with local amounts as high as eight inches. This event was unusual in that accumulating widespread snow fell in a band of precipitation ahead of an approaching occluded front. Warm air advection ahead of cold fronts or occluded fronts moving toward the Carolinas typically results in above-freezing temperatures that will cause precipitation to be liquid except, perhaps, in the higher elevations. In this case, sufficient low-level dry air existed to cause evaporational cooling that produced a vertical thermal structure featuring near or below freezing temperatures which allowed snow to reach the surface.

Acknowledgments
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