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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/or tornadoes are made up to 30 hours in advance. To 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.

Given the problems in discerning the primary mode of convection, we have accumulated a number of 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; and 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 forecast and occasional warning decisions, and they remain the primary tool for examining the vertical distribution of temperature, dew point, and wind data near deep, moist convection.

2. METHODOLOGY

2.1 Sounding Classification

In ED01, the authors obtained and analyzed 110 proximity soundings near 67 derechos. The period of study was from 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 air mass fueling the derecho.

In order 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 an attempt to develop a comparison database. The supercells were subjectively identified utilizing real time WSR-88d reflectivity and storm-relative wind radar data from 1998-2000. A cell was determined to be a *supercell* if it maintained a low level rotation in the 0.5^{o} scan that lasted 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 the supercells produced some type of severe weather, as defined by the National Weather Service, and the dataset was stratified into the following categories: Non-tornadic, Tornadic, Significantly tornadic and weakly tornadic. 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. Significantly tornadic supercells produced a tornado with damage qualifying the tornado as F2 or greater using the Fujita Scale. Weakly tornadic supercells produced no stronger than a F0-F1 tornado.

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. The data was interpolated as needed. In addition, several severe thunderstorm parameters were computed from each sounding, including 0-3 km storm-relative helicity, Bulk-Richardson Number (BRN), BRN-shear, and Energy-Helicity Index (EHI). Statistical analyses were computed for the various parameters and for temperature, dew point and wind component data at

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each level. This allowed plots of temperature and dew point to be made on a skew-T, and hodographs to be developed for each of the categories. Plots were created for the means and the 10th, 25th, 75th and 90th percentiles.

The speed and direction of each derecho and supercell motion were obtained so that storm-relative wind plots could be developed by subtracting the *U* and *V* components for each storm 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.

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 (not shown). Although this may be a reflection of climatology, it 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 PBL into the mid troposphere for derecho environments. 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 practically no different, with very little difference evident between the non-tornadic and weakly tornadic events (not shown). Only the significantly tornadic supercells indicated any noticeable separation from the other supercell categories (Fig. 1b). These events clearly have lower temperature-dew point spread from the surface through 850 mb. Significantly tornadic supercells occur within the highest boundary layer RH on average (Fig. 2). In contrast, these cases surprisingly have the greatest drop-off in RH between 800 mb and 700 mb. In fact, the significantly 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 stronger or on average in significantly tornadic supercells as compared to derechos. 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).

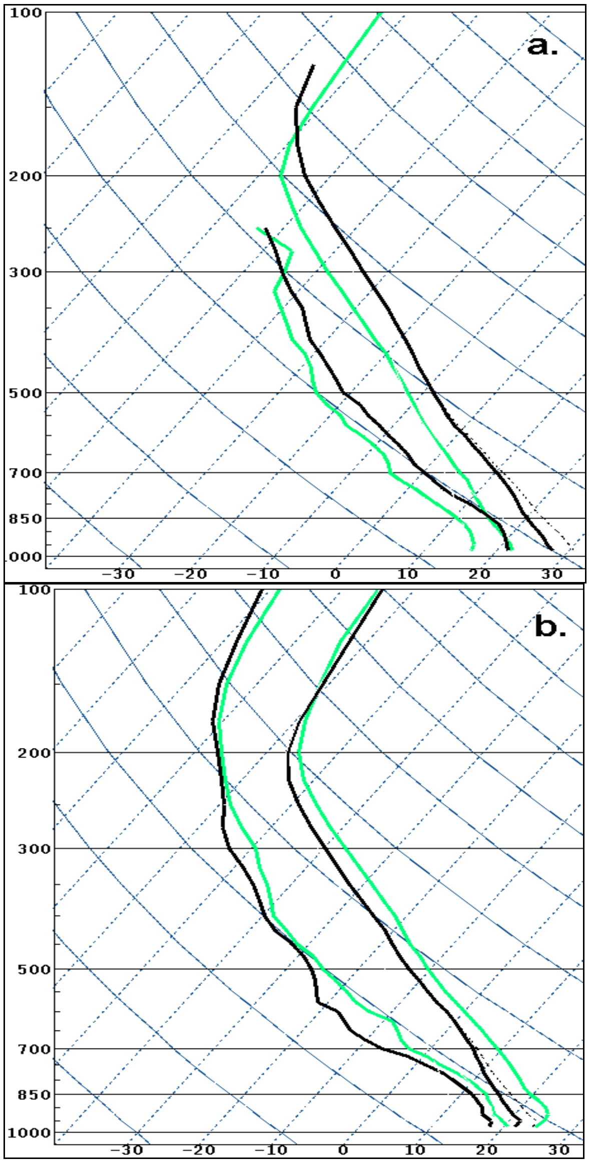

Figure 1. Mean temperature and dew point. (a) WF derecho (black) versus SF derechos (gray), (b) F2 or greater tornado (black) versus F0-F1 tornado (gray).

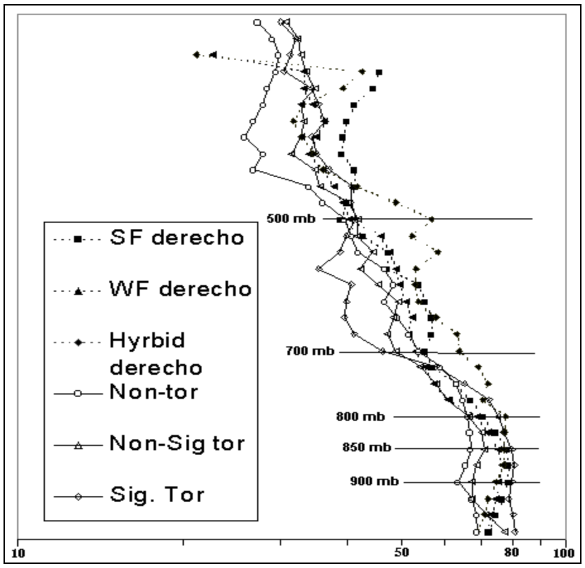

Figure 2. Average relative humidity every 25 mb from 975 mb through 200 mb.

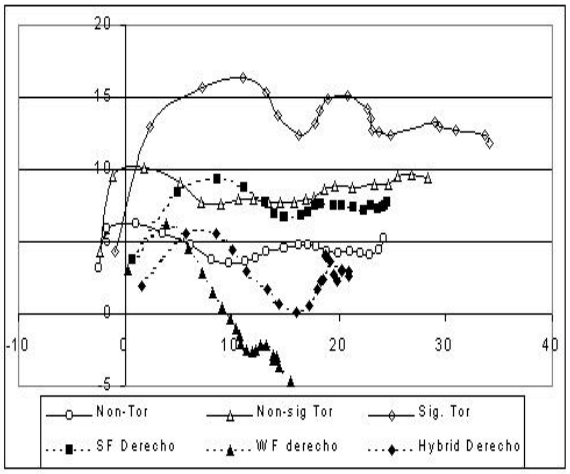

Figure 3. Mean hodograph plots (m s^{-1}).

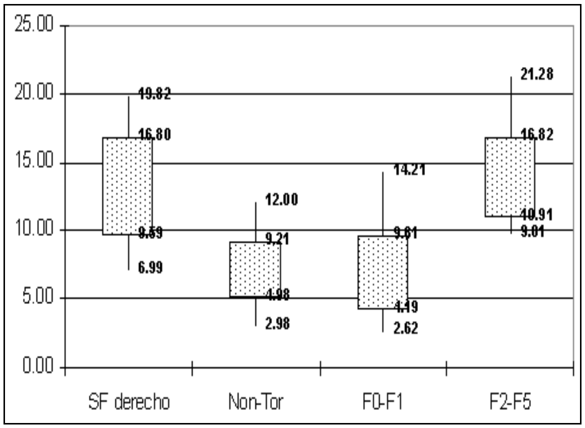

Figure 4. Box and whisker plot of 0-1 km shear (vector difference) in m s^{-1}. Lower and upper values denote 10th and 90th percentiles, respectively. Boxes represent the 25th through 75th percentile values.

3.2 Hodographs

A plot of composite hodographs reveals distinct differences between the derecho categories (Fig. 3). It is readily apparent that SF events occur in stronger flow and shear than the hybrid and WF cases, with a much longer hodograph plot. This is consistent with the shear magnitude findings from ED01. The WF and hybrid hodograph plots are similar in structure below 4 km; however, the hybrid cases are associated with stronger winds throughout the hodograph on average. In addition, the WF derechos indicate a strong northwest flow signal with near uniform, northwesterly flow in the midtroposhere (i.e. northwesterly 3-6 km winds around 10 m s^{-1}), which is consistent with Johns and Hirt (1987). The uniform flow in the mid-troposphere for the WF events suggests cell motions might be nearly identical to the preferred gust front motion on average. This maximizes both the inflow of high values of theta-e air and the time that convective elements maintain convergence along the leading edge of the cold pool (Weisman and Klemp 1986).

Figure 3 also indicates that the significantly tornadic supercell hodographs are much stronger on average than any other category, as would be expected. The SF derechos and tornadic supercells occur in similar wind fields, with strong shear in the lowest 1 km (fig. 4) and pronounced turning in the lowest 3 km on average. Though the mean hodographs suggest significantly 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 significantly tornadic supercells in our dataset (and vice-versa). This suggests that hodographs of significantly tornadic supercells and SF derechos can be very similar, and makes distinguishing between the two events quite problematic.

3.3 Storm-relative winds

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

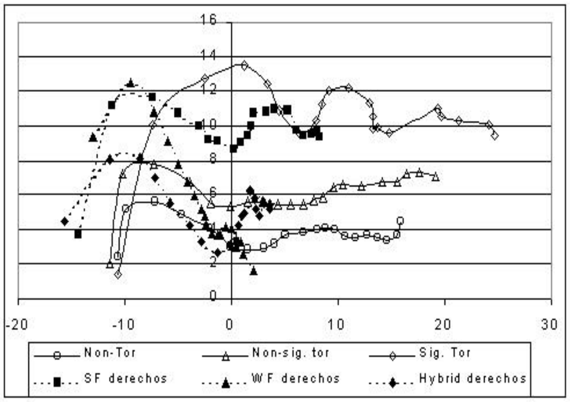

Figure 5. Mean storm-relative winds (m s^{-1}) every 500 m from the surface through 10 km. Each sounding was normalized to set the origin equal to the storm motion; every point to the left of the y-axis represents relative inflow.

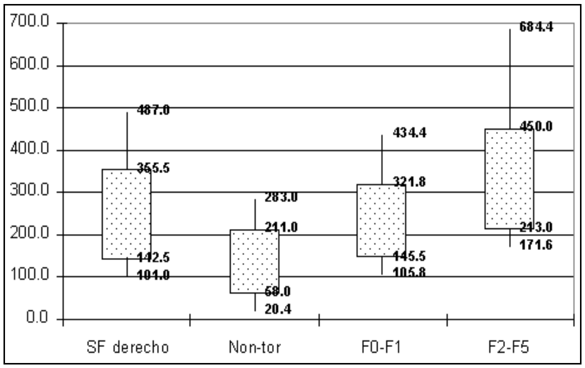

Figure 6. Same as figure 4, except for 0-3 km storm-relative helicity.

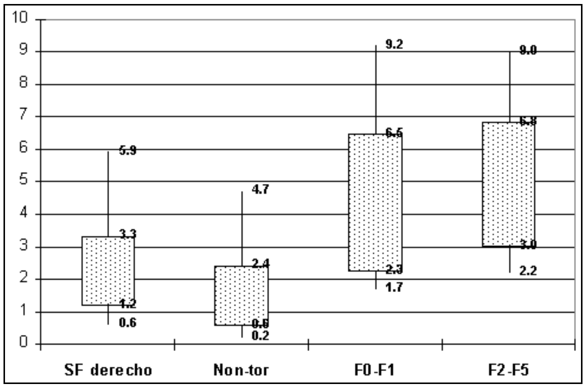

Figure 7. Same as figure 4, except for Energy helicity index.

3.4 Computed parameters

Both 0-3 km SRH (Fig. 6) and BRN-shear (not shown), have some merit in differentiating between the different supercell categories, especially between non-tornadic and significantly tornadic events. Though EHI (Fig. 7) appears to be best at distinguishing the tornado threat, with values in excess of 2.5 encompassing 75% of the tornado cases, and only 25% of the non-tornadic supercells.

Neither 0-3 km SRH, BRN-shear, or EHI are clear in distinguishing between weakly and significantly tornadic supercells. 0-1 km shear (Fig. 4) clearly is the most useful in this regard; 10 m s^{-1} of 0-1 km shear separates the significantly tornadic supercells from all but 25% of the non- and weakly tornadic supercells.

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

4. DISCUSSION

These results indicate proximity soundings can be useful in distinguishing 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. Storm relative winds above 4 km 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 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 delineating between non-tornadic and tornadic supercells. Once this is evident, 0-1 km shear, boundary layer RH (LCL height) and storm relative wind magnitude seem to have the most merit in distinguishing significant tornadoes from weaker ones. In fact, boundary layer relative humidity clearly distinguishes significantly tornadic supercells from any other category investigated here.

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

5. REFERENCES

Available upon request.