NOAA Technical Memorandum NWS SR – 231

DISTINGUISHING EFFECTS OF EL NIÑO SOUTHERN OSCILLATION FROM NATURAL SHORT-TERM CLIMATE VARIABILITY

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November 2009

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This publication has been reviewed
and is approved for publication by
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I. Abstract

There are regions of the United States where a positive correlation has been documented between ENSO warm and cold episodes and the departure from normal of average winter temperature and precipitation. There are other regions where the signal is more ambiguous or seemingly impossible to define. The question that often arises during ENSO climate studies is, "How can a climate effect caused by ENSO be distinguished from other short-term climate variability?" Perhaps, if we find a way to distinguish between particular climate trends that occur simultaneously, we will better understand the impact of El Niño in areas where the correlation is strong and in “ambiguous regions” (weak correlation). In the latter, a determination can be made as to whether ENSO anomalies actually exist but are masked by the background short-term climate variability. This “masking,” however, is difficult to unveil, largely because the temperature and precipitation data observed at any location during ENSO represent a comingling of several different climate phenomena. It is difficult, if not impossible, to determine exactly how much of a departure from normal for any particular variable can be attributed to any particular phenomenon. This is one reason for choosing a conservative analysis method whereby ENSO-related anomalies are not too quickly assigned to particular events. The analysis method used in this study is believed to be reasonably conservative. For each variable (temperature and precipitation) and ENSO event, two particular characteristics were assigned to the short-term climate: “prevailing climate” and “climate trend.” An ENSO-related anomaly was only considered to exist if the observed Nashville climate data signal during the ENSO event differed from both of the short-term climate signals. For instance, if the Nashville temperature data showed a strong positive deviation from normal during the ENSO and the short-term climate signals were “cool” and “cooling,” it was suggested that the Nashville ENSO data represented an anomaly likely caused by ENSO. Conversely, no anomaly would be suggested if the same set of Nashville ENSO data happened to be coupled with short-term climate signals that were “warm” and/or “warming.”

Previous studies have shown that Nashville, Tennessee falls into a region of the United States where the effects from ENSO are ambiguous. Not surprising, the data from this study also suggest the absence of a unique, routine ENSO anomaly in Nashville temperature and precipitation data. This could only be determined, however, after properly accounting for the effects of short-term climate variability through application of a particular analytical method which we refer to in the following text as a “climate filter.” This particular method was absent from previous studies.

Instead of revealing a unique ENSO anomaly in the Nashville weather data, the “climate filter” output pointed to a number of interesting correlations between the short-term climate and the observed weather at Nashville. Despite a limited sample size for some data sets, this study will show when ENSO is considered in context with other natural short-term climate variability of longer periodicity, there is evidence linking ENSO with particular climatic impacts at Nashville -- sometimes occurring as a climate anomaly and sometimes seeming to enhance other ongoing short-term climate trends.

This study will show the inadequacy of regional ENSO studies that do not give proper consideration to the effects of natural short-term climate variability. It will suggest that natural short-term climate variability likely plays a role in determining the type of weather a particular ENSO event will produce -- something that would be missed if simple correlations were the only focus of the study. It will be shown that the climatologically distinct period of the late 1950's and 1960's tended to produce particular types of weather at Nashville during El Niño and La Niña. Some of the effects were positively correlated with the short-term climate variability, whereas other effects were anomalous. Certain unique climate signals were also found in the data that might help forecasters make general weather predictions for upcoming months, and even entire seasons. Findings suggest that El Niño drying trends, as well as unusually warm La Niña weather, can likely be predicted for Nashville by closely observing local trends in the weather during the summer and fall months leading into an ENSO event.

The authors are not presenting a cause-and-effect theory. They are merely presenting statistical data. Tying El Niño to a physical cause is well beyond the scope of this paper.

II. Introduction

Climatologists and meteorologists have conducted numerous studies to look for correlations between ENSO warm and cold episodes and certain seasonal climate conditions. (See Section 3.) This is usually done by studying meteorological records during ENSO events in order to reveal anomalous deviations in prevailing weather patterns that might be attributable to the El Niño Southern Oscillation. Due to the complexities of climate variability, it is often debatable whether a certain fluctuation can be easily attributed to any particular source. Possible correlations can be tested for statistical significance, and statistical significance can be used to assess the confidence in a particular relationship. There are other times, however, when a climate signal related to ENSO appears highly ambiguous (i.e., no correlation with a reasonably high degree of significance can be established). These are the times when strict attention must be given to investigative methodology so that the climate variable of interest (in this case, effects from ENSO) can be effectively isolated from other natural short-term variability.

The weather for a particular spot or region tends to change in cyclical fashion over varying periods of time. It is reasonable to believe the type of weather defined as "average" or "anomalous," changes as well. Defining natural patterns and trends can be a tricky matter because ultimately it involves a certain degree of subjectivity. For instance, to investigate climate trends, one can choose from a variety of methods and time frames. Trigonometric best-fit polynomials can be used to approximate the data or, perhaps, running means can be used for the same purpose. A ten-year data set might be used or, perhaps, a 100-year data set may be desired. Different trends may appear in the data, depending upon which method and time frame are chosen. However, to ignore the important implications of such trends to an ENSO climate study such as this, can be detrimental to the degree of scientific confidence one can place in the conclusions. After all, if no attempt is made to define

natural short-term climate variability present in the climate record not attributable to El Niño, how can the significance of climate correlations associated with El Niño be fully understood or thoroughly defined? To help clarify the impact of short-term climate variability on the effect of

ENSO, a new series of web-based graphics has been provided by the Climate Prediction Center (CPC) that shows three-month average temperature and precipitation for the United States for the previous ten years. As such, these graphics, over time, will act as a moving short-term climate window, allowing us to see real-time changes between short-term ENSO (ten-year) climate averages and averages for the entire ENSO record.

Previous local studies at the National Weather Service in Old Hickory attempted to find correlation(s) between ENSO events and certain prevailing weather conditions. These studies were inconclusive (i.e., no correlations could be clearly established). This particular study differs from previous ones because the methodology includes a mechanism for placing Nashville weather experienced during ENSO events in context with the ongoing short-term climate trends, and also considers changes in the 30-year climatological averages (Appendix 5). These factors are considered so their contribution to the average weather conditions can be eliminated, thus allowing any possible ENSO-related anomalies to be more easily revealed. The overall methodology established by the authors to perform this task is called a "climate filter" and is defined in great detail in the succeeding text.

III. What is El Niño?

El Niño is generally defined as a warm temperature anomaly of the eastern Pacific Ocean. During this anomaly, the physical relationships between wind, ocean currents, and ocean and air temperatures create a pattern that has a significant impact on the weather around the world (NASA, 2006).

South Americans who fish the waters off the coast of Peru and Ecuador have known about El Niño for centuries. Every two to seven years during the months of December and January, fish in these coastal waters nearly vanish. Fishermen have given this phenomenon the name El Niño, which is Spanish for "the boy child" because it occurs around the time of the celebration of the birth of the Christ child.

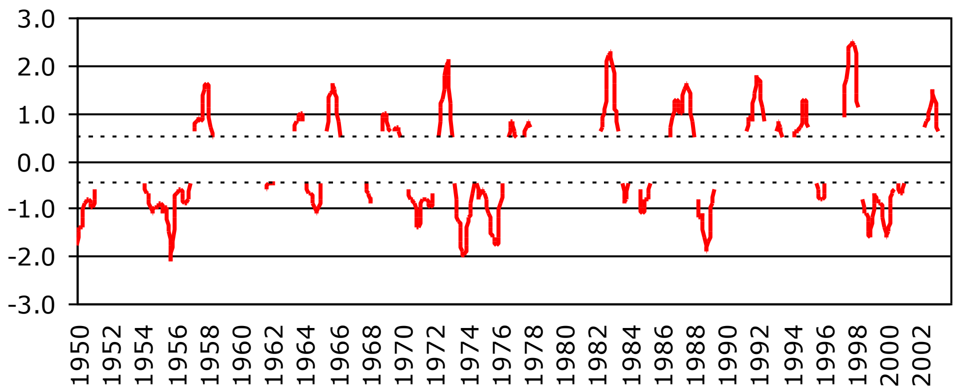
The development of El Niño has its origins in the western Pacific Ocean (NWS, 2006). Easterly trade winds diminish and a westerly anomaly develops. As a result, warming of the surface layers in the eastern and central equatorial Pacific Ocean occurs.

El Niño events occur irregularly at intervals of two to seven years, although the average is about once every three to four years. They typically last twelve to eighteen months, and are accompanied by the "Southern Oscillation" -- an inter-annual seesaw in tropical sea-level pressure between the eastern and western hemispheres. During the 54-year period of study contained in this paper, there were fourteen El Niño events, an average of one every 3.9 years. The average duration was thirteen months.

During El Niño, abnormally high atmospheric sea-level pressures typically develop in the western tropical Pacific and Indian Ocean regions, and abnormally low sea-level pressures develop in the southeastern tropical Pacific. This pattern contributes to a shift in mid-latitude synoptic weather patterns. Southern Oscillation tendencies for abnormally low pressures west of the date line and high pressures east of the date line have also been linked to periods of anomalously cold equatorial Pacific sea surface temperatures (SST's), sometimes referred to as "La Niña."

The Climate Prediction Center (CPC) notes that "During a warm episode winter, mid-latitude low pressure systems tend to be more vigorous than normal in the region of the Gulf of Alaska. These systems pump abnormally warm air into western Canada, Alaska, and the extreme northern portion of the contiguous United States. Storms also tend to be more vigorous in the Gulf of Mexico and along the southeast coast of the United States resulting in wetter than normal conditions in that region."

Figure 1. Sea Surface Temperature Anomalies of at Least |0.5°F|



According to the CPC, cold and warm episodes are defined when sea surface temperatures in the El Niño region differ from the climatological normal by at least 0.5°C, and exist for a minimum of five consecutive overlapping three-month periods (NCEP, 2006).

Figure 1 shows sea surface temperature anomalies of at least |0.5°C| which indicate all El Niño and La Niña events used in this study. (The zero line represents the climatological normal for the 1971-2000* base period.) Also note that the data used in this study are for El Niño region 3.4, which lies between 120°W and 170°W, and between 5°N and 5°S (Figure 2a). An example of observed La Niña conditions on 17 Oct 2007 can be seen in Figure 2b.

* NCEP applied the 1971-2000 climatological normals to the entire El Niño period of record used in this study. This is statistically possible because, according to Xue et al (2003), "The interdecadal changes in Niño-3 (5°S–5°N, 90°–150°W) are small (0.2°)…."

IV. Other Research on the El Niño Southern Oscillation

Several papers have been written on the effects of El Niño over a particular region. Fewer attempts have been made to document these effects at a specific location. A study by Lussky and Rieck (1998) analyzed departures from normal during several ENSO winters at La Crosse,

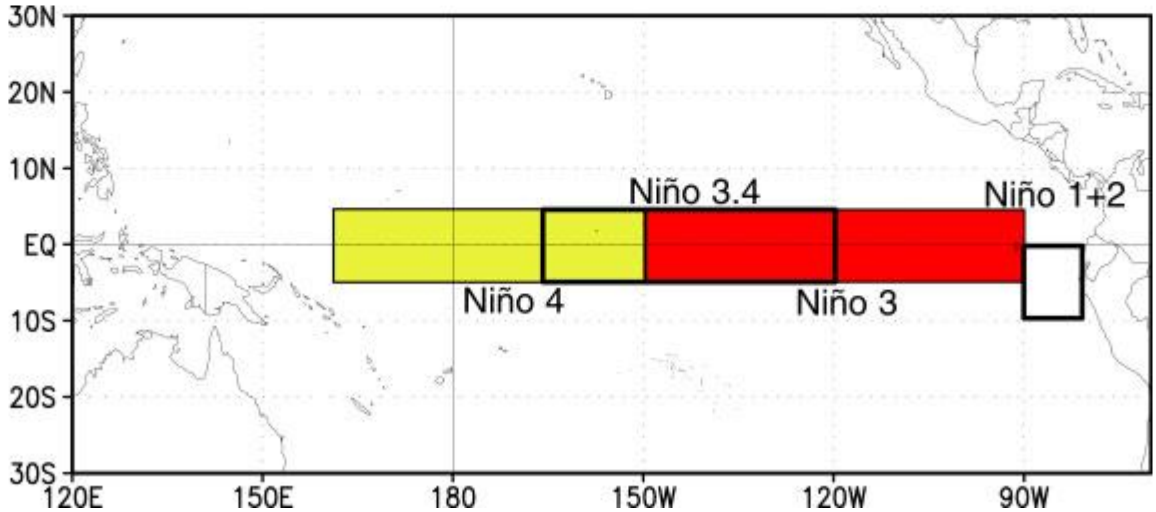


Figure 2a. ENSO SST regions. Adapted from NCEP (2007).

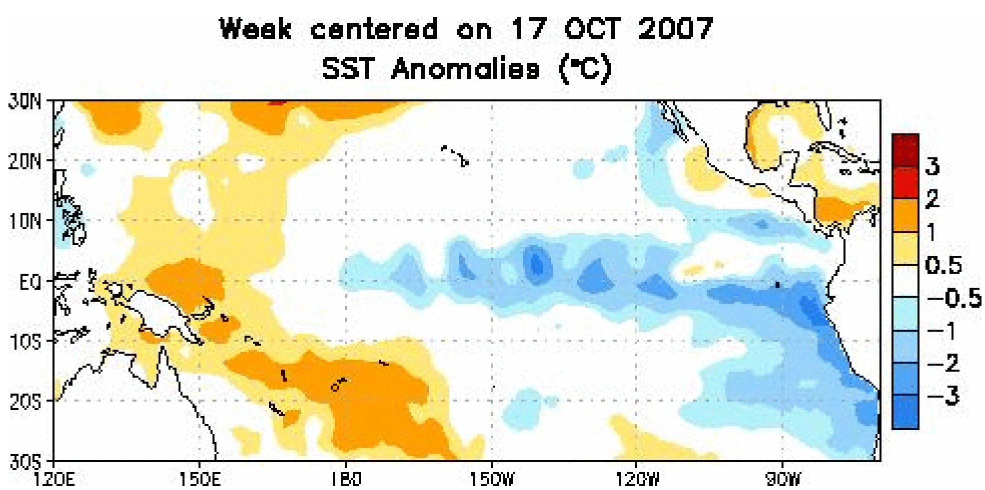


Figure 2b. SST anomalies of at least |0.5°C| during the La Niña of 2007. Adapted from NCEP (2007).

Wisconsin, but did not place these statistics in the larger context of the prevailing climatological pattern.

A similar study by Deedler (1997) presented departures from normal in Southeast Lower Michigan during three ENSO winters, but, again, did not place these statistics in the larger context of the prevailing climatological pattern.

Stachelski (2008) produced a summary of ENSO effects on the Central California Interior, but, again, did not place these statistics in the larger context of the prevailing climatological pattern.

Hagemeyer (1998) investigated significant extratropical tornado occurrences in Florida during strong ENSO events, ultimately concluding that "the threat of increased severe weather activity when significant El Niño's are forecast should be taken very seriously."

Nunn and DaGaetano (2004) authored a paper on the El Niño−Southern Oscillation and its role in cold-season tornado outbreaks across the Southeast and Midwest, but only considered climate data for November through February.

This is not a comprehensive list of ENSO-related research, but merely a sampling to illustrate the context in which previous local case studies regarding ENSO effects have typically been conducted.

V. Methodology

For the purposes of this study, it was determined that the most meaningful way to analyze ENSO-related climatological data would be to use a specially-designed "climate filter" (described later).

As stated earlier, the Climate Prediction Center (CPC) tracks changes in sea surface temperature departures from normal in the Niño 3.4 region (5^oN-5^oS, 120^o-170^oW). This information is then used to compute the Oceanic Niño Index (ONI). The ONI reflects a three-month composite average, and changes in the index are tracked using running means. To define a warm (El Niño) or cold (La Niña) episode there must be at least 5 consecutive periods when the ONI equals or exceeds the threshold of +/- 0.5^o.

Statistics provided by CPC show that the cold and warm episodes between 1950 and 2003 consisted of 347 cases when the ONI equaled or exceeded +/-0.5^o. Out of this set, there were 157 cases when ONI equaled or exceeded +/-1.0^o, 61 cases when ONI equaled or exceeded +/-1.5^o, and 15 cases when the index equaled or exceeded +/-2.0^o.

The average temperature and average precipitation at Nashville were calculated for each three-month period that CPC used to define the various warm and cold episodes. These data were then segregated based on the nature of the episode (warm or cold), and used to search for possible correlation with anomalies in Nashville's weather. They were also used to determine whether any possible weather anomalies in Nashville tended to increase or decrease with changes in SST intensity.

Realizing that 30-year averages show significant fluctuation over time, departures from normal for precipitation and temperature were always calculated using the base average pertinent for each of the 347 three-month periods. Normal values for the 1921-1950 period were used for ENSO occurrences during the 1950's, normal values for the 1951-1980 period were used for ENSO occurrences during the 1980's, etc.

For each ENSO event, attempts were made to find any anomalies in the temperature and precipitation data for Nashville that could be attributed to El Niño and La Niña. This was done by considering the data in context with the prevailing short-term climate and the short-term climate trend ongoing at the time of the ENSO event. Weather was defined as "anomalous" only when the data showed a departure from *both* the prevailing short-term climate and the short-term climate trend. This was done to try and "filter out" climate data that may have been influenced by other natural short-term climate fluctuations. In the following sections this derived process will be referred to simply as a "climate filter."

As best as can be determined, the “climate filter” used in this study represents a unique method developed by the authors. This is not to say, however, that similar methods have not been previously employed by other researchers -- only that the authors are unaware of such analyses. The methodology actually evolved during the course of the study as an attempt to obtain a set of relatively conservative results (i.e., limited conclusions with greatest confidence). There was always a desire to isolate possible sources of natural climate fluctuations, apart from El Niño itself that might explain the average weather at Nashville during El Niño events. In other words, a method was desired that would help “filter out” the background “noise” in the climate record contributed by natural sources with periodicities larger than El Niño. Realizing that all climate records are partly the result of a complex array of intersecting natural trends, a choice was made to smooth the data in a way that would highlight short-term trends with periodicities roughly on the order of five to ten years, and determine if these trends could feasibly explain the average observed weather at Nashville during El Niño events. In essence, part of the mission was to first ask, “Could observed conditions at Nashville be affected by natural sources other than El Niño?” In this way, it would be possible to isolate cases where confidence in an “El Niño connection” was greatest from those with lesser confidence. The authors wanted to produce a “conservative” set of results and developed this method to aid in that endeavor. Is there an understanding that other climate trends with longer periodicities -- perhaps on the order of centuries -- might also affect the average weather at Nashville? Of course. However, this particular study is limited to the effects of “short-term” trends (defined over a five-year period). Is there an understanding that the effects on certain atmospheric variables by different climatological sources are co-mingled and somewhat difficult to isolate? Yes, and this indicates a certain limitation on this particular study.

Smoothing of the ENSO-related climate data was achieved by calculating three-period running means (TPM) using the three-month temperature and precipitation departures from normal as the base data for each ENSO event. An example, taken from Table 22 (Appendix 2), showing temperature data for La Niña 1954-1957, is shown below.

Temperature Data			
Average during Period	Normal (1921-1950)	Departure from Normal	
58.8	59.2	-0.4	TPM
68.7	68.3	0.4	0.0
75.0	75.0	0.0	1.1
81.5	78.6	2.9	2.2
81.1	77.3	3.8	3.0
73.4	71.2	2.2	2.2

Table 22. La Niña 1954-1957

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1921-1950)	Departure from Normal		Total during Period	Normal (1921-1950)	Ratio of Total to Normal	
1954	MAM	-0.5	58.8	59.2	-0.4	TPM	12.44	12.75	0.98	TPM
1954	AMJ	-0.7	68.7	68.3	0.4	0.0	10.64	10.66	1.00	0.87
1954	MJJ	-0.7	75.0	75.0	0.0	1.1	6.93	10.93	0.63	0.70
1954	JJA	-0.8	81.5	78.6	2.9	2.2	4.74	10.46	0.45	0.58
1954	JAS	-1.0	81.1	77.3	3.8	3.0	6.60	10.01	0.66	0.71
1954	ASO	-1.1	73.4	71.2	2.2	2.2	8.82	8.57	1.03	0.88
1954	SON	-1.1	62.1	61.4	0.7	0.6	8.33	8.67	0.96	0.98
1954	OND	-1.0	49.8	50.9	-1.1	-0.7	9.62	9.99	0.96	0.85
1954	NDJ	-1.0	41.9	43.5	-1.6	-1.4	7.94	12.40	0.64	0.88
1955	DJF	-1.0	39.8	41.2	-1.4	-1.2	13.58	13.15	1.03	0.97
1955	JFM	-0.9	43.5	44.1	-0.6	-0.1	17.88	14.37	1.24	1.30
1955	FMA	-0.9	52.4	50.8	1.6	1.3	21.25	13.13	1.62	1.41

TPM (1954, AMJ) is the three-period running mean calculated by adding the departures from normal that occurred during periods "1954, MAM" (-0.4), "1954, AMJ" (0.4), and "1954, MJJ" (0.0), and dividing by three. Thus, the three-period running mean for TPM (1954, AMJ) is 0.0. The succeeding four values for TPM in Table 22 are:

TPM (1954, MJJ) = 1.1

TPM (1954, JJA) = 2.2

TPM (1954, JAS) = 3.0

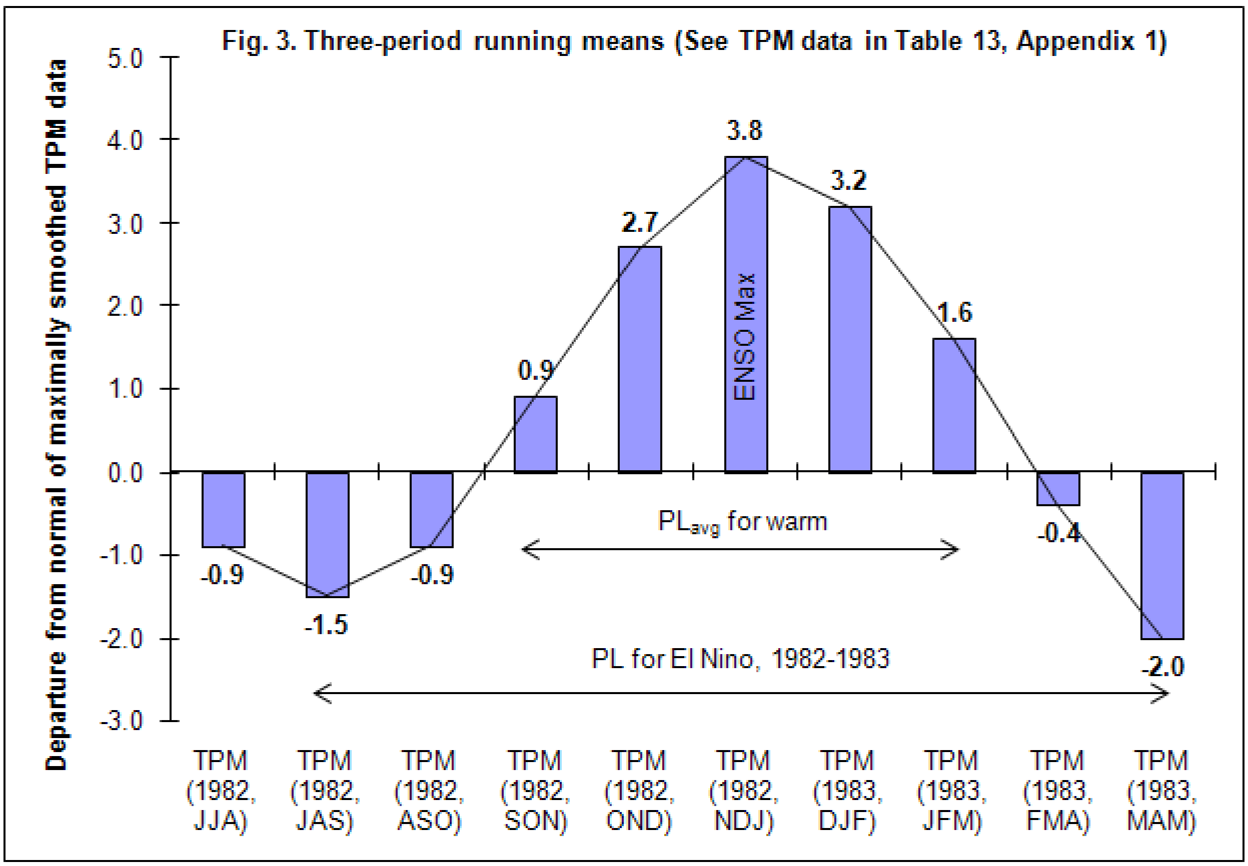
TPM (1954, ASO) = 2.2

This additional smoothing of data made it easier to distinguish climate cycles during ENSO events. Once the smoothing was completed, a search was made to locate the first inflection point *prior* to the ENSO maximum. An inflection point is defined as the point where an established trend first begins to change direction, even if that change only persists for one or two three-month periods. This would indicate a point in the data where the TPM changed from "decreasing" to "increasing," or vice versa. A trend of "decreasing" to "steady," or "increasing" to "steady" was considered insufficient criteria for defining an inflection point, where:

> "Decreasing" is associated with a negative value for the following equation, as we incrementally step our way back in time from the ENSO Max to earlier periods of the ENSO:
>
> $T_{ENSO\ Max\ -\ n} - T_{ENSO\ Max\ -\ n+1}$ (from n=0 to n=$n_{T\text{-}final}$),
>
> Where $n_{T\text{-}final}$ indicates the point in the TPM data, during the ENSO event, where either an inflection point was observed or the beginning point of the ENSO was reached (i.e., no inflection point was found).
>
> "Increasing" is associated with a positive value from the above equation.
>
> "Steady" is associated with a value of zero from the above equation.

The trend must have shown clear signs of reversal before it was defined as an inflection. No importance was attributed to the magnitude of the inflection. Thus, an inflection might indicate a relatively brief, minor interruption in a trend, or a relatively long, significant change in the trend. The important thing was to locate the point where a "new" trend first became clearly established that would persist until the time of the ENSO maximum. If an inflection point was found, the pattern length (PL) was defined as twice the length of time between the inflection point and the ENSO maximum. The pattern length always included an equal period of time before and after the ENSO maximum. This was done so that the period would be centered on the ENSO maximum itself, and would allow for analysis of a "post-ENSO Max" period where weather conditions at Nashville could conceivably still be influenced by a waning ENSO. When such cycles appeared in the data, the pattern length was noted and an average PL (PLavg) was later calculated for the warm episode data set (154 cases) and the cold episode data set (193 cases). The calculation of PLavg was done in order to see if it might be utilized in the future as part of a general forecast scheme. For instance, if a correlation is found between a certain type of climate trend and a certain type of ENSO event (i.e., "warm" or "cold"), it would be theoretically possible to utilize the characteristics of a developing ENSO, along with PLavg and a chart of running means for the developing ENSO event to reveal the initial stages of an ENSO-related climate trend.

It was assumed that if an inflection point could be found in the data during the early stages of an ENSO event, indicating the beginning of a temperature or precipitation trend, there would be an increased chance that a correlation might exist between Nashville weather and the presence of an ENSO event. Figure 3 shows a portion of the temperature trend analysis of the El Niño of JJA 1982 to MAM 1983 (using data from Appendix 1, Table 14).



The values for PLavg, for both the precipitation and temperature data, were then used to define a "climatologically significant period" for each El Niño and La Niña event. In other words, PLavg, for all intents and purposes, indicates the short-term period during which Nashville weather most often appeared to establish ENSO-related trends. It should be noted that there were some data sets where an inflection point could not be found. These were times when the early part of the ENSO event was either too brief to allow for determination of an inflection point (i.e., El Niño 1969-1970, temperature data), or a trend was found but no inflection point was observed (i.e., El

Niño 1965-1966, temperature data). (Refer to TPM columns and Appendix 4.) The pertinent TPM data for El Niño 1969-1970 and El Niño 1965-1966 are provided in the examples below:

Excerpt from Table 10. El Niño 1969-1970										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1931-1960)	Departure from Normal		Total during Period	Normal (1931-1960)	Ratio of Total to Normal	
1969	ASO	0.6	69.8	71.1	-1.3	**TPM**	6.34	8.05	0.79	**TPM**
1969	SON	0.7	59.3	60.9	-1.6	-1.8	5.90	8.47	0.70	0.70
1969	OND	0.7	48.1	50.5	-2.4	-2.9	11.87	9.79	1.21	0.92
1969	NDJ	0.6	38.6	43.2	-4.6	-4.1	11.02	12.96	0.85	1.00
1970	DJF	0.5	35.9	41.1	-5.2		13.55	14.19	0.95	

In the excerpt from Table 10, the SST maximum anomaly occurred very close to the beginning of the El Niño (SON, 1969). There was insufficient pre-ENSO Max TPM data to show an inflection point.

Excerpt from Table 8. El Niño 1965-1966										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1931-1960)	Departure from Normal		Total during Period	Normal (1931-1960)	Ratio of Total to Normal	
1965	MJJ	0.6	75.1	75.4	-0.3	**TPM**	9.18	10.69	0.86	**TPM**
1965	JJA	1.0	77.6	79.0	-1.4	-0.7	8.59	9.83	0.87	0.96
1965	JAS	1.2	77.2	77.5	-0.3	-0.7	10.87	9.45	1.15	1.01*
1965	ASO	1.4	70.7	71.1	-0.4	0.0	8.12	8.05	1.01	1.01*
1965	SON	1.5	61.7	60.9	0.8	0.6	7.41	8.47	0.87	0.74
1965	OND	1.6	52.0	50.5	1.5	0.7	3.40	9.79	0.35	0.58
1965	NDJ	1.5	42.9	43.2	-0.3	-0.2	6.76	12.96	0.52	0.49
1966	DJF	1.2	39.4	41.1	-1.7	-1.5	8.57	14.19	0.60	0.57
1966	JFM	1.1	41.3	43.7	-2.4	-1.4	8.95	15.19	0.59	0.65
1966	FMA	0.8	50.3	50.4	-0.1	-1.2	10.10	13.44	0.75	0.72
1966	MAM	0.5	58.1	59.1	-1.0		10.46	12.65	0.83	

In the excerpt from Table 8, the SST Maximum anomaly occurred deep in the ENSO event (OND, 1965) However, the pre-ENSO Max trend, as indicated by the TPM data in column 7, was "decreasing," then "steady," which does not provide sufficient evidence of an inflection point using our established criteria.

To define natural short-term climate trends that existed, separate and apart from ENSO, a classification methodology had to be established. An objective definition for "prevailing short-term climate" and "short-term climate trend" was established to characterize general short-term climate at Nashville. A subjective decision was made to use the length of time for the prevailing short-term climate as five years, centered on the year of the ENSO maximum. This seemed like a reasonable choice since the first-order smoothed data was based on five-year running means, where the average temperature and precipitation for yearn consists of the average values for yearn-2, yearn-1, yearn, yearn+1, and yearn+2. A subjective decision was made to use the length of time for a short term “trend” as five periods (where each period is defined by a five-year running mean). This decision seemed reasonable, based on a visual analysis of the plot for running means, offering a sufficiently conservative choice to prevent broad averaging across inflection points and decrease the possibility of mischaracterizing certain "warming" or "cooling" trends as "stable." A detailed explanation of this methodology can be found in Appendix 3. The maximally smoothed data, represented by the TPM data in Appendices 1 & 2, was calculated from the base data of three-month means, which correspond precisely with NCEP's three-month Oceanic Niño Index.

The short-term climate definitions were characterized as follows:

FOR TEMPERATURE DATA:

<u>Characteristics for prevailing short-term climate (El Niño)</u>
Near normal: departure from normal of 0.8° to -0.8°
Cool: departure from normal of -0.9° to -1.7°
Very Cool: departure from normal greater than -1.7°
Warm: departure from normal of 0.9° to 1.7°
Very Warm: departure from normal greater than 1.7°

<u>Characteristics for prevailing short-term climate (La Niña)</u>
Near normal: departure from normal of 0.6° to -0.6°
Cool: departure from normal of -0.7° to -1.2°
Very Cool: departure from normal greater than -1.2°
Warm: departure from normal of 0.7° to 1.2°
Very Warm: departure from normal greater than 1.2°

<u>Characteristics for short-term climate trend (El Niño)</u>
Stable: a change of 0.8° to -0.8°
Cooling: a change of -0.9° to -1.7°
Significant Cooling: a change greater than -1.7°
Warming: a change of 0.9° to 1.7°
Significant Warming: a change greater than 1.7°

<u>Characteristics for short-term climate trend (La Niña)</u>
Stable: a change of 0.6° to -0.6°
Cooling: a change of -0.7° to -1.2°
Significant Cooling: a change greater than -1.2°
Warming: a change of 0.7° to 1.2°
Significant Warming: a change greater than 1.2°

FOR PRECIPITATION DATA:

Characteristics for prevailing short-term climate (El Niño)
Near normal: departure from normal of 7% to -7%
Dry: departure from normal of -8% to -15%
Very Dry: departure from normal greater than -15%
Wet: departure from normal of 8% to 15%
Very Wet: departure from normal greater than 15%

Characteristics for prevailing short-term climate (La Niña)
Near normal: departure from normal of 8% to -8%
Dry: departure from normal of -9% to -17%
Very Dry: departure from normal greater than -17%
Wet: departure from normal of 9% to 17%
Very Wet: departure from normal greater than 17%

Characteristics for short-term climate trend (El Niño)
Stable: a change of 7% to -7%
Decreasing: a change of -8% to -15%
Rapidly Decreasing: a change greater than -15%
Increasing: a change of 8% to 15%
Rapidly Increasing: a change greater than 15%

Characteristics for short-term climate trend (La Niña)
Stable: a change of 8% to -8%
Decreasing: a change of -9% to -17%
Rapidly Decreasing: a change greater than -17%
Increasing: a change of 9% to 17%
Rapidly Increasing: a change greater than 17%

An explanation of why these particular thresholds were chosen is outlined in Appendix 3.

Below is an example showing the El Niño of JAS 1982 to MAM 1983 (using length = PL, as listed in Table 35), and its relative position in the short-term temperature trend and prevailing short-term climate.

As shown in Table 3a and Figure 3, the average temperature departure from normal experienced during El Niño 1982-1983 was 2.7^{o} (i.e., “very warm”). Thus, this El Niño exhibited anomalous weather because neither of the short-term climate signals was in phase with this particular type of weather. In other words, the weather during that particular El Niño can be convincingly distinguished from the two short-term climate signals. This same type of analysis was conducted on all other ENSO events and the results are provided in Tables 3a and 3b.

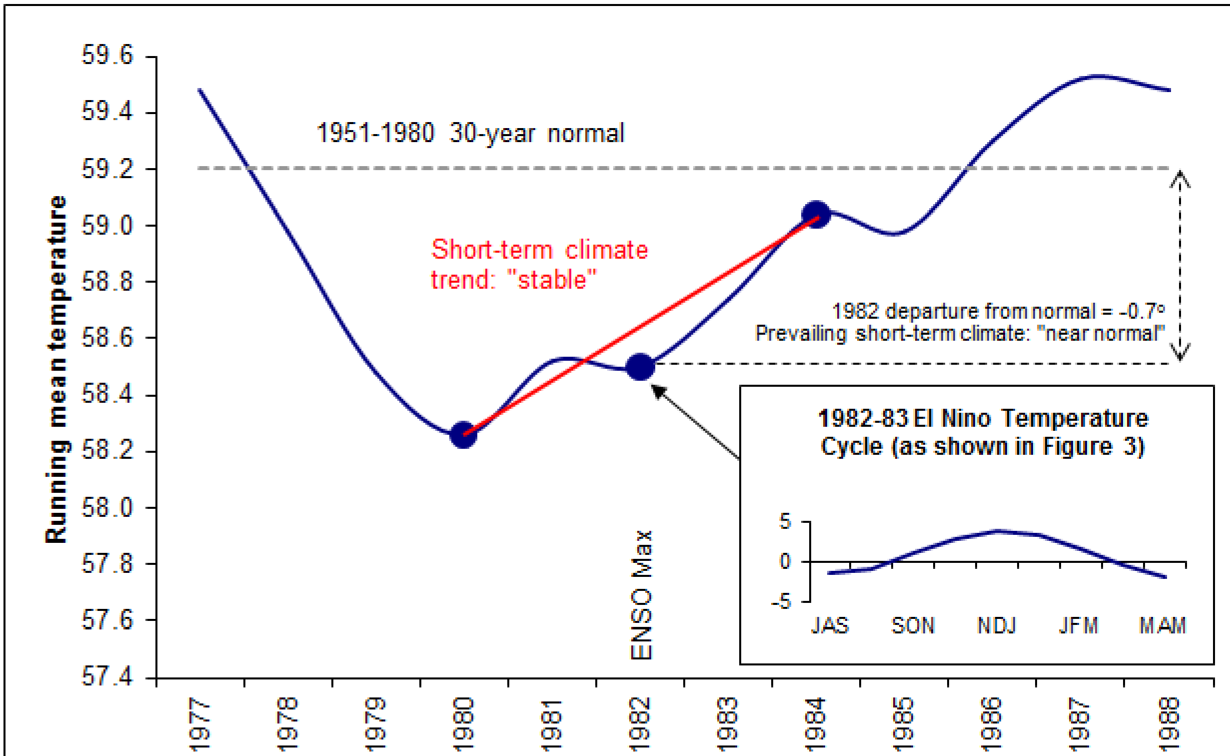


Figure 4. Climate history for the 1982-83 El Nino

SHORT-TERM CLIMATE TREND = [Running mean for 1984] - [Running mean for 1980] / 5 yrs

= (59.0 - 58.3) / 5 yrs (Note: Running means are shown in Figure 4b.)

= +0.7^{o} / 5 yrs

= "Stable" (See list above for definition.)

PREVAILING SHORT-TERM CLIMATE = [Running mean for 1982, year of ENSO Max] - [30-yr avg]

= 58.5 - 59.2 (Note: Running mean for 1982 is shown in Figure 4b and 30-year averages are listed in Appendix 5.)

= -0.7^{o}

= "Near normal" (See list above for definition.)

VI. Results

When attempting to ascribe significance to the following results, one must consider the important fact that historical data are available for only a limited sample size of El Niño and La Niña events.

Section I. Searching for climate anomalies at Nashville, without using a climate filter

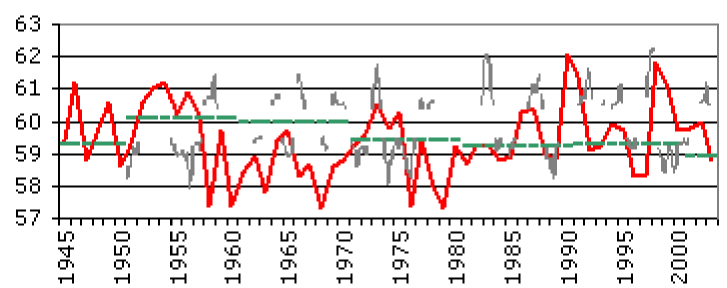
Table 1 (below) provides a general summary of climate statistics for Nashville, Tennessee, during El Niño and La Niña patterns between 1950 and 2003. Statistics accumulated for all events are included on the first line of the table, for SST anomaly ≥0.5°C. Each succeeding line includes statistics for increasingly smaller subsets of data for ENSO events exhibiting increasingly large SST anomalies.

Table 1. Temperature and Precipitation Departures from Normal at Nashville, Tennessee, during El Niño/La Niña Patterns (1950-2003)

SST Anomaly (°C)	El Niño			La Niña		
	Cases	Temperature Departure from Normal (°F)	Ratio of Observed Precipitation to Normal	Cases	Temperature Departure from Normal (°F)	Ratio of Observed Precipitation to Normal
≥0.5	154	-0.5	1.02	193	0.3	1.04
≥1.0	76	0.0	0.96	81	1.1	1.03
≥1.5	35	0.5	0.95	26	2.3	1.24
≥2.0	13	1.5	1.10	2	1.1	1.16

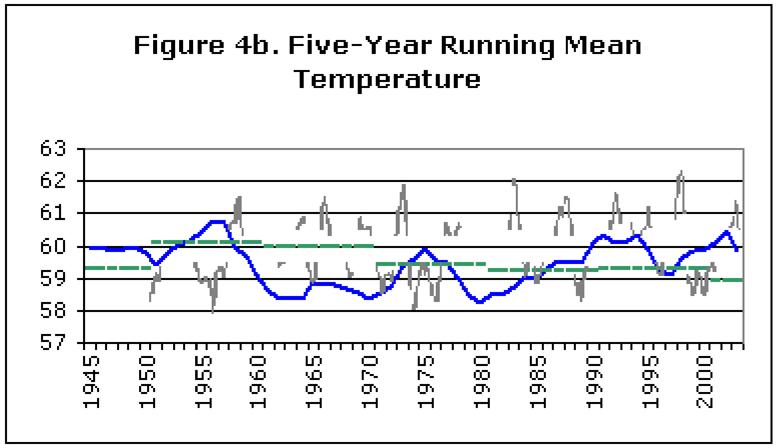
Of the four data subsets analyzed, only one showed any indication of being unambiguous -- the one for average temperature during La Niña events. The remaining three parameter subsets failed to show any evidence of a clear correlation with either a particular ENSO pattern type or the strength of the pattern. There was a hint, however, that increasing strength of La Niña might be associated with increased positive departures from normal of both temperature and precipitation (especially when the SST anomaly is ≥1.0°).

Figure 4a. Mean Annual Temperatures at Nashville



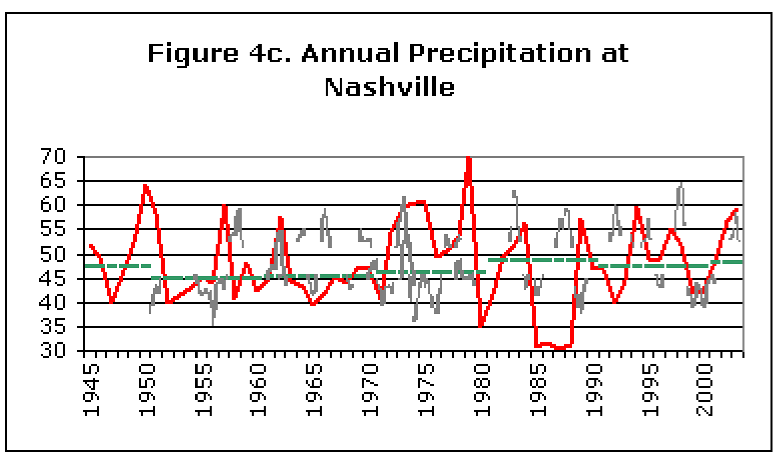
Section II. Searching for climate anomalies at Nashville through application of a "climate filter"

A brief set of statistical conclusions, as just provided in Section I, may not be the best way to define possible impacts of El Niño and La Niña on Nashville's climate -- especially when considering the ambiguous nature of most of the results. As discussed earlier, a more rigorous method should be applied, where individual El Niño/La Niña occurrences are studied in context with other natural short-term climate trends. Consider, for example, an ENSO occurrence that is associated with warm and dry conditions at Nashville. If the ENSO happens to be embedded in an overall short-term climate pattern that is warmer and drier than normal, then it becomes more difficult to suggest with confidence that the ENSO occurrence had a significant impact on the observed weather. On the other hand, if an ENSO occurrence is associated with a significant departure from the prevailing short-term climate and short-term climate trend, then a stronger case can be made that the ENSO may have impacted the observed weather. (This will be the focus of Section 6.)



To establish a method for defining the "prevailing short-term" climate and the "short-term climate trend" at Nashville during each ENSO event, Nashville climate data were smoothed by calculating five-year running means. This was done so that cycles and trends could be more easily observed. Figures 4a and 4c show Nashville's average annual temperature and precipitation, respectively. Figures 4b and 4d show plots of the running means. The origin for the graphs has been chosen to be 1945 in order that the prevailing trends leading into the period of study could be shown. A comparison of the graphs of the observed data and the running means clearly shows how the "noise" from random variability in the observed data has been minimized and general trends and cycles have become more obvious.

Figures 4a through 4d include dashed horizontal lines representing the normal temperature at Nashville during the applicable 30-year base period. The light gray overlay on each figure is the same sea surface temperature anomaly plot shown in Figure 1 which indicates the El Niño/La Niña periods.



In the section on research methodology, attempts were made to find a value for PLavg for the El Niño and La Niña data sets. This value was used to represent the average period during "warm" and "cold" episodes during which Nashville weather most often appeared to establish ENSO-related trends. The value for PLavg was calculated using the unique PL value for each ENSO event, where

$$PL = [2 \times N_{\text{pre-SST Max periods}}] + 1,$$

where Npre-SST Max periods indicates the number of periods between the SST Max anomaly and the pre-SST Max inflection point (indicated in the maximally smoothed temperature and precipitation data, or TPM data). As stated earlier, some ENSO events did not exhibit an inflection point and could not be considered when calculating PLavg.

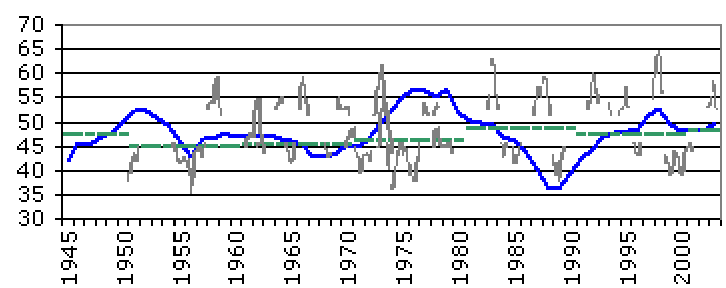


Figure 4d. Five-Year Running Mean Annual Precipitation

The base data used for calculating PLavg are provided in Tables 35 and 36 in Appendix 4. The PLavg for El Niño events, for both temperature data and precipitation data, was found to be 5. The PLavg for La Niña events, for both temperature data and precipitation data, was also 5.

Table 35, in Appendix 4, shows that during the ten El Niño events where an inflection point could be found in the "pre-SST Max" precipitation trend, the inflection was always characterized as a relative maximum. This was deemed significant. Therefore, an investigation was conducted to more completely define this pre-SST Max in the precipitation data.

The data in Table 2a show that the months of September and/or October had a high frequency of occurrence in the running means composite period at the place where the maximum tended to occur (located at "ENSO Max - 2" periods). This occurred 90% of the time in this subset of ten cases. October was represented in 100% of these cases and September was represented in 67%. When extending the subset to include cases where the ENSO record of smoothed data failed to extend past "ENSO Max - 1" and cases where length of the pre-SST Max period met criteria but failed to exhibit an inflection point, the subset size increased to 14. The percentage of these cases where September and/or October showed up in the running means composite "max" period was 86%. October was represented in 86% of the cases and September was represented in 64%.

When using the expanded subset of 14 El Niños, where the pre-SST Max ENSO record was extended to include the "ENSO Max - 1," we find that when September was part of the three-month running mean composite, 89% of those Septembers showed above-normal precipitation (Table 2b). When October was part of the three-month running mean composites, 69% of those Octobers showed above-normal precipitation (Table 2b). More importantly, in this subset of 14 cases, either September or October (or both) had above-normal precipitation 79% of the time.

The only two El Niños that failed to meet criteria for consideration in this part of the study were those in 1969-1970 and 1993. Each of these El Niños reached a maximum anomaly too early in the ENSO for consideration.

The average ratio of total precipitation to normal precipitation for all "pre-SST Max periods" (located at "ENSO Max – 2" or "ENSO Max – 1") was 1.23 (from Table 2a), indicating average precipitation that was 23% above normal. Using our previously defined thresholds, based on standard deviation, this would be defined as “very wet.”

Table 2a. Months included in the pre-ENSO Max inflection point for El Niño precipitation data (using the maximally smoothed data set)

Event	ENSO Max	Pre-SST Max period (located at "ENSO Max - 2" or "ENSO Max - 1")	Ratio of total to normal (TPM)
1957-58*	DJF	OND	1.48
1963-64	OND	ASO	1.26
1965-66*	OND	ASO	1.01
1968-69	DJF	OND	1.10
1969-70	SON	---	---
1972-73*	NDJ	SON	1.55
1976-77	OND	ASO	1.44
1977-78	OND	ASO	1.61
1982-83*	NDJ	SON	0.97
1986-88 (1)*	DJF	OND	1.13
1986-88 (2)*	JAS	MJJ	0.67
1991-92*	DJF	OND	1.17
1993	MAM	---	---
1994-95*	NDJ	SON	1.11
1997-98*	OND	ASO	1.30
2002-03*	OND	ASO	1.41

* indicates an El Niño event where a pre-SST Max inflection point could be found (as shown in table 35).

--- indicates that the El Niño event "maxed out" early in the event and prevented the consideration of a period located at "ENSO Max - 2" or “ENSO Max – 1.”

Table 2b. October and September rainfall during pre-ENSO Max periods (located at "ENSO Max – 2" or "ENSO Max – 1")				
Year	**Observed September rainfall/normal September rainfall**	**Computed ratio**	**Observed October rainfall/normal October rainfall**	**Computed ratio**
1957*	---/---	---	3.89/2.52	1.54
1963	3.43/3.59	0.96	T/2.32	0.00
1965*	5.02/3.59	1.40	0.57/2.32	0.25
1968	---/---	---	3.92/2.32	1.69
1972*	3.71/3.42	1.08	4.06/2.16	1.88
1976	5.08/3.42	1.49	5.17/2.16	2.39
1977	5.04/3.42	1.47	4.22/2.16	1.95
1982*	3.23/2.74	1.18	1.91/2.58	0.74
1986(1)*	---/---	---	2.19/2.58	0.85
1986(2)*	---/---	---	---/---	---
1991*	---/---	---	3.88/2.62	1.48
1994	4.20/2.87	1.46	3.31/2.62	1.26
1997	5.75/2.87	2.00	2.71/2.62	1.03
2002	6.29/3.09	2.04	4.48/2.87	1.56

* indicates that this particular ONI period also represented a pre-ENSO Max period and an inflection point in the precipitation trend

--- indicates that particular month was not part of the pre-ENSO Max period

Notes: (1) The two El Niño events that "maxed out" early in the event (1969-70 and 1993), and prevented the consideration of a period located at ENSO Max - 2 are not included in this table. (2) “Normal rainfall” refers to the normal for the preceding 30-year period (Appendix 5).

Summary of ENSO events and their placement in the overall short-term climate record at Nashville

The ENSO Nashville climate data were further summarized for inclusion in Tables 3a and 3b in order to place each event in context with the short-term climate at Nashville. The average observed departure from normal for temperature and precipitation that occurred within the boundaries of PLavg was calculated (with base data for these calculations noted by the green and red number sequences in the tables in Appendices 1 & 2). The prevailing short-term climate and short-term climate trends were noted for each El Niño/La Niña cycle and were based on a particular methodology utilizing the five-year running mean temperature and annual precipitation data. (See Appendix 3.) The color-coding of Tables 3a and 3b is intended to highlight some of the conclusions in Section 6.

There were some ENSO events when the maximum SST anomaly either occurred at the onset of the event or so close to the beginning of the event that the required number of "pre-SST Max periods" was not available for a full five-period calculation. However, the calculations were still made using a less-than-optimal number of periods and included in Tables 3a and 3b. Such calculations are denoted with an asterisk (*) in the tables, along with the number of periods used in the calculations (enclosed within parentheses).

Observed event departures were then compared with the prevailing climate and climate trends to note whether each El Niño/La Niña cycle produced general weather characteristics that differed from the short-term climate and climate trend (i.e. were most likely anomalous).

Table 3a. Summary of El Niño Occurrences

Event	Periods	Maximum SST Anomaly	Temperature Characteristics				Precipitation Characteristics			
			Prevailing short-term climate	ΔT	Average observed departure from normal for PL_{avg}		Prevailing short-term climate	ΔP	Ratio of observed precipitation to normal	
El Niño 1957-1958	15	1.6	Near normal	Cooling	-3.8	Very cool	Near normal	Increasing	1.01	Near normal
El Niño 1963-1964	7	1.0	Cool	Stable	-2.2	Very cool	Near normal	Stable	0.76	Very dry**
El Niño 1965-1966	11	1.6	Cool	Stable	0.0	Near normal	Near normal	Decreasing	0.67	Very dry
El Niño 1968-1969	7	1.0	Cool	Stable	-2.6	Very cool	Near normal	Stable	1.00	Near normal
El Niño 1969-1970	5	0.7	Cool	Stable	-2.5* (4)	Very cool	Near normal	Stable	0.89*(4)	Dry**
El Niño 1972-1973	11	2.1	Near normal	Warming	0.7	Near normal	Near normal	Rapidly increasing	1.37	Very wet
El Niño 1976-1977	6	0.8	Near normal	Stable	-6.6	Very cool**	Very wet	Stable	1.06	Near normal
El Niño 1977-1978	5	0.8	Near normal	Cooling	-2.6	Very cool	Very wet	Stable	1.39	Very wet
El Niño 1982-1983	14	2.3	Near normal	Stable	2.7	Very warm**	Near normal	Decreasing	0.92	Dry
El Niño 1986-1988	19	1.3	Near normal	Stable	0.6	Near normal	Very dry	Rapidly decreasing	0.79	Very dry
		1.6	Near normal	Stable	0.7	Near normal	Very dry	Rapidly decreasing	0.54	Very dry
El Niño 1991-1992	14	1.8	Near normal	Stable	2.3	Very warm**	Near normal	Rapidly increasing	0.93	Near normal
El Niño 1993	5	0.8	Near normal	Stable	-0.9* (4)	Cool**	Near normal	Increasing	0.99*(4)	Near normal
El Niño 1994-1995	12	1.3	Warm	Stable	2.4	Very warm	Near normal	Increasing	0.95	Near normal
El Niño 1997-1998	12	2.5	Near normal	Stable	0.2	Near normal	Wet	Stable	1.12	Wet
El Niño 2002-2003	11	1.5	Warm	Stable	-0.4	Near normal	Near normal	Increasing	1.21	Very wet

Note: In Tables 3a and 3b, an asterisk (*) indicates an ENSO event where the "pre-SST Max periods" were not sufficient to calculate an average for a full PLavg. The corresponding number in parentheses indicates the number of periods for each less-than-optimal case that was used for the calculation. A double asterisk (**) indicates an ENSO event where the observed temperature/precipitation was anomalous to both the prevailing short-term climate and ΔT/ΔP.

Table 3b. Summary of La Niña Occurrences

Event	Periods	Maximum SST Anomaly	Temperature Characteristics				Precipitation Characteristics			
			Prevailing short-term climate	ΔT	Average observed departure from normal for PLavg		Prevailing short-term climate	ΔP	Ratio of observed precipitation to normal	
La Niña 1950-1951	15	-1.8	Near normal	Stable	2.4* (3)	Very warm**	Near normal	Increasing	1.63*(3)	Very wet
La Niña 1954-1957	34	-2.1	Near normal	Warming	-1.1	Cool**	Near normal	Decreasing	1.04	Near normal
La Niña 1961-1962	8	-0.6	Very cool	Cooling	-0.6* (3)	Near normal**	Near normal	Stable	0.77*(3)	Very dry**
La Niña 1964-1965	11	-1.1	Very cool	Stable	-0.9	Cool	Near normal	Stable	1.01	Near normal
La Niña 1967-1968	7	-0.9	Very cool	Stable	-3.7	Very cool	Near normal	Stable	0.82	Very dry**
La Niña 1970-1972	19	-1.4	Cool	Warming	-1.3	Very cool	Near normal	Increasing	0.78	Very dry**
La Niña 1973-1974	15	-2.0	Near normal	Significant warming	4.2	Very warm	Near normal	Rapidly increasing	1.38	Very wet
La Niña 1974-1976	21	-1.8	Near normal	Stable	2.5	Very warm**	Very wet	Increasing	1.08	Near normal **
La Niña 1983-1984	5	-0.9	Near normal	Stable	-0.7	Cool**	Near normal	Stable	1.07	Near normal
La Niña 1984-1985	9	-1.1	Near normal	Warming	-0.2	Near normal	Near normal	Decreasing	0.98	Near normal
La Niña 1988-1989	13	-1.9	Near normal	Warming	0.9	Warm	Very dry	Decreasing	1.02	Near normal **
La Niña 1995-1996	7	-0.8	Near normal	Cooling	-1.8	Very cool	Near normal	Increasing	1.08	Near normal
La Niña 1998-2000	24	-1.6	Near normal	Warming	2.9	Very warm	Near normal	Stable	1.14	Wet**
		-1.6	Near normal	Warming	3.0	Very warm	Near normal	Stable	0.75	Very dry**
La Niña 2000-2001	5	-0.7	Near normal	Warming	-2.2* (4)	Very cool**	Near normal	Increasing	1.02*(4)	Near normal

VII. Conclusions

The objectives of this study have been two-fold. First, to develop a method whereby the prevailing short-term climate and short-term climate trend for Nashville, Tennessee, could be defined for any given year. The derived terms -- such as, "cool," "cooling," "very warm" and "warming" -- have been referred to as short-term "climate signals." Generally speaking, each year in the climate record could be represented by its own unique pair of climate signals. However, the focus of this study was narrow, involving only the years in which an El Niño or La Niña occurred. The second objective was to compare the averaged observed weather in Nashville during each ENSO event to the two derived climate signals for that year. If the observed weather showed similar characteristics to either of the two signals, the observed weather was designated as "non-anomalous." If the observed weather differed from *both* short-term climate signals, the observed weather was labeled "anomalous."

The data in this study clearly show that ENSO events are not routinely associated with any particular type of weather at Nashville. However, the findings strongly suggest that ENSO weather at Nashville might very well be tied, through some causal mechanism, to the type of short-term climate experienced at the time of the event. As discussed earlier, this was especially clear in the data from the late 1950's through the early 1970's.

In this study, the short-term climate was defined using two variables -- one to define the "*prevailing* short-term climate" and the other to define the general *trend* in the short-term climate. The specific temperature values used to define these two variables can be found in Appendix 3 under "TEMPERATURE CHARACTERISTICS." The specific precipitation values used to define these two variables can also be found in Appendix 3 under "PRECIPITATION CHARACTERISTICS."

1. El Niño

Finding #1: There are strong indications that the observed average temperature at Nashville during El Niño events is closely tied to the short-term temperature signals. Two of the most significant findings, involving the greatest number of cases, include:

(a) Historically, whenever the observed thermal conditions during a PLavg period of an El Niño were very cool, there was a clear absence of short-term climate signals that were either "warm" or "warming," and the presence of a "cool" or "cooling" signal. History verified this scenario five out of six times, four of which occurred during the climatologically cool period of the late 1950's through the 1960's. The fifth case occurred during a short-term cooling between 1975 and 1980.

(b) When the short-term temperature signals are "near normal" and "stable," it is likely that the observed temperature signal at Nashville will range from "near normal" to "very warm." History has verified this scenario five out of seven times.

The smallest subset of data involved ENSO events coincident with short-term temperature signals that were either "warm" or "warming." Such conditions occurred three times in the climatological record, and during two of those times the observed temperature at Nashville during El Niño ranged from "near normal" to "very warm." These results, along with those from 1(b), suggest that the majority of El Niño events have occurred when there was an absence of short-term signals that were "cool" or "cooling." Furthermore, during 70% of those times when such signals were absent, El Niño temperatures at Nashville averaged "near normal" to "very warm." In addition, as indicated in Table 1, the likelihood of warmer-than-normal conditions generally increased with maximum ENSO anomalies $\geq$ 1.5.

Finding #2: There are strong indications that when the observed average precipitation at Nashville during El Niño events tends toward the extreme, it is often closely tied to the short-term precipitation signals. First of all, when observed conditions were "very wet," at least one of the short-term signals was always similar (i.e., "very wet," "increasing," or "rapidly increasing"). There were three such cases. Similarly, if observed conditions were "very dry," at least one of the short-term signals tended to be similar (i.e., "very dry," "decreasing," or "rapidly decreasing"). This occurred on two out of three such occasions. Thus, data from five of these six cases, when the observed departures-from-normal were greatest, suggest there may have been other short-term climate fluctuations, unrelated to El Niño, that were also affecting the weather at Nashville and providing a more dominant influence.

As will be recalled, each short-term precipitation trend was calculated from annual precipitation totals for two particular years: that which occurred two years prior to the ENSO, and that which occurred two years after the event. However, during analysis of the precipitation data for El Niño events, it became clear there was a particular type of precipitation trend that usually occurred during the events themselves. As discussed earlier, there is usually a noticeable trend in precipitation highlighted by above-normal precipitation during the late summer and/or early fall (in the September-October period). The data further showed that this rainfall maximum was usually followed by a drying trend, which tended to reach its greatest value from late fall through early spring (when below-normal precipitation would become increasingly likely). Historically, this holds true for ENSO events that reach maximum SST anomaly between the periods OND and DJF (i.e., exhibit a late-year maximum). As shown in Table 2a, there was only one case when the maximum SST anomaly occurred at some other time of year.

The magnitude of the El Niño drying trend appears to be relative to the short-term climate signals in place at the time of the event. For instance, when a "dry" climate signal was in place during an El Niño year, the pre-ENSO maximum wet period during the late summer and early fall was suppressed or virtually extinguished. Conversely, pre-ENSO maximum wet periods with the greatest amount of precipitation occurred when the short-term signals were "wet," "very wet," "increasing," or "rapidly increasing." Tables 4a and 4b highlight this correlation between short-term climate signals and the pre-ENSO maximum "wet period":

Table 4a. El Niños (with late-year maximum anomaly) that occurred during times when short-term climate signals were "wet"

Year	Observed precipitation during pre-ENSO "wet period" (% of normal)
1957	165
1972	175
1976	216
1977	175
1991	127
1994	132
1997	148
2002	147

Table 4b. El Niños (with late-year maximum anomaly) that occurred during times when short-term climate signals were "dry"	
Year	**Observed precipitation during pre-ENSO "wet period" (% of normal)**
1965	101
1982	113
1986	121

Finding #3: It is important to note that in the absence of using a short-term "climate filter," it cannot be demonstrated that El Niño events between 1950 and 2003 (for the PLavg period) were associated with either drier-than-normal or wetter-than-normal conditions, or with the significance of the departure from normal. This was revealed in Section 5.1. Similarly, in the absence of using a short-term "climate filter," it cannot be demonstrated that El Niño events were associated with either colder-than-normal or warmer-than-normal conditions at Nashville, or with the significance of the departure from normal. Only after the application of our climate filter do the preceding conclusions become evident. Once again, it is asserted that regional or localized ENSO studies that do not give proper attention to, and consideration of, the effects of short-term climate variability, may misjudge the general nature of the weather that occurs at certain locations during ENSO events.

2. La Niña

Finding #1: Just as demonstrated with El Niño data, it can be shown that certain types of observed weather during La Niña events are typically associated with particular short-term climate signal combinations.

There is a large subset of La Niña events associated with a prevailing short-term temperature signal of "near normal" and a short-term temperature trend of either "stable" or "warming/significant warming." These signals were in place during ten of the fifteen La Niña events recorded between 1950 and 2001. There were seven times when the signal combination was "near normal" and "warming/significant warming" and three times when the combination was "near normal" and "stable." When these signal combinations were in place, the average observed temperature at Nashville was usually warmer than normal (i.e., sixty percent of the time), and oftentimes "very warm." Of the times when positive departures occurred with these signal combinations, the average departure was an impressive 2.7^{o}F. In the four remaining cases that were cooler than normal, the average negative departure was just 1.1^{o}F, with only a single case when the observed temperature departure was "very cool" (La Niña 2000-2001).

Since warmer-than-normal La Niña weather is often "very warm," it would be useful if a unique climate signal could be found in the historical temperature record that would help Nashville forecasters realize when a "very warm" La Niña is likely unfolding or about to unfold. In a similar way, we observed the "wet-type" September-October signal preceding an El Niño drying trend.

Upon closer scrutiny of the record of three-month running means for each La Niña, a unique climate signal can be isolated. If one looks at the three three-month periods that occur shortly before the SST Max, there is a strong tendency for two successive three-month running means to indicate significant positive departures from normal (>1.2^{o}). This long period of "very warm" weather typically occurs between late summer (the "JAS" period) and early winter (the "NDJ" period). If one is confident that the La Niña is approaching its maximum SST and two successive three-month running means appear that indicate *significant warmth*, there is a strong likelihood that a "very warm" La Niña is in the early stages of unfolding. Such a signal occurred four times in the La Niña record, with all four of them associated with an unusually long period of "very warm" weather at Nashville, extending well past the SST Max. When this criteria was met (i.e., this "unique signal" was observed), there were three to six subsequent periods, after the SST Max, where the three-month running means were "very warm," generally extending from late fall (the "OND" period) all the way through early spring (the "FMA" period). Again, based on the La Niña record, this signal was correlated with an unusually long period of "very warm" conditions 100% of the time. Even though this signal did not give advance indication of the onset of "very warm" conditions, it usually showed up during the late summer and fall and indicated that an unusually long period of "very warm" conditions was underway and would likely last through the upcoming winter and early spring. Also, as indicated in Section 5, there is some evidence to suggest that the increasing warmth is also most likely if the SST anomaly is >0.5°.

Note: As this study was entering its final stages, during the late summer and early fall of 2007, a strong La Niña was unfolding. The five, three-month periods between JAS and OND (2007) provided multiple consecutive cases where the "very warm" temperature signal showed up. Thus, based on the theory just presented, it was assumed that a "very warm" La Niña was in the process of unfolding. If positive verification of this theory was to occur, the periods "OND, 2007" through "FMA, 2008" would necessarily have to reveal "very warm" conditions. In the final analysis, four out of five of those periods were "very warm" and one was "near normal." Although, the forecast wasn't perfect (i.e., five out of five periods exhibiting "very warm" conditions), it was nearly perfect (i.e., four out of five periods verified as "very warm"). Indeed, the average departure for all five periods turned out to be +3.4°. Thus, it appears that the original theory may be quite useful in determining when an unfolding La Niña is likely to produce an extended period of very warm conditions at Nashville, extending from late summer through early spring.

Table 5. La Niña Events Exhibiting Significant Warmth

Event	SST Max period	Two warmest consecutive periods within the SST Max - 3 window		Successive back-to-back periods with "very warm" weather	Average warmth following the "very warm" signal
La Niña 1950-1951	DJF 1950	Cannot be determined*		N/A	N/A
La Niña 1954-1957	OND 1955	2.6° (JAS)	1.1° (ASO)	Criteria not met**	Criteria not met
La Niña 1961-1962	ASO 1961	Cannot be determined		N/A	N/A
La Niña 1964-1965	SON 1964	-1.2° (JJA)	-1.7° (JAS)	Criteria not met	Criteria not met

La Niña 1967-1968	JFM 1968	-1.7° (OND)	-3.0° (NDJ)	Criteria not met	Criteria not met
La Niña 1970-1972	DJF 1971	1.3° (SON)	0.7° (OND)	Criteria not met	Criteria not met
La Niña 1973-1974	NDJ 1973	3.0° (ASO)	5.3° (SON)	6 (OND – MAM)	+3.3°
La Niña 1974-1976	NDJ 1975	2.5° (OND)	1.5° (NDJ)	3 (DJF – FMA)	+4.5°
La Niña 1983-1984	OND 1983	Cannot be determined		N/A	N/A
La Niña 1984-1985	NDJ 1984	Cannot be determined		N/A	N/A
La Niña 1988-1989	OND 1988	2.0° (JAS)	-0.7° (ASO)	Criteria not met	Criteria not met
La Niña 1995-1996	NDJ 1995	1.2° (ASO)	-2.5° (SON)	Criteria not met	Criteria not met
La Niña 1998-2000	DJF 1999	3.6° (SON)	2.6° (OND)	3 (NDJ – JFM)	+3.6°
	NDJ 1999	2.2° (OND)	3.4° (NDJ)	3 (DJF – FMA)	+3.4°
La Niña 2000-2001	OND 2000	Cannot be determined		N/A	N/A

* If at least three three-month periods prior to the SST Max were not part of the La Niña record, the criteria (i.e., the "unique signal") could not be determined.

** Provided the La Niña record included three three-month periods prior to the SST Max, but two successive three-month running means of sufficient warmth (i.e., departure from normal >1.2°) did not occur, the status of the unique signal was "criteria not met."

All of the ten cases just discussed are unique insomuch as they exhibit times when there was a distinct absence of short-term climate signals of the "cool" variety. The remaining five cases, characterized by La Niña events that occurred when cool-type signals were in place, represent a minority of the data. However, just as with the El Niño record, these cases represent an important subset because of the strong positive correlation between the signals and the observed conditions. Every time La Niña occurred when one of the short-term temperature signals was "cool," "very cool," or "cooling," the observed conditions were in sync (i.e., the observed average temperature was below normal). This correlation is very similar to the one found for El Niños that occurred during the climatologically cool period of the late 1950's and 1960's. Indeed, of the three times when La Niña was associated with a prevailing short-term climate signal that was "very cool" we find all of them sandwiched in the 1960's, with observed conditions ranging from "near normal" to "very cool."

Finding #2: The precipitation record for La Niña events is highly ambiguous. The most common prevailing short-term precipitation signal was "near normal," which occurred on thirteen out of fifteen cases. The short-term precipitation trend signals ran the gamut, ranging anywhere from "decreasing," to "stable," to "rapidly increasing." There were no short-term precipitation signal combinations that correlated with any particular type of observed precipitation.

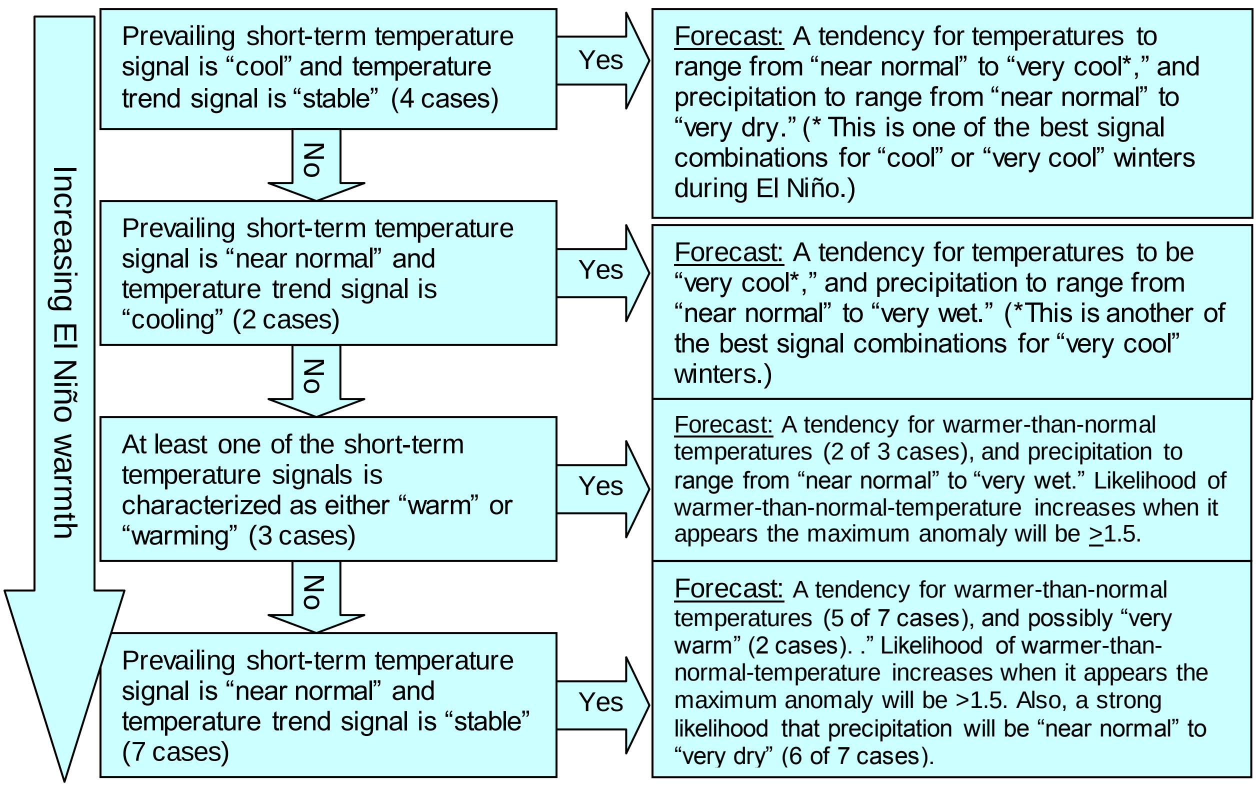
An interesting feature of the La Niña precipitation record is that whenever observed precipitation averages veered away from normal, they usually veered toward the extreme. For instance, of the seven cases that were not "near normal," six of them were either "very wet" or "very dry." In addition, five of the seven cases represented observed conditions that were anomalous (i.e., were dissimilar from both of the short-term climate signals). There were no particular short-term climate signals, or combinations thereof, that were associated with observed conditions that were either "very wet" or "very dry."

There were several cross-correlations, between observed temperature and observed precipitation, which seemed to show up in the data. For instance, of the three La Niña events when the average observed precipitation was "wet" or "very wet" the average observed temperature was *always* "very warm." Observed conditions that were "wet" or "very wet" *never* occurred with observed conditions that were "cool" or "very cool." Conversely, whenever observed conditions were "cool," "very cool" or "cooling," average precipitation ranged from "near normal" to "very dry." There was only a single case when "very dry" weather was associated with a "very warm" short-term temperature signal, and that occurred during the second ENSO maximum anomaly of the 1998-2000 La Niña.

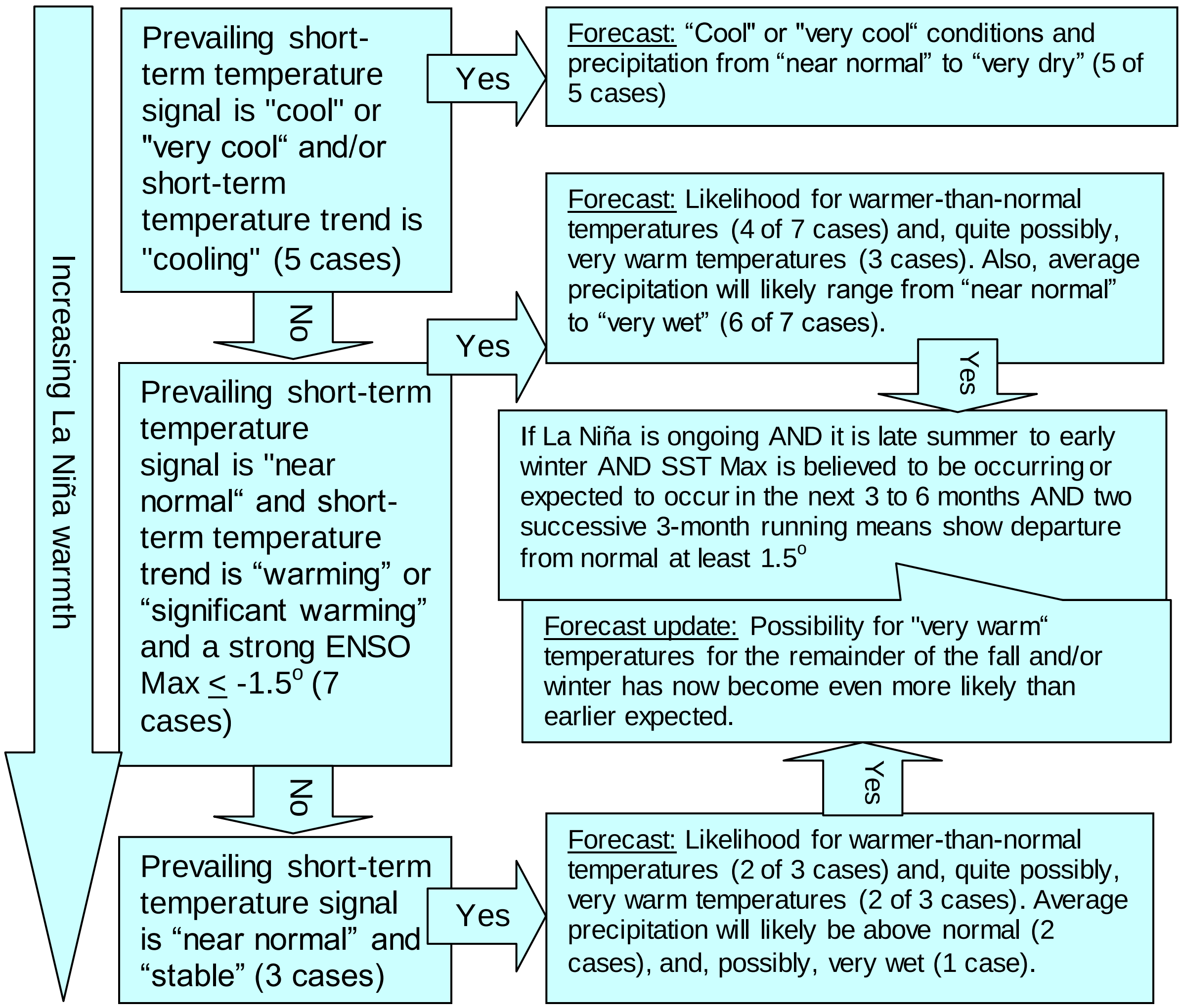
Finding #3: As with El Niño, it is important to note that in the absence of using a short-term "climate filter," it cannot be demonstrated that La Niña events between 1950 and 2001 (for the PLavg period) were associated with either drier-than-normal or wetter-than-normal conditions at Nashville, or with the significance of departure from normal. This was revealed in Section 5.1. Similarly, in the absence of using a short-term "climate filter," it cannot be demonstrated that La Niña events were associated with either colder-than-normal or warmer-than-normal conditions at Nashville. However, in regard to temperatures, there was some evidence that significant departures from normal during La Niña events were more common that insignificant departures. Nine of fifteen La Niñas exhibited average observed temperatures $>|1.2^{o}F|$. Nevertheless, it was only after the application of the "climate filter" that the preceding conclusions regarding La Niña temperatures became most clearly evident. Once again, it is asserted that regional or localized ENSO studies that do not give proper attention to, and consideration of, the effects of short-term climate variability, may misjudge the general nature of the weather that occurs at certain locations during ENSO events. On the other hand, the La Niña precipitation record was found to be so highly ambiguous that not even application of the climate filter could reveal any clear correlations.

3. *Operational forecast applicability -- A word of caution.*

Can any of these established scenarios be used to predict the general weather conditions at Nashville during an upcoming El Niño or La Niña? As far as trends in precipitation during El Niño events or extended very warm spells during La Niña are concerned, the answer is likely "yes." However, based on the criteria used to define the short-term climate signals in this study, the answer must otherwise be "no." This is largely due to the fact that someone making a forecast in the same year that an El Niño event is occurring will not have access to all of the five-year running mean annual data required to establish the short-term climate signals. Remember, calculation of both the climate trend signal and the prevailing climate signal involved the use of running means for several "post SST Maximum" years. The data for these years, of course, will be unknown at the time of the event. However, if a reasonable, educated guess can be made regarding the applicable climate signals, the following forecast flow charts could then be used to make a general prediction:



Flowchart for making seasonal or multi-month forecasts for Nashville during El Niño events using prevailing short-term temperature and temperature trends



Flowchart for making seasonal or multi-month forecasts for Nashville during La Niña events using prevailing short-term precipitation and precipitation trends

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VIII. Acknowledgements

The authors thank the following individuals for their reviews and assistance with this paper: Rusty Billingsley, Scientific and Technology Services Division Chief, National Weather Service Southern Region Headquarters, Fort Worth, TX; Chris Darden, Science and Operations Officer, WFO Huntsville, AL; Jon Zeitler, Science and Operations Officer, WFO Austin/San Antonio, TX; Henry Steigerwaldt, Science and Operations Officer, Larry Vannozzi, Meteorologist-in-Charge, and Tom Johnstone, Warning Coordination Meteorologist, WFO Nashville, TN.

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Appendix 1. Summary of El Niño Events and Related Meteorological Data

Table 6. El Niño 1957-1958										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1921-1950)	Departure from Normal		Total during Period	Normal (1921-1950)	Ratio of Total to Normal	
1957	MAM	0.6	60.3	59.2	1.1	**TPM**	13.87	12.75	1.09	**TPM**
1957	AMJ	0.7	70.0	68.3	1.7	1.0	18.08	10.66	1.70	1.45
1957	MJJ	0.8	75.3	75.0	0.3	0.4	17.12	10.93	1.57	1.45
1957	JJA	0.9	77.9	78.6	-0.7	-0.4	11.44	10.46	1.09	1.17
1957	JAS	0.9	76.4	77.3	-0.9	-1.3	8.47	10.01	0.85	1.06
1957	ASO	0.8	68.8	71.2	-2.4	-1.8	10.53	8.57	1.23	1.24
1957	SON	0.9	59.2	61.4	-2.2	-1.8	14.29	8.67	1.65	1.50*
1957	OND	1.2	50.0	50.9	-0.9	-1.3*	16.04	9.99	1.61	1.48
1957	NDJ	1.5	42.8	43.5	-0.7	-1.9	14.75	12.40	1.19	1.19
1958	DJF	1.6	37.2	41.2	-4.0	-4.0	10.05	13.15	0.76	0.84
1958	JFM	1.5	36.9	44.1	-7.2	-5.8	8.13	14.37	0.57	0.74
1958	FMA	1.1	44.7	50.8	-6.1	-5.2	11.88	13.13	0.90	0.83
1958	MAM	0.7	56.8	59.2	-2.4	-3.2	12.99	12.75	1.02	1.03
1958	AMJ	0.5	67.2	68.3	-1.1	-1.4	12.37	10.66	1.16	1.10
1958	MJJ	0.5	74.4	75.0	-0.6		12.17	10.93	1.11	

Table 7. El Niño 1963-1964										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1931-1960)	Departure from Normal		Total during Period	Normal (1931-1960)	Ratio of Total to Normal	
1963	JJA	0.6	76.7	79.0	-2.3	**TPM**	16.05	9.83	1.63	**TPM**
1963	JAS	0.8	74.8	77.5	-2.7	-1.8	16.39	9.45	1.73	1.58
1963	ASO	0.8	70.8	71.1	-0.3	-0.8	11.06	8.05	1.37	1.26
1963	SON	0.9	61.6	60.9	0.7	-0.6*	5.86	8.47	0.69	0.84
1963	OND	1.0	48.4	50.5	-2.1	-1.7	4.58	9.79	0.47	0.60
1963	NDJ	1.0	39.5	43.2	-3.7	-3.8	8.28	12.96	0.64	0.58
1964	DJF	0.8	35.5	41.1	-5.6		9.11	14.19	0.64	

Table 8. El Niño 1965-1966										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1931-1960)	Departure from Normal		Total during Period	Normal (1931-1960)	Ratio of Total to Normal	
1965	MJJ	0.6	75.1	75.4	-0.3	**TPM**	9.18	10.69	0.86	**TPM**
1965	JJA	1.0	77.6	79.0	-1.4	-0.7	8.59	9.83	0.87	0.96

1965	JAS	1.2	77.2	77.5	-0.3	-0.7	10.87	9.45	1.15	1.01*
1965	ASO	1.4	70.7	71.1	-0.4	0.0	8.12	8.05	1.01	1.01*
1965	SON	1.5	61.7	60.9	0.8	0.6	7.41	8.47	0.87	0.74
1965	OND	1.6	52.0	50.5	1.5	0.7	3.40	9.79	0.35	0.58
1965	NDJ	1.5	42.9	43.2	-0.3	-0.2	6.76	12.96	0.52	0.49
1966	DJF	1.2	39.4	41.1	-1.7	-1.5	8.57	14.19	0.60	0.57
1966	JFM	1.1	41.3	43.7	-2.4	-1.4	8.95	15.19	0.59	0.65
1966	FMA	0.8	50.3	50.4	-0.1	-1.2	10.10	13.44	0.75	0.72
1966	MAM	0.5	58.1	59.1	-1.0		10.46	12.65	0.83	

Table 9. El Niño 1968-1969										
Year	**Period**	**SST Anomaly**	**Temperature Data**				**Precipitation Data**			
			Average during Period	**Normal (1931-1960)**	**Departure from Normal**		**Total during Period**	**Normal (1931-1960)**	**Ratio of Total to Normal**	
1968	OND	0.6	48.8	50.5	-1.7	**TPM**	12.89	9.79	1.32	**TPM**
1968	NDJ	0.9	41.2	43.2	-2.0	-2.2	13.93	12.96	1.07	1.10
1969	DJF	1.0	38.3	41.1	-2.8	-2.9	13.02	14.19	0.92	0.92
1969	JFM	1.0	39.8	43.7	-3.9	-3.1	11.56	15.19	0.76	0.87
1969	FMA	0.9	47.8	50.4	-2.6	-2.7	12.63	13.44	0.94	0.91
1969	MAM	0.7	57.4	59.1	-1.7	-1.3	12.96	12.65	1.02	1.01
1969	AMJ	0.6	69.0	68.5	0.5		14.18	13.08	1.08	

Table 10. El Niño 1969-1970										
Year	**Period**	**SST Anomaly**	**Temperature Data**				**Precipitation Data**			
			Average during Period	**Normal (1931-1960)**	**Departure from Normal**		**Total during Period**	**Normal (1931-1960)**	**Ratio of Total to Normal**	
1969	ASO	0.6	69.8	71.1	-1.3	**TPM**	6.34	8.05	0.79	**TPM**
1969	SON	0.7	59.3	60.9	-1.6	-1.8	5.90	8.47	0.70	0.70
1969	OND	0.7	48.1	50.5	-2.4	-2.9	11.87	9.79	1.21	0.92
1969	NDJ	0.6	38.6	43.2	-4.6	-4.1	11.02	12.96	0.85	1.00
1970	DJF	0.5	35.9	41.1	-5.2		13.55	14.19	0.95	

Table 11. El Niño 1972-1973										
Year	**Period**	**SST Anomaly**	**Temperature Data**				**Precipitation Data**			
			Average during Period	**Normal (1941-1970)**	**Departure from Normal**		**Total during Period**	**Normal (1941-1970)**	**Ratio of Total to Normal**	
1972	AMJ	0.5	66.9	68.4	-1.5	**TPM**	9.64	11.59	0.83	**TPM**
1972	MJJ	0.8	72.5	74.9	-2.4	-2.1	12.46	11.31	1.10	1.07
1972	JJA	1.1	75.8	78.3	-2.5	-1.7	13.24	10.45	1.27	1.26
1972	JAS	1.3	76.7	76.8	-0.1	-0.7	14.41	10.16	1.42	1.37

1972	ASO	1.5	71.0	70.5	0.5	0.3	12.07	8.49	1.42	1.44
1972	SON	1.8	61.0	60.4	0.6	0.4*	12.99	8.71	1.49	1.55*
1972	OND	2.0	50.1	49.9	0.2	0.4*	17.42	10.07	1.73	1.51
1972	NDJ	2.1	42.6	42.3	0.3	0.3	16.76	12.66	1.32	1.39
1973	DJF	1.8	40.2	39.9	0.3	0.9	15.17	13.63	1.11	1.31
1973	JFM	1.2	44.9	42.7	2.2	1.2	16.91	14.18	1.19	1.27
1973	FMA	0.5	51.2	50.1	1.1		20.51	13.54	1.51	

Table 12. El Niño 1976-1977

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1941-1970)	Departure from Normal		Total during Period	Normal (1941-1970)	Ratio of Total to Normal	
1976	ASO	0.5	65.0	70.5	-5.5	**TPM**	18.30	8.49	2.16	**TPM**
1976	SON	0.7	53.8	60.4	-6.6	-6.1	11.55	8.71	1.33	1.44
1976	OND	0.8	43.8	49.9	-6.1	-7.0	8.28	10.07	0.82	0.87
1976	NDJ	0.8	33.9	42.3	-8.4	-6.9	5.64	12.66	0.45	0.61
1977	DJF	0.6	33.6	39.9	-6.3	-5.9	7.61	13.63	0.56	0.61
1977	JFM	0.5	39.6	42.7	-3.1		11.63	14.18	0.82	

Table 13. El Niño 1977-1978

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1941-1970)	Departure from Normal		Total during Period	Normal (1941-1970)	Ratio of Total to Normal	
1977	ASO	0.5	70.1	70.5	-0.4	**TPM**	13.91	8.49	1.64	**TPM**
1977	SON	0.7	60.5	60.4	0.1	-0.5	15.22	8.71	1.75	1.61
1977	OND	0.8	48.7	49.9	-1.2	-1.5	14.43	10.07	1.43	1.49
1977	NDJ	0.8	38.8	42.3	-3.5	-4.3	16.16	12.66	1.28	1.19
1978	DJF	0.7	31.8	39.9	-8.1		11.77	13.63	0.86	

Table 14. El Niño 1982-1983

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1951-1980)	Departure from Normal		Total during Period	Normal (1951-1980)	Ratio of Total to Normal	
1982	AMJ	0.6	66.3	67.8	-1.5	**TPM**	10.83	12.73	0.85	**TPM**
1982	MJJ	0.7	74.7	74.4	0.3	-0.9	11.94	12.08	0.99	0.96
1982	JJA	0.8	76.4	77.9	-1.5	-0.9	11.21	10.92	1.03	1.04
1982	JAS	1.0	75.2	76.7	-1.5	-1.5*	12.16	10.93	1.11	1.01
1982	ASO	1.5	68.9	70.3	-1.4	-0.9	8.60	9.69	0.89	0.97
1982	SON	1.9	60.7	60.4	0.3	0.9	9.01	9.81	0.92	0.97
1982	OND	2.2	53.6	49.9	3.7	2.7	12.14	10.73	1.13	1.02*

1982	NDJ	2.3	46.1	42.1	4.0	3.8	12.79	12.64	1.01	1.01
1983	DJF	2.3	43.2	39.4	3.8	3.2	11.85	13.15	0.90	0.85
1983	JFM	2.0	43.9	42.2	1.7	1.6	8.93	14.10	0.63	0.82
1983	FMA	1.6	49.3	49.9	-0.6	-0.4	13.17	14.08	0.94	1.01
1983	MAM	1.2	56.5	58.9	-2.4	-2.0	21.28	14.61	1.46	1.37
1983	AMJ	1.0	64.9	67.8	-2.9	-2.0	21.77	12.73	1.71	1.51
1983	MJJ	0.6	73.6	74.4	-0.8		16.68	12.08	1.38	

Table 15. El Niño 1986-1988

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1951-1980)	Departure from Normal		Total during Period	Normal (1951-1980)	Ratio of Total to Normal	
1986	JAS	0.5	78.0	76.7	1.3	**TPM**	6.34	10.93	0.58	**TPM**
1986	ASO	0.7	70.8	70.3	0.5	1.1	7.76	9.69	0.80	0.86
1986	SON	0.9	61.9	60.4	1.5	0.8	11.81	9.81	1.20	1.07
1986	OND	1.1	50.2	49.9	0.3	0.5	12.93	10.73	1.21	1.13*
1986	NDJ	1.2	41.9	42.1	-0.2	0.1*	12.35	12.64	0.98	0.98
1987	DJF	1.3	39.6	39.4	0.2	0.5	9.79	13.15	0.74	0.75
1987	JFM	1.2	43.7	42.2	1.5	0.9	7.66	14.10	0.54	0.59
1987	FMA	1.1	51.0	49.9	1.1	1.6	7.08	14.08	0.50	0.50
1987	MAM	1.0	61.0	58.9	2.1	1.6	6.62	14.61	0.45	0.53
1987	AMJ	1.0	69.5	67.8	1.7	2.1*	8.26	12.73	0.65	0.64
1987	MJJ	1.2	77.0	74.4	2.6	2.0	9.79	12.08	0.81	0.67*
1987	JJA	1.5	79.6	77.9	1.7	1.8	6.11	10.92	0.56	0.62
1987	JAS	1.6	77.9	76.7	1.2	0.6	5.24	10.93	0.48	0.45
1987	ASO	1.6	69.2	70.3	-1.1	-0.2	2.89	9.69	0.30	0.45
1987	SON	1.5	59.6	60.4	-0.8	-0.5	5.56	9.81	0.57	0.57
1987	OND	1.3	50.3	49.9	0.4	0.3	9.07	10.73	0.85	0.81
1987	NDJ	1.1	43.5	42.1	1.4	0.5	12.59	12.64	1.00	0.90
1988	DJF	0.8	39.0	39.4	-0.4	-0.1	11.21	13.15	0.85	0.80
1988	JFM	0.5	40.8	42.2	-1.4		7.93	14.10	0.56	

Table 16. El Niño 1991-1992

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1961-1990)	Departure from Normal		Total during Period	Normal (1961-1990)	Ratio of Total to Normal	
1991	AMJ	0.6	72.0	67.5	4.5	**TPM**	10.23	12.82	0.80	**TPM**
1991	MJJ	0.8	77.8	74.2	3.6	3.2	9.70	12.42	0.78	0.70
1991	JJA	0.9	79.2	77.7	1.5	2.0	5.86	11.00	0.53	0.75
1991	JAS	0.9	77.3	76.5	0.8	0.9	10.08	10.89	0.95	0.89
1991	ASO	0.8	70.6	70.1	0.5	0.3	11.14	9.54	1.18	1.13

1991	SON	1.0	60.2	60.7	-0.5	0.2*	12.22	10.20	1.20	1.22*
1991	OND	1.4	51.0	50.3	0.7	0.6	14.02	11.35	1.27	1.17
1991	NDJ	1.7	43.8	42.1	1.7	2.3	13.11	12.31	1.05	1.13
1992	DJF	1.8	43.4	39.0	4.4	3.0	12.84	12.00	1.00	0.93
1992	JFM	1.7	45.3	42.3	3.0	3.0	10.07	12.24	0.75	0.78
1992	FMA	1.6	51.9	50.2	1.7	1.4	7.87	13.03	0.60	0.65
1992	MAM	1.4	58.5	59.0	-0.5	-0.1	8.39	14.10	0.61	0.62
1992	AMJ	1.1	65.9	67.5	-1.6	-1.2	8.20	12.82	0.64	0.77
1992	MJJ	0.8	72.7	74.2	-1.5		13.32	12.42	1.05	

Table 17. El Niño 1993

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1961-1990)	Departure from Normal		Total during Period	Normal (1961-1990)	Ratio of Total to Normal	
1993	FMA	0.6	47.9	50.2	-2.3	**TPM**	12.16	13.03	0.93	**TPM**
1993	MAM	0.8	57.1	59.0	-1.9	-1.7	13.33	14.10	0.95	0.97
1993	AMJ	0.8	66.7	67.5	-0.8	-0.5	13.14	12.82	1.02	1.03
1993	MJJ	0.7	75.5	74.2	1.3	1.0	13.45	12.42	1.08	1.02
1993	JJA	0.5	80.1	77.7	2.4		10.71	11.00	0.97	

Table 18. El Niño 1994-1995

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1961-1990)	Departure from Normal		Total during Period	Normal (1961-1990)	Ratio of Total to Normal	
1994	MAM	0.5	59.0	59.0	0.0	**TPM**	17.04	14.10	1.21	**TPM**
1994	AMJ	0.6	68.1	67.5	0.6	0.0	17.56	12.82	1.37	1.31
1994	MJJ	0.6	73.5	74.2	-0.7	0.0	16.66	12.42	1.34	1.45*
1994	JJA	0.6	77.9	77.7	0.2	-0.7	17.95	11.00	1.63	1.42
1994	JAS	0.6	74.9	76.5	-1.6	-0.8*	14.07	10.89	1.29	1.41
1994	ASO	0.7	69.0	70.1	-1.1	-0.6	12.56	9.54	1.32	1.25
1994	SON	0.9	61.5	60.7	0.8	1.0	11.55	10.20	1.13	1.11
1994	OND	1.2	53.5	50.3	3.2	2.6	10.04	11.35	0.88	1.00
1994	NDJ	1.3	46.0	42.1	3.9	3.2	12.34	12.31	1.00	0.91
1995	DJF	1.2	41.4	39.0	2.4	2.7	10.11	12.00	0.84	0.92
1995	JFM	0.9	44.2	42.3	1.9	2.0	11.29	12.24	0.92	0.83
1995	FMA	0.7	51.8	50.2	1.6		9.63	13.03	0.74	

Table 19. El Niño 1997-1998

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during	Normal (1961-	Departure from		Total during	Normal (1961-	Ratio of Total to	

			Period	1990)	Normal		Period	1990)	Normal	
1997	AMJ	0.9	63.2	67.5	-4.3	**TPM**	14.00	12.82	1.09	**TPM**
1997	MJJ	1.4	71.6	74.2	-2.6	-2.8	14.84	12.42	1.19	1.17
1997	JJA	1.7	76.2	77.7	-1.5	-1.5	13.44	11.00	1.22	1.19
1997	JAS	2.0	76.2	76.5	-0.3	-0.8	12.53	10.89	1.15	1.21
1997	ASO	2.3	69.5	70.1	-0.6	-0.8	11.98	9.54	1.26	1.30*
1997	SON	2.4	59.1	60.7	-1.6	-1.4*	15.05	10.20	1.48	1.25
1997	OND	2.5	48.3	50.3	-2.0	-0.8	11.49	11.35	1.01	1.17
1997	NDJ	2.5	43.2	42.1	1.1	1.1	12.46	12.31	1.01	0.95
1998	DJF	2.4	43.3	39.0	4.3	3.3	9.98	12.00	0.83	0.91
1998	JFM	2.0	46.7	42.3	4.4	3.2	10.92	12.24	0.89	0.92
1998	FMA	1.4	51.2	50.2	1.0	2.0	13.55	13.03	1.04	0.97
1998	MAM	1.1	59.6	59.0	0.6		13.90	14.10	0.99	

Table 20. El Niño 2002-2003

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1971-2000)	Departure from Normal		Total during Period	Normal (1971-2000)	Ratio of Total to Normal	
2002	AMJ	0.7	68.2	66.9	1.3	**TPM**	12.05	13.08	0.93	**TPM**
2002	MJJ	0.8	74.2	73.8	0.4	1.1	13.38	12.92	1.06	1.04
2002	JJA	0.9	79.0	77.4	1.6	1.4	12.53	11.86	1.13	1.20
2002	JAS	0.9	78.4	76.1	2.3	2.1*	15.06	10.64	1.42	1.34
2002	ASO	1.1	72.1	69.7	2.4	1.8	13.90	9.74	1.47	1.41*
2002	SON	1.3	60.9	60.2	0.7	0.9	13.68	10.19	1.34	1.33
2002	OND	1.5	49.5	49.9	-0.4	-0.7	13.00	11.86	1.19	1.26
2002	NDJ	1.3	39.8	42.2	-2.4	-1.7	10.31	12.96	0.82	1.08
2003	DJF	1.1	37.1	39.5	-2.4	-2.2	15.87	12.20	1.23	0.99
2003	JFM	0.8	41.0	42.7	-1.7	-1.1	12.36	12.53	0.93	1.11
2003	FMA	0.6	50.7	50.0	0.7		15.46	12.49	1.17	

Appendix 2. Summary of La Niña Events and Related Meteorological Data

Table 21. La Niña 1950-1951										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1911-1940)	Departure from Normal		Total during Period	Normal (1911-1940)	Ratio of Total to Normal	
1950	DJF	-1.8	45.4	40.4	5.0	**TPM**	27.38	13.09	2.09	**TPM**
1950	JFM	-1.5	46.6	43.2	3.4	2.4	25.47	14.00	1.82	1.63
1950	FMA	-1.4	48.8	50.1	-1.3	0.3	13.13	13.37	0.98	1.17
1950	MAM	-1.4	57.7	58.8	-1.1	-0.9	9.45	13.11	0.72	0.86
1950	AMJ	-1.4	67.3	67.6	-0.3	-0.5	10.37	12.00	0.86	1.00
1950	MJJ	-1.2	74.3	74.3	0.0	-0.9	16.54	11.75	1.41	1.31
1950	JJA	-0.9	75.2	77.5	-2.3	-1.8	19.10	11.59	1.65	1.56
1950	JAS	-0.8	73.1	76.3	-3.2	-2.1	18.00	11.01	1.63	1.51
1950	ASO	-0.8	69.3	70.2	-0.9	-1.9	11.90	9.62	1.24	1.38
1950	SON	-0.8	59.0	60.6	-1.6	-1.8	11.84	9.41	1.26	1.17
1950	OND	-0.9	47.3	50.3	-3.0	-2.8	10.42	10.19	1.02	1.28
1950	NDJ	-1.0	39.0	42.8	-3.8	-2.9	19.31	12.46	1.55	1.26
1951	DJF	-1.0	38.6	40.4	-1.8	-1.7	15.65	13.09	1.20	1.36
1951	JFM	-0.8	43.8	43.2	0.6	-0.8	18.64	14.00	1.33	1.16
1951	FMA	-0.6	49.0	50.1	-1.1		12.85	13.37	0.96	

Table 22. La Niña 1954-1957										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1921-1950)	Departure from Normal		Total during Period	Normal (1921-1950)	Ratio of Total to Normal	
1954	MAM	-0.5	58.8	59.2	-0.4	**TPM**	12.44	12.75	0.98	**TPM**
1954	AMJ	-0.7	68.7	68.3	0.4	0.0	10.64	10.66	1.00	0.87
1954	MJJ	-0.7	75.0	75.0	0.0	1.1	6.93	10.93	0.63	0.70
1954	JJA	-0.8	81.5	78.6	2.9	2.2	4.74	10.46	0.45	0.58
1954	JAS	-1.0	81.1	77.3	3.8	3.0	6.60	10.01	0.66	0.71
1954	ASO	-1.1	73.4	71.2	2.2	2.2	8.82	8.57	1.03	0.88
1954	SON	-1.1	62.1	61.4	0.7	0.6	8.33	8.67	0.96	0.98
1954	OND	-1.0	49.8	50.9	-1.1	-0.7	9.62	9.99	0.96	0.85
1954	NDJ	-1.0	41.9	43.5	-1.6	-1.4	7.94	12.40	0.64	0.88
1955	DJF	-1.0	39.8	41.2	-1.4	-1.2	13.58	13.15	1.03	0.97
1955	JFM	-0.9	43.5	44.1	-0.6	-0.1	17.88	14.37	1.24	1.30
1955	FMA	-0.9	52.4	50.8	1.6	1.3	21.25	13.13	1.62	1.41
1955	MAM	-1.0	62.0	59.2	2.8	1.7	17.41	12.75	1.37	1.32
1955	AMJ	-1.1	68.9	68.3	0.6	1.1	10.48	10.66	0.98	1.02
1955	MJJ	-1.0	75.0	75.0	0.0	0.1	7.62	10.93	0.70	0.84

1955	JJA	-1.0	78.3	78.6	-0.3	0.8	8.72	10.46	0.83	0.84
1955	JAS	-1.0	79.9	77.3	2.6	1.1*	10.04	10.01	1.00	1.01
1955	ASO	-1.5	72.3	71.2	1.1	1.0	10.32	8.57	1.20	1.12*
1955	SON	-1.8	60.8	61.4	-0.6	-0.6	10.08	8.67	1.16	1.02
1955	OND	-2.1	48.5	50.9	-2.4	-2.0	7.03	9.99	0.70	0.91
1955	NDJ	-1.7	40.4	43.5	-3.1	-2.0	10.66	12.40	0.86	0.95
1956	DJF	-1.2	40.6	41.2	-0.6	-1.3	17.00	13.15	1.29	1.18
1956	JFM	-0.8	44.0	44.1	-0.1	0.0	20.06	14.37	1.40	1.37
1956	FMA	-0.7	51.4	50.8	0.6	0.1	18.62	13.13	1.42	1.23
1956	MAM	-0.6	59.1	59.2	-0.1	0.1	11.18	12.75	0.88	1.06
1956	AMJ	-0.6	68.0	68.3	0.3	0.1	9.52	10.66	0.89	0.81
1956	MJJ	-0.6	75.8	75.0	0.8	0.3	7.23	10.93	0.66	0.72
1956	JJA	-0.7	79.1	78.6	0.5	0.5	6.25	10.46	0.60	0.56
1956	JAS	-0.8	77.5	77.3	0.2	0.4	4.11	10.01	0.41	0.50
1956	ASO	-0.9	71.7	71.2	0.5	0.1	4.16	8.57	0.49	0.45
1956	SON	-0.9	61.0	61.4	-0.4	1.1	4.00	8.67	0.46	0.66
1956	OND	-0.9	54.0	50.9	3.1	1.4	10.25	9.99	1.03	0.97
1956	NDJ	-0.8	45.1	43.5	1.6	2.8	17.65	12.40	1.42	1.35
1957	DJF	-0.5	45.0	41.2	3.8		21.16	13.15	1.61	

Table 23. La Niña 1961-1962

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1931-1960)	Departure from Normal		Total during Period	Normal (1931-1960)	Ratio of Total to Normal	
1961	ASO	-0.6	69.8	71.1	-1.3	**TPM**	4.09	8.05	0.51	**TPM**
1961	SON	-0.6	60.9	60.9	0.0	-0.6	5.34	8.47	0.63	0.77
1961	OND	-0.5	50.1	50.5	-0.4	-0.6	11.49	9.79	1.17	1.04
1961	NDJ	-0.5	41.9	43.2	-1.3	-0.7	16.88	12.96	1.30	1.34
1962	DJF	-0.5	40.6	41.1	-0.5	-1.1	22.08	14.19	1.56	1.42
1962	JFM	-0.5	42.1	43.7	-1.6	-1.1	21.47	15.19	1.41	1.53
1962	FMA	-0.5	49.2	50.4	-1.2	-1.0	21.87	13.44	1.63	1.40
1962	MAM	-0.5	58.8	59.1	-0.3		14.67	12.65	1.16	

Table 24. La Niña 1964-1965

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1931-1960)	Departure from Normal		Total during Period	Normal (1931-1960)	Ratio of Total to Normal	
1964	MAM	-0.5	60.3	59.1	1.2	**TPM**	14.91	12.65	1.18	**TPM**
1964	AMJ	-0.7	69.9	68.5	1.4	0.8	12.11	10.71	1.13	1.03
1964	MJJ	-0.7	75.3	75.4	-0.1	0.0	8.41	10.69	0.79	0.91
1964	JJA	-0.8	77.8	79.0	-1.2	-1.0	7.93	9.83	0.81	0.86*

1964	JAS	-0.9	75.8	77.5	-1.7	-1.9*	9.37	9.45	0.99	0.97
1964	ASO	-1.0	68.3	71.1	-2.8	-1.9*	9.04	8.05	1.12	1.03
1964	SON	-1.1	59.8	60.9	-1.1	-1.4	8.15	8.47	0.96	1.06
1964	OND	-1.1	50.3	50.5	-0.2	0.1	10.65	9.79	1.09	0.99
1964	NDJ	-1.0	44.7	43.2	1.5	0.3	11.80	12.96	0.91	0.97
1965	DJF	-0.8	40.8	41.1	-0.3	-0.6	12.84	14.19	0.90	0.91
1965	JFM	-0.5	40.6	43.7	-3.1		13.82	15.19	0.91	

Table 25. La Niña 1967-1968										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1931-1960)	Departure from Normal		Total during Period	Normal (1931-1960)	Ratio of Total to Normal	
1967	SON	-0.5	56.8	60.9	-4.1	**TPM**	7.37	8.47	0.87	**TPM**
1967	OND	-0.5	48.8	50.5	-1.7	-2.9	11.32	9.79	1.16	1.02
1967	NDJ	-0.6	40.2	43.2	-3.0	-3.1	13.25	12.96	1.02	0.96
1968	DJF	-0.7	36.4	41.1	-4.7	-4.4	10.02	14.19	0.71	0.77
1968	JFM	-0.9	38.2	43.7	-5.5	-4.7	8.61	15.19	0.57	0.64
1968	FMA	-0.8	46.5	50.4	-3.9	-3.6	8.68	13.44	0.65	0.78
1968	MAM	-0.8	57.6	59.1	-1.5		14.32	12.65	1.13	

Table 26. La Niña 1970-1972										
Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1941-1970)	Departure from Normal		Total during Period	Normal (1941-1970)	Ratio of Total to Normal	
1970	JJA	-0.6	76.7	78.3	-1.6	**TPM**	13.33	10.45	1.28	**TPM**
1970	JAS	-0.8	77.8	76.8	1.0	0.4	9.36	10.16	0.92	1.07
1970	ASO	-0.8	72.3	70.5	1.8	1.4*	8.69	8.49	1.02	0.95
1970	SON	-0.8	61.7	60.4	1.3	1.3	7.90	8.71	0.91	0.93
1970	OND	-0.9	50.6	49.9	0.7	0.6	8.74	10.07	0.87	0.81
1970	NDJ	-1.2	42.0	42.3	-0.3	-0.1	8.46	12.66	0.67	0.78
1971	DJF	-1.4	39.2	39.9	-0.7	-1.4	10.96	13.63	0.80	0.73
1971	JFM	-1.4	39.6	42.7	-3.1	-2.2	10.31	14.18	0.73	0.78
1971	FMA	-1.2	47.2	50.1	-2.9	-3.3	10.99	13.54	0.81	0.75
1971	MAM	-1.0	55.2	59.1	-3.9	-3.0	9.22	13.21	0.70	0.78
1971	AMJ	-0.8	66.2	68.4	-2.2	-2.8	9.74	11.59	0.84	0.85
1971	MJJ	-0.8	72.5	74.9	-2.4	-2.0	11.40	11.31	1.01	1.07
1971	JJA	-0.8	76.9	78.3	-1.4	-1.6	14.34	10.45	1.37	1.22
1971	JAS	-0.8	75.9	76.8	-0.9	-0.1	12.98	10.16	1.28	1.25
1971	ASO	-0.9	72.5	70.5	2.0	1.5	9.25	8.49	1.09	0.96
1971	SON	-0.9	63.7	60.4	3.3	3.6	4.56	8.71	0.52	0.79
1971	OND	-1.0	55.3	49.9	5.4	4.4	7.62	10.07	0.76	0.73

1971	NDJ	-0.9	46.9	42.3	4.6	4.8	11.50	12.66	0.91	0.89
1972	DJF	-0.7	44.3	39.9	4.4		13.77	13.63	1.01	

Table 27. La Niña 1973-1974

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1971-2000)	Departure from Normal		Total during Period	Normal (1941-1970)	Ratio of Total to Normal	
1973	AMJ	-0.5	65.5	68.4	-2.9	**TPM**	17.52	11.59	1.51	**TPM**
1973	MJJ	-0.8	72.9	74.9	-2.0	-1.9	18.00	11.31	1.59	1.49
1973	JJA	-1.1	77.6	78.3	-0.7	-0.6	14.26	10.45	1.36	1.35
1973	JAS	-1.3	77.7	76.8	0.9	1.1	11.02	10.16	1.08	1.08
1973	ASO	-1.4	73.5	70.5	3.0	3.1	6.67	8.49	0.79	1.11
1973	SON	-1.7	65.7	60.4	5.3	4.1	12.66	8.71	1.45	1.22
1973	OND	-1.9	53.8	49.9	3.9	4.6*	14.33	10.07	1.42	1.50*
1973	NDJ	-2.0	46.8	42.3	4.5	3.7	20.46	12.66	1.62	1.40
1974	DJF	-1.8	42.6	39.9	2.7	4.0	15.69	13.63	1.15	1.34
1974	JFM	-1.6	47.5	42.7	4.8	3.1	17.71	14.18	1.25	1.10
1974	FMA	-1.2	52.0	50.1	1.9	2.9	12.23	13.54	0.90	1.08
1974	MAM	-1.1	61.2	59.1	2.1	0.8	14.26	13.21	1.08	1.12
1974	AMJ	-0.9	66.7	68.4	-1.7	-0.5	15.81	11.59	1.36	1.23
1974	MJJ	-0.7	73.1	74.9	-1.8	-2.0	13.94	11.31	1.23	1.28
1974	JJA	-0.5	75.7	78.3	-2.6		13.03	10.45	1.25	

Table 28. La Niña 1974-1976

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1941-1970)	Departure from Normal		Total during Period	Normal (1941-1970)	Ratio of Total to Normal	
1974	ASO	-0.5	68.2	70.5	-2.3	**TPM**	16.04	8.49	1.89	**TPM**
1974	SON	-0.7	59.0	60.4	-1.4	-1.0	18.14	8.71	2.08	1.67
1974	OND	-0.8	50.7	49.9	0.8	0.8	10.51	10.07	1.04	1.40
1974	NDJ	-0.7	45.3	42.3	3.0	2.5	13.71	12.66	1.08	1.02
1975	DJF	-0.6	43.5	39.9	3.6	3.0	12.70	13.63	0.93	1.19
1975	JFM	-0.6	45.1	42.7	2.4	2.0	22.24	14.18	1.57	1.35
1975	FMA	-0.7	50.2	50.1	0.1	0.7	21.12	13.54	1.56	1.61
1975	MAM	-0.8	58.7	59.1	-0.4	-0.1	22.42	13.21	1.70	1.44
1975	AMJ	-1.0	68.3	68.4	-0.1	-0.2	12.29	11.59	1.06	1.26
1975	MJJ	-1.1	74.9	74.9	0.0	-0.2	11.70	11.31	1.03	1.01
1975	JJA	-1.3	77.8	78.3	-0.5	-0.7	9.87	10.45	0.94	1.09
1975	JAS	-1.4	75.2	76.8	-1.6	-0.9*	13.07	10.16	1.29	1.37
1975	ASO	-1.6	69.8	70.5	-0.7	-0.6	15.97	8.49	1.88	1.60*
1975	SON	-1.6	60.8	60.4	0.4	0.7	14.28	8.71	1.64	1.60*

1975	OND	-1.7	52.4	49.9	2.5	1.5	12.98	10.07	1.29	1.27
1975	NDJ	-1.8	43.8	42.3	1.5	2.4	11.23	12.66	0.89	0.98
1976	DJF	-1.6	43.2	39.9	3.3	3.2	10.51	13.63	0.77	0.83
1976	JFM	-1.2	47.6	42.7	4.9	4.5	11.71	14.18	0.83	0.76
1976	FMA	-0.9	55.5	50.1	5.4	3.7	9.13	13.54	0.67	0.83
1976	MAM	-0.7	59.9	59.1	0.8	1.2	13.04	13.21	0.99	0.91
1976	AMJ	-0.5	65.7	68.4	-2.7		12.44	11.59	1.07	

Table 29. La Niña 1983-1984

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1951-1980)	Departure from Normal		Total during Period	Normal (1951-1980)	Ratio of Total to Normal	
1983	ASO	-0.5	73.1	70.3	2.8	**TPM**	4.58	9.69	0.47	**TPM**
1983	SON	-0.8	62.0	60.4	1.6	1.1	10.20	9.81	1.04	1.05
1983	OND	-0.9	48.7	49.9	-1.2	-1.1	17.50	10.73	1.63	1.33
1983	NDJ	-0.8	38.5	42.1	-3.6	-2.6	16.52	12.64	1.31	1.28
1984	DJF	-0.5	36.3	39.4	-3.1		11.92	13.15	0.91	

Table 30. La Niña 1984-1985

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1951-1980)	Departure from Normal		Total during Period	Normal (1951-1980)	Ratio of Total to Normal	
1984	SON	-0.6	60.4	60.4	0.0	**TPM**	13.17	9.81	1.29	**TPM**
1984	OND	-1.0	54.2	49.9	4.3	1.1	14.58	10.73	1.32	1.21
1984	NDJ	-1.1	41.1	42.1	-1.0	0.6	11.60	12.64	0.93	0.98
1985	DJF	-1.0	38.0	39.4	-1.4	-1.8	8.70	13.15	0.67	0.74
1985	JFM	-0.8	39.2	42.2	-3.0	-1.2	9.02	14.10	0.68	0.64
1985	FMA	-0.8	50.8	49.9	0.9	0.0	8.91	14.08	0.68	0.61
1985	MAM	-0.8	61.1	58.9	2.2	1.3	8.26	14.61	0.60	0.59
1985	AMJ	-0.7	68.6	67.8	0.8	1.1	7.09	12.73	0.55	0.54
1985	MJJ	-0.5	74.7	74.4	0.3		6.18	12.08	0.49	

Table 31. La Niña 1988-1989

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1951-1980)	Departure from Normal		Total during Period	Normal (1951-1980)	Ratio of Total to Normal	
1988	AMJ	-0.8	67.2	67.8	-0.6	**TPM**	4.40	12.73	0.35	**TPM**
1988	MJJ	-1.2	75.3	74.4	0.9	0.9	5.57	12.08	0.46	0.46
1988	JJA	-1.2	80.2	77.9	2.3	1.7	6.10	10.92	0.56	0.59
1988	JAS	-1.1	78.7	76.7	2.0	1.2	8.10	10.93	0.74	0.65

1988	ASO	-1.3	69.6	70.3	-0.7	0.1	6.38	9.69	0.66	0.79
1988	SON	-1.6	59.3	60.4	-1.1	-0.8*	9.48	9.81	0.97	0.88
1988	OND	-1.9	49.2	49.9	-0.7	0.7	10.98	10.73	1.02	1.03
1988	NDJ	-1.9	46.1	42.1	4.0	2.0	13.96	12.64	1.10	1.66
1989	DJF	-1.7	42.2	39.4	2.8	3.4	17.83	13.15	1.36	1.27
1989	JFM	-1.5	45.7	42.2	3.5	2.3	19.00	14.10	1.35	1.31
1989	FMA	-1.1	50.6	49.9	0.7	1.5	17.35	14.08	1.23	1.15
1989	MAM	-0.9	59.2	58.9	0.3	-0.1	12.60	14.61	0.86	1.10
1989	AMJ	-0.6	66.5	67.8	-1.3		15.16	12.73	1.19	

Table 32. La Niña 1995-1996

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1961-1990)	Departure from Normal		Total during Period	Normal (1961-1990)	Ratio of Total to Normal	
1995	ASO	-0.5	71.3	70.1	1.2	**TPM**	11.14	9.54	1.17	**TPM**
1995	SON	-0.6	58.2	60.7	-2.5	-1.2	12.22	10.20	1.20	1.20
1995	OND	-0.7	47.9	50.3	-2.4	-2.4*	14.02	11.35	1.24	1.17
1995	NDJ	-0.8	39.9	42.1	-2.2	-1.6	13.11	12.31	1.06	1.12
1996	DJF	-0.8	38.8	39.0	-0.2	-1.4	12.84	12.00	1.07	0.99
1996	JFM	-0.7	40.5	42.3	-1.8	-1.7	10.07	12.24	0.82	0.83
1996	FMA	-0.5	47.0	50.2	-3.2		7.87	13.03	0.60	

Table 33. La Niña 1998-2000

Year	Period	SST Anomaly	Temperature Data				Precipitation Data			
			Average during Period	Normal (1961-1990)	Departure from Normal		Total during Period	Normal (1961-1990)	Ratio of Total to Normal	
1998	JJA	-0.8	78.8	77.7	1.1	**TPM**	19.51	11.00	1.77	**TPM**
1998	JAS	-1.0	78.6	76.5	2.1	2.1	8.95	10.89	0.82	1.07
1998	ASO	-1.1	73.2	70.1	3.1	2.9	5.91	9.54	0.62	0.62*
1998	SON	-1.1	64.3	60.7	3.6	3.1	4.28	10.20	0.42	0.62*
1998	OND	-1.3	52.9	50.3	2.6	3.3	9.42	11.35	0.83	0.88
1998	NDJ	-1.5	45.9	42.1	3.8	3.7*	17.11	12.31	1.39	1.24
1999	DJF	-1.6	43.7	39.0	4.7	3.6	18.14	12.00	1.51	1.40
1999	JFM	-1.2	44.6	42.3	2.3	2.7	15.88	12.24	1.30	1.16
1999	FMA	-0.9	51.4	50.2	1.2	1.0	8.89	13.03	0.68	0.92
1999	MAM	-0.7	58.5	59.0	-0.5	0.7	10.91	14.10	0.77	0.75
1999	AMJ	-0.8	68.9	67.5	1.4	0.7	10.20	12.82	0.80	0.82
1999	MJJ	-0.8	75.3	74.2	1.1	1.4	11.10	12.42	0.89	0.86*
1999	JJA	-0.9	79.3	77.7	1.6	1.3	9.80	11.00	0.89	0.85
1999	JAS	-0.9	77.8	76.5	1.3	1.1	8.21	10.89	0.75	0.79
1999	ASO	-1.0	70.4	70.1	0.3	0.9*	7.06	9.54	0.74	0.73

1999	SON	-1.2	61.9	60.7	1.2	1.2	7.00	10.20	0.69	0.70
1999	OND	-1.4	52.5	50.3	2.2	2.3	7.53	11.35	0.66	0.69*
1999	NDJ	-1.6	45.5	42.1	3.4	3.2	9.01	12.31	0.73	0.74
2000	DJF	-1.6	43.1	39.0	4.1	3.8	9.77	12.00	0.81	0.80
2000	JFM	-1.5	46.3	42.3	4.0	3.4	10.61	12.24	0.87	0.90
2000	FMA	-1.1	52.2	50.2	2.0	2.3	13.32	13.03	1.02	1.04
2000	MAM	-0.9	59.9	59.0	0.9	1.0	17.23	14.10	1.22	1.15
2000	AMJ	-0.7	67.6	67.5	0.1	0.8	15.63	12.82	1.22	1.13
2000	MJJ	-0.6	75.5	74.2	1.3		11.65	12.42	0.94	

Table 34. La Niña 2000-2001										
Year	**Period**	**SST Anomaly**	**Temperature Data**				**Precipitation Data**			
			Average during Period	**Normal (1961-1990)**	**Departure from Normal**		**Total during Period**	**Normal (1961-1990)**	**Ratio of Total to Normal**	
2000	SON	-0.5	61.1	60.7	0.4	**TPM**	8.55	10.20	0.84	**TPM**
2000	OND	-0.7	47.5	50.3	-2.8	-2.2	10.09	11.35	0.89	0.93
2000	NDJ	-0.7	37.9	42.1	-4.2	-3.1	13.04	12.31	1.06	1.07
2001	DJF	-0.7	36.7	39.0	-2.3	-2.4	15.19	12.00	1.27	1.17
2001	JFM	-0.5	41.7	42.3	-0.6		14.48	12.24	1.18	

Appendix 3. Methodology for Determining "Prevailing Short-Term Climate" and "Short-Term Climate Trend"

Using the record of five-year running means for average annual temperature and precipitation, average temperature departure and average precipitation departure for PL_{avg} (as determined from the three-month ONI index periods in Appendices I & II), along with representative thirty-year climatological normals and a climatic trend of 5 years in length (centered at the year of the SST maximum), the following values were calculated for each ENSO event and included in Tables 3a and 3b:

1) characteristics of the prevailing short-term climate,

2) the short-term climate trend ("□T" for temperature trend and "□P" for precipitation trend), and

3) departure of the observed from normal.

Other definitions of terms pertinent to Tables 3a and 3b include:

Event: Individual El Niño/La Niña cycle described in more detail in Appendices 1 & 2.

Periods: Number of three-month periods where SST anomaly departure from normal is $\geq 0.5^{o}$.

Maximum SST Anomaly: The maximum SST anomaly observed during the event.

TEMPERATURE CHARACTERISTICS

Average observed departure from normal (highlighted in red in Appendices 1 & 2) is computed using PL_{avg}: the five periods centered on the maximum SST anomaly.

Prevailing short-term climate is based on a comparison between the five-year running mean annual temperature for the year during which the maximum SST anomaly occurred, and the thirty-year climatological normal. After determining the standard deviation for the Nashville temperature data for each El Niño/La Niña (Figures 5 & 6), a determination was made as to which departure from normal should represent "very warm" and "very cool" conditions. A departure greater than one standard deviation (SD) was chosen as that threshold, and SD's were then calculated separately for El Niño and La Niña events. Departures from normal of one-half SD or less are considered "near normal." Departures from normal greater than one-half SD, but no more than one SD, are considered either "cool" or "warm," depending on the sign. Based on these SD calculations, the following terms used in the tables are defined for the El Niño cases:

"Near normal" implies a departure from normal of 0.8^{o} to -0.8^{o}.
"Cool" implies a departure from normal of -0.9^{o} to -1.7^{o}.
"Very cool" implies a departure from normal greater than -1.7^{o}.
"Warm" implies a departure from normal of 0.9^{o} to 1.7^{o}.
"Very warm" implies a departure from normal greater than 1.7^{o}.

Similarly, the following terms used in the tables are defined for the La Niña cases:

"Near normal" implies a departure from normal of 0.6^{o} to -0.6^{o}.
"Cool" implies a departure from normal of -0.7^{o} to -1.2^{o}.
"Very cool" implies a departure from normal greater than -1.2^{o}.
"Warm" implies a departure from normal of 0.7^{o} to 1.2^{o}.
"Very warm" implies a departure from normal greater than 1.2^{o}.

For purposes of segregating the temperature departure data into categories for "large" departures and "small" departures, the use of standard deviation provides an objective threshold. After studying graphs of the data (Figures 5 & 6), it was determined that this threshold would effectively segregate the two primary data clusters. Using this threshold, nine El Niño cycles were determined to be associated with "large" departures from normal and the remaining seven were associated with small departures. Similarly, nine La Niña cycles were determined to be associated with "large" departures from normal and the remaining six were associated with small departures. Note that in Figures 5 & 6, the absolute value of each El Niño/La Niña average observed departure from normal (taken from Tables 3a & 3b) was plotted along the Y-axis. The X-axis values (labeled with each plot) indicate each ENSO event.

General trend in short-term climate (□T) is the difference between the five-year running mean annual temperature value two years following the year in which the maximum SST anomaly occurred and that two years prior. In order to maintain consistency, the aforementioned SD thresholds were used to define the following terms. For the El Niño cases, those terms are:

"Stable" implies a change of 0.8^{o} to -0.8^{o}.
"Cooling" implies a change of -0.9^{o} to -1.7^{o}.
"Significant cooling" implies a change greater than -1.7^{o}.
"Warming" implies a change of 0.9^{o} to 1.7^{o}.
"Significant warming" implies a change greater than 1.7^{o}.

And for the La Niña cases, those terms are:

"Stable" implies a change of 0.6^{o} to -0.6^{o}.
"Cooling" implies a change of -0.7^{o} to -1.2^{o}.
"Significant cooling" implies a change greater than -1.2^{o}.
"Warming" implies a change of 0.7^{o} to 1.2^{o}.
"Significant warming" implies a change greater than 1.2^{o}.

PRECIPITATION CHARACTERISTICS

Following is an explanation of the terms used in Tables 3a and 3b that pertain to precipitation:

Ratio of observed precipitation to normal is computed using PL_{avg}: centered on the maximum SST anomaly (highlighted in green in Appendices 1 & 2).

Prevailing short-term climate is based on the five-year running mean annual precipitation for the year during which the maximum SST anomaly occurred compared to the thirty-year climatological normal. After determining the standard deviation for the Nashville precipitation data for each El Niño/La Niña (Figures 7 & 8), a determination was made as to which departure from normal should represent "very wet" and "very dry" conditions. As with temperature characteristics, the standard deviation of the absolute value of the average departure from normal were calculated separately for El Niño and La Niña cases. A departure greater than one SD was selected as that threshold. Departures from normal of one-half SD or less were considered “near normal,” and departures from normal greater than one-half SD, but no more than one SD, were considered either “dry” or “wet,” depending on the sign. The following terms used in the table are defined for El Niño as follows:

"Near normal" implies a departure from normal of 7% to -7%.
"Dry" implies a departure from normal of -8% to -15%.
"Very dry" implies a departure from normal greater than 15%.
"Wet" implies a departure from normal of 8% to 15%.
"Very wet" implies a departure from normal greater than 15%.

Likewise, the following terms used in the table are defined for La Niña as follows:

"Near normal" implies a departure from normal of 8% to -8%.
"Dry" implies a departure from normal of -9% to -17%.
"Very dry" implies a departure from normal greater than 17%.
"Wet" implies a departure from normal of 9% to 17%.
"Very wet" implies a departure from normal greater than 17%.

For purposes of segregating the precipitation departure data into categories for "large" departures and "small" departures, the use of standard deviation provides an objective threshold. After studying graphs of the data (Figures 7 & 8), it was determined that this threshold would effectively segregate the two primary data clusters. Using this threshold, seven El Niño cycles were determined to be associated with "large" departures from normal and the remaining nine were associated with small departures. Similarly, six La Niña cycles were determined to be associated with "large" departures from normal and the remaining eight were associated with small departures. Note that in Figures 7 & 8, the absolute value of each El Niño/La Niña average observed departure from normal (taken from Tables 3a & 3b) was plotted along the Y-axis. The X-axis values (labeled with each plot) indicate each ENSO event.

General trend in short-term climate (□T) is the difference between the five-year running mean annual precipitation two years following the year in which the maximum SST anomaly occurred and that two years prior. In order to maintain consistency, the aforementioned SD thresholds were used to define the following terms. For the El Niño cases, those terms are:

"Stable" implies a change of 7% to -7%.
"Decreasing" implies a change of -8% to -15%.
"Rapidly decreasing" implies a change greater than -15%.

"Increasing" implies a change of 8% to 15%.
"Significantly increasing" implies a change greater than 15%.

And for the La Niña cases, those terms are:

"Stable" implies a change of 8% to -8%.
"Decreasing" implies a change of -9% to -17%.
"Rapidly decreasing" implies a change greater than -17%.
"Increasing" implies a change of 9% to 17%.
"Significantly increasing" implies a change greater than 17%.

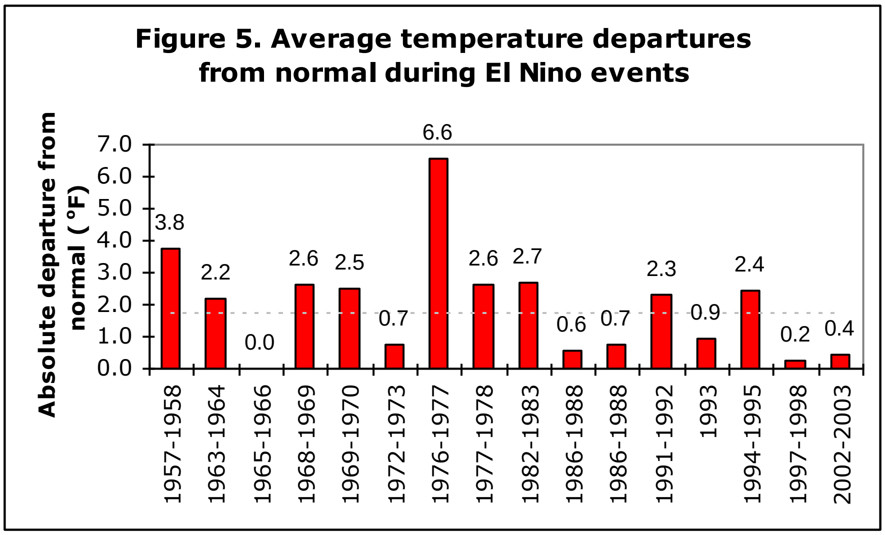

Figure 5. Standard deviation (1.7°) is represented by a dashed grey line.

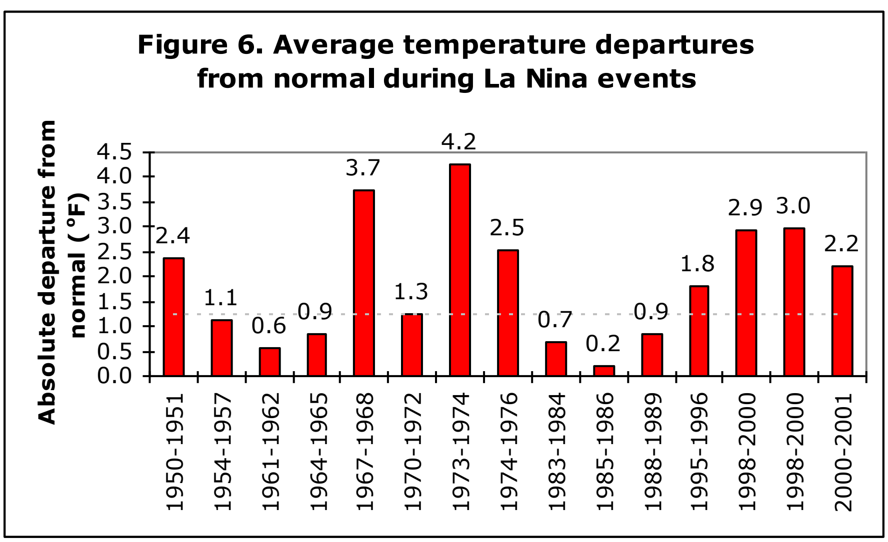

Figure 6. Standard deviation (1.2°) is represented by a dashed grey line.

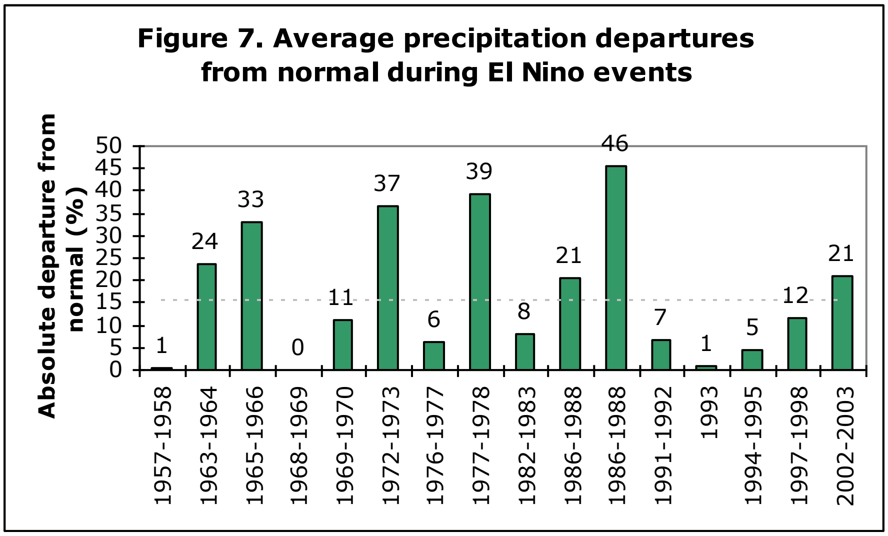

Figure 7. Standard deviation (15%) is represented by a dashed grey line.

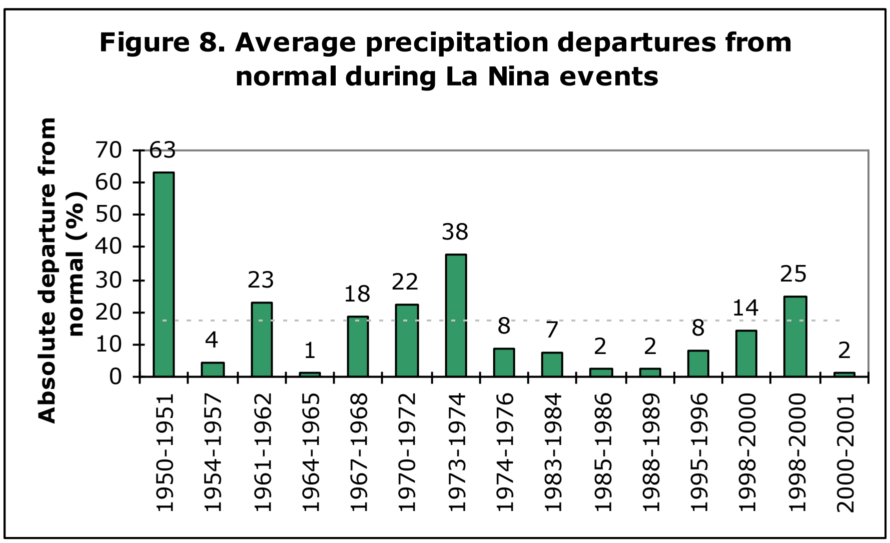

Figure 8. Standard deviation (17%) is represented by a dashed grey line.

Appendix 4. Supplemental Data Pertaining To Section IV.

Summary of El Niño smoothed data (centered on SST maxima)

Table 35. Summary of El Niño "pre-SST Max periods"		
Event	**Temperature inflection point**	**Precipitation inflection point**
El Niño 1957-1958	$N_{\text{pre-SST Max periods}}$ = 2 (maximum)	$N_{\text{pre-SST Max periods}}$ = 3 (maximum)
El Niño 1963-1964	$N_{\text{pre-SST Max periods}}$ = 1 (maximum)	No pre-SST Max inflection point
El Niño 1965-1966	No pre-SST Max inflection point	$N_{\text{pre-SST Max periods}}$ = 2.5 (maximum)
El Niño 1968-1969	El Niño not sufficiently long to verify a pre-SST Max inflection point	
El Niño 1969-1970	El Niño not sufficiently long to verify a pre-SST Max inflection point	
El Niño 1972-1973	$N_{\text{pre-SST Max periods}}$ = 1.5 (maximum)	$N_{\text{pre-SST Max periods}}$ = 2 (maximum)
El Niño 1976-1977	El Niño not sufficiently long to verify a pre-SST Max inflection point	
El Niño 1977-1978	El Niño not sufficiently long to verify a pre-SST Max inflection point	
El Niño 1982-1983	$N_{\text{pre-SST Max periods}}$ = 4 (minimum)	$N_{\text{pre-SST Max periods}}$ = 1 (maximum)
El Niño 1986-1988	$N_{\text{pre-SST Max periods}}$ = 1 (minimum)	$N_{\text{pre-SST Max periods}}$ = 2 (maximum)
	$N_{\text{pre-SST Max periods}}$ = 3 (maximum)	$N_{\text{pre-SST Max periods}}$ = 2 (maximum)
El Niño 1991-1992	$N_{\text{pre-SST Max periods}}$ = 3 (minimum)	$N_{\text{pre-SST Max periods}}$ = 3 (maximum)
El Niño 1993	El Niño not sufficiently long to verify a pre-SST Max inflection point	
El Niño 1994-1995	$N_{\text{pre-SST Max periods}}$ = 4 (minimum)	$N_{\text{pre-SST Max periods}}$ = 6 (maximum)
El Niño 1997-1998	$N_{\text{pre-SST Max periods}}$ = 1 (maximum)	$N_{\text{pre-SST Max periods}}$ = 2 (maximum)
El Niño 2002-2003	$N_{\text{pre-SST Max periods}}$ = 3 (maximum)	$N_{\text{pre-SST Max periods}}$ = 2 (maximum)

Temperature

The average number of "pre-SST Max periods" = 2 + 1 + 1.5 + 4 + 1 + 3 + 3 + 4 + 1 + 3 / 10 = 2.4.

Dropping the highest and lowest values, in order to eliminate potentially unrepresentative outliers, gives: 2 + 1.5 + 1 + 3 + 3 + 4 + 1 + 3 / 8 = 2.3 periods.

The period encompassing the temperature pattern centered at the SST maximum was defined as:

$$PL_{avg} = [2 \text{ x } N_{\text{pre-SST Max periods}}] + 1$$
$$\text{Thus } PL_{avg} = [2 \text{ x } N_{\text{pre-SST Max periods}}] + 1 = 5 \text{ periods.}$$

Precipitation

The average number of "pre-SST Max periods" = 3 + 2.5 + 2 + 1 + 2 + 2 + 3 + 6 + 2 + 2 / 10 = 2.6.

Dropping the highest and lowest values gives: 3 + 2.5 + 2 + 2 + 2 + 3 + 2 + 2 / 8 = 2.3 periods.

The period encompassing the temperature pattern centered at the SST maximum was defined as:

$$PL_{avg} = [2 \text{ x } N_{pre\text{-}SST\ Max\ periods}] + 1$$

Thus $PL_{avg} = [2 \text{ x } N_{pre\text{-}SST\ Max\ periods}] + 1 = 5$ periods.

Summary of La Niña smoothed data (centered on SST maxima)

Table 36. Summary of La Niña "pre-SST Max periods"		
Event	**Temperature inflection point**	**Precipitation inflection point**
La Niña 1950-1951	La Niña not sufficiently long to verify a pre-SST Max inflection point	
La Niña 1954-1957	$N_{pre\text{-}SST\ Max\ periods}$ = 3 (maximum)	$N_{pre\text{-}SST\ Max\ periods}$ = 2 (maximum)
La Niña 1961-1962	La Niña not sufficiently long to verify a pre-SST Max inflection point	
La Niña 1964-1965	$N_{pre\text{-}SST\ Max\ periods}$ = 1.5 (minimum)	$N_{pre\text{-}SST\ Max\ periods}$ = 3 (minimum)
La Niña 1967-1968	No pre-SST Max inflection point	No pre-SST Max inflection point
La Niña 1970-1972	$N_{pre\text{-}SST\ Max\ periods}$ = 4 (maximum)	No pre-SST Max inflection point
La Niña 1973-1974	$N_{pre\text{-}SST\ Max\ periods}$ = 1 (maximum)	$N_{pre\text{-}SST\ Max\ periods}$ = 1 (maximum)
La Niña 1974-1976	$N_{pre\text{-}SST\ Max\ periods}$ = 4 (maximum)	$N_{pre\text{-}SST\ Max\ periods}$ = 2.5 (maximum)
La Niña 1983-1984	La Niña not sufficiently long to verify a pre-SST Max inflection point	
La Niña 1984-1985	La Niña not sufficiently long to verify a pre-SST Max inflection point	
La Niña 1988-1989	$N_{pre\text{-}SST\ Max\ periods}$ = 1 (minimum)	No pre-SST Max inflection point
La Niña 1995-1996	$N_{pre\text{-}SST\ Max\ periods}$ = 1 (minimum)	No pre-SST Max inflection point
La Niña 1998-2000	$N_{pre\text{-}SST\ Max\ periods}$ = 1 (maximum)	$N_{pre\text{-}SST\ Max\ periods}$ = 3.5 (minimum)
	$N_{pre\text{-}SST\ Max\ periods}$ = 3 (minimum)	$N_{pre\text{-}SST\ Max\ periods}$ = 1 (minimum)
La Niña 2000-2001	La Niña not sufficiently long to verify a pre-SST Max inflection point	

Temperature

The average number of "pre-SST Max periods" = 3 + 1.5 + 4 + 1 + 4 + 1 + 1 + 1 + 3 / 9 = 2.2.

Dropping the highest and lowest values gives: 3 + 1.5 + 1 + 4 + 1 + 1 + 3 / 7 = 2.1 periods.

The period encompassing the temperature pattern centered at the SST maximum was defined as:

$$PL_{avg} = [2 \text{ x } N_{pre\text{-}SST\ Max\ periods}] + 1$$

Thus $PL_{avg} = [2 \text{ x } N_{pre\text{-}SST\ Max\ periods}] + 1 = 5$ periods.

Precipitation

The average number of "pre-SST Max periods" = 2 + 3 + 1 + 2.5 + 3.5 + 1 / 6 = 2.2.

Dropping the highest and lowest values gives: 2 + 3 + 2.5 + 1 / 4 = 2.2 periods.

The period encompassing the temperature pattern centered at the SST maximum was defined as:

$$PL_{avg} = [2 \text{ x } N_{\text{pre-SST Max periods}}] + 1,$$

$$\text{Thus } PL_{avg} = [2 \text{ x } N_{\text{pre-SST Max periods}}] + 1 = 5 \text{ periods.}$$

Appendix 5. Normal Temperature and Precipitation Values for Nashville, Tennessee Used in This Study

	1911-1940				1921-1950				1931-1960				1941-1970			
	Temperature		Precipitation		Temperature		Precipitation		Temperature		Precipitation		Temperature		Precipitation	
	Month	Period	Month	Period	Month	Period	Month	Period	Month	Period	Month	Period	Month	Period	Month	Period
DJF	38.6	40.4	4.76	13.09	39.9	41.2	4.93	13.15	39.9	41.1	5.49	14.19	38.3	39.9	4.75	13.63
JFM	41.6	43.2	4.13	14.00	42.3	44.1	4.16	14.37	42.0	43.7	4.51	15.19	41.0	42.7	4.43	14.18
FMA	49.2	50.1	5.11	13.37	49.8	50.8	5.28	13.13	49.1	50.4	5.19	13.44	48.7	50.1	5.00	13.54
MAM	59.0	58.8	4.13	13.11	59.7	59.2	3.69	12.75	59.6	59.1	3.74	12.65	60.1	59.1	4.11	13.21
AMJ	68.2	67.6	3.87	12.00	68.2	68.3	3.78	10.66	68.6	68.5	3.72	10.71	68.5	68.4	4.10	11.59
MJJ	75.6	74.3	4.00	11.75	76.9	75.0	3.19	10.93	77.4	75.4	3.25	10.69	76.6	74.9	3.38	11.31
JJA	79.1	77.5	3.88	11.59	80.0	78.6	3.96	10.46	80.2	79.0	3.72	9.83	79.6	78.3	3.83	10.45
JAS	77.8	76.3	3.71	11.01	78.7	77.3	3.31	10.01	79.2	77.5	2.86	9.45	78.5	76.8	3.24	10.16
ASO	72.3	70.3	3.71	9.69	71.8	70.1	3.46	9.54	71.3	69.7	3.59	9.74	71.8	70.2	3.42	9.62
SON	61.0	60.6	2.49	9.41	61.8	61.4	2.52	8.67	61.5	60.9	2.32	8.47	60.9	60.4	2.16	8.71
OND	49.0	50.3	3.50	10.19	49.3	50.9	3.41	9.99	48.5	50.5	3.28	9.79	48.4	49.9	3.46	10.07
NDJ	41.0	42.8	4.20	12.46	41.6	43.5	4.06	12.40	41.4	43.2	4.19	12.96	40.4	42.3	4.45	12.66
Yr	59.3		47.20		60.1		45.03		60.0		45.14		59.4		46.00	

	1951-1980				1961-1990				1971-2000			
	Temperature		Precipitation		Temperature		Precipitation		Temperature		Precipitation	
	Month	Period	Month	Period	Month	Period	Month	Period	Month	Period	Month	Period
DJF	37.1	39.4	4.49	13.15	36.2	39.0	3.58	12.00	36.8	39.5	3.97	12.20
JFM	40.4	42.2	4.03	14.10	40.4	42.3	3.81	12.24	41.3	42.8	3.69	12.53
FMA	49.0	49.9	5.58	14.08	50.2	50.2	4.85	13.03	50.1	50.2	4.87	12.49
MAM	59.6	58.9	4.47	14.61	59.2	59.0	4.37	14.10	58.5	58.6	3.93	13.87
AMJ	68.1	67.8	4.56	12.73	67.7	67.5	4.88	12.82	67.1	66.9	5.07	13.08
MJJ	75.8	74.4	3.70	12.08	75.6	74.2	3.57	12.42	75.1	73.8	4.08	12.92
JJA	79.4	77.9	3.82	10.92	79.3	77.7	3.97	11.00	79.1	77.4	3.77	11.13
JAS	78.4	76.7	3.40	10.93	78.1	76.5	3.46	10.89	77.9	76.2	3.28	10.64
ASO	73.2	71.2	2.74	8.57	72.8	71.1	2.87	8.05	72.0	70.5	3.09	8.49
SON	60.2	60.4	2.58	9.81	60.4	60.7	2.62	10.20	59.9	60.2	2.87	10.91
OND	48.6	49.9	3.52	10.73	50.0	50.3	4.12	11.35	49.3	49.9	4.45	11.86
NDJ	40.9	42.1	4.63	12.64	40.5	42.1	4.61	12.31	40.5	42.1	4.54	12.96
Yr	59.2		48.49		59.1		47.30		58.9		48.11	

Normals for each month and three month-period are given for temperature and precipitation. For example, in the first row of figures for the 1911-1940 climatological period, the normal mean temperature for January was 38.6^{o}. The normal mean temperature for the three-month period centered on January (DJF) was 40.4^{o}. Likewise, normal precipitation for January was 4.76 inches. Normal precipitation for the three-month period centered on January (DJF) was 13.09 inches.