P1.1 ENVIRONMENT CHARACTERISTICS ASSOCIATED WITH TORNADO EVENTS NEAR CLOSED COLD CORE 500 MB LOWS

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1. INTRODUCTION

Previous studies have discussed tornado events that occur in relatively close proximity to closed cold core 500 mb lows (hereafter C500L). Modest measures of low level moisture (namely in terms of surface dewpoints) and instability can render some tornado events near C500L difficult to forecast. Miller (1972) referred to these events as “type D” patterns. Subsequent studies by Goetsch (1988), Davies (1993), and McDonald (2000) have examined severe thunderstorms and tornadoes east of the Rocky Mountains associated with “cold core” or “small” (non-tropical) tornadic supercell patterns.

More recently, a preliminary study by Davies and Guyer (2004, hereafter DG04) examined the synoptic scale patterns (also see Davies 2006) and climatological tendencies associated with C500L tornadoes in the central and eastern United States over a five year period (1999-2003). A C500L was defined as at least one closed 30 m contour at 500 mb (Bell and Bosart 1989), with 500 mb temperatures of -10°C or colder. Most common during the transitional spring and fall months, tornadoes that occur within 320 km (approximately 200 statute miles) of a C500L were the focus of DG04. In close proximity to, and typically east or southeast of the C500L, DG04 found that tornadoes tend to occur along a boundary intersection focus point, oftentimes in the form of a surface occlusion and/or wind shift axis (Fig. 1). DG04 noted that C500L tornado environments are often characterized by marginal boundary layer moisture (surface dewpoints as low as 48-55 °F) and relatively weak instability (e.g. CAPE of 1000 J/kg or less). Readers of this manuscript are encouraged to consult DG04 and Davies (2006) for additional discussion on the preliminary patterns and climatology of C500L tornado events. As a follow-up to DG04, this study focuses on the thermodynamic and kinematic characteristics associated with C500L tornadoes. This includes a comparison of C500L tornado environments vs. a diverse dataset of traditional supercell tornado environments (section 3) and C500L tornado null events (section 4).

2. METHODOLOGY

Tornado time, location, and F-scale damage rating was determined from NWS Storm Data for tornadoes in the central and eastern United States that satisfied the criterion for C500L tornadoes in DG04. For each tornado case, RUC (Benjamin et al. 2004) 00-hr forecast soundings were gathered coincident with each tornado report. RUC soundings have been shown by Thompson et al. (2003) and Davies (2004) to serve as a reasonable proxy for direct observations in the mesoscale supercell tornado environment. The RUC soundings were gathered for the nearest available time and location in relation to the tornado event, typically within 0-1 hr preceding the tornado and 100 km of the tornado location. The C500L tornado database included 39 tornadic cases.

A database of 21 non-tornadic C500L null cases was gathered from days when/where the general synoptic pattern and environmental characteristics appeared favorable for the possibility of C500L associated tornadoes. In absence of a specific tornado report, RUC proximity soundings for C500L null cases were gathered based on the most likely location for cold core tornadoes identified in DG04, which was typically coincident with a surface intersection/wind shift within 320 km of the 500 mb low center (Fig. 1). Although the sample size of the C500L tornado and null case events are relatively small, they appear to provide meaningful statistical results.

3. C500L TORNADOES VS. TRADITIONAL SUPERCELL TORNADOES

Comparisons of environmental characteristics were made between the C500L tornado database and a version of an existing RUC-derived database by Davies (2004) consisting of 532 “traditional” supercell tornadoes. This “traditional” database excluded C500L tornado events, tornadoes associated with hurricane/tropical systems, and “landspout” non-supercell tornadoes. Table 1 provides a comparison between C500L tornadoes and typical supercell tornadoes showing median and 25th/75th percentiles for various thermodynamic and kinematic parameters.

3.1 *Instability*

In comparison to traditional supercell tornado environments, 500L tornadoes are associated with considerably lesser amounts of convective instability. Lowest 100 mb MLCAPE values with C500L events

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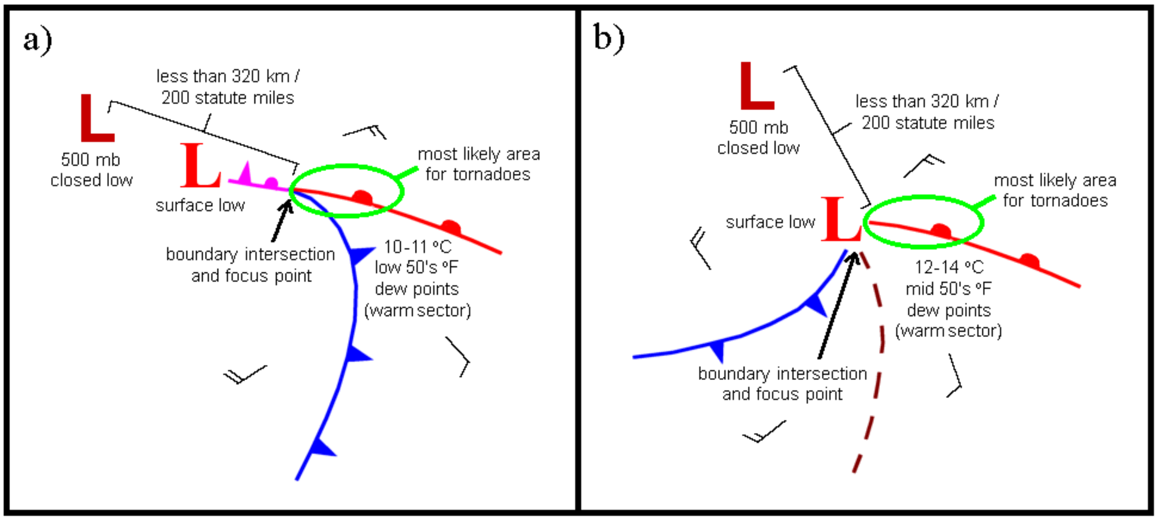

Fig. 1. Composite diagram adapted from Davies and Guyer (2004) with examples of surface features associated with an increased likelihood of C500L tornado events. Most likely area for C500L tornadoes denoted by green oval.

75th Percentile **Median** 25th Percentile	100 mb MLCAPE (J/kg)	SBCAPE (J/kg)	0-3 km MLCAPE (J/kg)	0-6 km Bulk Shear (kt)	0-1 km Bulk Shear (kt)	0-1 km SRH (m2/s2)	100 mb ML LCL (m)	100 mb ML LFC (m)	EL Height (m AGL)	Sig Tor Parameter (new)
C500L Tornadoes	1069 **755** 391	1756 **1221** 765	160 **108** 80	48 **33** 20	25 **17** 12	131 **76** 33	1091 **915** 764	1431 **1108** 966	9606 **8455** 7483	0.6 **0.2** 0.1
Typical Supercell Tornadoes	2729 **1787** 1015	3450 **2457** 1456	117 **76** 39	53 **45** 37	30 **22** 15	253 **162** 90	1405 **1045** 770	2159 **1681** 1265	12457 **11649** 10545	2.1 **1.1** 0.5

Table 1. Tabular comparison of the median (in bold) and 25th/75th percentiles for environmental parameters for C500L tornadoes vs. typical supercell tornadoes.

were roughly one-third, with surface-based (SB) CAPE values roughly one-half, of the broader supercell tornado dataset (Table 1). The median 100 mb MLCAPE was 755 J/kg and the SBCAPE 1221 J/kg for C500L tornadoes. In contrast, the median 100 mb MLCAPE for typical supercell tornado environments was 1787 J/kg, with a median SBCAPE of 2457 J/kg.

3.2 *Vertical Shear*

C500L tornado environments are associated with weaker vertical shear as compared to traditional supercell tornado environments, with respect to both deep layer and low level (i.e. 0-1 km) shear. The median deep layer (0-6 km) bulk shear was 33 kt for C500L tornadoes, with 25th and 75th percentile values of 20 kt and 48 kt, respectively. This is likely attributable to the weaker mid tropospheric winds closer to a vertically-stacked closed low, in addition to the low topped nature (i.e. EL height median of 8455 m or 27740 ft - Table 1) of C500L events. With emphasis that C500L tornado events can occur in rather weak deep layer vertical shear, nearly one-third of the C500L cases occurred with 0-6 km bulk shear of 30 kts or less, including 20% of cases with 15 kts or less of 0-6 km shear. Low level 0-1 km shear computations exhibit similar tendencies toward lower values for C500L cases. C500L tornadoes were associated with a median 0-1 km bulk shear of 17 kt, with 0-1 km Storm Relative Helicity (SRH) median of 76 m^2/s^2.

3.3 *Additional Characteristics*

Although the distribution of ML LCL heights associated with C500L tornadoes were slightly lower than other supercell tornadoes, considerable overlap existed with little discrimination between the C500L and traditional supercell tornado datasets. However, a greater separation was observed for ML LFC heights. The median ML LFC height for C500L tornadoes was 1108 m (3635 ft), as compared to the 1681 m (5515 ft) median for typical supercell tornadoes. Parallel to the observations of (moisture and) buoyancy being “concentrated” in the low levels, the typical LCL-LFC height separation was found to oftentimes be only 200-400 m (650-1300 ft) for C500L tornado environments.

75th Percentile **Median** 25th Percentile	0-3 km SBCAPE (J/kg)	0-1 km SB VGP	SBCAPE (J/kg)	50 mb MLCAPE (J/kg)	0-1 km SB EHI	50 mb ML LFC (m)	0-1 km SRH (m^2/s^2)	0-1 km Bulk Shear (kt)	SB LCL (m)
C500L Tornadoes	266 **210** 159	0.57 **0.43** 0.24	1756 **1221** 765	1221 **915** 654	1.1 **0.7** 0.2	1282 **948** 713	131 **76** 33	25 **17** 12	774 **560** 393
C500L Null	177 **132** 99	0.29 **0.18** 0.16	1303 **759** 495	913 **727** 340	0.4 **0.2** 0.0	1264 **1104** 993	98 **38** 9	22 **16** 8	845 **716** 492

Table 2. Tabular comparison of the median (in bold) and 25th/75th percentiles for potential discriminators between C500L tornadoes and C500L null tornado events.

4. C500L TORNADOES VS. C500L NULL TORNADO EVENTS

Statistical analysis revealed a relative emphasis on thermodynamic and kinematic computations derived from the lowest few kilometers for the discrimination of C500L tornado events vs. non-tornadic null cases. A tabular summary above (Table 2) compares the environmental characteristics of C500L tornado events vs. null cases, including median, and 25th/75th percentiles associated with each parameter.

4.1 *Lifted Parcel Discussion*

Findings in this study stress the importance of choosing the "best" lifted parcel choice based on the meteorological situation, whether it be a surface-based (SB) parcel or mixed layer (ML) parcel calculation of mean conditions through a given layer. Likely owing to the more modest buoyancy concentrated at lower levels, discrimination skill typically decreased when using a lowest 100 mb ML calculation in C500L environments. This suggests that the commonly used lowest 100 mb MLCAPE is too deep a mean lifted layer in C500L situations. There was 25-60% more total CAPE and 50-90% more low-level CAPE (0-3 km) when using SB or 50 mb ML parcels. This not only applies to CAPE calculations directly, but also derived parameters (i.e. EHI, VGP etc.) as well. Statistically, surface-based (SB) parcel calculations were found to be best, followed by a 50 mb parcel. Based on the findings in this study, the authors caution against using 100 mb ML parcel calculations (whether it be CAPE or derived fields) in C500L scenarios, with a preference for a SB or lowest 50 mb ML lifted parcel.

4.2 *Instability*

The median surface SBCAPE associated with C500L tornadoes was 1221 J/kg, with 25th/75th percentiles of 766-1756 J/kg, which was approximately 30-40% greater than C500L null events (Fig. 2) This study found that 0-3 km SBCAPE was the best discriminator between C500L tornadoes and C500L null tornado cases (Fig. 3). The median 0-3 km SBCAPE was 210 J/kg for tornado cases, with 75% of events in excess of 160 J/kg. In contrast, null cases featured less buoyancy "concentrated" in the lowest 0-3 km layer, with a median of 132 J/kg and 75% of cases ≤175 J/kg 0-3 km SBCAPE.

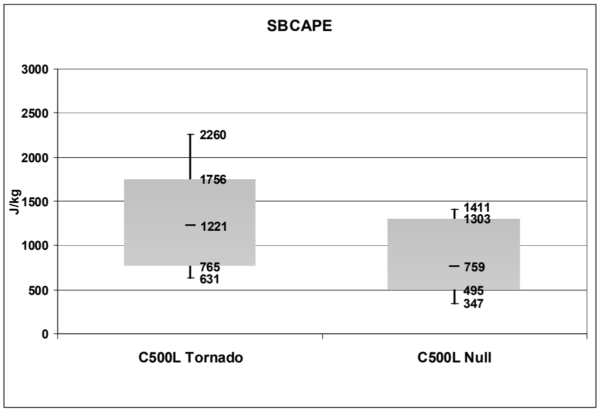

Fig. 2. Box and whiskers diagram of surface-based (SB) CAPE (J/kg) for C500L tornadoes vs. null events. Median with box denoting the 25th/75th percentiles, with outer whiskers represent the 10th/90th percentiles of values.

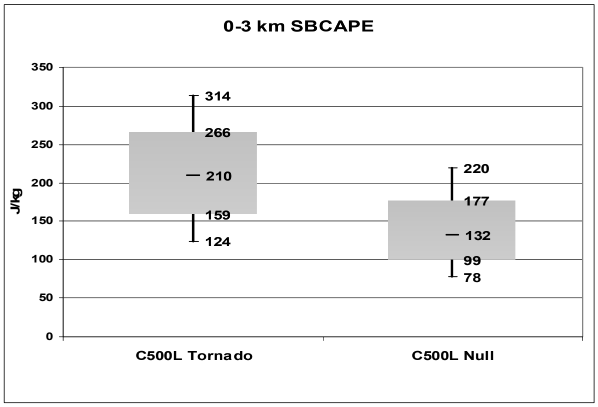

Fig. 3. Same as Fig. 2, except 0-3 km SBCAPE.

4.3 *Vertical Shear*

As discussed in section 3.2, C500L tornado events tend to occur in relatively weak deep layer shear, with a median 0-6 km bulk shear of 33 kt. For C500L tornadoes vs. null events, 0-6 km bulk shear exhibited virtually no skill in distinguishing between the two environments (not shown). Low level shear computations also exhibited little discrimination, with only slightly higher values of 0-1 km bulk shear (Fig. 4) and 0-1 km Storm Relatively Helicity (SRH) for C500L tornado cases (Fig. 5).

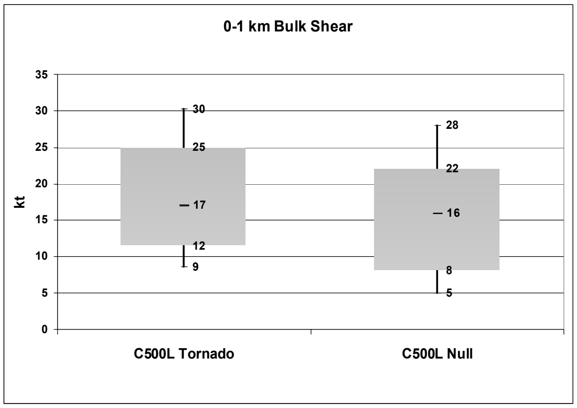

Fig. 4. Same as Fig. 2, except 0-1 km bulk shear (kt).

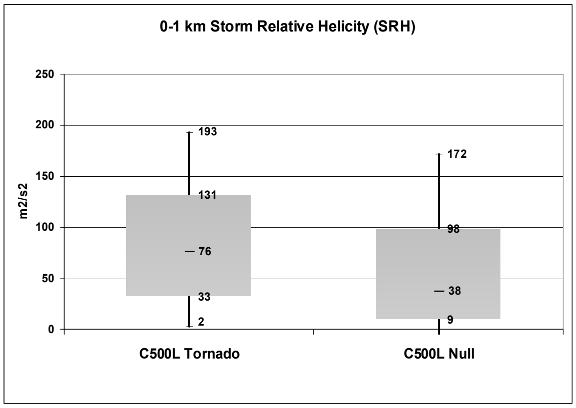

Fig. 5. Same as Fig. 2, except 0-1 km Storm Relative Helicity (SRH - m^2/s^2).

4.4 *Additional/derived parameters*

It was found that the Vorticity Generation Parameter (VGP – Rasmussen and Blanchard 1998) computed for the 0-1 km layer was a good discriminator between C500L tornado events and null cases (Fig. 6). The median 0-1 km VGP for tornadoes was 0.43, with 75% of cases greater than 0.24. Null events were associated with a median 0-1 km VGP of 0.18, with 71% of events below 0.24. It was also found that 0-1 km Energy-Helicity Index (EHI – Rasmussen 2003) values provided some discrimination between C500L tornadoes vs. null cases (Fig. 7). While relatively little variance was observed in LCL height (Fig. 8), LFC heights (Davies 2004) were lower (median of 948 m/3110 ft) with C500L tornadoes (Fig. 9).

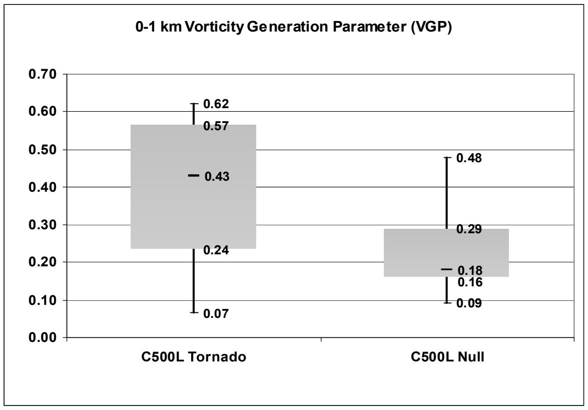

Fig. 6. Same as Fig. 2, except 0-1 km Vorticity Generation Parameter (VGP).

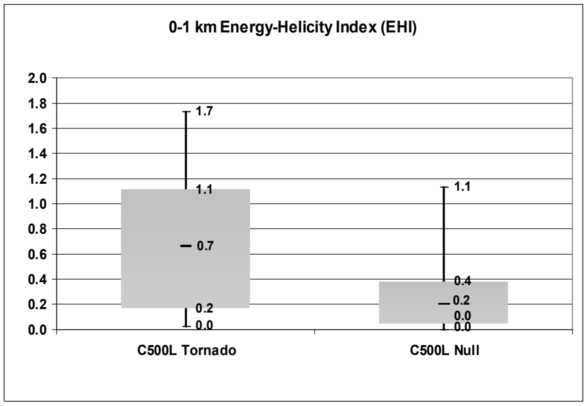

Fig. 7. Same as Fig. 2, except 0-1 km Energy-Helicity Index (EHI).

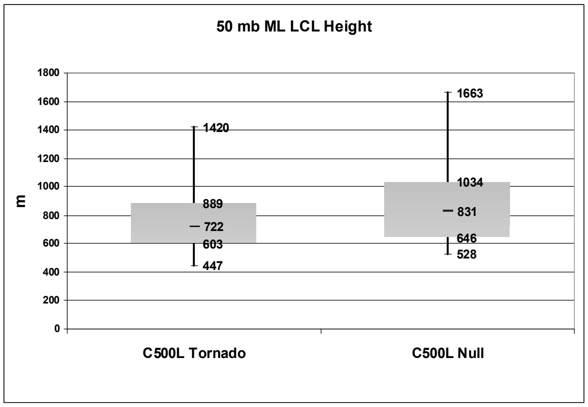

Fig. 8. Same as Fig. 2, except 50 mb ML LCL Height (m).

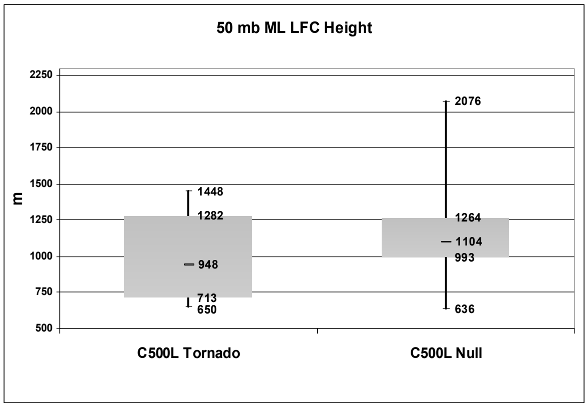

Fig. 9. Same as Fig. 2, except 50 mb ML LFC Height (m).

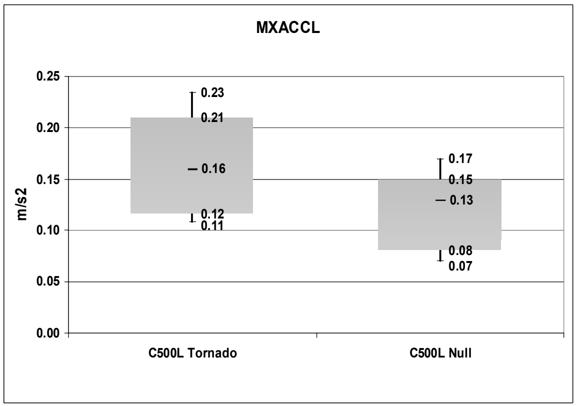

Fig. 10. Same as Fig. 2, except MXACCL (m/s^2).

4.5 *Vertical Distribution of CAPE and Maximum Parcel Acceleration (MXACCL)*

Because CAPE is located closer to the ground in most C500L settings, an experimental computation (MXACCL) was devised to estimate the maximum vertical parcel acceleration due to vertical buoyancy distribution through increasing depths in a sounding. This was found to be potentially useful for discriminating between C500L tornado environments and C500L tornado null cases. MXACCL is somewhat similar to CAPE density (Blanchard 1998), but rather than dividing the total CAPE by the entire depth from LFC to EL, CAPE from the LFC to ascending 25 mb increments in the sounding is summed and stored in a table. Then each accumulated CAPE value in the table is divided by the corresponding depth it represents. This yields a series of average accelerations (units m/s^2) from LFC to a particular 25 mb level as one ascends higher in the sounding. The largest of these average accelerations is called MXACCL. Although experimental, the potential advantage of MXACCL over CAPE density is that it more directly considers acceleration through portions of a sounding where CAPE increases rapidly with height, rather than averaging the acceleration through the entire depth of the LFC to EL layer.

The MXACCL, using a surface-based (SB) parcel appeared to exhibited some skill in distinguishing between C500L tornado environments and C500 null cases. The median value for MXACCL in C500L tornado events was found to be 0.16 m/s^2, while the median MXACCL for C500L null tornado events was 0.13 m/s^2 (Fig. 10).

5. CONCLUSIONS

Within the spectrum of tornadic supercells, tornadoes associated with C500L are typically characterized by lower amounts of convective instability, weaker vertical shear through a deep layer, and lower storm tops (EL heights). Comparing traditional supercell tornado environments with C500L tornado cases, C500L events cases tended to have considerably higher amounts of 0-3 km SBCAPE, often the result of a “fatter” positive CAPE area located relatively low in the vertical profile (e.g. closer to the ground, see Davies 2006). This suggests that low-level parcel accelerations and resultant stretching may be important for tornado development in events associated with C500L cases. It was found that C500L tornado cases tended to higher 0-1 km VGP and 0-1 EHI values, and slightly higher 0-1 km shear and 0-1 km SRH, in comparison to null C500L cases.

Additionally, it was found that CAPE calculations using a shallower mixed-layer lifted parcel (e.g. the lowest 50 mb), or surface-based (SB) parcels, appear better suited for assessing thermodynamic characteristics in tornado events associated with C500L. Given the relatively shallow moisture layer indicated by the RUC soundings in many such events, the lowest 100 mb often may be too deep a mixed layer to properly represent buoyancy and associated environment characteristics in such settings.

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