Association of the El Niño-Southern Oscillation Index and Monthly Temperature and Precipitation Records in Southeastern North Carolina

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The 1997-98 winter was an important El Niño season, received much media attention, and was blamed for many climatic aberrations worldwide. Although El Niño and the Southern Oscillation have been correlated with climate patterns in the circum-Pacific regions, there is a question as to what degree El Niño influenced climate as far away as southeastern North Carolina. The Southern Oscillation Index (SOI) is a climatological variable that assesses the El Niño situation in the Pacific. Correlation analysis is utilized to find a statistical link between the SOI and monthly averages of temperature, and monthly totals of precipitation. Lag correlations and other associations are also sought. Analysis showed that the magnitude of monthly SOI values does not directly correlate with the magnitude of monthly averages of temperature or monthly precipitation totals in southeastern North Carolina. Significant lag correlations indicate that subtler links may exist, but the SOI alone has little power for prediction of the climatic pattern in the region. Climate records indicate that not all El Niño/La Niña events are the same, nor do they exert the same influence on southeastern North Carolina. The public is advised not to perceive the "El Nino effect" as a catch-all explanation of all weather events. This paper illustrates that there is a need for more studies on global atmospheric circulation systems and their links to inter-regional climate patterns that affect southeastern North Carolina.

Introduction

Environmental education emphasizes that the entire world is linked ecologically. Climatic phenomena in one region may influence conditions in other regions, even at great distances. The winter and spring of 1997-98 were strong "El Niño" seasons and received much media attention, both nationally and locally. Unusually warm water of the eastern Pacific ocean, particularly off the west coast of South America, produced significant drought in the East Asia-Western Pacific Rim, and abnormally high precipitation, flooding, mudslides, etc. in the Americas. El Niño caused or was blamed for a number of synergistic environmental problems (Parris, 1998). Winter temperatures and precipitation totals were both above normal in the southern coastal plain of North Carolina (State Climate Office of NC, 1998). The local public enjoyed the mild winter (Jacobs, 1998), but perceived the high frequency of days with rain as a significant nuisance (Nilsen, 1998).

A global-scale atmospheric pressure reversal is monitored in the tropics and is linked to El Niño. The Southern Oscillation Index (SOI) is the difference between the sea level pressure measured in Tahiti and that measured in Darwin, Australia. When barometric pressure is higher than usual in the western Pacific, pressure is lower than usual in the eastern Pacific. This global-scale pressure swing is known as the "Southern Oscillation." The term "El Niño-Southern Oscillation" (ENSO) was coined by climatologists, however "El Niño" is just the name of the warm phase of fluctuation between warmer-than-usual and colder-than-usual ocean temperatures in the Eastern Pacific. Surface pressure at Darwin and Tahiti are strongly "negatively correlated." That is, when one is higher than normal, the other is lower than normal. Large negative values of the SOI indicate an El Niño phase (Allan, *et al.*, 1991). El Niño's cold, drought-associated, reverse counterpart is termed

"La Niña." Historically, an El Niño event irregularly recurs every three to seven years. Some evidence suggests that El Niño events are becoming increasingly common, and may explain weather aberrations worldwide.

The SOI is a simple, convenient, but also an important and accurate measure of the El Niño phenomena. It is the association of this measure with local climate records that are examined in this paper. Although the SOI has been statistically linked to greater precipitation along the Pacific Rim, the ENSO link to eastern regions of the U.S. has been studied less. An improved understanding of ENSO has economic value, particularly for U.S. agriculture (Solow, *et al.*, 1998). The occurrence of too much rain associated with El Niño may delay planting or waterlog crops, and La Niña associated drought could also affect crops. Successful prediction of El Niño-La Niña climate oscillations may result in long-term forecasts beneficial to US crop production (Keppenne,1995).

Many other factors directly influence weather patterns in southeastern North Carolina, but this study strives to find if indeed there is an SOI connection to the local climate. Conflicting opinions exist as to whether southeastern North Carolina experiences a cooler than normal winter (Clement, 1998) or a milder winter during an El Niño (Jacobs, 1998). The rule of thumb—if indeed there are any "rules"—is that during a typical El Niño year, southeastern North Carolina experiences a mild but wet winter, followed by a cool and wet spring, possibly followed by a drought-like summer as La Niña conditions prevail (NCDC, 1998). Highly variable day-to-day winter temperatures and extreme cold may also characterize a "typical" El Niño episode even when the average temperature for the entire season is "above normal." The lay public is aware that something unusual occurs during an El Niño year, but has a poor understanding of the phenomena. This paper attempts to find qualitative and quantitative links between the ENSO and records of temperature and precipitation in southeastern North Carolina.

Methods

Southern Oscillation Index Data

SOI is the difference between standardized air pressure (point data) at Darwin, Australia (12° South latitude, 131° East longitude) and standardized air pressure in Papeete, Tahiti, French Polynesia (17° South latitude). SOI calculations followed Allan *et al.* (1991). Monthly averages of raw SOI data were obtained from the National Oceanic and Atmospheric Association's (NOAA) Climate Prediction Center (CPC) web page.

The units of the SOI are dimensionless. The years 1951-1980 are the base period for the climatological "normal" of SOI , thus index values are reported above or below this average. Negative values of the SOI represent El Niño conditions. The lower (more negative) the SOI is, the more extreme the El Niño event. Positive SOI values indicate a La Niña episode. Although monthly SOI data exist back to 1882, data compiled before 1933 include significant gaps and are of questionable accuracy. These data are monthly means, January through December, for January 1933 through June 1998. The northern hemisphere winter season 1997-98 (December 1997, January 1998 and February 1998) will hence be referred to as the winter of year 1998.

Arguably, even the SOI may be misleading. Note that the SOI is an *index* and not a direct measure of warm El Niño waters. A better measure of El Niño is sea surface temperatures (SST) measured from moored ocean buoys and satellite remote sensors. However, buoy data and other direct observations exist for a much shorter time series than the SOI. A long time series is needed to examine the statistical link between El Niño and the North Carolina climate record.

Southeastern North Carolina Data

Temperature and precipitation data are divisional averages of several weather stations. Records from forty-two weather stations, past and present, across thirteen counties in North Carolina's Southern Coastal Plain region (Figure

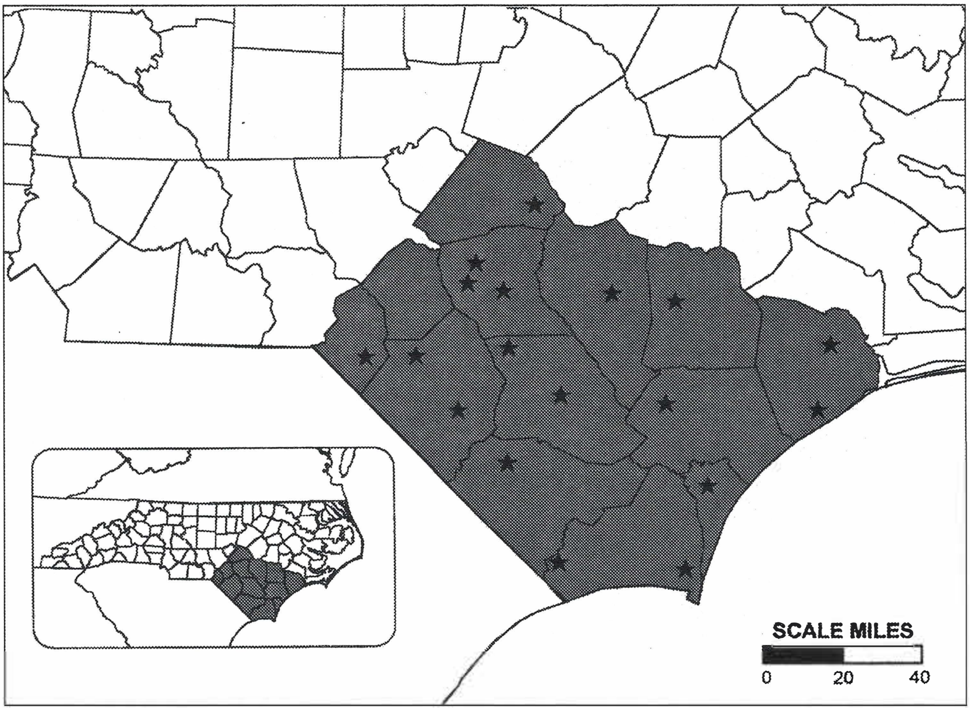

Figure 1. Location of North Carolina's Southern Coastal Plain Climate Division and Current Weather Observation Stations.

1) were compiled by NOAA's National Climatic Data Center (NCDC), to find climate division averages of monthly temperature and monthly precipitation total. Currently there are nineteen active stations (Figure 1) that comprise a divisional average. These raw data were obtained via FTP at the NCDC web page. The monthly divisional averages are useful because they smooth out spatial and short term irregularities in precipitation and temperature anomalies; however, important information about extremes and intra-regional variability may be lost. Average Monthly Temperature (AMT) and Monthly Precipitation Total (MPT) data were acquired to match the available period of the SOI, 1933 to 1998. Climatological "normal" values of AMT and MPT are 30 year averages (1961-1990) of these respective variables. Although metric units (degrees Celsius and centimeters, etc.) are standard in climatology, the NCDC collects and publishes data in English units (degrees Fahrenheit and inches). English units are disseminated by the NCDC for public use, thus English units will be used for reporting here.

Qualitative Methods

Tabular comparisons are made for the most important El Niño/La Niña months. SOI values are compared against the AMT and MPT deviation from their normals. January is chosen as a representative winter month when El Niño is often well developed, and June is chosen as a representative summer month when La Nina conditions prevail. The SOI, AMT, and MPT data time series for recent years are plotted and visually compared.

Quantitative Methods

Simple descriptive statistics are calculated for the monthly SOI, AMT, and MPT values. Pearson correlation coefficients and

Table 1. Comparison of Monthly SOI Values for Two Extreme El Niño Winters

1982-83 Southern Oscillation Index

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
-3.2	-4.0	-3.3	-3.6	-5.1	-4.6	-6.9	-7.6	-5.6	-2.2	0.7	-0.5

1982-83 Divisional average monthly temperature deviation from 1961-1990 normal (°F)

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
-0.1	+0.8	-1.9	-1.9	+1.8	+5.7	-0.8	-1.0	+0.4	-4.0	-0.8	-1.1

1982-83 Divisional monthly precipitation total's deviation from 1961-1990 normal (in.)

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
-0.51	-2.61	-0.42	+0.92	-0.92	+1.59	-0.14	+3.55	+4.49	+0.92	-2.29	-0.26

1997-98 Southern Oscillation Index

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
-1.7	-3.4	-2.6	-3.1	-2.3	-2.1	-5.4	-4.4	-5.6	-3.2	-0.2	1.0

1997-98 Divisional average monthly temperature deviation from 1961-1990 normal (°F)

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
+1.3	-1.2	0.0	+0.2	-3.1	-0.1	+5.5	+3.7	+0.6	+1.7	+4.2	+5.0

1997-98 Divisional monthly precipitation total's deviation from 1961-1990 normal (in.)

Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
+0.01	-3.77	+1.83	0.25	+2.07	+1.16	+2.95	+4.48	+2.35	+2.57	-0.01	-1.63

regression analyses are completed to determine a quantitative linear relationship between SOI and AMT and between SOI and MPT. The correlation between a given month's SOI, and the following month's SOI is tested. Similarly, the lag correlations for AMT and MPT are also tested. The correlation between SOI in any given month and AMT and MPT for following months (lag correlation) is also investigated. The possible linear change in all values of SOI, AMT and MPT over time is also tested. All significance tests are made at the 95% confidence level. Null hypothesis of no significant correlation is at $p < 0.05$. The Shapiro-Wilk test is used to test for the normality of all variables. SAS is utilized for the calculation of descriptive statistics, correlation analyses and significance tests (SAS Institute, 1996).

Results

Qualitative Comparisons

The winters of 1983 and 1998 were the two most memorable El Niño events in the period of analysis. SOIs for the 1982-83 months November through March were in the lowest 5% (Table 1). Total winter temperatures were milder than normal, but that was a result of the abnormally warm December. A cool spring followed. Winter and spring precipitation totals were both above normal. SOIs for November through March of 1997-98 were also very low, and within the lowest 10% of all values. Although the coastal plain experienced a mild winter, spring was warmer than usual. Winter and spring months were abnormally wet, with a high frequency of number of days with rain, even though total accumulations were not greatly above the climatological normal (US Dept. Of Commerce, 1998). Drought conditions began in late spring 1998, and continued through early summer (Helm, 1998).

It is useful to examine the 1980s and 1990s in detail, as this period contained very active ENSO cycles. There is some evidence of a cyclic trend in the SOI data since 1980 (Figure 2-A), but low values recur on uneven intervals from three to seven years. The AMT data were obviously cyclic because of seasonal

Table 2. Comparison of Lowest Ten Southern Oscillation Index* Values for January and January Average Monthly Temperature and Monthly Precipitation Total in Southeastern North Carolina

RANK	YEAR	SOI	Deg. from AMT Normal(°F)		Inches From MPT Normal (In.)	
1	1983	-6.9	41.6	(-0.8)	3.91	(-0.14)
2	1992	-5.6	45.0	(+2.6)	4.14	(+0.09)
3	1998	-5.4	47.9	(+5.5)	7.00	(+2.95)
4	1958	-3.8	38.8	(-3.6)	4.54	(+0.49)
5	1969	-3.2	40.7	(-0.8)	3.55	(-1.50)
6	1966	-2.8	39.8	(-2.6)	6.32	(+2.27)
7	1970	-2.3	37.3	(-5.1)	2.63	(-1.42)
8	1952	-2.0	50.7	(+8.3)	2.28	(-1.77)
9	1959	-2.0	43.4	(+1.0)	1.96	(-2.09)
10	1993	-2.0	47.3	(+4.9)	6.16	(+2.11)

* Large negative values indicate "El Niño" conditions.

Table 3. Comparison of Greatest Ten Southern Oscillation Index* Values for June and June Average Monthly Temperature and Monthly Precipitation Total in Southeastern North Carolina

RANK (In.)	YEAR	SOI	Deg. from AMT Normal(°F)		Inches From MPT Normal
1	1950	+2.0	76.7	(+1.4)	5.17 (+0.09)
2	1975	+1.8	76.1	(+0.8)	3.99 (-1.09)
3	1955	+1.7	72.3	(-3.0)	4.32 (-0.76)
4	1981	+1.7	79.6	(+4.3)	4.26 (-0.82)
5	1996	+1.6	76.3	(+1.0)	3.47 (-0.71)
6	1968	+1.4	76.0	(+0.7)	3.47 (-1.61)
7	1956	+1.3	76.3	(+1.0)	4.80 (-0.28)
8	1938	+1.3	74.4	(-0.9)	5.61 (+0.53)
9	1973	+1.3	76.1	(+0.8)	6.98 (+1.90)
10	1970	+1.2	75.4	(+0.1)	3.19 (-1.89)

* Large positive values indicate "La Nina" conditions.

temperatures, but there was an overall trend for milder winter temperatures toward the end of the 1990s (Figure 2-B). MPT is also somewhat cyclic, because of the summer precipitation maximum (Figure 2-C), but this does not visually match up with the SOI. The spikes in the MPT graph are explained by the summer convectional thunderstorms and occasional tropical storms characteristic of the climate of southeastern North Carolina.

The ten lowest January SOI values in the climate record are compared with the AMT and the MPT for each respective year that low SOI occurred (Table 2). The most extreme El Niño events do not necessarily dictate either a mild or a colder January. Average monthly temperatures in southeastern NC may be significantly above or below normal when the SOI of the Pacific is strongly negative. January 1952, 1959, 1992, 1993 and 1998 had strong SOIs, and AMTs for January in those years were above normal, yet January 1958, 1966, 1969, 1970, and 1983 also had strong SOIs when the AMT was below normal. Additionally, five years had MPTs above normal (1958, 1966, 1992, 1993, and 1998) and five years were below normal (1952, 1959, 1969, 1970, and 1983). A similar comparison of "La Niña" conditions found the ten highest SOI values for June had little relationship to AMT and MPT in June (Table 3). Seven of the ten largest La Niña episodes for June were characterized by below normal precipitation, and eight out of ten had warmer than normal temperatures. Thus, even when the most extreme El Niño/La Niña conditions exist, as measured by the SOI, monthly average temperatures or precipitation totals are not necessarily extremely high or low.

Correlation and Regression (Quantitative Analysis)

Monthly SOI values were found to be significantly correlated ($p < 0.05$) with SOI values of succeeding months (thus were autocorrelated). The value of any given month's SOI is strongly influenced by the magnitude of the preceding month's SOI. This "lag correlation" varied from a lag correlation of two months for February SOI to a lag correlation of ten months for March SOI.

However, the SOI for any given month was not correlated with the respective AMT or MPT of most months. Of the twelve monthly SOI's, none had a significant correlation with the AMT for its respective month. Furthermore, only two of the twelve monthly SOIs had a significant correlation with the respective month's MPT. The March SOI was significantly negatively correlated with precipitation in March. Low March SOI values were correlated with higher monthly precipitation totals ($p < 0.05$). The SOIs for September were significantly correlated with September precipitation. Higher September SOI values corresponded to higher precipitation totals in southeastern North Carolina. This contradicts the expected La Niña condition. If one considers a long time series, there is very little correlation overall between the Darwin-Tahiti pressure swing and temperature and precipitation patterns in southeastern North Carolina.

It should be expected that monthly precipitation totals would correlate with the magnitude of the SOI more than averages of monthly temperature. For example, a monthly average temperature of a winter month may include an unusual warm spell, but may also include a cold wave of a few days which would tend to balance out the "average" temperature. In such cases, ENSO influence may direct a west-to-east flow from a warm Pacific toward southeastern North Carolina. Localized and regional circulations of the atmosphere, influenced by other pressure systems, may act to balance out this warming. The presence of continental-scale pressure systems may create a northwest-to-southeast oriented jet stream, and cold fronts move into the southeast even during an El Niño year. Precipitation sums (MPT) are probably more directly associated with a warm Pacific and "typical" ENSO flow. The usual undulation of the jet stream flattens, and the weather flow across the

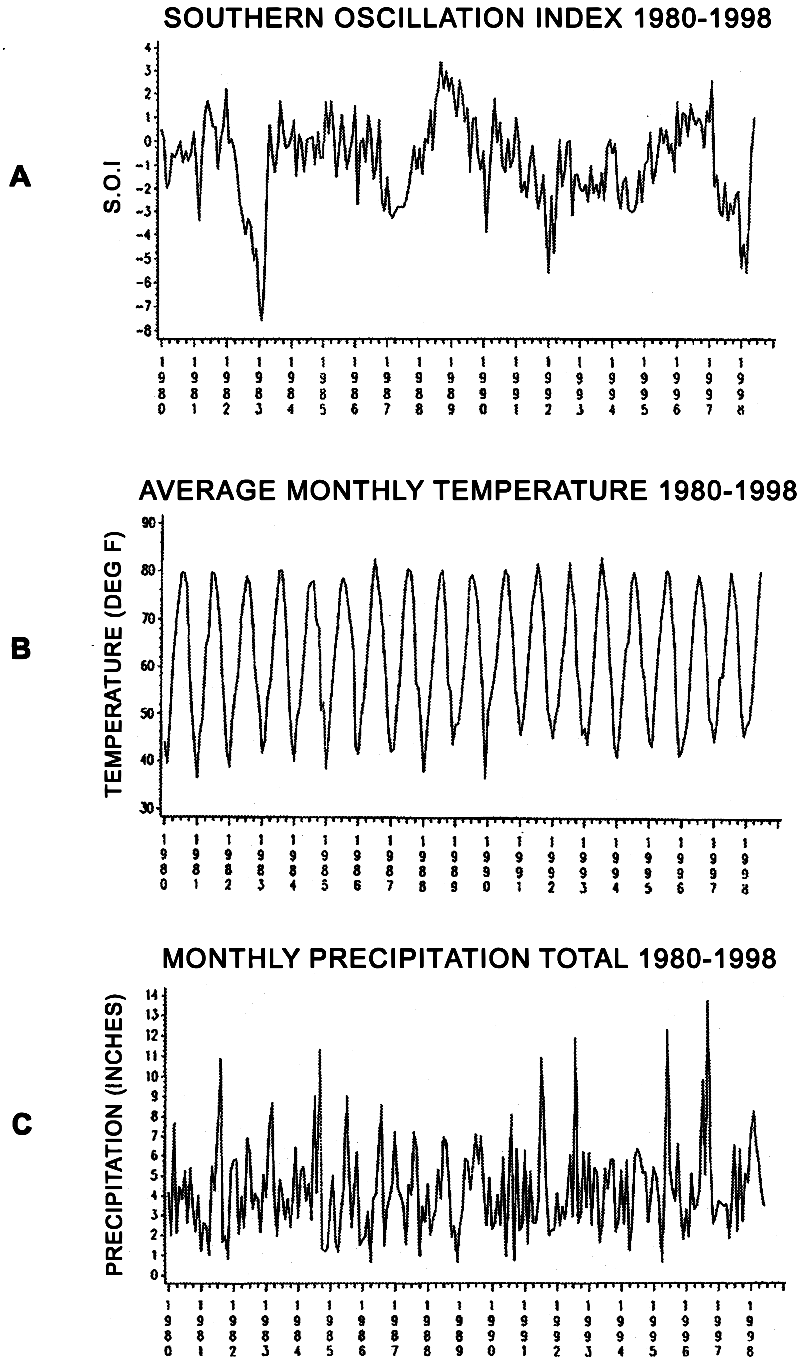

Figure 2. Time series graphs of the Southern Oscillation Index, Average Monthly Temperature and Monthly Precipitation Total in southeastern North Carolina, January 1980 to June 1998.

Table 4. Significant Lag Correlations and Pearson Correlation Coefficients of monthly SOI with AMT and MPT

Southern Oscillation Index Month:	Significant Correlation (+ or -) with Average Monthly Temperature or Monthly Precipitation Total in Southeastern NC
January SOI	- 29.1% February Precipitation - 38.7% March Precipitation - 28.2% July Temperature - 26.6% September Temperature - 29.5% November Temperature
February SOI	- 32.6% March Precipitation + 26.2% July Precipitation - 30.9% July Temperature - 29.9% August Temperature
March SOI	- 25.6% March Precipitation + 38.0% July Precipitation - 30.9% July Temperature
April SOI	+ 24.2% May Precipitation + 29.3% July Precipitation - 43.5% July Temperature + 27.2% October Temperature
May SOI	No significant correlations
June SOI	No significant correlations
July SOI	+ 35.1% September Precipitation + 40.8% February (of the following winter's) Temperature
August SOI	- 29.0% November Precipitation - 30.1% January (of the following winter's) Precipitation + 30.0 February (of the following winter's) Temperature - 25.6 March (of the following spring's) Precip.
September SOI	+ 24.0 September Precipitation + 30.6 February (of the following winter's) Temperature
October SOI	- 26.5% January (of the following winter's) Precipitation + 38.0% February (of the following winter's) Temperature + 24.1% May (of the following spring's) Precip.
November SOI	- 25.9% January (of the following winter's) Precipitation + 26.4% February (of the following winter's) Temperature + 27.3% May (of the following spring's) Precip.
December SOI	+ 31.1% (of the following) April's Temperature

Linear correlation is significant at greater than + 24.0% or less than -24% at 95% confidence.

southeast US becomes zonal (west-to-east). Low-pressure systems that originate from the Gulf track along the jet stream, producing increased precipitation in North Carolina (NC State Climate Office, 1999).

Although SOI was not correlated with any other month's AMT or MPT, other "lag correlations" were found. Because of a lag effect, SOI values in some months were significantly correlated with AMT or MPT in following months. For example, a low SOI for January was correlated with higher precipitation totals in February and March (Table 4). This follows the expected El Niño pattern that predicts a wet winter and spring. Lag correlations, although weak, may have predictive power, and the knowledge of an early season SOI could be useful for planning. For example, linear regression equations could be developed to predict March precipitation values from January's SOI (Figure 3). If March precipitation depends on the January SOI, then the significant regression equation can be given as:

$$\text{March MPT} = 10.43844 - 0.799103 \cdot \text{January SOI}$$

Significant lag correlations indicate that subtle links exist between the ENSO and North Carolina weather, and the causes of these links could be studied further. As more directly observed data of El Niño currents, continental-scale pressure systems, and local weather extremes are collected, these subtle links could be explored further.

There was a significant linear decline in the magnitude of the March and April SOI over time. Furthermore, January MPT and November MPT were also significantly correlated with time. There has been a significant linear increase for these values since 1933, but the significance of these linear relationships could be partly the result of short time series. Linear regression tests revealed no other significant relationships over time for any other monthly values of AMT, MPT, or SOI.

Conclusions

Although the El Niño/Southern Oscillation is not the usual direct cause of weather patterns in North Carolina, El Niño is sometimes associated with greater precipitation totals. The magnitude of the SOI-El Niño does not directly correspond to the magnitude of average temperatures and precipitation totals in southeastern North Carolina for any given month. The SOI alone has little predictive power for climatic patterns in the region. Thus, there is no guarantee that an El Niño year will always bring a warm wet winter, and the onset of La Niña does not necessarily signal a summer drought in southeastern North Carolina. (The current mild winter of 1998-99 is a good example. Temperatures and precipitation in January 1999 have both been above normal in southeastern North Carolina (NC State Climate Office, 1999). Winter 1999 has been an exceptionally mild winter yet 1999 is not an El Niño year!)

El Niño is not the only global atmospheric circulation system which influences regional weather patterns. The North Atlantic Oscillation, the Atlantic's SST and the status of the subpolar low pressure system all have an influence on weather patterns in the eastern US (Hurrell, 1995), but these phenomena have received much less media attention. "Catch-all" explanatory phrases for these phenomena do not exist as they do for El Niño. It is misleading to state that a certain weather event in southeastern North Carolina is "caused by El Niño" alone. Such oversimplifications have been perpetuated by the media. The El Niño relationship to any observed weather event is complicated by a number of factors, such as the state of the global or regional atmospheric circulation at the onset of El Niño. Furthermore, the characteristics of all "El Niño events" are not the same. It is difficult to obtain an uninterrupted sequence of causality for each El Niño occurrence that will match climate records. Likely, not every future El Niño event will have the same effect on southeastern North Carolina weather.

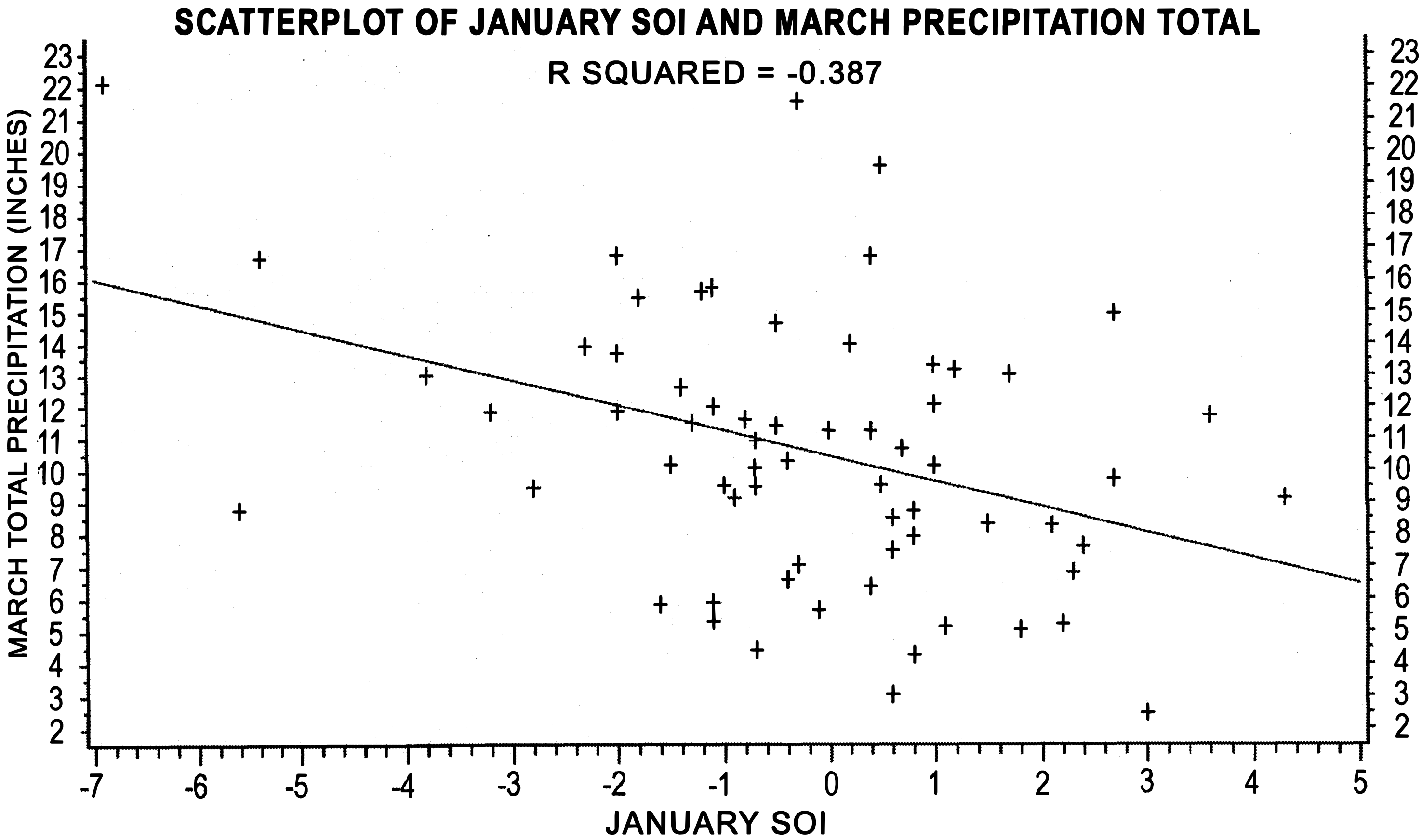

Figure 3. Scatterplot of January SOI and MPT for March. Correlation for these variables is significant ($p < 0.05$).

Unfortunately, the public may perceive what is "usual" or "expected" during an El Niño season to be what occurred in 1997-98 because of the sheer volume of media coverage that year. The climate record indicates that southeastern North Carolina has a good possibility of experiencing "opposite extremes" in the next El Niño/La Niña episode. Although the lay public may only relate to climate in the context of extremes the public is advised not to be misled by hysteria perpetuated by the media. Increasingly, the public demands to know more precise weather information, including a predictable pattern to regional climates. The climate system is complex however, and simple, all-encompassing explanations to atmospheric behavior are difficult to make and disseminate. Long term records may not match short term observations.

Although a direct link does not exist between SOI and a predictable weather pattern in southeastern North Carolina, this paper illustrates that there is a need for more studies on global atmospheric circulation systems and their links to inter-regional climate patterns.

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