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Analysis of a Left Moving Supercell that Produced Giant Hail Across Northeast South Carolina

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ABSTRACT

On 10 May 2011, a rare left moving supercell developed from a storm split and tracked across extreme northeast South Carolina producing softball sized hail in the city of Conway. This supercell was part of a much more significant outbreak of severe weather that produced 12 reports of tennis ball sized hail or larger, including 3 reports up to softball sized, making it one of the greatest hail events in the recorded history of northeast South Carolina. Synoptic analysis showed the potential for severe weather several days in advance as the Carolinas were located on the eastern periphery of an upper ridge with little convective inhibition. On the day of the event, examination of the mesoscale parameters indicated the potential for giant hail. Convective available potential energy (CAPE) approached 3000 J kg^{-1}*, with nearly 1000 J kg*$^{-1}$ *present in the -10°C to -30°C (hail growth) layer. Mid-level lapse rates were nearly 8°C km*$^{-1}$ *thanks to the presence of an elevated mixed layer (EML), and freezing levels were around 13,000 ft. Additionally, nearly linear hodographs suggested that splitting storms were possible which made severe hail even more likely since left movers frequently produce giant hail. Even though left moving supercells are known to be giant hail producers, analysis of this specific event showed that the largest hail was caused in part by a merger with an outflow boundary, so forecasters should be alert to mergers in future events to recognize truly giant hail potential.*

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1. Introduction

On the evening of 10 May 2011, northeast South Carolina experienced a significant severe weather outbreak involving multiple supercells. Supercells occurring in May over South Carolina are not incredibly rare, but what made this event unique was the widespread very large hail that fell from these thunderstorms. Since 1950, there have been 115 occurrences of significant severe hail, defined as 2 inches or greater in diameter, across the entire state of SC, and only 7 reports of hail exceeding 4 inches in diameter (National Climatic Data Center, Storm Data, 1950-2010). During the five hour period between 2030 UTC on 10 May and 0130 UTC on the 11th, 12 incidents of tennis ball sized (2.5 inch diameter) hail or larger fell across northeastern portions of the state (Fig. 1), including 3 reports of hail up to 4.5 inches in diameter. The most significant large hail occurred in Conway, where softball sized hail caused significant damage to vehicles and homes (National Weather Service Local Storm Report 2011). This event was rare not only because of the sheer number of reports of very large hail, but also because the giant hail that impacted Conway fell from a left moving supercell, which Bunkers (2002; hereafter B02) found comprised only about 11% of all central plains supercells. An in depth analysis of this particular storm and the environment is undertaken to provide forecasters better insight into giant hail events associated with left moving supercells.

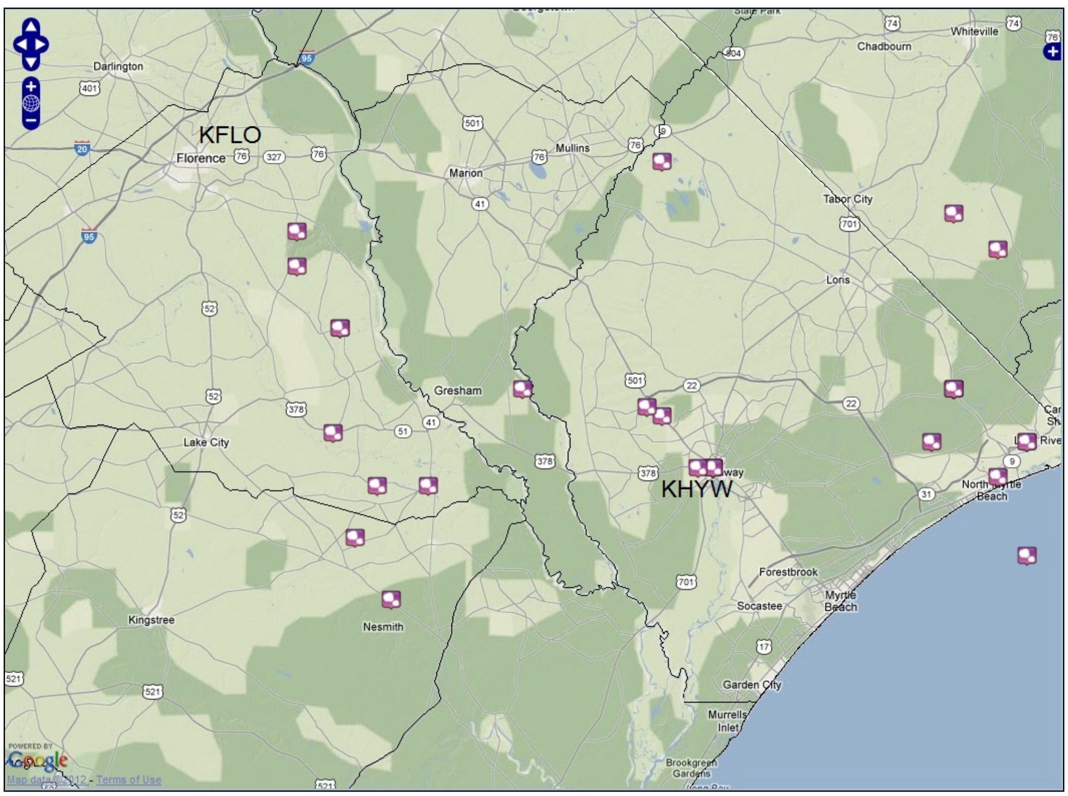


Figure 1. Map of northeast South Carolina showing the area of interest with many of the large/giant hail report locations overlaid. Note sounding locations, KFLO and KHYW are labeled.

2. Data and Methodology

Since this is a local significant weather event, post analysis required primarily use of the local archive at the National Weather Service (NWS) Wilmington, NC Weather Forecast Office. Meteorological data including WSR-88D radar reflectivity, base and storm relative velocity, satellite data, model forecast parameters, were obtained from the NWS Advance Weather Interactive Processing System (AWIPS) Weather Event Simulator (WES) archive. Observed forecast soundings were taken from the Charleston, SC (KCHS) upper-air site, while forecast soundings and hodographs were compiled from RUC analyses at 2100 and 2200 UTC on 10 May. RUC 1-hour forecast profiles were used in place of 2300 analyses which were not available on the WES. Radar cross sections were taken using Gibson Ridge Level 2 Analyst (GR2Analyst) using archived radar data from the National Climatic Data Center (NCDC). Local storm reports and maps were taken from the Storm Prediction Center (SPC) and the Iowa State University storm based verification site (IEM COW), while historical storm data was acquired from NCDC.

3. Analysis

a) Synoptic Analysis

As early as 5 May 2011, the 500 hPa flow began to show potential for an outbreak of severe weather across the eastern Carolinas. A large 585 dm upper-level ridge developed across the Mississippi River Valley, while individual vorticity maxima rotated around the periphery of the ridge and down across the Carolinas. This pattern, which is commonly referred to as the "ring of fire," (UCAR COMET Module, Ring of Fire, 2009) is a favorable setup for pulse convection as well as more widespread damaging wind events. In addition, a vertically stacked low pressure stalled off the northeast coast kept the ridge axis displaced to the west producing relatively lower heights and steeper lapse rates across the Carolinas.

By the afternoon of 10 May 2011, the environment became increasingly favorable for a severe weather event in South Carolina. At 1800 UTC an upper impulse moved southward across the Virginias along the periphery of the ridge while the stacked low continued to rotate in place east of New Jersey (Fig. 2). At the surface, a large Bermuda high pressure anchored off the southeast coast created warm and moist southerly flow while a stationary boundary hovered along the North Carolina/South Carolina border (Fig. 3). All of these parameters combined to create a synoptic environment characterized by high instability with multiple lifting mechanisms present to initiate convection.

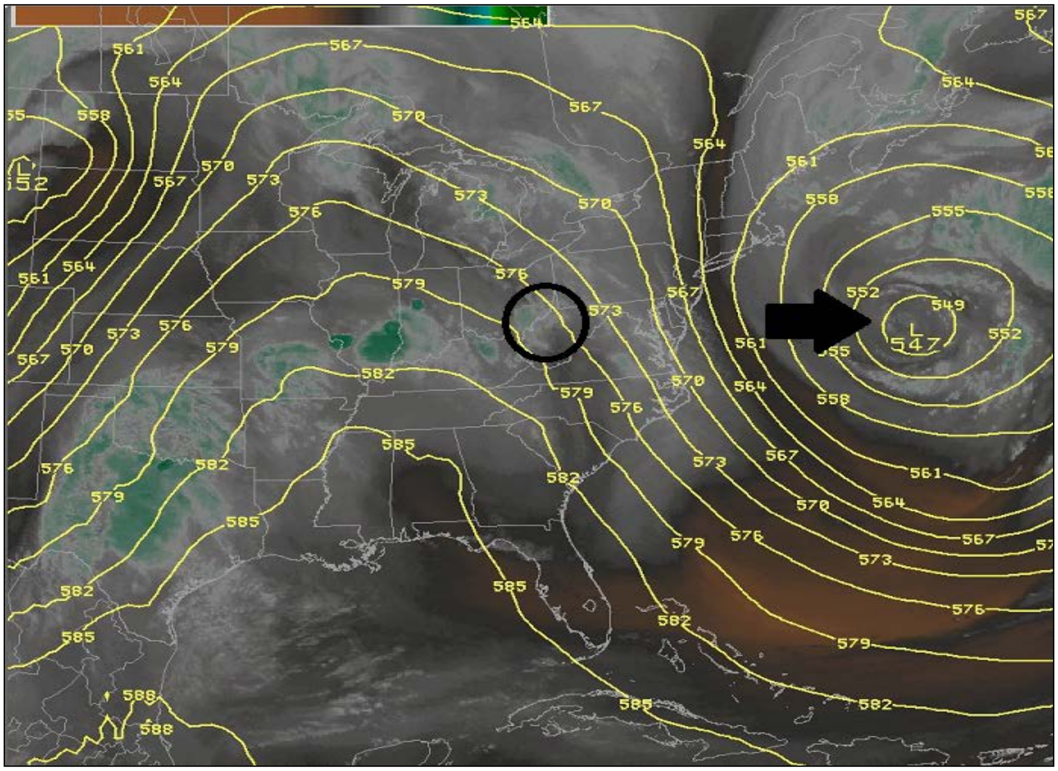


Figure 2. 1800 UTC 10 May 2011 GFS 500 hPa heights and 1715 UTC water vapor imagery with upper-level impulse circled and arrow pointing to vertically stacked low offshore.

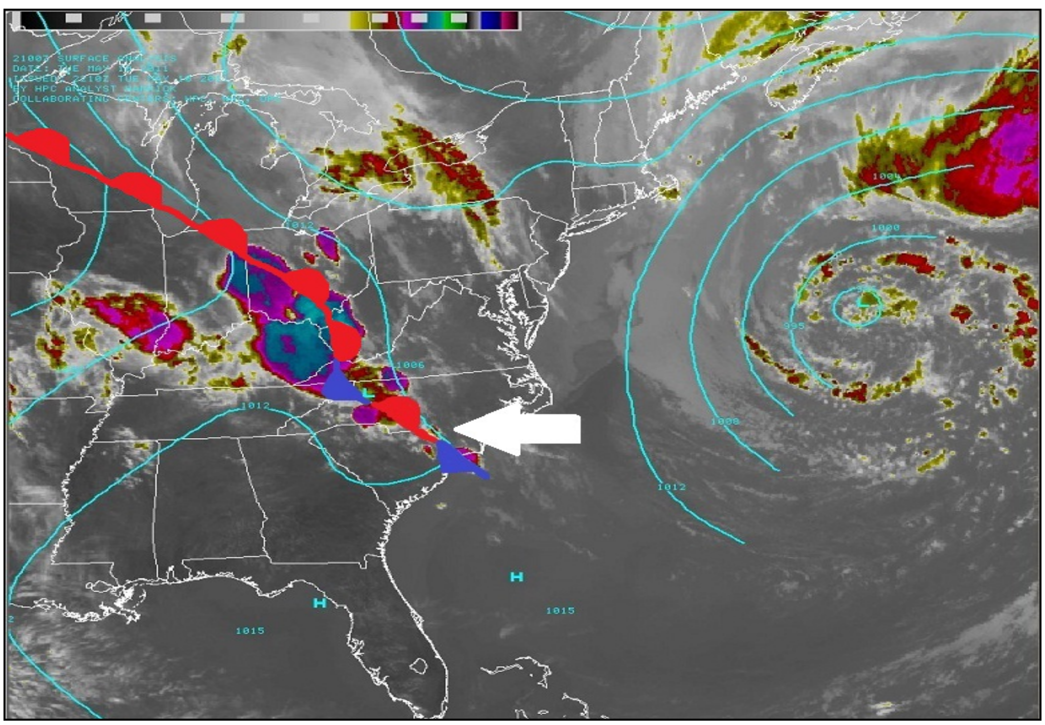


Figure 3. 2100 UTC 10 May 2011 NWS Weather Prediction Center surface analysis and 2125 UTC IR satellite imagery. Arrow points to relevant stationary boundary.

b) Mesoscale Analysis

Although the threat of severe weather was evident several days in advance, the storm mode did not become clear until the morning of 10 May 2011. Several important parameters to determining storm type became apparent from the 1200 UTC Charleston, SC sounding (Fig. 4). Although a surface inversion was present, more than 2800 J kg^{-1} of convective available potential energy (CAPE) was forecast for updraft strength, and this inversion eroded with diurnal heating which allowed surface based parcels to become unstable during the afternoon. An EML was noted from about 650 hPa to 550 hPa which helped to produce very steep lapse rates through the mid-levels of the column. A freezing level of 13,000 ft implied the possibility of large hail (Donavon and Jungbluth 2007) and an examination of the path of a surface parcel revealed a tremendous amount of CAPE in the -10°C to -30°C layer, making hail a significant threat. Although difficult to discern ahead of convective initiation, this highly unstable environment also meant that outflow boundaries from decaying storms would serve as foci for either new convection, or to potentially enhance ongoing convection through mergers (Markowski et al. 1998). This proved to be a key factor to the development of truly giant hail. Although the left moving supercell produced a swath of very large hail, it took interaction with an outflow boundary to produce truly giant hail.

The KCHS sounding displayed very little directional shear, and wind speeds actually decreased through the lowest 100 hPa of the column, so tornadic storms were not expected. However, strong unidirectional shear (Markowski and Richardson 2006) still showed the potential for severe thunderstorm development, with 0-6 km total shear values of 20-25 ms^{-1} falling into the lower thresholds for supercells (Bunkers et al. 2000; Rasmussen and Blanchard 1998). Examination of the hodograph associated with this sounding revealed a nearly straight line from 0-6 km (Fig. 5) which suggested splitting storms (Doswell 1991). Although some slight anticyclonic rotation existed in the lowest 1 km of the hodograph, this has been shown to be common in environments which produce storm splits (Edwards et al. 2004, hereafter E04; B02) and showed that both left and right moving storms may develop during the event.

The potential development of left moving supercells in an environment with significant CAPE in the hail growth zone made giant hail producers even more likely this day. Although left moving supercells are not as heavily documented in the literature as their right moving counterparts, there are many cases of left movers that produce large to giant hail. B02 found that 88% of all left movers produced severe hail, with the modal size of a golf ball (1.75 inches in diameter). Other references mentioned that left movers often produce hail greater than 2 inches (Edwards and Hodanish 2006, hereafter EH06) and can frequently produce extremely large hail or incredible amounts of hail (Warning Decision Training Branch 2009; E04; Mathews and Turnage 2000). Additionally, the combination of an environment favorable for left moving supercells and potential interaction with storm strengthening outflow boundaries (since widespread convection was anticipated) meant that a widespread large hail event seemed very likely. The Storm Prediction Center (SPC) began to highlight the potential in the day 3 convective outlook, and by 1300 UTC on 10 May, much of the state was highlighted in a 30% probability for significant severe hail (Fig. 6). At 1920

UTC, SPC issued a severe thunderstorm watch for northeastern South Carolina outlining the threat for severe hail up to 3.5 inches in diameter.

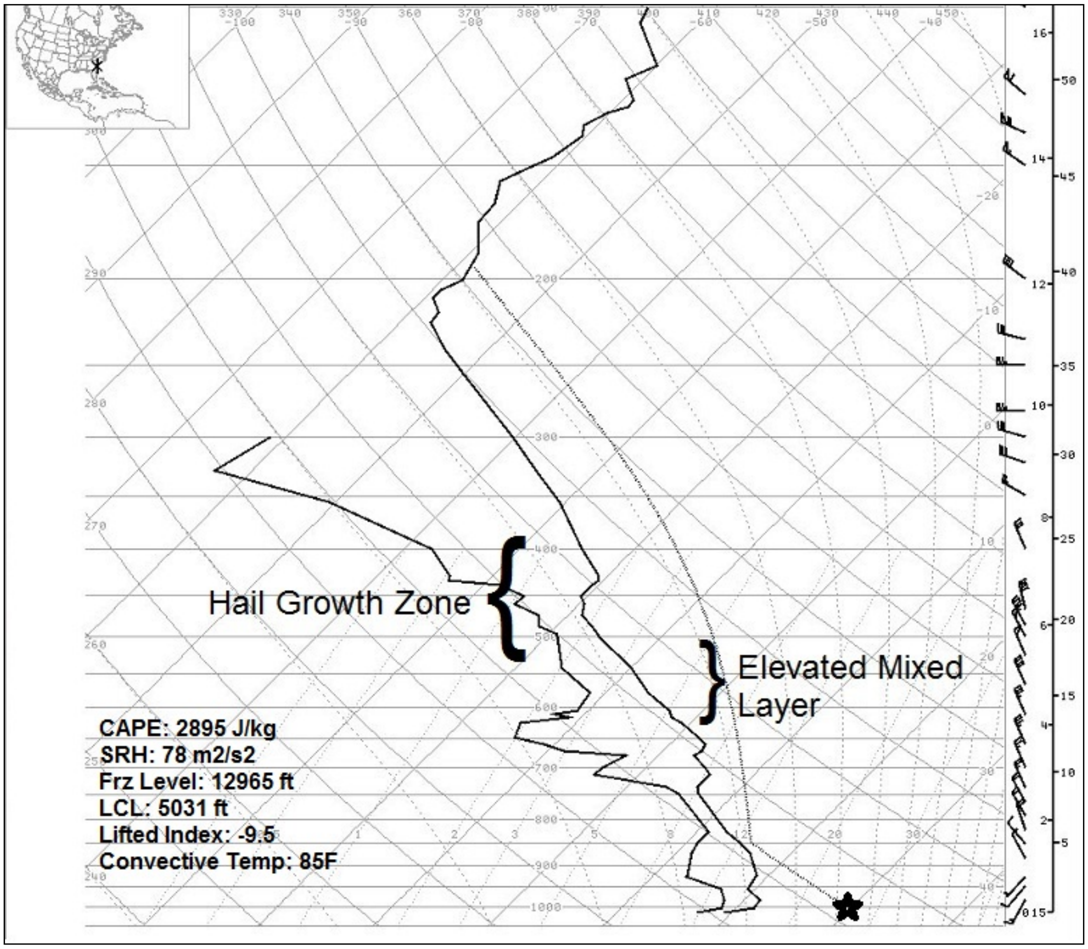


Figure 4. 1200 UTC 10 May 2011 KCHS sounding with the EML and hail growth zone highlighted. The star indicates the convective temperature. The modified version of this sounding had SBCAPE of over 2800 J kg^{-1}, much of which is in the hail growth region. Note also the deep NW flow above 900hPa.

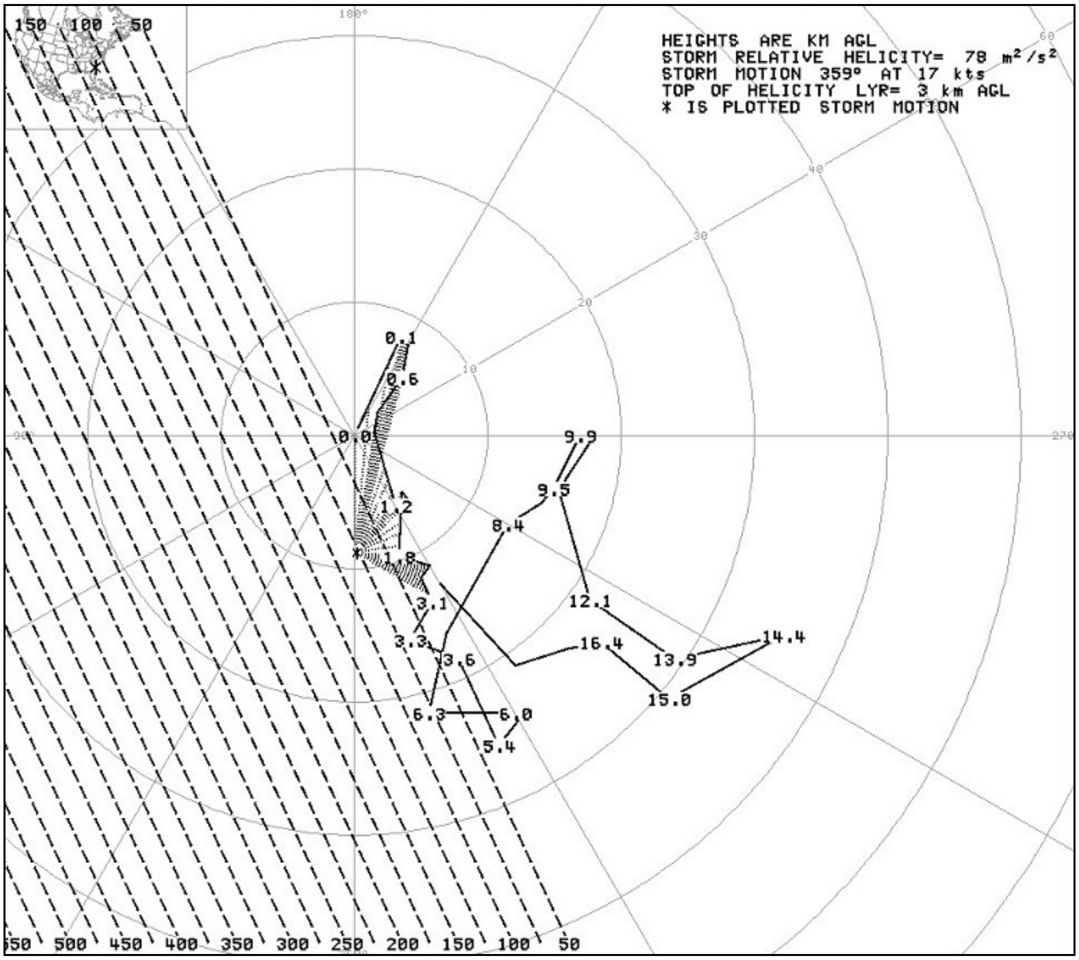


Figure 5. 1200 UTC 10 May 2011 hodograph from KCHS sounding. 0-3 km SRH is 78 m^2 s^{-2} for a right-moving supercell using 30 degrees to the right and 75% of the mean wind speed for the storm motion.

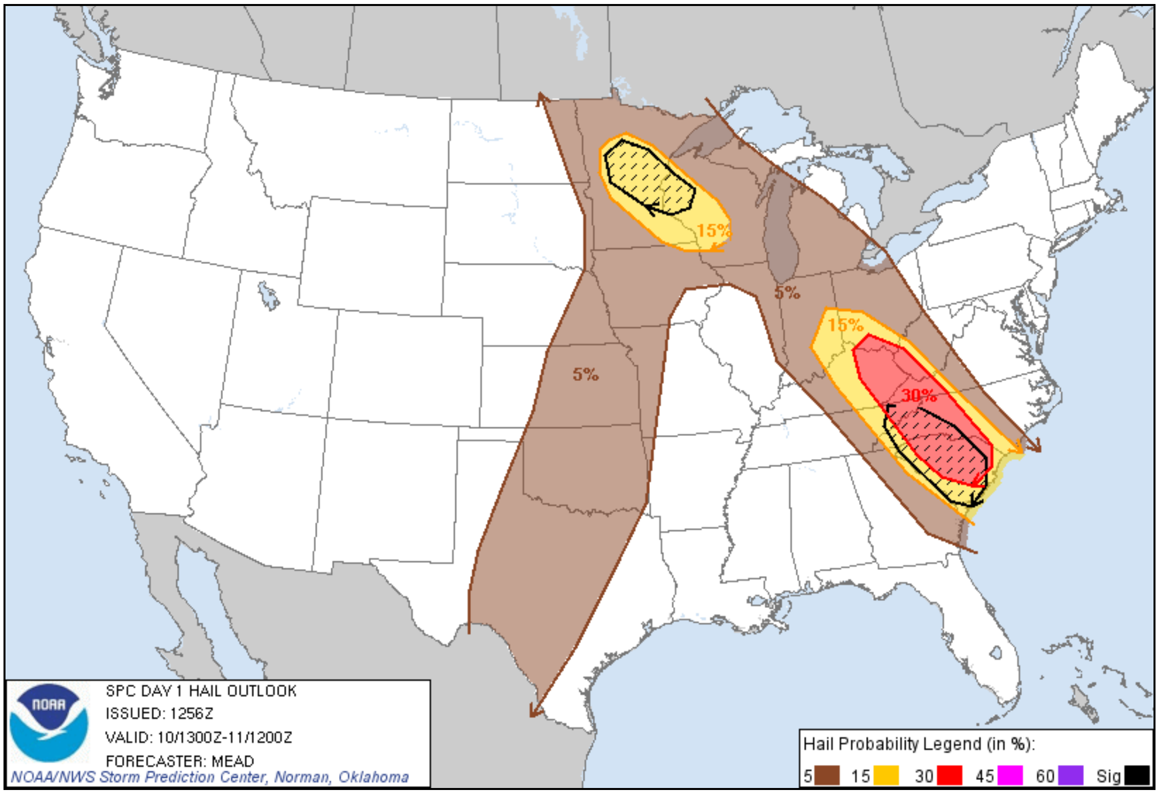


Figure 6. SPC day 1 hail outlook from 1300 UTC 10 May 2011.

c) Storm Initiation

By the late afternoon of 10 May 2011, surface temperatures reached the convective temperature of the low to mid 80s, and cell initiation began. The storm of interest developed and strengthened near Florence, SC producing baseball sized hail east of Evergreen at 2155 UTC (NWS Local Storm Report 2011). Shortly thereafter, the storm split occurred (Fig. 7) and the right mover produced baseball sized hail in Georgetown County, while the left mover produced tremendous hail up to softball size across Horry County (NWS Local Storm Report 2011).

Although the mesoscale environment has already been shown to be favorable for storm splitting and left moving storms, analysis of the storm scale environment is also important to understanding the behavior of the left moving supercell. RUC proximity soundings have been shown to be a reasonable proxy for near storm environments (Thompson et al. 2003). RUC sounding analyses at 2200 UTC over Florence (KFLO) and at 2200 UTC over Conway (KHYW) showed that the environment remained favorable for storm splits and left moving supercells near Conway. The soundings both had SBCAPE values well over 2000 J kg^{-1}, freezing levels around 12,500 ft, and significant -10°C to -30°C layer CAPE (not shown). Most interesting were the differences in the hodographs from KFLO (Fig. 8) and KHYW (Fig. 9). While clockwise rotation with increasing height existed in the 0-6 km layer over Florence, the hodograph near Conway remained relatively linear, suggesting that the environment was more favorable for a left moving supercell east, towards Conway.

Qualitatively, the 2200 UTC RUC hodograph at Conway (Fig. 9) looks very much like the composite hodograph from B02 for environments in which both left and right moving supercells develop, as was the case in this event. The 2200 UTC RUC hodograph at Florence has much stronger clockwise rotation and suggests that a left-moving supercell would have difficulty persisting in that area. Of course, simple observation of the hodographs is not enough to describe the environmental differences across the area.

Figure 10 shows the evolution of the 1-3 km left-moving SRH (LM-SRH) from 2100 UTC to 2300 UTC. Note that although the values are negative throughout all of northeast South Carolina, lower (more strongly negative) values are present in the vicinity of Conway. More than 98% of all left-moving supercells form in environments characterized by negative 1-3 km LM-SRH, which appears to be a discriminating factor in determining the potential for left-moving supercell development (B02). However, since the entire region was comprised of negative 1-3 km LM-SRH, this does not fully explain why the left-mover was more favored near Conway.

Another indicator for the potential of left-moving supercell development is the 0-3 km LM-SRH. Although 0-3 km LM-SRH can be positive, especially during situations in which both left-moving and right-moving supercells develop, the majority of events with left-moving supercells occur with 0-3 km LM-SRH also less than zero (B02). Figure 11 depicts how the 0-3 km LM-SRH changes during the event. Note that while values near Conway remain less than 0 throughout the lifetime of this supercell, areas west towards Florence are actually positive through much of the life cycle of this storm. So while the entire region could support left-movers, it is clear that the parameters were more favorable near Conway, and explains why this supercell developed and strengthened as it moved east.

The question needs to be asked then, with the synoptic environment nearly uniform, what mesoscale feature caused the more favorable environment near Conway. The most likely answer to this question is the afternoon sea breeze.

Observations at 2200 UTC (Fig. 12) show that surface winds at Conway had backed to the S/SE behind the afternoon sea breeze, which is easily visible in reflectivity just west of the KHYW observation. This is a typical sea breeze evolution across coastal northeast South Carolina in May, and causes increased S/SE winds in the lowest few thousand feet of the column during warm evenings. Although surface winds had increased and backed at Conway, winds at 4 kft (roughly 1 km) and higher were nearly the same as they were at Florence since the sea breeze is a relatively shallow feature. This is evidenced both by the RUC hodographs (Figs. 8 and 9), and by the VAD Wind Profile (VWP) from KLTX at 2200 UTC (Fig. 13). The sea breeze at the radar is clearly evident in the VWP by the low level southerly winds which veer quickly to the NW in the lowest 4 kft, indicating the top of this mesoscale feature.

Although the wind profile over Conway would not be identical to that within the VWP, it can be inferred through the RUC hodographs and examination of reflectivity along the sea breeze boundary that winds through the column would be quite similar. Since Florence is removed well inland from the sea breeze, the winds there do not show the stronger S/SE component present at Conway (Figs. 8 and 9).

Unfortunately, the exact depth of the

sea breeze boundary cannot be directly analyzed due to the vertical resolution of the VWP and the RUC soundings. However, from the differences noted in the RUC hodographs (Figs. 8 and 9), it is likely that the sea breeze penetrated to some depth just above 1 km. This is important because those stronger southerly winds at 1 km near Conway lengthened the 1-3 km portion of the hodograph with respect to left movers. This created lower (more negative) values of 1-3 km LM-SRH, such that values near Conway were around the 75th percentile for left-movers, while Florence remained below the median (B02). So while the environment across the entire area supported left-moving supercells, it was clearly more conducive nearer the coast.

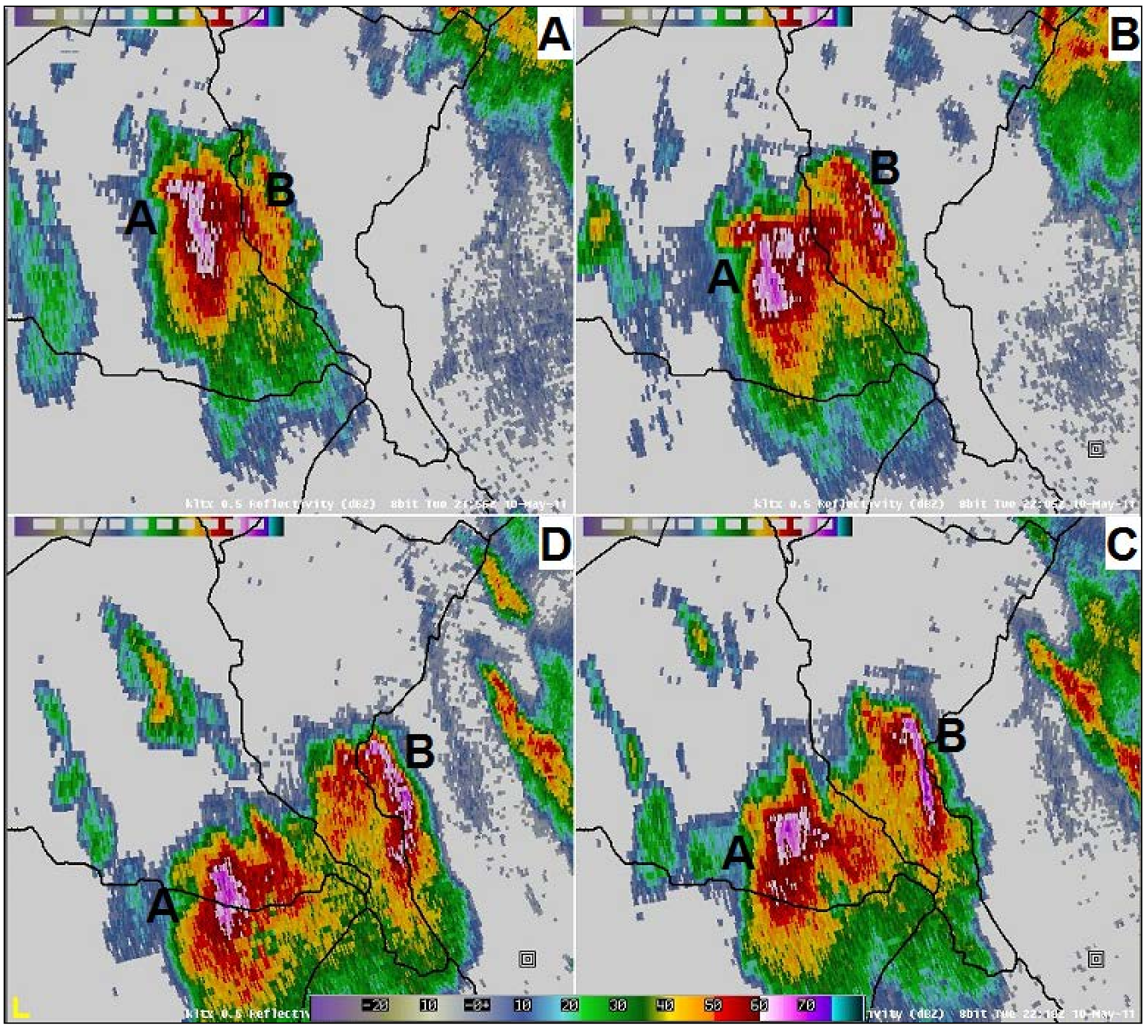


Figure 7. KLTX 0.5 degree reflectivity evolution of storm split which created the left moving supercell (cell B) from its parent cell (cell A). From top left to bottom right: (A) 2155 UTC, (B) 2205 UTC, (C) 2219 UTC, and (D) 2229 UTC 10 May 2011. Clockwise labeling of panels is consistent with standard AWIPS display.

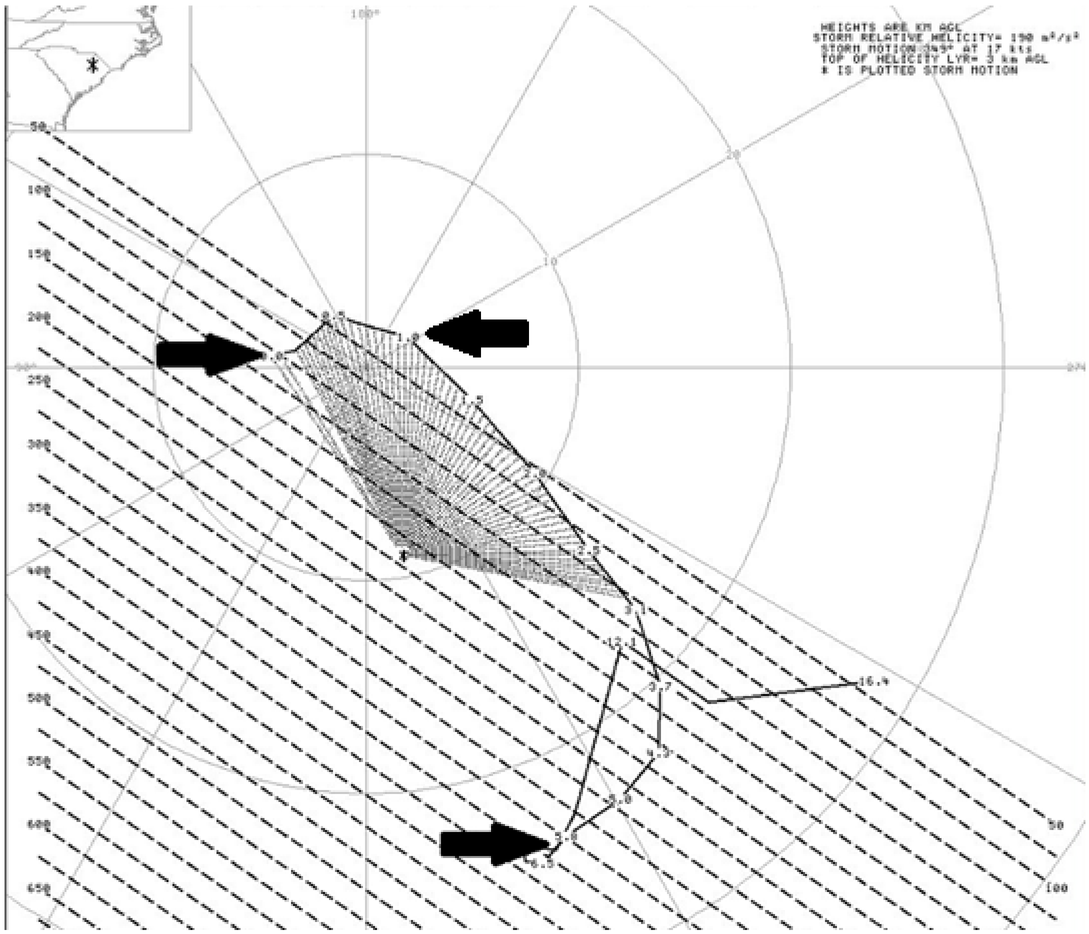


Figure 8. 2200 UTC 10 May 2011 RUC analysis hodograph over KFLO with right-facing arrows identifying the top and bottom of the 0-6 km layer to show the enhanced clockwise curvature. The left-facing arrow shows the hodograph depiction of the wind at 1 km AGL.

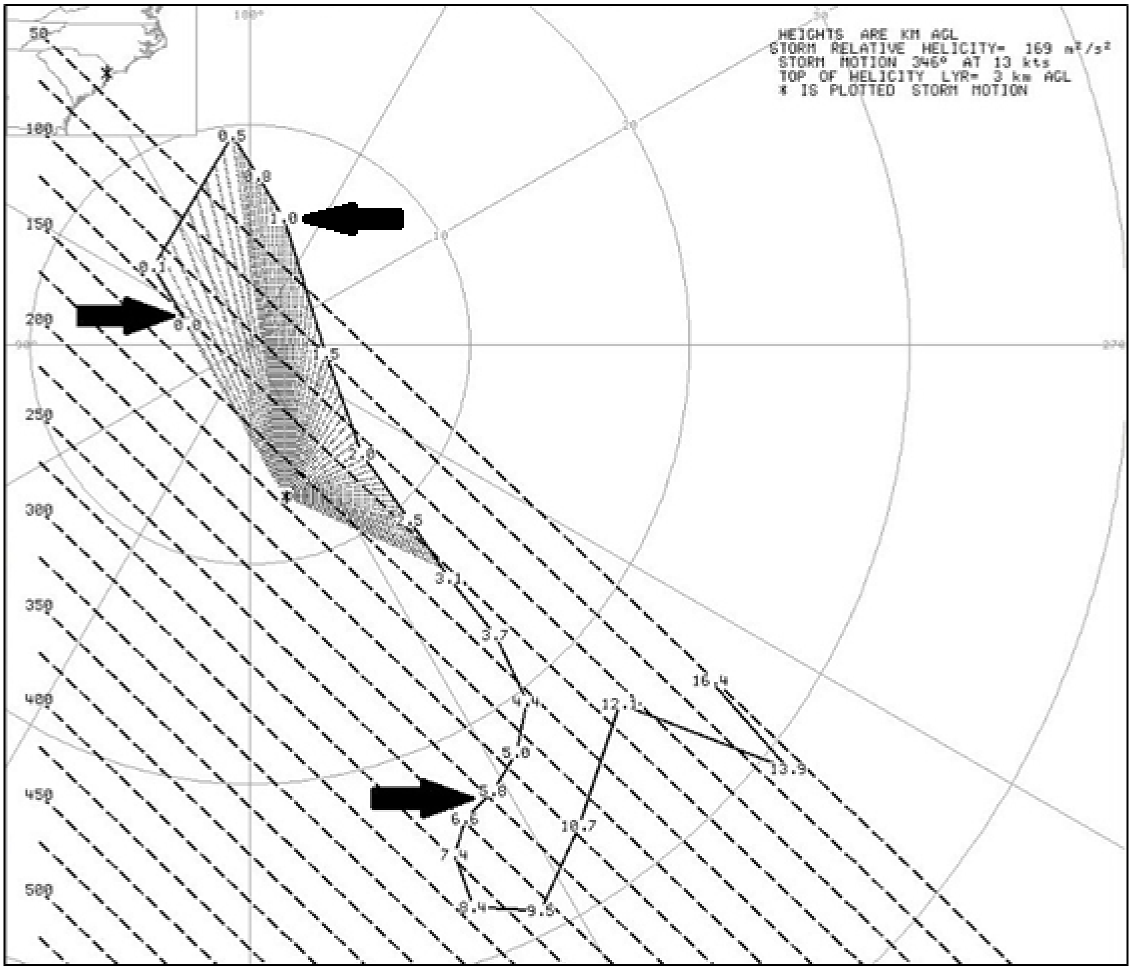
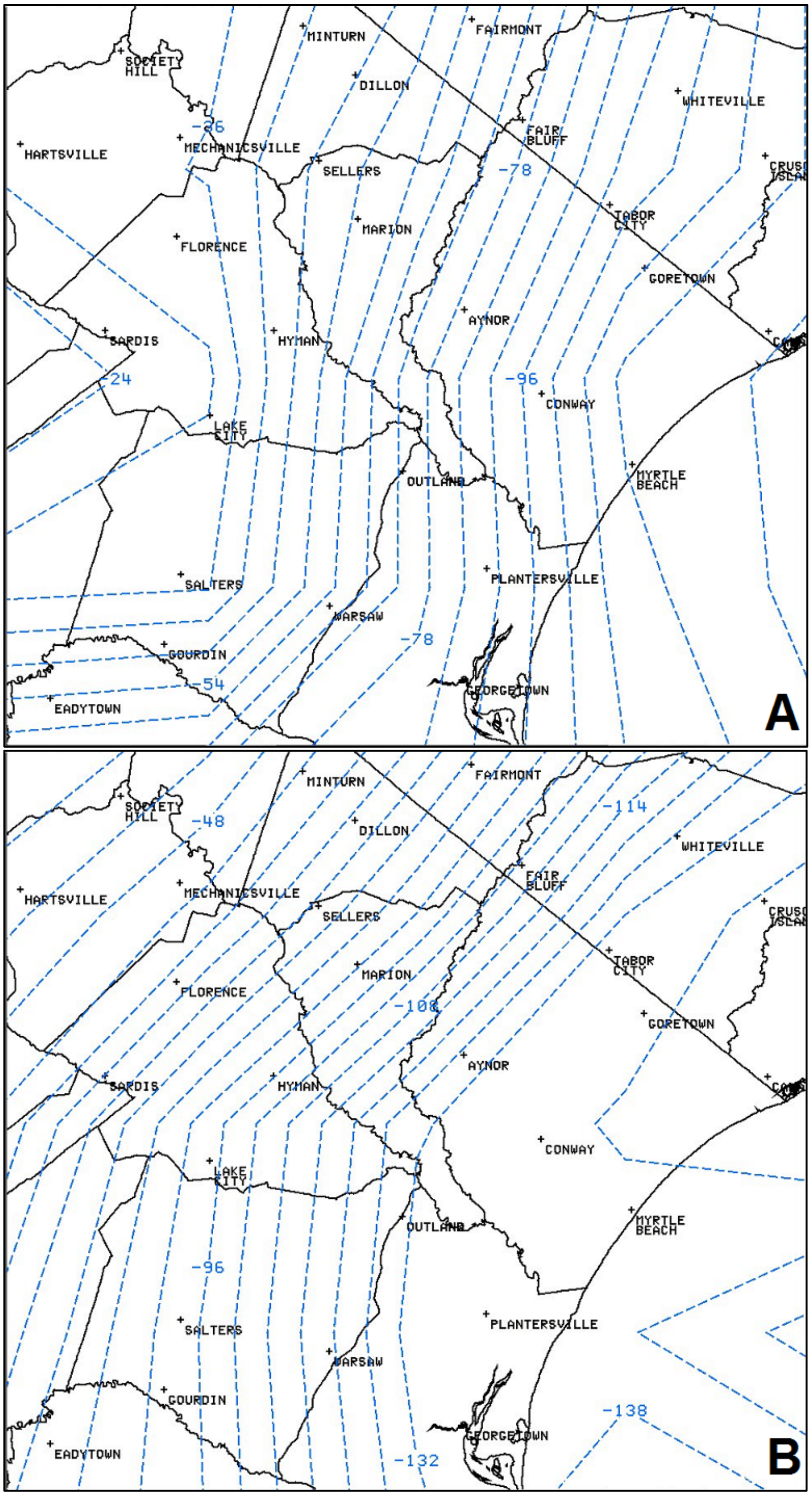


Figure 9. Same as Figure 8, except for KHYW.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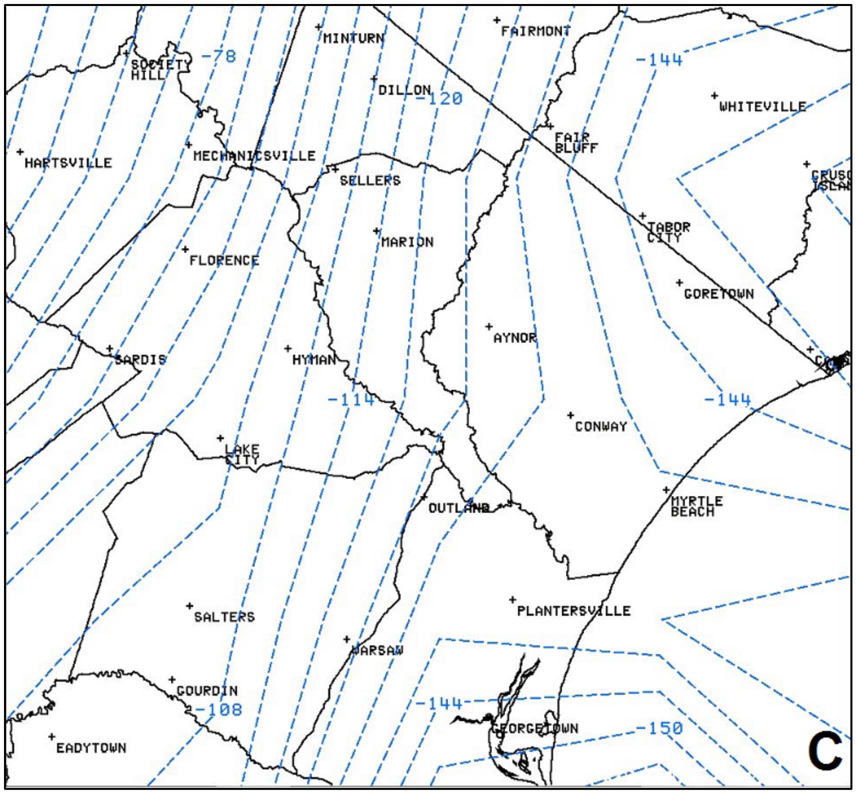
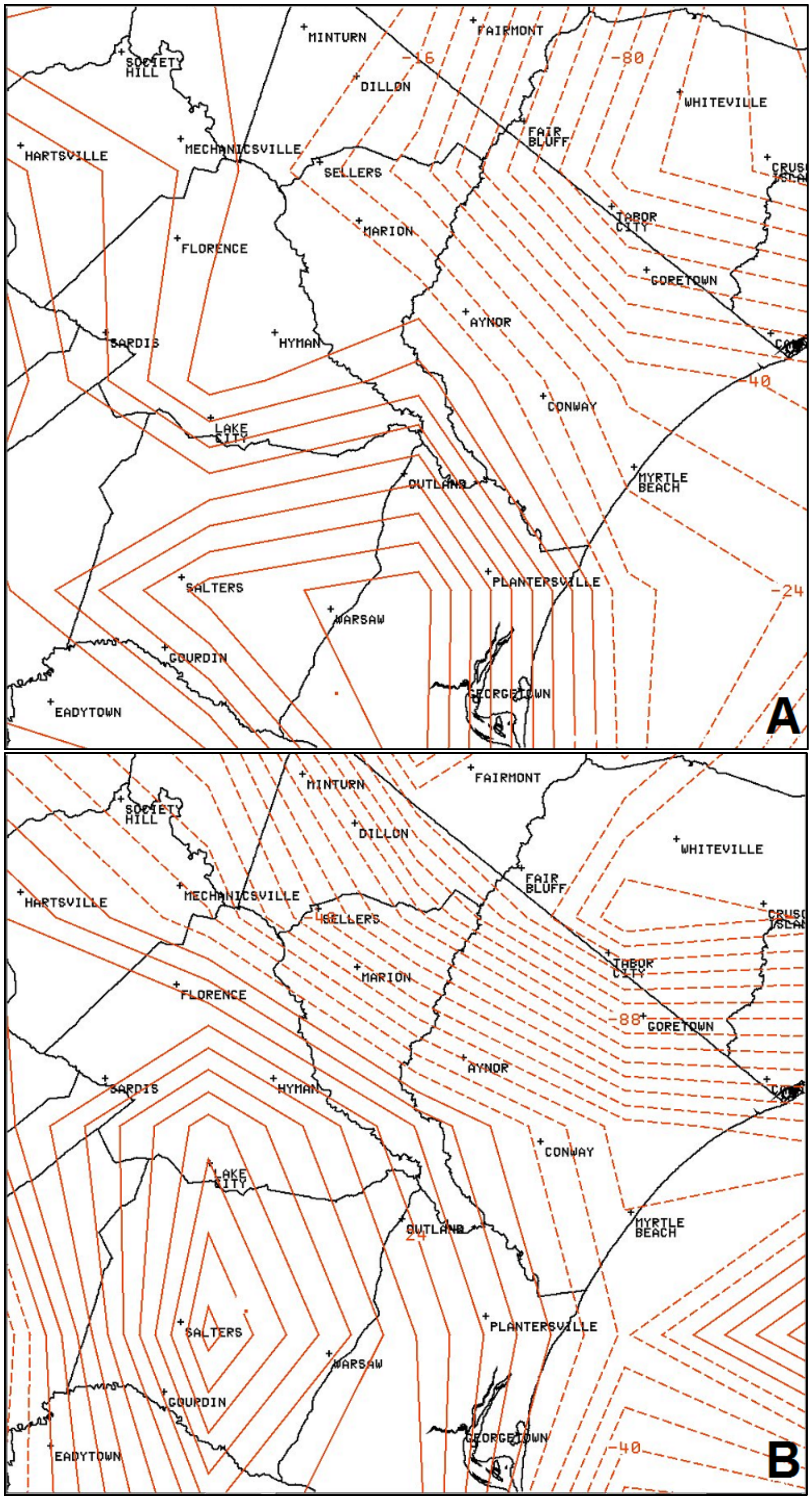


Figure 10. RUC analyses of 1-3 km LM-SRH at (A) 2100 UTC, (B) 2200 UTC and RUC 1-hr forecast of 1-3 km LM-SRH at (C) 2300 UTC on 10 May 2011.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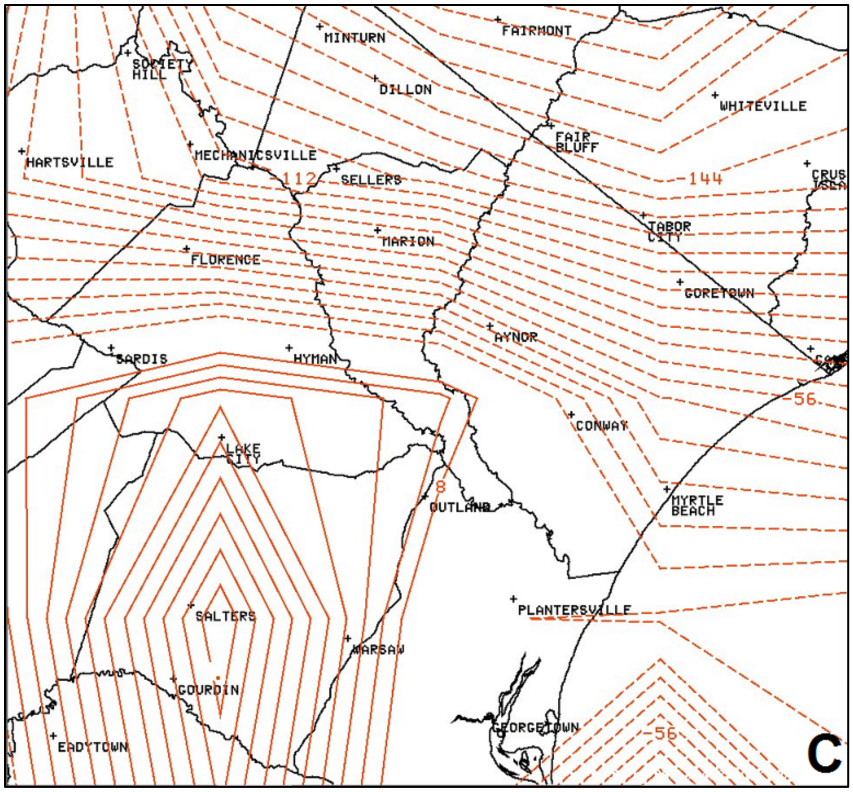

Figure 11. RUC analyses of 0-3 km LM-SRH at (A) 2100 UTC, (B) 2200 UTC and RUC 1-hr forecast of 0-3 km LM-SRH at (C) 2300 UTC on 10 May 2011.

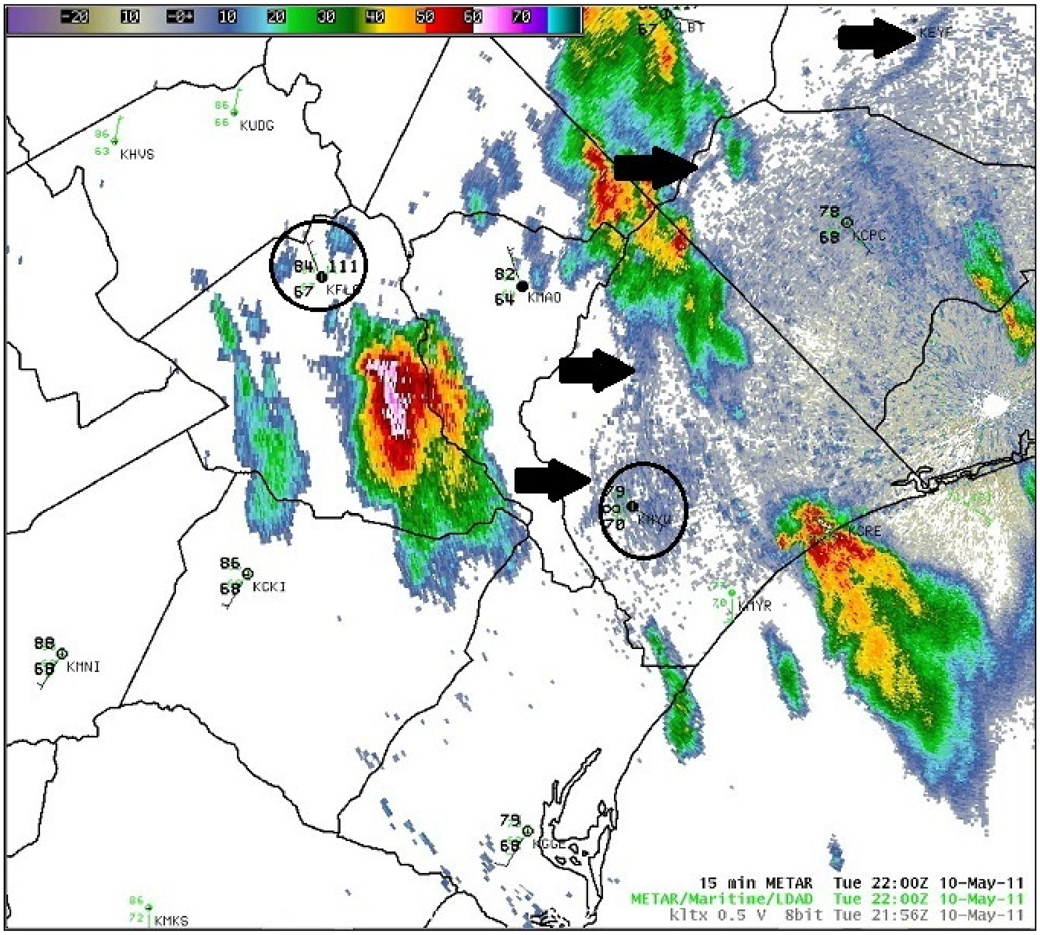

Figure 12. 2200 UTC 10 May 2011 observations with KFLO and KHYW circled. The sea breeze front is evident in reflectivity, and pointed to by the arrows.

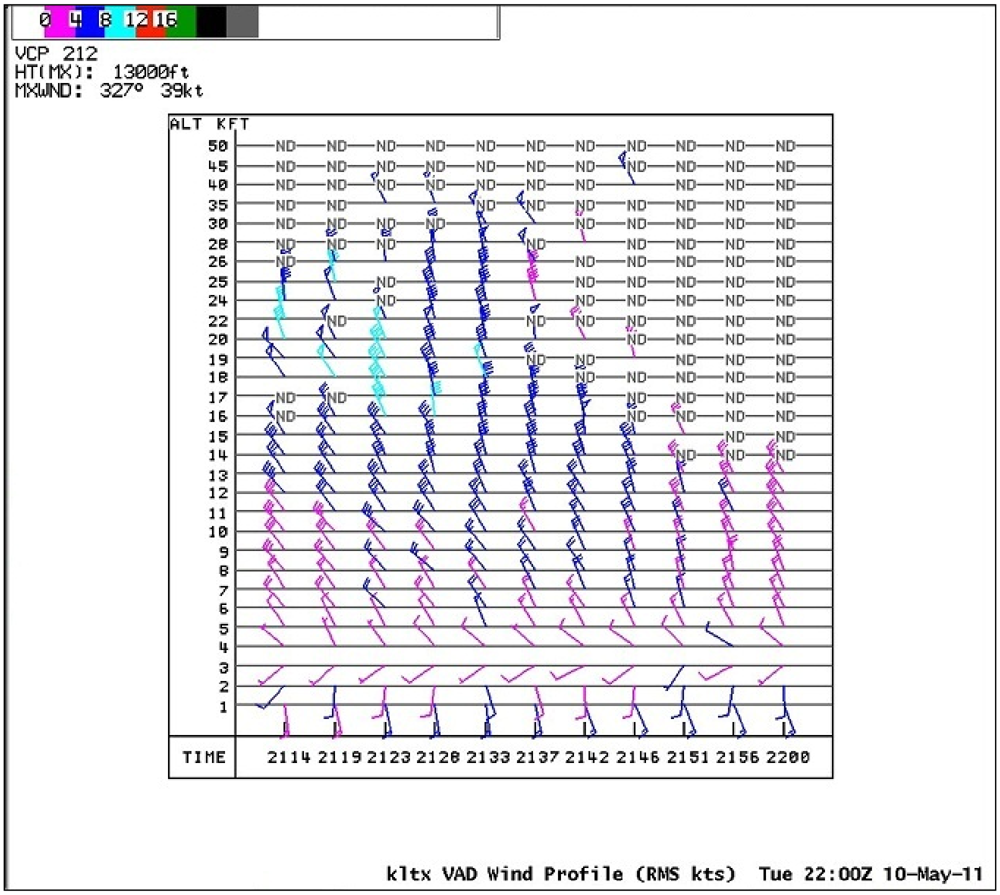

Figure 13. KLTX VWP at 2200 UTC 10 May 2011. Note the southerly near surface winds veering to NW in the lowest 4 kft.

d) Radar Interpretation

After the storm split, the thunderstorm strengthened and took on characteristics common to a supercell. By 2223 UTC, radar reflectivity on the KLTX 0.5° elevation scan increased to 70 dBZ at 3680 ft AGL, and by 2232 UTC rotation consistent with an mesoanticyclone appeared on the northeast side of the reflectivity core. This is consistent with the idea of left moving supercells as mirror images of right moving supercells (EH06). In addition, the left mover developed a tight reflectivity gradient on the inflow side, and an inflow notch, although weak, was evident. However, during this time there were no large hail reports submitted to the National Weather Service. This may be due to the storm passing over relatively unpopulated areas, since all other parameters suggested large hail at 2232 UTC (Fig. 14).

Most interesting is what occurred right around the time that the softball sized hail was reported in Conway. Between 2232 UTC and 2246 UTC, a second tight anti-cyclonic rotation formed near the Conway area (Figs. 15-17). This mesoanticyclone lasted longer than the previous one, and had more vertical depth with reflectivity above 50 dBZ reaching higher than 25,000 ft AGL. During this strengthening of the supercell, mid-level rotational shear quadrupled to 40 kts, reflectivity peaked as high as 75 dBZ at 2900 ft AGL on the KLTX 0.5° scan, and a well-defined inflow notch appeared (Fig. 18).

The updraft strength increased dramatically during this period, shown by an increase in reflectivity on the 10.0° elevation scan (Figs. 19-21). Between 2232 UTC and 2237 UTC, reflectivity increased in the highest elevations of the storm which is frequently used as a proxy for a strengthening updraft, and the spatial extent of echoes above 50 dBZ peaked at 2237 UTC before beginning to collapse by 2241 UTC (Figs. 19-21). The peak reflectivity reached above 55 dBZ on this 10.0° scan at 24,646 ft AGL at 2237 UTC, concurrent with a steep overhang on the inflow region of the storm (Fig. 22), both of which are common indicators of a strengthening supercell. The largest hail fell over Conway between 2240 UTC and 2245 UTC, coincident with the collapse of this intense reflectivity core (Figs. 22-24).

This left mover produced a swath of very large hail across western Horry County, which is consistent with other research on left movers (Warning Decision Training Branch 2009; E04; Mathews and Turnage 2000). However, two other left moving storms developed in similar environments during this event, neither of which produced the same giant hail. One other factor that likely played a role in creating truly giant hail was the interaction with an outflow boundary that occurred during the time of rapid updraft strengthening.

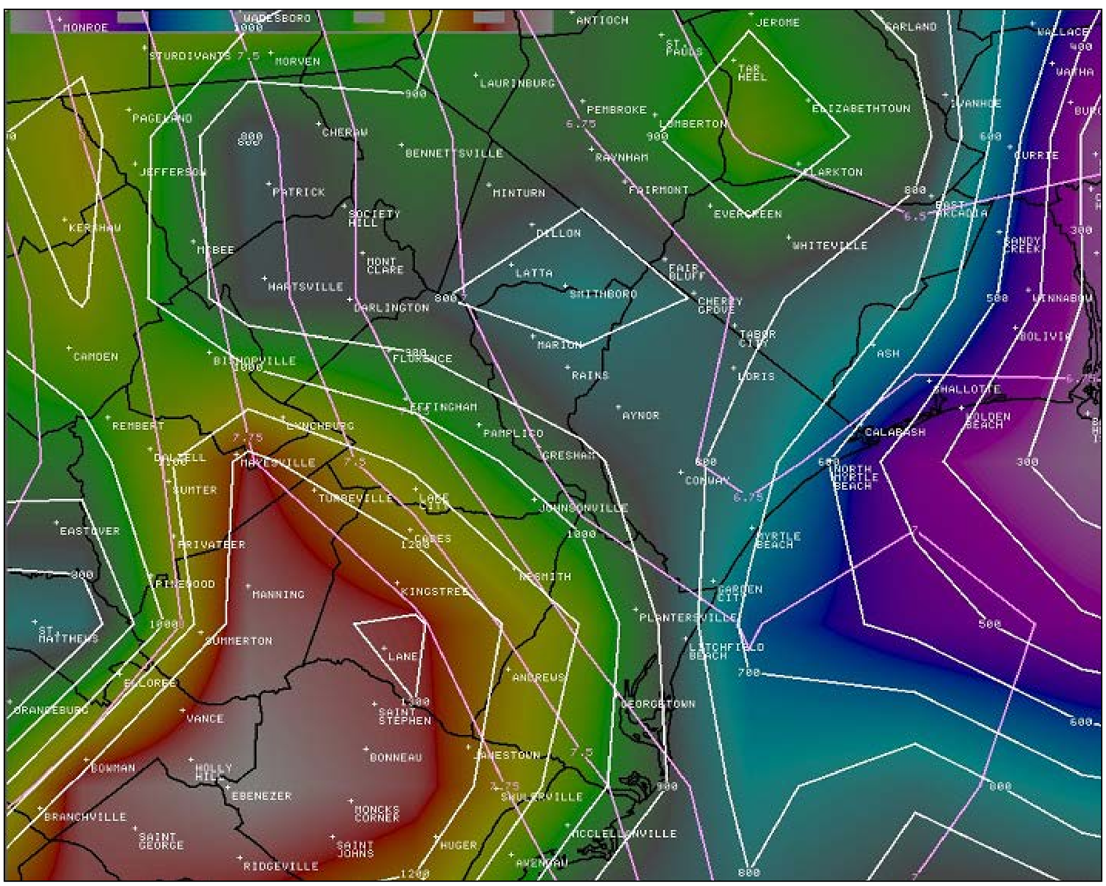

Figure 14. 2200 UTC 10 May 2011 RUC SBCAPE (shaded), 500-700 hPa Lapse Rates (red), and -10 C to -30 C computed CAPE (yellow). The light blue is over 2000 J kg^{-1}, lapse rates are around 7°C km^{-1}, and hail growth CAPE is around 800 J kg^{-1}.

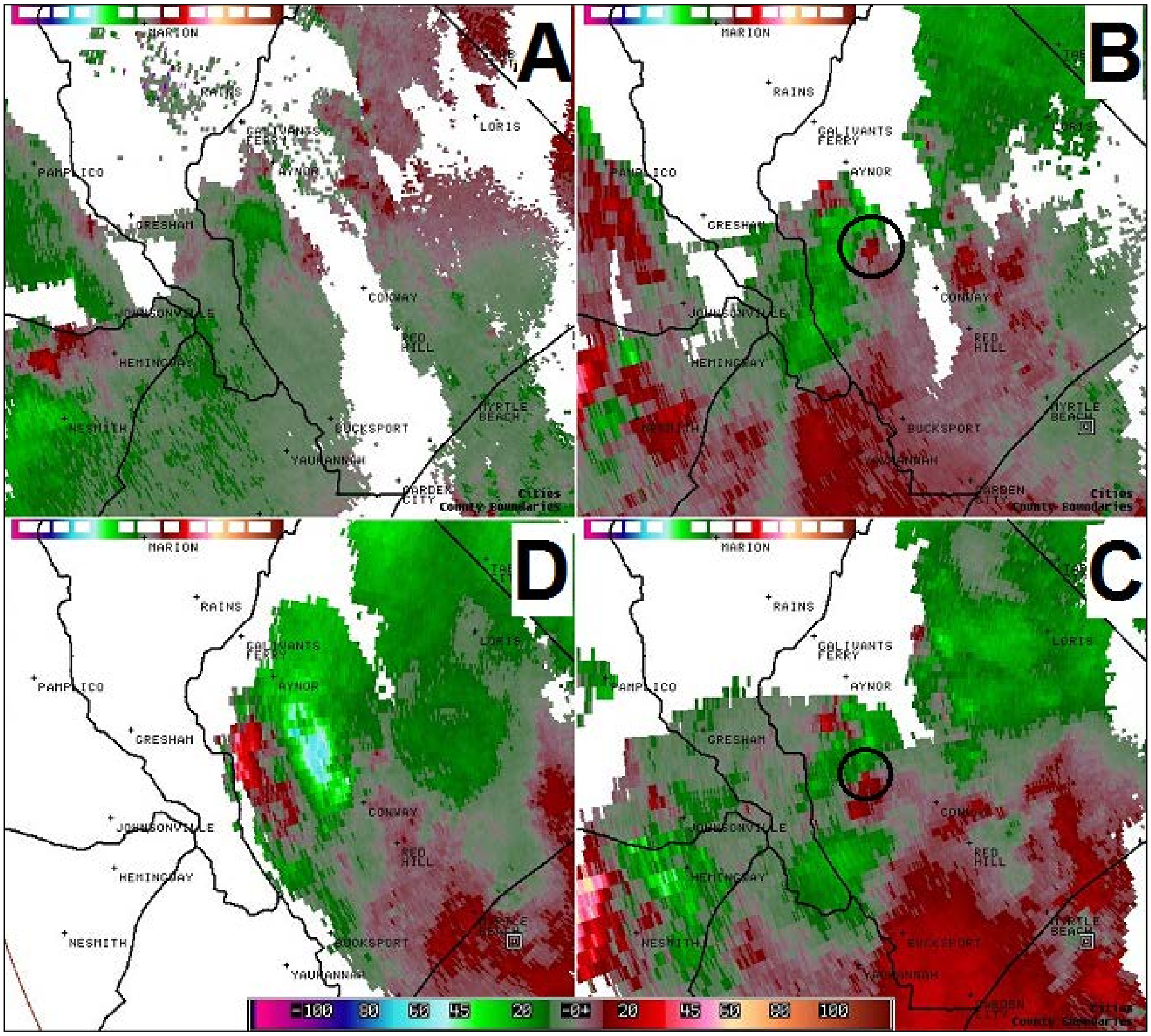

Figure 15. 4 panel SRM from KLTX at 2232 UTC 10 May 2011. Panels are (A) 1.3°, (B) 4.0°, (C) 6.4°, and (D) 10.0°. Note the mesoanticyclone (especially at 4.0° and 6.4°, circled) as the storm approaches Conway. Clockwise labeling of panels is consistent with standard AWIPS display.

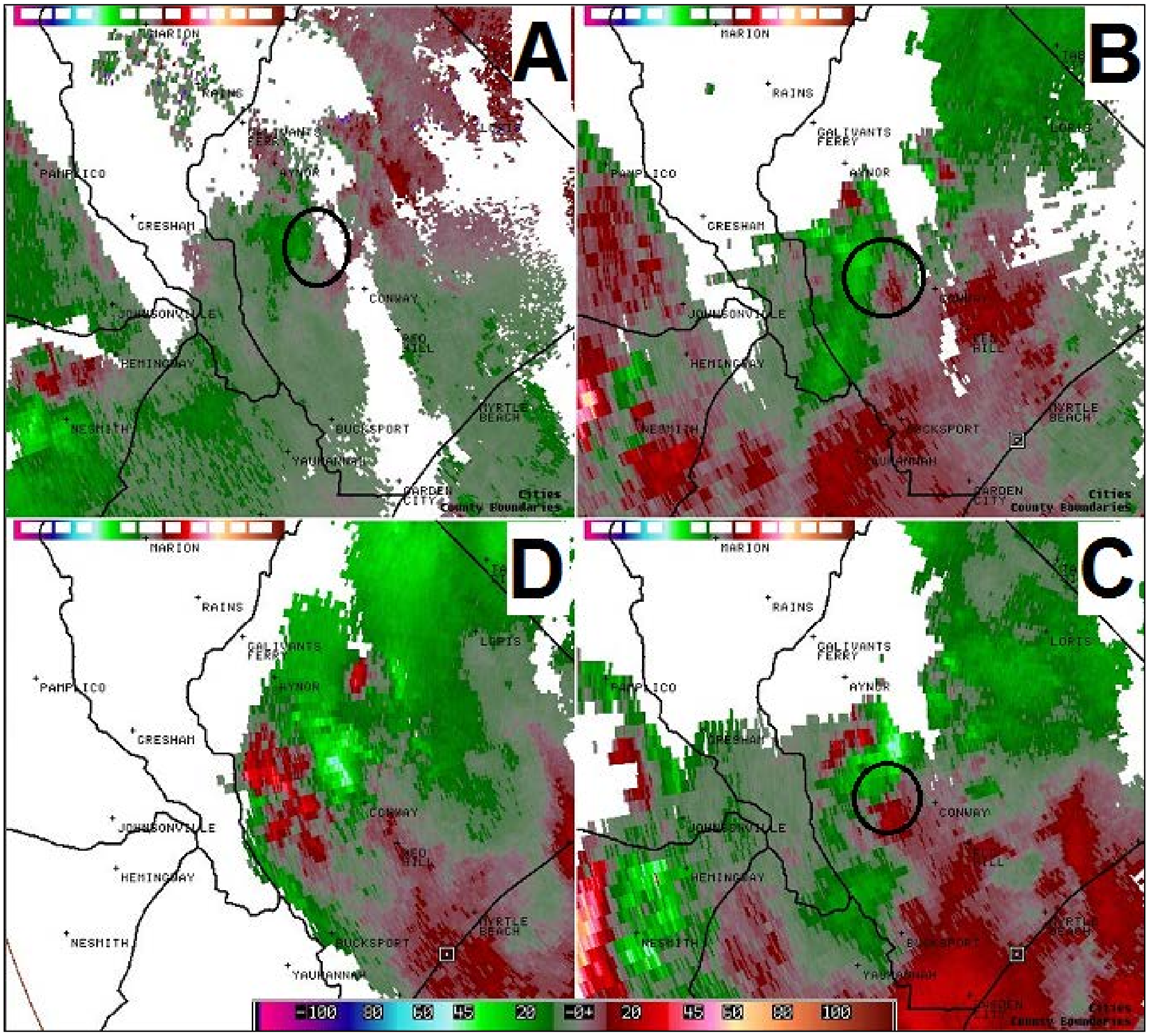

Figure 16. Same as Figure 15, except for 2237 UTC.

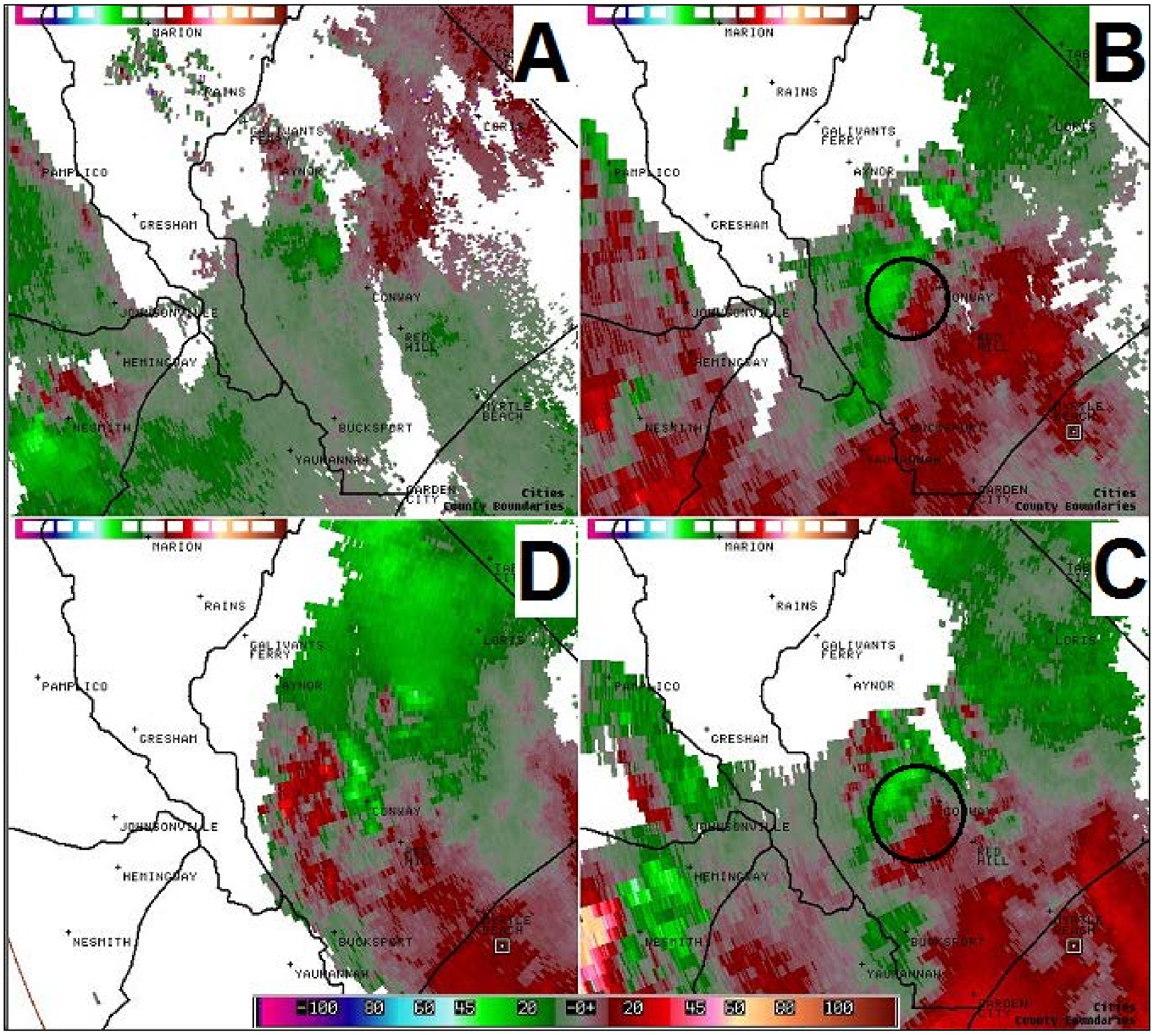

Figure 17. Same as Figure 15, except for 2241 UTC.

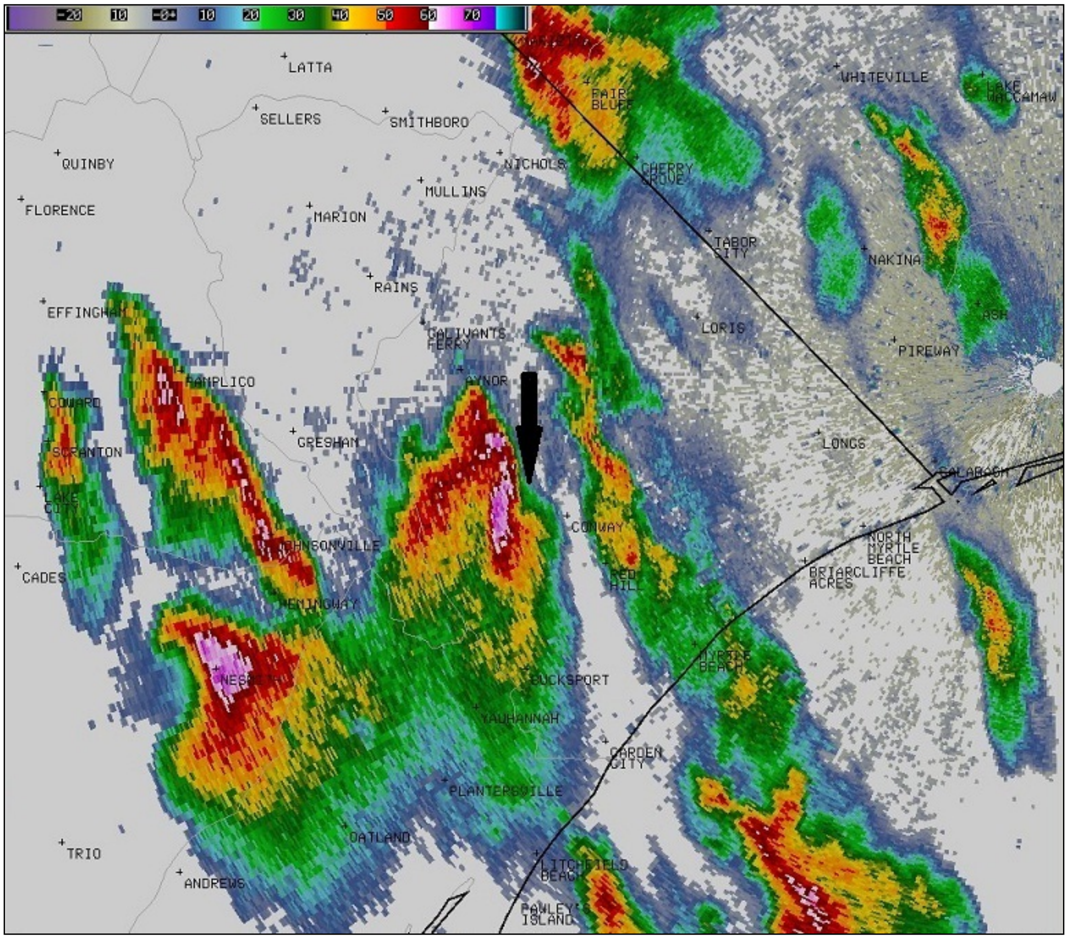

Figure 18. 0.5 degree reflectivity from KLTX at 2246 UTC 10 May 2011. The appended arrow indicates the inflow notch characteristic.

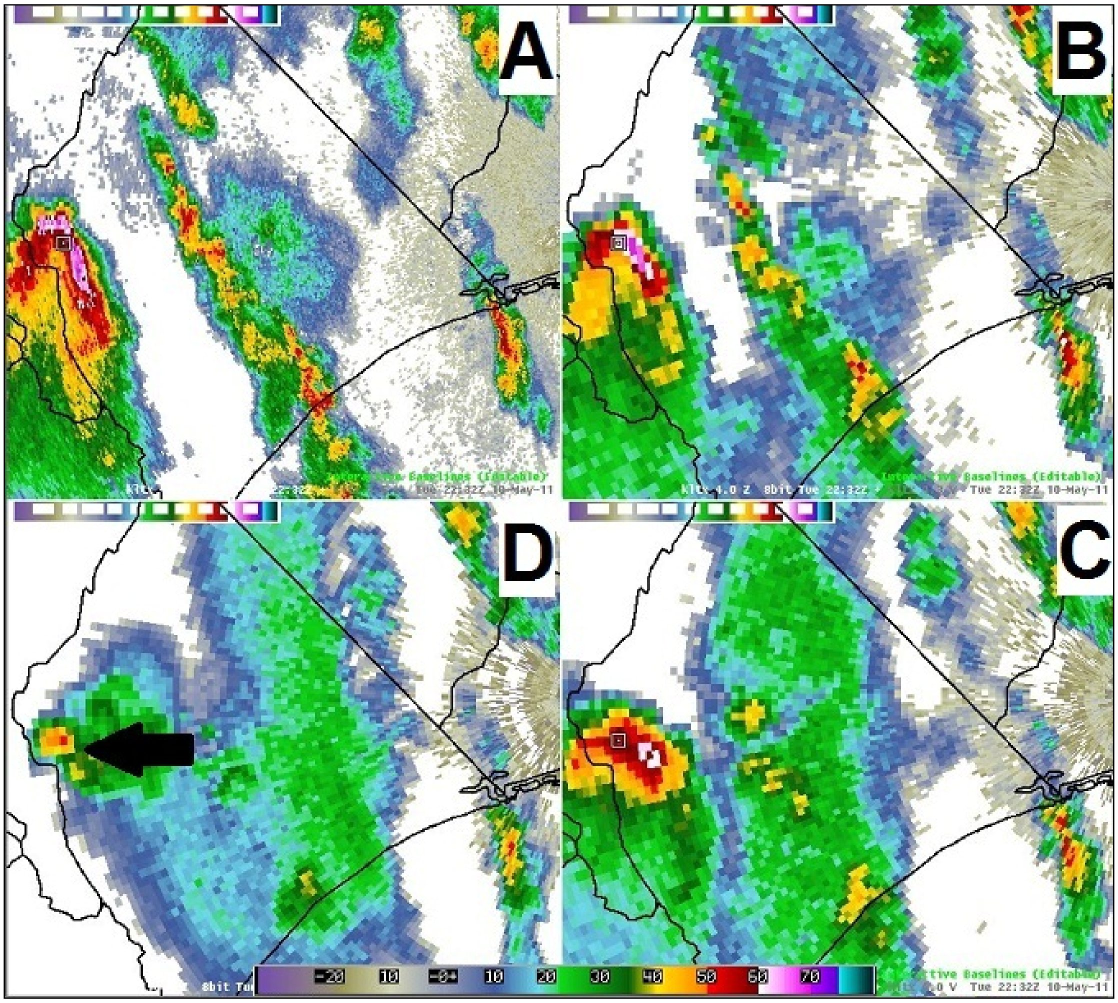

Figure 19. KTLX reflectivity at (A) 1.3°, (B) 4.0°, (C) 6.4°, and (D) 10.0° from 2232 UTC 10 May 2011. The arrow in (D) highlights the significant hail producing updraft. Clockwise labeling of panels is consistent with standard AWIPS display.

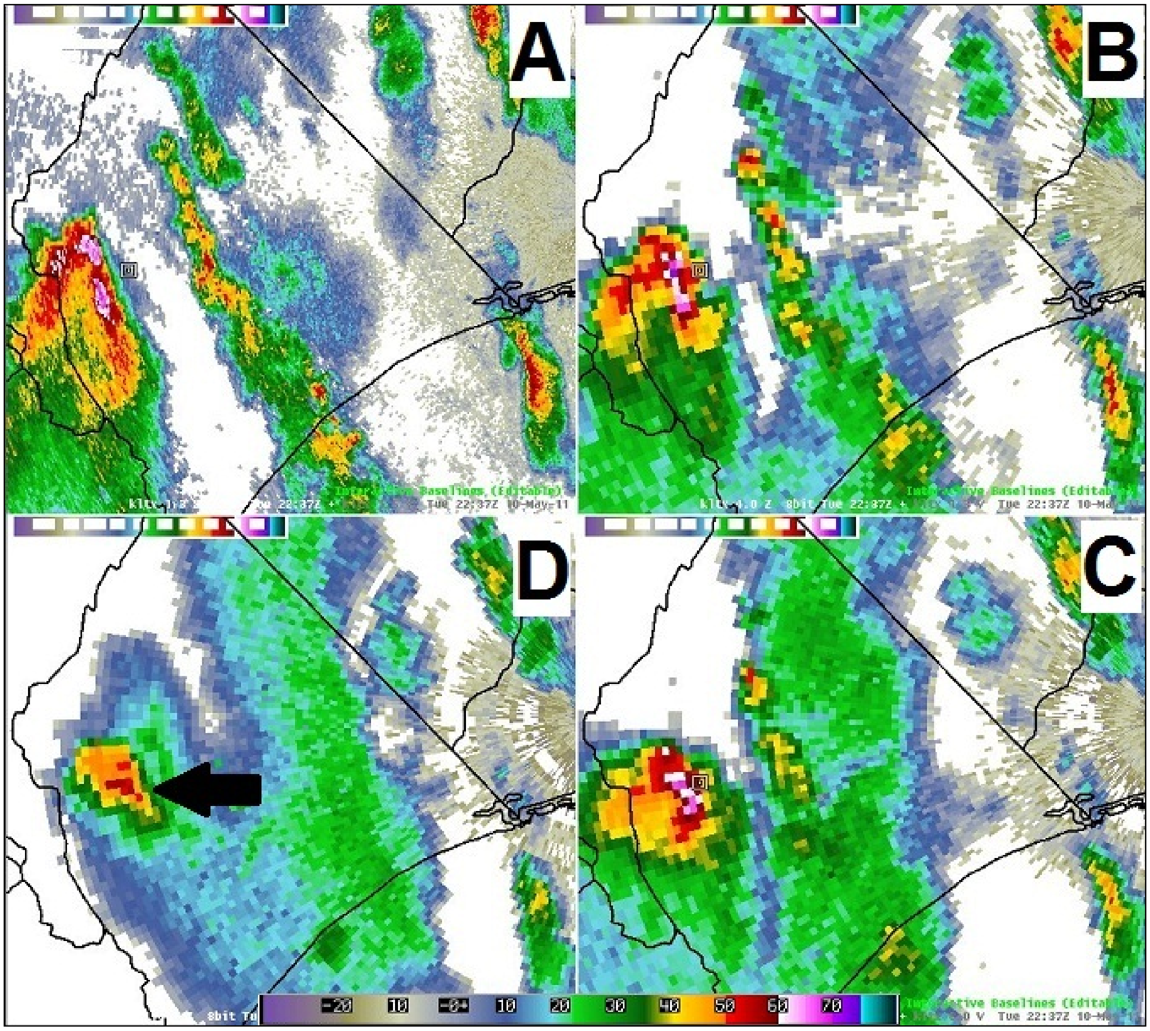

Figure 20. Same as in Figure 19, except for 2237 UTC.

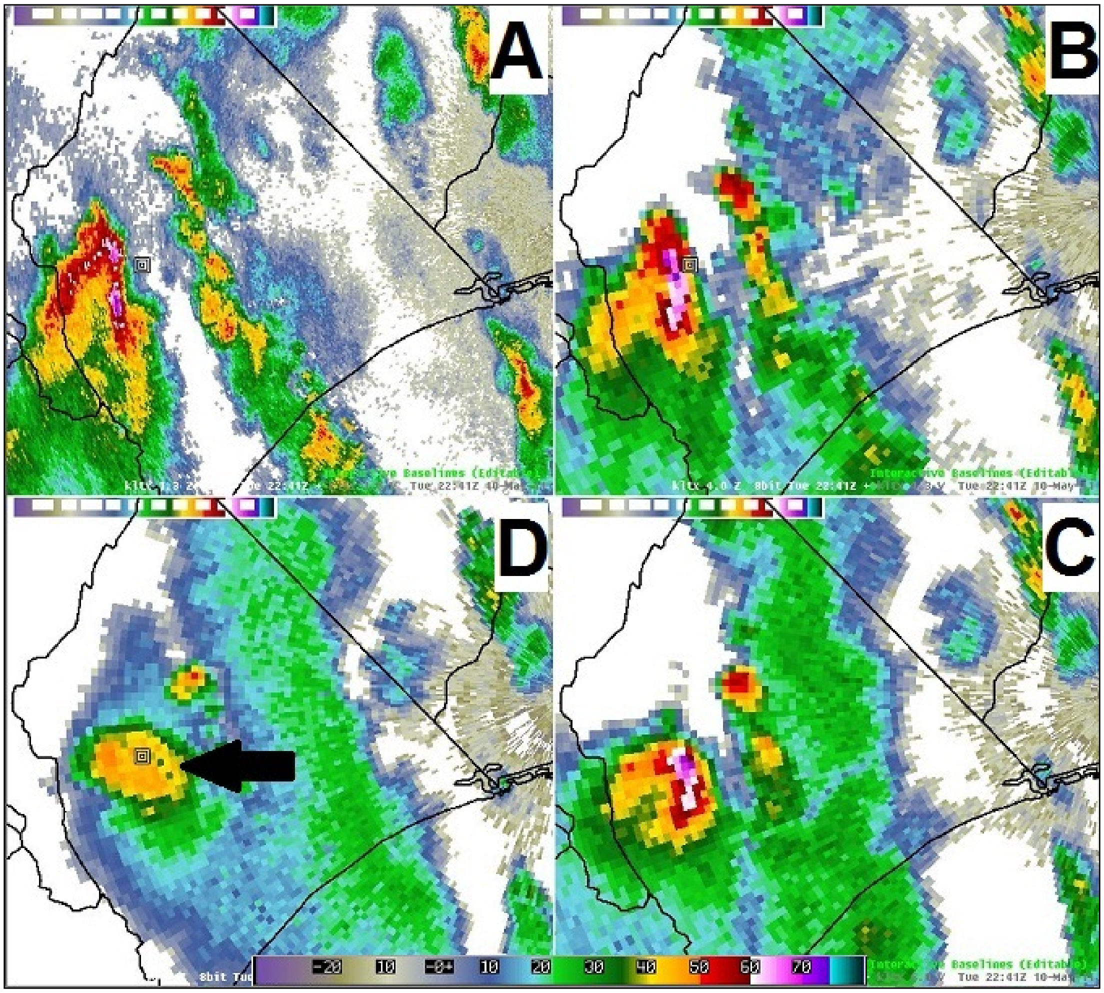

Figure 21. Same as in Figure 19, except for 2241 UTC.

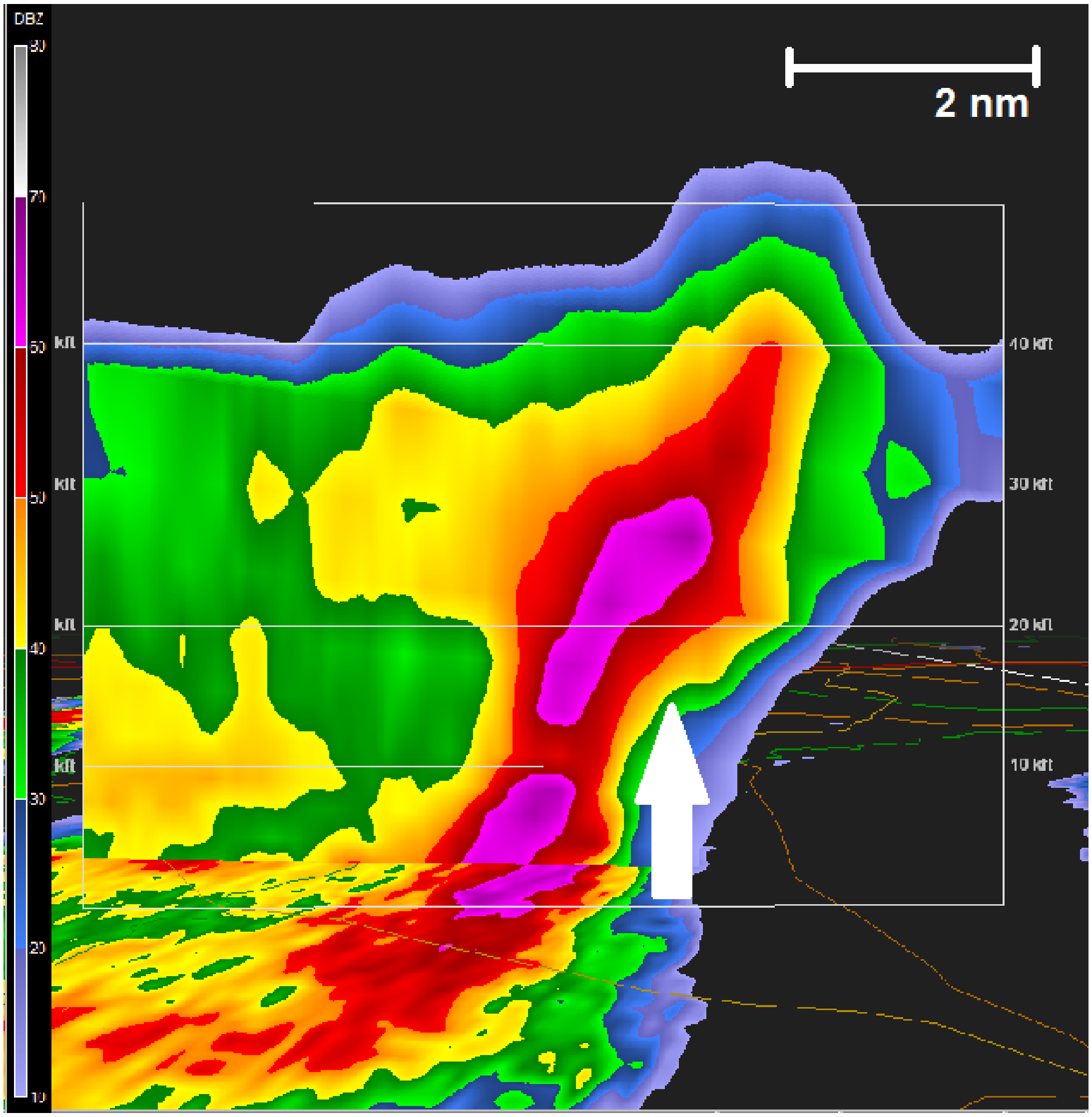

Figure 22. Cross section of reflectivity from left-moving supercell at 2237 UTC 10 May 2011. This was just before the giant hail fell over Conway. Note the core of 50 dBZ echoes extends above 40 kft. The arrow points to the overhang feature noted in the text.

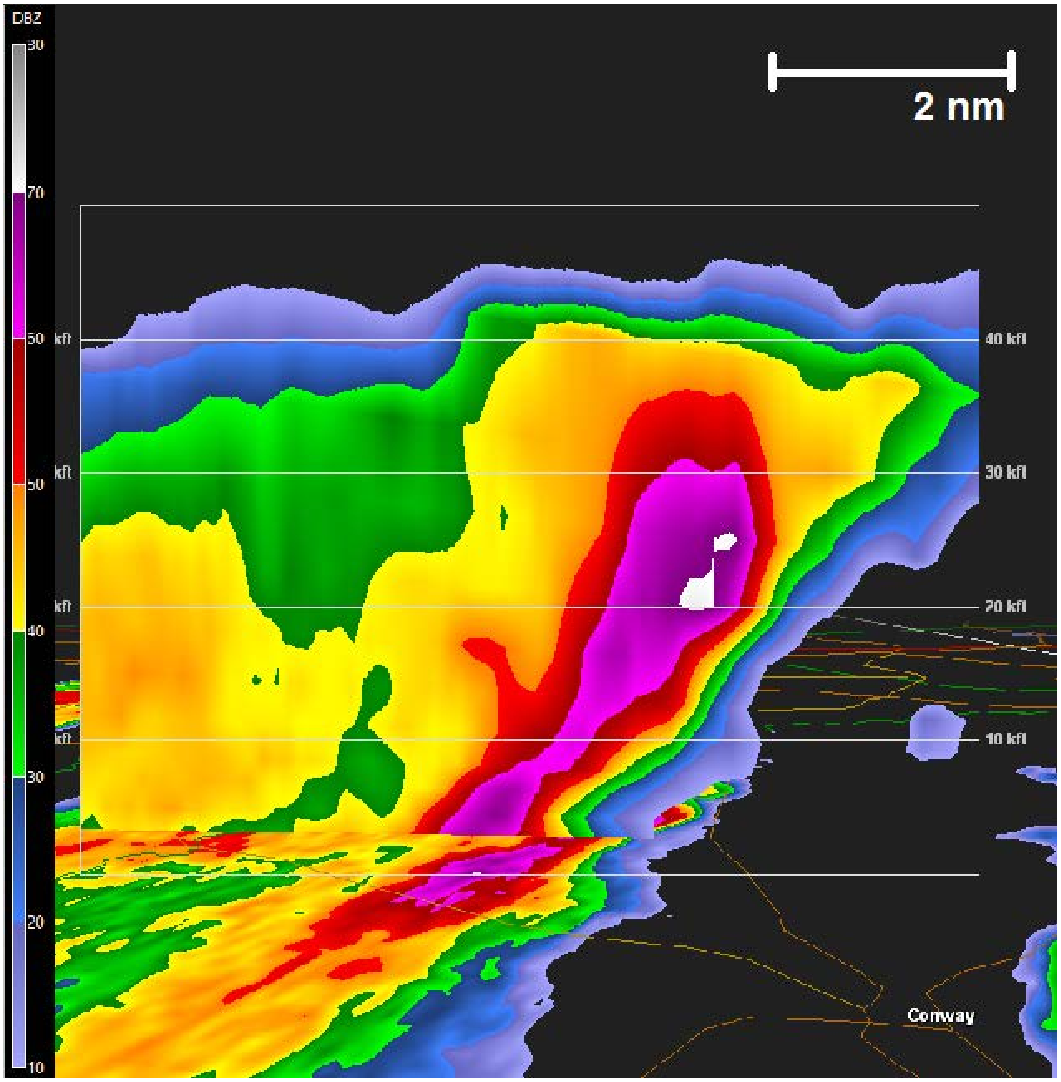

Figure 23. Same as in Figure 22, except for 2241 UTC. Note the 50 dBZ echoes are beginning to collapse, and a region of 70 dBZ reflectivity has developed near 20 kft.

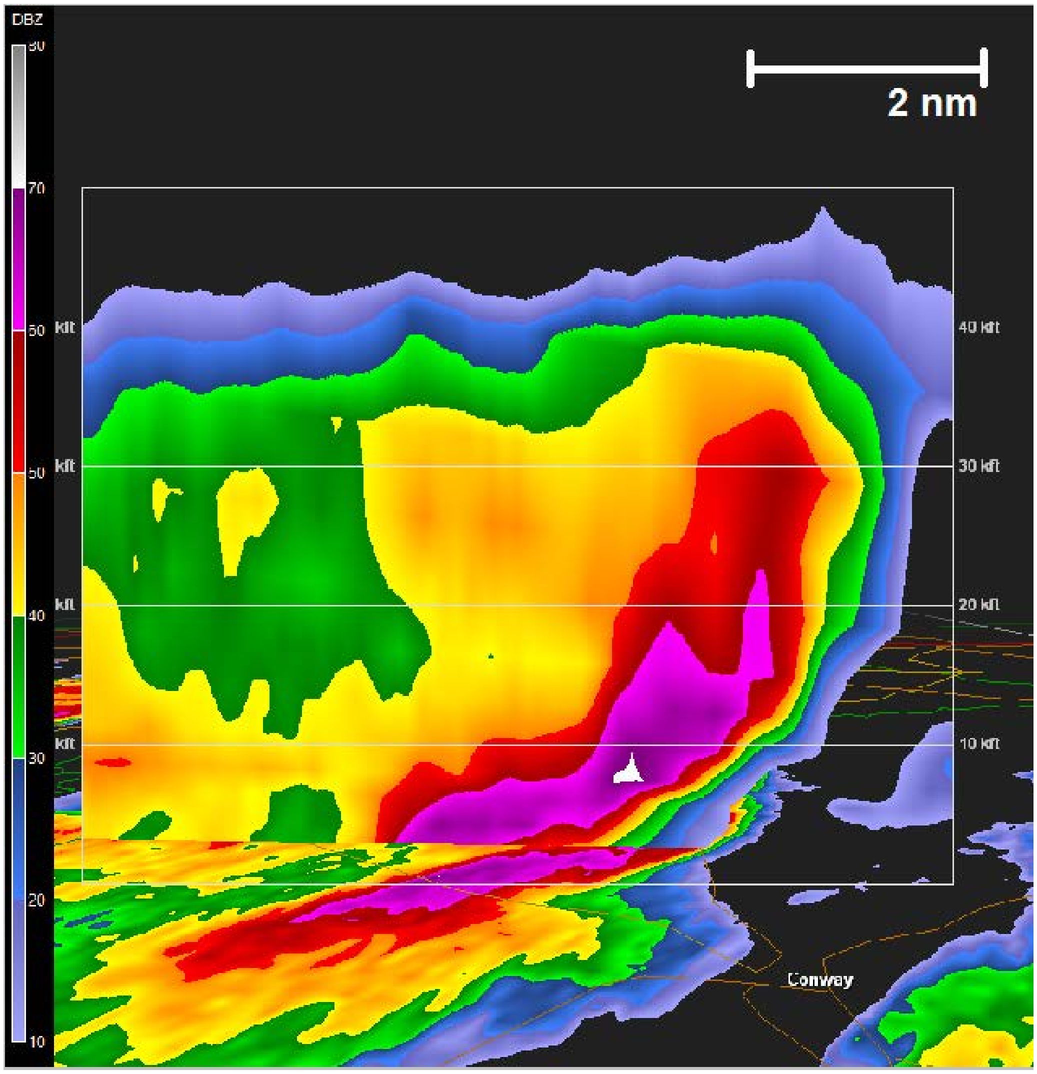

Figure 24. Same as in Figure 22, except for 2246 UTC. This was just after the giant hell fell over Conway. Note the strong collapse of the highest echoes, with the region of 70 dBZ confined below 10 kft.

e) Storm/Outflow Interaction

Storm interactions with boundaries (outflows, fronts, sea breezes) have long been identified as an origin for storm strengthening (Markowski et al. 1998). KLTX 0.5° reflectivity at 2228 UTC shows a weak north/south oriented outflow boundary from about Mullins to Conway (Fig. 25). Over the next 15 minutes, the westward moving outflow interacted with the eastward moving supercell. This type of collision is thought to be significant due to the enhanced convergence of the nearly perpendicular interaction of the storm with the outflow boundary (Rose and Boyd 2001). This case was no different, with the storm-boundary collision creating enhanced low-level convergence which aided in increasing updraft strength. This is seen both by the highest reflectivity on the 10.0° elevation scan occurring during this time, and enhanced velocity developing on the 0.5° scan just before and during the collision

(Figs. 26a-26b). The combination of these two features developing concurrently during the outflow impact with the supercell lends even more credence to this idea.

Analysis of the 0.5° reflectivity and base velocity more clearly demonstrates the result of this boundary interaction. Between 2218 UTC and 2237 UTC, the outflow boundary moved westward through Conway and began interacting with the left moving supercell (Figs. 27a-27f). The outflow boundary is easily visible in the base reflectivity as well as by a thin line of negative velocities indicating movement away from KLTX (Figs. 27a-27b). These two features in tandem point to an outflow boundary with winds that are backed to the east behind it. Additionally, the surface winds at Conway did become more easterly at 2237 UTC just after the outflow passed through the city (Fig. 27f), proving that winds were backed behind the boundary. This is important because it indicates that the collision between the eastward moving supercell and the outflow boundary was nearly perpendicular which maximized the low level convergence within the storm.

This outflow boundary interacted with the storm between 2232 UTC and 2237 UTC, positively reinforcing the updraft strength as shown by the maximum reflectivity at 10.0° occurring at the same time (Fig. 20). This additional strengthening is what allowed the storm to produce truly giant hail over Conway. As the left mover interacted with the outflow boundary, it enhanced low-level convergence, and this combined with mid-level lapse rates approaching 8°C km^{-1} to augment the updraft and strengthen the storm as noted by the highest reflectivity occurring at this time. The fact that the storm rapidly strengthened during this interaction, and nearly as rapidly dissipated once it moved off the outflow, is more evidence that the boundary merger played a key role in producing the giant hail. By 2313 UTC 0.5° maximum reflectivity decreased significantly (Fig. 28) and no further reports of large hail were received from this supercell.

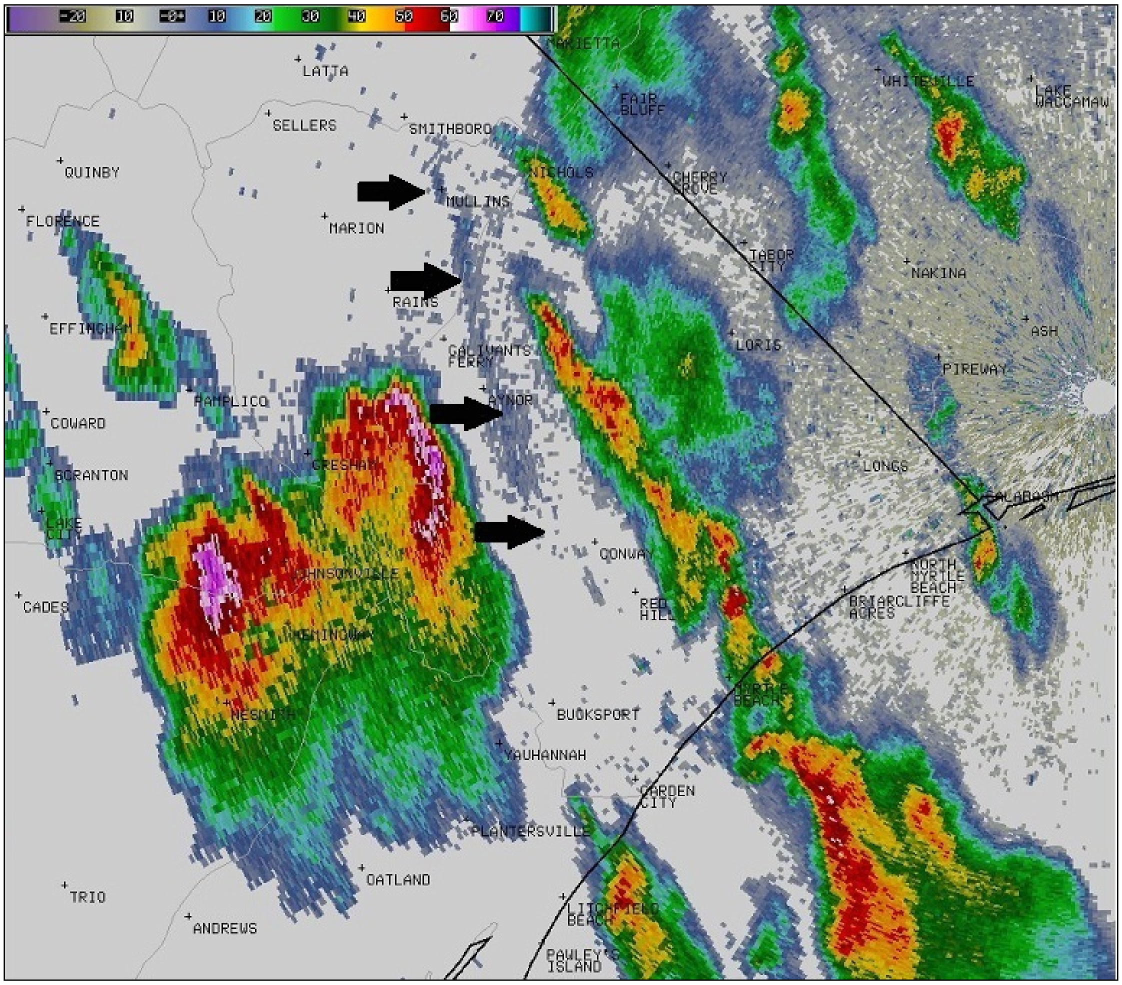

Figure 25. KLTX 0.5 degree reflectivity at 2228 UTC 10 May 2011 with arrows pointing to relevant outflow.

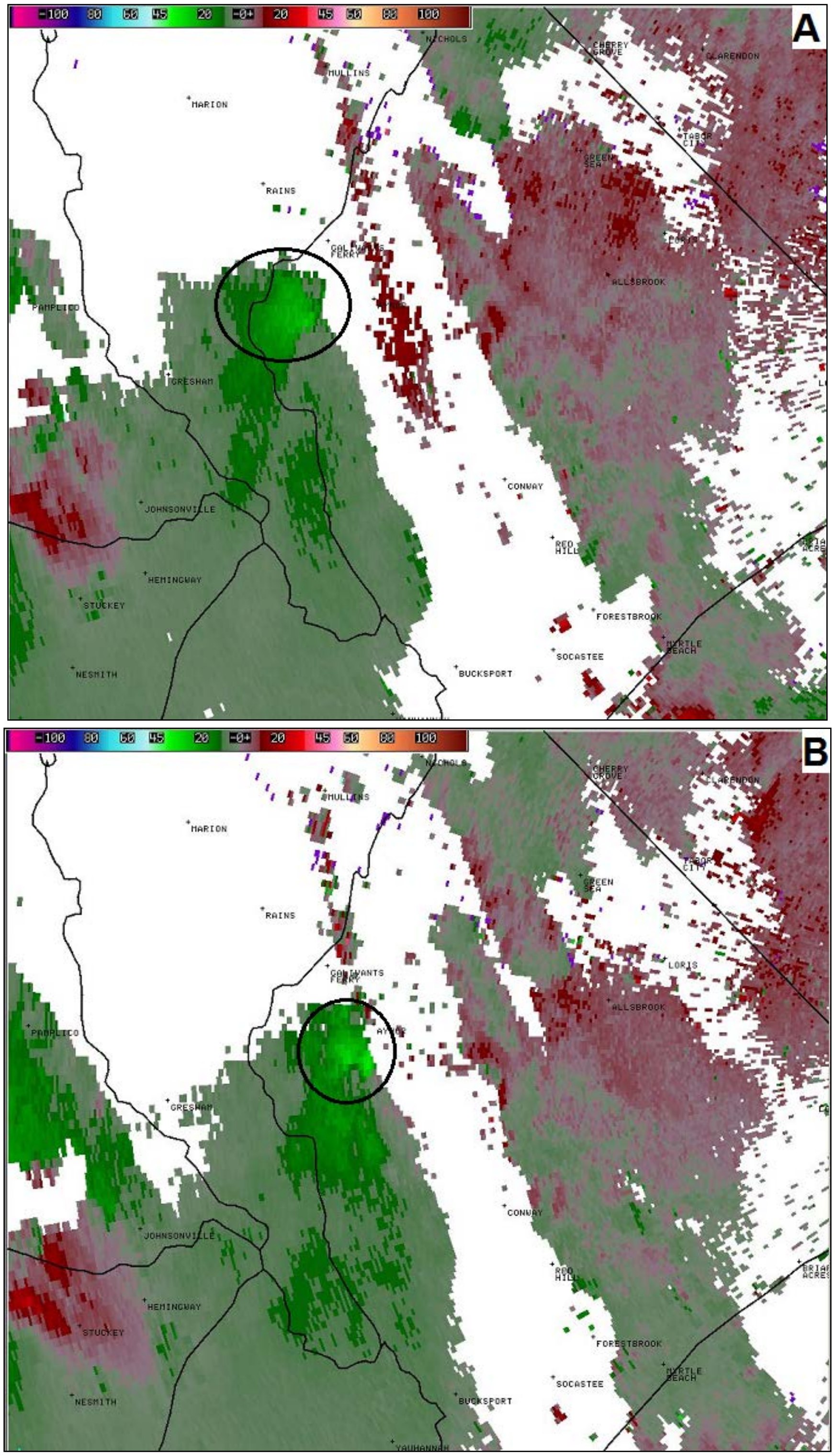

Figure 26. 0.5° base velocity showing enhancement of low level winds during storm-outflow interaction between (A) 2228 UTC and (B) 2237 UTC on 10 May 2011. Max velocity in (B) is 38 kts.

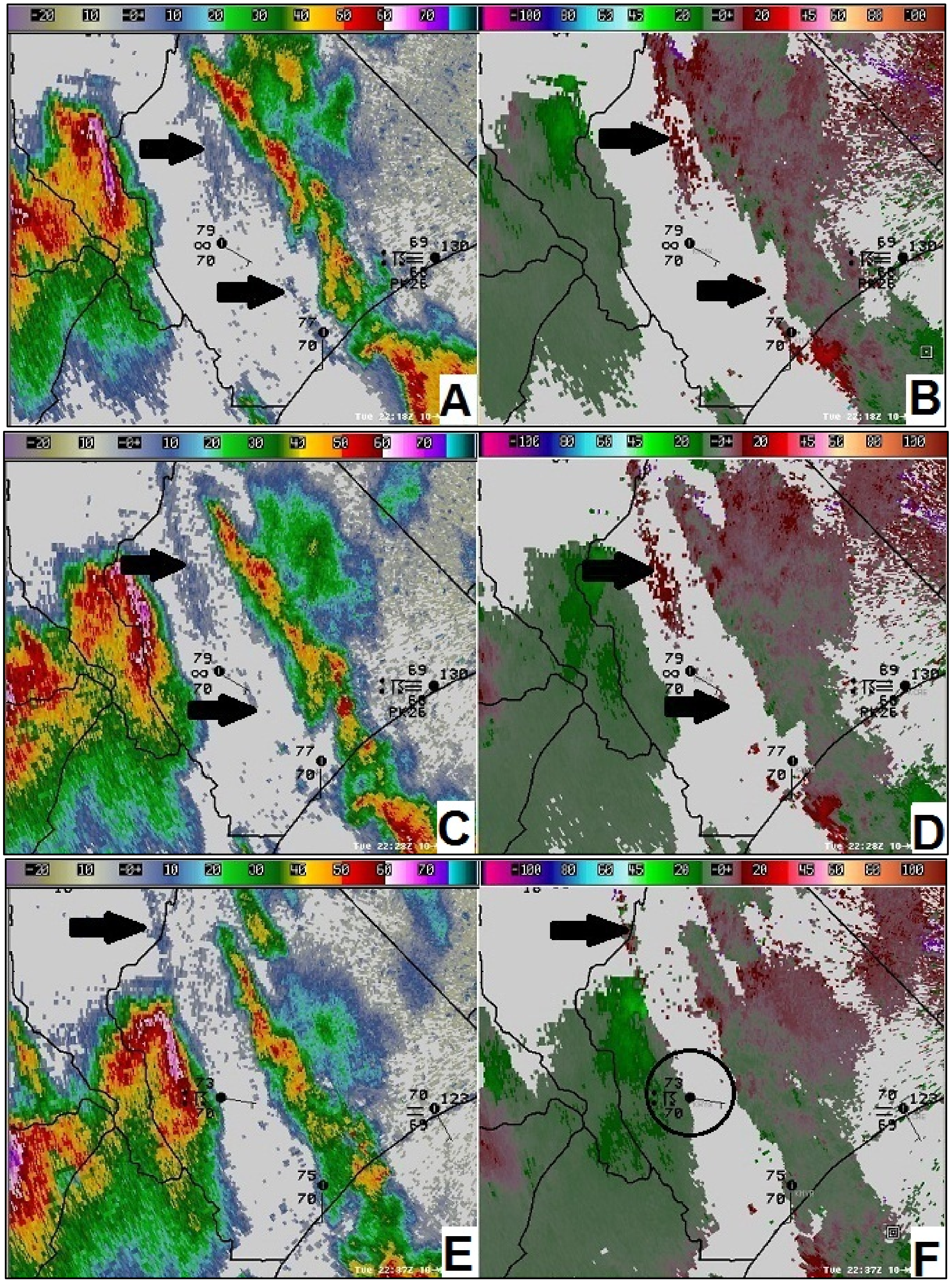

Figure 27. Evolution of reflectivity/base velocity of an outflow boundary. The arrows point to the boundary as it moved west through Horry County from (A/B) 2218 UTC to (C/D) 2228 UTC to (E/F) 2237 UTC 10 May 2011. Note the negative velocity associated with the boundary and the backing of the wind at Conway (circled) in 27f.

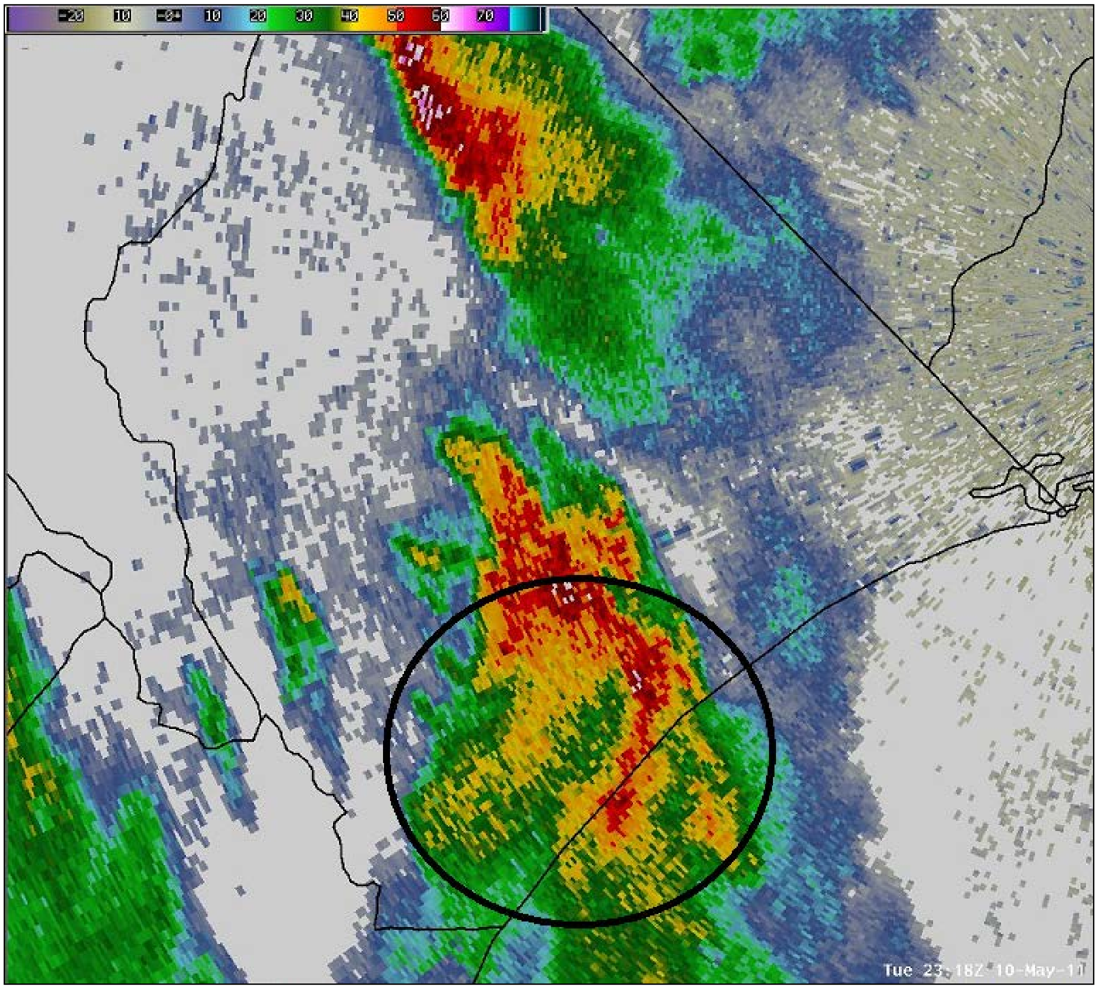

Figure 28. KLTX 0.5 degree reflectivity at 2318 UTC 10 May 2011. The highlighted portion shows the significant decrease in reflectivity. No more hail reports were received after this time.

4. Event Summary/Conclusion

Left moving supercells, although rare, have been recognized to be giant hail producers. The left mover that impacted the Conway, SC area on the evening of 10 May 2011 was no different. Although part of a larger outbreak that produced widespread significant severe hail, the supercell that impacted Conway was the most destructive, creating softball sized hail that damaged many vehicles and homes. This softball sized hail is now one of only ten occurrences of 4 inch diameter or larger hail to occur across South Carolina since 1950 (National Climatic Data Center, Storm Data, 1950-2010)

The environment for the severe outbreak was conducive to large hail and left movers. Both observed and model soundings reflected an EML which aided in steepening mid-level lapse rates to nearly 8°C km^{-1}. This helped increase SBCAPE to almost 3000 J kg^{-1} with contribution from the hail growth zone of up to 1000 J kg^{-1}. Hodographs from the event were relatively linear which explains why splitting supercells were possible, and why this left mover was able to develop. Although the left mover of interest produced large hail before affecting Conway, the giant hail only occurred for a short time just near the city. This was due to interaction with an outflow boundary which intensified low-level convergence and increased updraft strength. Although left movers are known to produce large hail, and this case was no different, it took a boundary interaction to produce truly giant hail and make this an exceptional event. Forecasters in the future should be aware of this potential, and be prepared to issue warnings with enhanced wording when boundary interactions involving left moving supercells in significant severe hail environments occur.

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References

Bunkers, M. J., 2002: Vertical wind shear associated with left-moving supercells. *Wea. Forecasting*, **17**, 845-855.

Bunkers, M. J., B. A. Klimowski, J. W. Zeitler, R. L. Thompson, and M. L. Weisman, 2000: Predicting supercell motion using a new hodograph technique. *Wea. Forecasting*, **15**, 61–79.

Donavon, R. A., and K. A. Jungbluth, 2007: Evaluation of a technique for radar identification of large hail across the Upper Midwest and Central Plains of the United States. *Wea. Forecasting*, **22**, 244–254.

Doswell, C. A. III, 1991: A review for forecasters on the application of hodographs to forecasting severe thunderstorms. *Natl. Wea. Dig.*, **16,** 2–16.

Edwards, R., and S.J. Hodanish, 2006: Photographic documentation and environmental analysis of an intense, anticyclonic supercell on the Colorado Plains. *Mon. Wea. Rev.*, **134**, 3753-3763.

Edwards, R., R. L. Thompson and C. M. Mead, 2004: Assessment of anticyclonic supercell environments using close proximity soundings from the RUC Model. Preprints, *22nd Conf. Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., (CD-ROM).

IEM Cow (NWS Storm Based Warning Verification) from Iowa State University Department of Agronomy. [Available online at http://mesonet.agron.iastate/edu/cow].

Markowski, P. M., E. N. Rasmussen, and J. M. Straka, 1998: The occurrence of tornadoes in supercells interacting with boundaries during VORTEX-95. *Wea. Forecasting*, **13**, 852-859.

Markowski, P. M., and Y. Richardson, 2006: On the classification of vertical shear as directional shear versus speed shear. *Wea. Forecasting*, **21**, 242-247.

Mathews, G. N., and T. J. Turnage, 2000: An example of a left-split supercell producing 5-inch hail: The Big Spring, Texas storm of 10 May 1996. Preprints, *20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., 526-529.

National Climatic Data Center, 1950-2010; Storm Data. [Available online at http://www.ncdc.noaa.gov/oa/climate/sd/].

National Weather Service Preliminary Local Storm Reports. Storm Prediction Center, 2011. [Available online at http://www.spc.noaa.gov/climo/reports/110510_rpts.html].

Rasmussen, E. N., and D. O. Blanchard, 1998: A baseline climatology of sounding-derived supercell and tornado forecast parameters. *Wea. Forecasting*, **13**, 1148–1164.

Rose, M. A., and B. Boyd, 2001: WSR-88D review of a downburst-producing thunderstorm induced by a westward-moving outflow boundary. *Electronic Journal of Operational Meteorology*, **2** (4), 1-7. [Available online at http://www.nwas.org/ej/2001-EJ4/].

Thompson, R. L., R. Edwards, J. A. Hart, K. L. Elmore and P. M. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243-1261.

University Corporation for Atmospheric Research, The COMET Program, 2009: Satellite Feature Identification: Ring of Fire. [Available online at http://www.meted.ucar.edu/norlat/sat_features/ringoffire/index.htm].

Warning Decision Training Branch, 2009: Distance Learning Operations Course Topic 7 Lesson 8: Supercell Morphology: Velocity Structure. [Available online at http://www.wdtb.noaa.gov/courses/dloc/topic7/lesson8/player.html].