2.4 DISCRIMINATION OF MESOSCALE CONVECTIVE SYSTEM ENVIRONMENTS USING SOUNDING OBSERVATIONS

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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). The synoptic patterns and environments that support long-lived, severe-wind producing MCSs (derechos) and MCSs in general have been examined in many contexts (Johns and Hirt 1987, Johns 1993, Coniglio et al. 2004b, Maddox 1983, Madoox et al. 1986, Anderson and Arritt 1998, Liang and Fritsch 2000, Parker and Johnson 2000). Although these studies shed light on the environments of MCSs, there has not been a specific investigation into the differences in the observed environments of MCSs of different intensities, in terms of more than two degrees of severe-wind production.

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. The focus of this work is to identify environmental variables that may help to determine if a given quasi-linear MCS will produce widespread severe surface winds on 3-12 h time scales. 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. Section 3 describes the kinematic, instability, and moisture variables used in the MCS environment discrimination. Results and a final discussion are found in section 4.

2. Methodology

a. Data collection and classification

Using radar images archived 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 between the years of 1998 and 2004. To focus on the types of MCSs that are usually associated with severe-wind potential, each MCS in the data set exhibited a nearly contiguous line of leading convection at least 100 km long for at least five continuous hours. Although these types of systems can occur year round anywhere in the United States, we restricted our search to the cases that occurred east of the Rocky Mountains between May and early September. In addition, the MCSs were included only 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. As part of the process of selecting the soundings, skew-T log-P diagrams were examined for each case and surface charts and radar data were examined in order to verify that the sounding was not contaminated by convection.

Each system was then categorized as a weak/non-severe MCS (WCS), a severe but non derecho-producing MCS (SCS), or a derecho-producing MCS (DCS) based on their production of severe surface winds (wind gusts ≥ 26 m s^{-1} or, in some cases, wind damage)[1]. Reports from both digitized versions of *Storm Data* (NCDC) and the SPC online database were used to categorize the events using the *SeverePlot* program (Hart and Janish 1999). To benefit the severe thunderstorm forecasters at the SPC, an MCS was classified as severe if it produced at least six severe wind reports, which reflects the guidelines for verifying the issuance of Severe Thunderstorm Watches by the SPC. Composite radar images from the aforementioned UCAR archive were used to verify that the severe wind reports emanated from the MCS in question. 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 classification for 2004 events.

Following Coniglio et al. (2004a), 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 in a chronological progression and in a concentrated area, and (3) the major axis of the line connecting the initial and final severe wind reports was at least 400 km long. If the second or third criterion was not met, the system was

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[1] We recognize that some of the MCSs may be under- or over-estimated in intensity due to population biases, inaccurate reporting, and/or a lack of *measured* severe wind events in the severe weather data base (see Weiss et al. 2002 and Trapp 2006 for discussion of this topic). The underlying assumption here in this study is that there is enough fidelity in this data to separate the weaker, shorter-lived systems from the intense, long-lived systems without an over-reliance on the accuracy of any given report.

classified as an SCS. We did not include the requirement of at least three reports of 33 m s^{-1} to define a DCS, which was used in Johns and Hirt (1987). Therefore, some of the systems that are defined as derechos in the present study may not have been considered derechos in Johns and Hirt (1987) [we refer the interested reader to see Coniglio et al. (2004a) for a discussion on the effects of not including this criterion on the derecho climatology].

At the time of the proximity sounding, the appearance and trends of the base radar reflectivity data were used to assess the mean speed and direction of the leading-line MCS motion near the sounding time, as well as the stage of the MCS in its life cycle. The stage of the MCS lifecycle surrounding the time of the observation is important to know since the environments associated with weakening MCSs are quite different than the environments during their earlier stages (Gale et al. 2002, Coniglio et al. 2006). The three life cycle stages considered in this study were (1) initial cells prior to MCS development, (2) a mature MCS with strengthening or quasi-steady high reflectivity echoes (50 dBZ or higher), or (3) a decaying MCS with significantly weakened or shrinking areas of high reflectivity or a loss of system organization without any later re-intensification. MCSs that were decaying around the time of the sounding were removed from the data set to focus on systems that were in their more intense stages. The quantities calculated from the proximity soundings in each category thus represent the collective conditions during MCS development and maturity. After the above restrictions were made, a total of 48 WCSs, 87 SCSs, and 53 DCSs were obtained (188 total), each of which had an associated proximity sounding.

b. Statistical methods

Several hundred kinematic and thermodynamic variables were calculated using the proximity sounding data. The goal is to find the variables that best discriminate between the MCS categories. Although substantial correlations exist among the variables in each MCS category, the procedure described below is designed to let the statistical methods reveal the best discriminators rather than to verify any pre-conceived hypotheses. We focus on the results from a handful of variables that are found to have the most statistically significant differences among the MCS categories as well as those variables that have been examined in previous studies for comparative purposes.

The 10th, 25th, 50th, 75th, and 90th percentiles of the distributions for each variable in each MCS category were calculated and select distributions are displayed in box-and-whiskers plots to gauge the relative magnitudes and the differences of the distributions between the three categories. To help the reader gauge the significance of these differences as well as the discriminatory ability of a particular variable, absolute values of Z-scores resulting from the statistical testing[2] are displayed for the select variables (the larger the Z-score magnitude, the better the separation between the two distributions). For reference, an absolute value of a Z-score above 1.645 (2.575) corresponds to a probability of less than 10% (1%) that the two distributions were drawn from the same population.

3. Results

a. Kinematic variables

The first examination into the differences in the MCS environments is performed on a variety of kinematic variables, but we focus on characteristics of the vertical wind shear and the mean winds among the three MCS categories. Although many methods of calculating wind shear were performed (bulk shear, total shear, shear components), the magnitude of the vector difference between the wind vectors at two levels (with units of m s^{-1}) (i.e. shear vector magnitude (SVM), or the “bulk shear”) is highlighted next.

1) VERTICAL WIND SHEAR

The SVMs over most layers tend to be largest in DCS environments (Fig. 1). However, when examining the ability of the SVMs to discriminate between the MCS categories (judging by the Z-scores), which is the primary goal of this study, it appears that the utility is highest when the layer through which the shear is distributed is deep (e.g., 0-6 and 0-10 km). Among the entire set of shear variables, the 0-10 km shear is found to discriminate the best among all three MCS environments, with median SVMs of only 21 m s^{-1} in WCS environments, but over 32 m s^{-1} in DCS environments. Wind shear in shallower layers (especially 0-2 km) is not found to be as good a discriminator as the 0-6 km and 0-10 km shears. Examination of the wind components indicates that the component normal (perpendicular) to the leading convective line in mid and upper levels appears to be the primary factor controlling the stronger magnitudes of the deep layer shear for the stronger MCS events (Fig. 2), suggesting that the stronger the line-normal wind in mid and upper levels, the greater the chance for the MCS to be long-lived and severe.

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[2] The Mann-Whitney non-parametric test statistic (Wilks 1995) was used to calculate the Z-scores. Nonparametric tests are fitting in applications with relatively small sample sizes since there is no requirement to assume a distribution to the data sample as required in the widely-used Student’s t-test. Another benefit of using the Mann-Whitney test statistic is that it can be interpreted as a standard Gaussian variable, and thus, probabilities can be ascribed easily with the symmetry of the Gaussian distribution.

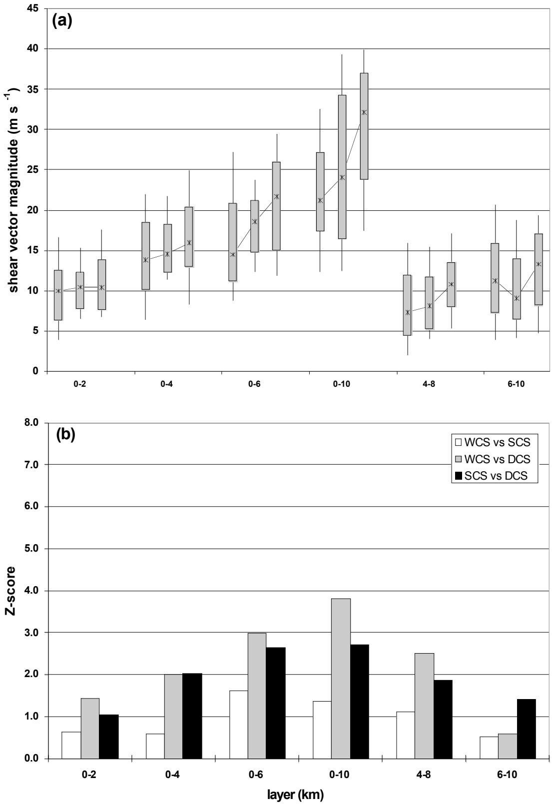

Fig. 1. (a) Box-and-whiskers plots for the 0-2 km, 0-4 km, 0-6 km, 0-10 km, 4-8 km, and 6-10 km shear. Each set of three categories indicates the results for the WCSs, SCSs, and DCSs, from left to right. The whiskers stretch to the 10th and 90th percentiles and the boxes enclose the 25th and 75th percentiles. The lines connect the medians (asterisks) for the distributions for each variable (b) Absolute values of Z-scores resulting from the Mann-Whitney test between WCSs and SCSs, SCSs and DCSs, and WCSs and DCSs for the 0-2 km, 0-4 km, 0-6 km, 0-10 km, 4-8 km, and 6-10 km shear.

The results of this study are consistent with the idea that a moderately sheared environment increases the potential for an MCS to produce severe surface winds (Weisman and Rotunno 2004). However, the relatively small difference in the low-level shear magnitudes between the MCS categories is noteworthy. As shown in Gale et al. (2002), Burke and Schultz (2004), Coniglio et al. (2004b), Stensrud et al. (2005), and in this study (Fig. 1a), shear exists in a much deeper portion of the real atmosphere in MCS environments compared to the more confined layers usually used in idealized modeling studies of quasi-linear MCSs (Rotunno et al. 1988, Weisman et al. 1988, Trapp and Weisman 2003, Weisman and Rotunno 2004, James et al. 2006). Most of these studies emphasize the importance of the low-level shear by design. Although the 4-8 km shear values are smaller than the 0-4 km shear values, the 4-8 km shear values are well above zero and may be more useful than the 0-4 km shear values in discriminating between weak and severe MCSs judging by the larger Z-scores for the WCS/SCS and WCS/DCS comparisons (Fig. 1b). However, the Z-scores for the 6-10 km shear are as small as the 0-2 km Z-scores, suggesting again that low-level and upper level shear *alone* are not useful for determining the ability of a system to produce severe surface winds (Fig. 1). Thus, the important point here is that *a measure of shear over a much deeper layer, such as the 0-10 km shear, which takes into account the benefits of low-level and upper-level shear, appears to be a better indicator of MCS intensity than either the low-level shear or upper-level shear alone*. Interestingly, this is also found when discriminating between mature and dissipating quasi-linear MCSs (Coniglio et al. 2005).

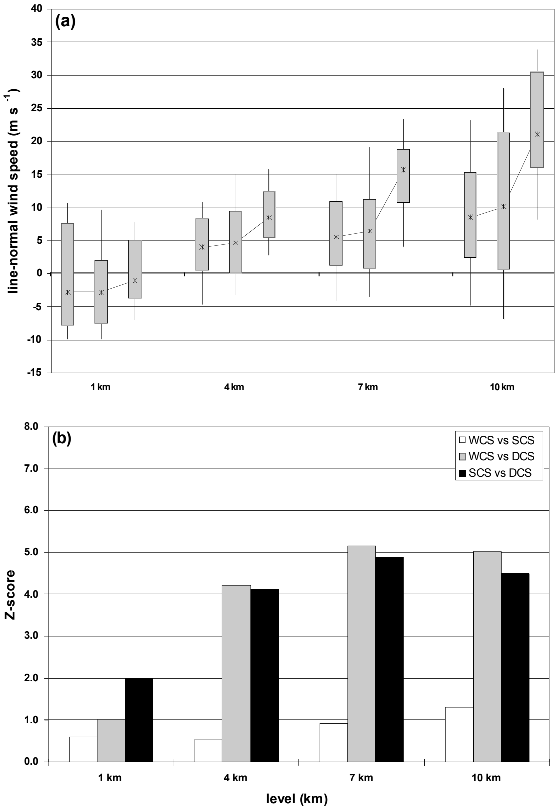

Fig. 2. Same as in Fig. 1, except for the line-normal component of the wind a 1 km, 4 km, 7 km, and 10 km.

2) GROUND-RELATIVE MEAN WINDS

Among the ground-relative mean wind speeds, it was found that layers that include upper tropospheric winds have the largest Z-scores and are found to be excellent discriminators between SCS and DCS environments and between WCS and DCS environments (Fig. 3). Concurrently, the differences in the surface-based mean wind speeds between MCS environments decrease with decreasing depth of the layer to a minimum at 0-4 km (Fig. 3). The Z-scores for the 0-2 km mean wind speeds are greater than the 0-4 km mean wind speeds, but the magnitudes of these winds are actually slightly smaller in DCS environments than in SCS and WCS environments.

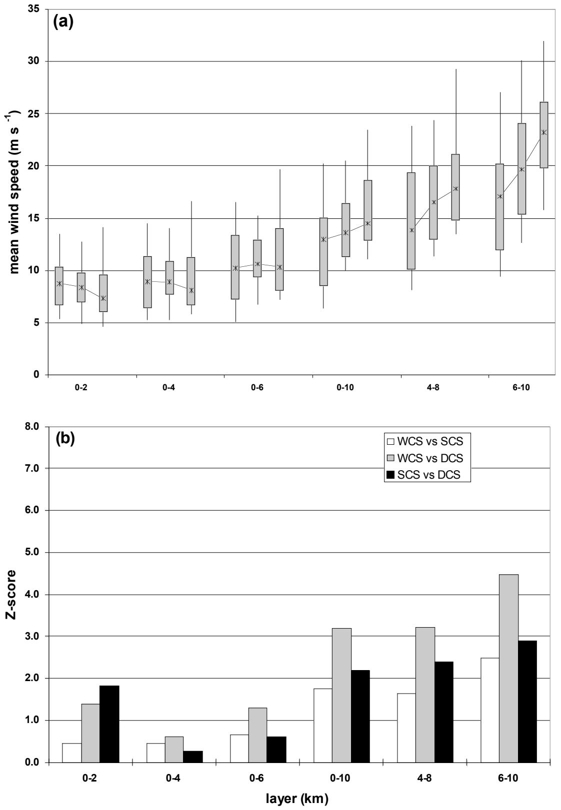

Fig. 3. Same as in Fig. 1, except for ground-relative mean wind speeds in the 0-2 km, 0-4 km, 0-6 km, 0-10 km, 4-8 km, and 6-10 km layers.

It is interesting that the Z-scores for the mean winds in upper levels alone are especially high (Fig. 3b); 75% of the 6-10 km mean wind speeds for the DCSs are above 20 m s^{-1} while 75% of the wind speeds for the WCSs are below 20 m s^{-1}. The physical importance of the upper-level wind speeds compared to the lower-level wind speeds is not obvious but may be tied to enhanced baroclinicity and the larger values of deep-layer wind shear observed for the stronger MCS events. Strong mean wind speeds at lower levels are thought to be an important part of long-lived convectively induced wind storms because of the line-normal transport of horizontal momentum to the surface (Johns and Hirt 1987, Hane and Jorgensen 1995, Evans and Doswell 2001). However, the results show that the ground-relative mean wind speeds in lower levels do not provide a very good discrimination (Fig. 3). Additionally, it is not likely that the stronger wind speeds in upper levels are directly affecting the strength of the surface winds through momentum transport since the convective downdrafts responsible for transferring stronger winds aloft to the surface are thought to typically originate in lower levels (3-5 km) (Knupp 1987).

It has also been shown that the motion of a cold pool, which is driven largely by the hydrostatic pressure variations between the cold pool and the environment, can be enhanced significantly by the mean wind speeds over the depth of the cold air (Seitter 1986, Rotunno et al. 1988, Corfidi 2003). However, the relationship between the mean wind speeds at lower levels and the MCS speeds is found to be weak, with correlation coefficients generally in the 0.05-0.25 range (not shown). Some of this poor relationship may be because the observations are of the mean speed of the leading line and not necessarily of the cold pool itself. But this suggests that the speeds of the ground-relative mean winds in lower levels are not very useful in determining the overall strength of the convectively generated surface winds or in determining the speed of the MCS. This result does not, however, translate into a lack of utility for the winds in a storm relative framework, as shown next.

3) STORM-RELATIVE FLOW PROPERTIES

As discussed previously, past studies have suggested that the inflow of unstable air in low-levels relative to the system can be important for determining its strength and longevity, and therefore, knowledge of the motion and propagation characteristics of the cold pool and the system itself is crucial. Regarding the motion of the MCS as it relates to MCS intensity, the forward speed of the leading line increases with MCS intensity, most notably for the DCSs (75% of the speeds exceed 18 m s^{-1} for the DCSs while almost 80% of the WCSs and SCSs move slower than 18 m s^{-1}). It is no surprise that the potential for a long-lived severe windstorm is strongly related to the speed of the MCS and, therefore, it is clear that a major component of forecasting MCS severity is the anticipation of the forward speed of the MCS itself.

This importance is evident when viewing aspects of the wind profile relative to the speed of the system, as done in previous studies (Evans and Doswell 2001, Gale et al. 2002, Coniglio et al. 2004b) (Fig. 4). The median 0-1 km system-relative wind speeds drop from 19 m s^{-1} in DCS environments to 12-13 m s^{-1} in WCS and SCS environments. Fig. 5a suggests that a quasi-linear MCS is likely to be a derecho if the mean system-relative inflow winds are > 18 m s^{-1} and is very likely to be weak or non severe if these winds drop below 10 m s^{-1}. This shows that once the MCS speeds are known, system relative inflow can be very useful in a nowcasting sense.

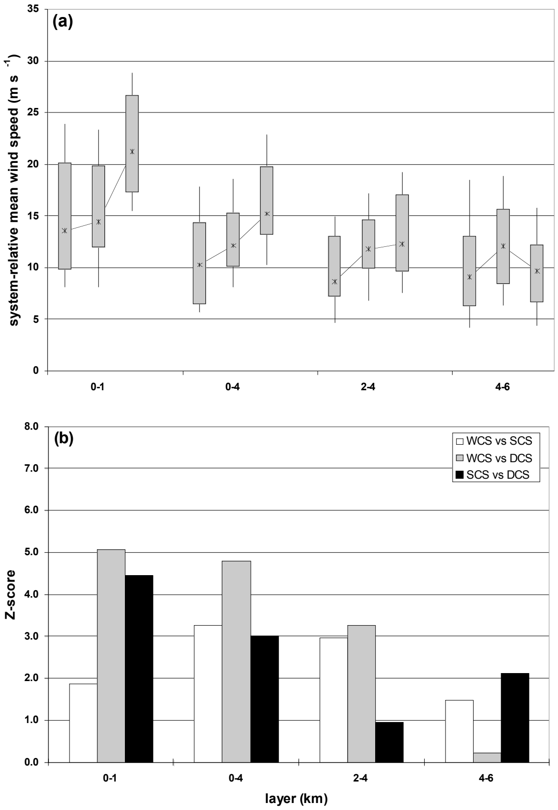

Fig. 4. Same as in Fig. 1, except for the system relative mean wind speeds in the 0-1 km, 0-4 km, 2-4 km, and 4-6 km layers.

It is also interesting that the mid-level system-relative winds (e.g. 4-6 km in Fig. 4) are not significantly different between all three categories, especially between the WCSs and DCSs, which was also found by Evans and Doswell (2001). We echo their suggestion that weak system-relative winds in midlevels, which facilitate cold pool development and strong outflows (Brooks et al. 1994), are not sufficient for discriminating the potential for WCSs versus DCSs by themselves. However, we emphasize that factors that contribute to the *motion* of the cold pool and the system, once they develop, are crucial.

It has been shown that the orientation of the cold pool relative to the low- to upper-level flow orientation can control the structure and propagation characteristics of the system (in fact, this is the determining factor for using the upwind versus downwind-propagating technique for forecasting MCS motion in Corfidi 2003). This is an important point, since the effects of the mean wind and its orientation relative to the cold pool are underemphasized aspects of forecasting the strength and structure of quasi-linear MCSs (Evans and Doswell 2001, Corfidi 2003, Parker and Johnson 2004, Kuchera and Parker 2006). Although the MCS motion vector is not an exact analog to the motion of the cold pool, this section examines various properties of the inflowing environment relative to the MCS motion vector to see if these may be used as an indicator of the potential severity of the system and to gain further insight into the propagation characteristics of MCSs.

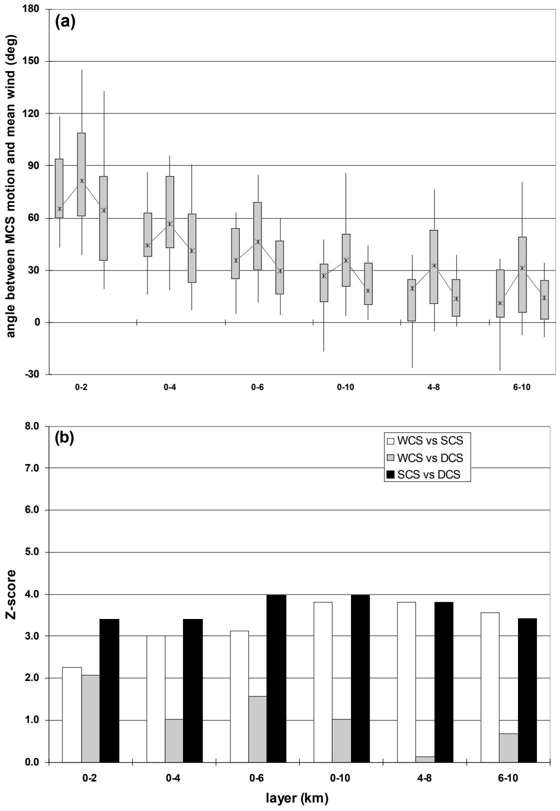

Fig. 5. Same as in Fig. 1, except for the angle between the MCS motion vector and the 0-2 km, 0-4 km, 0-6 km, 0-10 km, 4-8 km, and 6-10 km mean wind vectors.

The first measure examined is the angle between the MCS motion vector and the mean wind vector (α) over various layers[3]. This angle discriminates between WCS and SCS environments and between SCS and DCS environments with Z-scores above 2.0 when the winds in lower levels are included (Fig. 5). The MCS motion is more aligned with the mean low- to mid-level wind vectors in DCS environments than in SCS and WCS environments and the largest component of MCS motion away from the mean wind vector is found for the SCSs. The physical reasons for this are not clear, but one possibility discussed in previous research is the concept of the relationship between cell advection and propagation in determining overall MCS motion (Chappell 1986, Corfidi et al. 1996, Corfidi 2003). The small angles and slower speeds for the WCSs indicates that cell advection is likely dominating for the weaker events, but is less influential compared to cell propagation for the SCSs and DCSs. This is supported by the fact

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[3] A positive angle indicates MCS motion to the right (in natural coordinates) of the reference vector in question.

that the directions of the mean winds are not significantly different between the WCSs and SCSs (not shown), yet α between the WCSs and SCSs is quite different (Fig. 5). Furthermore, α is smaller once again for the DCSs. The mean flow is stronger and the axis of instability tends to be aligned with the mean directions for DCSs (Johns and Hirt 1987, Johns 1993, Coniglio et al. 2004). This configuration encourages propagation into the instability axis, which aligns the propagation along with cell advection and maximizes system speeds. This effect is likely prevalent in our data set since α is small for the DCSs, yet many DCSs are observed to move faster than the mean wind speeds over any layer, as first noted by Johns and Hirt (1987). In fact, 53% (28 out of 53) of the DCSs move faster than the 2-12 km mean wind speed, while only 14% (12 out of 87) of the SCSs move faster than this speed, which further highlights that propagation in the same direction of cell advections is a trait that separates the shorter-lived and longer-lived severe MCSs.

b. Thermodynamic variables

Several thermodynamic variables exhibit considerable ability to discriminate among the MCS environments. CAPE is calculated by lifting the surface parcel (SBCAPE), the most unstable single parcel (MUCAPE), and the most unstable parcel resulting from mixing any 100 hPa layer in the lowest 400 hPa (MLCAPE). The energy available for downdraft parcels is measured by DCAPE (Gilmore and Wicker 1998), which is calculated using a parcel that descends from the larger of two values: the height level of minimum Θ_e and the wet-bulb zero height.

1) CAPE VARIABLES

None of the CAPE variables discriminate well between SCS and DCS environments, but all of the CAPE variables discriminate at very high levels between WCSs and SCSs and WCSs and DCSs (Fig. 6). The differences between WCS and SCS/DCS environments is largest for MLCAPE; median MLCAPES range from around 1400 J kg^{-1} for WCSs to around 2600 J kg^{-1} for SCSs, to 2100 J kg^{-1} for DCSs. The smaller CAPE for DCSs compared to SCSs is due in part to the inclusion of DCSs that occurred in strongly forced environments with relatively small CAPE. The lack of a large difference in the CAPE variables between SCS and DCS environments may also reflect the inability of a sounding to detect differences in the spatial distribution of CAPE. It may be that the higher CAPE values are more elongated along fronts for the DCS events, much as previous studies have shown that higher low-level dewpoint air tends to “pool” along boundaries ahead of derechos (Johns 1993, Coniglio et al. 2004b). However, single values of CAPE alone do appear to provide some useful information on whether or not the MCS will produce severe winds, regardless of its longevity.

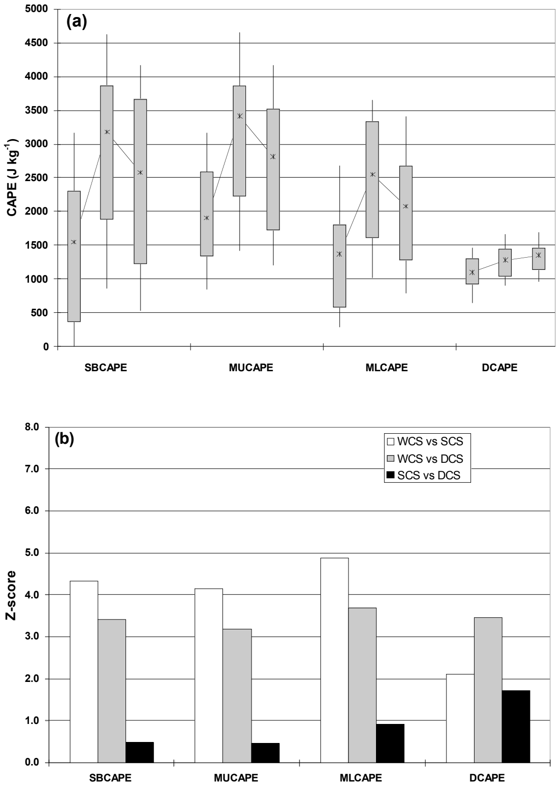

Fig. 6. Same as in Fig. 1, except for SBCAPE, MUCAPE, MLCAPE, and DCAPE.

Anticipation of the development of and strength of an organized cold pool is important for the warm season-type environments examined in this study, since it is likely that the cold pool is largely responsible for the system’s sustenance, as discussed previously. As such, we find that DCAPE increases with increasing MCS intensity (Fig. 6a), as found by Evans and Doswell (2001). The Z-scores of 1.5-3.5 among the three MCS categories suggest that DCAPE can be a good discriminator. Figure 6a also suggests that DCAPE may be useful in an exclusionary sense; if an MCS develops in an environment with DCAPE < 900 J kg^{-1}, it is likely to be weak or non-severe. However, we caution the reader on the use of DCAPE in practical applications for reasons given later in section 4.

2) LAPSE RATES

Despite the fact that CAPE was found to be greatest for SCSs, the mid-level environmental lapse rates are found to be greatest for DCSs (Fig. 7). In addition, the 2-4 km and 2-6 km, and 3-8 km lapse rates discriminate very well among all three MCS environments, despite the fact that CAPE couldn’t discriminate between these categories. Median values of the 2-6 km γ range from 6.6 °C km^{-1} for WCSs to 7.25 °C km^{-1} for DCSs. The distributions of the 2-6 km lapse rate suggest that an MCS is likely to be severe for values > 7 °C km^{-1} (Fig. 7a) and that this could be a way to use the environmental instability to discriminate weak and longer-lived severe MCSs.

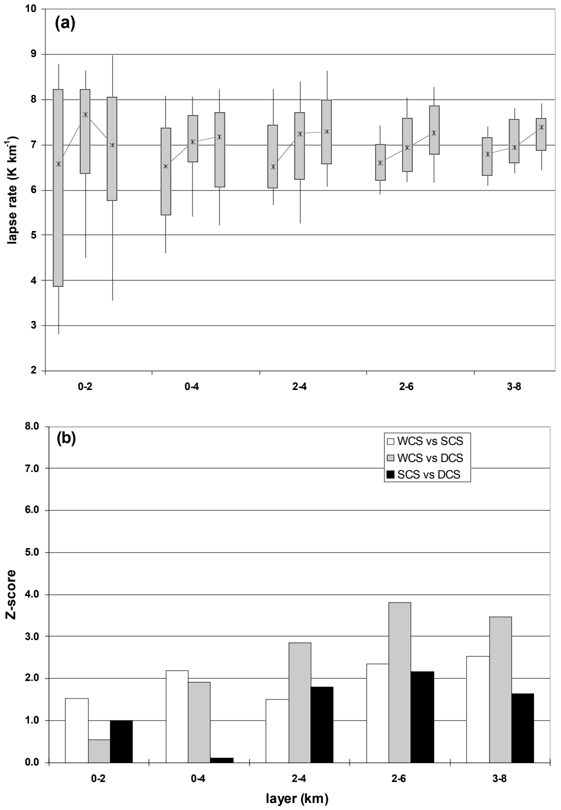

Fig. 7. Same as in Fig. 1, except for the 0-2 km, 0-4 km, 2-4 km, 2-6 km, and 3-8 km lapse rates (K km^{-1}).

It is interesting that the utility of the lapse rates as a discriminator diminishes with the surface-based layers. One of the factors thought to be important for wet microbursts (Atkins and Wakimoto 1991) in general is a large lapse rate below the melting level that extends to the surface (Proctor 1989, McCann 1994). Our results indicate that this does not appear to be true for organized systems, as the 0-2 and 0-3 km (not shown) lapse rates do not discriminate very well among the MCS categories. Although it is not a statistically strong result, the 0-2 km lapse rate is in fact less on average for the DCSs than the SCSs, and there is large variability to the distributions (Fig. 7a). This suggests that the processes responsible for the organization of mesoscale cold pools and deeper overturning tied to instability over deeper layers appear to be more important in determining the severity of a system than its potential to produce localized downdrafts. In other words, larger, faster-moving cold pools associated with severe MCSs likely aren't as dependent on large 0-2 km lapse rates as more isolated "pulse" type storms that occur more typically in weaker shear/mean flow environments and often produce their severe surface winds without an organized cold pool (Atkins and Wakimoto 1991). Because the lapse rates are considered over shallower layers of the atmosphere than CAPE, it is more likely to uncover small-scale instability features in the vertical that may be masked by CAPE. As a result, the mid-level lapse rates may generally be a better discriminator than CAPE (as supported by a comparison of the Z-scores for CAPE and the lapse rates), at least from a one-dimensional perspective.

3) EQUIVALENT POTENTIAL TEMPERATURE (θ_e)

The vertical difference in θ_e ($\Delta\theta_e$) in the 1-3 km, 1-5 km, and 1-7 km layers are found to be an excellent discriminator between WCS and both SCS and DCS environments (Fig. 8). $\Delta\theta_e$ is found to be least negative for WCS environments and generally most negative for SCS and DCS environments. It is apparent that with the correlation between $\Delta\theta_e$ and CAPE, the physical explanations for the differences in $\Delta\theta_e$ between the different MCSs are similar to those for CAPE, reflecting the convective instability.

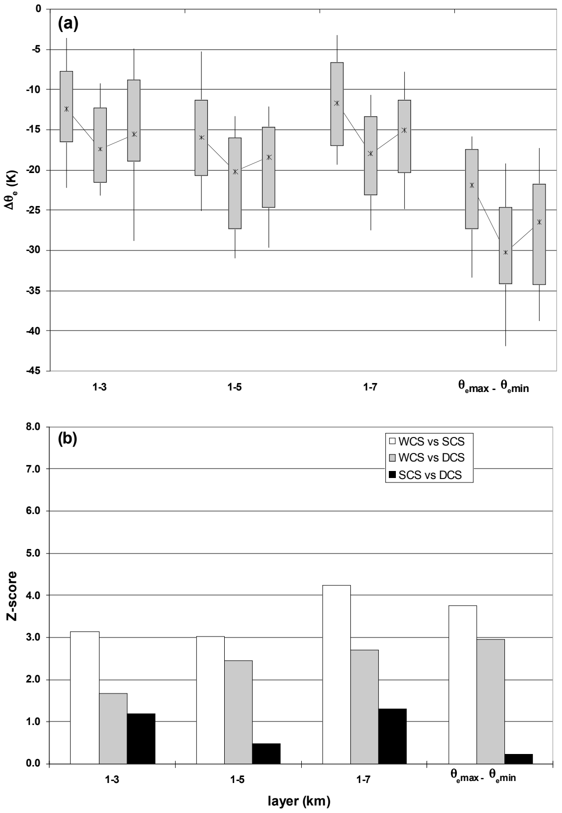

Fig. 8. Same as in Fig. 1, except for the vertical difference in θ_e between 1-3 km, 1-5 km, 1-7 km, and the levels of the maximum and minimum θ_e (θ_{emax}-θ_{emin}).

However, it is interesting to note that the 1-7 km $\Delta\theta_e$ and the $\Delta\theta_e$ between the maximum and minimum θ_e between low and mid levels ($\theta_{emin} - \theta_{emax}$) do a much better job discriminating between WCS and SCS environments than DCAPE (c.f. Figs. 6 and 8). The median of $\theta_{emin} - \theta_{emax}$ ranges from around -21 K for the WCSs to around -30 K for the SCS, to around -27 K for the DCSs. But it is important to point out that $\Delta\theta_e$ is not a good discriminator between SCS and DCS environments, and, therefore, $\Delta\theta_e$ is likely linked with any wind damage potential, regardless of its longevity, as suggested in Atkins and Wakimoto (1991). Nonetheless, although DCAPE and $\Delta\theta_e$ represent similar processes, we have shown that $\Delta\theta_e$ used in conjunction with DCAPE may be useful for discriminating between WCSs and SCSs, and between SCSs and DCSs, respectively.

4. Summary and Conclusions

This study presents an analysis of the ability of several meteorological variables to discriminate among the observed environments of MCSs of different intensities. Much of the discussion of the differences in the kinematic variables centers on the vertical wind shear and the vertical mean wind speeds. Regarding the wind shear, it is shown that the deep layer wind shear (0-6 to 0-10 km) is a better discriminator than the low-level shear (0-2 and 0-4 km). Combined with the result that upper-level shear alone did not provide a good discrimination suggests that a shear variable that includes the physical benefits of low-level and upper-level shear together, i.e., an integrated shear measure, such as the 0-10 km bulk shear, is the best way to use the environmental shear to forecast the potential for a quasi-linear MCS to produce severe winds.

Regarding the mean wind variables, DCSs tend to move in a direction more parallel to the mean mid- and upper-level winds and the deep-layer shear than SCSs and WCSs. This suggests that the propagation component of system motion is more aligned with the advective component for the more long-lived severe MCSs. The fact that MCS motion is strongly related to MCS severity shows that the techniques for assessing MCS speed and motion discussed by Corfidi (2003) may provide useful information regarding the severity of an MCS. Additionally, as in Evans and Doswell (2001), system-relative inflow was found to be positively correlated and significantly different among the MCS categories, but mid-level storm-relative winds were very similar between weak and severe, long-lived MCSs. Likewise, the present results suggest that the low-level inflow and the mean low-to-upper level winds, and their effects on system advection and propagation, may play a significant role in determining the overall severity of the MCS in conjunction with the shear. We feel that these mean wind interactions and their role in controlling the propagation and severity of MCSs are underemphasized aspects of the MCS forecasting problem.

Many thermodynamic variables are found to be positively correlated with MCS intensity and are found to be very good discriminators. The results suggest that the most useful variables may include the mid-level environmental lapse rates, the low-to-mid level difference in θ_e, and the most unstable 100 hPa mixed-layer CAPE.

This study provided a description of the environments associated with severe wind-producing MCSs based on the analysis of numerous variables derived from observed sounding data. With an understanding of these variables and their climatological distributions, the intention of this study is to provide forecasters with improved guidance on forecasting MCS severity.

It is important, however, to recognize the disconnect that is sometimes present between the statistical and the practical significance of results from studies of this type. The analysis was performed on observations taken near MCSs to obtain the best possible estimate of the surrounding environment, but the disadvantage of this method is that forecasters usually have to rely on estimates of the environment from other sources since the placement of an MCS in close proximity to an observed sounding is uncommon on a day-to-day basis. Objective analyses or short-term numerical forecasts of the environment are likely to be less accurate than direct observations from a sounding and can have biases which may decrease one’s confidence in the accuracy and utility of a particular forecast parameter. For instance, despite a relatively high statistical significance, this may be especially true for DCAPE, in which the difference in the median values between the MCS categories likely is not very large relative to observational and analysis error. We have found that the magnitude of DCAPE is fairly sensitive to the starting height of the downdraft parcel; DCAPE estimates often vary more than 200 J kg^{-1} for the same profile depending on the choice of starting height. This is a reflection of the highly variable nature of the low- to mid-level moisture profile. Furthermore, DCAPE assumes that the parcel maintains saturation throughout its descent, which likely is not realized in many convective situations (Gilmore and Wicker 1998). In reality, MCS cold pools likely are composed of negatively buoyant parcels from a variety of starting heights, many of which likely undergo dry-adiabatic warming through some portion of their descent. Future studies should attempt to examine DCAPE and the other forecast parameters from other data sources to determine the robustness and the practical utility of the results. This will serve to supplement the growing body of work describing various MCS environments.

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