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Left moving thunderstorms in a high Plains, weakly-sheared environment

by

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1. Introduction.

Severe and/or tornadic thunderstorms have historically been associated with large values of Convective Available Potential Energy (CAPE) and strong low-level shear (Humphreys 1914, 1920; Showalter & Fulks 1943;Fawbush & Miller 1954; Miller 1972). Upper tropospheric disturbances and lower tropospheric boundaries such as cold fronts, drylines, or low-level thunderstorm outflow (LTO) boundaries have also proven to be important (Humphreys 1920; Miller 1972; Purdom 1982; Doswell et al. 1993; Davies et al. 1994; Weaver et al. 1994; Weaver and Purdom 1995; Browning et al. 1997; Markowski et al. 1998). Environments containing all, or most, of these elements have been dubbed 'synoptically evident' by Doswell et al. (1993).

Most studies of severe thunderstorm outbreaks in the meteorological literature have focused on events occurring in synoptically evident environments. This type of outbreak frequently produces long-lived supercell storms that move to the right of the mean cloud layer wind. In such strongly-forced situations, the right-moving storm typically forms after the original storm undergoes a process called storm-splitting (Achtemeier 1969). Storms split when pressure gradients on the flanks of the original updraft enhance lift, and produce two new updrafts; one of which moves off to the right, the other to the left (Rotunno and Klemp 1982, 1985). In the case of a cyclonically-curved hodograph, a region of high pressure often develops above the low pressure area on the left flank, and the left-moving updraft dissipates (e.g., Wilhelmson and Klemp 1981).

Most operational forecasters are aware that severe thunderstorms – those producing large hail, damaging winds and perhaps even strong tornadoes – can develop in environments with substantially less shear than that required to produce 'classic' splitting storms and supercells. This paper looks at a severe weather outbreak that occurred in west Texas, in an environment where the mean wind from 2-10 km AGL was from 265^{o} at 19 kt, and the midday

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Storm Relative Environmental Helicity (SREH) was estimated to be about [100 $(m/s)^2$]. Left- and right-moving pairs were observed to develop with at least two of the strongest thunderstorms that formed as a result, but the left-movers did not weaken and die. Instead, they went on to produce severe weather at least as intense as their right-moving counterparts.

2. Synoptic setup.

Figure 1 shows the 500 mb heights and vorticity at 1200 UTC taken from the ETA initial analysis. Notice the light flow pattern and the embedded shortwave troughs over the southwestern United States. It is important to remember that with the weak flow aloft, vorticity advection would be relatively weak. Figure 2 shows the surface observations for 1500 UTC. The surface features are copied from the NCEP analysis.

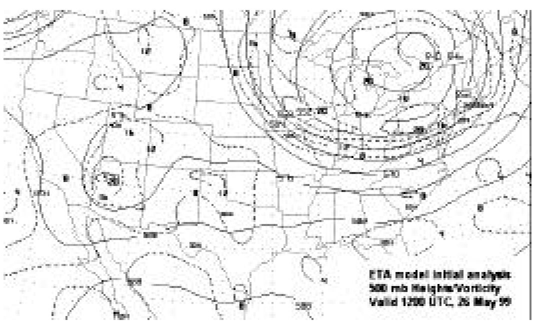

Figure 1. 500 mb heights and vorticity, 1200 UTC on 25 May 1999 from the ETA initial analysis.

Finally, figure 3 is a plot of data from the radiosonde released at Amarillo, Texas at 1800 UTC. Note the light winds from the surface to roughly 400 mb, and especially in the lowest 6 km of the sounding where shear is important for developing mesocyclones. The winds in the lowest kilometer of the sounding are from the northwest, indicating that the surface front had passed Amarillo. However, even south of the front, the winds in the lowest kilometer were less than 10 kts, though from the southeast.

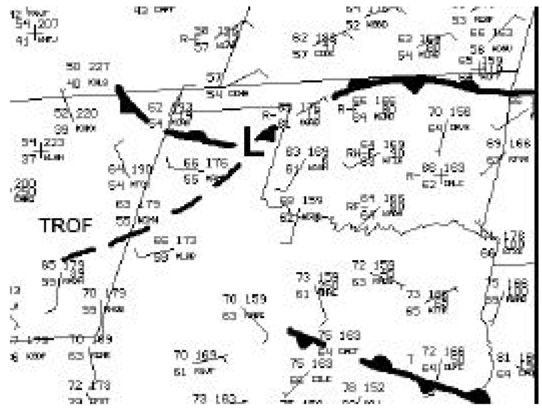

Figure 2. Surface analysis for 1500 UTC on 25 May 1999. Observations in English units, plotting convention is U.S. standard. Surface features from NCEP analysis.

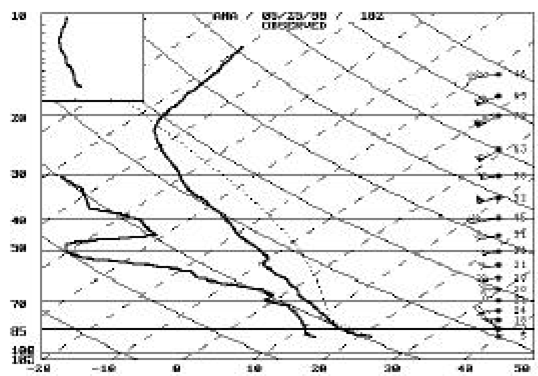

Figure 3. Plot of data from a special radiosonde released at Amarillo, Texas at 1800 UTC on 25 May 1999 on a Skew-T/Log P diagram. Wind speeds are in knots.

2. Sub-synoptic Factors.

The passage of a slow moving shortwave trough across west Texas brought several hours of heavy rain to that region overnight. Figure 4 shows an image that was made by averaging fifteen sequentia l infrared satellite photos together for the period 0600 UTC through 1200 UTC on 25 May 1999. Compare this figure with figure 5, which is a GOES-East, visible wavelength satellite image from 1500 UTC.

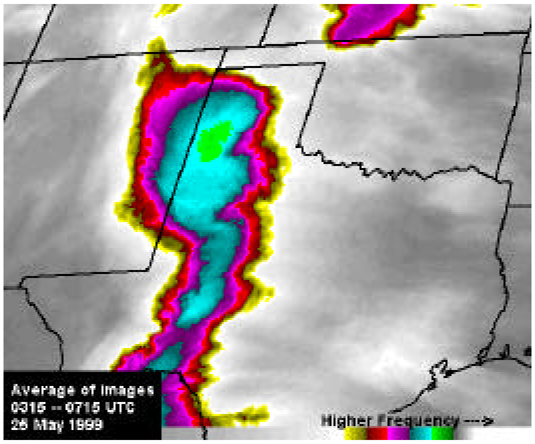

Figure 4. Average of fifteen GOES-East, 10.7 mm images from 0315 – 0715 UTC on 25 May 1999. This image highlights areas where cold storm tops were most persistent.

Note (see figure 5), the line of enhanced low-level cloudiness that stretches from northwest to southeast over west Texas. The western edge of the most persistent cold tops (figure 4) seems to correspond somewhat closely to this mesoscale boundary, though no evidence is available to establish whether or not the convergence line seen at 1845 UTC (figure 5) was actually related to the area of persistent overnight rain. The convergence may also have been a westward extension of the stationary front in southern Texas (figure 2), or a combination of both.

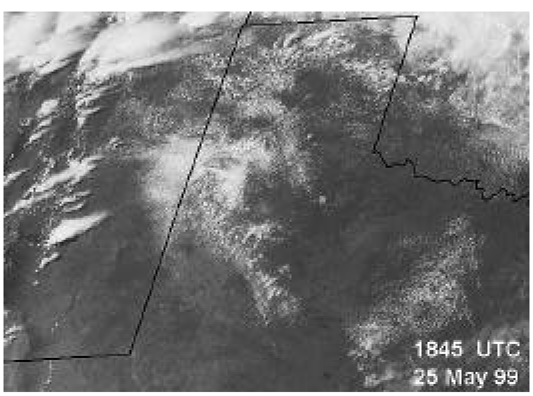

Figure 5. GOES-East visible wavelength image taken at 1845 UTC on 25 May 1999. The northwest-southeast oriented line of enhanced cloudiness near center of the image is the convergence line referred to in the text.

3. Splitting Storms and Cell Motion.

New storms formed in west Texas at approximately 1900 UTC along both the mesoscale boundary and the cold front in the northern panhandle. One large storm, which formed at approximately 2000 UTC to the northwest of Lubbock, produced a large LTO boundary that pushed rapidly northward. By 2100 UTC thunderstorms had formed on this boundary (figure 6). The largest of these left-movers, traveled from 206° at 18 kt) as the convergence and resulting updrafts propagated along with the boundary. At the same time, the primary cell moved off toward the southeast (from about 290° at 20 kt).

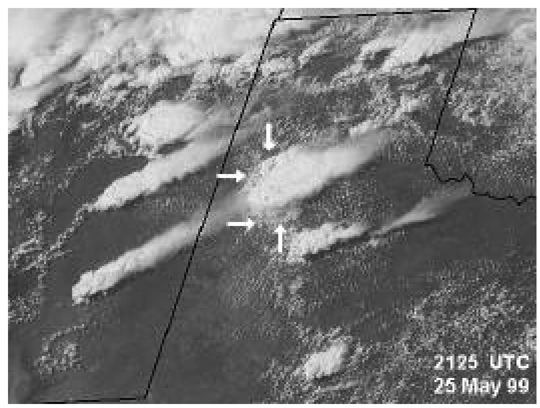

Figure 6. GOES-East visible wavelength image from 2125 UTC on 25 May 1999. Arrows around large storm in west Texas point LTO boundary. Note the new activity forming on the northern side of the storm (northernmost arrow)

Consider the wind profile from the 1800 UTC, AMA radiosonde release (figure 3). The density-weighted average wind vector in the 2-10 km layer is from 265° at 19 kt. Davies-Jones et al. (1990) suggest using an assumed supercell motion 30 degrees to the right of the mean wind and 75% of the speed to calculate SREH. Using a storm motion of 295° at 14 kt, the forecast SREH estimate is [122 $(m/s)^2$]. This is well below the threshold of [270-280 $(m/s)^2$]suggested as necessary for mesocyclone development by

Davies-Jones et al. (1990). However, most storms did not move as expected. The right-moving storms traveled from about 290° at 20 kt. This storm motion yields a SREH value of about [400 $(m/s)^2$] – more than sufficient to produce strong mesocyclones. At the same time, the primary left-mover traveled from 206° at 18 kt. SREH based on this motion yields an approximate value of [–100 $(m/s)^2$]. Negative values of SREH imply meso-anticyclonic updrafts.

Doppler radar data found well-defined mesocyclones in several of the right-moving storms (not shown). This includes the storm which formed just northwest of Lubbock, Texas at 2000 UTC (discussed above). Figure 7 shows the 2.4° elevation Doppler radar reflectivity from Lubbock at 2117 UTC. The southern cell is moving from about 290° at 20 kt. It is the right-mover noted above. The northern cell is the left-mover. It is traveling from 206° at 18 kt. Note the tight reflectivity gradient along the northern side of this cell where the updraft is undergoing continuous propagation on the northward moving outflow. Figure 8 shows a vertical cross-section of reflectivity, illustrating that the left-mover's updraft tilts to the north with height.

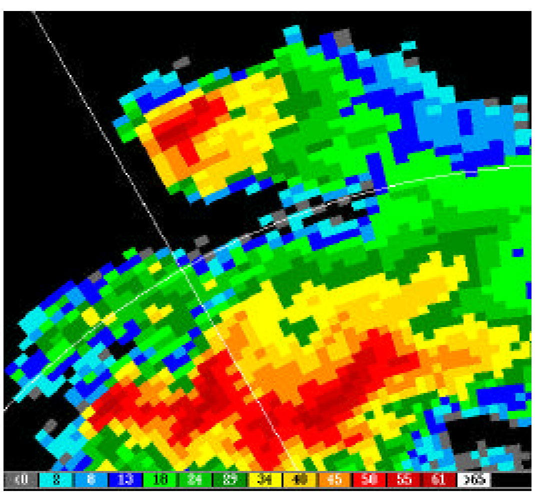

Figure 7. Doppler radar reflectivity data from the Lubbock, Texas WSR-88D. Image shows reflectivity (in dBz) from a 2.4° elevation, PPI scan taken at 2117 UTC on 25 May 1999.

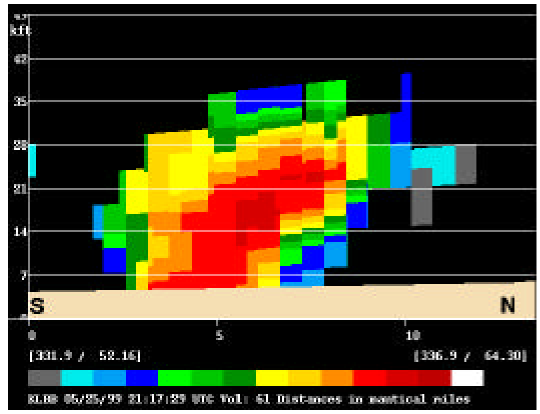

Figure 8. Doppler radar data from the Lubbock, Texas WSR-88D. Image is a vertical cross-section of reflectivity made from the volume scan corresponding to the PPI image shown in Figure 7. North is to the right.

Next, consider the Doppler velocity (Figure 9) corresponding to the reflectivity scan in Figure 7. The left-moving storm contains a couplet that is approximately 6 km across. Velocities on the west are about 30 kt away from the radar, on the east about 35 kt toward. There was continuity in this feature in both height and time. It is clearly a meso-anticyclone. It is what one might expect, given the negative values of SREH.

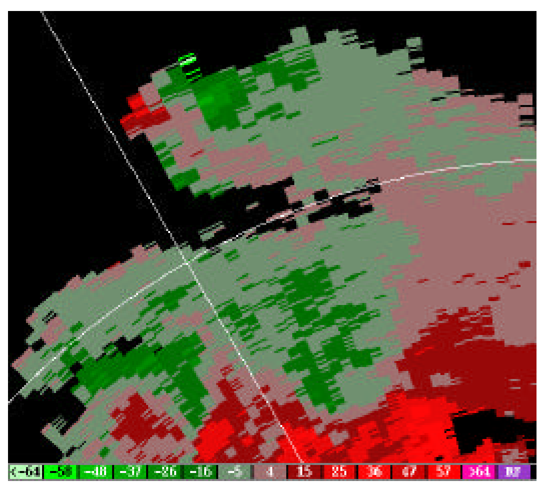

Figure 9. Doppler radar velocity data corresponding to the reflectivity scan shown in Figure 7. Image shows velocities (in kt) toward the radar in grays and green, velocities away from the radar in shades of red.

This left-moving thunderstorm was long-lived, and produced numerous incidents of severe weather, including large hail (up to 2.75" diameter), damaging winds, and even a small tornado. However, the tornado occurred immediately following a merger of the left-mover with an LTO boundary from a right-moving storm that formed on the cold front near Amarillo. The mechanisms associated with that merger and subsequent tornado-genesis will not be explored in this paper.

3. Concluding Remarks.

This paper has presented a few highlights from a severe thunderstorm event that occurred in west Texas on a day that was less than 'synoptically evident.' Winds throughout the lower- to mid-troposphere were weak (average wind vector in the 2-10 km layer 265^o at 19 kt), and shortwave troughs were moving very slowly. Thus, positive vorticity advection and associated vertical motion played little, if any, role. Severe weather ran the full gamut, including damaging winds (recorded gusts up to 66 mph), large hail (up to 2.75" in diameter), street flooding, and a couple of small tornadoes (F0-F1, though the tornadoes occurred over open country). Many of the thunderstorms in this case split into right- and left-moving components. Both right- and left-movers were equally long-lived, and they all produced severe weather.

Modeling studies have shown that when splitting storms develop in an environment where shear vectors veer with height, high pressure is found above the low pressure on the northern flank of the left-moving updraft. This juxtaposition normally causes the left-mover to weaken and die within 10-20 minutes of its inception. However, long-lived, left-moving thunderstorms can, and do, occur in nature. The factor that allows this to occur is low-level thunderstorm outflow. Wilhelmson and Klemp (1981) modeled a long-lived left-mover that occurred on 3 April 1964. Results indicated that the vertical shear in their case was detrimental to the longevity of the storm, but convergence along the northward moving gust front was sufficient to overcome this factor and assure the longevity of the storm.

To separate the 'classical' storm splitting situation (wherein left-movers weaken and die), from the type described in this paper, the forecaster should try to determine if the left-moving component is propagating on a northward moving outflow boundary. If so, there is a good chance that the left mover will not dissipate. In fact, the left-moving component may be as intense as its right-moving partner. That was the case on 25 May 1999.

When storms are propagating northward on an LTO boundary, the appearance of a meso-anticyclone at mid-levels of the storm may simply relate to the helicity relative to the storm motion (SREH). The updraft circulation, like that of the mesocyclone in a right-moving supercell, may help separate the updraft from the downdraft, and actually end up contributing to the longevity of the storm.

5. Acknowledgements.

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