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 appearing 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 component often forms after the original storm undergoes a process called storm-splitting (Achtemeier 1969). This process occurs 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 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 12:00 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 15:00 UTC. Fronts, low and trough are copied from the NCEP analysis.

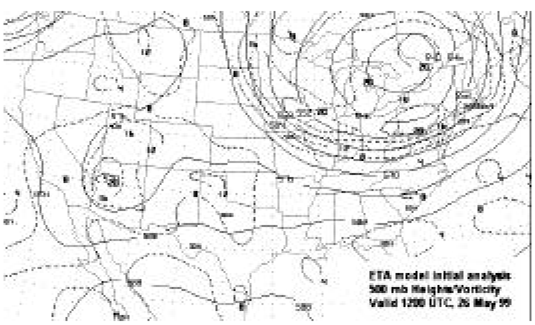

Figure 1. 500 mb heights and vorticity, 12:00 UTC on 25 May 1999 from the ETA initial analysis.

Figure 3 is a plot of sounding data from the radiosonde released in Amarillo, Texas at 18:00 UTC. Note the light winds from the surface to roughly 400 mb, and especially in the lowest 6 km, 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.

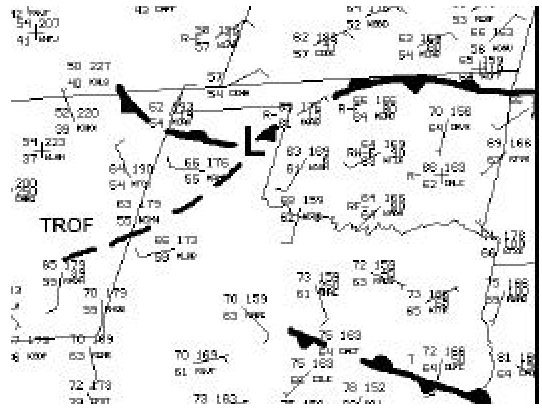

Figure 2. Surface analysis for 15:00 UTC on 25 May 1999. Observations in English units, plotting convention is U.S. standard. Surface features from NCEP analysis.

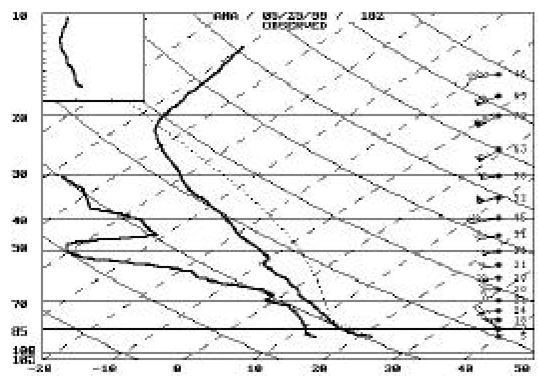

Figure 3. Plot of data from a special radiosonde released at Amarillo, Texas at 18:00 UTC on 25 May 1999 on a Skew-T/Log P diagram. Wind speeds are in knots.

2. Sub-synoptic Factors.

The passage of a slow moving shortwave trough across west Texas brought several hours of heavy rain to the region overnight. Figure 4 is a composite image made in the following manner. First, pixels in a series of 10.7 μm images were altered such that pixels warmer than –40°C were turned black, those –40°C, or below, were assigned a brightness of 100. Next, these bi-modal images were averaged over a given period. Fifteen sequential images for the period

03:15 UTC through 07:15 UTC on 25 May 1999 were chosen. The result shows the regions that had the most persistent cold tops overnight, and presumably the most persistent rain (though the exact nature of the correlation between persistent rain and persistent cold cloud tops has not been established). Compare this result with figure 5, which is a GOES-East, visible wavelength satellite image from 1500 UTC.

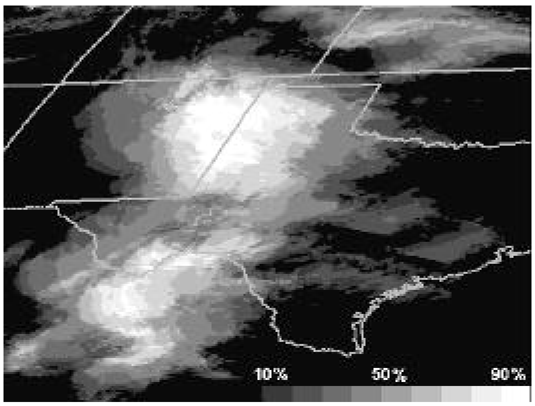

Figure 4. Average of fifteen GOES-East, 10.7 mm images from 03:15 – 07:15 UTC on 25 May 1999. This image highlights areas where cold storm tops were most persistent.

The region of most persistent cold tops seems to match a region of cumulus cloudiness observed later along the west Texas border (figure 5). On the other hand, notice the line of enhanced low-level cloudiness that stretches from northwest to southeast over west Texas. This line does not seem to correspond directly to anything in the composite image shown in figure 4. The cloud line may simply have been a westward extension of the stationary front in southern Texas shown in figure 2.

3. Splitting Storms and Cell Motion.

New storms formed in west Texas at approximately 19:00 UTC along both the line of enhanced cloudiness, and the cold front in the northern panhandle. One large storm, which formed at approximately 20:00 UTC to the northwest of Lubbock, produced a large LTO boundary that pushed rapidly northward. By 21:00 UTC thunderstorms had formed along this boundary (figure 6) with most becoming left-movers. The largest of the new storms traveled from 206^o at 18 kt) as the convergence and newly formed updrafts propagated along with the boundary. At the same time, the primary cell moved off toward the southeast (from about 290^o at 20 kt).

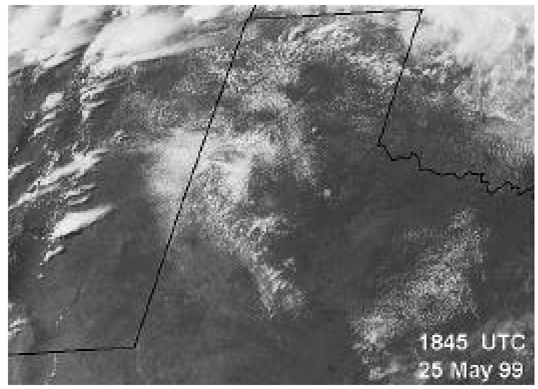

Figure 5. GOES-East visible wavelength image taken at 18:45 UTC on 25 May 1999. The northwest-southeast oriented line of enhanced cloudiness near center of the image is the convergence line referred to in the text.

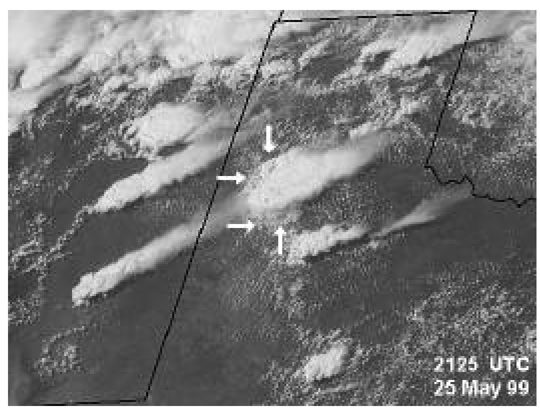

Figure 6. GOES-East visible wavelength image from 21:25 UTC on 25 May 1999. Arrows around large storm in west Texas mark the LTO boundary. Note the new activity forming on the northern side of the storm (northernmost arrow)

Consider the wind profile from the 18:00 UTC, AMA radiosonde release (figure 3). The density-weighted average wind vector in the 2-10 km layer is from 265^o 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^o at 14 kt, the forecast SREH is about [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^o 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^o 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, though threshold values are not known.

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 20:00 UTC (discussed above). Figure 7 shows the 2.4^o elevation Doppler radar reflectivity from Lubbock at 21:17 UTC. The southern cell is moving from about 290^o at 20 kt. It is the right-mover noted above. The northern cell is the left-mover. It is traveling from 206^o 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.

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 25 kt away from the radar, on the east about 64 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. 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 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.

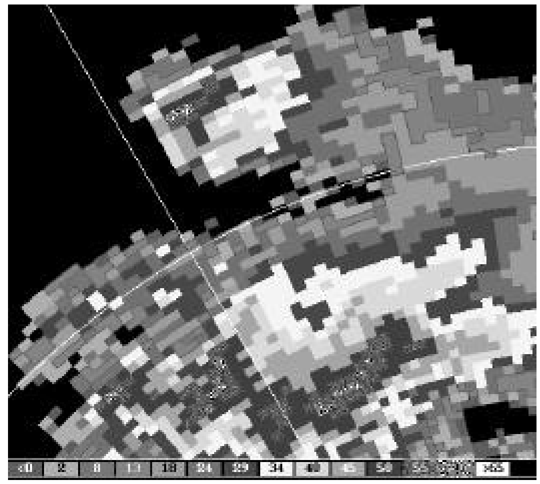

Figure 7. Doppler radar reflectivity data from the Lubbock, Texas WSR-88D. Image shows reflectivity (in dBz) from a 2.4^o elevation, PPI scan taken at 21:17 UTC on 25 May 1999.

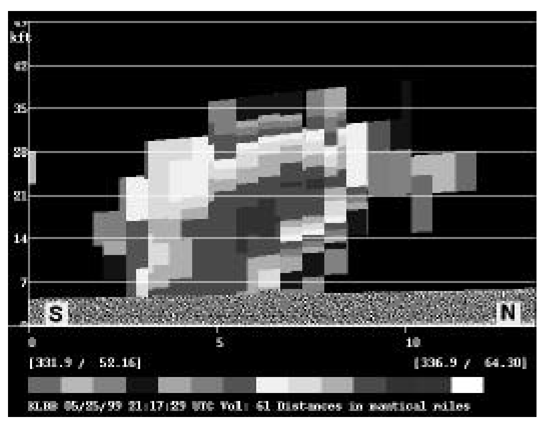

Figure 8. Doppler radar data from the Lubbock, Texas WSR-88D. Image is a vertical cross-section of reflectivity made from data corresponding to the PPI image shown in Figure 7. North is to the right.

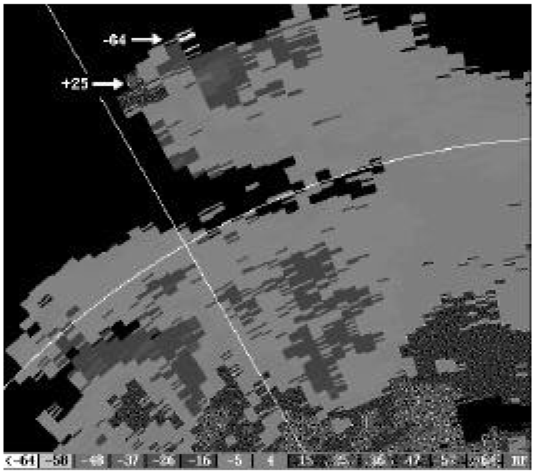

Figure 9. Doppler radar velocity data corresponding to the reflectivity scan shown in Figure 7. Image shows velocities (in kt) toward the radar in solid shades, velocities away from the radar in stippled.

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, and may have been considerably stronger). Many of the thunderstorms in this case split into right- and left-moving components. Both partners were equally long-lived, and they both 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 one long-lived, left-mover that occurred on 3 April 1964. Results indicate 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 must 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 simply relates to the helicity *relative* to the storm motion (SREH). The circulation within the updraft, like that of the mesocyclone in a right-moving supercell, probably helps separate the updraft from the downdraft, and results in a longer-lived storm. Thus, the appearance of a north-moving outflow on satellite or radar, and a meso-anticyclone on radar, are probably sufficient to identify the left-mover as something different from the "classical" case. One should not expect early dissipation, and (all else being equal) should expect the storm to be just as intense as it right-moving counterpart.

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