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INVESTIGATING DERECHO AND SUPERCELL PROXIMITY SOUNDINGS

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1. INTRODUCTION

Severe thunderstorm forecasting at the Storm Prediction Center is continuing to expand into a more probabilistic format, where specific forecasts of severe hail, winds and tornadoes are made up to 30 hours in advance. To successfully complete this task, forecasters need to correctly anticipate the primary *mode* in which the convection will develop and/or evolve into (i.e. discrete supercells versus a squall line). Though numerous modeling studies have examined the role of the thermodynamic and kinematic environments in determining convective mode (Weisman and Klemp 1986; Johns et al. 1993; Stensrud et al 1997), recent work by Bluestein and Weisman (2000) emphasizes other factors such as steering flow relative to the initiating mechanism in determining convective mode.

To address the challenges in discerning the primary mode of convection, we have accumulated proximity soundings associated with both derechos and discrete supercells. It can be argued that proximity soundings may not be representative of the *true* air mass and/or shear utilized by the storms; we concur with several studies that discuss the short-term modification of the surrounding environment ahead of MCSs and supercells (Brooks et al. 1994, Weisman et al. 1998). However, upper air soundings are still utilized operationally to aid in convective forecast and warning decisions, and they remain the primary tool for examining the vertical distribution of temperature, dew point, and wind data.

2. METHODOLOGY

2.1 Sounding Classification

In Evans and Doswell (2001; ED01) the authors obtained and analyzed 113 proximity soundings near 67 derechos. The period of study was 1983-1993, and cases were acquired in nearly every month of the year. To qualify as a proximity sounding, each sounding must have been taken within 2 hours and 167 km (100 mi) of the derecho's wind damage path, or the derecho's location as identified by radar composite charts. Further, the soundings were subjectively judged to be uncontaminated by convection and representative of the inflow air mass.

To assess the different environments supportive of derechos, the data set was subdivided into 3 categories based on a subjective analysis of the synoptic scale "forcing" associated with each event. Those occurring ahead of an advancing high-amplitude midlevel trough with an accompanying strong surface cyclone were considered "strong forcing" (SF) events. Derechos that developed and persisted within benign synoptic environments were labeled "weak forcing" (WF). Events which did not clearly fit either of the above two categories were classified as "hybrid" events.

Proximity soundings for 98 discrete supercells were also collected, using the same criteria, in order to develop a comparison database. The supercells were subjectively identified utilizing real time WSR-88d reflectivity and storm-relative velocity radar data from 1998-2000. A cell was determined to be a *supercell* if it maintained rotation in the 0.5^o elevation scan for at least 30 minutes. In addition, a supercell was only included if it remained *discrete*, in order to eliminate storms which were embedded within extensive squall lines or derechos. All of the supercells produced ¾" hail, 58 mph winds, wind damage and/or tornadoes. The dataset was stratified into non-tornadic and tornadic categories. To qualify as non-tornadic the storm must have been severe, but did not produce a report of a tornado. Tornadic supercells were associated with a report of any tornado. The tornadic supercells were further classified into significant tornadic (F2-F5) and weak tornadic (F0-F1) supercells.

2.2 Data Collected

Temperature and dew point data were collected at the surface and at 25 mb intervals for each of the proximity soundings. In addition, the *U* and *V* wind components were obtained for each sounding at 0.5 km intervals from the surface through 10 km AGL. The data were interpolated as needed. Several severe thunderstorm parameters were computed from each sounding, including 0-3 km AGL storm-relative helicity (SRH), Bulk-Richardson Number (BRN) and Energy-Helicity Index (EHI). Statistical analyses were computed for the various parameters and for temperature, dew point and wind component data at each level. For each of the classifications, skew-T plots of temperature/dew point and hodographs were

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constructed. Plots were created for the means and the 10th, 25th, 75th and 90th percentiles.

The speed and direction of movement of each derecho and supercell were obtained so that system-relative wind plots could be developed by subtracting the *U* and *V* components for each system motion from the ambient wind components at each level. Statistical plots were created for each of the derecho and supercell categories to examine the differences in storm-relative flow from the surface through 10 km AGL.

3. RESULTS

Using the above-mentioned criteria, 51 WF, 47 SF and 15 Hybrid derecho proximity soundings are included in this study. In addition, 46 non-tornadic and 52 tornadic supercell proximity soundings are used. Of the 52 tornadic supercells, 18 are associated with significant tornadoes and 34 with F0 or F1 tornadoes.

3.1 Thermodynamics

Figure 1a reveals WF derechos exist in a warmer environment and moister boundary layer on average, as compared to the SF events. The SF events have the coolest temperature profile, while the Hybrids are in between the SF and WF derechos (not shown). This is consistent with ED01 who found WF events are associated with greater instability. WF events in this dataset only occur during the warm season from May to August, while SF cases occur year round and include many cool season events. The derecho mean soundings (Fig. 1a) also reveal a dry layer and associated steep lapse rate in the mid troposphere, which suggests the most common source region for evaporation and enhancement of the downdraft may extend from just above the boundary layer into the mid troposphere. However, a well-mixed and dry sub-cloud layer can also support an enhanced downdraft and cold pool, with a resultant path of damaging surface winds (Corfidi 2000).

In contrast to the derecho events, the mean soundings for tornadic versus non-tornadic supercells are very similar; there is also very little difference evident between the non-tornadic and weak tornadic events (not shown). Only the significant tornadic supercells exhibited noticeable separation from the other supercell categories (Fig. 1b). These events clearly have a lower temperature-dew point spread from the surface through 850 mb. When relative humidity is examined, significant tornadic supercells occur within the highest boundary layer RH on average (Fig. 2). In contrast, these cases have the greatest drop-off in RH between 800 mb and 700 mb. In fact, the significant tornadic supercells have the lowest mean 700-500 mb RH of the six datasets (including the derechos)! This suggests mid-level drying *alone* cannot be used to determine the potential for sustained, long-lived wind damage; downdrafts might be as strong or stronger on

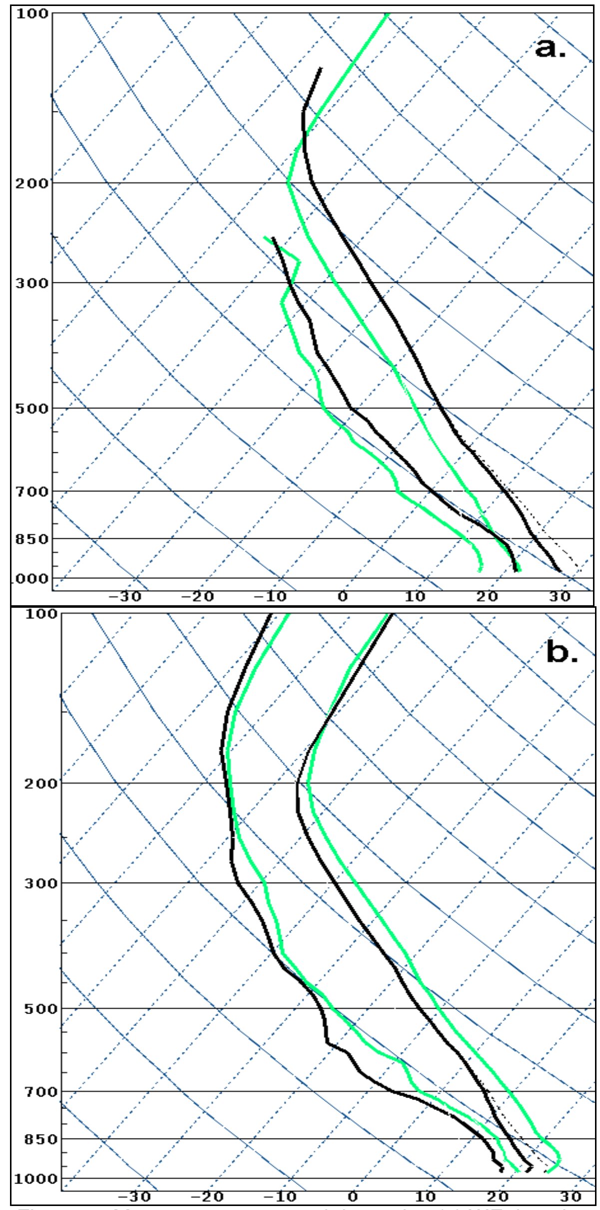

Figure 1. Mean temperature and dew point. (a) WF derecho (black) versus SF derechos (gray), (b) F2 or greater tornado (black) versus F0-F1 tornado (gray).

average in significant tornadic supercells as compared to derechos, assuming evaporation is the *primary* physical process in the production of strong downdrafts. In addition, the non-tornadic supercells show the lowest mean RH through 800 mb, followed closely by the weakly tornadic cases. This suggests boundary layer RH may be helpful in discriminating between not only tornadic and non-tornadic supercells, but also significant and weak tornadoes. Given the close association of boundary layer RH and LCL height, our findings support the belief that tornado potential and strength increase as boundary layer RH increases (LCL decreases) (Rasmussen and Blanchard 1998, Markowski et al. 2000, Johns et al. 2000).

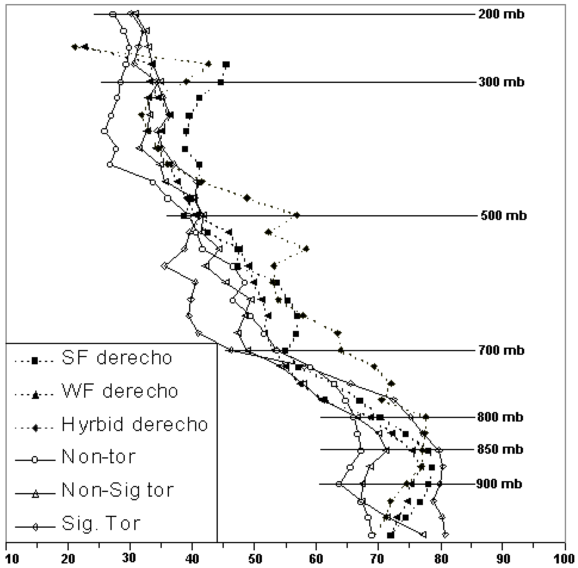

Figure 2. Average relative humidity every 25 mb from 975 mb through 200 mb.

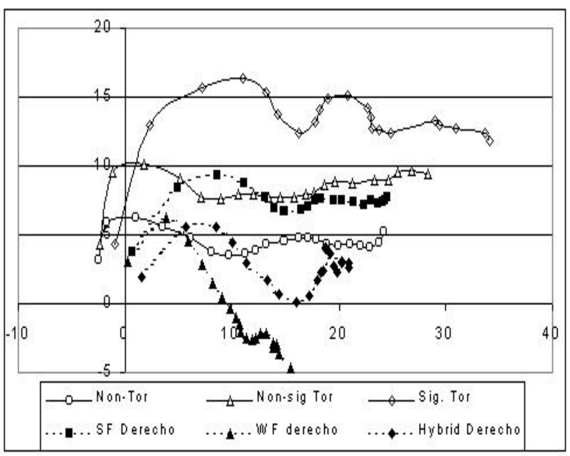

Figure 3. Mean hodograph plots (m s^{-1}) at 500 m intervals from the surface through 10 km AGL.

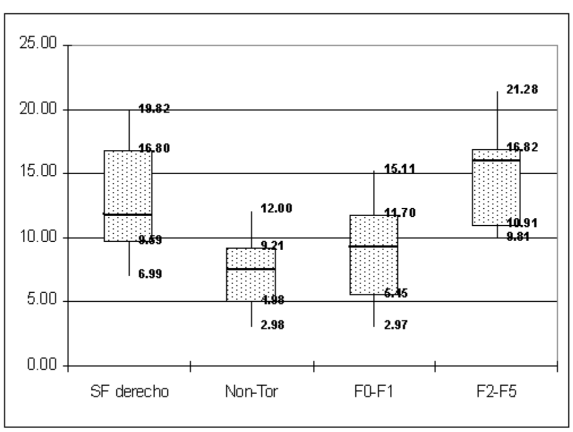

Figure 4. Box and whisker plot of 0-1 km AGL shear (vector difference) in m s^{-1}. Lower and upper values denote 10^{th} and 90^{th} percentiles, respectively. Boxes represent the 25^{th} through 75^{th} percentile values. Solid lines depict medians.

3.2 Hodographs

A plot of composite hodographs reveals distinct differences between the three derecho categories (Fig. 3). SF events occur in stronger flow and shear than the hybrid and WF cases, and they have a much longer hodograph. This is consistent with the shear magnitude findings from ED01. The WF and hybrid hodograph plots are similar in structure below 4 km AGL; however, the hybrid cases are associated with stronger winds throughout the hodograph on average. In addition, the WF derechos indicate a pronounced northwest flow signal with near uniform, northwesterly flow in the midtroposphere (i.e. northwesterly 3-6 km AGL winds around 10 m s^{-1}), which is consistent with Johns and Hirt (1987).

Figure 3 also indicates that significant tornadic supercell hodographs are much larger on average than all other categories. The SF derechos and tornadic supercells occur in similar wind fields, with strong shear in the lowest 1 km AGL (Fig. 4) and pronounced clockwise turning in the lowest 3 km AGL on average. Though the mean hodographs suggest significant tornadic supercells occur in stronger wind environments than SF derechos, further examination (not shown) indicates that the mean SF derecho hodograph falls well within the middle 50 percent of all significant tornadic supercells in our dataset (and vice-versa). This suggests that hodographs of significant tornadic supercells and SF derechos can be very similar; distinguishing between the two events from hodograph structure alone is quite problematic.

3.3 System-Relative Winds

When system-relative winds are examined (Fig. 5), it is apparent that derechos are associated with the strongest inflow in the lowest 1 km AGL. In addition, WF events develop and persist in environments with deep system-relative inflow (front-to-rear flow) from the surface through 8-9 km AGL. In contrast, the supercell dataset reveals pronounced rear-to-front flow above 2-3 km AGL, especially for the significant tornadic events. This is markedly evident above 4 km AGL, where only the supercells indicate rear-to-front system-relative flow increasing through 10 km AGL. These results are consistent with studies that found the distribution of hydrometers and precipitation is strongly influenced by the mid- and upper-level wind fields *relative* to the system's motion (Brooks et al. 1994, Thompson 1999, Rasmussen and Straka 1998, Parker and Johnson 2000).

3.4 Computed parameters

0-3 km SRH (Fig. 6) has some merit in distinguishing between the different supercell categories, especially between non-tornadic and significant tornadic events. However, EHI (Fig.7) appears to be better at distinguishing the tornado

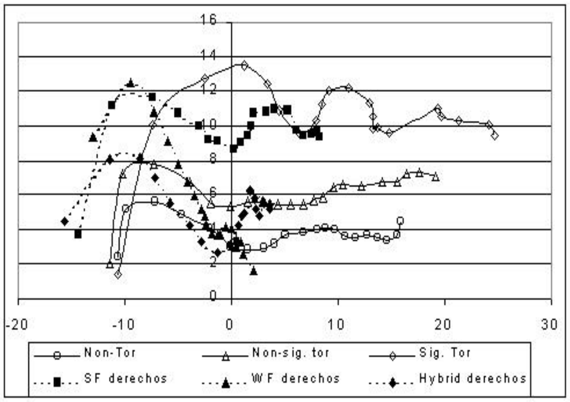

Figure 5. Mean system-relative winds (m s^{-1}) every 500 m from the surface through 10 km AGL. Each sounding was normalized to set the origin equal to the storm motion; every point to the left of the y-axis represents relative inflow.

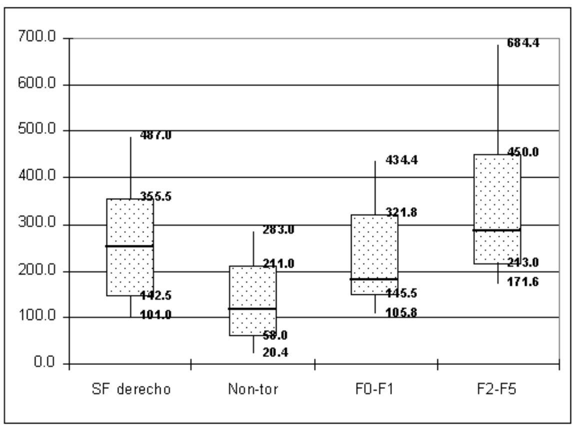

Figure 6. Same as figure 4, except for 0-3 km AGL storm-relative helicity.

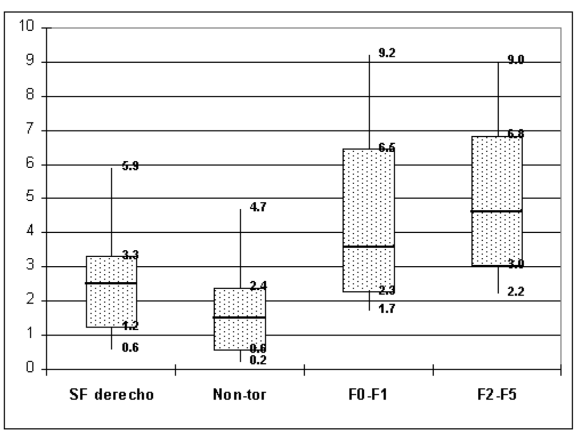

Figure 7. Same as figure 4, except for Energy helicity index.

threat, with values in excess of 2.5 encompassing 75% of the tornado cases, but only 25% of the non-tornadic supercells.

Neither 0-3 km AGL SRH or EHI show much ability to distinguish between weak and significant tornadic supercells. 0-1 km AGL shear (Fig. 4) clearly is the most useful in this regard; 10 m s^{-1} of 0-1 km shear separates the significant tornadic supercells from all but 25% of the non- and weak tornadic supercells.

To complicate matters further, the SF derecho and significant tornadic supercells occur in environments with comparable values of 0-1 km AGL shear and 0-3 km AGL SRH. However, EHI appears to have merit in distinguishing between environments favorable for significant tornadoes versus SF derechos.

4. DISCUSSION

These results indicate proximity soundings can be useful in distinguishing between the risk of tornadoes, and/or derecho formation, *if convective mode can be correctly anticipated!*

The large-scale organization of convection appears to be strongly associated to the distribution of hydrometeors *relative* to the recurring updrafts. Average system-relative winds above 4 km AGL are noticeably different between derechos and discrete supercells; rear-to-front flow progressively increases above this layer with discrete supercells. This suggests distribution of stratiform precipitation to the rear of the leading line of convection is paramount in derecho maintenance (especially in the absence of fast moving short wave troughs and strong large scale ascent). In contrast, advection of hydrometeors at the mid and upper levels must occur downwind from the updrafts in discrete supercells.

When discrete convection is anticipated, EHI and, to a lesser degree 0-3 km SRH, appear most useful in distinguishing between non-tornadic and tornadic supercells. Once this is evident, 0-1 km shear, boundary layer RH (LCL height) and system-relative wind magnitude seem to have the most merit in distinguishing significant tornadoes from weaker ones. In fact, boundary layer relative humidity clearly distinguishes significant tornadic supercells from any other category investigated here.

Though these results suggest several parameters can be used to distinguish between the different supercell and derecho categories, differentiating between the two distinct convective modes in advance is still extremely challenging. This is especially true along and ahead of an approaching cold front and a progressive upper-level trough, or conditions defined as “strongly forced”. SF derecho events clearly develop and persist within similar thermodynamic and kinematic environments as discrete tornadic supercells, which makes singling out the specific severe weather threat difficult. It appears that a number of complexities, such as how the storms are initiated or how storms move relative to surface fronts, can dictate whether convection will develop and evolve as discrete or linear convection.

5. REFERENCES

Available upon request.