P10.3 POSSIBLE TORNADOGENESIS MECHANISM DURING THE 15 NOVEMBER 2001 SOUTH TEXAS COASTAL BEND EVENT

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1. INTRODUCTION

On 15 November 2001, three separate F1 tornadoes developed, one over each of the South Texas counties of Live Oak, Goliad,and Bee. This tornado event was climatologically significant. From 1 January 1986 to 30 April 2002, only two, one , and six tornadoes, with F1 or greater intensity, were recorded in Live Oak, Goliad and Bee counties respectively. Available radar data indicates that the 15 November 2001 tornadoes developed very rapidly. Rapidly developing tornadoes present a challenge to National Weather Service (NWS) forecasters with respect to tornado warning lead time. However, despite the difficulty involved, there were clues well in advance of these three tornadoes. In other words, additional lead time could be achieved by anticipating tornadogenesis.

Anticipating tornadogenesis requires knowledge of at least some of the various tornadogenesis theories/mechanisms. Tornadoes associated with supercells have been theorized to develop initially aloft within the mid-level mesocyclone then descend to the surface (e.g. Leslie 1971; Trapp and Davies-Jones 1997). In addition, supercell tornadoes can develop within the sub-cloud layer as near-surface horizontal streamwise vorticity (associated with the rear flank downdraft) is tilted and stretched (e.g. Klemp 1987). Apparently, nonsupercell tornadoes can originate in the sub-cloud layer in response to horizontal shear, then stretch upward/intensify via storm updraft (e.g. Wakimoto and Wilson 1989, hereafter WW89). Tornadoes not associated with supercells can also develop when near-surface horizontal streamwise vorticity (not necessarily assoicated with a downdraft) is titled and stretched (Wilczak et al. 1992). Further, Lee and Wilhelmson (1996, hereafter LW96), and Roberts and Wilson (1995, hereafter RW95), have demonstrated that low-level convergence associated with outflow boundaries can contribute to the timing/intensity of non supercell tornadoes.

This study is an attempt to determine the tornadogenesis mechanism(s) responsible for the Bee and Live Oak F1 tornadoes,based on available data from a single Weather Surveillance Radar 1988-Doppler (WSR-88D) radar (Crum & Alberty 1993), co-located with the NWS Weather Forecast Office (WFO) in Corpus Christi, Texas (CRP). (the radar, identified here after as KCRP). The data was analyzed using the National Severe Storms Laboratory (NSSL) WSR-88D Algorithm Testing and Display System or WATADS (NSSL 1997), applied to base data. Detailed analysis of the developing tornadic circulation over Goliad County could not be ascertained owing to the distance away from the radar (the position of the Goliad F1 tornado was over 95-km from KCRP).

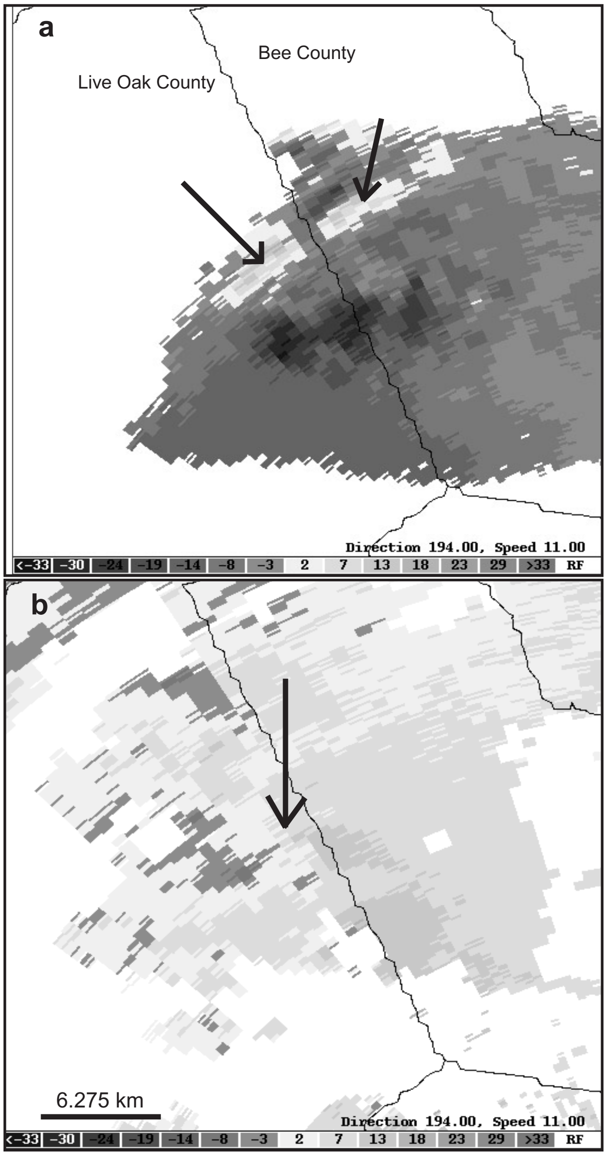

Figure 1. Storm relative radial velocities ($m\ s^{-1}$;in customized grey scale) associated with the Bee County storm, for the **(a)** 8.7 degree (2126 UTC) and **(b)** 0.5 degree (2122 UTC) elevation angles (~12.7 km and ~1.1 km AGL respectively) from KCRP. The arrow in the 0.5 degree image points to the approximate center of the shear region (from where the tornado eventually developed). The arrows at 8.7 degrees point to the outbound velocities associated with the upper divergent signature.

2. SYNOPTIC-MESOSCALE PATTERN AND NEAR STORM ENVIRONMENT

The 18 UTC 15 November 2001 National Centers for Environmental Prediction (NCEP) Eta model revealed an upper level disturbance over

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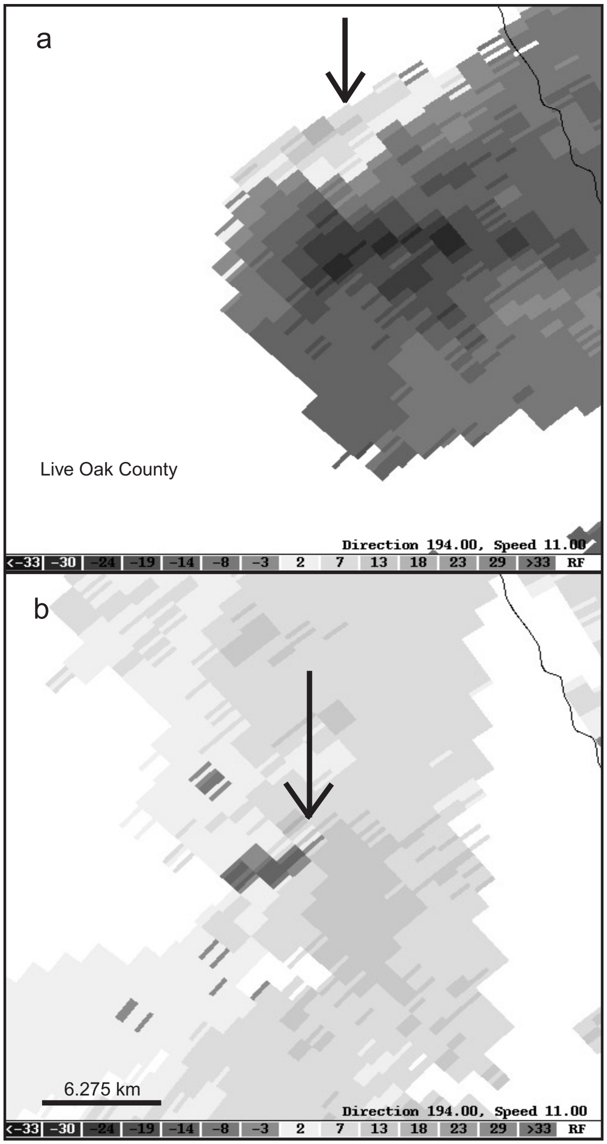

Figure 2. Storm-relative radial velocities (m s^{-1} ; in customized grey scale) associated with the Live Oak County storm, for the **(a)** 8.7 degree (2031 UTC) and **(b)** 0.5 degree (2027 UTC) elevation angles (~12.8 km and ~1.0 km AGL respectively) from KCRP. The arrow in the 0.5 degree image points to the approximate center of the shear region (from where the tornado eventually developed). The arrow at 8.7 degrees point to the outbound velocities associated with the upper divergent signature.

the Southwestern United States. At the surface, a low pressure center/trough existed over the Rio Grande region of Southern Texas. In response, surface southeast wind occurred over the South Texas Coastal Bend region. The environment over South Texas was moist - owing to advection of moisture from the Gulf of Mexico - with precipitable water values at CRP around 39.4 mm. The near storm environment was also statically unstable as the CRP sounding revealed a Convective Available Potential Energy or CAPE (taking virtual temperature into account) of 2713 (3621) J/kg and a Convective Inhibition (CIN) of 0 (0) at 1200 UTC 15 November 2001 (0000 UTC 16 November 2001). The nill CIN of course suggesting that little forcing was needed to trigger convection. The combination of near surface southeast winds and southwest winds aloft in advance of the foregoing upper disturbance, resulted in significant vertical wind shear over the area. The Bulk Richardson Number (BRN) was 121 (66), thus suggestive of an environment, during the 12 hours ending at 0000 UTC 16 November 2001, whereby convection would transition from multicellular to a combination of multi-cells and cells possessing some supercell characteristics (e.g. Weisman and Klemp 1984, hereafter WK84).

3. CONVECTIVE INITIATION AND STORM STRUCTURE

Preliminary analysis indicates that convection over the Coastal Bend was triggered in response to convergence owing to differential surface ambient wind vectors. The Live Oak and Bee storms developed some characteristics consistent with supercells. The 0-6 km ambient wind shear vector at 00 UTC 16 November 2001 (from the CRP radiosonde data) was pointed approximately toward the east. The shear vector also veered with height below 3-km. For supercells that develop within this kinematic structure, maximum upward vertical velocities would develop to the right of the 0-6 km shear vector (Rotunno & Klemp 1982). In both the Live Oak and Bee County tornadic storms, Weak Echo Regions or WERs (below storm top radial velocity divergence) developed on and to the right of the 0-6 km shear vector. However, during the ~30 minutes prior to the tornado for each storm, the storms traveled toward the northeast, consistent with the 0-6 km mean wind vector (based on the 0Z 16 November 2002 CRP sounding data) of 194 degrees and 11 m/s, or *left* of the 0-6 km shear vector.

4. TORNADOGENESIS

For the Bee and Live Oak F1 tornadoes, the vorticity source appeared to be horizontal shear. Storm-relative velocities (based on the 194 degrees/ 11 m/s storm motion) indicated the development of near-surface horizontal shear, which became oriented under strong storm-top divergence. While under strong storm-top divergence (figures 1 and 2), circulations developed within the shear regions, then increased in magnitude. This would suggest stretching - via updraft - of pre-existing vertical vorticity, contributing to the increasing intensity of the circulation. However, the radar data suggest that the transition to tornadic intensity was due to downdrafts. The following illustrates the foregoing for each case.

4.1 Bee County Tornado

Figure 1 depicts the storm-relative radial velocites at both the 0.5 degree (2122 UTC) and 8.7 degree (2126 UTC) KCRP elevation angles, associated with the Bee County storm in question. The lower level image depicts a horizontal shear region. The circulation, which eventually increased to tornadic intensity, developed within this shear region. Note that this shear region was located under a region of upper storm divergence. The author suggests that the updraft eventually stretched vorticity within this shear region resulting in a developing/strengthening circulation, consistent with WW89. This near surface horizontal shear/ upper storm divergence pattern was evident ~30 minutes in advance of the first report of the tornado.

Figures 3a and 3b are time-heights of the developing Bee County circulation, depicting the circulation intensity (shear)/reflectivity of the circulation center, and the circulation diameter/reflectivity of the circulation center, respectively (radar data was missing at the 2158 UTC volume scan above the 0.5° elevation angle.) Note that the circulation diameters suggest that the circulation, which became tornadic, was originally a mesocyclone (as opposed to a misocyclone) that extended down to at least 1-km. Radar analysis (not shown) revealed that this was the very mesocyclone associated with the storm's WER/primary updraft. Note that below a height of 1.5 km, the diameter of the circulation decreased to ~1/2 of the original in the five minute period ending around 2142 UTC, which was during a time the reflectivity core was aloft. This suggest that an updraft stretched the circulation, resulting in a smaller diameter, consistent with Brady and Szoke (1989). However, the circulation did not transition to a misocyclone (diameter 4-km or less; see Fujita, 1981) and the circulation intensity did not increase significantly until later, when the reflectivity core was descending. Note that after 2145 UTC, reflectivity values were increasing at each level below 3-km, concomitant with mid-level radial velocity convergence within the storm (not shown), consistent with an approaching downdraft (Roberts & Wilson, 1988). During this time, circulation intensity increased rapidly. From 2152 to 2158 UTC, the shear (diameter) at the 0.5 degree elevation angle (from KCRP), increased (decreased) from 8.3×10^{-3} s^{-1} (4.7 km) to 2.9×10^{-2} s^{-1} (1.6 km). The first report of the tornado, based on *Storm Data* (NOAA 2001) was at 2153 UTC, 16.1 km west of the community of Beeville. The author suggests that the apparent downdraft provided additional stretching to tornadic strength. The additional downdraft-related stretching sufficient to generate a tornado is supported by LW96, RW95, and Collins et. al (2000).

4.2 Live Oak County Tornado

Again as with the Bee County tornado, a similar mechanism is supported by the radar data. However in this case, the developing tornado and the mesocyclone were two separate circulations (not coincident) at all times. Figure 2 depicts PPIs for the 0.5 degree (2027 UTC) and 8.7 degree (2031 UTC) elevation angles, for the Live Oak County storm. Again, as in the Bee County case, near surface horizontal shear was coincident with upper storm divergence. As before, the tornadic circulation eventually developed within this shear region.

Figures 4a and 4b are the same as 3a and 3b, except for the Live Oak circulation. Note from figure 4a that initially, the strongest shear was located below 2-km. The circulation then extends vertically through 2020 UTC, when a reflectivity core was aloft. Note that while the reflectivity core remained aloft, the circulation diameter decreased at all levels within a few minutes around 2025 UTC. However, note that the circulation intensity reached a maximum near the time when the circulation was wrapped in higher reflectivities (~2037 UTC). From 2032 to 2037, the shear (diameter) at the 0.5° elevation angle (from KCRP) increased (decreased) from 8.8×10^{-3} s^{-1} (3.0 km) to 3.1×10^{-2} s^{-1} (1.3 km). The tornado was first reported at 2046 UTC, 8.1 km northeast of the community of George West.

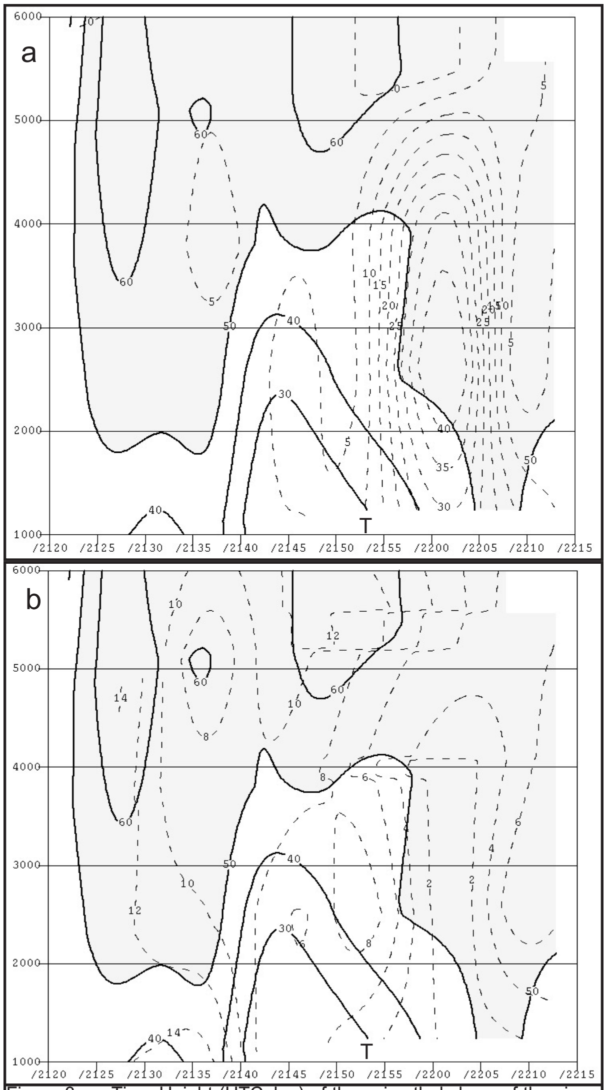

Figure 3. **a.** Time-Height (UTC, km) of the azimuthal shear of the circulaion (x 10^{-3} s^{-1} ; shear isolines dashed;) and reflectivity (solid isolines; dBZ; greater than 50 dBZ shaded) at the center of the circulation for the Bee County vortex. **b.** Same as a, except circulation diameter (km) instead of shear. The "T" represents the time of the tornado report.

5. DISCUSSION

Available data suggest that the Bee and Live Oak County F1 tornadoes in this study developed in response to stretching of pre-existing vertical vorticity, followed by additional stretching from downdraft- related convergence, consistent with previous research. However, it is important to note that there exist another mechanism that may have been responsible for these tornadoes.

One alternative is the tilting and stretching of pre-existing horizontal streamwise vorticity. Recall that the first step in the 'vertical vorticity only' development sequence, circulation is embedded in updraft. The second step involves the influence of the downdraft. It is this second step wherein the gust front-induced horizontal

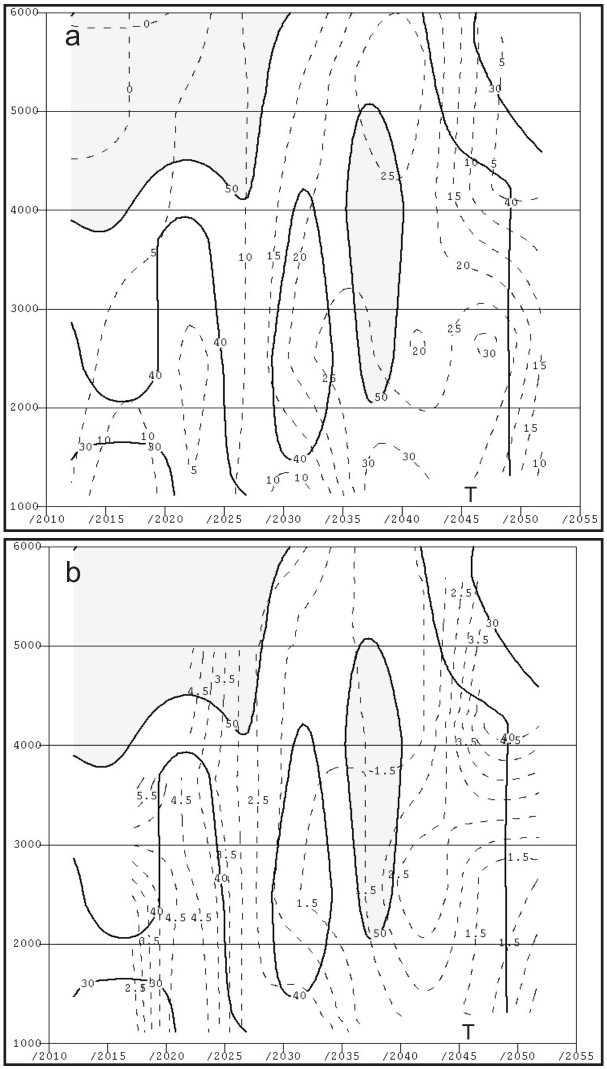

Figure 4. **a.** Time-Height (UTC, km) of the azimuthal shear of the circulaion (x 10^{-3} s^{-1} ; shear isolines dashed) and reflectivity (solid isolines; dBZ; greater than 50 dBZ shaded) at the center of the circulation for the Live Oak County vortex. **b.** Same as a, except circulation diameter (km) instead of shear. The “T” represents the time of the tornado report.

vorticity could have been oriented streamwise, then tilted and stretched while being ingested by storm updraft, consistent with Klemp (1987) and Wilczak et al (1992). However, dual-doppler analysis data (which is not available for this case) would be necessary in order to determine the complete wind field and hence calculate the contribution of the tilting term to the developing circulation.

To the extent that the mechanism suggested by the author generated the Bee/Live Oak tornadoes, this study indicates that tornadoes could have been anticipated well in advance in each case. For each of these tornadoes, the near surface horizontal shear region/upper divergence pattern was noted 20-30 minutes in advance of the first report of the tornado. Although a Probability of Detection (POD) of unity could be achieved for the two events in this study, using the strategy of issuing a tornado warning at the first volume scan involving near surface horizontal shear/upper storm divergence, may result in an undesirable False Alarm Rate (FAR). Thus, one could argue in favor of waiting for a more developed/stronger circulation or a TVS to develop before issuing a tornado warning. However, tornadoes that develop via the mechansim described herein can do so on a time scale within a volume scan (VS) or two of the WSR-88D in precipitation mode (each VS lasting 5-6 minutes), thus resulting in a small to nil lead time. More studies are needed in order to resolve this apparent dilemma.

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APPENDIX

A. The following are the criteria used to identify and calculate the (azimuthal) shear and diameter associated with the developing circulations

1. The *diameter* is defined as the distance between the maximum inbound and outbound velocities. WATADS was used to determine the inbound and outbound positions (azimuth and range). Then, software packages INVERSE and FORWARD (available interactively online from the NOAA/National Geodetic Survey at www.ngs.noaa.gov) were used to compute the distance between the inbound and outbound points.

2. The *shear* associated with the circulation was calculated by dividing the *maximum differential velocity* (the sum of the absolute values of the inbound and outbound velocities) by the diameter.

3. The circulation at each level must have an aspect ratio (radial distance/azimuthal distance) of 2.0 or less (early periods calculated; later periods determined qualitatively) and possess time and height continuity (determined subjectively).

B. Figures 3 and 4 were created using GEMPAK (GEneral Meteorology PAckage) software (www.unidata.ucar.edu/packages/gempak/index.html) programs *snedit* and *sncross*.

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