A Comparison of Sounding Parameters for the Southeastern United States During El Nino, La Nina, and Neutral Winters

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Abstract

Previous research based upon examinations of previous weather events speculates that the El Nino/Southern Oscillation affects severe weather in the United States. However, in this study, thermodynamic and kinematic parameters associated with severe weather are calculated from rawinsonde data to explore differences in the atmospheric stratification during the El Nino, La Nina, and Neutral ENSO phases. The soundings used in this investigation are taken over the southeastern United States during the winter season.

Two separate datasets are examined: one of soundings from severe weather events and another of all 00UTC soundings. Surface-3km Storm Relative Helicity, Surface CAPE, and Surface-6km Bulk Shear are analyzed for the severe weather dataset, and results show that severe weather occurs under the same atmospheric conditions regardless of ENSO phase. For the dataset of all weather soundings, three thermodynamic parameters (Mean Layer CAPE, Surface Convective Inhibition, and Mean Layer 300mb Lifted Index) and three kinematic parameters (Surface-6km Bulk Shear, Surface-1km Storm-related Helicity, and Surface-3km Storm-Related Helicity) are examined. The results from this analysis reveal that the thermodynamic parameters favor storm development during the La Nina ENSO phase and that the dynamic parameters favor the El Nino and Neutral phases for severe thunderstorms.

1. Introduction

Meteorologists, as well as the public, have speculated on possible relations between the El Nino/Southern Oscillation (ENSO) phases and severe weather events occurring in the United States. Schaefer and Tatom (1998) consider the number of tornadoes per year in the United States and sea surface temperatures in various portions of the Pacific Ocean to try to discern an impact of ENSO on the occurrence of tornadoes. Their statistical inquiries result in a finding of no major influence, but their data does show a signal that more tornadoes tend to occur in the mid-eastern states during the La Nina phase. Agee and Zurn-Birkhimer (1998) also use the annual total of United States tornadoes to attempt to determine a rise or decline in tornadoes during the El Nino phase. They conclude that tornado occurrences do not favor one ENSO phase but rather exhibit a shift in geographic location. For example, their results suggest that more tornadoes will occur in the lower mid-west, Ohio Valley, Tennessee Valley, and mid-Atlantic region during the La Nina phase than in any other phase.

Rather than focusing on past weather events, this study examines thermodynamic and kinematic parameters calculated from rawinsonde data to explore differences in the structure of the atmosphere during the El Nino, La Nina, and Neutral ENSO phases. With a better understanding of the atmospheric stratification during each phase, it will be possible to determine if any ENSO event is more likely to produce conditions that favor severe weather. This study concentrates on the southeastern region of the United States during the winter months (January, February, and March).

The paper is divided into two sections; the first focuses on parameters calculated from soundings associated with severe convective events from 1957 to 1996 while the second examines all winter 00UTC soundings taken from 1958 to 2003.

2. Data

Data provided by the Climate Prediction Center (2003) is referenced to specify the ENSO phase associated with each winter. The CPC has categorized every season by ENSO phase for all years dating back to 1950 by evaluating the sea surface temperature of the area along the equator extending from 150 degrees west to the international dateline. Each season is classified as either a weak La Nina, moderate La Nina, strong La Nina, weak El Nino, moderate El Nino, strong El Nino, or Neutral phase. The seasons classified as El Nino (EN) in this research are those categorized by the CPC as being either moderate EN or strong EN. La Nina (LN) was likewise classified. Weak EN and weak LN are grouped with the Neutral winters to create the Neutral (N) ENSO phase. Table 1 presents each winter with its corresponding ENSO phase.

The southeastern region, consisting of North Carolina, South Carolina, Georgia, Florida, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas, is chosen for investigation because previous research indicates that the most likely relation between severe weather and LN occurs there. Winter (January, February, and March) is chosen in agreement with Montroy (1997) who found that the months of November and January-March exhibit a connection between Pacific sea surface temperature and precipitation in the southeastern region.

3. Data and Methodology, Analysis, and Results for Severe Weather Soundings

a. Data and Methodology

The goal of this analysis is to determine whether or not a difference exists in the atmospheric structure associated with severe weather between the ENSO phases. To accomplish this goal, a dataset created by Brooks and Craven (2002) is utilized. This dataset consists of soundings taken within 100 nm and 3 hours of significant wind events (gusts greater than or equal to 65 knots), significant hail occurrences (hail greater than or equal to 2”), or significant tornadoes (tornadoes rated F2-F5) from 1957-1996. Approximately 70 parameters are calculated for each sounding. Those soundings associated with storms in the southeastern region during January, February, and March are extracted for analysis. There were approximately 240 such soundings.

The following parameters are examined for each sounding: Surface-3km Storm-Relative Helicity, Surface CAPE, and Surface-6km Bulk Shear. Table 2 lists these parameters along with their relation to severe weather. All parameters chosen are commonly used in forecasting severe weather, and when used together, give a general overview of the configuration of the atmosphere.

Surface-3km Storm-Relative Helicity (Sfc-3km SRH) is a measure of the combined effects of velocity and vorticity. This parameter is generally related to supercell, and therefore tornadic, rotation. Helicity is a measure of how fast the horizontal storm-relative winds carry vertical rotation (McNulty, 2003).High helicity values are associated with strong updrafts, and therefore signal storm development. (Glickman, 2000).

Surface CAPE (Sfc Cape) is the maximum amount of energy available to an ascending surface air parcel. Convective Available Potential Energy (CAPE) is computed using parcel theory and is the area on a thermodynamic diagram between the lifted parcel curve and the observed sounding. The more energy a surface parcel has available, the greater the possibility of the atmosphere to evolve into a severe storm or tornado. Thus, Sfc Cape is a good indicator for severe weather.

Surface-6km Bulk Shear (BKSHR) is the magnitude of the shear vector between the winds at the surface and those at 6km above ground level. This vector indicates the change of wind direction and speed across the lower troposhere. Severe weather is normally associated with high BKSHR, and as the severity of deep convection increases, BKSHR will also increase (Craven et al., 2002).

These parameters are categorized by ENSO phase (EN, LN and N), and their distributions are calculated to determine if there is a higher or lower propensity for severe weather. Parameter distributions are analyzed via a box plot created with PSI Plot Version 6 software. For an example, see Figure 2c. This box plot is able to display the distribution of each parameter clearly because it illustrates the minimum value, 10th percentile, 25th percentile, mean, 75th percentile, 90th percentile, and maximum value. The maximum and minimum values appear at the ends of the outer whiskers on the plot. The lower area of the shaded region represents the 10-25% portion of the data, and the upper shaded region is the 75-90% distribution. The central rectangle displays the inner 50% of the data, and the middle horizontal line is the mean.

b. Analysis

Surface-3km Storm Related Helicity

Figure 1a displays the Sfc-3km SRH data using only values of the parameter between 0-1000 m^2/s^2. These thresholds are used to expediently remove erroneous data, albeit at the expense of a few extreme outliers.

The spread of the Sfc-3km SRH data for the three different ENSO phases are very similar. The means of the three phases do not differ by more than 25 m^2/s^2; the mean for EN, LN, and N is 255.42 m^2/s^2, 231.28 m^2/s^2, and 238.88 m^2/s^2, respectively.

Surface Cape

A box plot for Surface CAPE associated with severe thunderstorms (Figure 1b) shows that the lower 90% of the data's distribution is remarkably similar for all ENSO phases. Accordingly, the only major difference between the three distributions is within the maximum values, which is not substantial because this is merely the upper 10% of the entire dataset.

Surface-6km Bulk Shear

The box plot of Sfc-6km Bulk Shear (BKSHR) for severe weather is shown in Figure 1c. At first glance, it appears as though the distributions are somewhat different because the LN phase has a very tight 75-90% spread compared to the EN and N phases. However, upon comparison of the middle 50% spread of the data, it is apparent that each phase is actually quite similar to the others: 45.52-63.68 kts is the EN 50% spread, 44.26-64.29 kts is the LN 50% spread, and 45.32-66.49 kts is the N 50% spread. Hence, BKSHR associated with severe convection is relatively independent of ENSO phase.

c. Results

The three parameters analyzed (Sfc-3km SRH, Sfc CAPE, and BKSHR) all suggest that severe weather is independent of ENSO phase. Thus validating the concept that severe thunderstorms develop from similar atmospheric stratifications no matter what physical processes were responsible for creating the pre-storm environment.

4. Data and Methodology, Analysis, and Results for All Weather Soundings

a. Data and Methodology

For the analysis of all weather soundings, the Storm Prediction Center's (SPC) archive of sounding data from 1958 to 2003 (inclusive) is used. The soundings taken in the southeastern United States during the winter months at 00 UTC are extracted, and parameters are calculated in the likeness of the Brooks and Craven (2002) set of parameters used above. Altogether, approximately 90,000 soundings are examined.

These soundings are categorized by ENSO phase using the classification scheme of Section 2. From this data, six sounding parameters, three thermodynamic and three kinematic, are chosen for investigation because of their association with severe weather and severe thunderstorm development (Table 3). Table 3 also indicates in a general sense how each parametric value is related to storm development.

100mb mean layer CAPE (ML CAPE) is similar to Surface CAPE except a parcel with the average temperature and mixing ratio of the lowest 100mb layer is lifted. ML

CAPE is examined here rather than Surface CAPE, which was examined in section 3, because the height of cloud base is more accurately determined by a layer average (Craven et al., 2002).

Surface Convective Inhibition (CIN) is the amount of energy that an air parcel must gain in order to be lifted from its original height to its level of free convection (LFC) (Glickman, 2000). The higher the CIN value, the more unlikely air is to reach its LFC and evolve into a severe convective storm. Therefore, this measurement is valuable in determining the probability of severe weather.

100mb Mean Layer Lifted Index at 300mb (ML LI) is the difference between the observed 300mb temperature and the temperature of the 100mb mean parcel after lifting to 300mb. It is similar to Galway's Lifted Index (Galway, 1956), except 300mb is used as the reference level instead of 500mb. This allows the stratification in the upper atmosphere to be used in the parametric calculations.

Sfc-6km Bulk Shear (BKSHR) and Sfc-3km Storm-Relative Helicity (Sfc-3km SRH) are variables that are examined in Section 3. Please refer back for a discussion of these parameters.

In addition to Sfc-3km SRH, Surface-1km Storm-Relative Helicity (Sfc-1km SRH) is examined. Sfc-1km SRH is considered because Wicker (1996) found that the helicity over a layer of air near ground level is better apt to represent the ability of the atmosphere to produce severe weather than a layer composed of higher levels.

The statistical distribution of these thermodynamic and kinematic variables is analyzed by ENSO phase. Results are plotted via a box plot created with PSI-Plot software like the graphs created in Section 3.

b. Analysis

1) Thermodynamic Parameters

Mean Layer Cape

ML CAPE (Figure 2a) has a compact spread but large extreme values. The excessively large positive ML CAPE values are likely the result of erroneous reporting. Since analysis of individual soundings is beyond the scope of this effort, those soundings with ML CAPE values outside of three deviations of the mean are excluded. Additionally, since ML CAPE values of zero are not generally associated with severe weather, they are excluded.

As revealed by Figure 2a, the LN phase has slightly more CAPE as compared to the N and EN phases. The mean and third quartile of LN are both higher in value than the means and third quartiles of the EN and N phases. This suggests that the atmosphere may exhibit a greater amount of CAPE during the LN phase.

Surface Convective Inhibition

The CIN data contains some very extreme values. In order to prevent the results from being affected by these outliers, the upper outer and lower outer fences, or thresholds, are calculated according to the equation in Wilks (1992):

Upper outer fence = $q_{0.75} + 3*(IQR)$

Lower outer fence = $q_{0.25} - 3*(IQR)$.

Where $q_{0.75}$ ($q_{0.25}$) is the 75th (25th) percentile or the 3rd (1st) quartile and IQR is the interquartile range (the difference between the 3rd and 1st quartiles). For example, the $q_{0.75}$ and $q_{0.25}$ for the LN phase of CIN is –24.89 j/kg and –372.38 j/kg, respectively, and the IQR is –347.49 j/kg.

The fences are the thresholds between data values that are outliers and those that are most likely erroneous. Values that are above/below the upper/lower outer fences are discarded. However, the upper outer fence for each ENSO phase of CIN is calculated to be a positive number. Since the upper limit of CIN is zero by definition, and data greater than zero must be erroneous. Thus, rather than the upper out fence value, zero is used as the upper threshold.

There are fewer days with strong CIN during LN as compared to the other phases. This is illustrated in the CIN box plot (Figure 2b) by the 90% value of the LN phase being approximately equivalent to the 75% value of the EN phase.

Mean Layer 300mb Lifted Index

The graph of ML LI (Figure 2c) shows very similar distributions during all ENSO phases. However, the LN phase's distribution is slightly lower than the distributions of the EN and N phases. This difference is most noticeable in the 10% to 25% range. The 25% value of the LN phase is approximately equivalent to the 10% value of both the EN and N phases. This indicates that the atmosphere is most unstable on about 25% of the LN days and only 10% of the EN and N days.

2) Kinematic Parameters

Surface-6km Bulk Shear

The BKSHR data contains very extreme values, so the upper and lower outer fences were calculated as described above. The lower outer fence for each ENSO phase of BKSHR is calculated to be a negative value. Since BKSHR is the magnitude of the vector difference and by definition must be a positive number, the lower threshold is zero rather than the value of the lower outer fence. Figure 3a is a box plot of BKSHR utilizing the data between 0 knots and the upper outer fence value for each respective phase. The upper outer fence excluded values that are most likely erroneous.

Figure 3a of BKSHR shows that there is slightly more shear during the EN and N phases than during the LN phase. This is most noticeable with a comparison of 10%-25% values for each phase. The 25% value for LN is approximately equal to the 10% values of both the EN and N phases. Although the difference is not great, it is obvious on the graph. This indicates that 25% of the LN days have a low value for BKSHR, which is 15% more days than the EN and N phases.

Surface-1km SR Helicity and Surface-6km SR Helicity

To remove outliers and erroneous data expediently from Sfc-3km SRH and Sfc-1km SRH, thresholds of 0 and 1000 are used. Box plots for these parameters are presented in Figures 3b and 3c.

The distribution of the LN phase on the Sfc-3km SRH graph (Figure 3b) has lower values than the distributions of the other phases. The same configuration is observed on the Sfc-1km SRH graph (Figure 3c). The lower amount of helicity during the LN phase may potentially inhibit rotation of storms and therefore tornadoes, but does not necessarily affect storm development.

c. Results

The thermodynamic and kinematic parameters have produced contrasting results concerning which, if any, ENSO phase is more apt to produce severe weather. The thermodynamic parameters (CAPE, CINH, and ML LI) reveal that the structure of the atmosphere is slightly more favorable for severe weather during the La Nina phase, but the indication is not meteorologically profound. Unlike the thermodynamic parameters, the kinematic parameters (BKSHR, 3km SRH, 1km SRH) are more favorable for severe weather during the EN and N phases. These signals are not entirely noteworthy, but, as seen in the graphs, do exist.

5. Discussion and Conclusions

The severe weather sounding parameters analyzed implies that storms will develop under the same conditions regardless of ENSO phase. Thus, as long as appropriate synoptic conditions arise, severe weather will occur. The question then remains: do parameters related with severe thunderstorms occur more frequently during any ENSO phase?

The examination of all 00UTC soundings attempts to determine if storm favorable conditions are preferentially found during any ENSO phase. Mixed signals are revealed. The thermodynamic parameters favor storm development during the LN phase, and the kinematic parameters favor storm development during the EN and N phases. These findings are physically reasonable upon examination of the shifts in the jet stream.

During the warm EN phase, the jet stream generally enters the United States through the southwestern states below the Rocky Mountain plateau (Climate Prediction Center, 2003). Over the southeast, the jet is positioned above the Gulf Coast. This promotes relatively strong winds in the mid to upper troposphere and produces high values to the kinematic parameters.

The cool LN phase is in contrast to the EN phase. The jet stream enters the western United States through the northwestern states (above the Rocky Mountains). The resulting lee trough over the eastern United States positions the jet stream across the southeastern states farther to the north. The vertical circulations associated with the jet bring warm, moist low level air into the area south of the jet and increase the magnitude of the thermodynamic sounding parameters over the area.

Future research could include the examination of more parameters, especially those concerning the stability of the middle and upper levels of the atmosphere. Such parameters include George’s K-Index and the Schowalter index. Other work that would prove beneficial would be to expand the 00UTC dataset to include soundings taken at 12UTC or to include months other than January, February, and March.

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El Nino	La Nina	Neutral		
1958	1971	1959	1975	1990
1966	1974	1960	1977	1991
1969	1976	1961	1978	1993
1973	1989	1962	1979	1994
1983	1999	1963	1980	1996
1987	2000	1964	1981	1997
1992		1965	1982	2001
1995		1967	1984	2002
1998		1968	1985	2003
		1970	1986	
		1972	1988	

Table 1. Winters classified by ENSO phase, 1958-2003.

Parameter:	Description:	Units:	Characteristic Promoting Storm Development:
Sfc CAPE	Surface CAPE	j/kg	High CAPE
BKSHR	Surface - 6km Bulk Shear (magnitude of vector difference)	knots	More BKSHR
3km SRH	SFC-3km Storm-Related Helicity	m^2/s^2	Greater SRH needed for mesoscale rotation

Table 2. Parameters analyzed for all severe weather soundings.

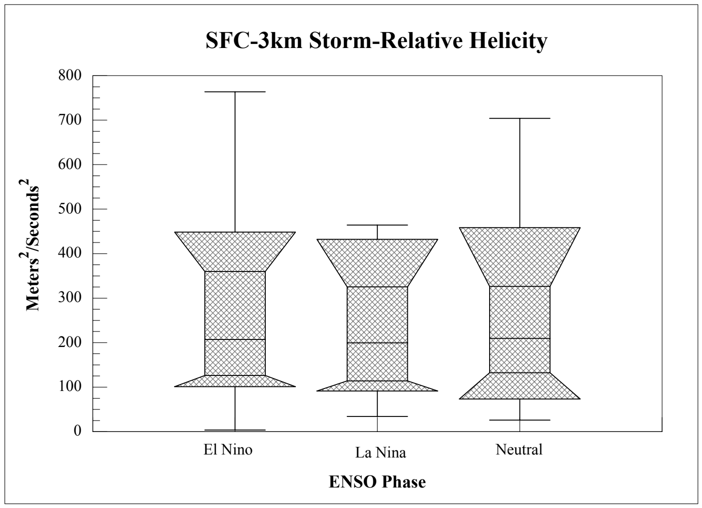
Thermodynamic:

Parameter:	Description:	Units:	Characteristic Promoting Storm Development:
CAPE	100mb Mean Layer CAPE	j/kg	High CAPE
CIN	Surface Convective Inhibition	j/kg	Low CINH
ML LI	100mb Mean Layer Lifted Index at 300mb		More Negative ML LI

Kinematic:

Parameter:	Description:	Units:	Characteristic Promoting Storm Development:
BKSHR	Surface - 6km Bulk Shear (magnitude of vector difference)	knots	More BKSHR
3km SRH	SFC-3km Storm-Related Helicity	m^2/s^2	Greater SRH needed for mesoscale rotation
1km SRH	SFC-1km Storm-Related Helicity	m^2/s^2	Greater 1km SRH needed for tornadic rotation

Table 3. Parameters analyzed for all 00UTC soundings.



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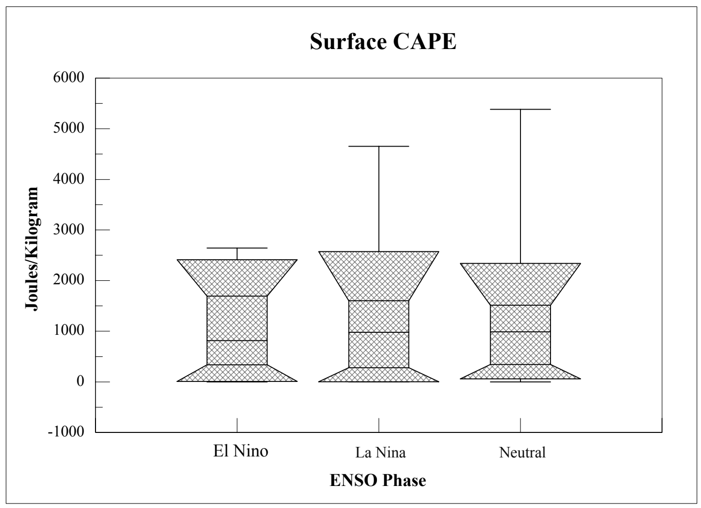

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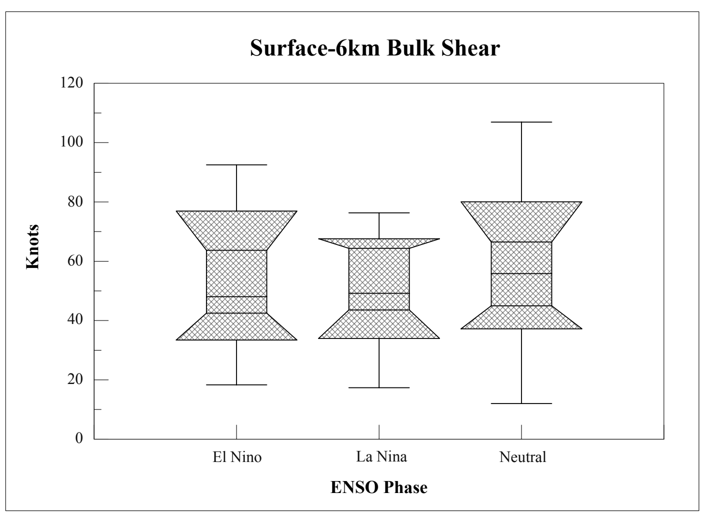


c.

Figure 1. Box plots for parameters analyzed for severe weather soundings. a.) Surface-3km Storm-Relative Helicity b.) Surface CAPE c,) Surface-6km Bulk Shear

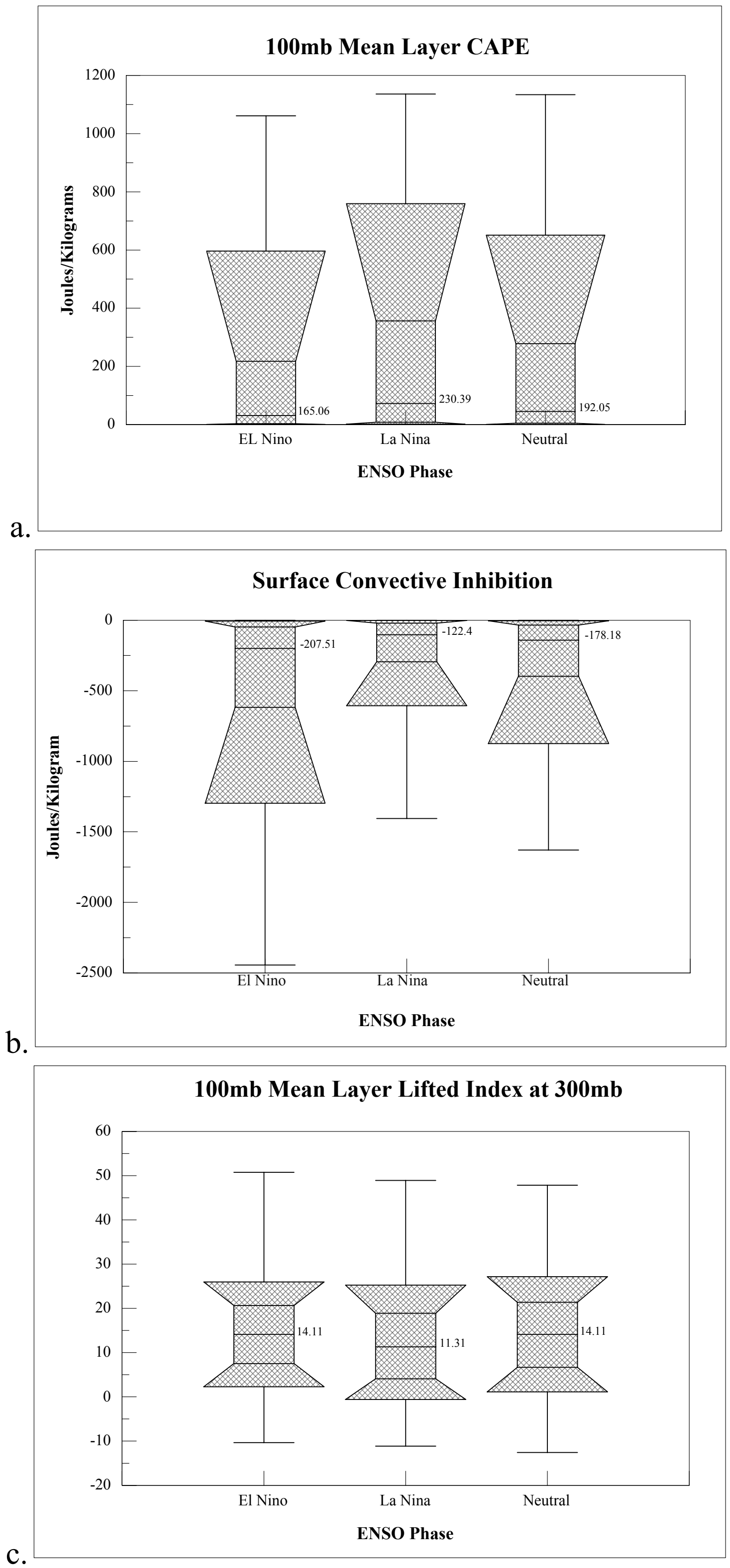
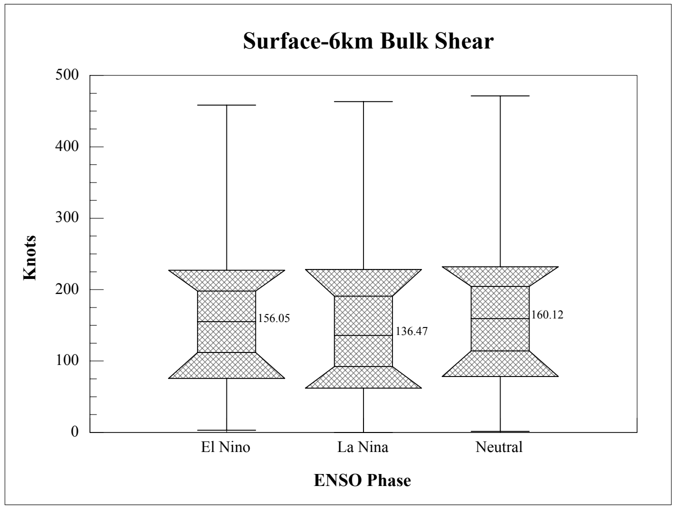


Figure 2. Box plots for thermodynamic parameters analyzed for all weather soundings. a.) 100mb Mean Layer CAPE b.) Surface Convective Inhibition c.) 100mb Mean Layer Lifted Index at 300mb



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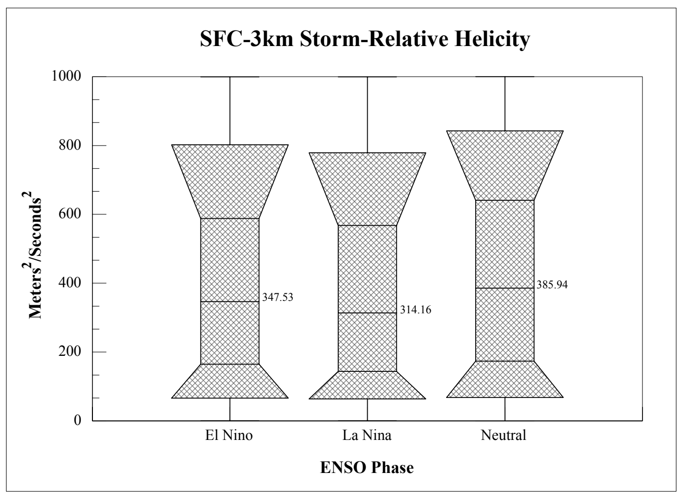

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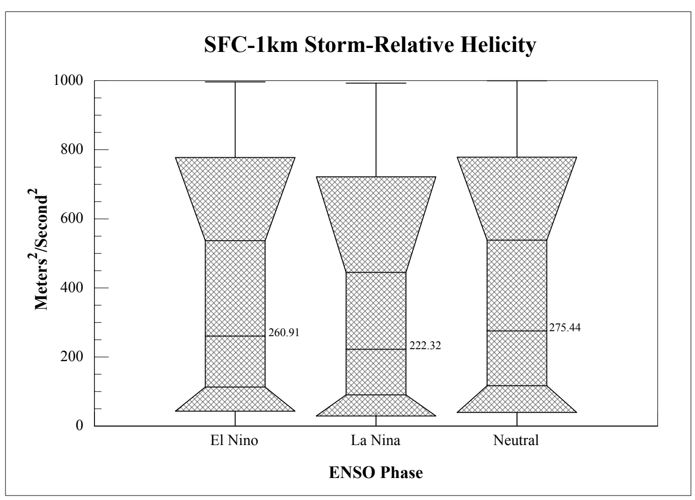

c.

Figure 3. Box plots for kinematic parameters analyzed for all weather soundings. a.) Surface-6km Bulk Shear b.) Surface-3km Storm-Relative Helicity c.) Surface-1km Storm-Relative Helicity