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An examination of thermodynamic and sheared environments associated with cool-season tornadoes in the southeastern United States

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AN EXAMINATION OF THERMODYNAMIC AND SHEARED ENVIRONMENTS ASSOCIATED WITH COOL-SEASON TORNADOES IN THE SOUTHEASTERN UNITED STATES

By

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AN EXAMINATION OF THERMODYNAMIC AND SHEARED ENVIRONMENTS

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Tornado research conducted across the southeastern United States suggests two peak tornado maxima. However, few studies have distinguished between the thermodynamic and shear environments between cool-season and warm-season tornadoes. Incorporating 100 mb mixed layer parcels, mean thermodynamic and shear parameters for non-significant (F0–F1) and significant (F2–F5) tornado environments were calculated. Cool-season tornado environments were characterized by relatively low amounts of instability and high shear. On the other hand, warm-season tornado events were characterized by higher amounts of instability and generally less shear. The Energy Helicity Index (EHI) remained nearly constant suggesting a balance of instability and shear between the tested seasons. During the cool-season, an increase in instability appears to distinguish between tornado strengths. Yet, an increase in shear during the warm-season may be indicative of significant tornado environments.

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CHAPTER I

INTRODUCTION

The southeastern United States, defined as Arkansas, Alabama, Louisiana, Mississippi, and Tennessee, typically does not generate as much attention with regards to severe weather as parts of the Great Plains, defined as Kansas, Oklahoma, Nebraska, and Texas. Not surprisingly, a large portion of the severe thunderstorm and tornado research focuses solely on the Great Plains region. However, tornado research that has focused on the southeastern United States suggests there is a year-round tornado threat (Gerard et al. 2005).

Grazulis (2001) states that any area that experiences above average tornado frequency will eventually be labeled a “tornado alley” and that dozens of such regions exist. While the Great Plains’ “Tornado Alley” garners most of the public’s attention, there is a “tornado alley” that is applicable to the Southeast, known as “Dixie Alley.” Although no formal documentation can be found on the origins of this area, it is believed the Dixie Alley region was named after the 1971 Mississippi Delta tornado outbreak (Gerard et al. 2005).

From 1998–2004, Gerard et al. (2005) found that Dixie Alley had 1.5 times the number of strong tornadoes, 42 more killer (at least 1 fatality reported) tornadoes, and twice the number of outbreak days (10 or more strong tornadoes reported) when compared to the Great Plains. Broyles and Crosbie (2004) found that the lower Mississippi Valley and Tennessee Valley showed the highest frequency of long track (path length of at least 25 miles) F3 to F5 tornadoes than any other region in the United States from 1880–2003. In addition, it has been well established that there are two peak annual tornado maxima in the Southeast, with the greatest probability of tornadoes in the months of April and again in November (Brooks et al. 2003). Work by Wasula et al. (2004) also shows the secondary peak of tornado occurrence during the cool season (November – February) in the Southeast. For the purpose of this study, the cool-season (winter) is defined as November – February while the warm-season (spring) is defined as April – May.

Galway and Pearson (1981) found that 68% of all December – February tornadoes in the United States occurred in the southeastern states. Their study also shows that more tornado deaths occur with winter tornado outbreaks than spring tornado outbreaks. Gerard et al. (2005) found in general that strong and killer tornadoes are not uncommon in Dixie Alley. Over the last decade, there have been several fall and winter tornado outbreaks in the Southeast, including the January 17–22, 1999, Arkansas and Mississippi Delta tornado outbreak and the November 10, 2002, Alabama and Mississippi tornado outbreak.

Given the threat of cool-season tornadoes in Dixie Alley, it is important to examine the cool-season thermodynamic and shear parameters of tornado environments, thereby providing a general climatology for this region. It is anticipated that the results of this study will have operational significance in the forecasting process of cool-season tornado environments in Dixie Alley.

OBJECTIVES AND HYPOTHESE

The objectives of this study are:

1) To present a thermodynamic and shear climatology of cool and warm-season tornado environments for the Southeast.

2) To differentiate between non-significant and significant tornado environments with regards to the mean thermodynamic and shear parameters associated with each season.

The two hypotheses tested will be:

1) A unique thermodynamic and shear environment exists for cool-season tornadoes as compared to warm-season events in Dixie Alley.

2) The strength of Dixie Alley cool-season tornado environments can be differentiated by using thermodynamic and shear parameters.

CHAPTER II

LITERATURE REVIEW

1. Synoptic Environment

The majority of Great Plains severe storms occur under a general synoptic-scale circulation allowing for the development of a deep surface layer of moist air, a mid-level dry intrusion, and a lifting mechanism capable of initiating deep convection (Carlson and Ludlam 1968). Brown (2002) states that while there can be variation in the general pattern, the classic situation for severe storm development can be described by the coexistence of three air streams. A southerly, low-level flow of moist air from the Gulf of Mexico, responsible for providing the sensible and latent energy needed for thunderstorm development, is the first air stream. The second air stream is a southwesterly flow in the lower-middle troposphere (approximately 700 mb). This mid-level air stream is responsible for advecting warm and dry air northeastward from the Mexican Plateau. This creates a capping inversion over the lower humid layer, allowing instability to build in the lower levels of the atmosphere (Carlson et al. 1983). The jet stream is the third air stream, and it serves as a mechanism to overcome any capping inversion that may be present in the atmosphere (Fawbush and Miller 1954). It also serves as a mass removal mechanism, which allows thunderstorms to initiate.

2. Regional Variation

Although there is a general pattern for thunderstorm development, tornado environments can differ regionally. For example, Brown (2002) found significant differences with regards to instability and shear environments between tornadic thunderstorms in the southern Atlantic states and the Great Plains, while Griffin (1995) found differences in tornadic environments between the Great Plains and the Southeast. Few studies, however, have compared the seasonal variation of tornado environments within a specific region (Garinger and Knupp 1993; Gaffin and Parker 2006). This study will look at instability and shear parameters for the warm (spring) and cool (winter) tornado seasons in the Southeast.

3. Mesoscale Parameters

Previous tornado research that has been conducted on the Southeast region of the United States region has mainly focused on tornado distribution and frequency (Anthony 1988, Wasula et al. 2004). Various instability and shear parameters are used in forecasting the potential for tornadoes, but these indices have not been studied thoroughly during the cool-season in Dixie Alley. Research that has been conducted on cool-season tornado events in the southeastern states suggests a high shear and low instability environment is most conducive for superecell and tornado formation (Galway and Pearson 1981; Guyer et al. 2006). However, no formal publications have established relationships between thermodynamic and shear values in cool-season and warm-season tornado environments.

a. *Lifted Index (LI)*

Galway (1956) stresses the importance of the stability of an air mass in the forecasting of local severe storms. The lifted index is a basic forecasting tool that provides a quick assessment of the stability of the atmosphere. The lifted index is defined as the temperature difference between the observed 500-mb temperature and a calculated 500-mb temperature of that parcel lifted from the surface (Galway 1956). The atmosphere is considered unstable if the calculated parcel temperature is warmer than the observed 500-mb temperature. LI values less than zero represent an unstable environment while LI values greater than zero represent a stable environment. LI values between -3 and -9 depict a moderate to very unstable atmosphere while LI values less than -9 represent extreme instability (Gordon and Albert 2007). Chaston (2002) states that the environment presents the greatest tornado potential when LI values are -6 or less. However, the LI is prone to inconsistent values of instability if the temperature at 500-mb is unrepresentative of the environment above or below 500 mb (Blanchard 1998). Despite the possibility of erroneous LI values, this stability parameter is still used in operational forecasting and will therefore be analyzed in this study.

b. Convective Available Potential Energy (CAPE)

Convective Available Potential Energy (CAPE) is a common forecasting stability parameter for supercell thunderstorms (Moncrieff and Miller 1976). CAPE is a vertically-integrated index that measures the buoyant force of the atmosphere from the level of free convection to the equilibrium level (Blanchard 1998). More specifically, CAPE develops when the parcel temperature becomes warmer than the environmental temperature. CAPE is a measure of the energy available to lift parcels of air vertically in the atmosphere.

Weisman and Klemp (1986) found that CAPE values greater than 1500 J kg^{-1} indicate the potential of deep convection. Johns et al. (1990), however, state that supercell thunderstorms can form in an extremely wide range of CAPE values, which can vary from 200 to 5300 J kg^{-1}. Guyer et al. (2006) discovered that the majority of F2 or greater tornadoes in the Gulf Coast states can occur with mean-layer CAPE values between 900–1700 J kg^{-1} with 25% of tornado events occurring with CAPE values less than 870 J kg^{-1}.

c. *0 – 3 km CAPE*

McCaul (1991) suggests that a greater distribution of CAPE in the lowest 3 km of the atmosphere can provide low-level parcel accelerations necessary for tornadic supercell environments. A study by Rasmussen (2003) showed that 0 – 3 km CAPE is able to discriminate between supercell thunderstorms and tornadic supercells, but not non-supercell thunderstorms and supercell thunderstorms, which suggests that some 0 – 3 km CAPE is necessary for tornadogenesis. It is hypothesized that 0 – 3 km CAPE interacts more efficiently with the low-level updraft strength and low-level wind shear (Rasmussen 2003). Both Davies (2001) and Rasmussen (2003) found that 0 – 3 km CAPE values of 60 J kg^{-1} or greater are favorable for tornadic environments. Furthermore, Davies (2006) and Guyer et al. (2006) found median values of 70 J kg^{-1} are indicative of environments capable of producing significant tornadoes during the cool-season.

d. *Convection Inhibition (CIN)*

Unlike CAPE, convective inhibition represents the amount of negative energy that must be overcome in order for thunderstorm development. Areas of CIN will suppress parcels of air from rising. Research on this parameter suggests that higher values of convective inhibition do not promote the development of tornadoes (Rasmussen and Blanchard 1998, Davies 2004). Along with the level of free convection (described later), CIN is a good tool to determine whether thunderstorms will be located in the boundary layer. High values of convective inhibition may be an indication of elevated thunderstorms, which are not conducive for tornadic development (Colman 1990).

Rasmussen and Blanchard (1998) discovered that three-fourths of significant tornado soundings occurred with CIN values less than 21 J kg^{-1}. However, 60 percent of the supercell soundings had CIN values that were greater than 21 J kg^{-1}. CIN values between 150 – 200 J kg^{-1} were not likely to produce significant tornadoes, while CIN values less than 50 – 100 J kg^{-1} were more conducive for producing significant tornadoes (Davies, 2002a). While 84 percent of the events in the study did not produce any tornadoes, Davies (2002a) found that only two significant tornadoes occurred with CIN values greater than 125 J kg^{-1}.

e. *0 – 3 km Storm Relative Helicity (0 – 3 km SRH)*

Storm relative helicity (SRH) in the lowest three kilometers above ground level was the most used shear parameter for forecasting supercells and tornadoes (Davies-Jones et al. 1990). SRH links updraft rotation to the storm motion, in addition to differentiating between speed shear (change in wind speed with height) and directional shear (change in wind direction with height) (Davies-Jones et al. 1990). A study of archived events (region/time frame not specified), conducted by Davies-Jones et al. (1990), found that weak tornadoes had mean SRH values of 278 $m^2 s^{-2}$, strong tornadoes had mean SRH values of 330 $m^2 s^{-2}$, and violent tornadoes had mean SRH values of 531 $m^2 s^{-2}$. While this seems to be a useful discrimination tool for tornado intensity, Rasmussen and Blanchard (1998) found national mean SRH values from 1942–1992 for tornadoes was 200 $m^2 s^{-2}$, but note that high values of SRH may not be associated with significant tornadoes. Jackson (2006) found Southeast region of the United State 0 – 3 km mean SRH values of significant tornadoes to be 240 $m^2 s^{-2}$ and nonsignificant tornadoes to be 196 $m^2 s^{-2}$. Davies (2002b) found that significant tornadoes can occur in environments where 0 – 3 km SRH values are small, provided that there is abundant low-level instability. SRH values in the lowest 3 km greater than 200 $m^2 s^{-2}$ are indicative of shear environments conducive to cool-season significant tornado environments in the Gulf Coast states (Guyer et al. 2006). These studies support the idea that large values of 0 – 3 km SRH increase the potential for tornadic development.

f. *0 – 1 km Storm Relative Helicity (0 – 1 km SRH)*

Markowski et al. (1998) and Wicker (1996) suggest that low-level boundaries and near-ground shear can affect the development of supercells and tornadoes. Storm relative helictiy (SRH) in the lowest 1 km is computed in the same manner as 0 – 3 km SRH, except the lowest 1 kilometer above ground level is considered. Work by Rasmussen (2003) suggests that storm relative helicity in the lowest one kilometer of the atmosphere may prove to be a useful tool for forecasting tornado environments. As with 0 – 3 km SRH, the higher the value of 0 – 1 km SRH, the greater the potential for tornadoes exist. Rasmussen (2003) found that 0 – 1 km SRH is a better forecasting parameter for differentiating between supercells and tornadic supercells than 0 – 3 km SRH. The study also notes that SRH values associated with tornado events in the lowest one kilometer are much larger than SRH values in the lowest second and third kilometers.

The 0 – 1 SRH forecasting parameter also seems to have some value in discriminating between significant and non-significant tornadoes (Edwards and Thompson 2000; Davies 2001). Thompson et al. (2003) found, when coupled with ample low-level moisture, 0 – 1 km SRH values greater than 75 m^2 s^{-2} are indicative of environments capable of producing significant tornadoes. Davies (2001) found, from the Rapid Update Cycle (RUC-2) soundings, that 0 – 1 km SRH values of 142 m^2 s^{-2} are suggestive of significant tornado environments. For the southeast United States, Jackson (2006) found mean values of 0 – 1 km SRH for non-significant tornado environments to be 142 m^2 s^{-2} and significant tornado environments to be 209

$m^2\ s^{-2}$. Similar to 0 – 3 km SRH, values of 0 – 1 km SRH greater than 200 $m^2\ s^{-2}$ support the potential for significant tornadoes in the Gulf States during the cool-season (Guyer et al. 2006). For the southeastern states, it is apparent that significant tornadoes are possible when 0 – 1 km SRH values are greater than 200 $m^2\ s^{-2}$.

g. *0 – 3 km Energy Helicity Index (0 – 3 km EHI)*

The Energy Helicity Index (EHI) is a forecasting tool that takes into account instability (CAPE) and wind shear (helicity). It is a unit-less parameter that is defined by Davies (1993) as

$$\text{EHI} = \frac{(CAPE \times SRH_{0-3})}{1 \times 10^{6}}$$

EHI is used for supercell and tornado environment forecasting where values larger than 1.0 represent a potential for supercells and values greater than 2.0 represent an enhanced probability of supercells (Rasmussen and Blanchard 1998). EHI appears to have some value discriminating between supercells and tornadic supercells (Rasmussen and Blanchard 1998). Davies (1993) found that 0 – 3 km EHI values approximately 2.0 and greater are common with tornado environments. While EHI values of 2.0 tend to produce environments conducive to mesocyclone-induced tornadoes, these tornadoes are usually not strong or violent. EHI values of 3.0 – 3.9 are common with strong tornado environments while EHI values over 4.0 are often associated with violent tornado environments. Mead (1997) conducted a study in the Southern Plains where the mean value 0 – 3 km EHI was 3.6 for tornado soundings, which is similar to the results of Davies (1993). However, Brooks et al. (1994) found the combination of instability and shear does not discriminate between supercell thunderstorms and tornadic supercells. Despite the conflict in findings, Rasmussen and Blanchard (1998) suggest 0 – 3 km EHI is a good forecasting tool to distinguish between non-supercell thunderstorms, supercell thunderstorms, and tornadic supercells. This is evident in the results where 90 percent of non-supercell environment soundings have EHI values less than 0.77, while only 60 percent of supercell environment soundings have EHI values less than 0.77, and less than one third of the tornado environment soundings have EHI values less than 0.77.

h. *0 – 1 km Energy Helicity Index (0 – 1 km EHI)*

With recent tornado research focusing on the lowest levels of the atmosphere (Markowski et al. 1998; Davies 2001; Rasmussen and Blanchard 2003), a modified version of the Energy Helicity Index was established. It is theorized that combined measures of CAPE and low-level shear perform better than individual measures of CAPE and shear alone (Rasmussen and Blanchard 1998). EHI in the lowest 1 km is calculated in the same manner as 0 – 3 km EHI, except the SRH in the lowest 1 kilometer above ground level is considered.

The formula for 0 – 1 km EHI is

$$\text{EHI} = \frac{(CAPE \times SRH_{0-1})}{1 \times 10^{6}}$$

EHI values between 1.0 and 1.5 suggest the potential for tornadic supercell formation (Davies 2001). In a study by Rasmussen (2003), only 25% of supercell soundings had 0 – 1 km EHI values greater than 0.5 while two thirds of the tornado soundings had 0 – 1 km EHI values greater than 0.5. Rasmussen (2003) found that 0 – 1 km is a poor discriminator between non-supercell thunderstorms and supercell thunderstorms but performed better in differentiating between supercell thunderstorms and tornadic supercells. This study also supports that 0 – 1 km EHI is quite useful in distinguishing between non-significant and significant tornado environments. Edwards and Thompson (2000) found similar results as their research shows mean EHI values of significant tornado environments to be 2.4 while mean values for non-significant tornado environments is 1.1.

i. *Lifting Condensation Level (LCL)*

The lifting condensation level (LCL) has long been used to estimate cloud heights (Stackpole 1967). Recent research has focused on the LCL's usefulness in forecasting tornado environments (Edwards and Thompson 2000; Davies 2001; Craven et. al 2002b; Rasmussen 2003). The lifting condensation level represents the height above ground level at which a rising parcel of air first becomes saturated. Rasmussen and Blanchard (1998) hypothesize that low values of relative humidity support more low-level cooling from the evaporation of rain, which would lead to stronger storm outflow. These low values of relative humidity would represent an environment that contains high LCL values, which implies a lower probability of tornadoes. Davies (2001) found that tornadoes do tend to form in areas with lower LCL heights. In addition, a study conducted by Hales (1988) showed that significant tornadoes are associated with environments possessing lower LCL heights. Lower

LCL heights are associated with higher amounts of boundary layer moisture and less evaporational cooling, which would decrease the chances of strong outflow. Further research has found that mesoscyclone and tornado formation takes place in low LCL environments because the strength of thunderstorm outflow is likely reduced (Rasmussen and Blanchard 1998; Edwards and Thompson 2000; Craven et al. 2002b; Markowski et al. 2002).

Rasmussen and Blanchard (1998) discovered that the LCL heights for tornadic supercell environments are significantly less than LCL heights for non-tornadic supercell thunderstorm environments. Half of the tornado soundings in their study had LCL heights below 800 m, while half of the supercell soundings had LCL heights above 1200 m. Davies (2001) noted that the supercell tornadoes are confined to LCL height environments below 1500 m while the strongest tornadoes occurred when LCL heights were below 1000 m. Thompson et al. (2003) did find significant differences in mean values of LCL heights between supercell thunderstorms and tornadic supercells as well as non-significant and significant tornadoes, but states that these differences only have operational usefulness in comparing supercell thunderstorm environments to significant tornado environments. Regardless of these differences, it appears reasonable to conclude that lower LCL heights favor environments capable of producing tornadoes.

j. *Level of Free Convection (LFC)*

The level of free convection (LFC) is the height above ground level in which an adiabatically or pseudo-adiabatically rising parcel of air becomes warmer than the surrounding environment. Above the LFC, parcels of air rise freely without the aid of any external lifting mechanism. Similar to LCL heights, research shows that lower LFC heights may be associated with environments capable of producing tornadoes (Colman 1990; Davies 2004). Lower LFC heights may be associated with more low-level instability (Davies 2001), while large values of convective inhibition are associated with high LFC heights (Colman 1990). It is reasonable to assume that LFC heights can discriminate between the environments associated with surface-based thunderstorms and elevated thunderstorms (Rasmussen and Blanchard 1998). Davies (2001) stated that tornadoes are most likely in environments possessing LFC heights below 2000 m. While an enhanced threat of tornadoes occurs when LFC heights are below 1600 m, a follow up study by Davies (2002) agrees with his previous findings in that tornadic supercells are associated with LFC heights below 2000–2200 m. Further evidence of lower LFC heights promoting tornadogenesis is apparent in a more recent study by Davies (2004). Out of 157 tornado events, only 3 tornadoes occurred when LFC heights were greater than 3000 m. From the research conducted on LFC heights, it seems plausible to conclude that lower LFC heights are more supportive of the development of tornadoes.

CHAPTER III

DATA AND METHODS

1. Study Area and Study Period

This study examined cool-season tornadic thermodynamic and shear environments for parts of the southeastern United States, a region known as "Dixie Alley". The states that encompass this study region are Alabama, Arkansas, Louisiana, Mississippi, and Middle and Western Tennessee (Figure 3.1). Eastern Tennessee and Georgia were excluded from the study so that terrain effects would not skew the data. For the purpose of this study, the cool-season months are November, December, January, and February. As previously stated, a comparison to the warm-season (April/May) tornado environments was included.

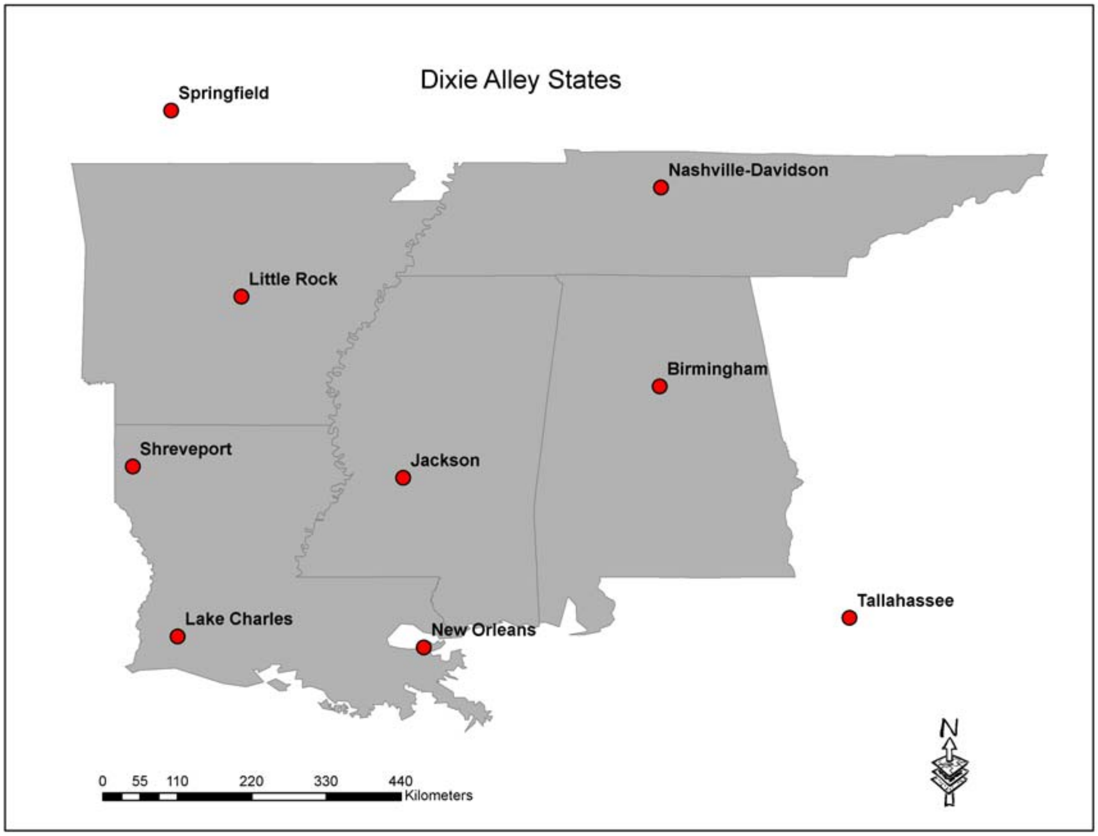

Figure 3.1. Map of study area and sounding sites.

2. Tornado Data

Tornado events were obtained from the Historical Severe Weather Report Database from the Storm Prediction Center in Norman, Oklahoma for the years 1960 – 2005. The information from this database includes date, state, Fujita Scale ranking, and genesis latitude and longitude of each tornado event. A recognized flaw with the tornado data is that it is prone to a population density bias (Kelly et al. 1985). More severe weather reports are generated from densely-populated areas as opposed to areas that are sparsely populated. A tornado event may go unreported in an area that is sparsely- populated. Conversely, a single tornado event may be reported multiple times in locations that are heavily populated, such as a large city or urban setting. Consequently, to eliminate multiple reported events, only events with different latitude and longitude origins will be used for analysis.

In order to differentiate between weak and strong tornadoes, the Fujita scale will be employed. This scale assigns an estimated wind speed based on the damage caused by a tornado (Fujita 1971). Table 3.1 depicts the various tornado intensities, the estimated wind speeds of each category, and the type of damage associated with each category. Non-significant (weak) tornadoes are F0 and F1 tornadoes while significant (strong/violent) tornadoes are F2, F3, F4, and F5 tornadoes.

Table 3.1. Fujita Tornado Damage Scale. (Fujita 1971)

Scale	Wind Estimate in MPH	Typical Damage
F0	< 73	Light Damage: Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	73 – 112	Moderate Damage: Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
F2	113 – 157	Considerable Damage: Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	158 – 206	Severe Damage: Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207 – 260	Devastating Damage: Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	261 – 318	Incredible Damage: Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air in excess of 100 meters (109 yards); trees debarked

3. Temporal and Spatial Proximity of Tornado Events

After the cool and warm-season tornado databases were developed, each tornado event was plotted using ArcMap GIS. A proximity sounding method was employed to eliminate events not within 100 miles of a sounding site. Only events with a temporal difference of plus or minus three hours of 00Z and 12Z will be examined. This is done to ensure the data extracted from each sounding site are representative of the tornado environment.

Once the tornado events that meet the proximity criteria have been identified, corresponding radiosonde data was collected. The radiosonde data was imported into the Rawinsonde Observation Program for Windows (RAOB), where the severe weather parameters previously described were computed. These data and the tornado data were combined and reanalyzed by month of occurrence and Fujita Scale intensity.

4. Thermodynamic Data

Thermodynamic sounding data of each event was collected from the North American Historical Radiosonde Database, which is maintained by the National Climatic Data Center. Various National Weather Service offices across the nation launch weather balloons twice daily (12Z and 00Z).

It should be noted that the lifted parcel method chosen for this study is the mean-layer parcel. This process computed thermodynamic parameters using a parcel with characteristics defined by the mean-layer temperature and dewpoint in the lowest 100 mb of the atmosphere. This method is preferred as it has been found to be more representative of the actual parcel in association with convective cloud development (Craven et al. 2002a). In addition, the virtual temperature correction (Doswell and Rasmussen 1994) will not be used in calculations of thermodynamic indices. Colquhoun and Riley (1996) found a strong correlation between two sets of instability data using virtual-temperature-corrected data and raw temperature. The omission of the virtual temperature correction will still produce plausible thermodynamic calculations.

First, equality of variance will be conducted on each parameter to determine whether the variance between seasonal datasets is significantly different. Then, two-tail independent statistical t-tests on each severe weather parameter will determine if the tornado environments between the cool and primary seasons are significantly different.

The statistical analysis for the study will focus on the following thermodynamic and shear parameters between cool and warm-season environments.

Stability

- Lifted Index (LI)
- Convective Available Potential Energy (CAPE, J kg^{-1})
- 0 – 3 km Convective Available Potential Energy (J kg^{-1})
- Convective Inhibition (CIN, J kg^{-1})

<u>Shear</u>

- 0 – 3 km Storm Relative Helicity (0 – 3 km SRH, $m^2 s^{-2}$)
- 0 – 1 km Storm Relative Helicity (0 – 1 kmSRH, $m^2 s^{-2}$)

<u>Combination of Stability and Shear</u>

- 0 – 3 km Energy Helicity Index (0 –1 EHI)
- 0 – 1 km Energy Helicity Index (0 – 1 EHI)

<u>Miscellaneous</u>

- Lifting Condensation Level (LCL, meters above ground level)
- Level of Free Convection (LFC, meters above ground level)

CHAPTER IV

RESULTS AND DISCUSSION

1. Tornado Data

Tornado events were extracted from the Historical Severe Weather Report Database from the years 1960 – 2005. After temporal and proximity constraints were applied to the tornado events, the data set was reduced from 1655 to 436 events in the warm-season and from 1679 to 371 events in the cool-season. The raw sounding data from these events were inserted into the RAOB program and the desired thermodynamic and shear parameters were analyzed. A visual inspection of the each sounding indicated that some of the event data were contaminated by the convective process (sounding indicative of a cold frontal passage). After these contaminated tornado data were removed, 194 cool-season (Figure 4.1) and 234 warm-season (Figure 4.2) tornado events remained for statistical analysis.

2. Statistical and Graphical Analysis

Once the final data set was organized, mean values of the tornado forecasting parameters were computed (Table 4.1). Levene's test for equality of variances was employed to ensure each data set was from the same population for events between seasons, and seasonal non-significant and significant tornadoes, and intra-seasonal non-significant and significant tornadoes. Next, independent sample t-tests assuming equal and unqueal variances (dependent on results on Levene's test) were calculated at $p < 0.05$ (95% confidence) and 0.01 (99% confidence) to determine which parameters were statistically different.

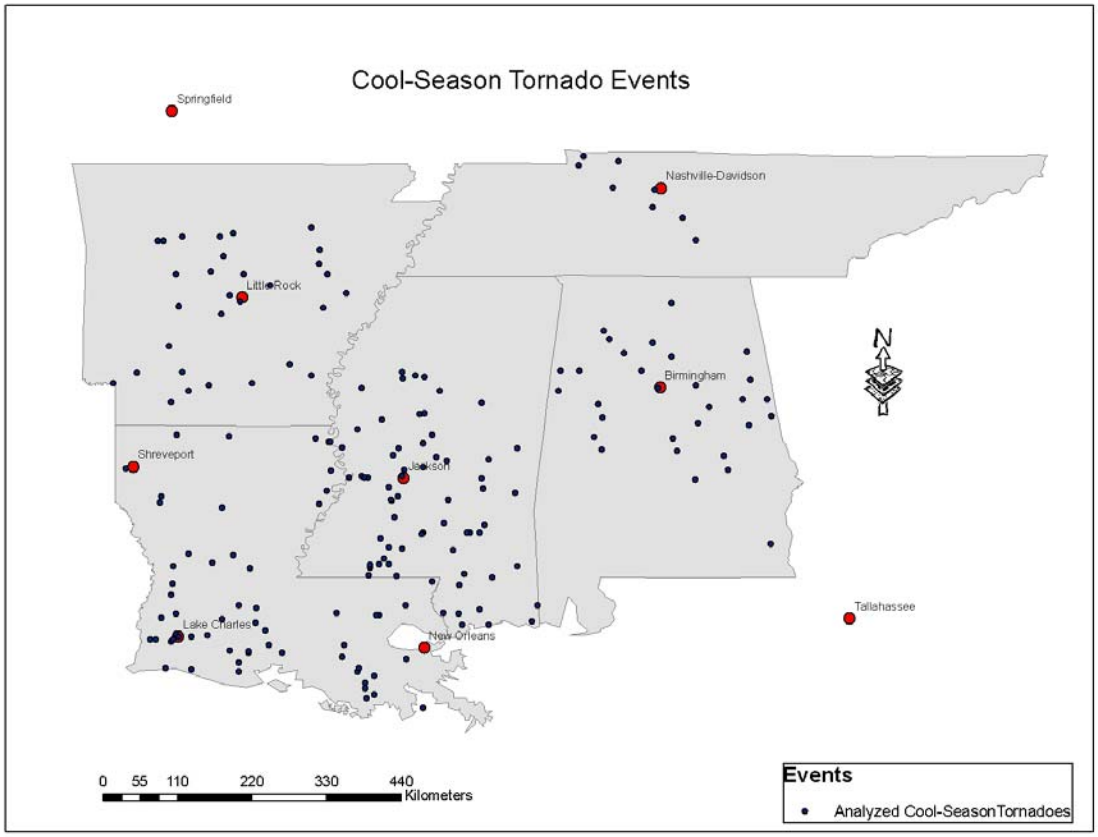

Figure 4.1. Map of analyzed cool-season tornado events.

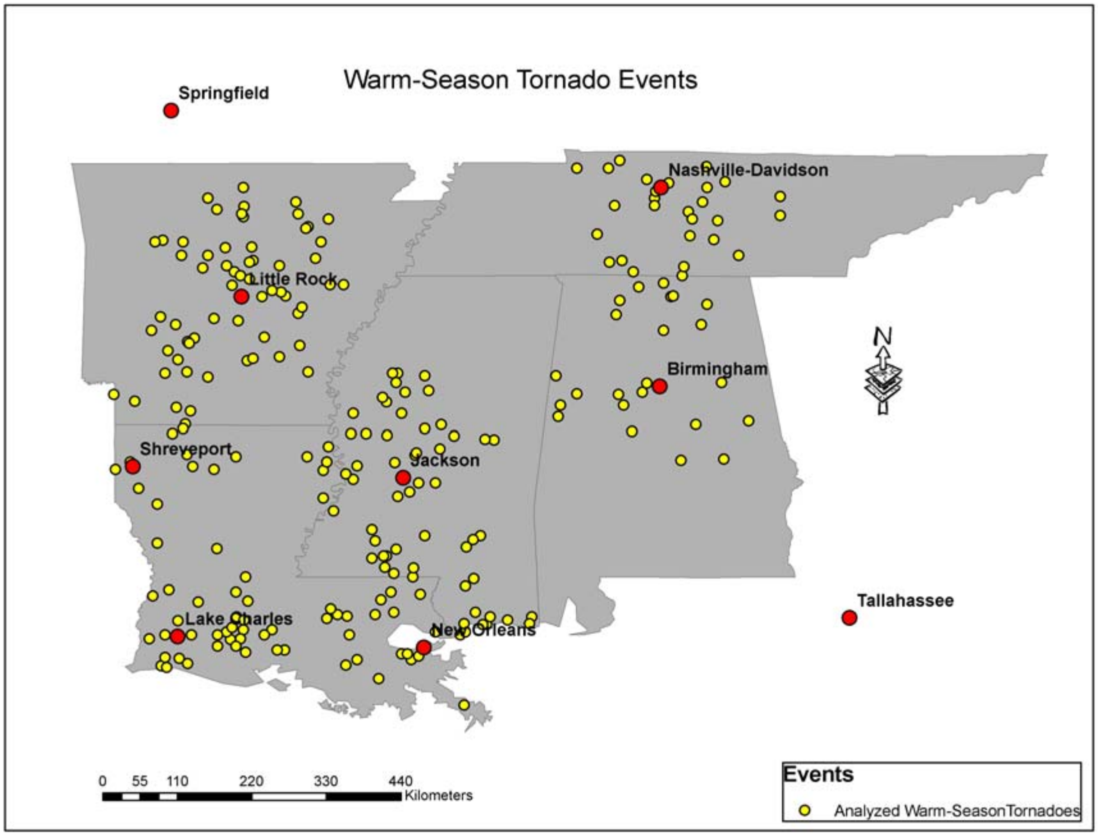

Figure 4.2. Map of analyzed warm-season tornado events.

Table 4.1. Example of tornado events that met proximity constraints and the associated thermodynamic and shear data for each tornado.

MONTH	DAY	YEAR	TIME	STATE	FSCALE	LAT	LONG	LI
2	28	1997	2315	MS	0	32.72	-90.27	-6.7
2	11	1998	104	MS	0	33.65	-90.22	-3.1
1	8	1999	2315	MS	0	33.10	-90.50	-1.4
12	10	1999	36	MS	3	32.63	-90.35	-2.8
1	3	2000	2328	MS	2	32.18	-89.15	-4.5
11	24	2001	1125	MS	4	32.43	-90.20	-1.1
11	26	2001	2252	MS	1	33.68	-90.05	-2.4
12	12	2001	2155	LA	0	32.15	-91.23	-0.8
12	23	2001	910	MS	0	32.32	-89.17	0.0
11	11	2002	130	MS	2	32.90	-89.83	-4.6
CAPE	**0-3CAPE**	**CIN**	**0-3SRH**	**0-1SRH**	**0-3EHI**	**0-1EHI**	**LCL**	**LFC**
1920	53	-50	359	309	5.9	4.7	663	2043
277	68	-3	483	297	1.2	0.6	911	911
90	43	-81	259	178	0.2	0.1	1115	1975
248	10	-52	217	238	0.5	0.4	771	1822
1011	73	-9	326	288	2.8	2.2	633	1418
1005	72	-7	506	336	4.1	2.5	732	1075
1201	65	-23	261	182	2.0	1.4	734	1393
308	11	-82	334	313	0.8	0.6	687	2488
40	0	-60	396	185	0.1	0.1	1116	2513
2230	104	-5	376	275	3.1	1.2	883	1082

Box and whiskers plots are used to display data distribution for the thermodynamic and shear parameters. The lower line of the box denotes the 1st quartile (25th percentile) while the top line of the box represents the 3rd quartile (75th percentile). The line inside of the box depicts the 50th percentile or the median value. The bottom whisker represents the 10th percentile with the top whisker representing the 90th percentile. Points that appear below and above the box and whisker plot represent the 5th and 95th percentiles, respectively.

3. Measures of Stability

a. Seasonal Variation of All Tornado Events

Mean values and t-test results (significance) of seasonal thermodynamic and shear parameters for all the Dixie Alley tornado events are given in Table 4.2. All parameters associated with instability and shear between seasonal tornado events were found to be significantly different at an alpha level of 0.01. Even though LI and mean layer CAPE values for cool-season tornadoes and warm-season tornadoes are representative of unstable environments, cool-season instability values are noticeably less than those associated with warm season tornado environments (Figure 4.3, 4.4). However, 0 – 3 km CAPE values for the cool-season tornado environments are higher than 0 – 3 km CAPE values in the warm-season tornado environments (Figure 4.5). This suggests that low-level accelerations in the 3 km above ground may be able to compensate for the weaker amounts of total CAPE during the cool-season. These findings of low-level CAPE approaching 60 J kg^{-1} or greater are in agreement with Davies (2006) and Guyer et al. (2006) with regards to cool-season tornado environments. Lastly, CIN values during the cool-season are significantly less than CIN values during the warm-season (Figure 4.6). Larger values of CIN are indicative of a deeper stable layer, which would be present during the warm-season months. This would be suggestive of a strong capping inversion advecting mid-level warmer and drier air over low-level warm, moist air. In addition, weaker CIN values suggest thunderstorms will more likely be surface based, which is necessary for the formation of tornadoes (Colman 1990).

Table 4.2. Mean thermodynamic and shear data and associated significance of all cool-season and warm-season tornado events.

All Tornado Events			
Parameters	**Cool-Season**	**Warm-Season**	**Significance**
LI	-2.42	-3.69	**
CAPE	745.54	1061.91	**
0-3 CAPE	56.17	38.97	**
CIN	-38.99	-66.82	**
0-3 SRH	267.92	190.78	**
0-1 SRH	224.33	141.21	**
0-3 EHI	1.47	1.44	
0-1 EHI	1.26	0.99	
LCL	699.25	878.71	**
LFC	1561.89	1880.64	**

**Significant at $p < 0.01$
*Significant at $p < 0.05$

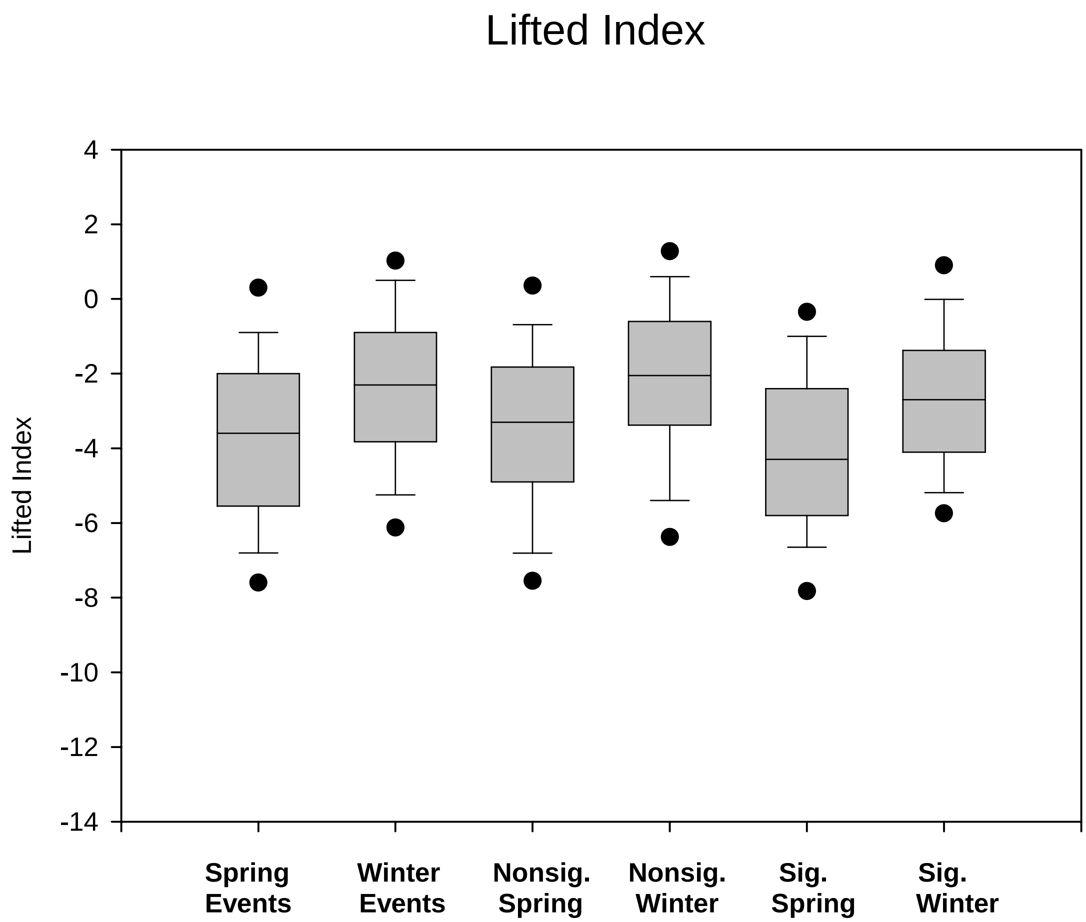

Figure 4.3. Box and whiskers plot of LI values for all seasonal tornado events and seasonal tornado strengths.

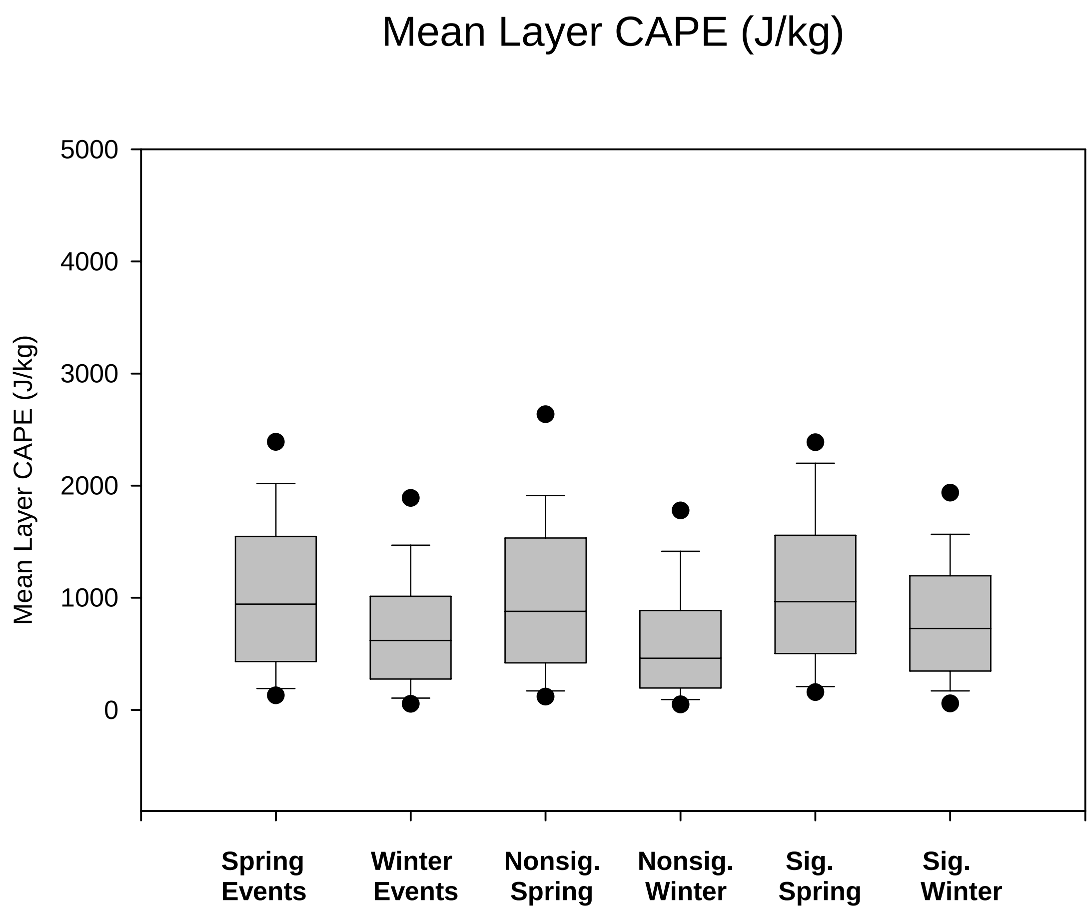

Figure 4.4. Box and whiskers plot of MLCAPE values for all seasonal tornado events and seasonal tornado strengths.

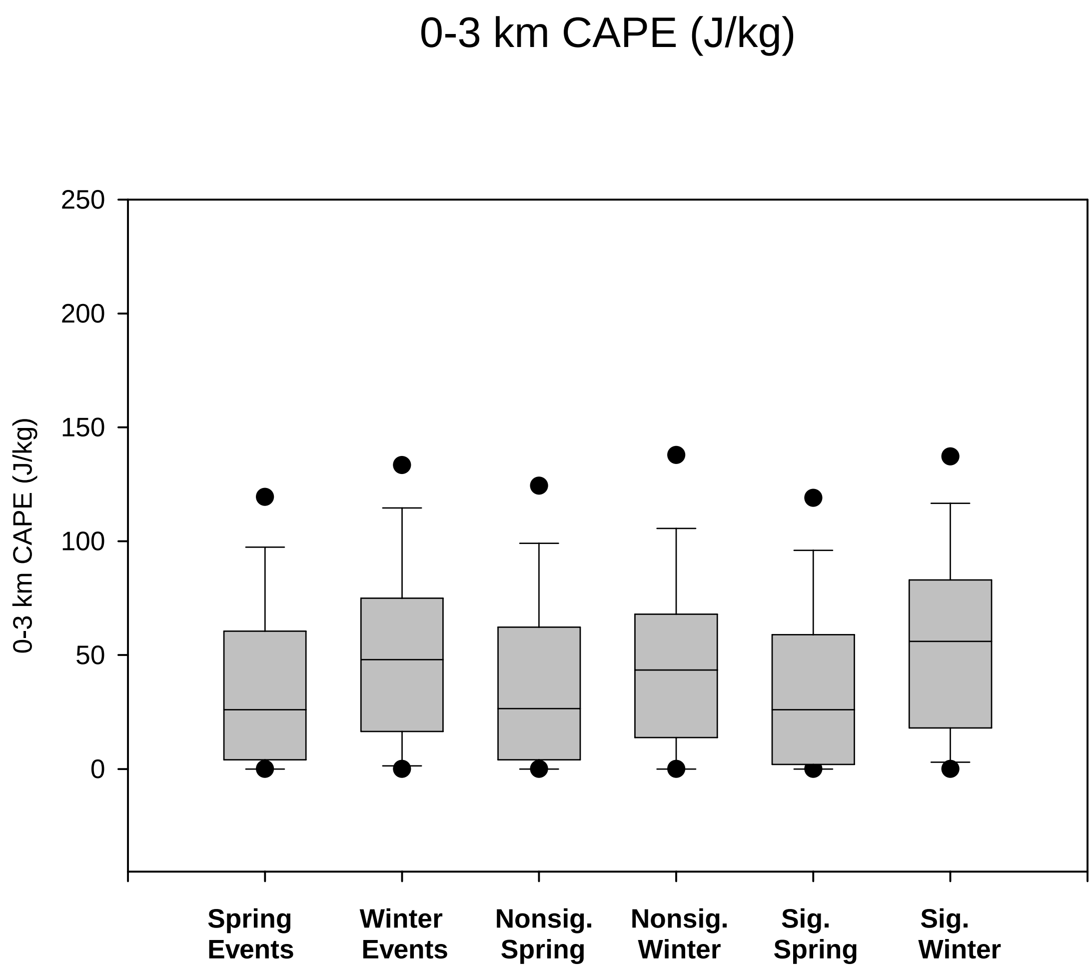

Figure 4.5. Box and whiskers plot of 0 – 3 km CAPE values for all seasonal tornado events and seasonal tornado strengths.

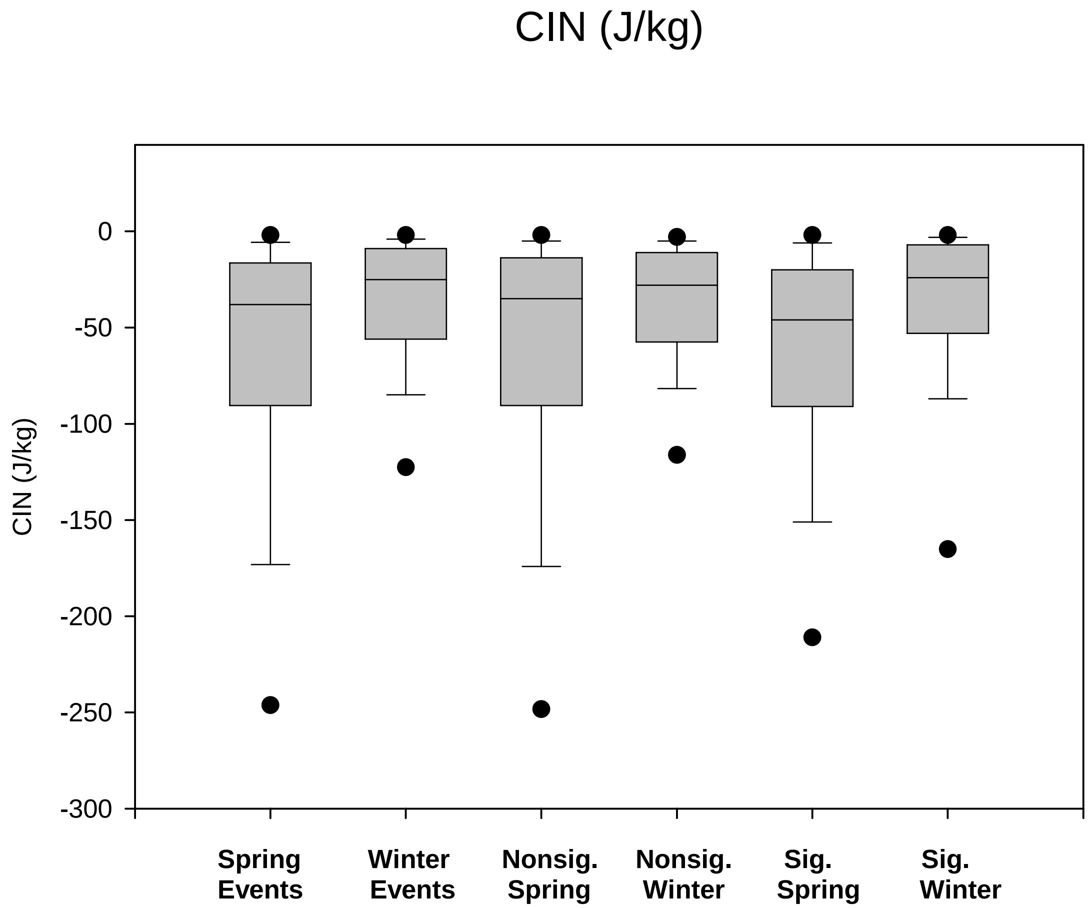

Figure 4.6. Box and whiskers plot of CIN values for all seasonal tornado events and seasonal tornado strengths.

b. Seasonal Variation of Non-significant Tornado Environments

Table 4.3 displays mean values of thermodynamic and shear parameters and associated level of statistical significance. LI, CAPE, and CIN values between non-significant tornado environments during the cool and warm seasons were found statistically different at $p < 0.01$. Yet, 0 – 3 km CAPE values were not statistically significant at $p < 0.01$ or $p < 0.05$. This suggests that the seasonal variation of non-significant tornadoes can be attributed to total CAPE, not low-level instability.

c. Seasonal Variation of Significant Tornado Environments

As with non-significant tornado environments, mean thermodynamic values and significance of thermodynamic and shear parameters were computed for significant (F2–F5) tornadoes during the cool and warm-seasons (Table 4.4). LI, CAPE, and CIN values were found significantly different at $p < 0.01$ and 0 – 3 km CAPE was significant at $p < 0.05$. Not surprisingly, instability values, regardless of season, are greatest with significant tornado environments.

4. Measures of Shear and Combination of Instability and Shear

a. Seasonal Variation of All Tornado Events

The shear parameters 0 – 3 km SRH and 0 – 1 km SRH were found to be statistically different at $p < 0.01$ between the cool-season and warm-season tornado events. SRH values during the winter months are much greater than the SRH values

Table 4.3. Mean thermodynamic and shear data and associated significance of non-significant cool-season and warm-season tornado events.

Non-significant Tornadoes			
Parameters	**Cool**	**Warm**	**Significance**
LI	-2.14	-3.46	**
CAPE	614.36	1024.98	**
0-3 CAPE	51.76	39.61	
CIN	-38.99	-66.23	**
0-3 SRH	265.87	177.91	**
0-1 SRH	207.69	120.86	**
0-3 EHI	1.19	1.23	
0-1 EHI	0.99	0.82	
LCL	677.59	887.68	**
LFC	1621.83	1857.89	*

**Significant at $p < 0.01$
*Significant at $p < 0.05$

Table 4.4. Mean thermodynamic and shear data and associated significance of significant cool-season and warm-season tornado events.

Significant Tornadoes			
Parameters	**Cool**	**Warm**	**Significance**
LI	-2.74	-4.09	**
CAPE	823.6	1109.76	**
0-3 CAPE	60.95	37.85	*
CIN	-38.99	-67.84	**
0-3 SRH	270.3	213.35	**
0-1 SRH	250.6	201.09	*
0-3 EHI	1.79	1.74	
0-1 EHI	1.69	1.42	
LCL	724.27	863.16	**
LFC	1492.62	1920.06	**

**Significant at $p < 0.01$
*Significant at $p < 0.05$

during the spring months. Figures 4.7 and 4.8 show nearly a quartile offset of 0 – 3 km SRH and 0 – 1 km SRH between cool-season tornado environments and warm-season tornado environments. As suggested by Guyer et al. (2006), wind fields tend to be stronger during the winter months due to the polar jet displaced further to the south and a strong subtropical jet. The increase in SRH in the lowest three and lowest one kilometers appear to offset the weaker amounts of instability present in the cool-season. Interestingly, 0 – 3 km EHI and 0 – 1 km EHI is not statistically significant at $p < 0.05$ and 0.01 between all seasonal tornado events. Very little data separation exists for both 0 – 3 km EHI (Figure 4.9) and 0 – 1 km EHI (Figure 4.10) between seasons.

Though the combination parameter of EHI does not show statistical significance between seasons, these results now documented between seasons have some forecasting use. These findings demonstrate the relationship/balance between instability and shear. The EHI value indicates the balance values of high CAPE/low shear and low CAPE/high shear environments. This parameter seems to have tremendous forecasting value regardless of season providing the forecaster recognizes the seasonal variations of CAPE and shear.

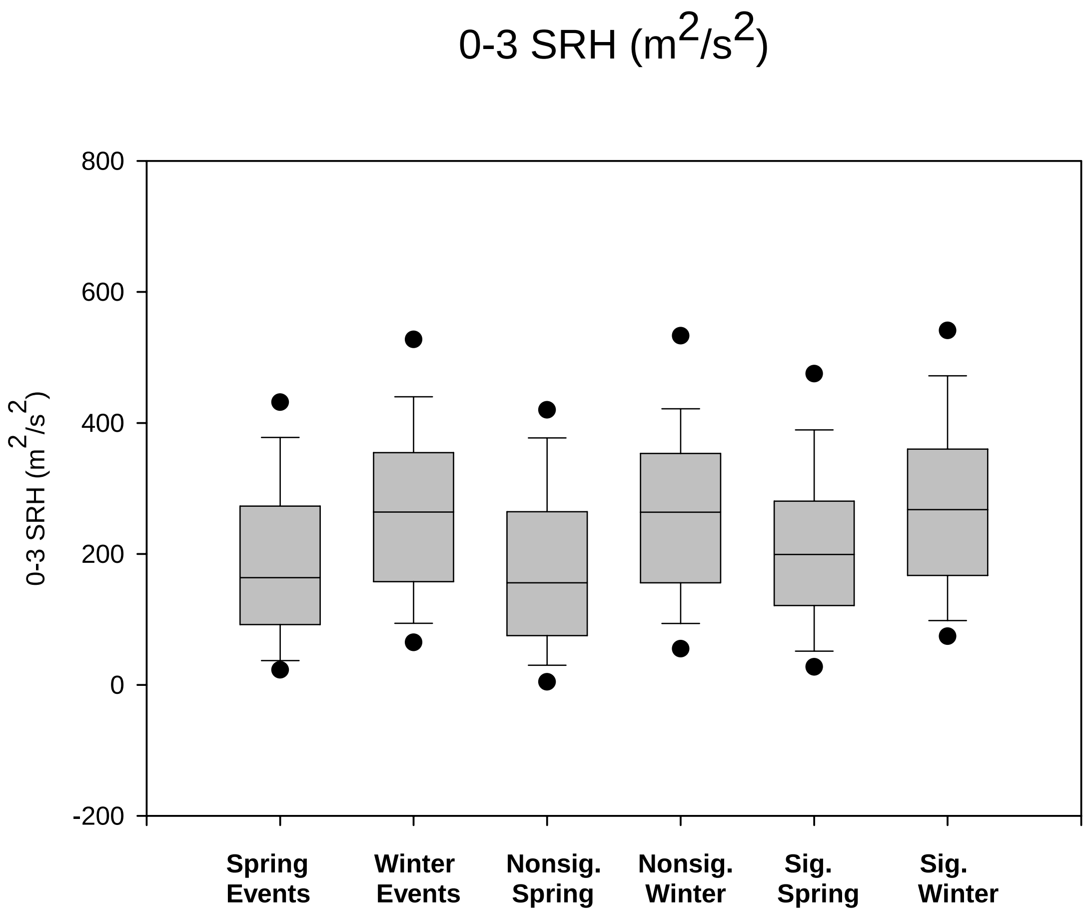

Figure 4.7. Box and whiskers plot of 0 – 3 km SRH values for all seasonal tornado events and seasonal tornado strengths.

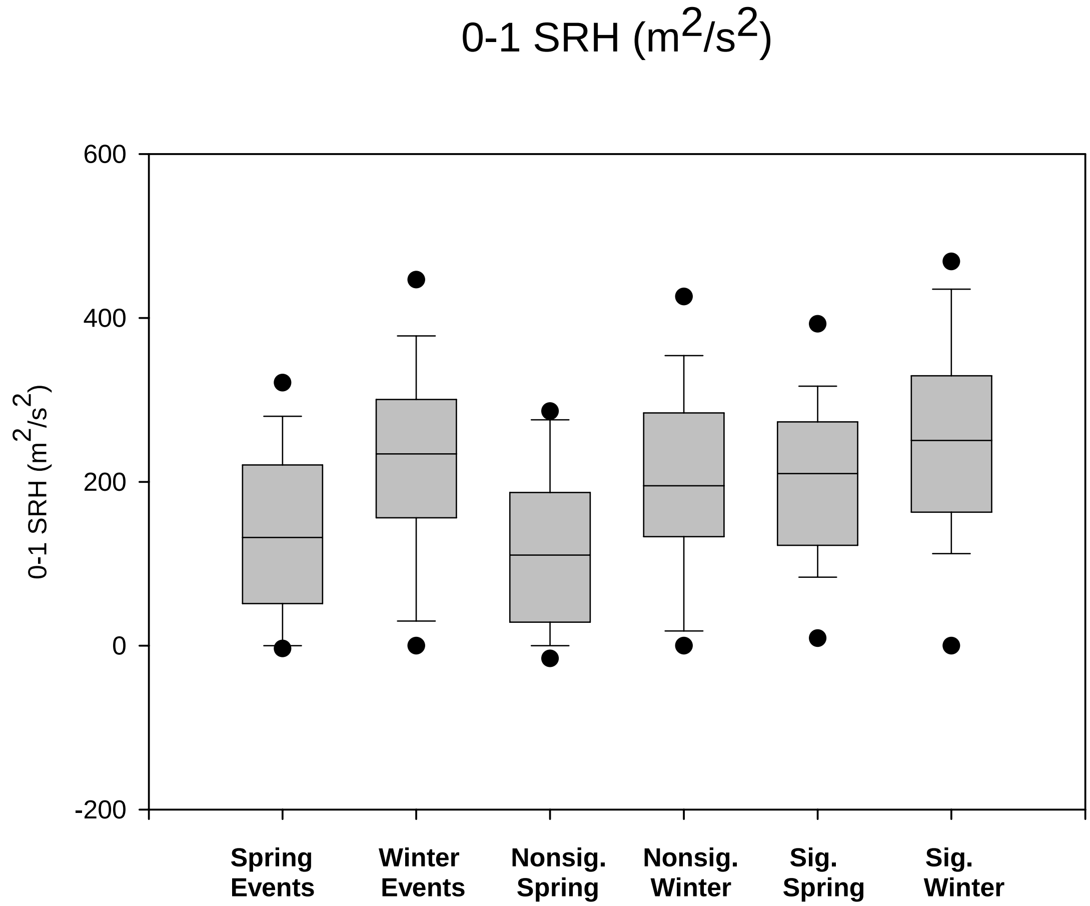

Figure 4.8. Box and whiskers plot of 0 – 1 km SRH values for all seasonal tornado events and seasonal tornado strengths.

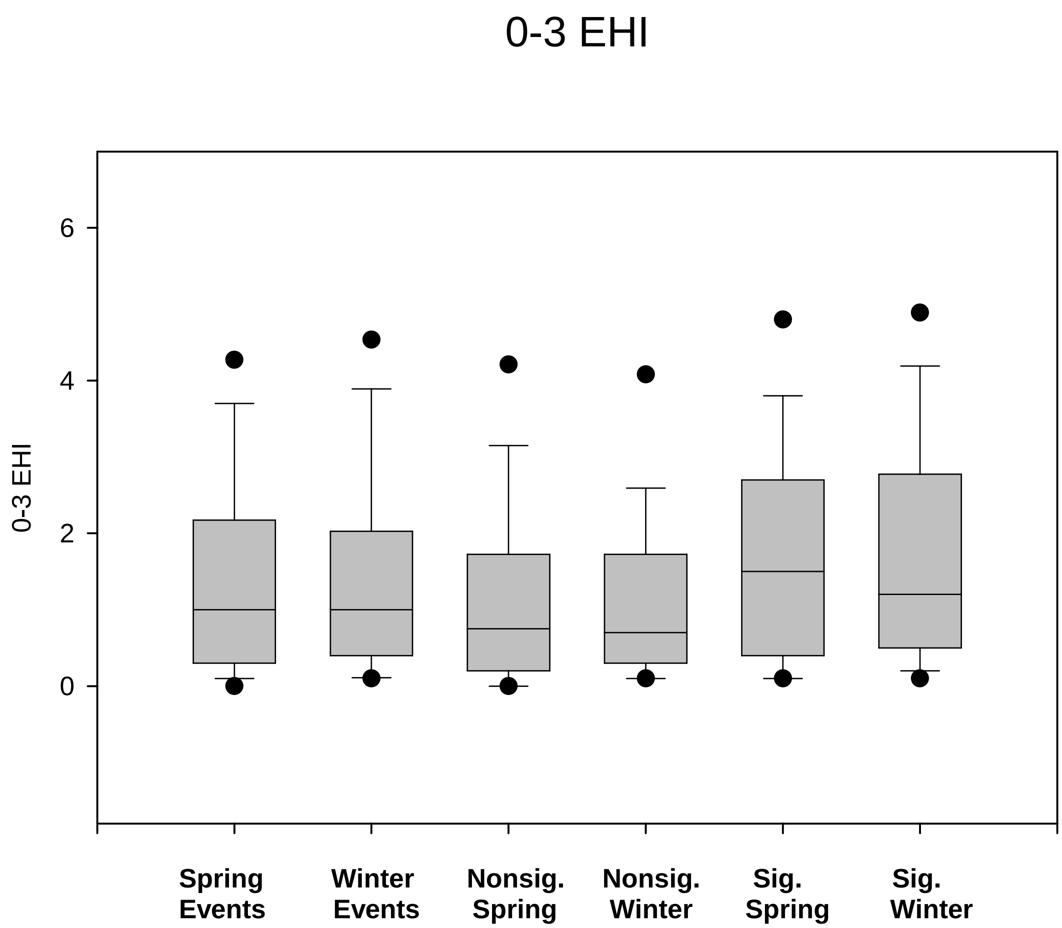

Figure 4.9. Box and whiskers plot of 0 – 3 km EHI values for all seasonal tornado events and seasonal tornado strengths.

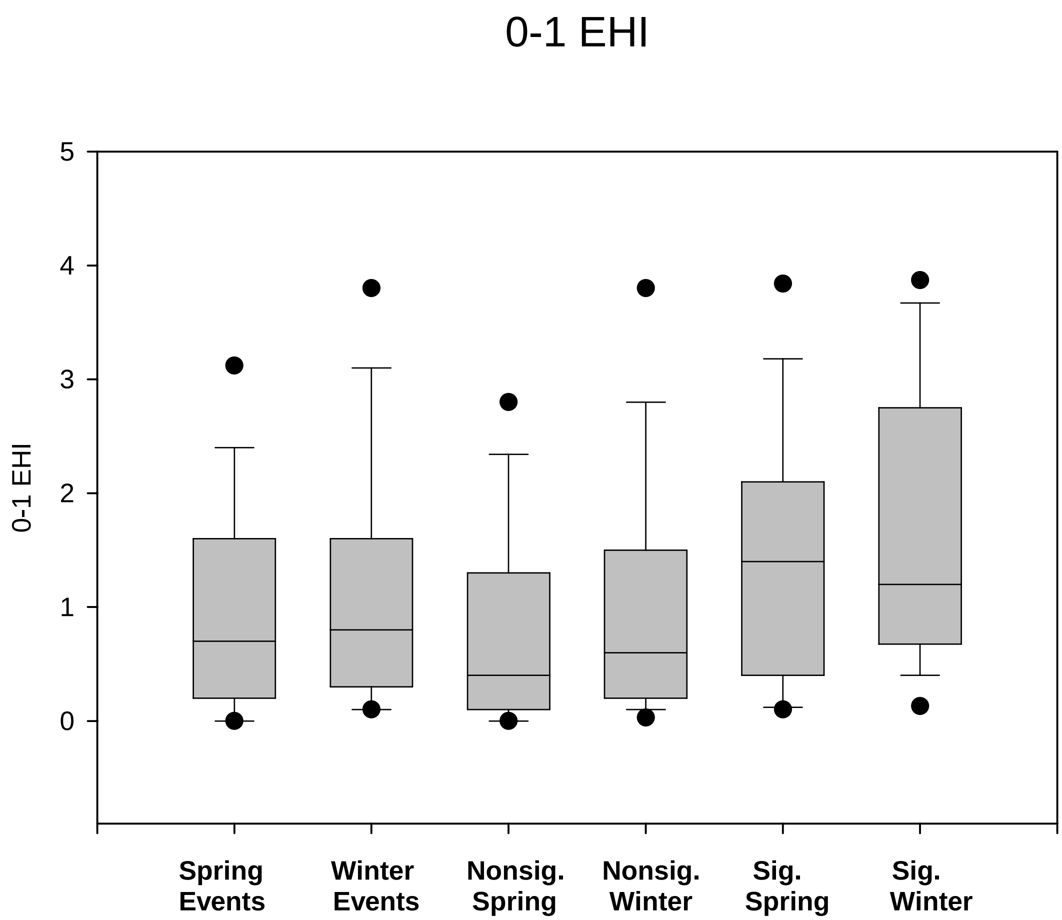

Figure 4.10. Box and whiskers plot of 0 – 1 km EHI values for all seasonal tornado events and seasonal tornado strengths.

b. Seasonal Variation of Non-significant Tornado Environments

Non-significant tornado shear parameters also showed statistical differences at $p < 0.01$ between the cool and warm-seasons. The 0 – 3 km and 0 – 1 km SRH values are slightly less for non-significant tornado environments when compared to all season tornado environments. Box and whisker plots (Figure 4.7, 4.8) show at least a quartile overlap with regards to 0 – 3 km and 0 – 1 km SRH. These findings are consistent with cool-season tornadoes requiring greater amounts of wind shear than warm-season tornadoes (Davies 2006; Guyer et al. 2006).

EHI values for seasonal non-significant tornado environments were also not statistically significant at $p < 0.05$. Box and whiskers plot (Figure 4.9, 4.10) display little offset in 0 – 3 km and 0 – 1 km EHI values for non-significant tornado environments. This further supports that EHI indicates an environmental balance between instability and shear necessary for tornado prediction.

c. Seasonal Variation of Significant Tornado Environments

As with the instability indices, 0 – 3 km and 0 – 1 km SRH environments were the greatest for significant tornadoes regardless of season. For significant tornado environments, 0 – 3 km SRH was significantly different at $p < 0.01$ while 0 – 1 km SRH was statistically different at $p < 0.05$. Nearly a quartile offset in 0 – 3 km(Figure 4.7) and 0–1km SRH (Figure 4.8) exists. As previously stated, wind shear is more prevalent during the cool-season months. When large amounts of helicity are combined with sufficient instability, the threat of significant tornadoes is increased.

Both 0 – 3 km and 0 – 1 km EHI behaved similarly to the EHI values of all seasonal tornado environments and seasonal non-significant tornado environments. Neither 0 – 3 km nor 0 – 1 km EHI were statistically significant at $p < 0.01$ and 0.05. Not surprisingly, little visual offset exists between the median values of 0 – 3 km (Figure 4.9) and 0 – 1 km EHI (Figure 4.10).

5. Miscellaneous Measures

a. Seasonal Variation of All Tornado Events

LCL heights were both found to be statistically different at $p < 0.01$ between all cool-season and warm-season tornado environments. Both seasons reflect environments with average LCL heights below 900 meters, which agrees with the findings of Rasmussen and Blanchard (1998), Edwards and Thompson (2000), Craven et al. (2002), and Markowski (2002). LCL heights (Figure 4.11) show a quartile offset in the data between the two seasons tested. The median value of cool-season tornadoes is roughly the same as the first quartile of warm-season events. As previously mentioned, due to the increased wind fields present during the winter months, greater amounts of moisture can be transported from the Gulf of Mexico into the Dixie Alley states. This influx of boundary layer moisture would serve to lower the LCL heights and increase chances of tornadogensis.

The LFC height marks the origin of positive buoyancy needed for thunderstorm development, and while not displaying as much of an offset as LCL heights, are statistically different for tornado events in each season. Lower LFC heights will signify increasing amounts of low-level instability, which has been hypothesized as a necessary ingredient for tornado development in the cool-season (Davies 2006). In this study, mean LFC heights are approximately 400 m less for cool-season tornado environments than warm-season environments (Figure 4.12).

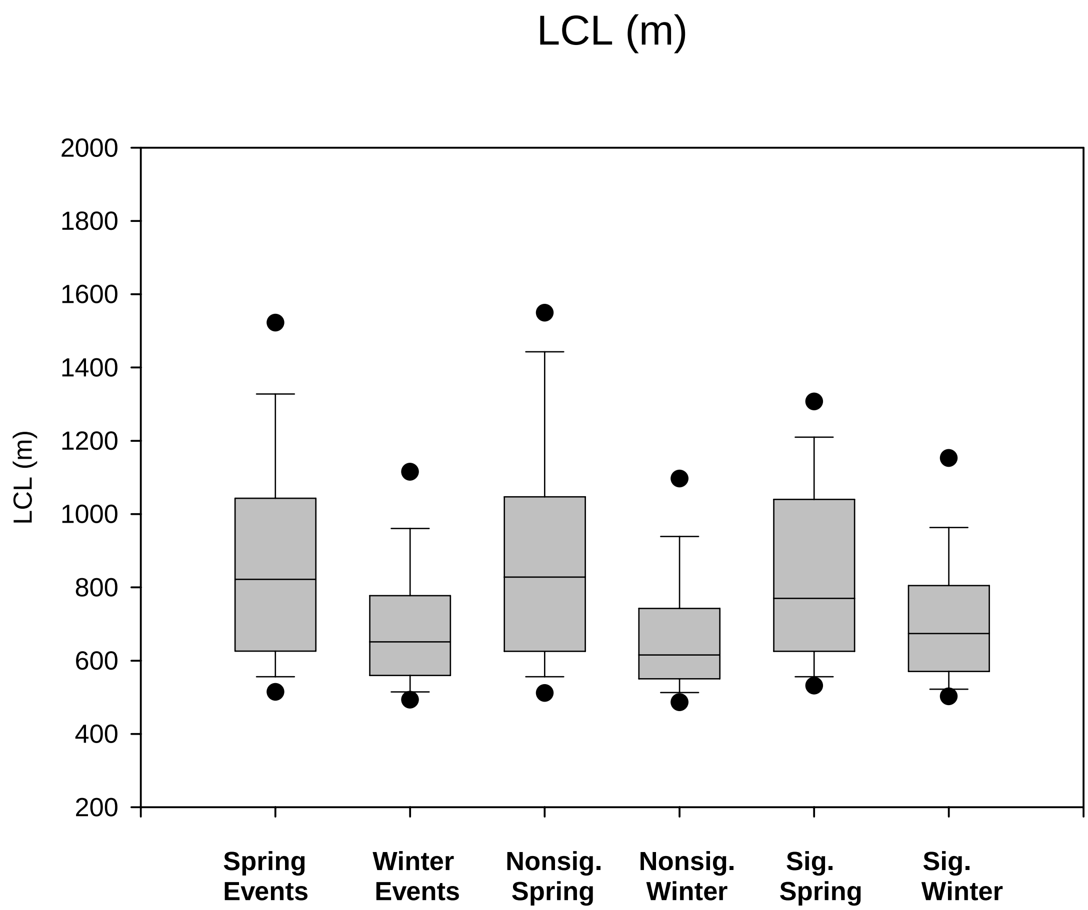

Figure 4.11. Box and whiskers plot of LCL heights for all seasonal tornado events and seasonal tornado strengths.

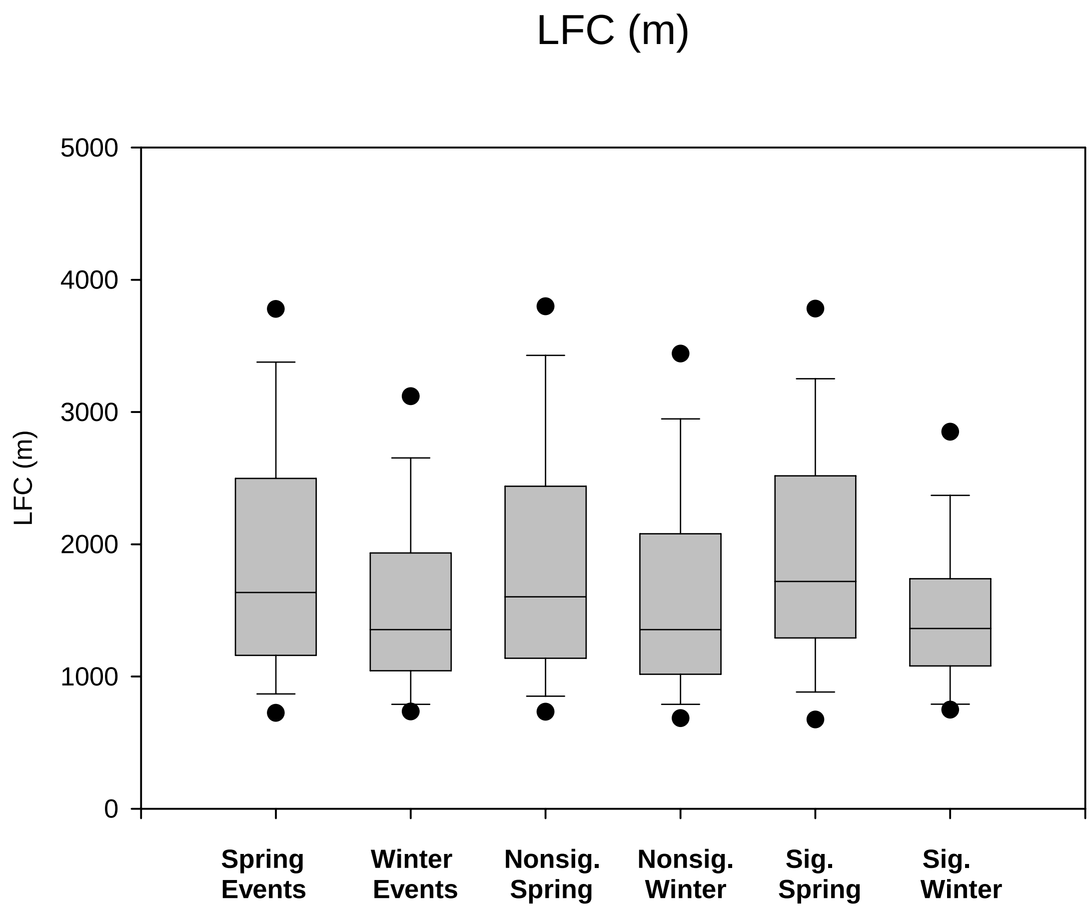

Figure 4.12. Box and whiskers plot of LFC heights for all seasonal tornado events and seasonal tornado strengths.

b. Seasonal Variation of Non-significant Tornado Environments

For non-significant tornadoes, LCL heights were found to be statistically different at $p < 0.01$ while LFC heights were statistically significant at $p < 0.05$. The box and whiskers plot of LCL heights (Figure 4.11) shows the median value for non-significant cool-season tornadoes is actually lower than the 25th percentile of warm-season non-significant tornadoes. Similar to all-seasonal events, this would argue for a decreased dewpoint depression during the cool-season. LFC heights (Figure 4.12) display less than a quartile offset between cool and warm-season non-significant tornado environments. LFC heights in both seasons are below 2000 m, therefore it is reasonable to conclude that tornadoes will form in environments with lower LFC heights (Davies 2001; Davies 2002).

c. Seasonal Variation of Significant Tornado Environments

Significant tornado environments in both seasons were characterized by low LCL and LCL heights. Both LCL and LFC heights were found to be statistically unique at $p < 0.01$ between seasons. Significant tornado LCL and LFC heights are lower than the all-seasonal and non-significant tornado groups. Cool-season significant tornadoes occurred in environments where LCL and LFC heights were lower than warm-season significant events. This is evident by the nearly one quartile offset in median LCL (Figure 4.11) and LFC (Figure 4.12) heights. With cooler temperatures during the winter months, dewpoint depression values would be less creating lower LCL heights.

6. Intra-Seasonal Variation in Tornado Strength

Cool and warm-season thermodynamic and shear parameters and associated statistical results are displayed in Tables 4.5 and 4.6. Generally, cool-season tornado events were characterized by the presence of relatively low instability and high shear environment. However, warm-season events were influenced predominantly by a high instability and relatively low shear environment. While these differences have usefulness in forecasting tornado environments in each season, it may be more practical to examine which parameters are able to distinguish between non-significant tornadoes and significant tornado environments within a given season.

a. Cool-Season Significant Parameters

The parameters LI, CAPE, 0 – 3 km EHI and 0 – 1 km EHI (Figures 4.13, 4.14, 4.17, Figure 4.18) appear to distinguish between non-significant and significant tornado environments in the cool-season. The instability parameters (LI and CAPE) for non-significant and significant tornadoes showed statistically significant differences at $p < 0.05$. Furthermore, the EHI parameter was found to be statistically different at $p < 0.01$ in differentiating between tornado intensity during the cool-season. Instability appears to drive the existence of significant tornado environments during the cool-season. With the amount of shear fairly similar in the cool-season months (Figure 4.15, 4.16), higher amounts of instability appear to increase the chances of developing environments conducive to significant tornadoes. Unlike comparing seasonal tornado environments, EHI also has some usefulness in discriminating between non-significant and significant tornadoes in the cool-season (Figure 4.17, 4.18). Since helicity values for tornado events throughout the winter months are fairly constant, variations with instability cause fluctuations in the observed EHI values.

Table 4.5. Mean thermodynamic and shear data and associated significance of non-significant and significant tornadoes in the cool-season.

Cool-Season			
Parameters	**Nonsig. Tornadoes**	**Sig. Tornadoes**	**Significance**
LI	-2.14	-2.74	*
CAPE	614.36	823.6	*
0-3 CAPE	51.76	60.95	
CIN	-38.99	-38.99	
0-3 SRH	265.87	270.31	
0-1 SRH	207.69	250.6	
0-3 EHI	1.19	1.79	**
0-1 EHI	0.99	1.69	**
LCL	677.59	724.27	
LFC	1621.82	1492.62	

**Significant at $p < 0.01$
*Significant at $p < 0.05$

Table 4.6. Mean thermodynamic and shear data and associated significance of non-significant and significant tornadoes in the warm-season.

Warm-Season			
Parameters	**Nonsig. Tornadoes**	**Sig. Tornadoes**	**Significance**
LI	-3.46	-4.09	*
CAPE	1024.98	1109.76	
0-3 CAPE	39.62	37.85	
CIN	-66.23	-67.84	
0-3 SRH	177.91	213.35	*
0-1 SRH	120.86	201.09	**
0-3 EHI	1.23	1.74	*
0-1 EHI	0.82	1.42	**
LCL	887.68	863.16	
LFC	1857.89	1920.06	

**Significant at $p < 0.01$
*Significant at $p < 0.05$

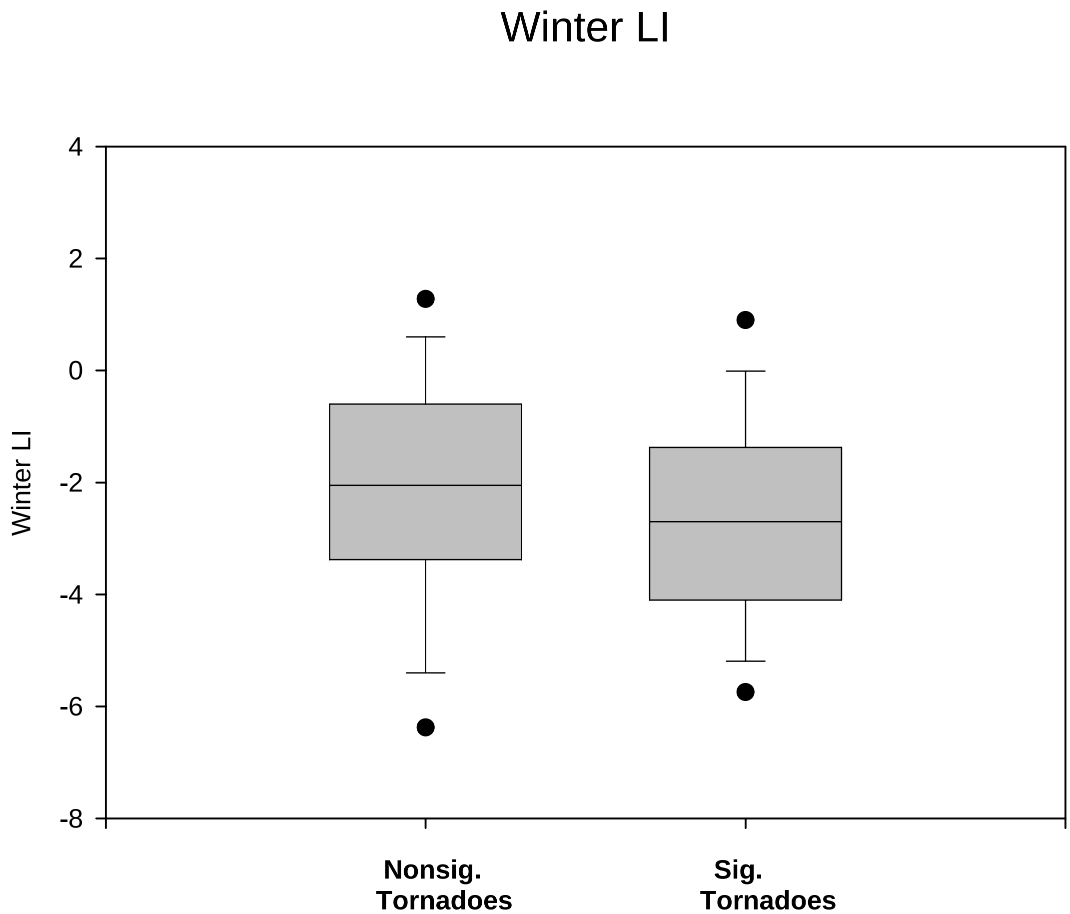

Figure 4.13. Box and whiskers plot of LI values for non-significant and significant tornadoes during the cool-season.

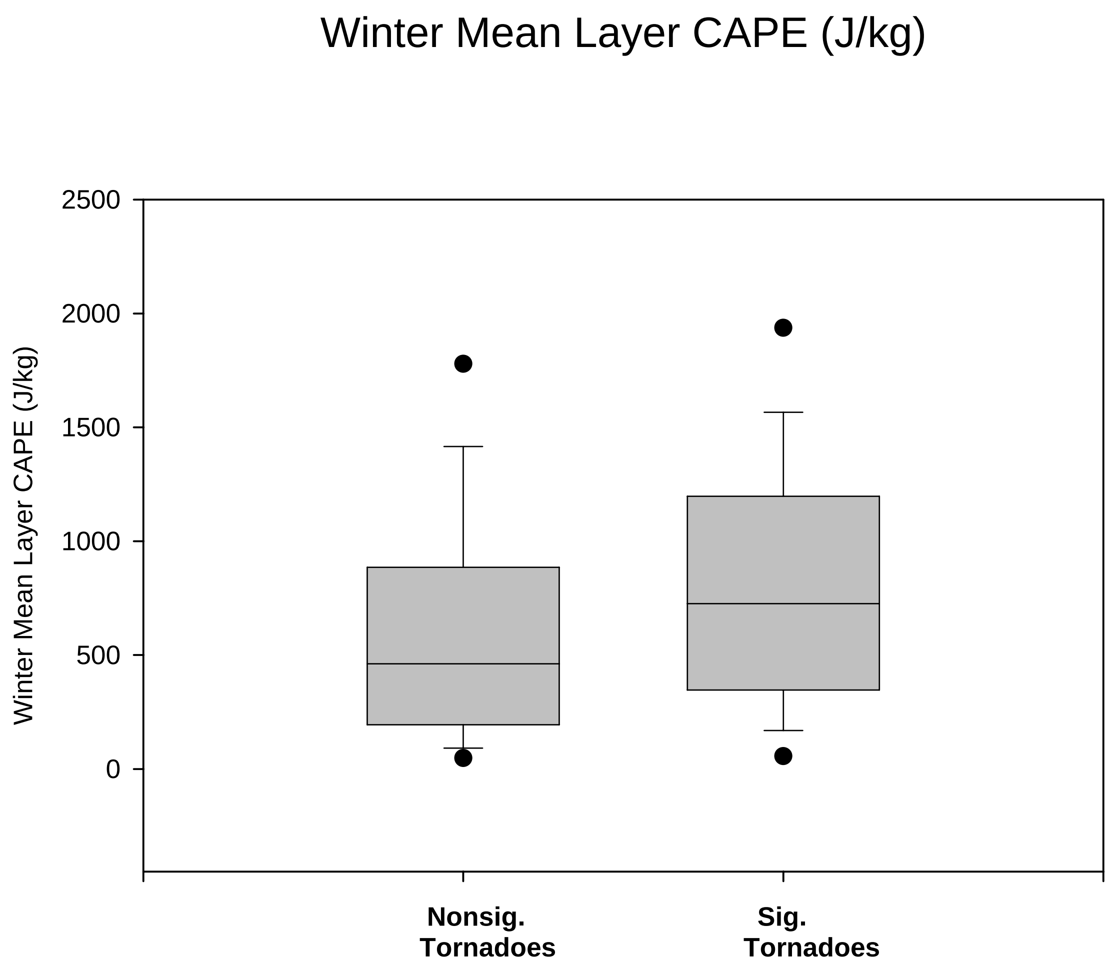

Figure 4.14. Box and whiskers plot of MLCAPE values for non-significant and significant tornadoes during the cool-season.

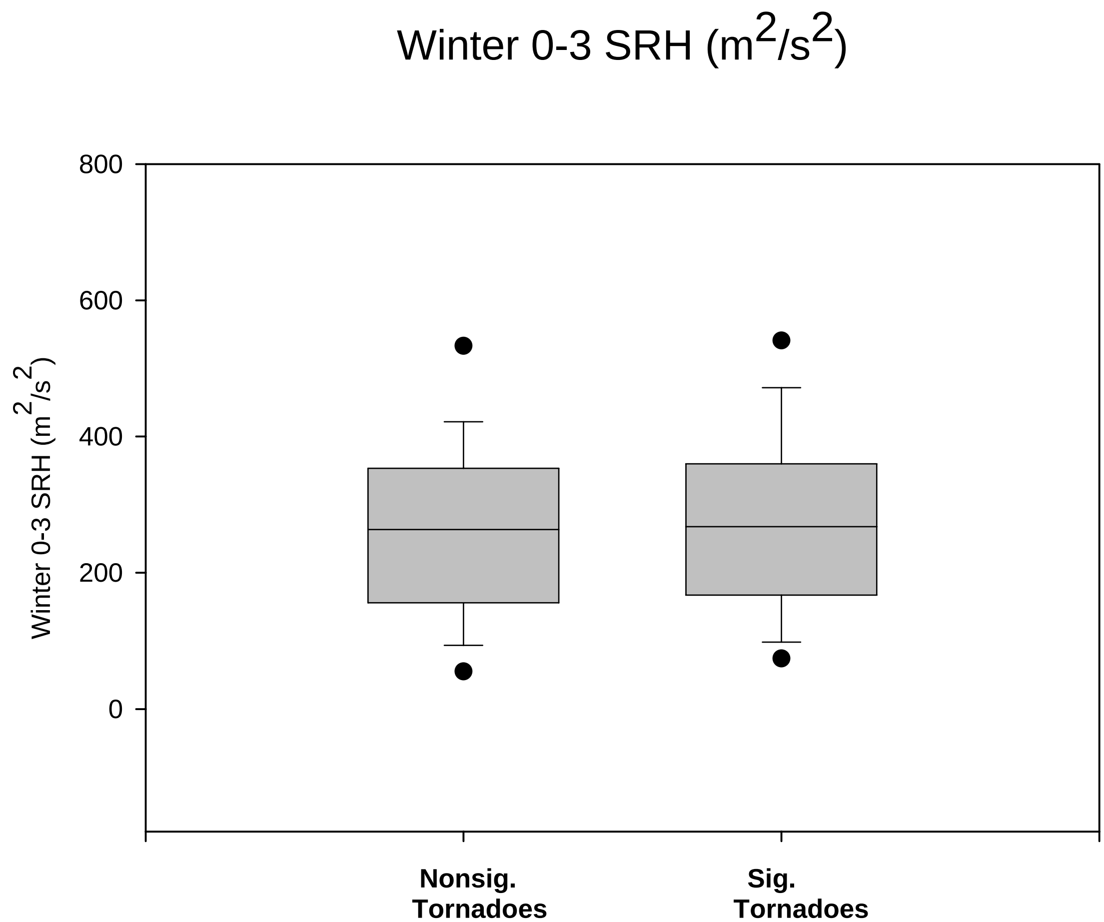

Figure 4.15. Box and whiskers plot of 0 – 3 km SRH values for non-significant and significant tornadoes during the cool-season.

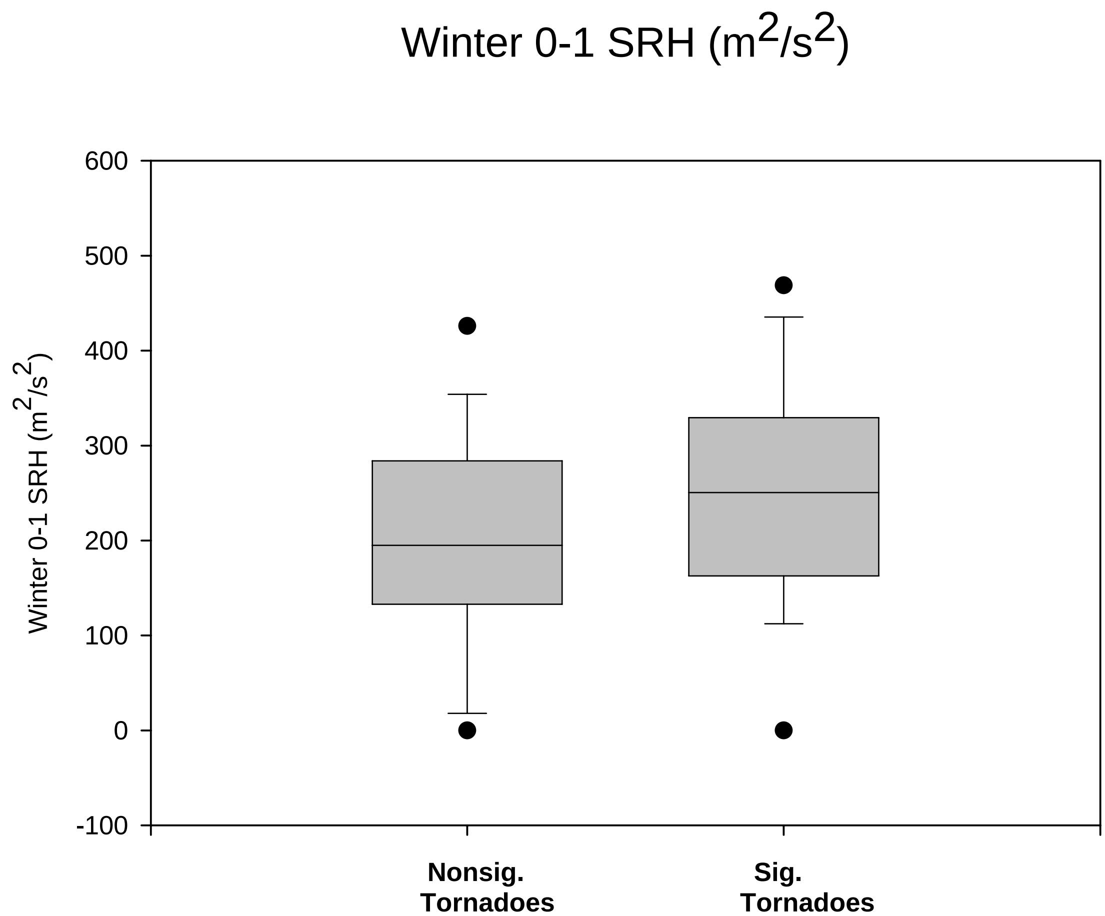

Figure 4.16. Box and whiskers plot of 0 – 1 km SRH values for non-significant and significant tornadoes during the cool-season.

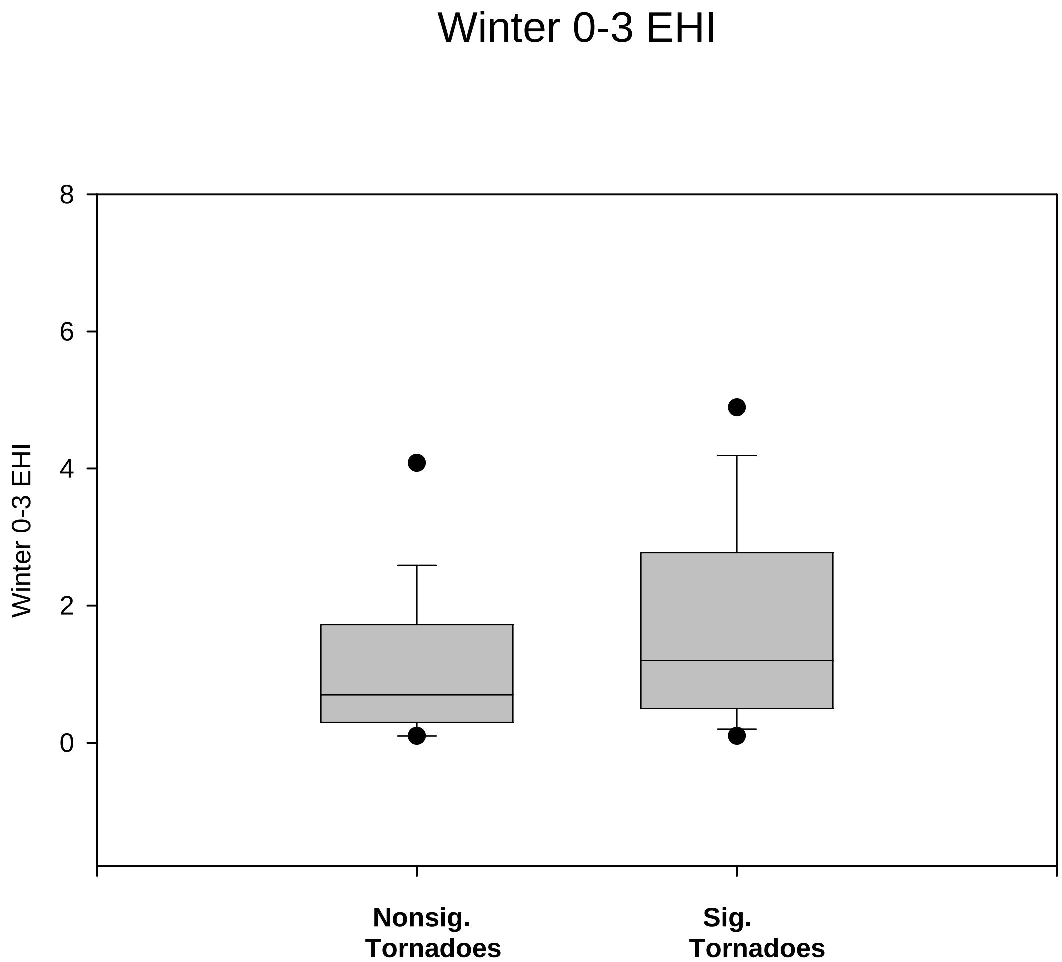

Figure 4.17. Box and whiskers plot of 0 – 3 km EHI values for non-significant and significant tornadoes during the cool-season.

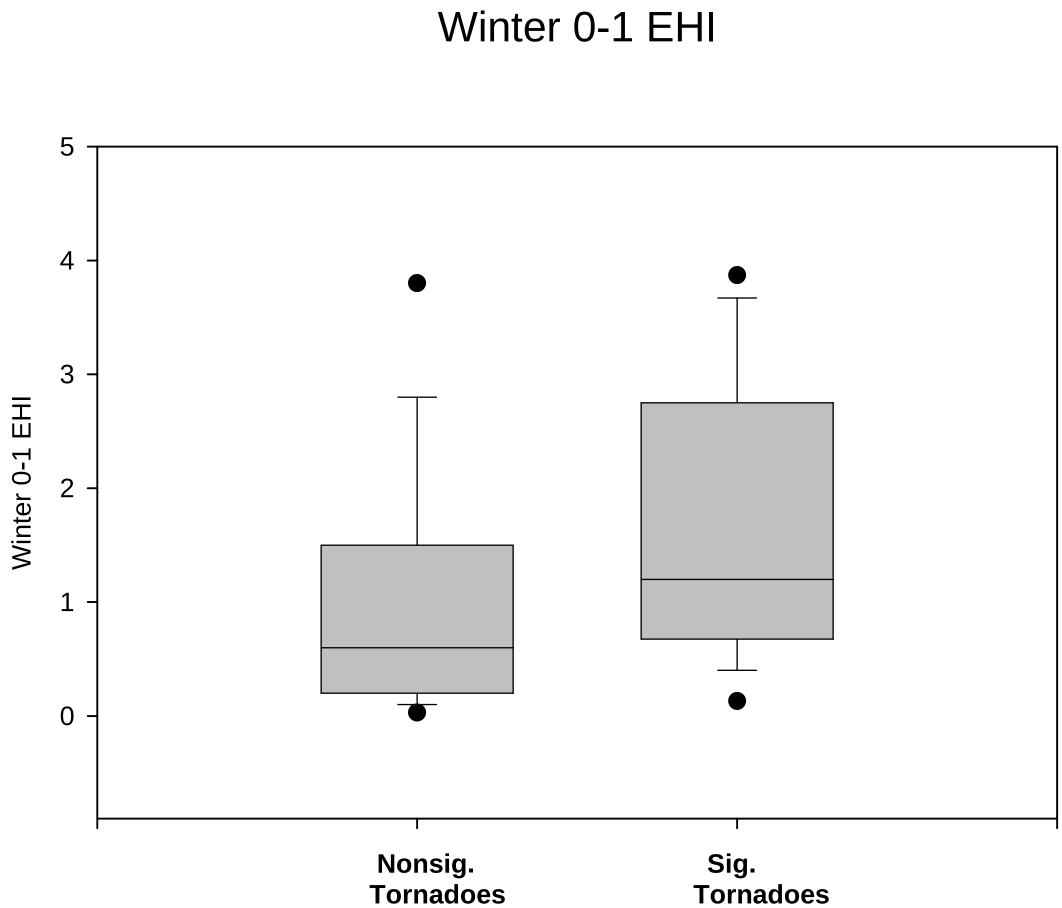

Figure 4.18. Box and whiskers plot of 0 – 1 km EHI values for non-significant and significant tornadoes during the cool-season.

b. Warm-Season Significant Parameters

Warm-season parameters that differentiate between non-significant and significant tornado environments are LI, 0 – 3 km SRH, 0 – 1 km SRH, 0 – 3 km EHI, and 0 – 1 km EHI. Median LI values (Figure 4.19) for each tornado strength group show a slight offset that is statistically different at $p < 0.05$. However, median CAPE values show virtually no offset in the data and are found statistically similar. Since CAPE is a more robust tool for forecasting instability due to a column integration of instability, LI values may not have operational usefulness in distinguishing between warm-season non-significant and significant tornado environments. Instead, it appears that the amount of environmental shear differentiates between warm-season non-significant and significant tornadoes. Since instability for warm-season tornadoes exhibits small variability (Figure 4.20), any dramatic increase of shear will consequently affect EHI values. Values of 0 – 3 km SRH (Figure 4.21) and 0 – 3 km EHI (Figure 4.23) are found to be statistically unique while only exhibiting a slight offset in the box and whisker plot. On the other hand, 0 – 1 km SRH (Figure 4.22) and 0 – 1 km EHI (Figure 4.24) are significant at $p < 0.01$ with more than a quartile offset with regard to the median values (Figure 4.28, 4.30). It appears that shear and combination parameters show promise in distinguishing between non-significant and significant tornado environments in the warm-season.

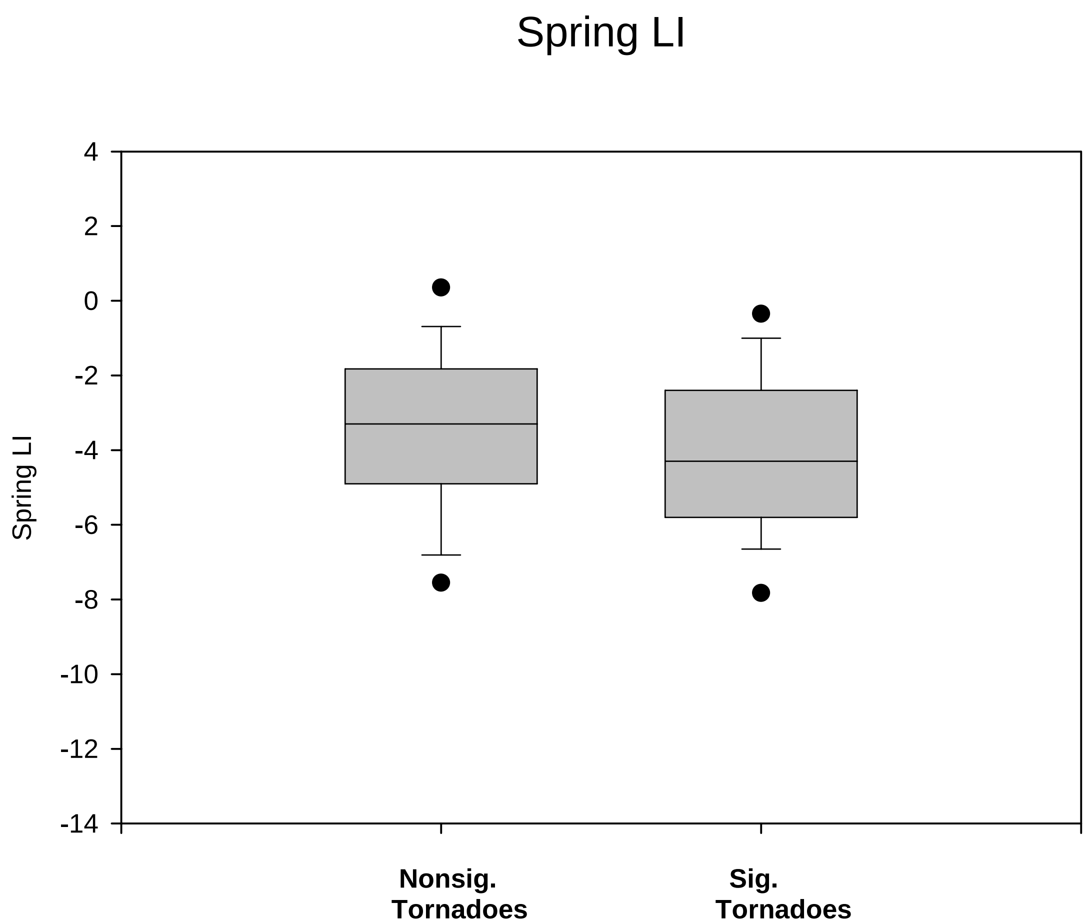

Figure 4.19. Box and whiskers plot of LI values for non-significant and significant tornadoes during the warm-season.

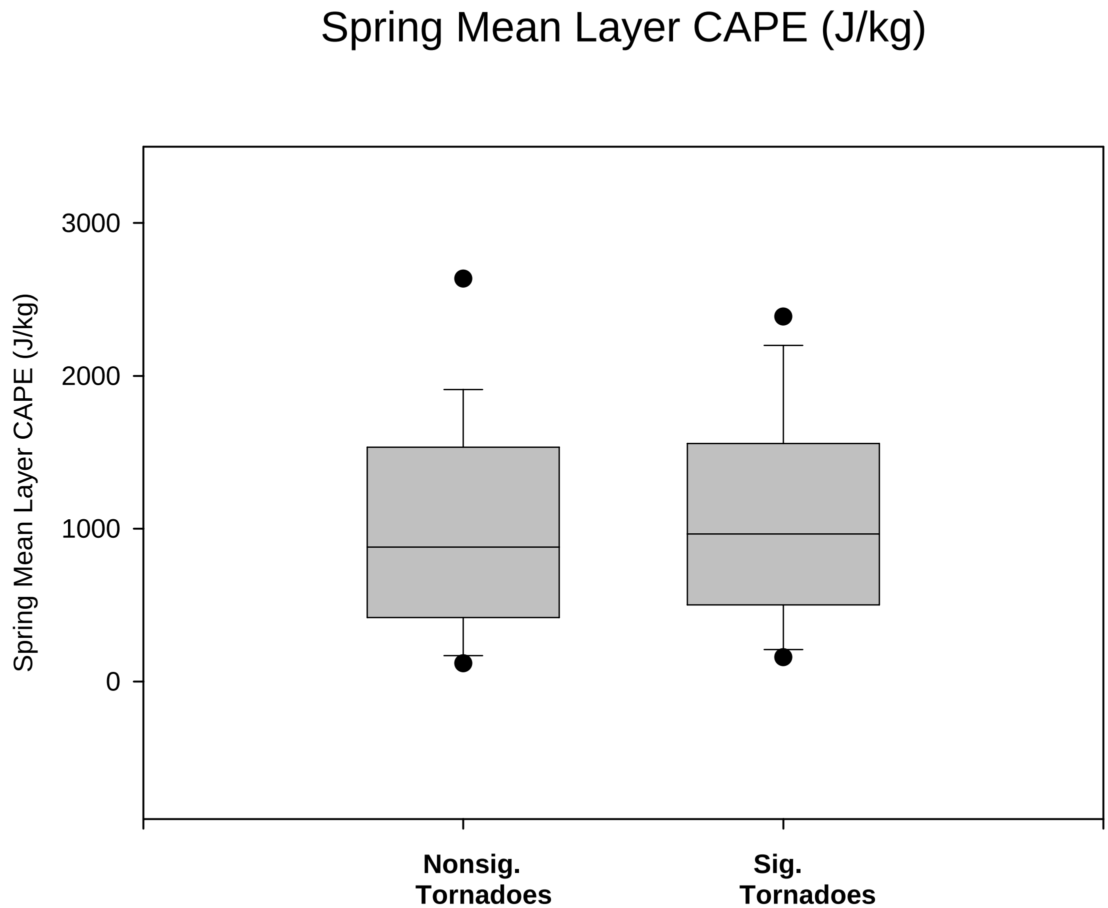

Figure 4.20. Box and whiskers plot of MLCAPE values for non-significant and significant tornadoes during the warm-season.

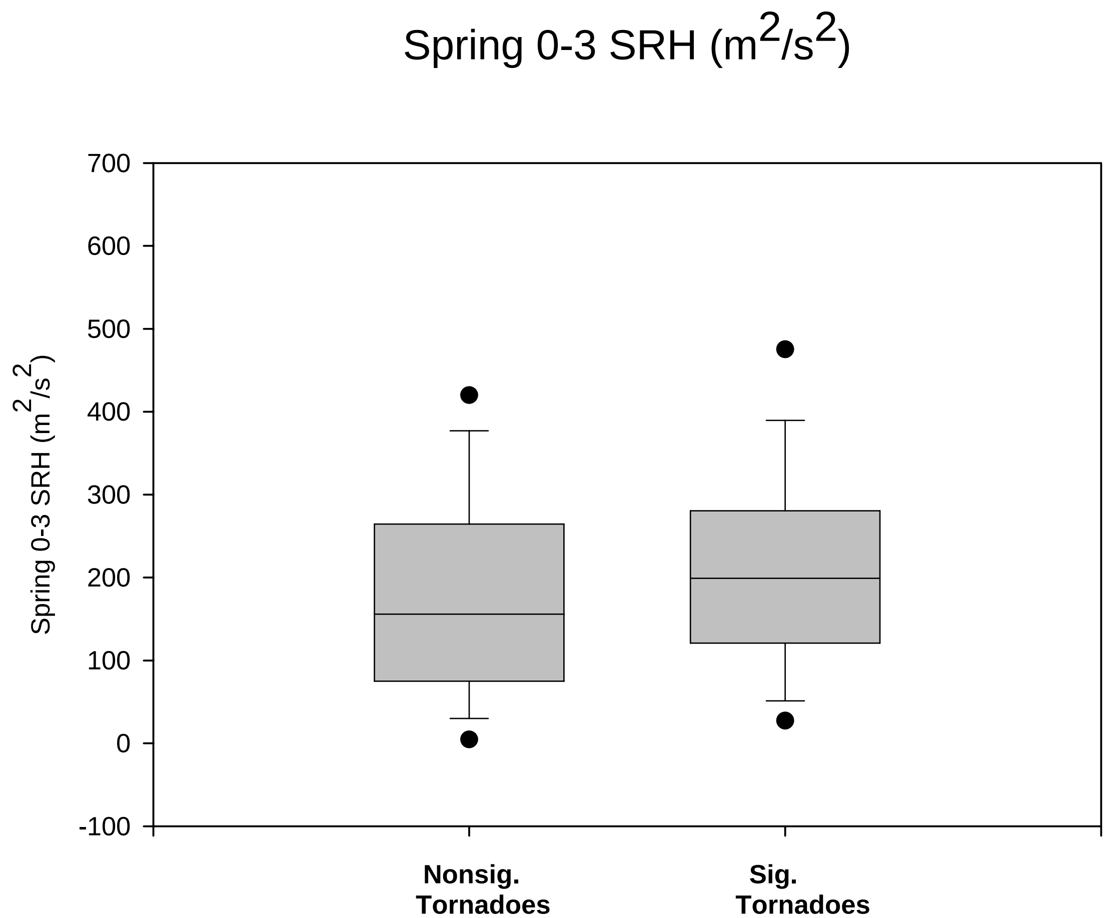

Figure 4.21. Box and whiskers plot of 0 – 3 km SRH values for non-significant and significant tornadoes during the warm-season.

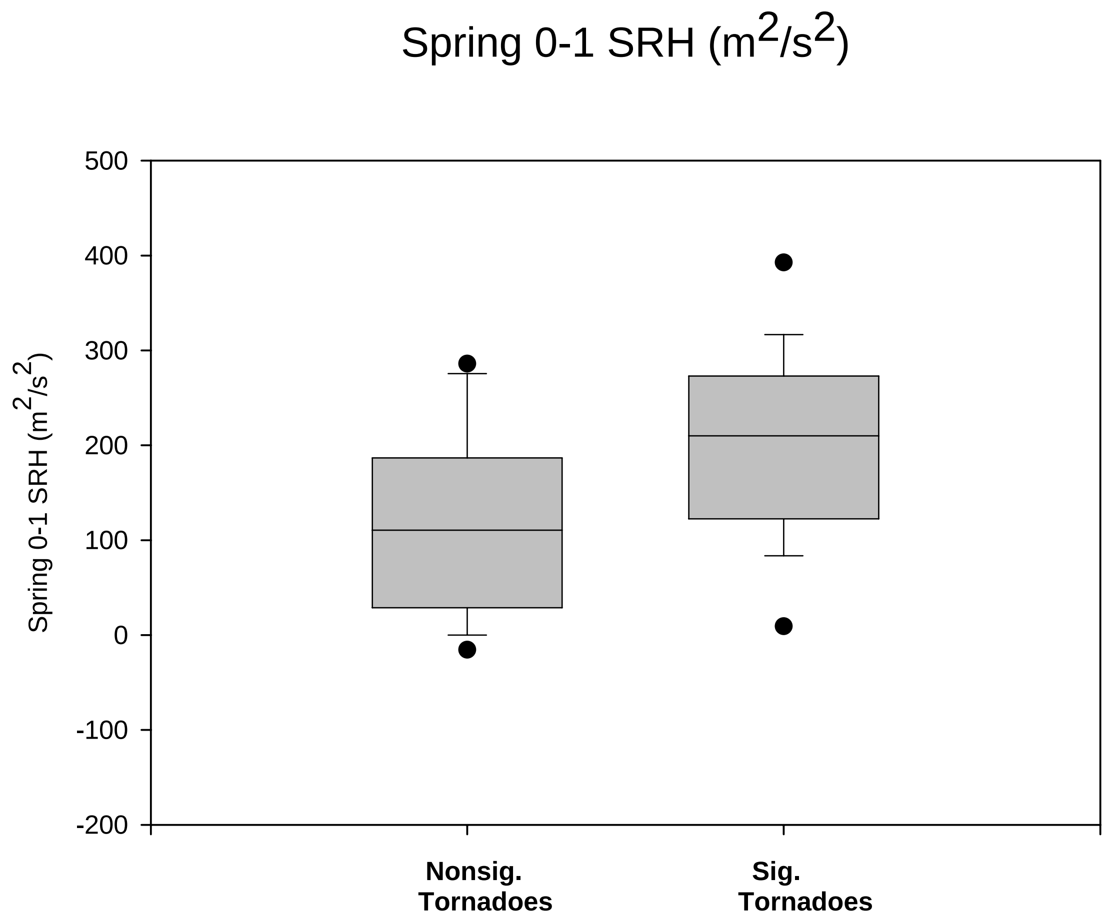

Figure 4.22. Box and whiskers plot of 0 – 1 km SRH values for non-significant and significant tornadoes during the warm-season.

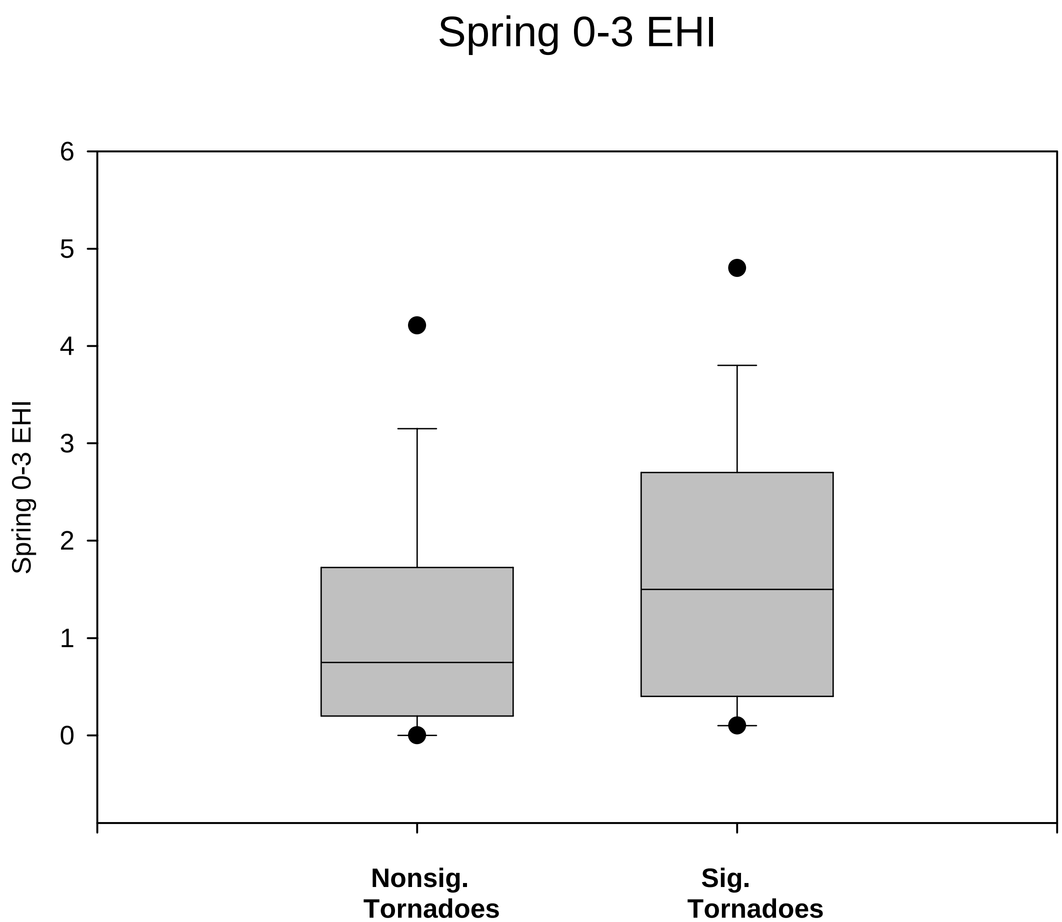

Figure 4.23. Box and whiskers plot of 0 – 3 km EHI values for non-significant and significant tornadoes during the warm-season.

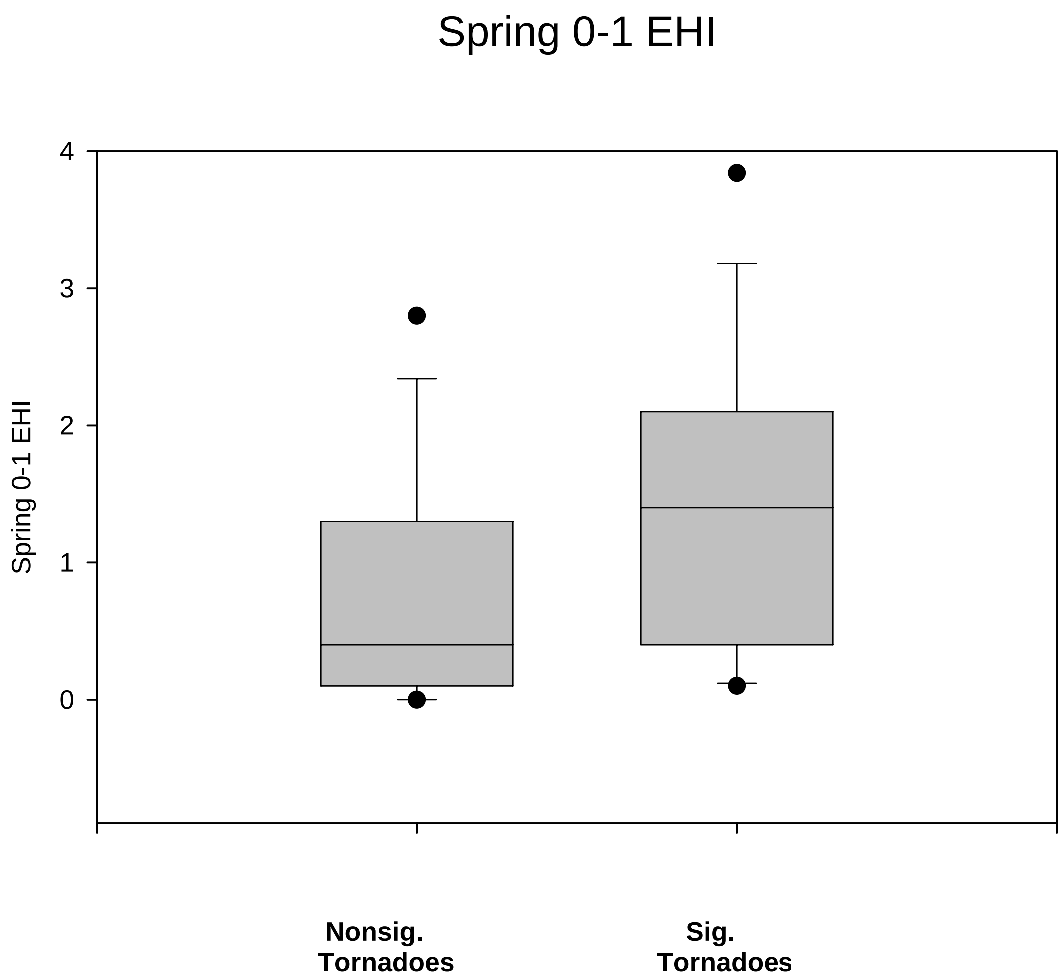

Figure 4.24. Box and whiskers plot of 0 – 1 km EHI values for non-significant and significant tornadoes during the warm-season.

7. Intra-Seasonal Non-Significant Parameters

The parameters that were not able to differentiate between seasonal non-significant and significant tornadoes in the either season are 0 – 3 km CAPE, LCL and LFC heights, and CIN. Amounts of low-level instability appear relatively similar during both seasons (Figure 4.25, Figure 4.29). Convective cloud heights also remain fairly uniform in each season as LCL heights are not statistically significant (Figure 4.27, 4.31). In addition, LFC heights for non-significant and significant tornado environments in the cool and warm-seasons are not statistically different (Figure 4.28, 4.32). As previously stated, LFC heights mark the origin of areas of positive CAPE. Since low-level instability is not a good discriminator of tornado strength, LFC heights would tend to display little variation as well. CIN values during the cool-season and warm-season are nearly identical for non-significant and significant tornado environments. This is evident by the box and whisker plots for cool-season and warm-season tornado environments (Figure 4.26, 4.30) exhibiting a large overlap in data.

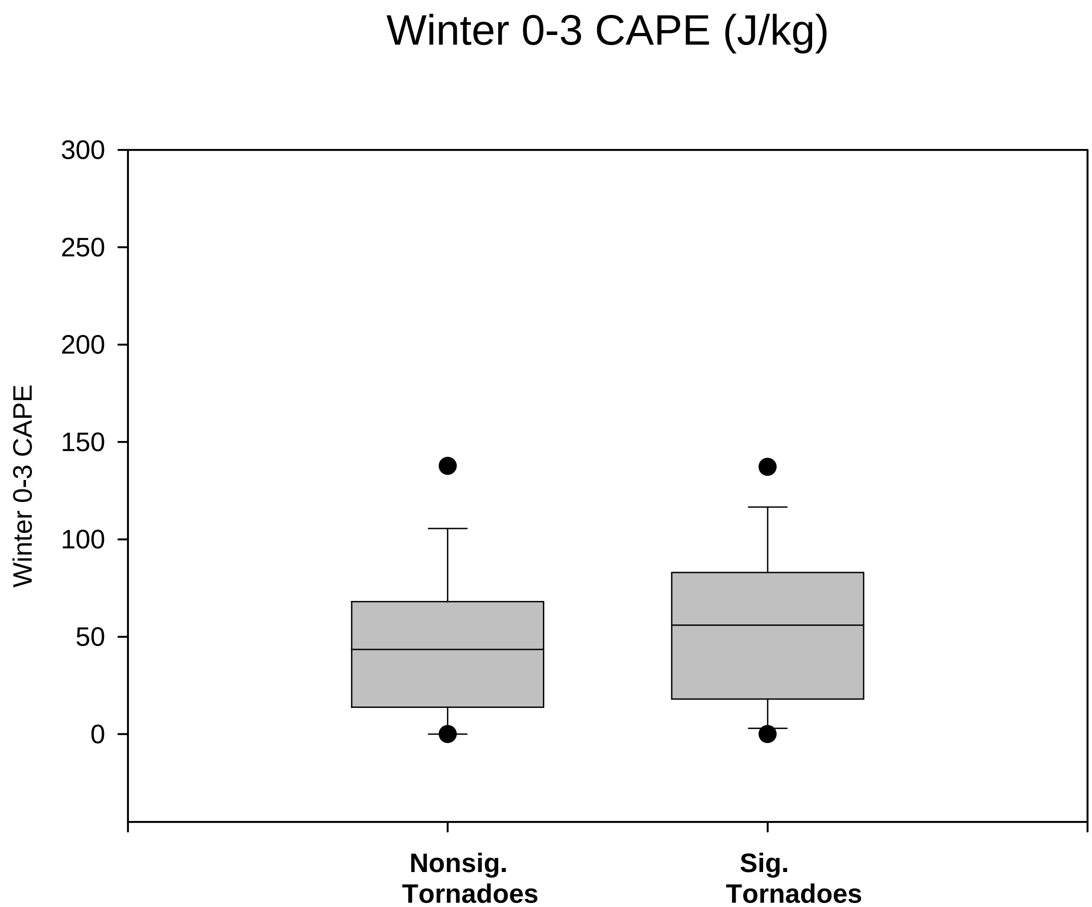

Figure 4.25. Box and whiskers plot of 0 – 3 km CAPE values for non-significant and significant tornadoes during the cool-season.

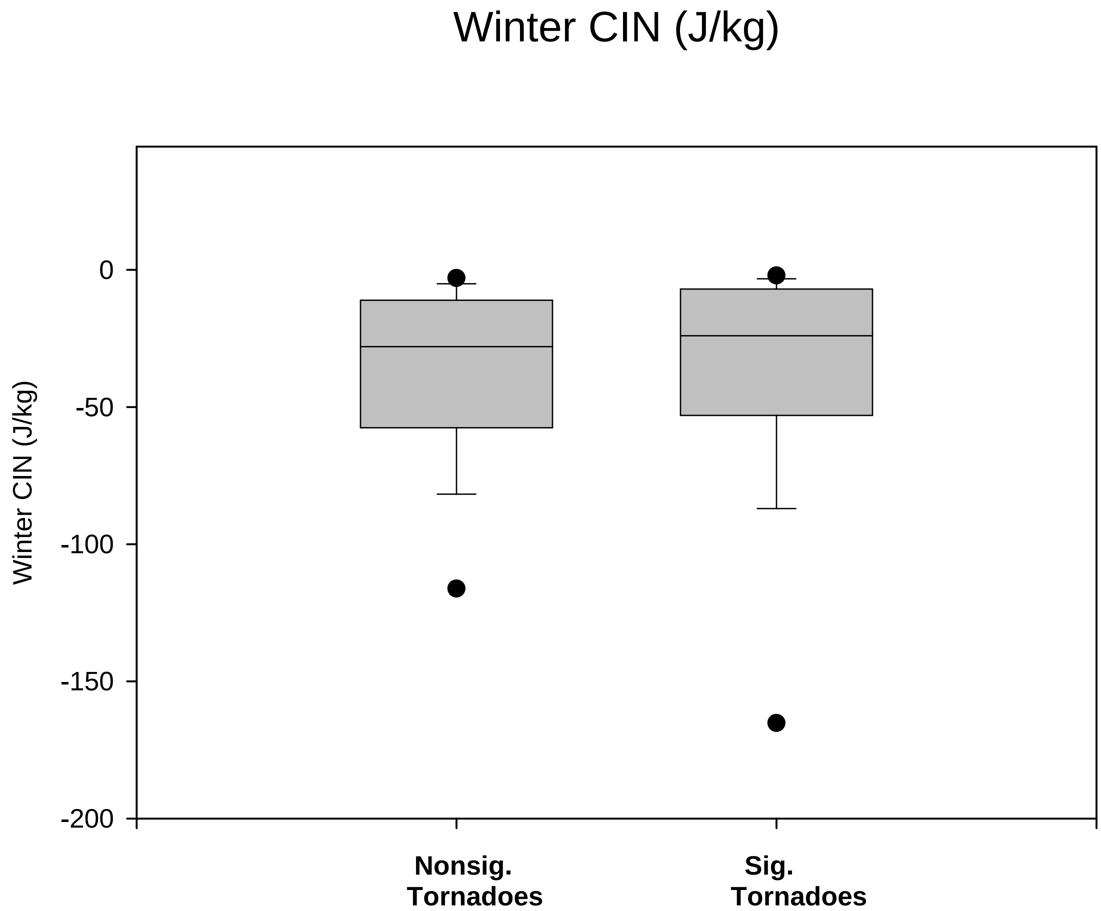

Figure 4.26. Box and whiskers plot of CIN values for non-significant and significant tornadoes during the cool-season.

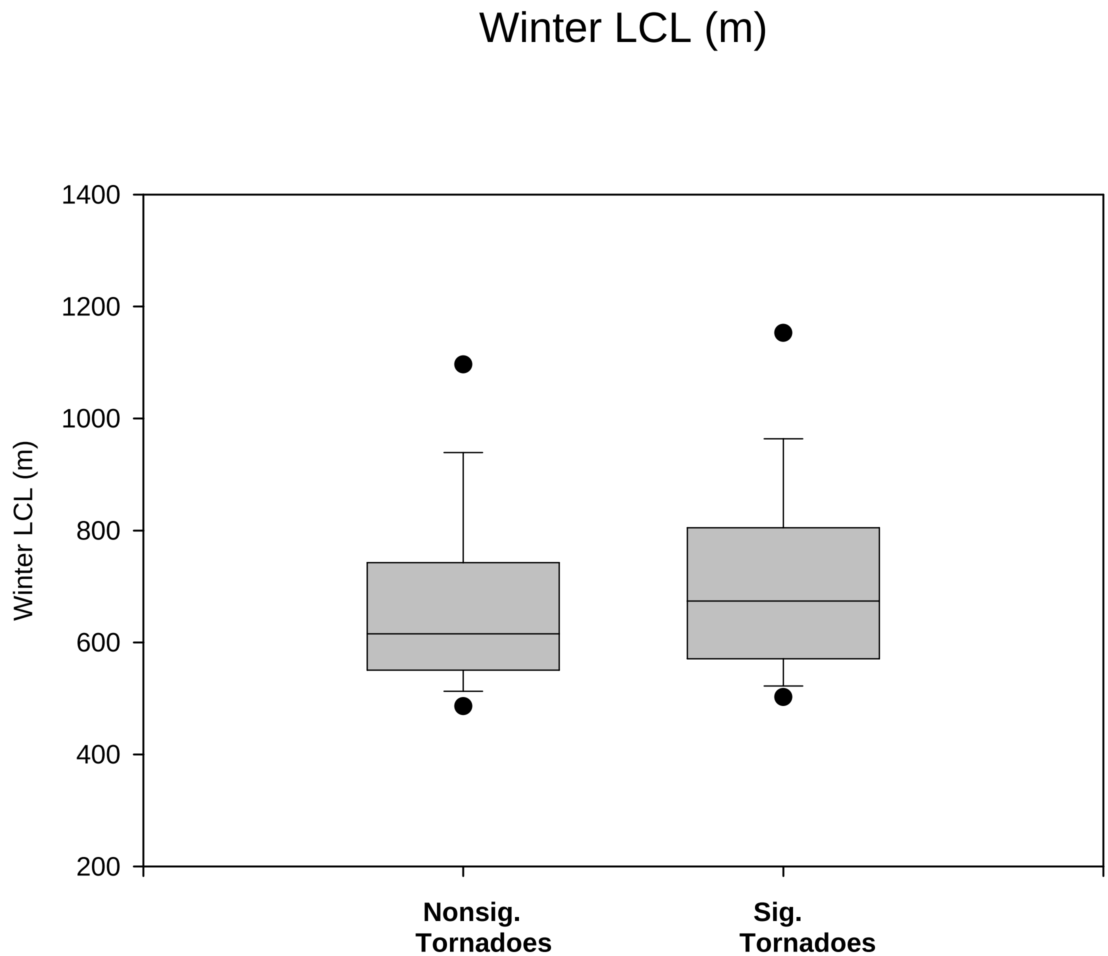

Figure 4.27. Box and whiskers plot of LCL heights for non-significant and significant tornadoes during the cool-season.

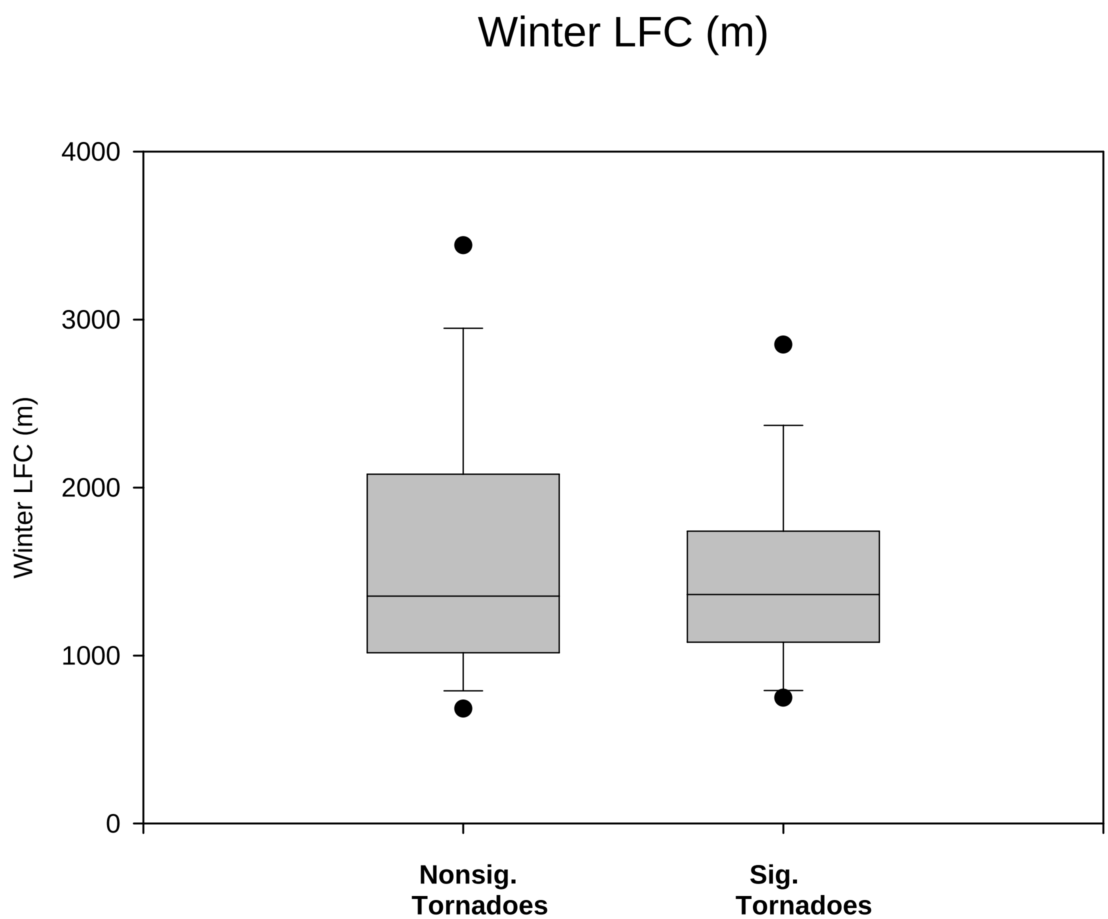

Figure 4.28. Box and whiskers plot of LFC heights for non-significant and significant tornadoes during the cool-season.

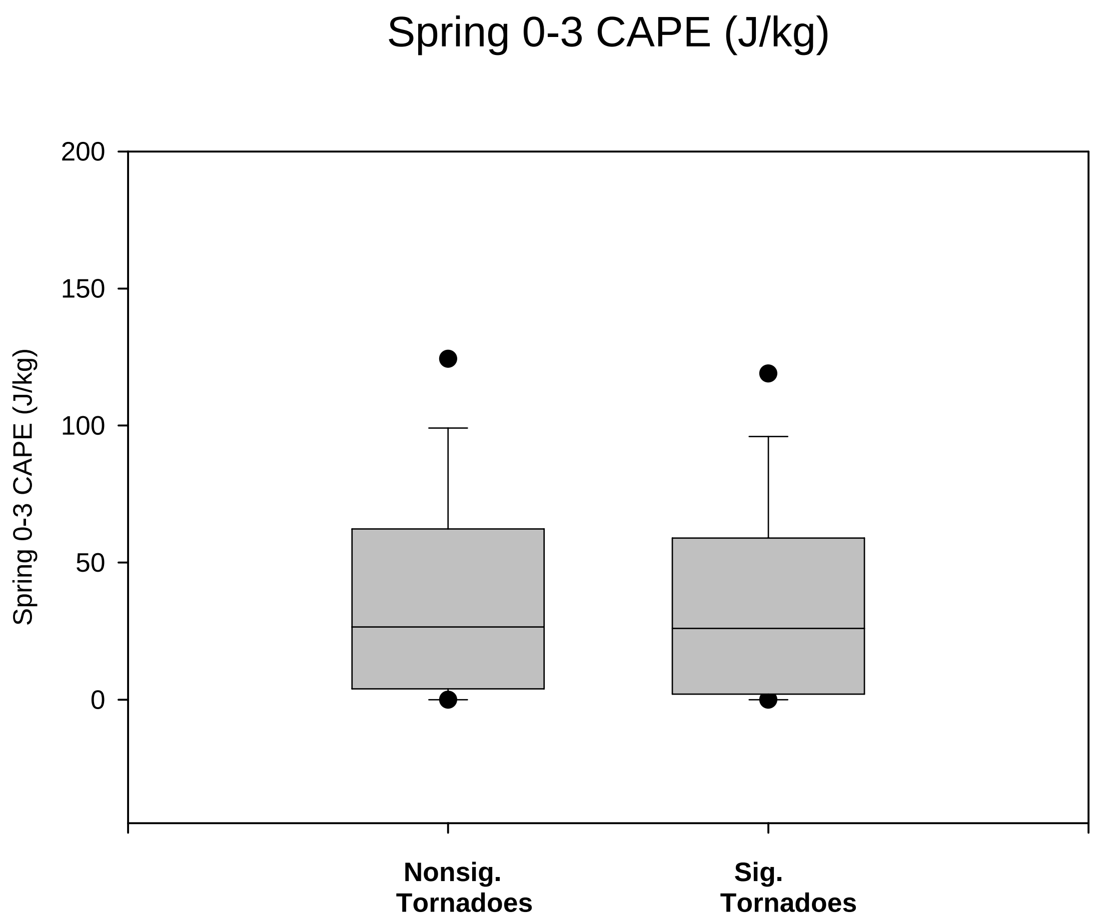

Figure 4.29. Box and whiskers plot of 0 – 3 km CAPE values for non-significant and significant tornadoes during the warm-season.

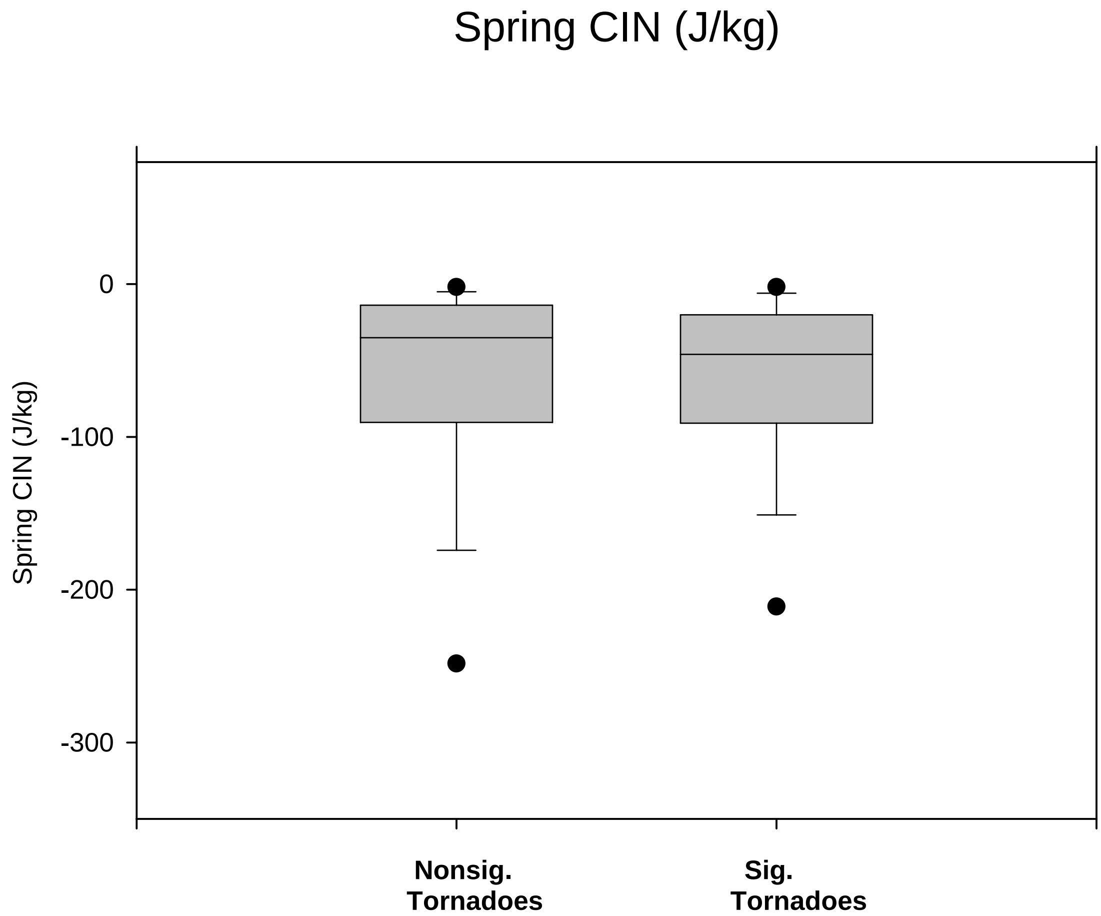

Figure 4.30. Box and whiskers plot of CIN values for non-significant and significant tornadoes during the warm-season.

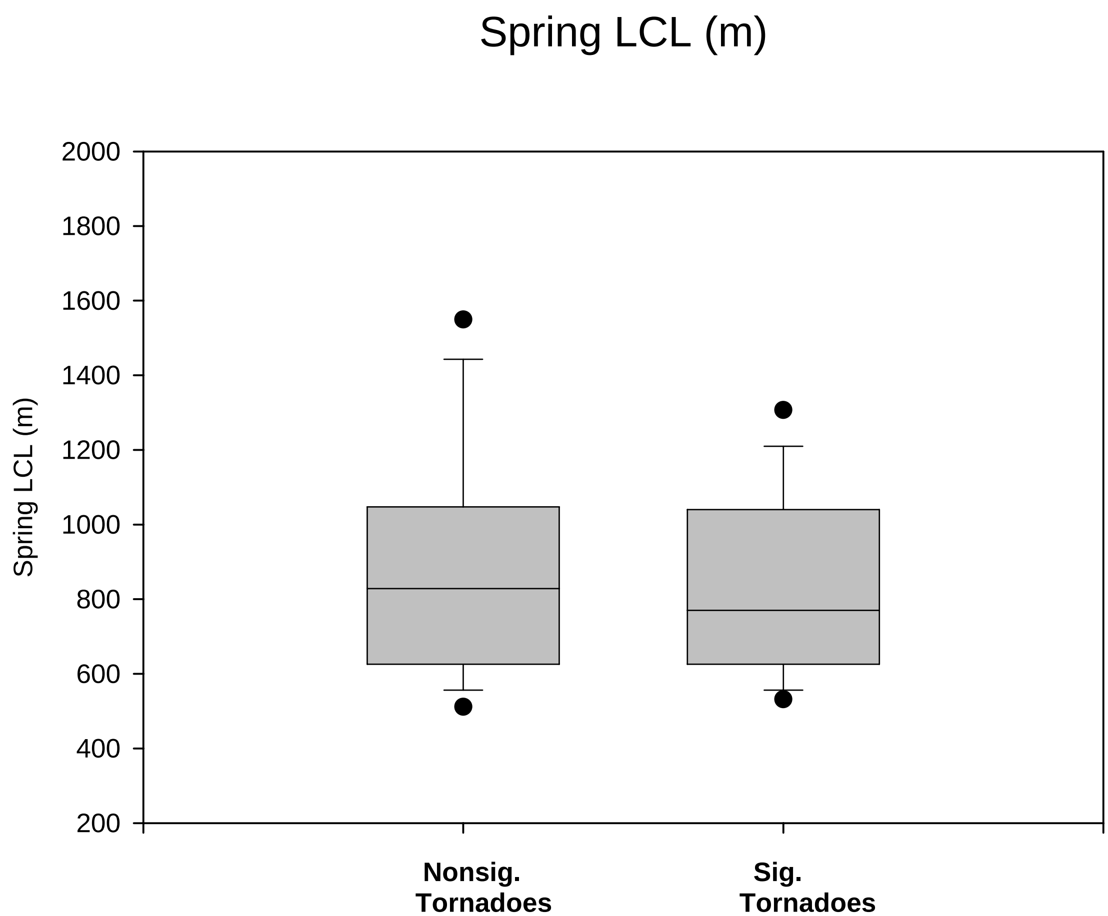

Figure 4.31. Box and whiskers plot of LCL heights for non-significant and significant tornadoes during the warm-season.

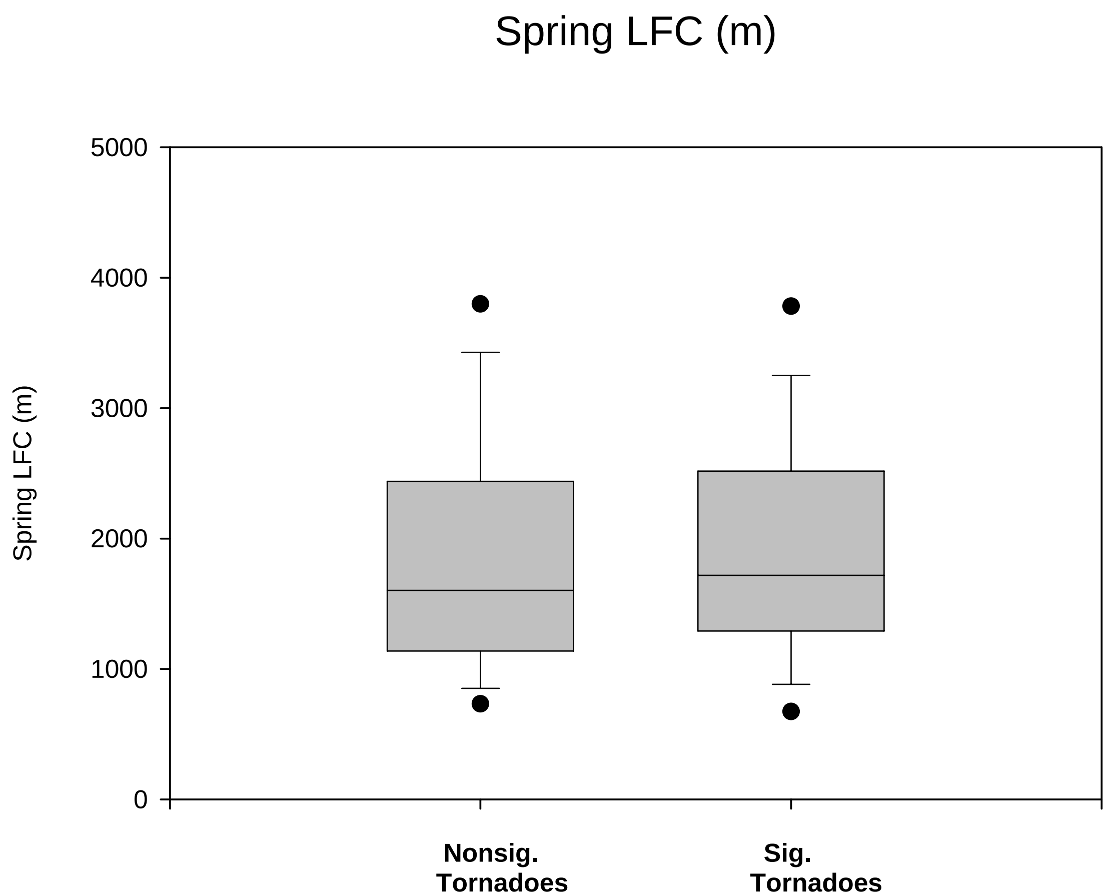

Figure 4.32. Box and whiskers plot of LFC heights for non-significant and significant tornadoes during the warm-season.

CHAPTER V

SUMMARY AND CONCLUSIONS

Previous research by Galway and Pearson (1981) and Gerard et al. (2005) showed a significant threat of tornadoes across parts of Dixie Alley. These studies, and others, indicate a secondary maximum of tornadoes during the cool-season months of November – February. While two distinct tornado seasons are well-established, few studies have looked at the variation of tornadic environments between these seasons (Garinger and Knupp 1993; Davies 2006). It was therefore imperative to establish a cool-season tornado climatology for Dixie Alley.

All thermodynamic and shear parameters between the cool and warm-season tornado environments were statistically different with the exception of the EHI parameter. The parameters behaved similarly between seasonal non-significant and significant tornado environments except for 0 – 3 km CAPE with non-significant tornado environments. Generally, cool-season tornado environments were characterized by lower instability and higher shear when compared to the warm-season environments. These findings are similar to Guyer et al. (2006), who recently found high shear and low instability were most prevalent for F2 or greater Gulf Coast tornadoes during the cool-season. It is anticipated that these findings will aid operational forecaster in recognizing and differentiating between thermodynamic and shear environments associated with cool and warm-season tornadoes.

Another goal of this study was to differentiate between thermodynamic and shear environments between non-significant and significant tornadoes in each season. While the shear remains quite high during the cool-season, an increase in instability appears to be the determining factor in developing non-significant and significant tornado environments. Summary tables were included to highlight the important findings of this study (Table 5.1 and 5.2).

Table 5.1. Summary of findings with regard to seasonal variation of tornado environments.

Differentiating Between Seasonal Tornado Environments
• Instability: Lower in the cool-season; higher in the warmer-season
• Shear: Higher in the cool-season; lower in the warm-season
• EHI: Well-balanced between both seasons
• LCL/LFC heights: Lower in the cool-season; higher in the warm-season

Table 5.2. Summary of findings with regard to variation of tornado strengths in each season.

Differentiating Between Tornado Strengths In Each Season
Cool-Season
• Increase in total instability and EHI values
Warm-Season
• Increase in shear and EHI values

Comments and Limitations

The results from the combination instability and shear parameter (EHI) yielded interesting statistics. When comparing all seasonal tornado events and seasonal tornado events by strength, EHI was not statistically significant between the tested groups. This demonstrates that EHI is an effective measure for the balance between instability and shear values. Though this parameter was not statistically significant, the EHI parameter does retain operational usefulness. However, when analyzing EHI values for a potential severe weather event, it is advised that forecasters remain aware of the seasonal variations of instability and shear. On the contrary, EHI becomes statistically significant when comparing non-significant and significant tornado environments within a season. Since shear in the cool-season and instability in the warm-season remain fairly similar, an increase of instability in the cool-season or shear in the warm-season will generate statistically different EHI values.

Thermodynamic data availability across the southern states can be described as sparse. Not all National Weather Service offices in Dixie Alley contain an atmospheric sounding site, creating spatial voids in the thermodynamic data. As a result, a proximity sounding method must be employed to gain reliable results. It should be noted that the proximity sounding method may not represent the exact thermodynamic and shear environment of the atmosphere at the time of tornadogensis. However, given stringent temporal and spatial constraints, reasonable inferences on the state of the atmosphere at the time of tornadogensis can be made.

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