

6.7 EL NIÑO/SOUTHERN OSCILLATION IMPACTS ON PEAK WIND GUSTS IN THE UNITED STATES

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1. INTRODUCTION

Wind gusts have a wide range of influence on human activities. Potential magnitude of the wind gust also is crucial to the transportation industry. This knowledge is crucial to airport operators, as a strong burst of wind at the surface can prove fatal during take off and landing. A sudden severe gust of wind (e.g. gale force) can overturn small sea craft; complicate operation of tractor-trailers, motor homes, or other high-profile vehicles, even aid in the spread of forest fires. Recreational activities, such as hang gliding or skydiving, are also greatly impacted by this parameter. Foreknowledge of wind gusts can also prove valuable to those who harness the energy created by wind. Structural engineers must have detailed knowledge of wind potential, as the force on a structure is proportional to the square of the wind speed. The occurrence of multiple days of high wind gusts have a much different impact on bridges, buildings, or other structures than does a constant wind (average). Knowledge of wind gust magnitudes and frequencies is critical in the construction of various structures.

The study is motivated by a desire to better understand the impact of the El Niño/Southern Oscillation (ENSO) on the climate in the United States. The ENSO cycle has been shown to have significant impacts on various atmospheric parameters and phenomena over the continental United States. Past studies have shown the association of ENSO with temperature (Ropelewski and Halpert 1986, Sittel 1994), precipitation (Ropelewski and Halpert 1995, Smith et al. 1998), snowfall (Smith and O'Brien 2001), Lake-Enhanced Snow (Najuch 2002), hurricane landfall (Bove 1998), and even tornadic activity (Bove 1998) over the United States. The present study focuses on wind; more specifically, on the upper tail of the wind distribution, the peak wind gust magnitude, to identify patterns associated with the ENSO cold and warm phases.

Changes in the peak wind gust magnitude are identified over the contiguous United States in association with the warm and cold phases of ENSO, including differences in mean peak wind gust and frequency of gale force wind gust. Hypotheses are presented to relate physical processes associated with ENSO and the observed signals in the study.

Being able to identify the relationship between cycles that impact our atmosphere and their effects on climate and weather can lead to better forecasting ability. With this new information on the association between ENSO and the peak wind gust, coupled with the increased capacity for forecasting ENSO warm and cold phases, improvements in forecasting can be made, thereby mitigating financial impacts, increasing safety awareness, and potentially increasing the benefits of wind power.

2. DATA

Daily peak wind gust magnitude data were obtained from the First Order Summary of the Day (FSOD) dataset (NCDC 1998) provided by the National Climatic Data Center. The FSOD peak wind gust magnitude is defined as the highest, five-second time-averaged magnitude of wind speed recorded in knots by a station's anemometer for a given 24-hour period. The FSOD data contain observations from stations worldwide collected by certified observers from the National Weather Service (NWS), U.S. Air Force (Air Weather Service), U.S. Navy (Navy Weather Service), and the Federal Aviation Administration (FAA). The present study focuses on the contiguous United States.

First order station data date back to 1948. However, prior to 1 January 1955, the recorded units of the data are unclear. The data's documentation states that prior to 1955, the stations' recorded wind speeds are in miles per hour, whereas from 1955 until the end of the dataset, wind speed are recorded in knots. The exception is that the Navy stations consistently used knots as their unit of measure for the entire period of record. In the list of stations provided, differentiation of Navy stations was not clear. Consequently, all data preceding 1955 are excluded. The units problem limits the period of the present study to 1 January 1955 through the end of the dataset, 31 August 1998.

The number of active stations varies throughout the study period. Of the stations that exist for the entire period, most have some missing data. A 90% completeness criterion is invoked to ensure a level of quality of the monthly averages computed from the data. Any month with less than 90% of the data is not included in the climatological calculations for that month. A total of 169 stations pass this criterion and are included in the present study.

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ENSO events are classified using the Japan Meteorological Agency (JMA) Sea Surface Temperature (SST) index. Extremes in ENSO typically develop during summer, climax in the fall, and subside in the following spring. Therefore, an ENSO year is defined as beginning in October of the onset year and continuing through September of the following year (Green 1996). For example: the 1997 warm event year begins in October 1997 and ends in September 1998. This year is used to highlight the effects of the ENSO event from its maturity in the fall. The JMA index is also more sensitive to La Niña events than other indices (Hanley et al. 2002).

The JMA SST Index defines phases of ENSO based on SST anomalies in the region 4° N to 4° S and from 150°W to 90°W. A warm (cold) phase is defined when the five-month running mean of SST anomalies in the defined region is greater than 0.5°C (less than -0.5°C) for at least six consecutive months – otherwise, the ENSO phase is classified as neutral (Marine Department, Japan Meteorological Agency, 1991). The event must begin before the start of the ENSO year (October) and include October, November, and December (Sittel 1994).

3. METHODOLOGY

Monthly averages of the peak wind gust were computed for the 169 stations. The averages were then classified according to ENSO phase (Table 1). For the 44 years of data, from 1 January 1955 to 31 August 1998, there are ten cold phases for each month (9 for October, November, and December, since the data do not begin until January of the 1954 cold phase year), 23 neutral phases, and eleven warm phases (10 for September, since the data set ended in August of the 1997 warm phase).

Table 1. ENSO phases based on the JMA SST index for the period 1954-98. Each year indicates the beginning of the ENSO year (e.g., 1982 indicates a warm phase from October 1982 to September 1983).

ENSO phase	ENSO year
Warm	1957, 1963, 1965, 1969, 1972, 1976, 1982, 1986, 1987, 1991, 1997
Cold	1954, 1955, 1956, 1964, 1967, 1970, 1971, 1973, 1975, 1988
Neutral	1958, 1959, 1960, 1961, 1962, 1966, 1968, 1974, 1977, 1978, 1979, 1980, 1981, 1983, 1984, 1985, 1989, 1990, 1992, 1993, 1994, 1995, 1996

Long-term, monthly averages are computed for each phase. Calculating a station's long-term, monthly mean

for the warm (neutral, cold) phase requires a minimum of three (seven, three) months to have peak wind averages during a warm (neutral, cold) phase. For example, to compute the January warm phase long-term, monthly average for Spokane, WA, there would need to be at least three warm phase Januaries that passed the 90% criterion in the Spokane daily peak wind. Calculations using higher thresholds (5 warm, 10 neutral, 5 cold and 7 warm, 12 neutral, 7 cold) were also examined and revealed the same patterns as with the lesser criteria.

Maps are generated to spatially plot differences in the ENSO extreme event (warm, cold) peak wind gusts relative to neutral (Fig. 1). The neutral phase is used as the base for this study since mean values are influenced by the extremes. The percent change is calculated for each month at each station (Eqn. 1).

Equation 1. Percent change of the extreme phase monthly mean peak wind gust (PKGS), relative to neutral phase

$$\frac{PKGS_{warm/cold} - PKGS_{neutral}}{PKGS_{neutral}} \times 100\% \quad (1)$$

Stations that exhibit significant changes in peak wind during the extreme ENSO phases are determined by constructing monthly distributions for each phase at each station from the daily observations. The distributions are normalized and multiplied by 100 to reflect percentages. The Kolmogorov-Smirnov (K-S) test is used to ascertain whether the peak wind gust distribution of the ENSO extreme event for a given month is significantly different from the corresponding neutral distribution. The K-S test is a distribution-free test for general differences in two populations and tests the difference of the entire distribution (Hollander and Wolfe 1999). The test does not reveal significant differences at any particular percentile. For the present study, the observed significance level at which the distributions are considered significantly different is five percent. The results of the K-S test are plotted spatially along with the difference in means (Fig. 1).

The difference in the probability of a severe occurrence (i.e., a high wind speed) between neutral and extreme phases is computed to quantify the upper tails of the distribution of peak wind gust. The occurrence selected for the present study is a peak wind gust that meets or exceeds a threshold of 28 knots, the minimum classification of a gale force (moderate gale) wind speed, according to the terrestrial-modified Beaufort wind scale (Ludlum 1991). A gale-force wind gust has potential adverse effects on industry, as well as recreation, for maritime or terrestrial activities. A monthly mean frequency of gale force gusts was computed at each station and classified by ENSO phase. The differences between the extreme and neutral phases are plotted spatially (Fig. 2).

4. RESULTS

The strongest, most persistent peak wind gust signals occur during the fall and winter for both extreme phases of ENSO. It is not uncommon for patterns associated with ENSO to have their peak magnitudes in these colder months, as both the warm and cold phases reach maturity during the fall (Glantz 1988, Philander 1990). Other wintertime peaks in observed signals associated with ENSO over the contiguous United States have been noted in previous studies, such as temperature (Sittel 1994, Green 1996) and precipitation (Sittel 1994, Smith et al. 1998). The peak wind gust patterns associated with the warm phase are not equal and opposite to those observed with the cold phase. There is a clear, dominant, cold phase, wintertime signal. Relative to neutral, the cold phase is characterized by more stations that demonstrate significant shifts in distribution, larger positive differences in the monthly mean, and higher frequency of gale force wind gusts than occur during a warm phase. The signals associated with El Niño lack consistency in temporal and spatial patterns. The region with the highest contrast in signals between the two extreme phases is the Northwest (Washington, Oregon, Idaho, Montana, Wyoming, and Colorado). The Northwest has large, positive shifts in the mean and frequency of gale force gusts during the cold phase cold months, while in the warm phase fall and winter months, smaller magnitudes of negative values dominate.

4.1 La Niña Impact

The strongest signal associated with the cold phase is focused about the Northwest in the fall and winter months of the year (Fig. 1). A second region is also observed to exhibit a cold phase signal during the period from November through March over the Ohio River Valley and a third over the Southern Great Plains. Over most of the year and over most of the country, La Niña is associated largely with positive differences in monthly means of the peak wind gust and the frequency of gale force wind gusts (Fig 2). There is an exception in late summer when the presence of these positive differences is not as evident.

The observed signals associated with the cold phase of ENSO are characterized by larger magnitudes of differences in the monthly mean than are observed with warm phase signals, particularly from November to March.

During the cold phase, the months from November to March display the highest percentage of stations that report a difference in means of greater than 10% (Fig. 3). Consequently, the computation of the K-S test reveals these months to exhibit the highest percentage of stations whose cold phase and neutral phase

distributions are significantly different (Fig. 4). The highest concentration of stations with these large

Mean Peak Wind Gust Percent Change Relative to Neutral

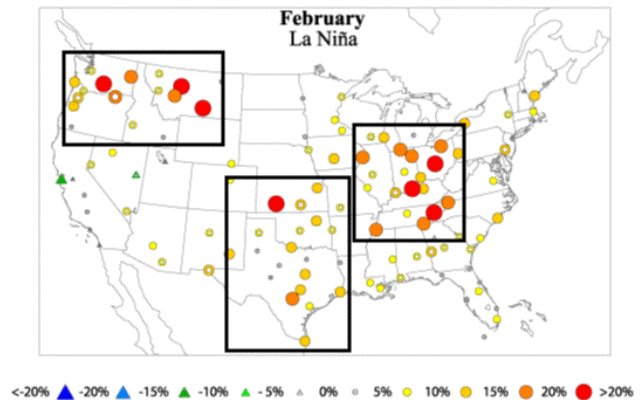


Figure 1. The map displays percent change in monthly mean peak wind gust for the La Niña phase relative to neutral phase for the representative fall/winter month of February. The magnitude and sign of the mean difference are represented by the size and shape of the symbols, respectively. Filled (hollow) symbols represent stations whose La Niña and neutral distributions are rejected (not rejected) as being equal at the 5% level of significance according to the K-S test. The boxes outline the three regions of greatest cold phase fall/winter impact (Pacific Northwest, Southern Great Plains, Ohio River Valley).

28-Knot Peak Wind Gust Monthly Frequency Change Relative to Neutral

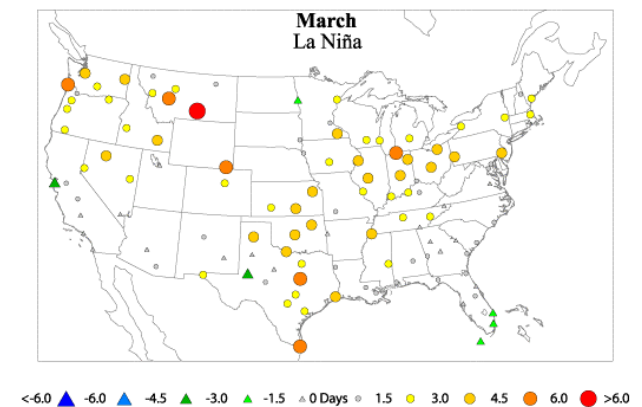


Figure 2. The map displays the difference in frequency of number of days that experience a minimum 28-knot wind gust for the La Niña phase relative to neutral phase for the representative fall/winter month of March. The magnitude and sign of the mean difference are represented by the size and shape of the symbols, respectively.

differences in the mean and significant shifts in distribution occur in the in the Pacific Northwest, Southern Great Plains, and the Ohio River Valley (Fig 1). A signal could not be determined over the Northern Great Plains due to the lack of data.

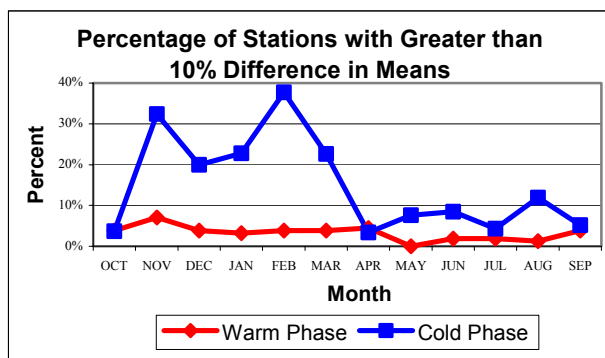


Figure 3. The chart shows percentage of stations studied with a greater than 10% change in the monthly mean peak wind gust relative to neutral for El Niño (red) and La Niña (blue).

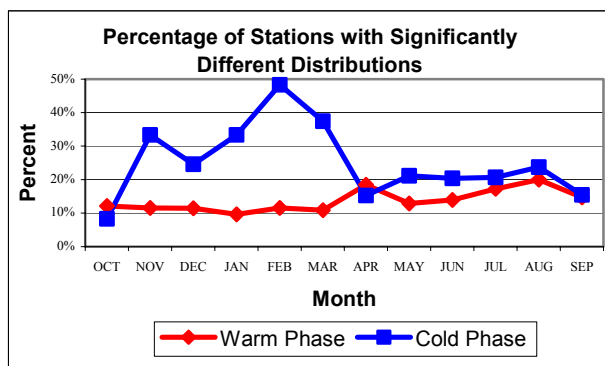


Figure 4. The chart shows percentage of stations studied with significantly different warm and neutral phase distributions (red) and cold and neutral phase distributions (blue), as determined by the K-S test.

4.2 El Niño Impact

The observed patterns associated with the warm phase of ENSO are not as robust as signals observed during the cold phase. The differences in the warm and neutral monthly means are small and not persistent from month to month. The surface observation stations record these percent changes as relatively weak, rarely of greater magnitude than -10% (Fig. 5). Though strong differences in means are not observed, there is a general reduction in peak wind gust in the contiguous United States during El Niño, as well as a reduction in occurrences of gale force wind gusts (Fig. 6). As in La

Niña, this general effect is persistent throughout all seasons with the exception of the July-August-September summer, when there is a primarily positive

Mean Peak Wind Gust Percent Change Relative to Neutral

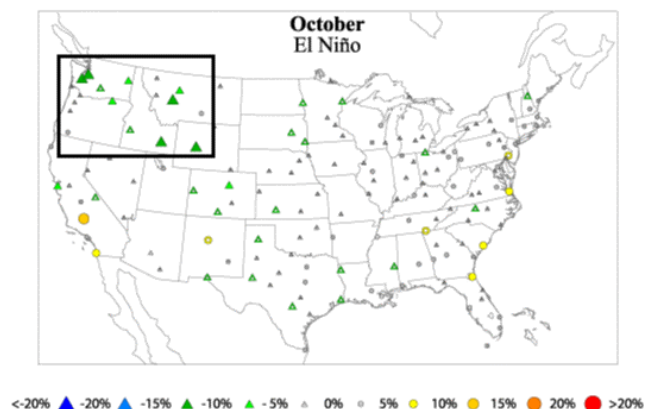


Figure 5. The map displays percent change in monthly mean peak wind gust for the El Niño phase relative to neutral phase for the representative fall/winter month of October. The magnitude and sign of the mean difference are represented by the size and shape of the symbols, respectively. Filled (hollow) symbols represent stations whose La Niña and neutral distributions are rejected (not rejected) as being equal at the 5% level of significance according to the K-S test. The box outlines the region of greatest warm phase fall/winter impact (Pacific Northwest).

28-Knot Peak Wind Gust Monthly Frequency Change Relative to Neutral

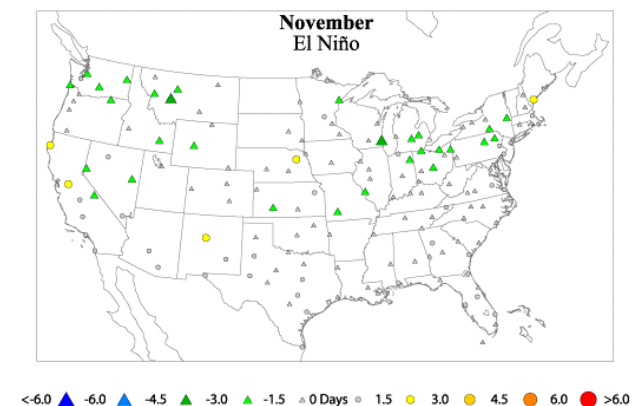


Figure 6. The map displays the difference in frequency of number of days that experience a minimum 28-knot wind gust for the El Niño phase relative to neutral phase for the representative fall/winter month of November. The magnitude and sign of the mean difference are represented by the size and shape of the symbols, respectively.

shift. The K-S test reveals far fewer stations having significant differences in the warm and neutral phase distributions than seen between the cold and neutral phases (Fig. 4).

Mean Peak Wind Gust Percent Change Relative to Neutral

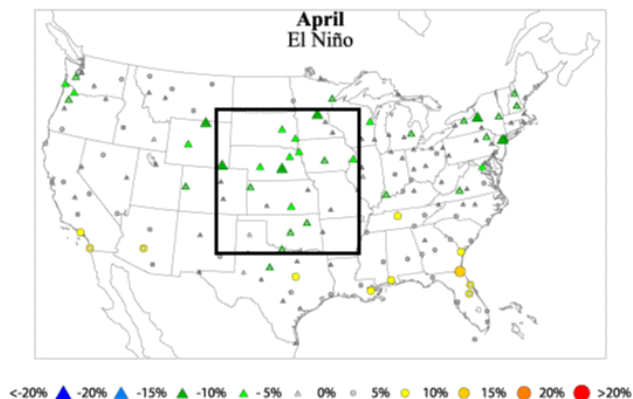


Figure 7. The map displays percent change in monthly mean peak wind gust for the El Niño phase relative to neutral phase for the representative spring month of April. The magnitude and sign of the mean difference are represented by the size and shape of the symbols, respectively. Filled (hollow) symbols represent stations whose La Niña and neutral distributions are rejected (not rejected) as being equal at the 5% level of significance according to the K-S test. The box outlines the region of greatest warm phase fall/winter impact (Central Plains).

28-Knot Peak Wind Gust Monthly Frequency Change Relative to Neutral

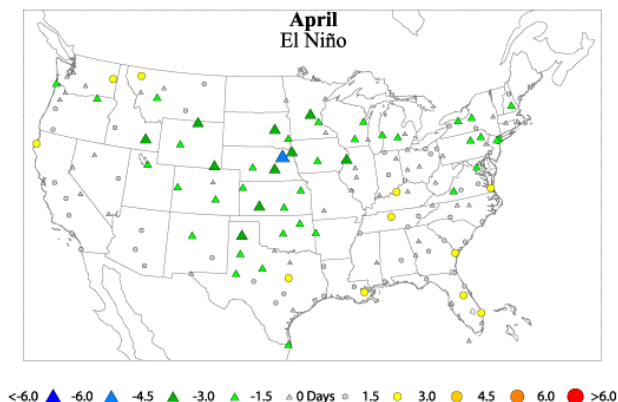


Figure 8. The map displays the difference in frequency of number of days that experience a minimum 28-knot wind gust for the El Niño phase relative to neutral phase for the representative spring month of April. The magnitude and sign of the mean difference are represented by the size and shape of the symbols, respectively.

One persistent warm phase signal, though weak, is observed in the Northwest (Fig. 5). Beginning with the start of the warm phase year (October) through February, a general weak reduction in the monthly mean peak wind gust (usually 0 to -5%) spans most of the country. However, percent changes of -5% to -10% are more common in the Northwest during these months.

During the spring in the Central Great Plains the wind gusts experience a reduction in magnitude. The signal of reduced mean gust and reduced frequency in gale force gusts is present during April and June, but lacking in the month of May (Fig. 7 and 8).

5. SUMMARY

The results show a dominant, ENSO cold phase, wintertime signal. Regions most greatly affected are the Pacific Northwest, Southwest, Great Plains, and the Ohio River Valley including the Great Lakes and Texas. During the cold phase months from November to March, these regions experience an overall increase in the gustiness of the winds. The warm phase is associated with overall decreased gustiness in the Pacific Northwest during these months; however, the signal is of a lesser magnitude. There is also an observed decrease in the Central Great Plains during the warm phase months of April and June. These results along with improved ENSO forecasting can work towards mitigating adverse effects of strong wind gusts as well as increase utilization of wind power.

6. ACKNOWLEDGEMENTS

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