# The New Year 2012 Northwest Flow Snow Event


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## 1. Introduction

A short wave trough moved into the Pacific Northwest on Friday, 30 December 2011. It subsequently crossed the Rocky Mountains and developed into a significant 500 mb trough over the central United States on New Year's Day. A surface low organized in the lee of the Rockies northeast of Denver on 31 December as the upper trough approached. The surface low moved northeast to the Great Lakes on 1 January then to Quebec on 2 January. A cold front extended south from the low and swept across the central and southern Appalachians late on 1 January. Following the frontal passage, strong northwest winds developed over the western Carolinas and extreme northeast Georgia. A cold high pressure system moved southward from Canada into the central and eastern United States. An extensive layer of low clouds (stratus, stratocumulus) in the cold air was lifted over the southern Appalachians and provided sufficient moisture for the development of upslope snowfall on 2 and 3 January 2012. Snowfall amounts in the County Warning Area (CWA) of the Greenville-Spartanburg (GSP) Weather Forecast Office (WFO) ranged from a trace to six inches (Fig. 1). Even though accumulations were not great, travel was disrupted on mountain roads due to a thin layer of ice that formed when some of the initial precipitation melted just prior to a rapid drop in temperature.

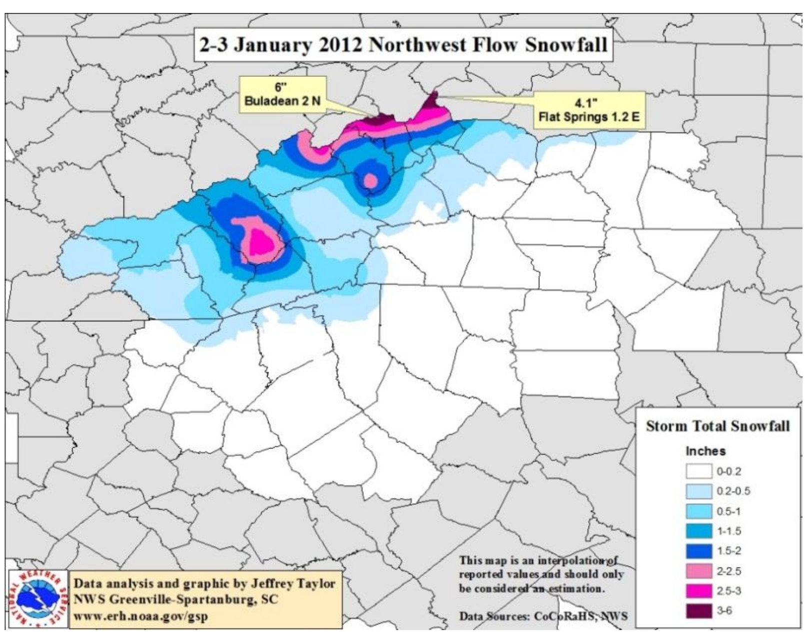


**Fig. 1. Snow accumulation on 2 and 3 January 2012 in the WFO GSP CWA.**

## 2. Upper-level and Surface Features

The 500 mb trough from central Canada to the Gulf Coast at 1200 UTC on 1 January 2012 evolved from a short wave trough that moved onshore in the Pacific Northwest on 30 December 2011 (Fig. 2). Upon close inspection, it can be seen that the trough at 1200 UTC on 1 January consisted of several short waves troughs: 1) western Manitoba and northern Minnesota, 2) Wisconsin and Illinois, 3) Illinois to Arkansas, and 4) Louisiana. By 0000 UTC 2 January, the trough had become rather broad and was the primary upper-level feature across most of the country east of the Rockies.

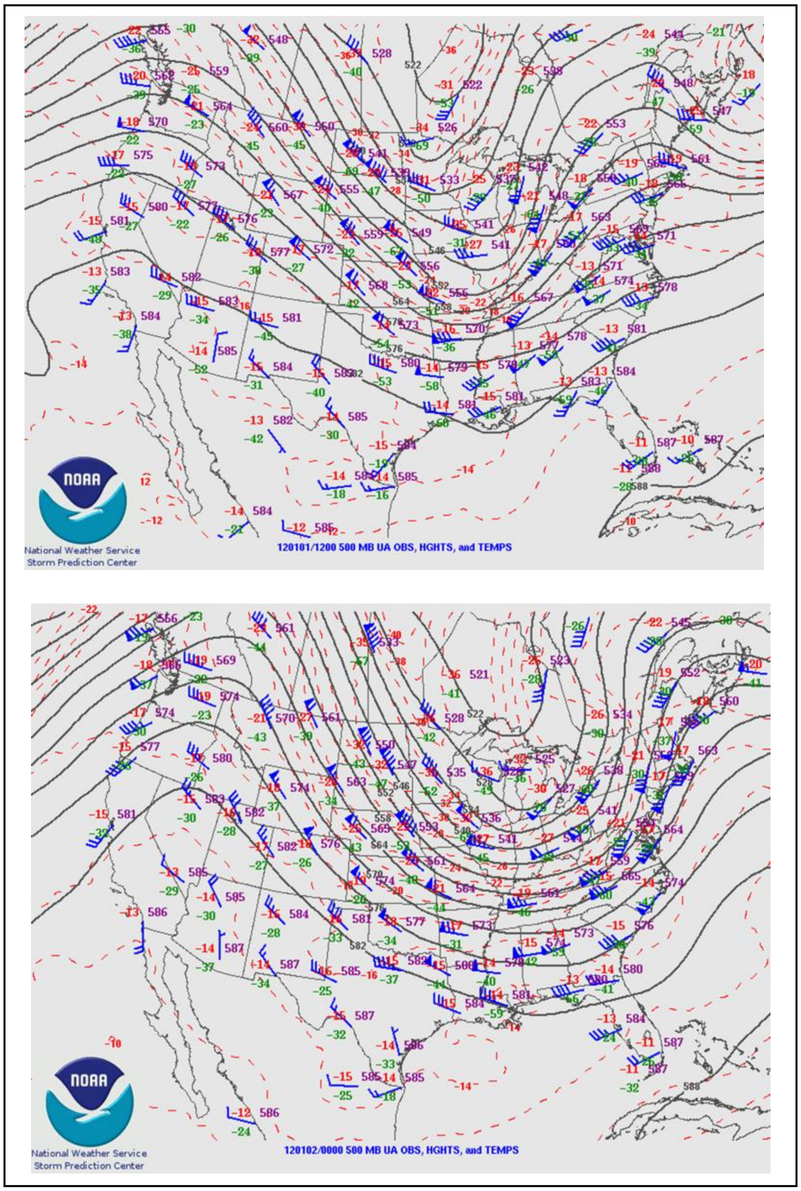


**Fig. 2. Storm Prediction Center (SPC) 500 mb analysis at 1200 UTC on 1 January 2012 (top) and 0000 UTC on 2 January 2012 (bottom). Geopotentialheight (dm; solid contours), wind (kt; flags), temperature ($^{o}$C; red dashed contours).**

The 850 mb analyses at 1200 UTC on 1 January and 0000 UTC on 2 January (Fig. 3) showed the low level trough moved from the central states into the Appalachians. Very warm air over the western Carolinas in the morning was replaced by cold air late in the day.

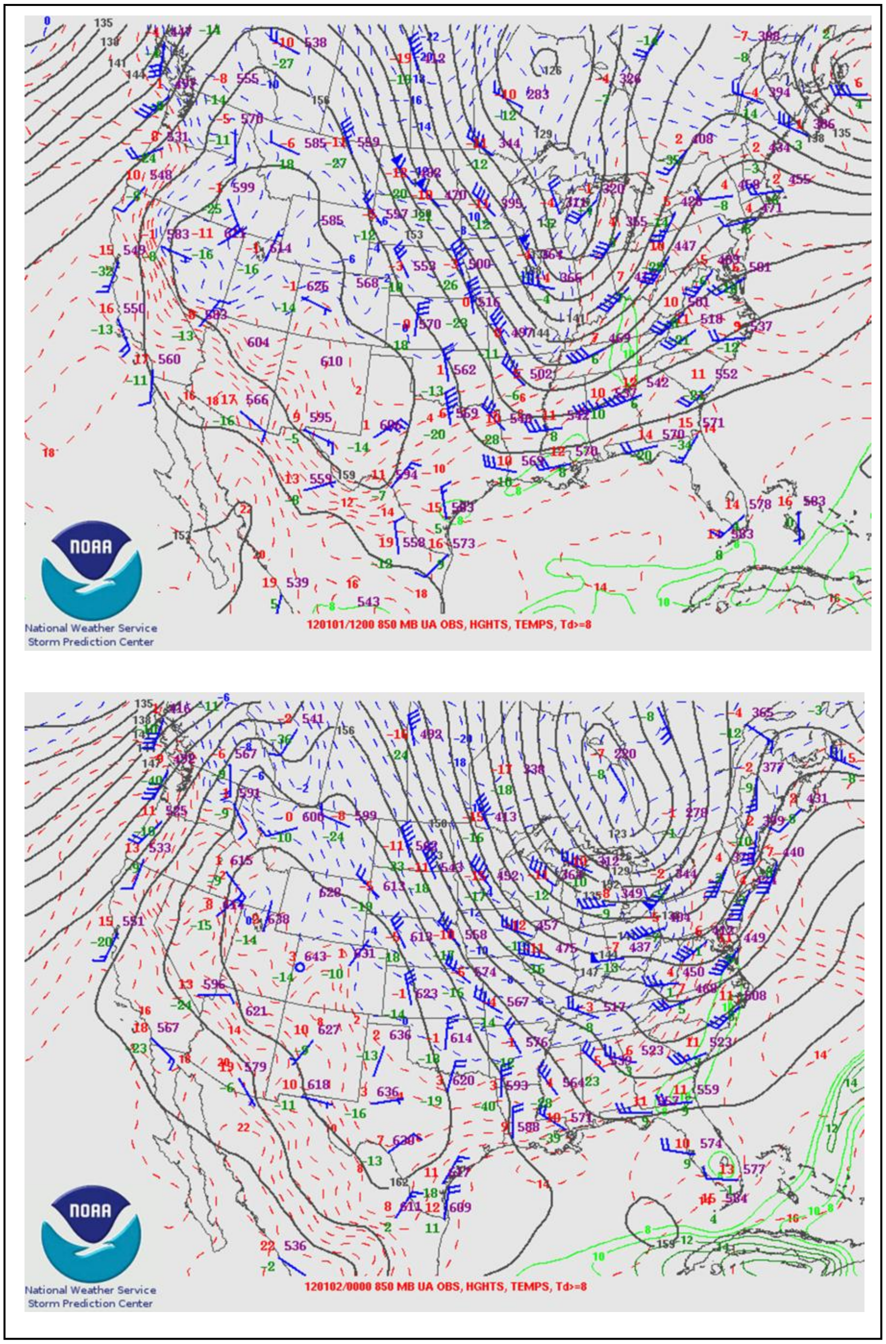


**Fig. 3. SPC 850 mb analysis at 1200 UTC on 1 January 2012 (top) and 0000 UTC on 2 January 2012 (bottom). Geopotential height (dm; solid contours), wind (kt; flags), temperature (oC; red dashed contours); dew point ≥ $8^{0}$ C (solid green contours).**

The surface analyses (Fig. 4) showed the cold front extended from the western Great Lakes to the Texas coast at 1200 UTC on 1 January, and it moved east of the southern Appalachians by 0000 UTC 2 January.

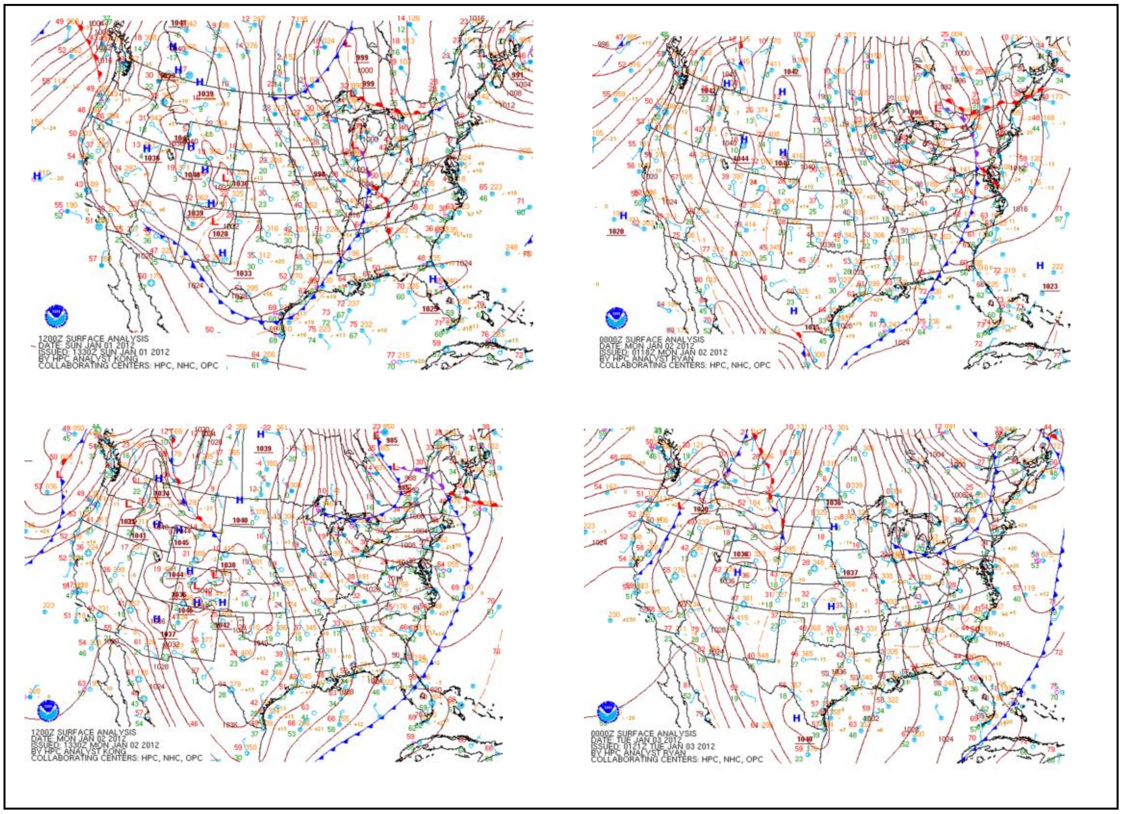

**Fig. 4. Hydrometeorological Prediction Center surface analyses at 1200 UTC on 1 January 2012 (top left); 0000 UTC on 2 January 2012 (top right); 1200 UTC on 2 January 2012 (bottom left); and 0000 UTC on 3 January 2012.**

## 3. Satellite and Radar Imagery

An expansive field of stratiform cloudiness spread southeastward after the cold front moved offshore. During the day on 2 January, the infrared satellite imagery displayed a progressively less uniform cloud top appearance over the Great Lakes region and Ohio Valley (Fig. 5). Even though the air mass was cold, there was no snow cover so daytime heating provided sufficient boundary layer warmth for upright convective elements to develop. The clouds organized into patches where upward motion predominated and nearly cloud free areas where subsidence occurred. Convective mixing probably also contributed to the decreasing extent of the clouds as dry air was entrained into the moist, cloudy air. By the morning of 3 January, clouds in the infrared imagery were confined to the central and southern Appalachians where orographic lift occurred. The southeastward surge of cold air is evident in the rapid expansion and enhancement of the stratus and stratocumulus clouds off the coast of the southeastern United States from 1815 UTC on 2 January to 1225 UTC on 3 January.

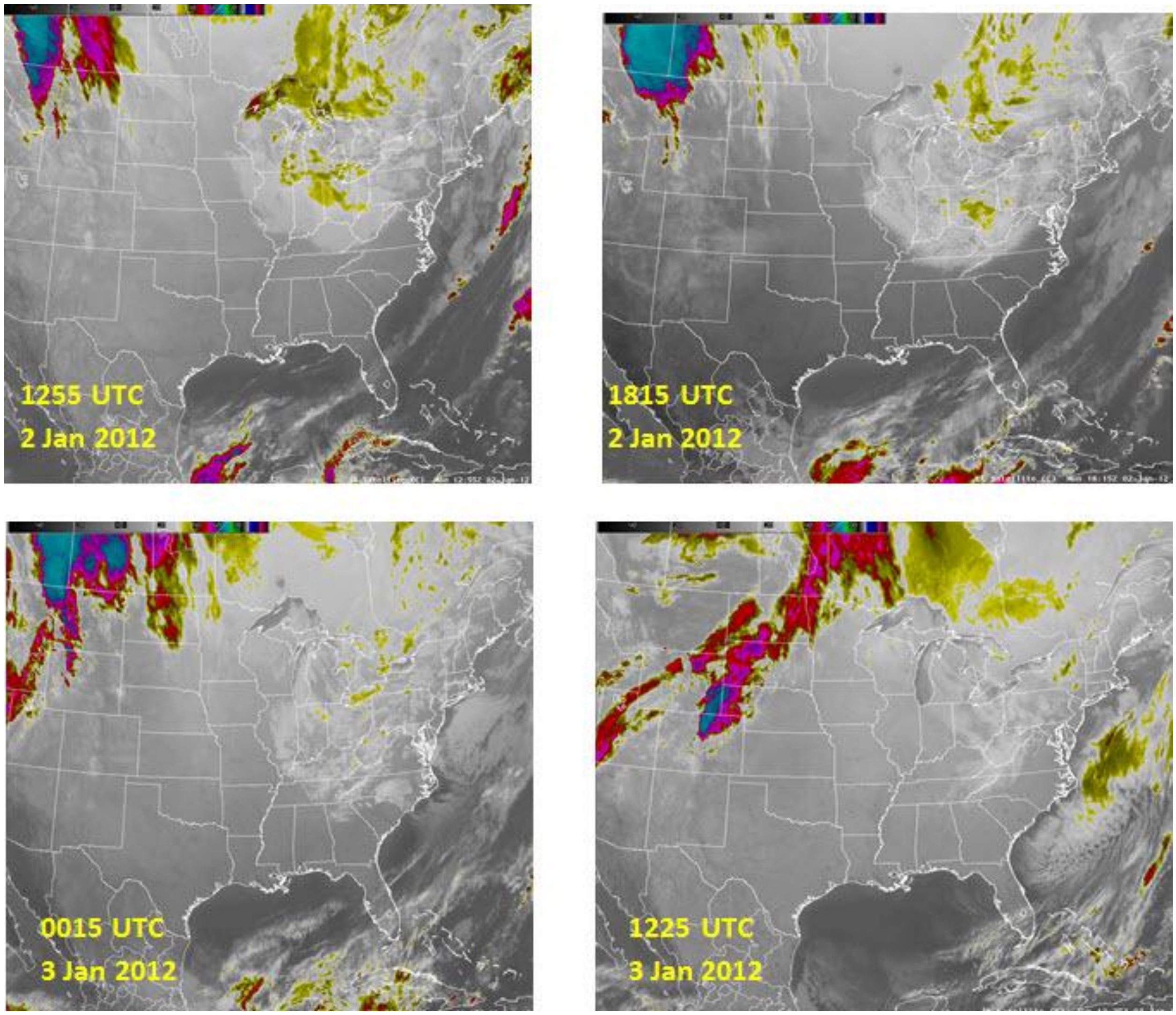


**Fig. 5. GOES-East satellite infrared imagery on 2 and 3 January 2012. Yellow to purple to blue shades represent increasingly cold cloud tops. Lower clouds depicted by shades of gray.**

The visible satellite imagery also provided a view of the change in character of the cloud field as the cold air moved southeastward during 2 January (Fig. 6). The cellular convection that developed from Illinois to Kentucky and Tennessee as the surface warmed was quite evident when comparing the morning and afternoon images.

The convection was confined to a shallow, near-surface layer, but enough moisture was available and the convection was strong enough to produce small precipitation elements that were detected by regional WSR-88D radars (Fig. 7). During the early evening, the boundary layer was cooling which probably contributed to weakening vertical convective motions and decreasing coverage of the precipitation as it moved into western North Carolina. However, the mode of precipitation still retained the cellular pattern that dominated during the warmest part of the day.

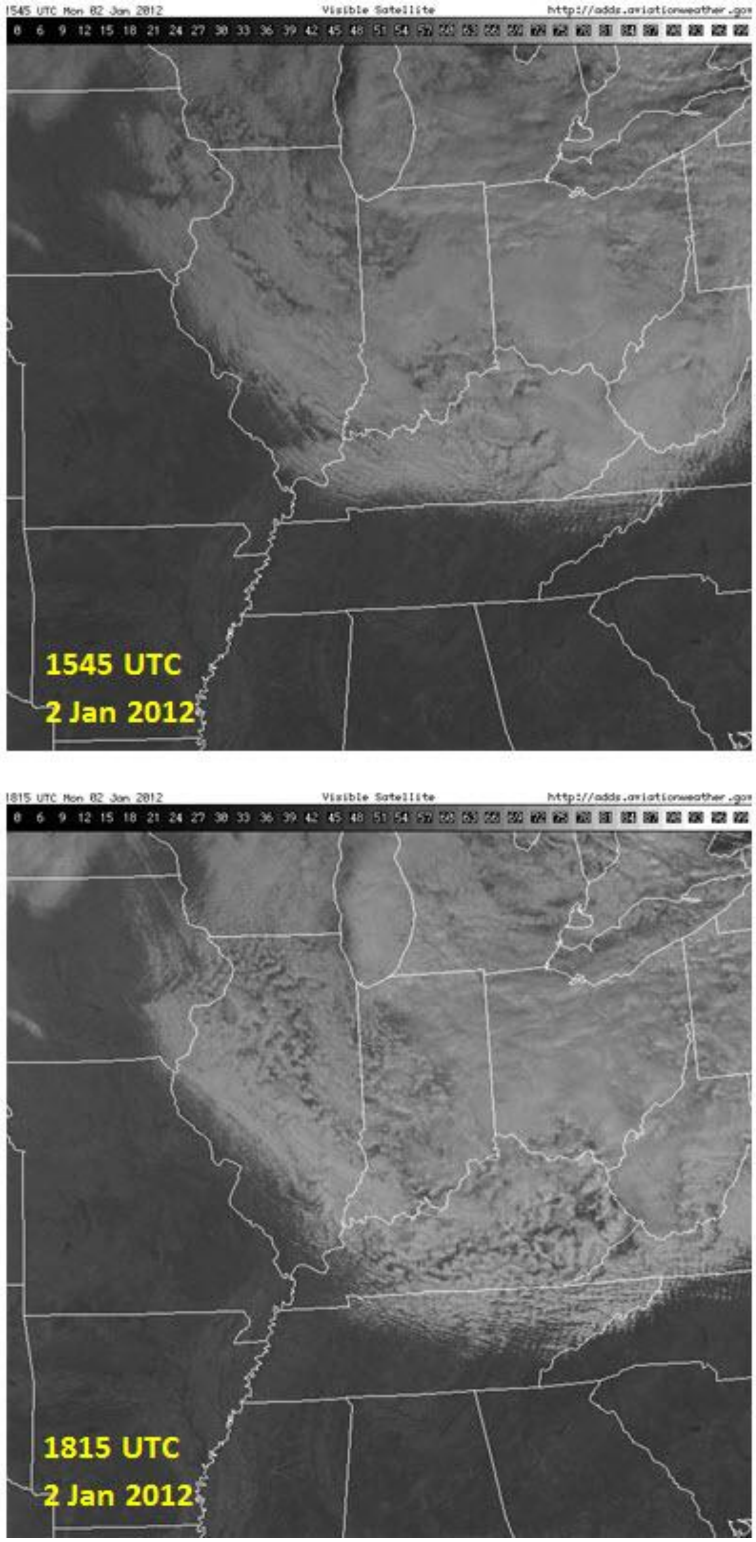


**Fig. 6. GOES-East visible satellite imagery on 2 January 2012. The transition from a stratiform to a cellular pattern is seen by comparing the morning (top) and afternoon (bottom) images.**

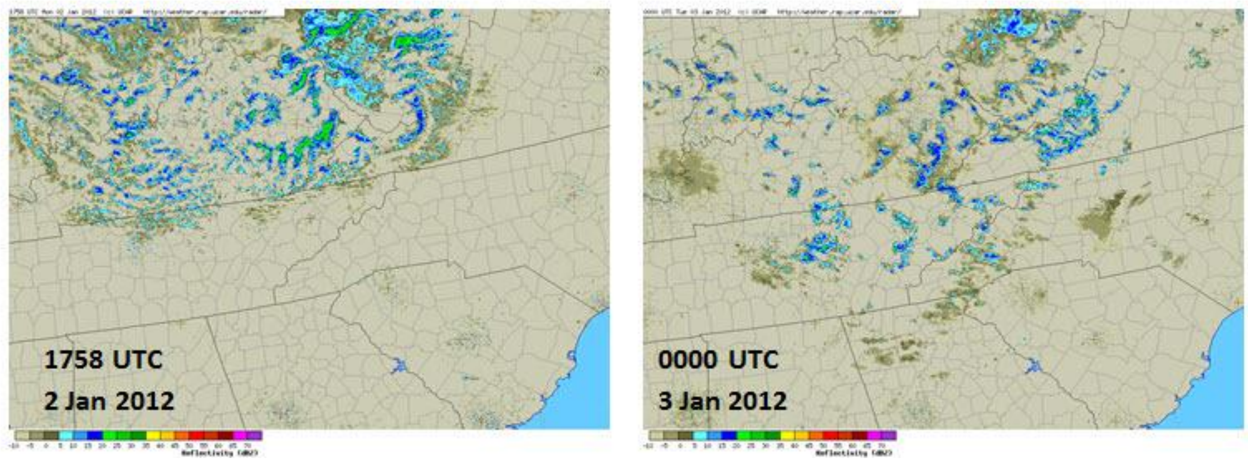


**Fig. 7. Regional WSR-88D reflectivity mosaic at 1758 UTC on 2 January 2012 (left) and at 0000 UTC on 3 January 2012 (right). The transition from a cellular structure to a linear structure is evident by comparing the afternoon (left) and early evening (right) images.**

An interesting change in character of the precipitation elements occurred during the night. Cold air advection continued across the area, and the lack of insolation prevented boundary layer warming. As a result during the late evening and overnight hours, the precipitation mode lost its cellular character and became more linear (Fig. 8).

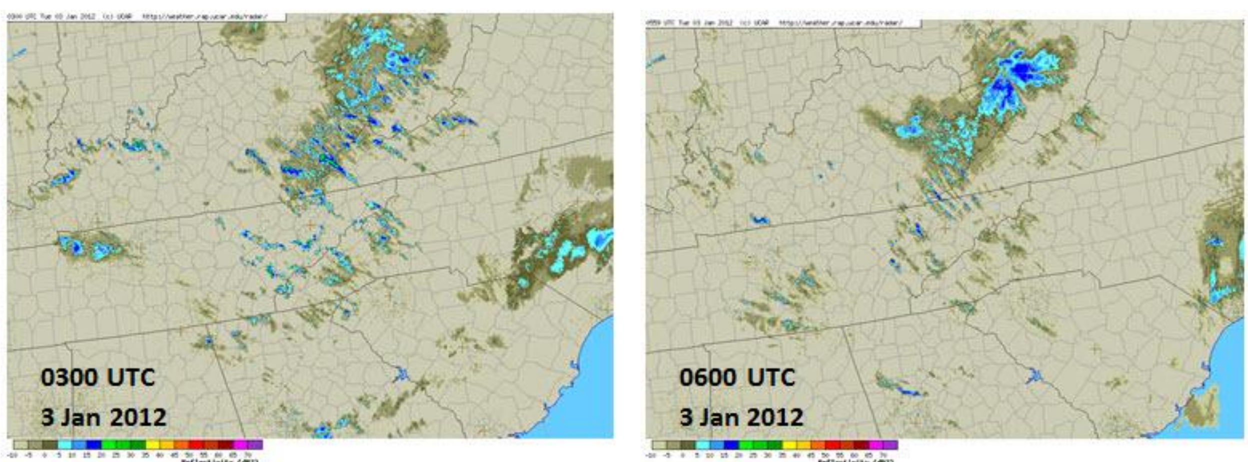


**Fig. 8. Regional WSR-88D reflectivity mosaic at 0300 UTC on 3 January 2012 (left) and at 0600 UTC on 3 January 2012 (right).**

A more detailed view of the transition of convective mode from cellular to linear was evident by examining the WSR-88D composite reflectivity mosaic focused on the WFO Morristown and WFO Greenville-Spartanburg radar coverage. The 0000 UTC on 3 January image showed scattered enhanced precipitation elements in east Tennessee and western North Carolina (Fig. 9). More widespread areas of low reflectivity were also detected. The 20 to 30 dbZ values over Henderson County and southern Buncombe County were particularly noteworthy. Northwest flow snow events typically do not produce measurable snow in these areas. However, this event was accompanied by enough snow on top of a layer of ice to disrupt travel and alter school schedules.  Snow flurries and isolated slight accumulations were also observed in upstate South Carolina.

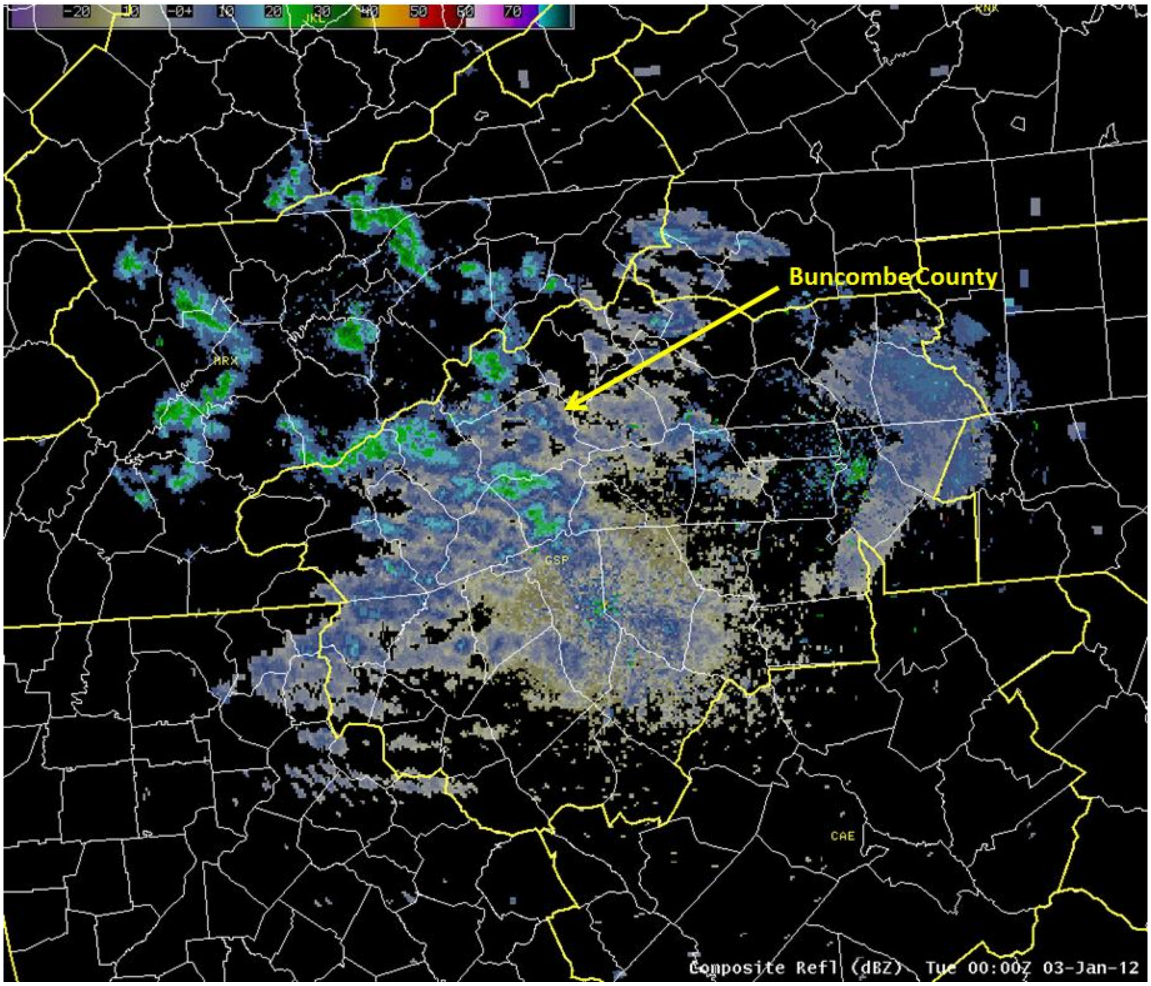


**Fig. 9.  WSR-88D composite reflectivity at 0000 UTC on 3 January 2012.  The arrow shows the location of Buncombe County, North Carolina.  The WFO GSP County Warning Area is in the middle of the image.**

The composite reflectivity at 0600 UTC on 3 January showed precipitation occurring over the same general area, but the linear nature of the precipitation elements was clearly evident (Fig. 10).  Weckwerth et al. (1999) suggested that a change in convective cloud type can be related to diurnal variations in the planetary boundary layer depth.  However, an explanation of the switch in convective mode from cellular to linear in the current case is beyond the scope of this review.  It is likely that changes in the depth of the boundary layer, stability, and wind shear played a role.  Additional observations of linear convection in northwest flow snow events have been documented by others [e.g, Moore 2006; Hudgins and Stonefield (2008)].  A detailed discussion of banded snow in cold air advection was provided by Schultz et al. (2004).

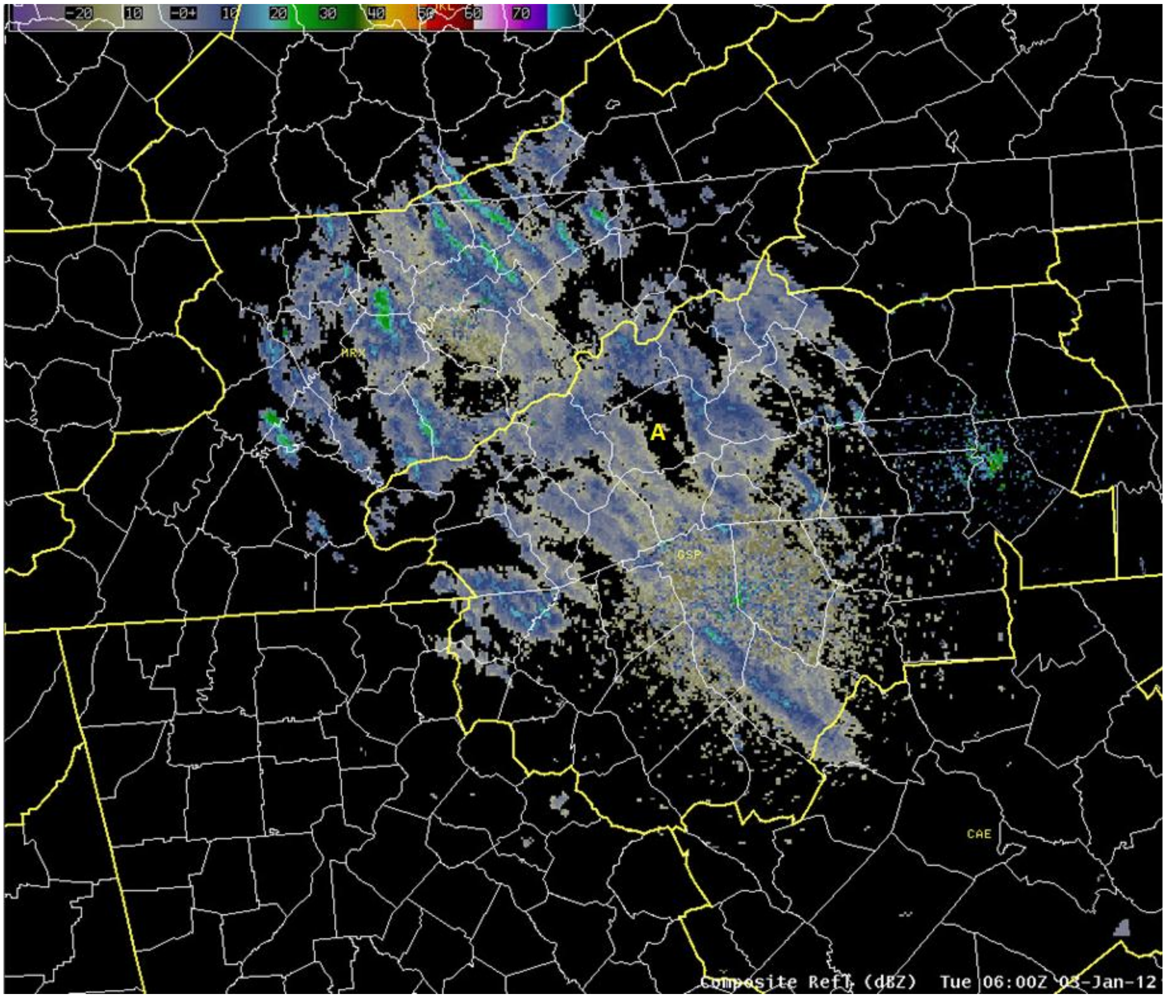


**Fig. 10. Same as Fig. 9 except at 0600 UTC on 3 January 2012. The letter "A" dentotes the approximate location of the city of Asheville, North Carolina.**

**3. Forcing for Vertical Motion**

One of the interesting aspects of this event – and of many other northwest flow snow events – was the fact that synoptic scale atmospheric conditions were not favorable for the production of clouds and precipitation through a deep layer. Several of the primary numerical weather prediction models showed that the 700 mb (Fig. 11) and 500 mb (not shown) trough axes were east of the southern Appalachians at 0600 UTC on 3 January, and considerable downward motion was moving into the area. At the same time, bands of snow extended from southeastern Kentucky across east Tennessee into the western Carolinas (Figs. 8 and 10).

The model cross section in Fig. 12 clearly shows that the moisture was confined to the layer below 750 mb. The northwest wind flow played a prominent role in the generation of the precipitation by lifting the moisture over the higher terrain. The terrain-induced upward motion on the west side of the mountains coincided with the moisture (relative humidity) maximum. A less well-defined couplet of upward and downward motion was also evident in the vicinity of the Cumberland Plateau in east Tennessee. The strong wind flow nearly perpendicular to the Appalachians produced a mountain wave that was apparent in the potential temperature and vertical motion fields.

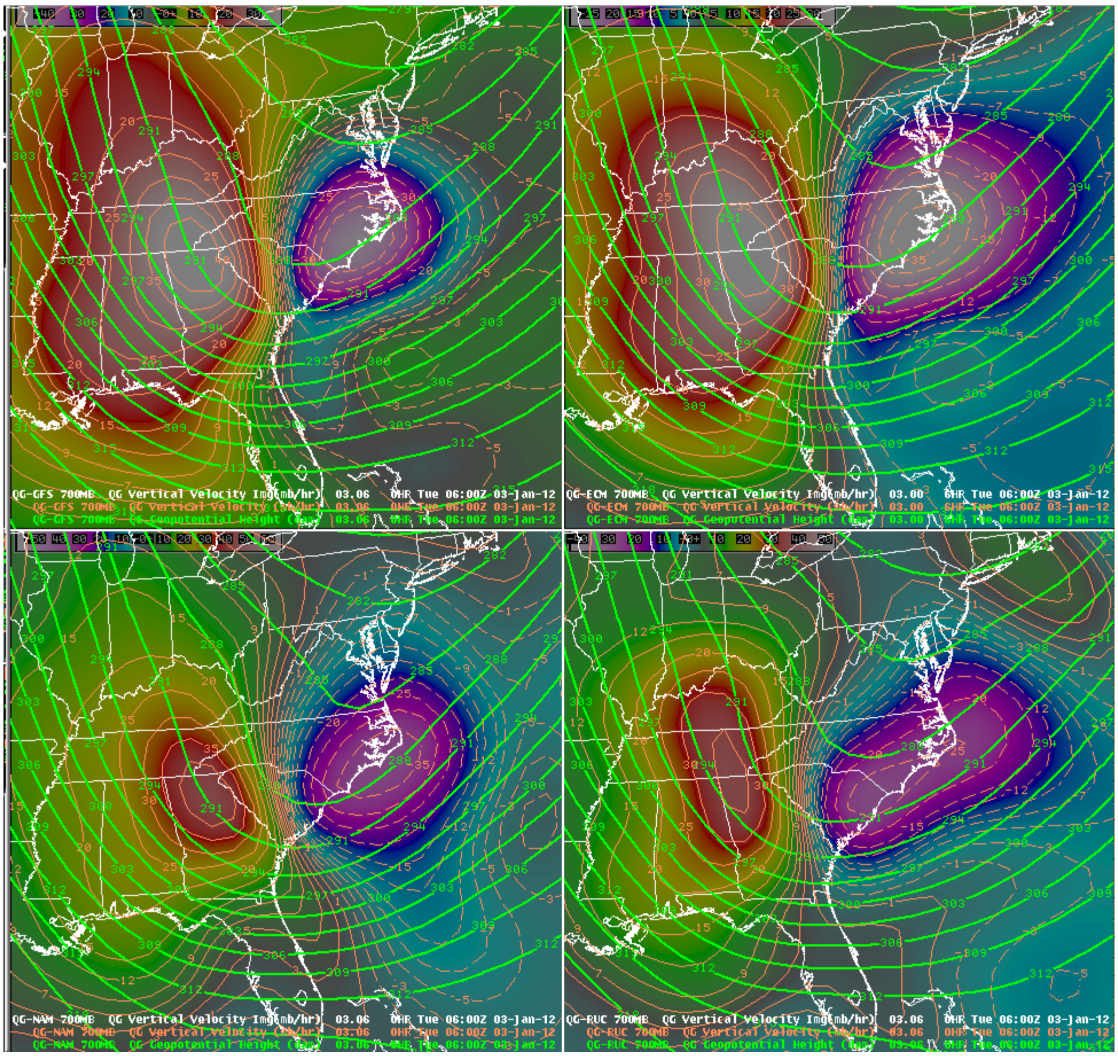


**Fig. 11. Quasigeostrophic 700 mb diagnostic charts at 0600 UTC on 3 January 2012. Height contours are green solid lines. Shading denotes vertical motion (downward, yellow and red; upward, blue and purple). Models clockwise from upper left: GFS (Global Forecast System), ECMWF (European Center for Medium Range Weather Forecasts), RUC (Rapid Update Cycle), and NAM (North American Mesoscale). [Thaler and Nutter (2009)]**

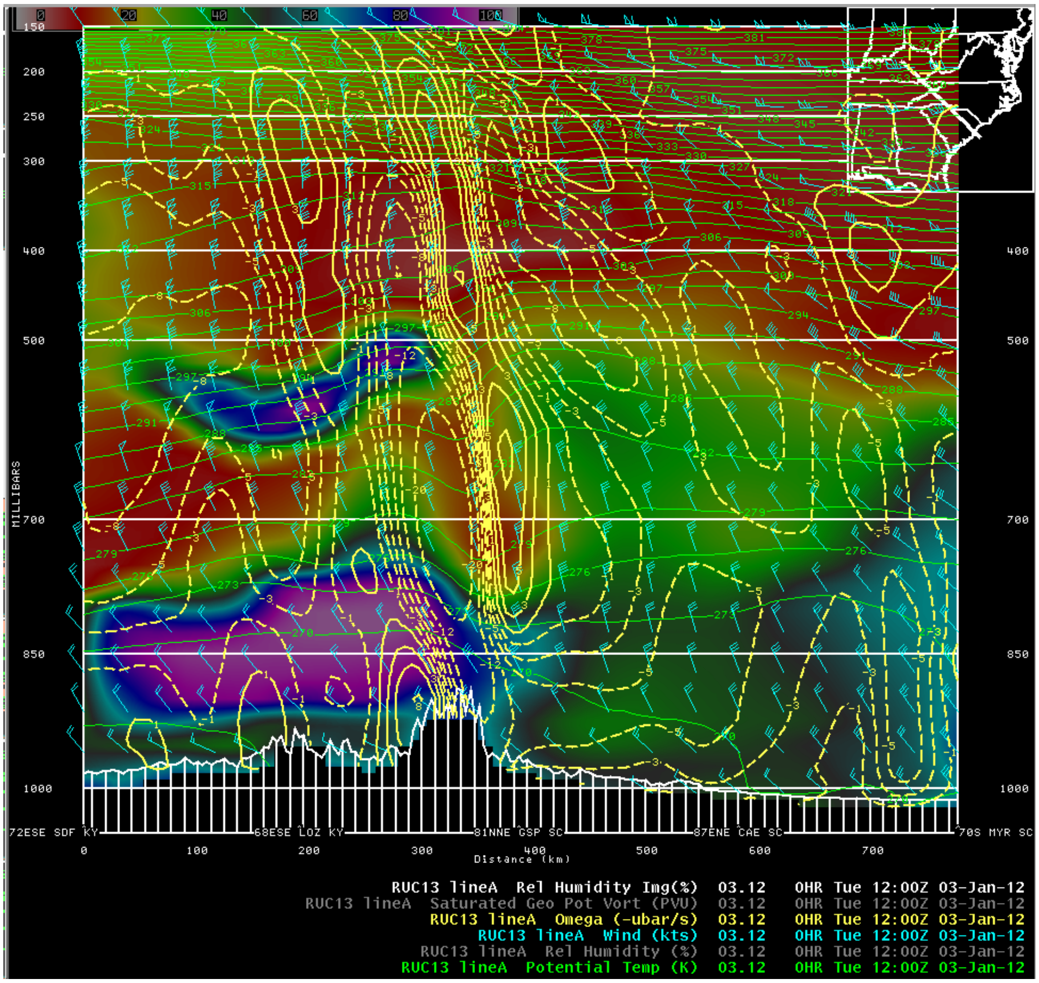


**Fig. 12. RUC cross-section from eastern Kentucky (left-hand side) to the South Carolina coastal waters (right-hand side) at 1200 UTC on 3 January 2012. Orange to green to purple shades represent increasing relative humidity. Yellow lines depict vertical motion (solid, upward; dashed, downward). Potential temperature is represented by solid green contours, and wind speed and direction are denoted by flags.**

The WFO GSP recently has been investigating ways to better assess the potential for accumulating snowfall when moist northwest flow arrives in the southern Appalachians. In particular, a quantity known as the Froude number (Stull 1988) is being routinely archived from computer model simulations. The Froude number is a dimensionless value that reflects the ratio of wind speed perpendicular to the mountain chain to the stability of the air parcels impinging on the mountains. Previous studies (Holloway 2007) indicate that air parcels upstream of the western North Carolina mountains often exhibit fairly high Froude numbers when accumulating northwest flow snowfall occurs. It is believed that these elevated Froude numbers result from both the higher wind speeds in typical northwest flow snow scenarios and the transfer of surface moisture into the boundary layer – possibly from the Great Lakes.

The northwest flow snow episode of 2 and 3 January 2012 provided an interesting case in which Froude numbers were observed to be elevated, but the source of the upstream moisture was somewhat in question. To examine the history of an air parcel arriving in the southern Appalachians, a backward trajectory plot from Boone, NC (TNB) starting at 0000 UTC on 3 January 2012 was examined (Fig. 13). This simulation was produced from the 1200 UTC on 31 December 2011 run of the Global Forecast System (GFS) model. Parcels arriving at 500 m above TNB appeared to originate from western Canada and the northern Great Plains. There seems to be little to no evidence of any significant Great Lakes moisture tap for this period, which marked the start of the most intense northwest flow.

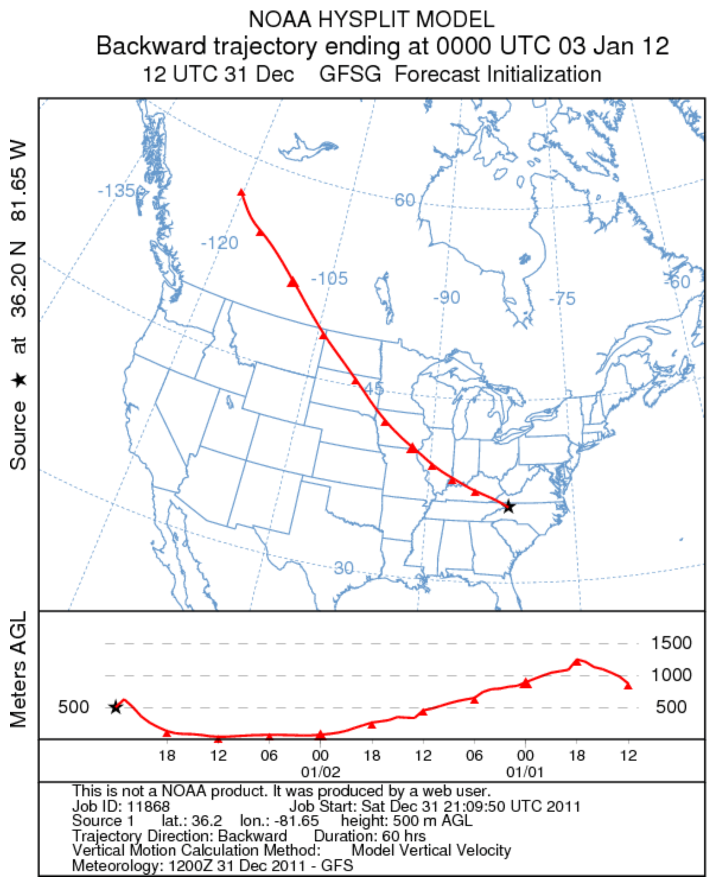


**Fig. 13. NOAA HYSPLIT model GFS backward trajectory originating at Boone, North Carolina at 0000 UTC on 3 January 2012 and ending at 1200 UTC on 31 December 2011.**

The resulting shallow moisture in the northwest flow on the GFS produced some rather meager storm total snowfall accumulation forecasts in the upslope prone locations (Fig. 14). Projected snowfall accumulations were less than one-half inch through 1200 UTC on 3 January 2012 across the Tennessee border area of the northern and central North Carolina mountains.

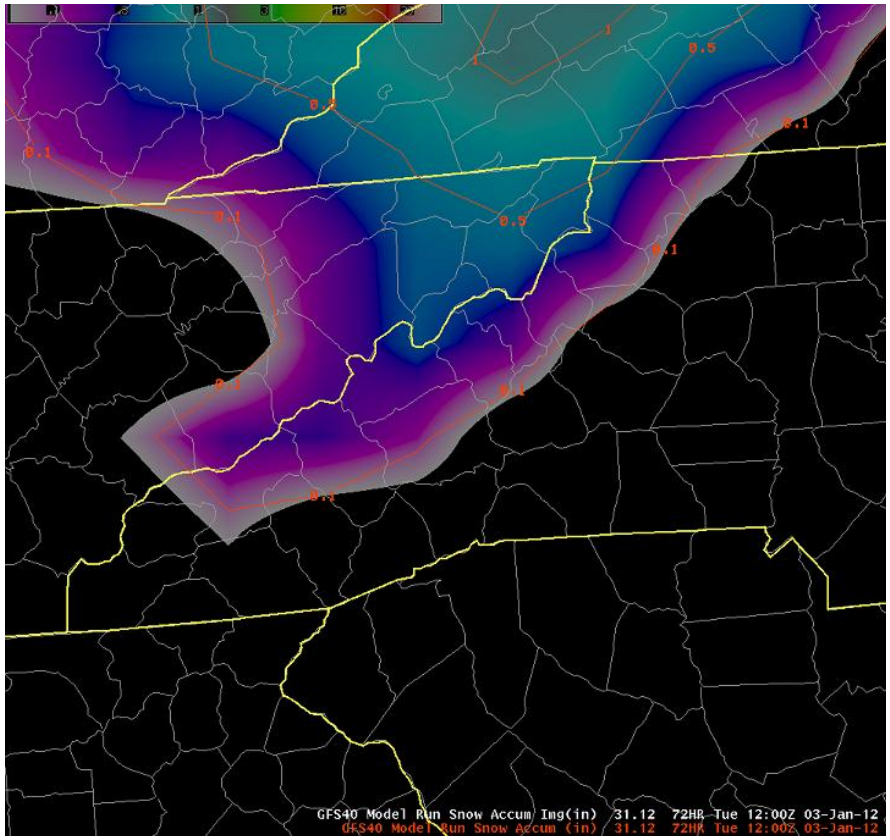


**Fig. 14. GFS snow accumulation through 1200 UTC on 3 January 2012. Red contours are 0.1, 0.5, and 1.0 inch.**

Interestingly, however, upstream Froude numbers from the GFS indicated a fairly solid area of 6.0 units northwest of the southern Appalachians at 0000 UTC on 3 January 2012 (Fig. 15). An informal examination of northwest flow snow events from the winter of 2010 - 2011 indicated some correlation between upstream Froude numbers greater than 1.0 and advisory level snowfall (greater than 2 inches) when typical northwest flow indicators were present (e.g., low-level moisture, orthogonal northwest flow, and temperature profiles supportive of snow as the predominant precipitation type). Values as high as 6.0 in such flow regimes would seem to indicate very high potential for advisory criteria accumulation. (Note that no significant correlation has yet been established between upstream Froude numbers and warning criteria snowfall; i.e., accumulations greater than 4 inches.)

It appears possible in this case that the relatively high Froude numbers may have been partially due to very moist soil conditions across much of the Midwest (Fig. 16). The moist surface conditions could have provided a source of low level moisture and resulting instability in the absence of any significant or prolonged fetch from the Great Lakes.

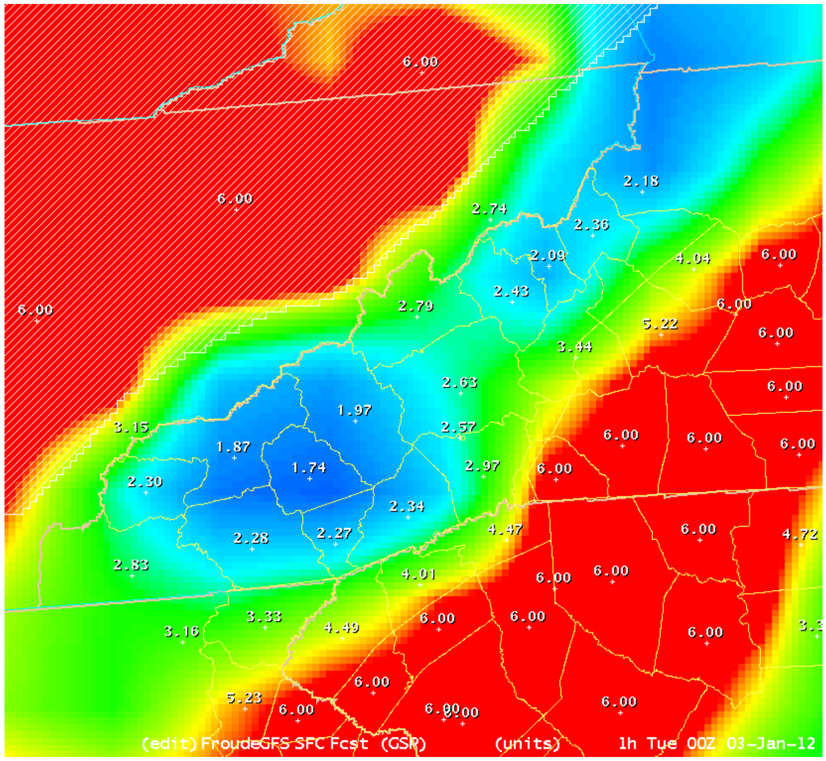


**Fig. 15. GFS Froude numbers valid at 0000 UTC on 3 January 2012.**

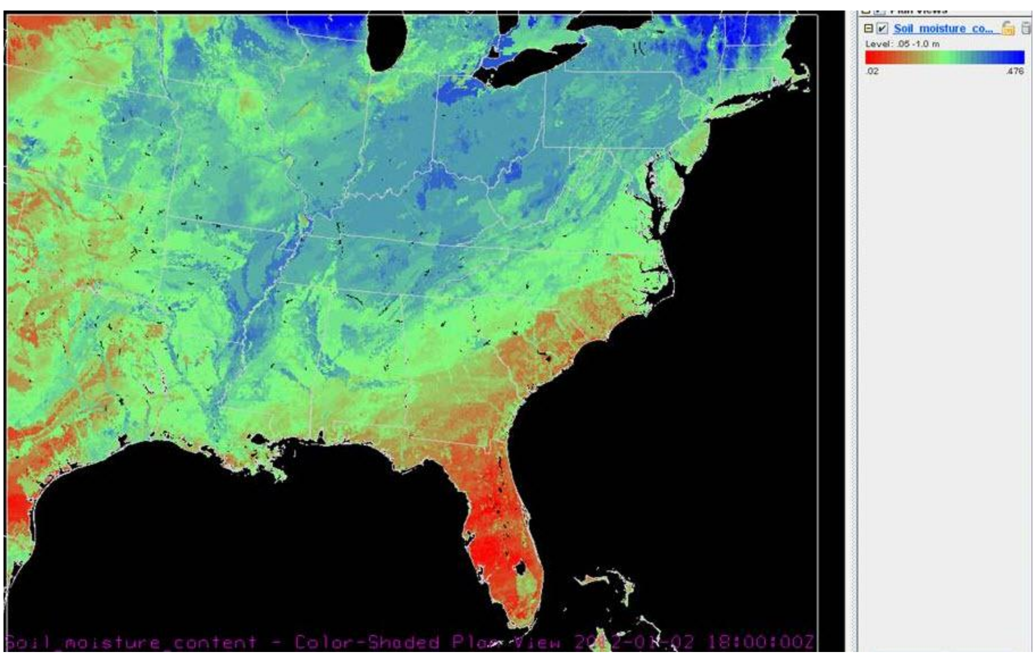


**Fig. 16. NASA SPoRT (Short-term Prediction Research and Transition Center) 0 - 10 cm soil moisture content analysis at 1800 UTC on 2 January 2012. Scale is in the upper right. Moisture increases from red through green to blue.**

Future events will be examined to monitor the correlation between upstream Froude numbers and resulting northwest flow snow accumulations to see if quantitative guidance can be developed.

### 4. Observations

The surface observations at the Asheville Regional Airport (KAVL) displayed the typical variability of weather elements observed during northwest flow snow events (Table 1). Strong and gusty northerly winds were accompanied by rapidly changing ceiling and visibility as snow showers moved across the area. Only a trace of snow was observed. A number of other locations in the WFO GSP CWA had small accumulations (Table 2).

**Table 1**

| Asheville Regional Airport | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Date** (January) | **Time** (EST) | **Wind** (mph) | **Visibility** (mi.) | **Weather** | **Sky** (ft. AGL) | **Air** (°F) | **Dewpoint** (oF) |
| 2 | 1654 | N14G28 | 10.00 | Few Clouds | FEW060 | 31 | 9 |
| 2 | 1754 | N16G28 | 6.00 | Light Snow | BKN021 OVC060 | 26 | 18 |
| 2 | 1854 | N20G25 | 1.75 | Light Snow | BKN013 OVC019 | 24 | 20 |
| 2 | 1954 | N21G30 | 1.75 | Light Snow | BKN027 BKN035 | 22 | 16 |
| 2 | 2054 | NW20G25 | 2.00 | Light Snow | OVC024 | 21 | 14 |
| 2 | 2154 | NW22G30 | 7.00 | Light Snow | BKN041 OVC048 | 21 | 11 |
| 2 | 2254 | N16G33 | 9.00 | Light Snow | OVC036 | 20 | 9 |
| 2 | 2354 | N9G18 | 10.00 | Mostly Cloudy | FEW030 BKN043 | 19 | 9 |
| 3 | 0054 | NW22G29 | 1.75 | Light Snow | OVC020 | 17 | 11 |
| 3 | 0154 | NW24G32 | 9.00 | Light Snow | BKN026 OVC034 | 18 | 8 |
| 3 | 0254 | NW21G33 | 10.00 | Overcast | OVC033 | 18 | 7 |

**Table 2**

| Snow Accumulation – 2 and 3 January 2012 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Georgia** | **Amount (in.)** | **South Carolina** | **Amount (in.)** | **North Carolina** | **Amount (in.)** | **North Carolina** | **Amount (in.)** |
| Clayton | Trace | Caesar's Head | Trace | Flat Springs 1E | 3.1 | East Flat Rock | 0.5 |
| Rabun Gap | 0.2 | Travelers Rest | Trace | Beech Mountain | 1.5 | Cullowhee | 0.7 |
| Dillard | 0.1 | | | Asheville 6 NNW | 0.5 | Highlands | 1.5 |
| | | | | Barnardsville 2 SE | 0.7 | Marshall | 1.0 |
| | | | | Stecoah | 0.5 | Brevard 1 W | 1.0 |
| | | | | Waynesville 4E | 4.2 | Mt. Mitchell | 3.0 |
| | | | | Buladean 2 N | 6.0 | Banner Elk 2 NNW | 2.5 |

Upper air observations every three hours from 0000 UTC until 1200 UTC on 3 January were provided by a team from the Department of Atmospheric Sciences at the University of North Carolina – Asheville. The data collection was initiated during an intensive observation period (IOP) as part of the $SEMPE_{1112}$ field project.[1] The soundings were released from the campus of Warren Wilson College in Swannanoa, North Carolina, which is about nine miles east of downtown Asheville and about fifteen miles northeast of KAVL.

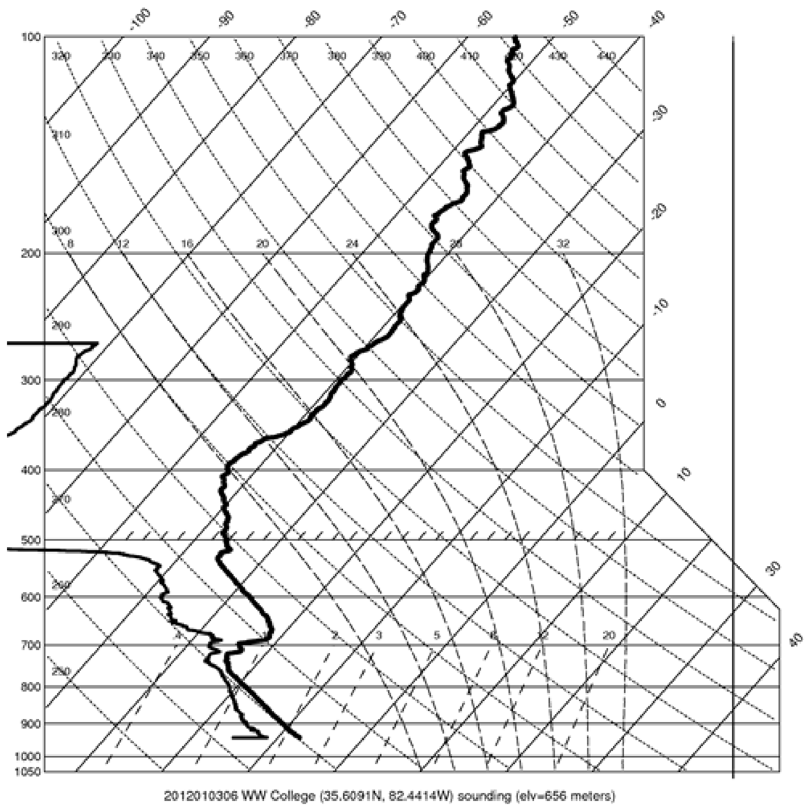


**Fig. 17. Temperature and dewpoint profile from a $SEMPE_{1112}$ IOP-2 sounding at Swannanoa, North Carolina at 0600 UTC on 3 January 2012.**

The 0600 UTC temperature and dew point profile showed that most of the moisture was confined to the layer below an inversion near 700 mb. The surface (2152 ft MSL; 941.5 mb) temperature was -7.5$^{o}$ C, and the 850 mb temperature was -14.8$^{o}$ C. The time of this sounding coincided with the radar reflectivity image in Fig. 10. The $SEMPE_{1112}$ field team observed light snow when the balloon was launched.

[1] The Sounding-based Experiment on Mixed Precipitation Events (SEMPE) over the past three winters (2009-2010, 2010-2011, 2011-1012) has been funded by internal research grants at UNC Asheville. The experiment is designed to record observations during potentially high-impact cold season events for Buncombe County, focusing primarily on precipitation and/or wind storms that can impact travel in the region. It is intended to serve as a prototype for an eventual collaboration between future and current science teachers in the Buncombe County Schools as a new instrument for teaching science to undergraduate and K-12 students.

Wind data were not available from the SEMPE$_{1112}$ sounding. A NAM 0600 UTC profile (Fig. 18) provided a model depiction of the wind structure at KAVL – about fifteen miles southwest of Swannanoa. Northwest winds existed through a deep, surface-based layer, and speeds were generally between 30 and 35 kt near ridge top level (approximately 800 mb). The NAM profile also showed the favorable snow growth temperatures (-12°C to -18°C) in the shallow layer of low-level moisture.

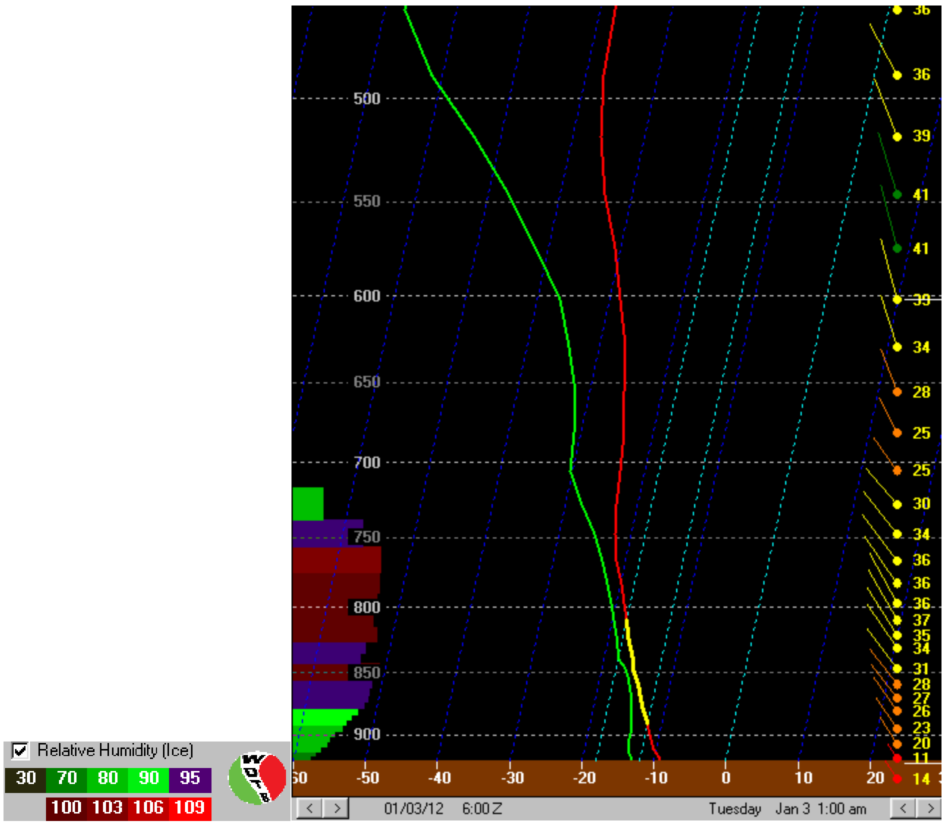


**Fig. 18. NAM 0600 UTC on 3 January 2012 0-hour profile of temperature (red line), dewpoint (green line), and wind (vector and speed in kt) at KAVL. Favorable snow growth temperatures highlighted in yellow. Color bars on left-hand side represent relative humidity with respect to ice (key to left of image). [Created with Bufkit v11.]**

## 5. Summary

A period of northwest flow snow occurred in the southern Appalachians following the passage of a cold front on New Year's Day 2012. Snow accumulations in the mountains of North Carolina, upstate South Carolina, and extreme northeast Georgia ranged from a trace to about six inches. Even though accumulations were not great, significant travel disruption occurred because a thin layer of ice formed in many locations at the onset of the precipitation and many of the snow showers produced reduced visibility. A significant moisture source was the large field of stratiform clouds that was left in the wake of the low pressure system that moved across the northeastern United States. Satellite and radar imagery showed the precipitation was associated with small convective elements that were cellular in nature during the day and generally linear at night. An experimental low-level stability analysis tool and backward air parcel trajectories indicated that another possible source of boundary layer moisture was evaporation from areas west of the mountains that moist soil conditions.

*Acknowledgments*

The upper air maps were obtained from the NCEP/Storm Prediction Center. The surface analyses came from the NCEP/Hydrometeorological Prediction Center. The UCAR/NCAR Research Applications Laboratory created the regional radar reflectivity mosaics. The backward trajectory analysis was computed using the NOAA/Air Resources Laboratory HYSPLIT model. NWS Eastern Region Scientific Services Division provided the NASA Short-term Prediction Research and Transition (SPoRT) Center Land Information System soil moisture content analysis. Dr. Douglas K. Miller, Department of Atmospheric Sciences at the University of North Carolina-Asheville, supplied information regarding $SEMPE_{1112}$. Patrick Moore reviewed this report and provided quality control.

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