P3.6 AN INVESTIGATION OF THE SIGNIFICANT TORNADO OUTBREAK IN SOUTHERN SOUTH CAROLINA AND NORTH COASTAL GEORGIA ON MARCH 15, 2008

Frank W. Alsheimer*, Robert Bright, Jonathon Jelsema, Wendy Moen, John Quagliariello, and Douglas Berry
NOAA/National Weather Service, Charleston, South Carolina

1. INTRODUCTION

On March 15, 2008, an unusually large tornado outbreak occurred in portions of South Carolina and Georgia. Included in this outbreak was the county warning area (CWA) of the National Weather Service (NWS) office in Charleston, SC (KCHS), covering southern South Carolina and north coastal Georgia. During the day, 6 tornadoes occurred over the CWA, including 3 rated EF2 and 3 rated EF1. Never before had 3 or more EF2 or stronger tornadoes been reported across the area on a calendar day (unfortunately, this record was met again on May 11, 2008). In all, 39 tornadoes were confirmed over South Carolina and eastern Georgia on March 15th.

The purpose of this study is to look into the very unusual event, both from a meteorological point of view as well as a customer service point of view. The atmospheric state before and during the event will be discussed, as well as the ability of readily available computer models to capture the details critical to the evolution of the tornadic supercells. In addition, NWS products both leading up to the event and during the event will be examined, including issues related to the relatively new storm-based warning methodology rolled out nationwide by the NWS on October 1, 2007.

2. DATA

The radar, satellite, and model data used for the study was archived from the NWS Advanced Weather Interactive Processing System (AWIPS; Wakefield, 1998) system at the Charleston, SC (KCHS) forecast office. The archived data was then viewed and manipulated on the NWS Weather Event Simulator (WES; Ferree et al. 2002). Upper air sounding data was saved on the internal office Local Area Network (LAN) for use in the RAwinsonde OBservation program (RAOB). Statistics and details of the tornado events were gathered from the National Climate Data Center's (NCDC) Storm Data publication.

3. RESULTS

3.1. Event Overview

The potential for a significant convective event on March 15th was anticipated a few days in advance. Computer models indicated the synoptic scale would evolve favorably for a severe weather threat based on local climatology (Alsheimer et al. 2008). The NWS Storm Prediction Center (SPC) warned of a slight risk of severe weather in its convective outlook issued at 0722 UTC on March 13th. Area Forecast Discussions (AFD) and Hazardous Weather Outlooks (HWO) issued by NWS KCHS also highlighted the potential for severe weather on March 15th.

On the morning hours of March 15th, favorable conditions were beginning to come together for a significant severe weather outbreak over the southeastern states. In fact, SPC upgraded most of South Carolina to a moderate risk at 1630 UTC due to both the strong activity upstream over northern Georgia and the environmental conditions turning increasingly favorable. By 1800 UTC, despite quite a bit of low cloud cover (Fig. 1), surface-based Convective Available Potential Energy (CAPE) values had increased to greater than 1000 J/kg over most of the area (Fig. 2), with max values near 2000 J/kg over the extreme southern portion of the CWA. Additionally, mid level lapse rates indicate significant instability with values greater than 7°C/km (Fig. 3).

An important feature in both Figures 1 and 2 is noted at this time. The sea breeze had moved inland over portions of the area, with further penetration over South Carolina. The observations do indicate some low level convergence with winds at North Myrtle Beach, SC (KCRE), Beaufort, SC (KNBC) and Hunter Army Airfield, GA (KSVN) all backing onshore. Also, cooler temperatures southeast of the boundary due to the influence of the marine environment produced a shallow stable layer, thus the lower surface based CAPE values in Figure 2.

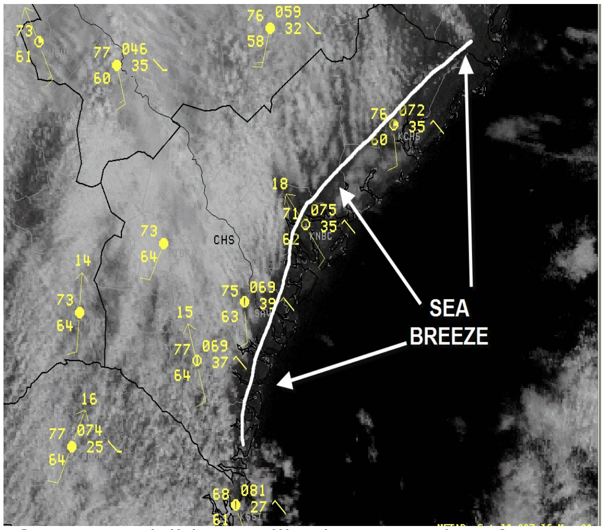

Figure 1. Visible satellite image and surface observations in conventional format at 1800 UTC March 15, 2008.

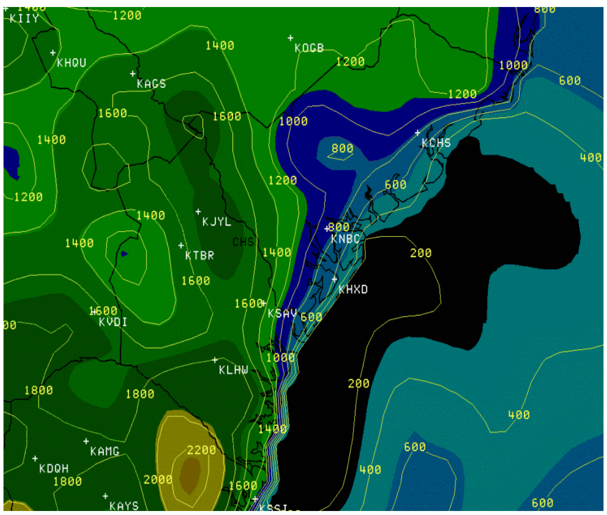

Figure 2. Surface based CAPE (J/kg) at 1800 UTC March 15, 2008.

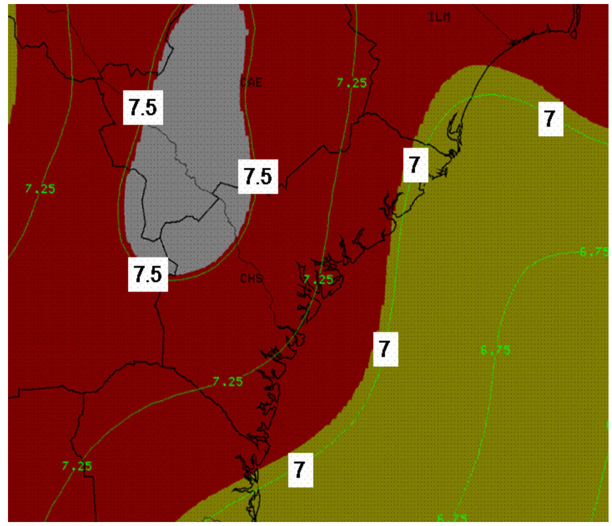

Figure 3. Lapse rates from 700-500 hPa at 1800 UTC March 15, 2008.

Further upstream, the winds were strengthening (Fig. 4). The 850 hPa wind fields showed a rather large area of speeds in excess of 50 knots, while a very strong 500 hPa jet in excess of 90 knots was moving into northern Alabama, with 70 knot winds extending as far east as northern Georgia (Fig. 4).

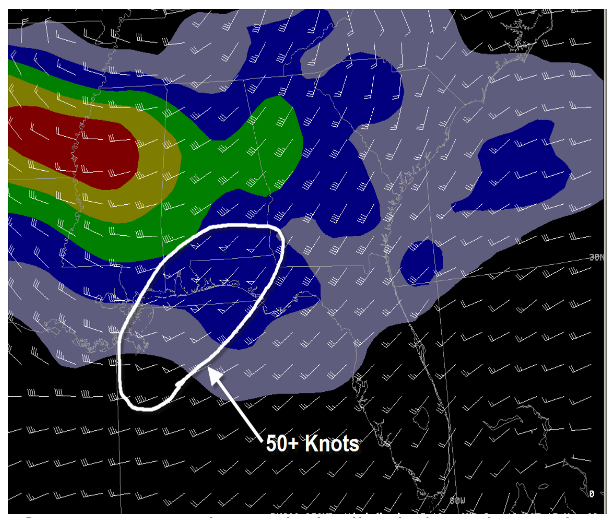

Figure 4. 850 hPa winds (barbs) and 500 hPa wind speeds (kts., color shading) at 1800 UTC March 15, 2008. Red shading represents values greater than 90 knots.

Due to the impending severe weather threat, KCHS conducted a special 1800 UTC upper-air observation. The data showed some significant changes from 1200 UTC (Fig. 5). Winds at 850 hPa had increased from 20 to 35 knots, with the 0-6km shear increasing from 42 to 57 kts. Other notable changes were a sharp increase in BRN shear from 16.3 to 96.9 m^2/s^2 and a large increase in CAPE in the hail growth zone. The hodograph at 18Z also had a strongly curved representation indicating the threat for supercells was increasing (not shown).

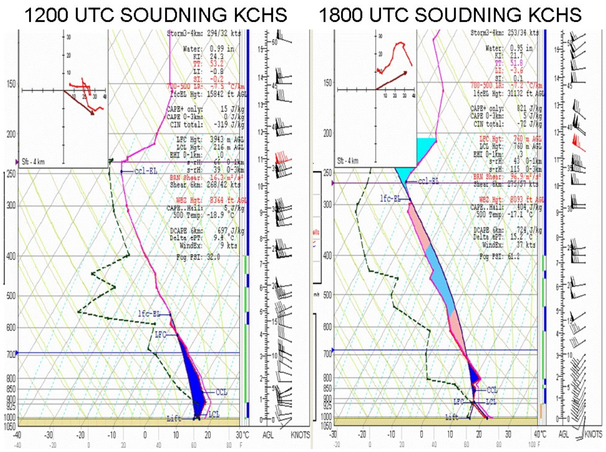

Figure 5. Upper air soundings from 1200 and 1800 UTC March 15, 2008 at KCHS.

By 2100 UTC, a significant line of supercells with a history of producing severe weather, including tornadoes, was approaching the area from the northwest. By then, SPC had further increased the threat to a high risk over the inland portions of the South Carolina counties in the KCHS CWA with a moderate risk throughout the remainder of South Carolina. Stability values continued to support strong convection with mid level lapse rates still in excess of 7°C/km. By 2100 UTC, the location of the sea breeze, which remained pinned along the Georgia coast, moved quickly inland across southeast South Carolina. The quick inland progression of the sea breeze was likely due to a combination of significant pressure falls to the north (Fig. 7), which were in excess of 5 hPa in three hours over northeastern South Carolina, and strong inland heating causing temperature differentials in excess of 5°C between land and marine areas. Surface based CAPE values fell below 600 J/kg over coastal South Carolina behind the sea breeze (Fig. 8).

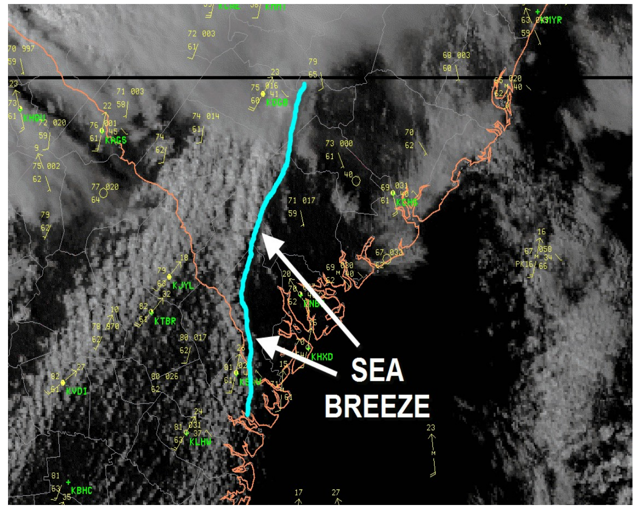

Figure 6. Visible satellite image and observations at 2100 UTC March 15, 2008.

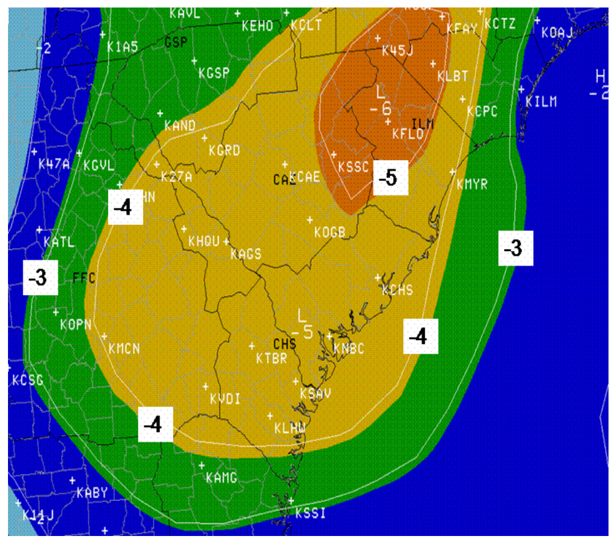

Figure 7. 3-hour surface pressure change valid at 2100 UTC March 15, 2008.

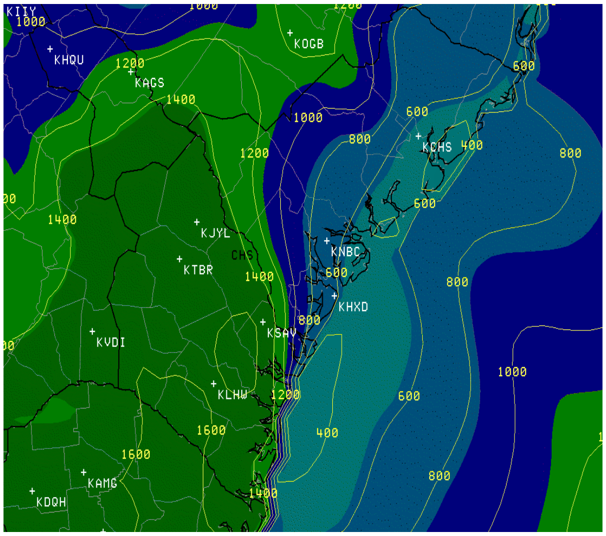

Figure 8. Surface based CAPE (J/kg) at 2100 UTC March 15, 2008.

Very strong winds continued to move toward the area as well, with the 850 hPa jet moving into southern Georgia, while an extension of the 90 knot jet at 500 hPa moved into central Georgia in closer proximity to the low level jet than was seen at 1800 UTC (Fig. 9).

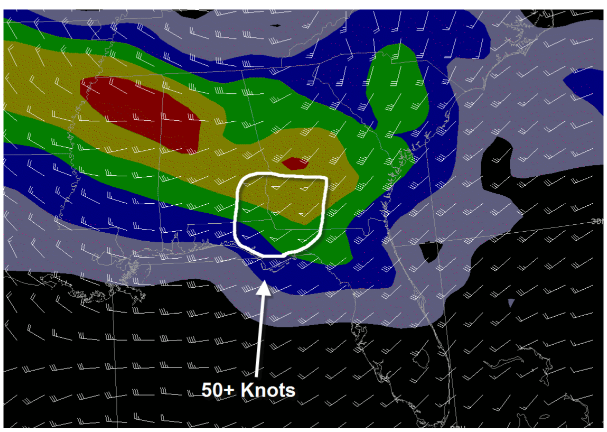

Figure 9. Same as in Figure 4, except for 2100 UTC.

Three hours later, the event was well underway and damage had already been reported in the CWA. A line of supercells was located across the northern tier of the area (Fig. 10).

The 0000 UTC March 16 sounding, when corrected to use virtual temperature, indicated a continued increase in the threat for tornadoes. The LFC was below 500 meters, which has been found to indicate an increasing risk for existing supercells to become tornadic (Davies, 2002). The Lifting Condensation Level (LCL) remained favorable for tornadoes throughout the day with heights between 600 to 800 meters. An LCL below 800 meters also suggested tornadic thunderstorms were more likely to occur (Rasmussen and Blanchard, 1998).

An increasing amount of speed and directional shear existed over Charleston by 00z as a low level jet and an upper level jet entered southeast South Carolina. Wind data from the 00z observed sounding was missing, but the 00z VAD wind profile (VWP) from the WSR-88D KCLX indicated 60 knot winds at 850 hPa and 86 knot winds at 500 hPa (not shown).

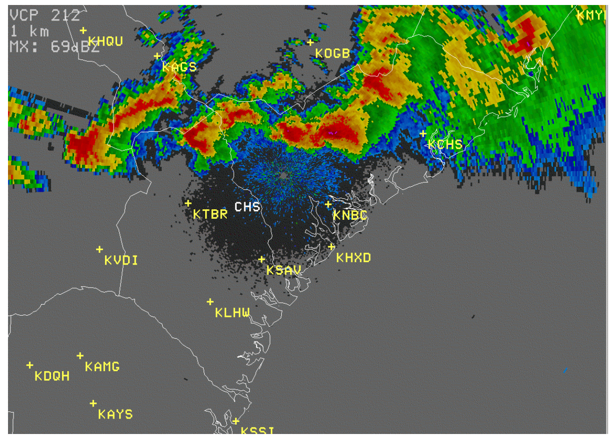

Figure 10. KCLX WSR-88D base reflectivity at 0001 UTC March 16, 2008.

3.2 Operational Model Performance

Several days before the event, the GFS model indicated a pattern that suggested the threat for severe weather on March 15th. In fact, on March 11, the forecasters at KCHS noted the model's suggestion of the potential for severe weather in their AFD. However, the details were still under some question. Specifically, the amount of instability and the location of the best shear and surface convergence remained in doubt. As the day of the event approached, it became clear the area was under a threat for some severe weather and possibly tornadoes, but the operational models still struggled with the details. For instance, the GFS and NAM showed different locations of the primary surface low, and the models' (or model) representation of convection differed significantly (not shown).

For the 1200 UTC March 15 model cycle, the cycle on which many decisions would have to be made by the NWS forecasters, both the GFS and NAM initialized the mid and upper wind fields well across the southeast when compared to the upper air data available from the rawinsonde network. There were some differences at lower levels, however. For instance, the NAM sounding at initialization over KCHS showed a saturated layer in the lowest 100 hPa which did not exist in the sounding data (Fig. 11). This oversaturation may have led to the NAM holding on to the low clouds over KCHS too long during the day.

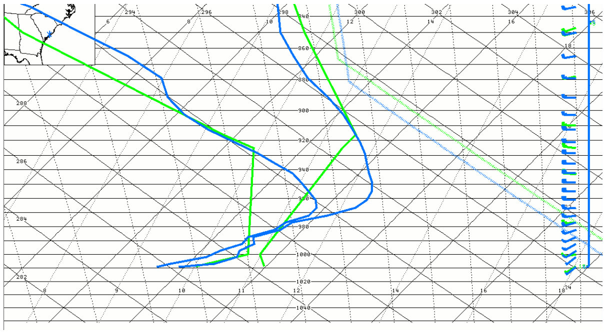

Figure 11. Comparison of NAM model initialized sounding (blue) and actual sounding (green) on 1200 UTC March 15, 2008.

Unfortunately, the 1200 UTC model solutions started to diverge from the real-time analyses rather quickly. By 1800 UTC, a meso-low had formed along the warm front to the north, which neither the NAM nor the GFS handled (Fig. 12).

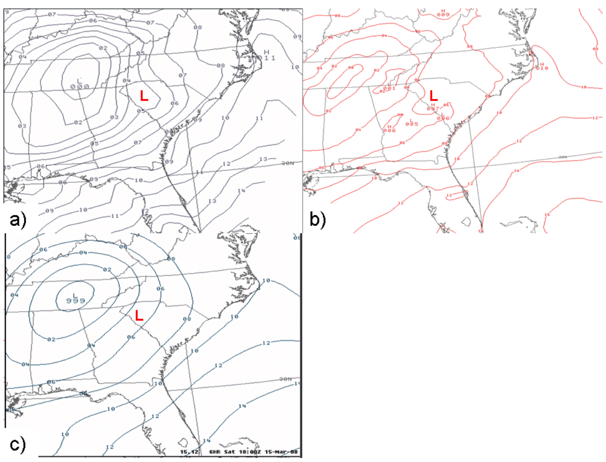

Figure 12. Comparison of MSLP from a) MSAS analysis, b) NAM 6-hr forecast, and c) GFS 6-hr forecast all valid at 1800 UTC, March 15, 2008. The meso-low is marked by the red L.

Model differences continued through the afternoon and into the evening to the point where the 12 hour forecast from the 1200 UTC cycle NAM solution was significantly different from what verified. The NAM depicted the lowest surface pressures much further north over North Carolina with a front extending southwestward through the upstate of South Carolina into northern Georgia. The analysis shows that the lowest pressures were actually associated with the supercell complex in the South Carolina midlands.

A comparison of radar base reflectivity and model simulated reflectivity at 0000 UTC March 16 shows the potential benefit of using a mesoscale model with fine grid spacing (4km) and explicit convection over the more course NAM model. Figure 13b depicts the 12km NAM model run by the National Centers for Environmental Prediction (NCEP) (which is readily available to NWS forecast offices through their AWIPS workstations) initialized at 1200 UTC March 15. Figure 13c represents the 4km NSSL WRF-ARW run (http://www.nssl.noaa.gov/wrf/) of simulated reflectivity initialized at 0000 UTC March 15. Despite the fact that the NAM was initialized 12 hours later, its 12-hour forecast of simulated reflectivity is displaced well north and west of the actual complex and shows just some isolated convection associated with the sea breeze boundary. On the other hand, the WRF NSSL 24-hour forecast of simulated reflectivity is a much improved forecast of intensity and location of the convection over southern South Carolina.

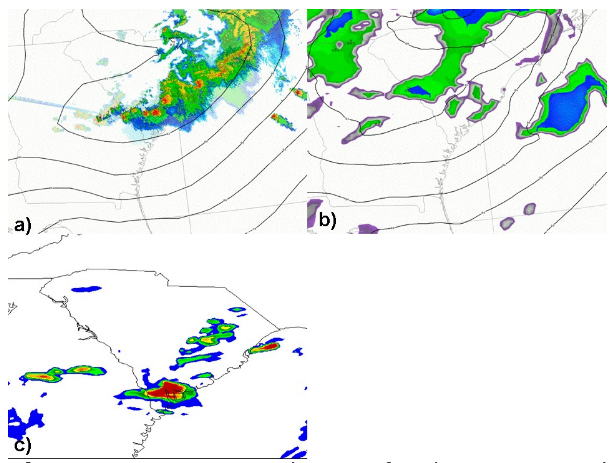

Figure 13. Comparison of a) MSLP and reflectivity from MSAS, b) MSLP and simulated reflectivity from NAM 12-hr forecast, and c) simulated reflectivity from NSSL WRF, valid at 0000 UTC, March 16, 2008.

3.3 Radar Interrogation

With a large, broken line of supercells moving into the area and environmental support for the continuation of supercell organization, an important task for the radar operator becomes the attempt to distinguish between tornadic and non-tornadic supercells. Many papers have been written over the years on this topic, but we decided to investigate a subset of the supercells which occurred that afternoon and evening. Four supercells were chosen to represent the range of severe weather experienced, one associated with an EF2 tornado, one associated with an EF1 tornado, one associated with very large and damaging hail (up to 2 ¾ inches in diameter) , and one associated with marginally severe hail (1 inch diameter).

What is clear in looking at the radar signatures is that most if not all of the convective cells that evening were consistent with the definition tornado producing supercells (Lemon and Doswell, 1979). They contained both rear and forward flank downdrafts, low level inflow notches, persistent mesocyclones, and elevated reflectivity cores downstream from the inflow notch (Fig. 14).

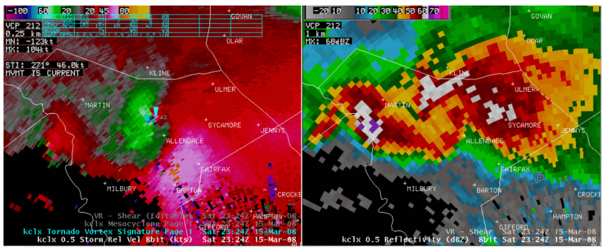

Figure 14. Storm relative velocity (SRM) and base reflectivity from KCLX at 2324 UTC March 15, 2008.

Despite the many similarities, there were some differences in the supercells that were tornadic. The average lowest level gate-to-gate velocity for the 6 tornadic supercells was 31 knots compared to just 25 knots for the non-tornadic supercells. When only the supercells that produced the EF-2 tornadoes were considered, the average gate-to-gate velocity increased to 38 knots. Additionally, the supercells that produced the stronger tornadoes had better radar signatures with stronger reflectivity gradients than those that produced the weaker tornadoes. However, this may be at least somewhat a result of radar sampling issues.

Despite the values noted above, there were at least a couple of supercells which looked very similar in both reflectivity and velocity representations, but one produced an EF2 tornado while the other produced only large hail with no tornado.

The authors conclude that one reason for the different severe weather mode was the low level boundary conditions. The storms that moved into the inland tier of counties in South Carolina encountered the sea breeze, which had moved inland earlier in the day. This likely added some low level convergence and helped to support tornadic development. However, as the supercells move closer to the Atlantic, the shallow stable layer behind the sea breeze worked against the development of tornadoes and instead allowed large hail to be the main severe weather threat.

Another likely factor was the dynamics of the environment. The supercells further inland were closer to the strongest wind shear, which was north of the CWA. The shear environment became slightly less conducive further south, closer to the coast.

3.4 Customer Service

The severe weather outbreak on 15 March was anticipated by both the SPC and KCHS forecast staff. Discussions, statements, and outlooks issued from the offices discussed the potential for severe weather as much as 4 days in advance. Further, local briefings were provided to key stakeholders early in the day prior to the start of the severe weather episode.

Once the event began and the first warnings were issued, a couple of challenges were faced. First, forecasters had to develop an effective method for issuing warnings compatible with the relatively new storm-based warning strategy. The storm-based warning initiative was developed to help reduce the percentage of a county that would be falsely alarmed to impending severe weather, providing residents with both social and economic benefits (Jacks and Ferree, 2007) The prior county based warning strategy would warn the entire county of the severe weather threat, while the new storm-based strategy ideally reduces the number of people warned by drawing polygons only for areas that are directly in the path of a severe storm. The KCHS NWS operational forecast staff had been trained using the WES on how to best issue weather warnings in the new storm-based warning era, but most forecasters had little experience with “real-time” issuances prior to March 15th, and certainly not on the scale of the event on that day (Fig. 15). Forecasters do not want to send the wrong message to those under the warnings by cancelling a portion of a tornado warning where severe weather upstream was still a threat. For instance, how should a forecaster handle a situation where severe weather upstream may move into an area already under a warning for threats from a different cell? (see the dotted area with a question mark in Fig. 16). The warning forecasters during the event decided that it would not be prudent to cut back on the polygon threat area of the first supercell to avoid residents having the false impression that the threat might be over. However, the downside to this decision is that the polygon itself no longer represents the cell which is the real threat at that time.

A second challenge was the shear number of warnings issued in a relatively short period of time. During the event, forecasters at KCHS issued 18 tornado warnings and 15 severe thunderstorm warnings. Additionally, many of the supercells traveled close to or nearly over the same path through the KCHS forecast area (Fig. 15). This made appropriate wording in the warnings and statements even more important than usual to try and spell out the exact threat type and area when counties were under multiple severe weather warnings at the same time.

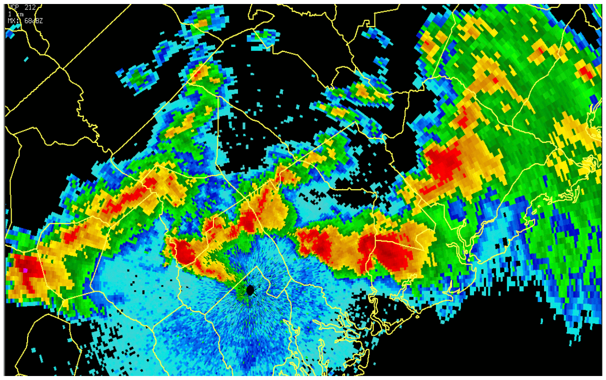

Figure 15. Base reflectivity from KCLX at 0024 UTC March 16, 2008.

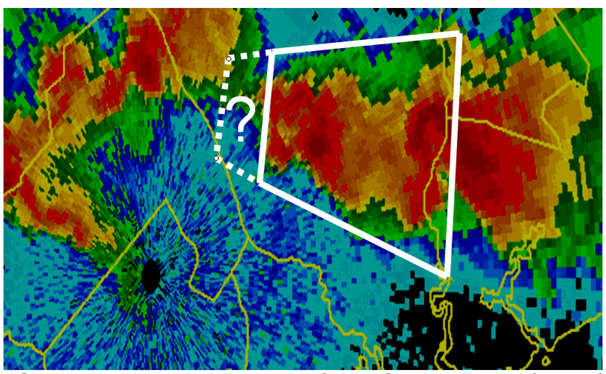

Figure 16. An example of a storm-based warning decision for a warning forecaster.

4. SUMMARY AND CONCLUSIONS

The tornado outbreak of March 15, 2008 was highly unusual event in southern South Carolina and northern coastal Georgia. Very strong winds in the low to mid levels, likely accelerated somewhat by the development of a meso-low on a warm front north of the area, produced a significantly sheared environment. The stronger low level winds transported higher than normal low level dew points into the area, helping maintain some low level instability. Meanwhile, lapse rates in excess of 7°C/km provided strong mid level instability. The result was the development of a large number of well-defined, long-lived supercells, many of which became tornadic.

The details of the event proved to be challenging to forecast in advance. Even on the morning of the event, the readily available computer models in the NWS KCHS AWIPS system did not offer much additional insight into the details of the upcoming severe weather event other than showing the atmosphere was going to be conducive for severe weather later in the day. In fact, the 12-hr. NAM forecast valid at 2100 UTC showed some very important differences in surface pressure fields, low level wind fields, and associated convection from the verifying analyses. Strictly following the guidance would have led the forecaster to believe most of the convection was to stay north of the area.

Despite the classic structure of most of the supercells, another challenge was determining which cells were going to produce tornadoes vs. those that only produced large hail and straight line winds. While there were some higher values found in the lowest level shear and rotational velocity signatures, even the non-tornadic supercells exhibited many characteristics of tornado producing storms. The two factors which likely allowed storms further north to become tornadic whereas others did not were the closer proximity to the strongest shear and the location of the sea breeze.

Finally, issues with the storm-based warning initiative in the case of training supercells were discussed. It was determined that leaving up warnings for areas that had seen the threat of a specific cell pass by was prudent due to the potential threats coming from upstream. While that approach does leave up a warning for a little longer than desired for an area, it is better than the residents of that area incorrectly perceiving that the threat for any severe weather had passed.

Acknowledgements

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