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A Preliminary Climatology of Tornado Events with Closed Cold Core 500 mb Lows in the Central and Eastern United States

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1. Introduction

Tornado events that occur in near proximity to closed 500 mb lows having a core of cold temperatures aloft are not uncommon. Miller (1972) identified such synoptic settings and referred to them as "type D" patterns. Similar settings associated with severe thunderstorms and tornadoes east of the Rocky Mountains were also discussed by Goetsch (1988), Davies (1993), and McDonald (2000). Patterns associated with tornadic thunderstorms in California (e.g., Monteverdi et al. 2003) at times involve closed 500 mb lows.

In line with observations by Goetsch (1988), operational experience during recent years has confirmed that potential for tornadoes near closed 500 mb low systems can be easily overlooked by forecasters. This is especially true when moisture as indicated by surface dew points with such systems appears marginal compared to more "typical" scenarios associated with tornadoes (e.g., Williams 1976).

To date, little work has been done regarding climatology and frequency of tornado-producing events in close proximity to closed cold core 500 mb lows (hereafter "C500L" for brevity). This study is intended as a preliminary step in that direction, utilizing cases in the central and eastern United States (U.S.) because of similarity in moisture source (usually the Gulf of Mexico) and lack of mountainous topography, although cases were included near and east of the Appalachian mountains. Characteristics of such systems during a five year period were examined to determine whether there may be some common features among tornadic cases, and some general differences between events that produce tornadoes within 320 km (roughly 200 statute miles) of the midlevel closed low and events that do not.

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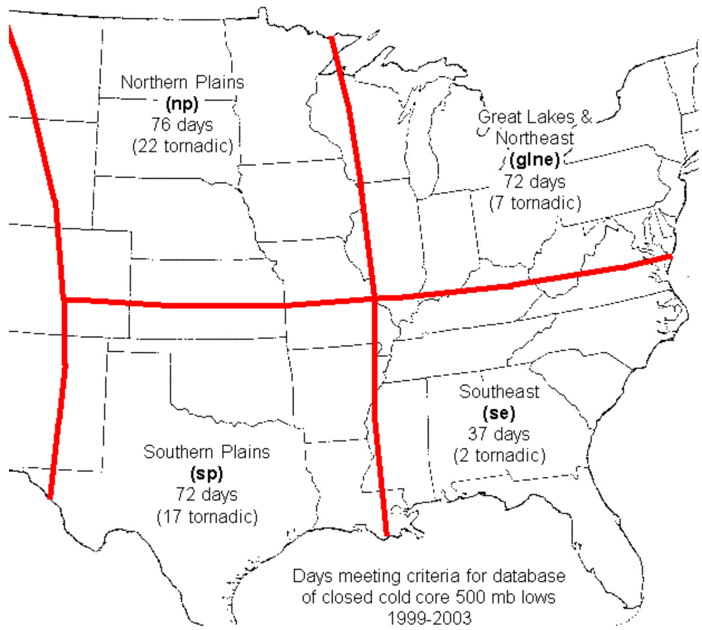

Fig. 1. *Geographical distribution of days in database of C500L systems 1999-2003 meeting the criteria for this study.*

2. Methodology

Convective events associated with C500Ls east of the Rocky Mountains during the period 1999-2003 were located using 500 mb charts and surface maps in conjunction with severe weather reports in the publication *Storm Data*. A wider range of years was originally targeted for examination, but time constraints for this paper dictated a period of 5 years, which nevertheless yielded a reasonable number of events for preliminary study.

The following simple criteria were used to develop a database of days to be examined involving C500Ls:

1) A C500L was present in the central or eastern U.S. along or east of the front range of the Rocky Mountains, defined by at least one closed 30 m contour as in Bell and Bosart (1989) using 00 UTC analyses.

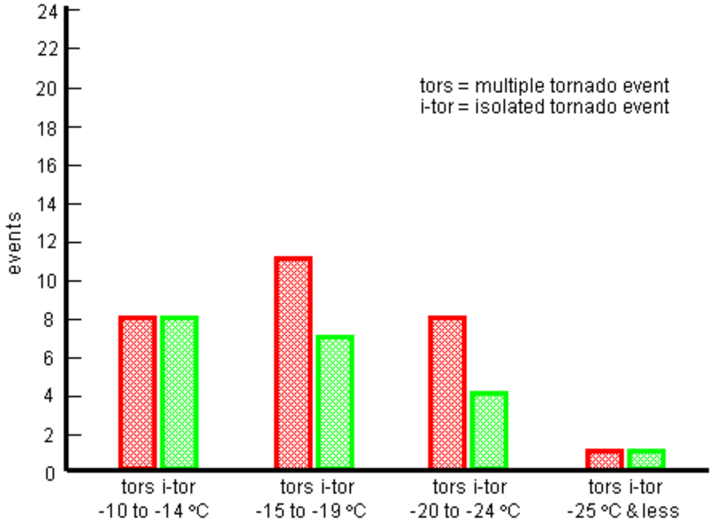

Fig. 2. *Temperatures near center of C500Ls associated with multiple (red bars) and isolated (green bars) tornado events from database in this study.*

2) To avoid inclusion of warm core tropical systems, the C500L system was selected only if the 500 mb temperature near the center of the low was –10 ^{o}C or less.

3) Surface dew points of 5 to 9 ^{o}C (low to mid 40's ^{o}F) or greater were present within 320 km (200 statute miles) to the east through south of the C500L to suggest moisture levels that might support *convective* precipitation reasonably close to the midlevel low.

The dew point guideline was chosen to ensure inclusion of severe events occurring with low surface dew points (Johns 1982).

It should be emphasized that the focus of this study was tornado events *occurring near the C500L* (within approximately 320 km/200 statute miles). These events were assumed to be associated directly with the C500L, and from the authors' experience are at times difficult to forecast because of surface dew points that appear insufficient to support severe thunderstorms. Surface dew points deeper within the warm sector and further from the midlevel low are often more suggestive of severe or tornadic potential.

Several features and characteristics of events were catalogued. These included 500 mb temperature near the low center, direction of movement of the C500L (speed was not specifically examined except to note C500Ls that were nearly stationary over a 24 hr period), maximum surface dew points within 320 km/200 statute miles to the east through south of the low center, and distance of any associated surface low and warm sector boundary intersection convergence area from the C500L. Seasonal frequency and geographical location were also examined.

3. Midlevel characteristics associated with C500L tornado events

Using the selection criteria from the previous section, there were 257 days during the period examined that involved C500Ls somewhere in the central or eastern U.S. accompanied by surface dew points suggesting potential for convection, shown in Fig. 1 by four arbitrary geographical regions of roughly equal size. If a midlevel low was located near or on the border of one of these regions, it was assigned to the region most affected by convection and any severe reports within 320 km/200 statute miles of the C500L.

From these days and criteria, 48 tornado events occurring near C500Ls were found. Of these events, 28 involved *multiple* tornadoes (more than 2 tornado reports), and 20 involved *isolated* tornadoes (only 1 or 2 tornado reports). These definitions were applied to separate the more prolific events (involving *several* tornadoes, more than 2) from those that appeared more isolated and often brief in nature. The figures in this section will show multiple and isolated tornado events separately because the multiple events tended to be associated with more significant tornadoes (see F-scales in Fig. 12 later in this paper).

Tornado events were categorized by temperature near the center of the associated C500L (Fig. 2). This information suggests that tornado events near C500Ls occur with a broad range of 500 mb temperatures, but appear to be rare when temperatures near the center of the low are colder than –25 ^{o}C.

Fig. 3 shows tornado events categorized by direction of movement of the C500L. Tornadoes were

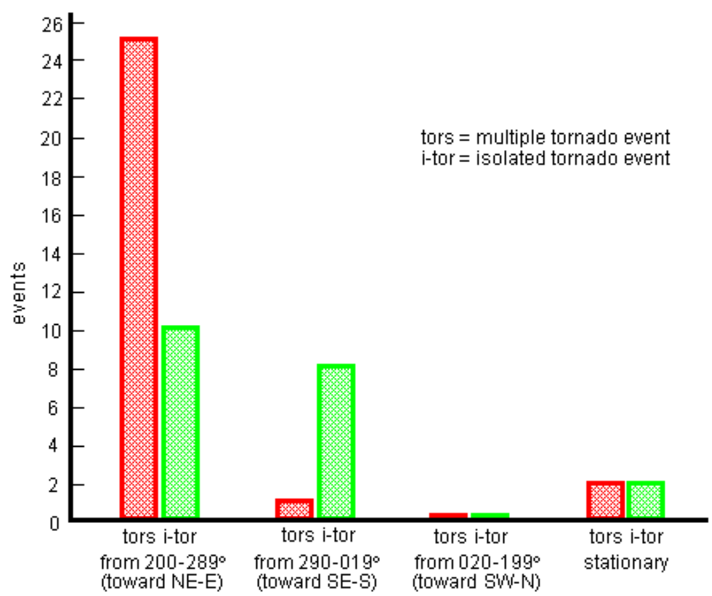

Fig. 3. *As in Fig. 2, except direction of movement of C500L.*

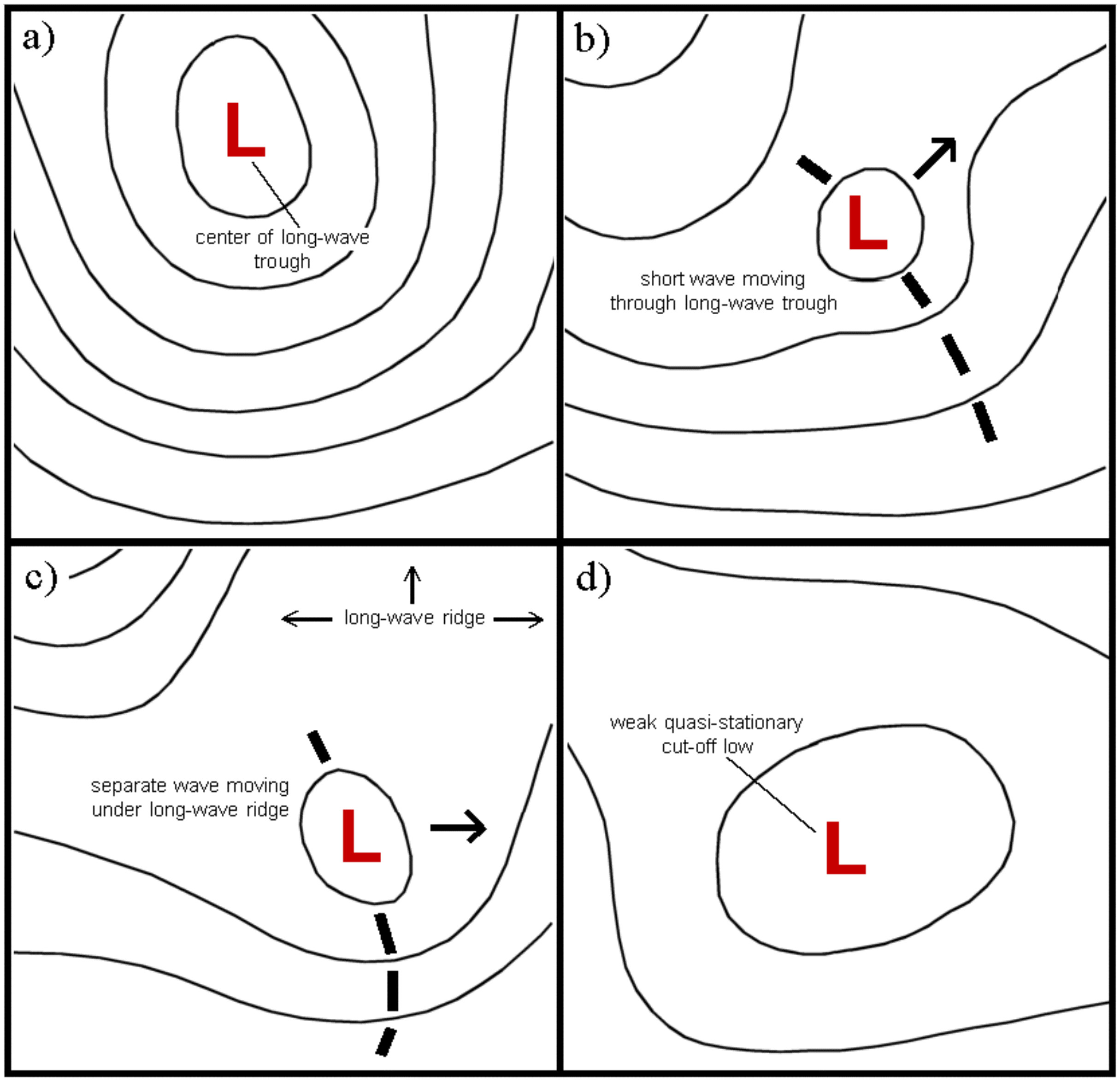

Fig. 4. *Examples of C500L "types" used as categories for this study.*

most associated with C500Ls that moved toward the east or northeast, instead of those that moved southeast or south, or were stationary. However, as will be seen in section 5, this tendency was a result of the general distribution of total days in the database among movement categories, and not a characteristic specific to tornado events. It still may be worth noting that multiple tornado events from Fig. 3 appeared to be most strongly associated with midlevel lows that moved in an easterly or northeasterly direction.

As illustrated in Fig. 4, C500Ls encountered in this study were found to be of four general "types": 1) lows anchored within the center of a long wave trough, 2) lows associated with a short wave moving through a long wave trough, 3) lows associated with a wave moving independent of long wave troughs and ridges, and 4) weak lows (often meandering or stationary) that were cut-off from significant midlevel flow. Tornado events were subjectively categorized into these types, although some events were difficult to categorize because of evolution from one type to another or borderline characteristics between types. In difficult cases, the event was put into the category that seemed the best fit from observing continuity on successive 500 mb charts, drawing on the authors' subjective experience and judgment. This resulted in Fig. 5, showing a fairly broad distribution between types. Tornadoes were least associated with weak cut-off C500Ls, and there was perhaps a slight tendency for tornadic events to favor C500Ls within waves that were analyzed as separate from and moving independent of long wave flow features.

It may also be worth noting that there was a tendency for C500Ls associated with events involving

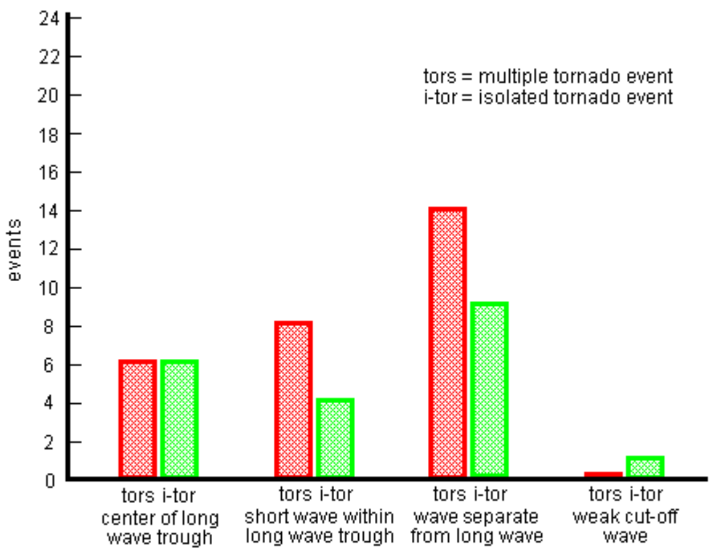

Fig 5. *As in Fig. 2, except C500L "type" as shown in Fig. 4.*

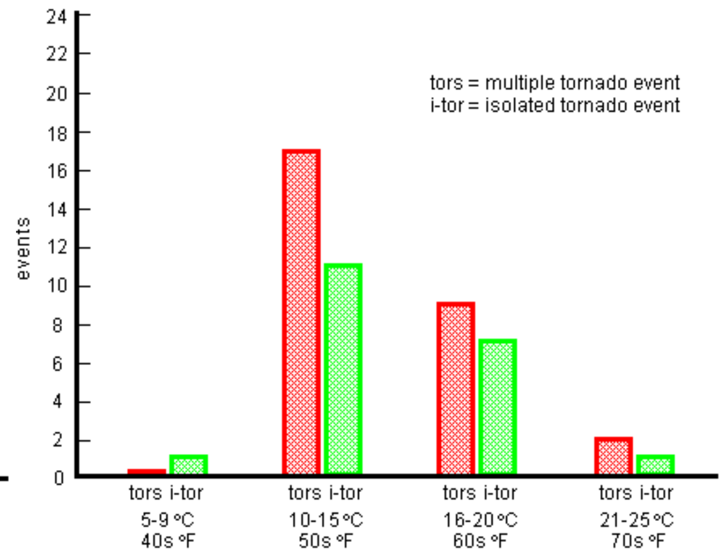

Fig. 6. *As in Fig. 2, except surface dew points associated with C500L tornado events.*

multiple tornadoes to be somewhat smaller in size (not shown). In 22 of the 28 multiple tornado events, the 500 mb closed contours spanned an area less than 640 km (roughly 400 statute miles) in width. Isolated tornado events were more evenly distributed between "smaller" and "larger" closed lows.

Evolution characteristics of C500Ls were also examined regarding whether the midlevel lows were closing off or opening up in the 24 hours prior to and following an event (not shown). No notable tendencies regarding tornado events emerged when examining these evolution characteristics.

4. Surface characteristics associated with C500L tornado events

Surface features and characteristics associated with C500L tornado events were found to be important elements of this study. Fig. 6 shows surface dew points associated with tornadic events occurring within 320 km/200 statute miles of the C500L center, grouped as "multiple" and "isolated" as defined in the prior section. It can be seen that tornadic cases occurring close to C500Ls in this study were associated almost exclusively with dew points of 10 ^{o}C (50 ^{o}F) or greater. It is worth noting that 25-30% of the tornado events were associated with surface dew points of 10-12 ^{o}C (low 50s ^{o}F), less than the 13 ^{o}C (55 ^{o}F) "limit" from Miller (1972) used by many forecasters to assess severe thunderstorm potential. Such events fall into the low dew point ranges associated with severe weather studied by Johns (1982), and reaffirm that some tornado events near C500Ls do indeed occur with what can appear to be marginal surface dew points.

Figs. 7 and 8 show the relative distance of surface lows and any notable surface boundary intersection "focus point", respectively, from the associated C500L in tornadic events (see Figs. 9 and 10 for examples). These features were examined separately because they are not the same, and were found to be at varying distances from the midlevel low, or in some cases absent or poorly defined. Figs. 7 and 8 suggest that tornadic cases with C500Ls in this study strongly favored the presence of a well-defined surface low with a nearby boundary intersection focus point, both located *less than 320 km or 200 statute miles* from the center of the C500L, typically to the east or southeast.

It is also interesting to note that tornado cases tended to favor surface lows that were displaced at

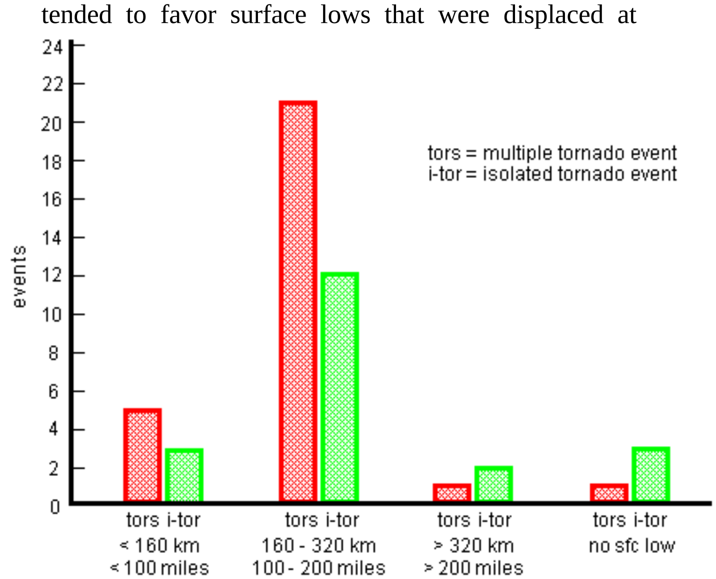

Fig. 7. *As in Fig. 2, except distance of surface low from C500L center.*

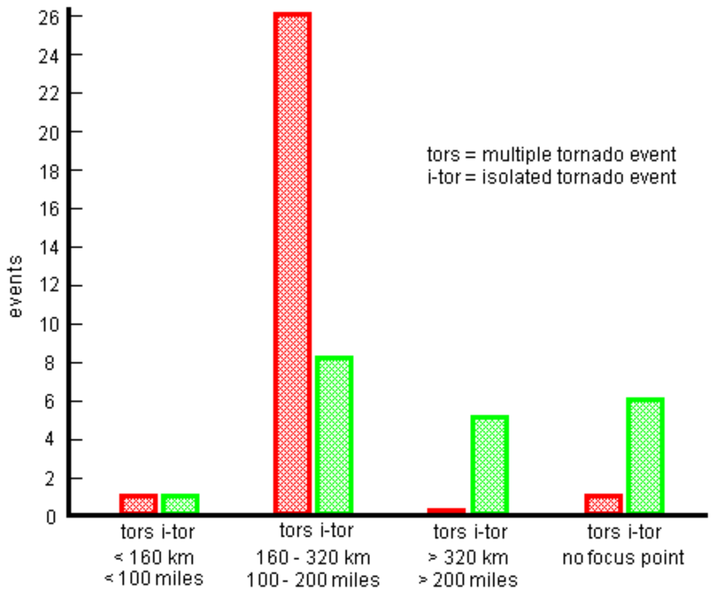

Fig. 8. *As in Fig. 2, except distance of surface boundary intersection "focus point" from C500L.*

least 160 km (100 statute miles) from the midlevel low center. This suggests that atmospheric low pressure systems that are vertically stacked (e.g., occluded) are not frequently associated with tornado events.

Figs. 7 and 8, and the dew point characteristics in Fig. 6, suggest the importance in C500L tornado events of an organized warm sector surface system with a minimal amount of moisture located within a certain distance of the midlevel closed low. Fig. 9 shows examples of surface system characteristics that, from this study, appear to increase likelihood of tornadoes within 320 km/200 statute miles of the C500L because of the proximity and alignment of surface features relative to the midlevel low. These are contrasted in Fig. 10 with examples of surface features suggesting decreased likelihood of tornadoes near the C500L.

5. Discrimination between tornadic and non-tornadic C500L events

Tables 1, 2, 3, and 4 show *all days* in the C500L database for this study broken down according to the midlevel low characteristics discussed earlier in section 3, here categorized by nonsevere, severe nontornadic, and tornadic (multiple and isolated events together). When looking for possible discriminating factors between tornadic and nontornadic C500L events, it can be seen from these tables that midlevel low characteristics *alone* did little to offer useful discrimination. As an example, Fig. 3 from section 3 suggested that movement of the midlevel low toward the east or northeast was a strong common factor for many C500L tornado events. However, it can be seen from Table 2 that the majority of C500Ls in the database moved toward the east or northeast and that the relative distribution of tornadic days by C500L movement was essentially the same as for all days in the database. Therefore, what appeared to be a possible discriminating factor for tornado events in Fig. 3 is in reality more likely the result of the general distribution of all days in the C500L database.

From examination of Tables 1, 2, 3, and 4, it does appear that a couple characteristics may offer some marginal discrimination for tornadic events compared to the general distribution of total days in the C500L database. These characteristics are midlevel low "type" (Table 3), showing a slight preference for tornado events to be associated with C500Ls within waves that were separate from long wave features (section 3 and Fig. 5), and size of the midlevel low

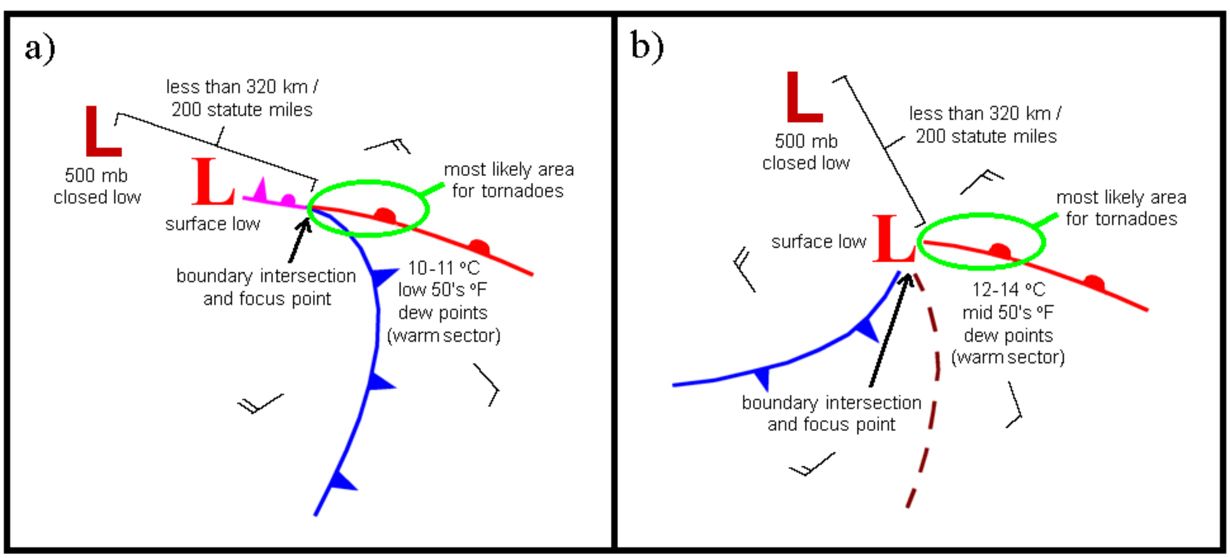

Fig. 9. *Examples of surface features (relative to C500L location) that increased likelihood of C500L tornado events in this study.*

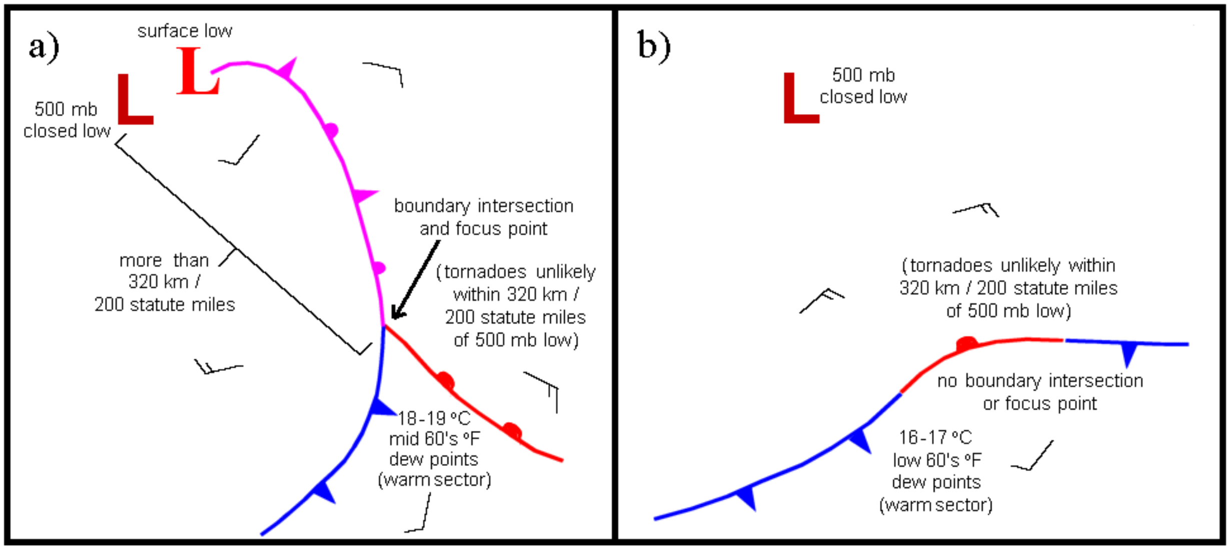

Fig. 10. *As in Fig. 9, except examples of surface features that <u>decreased</u> likelihood of C500L tornado events in this study.*

Table 1. Days in C500L database by temperature near center of 500 mb low

	-10 to -14 °C	-15 to -19 °C	-20 to -24 °C	≤ -25 °C
nonsevere (141)	25	35	56	25
severe nontornadic (68)	27	20	19	2
tornadic (48)	16	18	12	2
total	68	73	87	29

Table 2. Days in C500L database by direction of movement of 500 mb low

	NE-E	SE-S	stationary	other
nonsevere (141)	103	28	9	1
severe nontornadic (68)	35	19	12	2
tornadic (48)	35	9	4	0
total	173	56	25	3

Table 3. Days in C500L database by type of 500 mb low (see Fig. 4)

	center of L/W trough	S/W within L/W trough	wave separate from L/W flow	weak cut-off
nonsevere (141)	81	12	37	11
severe nontornadic (68)	29	3	28	8
tornadic (48)	12	12	23	1
total	122	27	88	20

Table 4. Days in C500L database by size of 500 mb low (width of largest closed 30 m contour)

	small (< 640 km / 400 mi)	large (≥ 640 km / 400 mi)
nonsevere (141)	63	78
severe nontornadic (68)	31	37
tornadic (48)	32	16
total	126	131

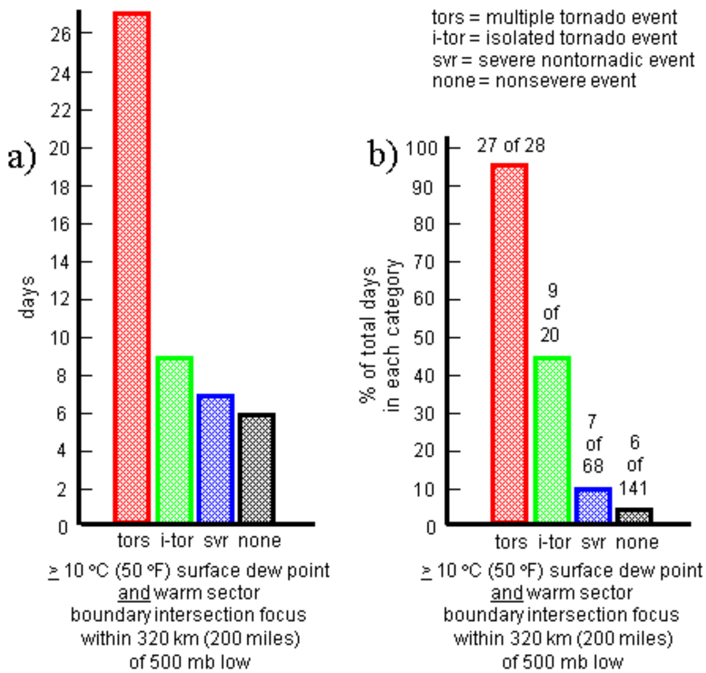

Fig. 11. *Number of days (a), and percentage of total days (b) in C500L database from this study when surface dew points were ≥ 10 °C (50 °F) and a warm sector boundary intersection "focus point" was found within 320 km (200 statute miles) of a C500L center, listed by categories. Red and green bars are multiple and isolated tornado events, respectively, blue bars are nontornadic severe events, and black bars are nonsevere events.*

(Table 4), showing a tendency for tornado events to be associated with C500Ls that are somewhat "smaller" in size (also section 3). However, these tendencies do not appear particularly strong, and require a larger database of events to determine their statistical significance.

Surface features and characteristics in proximity to midlevel lows appear to be the *most important* factors in offering useful discrimination between tornadic and nontornadic C500L events, as suggested in section 4. This was particularly true in the C500L database when only two factors, *surface dew point* and *location of a warm sector boundary intersection focus point*, were considered regarding their location relative to the midlevel low. Fig. 11 shows events/days from the C500L database (categorized by multiple tornadoes, isolated tornadoes, nontornadic severe, and nonsevere) that had dew points of 10 °C (50 °F) or greater *and* a warm sector boundary intersection focus point present within 320 km/200 statute miles of the C500L, similar to the examples in Fig. 9. It seems apparent from the information in Fig. 11 that C500L tornadic events, especially those involving multiple tornadoes, strongly favor the presence of a well-defined warm sector surface system with minimal moisture requirements in close proximity to the midlevel low.

6. Seasonal and geographical results

Fig. 12 shows monthly distribution of multiple and isolated tornado events from the 5-year sample examined for this study, along with maximum tornado

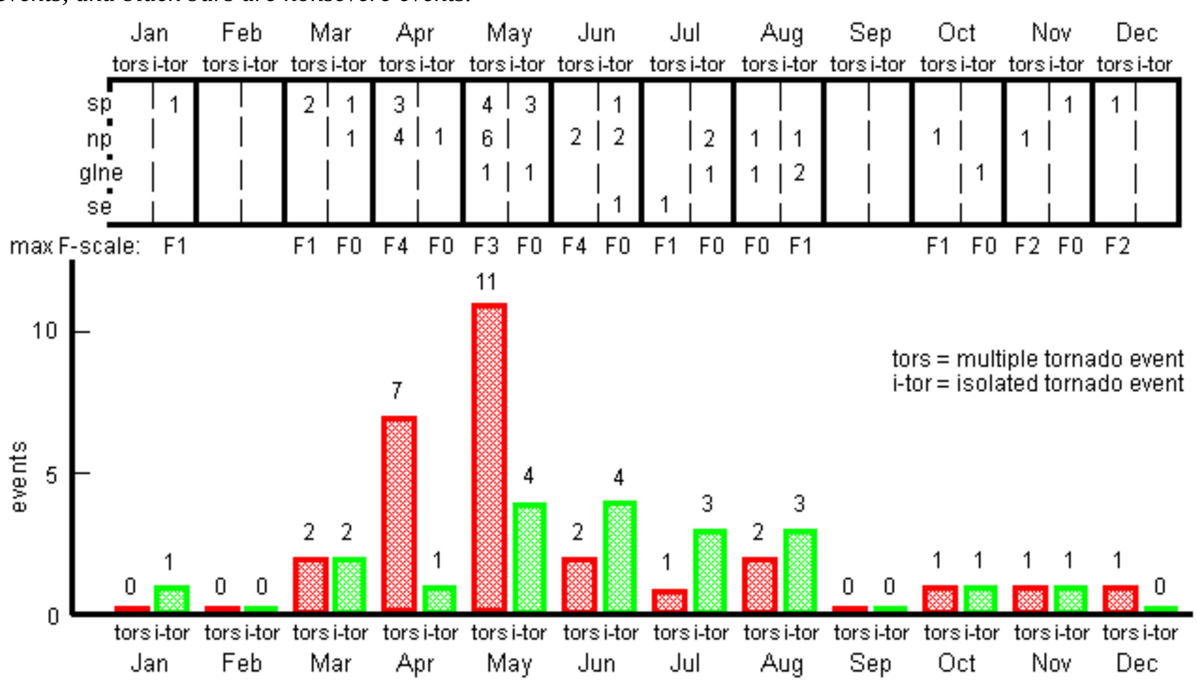

Fig. 12. *Monthly distribution of multiple tornado events (red bars), and isolated tornado events (green bars) in C500L database from this study, with geographical distribution by regions in Fig. 1 shown in boxes at top. Maximum tornado F-scale intensity associated with each grouping is also shown.*

intensity by F-scale in each month. April and May appeared to be the most active months for events involving multiple and more intense tornadoes (several of F2-F4 intensity) directly associated with C500Ls. This is roughly consistent with U.S. tornado climatology in general (e.g., Grazulis 1993).

Tornado events associated with C500Ls were also categorized by geographical region using the four areas of the U.S. depicted in Fig. 1 from earlier. This information is included in Fig. 12, which suggests that tornado events directly associated with C500Ls tend to occur in the Southern Plains earlier in the year, while tornado events in the Northern Plains carry over into the summer, again consistent with U.S. tornado climatology. Tornado events near C500Ls were least common in the southeastern U.S., and most common in the Plains. It is interesting to note that a couple of the Northern Plains multiple tornado events occurred during fall, including one in North Dakota (on 1 November 2000), suggesting that midlevel low systems late in the year over the northern United States can't be entirely ignored regarding tornado potential.

It should be emphasized that the seasonal and geographical information in Fig. 12 is *preliminary* because it covers only a 5-year period.

7. Conclusions and discussion

Results from this preliminary study suggest that tornado events close to and associated directly with C500Ls are most likely when:

1) Surface dew points are 10 ^{o}C (near 50 ^{o}F) or greater within 320 km (200 statute miles) east through south of the C500L center.

2) A surface boundary intersection focus point is located near or east of the surface low associated with the C500L, in the warm sector within 320 km (200 statute miles) east through south of the C500L.

As seen in examples from section 4 and Fig. 9, the surface focus point is typically an intersection of synoptic-scale boundaries such as a warm front and dryline joining dry, warm, and cool sectors just east of the surface low. In other cases, the intersecting boundaries may be more defined by surface wind shift axes than by air mass discontinuities. If tornadoes are involved, this study suggests that they are most likely to occur near this surface focus point of intersecting boundaries and associated convergence.

Although an assessment of near-storm environment was beyond the scope of this preliminary investigation, the above ingredients imply that a minimal amount of warm sector moist air was close to the C500L in near proximity to the cold pool aloft for the tornadic cases, generating instability and steep low-level lapse rates for rapid stretching within updrafts. The presence of a surface low and nearby boundary focus point also implies that convergence and *vertical vorticity* was available (e.g., Wakimoto and Wilson 1989), along with backed low-level winds that might in some cases generate additional shear (*horizontal streamwise vorticity*, Davies-Jones 1984) for tornadic storms as a result of environment enhancement near the boundaries (e.g., Maddox et al. 1980; Markowski et al. 1998).

While the close proximity of warm sector surface features to the midlevel low was important in this study, section 4 and Fig. 7 also suggested that tornadic C500L events tend to favor surface lows that are displaced slightly to the east of the midlevel low, roughly 160 km (100 statute miles) or more from the midlevel low center. Atmospheric low pressure systems that are vertically stacked with little or no separation between the C500L center and the surface low seem less likely to be associated with tornadic events.

Diurnal heating is a factor in most tornado events near a C500L (Goetsch 1988), and is one reason such events tend to occur in the afternoon or evening hours (Miller 1972). Surface temperatures were not tracked specifically for cases in this study as there was large seasonal variation, but results from sections 4 and 5 imply that *well-defined surface warm sector systems located in near proximity to a cold core low aloft* incorporated significant surface heating as an important ingredient, increasing local instability when marginal surface dew points were present.

Characteristics of midlevel lows *alone* showed no strong discriminating factors between tornadic and nontornadic cases in this study (section 5). There may be some tendencies, such as a preference for C500L tornado events in the database to be more associated with "smaller" midlevel lows, but these tendencies await a larger sample of events to confirm their significance. It may be worth noting that more significant C500L tornado events involving multiple tornadoes were almost exclusively associated with midlevel lows moving in a northeasterly or easterly direction (section 3 and Fig. 3), although it was also apparent from section 5 and Table 2 that the majority of C500L systems in the total database moved in a similar direction.

The seasonal distribution of tornadic events in this investigation associated with C500Ls east of the Rocky Mountains (section 6 and Fig. 12) tends to peak in the spring months (April and May). Such events appear least common in the southeastern United States. The fact that several of the multiple tornado events from this study involved F2-F4 intensity tornadoes illustrates that tornadoes occurring near C500Ls cannot be assumed to be weak or insignificant.

As noted in the introduction and seen from some events in this study, surface dew points near C500Ls that produce tornadoes can appear limited (e.g., 10-12 ^{o}C; low 50s ^{o}F) compared to dew points found deeper in the warm sector. On 187 of the 257 database days with C500Ls examined for this paper, severe weather not directly associated with the C500L center occurred a notable distance away within the warm sector. The combination of these factors in some C500L cases may encourage forecasters to focus more attention on areas of the warm sector characterized by larger dew points, and perhaps to overlook the possibility of tornadoes close to the midlevel low.

It is hoped that an awareness of ingredients and characteristics summarized in this study will help forecasters better recognize C500L systems that may have potential for tornadoes close to the midlevel low pressure center, particularly when the focus for severe weather is more obvious a greater distance from the C500L. Future work may explore additional C500L characteristics, and an expansion of the database in this study to a broader range of years is planned.

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