P 11.2 THE 29 MAY 2001 LAMAR, COLORADO TORNADIC EVENT: A BOUNDARY-DRIVEN SIGNIFICANT TORNADIC STORM IN A HIGH CAPE/WEAK SHEAR ENVIRONMENT

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1. Introduction

On 29 May 2001, thunderstorms developed across southeast Colorado, producing numerous reports of severe weather, including 9 tornadoes. This severe weather episode was part of a larger 2 day outbreak which occurred over the same region (Hodanish 2002, this volume). Although numerous tornadoes occurred on this date, this paper will concentrate on one small area of severe convection which developed in the vicinity of Lamar, Colorado. This convection originated on a boundary and produced 7 tornadoes. Video documentation of the event indicated the first 6 tornadoes were non-supercell in character, but the seventh tornado occurred while the storm exhibited clear visual supercell characteristics (e.g., rear flank downdraft, clear slot and occlusion process).

The Lamar event was unique for a variety of reasons. Meteorologically, this small convective complex moved very little during a lifetime of over 2 hours, with all of the tornadic activity remaining within a 3 mile radius of the Lamar municipal airport (KLAA). Synoptic conditions did not appear to favor significant tornadic activity, yet the last tornado produced F3 damage, and persisted nearly 30 minutes. The complex quickly became tornadic, and gradually transformed visually from non-supercell tornadic updrafts to a supercell producing a significant tornado. From a historic perspective, this was the first documented F3 tornado in southeast Colorado since 1979 (Grazulis 1993).

2. Meteorological Background

Analysis of 500 mb data at 1200 UTC 29 May 2001 indicated a short wave trough over western Colorado. A 25-32 m s^{-1} speed maximum associated with this trough extended from southern New Mexico to the Texas panhandle, with much weaker 500 mb flow over Colorado (7 to 13 m s^{-1}). The 1200 UTC Denver sounding (not shown) indicated a stable low-level atmosphere with modest westerly flow just above the surface and a deep elevated mixed layer extending up to 500 mb. The 1200 UTC sounding at Dodge City (Fig. 1) indicated a much more unstable atmosphere, as rich low level moisture (w = 11.5 g kg^{-1}) extended from the surface to around 830 mb. The unmodified surface-based lifted index from this sounding was –6 ^{o}C. Shear in low-levels was strong (0-3 km SRH > 400 $m^2 s^{-2}$), indicative of a morning low-level jet present over western Kansas. Deep layer shear (0-6 km) was more modest than the low-level shear, with values of ~15 m s^{-1}.

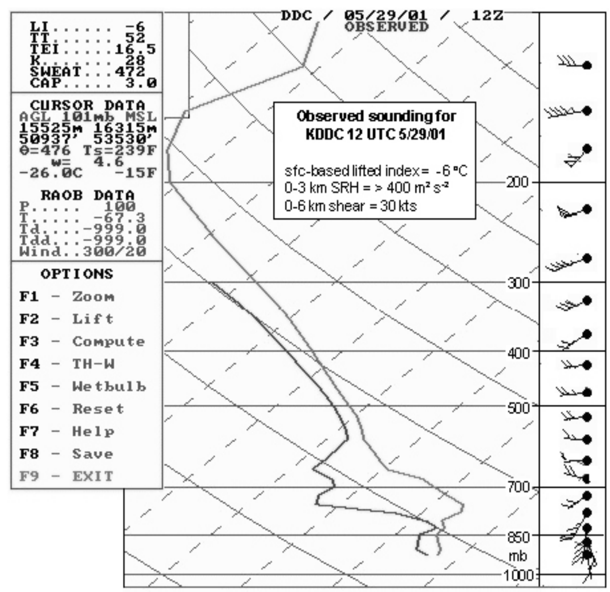

Figure 1. *1200 UTC 29 May 2001 sounding from Dodge City, KS*.

The mesoscale environment became conducive for deep convection by late morning as the low-level atmosphere became quite unstable. Model-derived analysis fields (not shown) indicated CAPE values between 2000 and 3000 J kg^{-1} over far southeast Colorado. Of more significance, visible satellite imagery showed two boundaries over the eastern Colorado plains. The first extended east-west across

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east central Colorado and into west central Kansas, while the second boundary was oriented NE-SW over far southeast Colorado. This second boundary extended over the immediate Lamar area (Fig. 2).

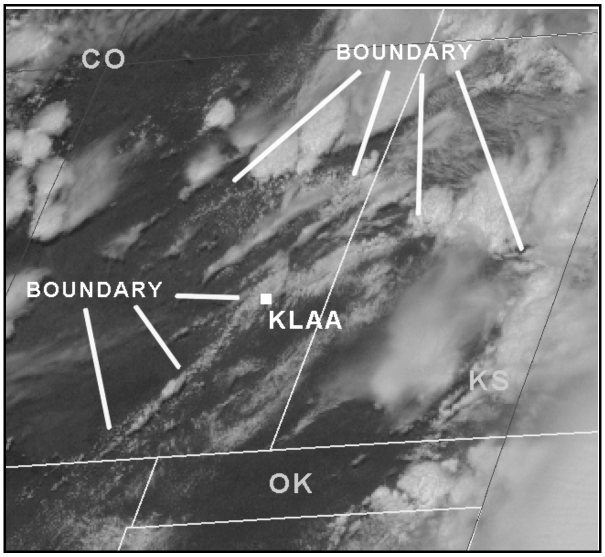

Figure 2. *1715 UTC visible satellite picture indicating the two boundaries over southeastern Colorado.*

The initial convective updraft developed along the boundary in the vicinity of Lamar and rapidly became tornadic. KPUX composite reflectivity data indicated the first identifiable echo (>18 dBz) was observed at 1730 UTC. Within 19 minutes, the first non-supercell tornado was reported by law enforcement just west of Lamar. Rapid tornadogenesis of this type is not uncommon, as Brady and Szoke (1989) and Wakimoto and Wilson (1989) have shown that vertical vorticity associated with low-level boundaries can be stretched by rapidly developing updrafts, producing non-supercell tornadoes. During the next hour, this small convective cluster would produce 5 additional non-supercell tornadoes, some of them on the ground simultaneously.

3. Radar analysis

WATADS analysis of KPUX reflectivity data indicated an interesting evolution of the convection in the Lamar area. As discussed above, the first updraft initiated on the boundary at 1730 UTC 3-6 km south-southwest of Lamar. This initial updraft moved slowly northeast, gradually reaching an intensity of 50 dBz 3-6 km north of Lamar by 1800 UTC. The first tornado developed at 1749 UTC, 19 minutes after initiation, 3 km west of Lamar in an area of 20-30 dBz reflectivity. Between 1800 and 1830 UTC, two additional updrafts developed just southwest of Lamar and moved slowly northeast while gradually intensifying to 50-55 dBz north of Lamar. During this time, 3 additional non-supercell tornadoes developed in the vicinity of the first tornado, once again in an area of 20-30 dBz reflectivity.

At 1830 UTC, an updraft reaching 50-60 dBZ developed immediately to the north and east of Lamar and gradually expanded in areal coverage and intensity. Unlike the previous cells, this cell remained stationary through 2000 UTC, dropping hail up to 7.6 cm in diameter in Lamar. The last two non-supercell tornadoes developed between 1830 and 1845 UTC just west of Lamar.

Between 1900 and 1930 UTC, the 7th and last tornado developed 4 km southwest of Lamar. This tornado intensified and produced F3 damage as it moved slowly on a convoluted northerly track. It was during this time that the structure of the storm showed supercell characteristics (Fig. 3). Shortly after 2000 UTC, the storm began to move east and off the boundary. After this time, reports of severe weather with this storm ceased.


Figure 3. *Photograph of the F3 Lamar tornado looking south-southeast. Note the well defined dry slot. Photo courtesy J. Faull, Prowers county sheriff.*

4. Examination of the Near Storm Environment

Although this small complex of convection produced several non-supercell tornadoes within a one hour time frame, this type of tornadic morphology has been documented in other cases (e.g., Blottman and Padavona, 1998). What is somewhat unique is the fact that this storm produced a significant tornado (F3) in an environment where synoptic conditions did not appear conducive for significant tornado activity. Fortunately, this storm developed within 27 km of the Granada profiler, which, in combination with KLAA metar surface data and model analysis data, allowed for an examination of the near storm environment.

Figure 4 is a sounding derived from a combination of the Granada profile (1900 UTC winds), the 1800 UTC MesoETA analysis (thermodynamic data above the surface) and the 1900 UTC KLAA surface observation. This derived sounding suggested a large amount of CAPE in the area, with values of ~2900-3500 J kg^{-1} using parcels in the bottom 100 mb. However, the low-level and deep layer shear from profiler data were not very suggestive of significant tornado activity. Shear in the 0-6 km layer at 1900 UTC was only around 15 m s^{-1}, and 0-3 km SRH values were only 127 m^2 s^{-2} (0-1 SRH 43 m^2 s^{-2}) based on the storm's stationary position. SRH in particular was much smaller than that indicated by the morning Dodge City sounding in Figure 1. Of note, winds aloft did increase significantly, reaching 25 m s^{-1} above the 300 mb pressure surface.

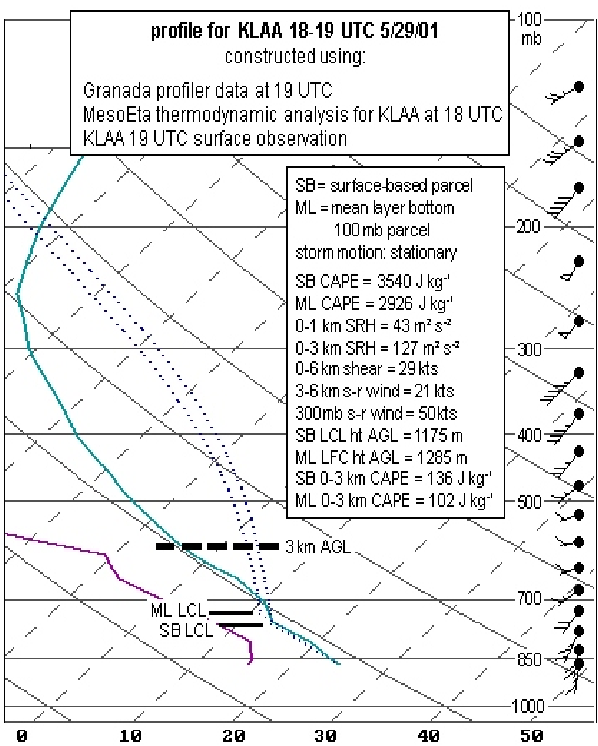

Figure 4. *Derived sounding for the Lamar, Colorado area*

An important feature of this case appeared to be the potential enhancement of low-level stretching of vorticity due to the juxtaposition of significant low-level CAPE and the pre-existing boundary (see Davies 2002, this volume). A closer examination of the sounding in Fig. 4 suggests a significant amount of surface-based CAPE was present in low-levels (~135 J Kg^{-1} below 3 km), with a "lifted index" value of –6 ^{o}C calculated at 3 km AGL. The boundary/stretching concept discussed in Wakimoto and Wilson (1989) and Brady and Szoke (1989) was likely a mechanism for the tornadoes in this case, with stretching over the boundary possibly enhanced by the rapid increase in low-level buoyancy and associated potential for large parcel accelerations. Supercell characteristics may have developed because the storm persisted over a long period, taking advantage of whatever vorticity (horizontal and vertical) was available in the environment. On the other hand, this may be a case where a strong tornado developed by largely non-supercell processes. Similar evolutions have been documented elsewhere (e.g., Szoke 1996).

It is also hypothesized that strong storm-relative flow, resulting from the 25 m s^{-1} upper tropospheric winds in Fig. 4 and the storm's stationary position on the boundary, played a role in the longevity of this tornado event. Strong winds aloft likely acted to keep the heaviest precipitation away from the inflow region of this storm, decreasing the potential for cold outflow which could interfere with inflow and updraft. An additional factor may have been the LCL height (1100-1300 m estimated from parcels in the lowest 100 mb), which was relatively low by eastern Colorado standards. This subtle increase in humidity in low-levels may have also helped to reduce adiabatic cooling and potential for outflow. It is notable that no straight-line severe winds or wind damage were reported with this event.

5. Forecast Applications

Significant tornadic storms developing in low shear/high cape environments, similar to this case, continue to be documented (See Davies 2002, this volume). Operational warning meteorologists need to be alert to these environments, which at first glance, do not appear to favor significant tornadic activity. These cases have the following features in common:

1. A pre-existing boundary is in place.
2. High CAPE air is collocated with the boundary, and this CAPE increases rapidly above the LFC. Values of CAPE measured in the 0-3 km region are typically greater than 100 J Kg^{-1}.
3. Traditional low-level and deep-layer shear are relatively "weak" (0-3 km SRH 100-125 m s^{-1} or less, and 0-6 km shear less than 15 m s^{-1}.

4. The storm remains "anchored" to the boundary, resulting in a motion that is deviant from what would be expected from the given wind profile.

5. 300 mb storm relative flow values typically exceed 20 m s^{-1}.

Table 1 list representative parameter values associated with significant tornado events in high CAPE/low shear environments compared with those typically found in more traditional supercell tornado environments. Data for the high CAPE/low shear significant tornadoes in Table 1 come from Davies 2002 and this case while data for significant supercell tornadoes is from Rasmussen and Blanchard (1998).

6. Conclusions

This paper documents a small stationary multiple tornadic storm which lasted more than 2 hours in a relatively weak low-level shear environment. It is believed that stretching over the well-defined boundary on which this storm developed was the primary tornadogenesis mechanism. The combination of the storm remaining anchored to the boundary, strong storm-relative flow in upper levels, significant low-level CAPE, and a relatively low LCL appeared to play key roles in the production of multiple tornadoes. Significant stretching on the boundary (possibly aided by increased CAPE in low-levels), and the longevity of the storm (aided by favorable upper level storm-relative winds) were likely important contributors to the eventual development of a significant F3 tornado.

An accompanying web document regarding this case can be found at:

http://www.crh.noaa.gov/pub/29may01_storm_data.html

7. Acknowledgments

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	Significant Supercell Tornadoes	**High CAPE/Low Shear Significant Tornadoes**
0-6 km Shear	18.4 m s^{-1}	12.6 m s^{-1}
SRH	180 m^2 s^{-2}	88 m^2 s^{-2}
CAPE	1314 J Kg^{-1}	4137 J Kg^{-1}
Storm Relative Upper Tropo-spheric Flow	19.5 m s^{-1}	21.8 m s^{-1}

Table 1.*Comparison of shear and thermodynamic variables for significant supercell tornadoes (from Rasmussen and Blanchard 1998) and high CAPE/low shear significant tornadoes (this paper and Davies 2002).*

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