JP5.2 THE EL NINO SOUTHERN OSCILLATION AND ITS ROLE IN COLD-SEASON TORNADO OUTBREAK CLIMATOLOGY

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1. INTRODUCTION

There have been several efforts made, over the past few years, to determine the existence of statistical and/or causative links between specific phases of the El Niño Southern Oscillation (ENSO) and United States tornado climatology. In many of these studies, tornado climatology during the entire year was considered (e.g. Schaefer and Tatom, 1998). However, this paper will consider only tornadoes occurring during the cold season, defined as November, December, January, and February. In addition, tornado events defined as “major” outbreaks will be isolated for study.The intent is not to attempt to associate a particular ENSO cycle with specific tornado events. Instead, tornado outbreak climatology over a 45 year period will be considered. The main goal of this study is to identify whether certain ENSO phases may be especially conducive for synoptic-scale patterns which may, in turn, lead to major tornado outbreaks in an otherwise “unseasonable” time of year.

2. DEFINING AND COUNTING OUTBREAKS

While the occurrence of as little as two tornadoes in areas such as the Pacific Northwest or Northern New England may be deemed “outbreaks” by those who experience them, for the sake of this study only the areas between the Rockies and the Appalachians will be considered for outbreak definition purposes. Galway (1977) defines any occurrence of 10 or more tornadoes from a single storm in a given time period to be a “moderate” or “large” outbreak. This methodology is reinforced when applied to winter tornado outbreaks (Galway and Pearson 1981). Furthermore, Grazulis (1993) defines an outbreak as a series of tornadoes from the same storm system that occur with no more than a six-hour lull between individual events.

For the purposes of counting historical outbreaks, only significant (F2-F5) tornadoes will be considered, since the reporting of weak tornadoes has not been consistent for the entire study period of 1950-1995. Historically, approximately two-thirds of all recorded tornadoes have been weak (F0-F1).Therefore, using the ten tornado outbreak as a starting point, it can be assumed that, on average, three of those tornadoes will be of significant intensity. The method for determining the occurrence of a major outbreak in history is to look for events in which three or more significant

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tornadoes occurred, with no lull of six hours or more between significant tornadoes.

Outbreaks were tallied on a regional scale, with the following regions used:

- **Deep South:** Texas, Louisiana, Mississippi, Alabama, Georgia, Florida
- **Mississippi Valley:** Wisconsin, Iowa, Missouri, Arkansas, Oklahoma, Kansas
- **Ohio Valley:** Tennessee, Kentucky, Ohio, Indiana, Illinois

The regions were separated based on the similarities in the climates of their constituent states. For example, each region experiences their maximum in tornado activity at a unique time of year: MS, AL, et. al in the winter, OK, KS et. al in the late spring, etc. In the period 1950-1995, the Deep South region had 90 major cold-season outbreaks; the Mississippi Valley had 47 outbreaks; and the Ohio Valley had 43 outbreaks. After obtaining these totals, the next step was to separate the events by ENSO phase.

3. DETERMINING SEASONAL ENSO PHASE CLASSIFICATIONS

An El Nino cycle is characterized by calming of equatorial “trade” winds in the East-Central Pacific. The weakening of these winds leads to a decrease in upwelling of colder waters in the East Pacific region, which in turn allows for gradual warming of the waters. This process is sometimes referred to as a “warm phase” El Nino, or simply “El Nino”; the abnormal cooling of East Pacific waters is referred to as “La Nina,” “El Viejo” (the Old Man), or a “cold phase” El Nino, as will be discussed later. The strength of a particular El Nino event can be quantified in terms of sea-surface temperature (SST) measurements (usually presented in terms of deviation from mean SST values), or by the Southern Oscillation Index (SOI). The Southern Oscillation Index is a function of the difference between standardized sea-level pressure values in Darwin, Australia and Tahiti. The more negative the SOI, the more indicative conditions are of an El Nino event. The SOI has been put to use in determining when El Nino or La Nina events occurred in past years.

Traditionally, SOI values between 1 and –1 have denoted neutral phase conditions. Values greater than 1 have defined a La Niña or “cold” phase, and values less than –1 have defined an El Niño or “warm” phase (the “warm” and “cold” corresponding to the departure from average of seas-surface temperatures in the equatorial Pacific). For each four-month cold-season period studied, average SOI values were determined based on monthly SOI values. For the purposes of this study, seasons that have an SOI average of less than –0.7 are considered to be El Nino seasons while seasons that have SOI values greater than 0.7 are classified as La Nina seasons. This modification to the traditional definitions was made to allow for the influence of synoptic-scale patterns that may outlive the planetary-scale anomalies associated with the El Nino or La Nina cycle.

In counting the numbers of seasons under each phase classification, 15 seasons from 1950 to 1995 were found to be El Nino; 8 were classified as La Nina; and 22 had neutral conditions (Table 1). Each region’s outbreaks were then separated by the phase of each season (Table 2).

Table 1: ENSO Phase Classification by Season

YEAR	NOV	DEC	JAN	FEB	AVG. SOI	Phase
1950-51			1.7	0.6		LN
1951-52	-1	-1	-1.2	-1.1	-1.075	EN
1952-53	-0.2	-1.6	0.2	-1	-0.65	N
1953-54	-0.4	-0.7	0.6	-0.7	-0.3	N
1954-55	0.1	1.5	-0.7	1.8	0.675	N
1955-56	1.3	1	1.4	1.5	1.3	LN
1956-57	0.1	1	0.6	-0.5	0.3	N
1957-58	-1.2	-0.5	-2.3	-1	-1.25	EN
1958-59	-0.6	-0.9	-1.2	-2	-1.175	EN
1959-60	1	0.8	0	-0.3	0.375	N
1960-61	0.5	0.8	-0.4	0.7	0.4	N
1961-62	0.6	1.6	2.2	-0.7	0.925	LN
1962-63	0.3	0	1.1	0.4	0.45	N
1963-64	-1	-1.6	-0.5	-0.3	-0.85	EN
1964-65	0	-0.5	-0.6	0.1	-0.25	N
1965-66	-1.8	0	-1.7	-0.7	-1.05	EN
1966-67	-0.1	-0.6	1.9	1.6	0.7	LN
1967-68	-0.6	-0.8	0.4	1.1	0.025	N
1968-69	-0.5	0	-2	-1.1	-0.9	EN
1969-70	-0.2	0.3	-1.4	-1.6	-0.725	EN
1970-71	1.7	2.1	0.3	1.9	1.5	LN
1971-72	0.5	0	0.4	0.8	0.425	N
1972-73	-0.5	-1.6	-0.5	-2	-1.15	EN
1973-74	2.9	2	2.7	2	2.4	LN
1974-75	-0.3	0	-0.8	0.6	-0.125	N
1975-76	1.3	2.3	1.5	1.6	1.675	LN
1976-77	0.7	-0.6	-0.7	1.1	0.125	N
1977-78	-1.6	-1.4	-0.4	-3.5	-1.725	EN
1978-79	-0.1	-0.3	-0.7	0.8	-0.075	N
1979-80	-0.6	-1	0.3	0	-0.325	N
1980-81	-0.5	-0.3	0.2	-0.6	-0.3	N
1981-82	0.1	0.5	1.3	-0.1	0.45	N
1982-83	-3.2	-2.8	-4.2	-4.6	-3.7	EN
1983-84	-0.2	-0.1	0.1	0.6	0.1	N
1984-85	0.2	-0.4	-0.5	1	0.075	N
1985-86	-0.3	0.1	0.9	-1.6	-0.225	N
1986-87	-1.5	-1.8	-0.9	-1.9	-1.525	EN
1987-88	-0.1	-0.7	-0.2	-0.9	-0.475	N
1988-89	1.9	1.3	1.7	1.1	1.5	LN
1989-90	-0.4	-0.7	-0.2	-2.4	-0.925	EN
1990-91	-0.7	-0.5	0.6	-0.1	-0.175	N
1991-92	-0.8	-2.3	-3.4	-1.4	-1.975	EN
1992-93	-0.9	-0.9	-1.2	-1.3	-1.075	EN
1993-94	-0.2	0	-0.3	-0.1	-0.15	N
1994-95	-0.7	-1.6	-0.6	-0.5	-0.85	EN

4. STATISTICAL RELATIONSHIPS

In order to establish a statistical basis for ENSO-outbreak relationships, a series of chi-squared tests were performed. Each region’s outbreak statistics were expressed in terms of how many outbreaks each region counted per season (for example, the Deep South experienced 19 seasons with one outbreak, 9 with two outbreaks, etc. – see Table 3). For the entire study area, the seasonal average for outbreaks was roughly one outbreak per year per region. In a 45-season period as was studied, one could expect there to be an equal distribution between above normal, normal, and below normal seasons in terms of numbers of outbreaks per season, i.e. one-third of the seasons will be above normal and two-thirds will be at or below normal. Upon reviewing the outbreak statistics in the study area, this relationship was indeed evident, as the bulk of the seasons had less than or equal to one outbreak in all regions (Table 3).

Table 2: Cold-Season Outbreaks by Region and ENSO Phase

Region	El Nino	La Nina	Neutral
Deep South	28	22	40
Miss. Valley	10	17	22
Ohio Valley	18	17	8

Table 3: Cold-Season Outbreak Frequency by Region and ENSO Phase

Region	Outbreaks/Season	# of Seasons	El Nino	La Nina	Neutral
Deep South	0	4	3	0	1
	1	19	5	2	12
	2	9	3	4	2
	3	5	1	0	4
	>3	8	3	2	3
Miss. Valley	0	18	9	1	8
	1	11	3	1	7
	2	11	2	3	6
	3	4	1	2	1
	>3	1	0	1	0
Ohio Valley	0	22	7	1	14
	1	12	3	1	8
	2	5	2	3	0
	3	5	3	2	0
	>3	3	2	1	0

Chi-squared tests were run for each region, with the two categories being above normal seasons and at or below normal seasons (Table 4).

The chi squared values calculated for each region based on total outbreak numbers regardless of phase indicated strong deviation from the expected values. This indicates that the “one outbreak per region per season” hypothesis was not supported by the data. Furthermore, when chi-squared tests were run based on phase, deviation based on X^2 values was seen to be a function of phase. In all regions, the X^2 values of less than one for El Nino seasons indicated that “normal” levels of outbreaks did occur during those particular seasons. However, each region had X^2 values of 5.07 for La Nina seasons, indicating a deviation from normal during those periods. The X^2 values for neutral seasons showed little deviation for the Deep South and Mississippi Valley, but strong deviation for the Ohio Valley, owing to the complete lack of above-normal seasons in that region during the neutral phases of ENSO.

These results show a general deviation from normal outbreak levels for La Nina seasons, and a tendency towards normal levels for other phases, excluding neutral seasons in the Ohio Valley. Now that a statistical basis has been set, causative teleconnections between ENSO phases and outbreak frequency must be found in order to make that data of merit.

Table 4: X^2 Grids by Region. Bracketed numbers represent the expected numbers of outbreaks per season in each category (above mean or at/below mean) for each phase.

Deep South			
Phase	Above Mean	At or Below Mean	X^2
El Nino	7 [5]	8 [10]	0.675
La Nina	6 [2.67]	2 [5.33]	5.07
Neutral	7 [7.33]	15 [14.67]	0.0059
Total X^2:	7.45		

Miss. Valley			
Phase	**Above Mean**	**At or Below Mean**	X^2
El Nino	3 [5]	12 [10]	0.675
La Nina	6 [2.67]	2 [5.33]	5.07
Neutral	9 [7.33]	13 [14.67]	0.27
Total X^2:	8		

Ohio Valley			
Phase	**Above Mean**	**At or Below Mean**	X^2
El Nino	7 [5]	10 [10]	0.45
La Nina	6 [2.67]	2 [5.33]	5.07
Neutral	0 [7.33]	22 [14.67]	9.5
Total X^2:	18.02		

5. CLIMATIC EFFECTS OF THE ENSO

As noted above, warmer than average sea-surface temperatures are associated with the El Nino or “warm phase” of the ENSO. The abnormally warm East Pacific waters, through increased convection and subsequent atmospheric heating, push the baroclinic zone that typically defines the polar jet (the “polar front”) further north over the Pacific. This in turn leads to the formation of a strong high in the vicinity of the Gulf of Alaska and a northerly retreat of the polar jet. However, as the sea surface warming associated with El Nino has no counterpart at similar latitudes in the Atlantic, the retreat of the jet is not uniform in all areas. The amplitude of the planetary wave associated with the polar jet is increased in the Eastern Pacific, and this increased amplitude is translated across the rest of North America. All of the climatic effects noted here are those found in the cold season during El Nino and La Nina events.

During El Nino events, in addition to a strong ridge over the Eastern Pacific off of North America, an unusually deep trough is seen to build over the Central U.S. A correspondingly steep ridge accompanies, which is typically situated over either the Eastern Seaboard or the Western North Atlantic. Some of the climatic effects associated with this pattern are cooler than average conditions in the southern states and warmer than average conditions in the Pacific Northwest, Alaska, and the Northeast.

In addition to altering the amplitude of the polar jet, El Nino conditions also affect the strength of the subtropical jet. The warming of Eastern Pacific waters increases convective activity in areas offshore from Western Central America. This leads to the formation of an upper-level low over the area. The subsequently tightened pressure gradient between the Central American low and the aforementioned Alaskan high, coupled with a sharply defined baroclinic zone between the unusually warm tropical Pacific waters and the normally cool subtropical waters increase the speed of the subtropical jet. Moisture transport into the southern U.S. is exacerbated in this pattern, and a few observed byproducts have been increased storm intensity in northern Mexico and southern California and wetter than normal conditions in general over areas adjacent to the Gulf of Mexico.

During La Nina cycles, cooler than average sea surface temperatures are observed over the Eastern Pacific. The subtropical jet weakens and the polar jet assumes a more zonal configuration than what is seen during El Nino episodes. In addition, the polar jet increases in strength and effectively comes to dominate the synoptic patterns over North America. As a result, the southern half of the U.S. experiences drier and warmer conditions than are normally expected. Along the polar jet further to the north, wetter than normal conditions can be expected. The root causes of La Nina cycles are not fully understood, and much of what are assumed to be relationships between La Nina and North American climate are, as with El Nino, largely empirical.

An increase in baroclinity between the warm and cold continental air masses in the U.S. would favor the development of strong synoptic-scale storms. As the previous statistical observations seem to suggest, this increase in the strength and number of synoptic-scale storms over North America is a byproduct of the La Nina phase.

6. CONCLUSION

Statistics seem to support La Nina seasons as the most conducive to numerous cold-season tornado outbreaks. The ingredients needed for strong, tornado-producing cyclones – a strong polar jet over the continental U.S., warm air over the outbreak areas, and cold air intruding from the north – have been shown to be most prevalent during the cold season in La Nina periods. El Nino seasons, while having seen some major cold-season outbreaks, are apparently not conducive for numerous outbreaks, as the chi-squared relationships show. Furthermore, the Ohio Valley region seems to observe a cold-season outbreak minimum during neutral phases of ENSO. This can perhaps be owed to the fact that warm air only rarely makes its way as far north as the Ohio Valley in neutral seasons, and does so much more often during La Nina seasons.

This is not to say that any particular cold-season storm can or should be automatically linked to any particular ENSO phase. The occurrence of one major tornado outbreak cannot by any means indicate an El Nino or La Nina event occurring. However, further study of cold-season outbreak frequency anomalies and their relationship to ENSO phase, combined with what we already know about more well-studied tornado outbreaks that occur in the warm season, may yet provide more clues as to the extent of the true effects of ENSO cycles at every scale, not just the planetary scale.

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