An Early Season Snow Event – 28-31 October 2012

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1. Introduction

Cold air and moisture circulating around the western periphery of Hurricane and Post-tropical Storm Sandy contributed to a period of primarily northwest flow snow in the southern Appalachians during the last few days of October 2012. The storm moved inland as an extratropical cyclone in southern New Jersey during the evening hours on 29 October and subsequently traveled westward into Pennsylvania on 30 and 31 October before drifting northward into Canada (Blake et al. 2013; Fig. 1). The track and slow movement of the storm prolonged the upslope-enhanced precipitation across the mountains of North Carolina. Snowfall totals in excess of four inches were common in the Tennessee border counties, and there were isolated reports of snow depths exceeding 24 inches (Fig. 2 and list in Summary section).

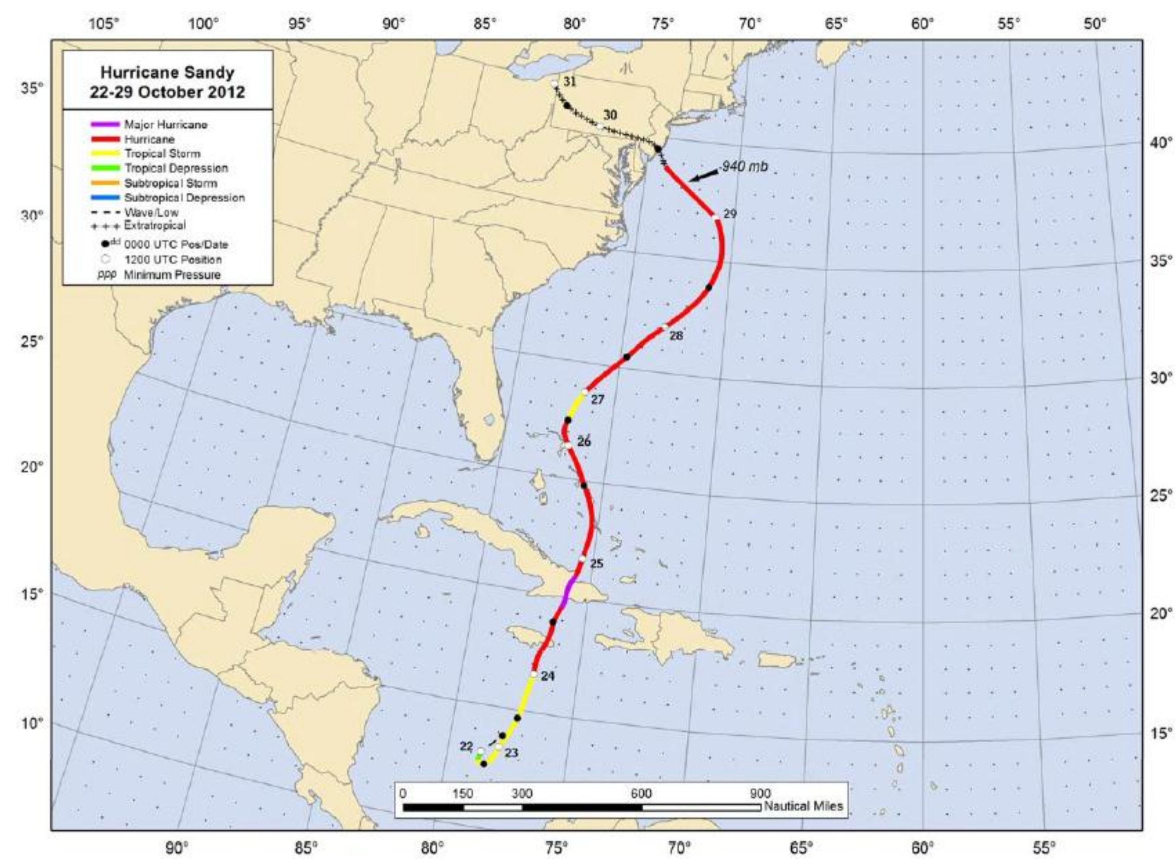


Fig. 1. National Hurricane Center best track positions for Hurricane Sandy from Blake et al. (2013).

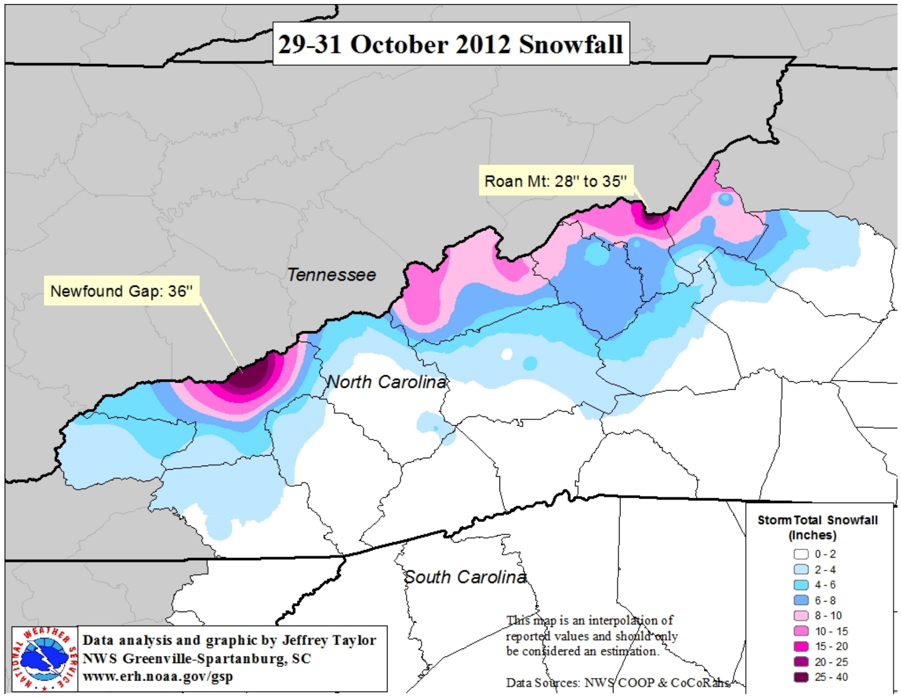


Fig. 2. Total snowfall 29-31 October 2012.

2. Synoptic Pattern

On 27 October, a deepening 500 mb trough over the central United States pushed a cold front across the Appalachians. The front on 28 October was generally aligned with the strong southerly flow aloft on the east side of the upper trough (Fig. 3a,b). Hurricane Sandy was moving northward just off the East Coast.

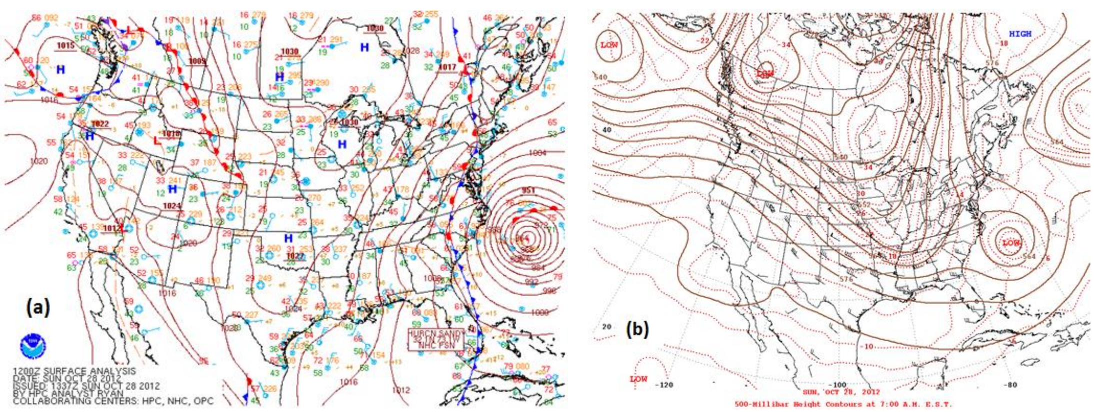


Fig. 3. Hydrometeorological Prediction Center (HPC) 1200 UTC 28 October 2012 (a) surface analysis and (b) 500 mb analysis .

Twenty-four hours later at 1200 UTC on 29 October, the southern portion of the 500 mb trough had cut off and joined with the 500 mb low associated with Hurricane Sandy to produce a double-barrel upper level low. The two low height centers were analyzed over the southern Appalachians and just east of Virginia. The surface cold front moved eastward and became ill-defined as the cold air mass swept offshore into the circulation around Sandy (Fig. 4a,b).

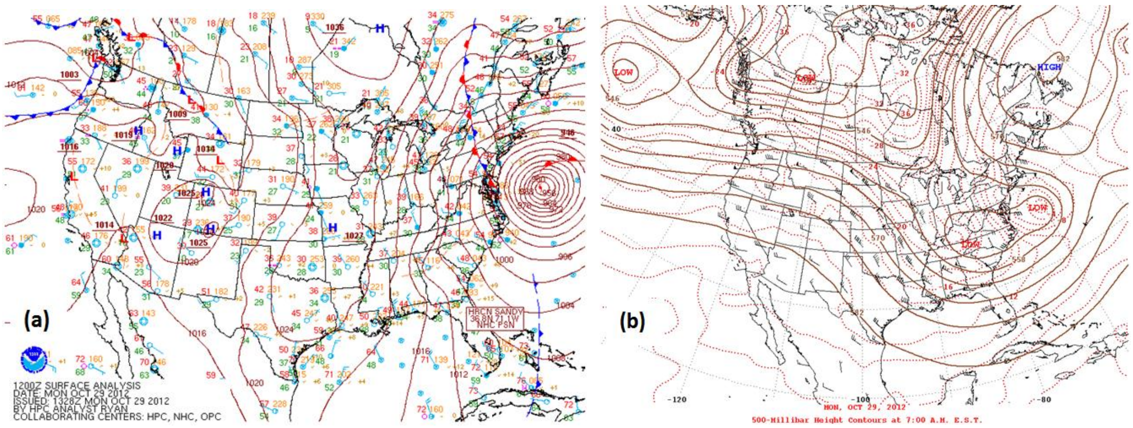


Fig. 4. Same as Fig 3a,b except at 1200 UTC 29 October 2012.

3. Precipitation Development

The northwest wind flow in the lower levels contributed to a favorable setup for terrain-enhanced snowfall in the southern Appalachians. The mountains forced strong orographic lift that produced precipitation with subsequent drying in the downslope flow in the lee of the highest ridges. Also, the mountains delayed the southeastward spread of the cold air which created a well-defined 850 mb thermal boundary from West Virginia to Georgia (Fig. 5a,b).

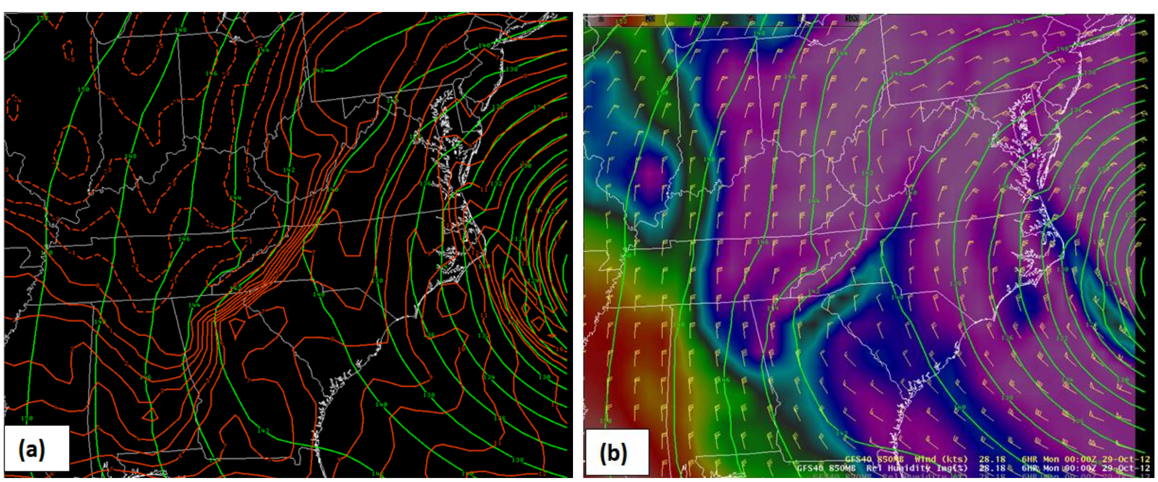


Fig. 5. (a) Global Forecast System (GFS) 850 mb height (decameters; green contours) and temperature (degrees Celsius; red contours) at 0000 UTC 29 October 2012, and (b) GFS 850 mb height (decameters; green contours), ind (knots; standard flags), and relative humidity (low to high, red to purple).

The cold air and moisture that moved into the Tennessee border counties of western North Carolina produced a vertical temperature and moisture profile favorable for snow (Fig. 6a,b). The Rapid Refresh (RAP) model 2300 UTC 29 October profile at Flat Springs in northern Avery County, North Carolina, indicated the temperature was near freezing at the surface and below freezing aloft. The Asheville Regional Airport (KAVL) RAP profile at the same time had a subfreezing temperature profile aloft, but the surface temperature was above freezing. The 2300 UTC observed surface temperature at KAVL was 39°F. The freezing level at KAVL was approximately 1,520 ft above ground level, but it lowered to just a few hundred feet by the end of the event.

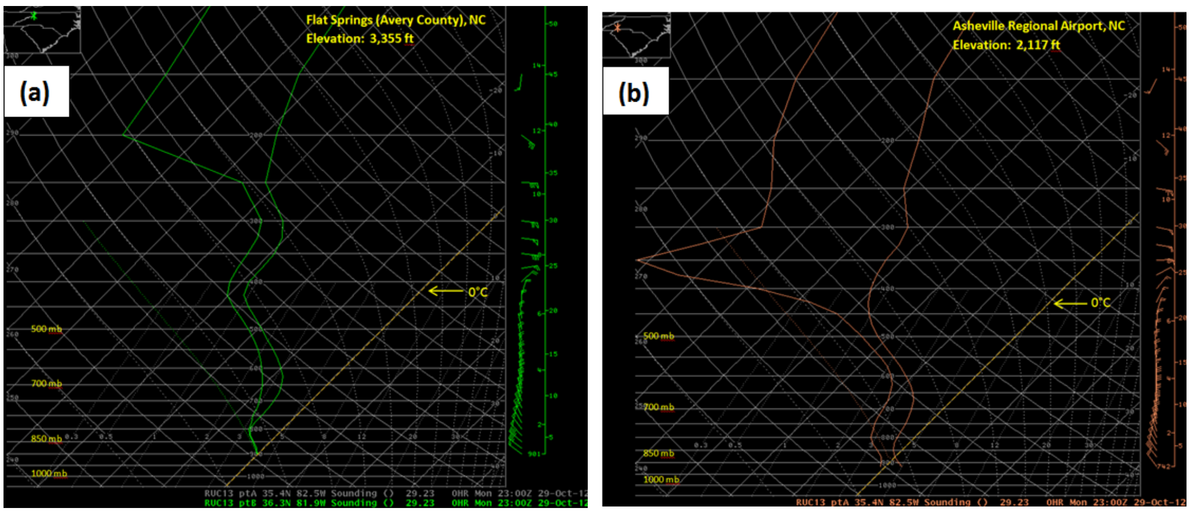


Fig. 6. RAP temperature, dew point, and wind profiles at Flat Springs, North Carolina (a) and Asheville Regional Airport (b) at 2300 UTC on 29 October 2012.

Most of the precipitation occurred where the orographic lift was strongest which was over and just downwind of the higher terrain north and west of Asheville, North Carolina. The storm total liquid equivalent precipitation at Flat Springs was 1.36 inches. The snowfall total was 10.2 inches which produced a snow to liquid ratio of 8:1. At the Mobile Precipitation Research and Monitoring Station[1] (MOPRAM) on Roan Mountain, North Carolina (elevation 6,150 ft), the snowpack contained 3.45 inches liquid equivalent and the weighing precipitation gauge contained 3.13 inches liquid equivalent. The storm total snow depth on Roan Mountain was estimated to be between 28 and 35 inches (Fig. 7).

[1] MOPRAM is funded by a grant from the National Science Foundation to the Appalachian Atmospheric Interdisciplinary Research (AppalAIR) group at Appalachian State University.

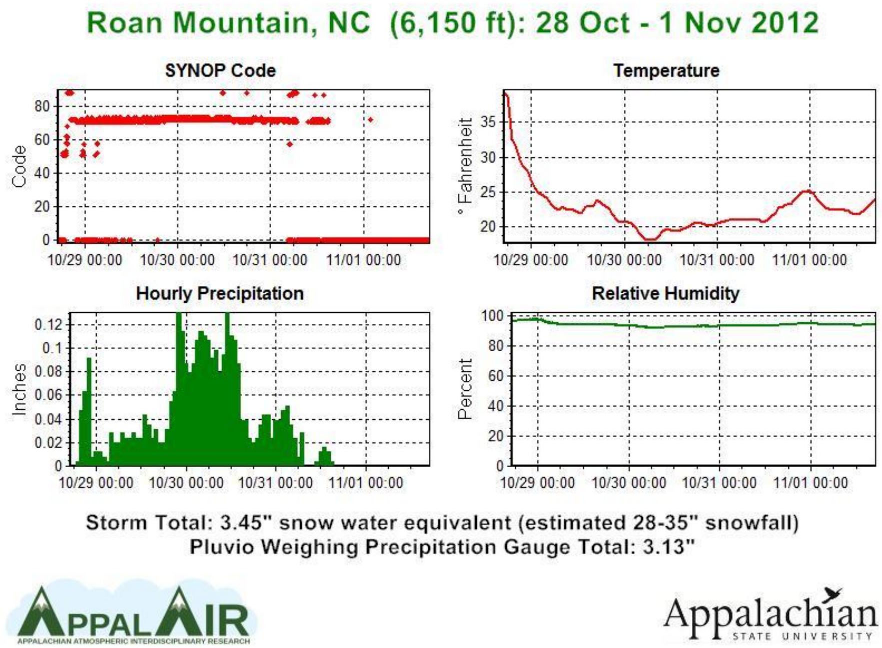


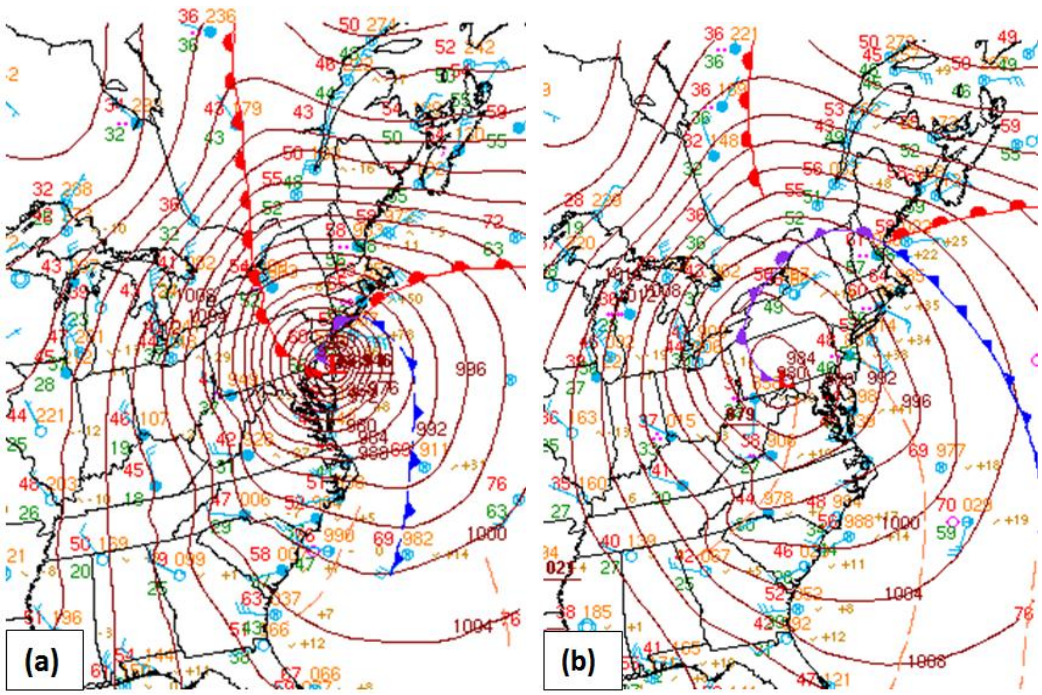
Fig. 7. Observations from MOPRAM on Roan Mountain along the North Carolina and Tennessee border. The precipitation (SYNOP) code from 71 to 73 indicates snow. Date and local standard time are on the horizontal axis of each plot. Source: Baker Perry, Ph.D., Appalachian State University.

Only 0.09 inch of rain and no snow were measured at KAVL (on 28 October). The lowest KAVL temperature during the entire event was 36°F on 30 October. The National Weather Service cooperative observation taken by the National Climatic Data Center in downtown Asheville documented 0.28 inch of liquid precipitation from 28 through 30 October which included 0.2 inch of snow on 30 October. The extended remarks portion of the downtown observation included: "…lite [light] snow on grassy sfc [surface]; numerous snow showers." The lowest downtown temperature was 32°F, also on 30 October.

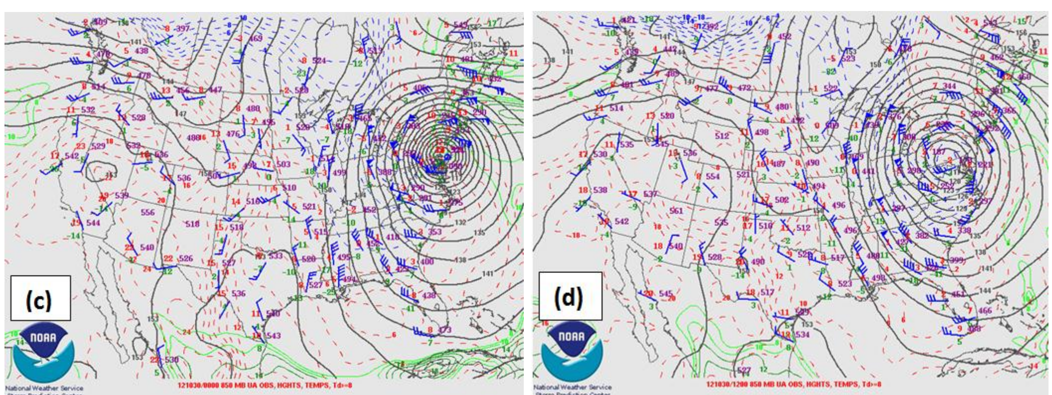
4. Mountain Wave

The remnants of Sandy moved slowly into Pennsylvania on 30 October and continued the moist upslope wind flow across the southern Appalachians (Fig. 8a,b,c,d). Throughout the event, the northwest winds from the surface to almost 700 mb maintained a vertical moisture distribution characterized by a sharp horizontal gradient across the mountains (Fig. 5b). A vertical cross-section from Kentucky to South Carolina and a plan view of the same area show the large scale terrain-induced waves that promoted upward motion over the windward slopes and downward motion in the lee (Fig. 9a,b).

Such a wave pattern is typical of northwest flow snow events and explains to a certain extent why the Tennessee border counties are prone to more precipitation in these regimes than counties to the east and southeast. What is not evident in the flow pattern across the smoothed model terrain, are the complexities introduced by smaller, ridge- and valley-scale vertical motions. The superposition of the small-scale motions on the background large-scale wave patterns contributes greatly to the highly variable snowfall amounts during periods of northwest flow.



0000 UTC - 30 October 2012 - Surface   1200 UTC - 30 October 2012 - Surface



0000 UTC – 30 October 2012 – 850 mb   1200 UTC – 30 October 2012 – 850 mb

Fig. 8. Surface (a,b) and 850 mb (c,d) analyses at 0000 UTC (left) and 1200 UTC (right) on 30 October 2012. Brown contours on surface analyses are pressure (mb). Solid contours on 850 analyses are height (dm). Dashed lines on 850 mb analyses are temperature (°C). Green contours on 850 mb analyses are dew point ≥ 8°C).

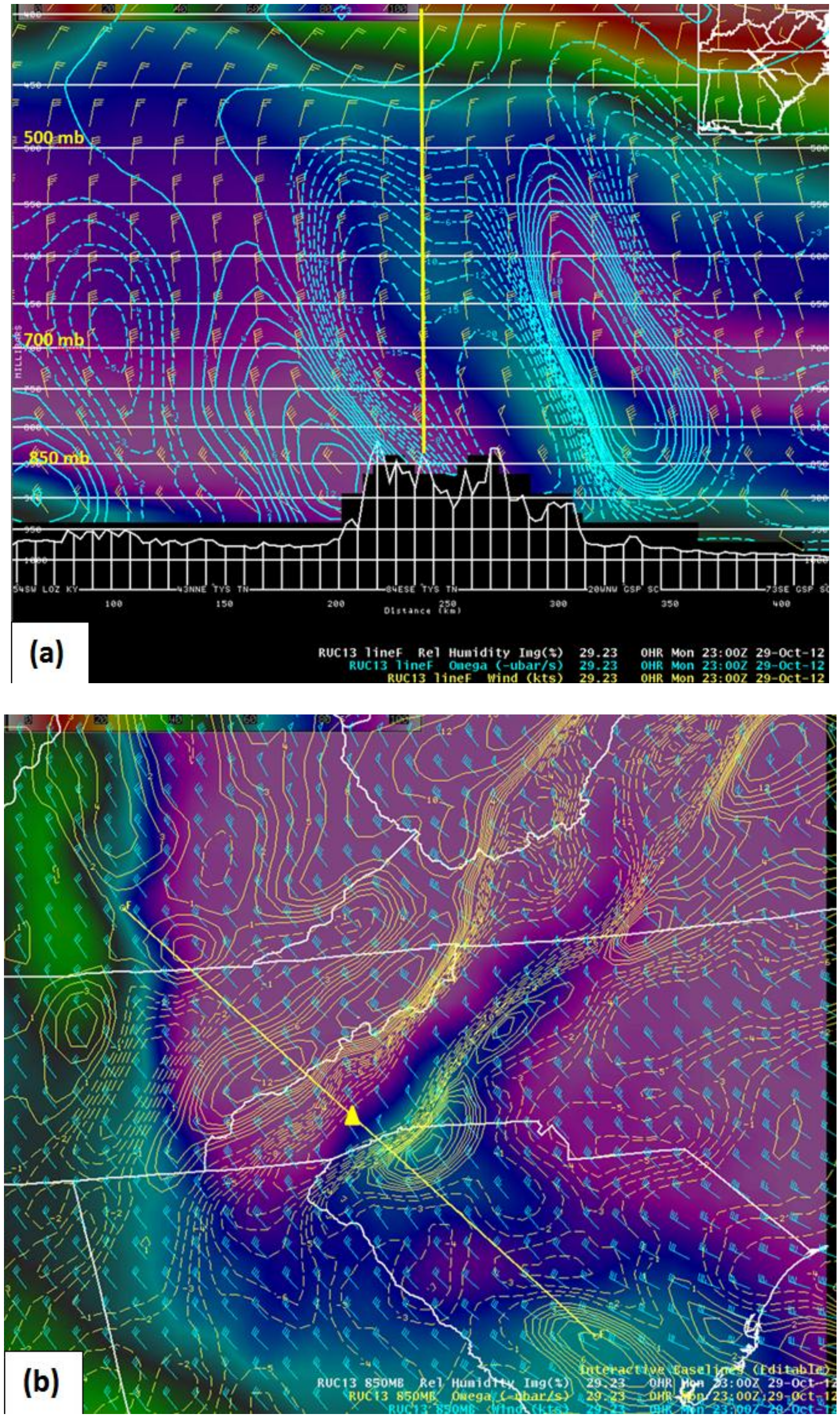


Fig. 9. (a) RAP 2300 UTC 29 October 2012 cross-section from southeast Kentucky to central South Carolina. Omega represented by blue contours (dashed, downward motion; solid, upward motion), relative humidity depicted by shades (blue, 60 to 85 percent; purple, 85 to 100 percent), and standard wind flags. Vertical line identifies approximate midpoint of cross section (triangle in bottom frame). (b) RAP 2300 UTC plan view of southern Appalachian region. Omega represented by yellow contours (dashed, downward motion; solid, upward motion), relative humidity depicted by shades (blue, 60 to 85 percent; purple, 85 to 100 percent), and standard wind flags. Line identifies cross-section in top panel. Yellow triangle identifies approximate midpoint.

5. Wind

The tight surface pressure gradient around the low pressure center produced rather strong and gusty wind. The speeds were not high enough to produce more than scattered tree damage and some power outages primarily in Buncombe, Henderson, and Polk counties in North Carolina. The highest wind gust at KAVL was 49 mph from the northwest on 29 October, and on Beech Mountain, North Carolina (5500 ft MSL), the highest wind gust was 40 mph from the west northwest on 30 October (Fig. 10). An interesting difference between the two sites, with regard to wind speed, was the greater percent of time that higher speeds were measured at Beech Mountain. This is not surprising given the elevation of the observation location.

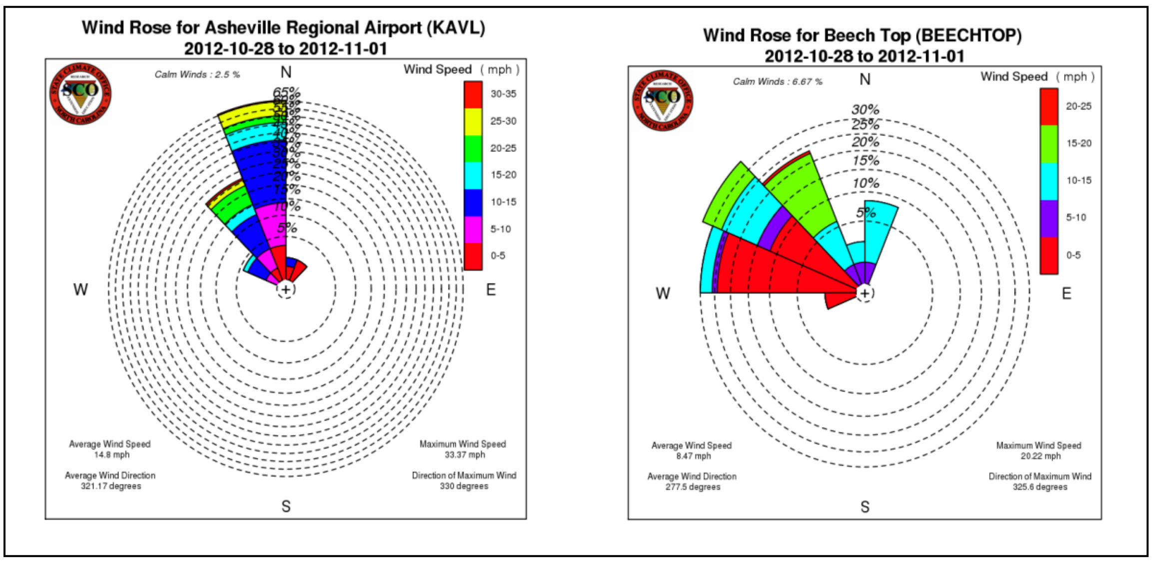


Fig. 10. Wind roses for Asheville Regional Airport (KAVL; left) and Beech Mountain (Beech Top; right) for the period 28 October through 1 November 2012. The predominant north northwest direction at KAVL is caused by the north to south orientation of the French Broad River valley. The west northwest direction at Beech Mountain is more representative of the ambient wind flow. Percentages indicate the percent of time the wind from an indicated direction had a speed in the range indicated by the color bar. Source: State Climate Office of North Carolina.

6. Radar

a. WSR-88D

During the afternoon of 28 October, an initial band of precipitation moved from southwest to northeast across the North Carolina mountains, associated with the passage of a short wave trough axis and vorticity maximum at 500 mb. The precipitation fell mainly as rain across the Great Smoky Mountains as the band moved slowly across the area from 1200 UTC to 2100 UTC. The leading edge of the precipitation band encroached upon the northern mountains of North Carolina after 1800 UTC. The National Weather Service (NWS) Doppler radar (WSR-88D) at Morristown, Tennessee (the KMRX radar), showed an apparent weakening trend in both coverage and intensity of reflectivity from 1900 UTC to 2200 UTC as the band traversed the northern mountains. At the same time, the 0.5 degree elevation scans indicated a change in precipitation type at the level of the radar beam (approximately 1000 to 5000 feet AGL). A melting layer was indicated after 2000 UTC by the zone of relatively noisy Correlation Coefficient (CC) with values in the 0.80 to 0.95 range. The top of the melting layer was approximately 4000 to 4500 feet MSL. The radar beam cut through the top of the melting layer at a range of about 46 miles, beyond which the radar showed relatively high CC values coincident with an expanding area of relatively low (0 to -0.5 dB) differential reflectivity (ZDR), indicative of dry snow. Not all the precipitation was reaching the ground as snow across the northern mountains, as indicated by the meteogram of the Roan Mountain, North Carolina, observation site (see Fig. 7). Once the back end of the precipitation band moved away from the northern mountains after 2200 UTC, a brief lull occurred across the North Carolina mountains as radar echoes diminished in coverage and cloud top temperatures warmed above -8 ^{o}C on infrared satellite imagery.

Precipitation redeveloped into the Great Smoky Mountains from eastern Tennessee after 2300 UTC on 28 October as another short wave trough approaching from the west northwest enhanced vertical motion. The precipitation extended up the mountain chain to include Madison County, North Carolina, by 0000 UTC on 29 October. The upper limit of the melting layer as detected by the KMRX radar was located very near the border between Tennessee and North Carolina, which indicated the precipitation was probably falling as either rain or wet snow depending on elevation. The precipitation appeared to be confined mainly to the Great Smoky Mountains through about 0400 UTC on 29 October, although the precipitation most likely had a shallow vertical extent preventing its detection by the lowest elevation scan of the radar. Cloud top temperatures remained warmer than -9 ^{o}C across the northern mountains apart from immediate Tennessee border area through daybreak. The cellular appearance of the radar echoes through the early morning hours of 29 October suggested a more intermittent precipitation, which was also indicated at Roan Mountain. The precipitation tapered off after approximately 0730 UTC, after which another relative lull occurred through at least 1130 UTC.

The detection of light precipitation resumed in the upslope areas of eastern Tennessee and into the mountains of North Carolina during the morning of 29 October (Fig.11) as the flow at 850 mb backed more northwesterly and strengthened in response to the movement of Hurricane Sandy (see Fig. 4). The extent of cloud top temperatures below -9 ^{o}C expanded across northeast Tennessee and over the North Carolina mountains with the exception of the upper French Broad River valley after 1200 UTC, suggesting that any precipitation could fall as snow because ice nuclei would be activated. Reflectivity on the KMRX radar was relatively low, generally under 20 dBZ, and coverage was scattered, mainly over northeast Tennessee (Fig. 12). The very high CC (greater than 0.99), low ZDR (less than -0.1 dB) and low Specific Differential Phase (KDP, less than 0.15 deg km^{-1}) indicated a dry, light snow. In fact, the precipitation in the upslope areas fell exclusively as snow at elevations above 3500 feet from this point in time onward.

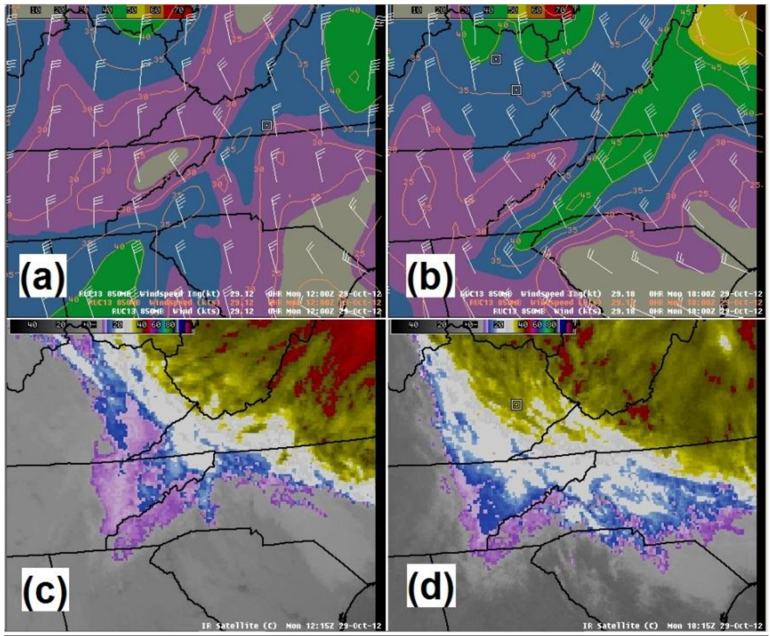


Fig. 11. Wind speed and direction (kt; isotachs and barbs) at 850 mb from the RAP initial analysis and GOES-13 Infrared satellite cloud top temperatures (°C; color fill) imagery at (a, c) 1200 UTC and (b, d) 1800 UTC on 29 October 2012. In the satellite images, purple shades correspond to temperatures in the -9 to -12 °C range, blue shades -12 to -18 °C, and white shades below -18 °C.

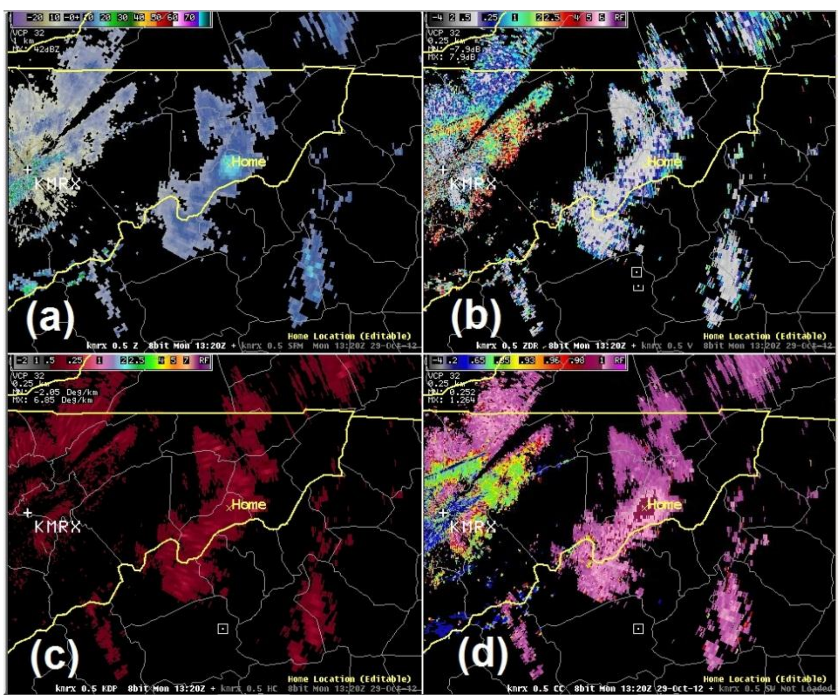


Fig. 12. KMRX 0.5 degree scans of (a) base reflectivity, (b) differential reflectivity, (c) specific differential phase, and (d) correlation coefficient at 1320 UTC on 29 October. The location labeled "home" corresponds to one of the snow-producing showers.

The coverage and intensity of radar echoes on the KMRX radar increased steadily after approximately 1600 UTC on 29 October (Fig. 13), which heralded the start of the main northwest flow snow production phase of the event. Up until that point, the NWS Doppler radar at the Greenville – Spartanburg International Airport (the KGSP radar) could only detect light precipitation echoes across Avery County, North Carolina, and east of the Blue Ridge. After 1700 UTC, the KGSP radar also detected more reflectivity across the northern mountains of North Carolina and over extreme northeast Tennessee and southwest Virginia. By this time, the center of Sandy had changed course and was moving west-northwestward toward New Jersey. The course change and the expansion of the circulation as the storm approached land allowed more moisture to advect southwestward at mid-levels (approximately 600 mb to 400 mb) during the afternoon of 29 October, providing more moisture for precipitation production (Fig. 14).

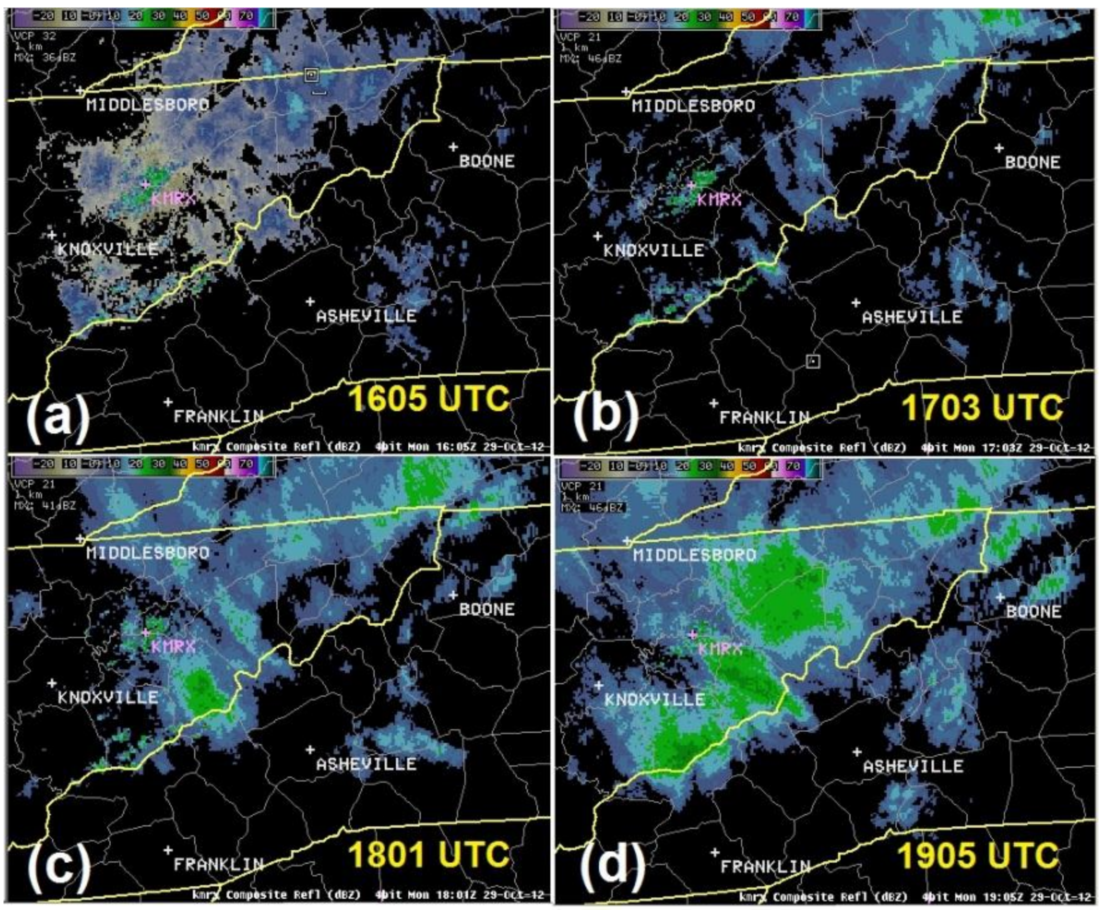


Fig. 13. Composite reflectivity from the KMRX radar at (a) 1605 UTC, (b) 1703 UTC, (c) 1801 UTC, and (d) 1905 UTC on 29 October 2012. The radar changed from "clear air" mode (VCP 32) to precipitation mode (VCP 21) on the 1703 UTC scan.

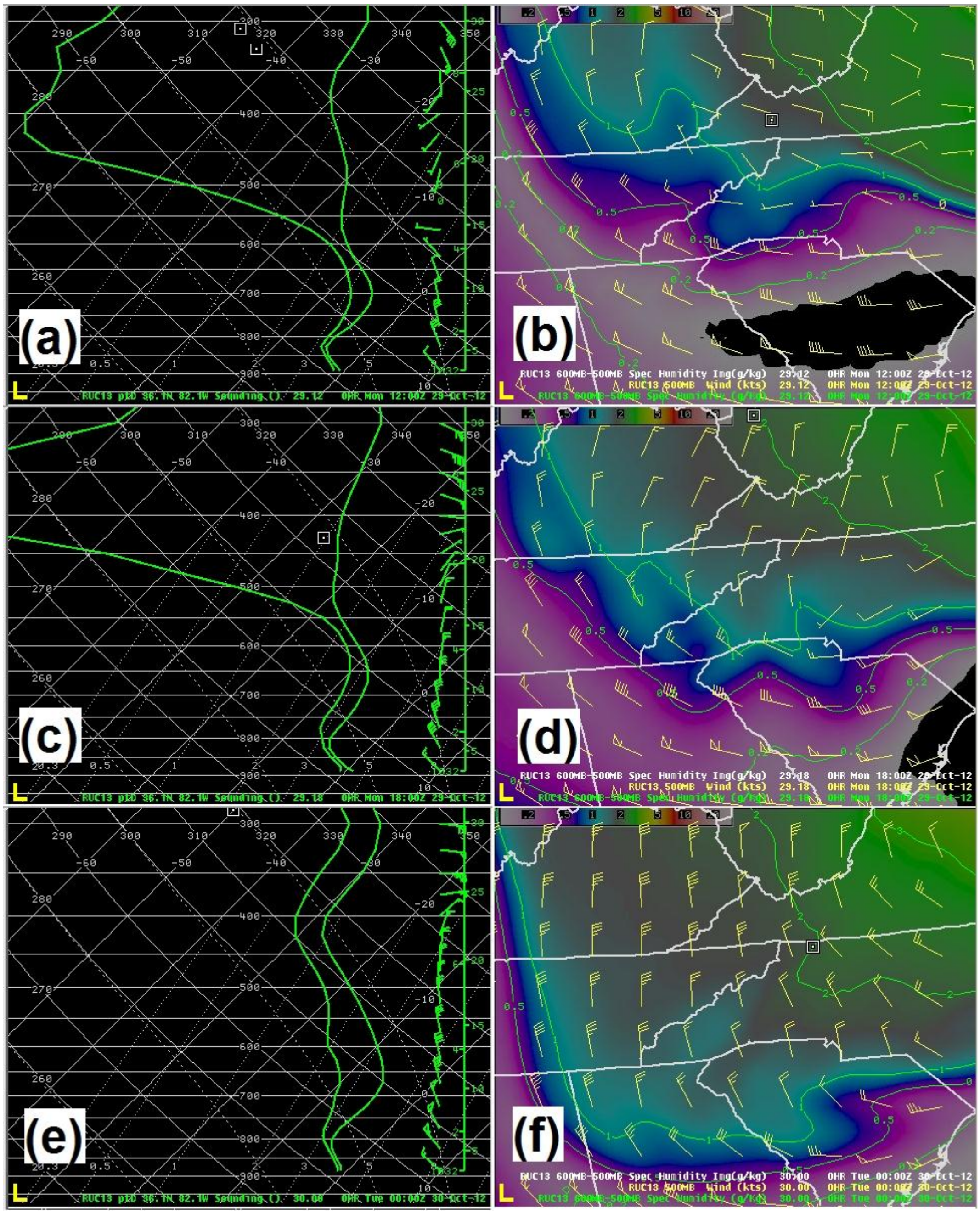


Fig. 14. RAP initial hour temperature, dewpoint, and wind profiles (left hand images) and specific humidity in the 600 - 500 mb layer (g kg^{-1}; green contours and color fill) and 500 mb wind (kt; barbs) (right hand images) at (a, b) 1200 UTC 29 October 2012, (c, d) 1800 UTC 29 October 2012, and (e, f) 0000 UTC on 30 October 2012.

The label "northwest flow snow" was somewhat of a misnomer for this event, at least at the beginning. Between 1600 UTC on 29 October and 0000 UTC on 30 October, the radar echoes with a reflectivity of greater than 20 dBZ showed a pronounced north-northeast to south-southwest movement (Fig. 15). The unusual direction of motion was perhaps due to a mean wind in the cloud-bearing layer that contained a significant northerly to northeasterly component as the result of a shear axis on the outer edge of the circulation associated with Hurricane Sandy off the East Coast. Initial hour vertical profiles of temperature, dewpoint, and wind from the 0000 UTC run of the RAP model showed northwest flow up to about 650 mb, but above that pressure level the wind veered to a northerly direction up to about 400 mb (see Fig. 14e). Around 350 mb, the wind veered sharply to the east and strengthened as a manifestation of the enhanced anticyclonic outflow from Sandy. Meanwhile, the small difference between the temperature and dewpoint profile up to 250 mb indicated the atmosphere was saturated with respect to ice well above 30000 feet, which made the profiles even more noteworthy. It was not until after 1700 UTC on 30 October that RAP initial hour soundings showed a deep (*i.e.,* surface to tropopause) northwesterly flow, which continued from that point onward until the end of the event.

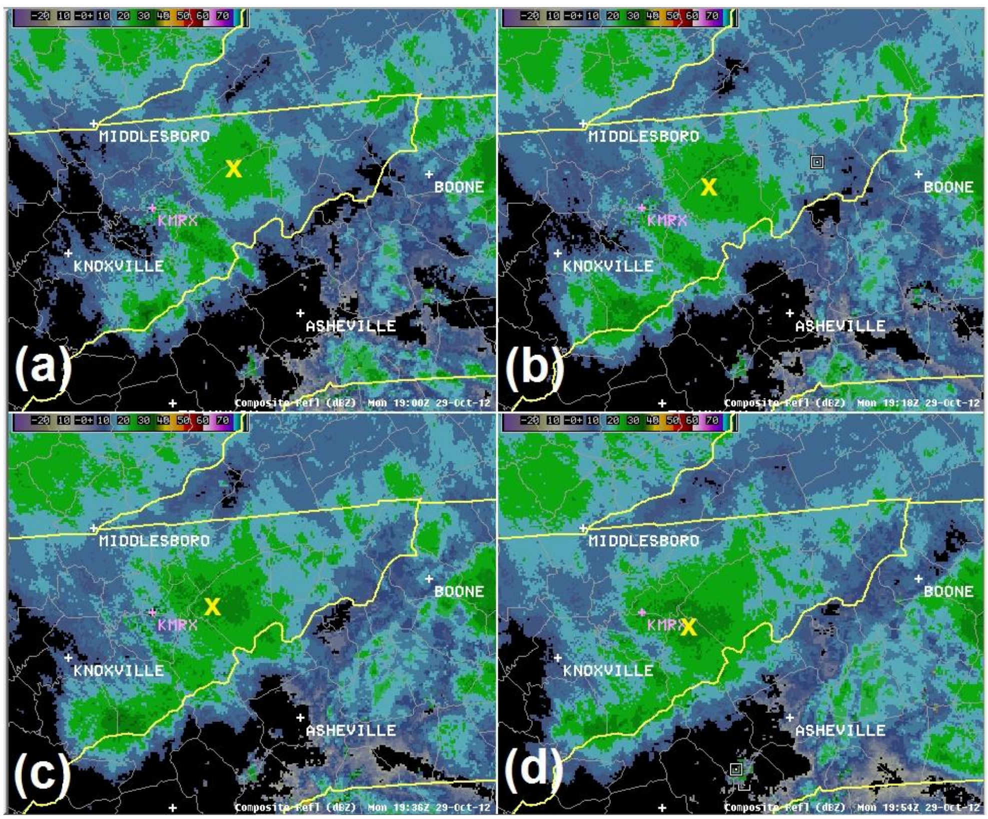


Fig. 15. Composite radar reflectivity mosaic at (a) 1900 UTC, (b) 1918 UTC, (c) 1936 UTC, and (d) 1954 UTC on 29 October 2012. An area of higher reflectivity moving south southwest over northeastern Tennessee is marked with an 'x' for clarity.

Meanwhile, the increase in moisture above 700 mb after 1700 UTC on 29 October revealed the presence of the mountain wave (see Fig. 9) on the east slopes the Appalachians as hydrometeors grew to a large enough size and concentration to be detectable by the KMRX radar. The reflectivity images from KMRX on the lowest four elevation scans at 2300 UTC on 29 October clearly show the band of enhanced reflectivity oriented parallel to the mountain chain denoting the upward moving current in the lee side mountain wave, tilted in the upstream direction with height (Fig. 16). The detection of the wave feature by radar was significant because it was indicative of the mechanical forcing provided by the strong northwesterly upslope flow at low- to mid-levels and the relatively deep moisture that could fuel the production of light snow over the western slopes of the mountains. The radar signature of the mountain wave on the KMRX radar persisted until the late afternoon of 30 October, but could be seen once again as it redeveloped during the early morning hours on 31 October.

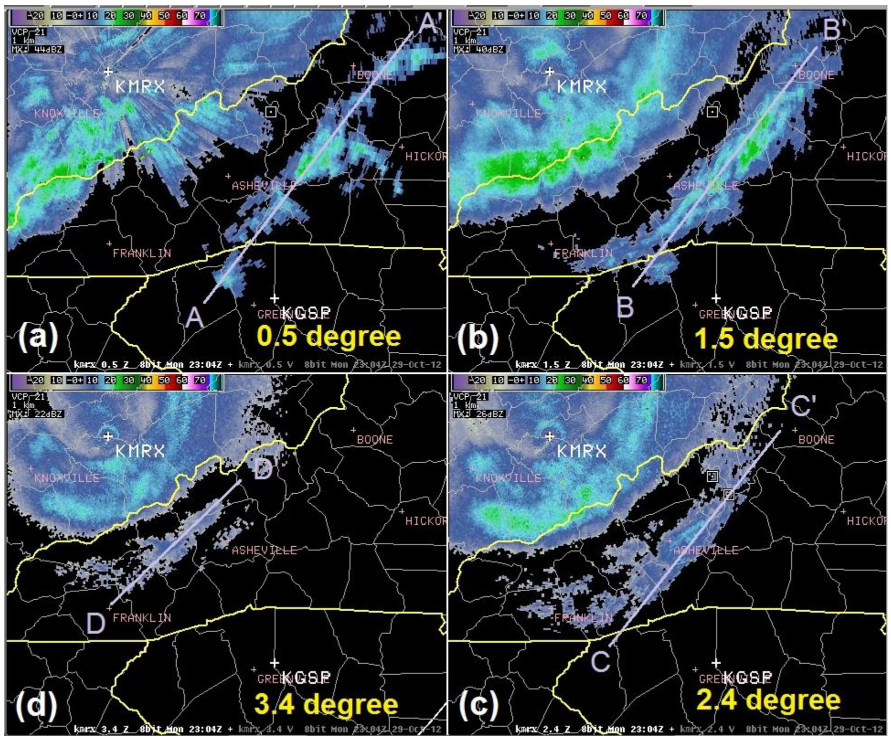


Fig. 16. Base reflectivity from the KMRX radar at 2304 UTC on 29 October 2013 on the (a) 0.5 degree, (b) 1.5 degree, (c) 2.4 degree, and (d) 3.4 degree scans. The lines indicated in each quadrant correspond to the mountain wave signature at that elevation.

After about 2200 UTC on 29 October, the composite reflectivity product from KMRX showed a large area of reflectivity greater than 5 dBZ covering nearly all of southeastern Kentucky, southwestern Virginia, and northeast Tennessee within 105 miles of the radar. The widespread low reflectivity while the radar was in precipitation mode (Volume Coverage Pattern [VCP] 21) with higher amounts (up to 20 to 25 dBZ) over portions of the Smokies was indicative of the light snow falling from northeast Tennessee and into the mountains of North Carolina. The widespread coverage of light reflectivity continued unabated overnight and did not wane until after 1500 UTC on 30 October. This time period corresponded roughly to the most intense precipitation accumulation observed at Roan Mountain. Numerous linear wave-like features were noted in the reflectivity field moving from northeast to southwest (Fig. 17), and were even more apparent after the radar was placed in clear-air mode (VCP 32) after 0600 UTC. The waves might have been related to the circulation around Sandy, the center of which moved across southern New Jersey to south central Pennsylvania during the night of 29 October and morning of 30 October. The cessation of these wave-like features corresponded roughly to the rapid backing of the flow from northeast to northwest in the layer from 500 mb to 300 mb in the 1400 UTC to 1700 UTC time frame seen on RAP initial hour soundings on 30 October (Fig. 18). The center of the remnant circulation of Sandy also turned northward across southwestern Pennsylvania between 1500 UTC and 1800 UTC. It was during this time period that a general decrease in radar coverage was also observed, with echoes displaying a northwest to southeast motion after 1700 UTC.

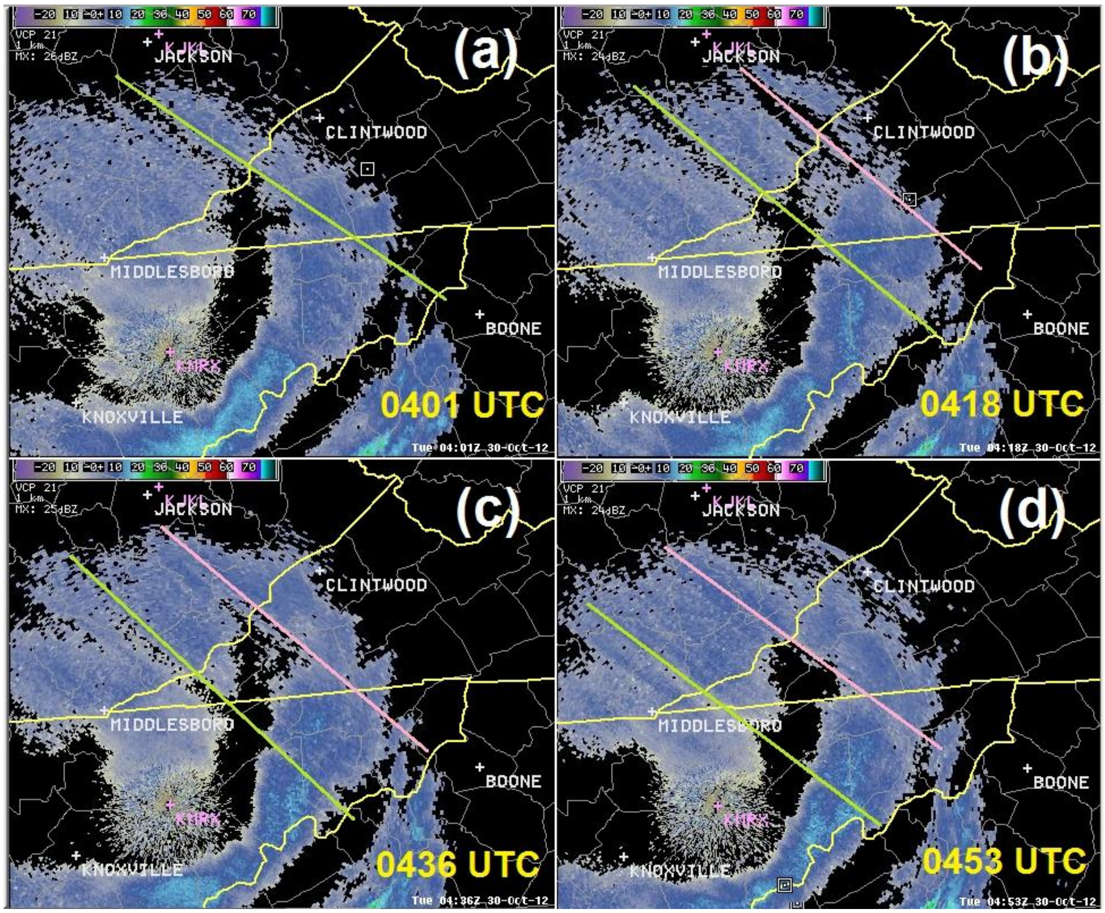


Fig. 17. KMRX base reflectivity on the 2.4 degree elevation scan at (a) 0401 UTC, (b) 0418 UTC, (c) 0436 UTC, and (d) 0453 UTC on 30 October 2012. The first wave-like feature is shown by the green line and the second wave is shown by the pink line. The approximate height of the radar beam in the vicinity of the wave features is between 10000 feet and 20000 feet MSL.

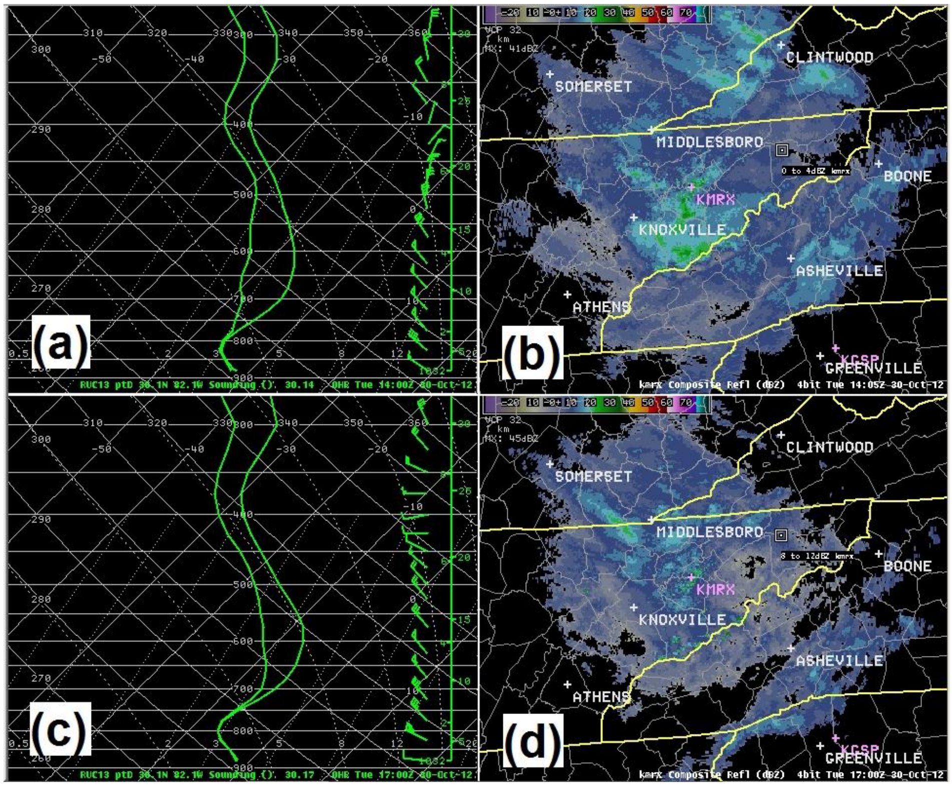


Fig. 18. RAP initial hour profiles of temperature, dewpoint, and wind (left hand images) and KMRX composite reflectivity (right hand images) at (a, b) 1400 UTC and (c, d) 1700 UTC on 30 October 2012.

The expanding shield of high cloudiness around the remnant circulation of Sandy made it difficult to discern the path of moisture moving toward the North Carolina mountains at low and mid-levels. It was not until the remnant circulation turned northward on the morning of 30 October and the high clouds thinned that a plume of cloudiness and moisture was revealed in the infrared imagery curving northwest and north from northwest North Carolina to the vicinity of Lake Michigan (Fig. 19). The visible imagery continued to be masked by mid- level clouds. The RAP initial hour analysis at 1700 UTC on 30 October showed a channel of surface-based convective available potential energy (CAPE, on the order of 25 to 50 J kg^{-1}) that stretched from Lake Michigan to the northern mountains of North Carolina. This band of CAPE persisted from 1500 UTC to about 2300 UTC on 30 October. Wind streamlines in the 0-1 km layer also showed the flow moving down the long axis of Lake Michigan and curving southeasterly to northwest North Carolina. Backward wind trajectories calculated from the NOAA HYSPLIT model (Draxler and Rolph, 2013; Rolph 2013) for the 48 hour period leading up to 1800 UTC on 30 October also showed the flow at 100 m, 500 m, and 1000 m AGL could be traced to the area around Lake Michigan (Fig. 20). However, the radar imagery never displayed a change to more cellular radar echoes as has been observed in other northwest flow events in the presence of weak surface-based CAPE during daylight hours (Fig. 21). After 0000 UTC on 31 October, the RAP indicated that any connection to the Great Lakes would be directed toward West Virginia and southwest Virginia.

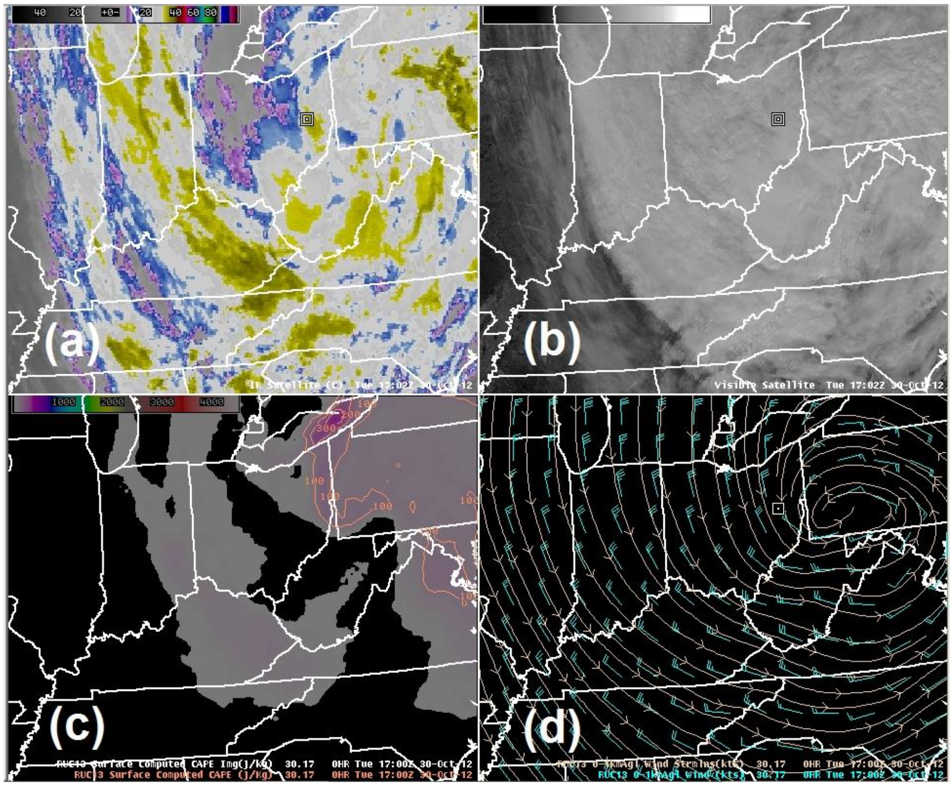


Fig. 19. GOES-13 satellite imagery in the (a) IR window and (b) visible window, along with RAP initial analysis of (c) surface based CAPE (J kg^{-1}; orange contours and color fill) and (d) wind (kt; barbs and streamlines) in the 0-1 km layer at 1700 UTC on 30 October 2012.

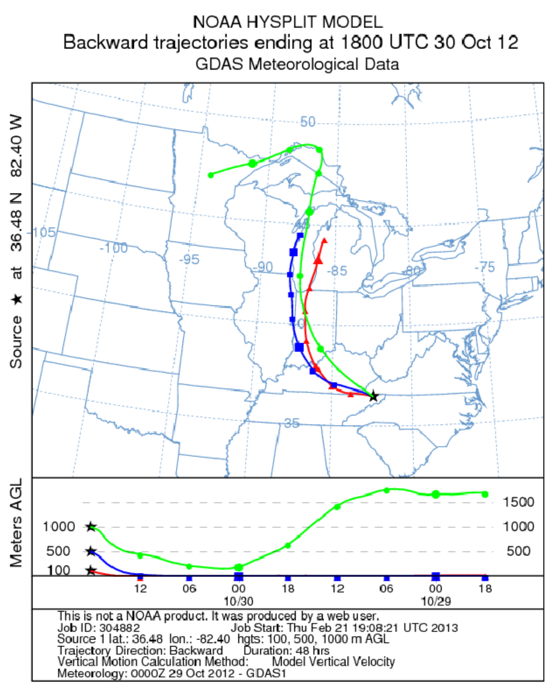


Fig. 20. Backward trajectories at the Tri-Cities airport, Tennessee, from the NOAA HYSPLIT model at 100 m (red line), 500 m (blue line), and 1000 m (green line) for the 48 hour period ending at 1800 UTC on 30 October 2012.

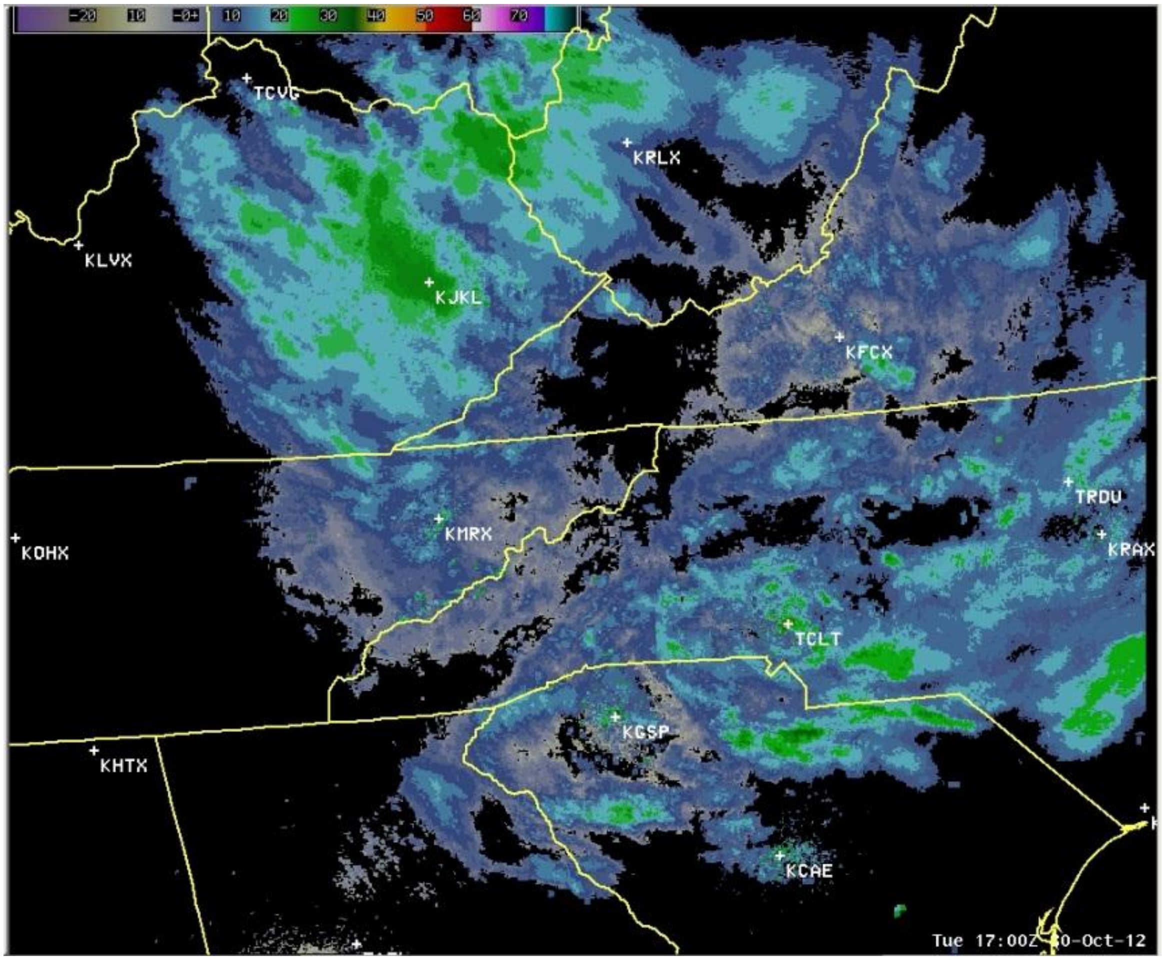


Fig. 21. Radar mosaic of composite reflectivity at 1700 UTC on 30 October 2012.

A decreasing trend in radar reflectivity coverage began around 0000 UTC on 31 October that coincided with warming cloud top temperatures in the plume of cloudiness streaming south southeast from Lake Michigan and the upper Midwest (Fig. 22). Precipitation echoes were no longer detected by the KMRX radar moving toward the northern mountains of North Carolina after about 0200 UTC and radar coverage decreased dramatically after about 0400 UTC. After that time, the most significant reflectivity signatures were seen over eastern Kentucky and in the vicinity of another mountain wave that developed near the Blue Ridge in North Carolina. The significant precipitation ended at the Roan Mountain site between 0600 and 0700 UTC with very little reflectivity seen on the KMRX radar. Some light returns accounted for additional precipitation during the morning of 31 October, but the event ended by 1500 UTC.

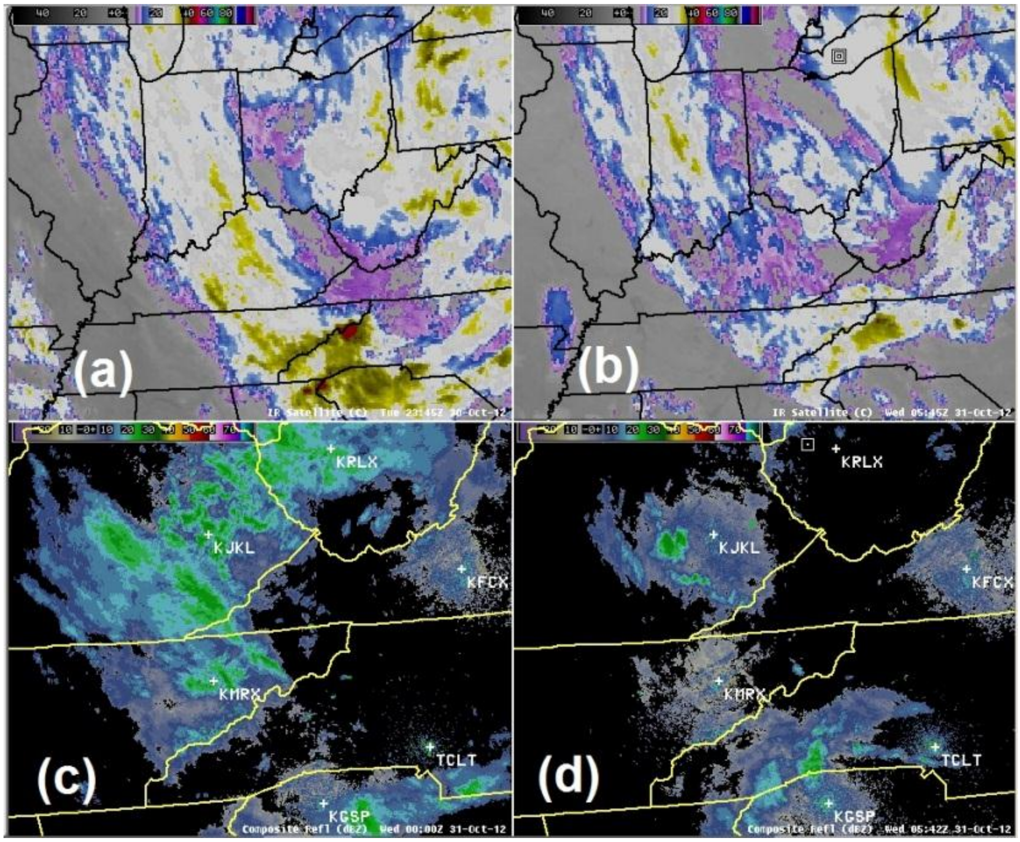


Fig. 22. GOES-13 infrared satellite imagery at (a) 2345 UTC on 30 October 2012 and (b) 0545 UTC on 31 October 2012, and composite radar reflectivity mosaic at (c) 0000 UTC on 31 October 2012 and (d) 0542 UTC on 31 October 2012.

The northwest flow precipitation event on 30 October afforded a comparison between the reflectivity observed by a radar with a dual polarized beam (KMRX) and one that had not yet been upgraded (the NWS Doppler radar at Jackson, Kentucky [KJKL]). Pre-deployment testing of the dual polarization radars revealed a signal loss of approximately 3-4 dB compared to the old single polarized radar during light precipitation events (Saxion et al., 2011). Scans from KMRX and KJKL at 1159 UTC on 30 October demonstrated the lower signal detected by the dual-polarized KMRX radar. The center point of the radar beam on the 1.5 degree elevation scans from both radars passed through approximately the same location around 9350 feet MSL in northwest Harlan County, Kentucky (Fig. 23). The dual-polarized KMRX radar detected a reflectivity of 19 dBZ while the single-polarized KJKL radar showed a reflectivity of 22 dBZ at the same approximate location. Other nearby range gates showed a similar reflectivity loss from KMRX. The signal loss of the dual-polarization radars should be taken into account when interpreting the imagery relative to prior experience with northwest flow events.

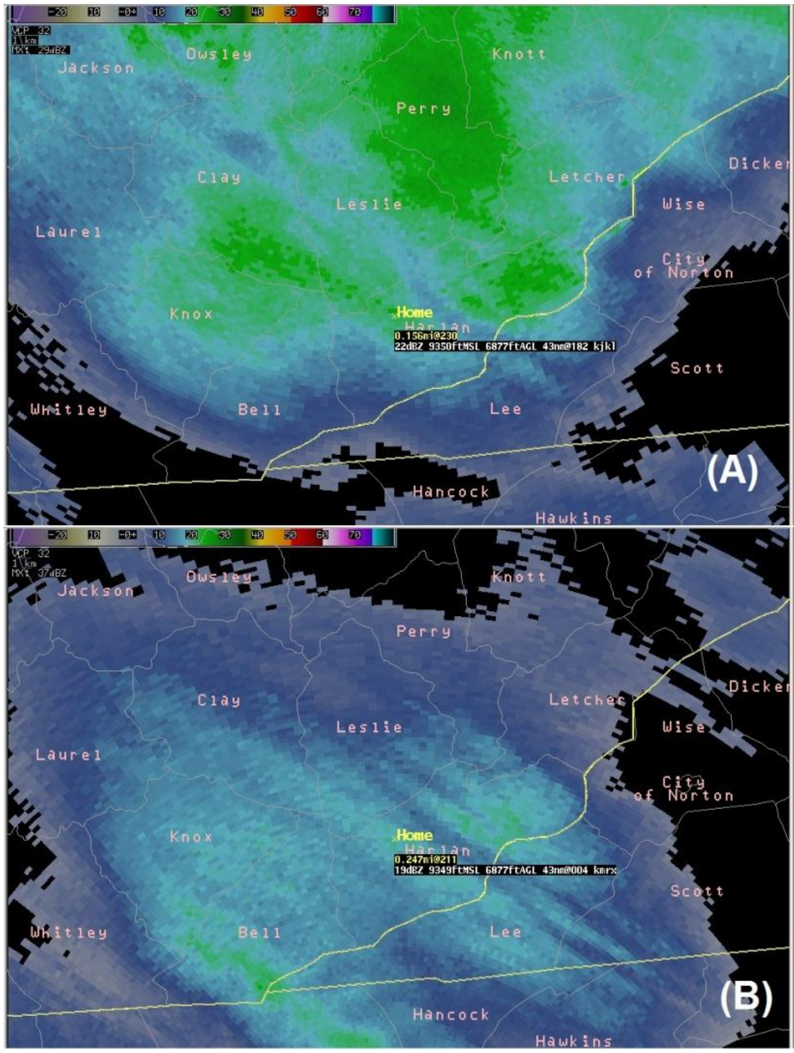


Fig. 23. Base reflectivity on the 1.5 degree elevation scan from (A) the KJKL radar and (B) the KMRX radar at 1159 UTC on 30 October 2012. The location marked "Home" corresponds to a point equidistant from both radars where the beam passes through.

b. Vertically Pointing Research Radar

A vertically pointing Appalachian State University research radar at Poga Mountain, North Carolina, collected data during a large portion of the event (Fig. 24). (Data were missing from 1800 UTC to 2100 UTC on 29 October.) A well-defined 500 mb short wave trough (not shown) moved across the area on the 28 October and produced the tower of reflectivity and Doppler velocity returns between 2100 and 2300 UTC. Thereafter, the precipitation consisted of fairly shallow elements and low reflectivity returns. The elevated velocity near 2 m s^{-1} (blue) was probably snow that accumulated rime as it fell which increased the fall speed to 3 to 4 m s^{-1} (green). The two periods of enhanced reflectivity (2100 UTC, 29 October and 1000 UTC, 30 October) coincided approximately with the snow aloft signatures.

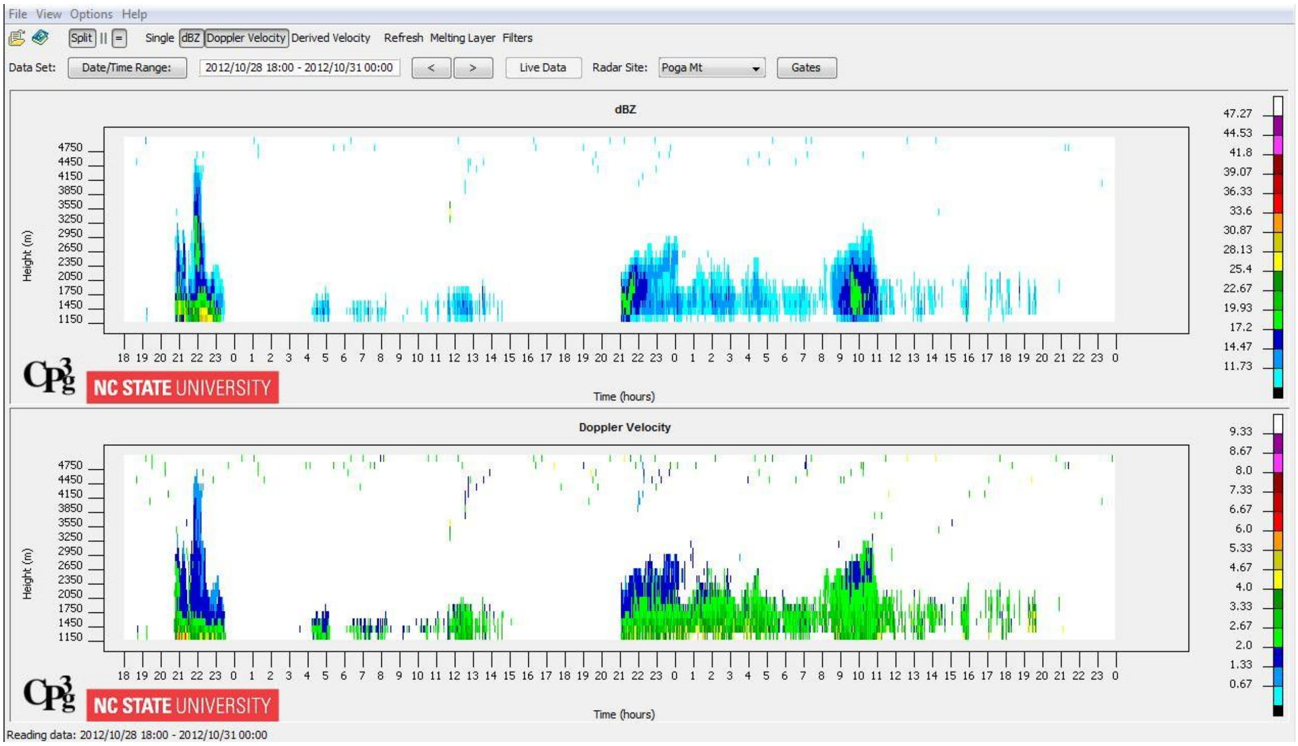


Fig. 24. Reflectivity (top; dBZ) and Doppler velocity (bottom; m s^{-1}) at Poga Mountain, North Carolina. Time advances from left to right (1800 UTC, 28 October 2012 to 0000 UTC, 31 October 2012). Data are missing between 1800 and 2100 UTC on 29 October. Source: Baker Perry, Ph.D., Appalachian State University.

7. Satellite Perspective

NASA MODIS[2] imagery from the morning Terra and afternoon Aqua satellite passes on 26 – 31 October showed the evolution of the large scale features including the cold frontal cloud band that crossed the mountains on 28 October and the northward movement of Sandy along the East Coast. The expansive cloud shield containing the precipitation that spread across the southern Appalachians was clearly evident as it wrapped around the western periphery of the storm (Figs. 25 and 26).

[2] Moderate Resolution Imaging Spectroradiometer (http://modis.gsfc.nasa.gov/)

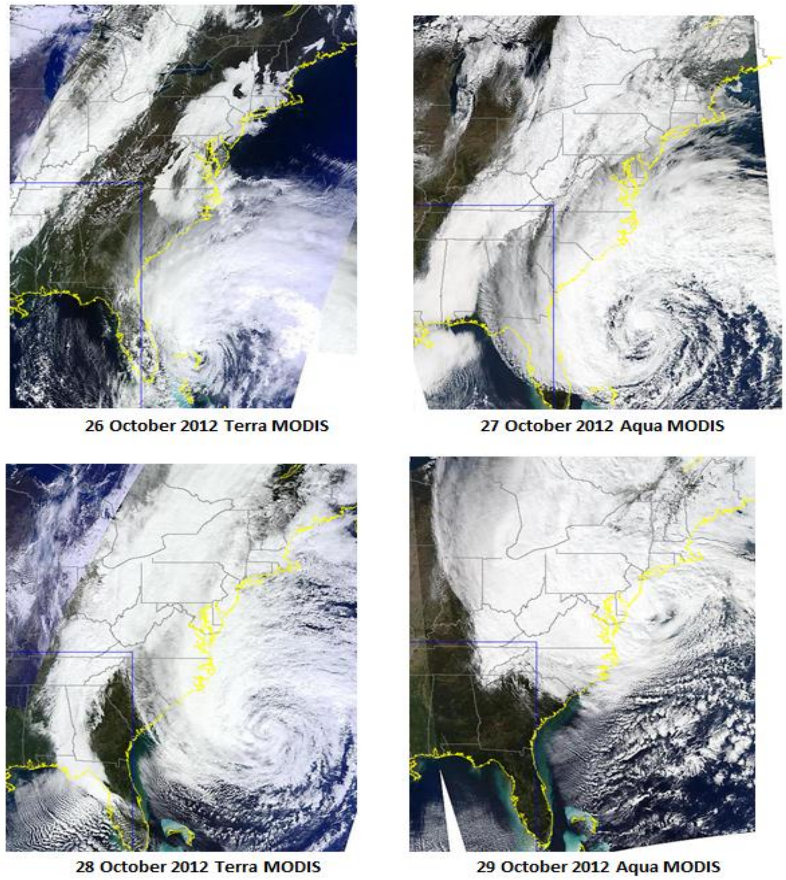


Fig. 25. NASA Terra and Aqua MODIS imagery 26 – 29 October 2012. Source: Space Science and Engineering Center, University of Wisconsin-Madison.

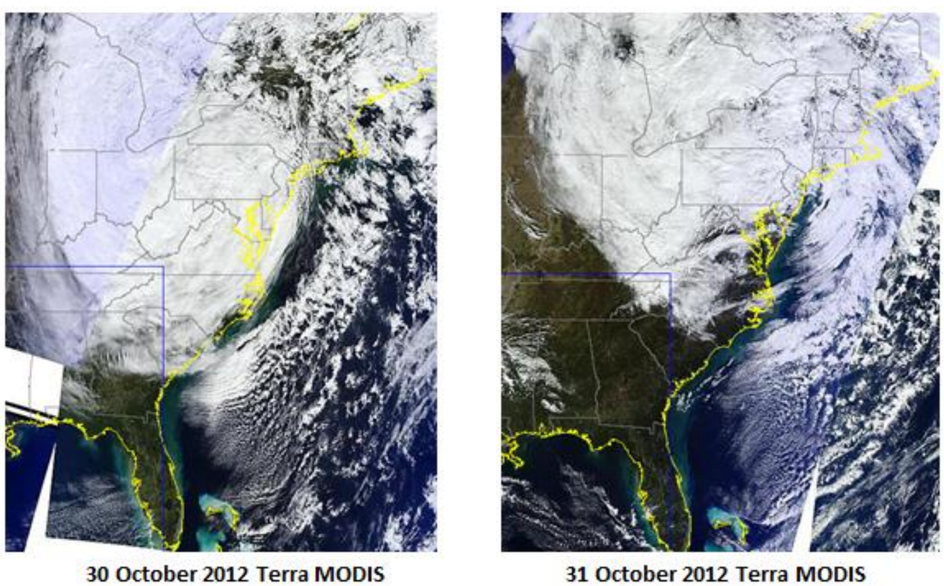


Fig. 26. Same as Fig. 25 except 30 – 31 October 2012.

The Terra MODIS image on the morning of 1 November showed the snow cover in the higher elevations of the North Carolina mountains (Fig. 27).

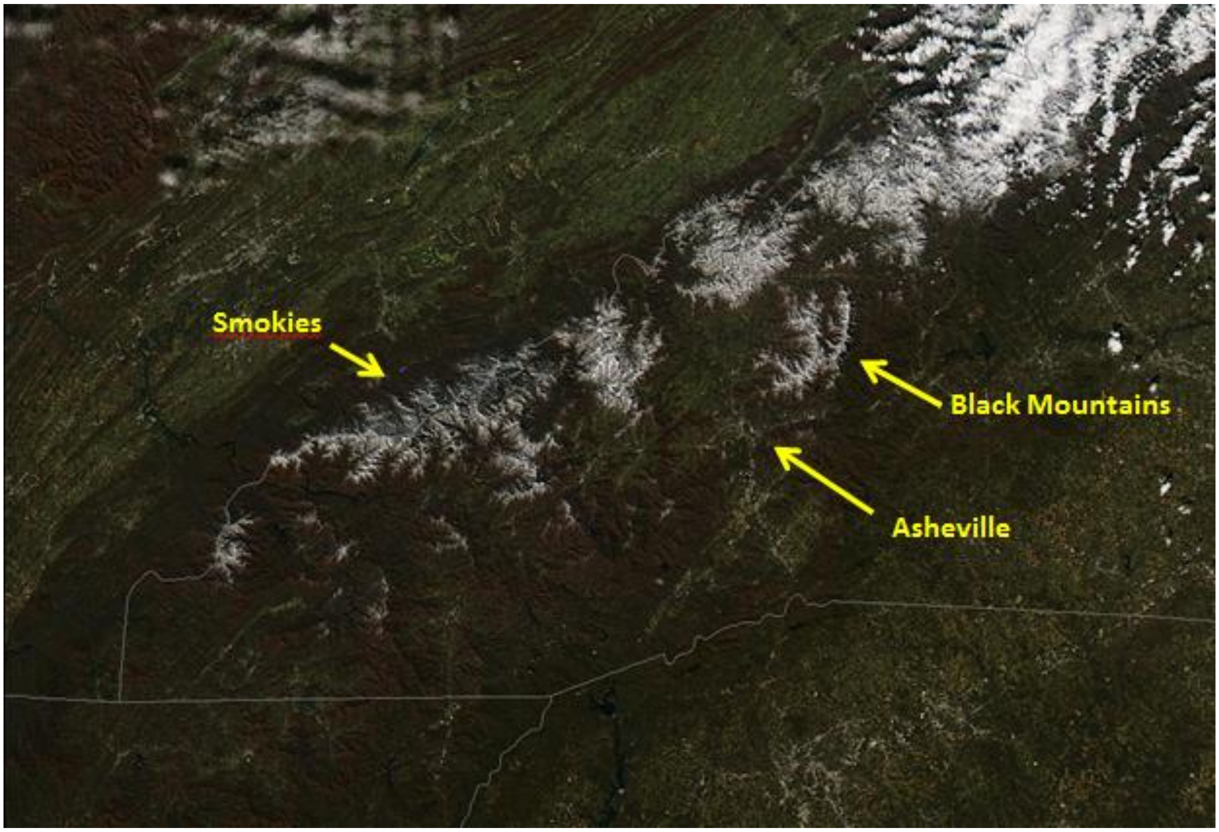


Fig. 27. NASA Terra MODIS image on the morning of 1 November 2012. Source: Space Science and Engineering Center, University of Wisconsin-Madison.

8. Additional Data from Mountain Research Stations

In addition to the Roan Mountain MOPRAM site (see Fig. 7), the Appalachian Atmospheric Interdisciplinary Research (AppalAIR) group[3] at Appalachian State University also supports meteorological research observation sites at Flat Springs, North Carolina (Poga Mountain), and Grandfather Mountain, North Carolina. Data from these sites provided a continuous record of key weather elements during the Sandy snow event (Figs. 28 and 29).

[3] http://appalair.appstate.edu/

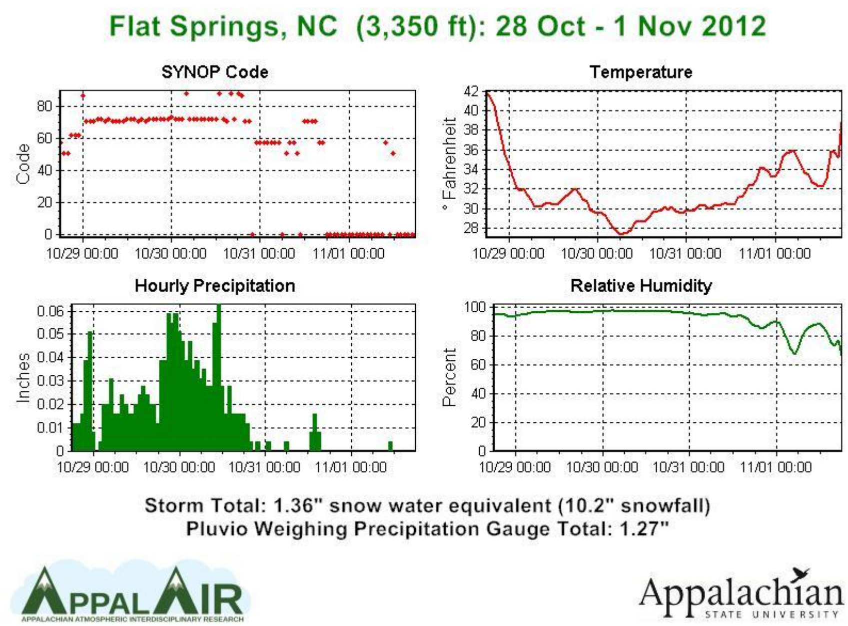


Fig. 28. Observations from Flat Springs, North Carolina (Poga Mountain). The precipitation (SYNOP) code from 71 to 73 indicates snow. Date and local standard time are on the horizontal axis of each plot. Source: Baker Perry, Ph.D., Appalachian State University.

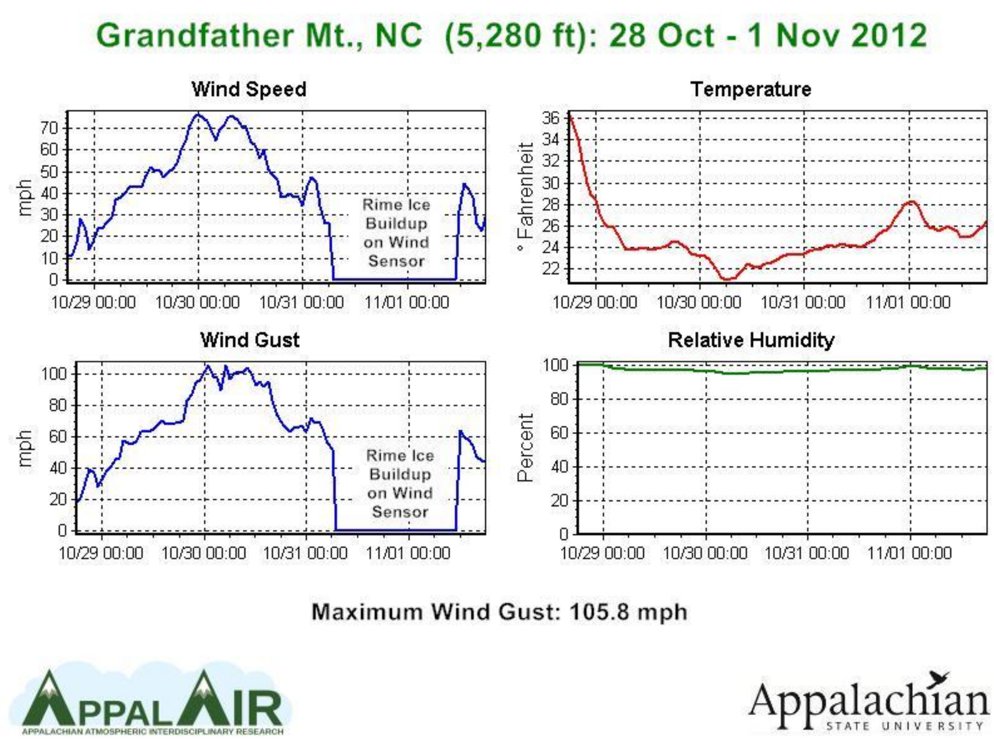


Fig. 29. AppalAIR observations from Grandfather Mountain, North Carolina. Date and local standard time are on the horizontal axis of each plot. Source: Baker Perry, Ph.D., Appalachian State University.

9. Summary

Hurricane Sandy moved northward just off the East Coast during the last week of October 2012 then curved to the northwest making landfall as a post tropical storm during the evening of 29 October. While Sandy was moving north off the mid-Atlantic coast and following a cold front passage across the western Carolinas and extreme northeast Georgia on 27 October, moisture wrapping around Sandy's western periphery spread southward along the western slopes of the Appalachians. By 30 October, Sandy moved slowly westward into Pennsylvania prolonging the period of moist, upslope flow along the North Carolina and Tennessee border. Snow fell in the Tennessee border counties of North Carolina and produced a number of snowfall totals in excess of 4 inches. Isolated accumulations in excess of 24 inches were measured.

Snowfall 29-31 October 2012			
Location	**Amount (inches)**	**Location**	**Amount (inches)**
Newfound Gap	36.0	Barnardsville 1 NNE	4.0
Roan Mountain	28 .0 – 35.0	Burnsville 4.6 N	4.0
Cove Creek 10 NW	24.0	Whittier 3.5 ESE	3.5
Bakersville 5.4 N	15.0	Asheville 4 NE	3.0
Elk Park	14.0	Hot Springs 8.4 SSW	2.5
Hot Springs 5 WNW	14.0	Burnsville 7.0 W	2.0
Beech Mountain	13.5	Fairview 3.8 ENE	2.0
Buladean 2 N	13.0	Waynesville 3.9 E	2.0
Faust 3 NNW	13.0	Asheville 5.7 NNW	1.7
Linville	12.7	Asheville 5.6 NNW	1.5
Beech Mountain	12.5	Lake Junaluska 5.1 N	1.5
Spring Creek	12.0	Marshall 4.9 WNW	1.5
Sams Gap	11.0	Maggie Valley 2.9 ENE	1.3
Flat Springs 1 E	10.2	Linville Falls 0.5 SW	1.2
Wolf Laurel	9.4	Blowing Rock 2.8 ENE	1.0
Mars Hill 5.0 NNE	8.9	Swannanoa 2.7 NNW	0.8
Mt Mitchell	7.6	Highlands	0.7
Newland	7.0	Spruce Pine 2 NE	0.5
Linville 2.4 ENE	6.2	Waynesville 4.7 W	0.4
Bakersville 2.5 SE	6.0	Canton 10.3 S	0.3
Burnsville 6.5 SSW	6.0	Asheville (NCDC)	0.2
Marshall	6.0	Asheville 3.3 SE	0.1
Bakersville	5.5	CANDLER 5.0 SW	0.1
Asheville 4.0 NNE	5.0	Cullowhee	0.1
Cruso 3 ESE	5.0	Fletcher 2.5 E	0.1
Weaverville 4.3 N	5.0	Waynesville 0.7 ENE	0.1
Banner Elk	4.0	Waynesville 1.0 NW	0.1
Observations from NWS cooperative observers, Community Collaborative Rain, Hail, and Snow (CoCoRaHS) Network*, law enforcement, emergency management, and public. *http://www.cocorahs.org/			

Acknowledgments. Baker Perry, Ph.D., Department of Geography and Planning at Appalachian State University (ASU), provided the ASU Roan Mountain MOPRAM data, the ASU Poga Mountain and Grandfather Mountain AppalAIR data, and the Poga Mountain MicroRain Radar data. The Asheville and Beech Mountain wind roses were obtained from the State Climate Office of North Carolina. The NASA Aqua and Terra MODIS satellite imagery was obtained from the Space Science and Engineering Center at the University of Wisconsin-Madison. National Weather Service Cooperative Observers, CoCoRaHS observers, law enforcement and emergency management officials, and the public provided snowfall reports that aided in the documentation of this event.

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