THE SOUTHERN OSCILLATION AND ITS EFFECT ON TORNADIC ACTIVITY IN THE UNITED STATES

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Abstract

The Southern Oscillation has been shown in previous research to cause changes in the weather patterns over the continental United States. These changes, caused by either the warm El Niño or cold La Niña, could potentially effect numbers, locations, and strengths of tornadoes in the United States.

Using a variation of the Southern Oscillation Index, the seven strongest El Niño and five strongest La Niña events during the period 1953–1989 were examined to see what effect, if any, that they would have on: 1) Total tornado numbers, 2) Violent tornado track length, 3) Violent tornado numbers, and 4) $\geq$40 tornado outbreaks.

Little difference was found in total tornado numbers between El Niño and La Niña events. However, significant differences were found in the number of violent tornadoes, and in large number tornado outbreaks. La Niña event years were found to have longer than average track lengths, more violent tornadoes, and a good probability of having an outbreak of 40 or more tornadoes. El Niño event years were found to have shorter than average track lengths, less violent tornadoes, and only a slim possibility of having an outbreak.

Possible reasons for the above conclusions include: 1) Warmer than normal temperatures in the western U.S./Canada along with cooler than normal temperatures in the southern U.S. during El Niño years; and 2) Colder than normal temperatures in the western U.S./Canada along with warmer than normal temperatures in the southern U.S. during La Niña years. This would act to weaken/strengthen the interactions between warm and cold air in the midwest U.S. during El Niño/La Niña event years and decrease/increase the numbers and lengths of violent tornadoes.

1. Introduction

The Southern Oscillation has been shown to cause dramatic changes in the long-term climate of the Pacific Basin (Bigg, 1991). These changes eventually make their presence known in the continental United States. The movement of the west Pacific convergence zone alters the upper tropospheric atmospheric circulation over a large part of the globe, creating a variation of the Pacific/North American (PNA) pressure pattern found by Wallace and Guetzler (1981). A consequence of this pressure pattern is the southward diversion of frontal systems in the North Pacific and high rainfall in the western and southern United States. The PNA emphasizes colder than normal temperatures in the Southeast and warmer than normal temperatures in the western third of the United States during El Niño episodes and warmer than normal temperatures in the Southeast and colder than normal temperatures in the western third of the United States during La Niña[1] episodes (Barnston et al., 1991).

The southward diversion of the frontal systems by the PNA pattern could potentially effect numbers, locations, and strengths of tornadoes in the United States. This study investigates the effect of the Southern Oscillation on tornadic activity in the United States. It examines both aspects of the Southern Oscillation, including the warm El Niño and the cold La Niña events. Overall tornado numbers, damage lengths, violent tornado numbers, and outbreaks with $\geq$40 tornadoes were compared for both events to determine if any specific statistical patterns occurs.

2. The Southern Oscillation

A brief discussion of the Southern Oscillation from Bigg (1990) follows. The climatic oscillation between 'warm' and 'cold' periods in the tropical Pacific is known as the Southern Oscillation. The usual or 'cold' state of the oscillation is known as the Walker Circulation.

[1] The use of the term La Niña has bee adopted for this paper, although it has no cultural basis for its use, unlike the term El Niño which originated from the local coastal population in Peru. The term La Niña was introduced by oceanographers and meteorologists for contrasting ocean-atmospheric conditions to those found during an El Niño event.

Every few years, however, radical alterations to the Walker circulation occur. These alterations are known as El Niño and La Niña. The development and decay of El Niño and La Niña characteristically occurs over a period of 12 to 18 months and appear roughly every 3-4 years, but can vary between two years and a decade.

This study uses the January-February Southern Oscillation Index (SOI) developed by Barnston et al. (1991). The SOI was computed from two equally weighted components; the standardized anomaly of Tahiti minus Darwin sea level pressure and that of the average sea surface temperature in the east-central tropical Pacific. The anomalous sea level pressure (SLP) difference is an indicator of the relative strengths of the Indo-Australian Convergence zone and the subtropical high pressure area. Sea surface temperatures (SST) indicate the degree of warming/cooling relative to the event type. The SOI gives a more stable and complete reading than either the SST or SLP provides alone. Using this criterion, the strongest El Niño events from 1953-1989 are 1983, 1958, 1987,1973, 1969, 1978, and 1966. Note that 1969, 78 and 66 are used due to the extreme closeness in SOI values. This yields seven El Niño events instead. The five strongest La Niña events are 1974, 1976, 1971, 1989, and 1956.

Also of importance to the study is the thermal response of the atmosphere to the changes in sea surface temperature (Reid et al., 1989). In the troposphere (850-150 mb), studies found that the atmosphere lagged behind the ocean by 1-4 months in the tropical Pacific. SST lag between a tropical and subtropical area was discussed by Rasmusson et al. (1982). It was shown that a typical lag in weather effects between the west coast of South America and Hawaii was typically 2-4 months. Thus, the lag between the maximum SST off the coast of South America and it being 'felt' in the continental United States would be around 3-5 months. Since the SST max usually occurs from January through June in the tropical Pacific, the maximum effect of the El Niño/La Niña would occur from March through November in the United States (Rasmusson et al., 1982). With April through July being the most active time for tornadoes in the United States, El Niño and La Niña could have a direct impact on tornadic activity in the United States. Thus, if a year is identified as an El Niño or La Niña year, the tornado statistics used will be for that year.

3. Tornadoes

The eastern two-thirds of the United States is home to the greatest concentration of tornadoes on the planet (Grazulis, 1991). Tornadoes can form under a variety of conditions, including downburst thunderstorms, squall lines, towering cumulus, and the supercell. The supercell thunderstorm gives birth to the largest of tornadoes (F4/F5). This study will concentrate on tornadoes occurring since 1953. This is because 1953 was the first year that the weather bureau began issuing tornado watches. The subsequent verification efforts boosted the number of tornadoes from a yearly average of 227 (1948-1952) to a yearly average of 585 (1953-1957).

Comparisons between the seven strongest El Niño and five strongest La Niña events are in the following categories; total number of tornadoes per year, median tornado track length in miles for violent tornadoes, and number of violent tornadoes per year. An overall comparison of all El Niño and La Niña years for $\geq$40 tornado outbreaks is also given.

a. *Total Tornadoes*

During an average year (1953-1989) in the United States, there were approximately 750 tornadoes. The majority of the tornadoes occurred beginning in March, continued through August and were concentrated in the midwestern part of the United States. One must again keep in mind the bias in tornado data from the 1950's and 1960's. Averages in the 1950's and 1960's were just under 500 and 600, respectively, while figures for the 1970's and 1980's climb to over 800. Again, this was due to an increase in emphasis to report and confirm tornado occurrences.

Table 1 lists the specific averages by event type. Figure 1 depicts the number of tornadoes occurring during both El Niño and La Niña events. Points having a negative SOI number are El Niño and those that are positive are La Niña events. The SOI number is the composite January/February SLP/SST score standardized over a 39 year period (1951-1989). The higher the number (either negative or positive), the stronger the event. For reference, SOI strengths for the El Niño events of 1983, 1958, 1987, 1973, 1969, 1978, and 1966 are -2.9, -1.4, -1.4, -1.2, -1.1, -1.1, and -1.1, respectively. SOI strengths for the La Niña events of 1974, 1976, 1971, 1989, and 1956 are 2.2, 1.9, 1.5, 1.5, and 1.0, respectively.

Table 1: Overall Tornado Summary

Event Type	Average Per Year	Average for Strongest El Niño Years	Average for Strongest La Niña Years	Average for all El Niño Years	Average for for all La Niña Years
Total Tornadoes	750.0	747.0	805.2	711.0	757.5
Violent Tornadoes	10.85	6.4	16.2	7.8	12.6

	Total (1953-1989)	Total for Strongest El Niño Years	Total for strongest La Niña Years	Total for All El Niño Years	Total for All La Niña Years
Tornado Outbreaks >39	14	0	3	3	8

b. *Violent (F4/F5) Tornadoes*

Violent tornadoes are defined as being F4/F5 tornadoes. The 'F' in the F4/F5 signifies a rating scale developed by Fujita (1971), and relates the damage done by a tornado in a specific wind speed range. Violent tornadoes are extremely important in that almost half of all tornado related fatalities occurred on days with more than one violent tornado (Leftwich and Sammler, 1986). F4 tornadoes have a wind speed range of 207-260 miles per hour, and F5 tornadoes have a wind speed range of 261-318 miles per hour. F4 tornadoes level

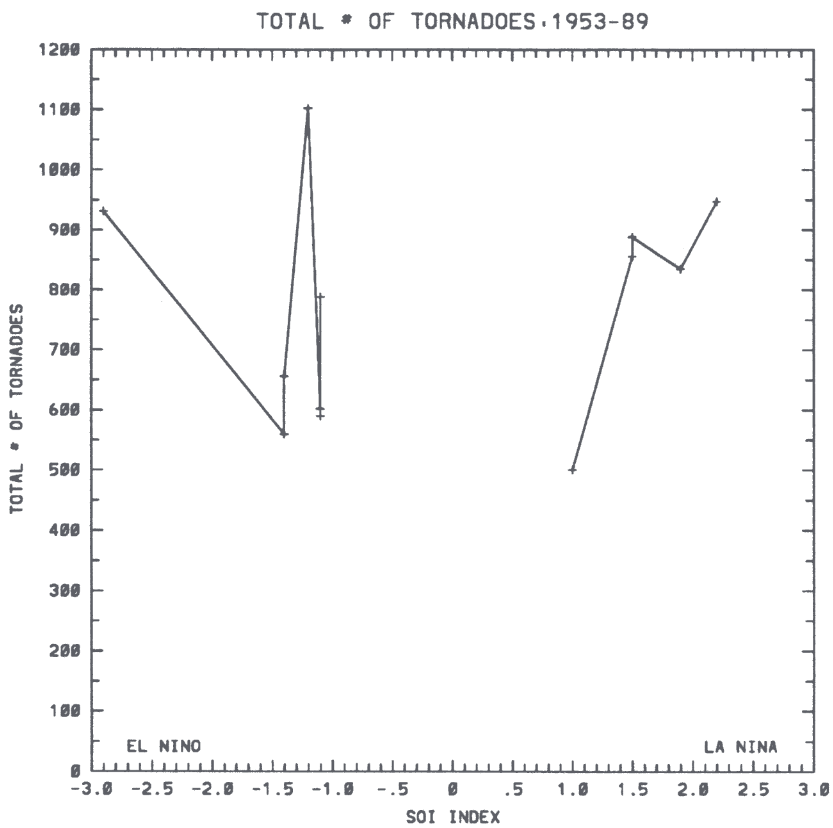

Figure 1: Total Tornadoes by SOI

well-constructed houses, blow off structures with weak foundations, and toss automobiles around. F5 tornadoes lift strong frame houses off foundations, toss automobiles in excess of 100 yards, debark trees, and badly damage steel-reinforced concrete structures. Caution, of course, must be used in employing the F-scale as this scale is a damage scale, not an intensity scale (Doswell and Burgess, 1988). Table 1 lists the specific averages by event type. Figure 2 depicts the number of violent tornadoes occurring during both El Niño and La Niña events.

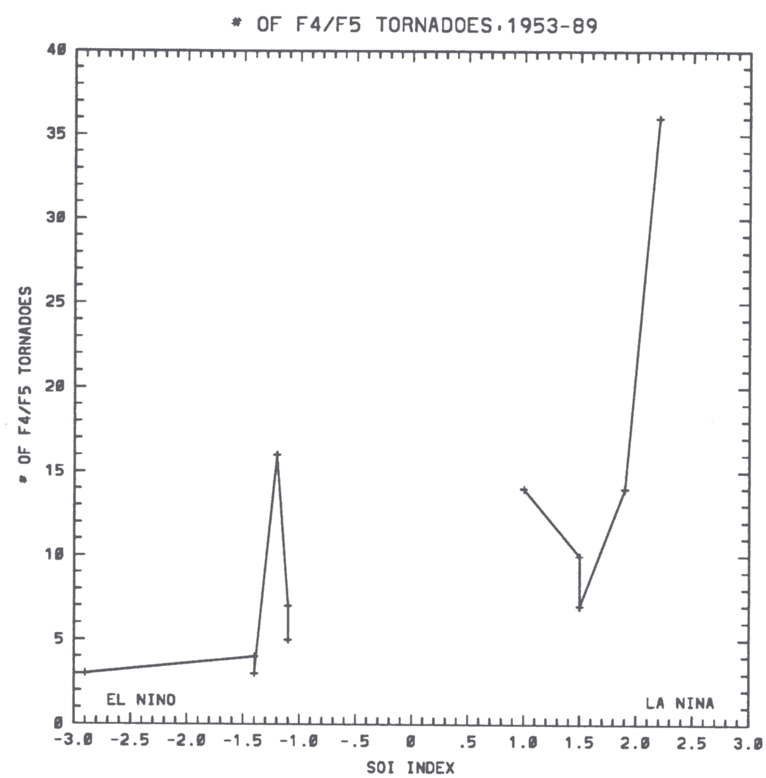

Figure 2: Violent Tornadoes (F4/F5) by SOI

c. *≥40 Tornado Outbreaks*

The term outbreak is used when referring to 40 or more tornadoes which are spawned by the same general weather system. The end of an outbreak is marked by a greater than 6 hour lull in tornado activity (Grazulis, 1991). Most of the original outbreak work was completed by Galway (1975, 1977), working with local, progressive, and line outbreaks. Table 2 lists all of the outbreaks from 1953-1989. The outbreaks are listed by event type (either El Niño or La Niña), SOI strength (negative for El Niño and positive for La Niña), number of tornadoes in the outbreak, and the date of the outbreak. Note that three of the La Niña events (marked with asterisks) are listed as having 39 tornadoes. Grazulis lists these events as having 40 or more tornadoes, but some questions have been raised on the possibility of segments and border crossers. That is, some of the tornadoes may have been counted more than once. The numbers for the other outbreaks have also been adjusted for this possible problem. More research into this problem is needed. Table 1 lists the specific outbreak numbers by event type. Note that the numbers given for the outbreaks are not yearly averages. They are the total number of outbreaks that occurred during either El Niño or La Niña years.

d. *Summary*

Total tornado numbers were close to the yearly average (750) during the seven strongest El Niño years (747.0) and higher than the yearly average during the five strongest La Niña years (805.2), but the difference is not statistically significant.

Of more significance statistically are the results for violent tornadoes, and tornado outbreaks. Numbers for violent tornadoes were much lower than the yearly average (10.85) during the seven strongest El Niño years (6.4) and much higher than the yearly average during the five strongest La Niña years (16.2). When the entire period between 1953 and 1989 is considered regardless of SOI strength, but with only the sign of the SOI considered,

Table 2: Major Tornado Outbreaks by Event Type, SOI Strength, and Number of Tornadoes.

Event Type	SOI Strength	Number of Tornadoes in Outbreak	Date of Outbreak
El Niño	-.8	49	4-5 May 1959
El Niño	-.6	59	8 May 1988
El Niño	-.6	42	15 November 1988
La Niña	2.2	147	3-4 April 1974
La Niña	1.9	63	20-21 March 1976
La Niña	1.5	40	14 December 1971
La Niña	.8	51	25-26 May 1965
La Niña	.8	39*	11-12 April 1965
La Niña	.7	111	19-23 September 1967
La Niña	.7	44	21 April 1967
La Niña	.5	41	9-10 January 1975
La Niña	.5	39*	15-16 May 1968
La Niña	.3	60	2 April 1982
La Niña	.1	39*	7-8 June 1984

*Note some questions remain on the number of tornadoes occurring on these days. The 39 listed is a minimum.

violent tornado numbers differ less. El Niño years average 7.8 and La Niña years average 12.6 violent tornadoes.

There have been 14 tornado outbreaks of 39 and larger from 1953-89. Tornado outbreaks were non-existent during the seven strongest El Niño years (0) and a good possibility during the five strongest La Niña years (3). Of the 14 events, 11 were considered to have occurred during La Niña years regardless of strength, and 3 were considered to have occurred during El Niño years regardless of strength.

4. Conclusions

Using the above information, the following conclusions from this study can be made. The strongest El Niño years in the United States are characterized by a slightly lower than average number of total tornadoes, much fewer violent tornadoes, and no outbreaks with

40 or more tornadoes. El Niño years taken regardless of strength are characterized by lower than average total tornadoes, fewer that average violent tornadoes, and lower than average chance of a tornado outbreak with 40 tornadoes or more. Conversely, the strongest La Niña years in the United States are characterized by a higher than average number of total tornadoes, more violent tornadoes, and a good possibility of having an outbreak of 40 or more tornadoes.

Some possible reasons for the above conclusions are that warmer than normal temperatures in the western US/Canada along with cooler than normal temperatures in the southern United States during El Niño events would lessen the interactions between warm and cold air in the midwest part of the United States (Ropelewski et al., 1986) that typically occurs in late spring-early summer. And, since the majority of violent tornadoes occur in the midwest (Grazulis, 1991), strong El Niño events would act to lower the occurrence of violent tornadoes. Colder than normal temperatures in the western US/Canada along with warmer than normal temperatures in the southern United States during La Niña events would act to strengthen the interactions between warm and cold air in the midwest (Barnston et al., 1991). There would be an increase in the number of days favorable for tornadic development. This would act to increase the number of violent tornadoes that occur during the late spring-early summer. Large multiple tornado outbreaks are more likely for the same reason. Since tornado outbreaks typically occur in the midwestern and southern parts of the United States, there should be much fewer outbreaks during El Niño years than during La Niña years.

These conclusions were drawn from a statistical analysis of the data. Breaking down specific events by region, season, and strength are possible future areas of study. Also, very little work has been done on the large-scale effects of La Niña events.

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