P12.7 THE ROLE OF A SURFACE BOUNDARY AND MULTIPLE CELL-MERGERS IN THE DEVELOPMENT OF THE 21 APRIL 2003 TORNADO IN UPSTATE SOUTH CAROLINA

Bryan McAvoy
NOAA/National Weather Service
Greer, SC

1. INTRODUCTION

During the late afternoon hours of 21 April 2003, several discrete multicell thunderstorms developed over northeast Georgia and southern Upstate South Carolina. The storms formed on the north side of an east-west oriented low-level baroclinic zone. One of these cells exhibited a mesocyclone for over an hour as determined by the KGSP WSR-88D. The mesocyclone gradually strengthened as the parent storm encountered a succession of weaker cells moving across the boundary. At 2205 UTC, one hour after the mesocyclone developed, a brief tornado occurred, resulting in F1 damage in the Parson's Mountain Recreation Area. The "Mountain" in reality is a 300 foot rise located in the Sumter National Forest in southeast Abbeville County.

Fig. 1. *Center of the tornado damage path. View is to the west.*

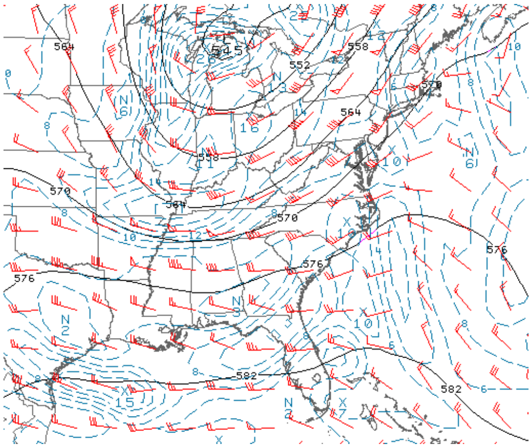

Fig. 2. *500 hPa geopotential heights, winds (kts), and vorticity (s^{-1}).*

As reports of F0 and F1 tornado damage are often found to be "erroneous" (Rasmussen and Blanchard 1998), many of the more influential and important studies of near-storm environmental conditions and forecast parameters associated with tornadogenesis discard events where only weak tornado damage occurs. Therefore, it is important to demonstrate that the damage in Abbeville County was indeed caused by a tornado, albeit a very brief one. The damage path was only ¼ mile long, with 75% of the forest canopy blown down over a 20 acre section of the Parson's Mountain Recreation Area. On the left side of the damage path, several dozen trees fell to the west northwest, in direct opposition to the storm movement. Several hundred trees fell to the east southeast on the south side of the track. The center of the path exhibited convergent damage as trees fell at nearly right angles to one another in an overlapping pattern (Fig. 1). These observations strongly support the argument that the damage was caused by a tornado.

2. SYNOPTIC AND NEAR-STORM ENVIRONMENT

Widespread rain fell across Upstate South Carolina and northeast Georgia during the morning and early afternoon hours of 21 April. By late afternoon, a 5-7°C temperature gradient,

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Corresponding author address: Bryan McAvoy, National Weather Service, 1549 GSP Drive, Greer, SC 29651; e-mail: bryan.mcavoy@noaa.gov

and considerable backing of the surface winds, existed roughly along a line from Athens to Columbia (Figure 3). The distance of this low-level boundary from surrounding radars prohibited an exact placement through the possible detection of a radar fine line. Therefore it was necessary to use surface plots to place the boundary. RUC model 0-3 km storm-relative helicity (SRH) values, valid at 2100 UTC, increased from less than 100 m^2 s^{-2} south of the boundary to 200-225 m^2 s^{-2} to its north. The latter SRH values were sufficient for mesocyclone formation as described by Davies-Jones et al. (1990). LAPS and MSAS stability parameters were contaminated by bad AWOS dewpoints, a frequent and vexing problem. However, a 2100 UTC RUC model sounding, modified for the conditions at the Greenwood, SC ASOS, 25 km to the northeast of Parson’s Mountain, resulted in SBCAPE values around 1400 J kg^{-1} (Figure 4). The sounding derived lifted condensation level (LCL) was only 225 m and there was a modest amount of 0-3 km CAPE. There was little difference between the 2100 UTC and 2200 UTC RUC soundings. However, the earlier sounding better captured the light southeast flow north of the boundary. Many surface plots north of the boundary continued to report light southeast winds at 2200 UTC, while the Greenwood ASOS did not. This is why the 2100 UTC and not the 2200 UTC sounding was selected.

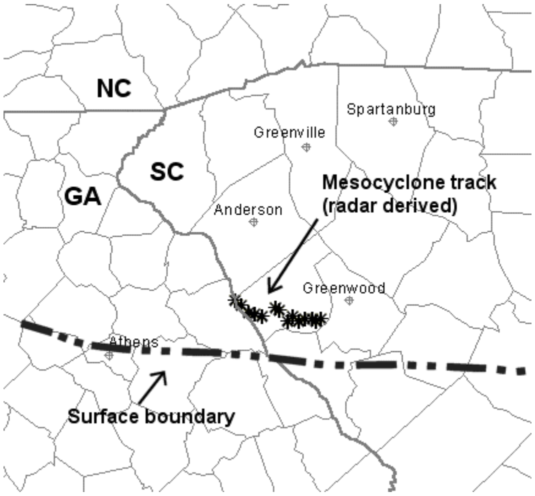

Fig. 3. *Radar defined mesocyclone track through Abbeville County and location of surface boundary.*

Diffluent middle and upper tropospheric flow was found over the region ahead of a long wave trough. The 1200 UTC run of the Eta model, valid at 0000 UTC on 22 April 2003, had a 500 mb short wave trough just west of the region (Figure 2). Eta model mid-level winds were from the west at 35-40 kts, consistent with the RUC soundings and with the KGSP WSR-88D velocity azimuth display wind profile. Considering that surface winds were on the order of 5-10 kts from the southwest on the warm side of the boundary, 0-6 km bulk shear values were in the range of 30-35 kts. This amount of shear is generally insufficient for the development of supercells according to the work done by Thompson et al. (2002). North of the boundary, considering the light southeast surface winds, the 0-6 km bulk shear was in excess of 40 kts.

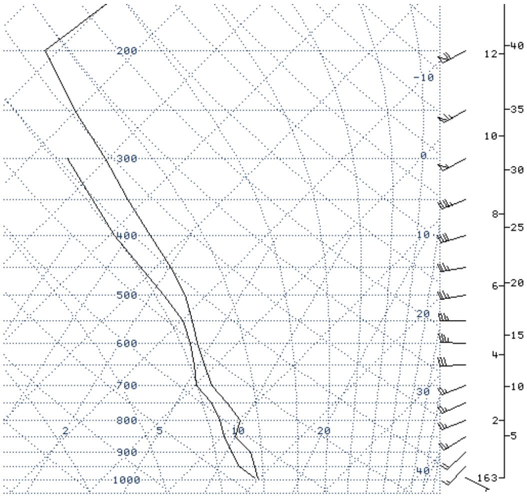

Fig. 4. *RUC sounding for 2100 UTC 21 April 2003 located at the Greenwood municipal airport (ASOS location) 25 km northeast of Parson's Mountain.*

3. STRUCTURE AND EVOLUTION OF THE PARSON’S MOUNTAIN STORM

While many of the discrete multicell storms that developed in the vicinity of the boundary exhibited brief periods of weak rotation, the Parson’s Mountain (PM) cell was the only one that exhibited a radar defined mesocyclone during the nearly 3 hour period for which data were reviewed on the Weather Event Simulator. For most of the PM cell’s existence, the reflectivity structure of the storm was not consistent with that of a supercell, lacking a persistent WER, BWER or pendant. Beginning about 2145 UTC the cell began to develop a midlevel reflectivity notch on its southwest flank. This feature persisted through the time of tornado formation and was likely the result of a developing RFD.

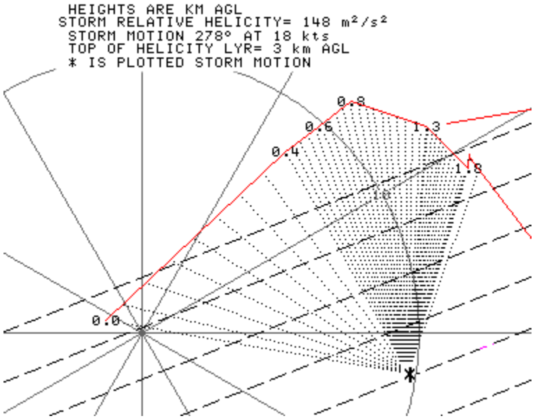

Fig. 5. *RUC 0-3 km SRH, valid same time and location as Figure 4.*

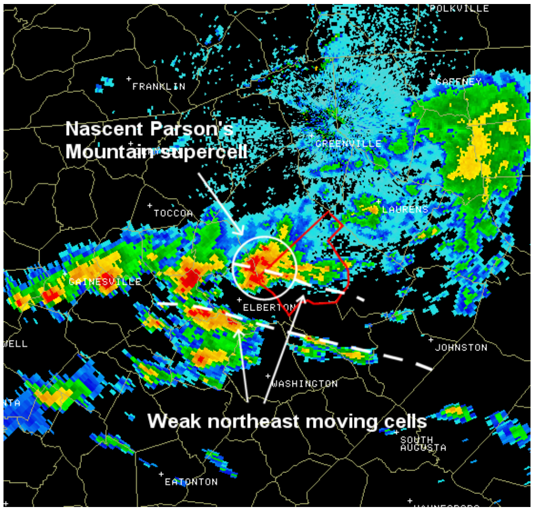

Fig. 6. *KGSP WSR-88D plan-view reflectivity image for 2105 UTC 21 April 2003. Merging cells delimited by dashed line. Developing supercell circled. Abbeville County outlined in red.*

The PM storm possessed a comparatively shallow mesocyclone that averaged 3.7-5.5 km in diameter for much of its lifetime. The rotational velocity (Vr) and mesocyclone diameter were consistent with those associated with mini supercells (Grant and Prentice 1996), though the PM storm frequently had echo tops that were higher (45-50 kft) than the 25-30 kft echo tops common for mini supercells. Thus, there is some uncertainty as to whether the storm, which exhibited marginal supercell characteristics, should be classified as a supercell or a multicell severe. Owing to the persistent rotation, it will be classified herein as a supercell, but certainly it deserves the “marginal” label.

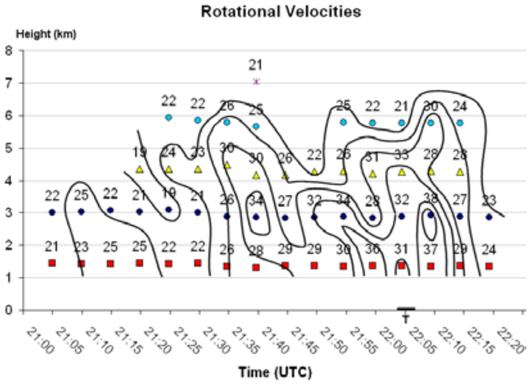

Fig. 7. *Rotational Velocity (Vr) time-height section for the Parson's Mountain supercell. Y-axis is height in km and X-axis is UTC time. Tornado occurrence denoted by thick black line and "T" symbol.*

There were at least 3 discrete cell mergers (detailed in the next section) during the life of the PM supercell, each of which changed the character of the storm. In all instances a broken low-topped line of weak cells originated well on the warm side of the boundary. The cells moved from approximately 210-220 degrees and eventually crossed the low-level baroclinic zone. Thereafter the cells would exhibit some strengthening shortly before they intersected, and were usually subsumed by the PM supercell.

4. MESOCYCLONE AND TORNADO EVOLUTION

A radar-defined mesocyclone first developed in the northwest part of Abbeville County at 2105 UTC, immediately following the first cell merger (Figure 6). During the next 15 minutes, the circulation was quite weak and confined to elevations no higher than 3 km above radar level (ARL), though the cell itself became considerably stronger and taller during this time, with a pronounced southward jog of the reflectivity core. Low-level mesocyclones have been defined by Trapp and Stumpf (2002) and Markowski et al. (1998) as those which are found at or below 3 km ARL.

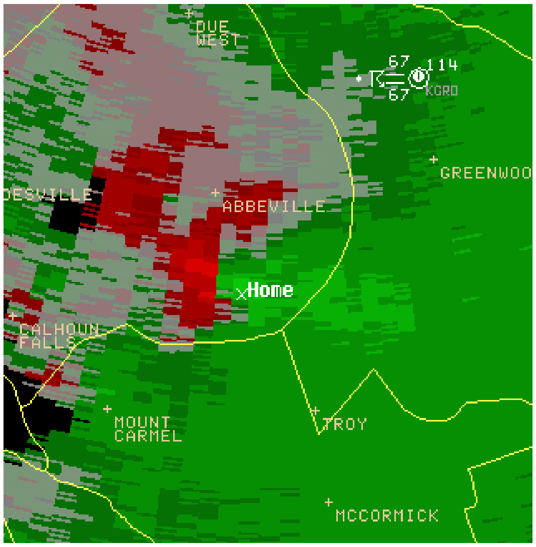

Fig. 8. *KGSP WSR-88D 8-bit plan-view SRM image for 2200 UTC 21 April 2003, one volume scan before tornado touchdown. "Home" denotes the location of Parson's Mountain.*

There was a second cell merger at 2125 UTC, at which time the mesocyclone increased in depth to approximately 6 km (Figure 7). The Vr gradually increased, reaching a velocity of 34 kts at 2.8 km at 2040 UTC. At this time, a third cell merger occurred. From this point forward it became difficult to determine when cell mergers occurred as the PM supercell was almost continually in contact with weaker cells crossing its path. From 2145-2210 UTC, the strongest Vr's generally remained at or below 3 km, with the maximum Vr occurring one volume scan after the tornado with a peak rotation of 37 kts, and a gate-to-gate shear of 73 kts. The mesocyclone diameter decreased to 2 km (1.5 km) at 2200 UTC (2210 UTC), but was actually a little wider than that at the time of the tornado, at least above 1 km ARL. While the mesocyclone did appear to exhibit descending characteristics, it did so only from 3 km.

The circulation most likely responsible for the PM tornado was only .27 nm across as seen on the 8-bit SRM data (Figure 8). As a result, in a gross sense, the 4-bit SRM data actually showed the circulation better at times as it expanded the peak velocities in space (Figure 9). This is something that radar operators at KGSP, and other offices that often deal with small vortices, will have to be careful of now that the .13 nm velocity and SRM data are the standard storm interrogation products.

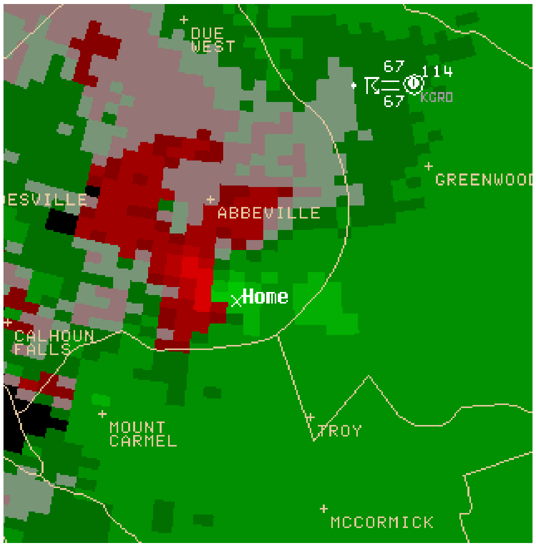

Fig. 9. *Same as Figure 8 except for 4-bit SRM image.*

5. DISCUSSION AND CONCLUDING REMARKS

While many recent studies of tornado forecast parameters have focused only on strong and violent tornado environments, it seems logical that those parameters which support low-level mesocyclogenesis should apply to weak tornadoes as well. In this case, the existence of "some" CAPE (Rasmussen 2003) in the 0-3 km layer (Figure 4), and very low LCL's on the cool, moist side of a low-level boundary, point to an environment conducive to low-level mesocyclone and tornado development. A RUC model sounding taken 25 km on the cool side of the tornado track revealed 0-3 km SRH values of 148 m2 s-2; however, all of that SRH was realized below 1.8 km. The 1.8-3 km layer actually subtracted from the SRH (Figure 5). Away from the surface boundary, conditions were not as favorable for either mid-level or low-level mesocyclone development.

Considering the above, it is easier to understand the behavior of the PM supercell, a storm that was dominated by a low-level mesocyclone that deepened each time the parent storm merged with weaker cells crossing into the cooler air. One hypothesis for this mode of development is that multiple cell mergers were required to augment the modest updraft of the parent cell to the point where sufficient streamwise horizontal vorticity could be tilted into the vertical and result in a mesocyclone. Apart from these processes, there appears to have been insufficient forcing for the maintenance of a midlevel mesocyclone. This may also explain why the cell had storm tops far in excess of those typically associated with mini-supercells, but a mesocyclone with very similar characteristics to that type of storm.

It is interesting to note that the tornado occurred coincident with the parent mesocyclone's transit of an unusually tall topographic feature in the southern Upstate. The damage began just east of Parson's Mountain Lake and ran a little beyond the crest of the north spur of the "mountain", a rise of about 200 feet. As this was also coincident with the mesocyclone's greatest strength, it does not appear likely that terrain played much of a part in the tornado development.

Trapp and Stumpf (2002) showed that for a large mesocyclone sample set, only 14.6% of midlevel mesocyclones were tornadic, while over 40% of low-level mesocyclones were tornadic, with the highest percentage of those tornadoes occurring with mesocyclones whose bases were at or below 250 m ARL. Familiarity with the Trapp and Stumpf study, and the favorable low-level conditions for mesocyclone and tornado development immediately north of a low-level boundary, gave the radar operator sufficient confidence to issue a tornado warning at 2145 UTC, achieving a 20 minute lead time.

6. ACKNOWLEDGEMENTS

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