12.2 A MESOSCALE AND STORM-SCALE ANALYSIS OF THE RAPID MINI-SUPERCELL FORMATION AND TORNADOGENESIS ASSOCIATED WITH A REMNANT TROPICAL SYSTEM

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1. Introduction

During the early morning hours of 13 August 2004 the remnants of Tropical Storm Bonnie crossed the WFO Wilmington, NC CWA (Fig.1). A line of thunderstorms accompanied the tropical system as it moved north-northeast along the coast. Several of the thunderstorms prior to 0745 UTC developed short-lived but well defined rotation signatures on the Wilmington WSR-88D (KLTX) but no instances of severe weather were noted. One such rotation signature however quickly intensified around 0800 UTC and produced an F2 (Fujita 1971) tornado near Rocky Point, in Pender County North Carolina. The tornado resulted in three fatalities, numerous injuries, and the destruction of 17 homes and two businesses along an 8 km long, 90-300 m wide damage path.

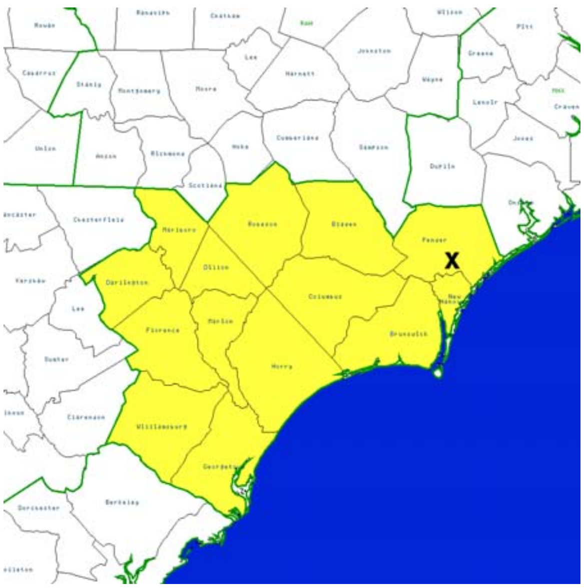

Fig.1. County Warning Area (CWA) of NWS ILM. X denotes location of Rocky Point.

A mesoscale coastal boundary likely played a key role in the formation of the Rocky Point tornado. While several of the stronger thunderstorms associated with this event were located along or near this boundary, the Rocky Point storm remained the only one to produce any severe weather. Mesocylones and tornadoes associated with tropical systems have been found to vary considerably in spatial and temporal scale (Sharp et al. 1997).

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The role of surface boundaries in tornadogenesis has also been well documented and verified empirically in both Great Plains supercells (Markowski et al. 1998b), and also within a remnant tropical cyclone environment (Hudgins and Frederick 1997). This paper will examine the meteorological factors, particularly those on the mesoscale and storm scale, that lead to the rapid intensification and tornadogenesis of the Rocky Point storm in the environment that otherwise produced no severe weather.

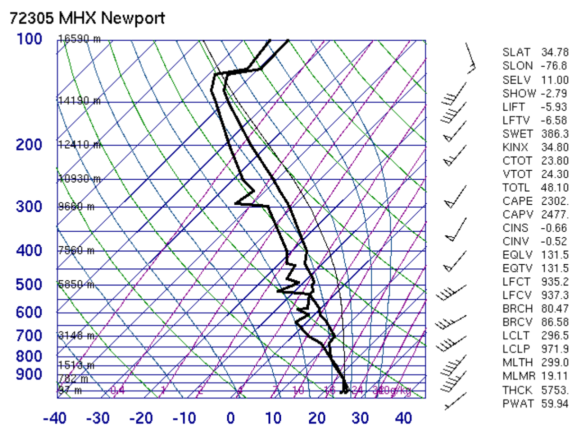

Fig. 2. MHX Upper Air sounding from 1200 UTC 13 August 2004.

2. Synoptic/Upper Air Overview

At 0600 UTC on 13 August 2004 the 500 hPa flow across North America was amplified with a well defined ridge axis across the Pacific Northwest, a trough extending from the Great Lakes to the north-central Gulf of Mexico, and a ridge axis in the Western Atlantic east of New England. A shortwave crossing northern Mississippi was contributing to a mid level speed max of 40-43 m s^{-1} (80-85 knots) east of the Appalachians. Upper air data from 0000 UTC on 13 August 2004 (not shown) indicated a low-level jet of 15-20 m s^{-1} (30-40 knots) from Jacksonville, Florida to the North Carolina Outer Banks. A surface cold front was stalled along the eastern slopes of the Appalachians. Ahead of this boundary, the residing air mass across the Southeast United States was warm and humid with both temperatures and dewpoints ranging from 21° C to 24° C (70° F to 75° F). The remnants of Tropical Storm Bonnie became embedded in this flow after an initial landfall near

Vincent Island, Florida on 12 August 2004, and traveled northeast along the coast as a tropical depression from Savannah, Georgia to the North Carolina/Virginia border.

Synoptic and mesoscale analyses indicated that sufficient instability was present such that the increase in low level wind shear associated with the remnants of Tropical Storm Bonnie could support isolated tornadoes. The 1200 UTC upper air sounding on 13 August 2004 from Newport, NC (MHX) indicated a Convective Available Potential Energy (CAPE) value of 2300 J kg^{-1} (Fig. 2) while wind shear values in the lowest 6 km favored organized convection/supercells. These instability values greatly exceed those considered average for TC tornado environments by McCaul (1991).

3. Mesoscale Analysis

Manually derived streamline analysis at 0600 UTC (Fig. 3) indicated a narrow surface boundary of both a wind shift and a 4°C dewpoint gradient was positioned nearly parallel to the coast a few hours preceding the Rocky Point tornado. This boundary led to a local maximum in low-level vertical vorticity along the coast, which contributed to a local maximum in storm-relative helicity (SRH). The baroclinically induced horizontal vorticity that resulted from the density gradient was largely streamwise, which has been found to be a common occurrence (Markowski et al. 1998a). Manual analysis showed that the boundary was narrower (e.g., a tighter thermal and moisture gradient) across Pender County than what was indicated by objective analysis programs available to NWS meteorologists and that SRH was being underestimated by the automated analysis.

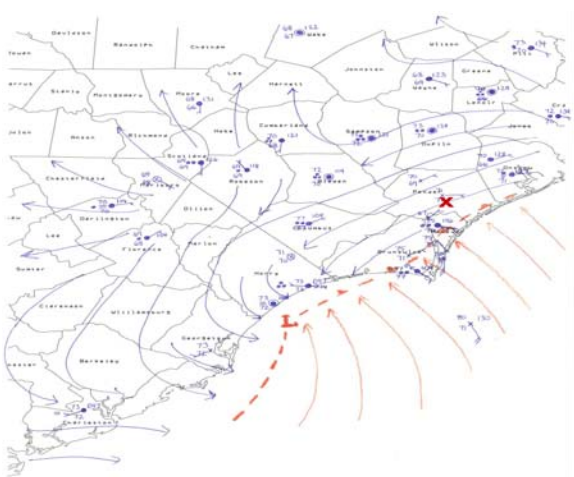

Fig. 3. Manual surface and streamline analysis of ILM CWA at 0600 UTC 13 August 2004. X denotes location of Rocky Point.

Buoyancy was maximized southeast of the surface boundary as low level convergence pooled high surface theta-E values along the coast. The higher theta-E values indicated a lower Lifting Condensation Level (LCL), which has been found to favor tornadogenesis (Rasmussen and Blanchard 1998). A hodograph derived from KLTX WSR-88D Vertical Azimuth Display (VAD) Wind Profile (VWP) showed a substantial increase in 0-3 km SRH values from 225 m^2 s^{-2} to 417 m^2 s^{-2} from 0601 UTC to 0617 UTC (not shown) as the mid-level circulation passed the KLTX WSR-88D radar. The increasing winds and SRH indicated that the environment was rapidly becoming more favorable for organized convection. By 0700 UTC, small but intense circulation signatures were noted on velocity data with no occurrences of severe weather. One notable storm at 0714 UTC (Fig. 4) showed a strong, descending rotation signature

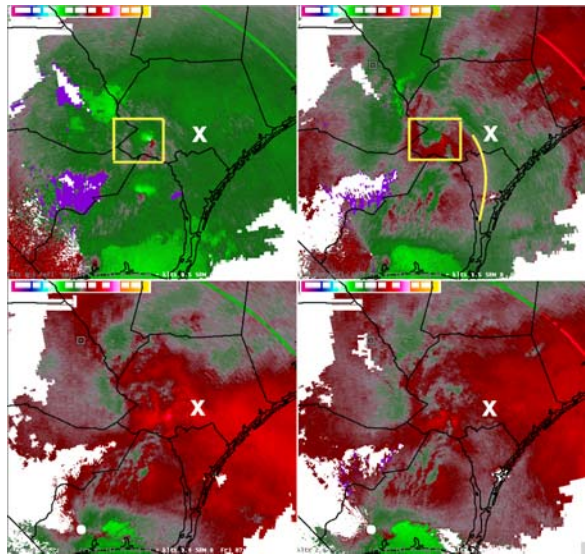

Fig. 4. KLTX Storm Relative Velocity 4 panel display of 0.5º (top left), 1.5º (top right), 2.4º (bottom right), and 3.4º (bottom left) at 0714 UTC 13 August 2004. X denotes Rocky Point. Square denotes mesocyclone location. Yellow line denotes developing rear flank downdraft (RFD). Radar is to the southwest.

with a VR shear value approaching 0.025 s^{-1}, which far exceeds the value found by Spratt et al. (1997) to be indicative of likely tornadogenesis in tropical cyclone outer rainbands. Apparently additional processes were required to produce severe weather, particularly for adequate vortex stretching leading to tornadogenesis.

4. Storm Scale Features/Radar Analysis

Shortly after 0700 UTC some storm scale features taking place within the squall line led to the strengthening of the updraft that would eventually bear the Rocky Point tornado. At 0709 UTC, SRM indicated a rotation signature within an updraft that was located 26 km (16 miles) west of Rocky Point, NC. At this time the rotation within this storm was strongest at elevations of approximately 2400-3000 m

(8000-10000 ft) above ground level (AGL). On the subsequent volume scan the rotation had translated down to the 0.5º elevation, which at the given range was approximately 700 m (2200 ft) AGL at 0714 UTC (Fig. 4). Similar descending behavior in Tornado Vortex Signatures (TVS) was not found to be a definitive precursor to tornadogenesis in Trapp et al. (1999). Although no severe weather occurred with this storm, its structure and strength allowed a rear flank downdraft (RFD)-induced outflow boundary to form and remain in place to the southwest in the wake of the updraft as indicated KLTX velocity data.

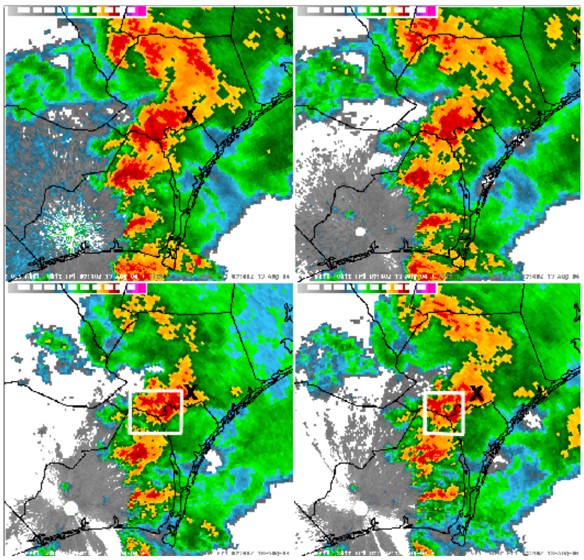

Fig. 5. KLTX Reflectivity 4 panel display of 0.5º (top left), 1.5º (top right), 2.4º (bottom right), and 3.4º (bottom left) at 0729 UTC 13 August 2004. X denotes Rocky Point. White square denotes location of bounded weak echo region (BWER).

The presence of this outflow boundary strengthened the horizontal vorticity associated with the preexisting mesoscale coastal boundary by generating a locally enhanced wind shift line along the outflow and by increasing the buoyancy gradient due to the rain-cooled air within. This newly strengthened boundary then became a localized maximum in horizontal vorticity and SRH. Markowski et al. (1998a) indicated that storm-scale variations in SRH occur on temporal and spatial scales that cannot be resolved by current observational networks. The updraft that would spawn the Rocky Point tornado traversed this boundary soon thereafter and began to interact with the higher SRH values by 0724 UTC.

The storm that would produce the Rocky Point tornado quickly intensified almost immediately after moving into this region of enhanced SRH as evident by the development of a bounded weak echo region (BWER) in reflectivity data at 0729 UTC at the 2.4º elevation (Fig 5), which corresponded to a sampling elevation of approximately 2040 m (6700 ft) AGL. Minutes later, at 0740 UTC the BWER had deepened and the storm took on a supercellular reflectivity appearance (not shown). In the next volume scan the final storm-scale feature leading to tornadogenesis just south of Rocky Point took shape (Fig. 6). At 0745 UTC reflectivity and velocity products showed a developing RFD south of the updraft. An inflow notch was also becoming apparent at the base of the updraft on the northern end of the RFD. The updraft/inflow notch was now located at the vertex between the RFD and the RFD of the front-running storm discussed previously (Fig. 4). Note the similarity between this positioning of features and those in the conceptual model for a supercell updraft in relation to the RFD and the forward flank downdraft (FFD). Such juxtaposition has been shown to lead to inflow acceleration and increased tilting of horizontal vorticity into the vertical and also vortex stretching (Markowski, 2002). The presence of the BWER, accelerating inflow, and mesoscale boundary suggested that tornadogenesis could be imminent.

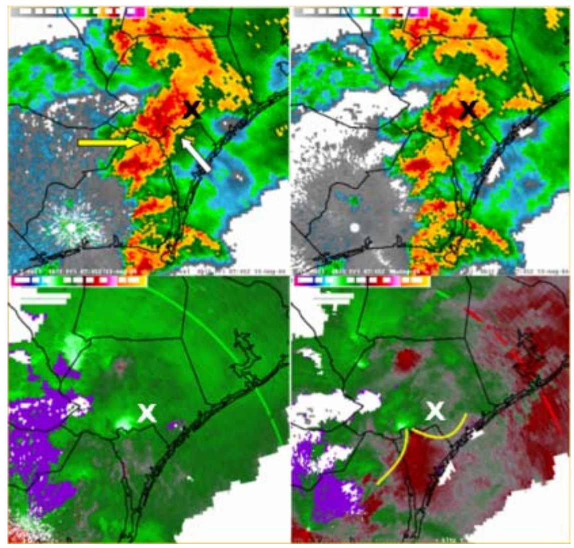

Fig. 6. KLTX Reflectivity (top) and SRM (bottom) display of 0.5º (left) and 1.5º (right) at 0745 UTC. Yellow lines denote outflow structure. Arrows indicate outflow (yellow) and inflow (white) reflectivity notches. X denotes Rocky Point.

Tornadogenesis did in fact ensue very rapidly. Storm surveys by ILM personnel indicated a touchdown at approximately 0755 UTC. A vertical cross section of the rotational shear values from KLTX (Fig. 7) indicates almost immediate strengthening to values approaching 0.10s^{-1} through a depth of over 3000 m (10000 ft) by the 0756 UTC volume scan, which was coincident with tornadogenesis. VR shear values of 0.10s^{-1} "should be considered prime candidates for tornadogenesis" within tropical cyclone outer rainbands according to Spratt et al. (1997). This event, although only a single case, supports a similar shear value criterion for tornadogenesis within a remnant tropical system.

The 0801 UTC volume scan displayed the most rapid and dramatic intensification of the Rocky Point storm. At this time the VR shear time height (Fig. 7) shows intense strengthening of the mesocyclone and also a rapid increase in depth. The strong inbound velocity values in SRM that had been evident since 0750 UTC in association with the storm updraft (not shown) became coupled with a very strong outbound signature at the base of the updraft and along the vertex between the FFD and RFD. This volume scan (0801 UTC) was the first TVS detected by KLTX (Fig. 8). Since the tornado was already on the ground this case was consistent with Trapp et al. (1999) findings that most (86%) of the time a TVS will not descend in a quasilinear convective line and be of little use in warning decision-making. It is at this time that the NWS ILM storm survey team found that the tornado had strengthened to F2 on the Fujita scale. This is also the time that the three fatalities occurred as the tornado completely destroyed several homes.

Another TVS was indicated in the next volume scan at 0806 UTC. The time-height cross section of VR shear values (Fig. 7) shows that although the shear remained very strong in the lowest 2100 m (7000 ft) the shear had weakened dramatically above this level. SRM data at the same

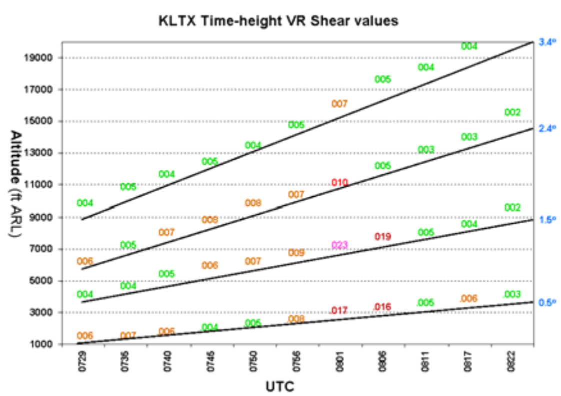

Fig. 7. Time-height KLTX VR shear values 0729-0822 UTC 13 August.

time frame (not shown) depicts this as well, while the reflectivity data indicates the RFD is about to cut off the updraft base. By the next volume scan (not shown) the VR shear had weakened to 0.05 s^{-1} or less throughout the depth of the storm. Also at 0811 UTC reflectivity and velocity data showed that the RFD had indeed undercut the updraft. The tornado and parent mesocyclone formed nearly simultaneously through their entire depth, much as the nondescending TVS's of Trapp et al. (1999). The rapid weakening even before the RFD occlusion suggests that the whole circulation would have likely dissipated just as it formed; simultaneously through its entire depth. By 0811 UTC (not shown) the storm had lost nearly all of its structure on both reflectivity and SRM. The total time elapsed from the beginning of the mini supercell updraft rotation (with a depth of 3000 m or more) to tornadogenesis and then RFD occlusion and dissipation of the mesocyclone was a mere 25 minutes.

5. Conclusion

NWS meteorologists are charged with protecting the public from hazardous weather via the timely and accurate issuance of watches, warnings, and advisories. Since WSR-88D is so heavily used in the warning decision making process, the Rocky Point tornado illustrates one of its well-known shortcomings - KLTX did not indicate a TVS until the tornado was already on the ground. The rapid intensification into a tornadic storm indicates that a warning forecaster would often benefit from a faster volume coverage pattern (e.g., more rapid updates). With the field deployment of Volume Coverage Pattern (VCP) 12 during the ORPG Build 5.0 upgrade of the WSR-88D in 2004, the total volume scan time has been reduced to about 4 minutes. Even faster VCPs would prove helpful for forecaster and algorithm identification of rapidly intensifying updrafts, and also help provide more warning lead time for non-descending tornadoes.

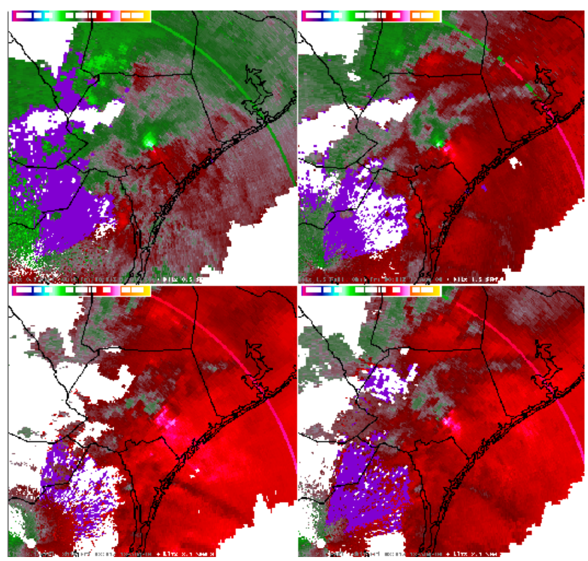

Fig. 8. Same as Fig. 4 except at 0801 UTC. Upper two panels indicate strong rotational couplet over Rocky Point.

Faster VCPs may be obtained either via faster dish rotation rates, fewer elevation slices of sampling, or a combination of both. The elimination of elevation slices would likely prove detrimental to volume products such as vertically integrated liquid (VIL) and composite reflectivity, which are both heavily utilized by most forecasters. Faster dish rotation rates sacrifice some data quality due to reduced sampling. This could end up compromising certain baseline data quality requirements as mandated by the guidelines found in the Nexrad System Specifications (ROC, 2006). With only a very slight relaxation of System Specifications the NWS Radar Operation Center (ROC) would be able to develop a VCP with a volume coverage time of approximately 2.5 minutes with only minimal impact to operational concerns (R. Steadham, personal communication, June 22, 2006). This is likely the most feasible way to come up with a VCP with a rapid enough volume coverage capable of detecting nondescending tornadoes typical of those within a tropical system. Such detection capability would prove to be a very useful tool for NWS forecasters and greatly improve their ability to issue timely warnings in such a situation.

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