La Niña, El Niño, and Atlantic Hurricane Damages in the United States

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ABSTRACT

Hurricanes result in considerable damage in the United States. Previous work has shown that Atlantic hurricane landfalls in the United States have a strong relationship with the El Niño–Southern Oscillation phenomena. This paper compares the historical record of La Niña and El Niño events defined by eastern Pacific sea surface temperature with a dataset of hurricane losses normalized to 1997 values. A significant relationship is found between the ENSO cycle and U.S. hurricane losses, with La Niña years exhibiting much more damage. Used appropriately, this relationship is of potential value to decision makers who are able to manage risk based on probabilistic information.

1. Introduction

La Niña and El Niño are the popular terms for alternating cold and warm phases of ocean temperatures in the eastern and central Pacific Ocean off the coast of South America (Glantz 2000). The entire cycle is referred to as the El Niño–Southern Oscillation (ENSO) and has gained prominence over the past year with the occurrence of one of the strongest El Niño events on record (Bell and Halpert 1998). Reliable predictions of the onset and development of various phases of the ENSO cycle and their associated worldwide climate anomalies [or teleconnections; see Glantz et al. (1991)] hold the promise of benefits to decision makers with the ability to use them effectively. To date, the scientific community generally predicts sea surface temperatures in one of several regions of the Pacific and then forecasts general weather tendencies based on documented relationships from climatological records. This process makes the connection of ENSO forecasts and societal benefits difficult for most decision makers.[1] Consequently, few decision makers are able to directly use information on Pacific sea surface temperatures to their benefit (Latif et al. 1998). This paper discusses the relationship of sea surface temperatures and Atlantic hurricane damages in the United States, and strongly suggests that a reliable forecast of Pacific sea surface temperatures is of potential value to decision makers capable of hedging with probabalistic information.

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2. El Niño–Southern Oscillation and Atlantic hurricanes

While there is general agreement in the scientific community as to most El Niño and La Niña events of this century, definitions of El Niño and La Niña differ (Trenberth 1997; Glantz 2000). The analysis in this paper uses the definitions of El Niño and La Niña similar to those of Trenberth (1997). That is, an El Niño (La Niña) is said to occur when sea surface temperatures in the region of the Pacific known as Niño 3.4 (5°N–5°S and 120°–170°W; Fig. 1a) are greater than

[1]Although there are important exceptions, e.g., Cane et al. (1994) show a remarkable relation between ENSO and maize yield in Zimbabwe.

or equal to 0.4°C warmer (cooler) than the long-term average during August, September, and October (ASO). These months are of particular importance to the Atlantic hurricane season as 95% of Saffir–Simpson category 3, 4, and 5 hurricane activity occur during August to October (Landsea 1993). Figure 1b shows ASO Niño 3.4 temperature anomalies during 1925–97. The sea surface temperature dataset is a reconstruction of historical observations by Kaplan et al. (1998) to 1991, appended with data from Reynolds and Smith (1994) using a methodology that minimizes inhomogeneities between the two datasets (Landsea et al. 1999). If months other than ASO or regions other than Niño 3.4 are utilized for studies of other climate teleconnections (such as U.S. wintertime temperatures and precipitation), then the selection of El Niño and La Niña years will vary. For the 73-yr period examined in this paper (limited by the economic data discussed below), this definition results in 22 El Niño years, 29 neutral years, and 22 La Niña years (Table 1).

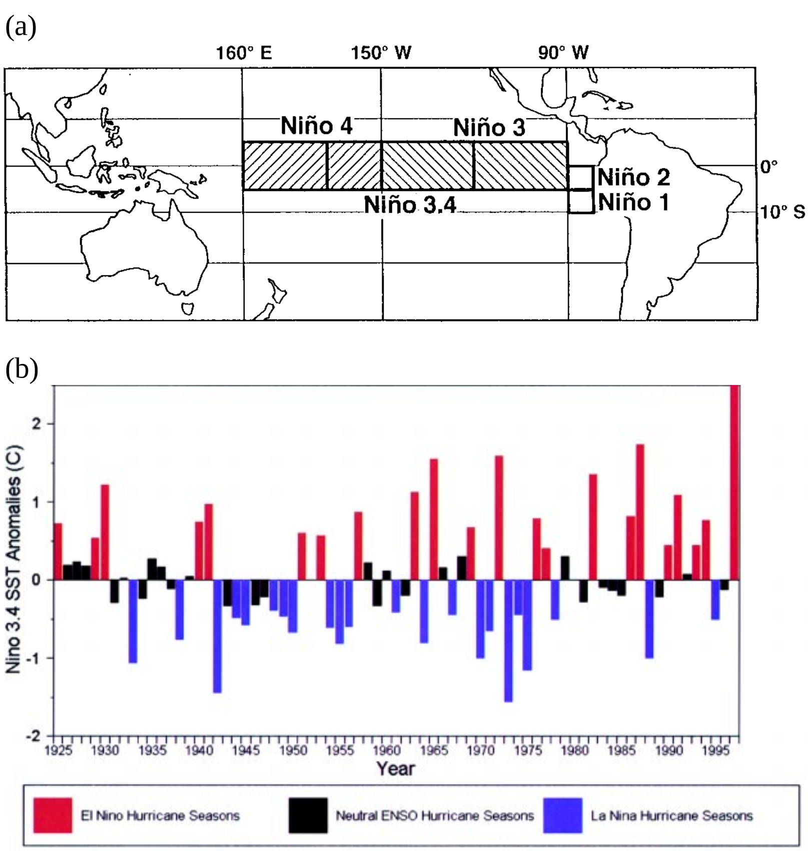

FIG. 1. (a) Location of the Niño 3.4 sea surface temperature region (5°N–5°S, 120°–170°W). Also shown are the Niño 1, 2, 3, and 4 regions (figure provided courtesy of M. H. Glantz). (b) ASO Niño 3.4 sea surface temperature anomalies for the period 1925–97. Anomalies are from a 1950–79 base period. Values equaling or exceeding +0.4°C (–0.4°C) are shown in red (blue) and termed "El Niño" ("La Niña") years. Neutral years are in black.

For many years, meteorologists have known that ENSO strongly affects tropical cyclone activity around the world. In some basins, El Niño events increase tropical cyclone activity (e.g., the central North Pacific near Hawaii, the South Pacific, and the northwest Pacific between 160°E and the date line) (Chan 1985; Chu and Wang 1997; Lander 1994). Tropical cyclone activity decreases in other basins (e.g., the Atlantic, the northwest Pacific west of 160°E, and the Australian region) (Nicholls 1979; Revelle and Goulter 1986; Gray 1984a). La Niña events typically bring opposite conditions. Hurricane activity in the Atlantic basin is affected by ENSO remotely through changes in the Atlantic atmospheric circulation, largely through the vertical shear wind profile. During El Niño events, increased vertical shear is primarily due to increases in the climatological westerly winds in the upper troposphere (and reduced westerlies and shear during La Niña) (Gray 1984a; Shapiro 1987). The larger (smaller) vertical shear accompanying El Niño (La Niña) events contributes directly to decreased (increased) numbers of Atlantic tropical storms and hurricanes. A tropical storm has sustained (1 min) surface wind speeds of 18–32 m s^{-1}; a hurricane has wind speeds of 33 m s^{-1}; and an intense hurricane wind speeds of 50 m s^{-1} [i.e., categories 3–5 of the familiar Saffir–Simpson scale; Simpson (1974)]. Goldenberg and Shapiro (1996) identified the area between 10° and 20°N from North Africa to Central America as having the largest sensitivity to changes in vertical shear. Tropical storms and hurricanes forming over the subtropical waters farther north do show a similar, though much weaker, modulation due to ENSO (Landsea et al. 1999).

Gray (1984a) has also shown a three-to-one ratio in continental U.S. landfalling intense hurricanes, with 0.74 per year striking during non–El Niño years and only 0.25 per year during El Niño events. Recently, Bove et al. (1998) analyzed all continental U.S. landfalling hurricanes and intense hurricanes of this century by the concurrent phase of ENSO. They found that the probability of at least two hurricanes striking the United States is 28% during El Niño years compared with 48% during neutral years and 66% during La Niña years. Likewise, the probabilities for at least one intense hurricane striking are 23%, 58%, and 63% for El Niño, neutral, and La Niña years, respectively.

3. Data on hurricane damages

The National Oceanic and Atmospheric Administration's National Hurricane Center has kept records of total continental U.S. damages related to hurricanes since 1900 (Hebert et al. 1997). The raw data are inappropriate for climate trend analysis because large societal changes have resulted in a dramatic growth in recorded losses, even as hurricane landfalls decreased during the later decades of this century (Landsea 1993; Pielke and Landsea 1998). Nevertheless, it is possible to normalize the dataset to present-day values by accounting for the most significant societal changes.[2]

To normalize past impacts data to 1997 values, losses are adjusted based on three factors: inflation, wealth, and population. Data on all three factors are kept by the U.S. government and allow for the creation of a normalized loss dataset for 1925–97. The result of normalization is an estimate of the economic impact of any storm had it made landfall in 1997. While such estimates are likely conservative for several reasons, it does allow for trend analysis of an underlying climatic signal.

TABLE 1. Categorization of the Atlantic hurricane season into El Niño (based upon the ASO Niño 3.4 SST anomalies warmer than or equal to +0.4°C) and La Niña (ASO Niña 3.4 SST anomalies cooler than or equal to −0.4°C) events from 1925–97. The 10 most intense events of each type are highlighted in bold.

El Niño	La Niña
1925	**1933**
1929	**1938**
1930	**1942**
1940	1944
1941	1945
1951	1948
1953	1949
1957	**1950**
1963	1954
1965	**1955**
1969	1956
1972	1961
1976	**1964**
1977	1967
1982	**1970**
1986	1971
1987	**1973**
1990	1974
1991	**1975**
1993	1978
1994	**1988**
1997	1995

4. ENSO and hurricane damages

Figure 2 shows the damage record normalized to 1997, where the blue bars represent La Niña years; red, El Niño years; and black, neutral years. Over the 73-yr period, the mean annual loss is $5.2 billion and the median loss is $1.1 billion. Table 2 shows the mean, median, and standard deviation for La Niña, neutral, and El Niño years. The large differences between the mean and the median for each distribution indicates that the data are highly skewed. This conclusion is supported by observing the number of years with damages above and below one standard deviation from the mean: four years above and none below for La Niña years, two years above and none below for neutral years, and three years above and none below for El Niño years.

[2]The normalization methodology is described in detail in Pielke and Landsea (1998).

TABLE 2. Median and mean losses (with standard deviation) by phase of ENSO cycle presented in normalized 1997 U.S. dollars.

	Median ($ million)	Mean ($ million)	Std dev ($ million)
La Niña	3,292	5,887	6,991
Neutral	927	6,979	15,856
El Niño	152	2,056	4,228

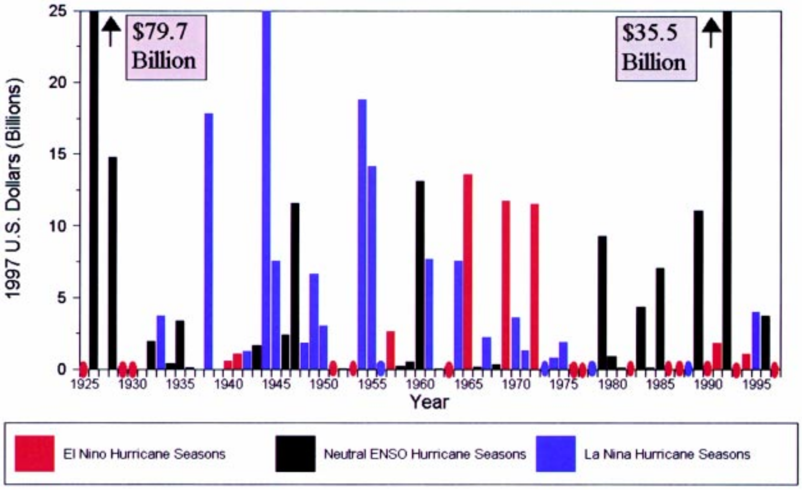

FIG. 2. Normalized U.S. hurricane damage record for 1925–97. Years designated as La Niña events are shown in blue, El Niño events in red, and neutral years in black. Values less than $500 million are shown as an ellipse on the *x* axis.

Table 3 shows that the mean and median values of hurricane damage between El Niño and La Niña years have strongly significant differences, with much more damage in the La Niña phases. Because of the high degree of skewness, significance of the mean values is calculated based on a logarithmic transformation of the data. The mean damage values after the logarithmic transformation (log-mean) are 2.26, 2.73, and 3.37 for El Niño, neutral, and La Niña years, respectively. Median values are not transformed. The comparison shows significant differences between El Niño and La Niña years for both the mediate and log-mean comparisons. For La Niña years versus neutral ENSO years, both the median and log-mean values are higher in La Niña years, but only significantly for the log-mean comparison. El Niño years have smaller damage amounts versus neutral years in both the median and log-mean comparisons, though neither quite reach significance at the 90th percentile level.

Table 4 shows the number of years in which $1 billion, $5 billion, and $10 billion thresholds were exceeded versus the phase of the ENSO cycle. Table 5 shows that moderate (> $1 billion) and large events (> $5 billion) display a strong relationship with ENSO, while the most catastrophic events (> $10 billion) do not. In comparisons versus the neutral years, only the number of moderate (> $1 billion) events shows significantly higher frequencies in La Niña years. All of the El Niño to neutral year comparisons demonstrated lower frequencies of damaging events in El Niño years, though none are significant.

5. Discussion

This analysis suggests strongly that U.S. Atlantic hurricane damages are modulated by the phase of ENSO, with increased losses during La Niña events and reduced losses during El Niño events. These variations are highlighted by the differences in the probabilities of incurring at least $1 billion in damages: 0.77 in La Niña years, 0.48 in neutral years, and 0.32 in El Niño years. Such modulation is not as apparent for the extremely catastrophic (> $10 billion) events. Given the relatively small number of such catastrophic storms in La Niña and El Niño years in the normalized record, further experience may show a significant

TABLE 3. Levels of significance in differences in losses between phases of the ENSO cycle calculated using a two-tailed *t* test. Mean values calculated using a logarithmic transformation; median values are not transformed.

	La Niña	Neutral
Neutral	Log-mean = 94% Median = 61%	
El Niño	Log-mean = > 99% Median = 98%	Log-mean = 81% Median = 83%

TABLE 4. Number of damaging events that exceed certain thresholds by phase of the ENSO cycle, shown as years and percentages.

	La Niña	Neutral	El Niño
> $1 billion	17 (of 22) 77%	14 (of 29) 48%	7 (of 22) 32%
> $5 billion	8 (of 22) 36%	8 (of 29) 28%	3 (of 22) 14%
> $10 billion	4 (of 22) 18%	6 (of 29) 21%	3 (of 22) 14%

TABLE 5. Levels of significance calculated using a two-tailed *t* test, comparing phase of ENSO cycle for three loss-exceedance thresholds.

	La Niña	Neutral
Neutral	> \$1 billion = 96%	
	> \$5 billion = 48%	
	> \$10 billion = 22%	
El Niño	> \$1 billion = > 99%	> \$1 billion = 74%
	> \$5 billion = 90%	> \$5 billion = 74%
	> \$10 billion = 27%	> \$10 billion = 48%

difference for these events as well. The analysis supports the following four conclusions.

a. La Niña means a greater frequency of damaging storms and more damage per storm

During cold events in the eastern Pacific, the odds are significantly higher that the United States will experience greater impacts because of a larger number of tropical cyclones and higher intensities for each storm. Over the 73 years covered by this study, the total numbers of tropical storms and hurricane landfalls were 58 during El Niño years versus 82 during La Niña years. The average Saffir–Simpson category of landfalling tropical cyclones (counting tropical storms as zero) is 0.93 during El Niño years and 1.33 during La Niña years. This translates to a modest, but significant (at the 94% level), difference of about 6 m s^{-1} in wind speed (from 30.6 to 36.3 m s^{-1}). Because damage increases with at least the square of wind speed (Pielke and Landsea 1998), the greater intensity translates to a substantial increase in damage. The average damage per storm of El Niño years is \$800 million versus \$1,600 million in La Niña years. Because the relation of ENSO and hurricane damage is quite similar to climatological variations (Gray 1984a; Bove et al. 1998), it supports claims that a normalization methodology can account for societal change to provide useful climatological information (Pielke and Landsea 1998).

Decision makers should focus on variance in losses as well as central tendency, as even in a relatively inactive season a single storm can have significant impacts, for example, Andrew (1992), with more than \$30 billion in losses. The largest normalized loss in the record is more than \$65 billion in damages due to the great 1926 Miami hurricane, which had a second landfall in the Florida panhandle–Alabama area with about \$10 billion in losses.

b. El Niño does not mean no *hurricanes, as several El Niño years have seen large impacts*

The 1997–98 El Niño event depressed activity of the 1997 hurricane season and losses were minimal (\$100 million). However, this is not always the case. Two El Niño years resulted in large losses: in 1965 Betsy resulted in more than \$13 billion in normalized losses, and in 1972 Agnes had more than \$11 billion. Three of the top five normalized storm losses occurred in neutral years (the other two were in La Niña years). What this means for decision makers is that large losses are possible in any year. However, the relationships documented in this paper suggest that the probabilities of losses exceeding \$1 billion are significantly different depending upon the state of the ENSO cycle. It is imperative that decision makers do not equate El Niño years with "no losses." The occurrence of an El Niño should not lead to complacency about hurricane impacts. Large losses can occur during any year, and experience has shown that society is generally ill-prepared for hurricane impacts (Pielke and Pielke 1997).

c. The ASO Niño 3.4 SSTs provide a statistically significant indicator of damage, but the use of this relation in decision making should be in consideration of its limitations

The analysis in this paper strongly suggests that with a reliable prediction of ASO sea surface temperatures, certain decision makers might be able to derive benefits. However, we offer three reasons for decision makers to exercise caution in the use of this information. First, predictions of El Niño or La Niña conditions are always uncertain, and a significant error in the prediction of SST might lead to costs rather than benefits, compared with a situation with no prediction.[3] Second, these hurricane damage–ENSO relations, while significant, provide information with which to hedge, but should not be used to bet an entire stake. Climate patterns change. There is always uncertainty as to how closely the future will resemble the past.

[3]Indeed, Knaff and Landsea (1997) and, more recently, Landsea and Knaff (1999, manuscript submitted to *Bull. Amer. Meteor. Soc.*) have shown that there is no skill in forecasting Niño 3.4 SST anomalies above that of a simple climatology and persistence model (ENSO–CLIPER) at 0–8-month lead times (cf. Barnston et al. 1999).

Third, this information will likely be of most potential value to sophisticated decision makers who can finely balance risk using probabalistic information. Consider the following two instances where such information could be of value.

- The reinsurance industry and financial markets assess the risk of catastrophic loss primarily using catastrophe models (Musulin 1997). These models typically assume a stationary distribution of hurricanes; that is, they do not take into consideration climatological variations such as are associated with ENSO. The information presented in this paper might be used in such models to develop a more accurate understanding of risk based upon climate variability.
- The federal government typically does not budget in advance for natural disasters (Sylves 1998). Instead, these costs are handled through supplemental appropriations. The analysis in this paper might be used to set aside supplementary funds for disaster-related costs during years that are identified as particularly active.

For an average coastal resident or community, this information might suggest accelerating preparedness plans with a pending La Niña event, but improved preparedness makes sense at any time (Pielke and Pielke 1997).

d. Niño 3.4 ASO SST is not the only climate factor related to U.S. hurricane damage, there are others that sophisticated users should consider

Even though about 40% of the years analyzed in this study had no significant El Niño or La Niña event occurring during the peak of the Atlantic hurricane season, substantial variations of Atlantic hurricanes and U.S. hurricane-caused damage occur in neutral years (see Fig. 2). Other environmental factors impact Atlantic hurricanes (at least partially independent of ENSO)—such as the Atlantic sea surface temperatures, the stratospheric quasi-biennial oscillation, Caribbean sea level pressures, and West Sahel rainfall (Gray 1984a,b; Gray et al. 1993; Landsea et al. 1999). Judicious use of these environmental controls in statistical models has produced skillful experimental seasonal hurricane forecasts by the Tropical Meteorology Project at Colorado State University led by Professor B. Gray (Landsea 1999).

The strong relation of Pacific sea surface temperatures and Atlantic hurricane damages in the United States offers a tantalizing opportunity for the direct use of scientific information about the ENSO phenomenon to society's benefit. It also offers an opportunity for a closer connection of scientists and decision makers to the enrichment of both.

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