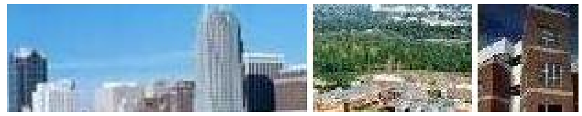
Event Summary
National Weather Service, Raleigh NC



March 28 and 29, 2010 North Carolina Tornado Outbreak

Note that this is a PDF version of the event summary and that some links, media or resources may not be avaiable in this format.

Event Headlines -
...Four tornadoes were confirmed in the RAH CWA with no tornado related fatalities...
...An EF-3 tornado touched down in High Point in Guilford County injuring three people, damaging over 600 structures and destroying 40 homes...
...This event is consistent with many other high shear-low CAPE (HSLC) severe weather episodes across the Carolinas. The upper air pattern was amplified with an anomalously strong mid and low level flow which resulted in strong deep layer shear while low level instability was limited with surface-based CAPE analyzed less than 500 J/kg...
...Thunderstorms developed in a localized maximum of instability and then moved northeast near a well defined surface boundary and gradient of enhanced low level shear. The thunderstorms developed persistent updrafts which allowed them to become severe with two supercell thunderstorms producing all of the tornadoes in central North Carolina...
...The TCLT TDWR radar was invaluable in issuing timely and effective warnings especially in ensuring good lead time and a high probability of detection...
...The first three tornadoes occurred between 650 and 730 PM EDT (550 PM and 630 PM LST) which is consistent with a 55 year climatology that showed that tornadoes in central North Carolina occur with the greatest frequency between 500 PM and 700 PM LST (Locklear 2008)...

Event Overview -
A significant severe weather and a flash flood event occurred during the evening of Sunday, March 28 and the early morning hours of Monday, March 29, 2010. There were 4 confirmed tornadoes in the RAH CWA with no tornado related fatalities. The number or injuries was difficult to determine but estimates range up to 8 significant injuries (broken bones) with numerous other minor injuries. Local authorities report that there was damage to over 600 structures in the High Point area alone.

Two fatalities were reported in Johnston County when a car with two high school students hydroplaned when around 6 inches of water covered a road. The car slid and then flipped into a flooded creek, with both of the occupants drowning.

Event Details -
A surface high pressure system centered over the northeast U.S. and southern Quebec ridged south into the Carolinas at 12 UTC on March 27, 2010. The surface high and ridge axis moved offshore by 12 UTC on March 28 allowing a return flow off the Atlantic Ocean to become established over central North Carolina. A mature mid and upper level cyclone was positioned over the mid-Mississippi River Valley with a positive or neutral tilted trough extending south-southwest from the cyclone. Winds at 500 hPa were robust with a core of 90-95 kt winds rotating through the trough over Mississippi and Alabama. The upper level jet exceeded 120kts and was located over northern Louisiana, resulting in the best upper level divergence over the Ohio Valley in eastern Kentucky and West Virginia. The low level jet was positioned from the border of Alabama and Georgia northeast into Tennessee and the western sections of North Carolina and Virginia.

During the mid afternoon hours on March 28, the surface temperatures across North Carolina ranged in the lower 50s with dew points in the upper 40s across the Northwest Piedmont while temperatures were in the upper 60s and dew points were in the upper 50s across the eastern Piedmont and Coastal Plain. A surface boundary developed between the two air masses and would play a significant role in the severe weather event a few hours later. Upper level divergence associated with the strong upper level jet combined with impressive 500 hPa height falls in the Tennessee Valley and a strong low level jet producing warm air and mositure advection provided synoptic scale lift.

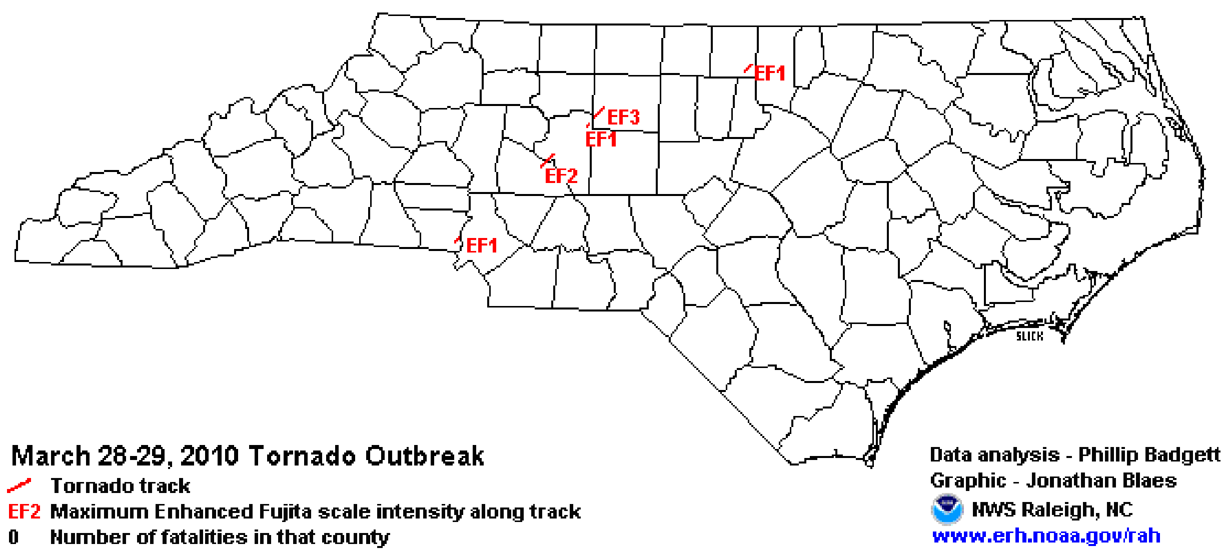
An initial wave of showers moved across western North Carolina at around 18 UTC and led to an insitu cold air damming event across the western Piedmont of North Carolina. Just after 19 UTC, isolated thunderstorms began to develop in northeast Georgia, western South Carolina, and south central North Carolina in a region of slowly increasing instability. The instability axis was bordered to the west by a significant surface boundary or Thermal Moisture Boundary (TMB) which is easily seen extending from southwest to northeast across the western Carolinas in the surface dew point, temperature, and wind analysis at 19 UTC. Wedged between the southern Appalachians to the west and the TMB to the east, was a shallow stable air mass associated with cold air damming. The TMB along the eastern periphery of the cold air damming or wedge air mass is often referred to as a wedge front. This resulted in a complex surface pattern with a parent low over the western Ohio Valley, a developing surface wave across southern Alabama with a wedge front located across the western Piedmont of North Carolina.

Experience has shown that severe convection can develop near and especially in the region south and east of the wedge front boundary in a warmer and more unstable air mass. Shear was impressive in this region with bulk shear values of 60-80 kts and 0-1 km SRH values exceeding 250 m2/s2. Surface based instability was marginal with surface dew points in the lower 50s in the western Piedmont and Triad region resulting in analyzed surface based CAPE values of less then 250 J/kg and more likely around 100 J/kg.

During the next few hours, thunderstorms would continue to develop near and just east of the wedge front in the western Piedmont region of North and South Carolina. Several discrete supercells moved northeast across the Piedmont of North Carolina from the Charlotte area into the Piedmont Triad region beginning at around 2000 UTC on 3/28 and continuing through 0000 UTC 3/29. The surface based CAPE changed very little across western North Carolina between 19 UTC and 23 UTC with the mixed-layer CAPE showing very little change as well. The shear remained impressive with bulk shear values of 60-70 kts and 0-1 km SRH values increasing from around 300 m2/s2 at 19 UTC to more then 450 m2/s2 at 23 UTC. A developing thunderstorm near the Greenville-Spartanburg, SC area at around 2030 UTC would intensify and become a supercell which would eventually produce 4 tornadoes in the interstate 85 corridor from Belmont near Charlotte north and east to the High Point area.

During the late evening hours, dew points increased across the northern Piedmont and eventually approached 55 degrees by 04 UTC on 3/29. Another tornadic thunderstorm developed across Person County near the Virginia border just before 04 UTC. During the late evening and overnight hours, the convection grew into a large area of showers and thunderstorms with a few embedded severe thunderstorms. Additional severe weather did not develop in the eastern Piedmont, Sandhills, or Coastal Plain during the overnight. Several factors appear to be to responsible for the lack of severe weather overnight including the lack of focus or organization of the convection ahead of the large cool pool moving east from the western Piedmont. Large scale lift resulted in the development of numerous showers and thunderstorms with very heavy rain which likely competed with each other for the limited instability. Rainfall amounts exceeded 3.5 inches across parts of Johnston, Wake, and Nash Counties which resulted in numerous reports of flooding and likely contributed to two fatalities in Johnston County when a car with two high school students hydroplaned, slid, and then flipped into a flooded creek, with both of the occupants drowning.

Severe Weather Reports -
Text of severe weather reports across central North Carolina



The Linwood EF-2 Tornado

An EF1 tornado exited Rowan County, crossed the Yadkin River and entered far southern Davidson County at approximately 651 PM EDT. The tornado reached a wooded area south of Seven Oaks Drive at approximately 655 PM EDT. Ten to fifteen hardwood trees were either sheared off or uprooted. Minor structural damage was sustained at a nearby residence when a carport was ripped from a brick home. Two out buildings were also destroyed. The tornado tracked northeast about a half mile across an open field before it proceeded to damage a vacant steel framed flea market building. The tornado struck the southeast corner of the metal building, tearing it away from the remainder of the building. The debris field from the metal building was blown one mile downstream from the site. Sections of sheet metal from the building were found twisted around several trees and high tension power lines.

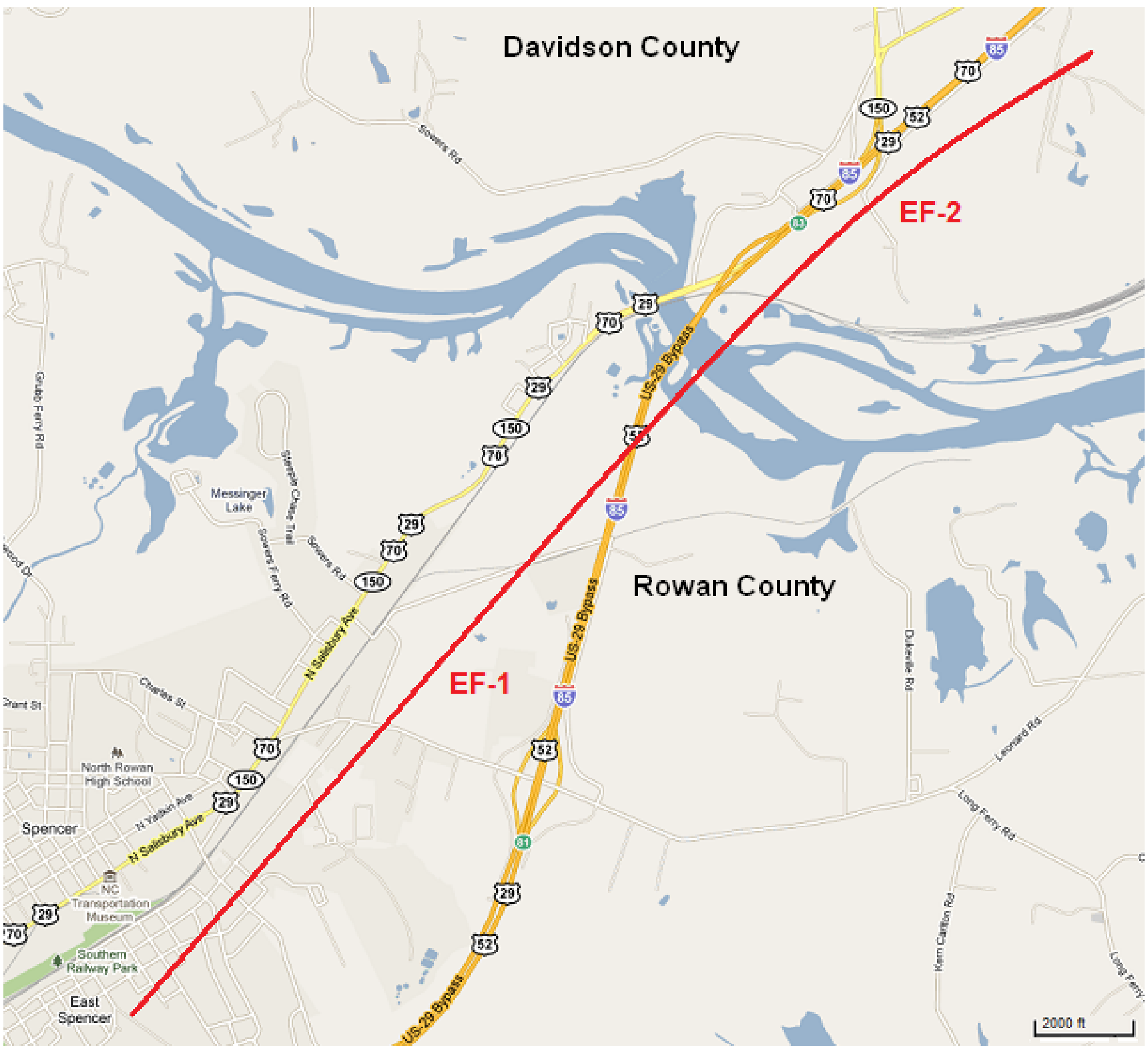
In the adjacent Chestnut Grove mobile home park, located at the Intersection of Clark Road and Windy Hill Drive, three mobile homes were completely destroyed and two others sustained significant damage. Approximately five people were treated for injuries, with two injuries significant enough to require transport to a local hospital. There were no fatalities with this event. The tornado quickly dissipated in a wooded area northeast of Clark Road.

The total length of the damage path was approximately one mile in length and approximately 50-75 yards in width. Damage was consistent with wind speeds of 100-120 MPH, rating this an EF-2 tornado on the Enhanced Fujita Scale.

Time/Date: 651 PM EDT Sunday March 28, 2010
Tornado: EF-2
Peak Wind: 100-120 MPH
Path Length: 1 mile
Maximum Path Width: 50 to 75 yards
Fatalities: 0
Injuries: 2

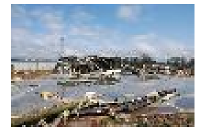
Special thanks are extended to the Davidson County Emergency Management team for providing information on the event as well as guided access to each damage site.

Linwood Tornado Track -

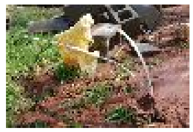
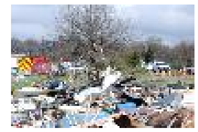


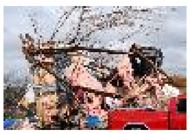
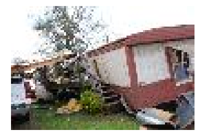
Linwood Damage Photos -

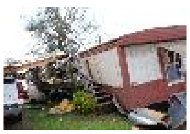
Photos courtesy of the National Weather Service.
click on the image to enlarge

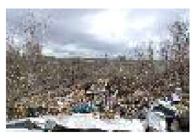
    

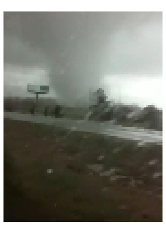
    

Linwood Tornado Video -

Video courtesy of an anonymous spotter who granted permission.
click on the image to show video

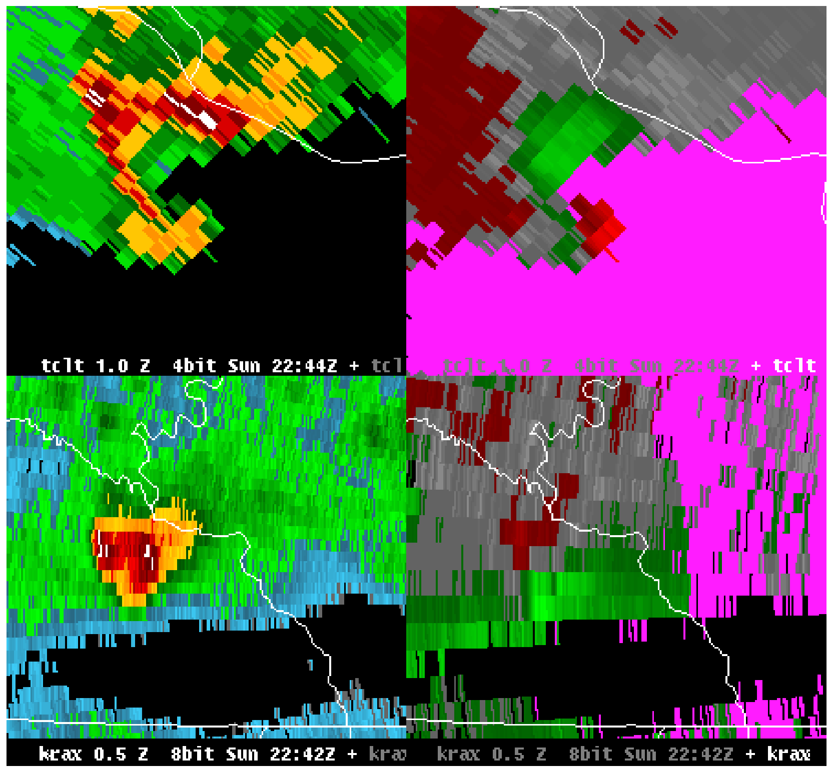


Linwood Tornado Radar Imagery -

From a radar perspective, the supercell that produced the EF-2 tornado in Linwood was very challenging to interrogate, requiring the use of two WSR-88Ds (KRAX, KFCX) and one TDWR (TCLT). Although multiple radars are frequently used to get varying perspectives when interrogating convection, the use of multiple radars was essential in the tornado warning decision making process with this supercell. The primary complicating factor with regard to the tornado warning decision making process was related to the location of the storm relative to the available WSR-88Ds. The storm was approximately 90 nm west of KRAX and 70 nm south of KFCX, with the lowest elevation angle (0.5 degrees) intersecting the storm at roughly 11,000 ft AGL from KRAX and 7000 ft AGL from KFCX. The storm was located only 40 nm from the TCLT TDWR, with the lowest elevation angle (0.2 degrees) intersecting the storm at approximately 1500-2000 ft AGL.

The Terminal Doppler Weather Radar (TDWR) was designed primarily to support FAA activities and detect wind shear and microbursts near airports. In order to detect these smaller scale features, TDWRs operate at a lower elevation scanning angle ranging from 0.1 degrees to 0.3 degrees compared to the fixed 0.5 degree lowest elevation scan used in WSR-88D radars. TDWRs also have a narrower azimuthal beamwidth of 0.5 degrees. This nearly doubles the resolving power compared to the 0.9 degree beamwidth used in the WSR-88D. Signal attenuation for the C Band TDWR (5 cm) is slightly greater than for the S band (10 cm) WSR-88D radar in precipitation. Note that the effective range of a TDWR is smaller than that of a WSR-88D. Although the TCLT TDWR allowed an excellent upstream view of the lower levels of the storm as it moved northeast through Rowan County, the storm moved beyond the effective range of the radar shortly after it moved into Davidson County.

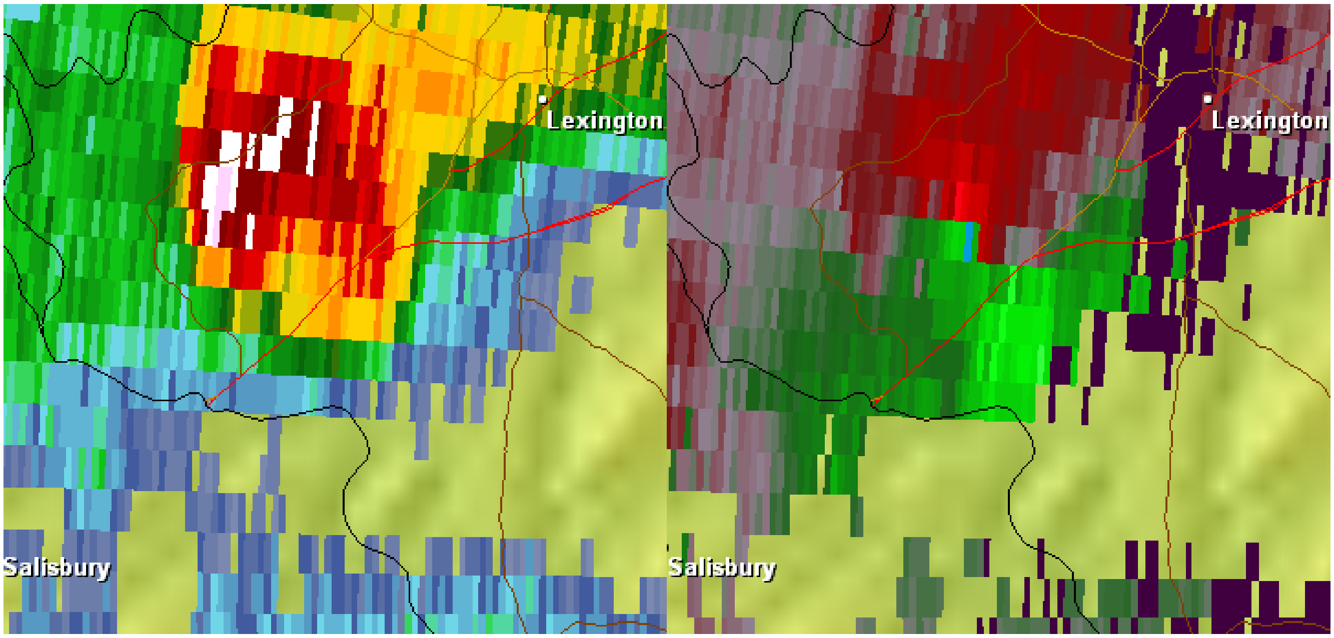
Although the tornado warning decision process involves the consideration of numerous factors (i.e. environmental conditions, radar imagery, spotter reports, and upstream history), without credible spotter reports or upstream history, the decision making process is heavily weighted toward radar data. Due to increasing beam width and elevation while considering that a strong low-level mesocyclone is usually the best indicator of tornadic potential, radar signatures indicative of a tornado (or tornadic potential) become increasingly difficult to resolve the further the storm is from a WSR-88D. In the case of the Linwood tornado, the supercell was not sampled below 7,000 ft AGL from KFCX and 11,000 ft AGL from KRAX. As a result, the lowest elevation angles from KRAX and KFCX were intersecting the storm at an elevation that would likely overshoot a portion of the low-level mesocyclone. Radar data from KRAX and KFCX did show a strong mid-level mesocyclone prior to tornadogenesis, however, the rotation was rather broad. Although supercell thunderstorms are unique in their capacity to produce strong to violent tornadoes, only a small percentage (recent research has shown this may be as little as 20 percent) actually produce tornadoes, and the presence of a strong mid-level mesocyclone is generally insufficient to gauge tornadic potential. Interestingly, although KRAX was sampling the storm at a longer range and higher elevation than KFCX, KRAX showed the best radar signature at the time of tornadogenesis (2256Z volume scan), with a gate-to-gate SRM couplet of 73 knots inbound and 30 knots outbound. It is also important to note that the confirmation of a tornado touchdown in Mecklenburg County at 2140 UTC bolstered confidence in issuing a tornado warning with this same supercell as it approached Davidson County around an hour later.



The image to the right is a comparison of radar imagery from the TCLT TDWR and the KRAX WSR-88D at 2244 UTC and 2242 UTC respectively when the supercell was located in northeastern Rowan county, just before it moved into Davidson County (click on the image to enlarge). The top row shows data from the TCLT TDWR and the bottom row shows data from the KRAX WSR-88D. The upper left image is the 1.0 degree base reflectivity data from TCLT sampling the storm at around 4,300 feet from 40nm while the lower left image is the 0.5 degree base reflectivity data from KRAX sampling the storm at around 7,000 feet from 90nm away. The upper right image is the 1.0 degree storm relative velocity data from TCLT while the lower left image is the 0.5 degree storm relative velocity data from KRAX.

The reflectivity and velocity structure is resolved much more clearly from the TDWR data with a well defined hook echo in the reflectivity imagery and a velocity couplet while the KRAX imagery shows a thunderstorm that has a rather poorly defined reflectivity structure with broad rotation. At the time of these images, a tornado warning was already in effect for Rowan County from the NWS Greenville-Spartanburg and the NWS in Raleigh would issue a tornado warning for Davidson County a few minutes later at 2247 UTC, largely based on the TDWR imagery. The clearer storm structure in the TDWR data results from several factors including being much closer to the storm, sampling the storm at a lower elevation, a narrower azimuthal beam width of 0.5 degrees compared to the 0.9 degree beam width used in the WSR-88D.

The radar image below is from the KRAX radar at 2256 UTC showing the 0.5 degree base reflectivity image on the left and the 0.5 degree storm relative velocity image on the right which shows the strongest rotational velocity as sampled from the KRAX radar for the supercell thunderstorm that produced the Linwood tornado. At this point, the tornado had already touched down and a tornado warning had been in effect for 9 minutes. The 0.5 degree storm relative velocity data indicated an outbound velocity of 30 knots and an inbound velocity of 73 knots producing a rotational shear value of 51.5 knots at 90 nm from the radar and at 10,000 ft AGL. The 51 knots of rotational shear at 90 nm from the radar with a mesocyclone diameter of 1 to 3.5 nm corresponds to a strong mesocyclone.



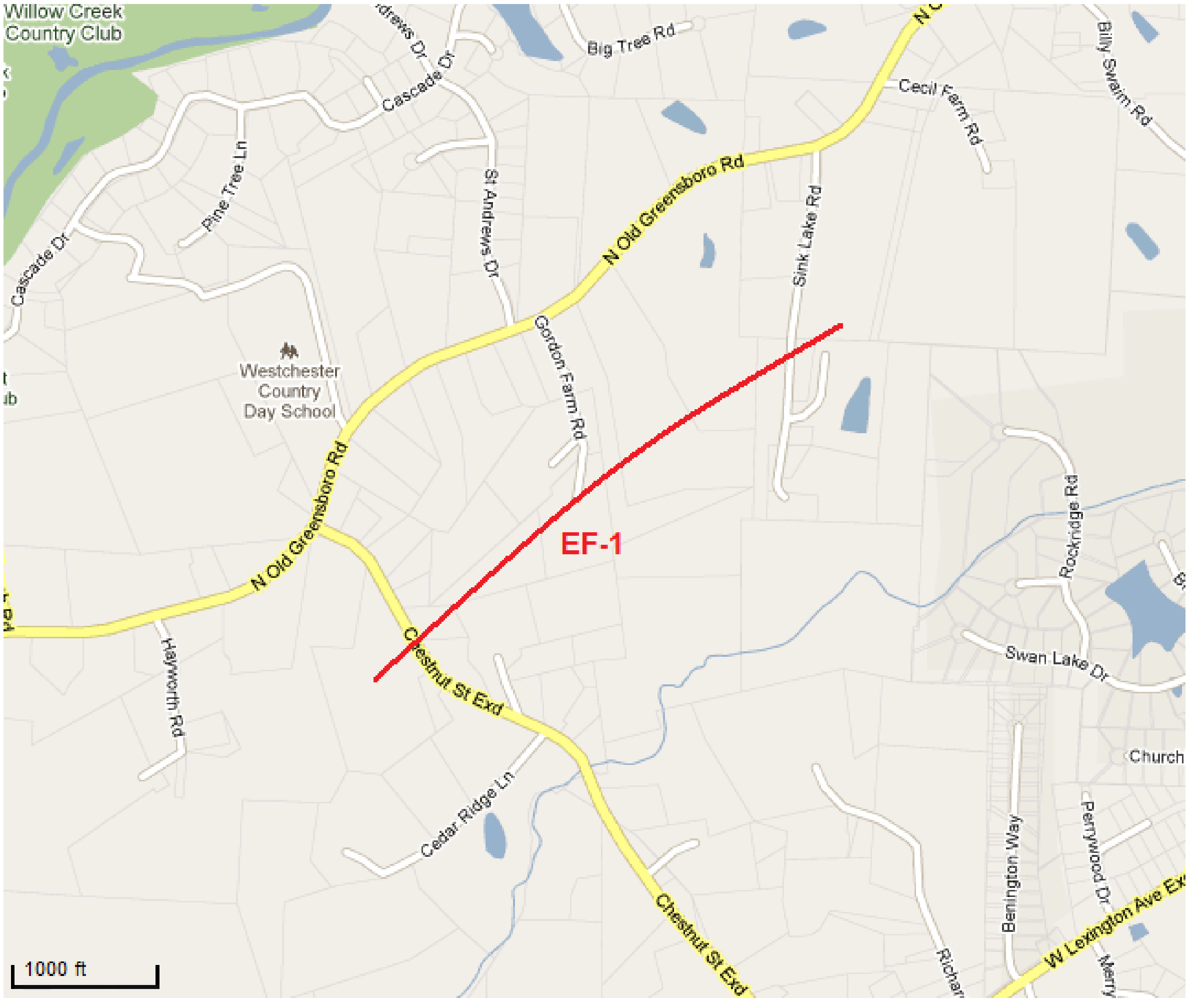
The Sink Lake EF-1 Tornado

At approximately 715 PM EDT, a second tornado touched down in Davison County. The touchdown was in a wooded area and caused extensive tree damage south of Carpenter Road extension. The tornado tracked northeast across Carpenter Road extension where it caused minor damage to a single family residence when it destroyed the attached carport. The tornado then tracked one half mile over a wooded area where it then hit the southeastern corner of the valley mobile home park located off Sink Lake Road. One mobile home was completely destroyed when it was blown from the anchor points and displaced into an adjacent lake. Four occupants were inside the home and had to swim to shore. Along with the mobile home, a full sized SUV was also lifted and deposited into the lake. An additional five to six mobile homes sustained significant damage from fallen trees and flying debris as well as being shifted from their anchor supports. Remarkably, there were no serious injures. The tornado quickly lifted in a wooded area about 100 yards north of the mobile home park. The total length of the tornado path was approximately 0.7 miles long and 25-50 yards in width. Damage was consistent with wind speeds of 80-100 MPH, rating this an EF-1 tornado on the Enhanced Fujita Scale.

Time/Date: 715 PM EDT Sunday March 28, 2010
Tornado: EF-1
Peak Wind: 80-100 MPH
Path Length: 0.7 miles
Maximum Path Width: 25 to 50 yards
Fatalities: 0
Injuries: 0

Special thanks are extended to the Davidson County Emergency Management team for providing information on the event as well as guided access to each damage site.

Sink Lake Tornado Track -



Sink Lake Damage Photos -

Photos courtesy of the National Weather Service.
click on the image to enlarge






The High Point EF-3 Tornado

The National Weather Service in Raleigh NC in cooperation with Guilford County Emergency Services confirmed an EF-3 tornado with winds up to 138 MPH in High Point which is located in southwestern Guilford County on 03/28/2010. This tornado appears to be the third tornado in the NWS RAH County Warning Area produced by the same thunderstorm which produced tornadoes in Linwood and Sink Lake Road in Davidson County. The tornado in High Point initially touched down as an EF-1 tornado with winds around 100 MPH at approximately 730 PM EDT near Old Plank Road in southwestern Guilford County. It was in this area where the Apple Tree Academy sustained significant damage and 2 vehicles including a small bus were rolled 50 yards across the street. From this point the tornado continued northeast across Highway 311.

The next area to experience damage was just north of highway 311 and south of Old Mill Road along Langadle, Imperial and Impala Drives. Tornado damage in this area continued to indicate EF-1 wind speeds with numerous trees blown down along with a number of homes with roof and siding damage. As the tornado crossed Old Mill Road moving toward Johnson Street the tornado intensity increased to EF-2.

Just north of Old Mill Road, the EF-2 tornado severely damaged numerous homes along Brandon Drive. In one instance, an entire bedroom was blown off of a single story home. Three individuals taking shelter in a closet in the bedroom were carried about 50 feet and were buried under the debris of the house. One individual experienced several broken bones, but overall injuries were not serious. The remainder of the house was shifted on the foundation about 8 inches which severely damaged the entire structure.

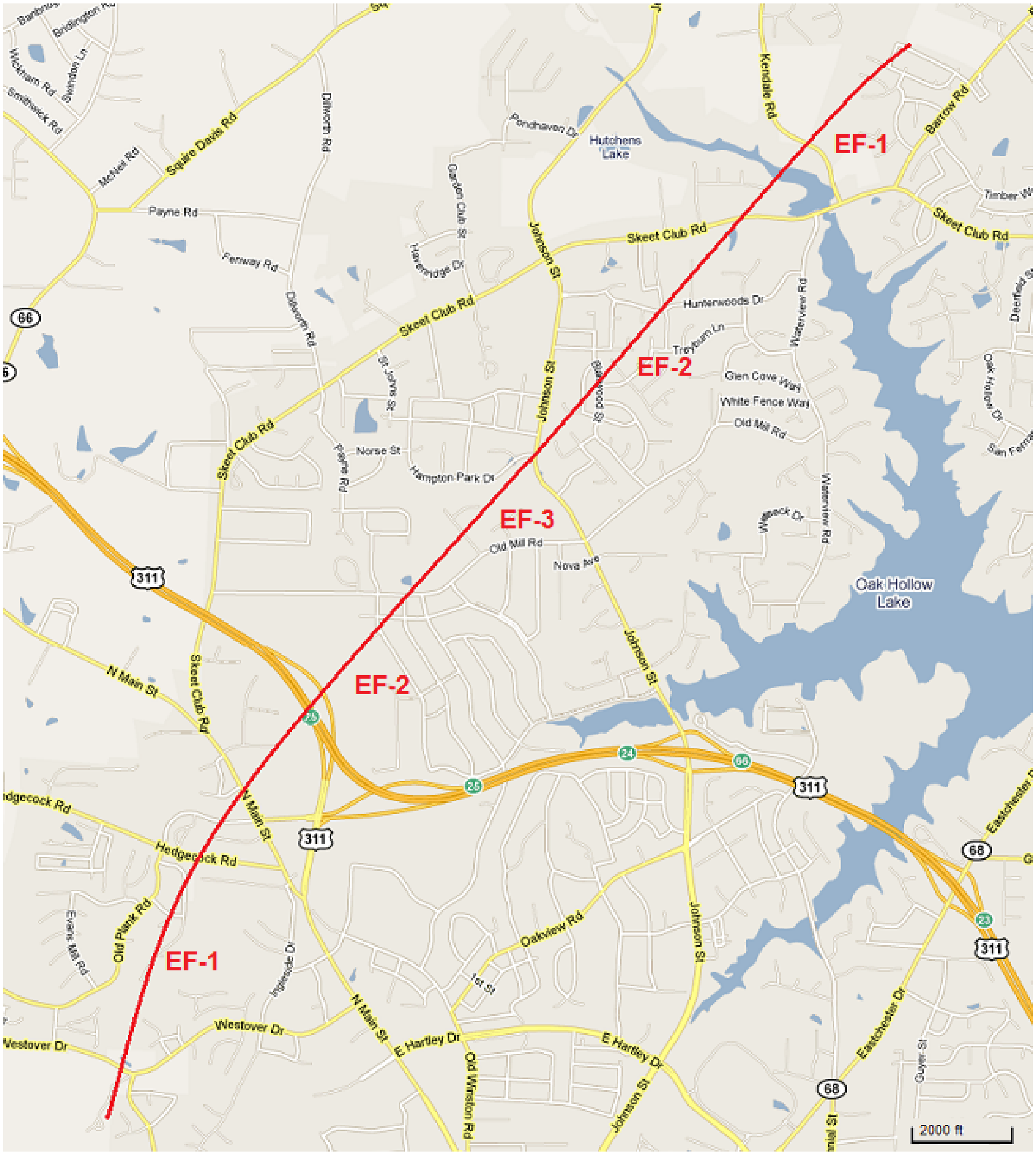
Damage surveyed north of Old Mill Road to Skeet Club Road along either side of Johnson Road indicated the tornado was an EF-2 with winds around 130 MPH for most of its duration. The tornadoe briefly reached EF-3 intensity with winds of 138 MPH near Hampton Park Drive. The EF-3 rating with peak winds of 138 MPH was estimated at 1278 Silverstone Court where most of the upper floor of a two story, stick built, home was blown off. In this area along Hampton Park Drive, Scarlet Drive, Ruskin Drive and Johnson Road at least 50 to 60 homes were damaged.

The tornado crossed Johnson Road as an EF-2 crossing Elmwood Avenue, Oak Forest Drive and Maplewood Avenue. Nearly every house in this highly urbanized area experienced minor to major damage. The second floor of a two story home was blown off of a residence at the end of Elmwood Ave. As the tornado crossed Maplewood Avenue and Wellingham Lane, it weakened to an EF-1 but continued to damage numerous homes removing potions of roofs and siding. Once crossing Skeet Club Road near Poplar Creek Lane, the tornado continued north finally lifting off the ground near Kendale Road just north of the lake.

Time/Date: 730 PM EDT Sunday March 28, 2010
Tornado: EF-3
Peak Wind: 138 MPH
Path Length: 5 miles
Maximum Path Width: 250-300 yards
Fatalities: 0
Injuries: 3

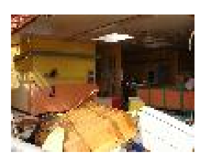
The National Weather Service would like to thank Guilford County Emergency Services for their assistance during the tornado survey.

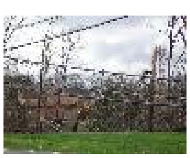
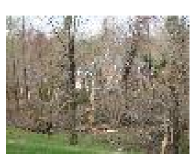
High Point Tornado Track -



High Point Damage Photos -

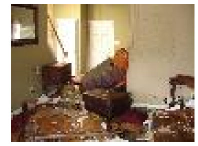
Photos courtesy of the National Weather Service.
click on the image to enlarge















High Point Tornado Video -

Video courtesy of an anonymous spotter.
click on the image to show video

High Point Tornado Fire Department Radio Traffic -

Audio courtesy of firescenaudio.com (note this disclaimer)

High Point Fire Department Audio Clip 1

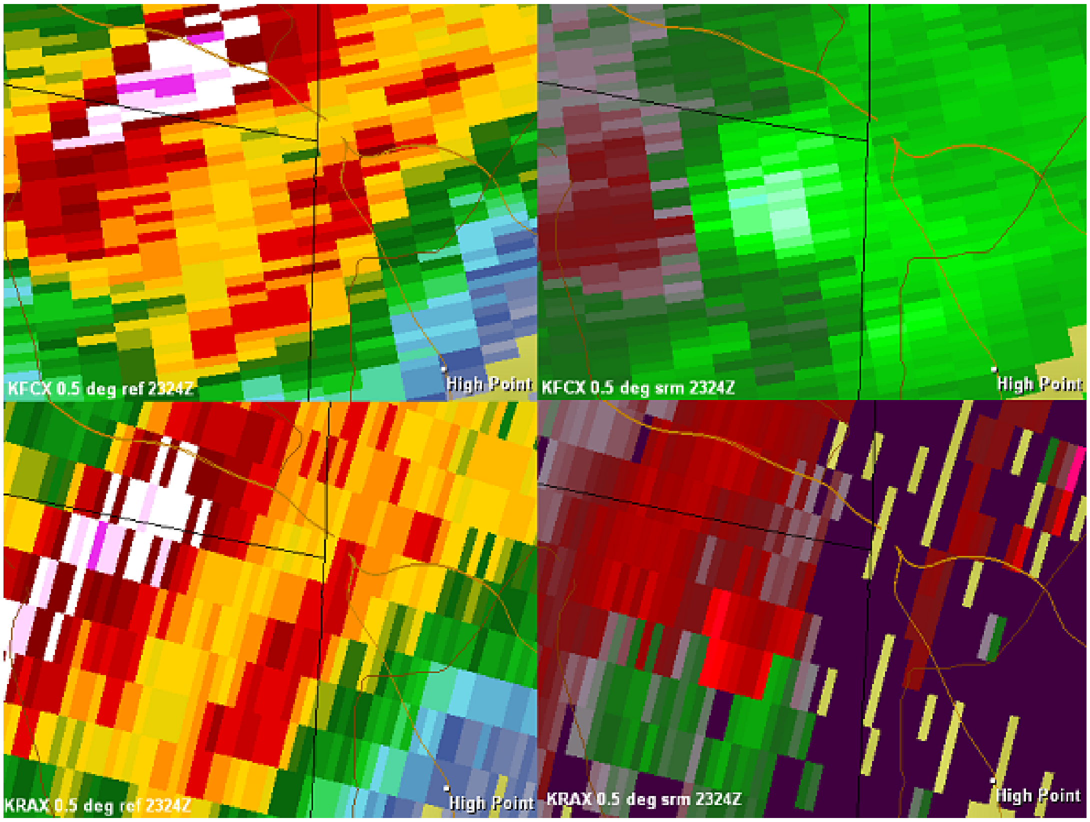
High Point Fire Department Audio Clip 2

High Point Tornado Radar Imagery -

The same supercell that produced an EF-2 tornado in Linwood and Sink Lake, moved northeast and produced an EF-3 tornado in High Point 30 minutes later. From a radar and warning perspective, the supercell that produced the EF-3 tornado in High Point was even more challenging. Just prior to and during tornadogenesis, the storm was located roughly 80 nm WNW of KRAX and 60 nm south of KFCX, with the 0.5 degree elevation slices intersecting the storm at 8500 ft AGL and 5500 ft AGL, respectively. Radar data from KFCX did show a moderate to strong mid-level mesocyclone prior to tornadogenesis, however, the rotation was rather broad, and actually weakened at 2329Z when the tornado was occurring. Velocity data from KRAX was limited in this case, as most of the data was range-folded. This made the identification of the supercell as tornadic, even more difficult, even at the time it was producing an EF-3 tornado.

The radar image below is from the KFCX and KRAX radars at 2324 UTC showing the 0.5 degree base reflectivity image on the left and the 0.5 degree storm relative velocity image on the right over northeastern Davidson, southeastern Forsyth, and southwestern Guilford Counties. The reflectivity pattern from both the KRAX and KFCX radars show a region of higher reflectivities but without any readily apparent structure at 0.5 degrees. The storm relative velocity (SRM) images from the KRAX and KFCX radars are very different. The KFCX SRM imagery shows an impressive but broad area of rotation associated with the mesocyclone. While there was no gate-to-gate rotational signature, the SRM data from KFCX indicated an outbound velocity of 11 knots and an inbound velocity of 53 knots producing a rotational shear value of 32 knots at 62 nm from the radar and at 5,500 ft AGL. The 32 knots of rotational shear at 62 nm from the radar with a mesocyclone diameter of 1 to 3.5 nm corresponds to a weak to moderate mesocyclone. The mesocyclone weakened on the following 2229 UTC scan from KFCX. The SRM data from KRAX indicated an outbound velocity of 36 knots and an inbound velocity of 22 knots producing a rotational shear value of 29 knots at 80 nm from the radar and at 8,500 ft AGL. It's worth noting that the rotation associated with the mesocyclone as observed in the 2229 UTC 0.5 degree SRM from KFCX weakened as the storm produced the tornado in High Point at 730 PM EDT.

Forecasters used upstream reports and storm history along with the presence of a mesocyclone tracking near or along a strong low-level baroclinic zone with favorable environmental conditions to justify a tornado warning.



The Timberlake EF-1 Tornado

The National Weather Service in Raleigh NC, in cooperation with Person County Emergency Services, confirmed that an EF-1 tornado with winds up to 100 MPH touched down in Person County on March 28, 2010.

The initial touchdown of the tornado occurred along Fire Tower Road off Moores Mill Road in extreme southeastern Person county as a weak EF-0 tornado with wind speeds of 65-70 MPH. The tornado then moved northeast crossing Helena-Moriah Road. Trees including both pines and hardwoods were sheared off a quarter to halfway up the trunk. Damage in this location was rated as EF-0 (70-80 MPH).

The tornado continued moving northeast, striking a subdivision off Stoney Mountain Road and Mountain Ridge Road. Several trees were twisted off and uprooted, and a couple of modular homes sustained damage when trees fell on them. Estimated winds were 75-85 MPH rating the damage as EF-0.

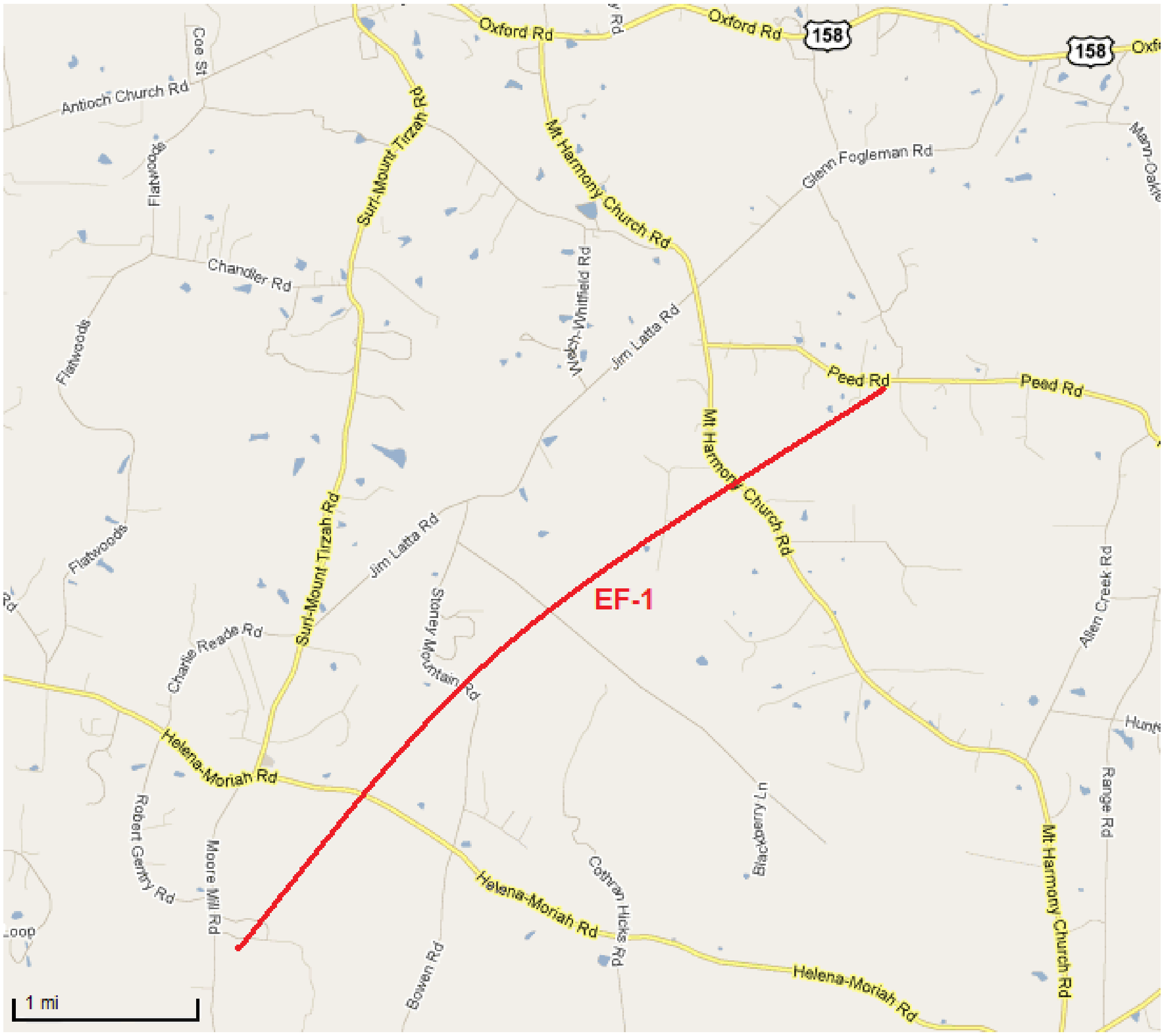
The worst damage occurred as the tornado moved northeast across Medford Oakley Road. Numerous pines and hardwoods were snapped off and uprooted. A modular home was moved off its foundation. The tornado reached EF-1 strength in this location with winds of 90-100 MPH.

The tornado then moved into a wooded area where it weakened producing minor damage to an old barn and minor tree damage near Peed Road. Wind speeds in this location were estimated at 65 MPH. Damage may have been from the weakened tornado or from straight line wind damage.

Time/Date: 1155 PM EDT Sunday March 28, 2010
Tornado: EF-1
Peak Wind: 100 MPH
Path Length: 4 miles
Maximum Path Width: 75 yards
Fatalities: 0
Injuries: 0

The National Weather Service would like to thank Person County Emergency Services for their assistance during the tornado survey.

Timberlake Tornado Track -



Timberlake Damage Photos -

Photos courtesy of the National Weather Service.
click on the image to enlarge

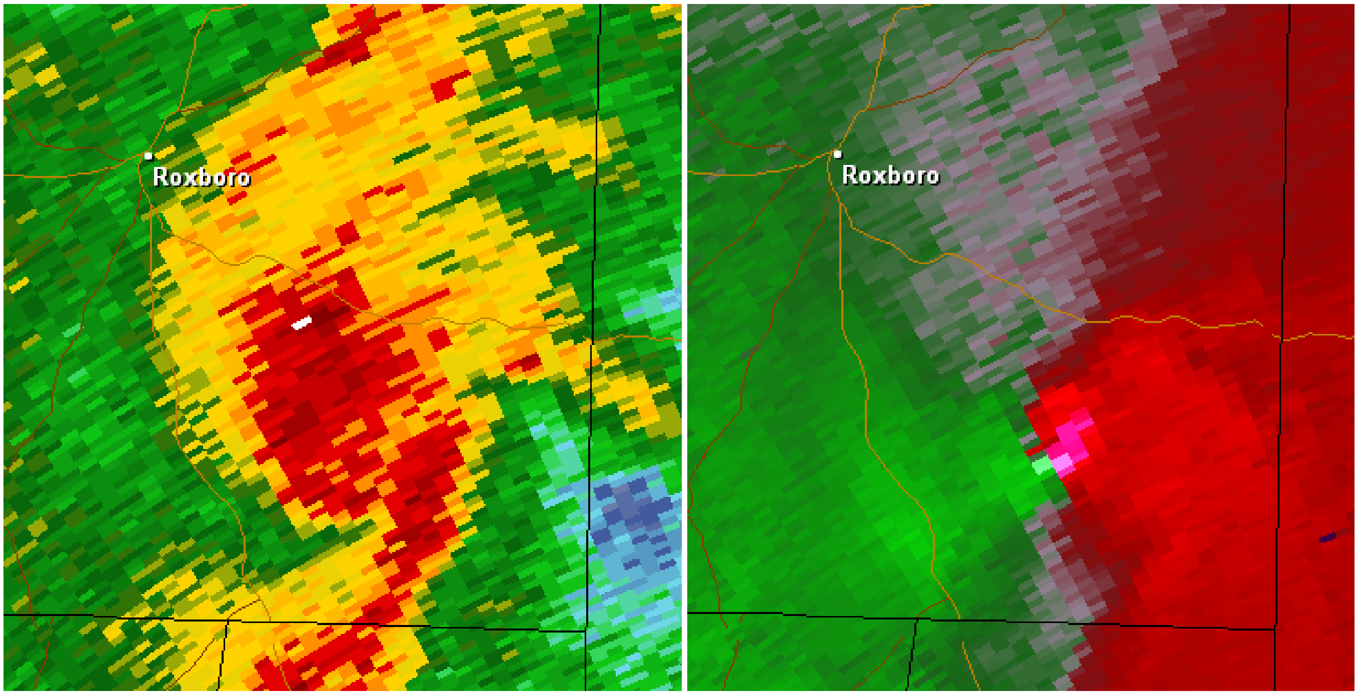
    

Timberlake Tornado Radar Imagery -

The storm that produced the Timberlake EF-1 tornado appears to have first developed at around 0215 UTC in Randolph County and can be best described as a rain-wrapped supercell. The storm subsequently moved northeast into Alamance County by around 0256 UTC, and first began to show signs of rotation at around 0310 UTC in south central Alamance County. The updraft and rotation may have been enhanced slightly by a cell merger between 0300 and 0310 UTC. The storm continued moving northeast through central and northern Orange County between 0310 UTC and 0345 UTC. At 0348 UTC in extreme northeast Orange County, low level rotation noticeably strengthened on the 0.5 degree elevation angle scan from KRAX. Rotation further strengthened, becoming impressive between 0352 UTC and 0357 UTC in southern Person County. The relative close proximity of the storm to the KRAX radar (relative to the tornadic storms in the Triad) allowed the low level mesocyclone to be well sampled. Unfortunately, the TRDU TDWR was not available during this event. The maximum storm relative velocities sampled were a 47 kt inbound adjacent to a 61 kt outbound, gate-to-gate at 3500 feet AGL at 0357 UTC. The 54 knots of rotational shear at 40 nm from the radar with a mesocyclone diameter between 1 nm and 3.5 nm corresponds to a strong mesocyclone at 3500 feet AGL. Rotation within the storm weakened considerably by the next volume scan (0402 UTC) and continued to weaken as it moved northeast through northern Granville/Vance counties into southern VA.

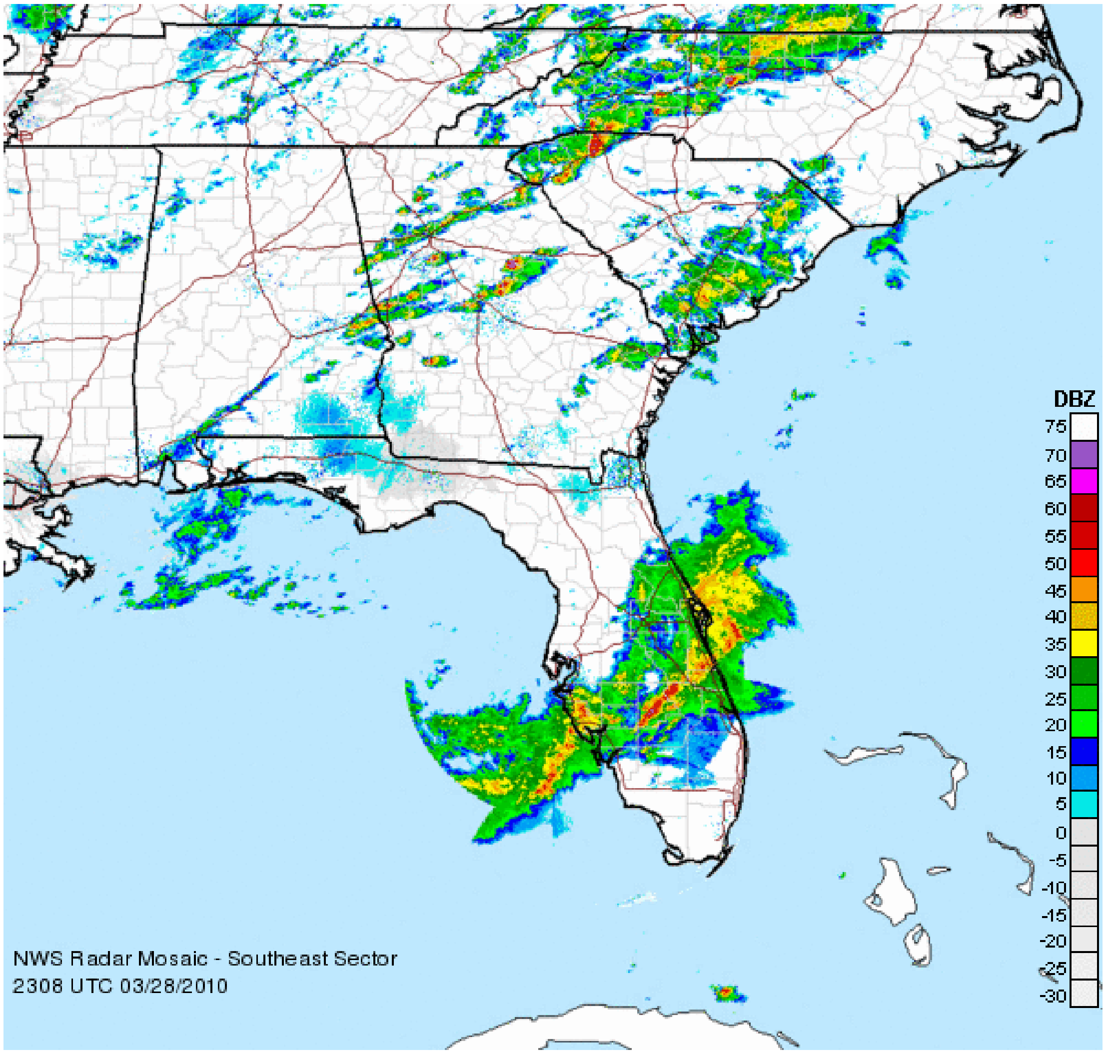


Regional Radar Loop

A nearly 18 hour Java loop of regional reflectivity imagery from 1758 UTC on March 28 through 1148 UTC on March 29, 2010 is available **here**. Note - this loop includes 78 frames.

The loop shows several discrete supercells that moved northeast across the Piedmont of North Carolina from the Charlotte area to the Piedmont Triad region beginning at around 2000 UTC on March 28 and continuing through 0000 UTC on March 29. One supercell moved northeast from the Charlotte area between 2000-2100 UTC and produced some large hail before dissipating. Another thunderstorm that developed near the Greenville-Spartanburg, SC area at around 2030 UTC, intensified and became a supercell as it crossed into North Carolina at around 2100 UTC. This supercell would eventualy produced 4 tornadoes as it moved northeast from Belmont to the High Point area. During the late evening, especially after 0200 UTC, the coverage of the convection expanded into a large area of showers and thunderstorms with a few embedded severe thunderstorms.

The regional reflectivity image below is from 2308 UTC on March 28, 2010. This was just a few minutes after the Linwood tornado touchdown and just before the Sink Lake and High Point tornadoes.



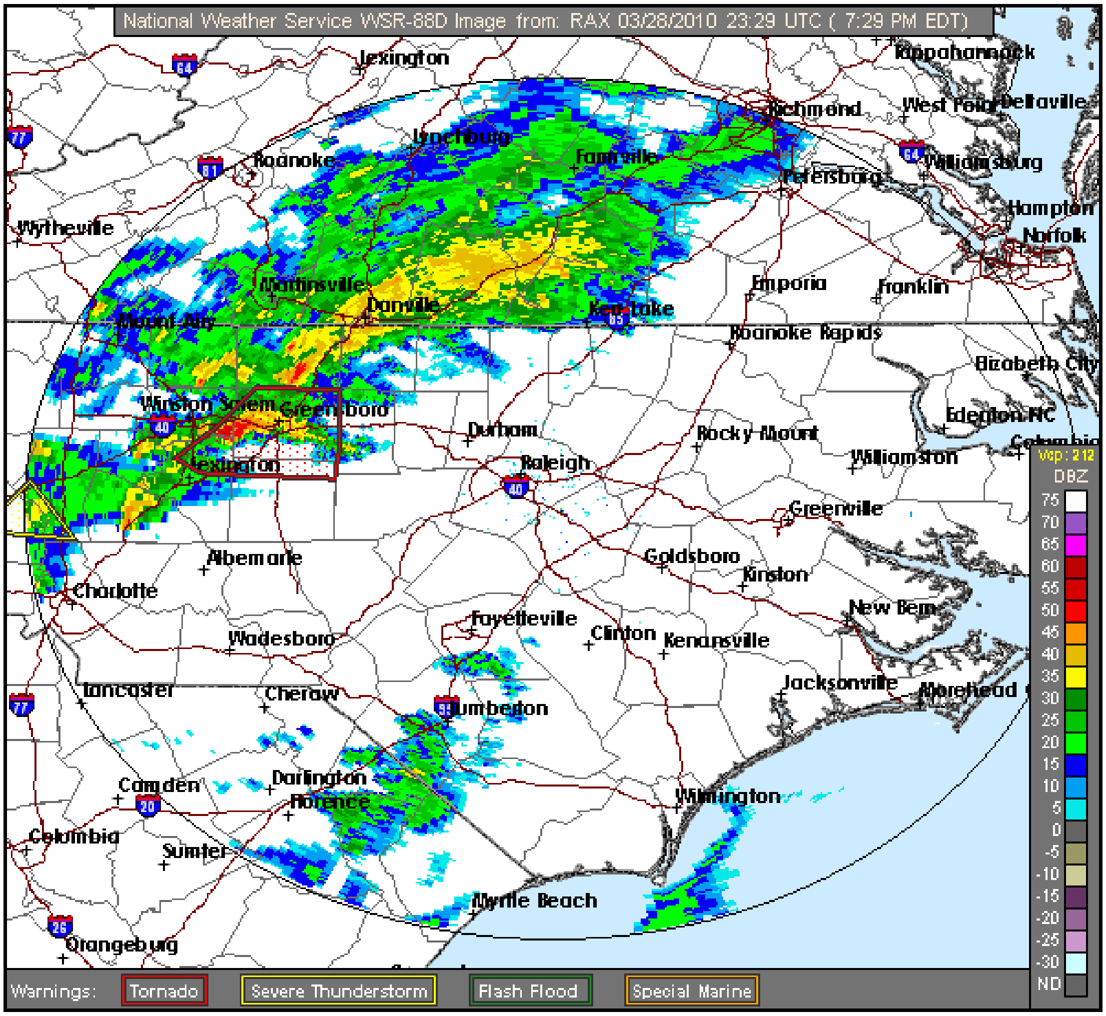
KRAX Radar Loops

Overview of the entire event with images from every 15 minutes between 1958 UTC (358 PM EDT) on March 28 through 1200 UTC (800 AM EDT) on March 29, 2010.
Java loop of KRAX reflectivity imagery every 15 minutes from 1958 UTC on 3/28 through 1200 UTC on 3/29.
Note - this loop includes 65 frames

Overview of the first part of the event with images from every volume scan between 1958 UTC (358 PM EDT) on March 28 through 0603 UTC (203 AM EDT) March 29, 2010.
Java loop of KRAX reflectivity imagery from 1958 UTC on 3/28 through 0603 UTC on 3/29.
Note - this loop includes 129 frames

Overview of the second part of the event with images from every volume scan between 0559 UTC (159 AM EDT) on March 29 through 1200 UTC (800 AM EDT) on March 29, 2010.
Java loop of KRAX reflectivity imagery from 0559 UTC on 3/29 through 1200 UTC on 3/29.
Note - this loop includes 77 frames

The KRAX reflectivity image below is from 2329 UTC or 729 PM EDT on March 28, 2010, just as the High Point tornado was touching down. This same supercell can be tracked backwards several hours on this radar view to its location just northwest of Charlotte at 2146 UTC with modest reflectivity values of 35-45 dBZ.



Severe Convection and the Wedge Front

The 3 tornadoes that occurred between 2250 and 2330 UTC (650 and 730 PM EDT) across the western portion of the RAH County Warning Area (CWA) all occurred near a well defined Thermal Moisture Boundary (TMB). The TMB separated an insitu Cold Air Damming (CAD) air mass across the western Piedmont of the Carolinas with a warmer and more unstable air mass to the east. The CAD air mass is sometimes referred to as the "wedge" and the TMB located along the periphery of the CAD dome is sometimes referred to as the “wedge front.” Objective analysis products from 22 UTC allows the location of the wedge front to be identified fairly readily with the tight gradients of stability fields (see the 0-3 km lapse rate, surface temperature and dewpoint, surface LI, and surface frontogenesis.) Subjective analysis of the location of the wedge front shows that it generally moved very little between 21 UTC and 23 UTC while at 22 UTC it stretched from just west of Charlotte near Gastonia, north and east to near Statesville to just west of Winston-Salem to near Danville.

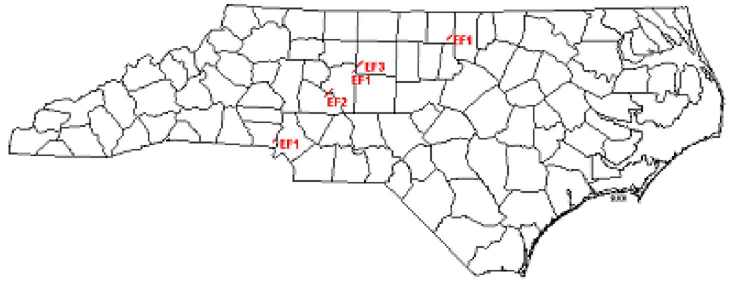
CAPE values (surface based, mixed layer, most unstable) were very low throughout the event with values generally below 500 J/kg. The supercell responsible for the tornadoes originated in an air mass in which the 3 km Energy Helicity Index (EHI) was 1 to 2. The shear remained impressive with bulk shear values of 60-70 kts and 0-1 km SRH values more then 450 m2/s2 at 23 UTC. Surface vorticity increased from 3-4 units at 19Z to 5-6 units by 22Z. A surface wave developing over upstate SC per the surface wind field was likely responsible for the increase in frontogenesis and the surface vorticity. The Lifting Condensation Level (LCL) was below 1000 m during the entire episode, and primarily ranged between 500 and 750 m through most of the event.

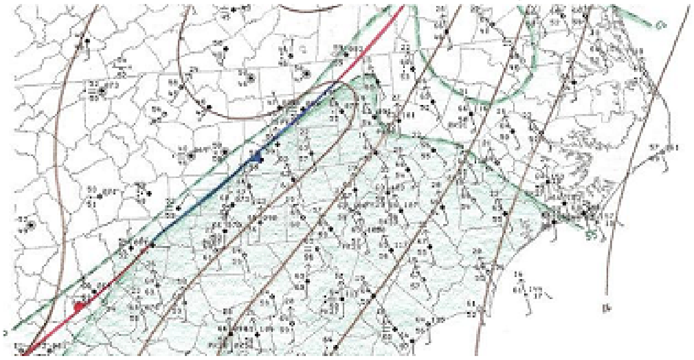
These 3 tornadoes all occurred in locations with very limited low level instability with the surface-based CAPE analysis from the SPC Mesoanlysis page depicting less than 250 J/Kg. An obvious question is how do multiple tornadoes, including an EF-3, develop with very limited low level instability? One possibility is that the RUC based analysis products from SPC under represented the instability.

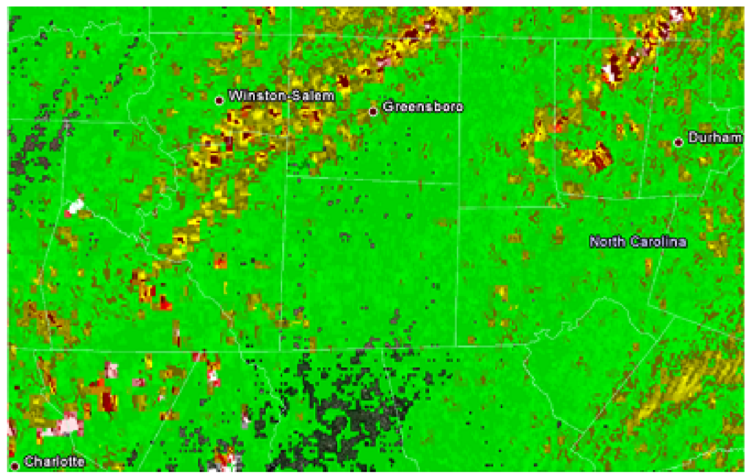
In addition, it should be noted that this thunderstorm developed and intensified in a region of slightly greater instability and then moved northeast into a slightly more stable air mass while remaining rooted in the boundary layer. The supercell produced a brief EF-1 tornado near Belmont NC just before 2140 UTC and another EF-1 tornado near Spencer at around 2245 UTC, just before it moved into the RAH CWA. A similar pattern of thunderstorms developing in region of greater instability in South Carolina and then moving north into a more stable air mass in central North Carolina has been observed with other severe thunderstorm or tornado events including the March 27, 2009 Tornado Event, Since the thunderstorm initiated and matured in a region of greater instability, it developed a stronger updraft which was acted upon by the impressive shear, resulting in a persistent rotating updraft consistent with a supercell. Because of the rotation about a vertical axis within the supercell, dynamical processes associated with the vertical pressure perturbation leads to an even stronger updraft in the middle-levels, which in turn causes even more rotation (due to vertical stretching) as the updraft speed increases with height, which in turn can feed back and cause an even stronger middle-level pressure perturbation.

Recent research has shown that convection that develops near a wedge front, in an environment with sufficient instability, typically experiences increased low level shear as compared to situations without the wedge front. These storms near the wedge front tend to have a more discrete cell structure. In addition, the wedge front was found to be more important as a mechanism to provide additional shear in situations in which shear may be lacking as opposed to high shear events like this one.

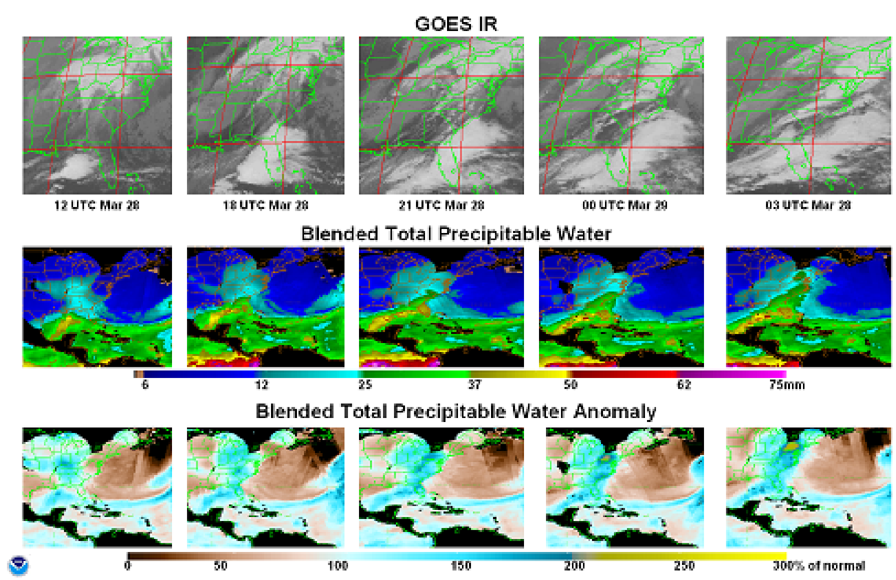
It is still unclear as to why one particular cell produced the tornadoes from Rowan County through Guilford County while other supercells which moved across the same region produced very little damage and no tornadoes.







Total Precipitable Water (TPW)



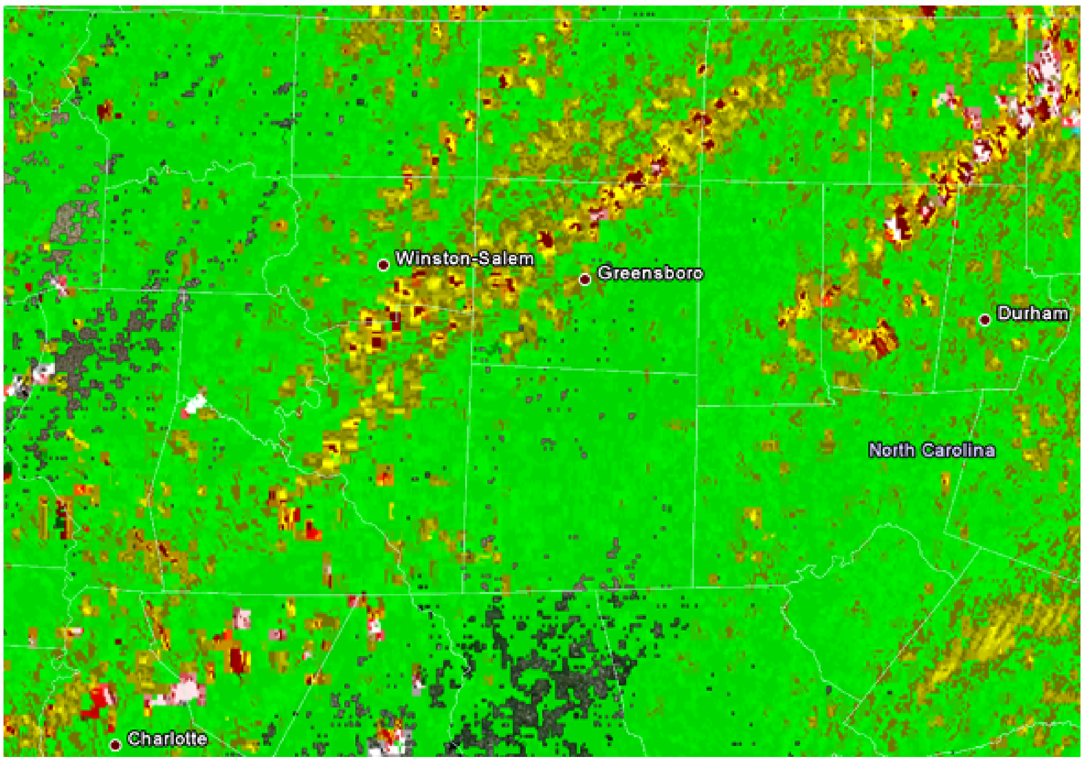
Total precipitable water (TPW) is the amount of water that can be obtained from the surface to the "top" of the atmosphere if all of the water and water vapor were condensed to a liquid phase. Water vapor in the atmosphere is critical for the development of clouds and rain. The Operational Blended TPW Product combines measurements from low earth orbiting microwave satellites over water, and uses global positioning system (GPS) data over the land and the Geostationary Orbiting Environmental Satellite (GOES) sounder information to fill in the gaps, resulting in a seamless presentation of total precipitable water. This data was added to AWIPS in the spring of 2009. Some additional information and examples of the data in AWIPS is available via the CIMSS Satellite Blog. The Blended TPW products show forecasters the amount of moisture in the low and mid levels of the atmosphere, around 900-600 hPa (approximately 3,000 ft to 14,000 ft above the ground), and how this relates to seasonal normals. The TPW anomaly imagery, can tell forecasters if the air over (or moving into) a particularly area is moist, dry, or near normal for that time of year. The tan/brown shading indicates below-normal TPW, while the aqua/blue shading shows above-normal TPW.

In the Blended TPW chart, you can see moisture steadily increasing over North Carolina through the day on March 28, beginning at 8 AM EDT (1200 UTC). The increase in moisture becomes particularly profound in the period from 3 PM to 6 AM EDT (1900-2200 UTC) along the North Carolina / South Carolina border and up through the Southern Piedmont of North Carolina. During this time frame, the first tornadoes touched down in southern North Carolina. This increase in moisture was noted at the surface which showed rapidly increasing dew points prior to tornado development) along with cooling and drying in the mid levels as noted at 500 hPa which destabilized the column and favored more intense convection, heavy rain and the resultant flooding.

Recent research has noted the relevancy of precipitable water with tornado development. One study, *Cool Season Significant (F2-F5) Tornadoes in the Gulf Coast States* showed that significant tornadoes were associated with mean precipitable water (PW) values around 1.5 inches, with values between 1.2 and 1.8 inches accounting for 73% of cases during the study period. Another study, *Forecasting Tornado Potential in Alberta Using Environmental Sounding Data* noted that significant tornadoes have been associated with precipitable water values in the 0.91-1.26 inch (23-32 mm) range, as compared to 0.75-0.98 inch (19-25 mm) range for weak tornadoes and non-tornadic storms. It should be noted that other researchers have commented that it is unclear whether the moisture increase is responsible or even just played a part in supporting the intense convection.

No KGSO RAOB was available from 00 UTC 3/29, but the 00 UTC 3/29 RAOB KMHX indicated observed precipitable water (PW) of 0.99 inches which exceeds the 75th percentile for late March but is within two standard deviations of the mean/average value according a surface to 300mb PW climatology.

NSSL's Rotational Track Product



NOAA's National Severe Storms Laboratory (NSSL) has developed a gridded dataset that contains rotational shear from single and multiple radars that is accumulated over time providing tracks of radar detected rotation. The basic process for creating these products is initiated when velocity data from each radar is run through a Linear Least Squares Derivative (LLSD) filter creating an azimuthal shear field. The azimuthal shear fields in a 0-3 km layer from each radar across the CONUS are then combined and the maximum value at each 250 m² grid point is plotted over the time period providing the graphic.

The process was further improved when the WDSS-II (Warning Decision Support System - Integrated Information) group at NSSL made the "Rotational Tracks" data available for display in Google Earth. Using Google Earth with an overlay of near real-time "rotational tracks" allows forecasters to estimate where a storm's low-altitude circulation was most intense and to determine locations of possible damage. The satellite images and high density maps in Google Earth often make it possible to determine the location down to a neighborhood or possibly even a street. This simplifies the verification process by reducing the amount of time that is spent searching for reports. This data has been used for numerous events across central North Carolina during the past few years including the April 25, 2010 Tornado Event, the March 27, 2009 Tornado Event, and the November 15, 2008 Outbreak.

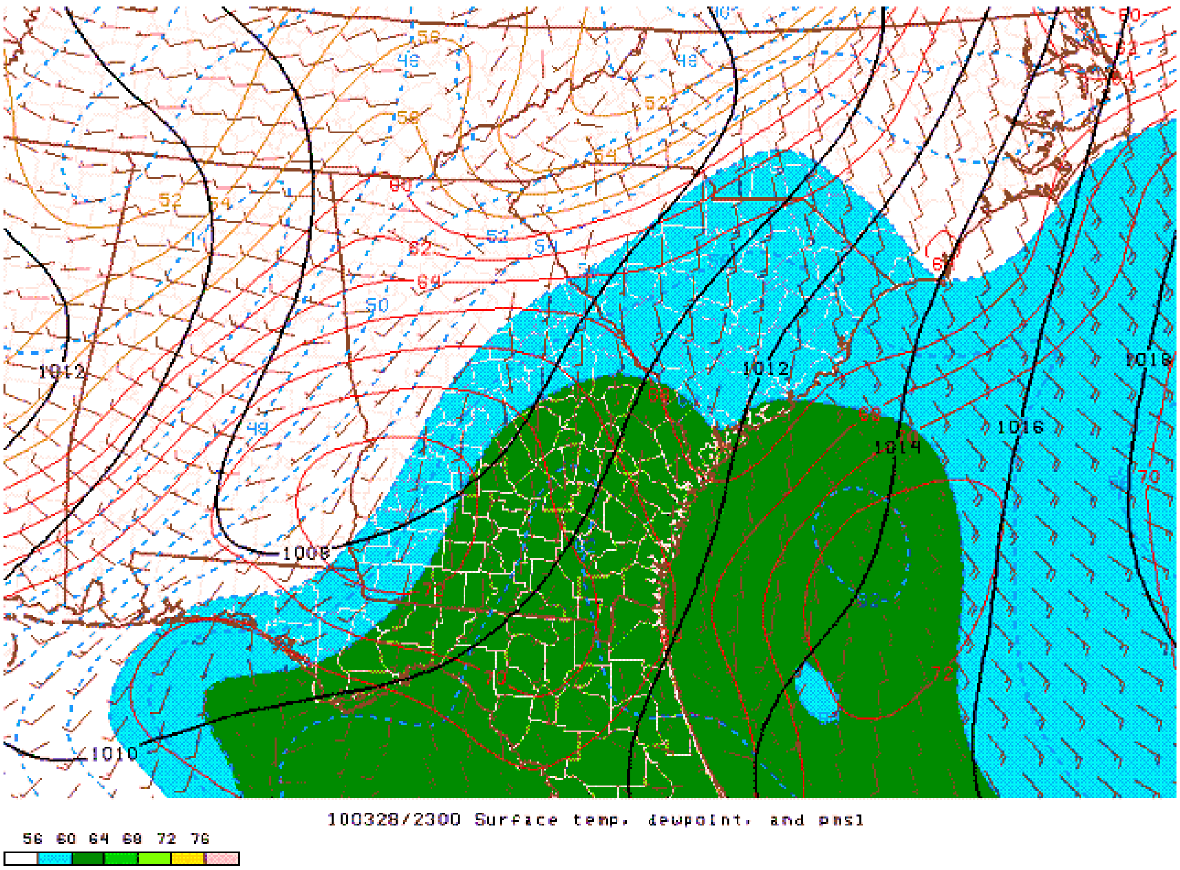
The rotational track product for this event from 20 UTC 3/28 through 05 UTC on 3/29 is shown above (click on it to enlarge). The product shows multiple corridors of enhanced rotation including the two tracks associated with the tornado producing supercells that moved across the Triad and Person County. The long track of the supercell that produced the tornado in the Davidson and Guilford Counties originates north of Charlotte and can be seen in the imagery. Additional nearly parallel tracks of enhanced rotation are also evident in the Triad as multiple rounds of thunderstorms with rotation moved across the Triad region.

Mesoscale Data

Forecasters at the NWS Raleigh, NC routinely use the SPC meso-analysis products during severe weather operations. During this event, the SPC meso-analysis products were consulted frequently to monitor the evolving environment, identify the location of low level instability, and locate the region of greatest tornado threat. The images and discussion below highlight several of the SPC meso-analysis products that provide insight into the evolution of the severe weather event. Several analysis products shown below provide insight and important details about the mesoscale environment that supported the development of the supercells and tornadoes.

Analyzed surface temperatures (red), dew points (blue) and shaded, and wind barbs from SPC at 2300 UTC on Sunday, March 28, 2010

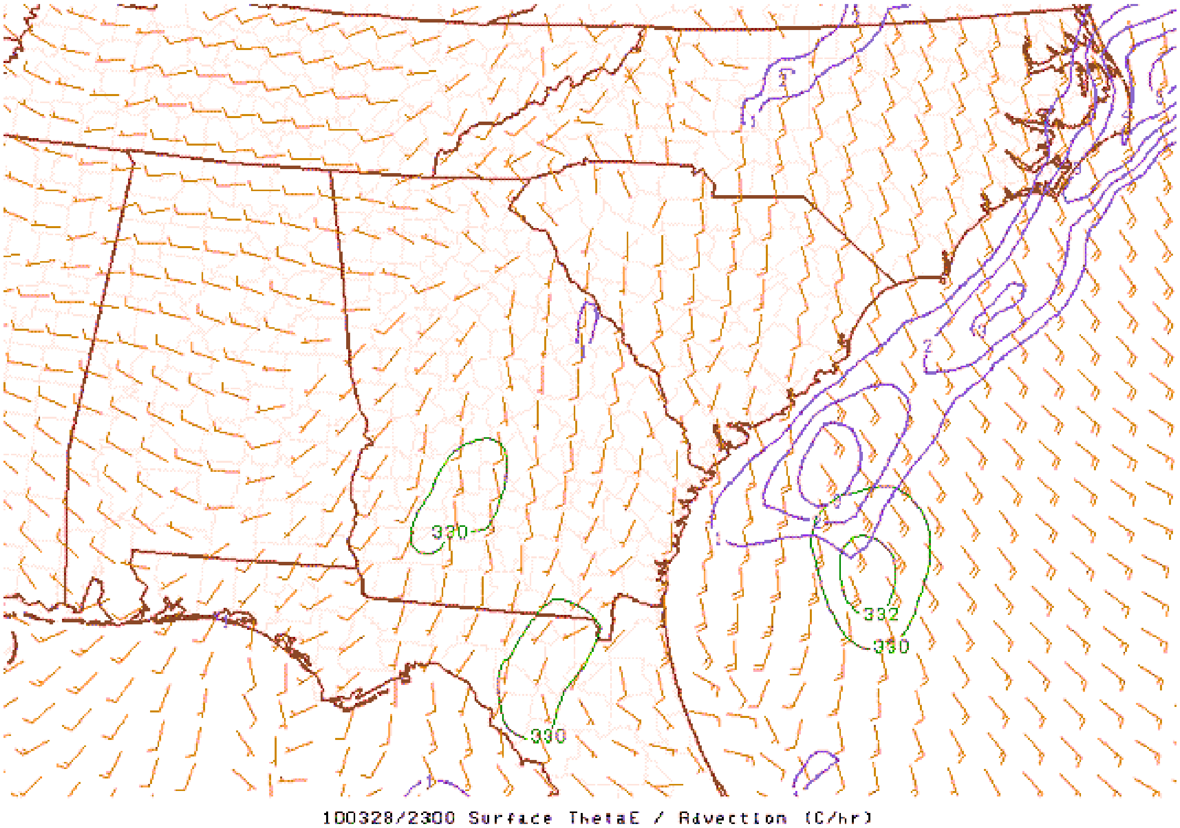
A complex surface pattern is shown in the analysis below. A cold front extends south from eastern Tennessee across Georgia and then southwestward to the far western Florida panhandle. A warm front (wedge front) separating a cooler and more stable air mass across northeast Georgia, far western South Carolina and western North Carolina is indicated by the 54 degree F isodrosotherm and the light northerly winds north of the front in the far western Piedmont and Foothills region. Note the large area of south-southeast winds across central North Carolina which is anomalous and the limited northward penetration of the unstable surface air mass with 60 degree dew points restricted to eastern Georgia and far southern South Carolina.



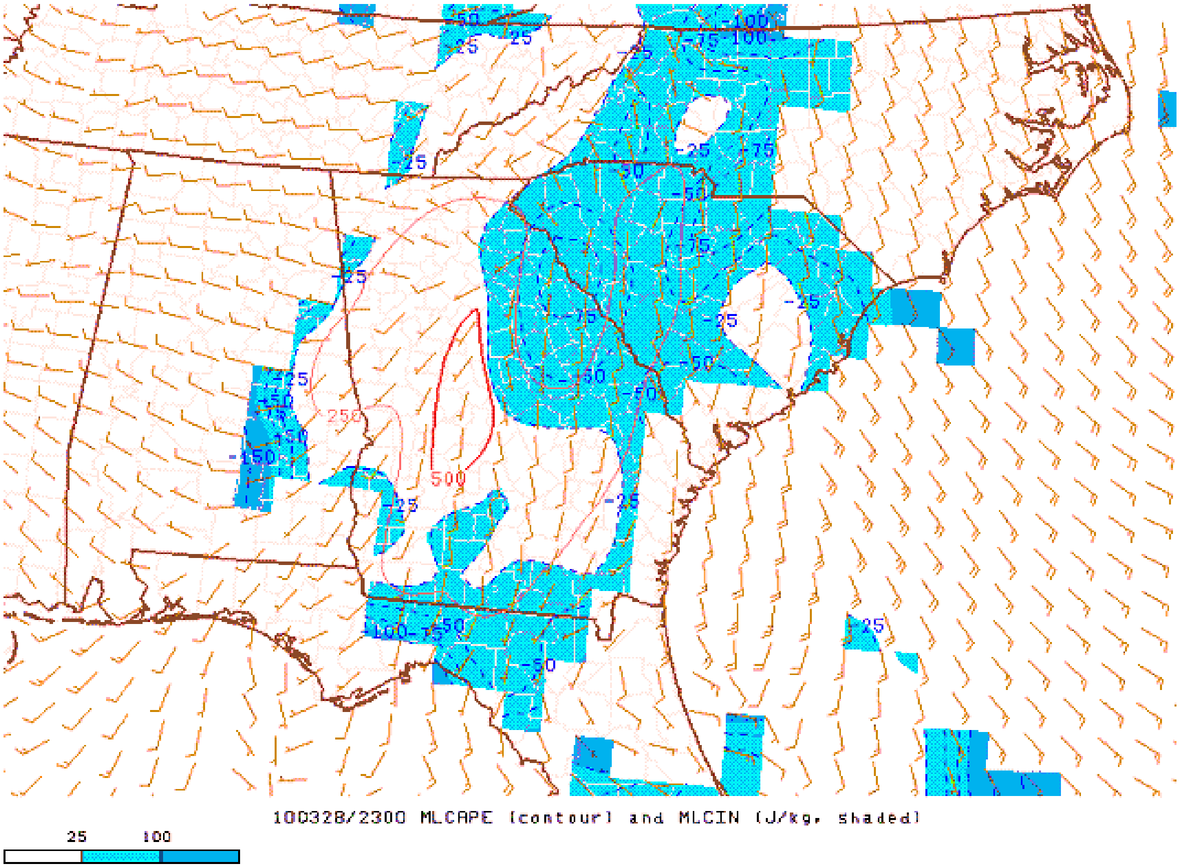
Analyzed surface Theta-e (green contours), Theta-e convergence (purple contours) and wind barbs from SPC at 2300 UTC on Sunday, March 28, 2010

The warm front (wedge front) across far western North Carolina and South Carolina is easily seen in the wind analysis and the axis of surface theta-e convergence. Note that the surface theta-e is less then 320 degrees K across all of the Carolinas and Virginia.

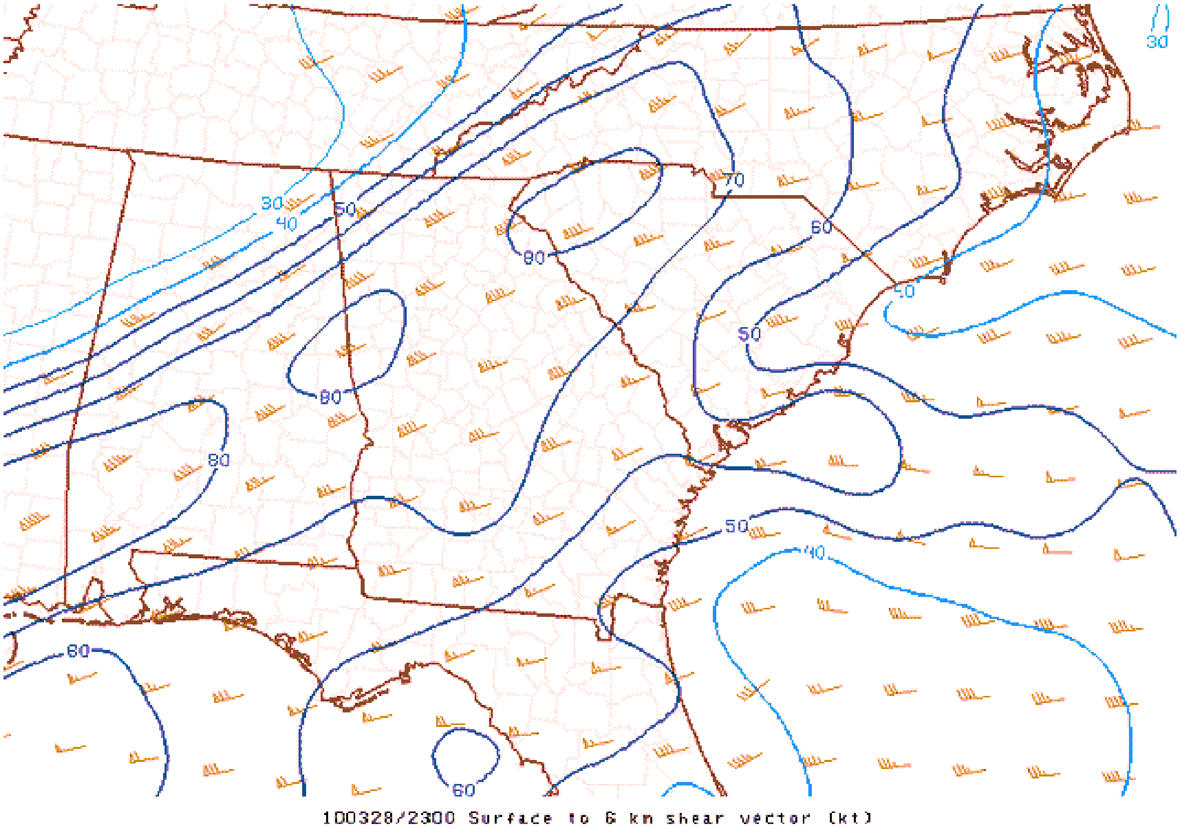
(Click on the image below to enlarge)



Analyzed mixed layer convective available potential energy (MLCAPE) (red) and mixed layer based convective inhibition (MLCIN) (blue lines - shaded) from SPC at 2300 UTC on Sunday, March 28, 2010
Note that the greatest MLCAPE values range near 500 J/kg across central Georgia with an axis of very weak instability, around 250 J/kg of MLCAPE, extending northward across central and western South Carolina. This analysis suggests that MLCAPE values were less then 250 J/kg across North Carolina, even in the locations with tornadoes. In fact, western North Carolina had a widespread area with CIN values of 25 to 100 J/kg. The 3 hour analysis of MLCAPE change suggests that the mixed layer instability across central North Carolina did not experience any significant change.
(Click on the image below to enlarge)



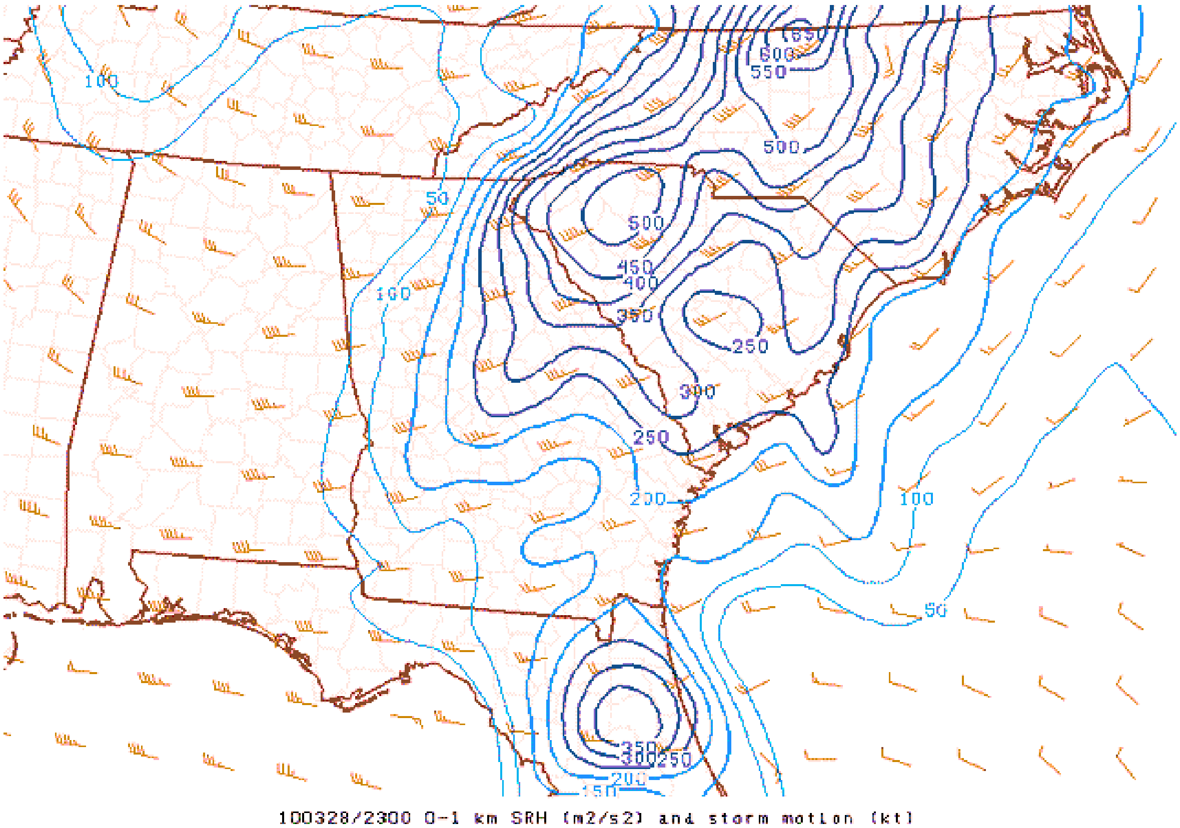
0-6 km Bulk Shear (blue) and storm motion (brown) from SPC at 2300 UTC on Sunday, March 28, 2010
The 0-6 km bulk shear values were very high across western and central North Carolina with between 60-80 kts of bulk shear. Given sufficient instability, thunderstorms tend to become more organized and persistent as vertical shear increases. Supercells are commonly associated with vertical shear values of 35-40 knots and the analysis at 2300 UTC supports the potential of supercells.
(Click on the image below to enlarge)



0-1 km Storm Relative Helicity (SRH) (shown in blue) and storm motion (brown) from SPC at 2300 UTC on Sunday, March 28, 2010

Note that the 0-1 km SRH values ranged between 300 and 600 m^2/s^2 across central and western North Carolina. The SRH is a measure of the potential for cyclonic updraft rotation in right-moving supercells. Studies have shown that larger values of 0-1 km SRH, greater than 100 $m^2 2/s^2$, suggests an increased threat of tornadoes and that very large values of 0-1 km SRH (perhaps greater than 200 to 300 m^2/s^2) are indicative of significant tornado potential.

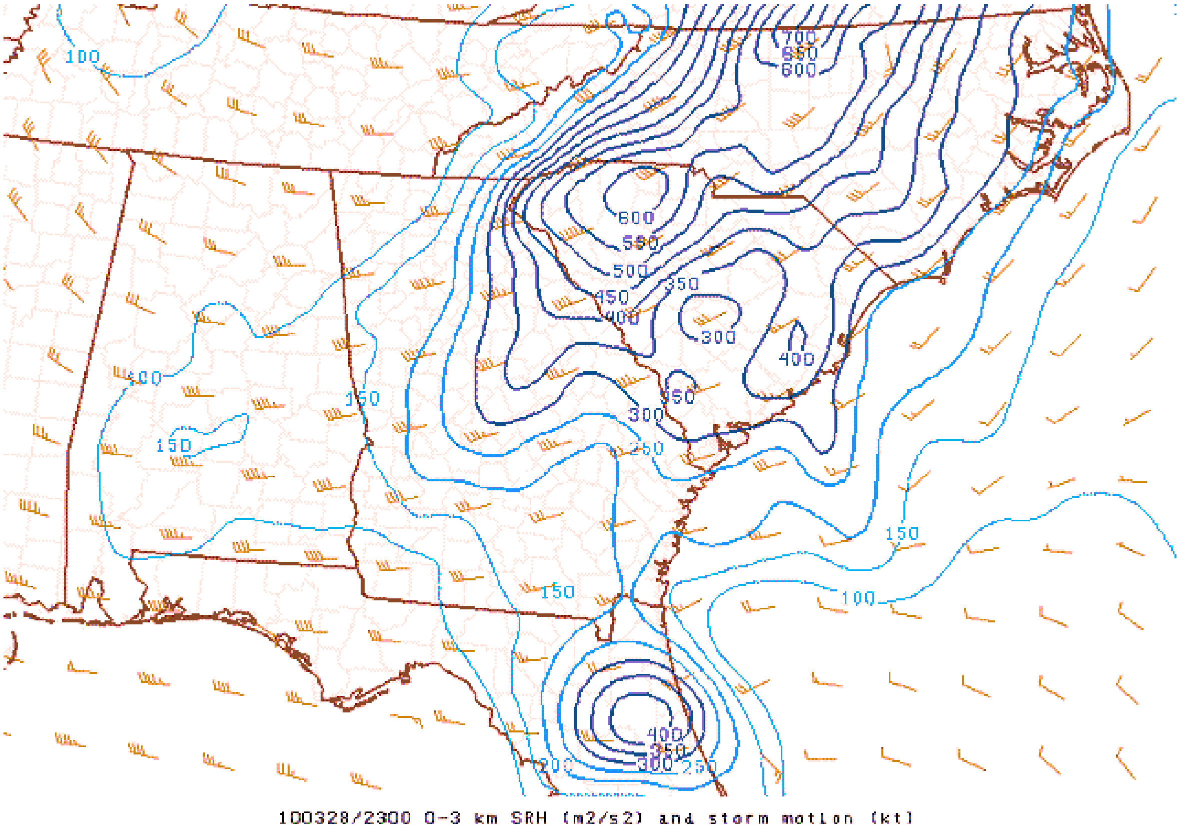
(Click on the image below to enlarge)



0-3 km Storm Relative Helicity (SRH) (shown in blue) and storm motion (brown) from SPC at 2300 UTC on Sunday, March 28, 2010

Note that the 0-3 km SRH values range between 400 and 600 m^2/s^2 across central North Carolina. The SRH is a measure of the potential for cyclonic updraft rotation in right-moving supercells. Larger values of 0-3 km SRH (greater than 100 m^2/s^2) suggest an increased threat of supercells and tornadoes. Some studies suggest that the 0-3 km SRH is a better indicator of storm rotation, which is related to tornadoes, but not directly the potential for tornadoes themselves.

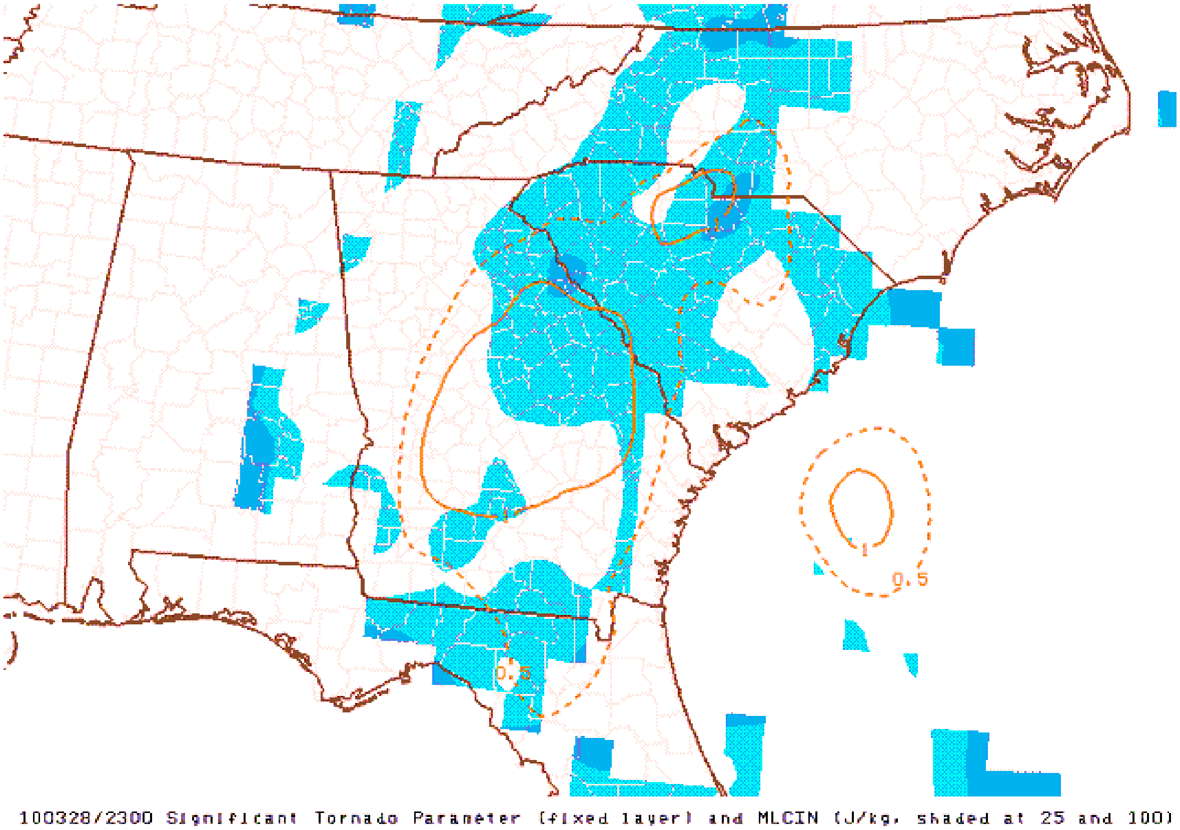
(Click on the image below to enlarge)



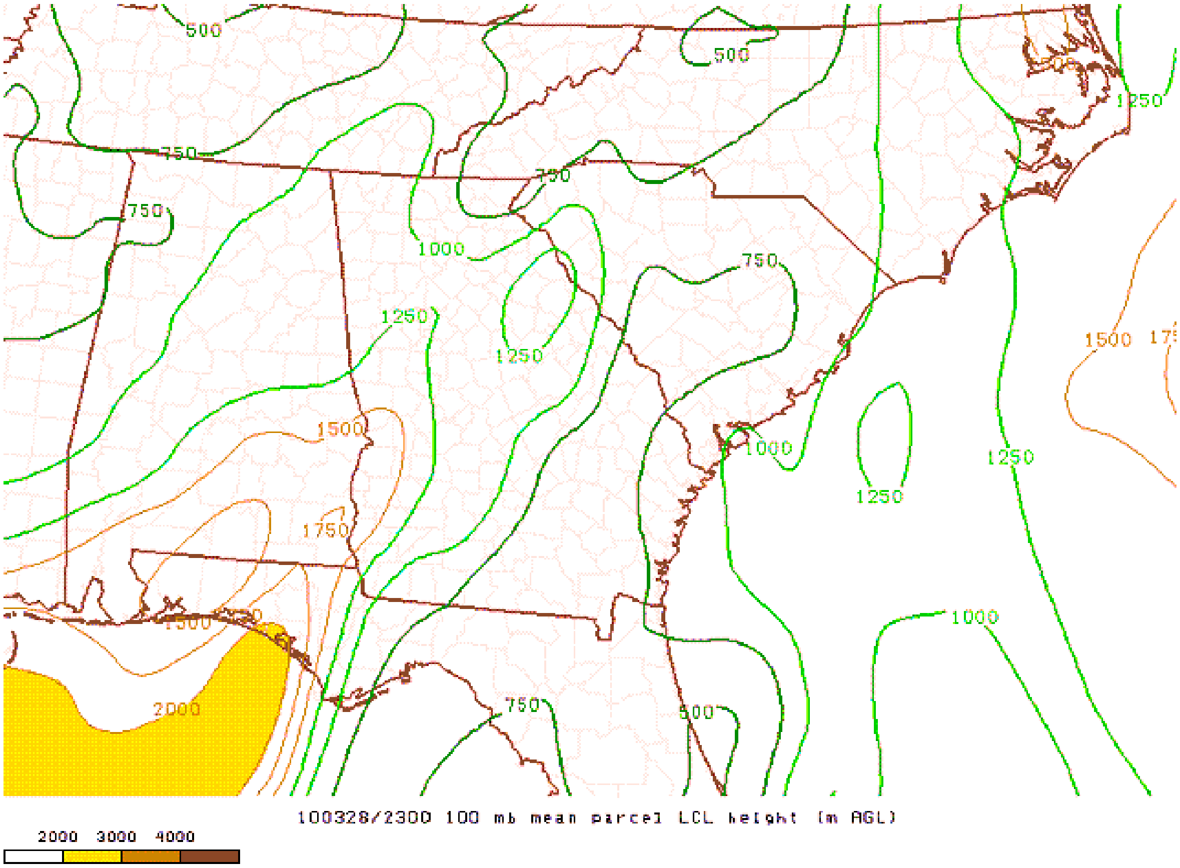
Analyzed Significant Tornado Parameter (STP) (shown in yellow and red) and the mixed layer convective inhibition (MLCIN) from SPC at 2300 UTC on Sunday, March 28, 2010

The STP is designed to highlight areas favoring right-moving tornadic supercells. The STP is a multiple ingredient, composite index that includes effective bulk wind difference (EBWD), effective storm-relative helicity (ESRH), 100-mb mean parcel CAPE (MLCAPE), 100-mb mean parcel CIN (MLCIN), and 100-mb mean parcel LCL height (MLLCL). Analyzed values across central North Carolina show that the tornado outbreak area was near and just north of STP values of 0.5 to 1.0 which were located across south central North Carolina and western South Carolina. Several of the supercells that moved across western North Carolina originated in the region of higher STP. Additional details on the Analyzed Significant Tornado Parameter (STP) is available in this reference.

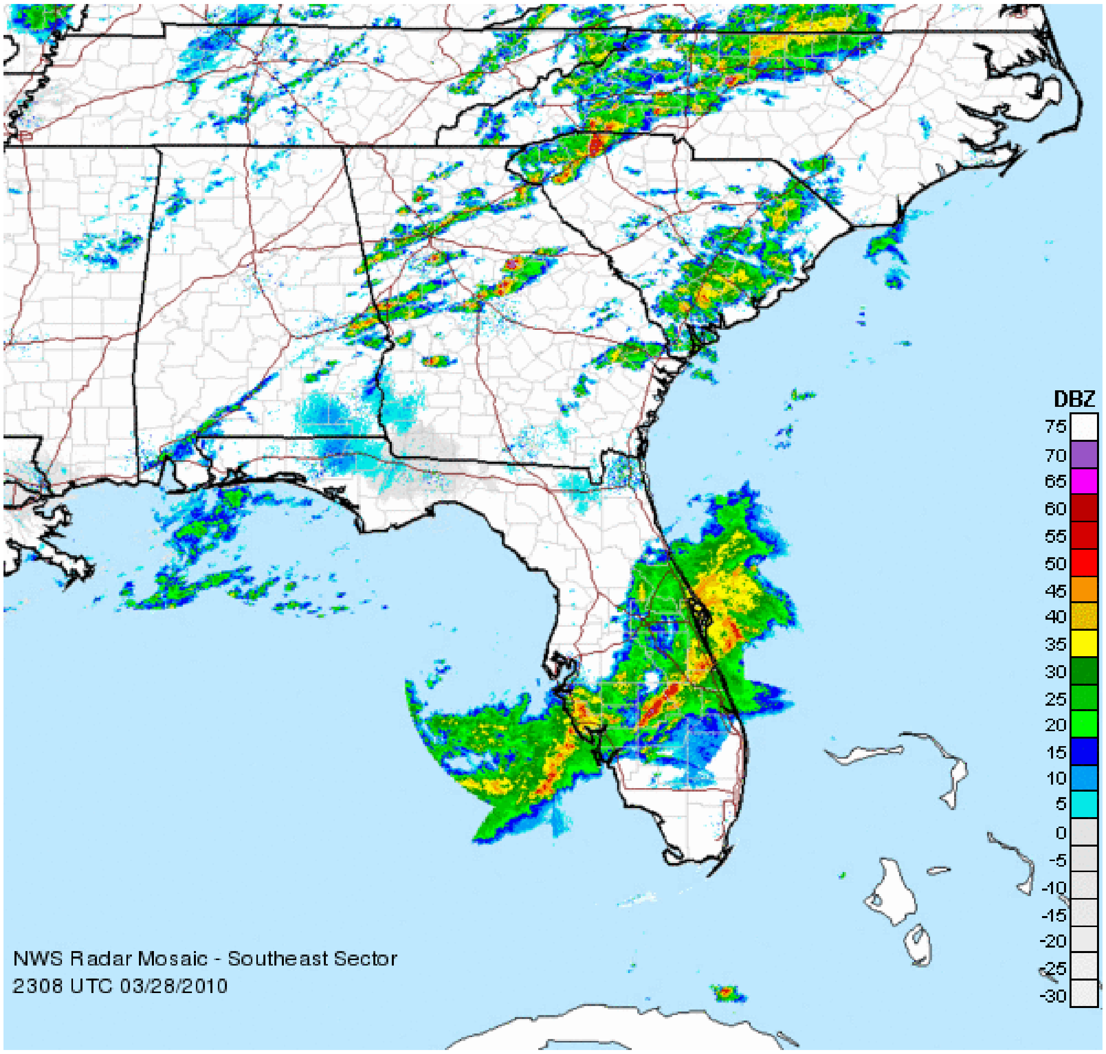
(Click on the image below to enlarge)



Analyzed Lifting Condensation Level (red, blue, and green) from SPC at 2300 UTC on Sunday, March 28, 2010
The LCL height is the height at which a parcel becomes saturated when lifted dry adiabatically. LCL heights were less than 750m in the region where the tornadoes touched down and less then 1000m in most of central North Carolina. The LCL height was below 1000 m during the entire episode, and mainly between 500 and 750m through most of the event. The importance of the LCL height is thought to relate to sub-cloud evaporation and the potential for outflow dominance. Low LCL heights imply less evaporational cooling from precipitation and less potential for a strong outflow that would likely inhibit low-level mesocyclone development. Thunderstorms that produce significant tornadoes generally have a lower LCL height with LCL heights less than 1,000 meters typically favorable for tornado development. The LCL values during this event in the areas where tornadoes occurred ranged between 500 to 750 meters.
(Click on the image below to enlarge)



NWS composite radar reflectivity imagery from 2308 UTC on Sunday, March 28, 2010.
The regional composite reflectivity imagery is from the approximate time in which the analysis imagery above is valid.



Archived Text Data from the Severe Weather Event

Select the desired product along with the date and click "Get Archive Data."
Date and time should be selected based on issuance time in GMT (Greenwich Mean Time which equals EST time + 4 hours).

Product ID information for the most frequently used products...

RDUAFDRAH - Area Forecast Discussion
RDUZFPRAH - Zone Forecast Products
RDUAFMRAH - Area Forecast Matrices
RDUPFMRAH - Point Forecast Matrices
RDUHWORAH - Hazardous Weather Outlook
RDUNOWRAH - Short Term Forecast
RDUSPSRAH - Special Weather Statement
RDULSRRAH - Local Storm Reports (reports of severe weather)
RDUSVRRAH - Severe Thunderstorm Warning
RDUSVSRAH - Severe Weather Statement
RDUTORRAH - Tornado Warning

* Scroll down for list from March 27 2010

Get Archive Data

Lessons Learned and Final Thoughts

This event is consistent with many other high shear-low CAPE (HSLC) severe weather episodes across the Carolinas. The upper air pattern was amplified with an anomalously strong mid and low level flow which resulted in strong deep layer shear while low level instability was limited with analyzed surface-based CAPE values less than 500 J/kg.

The first three tornadoes occurred between 650 and 730 PM EDT (550 PM and 630 PM LST) which is consistent with a 55 year climatology that showed that tornadoes in central North Carolina occur with the greatest frequency between 500 PM and 700 PM LST (Locklear 2008).

The High Point tornadic supercell developed in far northern South Carolina and moved into the Charlotte area, in a region of slightly greater instability. As the storm matured into a supercell, the mid level rotation and lowering of pressures in the mid levels likely enhanced the updraft due to the dynamically-induced pressure gradient force. This process likely contributed to the cell's persistence and intensity as it moved into a region of reduced instability in the Triad.

The supercell that produced the first three tornadoes moved nearly parallel but on the warm side of the Thermal Moisture Boundary (TMB). The similarities in the location and orientation of the TMB and the supercell track is remarkable. While the large scale deep layer shear and helicity was sufficient for supercells, the TMB likely provided a region of localized vorticity to be ingested into the tornadic supercell. In addition, it is possible that the frontogentical circulation associated with the boundary could have played a role in maintaining and enhancing the convection.

The TCLT TDWR radar was invaluable in issuing timely and effective warnings especially in ensuring good lead time and a high probability of detection. Forecasters commented that the tornado warning issued for Davidson County was nearly entirely based on the TDWR data. The value of the TDWR is easily shown with a comparison of radar imagery from the TCLT TDWR and the KRAX WSR-88D at 2244 UTC and 2242 UTC respectively when the supercell was located in northeastern Rowan county, just before it moved into Davidson County.

Forecasters used “tornado emergency” wording appropriately in three Severe Weather Statements (SVS) as the High Point tornado was touching down and moving northeast across the Triad. Frequent SVS updates provided updated “impacts” and “locations” along with the latest reports of damage or tornado touchdowns. The value of these updates can be heard in the audio from the High Point Fire Department emergency radio network.

Around 17 individuals including local media, SKYWARN and emergency managers were logged into the NWSChat during the event. NWS forecasters were proactive in the chat providing detailed information, added insight, as well as soliciting tornado confirmation. In all, there were 52 individual chats between NWS staff, SKYWARN, media and emergency management sharing information on radar signatures, damage, 911 reports, watch status and more.

Finally, this was obviously a very significant severe weather event. Nearly every staff member at the office participated, in some way, in the successful and timely services provided during or after the event. This included everything from ensuring that equipment was available, to issuing the forecasts and statements preceding the event, issuing the warnings and coordinating with users during the event, participating in the damage surveys and creating the survey reports, covering shifts or providing resources during or after the event, or by participating in this event summary.

Future Work

As a high shear-low CAPE (HSLC) severe weather event, this event is worth documenting and examining as forecaster feedback notes this is a significant forecast and warning issue. Several aspects of this event are worth examining further including: the role that the wedge front played in the development, evolution, character, and degree of the severe weather. Identifying both boundaries and understanding their role in the future events is important.

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Acknowledgements

Many of the images and graphics used in this review were provided by parties outside of the NWS Raleigh. Photos were provided by Jonna Bingham and Eric Sifford. In addition, the NWS in Greenville-Spartanburg, in particular Pat Moore, provided several photographs and other spotter or damage information. The surface analysis graphics were obtained from the Hydrometeorological Prediction Center. GOES satellite data was obtained from National Environmental Satellite, Data, and Information Service. SPC meso-analysis graphics provided by the Storm Prediction Center. Base maps for the tornado tracks were provided by Google Maps and Google Earth - Google Earth map imagery used under license. The TPW imagery was provided by and the NESDIS Operational Blended TPW Products page and Sheldon Kusselson. NSSL's Rotational Track product provided by the WDSS-II (Warning Decision Support System - Integrated Information) group at NSSL. Local storm reports and warning polygons KMZ data provided by the National Climatic Data Center.

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