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A PRELIMINARY INVESTIGATION OF DERECHO-PRODUCING MCSs IN ENVIRONMENTS OF VERY LOW DEWPOINTS

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1. INTRODUCTION

Because of the damaging winds and other severe weather threats with which they are associated, derecho-producing mesoscale convective systems (MCSs) pose an important challenge to forecasters (Wakimoto 2001). In late spring and summer, derecho MCSs typically occur in environments of substantial convective instability, with very moist boundary layer inflow (Johns and Hirt 1987). During the cool season (October through April), when derechos are more commonly associated with amplifying disturbances in the westerlies, they occasionally occur in environments of only modest convective instability (e.g., Wolf 1998, Evans and Doswell 2001, Burke and Schultz 2004). Nevertheless, lower tropospheric moisture content in such situations is typically above seasonal norms.

More rarely, derecho-producing MCSs occur in environments of very limited moisture (surface dewpoints at or below 10 C and/or mean precipitable water at or below 1.25 cm) and correspondingly low convective available potential energy (CAPE). Such systems have been observed throughout the year and over much of the continental United States. Because low dewpoint derechos (LDDs) develop in environments not commonly associated with widespread severe convective weather, these events sometimes catch forecasters by surprise (e.g., Fenelon 1998, Corfidi 2003).

This paper examines the synoptic and mesoscale environment associated with eight LDDs that have been identified over the continental United States since the mid 1970s. Emphasis is placed on those factors that appear to be most strongly associated with LDD initiation and sustenance in an attempt to better anticipate these uncommon events.

2. METHODOLOGY

The cases studied were selected on the basis of data availability and knowledge of the event by the authors (Table 1). A more exhaustive search will be performed at a future date to identify other LDDs undoubtedly present in the Storm Prediction Center

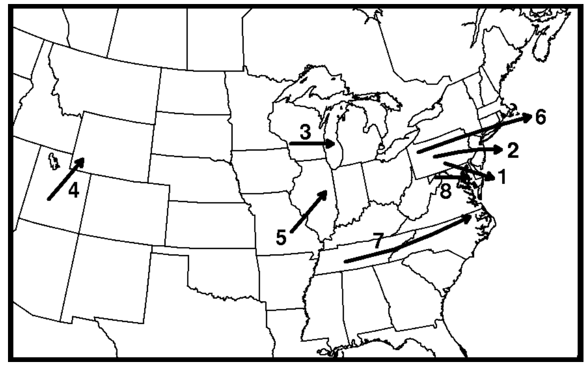

Figure 1. Paths taken by LDD events studied. Numbers refer to cases listed in Table 1.

(SPC) severe weather database. Care was taken to eliminate any cases for which the convection did not appear to be surface-based. The surface dewpoint criterion used --- aerially averaged values at or below 10 C --- excluded cases involving strongly forced convective bands occurring in environments of intense low level shear and nearly moist adiabatic thermodynamic profiles along cold fronts associated with cool season extratropical cyclones.

In accordance with Johns and Hirt (1987) and Coniglio et al. (2004), each LDD produced a continuous swath of non-random, convective wind damage and/or measured convective gusts in excess of severe limits (≥ 58 kts (26 ms^{-1})). The path length criterion, however, was reduced to 200 km to include a sufficient number of cases to create meaningful composites.

The data set includes both warm and cool season LDDs that affected wide-ranging parts of the country (Figure 1 and Table 1). The systems collectively caused at least a dozen injuries in addition to significant damaging wind. Measured gusts in three cases exceeded 80 kts (40 ms^{-1}). Average surface dewpoints were 17 C for the 5 July 1997 event over Tennessee and North Carolina. The case was nevertheless included as moisture was unusually sparse (precipitable water values at or below 1.5 cm) for a day with significant severe convection, given the location and time of year. While average event duration was approximately four hours, two of the LDDs lasted more than six hours. Three of the systems which affected the eastern United States were producing damaging winds as they moved into

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Table 1. List of events studied. Time refers to that of radiosonde observation used in creation of composite maps. Symbol "+" in length column denotes cases for which severe weather was occurring as convective system moved beyond the continental United States.

Case	Date (yymmdd)	Time (UTC)	Location	Length (km)
1	770509	0000	PA / MD	250+
2	891121	0000	PA / NJ	450+
3	940419	0000	WI / MI	300
4	940531	1200	UT	350
5	941121	0000	MO / IL	350
6	950404	1200	PA / NY	650+
7	970705	0000	TN / NC	900
8	010314	0000	VA / MD	200

the Atlantic. Average translational speed was 50 kts (25 ms^{-1}).

Similar to the methodology followed by Johns et al. (1990), composite charts were prepared to depict mean observed conditions at the surface and at the 925, 850, 700, 500 and 250 mb levels. The data obtained for each event and for each level were collected using a transparent, 6 x 6 grid overlay that covered 5 million km^2. The 450 km grid spacing used roughly approximates that of the radiosonde network in North America. Hand-drawn analyses were employed to incorporate radar and satellite data (where available), and to maintain thermal and moisture gradients so identified. Average values of observed geopotential height, temperature, dewpoint, wind speed and direction were then determined for each grid point. Values were also tabulated for an additional point at the center of the grid. This point was positioned at the centroid of wind damage and severe gust reports for each event contained in the SPC database. Wind compositing was accomplished by calculating arithmetic means of direction and speed.

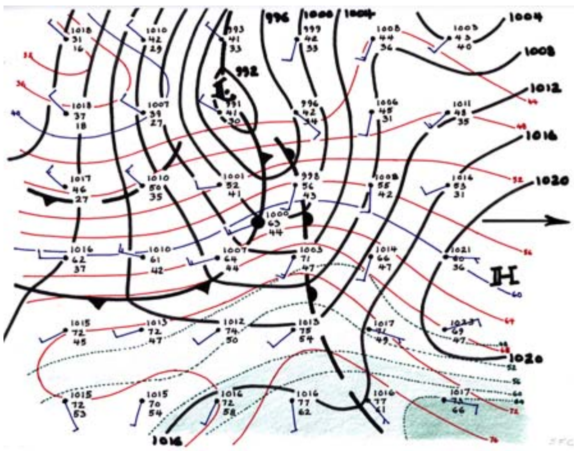
In contrast to Johns et al. (1990), the grid overlay was aligned along the direction of predominant forward motion of the MCS, with the center of the grid placed on the centroid of damage and gust reports. This was done to account for the fact that LDDs occur in a wide variety of large scale flow patterns, and to limit the loss of detail due to the averaging process. A line drawn through the major axis of the reports was used to identify path direction. The time and location of the first and last reports defined event path length and duration.

The radiosonde data times (0000 or 1200 UTC) selected for analysis were those believed to be most representative of the MCS initiation environment. The midpoint time of each event was less than three hours removed from the selected radiosonde time for six of the eight events. For two cases (31 May 1994 and 21 November 1994), the selected radiosonde times preceded the event by nearly 6 hours, but the data nevertheless appeared to be representative of conditions at event initiation. Surface charts valid three hours prior to or three hours following selected radiosonde time were used in three cases to better depict conditions associated with event initiation. Because of their comparatively short duration relative to the twice daily radiosonde cycle, no attempt was made to identify separate "beginning," "mid point" or "end time" conditions for the events.

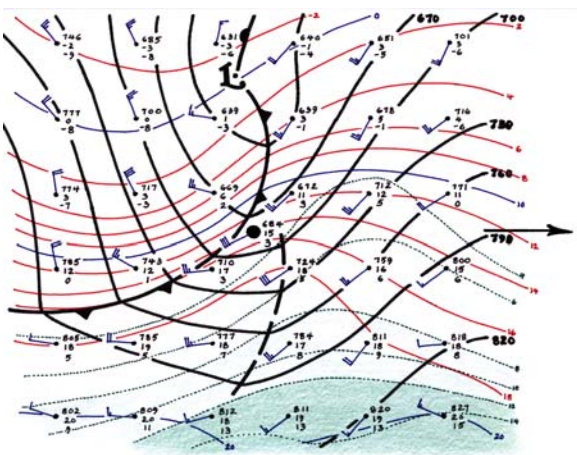
3. RESULTS

Not surprisingly perhaps, the composite charts in Figure 2 depict mean kinematic and thermodynamic patterns that differ notably from those normally associated with long-lived derechos (e.g., Johns et al. 1990). In particular, a decided cyclonic pattern is apparent at all levels in the LDD region. In this sense the synoptic environment most resembles the "upstream trough pattern" identified by Coniglio et al. (2004) in their observational study of derecho-producing convective systems. Environments of this type are characterized by the presence of a well-defined, progressive shortwave trough just upstream from the derecho location. Typically, such systems occur in close proximity to a maximum in the mid tropospheric flow. The 500 and 250 mb composite charts (Figures 2e and f) reveal that this is indeed true of LDDs, with the mean centroid located in the left exit region of an upper tropospheric jet streak.

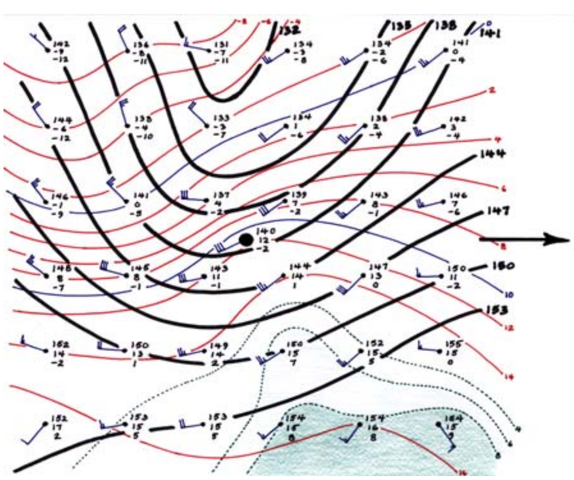
Examination of the mean surface, 925 and 850 mb patterns (Figures 2a, b and c) indicates that LDDs tend to occur within a low level thermal ridge axis ahead of a strong cold front. As might be expected given the amplified nature of the large scale flow, a well-defined dipole is apparent in the low level thermal advection field. The convective systems occur near the dipole center, immediately downstream from a pronounced maximum of cold advection. The magnitude of the cold advection maximum is greater than that of the corresponding warm advection area located downstream from the LDD. This imbalance is also apparent at 700 and 500 mb (Figures 2d and e), suggesting that the upstream shortwave impulse in an LDD environment typically is undergoing amplification.



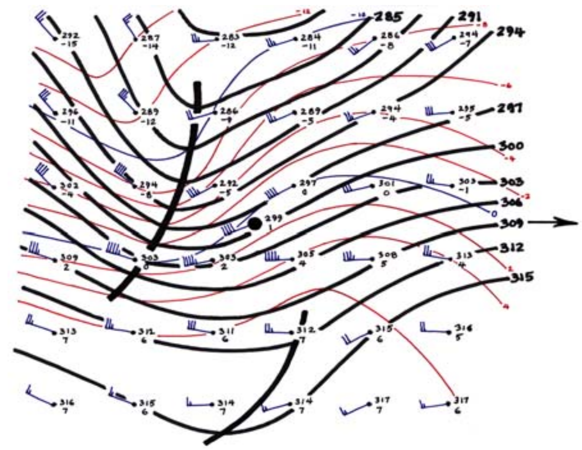
a. Surface



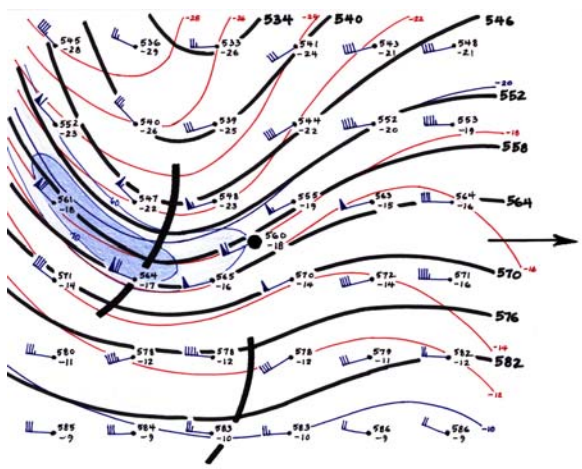
b. 925 mb



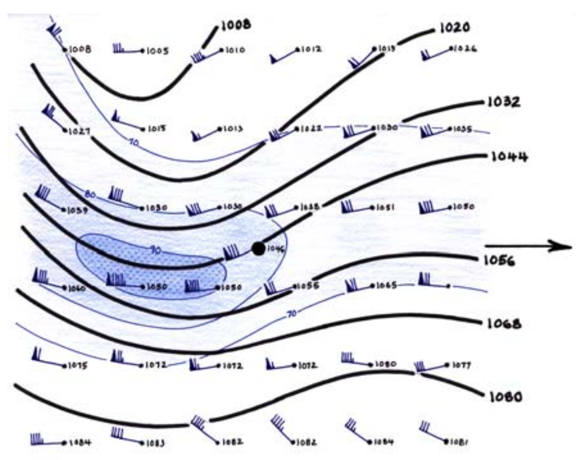
c. 850 mb



d. 700 mb



e. 500 mb



f. 250 mb

Figure 2. Mean surface and upper air patterns for LDD events studied. Thick lines: Surface pressure (in mb), or geopotential height (in decameters). Thin lines: Temperature (red/blue) and dewpoint (green) in degrees Celsius. Temperatures in 2 degree increments, except 4 degrees at the surface. Dewpoints not depicted at 700, 500 and 250 mb. Wind speed in knots (flag, 50 kt; full barb, 10 kt; half barb 5 kt). Isotachs (in knots) depicted in blue at 500 and 250 mb. Heavy dot: Location of LDD centroid. Arrows indicate time-averaged direction of LDD motion.

The lower tropospheric composite charts also reveal the recent passage of a trough or wind shift line in the vicinity of the system centroid. The trough may in part reflect the presence of the secondary or "southern stream" shortwave disturbance that is apparent at both 700 and 500 mb (Figures 2d and e), and the low level flow veers to a more system-parallel (generally westerly) direction in the wake of the trough. While the feature also evidently marks the leading edge of comparatively dry air advection at lower levels, the higher moisture values downstream and equatorward from the LDD location may, however, simply be an artifact of the data set which included several cases from the Mid Atlantic region.

A mean sounding constructed for the LDD centroid is shown in Figure 3. The sounding depicts a low to mid tropospheric environment that is quite dry relative to other organized severe convective weather situations; the mean relative humidity in the lowest 300 mb is 45%. The temperature profile, nevertheless, is one of notable conditional instability owing to the presence of lapse rates that are considerably greater than the climatological norm (Bluestein and Banacos 2002). This is especially apparent in the 700 to 500 mb layer, where the mean lapse rate exceeds 7 degrees C per km. Assuming that moist convection is able to develop, the combination of steep low to mid level lapse rates and large temperature-dewpoint spreads yields a mean thermodynamic environment that is amply suited for strong convective downdraft development.

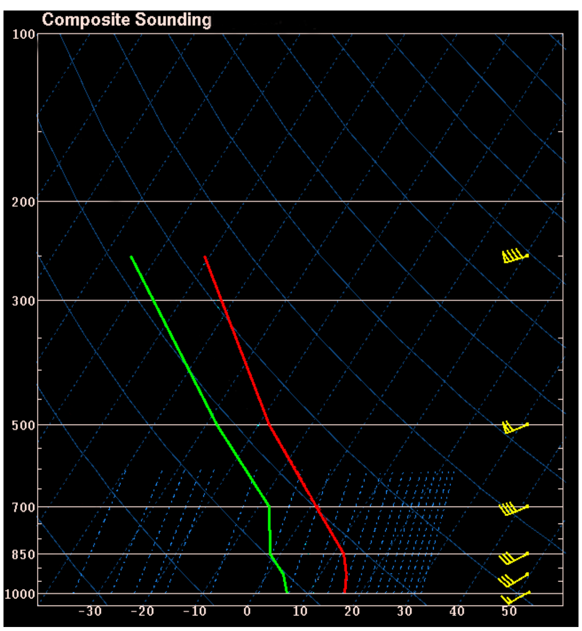


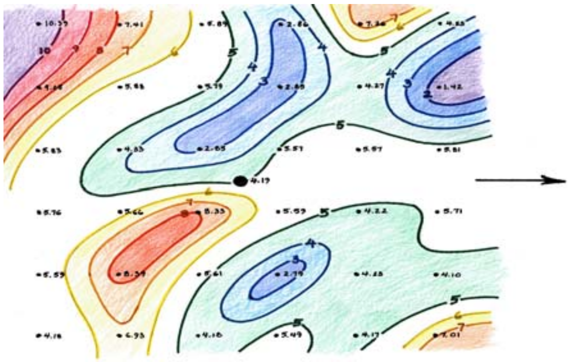
Figure 3. Mean sounding for LDD centroid location. Temperature depicted in red, dewpoint in green. Surface data plotted at 1000 mb. Wind speeds in knots.

To further investigate the thermodynamic environment of LDDs, plan-view plots of mean low to mid level lapse rates are provided in Figure 4. These charts further indicate that while the low level LDD environment is indeed dry, there exists a considerable degree of conditional instability. For example, in the 925-850 mb layer (Figure 4a), the LDD centroid is located within a pronounced low level lapse rate gradient, immediately downstream from a regional maximum containing mean values in excess of 8 degrees C per km. This is noteworthy considering that (1) most of the cases selected occurred in areas well removed from the source region of strongly-mixed boundary layer environments over the southwestern United States, and (2) that half of the events were observed during the cool season. The degree of conditional instability is also significant considering that aerially-averaged mean lapse rates in the 925-850 mb layer over the central and eastern United States range from near moist adiabatic to isothermal (Bluestein and Banacos 2002).

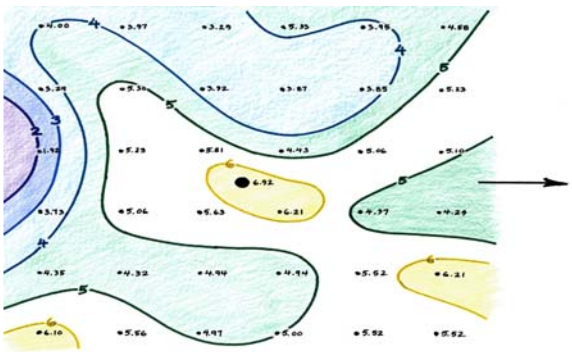
A mean hodograph constructed for the LDD centroid is shown in Figure 5. Recall from the compositing procedure that directions are relative to system motion, with the x axis oriented parallel to the observed system motion. The hodograph is decidedly linear, exhibiting moderate to strong shear that increases monotonically through 250 mb. While shear in the lowest 1 km is rather modest (17 kts or 8 ms^{-1}), the mean surface-to-6 km shear is nearly 70 kts (35 ms^{-1}). This, of course, reflects the strongly baroclinic nature of the environments in which LDD events occur. It is also worth noting that the wind profile is largely unidirectional. Unidirectional wind profiles favor coherent motion of storm-scale downdrafts and promote rapid elongation of the resulting MCS cold pool in the downstream direction (Corfidi 2003). These factors can strengthen and deepen low-level system relative inflow, and therefore foster LDD initiation and sustenance.

With the average observed system speed being 50 kts (25 ms^{-1}), it is apparent that LDDs exhibit unusually deep system-relative, front-to-rear inflow. This sets LDDs apart from other strongly forced derecho-producing systems which tend to have comparatively shallow system-relative inflow (Evans and Doswell 2002, Coniglio et al. 2004). ***This observation --- in conjunction with the fact that LDDs are characterized by thermodynamic environments favorable for cold convective downdraft development --- suggests that system propagation (i.e., the development of new cells relative to existing activity) more than likely plays a disproportionate role in LDD movement compared to other strongly forced MCSs.***

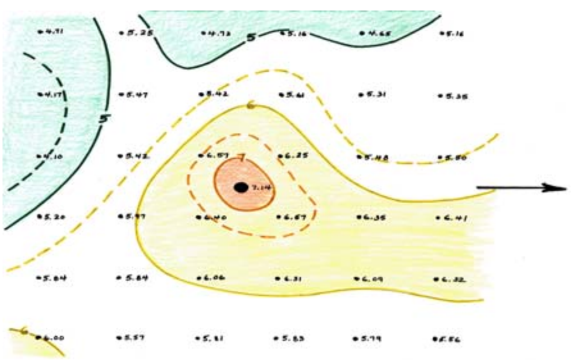
In summary, the data presented in this preliminary study suggest that while strong mesoscale forcing for ascent is indeed necessary to "jump start" LDD development, such systems are subsequently



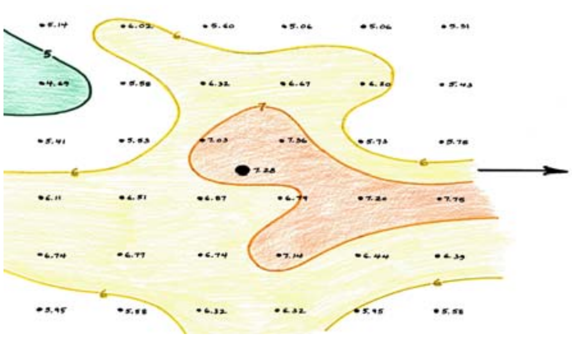
a. 925-850 mb



b. 850-700 mb



c. 850- 500 mb



d. 700-500 mb

Figure 4. Mean lapse rates in degrees C per km for the (a) 925-850 mb, (b) 850-700 mb, (c) 850-500 mb, and (d) 700-500 mb layers, contoured in 1 degree increments.

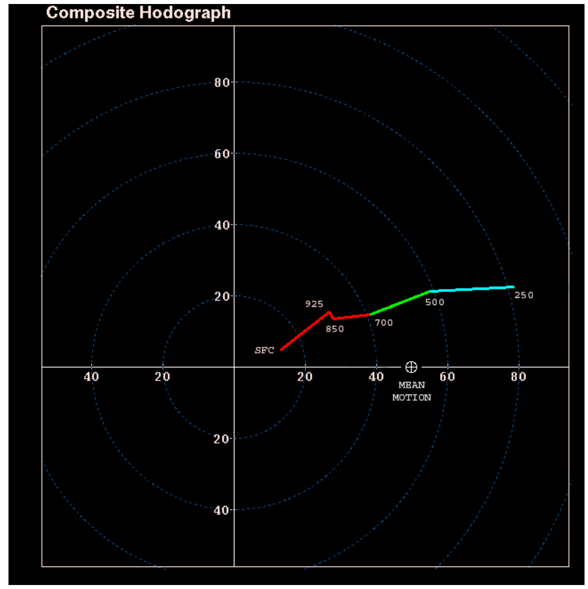


Figure 5. Mean hodograph for LDD centroid location, with range rings labeled in knots. Numbers refer to heights in mb. The x axis is oriented parallel to the direction of observed mean LDD motion, with the speed of mean motion (50 knots) given by white cross.

maintained by a thermodynamic and kinematic environment which supports organized, sustained downwind cell propagation. The deeply mixed boundary layer, in conjunction with the moderate to strong and largely unidirectional mean wind profile, promotes an “organized microburst” convective mode in which the incipient MCS is sustained by a series of downwind-directed microbursts. These microbursts allow the convective system to discretely propagate in the downstream direction until the potential for convective initiation and cold downdraft development diminishes.

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