# P1.15 DISCRIMINATING AMONG NON SEVERE, SEVERE, AND DERECHO-PRODUCING MESOSCALE CONVECTIVE SYSTEM ENVIRONMENTS

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## 1. Introduction

Organized clusters of thunderstorms meeting particular spatial and temporal requirements are known as mesoscale convective systems (MCSs) (e.g. Zipser 1982; Hilgendorf and Johnson 1998; Parker and Johnson 2000). Knowledge of the environmental parameters that govern MCS intensity is essential in operational meteorology. This is especially true of convective systems that produce widespread damaging surface winds. Herein, we examine a subset of organized, long-lived systems of this type referred to as derecho-producing convective systems, or DCSs.

One of the first detailed examinations of DCSs was Johns and Hirt (1987). This work was based on a data set of 70 MCSs occurring during the warm season (May-August) of the years 1980-1983. The study discussed the relationship between DCS position, motion, synoptic scale boundaries, and environmental parameters. They found that large convective instability, and the presence of dry air at mid levels above moist air in the low levels, were characteristics common to many DCS environments. The authors inferred that the dry-over-moist moisture profiles allowed for the development of large negative buoyancy in the lower levels that fostered development of strong downdrafts and severe surface winds.

Johns and Hirt (1987) also suggested that relatively strong mean mid- and upper-level wind speeds were associated with DCSs. Evans and Doswell (2001), meanwhile, suggested that strong system-relative winds in the low-levels and weak system-relative winds at mid-levels were important to DCS development.

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Additionally, they emphasized that the convective available potential energy (CAPE) and vertical wind shear vary widely among derecho events. Recently, Coniglio et al. (2004) showed that the shear often extends through a large depth and weakens as derechos decay.

To build on this work, we present a study on the variables that discriminate among non–severe MCSs, severe but non derecho-producing MCSs, and DCS environments. Accordingly, the purpose of the present work is to examine the differences in meteorological variables derived from proximity soundings among three categories of MCS intensity and to discuss the physical implications of these results. Section 2 describes the data set of MCSs considered in this study, the scheme used to rate the MCSs in the data set, and the statistical analyses applied to the data set. Sections 3, 4, and 5 describe the use of the kinematic, instability, and moisture variables, respectively, used in the MCS environment discrimination. Results are summarized in section 6.

## 2. MCS Data Set, MCS Intensity Rating Scheme, and Statistical Analyses

Using archived radar images provided by the University Corporation for Atmospheric Research (UCAR) and the Storm Prediction Center (SPC) (available online at http://locust.mmm.ucar.edu/case-selection/ and http://www.spc.noaa.gov/exper/archive/events), 269 MCSs were identified for this study that had an associated proximity sounding from upper air observations (see Coniglio et al. 2005 for a description of this data set). Each MCS exhibited a contiguous line of leading convection at least 100 km long for at least five continuous hours. These MCSs occurred east of the Rocky Mountains between May and early September from 1998 through 2004.

The MCSs were selected if the nearest part of the 50 dBZ radar reflectivity contour of the MCS was no more than 200 km and three hours removed from an observed sounding. The data were examined to verify that none of the soundings were contaminated by convection. At the time of the proximity sounding, the appearance and trends of the radar reflectivity data were used to assess the mean speed and direction of the leading-line MCS motion near the sounding time, and the stage of the MCS in its life cycle. The four life cycle stages considered in this study were (1) initial cells prior to MCS development, (2) mature MCS, with strengthening or quasi-steady high reflectivity (50 dBZ or higher), (3) decaying MCS, with significantly weakened or shrinking areas of high reflectivity, and (4) dissipating MCS, with loss of system organization and associated areas of high reflectivity.

Following the above preliminary work, each system was categorized as a non severe MCS (NCS), a severe but non derecho-producing MCS (SCS), or a DCS. Since this study focuses on convective systems that produce severe convective winds (wind gusts ≥ 50 knots or, in some cases, wind damage), we did not consider the occurrence of tornadoes or hail. The MCSs were categorized using composite radar images from the aforementioned UCAR archive, and storm reports from both Storm Data (NCDC) and the SPC data base. For all 269 MCSs, the number of severe wind reports produced by the MCS was determined using the SeverePlot program (Hart and Janish 1999), which displays the finalized dataset from NCDC. Since 2004 data were not yet available to SeverePlot at the time of classification, preliminary storm reports archived by the SPC (available online at http://www.spc.noaa.gov/climo) were used to perform the same classification process for that year).

Several of the criteria for classifying the MCSs, especially for the identification of DCSs, were adapted from the discussion provided in Coniglio et al. (2004). For an MCS to be classified as an SCS or as a DCS, it must have produced at least six severe wind reports. If an MCS did not meet this criterion, it was classified as an NCS.

Three criteria were used to define a DCS: (1) there were at least six severe wind reports produced by the MCS, (2) successive severe wind reports occurred within three hours or 250 km of each other, and (3) the major axis of the line connecting the initial and final severe wind reports was at least 400 km long. If all of these criteria were not met, the system was classified as an SCS.

We recognize that some of the MCSs may have been under- or over-estimated in intensity due to inaccurate reporting and/or a lack of *measured* severe wind events in the severe weather data base (see Weiss et al. 2002 for further discussion on this topic). However, the NCDC data base provides the only means to produce climatological studies of this type, and we assume that there is enough fidelity in this data to separate the weaker, shorter- lived systems from the intense, long-lived systems.

Finally, MCSs that were decaying or dissipating around the time of the sounding are removed from the data set to focus on systems that were in the more intense stages of development. The quantities calculated from the proximity soundings in each category thus represent the collective conditions during MCS development and maturity. After the above two stratifications were made, a total of 49 NCSs, 87 SCSs, and 52 DCSs were obtained.

Several hundred variables were calculated using the proximity sounding data that represented the kinematic, instability, and moisture environment of each MCS. Although it is inevitable that substantial correlations will exist among the variables, we did not want to make any prior assumptions about which of these variables are good discriminators. Therefore, we will focus on a handful of variables that are found to have the largest statistically significant differences among the MCS categories, and those variables that have been emphasized in previous studies.

The 10$^{th}$, 25$^{th}$, 50$^{th}$, 75$^{th}$, and 90$^{th}$ percentiles for each variable in each MCS category were calculated and displayed in box-and-whiskers plots to gauge relative magnitudes of each variable in each MCS environment. Additionally, absolute values of Z-scores resulting from hypothesis testing between various severity levels for each variable are displayed. The Mann-Whitney test, a non-parametric hypothesis test (Wilks 1995), was used in the determination of the Z-scores. In this study, we define an absolute value of a Z-score above 1.645 (2.575), which corresponds to a probability of less than 10% (1%) that the two distributions are the same, as indicating a “very good” (“excellent”) discrimination between two categories.

## 3. Kinematic variables

For a given proximity sounding, mean winds are determined by taking the square root of the sum of the squared average u- and v-components of the wind at each standard and significant level within the layer under consideration. Within the upper troposphere (8-12 km), mean winds are found to be excellent discriminators between SCS and DCS environments and between NCS and DCS environments (Figs. 1 and 2).

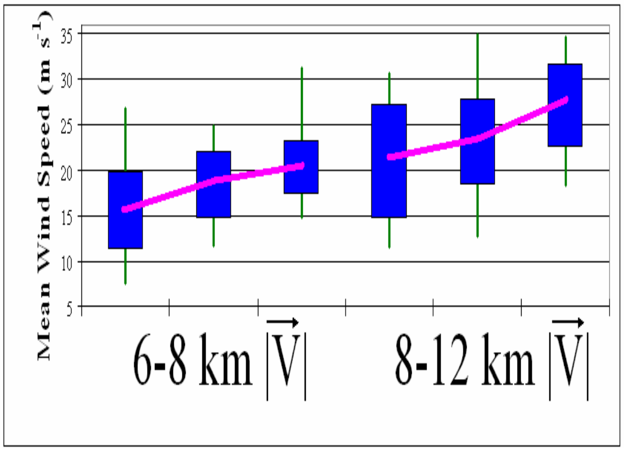


***Fig. 1. Box-and-whiskers plots for the 6-8 km and 8-12 km mean wind speed. Each set of three categories indicates the results for the NCSs, SCSs, and DCSs, from left to right. The bottom and top whiskers represent the 10th and 90th percentiles, respectively, the bottom and top of the boxes represent the 25th and 75th percentiles, respectively, and the connecting line represents the 50th percentile.***

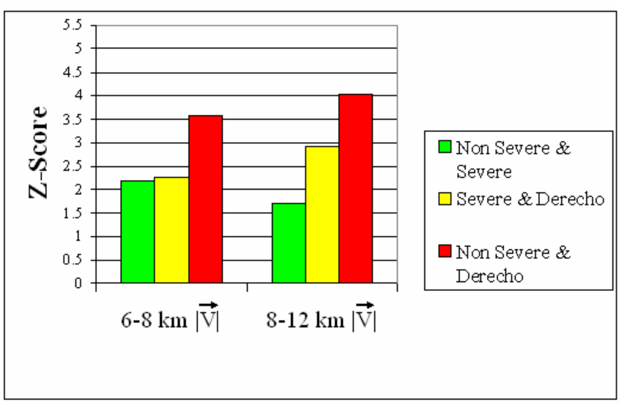


***Fig. 2. Absolute values of Z-scores resulting from hypothesis testing shown by green, yellow, and red bars, respectively, between NCSs and SCSs, SCSs and DCSs, and NCSs and DCSs for 6-8 km and 8-12 km mean wind speed .***

We also find that the MCS forward speed increases with MCS intensity (Figs. 3 and 4).

This provides quantitative evidence of the long-held notion that MCS severity is strongly related to the speed of the MCS. In fact, Corfidi (2003) assumed that the mean mid- and upper-level environmental winds are associated with increasing MCS forward speed and used a mean cloud-layer wind speed over a deep layer as an important component of assessing cold pool motion. Our findings support this assumption since mean mid- and upper-level environmental wind speeds in the present study were found to be linked with MCS severity (Figs. 1 and 2), and MCS severity is very strongly correlated with MCS speed.

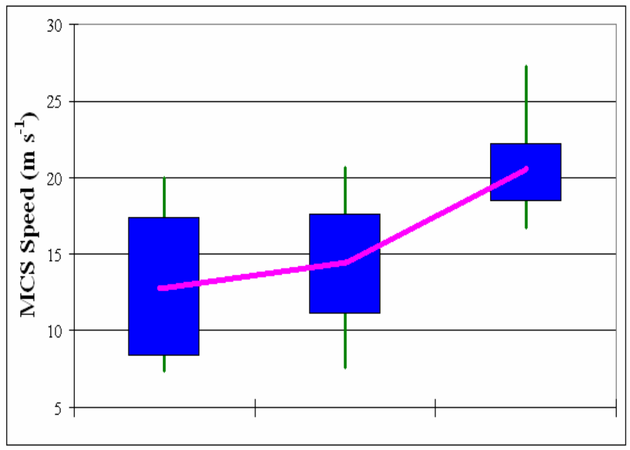


***Fig. 3. Same as in Fig. 1, except for MCS speed.***

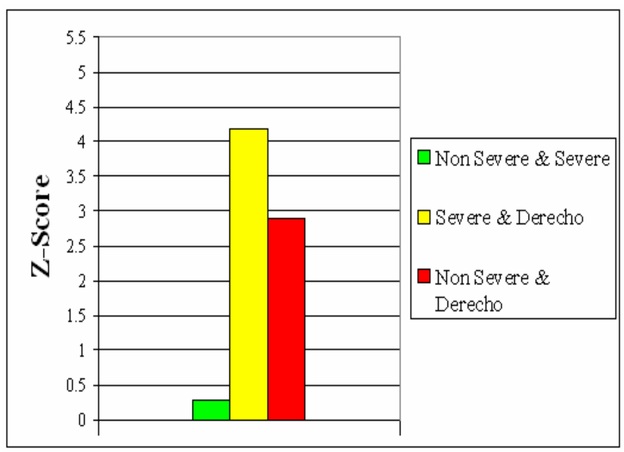


***Fig. 4. Same as in Fig. 2, except for MCS speed.***

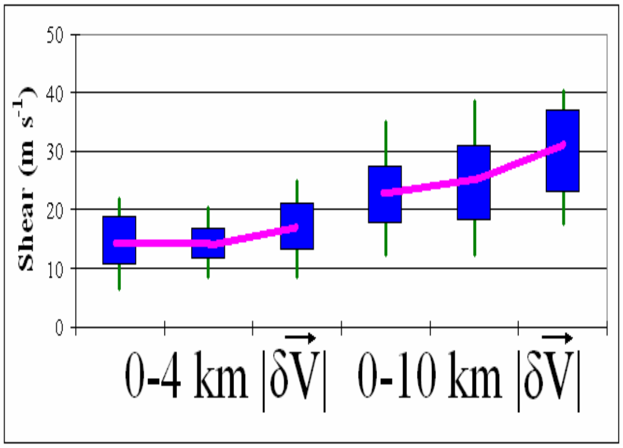


***Fig. 5. Same as in Fig. 1, except for 0-4 km and 0-10 km wind shear.***

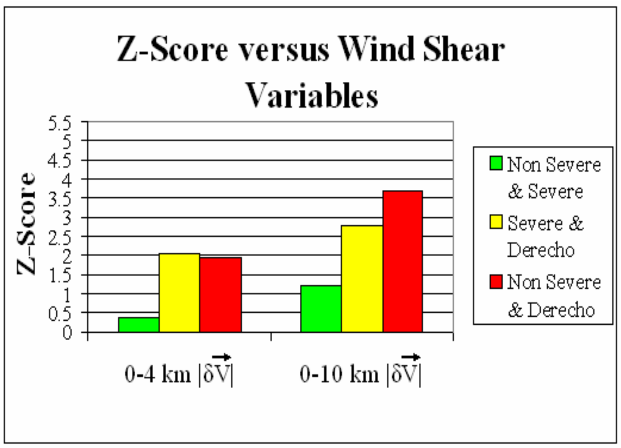


***Fig. 6. Same as in Fig. 2, except for0-4 km and 0-10 km wind shear.***

The magnitudes of the wind shear vectors are found to be largest in DCS environments (Figs. 5 and 6). The 0-6 km, 0-8 km, and 0-10 km mean shears are very good discriminators between SCSs and DCSs and between NCSs and DCSs; Figs. 5 and 6 show the results for the 0-4 and 0-10 km layers. The utility of the shear variables is especially high when the layer through which the shear is distributed is deep. Among the entire set of shear variables, the 0-10 km shear is found to discriminate best among all three MCS environments. However, wind shear in shallower layers, especially those near the surface (e.g. 0-4 km shear), was not found to be as good a discriminator as the 0-6 km, 0-8 km, and 0-10 km shears. In general, wind shear is not as good a discriminator as mean wind speed, as is indicated by the lower Z-scores for the shear variables.

It thus appears that mean-wind/cold pool comparisons may be more useful in assessing MCS intensity than wind shear/cold-pool comparisons. However, the practical significance of these differences is not clear since the shear and the mean wind speed are correlated (Evans and Doswell 2001). In this study, the correlation coefficient between the 0-6 km mean wind and the 0-6 km wind shear is 0.674 for NCSs, 0.444 for SCSs, and 0.513 for DCSs. These moderate to strong correlations prevent a definitive statement on the relative physical importance of the mean wind versus the wind shear. However, from an operational standpoint, both the speed and shear of the mid and upper level winds provide useful information on the potential severity of the MCS.

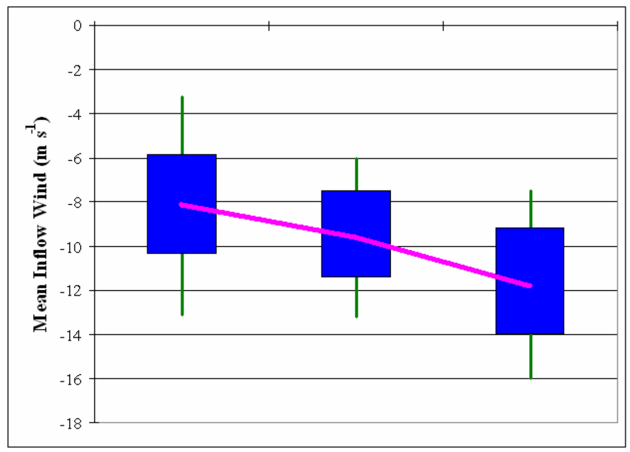


***Fig. 7. Same as in Fig. 1, except for mean system-relative winds in the inflow layer.***

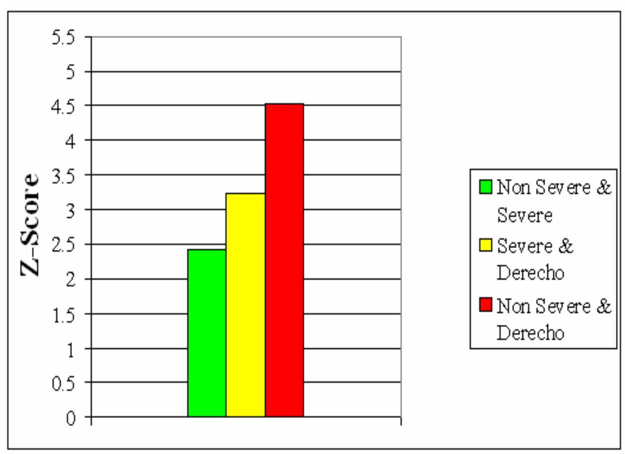


***Fig. 8. Same as in Fig. 2, except for mean system-relative wind in the inflow layer.***

Evans and Doswell (2001) identified the importance of system-relative inflow, especially in the 0-2 km layer, as a discriminator among non-derecho and DCS environments. Much of this relationship is attributed to the faster motion of DCSs over non-derecho-producing systems. The mean inflow winds are generally found to be slightly more than half of the MCS speed within each MCS severity level (cf. Figs. 3 and 7). This suggests a strong relationship between system-relative wind and MCS speed similar to what was found in Evans and Doswell (2001). Since we found that MCS speed was an excellent discriminator among MCS categories, it is not surprising that mean system-relative inflow also is found to be a good discriminator among all three MCS environments (Figs. 7 and 8).

From each observed MCS speed and direction, storm-relative helicity in both the 0-1 km and 0-3 km layers was calculated. Storm-relative helicity in the 0-1 km and 0-3 km layers is found to be a poor discriminator among the MCS environments (Figs. 9 and 10), as might be expected. The range of helicity values experienced by the MCS within the dataset is large and generally similar among all MCS environments. This confirms that environments conducive to rotating updrafts are clearly not necessary for the development and sustenance of many MCSs, although MCSs and supercells certainly can coexist, as suggested by the 25th percentile of the 0-3 km helicity values extending to nearly 300 $m^2 s^{-2}$ (Fig. 9).

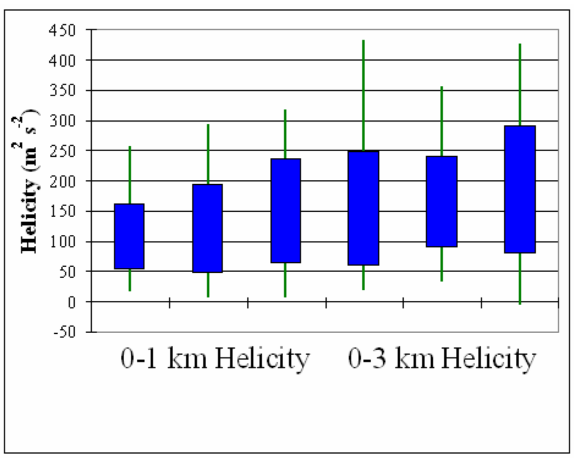


***Fig. 9. Same as in Fig. 1, except for 0-1 km and 0-3 km helicity.***

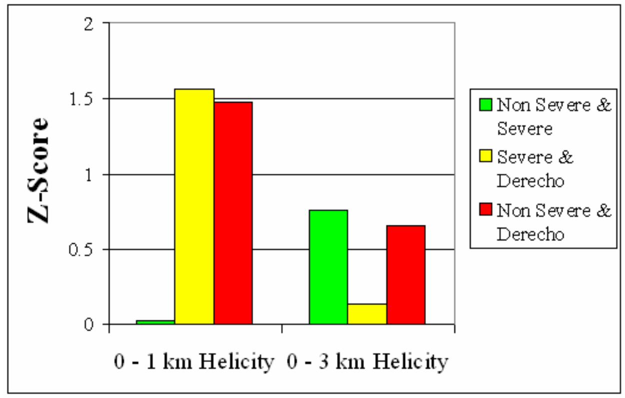


***Fig. 10. Same as in Fig. 2, except for 0-1 km and 0-3 km helicity.***

### 4. Instability variables

As expected, several instability variables exhibit considerable skill in discriminating among the MCS environments (Figs. 11 through 14). In fact, instability variables appear to be the best discriminators, as their Z-scores are the highest, on average, of any tested in this study.

In this study, CAPE is calculated by lifting a surface parcel (SBCAPE), the most unstable single parcel (MUCAPE), and the parcel resulting from mixing the lowest 50 hPa of the atmosphere (50-hPa MLCAPE). DCAPE is used to designate downdraft CAPE (Evans and Doswell 2001), which is calculated using a parcel that descends from the larger of two values: the level of minimum equivalent potential temperature and the wet-bulb zero height. All of the CAPE variables do not discriminate between SCS and DCS environments at the 10% level, but do discriminate at very high levels between NCSs and SCSs and NCSs and DCSs (Figs. 11a, 11b, 12a and 12b).

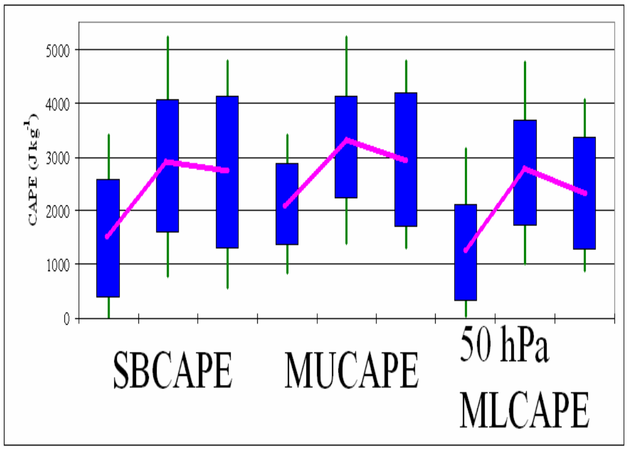


*Fig. 11a. Same as in Fig. 1, except for SBCAPE, MUCAPE, and 50-hPa MLCAPE.*

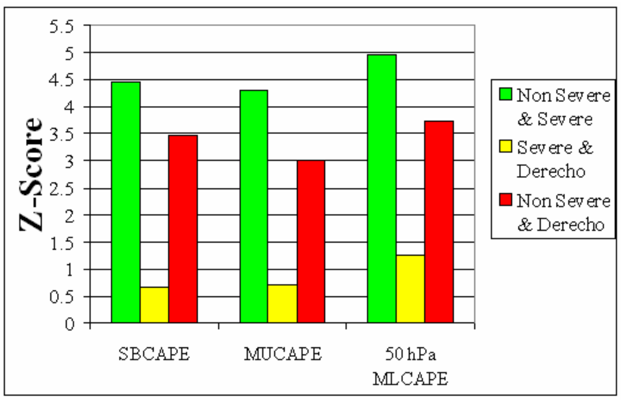


*Fig. 12b. Same as in Fig. 2, except for SBCAPE, MUCAPE, and 50-hPa MLCAPE.*

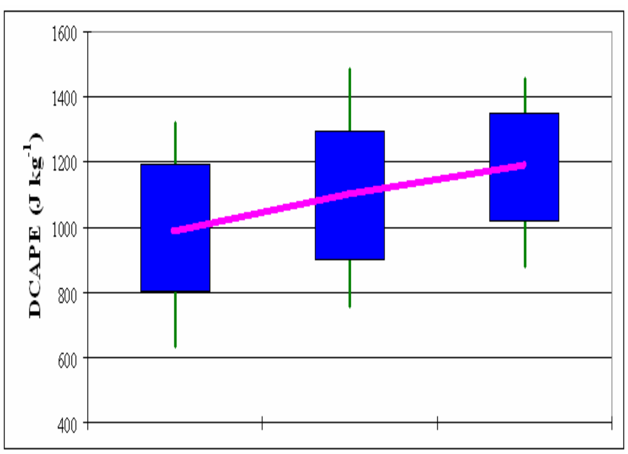


*Fig. 13a. Same as in Fig. 1, except for DCAPE.*

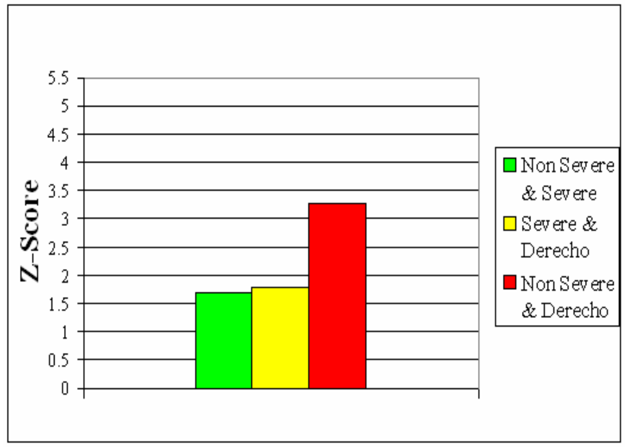


*Fig. 12b. Same as in Fig. 2, except for DCAPE.*

CAPE on average is found to be smaller in DCS than in SCS environments. CAPE may fail to strongly discriminate between SCS and DCS environments in part because the data set included more DCSs that occurred in strongly forced environments with relatively small CAPE, which lowered the mean CAPE for the DCS category. The lack of any statistically significant difference in the CAPE variables between the SCS and DCS environments may also reflect the inability of a one-dimensional proximity sounding to detect differences in the spatial distribution of CAPE. However, CAPE alone does appear to provide some useful information on whether or not the MCS will produce severe winds, regardless of its longevity.

Evans and Doswell (2001) indicated that DCAPE can be used to approximate cold pool strength, as DCAPE is a measure of the potential for cold downdraft development. For the warm season-type environments examined in this study, it is likely that the cold pool is largely responsible for the system's sustenance. As such, we find that DCAPE increases with increasing MCS intensity (Figs. 12a and 12b), as found by Evans and Doswell (2001). These differences are by far the most significant, however, among the NCS and DCS categories.

Despite the fact that CAPE was found to be greater for SCSs than for DCSs and NCSs, the environmental lapse rate (γ) was found to be greatest for DCSs in the 4-6 km, and 4-8 km layers (Figs. 13 and 14). The 4-6 km and 4-8 km environmental lapse rates both discriminate very well among all three MCS environments, with Z-scores above 1.645. The distinction is especially evident between NCSs and DCSs. Because environmental lapse rates, unlike CAPE, are not integrated quantities, lapse rates are more likely to uncover small-scale instability features in the vertical that may be masked by CAPE. As a result, mid-level environmental lapse rates may generally be better discriminators than CAPE, at least from a one-dimensional perspective.

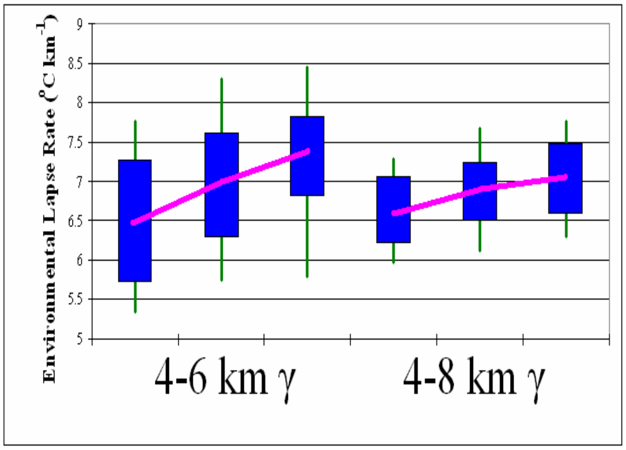


*Fig. 14. Same as in Fig. 1, except for 4-6 km and 4-8 km environmental lapse rates.*

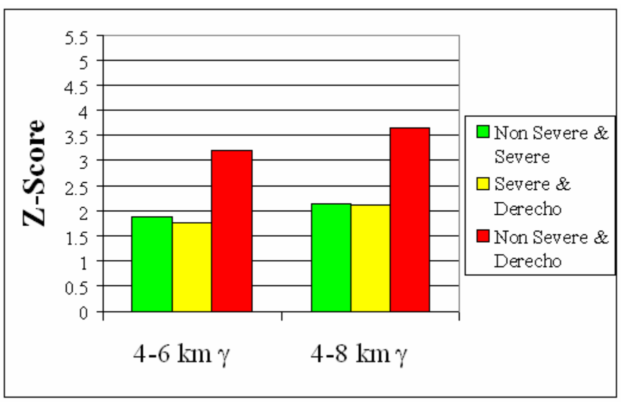


*Fig. 15. Same as in Fig. 2, except for 4-6 km and 4-8 km environmental lapse rates.*

## 5. Moisture variables

The vertical gradient in $\theta_e$ between low and mid levels (1-5 km) is found to be an excellent discriminator between NCS and both SCS and DCS environments (Figs. 15 and 16). This reflects the strong ability of DCAPE to discriminate between NCS and DCS environments and reflects the positive relationship between DCAPE and the vertical gradient in $\theta_e$. The $\theta_e$ gradient is found to be least negative for NCS environments and generally most negative for SCS and DCS environments. From this it may be concluded that $\theta_e$ decreases more rapidly with height in SCS and DCS environments than it does with NCSs.

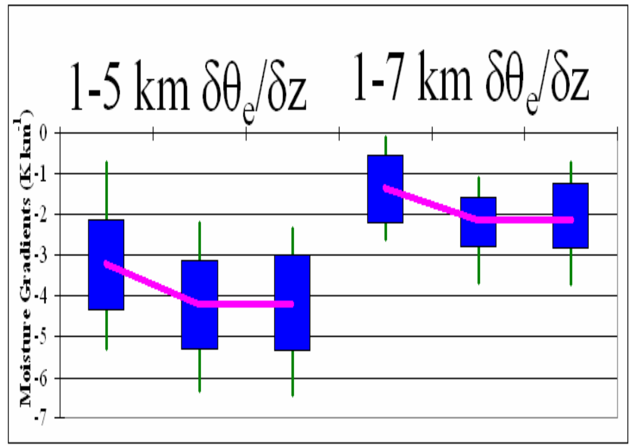


*Fig. 16. Same as in Fig. 1, except for 1-5 km and 1-7 km moisture gradients.*

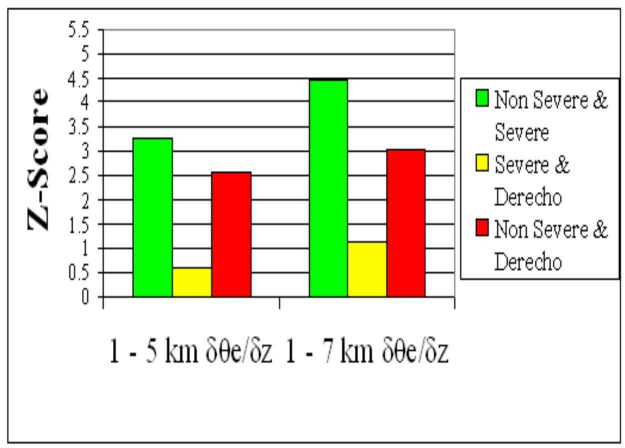


*Fig. 17. Same as in Fig. 2, except for1-5 km and 1-7 km moisture gradients.*

However, since the vertical gradient of $\theta_e$ is not a good discriminator between SCS and DCS environments, a vertical gradient of $\theta_e$ is likely linked with any wind damage potential, regardless of its longevity, as suggested in Atkins and Wakimoto (1991) and Wakimoto (2001). There are two distinct physical processes associated with a large negative vertical gradient in $\theta_e$ related to the enhancement of severe surface winds: (1) the initial formation of deep, convection resulting from convective instability (Schultz et al. 2000), and (2) the effects on the downdrafts. The effect on the downdrafts manifests itself in the development of negative buoyancy as precipitation falls through subsaturated air. In addition, if the downdraft can maintain saturation, the downdraft is enhanced as it encounters the relatively large virtual temperatures of the warm, moist low levels (Wakimoto 2001).

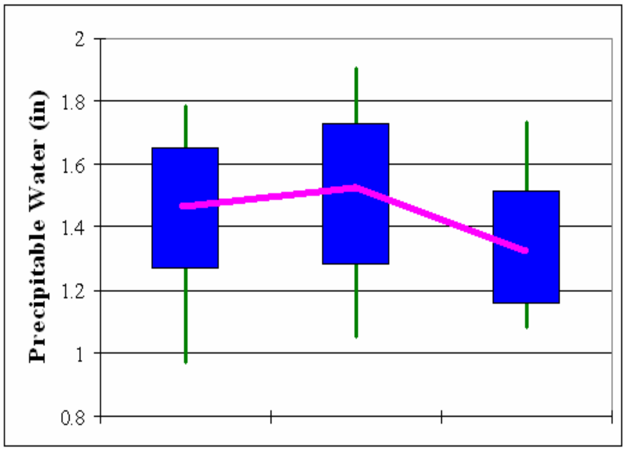


*Fig. 18. Same as in Fig.1, except for PWAT.*

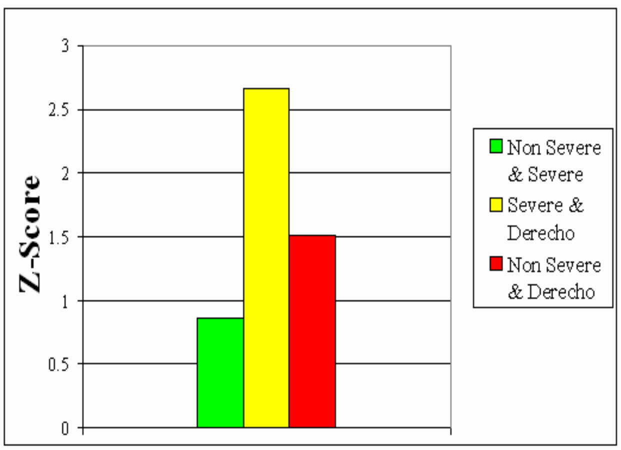


*Fig. 19. Same as in Fig. 2, except for PWAT.*

In MCS environments with nearly saturated thermodynamic profiles, $\theta_e$ varies much less with height, yielding smaller gradients in $\theta_e$. In these nearly saturated profiles, the process of dry air entrainment and resulting evaporational cooling occurs less effectively. However, it is interesting that the precipitable water (PWAT) is found to be a very good discriminator between SCSs and DCSs (Figs. 17 and 18), despite the fact that the vertical gradient in $\theta_e$ is not a good discriminator between these two groups (Figs. 15 and 16). Since PWAT is smaller in DCS environments than in SCS environments, the overall moisture content in DCS environments is smaller than in SCS environments, which is likely the result of drier conditions in mid-levels. A possible explanation is that the larger lapse rates observed for the DCSs counter the lower integrated moisture content to produce similar vertical gradients in $\theta_e$. In any case, these results suggest that the vertical gradient in $\theta_e$ could be used together with PWAT to help discriminate effectively between SCSs and DCSs.

## 6. Summary and Conclusions

This study provided discussion of several meteorological variables that can be used to discriminate among the environments associated with different intensities of MCSs. Three MCS types are defined from a set of 269 warm season MCSs: non severe MCSs (NCSs), severe but non derecho-producing MCSs (SCSs), and derecho-producing MCSs (DCSs).

Variables that are positively correlated with MCS intensity and that are very good discriminators include mid-level environmental lapse rates, mean mid- and upper-level winds, and deep-layer wind shear. This study also showed that CAPE discriminates well between NCS and SCS environments, and between NCS and DCS environments, but not between SCSs and DCSs.

Concepts presented in two papers (Corfidi (2003) and Evans and Doswell (2001)) were also explored in this study. Corfidi (2003) suggested that the advective component of MCS motion (represented by the mean cloud-layer wind) may be added twice to the propagation vector to obtain an estimate of the net motion of a forward propagating MCS. In the light of the present study, this seems like a reasonable approach, since both MCS motion and mean wind speed were found to increase with increasing MCS intensity. And, as in Evans and Doswell (2001), system-relative inflow was found to be positively correlated with MCS intensity.

This study provided a description of the environments associated with severe wind-producing MCSs based on the analysis of numerous variables derived from sounding data. The variables examined may be used to describe the vertical structure of the atmosphere and the way that structure relates to MCS intensity. Combined with an understanding of how the horizontal distribution of these variables affects MCS development and evolution, one can gain a more complete understanding of the factors contributing to MCS intensity with the results produced in this study.

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