The Northwest Flow Snow Event of 11 February 2012

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1. Introduction

Following the passage of a cold front on 11 February 2012, snow developed across the mountains of western North Carolina as low-level moisture in the northwest flow was lifted over the higher terrain. Snowfall accumulations ranged from a trace to 9 inches.

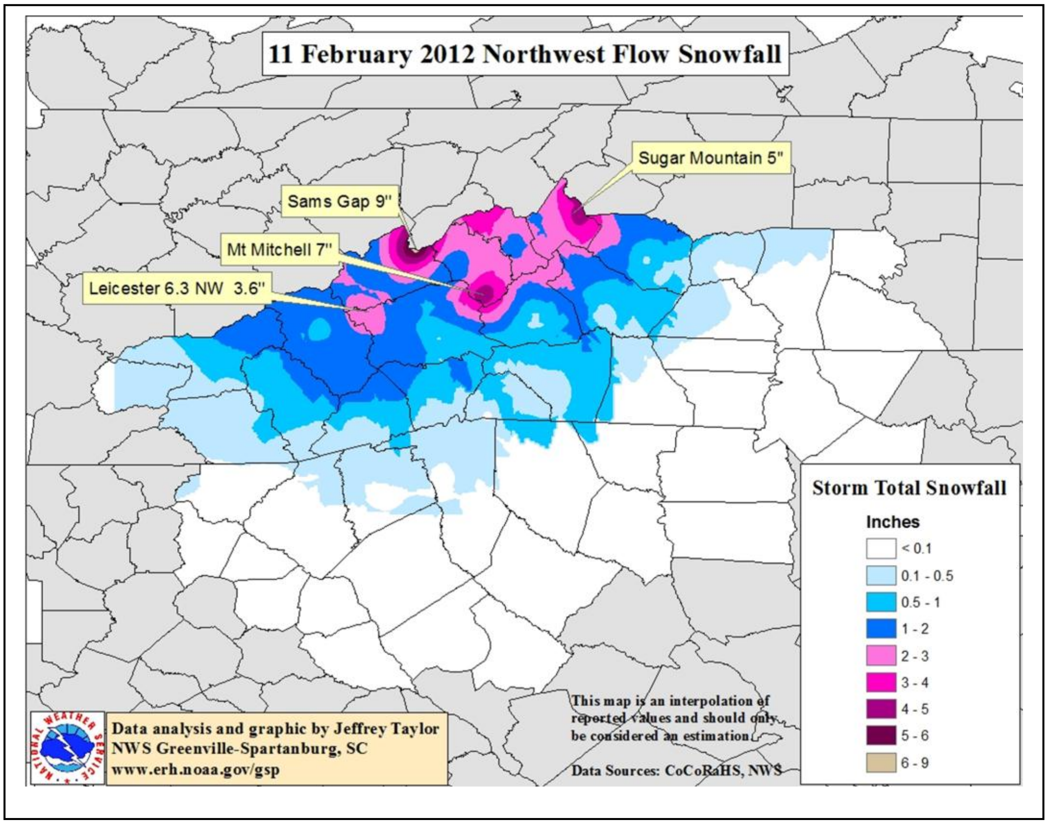
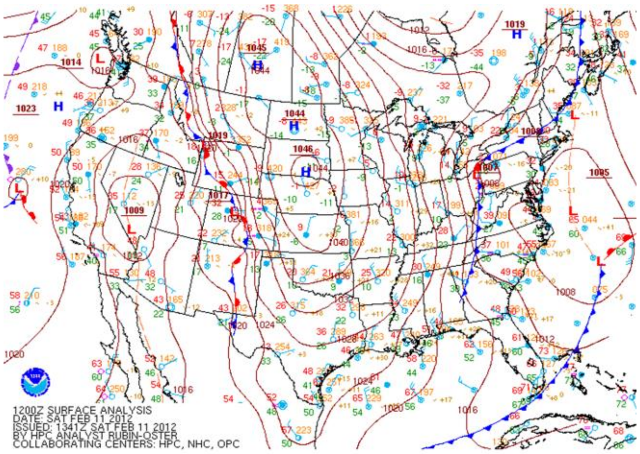


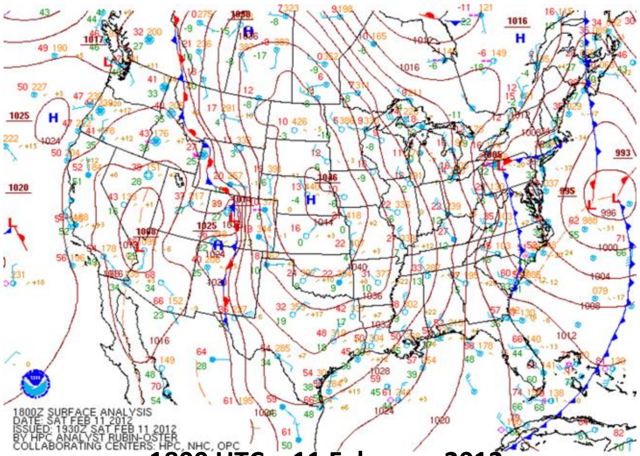
Fig. 1. Snowfall on 11 February 2012 across the County Warning Area of the Greenville-Spartanburg National Weather Service office.

2. Surface and Upper Air Features at 1200 UTC on 11 February

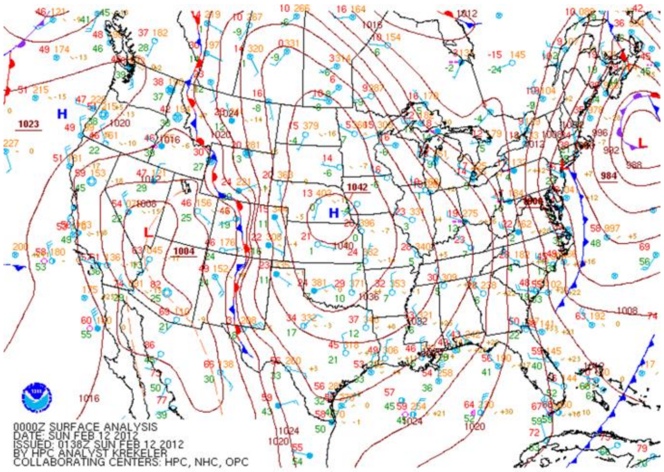
A front representing the leading edge of a very cold air mass over the central United States moved into the western Carolinas and extreme northeast Georgia at approximately 1200 UTC on 11 February 2012. The cold front moved steadily eastward reaching the coastal plain and coastal area during the afternoon (Fig. 2).



1200 UTC – 11 February 2012



1800 UTC – 11 February 2012



0000 UTC – 12 February 2012

Fig. 2. Hydrometeorological Prediction Center surface analyses.

The strength of the front was evident in the tight temperature gradient in the 925 mb and 850 mb 1200 UTC analyses (Fig. 3). The strong northwest wind following the frontal passage contributed to rapid cold air advection that caused rapidly falling temperatures across the mountains – even during the daytime when boundary layer warming typically occurs (Fig. 4).

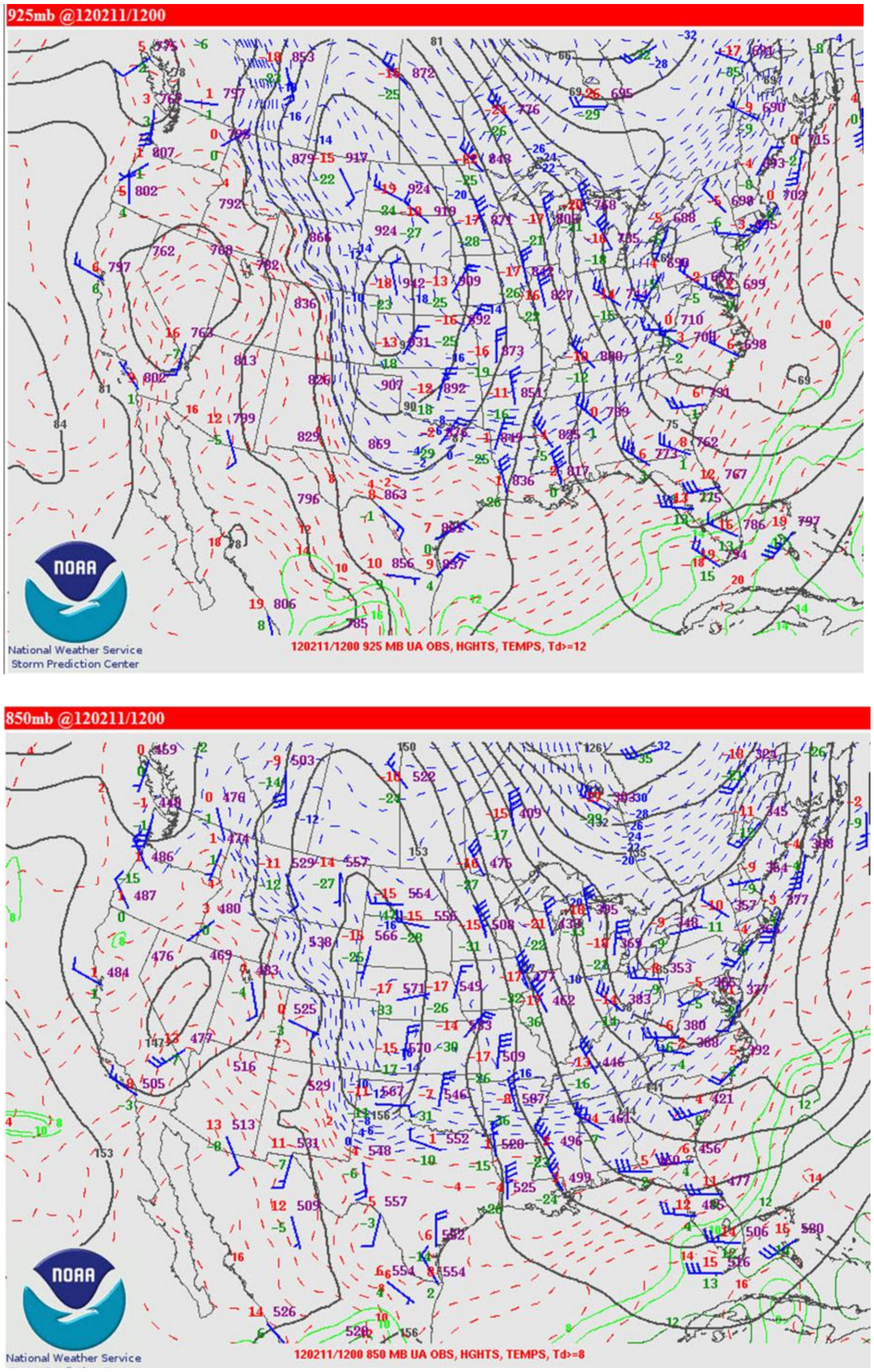


Fig. 3. Storm Prediction Center 925 mb analysis (top) and 850 mb (bottom) at 1200 UTC on 11 February 2012. Geopotential height (dm; solid contours), wind (kt; flags), temperature (^{o}C; dashed contours); dew point ≥ 12 ^{o}C at 925 mb and ≥ 8 ^{o}C at 850 mb (solid green contours).

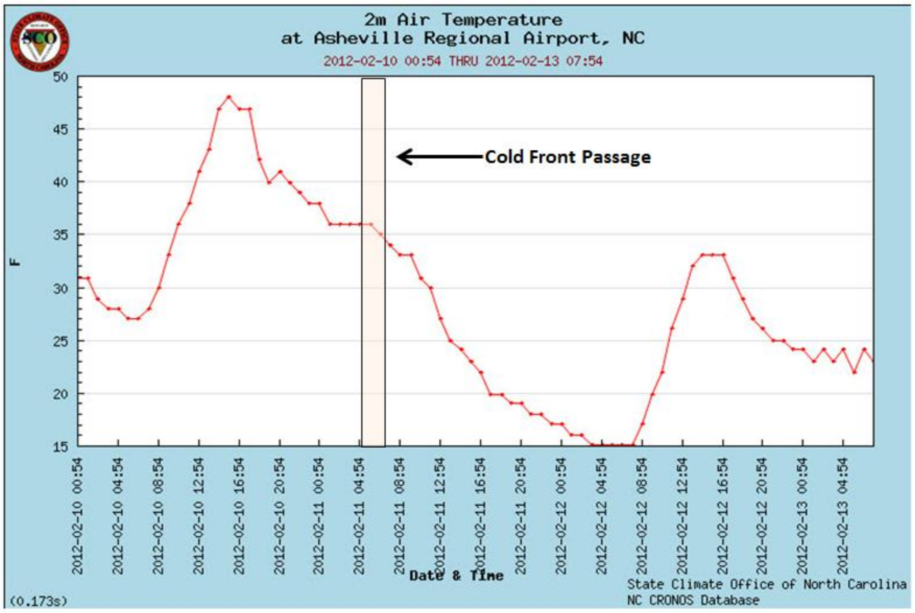


Fig. 4. Two-meter temperature (red line) at Asheville Regional Airport from 0600 UTC/0100 EST on 10 February 2012 until 1400 UTC/0900 EST on 13 February 2012. Vertical bar indicates the cold frontal passage. Figure from North Carolina State Climate Office (http://www.nc-climate.ncsu.edu/).

The primary feature at 500 mb associated with the air mass transition across the region was the broad trough moving into the eastern United States at 1200 UTC. An 80 to 90 kt wind maximum moving into the base of the trough was helping to drive the cold air southeastward (Fig. 5).

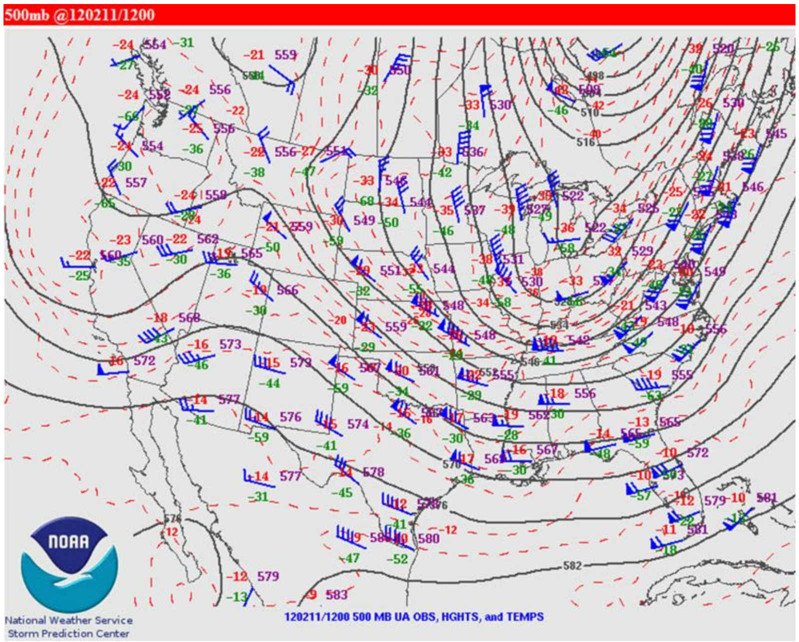


Fig. 5. Storm Prediction Center 500 mb analysis at 1200 UTC on 11 February 2012. Geopotential height (dm; solid contours), wind (kt; flags), temperature (^{o}C; red dashed contours).

3. Satellite, Radar, and Wind Observations

The air mass behind the cold front was characterized by low-level moisture as well as rapidly falling temperatures. Infrared satellite imagery at the time the cold front was crossing the mountains showed an extensive area of cloudiness extending from the central and southern Appalachians west through the Ohio and Tennessee valleys (Fig. 6). Soundings taken west of the mountains confirmed the limited vertical extent of the moisture. The Nashville, Tennessee, 1200 UTC temperature and moisture profiles (Fig. 7) showed the moisture was confined to a thin layer just below 850 mb[1]. The slightly colder (lighter gray) infrared image cloud tops just west of the mountains indicated deeper moisture that likely was associated with the cold front.

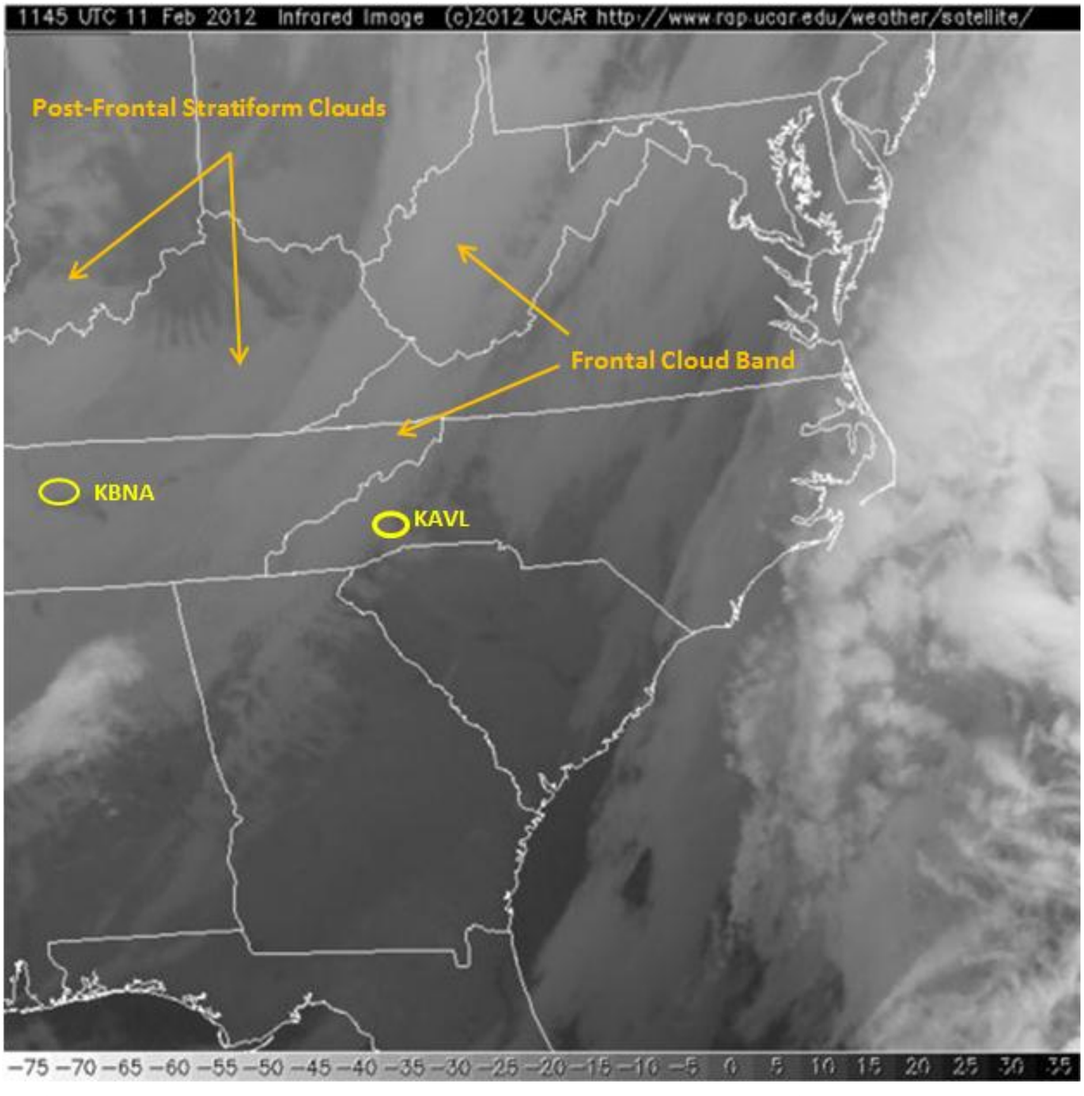


Fig. 6. Infrared satellite image at 1145 UTC on 11 February 2012. Locations of Asheville Regional Airport (KAVL) and Nashville (KBNA) are indicated. (Image from: http://weather.rap.ucar.edu/satellite/)

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[1] The 1153 UTC (0553 LT) surface observation at KBNA indicated the sky condition was overcast at 3400 ft AGL.

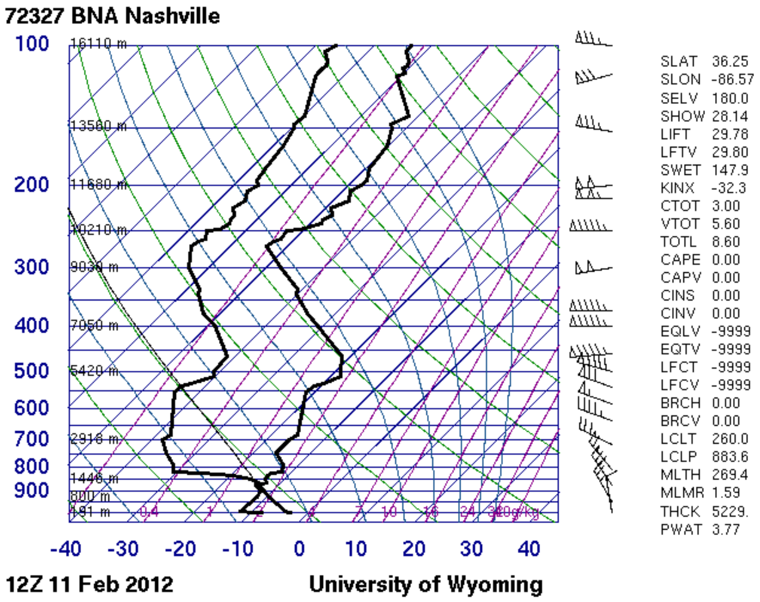

Fig. 7. Sounding at Nashville, TN at 1200 UTC on 11 February 2012.

The defining characteristic of northwest flow snow events (viz., persistent northwest boundary layer wind) was evident in the wind rose from Beech Mountain, NC (Avery County) at an elevation of 5500 ft (Fig. 8). The west and southwest wind directions occurred prior to the cold frontal passage. The predominant direction during the period of northwest flow was approximately 310°.

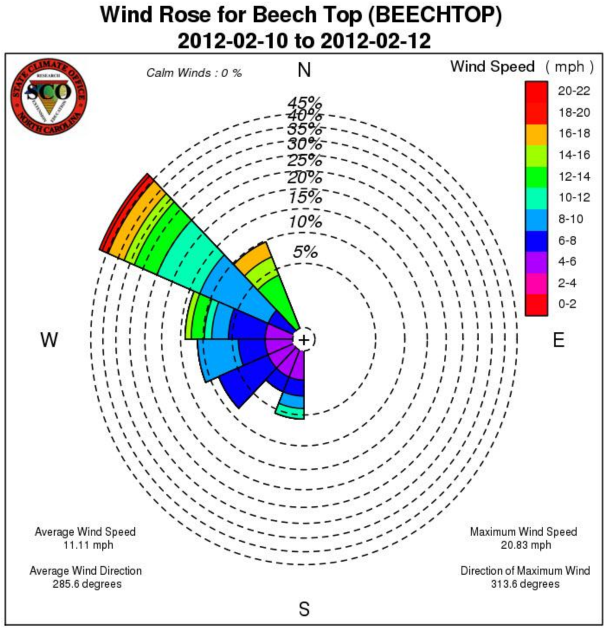

Fig. 8. Wind rose at Beech Mountain, NC (Beech Top; elevation 5500 ft) for 10, 11, and 12 February 2012. Image from North Carolina State Climate Office.

A regional WSR-88D radar reflectivity mosaic (Fig. 9) showed that precipitation was occurring along the Tennessee – North Carolina border at 1200 UTC. Another area of precipitation was over the eastern portion of the Cumberland Plateau in Tennessee and Kentucky. Subsequent radar imagery at three-hour intervals (Fig. 9) indicated the areal extent of the moisture gradually diminished, but the structure of the precipitation elements assumed a quasi-linear configuration akin to horizontal convective rolls. A similar pattern of clouds and precipitation in cold air advection was documented by Schultz et al. (2004), and it has been observed in other northwest flow snow events [e.g., Moore 2006; Hudgens and Stonefield (2008)].

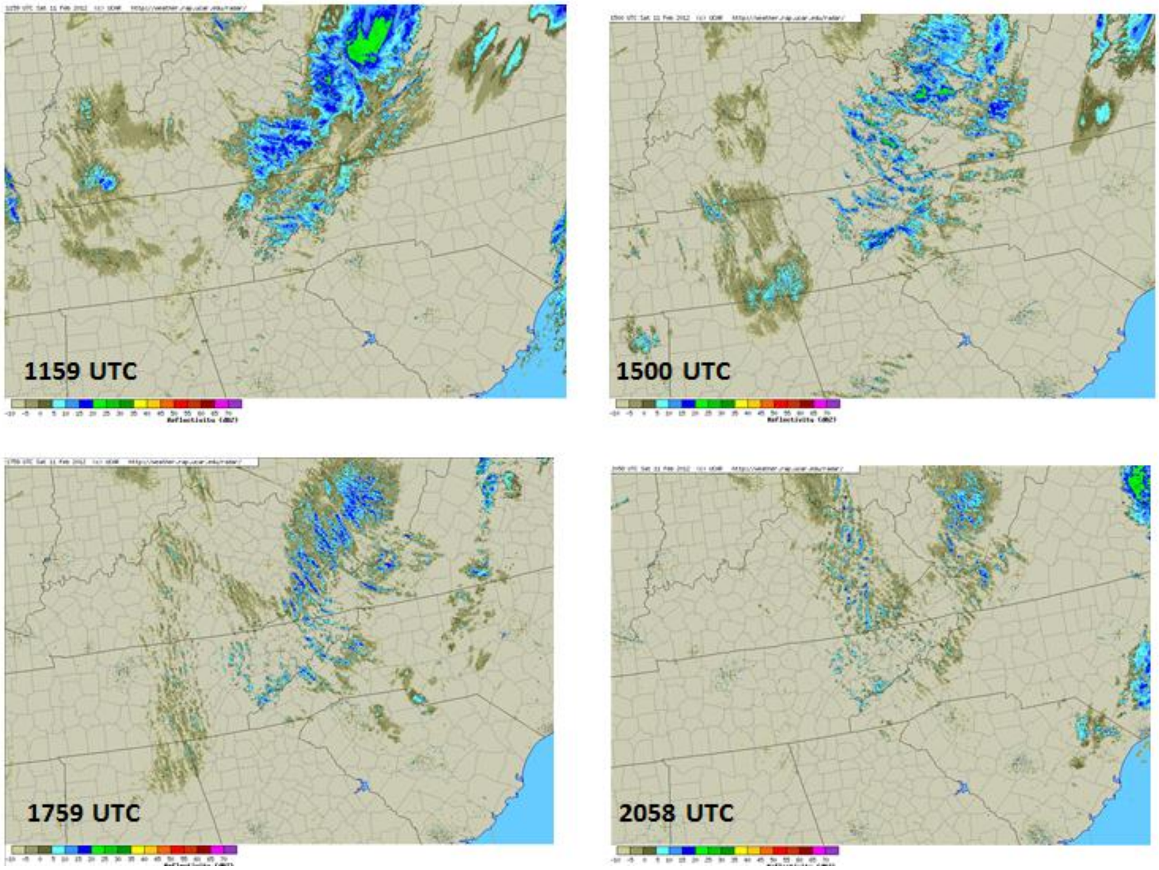

Fig. 9. Regional WSR-88D reflectivity mosaic on 11 February 2012.

The nearly linear cloud elements, approximately parallel to the surface wind, also were evident upstream of the Appalachians in visible satellite imagery (Fig. 10). This cloud pattern occurred where the cold air was moving from a region with snow cover (Midwest and upper Ohio River valley) to the Tennessee River valley where very little snow was on the ground (Fig. 11). Cloud bands – approximately perpendicular to the surface wind – extended from northeast Alabama into east Tennessee. This cloud orientation was due to waves generated by flow across the Cumberland Plateau. A fairly extensive area of cloud was along the North Carolina-Tennessee border where the orographic lift was focused along the mountain chain. The 1500 UTC radar image (Fig. 9) showed a similar orientation in the precipitation pattern consisting of quasi-linear elements upstream of the mountains and a concentration of precipitation along the state line.

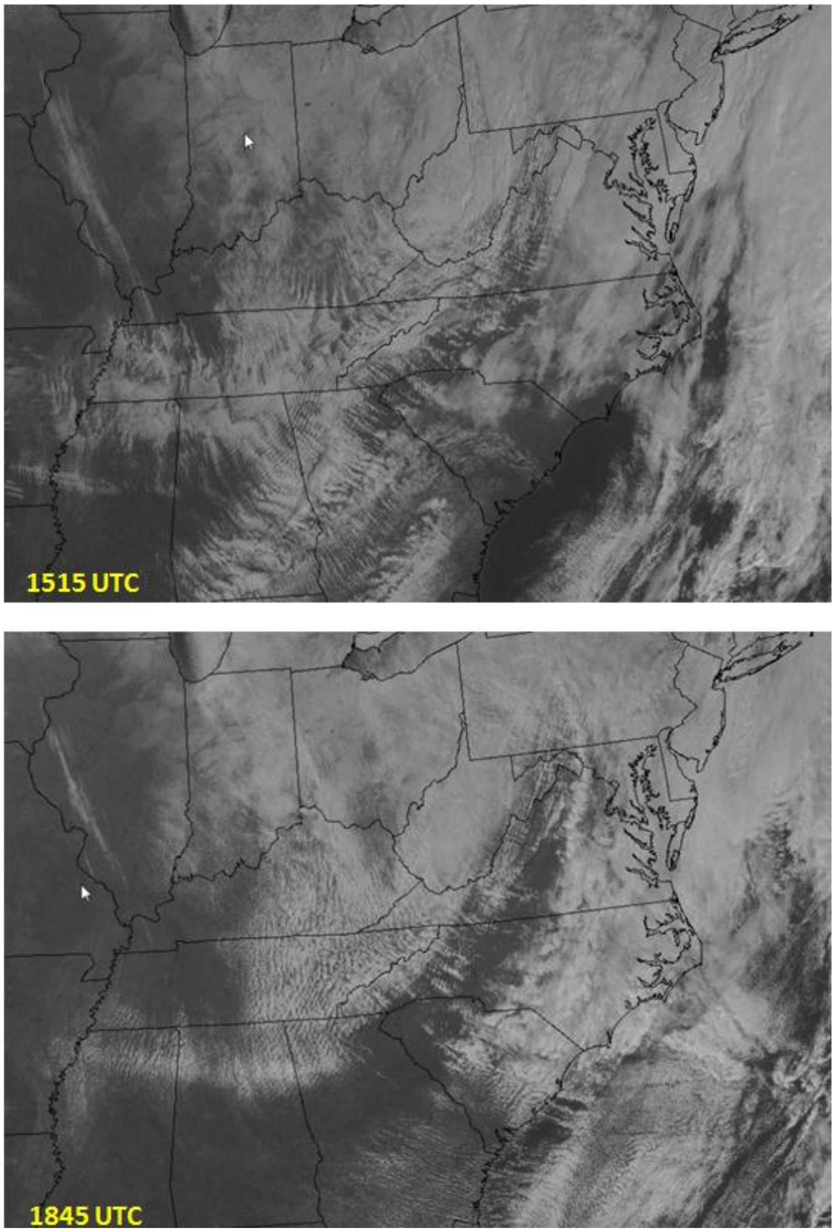

Fig. 10. GOES-EAST visible satellite imagery at 1515 UTC (top) and 1845 UTC (bottom) on 11 February 2012. Images from Storm Prediction Center.

Of the three primary cloud patterns (viz., narrow bands parallel to the wind, Cumberland Plateau-induced waves perpendicular to the wind, and orographic along the Appalachians), only the quasi-linear cloud streets and the orographic, terrain-parallel cloud elements produced most of the detectable precipitation. In this particular case, radar did not identify significant precipitation in the wave clouds. Close examination of the 1515 UTC visible satellite image revealed Appalachian-induced wave clouds over far western North Carolina near the Tennessee border. It was not apparent that the upward motion associated with these waves augmented the orographic lift occurring in the same area, but that possibility existed.

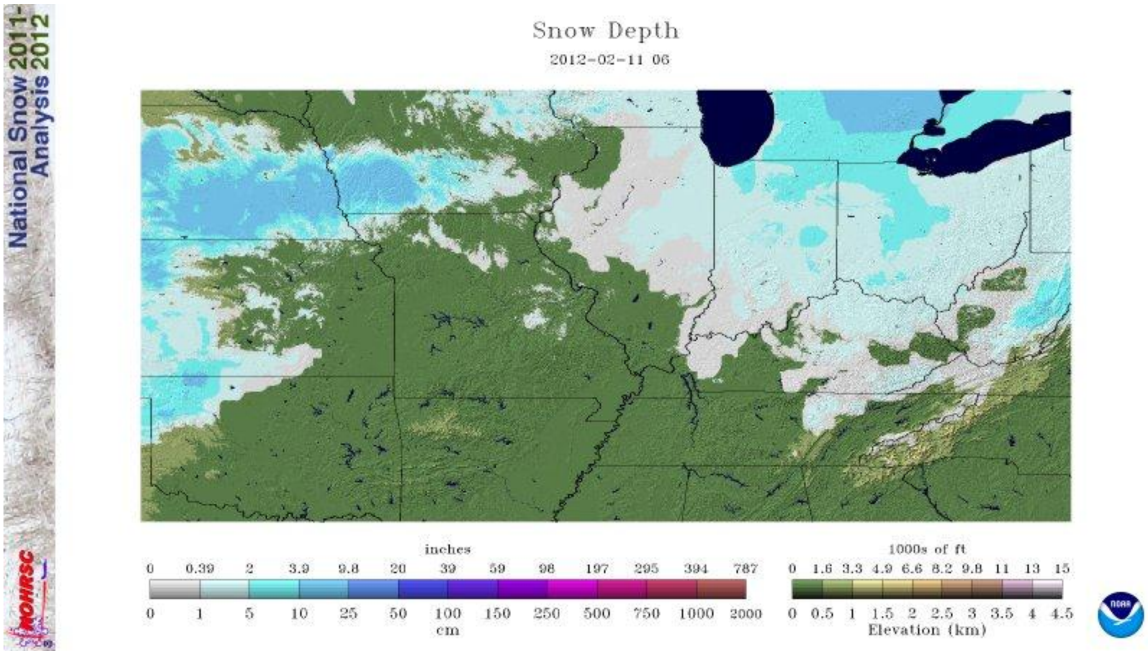

Fig. 11. Regional snow depth analysis on 11 February 2012. Image from NOAA/National Operational Hydrologic Remote Sensing Center.

Boundary layer warming was a possible contributor to the more cellular appearance in the cloud field west of the Appalachians during the afternoon (Fig. 10)[2]. Wave clouds in the Great Valley of east Tennessee were still discernible, and the most concentrated cloudiness persisted near the North Carolina-Tennessee border where the terrain-induced lift continued. Downslope flow produced a clearing zone from northern Virginia southward through the Carolinas to Georgia. Several bands of cloud extending from the mountains into the Piedmont were probably produced by local lines of convergence caused by air flowing through valleys and around terrain obstacles. The 1759 UTC radar image (Fig. 9) showed that precipitation continued into the afternoon, particularly where orographic lift persisted, but the overall pattern displayed a diminishing trend as the moist air moved northeast away from the area.

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[2] Surface observations from Kentucky and Tennessee indicated temperatures at some locations increased a few degrees from morning to afternoon – even during the cold advection. Schultz et al. (2004) suggest the likelihood of horizontal convective rolls being the dominant form of convection decreases as the instability of the environment increases.

4. Air Mass Characteristics

Previous work (e.g., Perry and Konrad 2005; Perry et al. 2007; Holloway 2007) suggested that the Great Lakes provided moisture and heat that contributed to northwest flow snow during other events in the southern Appalachians. A thorough examination of that process is beyond the scope of this report, but simple application of a trajectory analysis showed that the Great Lakes could have been a contributor to the moisture that subsequently produced the snow. Even though others (e.g., Sousounis and Fritsch 1994; Sousounis and Mann 2005) have demonstrated the importance of viewing the lakes collectively as a moisture and heat source, a narrower focus was taken here. Using the NOAA/Air Resources Laboratory HYSPLIT model, it was shown that near-surface air parcels within an envelope bounding southern Lake Michigan arrived over the southern Appalachians at the time precipitation occurred (Fig. 12).

The trajectory in Fig. 13 originated over water in southwestern Lake Michigan. The bottom frame of Fig. 13 depicts the increasing depth of the mixing layer that occurred as the air parcel moved southeastward, especially during the daytime (1200 UTC to 2100 UTC).

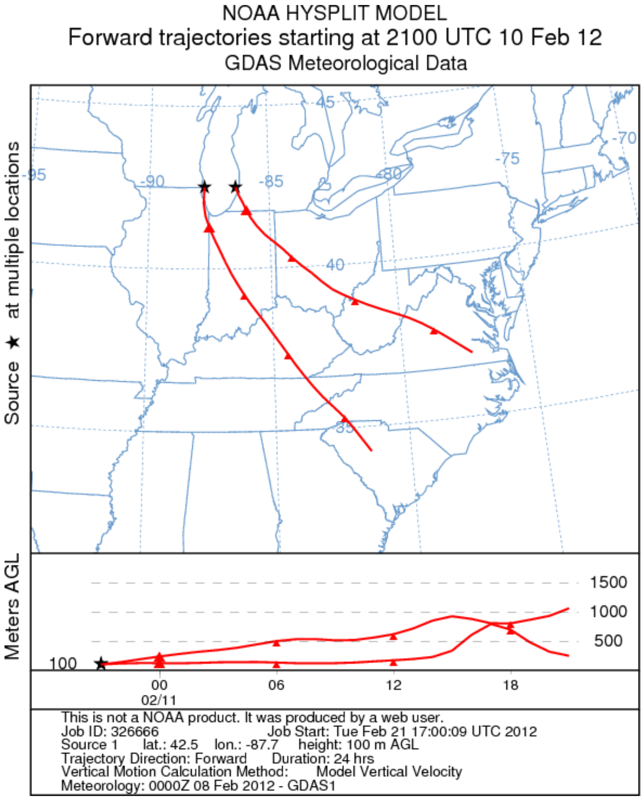

Fig. 12. NOAA/ARL HYSPLIT 24-hour forward trajectories originating at 100 m above the surface on the western and eastern shores of southern Lake Michigan at 2100 UTC on 10 February 2012. The air parcel height is displayed in the bottom frame. The westernmost trajectory ends near 250 m.

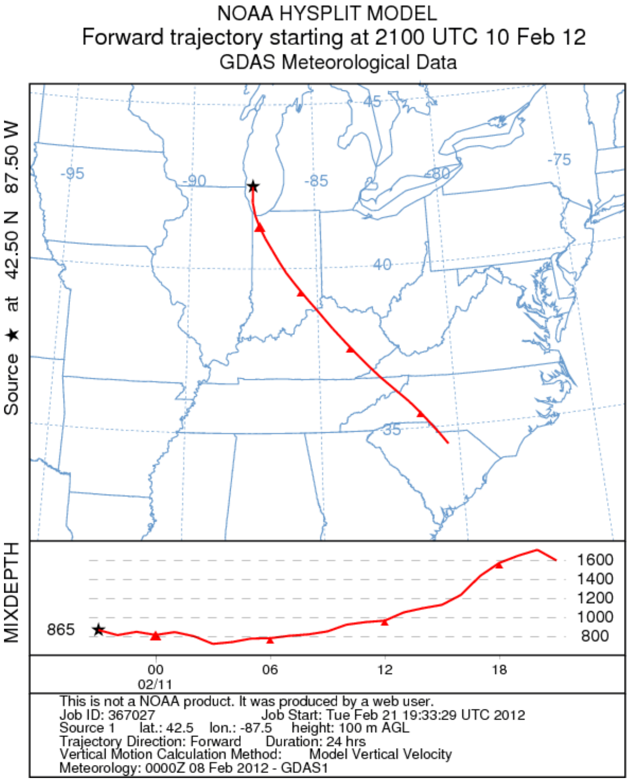

Fig. 13. NOAA/ARL HYSPLIT 24-hour forward trajectory beginning at 2100 UTC on 10 February 2012 over southwestern Lake Michigan 100 m above the surface. Bottom frame displays the mixing depth along the trajectory.

An analysis of upstream Froude numbers specifically computed for northwest flow into the southern Appalachians was also consistent with a Great Lakes moisture connection. During the afternoon, Froude numbers spiked around 4.0 units (Fig. 14). Reviews of northwest flow snowfall events during the past three winter seasons suggested correlation between elevated Froude values (generally greater than 1.0 unit) during the hours leading up to the event and advisory level snow accumulations (greater than 2 inches) in the favored northwest flow locations. Additional study of the Froude number approach is needed, however, as it has tended to over-forecast snow accumulations when upstream moisture is very shallow, or when the event is of short duration.

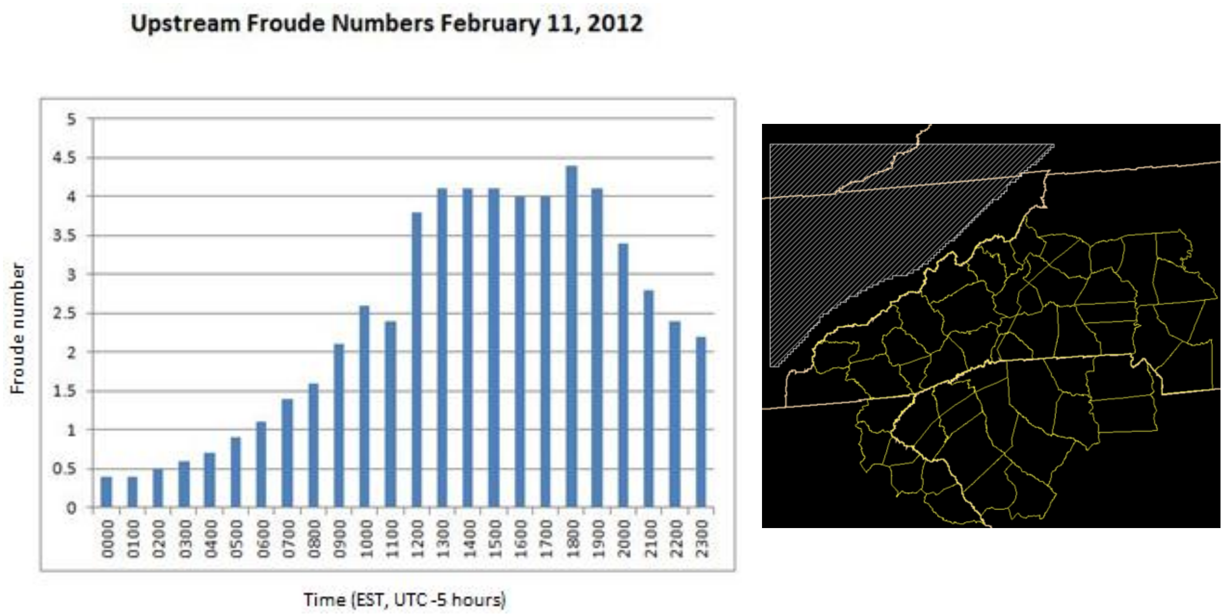

Fig. 14. Hourly average Froude numbers (left) computed upstream of the southern Appalachians (hatched area on right). Froude numbers were averaged over four models (RUC, GFS, NAM, and local WRFARW).

5. Summary

A cold air mass containing a field of stratus and stratocumulus clouds moved into the southern Appalachians following the passage of a cold front on Saturday, 11 February 2012. Snow flurries and snow showers developed in weak and shallow convection upwind of the mountains, but the upslope flow enhanced the precipitation and resulted in accumulations that ranged from a trace to 9 inches (Figs. 1 and 15). The origin of the entire moisture field that supported the precipitation was not known, but air parcel trajectories indicated the Great Lakes might have contributed to some of the snow showers and snow flurries.

Selected Snow Accumulations **NWS Cooperative Observer, CoCoRaHS, Spotter, Media, Law Enforcement, and Public Reports** 11 February 2011					
North Carolina					
Location	**Amount** (inches)	**Location**	**Amount** (inches)	**Location**	**Amount** (inches)
Sams Gap	9.0	Bakersville 5 N	2.5	Marshal 14 NNW	1.2
Cold Spring	9.0	Flat Springs 1 E	2.5	Marshall 5 WNW	1.1
Mt. Mitchell	7.0	Mars Hill 5 NNE	2.5	Oconaluftee	1.0
Beech Mountain 1 SE	6.5	Waynesville 4 E	2.2	Clyde 2 SW	1.0
Beech Mountain	6.0	Asheville 6 NNW	2.1	Bakersville 3 SE	1.0
Sugar Mountain	5.0	Newland	2.0	Maggie Valley 3 ENE	0.9
Linville	5.0	Leicester 2 SE	1.6	Weaverville 4 N	0.7
Buladean 2 N	4.0	Bald Creek 1 NW	1.6	Stecoah	0.5
Banner Elk 5 ESE	4.0	Canton 10 S	1.5	Robbinsville 2 NNW	0.5
Leicester 6 NW	3.6	Bakersville 5 N	1.5	Lake Junaluska 5 N	0.5
Candler 3 ENE	3.0	Burnsville 7 SSW	1.5	Fairview 4 ENE	0.2
Flat Springs 1 E	2.5	Burnsville 7 W	1.4	Asheville 3 N	0.2
Banner Elk 2 NNW	2.5	Candler 3 ENE	1.2	Franklin 7 N	0.2

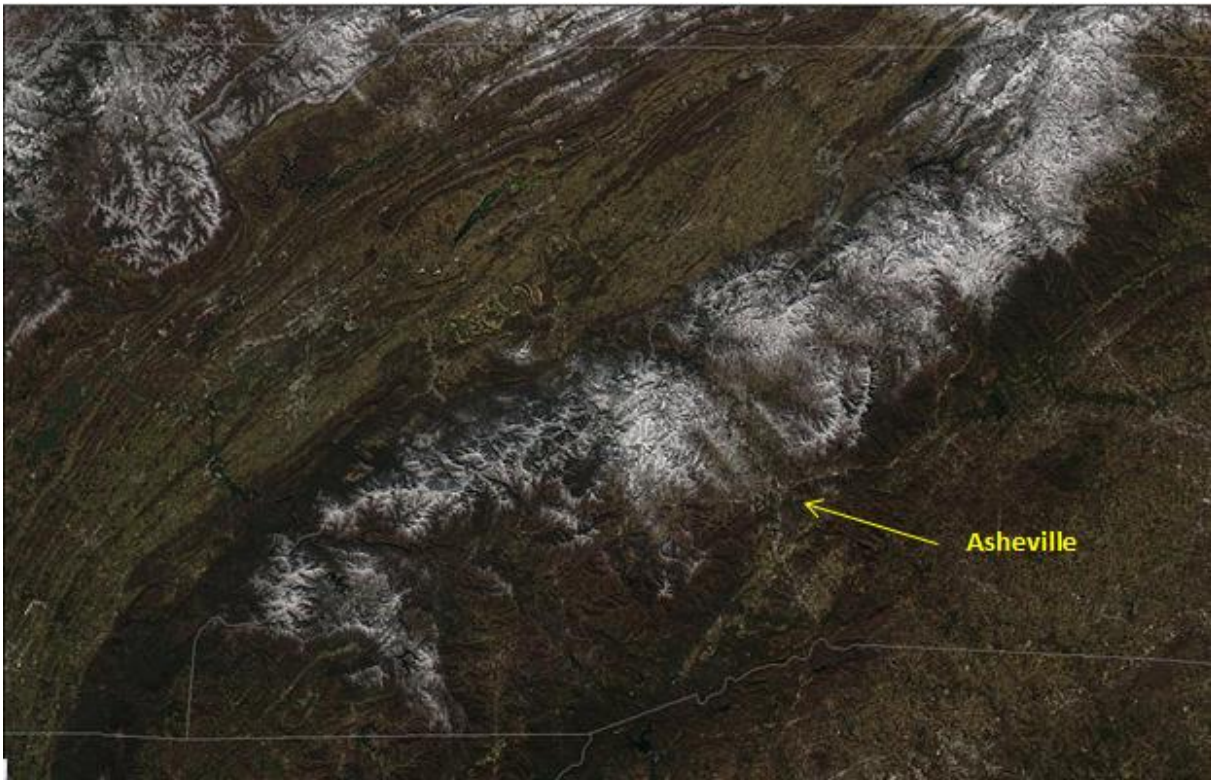

Fig. 15. Aqua MODIS image at approximately 1843 UTC on 12 February 2012 showed the snow cover in western North Carolina. (Image from University of Wisconsin – Madison Space Science and Engineering Center.)

Acknowledgments

The surface analyses were prepared by the NOAA/NCEP/Hydrometeorological Prediction Center and obtained from the NOAA/NESDIS/National Climatic Data Center. The upper air analyses and the visible satellite imagery were provided by the NOAA/NCEP/Storm Prediction Center. The North Carolina State Climate Office provided the online resources to create the Asheville hourly temperature plot and the Beech Mountain wind rose. The Nashville sounding plot was obtained from the Department of Atmospheric Science at the University of Wyoming. The radar and infrared satellite images were obtained from the National Center for Atmospheric Research, which is operated by the University Corporation for Atmospheric Research. The snow depth analysis was created by the NOAA/National Operational Hydrologic Remote Sensing Center. The trajectory plots were created using the online resources of the NOAA/Air Resources Laboratory HYSPLIT model. The Terra MODIS image was obtained from the University of Wisconsin-Madison Space Science and Engineering Center. Patrick Moore provided a helpful review and quality control of this document.

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