SOUNDING-DERIVED LOW-LEVEL THERMODYNAMIC CHARACTERISTICS ASSOCIATED WITH TORNADIC AND NON-TORNADIC SUPERCELL ENVIRONMENTS IN THE SOUTHEAST UNITED STATES

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Abstract

Recently, several studies have suggested the importance of near-surface environments in the tornadogenesis process. Utilizing temporal and spatial proximity soundings for severe storms archived for the period from 1980 through 2002, this study attempts to identify the representative near-surface tornado environment in the Southeast region of the United States. Using surface-based parcels, mean thermodynamic (uncorrected for virtual temperature) and shear parameter values for significant (F2-F5), weak (F0-F1) on the legacy Fujita scale, and non-tornadic supercell environments are constructed and tested between groups. This study provides the forecaster with baseline values for commonly used stability, shear, and combination parameters for the various environments in the Southeast U.S. Results suggest that while stability varies between event environments, shear-based parameters, specifically 0-1 km storm relative helicity (SRH) and 0-1 km energy helicity index (EHI) are the most promising parameters for discriminating between non-tornadic supercell, weak, and significant tornado environments.

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1. Overview

Not surprisingly, the majority of empirical tornado research is concentrated in the natural tornado laboratory of the Great Plains region (defined here as northern Texas, Oklahoma, Kansas, and Nebraska) of the U.S. Comparatively little research has been conducted in other regions of the country, including the Southeast (defined here as Alabama, Arkansas, Georgia, Louisiana, Mississippi, and central and eastern Tennessee). While Rasmussen and Blanchard (1998), Thompson et al. (2004), and Davies (2004) utilized data collected from soundings taken in the Southeast U.S., these studies do not segregate the Southeast into its own unique region. There has been no formal study specifically related to supercell tornado forecast parameters in the Southeast U.S., a region known for its many cool season tornado events/outbreaks and a high tornado related death rate per 10,000 people (Ashley 2007).

When compared to other regions, the temporal tornado climatology in the Southeast is similar, showing a prominent spring maximum. However, the late fall tornado event maximum in the Southeast is considerably more pronounced when compared to the Great Plains region of the U.S. (Gerard et al. 2005). Alabama, Louisiana, and Mississippi have the greatest threat of a tornado in late February compared to the remaining regions of the U.S. (Brooks et al. 2003). While the greatest tornado threat shifts farther north and west in April, a relatively high tornado potential still exists for Alabama, Arkansas, Georgia, Louisiana, and Mississippi. Southeast region tornadoes are relatively rare during the summer months as the core of the jet stream remains over the northern U.S. However, an increased threat shifts back to the Southeast in November with southwest Mississippi having the highest probability of a tornado event (Brooks et al. 2003). Recent fall tornado outbreaks in Alabama have made November the most active month of the year for that state. Since the new millennium, many southeastern states have been hardest hit during the late fall (e.g. November 24, 2001 in Mississippi and Alabama; November 10, 2002 in Mississippi, Alabama, and Tennessee; November 23-24, 2004 in Alabama; and February 5-6, 2008) rather than during the typical spring tornado maximum.

Tornado records from the Storm Prediction Center (SPC) indicate that many Southeast region states rank high in terms of tornado-related deaths per capita, when compared to the Great Plains states. In fact, Gerard et al. (2005) found that the Southeast U.S., a region they termed "Dixie Alley", has nearly 1.5 times the number of strong tornadoes and nearly three times the deaths as compared to the Great Plains Tornado Alley. Possible reasons for the high number of deaths may include poor home construction, the extensive use of manufactured housing, the time of the year and time of day of tornado occurrence. Regardless of the reasons for the high tornado death rates, a greater understanding of tornado environments in the Southeast region of the U.S. is needed. This study will examine low-level thermodynamic and kinematic characteristics of tornadic and non-tornadic supercell environments in the southeast United States using close proximity observed soundings. The following section will summarize the low-level thermodynamic and dynamic parameters used to investigate near-surface tornado environments. Section three will describe the database and methodology used for computation and analysis in this study. Section four will provide the results of the study and section five will provide a summary.

2. Summary of Parameters Investigated

The thermodynamic and kinematic parameters analyzed in this study include: convective available potential energy (CAPE), 0-3 km CAPE; 0-1 km storm relative helicity (SRH), 0-3 km SRH; 0-1 km energy helicity index (EHI), 0-3 km EHI; lifting condensation level (LCL); and level of free convection (LFC).

a. Stability (CAPE and 0-3 km CAPE)

CAPE is considered the best index for measuring latent instability in the atmosphere (Darkow 1986) and is a raw estimate of vertical motion. As a representation of the amount of buoyant energy available to accelerate a parcel vertically, CAPE is computed by integration between the environmental temperature curve and the trace of a vertically moving parcel between the level of free convection and the equilibrium level. Still, there are assumptions and problems when using CAPE to assess vertical motion in the atmosphere. Vertical motion estimates need to include the effects of water loading, entrainment, nonhydrostatic pressure gradients, and ice processes (Doswell and Rasumussen 1994). In most cases, CAPE is often overestimated due to dry air entrainment and water loading. Edwards and Thompson (2000) found that CAPE values greater than 3,500 J kg^{-1} were more prevalent in tornadic supercell environments compared to non-tornadic environments. Rasmussen and Blanchard (1998) found significantly lower values of CAPE in ordinary thunderstorm environments when compared to environments that produced non-significant tornadoes or significant tornadoes. While CAPE only takes into account the potential amount of energy in the atmosphere, it is likely the most widely used measure of instability and, in a sheared environment, has a great amount of value as a forecast parameter in the prediction of supercells. However, it is recognized that CAPE values related to tornadic environments can greatly differ depending upon season and region of interest.

Interestingly, the utilization of 0-3 km CAPE began with a study of tornadoes associated with landfalling hurricanes. McCaul (1991) discovered the importance of tilting and stretching within the lowest levels of hurricane-spawned supercells that produced tornadoes. More recently, Rasmussen (2003) found that regions of near-ground CAPE, if realized, may promote more effective tilting and stretching of the low-level shear (if any exists). Davies (2001) suggests that tornadic supercell storms have greater 0-3 km CAPE in their environments compared to non-tornadic supercells. Davies (2006) suggests that because 0-3 CAPE represents the amount of buoyancy near the surface, it may be more consistently useful in discriminating tornado environments when compared to parameters using a single point (such as LFC).

b. Shear (0-3 km and 0-1 km SRH)

SRH depends on estimated storm motion and is a widely used index by forecasters to predict severe weather, especially supercells and tornadoes (Thompson et al. 2004). 0-3 km SRH was the primary shear parameter used to forecast supercells and tornadoes after it was first identified by Davies-Jones et al. (1990). A study conducted by Davies (2001) found that much higher helicity values were found with tornadic supercell environments when compared to non-tornadic supercell environments. Davies-Jones et al. (1990) found that weak tornado environments had a mean 0-3 km SRH value of 278 $m^2\ s^{-2}$, strong tornado environments had a mean value of 330 $m^2\ s^{-2}$, and violent tornado environments had a mean value of 531 $m^2\ s^{-2}$. However, Davies (2001) notes that significant tornadoes can occur when 0-3 km SRH values are weak (less than 100 $m^2\ s^{-2}$), especially if large low-level buoyancy is available and small-scale boundaries are present, which would increase local SRH values.

Rasmussen (2003) found that 0-1 km SRH is a good discriminator between tornadic supercell and non-tornadic supercell environments, with tornado environments preferentially having larger 0-1 km SRH. Results from Markowski et al. (1998a) suggest that SRH is highly variable on a spatial and temporal scale and might not be captured by the upper-air network. Regardless, the large local variations in SRH may be important in the tornadogenesis process.

c. Instability and shear combination (0-3 km and 0-1 km EHI)

0-3 km EHI is the product of an empirical formula that combines CAPE and SRH, where SRH is calculated from the surface to some above ground level (AGL) (Davies 1993) (for this work 1 km and 3 km AGL will be used). The EHI is calculated using the formula:

$$EHI_{0\text{-}3\ km/0\text{-}1\ km} = (CAPE)\ (SRH_{0\text{-}3\ km/0\text{-}1\ km})\ /\ 160{,}000\ \text{(unitless)} \qquad (1)$$

It is generally understood that an increase in EHI serves to increase the possibility of tornadoes (significant or weak) within a given region. A study by Rasmussen and Blanchard (1998) found that 0-3 km EHI is a good discriminator between significant tornado, weak tornado, and non-severe thunderstorm environments. The authors found that 10% of non-severe thunderstorms have EHI values greater than 0.77. In contrast, 40% of weak tornadoes have EHI values greater than 0.77 and 67% of significant tornadoes are associated with EHI values greater than 0.77. A later study by Rasmussen (2003) suggested that the 0-3 km EHI is better at discriminating between tornadic supercells and general thunderstorms rather than between significant and weak tornadoes. While there seems to be conflicting ideas with respect to the discrimination ability of 0-3 km EHI, the most recent research (after 1999) suggests that the 0-1 km layer EHI is more effective with respect to determining significant versus weak tornado environments. Edwards and Thompson (2000) and Thompson et al. (2003) seem to favor 0-1 km EHI over 0-3 km EHI when differentiating between significant tornadoes and weak tornadoes.

In their national study, Edwards and Thompson (2000) found a mean 0-1 km EHI value of 2.4 for significant tornadoes and 1.1 for weak tornadoes. In addition, they found that nearly two-thirds of significant tornado soundings had 0-1 km EHI values greater than 0.5, whereas 75% of weak tornadoes had values less than 0.5. Using the Rapid Update Cycle-2 (RUC-2) model proximity soundings, Thompson et al. (2003) found statistically significant differences in mean values of 0-1 km EHI for all types of storm groups (significant tornado, weak, supercell, marginal supercell, and regular thunderstorm environments).

d. Miscellaneous parameters (LCL and LFC heights)

The importance of LCL heights may be linked to the amount of evaporational cooling that takes place within the downdraft of a supercell. Relatively high LCL heights are associated with lower boundary layer moisture which may allow for greater evaporation, and related low-level cooling, which would lead to stronger outflow as suggested by Rasmussen and Blanchard (1998). In contrast, lower LCL heights are characterized by higher planetary boundary layer

(PBL) moisture, which may prevent the disruption of the low-level mesocyclone by the cold pool. In fact, supercells in environments with high dew point depressions, high LCL heights, large CAPE, and strong shear often do not produce tornadoes as noted by Edwards and Thompson (2000). Studies that have investigated the LCL height and related tornado environments suggest that tornadogenesis is more likely to occur with lower LCL heights (Rasmussen and Blanchard 1998; Edwards and Thompson 2000; Davies 2001; Brooks and Craven 2002). Edwards and Thompson (2000) indicated that the LCL height of significant tornado environments was half that of non-tornadic supercell environments. Markowski et al. (2002) shows that high boundary layer moisture may be more conducive to rear flank downdrafts (RFDs) with high buoyancy, which increases the likelihood of tornadogenesis.

Generally, as LFC heights increase so does the potential for elevated convection and a decrease in LFC heights indicates that convection is or may become rooted in the PBL. It has been suggested that tornadoes are less likely when supercells are elevated (Rasmussen and Blanchard 1998; Davies 2004). The reason for this reduction in tornadoes may be related to the importance of Convective Inhibition (CIN) in that the stretching of a parcel in an updraft may be impeded due to an area of negative buoyancy in the low-levels (Davies 2004). LFC heights were shown to be a strong discriminator between significant, weak, and non-tornadic thunderstorm environments; this relationship was especially evident between significant tornadoes and non-tornadic thunderstorms (Davies 2001).

This study will develop a set of baseline values for the indices described above that are unique to the Southeast region of the U.S. It is anticipated that this work will give forecasters in the Southeast a better perspective of low-level parameters associated with significant, weak, and non-tornadic supercell environments.

3. Data and Methodology

a. Tornado dataset development

The tornado data used in this study were collected from the Historical Severe Report Database compiled by the SPC. This comprehensive database lists specific information regarding each tornado event including the year, month, day, events' location (by state), Fujita scale rating, path length and width, fatalities, injuries, and beginning latitude and longitude. For a tornado or any other severe weather event to be accurately entered into the Severe Report Database, an observer must witness the event, perceive the event as severe and properly report the event (Kelly et al. 1985). Therefore, a recognized weakness with this study lies with the tornado data and the likelihood of temporally and spatially non-linear population biases. However, given the size of the database and the statistical methods employed, reasonable and operationally useable results are expected.

Tornado event data for this study were extracted for the years 1980 through 2002 inclusive for the states of Alabama, Arkansas, Georgia, Louisiana, Mississippi, and Tennessee. Due to the proximity to the Gulf of Mexico and the Atlantic Ocean, Florida was excluded from the study. It is believed that Florida would require more strict proximity criteria to ensure a reasonable estimate of the storm environment. The primary reasons for using the 1980-2002 period are data availability and to ensure the inclusion of significant wind data in the calculation of the shear parameters. In addition, this study period was chosen because it is expected that more recent tornado events would be more accurately reported and represented in the historical database.

Tornado event data were plotted by latitude and longitude using GIS (Geographic Information System). This spatial distribution of the data makes it possible to determine the distance of each tornado event from the balloon sounding sites. Brooks et al. (1994) points out that in order for sounding data to be representative, they must be spatially and temporally accurate; and they must represent the same air mass in which the tornado formed. To obtain the most environmentally representative results for this study, only tornado events within 100 statute miles of an individual sounding site and plus or minus two hours of the sounding time were used. Individual soundings were further scrutinized in order to ensure the environment measured was representative of the environment in which the tornado developed (i.e. ensuring measured data are located in the inflow air mass related to the storm) (Rasmussen and Blanchard 1998).

The majority of low-level thermodynamic studies (Rasmussen 2003; Brooks and Craven 2002; Davies 2001) discriminate between non-tornadic supercell and weak and significant tornado environments. For this study, a non-tornadic supercell was defined as any severe hail event 2 inches in diameter or larger, but without a report of a tornado anywhere within the study region. The same methodology used for tornado events was also employed to identify the non-tornadic supercell study events. The hail data were also extracted from the Historical Severe Report Database from the SPC for the years 1980-2002 and were evaluated based upon the spatial proximity sounding criteria previously mentioned.

b. Thermodynamic and dynamic data

The thermodynamic data for this study were extracted from the North American Historical Radiosonde Database developed by the National Climatic Data Center (NCDC) and individual thermodynamic parameters (discussed earlier) were derived using the Rawinsonde Observation Program (Environmental Research Services, Limited Liability Corporation). 0000 UTC soundings were used for the proximity corrected tornado event dataset (100 miles from a sounding site) and plus or minus two hours from 0000 UTC. The sounding sites that were used included Birmingham and Centreville, AL; Little Rock, AR; Athens and Peachtree City, GA; Lake Charles, Shreveport, and Slidell, LA; Jackson, MS; Nashville, TN; Springfield, MO; and Tallahassee, FL.

For this study, the calculations of the thermodynamic parameters utilized a surface-based parcel and neglected the virtual temperature correction for CAPE calculations. Colquhoun and Riley (1996) compared CAPE values with and without the virtual temperature and both sets of data showed a high correlation coefficient ($r = 0.996$), which suggests that neglecting the virtual temperature should still yield representative results. A high correlation coefficient between the two data sets does not imply that the values are the same. Therefore, caution should be used when interpreting the results of the CAPE-based thermodynamic parameters due to the neglection of the virtual temperature correction. In fact, Doswell and Rasmussen (1994) showed that ignoring the virtual temperature correction introduces large relative errors when CAPE is small. Implications on the results of ignoring the virtual temperature for this study will be discussed in the summary.

c. Descriptive statistics

Mean and standard deviation values were calculated for each of the thermodynamic parameters for significant tornado, weak tornado, and non-tornadic supercell environments. In order to visually inspect the distribution of the data between the various environments, these data are displayed using box and whisker plots. The top of each box represents the 75% percentile, the bottom of the box represents the 25% percentile and the line within the box is the median or 50% quantile. The top whisker represents the 90% quantile and the bottom whisker represents the 10% data quantile. The dots that appear at the ends of the graph indicate the 95th and 5th percentile of the data.

d. *Analytical statistics*

Levene's test for equality of variances was employed to ensure each environment's (significant, weak, and non-tornadic supercell) dataset is from the same statistical population. The Levene test was chosen as it does not assume a normally distributed dataset. Similar to Brown (2002), two-tailed T-tests between these groups for each thermodynamic parameter were then performed in order to identify any significant thermodynamic differences between the various environments, which should prove helpful for forecasting these environments.

4. Results

a. Temporal and spatial distribution

Figure 1 shows the monthly distribution of all tornado events (1980-2002) in the Southeast. The region clearly experiences two active seasons during the spring and late fall due to the equatorward shift of the polar jet. Conversely, a minimum of tornado activity exists in the summer months due to the poleward shift of the polar jet. The diurnal distribution (Fig. 2) of all tornadoes in the region indicates a late afternoon maximum related to increased sensible energy available to thunderstorms.

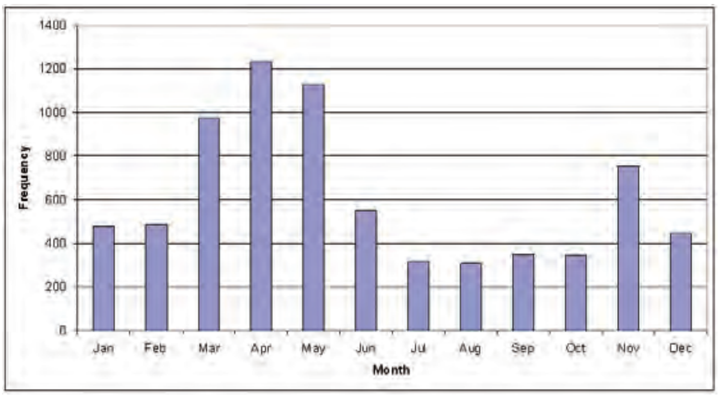

Fig. 1. Monthly distribution of Southeast U. S. region tornadoes, 1980-2002.

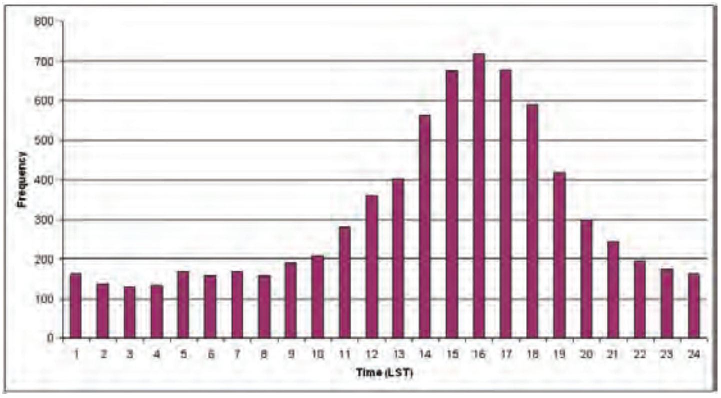

Fig. 2. Hourly distribution of Southeast U. S. region tornadoes, 1980-2002.

Figure 3 indicates the spatial distribution of tornadic and non-tornadic supercell events (1980-2002) using the post-proximity sounding constrictions (discussed earlier). As a result of these proximity limitations, it is clear that many sub-regions of the Southeast are not represented. However, given the mesoscale nature of thunderstorm and tornado environments, the temporal and spatial reduction of data is necessary so that representative environments can be recorded. A total of 450 tornado events (136 significant and 214 weak) were examined along with 58 non-tornadic supercell events.

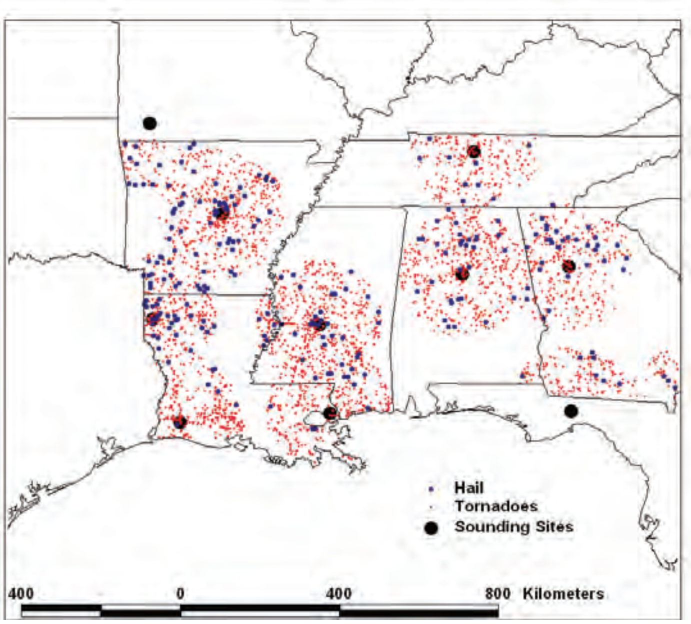

Fig. 3. The study region spatial distribution of all tornado and hail events from 1980 through 2002 using the proximity sounding constrictions (100 km from sounding site and +/- 2 hours from 0000 UTC). Sites used in the study, but not shown on this map, are Athens, GA and Centreville, AL.

b. Thermodynamic and kinematic environment

1) Stability (CAPE and 0-3 km CAPE)

The mean CAPE values for tornadic storm environments are considerably higher than non-tornadic supercell environments (Table 1) and not surprisingly there is a visual upward trend from non-tornadic supercells through significant tornadic storm environments (Fig. 4). These results are similar to those of Davies (2001) and Rasmussen and Blanchard (1998). Additionally, the T-test for CAPE suggests that CAPE may be a useful discriminator between tornado and non-tornadic supercell environments (Table 1).

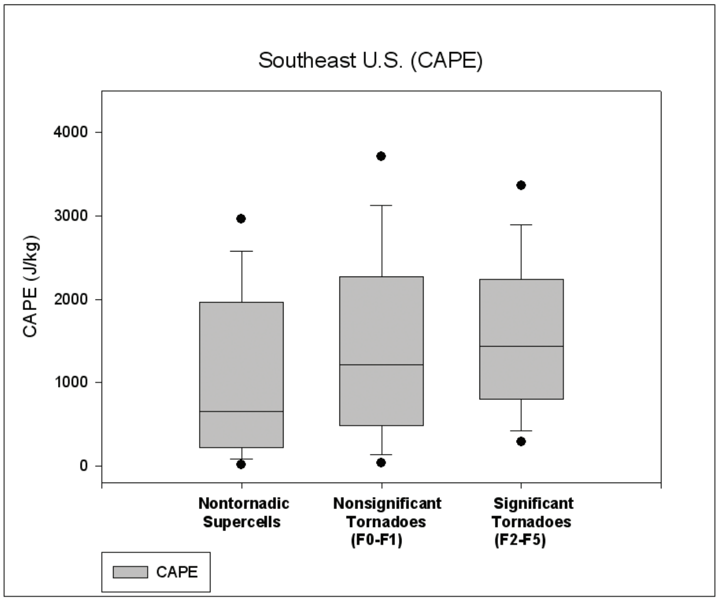

Fig. 4. Box and whiskers graph of CAPE (J kg^{-1}) associated with non-tornadic supercells, weak and significant tornadoes in the Southeast U.S. from 1980 through 2002.

Parameter	Sig. Tor Mean	Non-Tor Sup Mean	T Value	P Value	Significance
CAPE	1592.857	1077.960	-3.180	8.75E-04	**
0-3 CAPE	70.101	64.610	-0.449	0.327	
0-1 SRH	209.300	70.050	-6.318	2.71E-09	**
0-3 SRH	239.858	120.890	-5.380	1.10E-07	**
0-1 EHI	2.162	0.530	-6.125	9.94E-09	**
0-3 EHI	2.912	0.940	-5.051	5.84E-07	**
LCL	824.711	706.670	-1.999	0.024	*
LFC	1954.674	1738.490	-1.700	0.046	*

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

Table 1. Low-level thermodynamic indices tested for significant tornadoes and non-tornadic supercells in the Southeast.

The mean 0-3 km CAPE value is only slightly greater for significant tornado environments compared to weak tornadoes (Table 2). Oddly, mean 0-3 km CAPE is higher for non-tornadic supercell environments than cases involving weak tornadoes (Table 3). These results are contradictory to the Great Plains region studies of Rasmussen (2003) and Davies (2001). However, these results were not unexpected for the Southeast U.S. since this region is often characterized by deep lower-tropospheric moisture regardless of severe weather regime. This deep moisture and associated weak low-level lapse rates contribute to nearly constant 0-3 km CAPE values across all storm types (Fig. 5). Furthermore, with the common absence of an Elevated Mixed Layer (EML) in the Southeast region, 0-3 km CAPE may not be as important a variable in the Southeast, compared to the Great Plains region. These results do not suggest that 0-3 km CAPE is not important in the tornadogenesis process in the Southeast, but instead, caution should be used by a forecaster if attempting to differentiate between environments with this parameter alone.

2) Shear (0-3 km and 0-1 km SRH)

As seen in Tables 2 and 3, the mean values of 0-1 and 0-3 km SRH are much higher for tornadic storm environments when compared to non-tornadic supercell environments. Statistical tests for 0-1 and 0-3 km SRH between tornadic and non-tornadic supercell environments indicate a strong

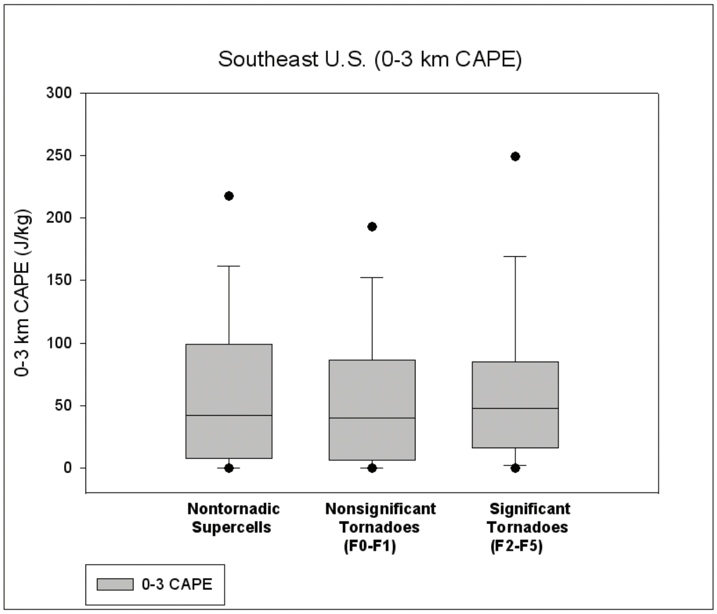

Fig. 5. Same as Fig. 4 except for 0-3 km CAPE (J kg^{-1}).

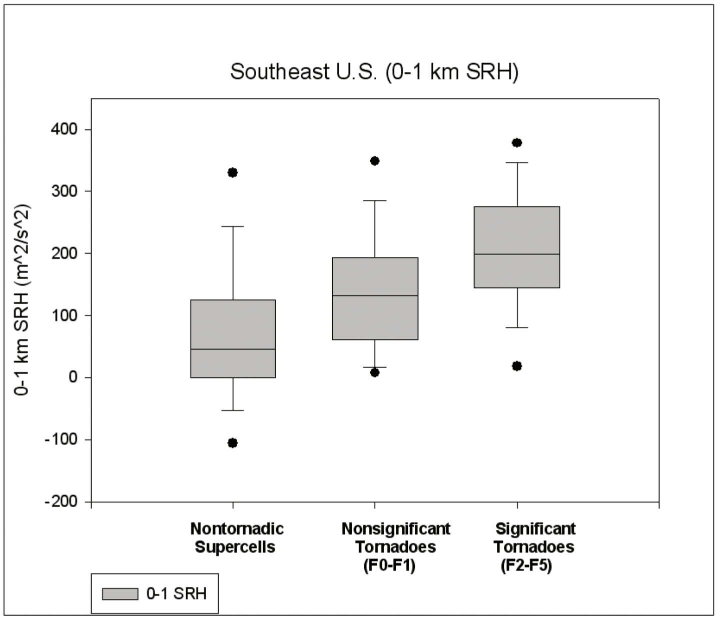

Fig. 6. Same as Fig. 4 except for 0-1 km SRH (m^2 s^{-2}).

Parameter	Sig. Tor Mean	Weak Mean	T Value	P Value	Significance
CAPE	1592.857	1467.786	0.965	0.168	
0-3 CAPE	70.101	61.471	0.932	0.176	
0-1 SRH	209.300	142.127	4.180	2.21E-05	**
0-3 SRH	239.858	196.276	2.850	0.002	**
0-1 EHI	2.162	1.238	3.770	1.13E-04	**
0-3 EHI	2.912	1.645	4.940	6.55E-07	**
LCL	824.711	798.846	0.603	0.273	
LFC	1954.674	2076.783	-1.240	0.108	

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

Table 2. Low-level thermodynamic indices tested for significant and weak tornadoes in the Southeast U.S.

statistical difference (Tables 2 and 3). Figures 6 and 7 show a clear visual upward trend from non-tornadic supercell to significant tornadic storms, which is most prominent with the 0-1 km SRH. In fact, 0-1 km SRH, shows nearly a one quartile offset between significant and weak tornado environments (Fig. 6). These results agree with the findings of Rasmussen (2003), Thompson et al. (2003), Edwards and Thompson (2000), and Davies (2006). While the data offset between 0-3 km SRH is slightly less (Fig. 7), there is still enough evidence to suggest that significant tornadoes are generally associated with environments containing greater amounts of helicity than weak tornado environments. These results also agree with the findings of Davies (2006) and Rasmussen and Blanchard (1998) and suggest that 0-1 and 0-3 km SRH has good discrimination potential between non-tornadic supercell, weak, and significant tornado environments.

3) Instability and shear combination (0-3 km and 0-1 km EHI)

Given the SRH results, it is not surprising that the mean 0-1 and 0-3 km EHI values are considerably higher for tornadic versus non-tornadic supercell environments (Figs. 8 and 9). These results are again similar to Thompson et al. (2003), Davies (2006), Edwards and Thompson (2000), and Rasmussen and Blanchard (1998), where statistical testing shows

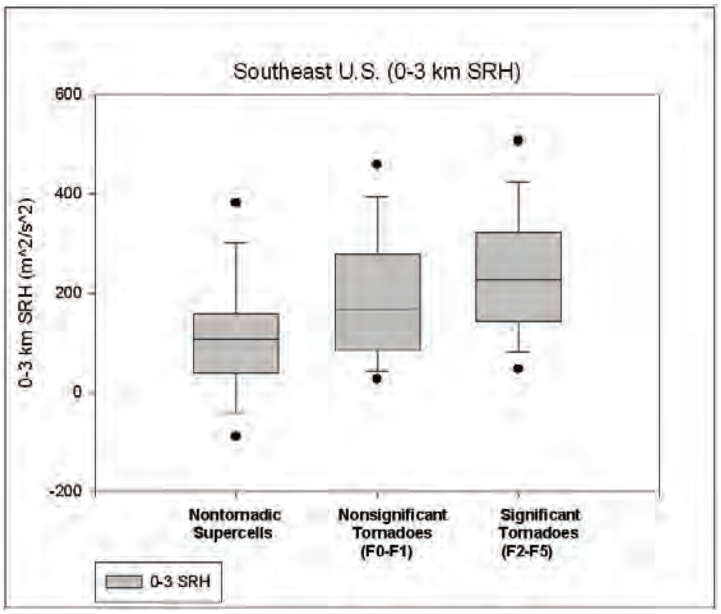

Fig. 7. Same as Fig. 4 except for 0-3 km SRH ($m^2 s^{-2}$).

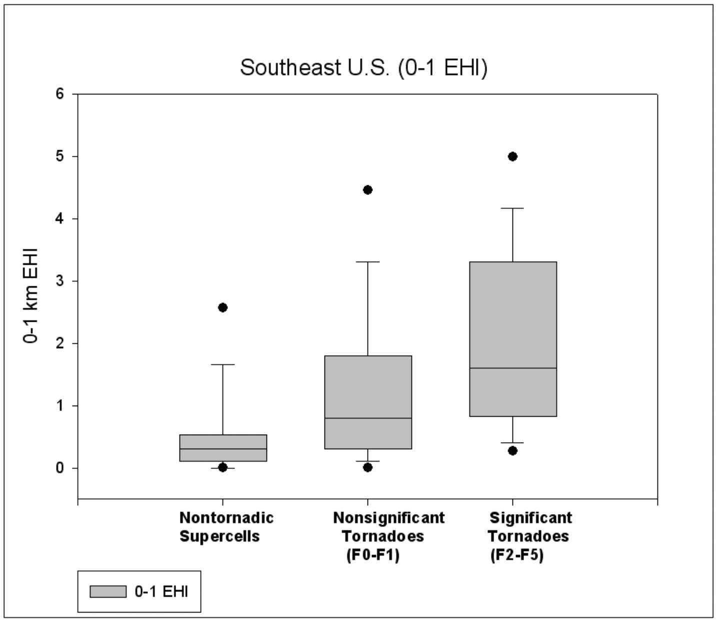

Fig. 8. Same as Fig. 4 except for 0-1 km EHI.

Parameter	Weak Tor Mean	Non-Tor Sup	T Value	P Value	Significance
CAPE	1467.786	1077.960	-1.808	0.036	*
0-3 CAPE	61.471	64.610	0.241	0.405	
0-1 SRH	142.127	70.050	-3.921	6.27E-05	**
0-3 SRH	196.276	120.890	-3.436	3.43E-04	**
0-1 EHI	1.238	0.530	-3.335	5.32E-04	**
0-3 EHI	1.645	0.940	-2.462	7.27E-03	**
LCL	798.846	706.670	-1.500	0.068	
LFC	2076.783	1738.490	-2.320	0.011	*

*Indicates significance at $p < 0.05$
**Indicates significance at $p < 0.01$

Table 3. Low-level thermodynamic indices tested for weak tornadoes and non-tornadic supercells in the Southeast.

strong significant differences between non-tornadic supercell and tornado environments with respect to 0-1 and 0-3 km EHI. These results suggest that EHI can be helpful to a forecaster in distinguishing between tornadic and non-tornadic supercell environments in the Southeast U.S.

4) Miscellaneous parameters (LCL and LFC heights)

One surprising result from this study is that the mean LCL heights were found to be lower for non-tornadic supercells than tornadic storms (Tables 1 and 3). While the statistical testing for LCL height between non-tornadic supercells and significant tornado environments indicates significant differences, the result is opposite of work done by Rasmussen (2003) that shows that stronger tornadoes are accompanied by much lower LCL heights than non-tornadic supercells. While LCL heights are lower for non-tornadic supercell environments (Fig. 10), testing between non-tornadic supercell and weak tornado environments indicates no statistically significant differences. These results differ with the findings of Thompson et al. (2003), Brooks and Craven (2002), Davies (2006), and Edwards and Thompson (2000), and clearly suggest that LCL heights may be a poor discriminator for tornado strength in the Southeast. However, the results do agree with the Rasmussen (2003) argument that LCL heights may not have much skill when discriminating between non-tornadic supercell and tornadic environments in the eastern United States due to non-tornadic supercell events being less common in this region. These results might be attributed to the region's proximity to the Gulf of Mexico and the homogenous distribution of moisture entrained into mid-latitude low pressure systems traversing the Southeast, regardless of mesoscale storm environment. Apart from the discrimination potential between these groups, it should be noted that LCL heights for significant tornadic environments are quite low and suggests that the LCL may be a critical factor for significant tornadogenesis as found by Rasmussen (2003). Although the other environments are characterized by low LCL heights, it suggests that other processes may be responsible for tornadogenesis rather than LCL height alone.

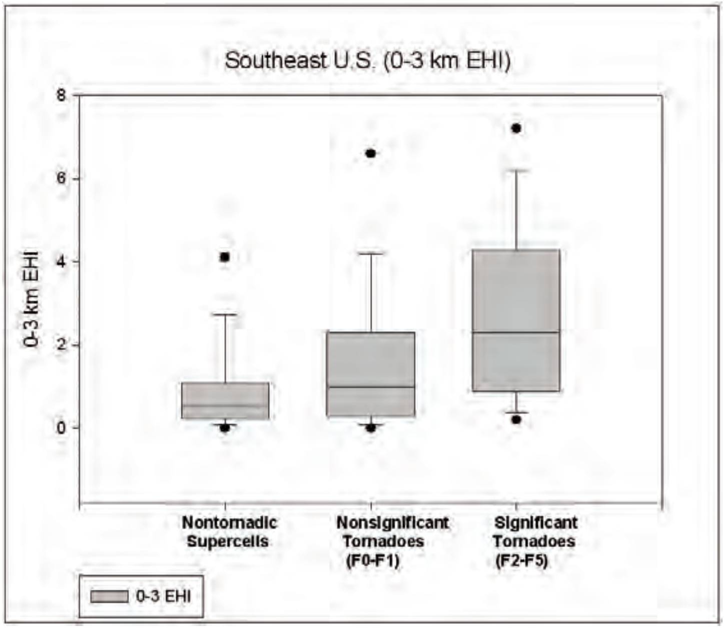

Fig. 9. Same as Fig. 4 except for 0-3 km EHI.

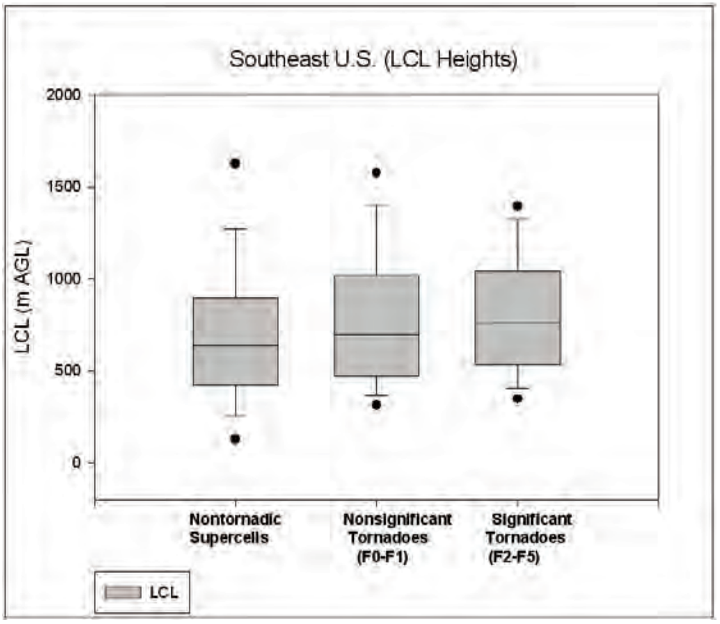

Fig. 10. Same as Fig. 4 except for LCL heights (m).

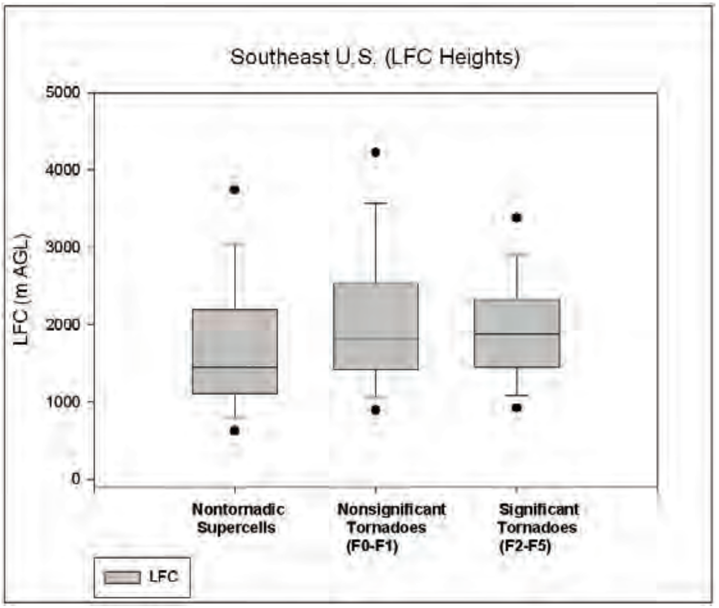

Fig. 11. Same as Fig. 4 except for LFC heights (m).

Mean LFC height values are lower for non-tornadic supercell environments compared to tornadic environments (Tables 1 and 3), which again makes the authors question its usefulness with respect to tornado forecasting in the Southeast. These results are again contradictory with those of Davies (2001 and 2004). The most plausible explanation is that LFC heights may be higher than expected in the Southeast due to weak low-level lapse rates. The similarity in LFC height between storm types (Fig. 11) is again likely a result of the study region's proximity to the Gulf of Mexico. Low-level air is often more moist in the Southeast when compared to the Great Plains, and the related decrease in the amount of potential evaporative cooling that takes place does not allow lapse rates to steepen as they would in a less moist low-level environment, leading to higher LFC heights.

While these results give the forecaster a better understanding of non-tornadic supercell, weak and significant tornado environments in the Southeast region, there are recognized limitations to this study. Future research in this region of the U.S. should consider utilizing various methods/heights of lifted parcels (similar to Craven et al., 2002), the inclusion of 1200 UTC sounding data and non-severe thunderstorm environments, and incorporating the virtual temperature correction.

5. Summary

After the findings of Project VORTEX in 1995 (Markowski et al. 1998b), a new emphasis has been placed on the lowest levels of the troposphere with respect to tornadogenesis. Prior to conducting this current study, little research regarding the low-level thermodynamics of severe storm environments in the Southeast U.S. existed. The Southeast states in this study statistically rank in the top ten in tornado categories such as deaths, injuries, number of significant tornadoes, and tornadoes per 10,000 sq mi, etc. (Grazulis 1993). Clearly, any research in this region of the county can be beneficial to the mission of savings lives and property.

This study shows that tornado events are produced in a moderately unstable and highly sheared environment. Forecasters should pay particular attention to the shear parameters used in this study as these show strong discrimination potential between the cases. Statistically significant differences and good data distribution offset between significant tornado, weak tornado, and non-tornadic supercell environments were noted for CAPE, 0-1 and 0-3 km SRH, 0-1 and 0-3 km EHI. Due to a relatively homogenous distribution of rich, low-level moisture from the Gulf of Mexico, the Southeast states typically have low LCLs for tornado events. In the Southeast, warm, moisture-rich air in the lowest layers of the troposphere may limit the evaporational cooling potential and inhibit the steepening of low-level lapse rates. As a result the LFC heights for this region are higher than one might expect. An important consideration when interpreting these results is that the virtual temperature correction was not used in this study. Consequently, the values for CAPE, EHI, LCL and LFC heights, and CIN would have been greater if the virtual temperature correction had been used. On the other hand, 0-3 km CAPE would likely have been slightly less owing to an increase in CIN and LFC height.

The parameters that show the most operational discrimination between non-tornadic supercell and tornadic storm environments in the Southeast are the 0-1 km SRH and related EHI. Approximately 75% of the weak tornado environment data are greater than the non-tornadic supercell median value of 42 $m^2 s^{-2}$ for SRH and 0.2 for EHI. In addition, approximately 75% of the significant tornado environment data are greater than the weak tornado median of 120 $m^2 s^{-2}$ for SRH and 0.8 for EHI. When compared to the national study by Edwards and Thompson, (2000) the Southeast 0-1 km SRH values are greater for weak and significant tornado environments while 0-1 km EHI values are less. This is likely an artifact of comparing studies at two different spatial scales and reinforces the importance of regional climatologies.

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