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BASELINE CLIMATOLOGY OF SOUNDING DERIVED PARAMETERS ASSOCIATED WITH DEEP, MOIST CONVECTION

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1. INTRODUCTION

Meteorologists at the Storm Prediction Center (SPC) routinely prepare forecasts of severe thunderstorm potential for the lower 48 states. Since 1999, SPC has been issuing probabilistic forecasts of tornadoes, damaging winds, and large hail. In addition, probabilistic forecasts of significant severe weather (i.e. F2+ tornadoes, 65+ knot wind gusts, or 2+ inch hail) are composed.

The purpose of this study is to use rawinsonde data to examine several parameters commonly used to forecast severe thunderstorms and tornadoes. The research compliments work by Rasmussen and Blanchard (1998), but includes a much larger data set (an order of magnitude larger), null cases, and does not attempt to determine convective mode. Special emphasis is placed on low and middle level lapse rates, 100 mb mean layer CAPE (MLCAPE), low level shear, and 100 mb mean layer LCL height (MLLCL) AGL. The 100 mb mean layer CAPE and LCL height values are computed by lifting a parcel characterized by mean temperature and moisture in the lowest 100 mb.

2. EVENTS

Lightning data from Global Atmospherics, Inc., (Orville, 1991) and convective severe weather reports (Storm Data, 1997-1999; Hart and Janish, 1999) are utilized to subdivide the data set into 5 categories (Table 1). Of the more than 60,000 possible events, 32,141 (53%) had non-zero CAPE. Of the 45,508 no thunder events, 17,559 (39%) had non-zero CAPE. The categories are exclusive, and each event was assigned using the most severe report (i.e. an F2 tornado event was only assigned to significant tornadoes, even if 1 inch hail also occurred).

The lightning strike threshold of 2 or more cloud to ground (CG) strikes is consistent with the criteria established by Reap (1986) and Orville (2001-personal communication), similar to the 3 or more CG strike threshold used by Hamill and Church (2000), but significantly less than the 10 or more CG strike criteria used by Rasmussen and Blanchard (1998).

Table 1. Definitions and number of proximity soundings for the five convective categories

Number	Category	Definition
45508	No Thunder	0-1 CG strikes
11339	General Thunder	≥ 2 CG strikes
2644	Severe	0.75-1.99" hail
	and/or	50-64 knot gust
	and/or	wind damage
	and/or	F0 or F1 tornado
512	Significant Hail/Wind	≥ 2.00" hail
	and/or	≥ 65 knot gust
87	Significant Tornadoes	F2-F5

3. PROXIMITY CRITERIA

0000 UTC rawinsonde soundings from 1997-1999 for the lower 48 states are collected. A total of 60,090 soundings are included. Proximity is defined as being within 100 nm (185 km) of the sounding release location, and during the period from 2100 UTC to 0300 UTC (6 hour period centered on the 0000 UTC sounding). The 185 km threshold lies within the range of 80 km (Darkow, 1969; Schaefer and Livingston, 1988; Brooks et al., 1994) and 400 km criteria utilized by Rasmussen and Blanchard (1998). For a detailed discussion on the difficulty of defining and selecting a proximity sounding, see Brooks et al. (1994).

4. QUALITY CONTROL

No attempt was made to modify the soundings. It was anticipated that the effects of unrepresentative, contaminated, or erroneous data would be damped out in the statistical analysis. A simple objective quality control procedure for the severe, significant hail/wind, and significant tornado soundings removed all soundings with most unstable parcel in the lowest 300 mb CAPE (MUCAPE) less than 150 J kg^{-1} (Brooks et al., 1994). General thunder soundings were removed if no MUCAPE was present. All CAPE values were calculated using the virtual temperature correction (Doswell and Rasmussen 1994).

Subjective quality control was minimal because of the size of the data set. Lapse Rates greater than 11 °C km^{-1} in 0-3 km AGL layer and 10.2 °C km^{-1} in 0-6 km AGL layer, 850-700 mb layer, and 700-500 mb layer were removed. 0-1 km AGL shear

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greater than 50 m s^{-1} and 0-6 km AGL shear greater than 100 m s^{-1} were also excluded. In addition, all soundings with MUCAPE and/or MLCAPE greater than 5000 J kg^{-1} were manually inspected and erroneous and/or contaminated soundings were excluded. A total of 55 soundings were removed.

5. PARAMETERS

A list of the parameters computed from the sounding data set is shown in Table 2. These parameters cover three main groups a) instability/lapse rates, b) LCL heights, and c) vertical wind shear.

Table 2. Parameters computed from soundings

Parameter	Units
MUCAPE (most unstable parcel CAPE)	J kg^{-1}
MUCIN (MU parcel convective inhibition)	J kg^{-1}
MLCAPE (100 mb mean layer CAPE)	J kg^{-1}
MLCIN (100 mb ML convective inhibition)	J kg^{-1}
0-3 km AGL Lapse Rate	° C km^{-1}
0-6 km AGL Lapse Rate	° C km^{-1}
700-500 mb Lapse Rate	° C km^{-1}
850-700 mb Lapse Rate	° C km^{-1}
DCAPE (Downdraft CAPE)	J kg^{-1}
LCL height (lifted condensation level)	m AGL
MLLCL height (100 mb ML LCL height)	m AGL
0-1 km shear (magnitude of vector difference)	m s^{-1}
0-6 km shear (magnitude of vector difference)	m s^{-1}

6. RESULTS

We analyze the statistical distributions of each parameter for the different event types using “box and whisker” diagrams. To discriminate between thunder and no thunder soundings, the best parameters were CAPE and low level lapse rates. MLCAPE has been shown to more accurately represent convective cloud heights/parcel path (Craven et. al 2002) using 0000 UTC soundings. For this database, 90 percent of the no thunder events had less than 250 J kg^{-1} of MLCAPE, while about 50 percent of thunder events had more MLCAPE (Fig. 1). Although there is a tendency to have higher values of instability with the more significant severe events, there is considerable overlap, especially between severe and significant events.

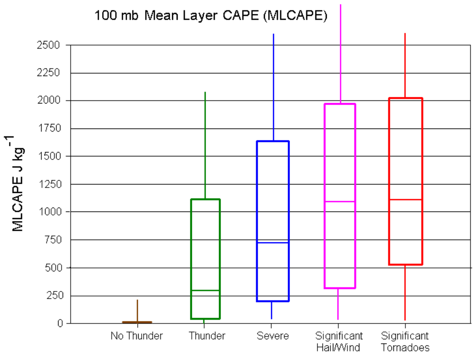

Figure 1. Box and whisker plot of 100 mb mean layer CAPE (MLCAPE). 10th, 25th, 50th, 75th, and 90th percentiles are shown.

Individual parameters did not discriminate well between thunder and severe events. However, when considering both instability and shear (Davies and Johns 1993) simultaneously, the results showed a noticeable improvement. Calculating the product of MLCAPE and 0-6 km shear yielded a small overlap between the middle 50 percent of the thunder and severe distributions, especially for the significant severe/tornado categories (Fig. 2)

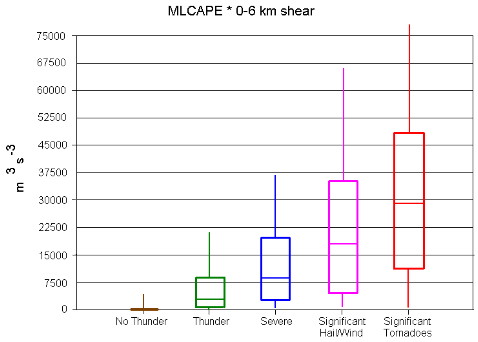

Figure 2. As in Fig. 1, except for product of MLCAPE and 0-6 km shear.

The most striking results were in discriminating between significant hail/wind events and significant tornadoes. The low level shear parameter, 0-1 km AGL shear, indicated little difference between the first four categories (Fig. 3). However, there was no overlap in the middle 50 percent between the significant tornado category and the other events. Much like the lower threshold that has been established for deep layer shear and supercell development (i.e. 20 m s^{-1}; Weisman and Klemp 1982; Davies and Johns 1993; Rasmussen and Blanchard 1998; Bunkers et al. 2000; Craven 2000), it appears that 10 m s^{-1} (20 kts) may be used as a lower threshold for significant tornado events. Stronger low level shear appears to be associated with a higher frequency of significant tornado events.

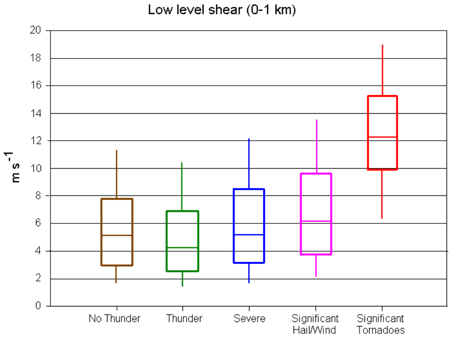

Figure 3. As in Fig. 1, except for 0-1 km shear.

These results are consistent with Edwards and Thompson (2000), who found a substantial difference between the mean 0-1 km Storm Relative Helicity for supercells with significant tornadoes versus supercells with either weak or no tornadoes observed.

A similar signal was found using MLLCL height AGL, with very little overlap between the middle 50 percent of the significant tornado category versus the other four categories (Fig. 4). Lower MLLCL heights and thus lower cloud bases are associated with higher boundary layer moisture and appear to indicate a higher frequency of significant tornado events.

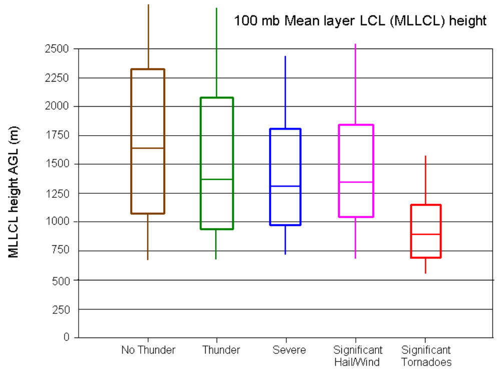

Figure 4. As in Fig. 1, except for 100 mb mean layer LCL (MLLCL) height.

These results are consistent with earlier research which indicated that mean LCL heights are about 500 m lower for significant tornado events compared to weak tornadic or non-tornadic storms (Rasmussen and Blanchard 1998: Edwards and Thompson 2000; Johns et al. 2000; Markowski et al. 2000).

Examining low level shear and MLLCL height yields a strong signal between significant tornadoes and significant hail/wind (Fig. 5). Significant tornadoes tend to occur with relatively high 0-1 km shear (e.g. > 10 m s^{-1}) and relatively low MLLCL height (e.g. < 1500 m AGL). Storms that produce hail greater than or equal to 2 inches and/or wind gusts greater than or equal to 65 knots but no strong/violent tornadoes tend to have weaker low level shear and higher cloud bases.

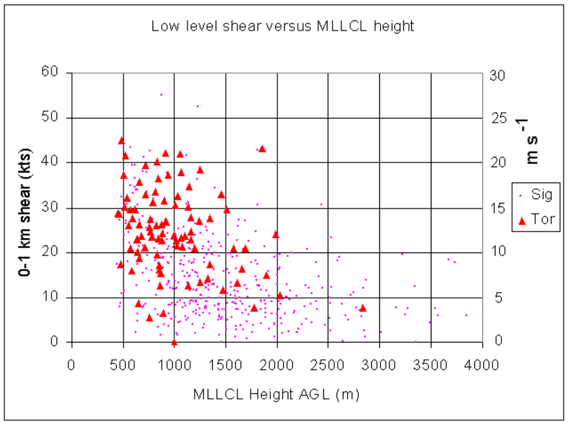

Figure 5. Scatter plot of 0-1 km shear versus MLLCL height for significant tornadoes (triangles) and significant hail/wind events (dots).

The data were also partitioned in six two month groups to account for seasonal variability. There was much less variation in the median 0-1 km shear for the significant tornado category than the other four categories (Fig. 6). Although low level shear appears to help distinguish between significant tornadoes and other categories throughout the year, its effectiveness is most pronounced during the warm season. The median value for significant tornadoes exceeds that of significant severe by more than 5 m s^{-1} from March through October.

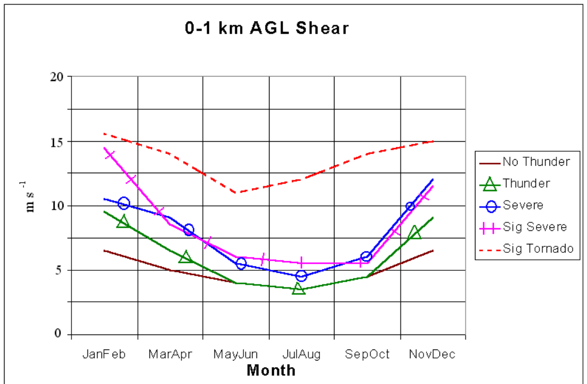

Figure 6. Seasonal variation in 0-1 km shear for each category.

Similarly, there is minimal seasonal variation in the median MLLCL height AGL for significant tornadoes, while the other categories increase 400-600 meters from the cold to the warm season (Fig. 7). During the cold season, there is little difference in the median convective cloud base height for the different event types, while the difference increases to 300-500 meters during the warm season.

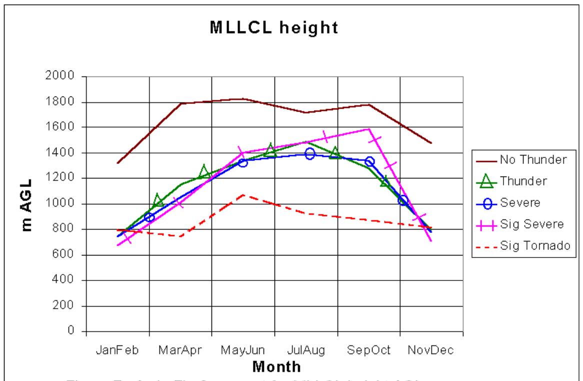

Figure 7. As in Fig 6., except for MLLCL height AGL.

7. SUMMARY

Inspection of a large data base of soundings from the CONUS from 1997-1999 yielded the following results:

1) MLCAPE discriminates well between no thunder and thunder soundings, but there is considerable overlap between thunder and the three severe categories.

2) The best discriminator between thunder and severe was the product of MLCAPE and 0-6 km shear.

3) 0-1 km shear and MLLCL height both discriminate well between significant tornado events and other severe events.

4) There is minimal seasonal variation in 0-1 km shear and MLLCL height for significant tornadoes. Considerable seasonal variation is noted in the other four categories. In addition, these parameters are better at discriminating during the warm season.

8. ACKNOWLEDGMENTS

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