On the definition of El Niño and associated seasonal average U.S. weather anomalies

Narasimhan K. Larkin[1] and D. E. Harrison[2,3]

Received 16 February 2005; revised 19 April 2005; accepted 29 April 2005; published 12 July 2005.

[1] A new NOAA definition of El Niño identifies a number of additional El Niño seasons beyond those conventionally agreed. These additional seasons are characterized by SST anomalies primarily in the western central equatorial Pacific. We show here that the seasonal weather anomalies over the U.S. associated with these additional Dateline El Niño seasons are substantially different from those associated with conventional El Niño seasons. Although some regions have similar associated anomalies, most of the major regional anomalies are quite different. Treating the two as a single phenomenon yields weaker overall seasonal weather associations and does not take advantage of the stronger associations available when the two are treated separately.

Citation: Larkin, N. K., and D. E. Harrison (2005), On the definition of El Niño and associated seasonal average U.S. weather anomalies, *Geophys. Res. Lett.*, *32*, L13705, doi:10.1029/2005GL022738.

1. Introduction

[2] The El Niño–Southern Oscillation (ENSO) is a coupled ocean-atmosphere tropical Pacific phenomenon with global reach. Regional weather anomalies associated with warm ENSO conditions have been documented around the globe [e.g., *Ropelewski and Halpert*, 1987, 1996; *Trenberth and Caron*, 2000]. There are substantial anomalies in U.S. seasonal temperature and precipitation [e.g., *Harrison and Larkin*, 1998b, hereinafter referred to as HL98b; *Smith et al.*, 1999], which can provide a foundation for U.S. seasonal forecasts when they are statistically significantly and robustly associated with El Niño. While there has not been international agreement in detail on the definition of El Niño, many events (11 since 1950) are widely agreed upon (Table 1), and the "El Niño weather" patterns that have become familiar over the past decade (e.g., HL98b) typically were based on anomalies associated with these "Conventional" El Niños.

[3] The National Oceanic and Atmospheric Administration (NOAA) has recently issued an official definition of El Niño. This definition has been adopted by the World Meteorological Organization Region IV:

> A phenomenon in the equatorial Pacific Ocean characterized by a positive sea surface temperature departure from normal (for the 1971–2000 base period) in the NINO 3.4 region greater than or equal in magnitude to 0.5°C, averaged over three consecutive months. (NOAA, NOAA gets U.S. consensus for El Niño/La Niña index, definitions, 2003, available at http://www.noaanews.noaa. gov/stories/s2095.htm)

This definition, based on the existence of modestly persistent surface temperature anomalies over the central equatorial Pacific (the NINO-3.4 index region spans 5°S to 5°N, 170°W to 120°W), does not take into consideration conditions in the eastern equatorial Pacific. Conventional El Niños typically exhibit warming from the Dateline to the South American coast, but the NINO-3.4 region sometimes warms without significant cold tongue warming, resulting in a more "Dateline" El Niño.

[4] Under the official NOAA definition an El Niño season is any 3-month running period in which the SST criterion is satisfied. NOAA Climate Prediction Center (CPC) modifies this definition for retrospective analysis in practice by requiring the definition be met for 5 consecutive months (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml). The number of seasons that are identified as El Niño in either of these manners increase substantially from those that have been conventionally identified; we designate these additional seasons as "Dateline" El Niño seasons. We explore here how the seasonal weather anomalies associated with these "Dateline" El Niño seasons compare with the familiar El Niño weather anomalies.

[5] El Niños are widely considered to have a lifecycle [e.g., *Harrison and Larkin*, 1998a], but we note that the analysis presented here depends on neither the notion nor the characteristics of this lifecycle. We focus here only on the weather anomalies associated with the presence of El Niño conditions, because the atmosphere responds quickly to tropical SST anomalies.

[6] Using seasonal temperature and precipitation data from the U.S. Climate Division data set [*National Climatic Data Center* (*NCDC*), 1994], we compare anomalies present during seasons when "Conventional" El Niño conditions exist and those present during the additional seasons when only "Dateline" El Niño conditions exist. We examine the average seasonal anomalies for boreal fall (S-O-N) and winter (D-J-F). We also examine the likelihood that an extreme seasonal anomaly (top 20%) will occur during these El Niño seasons.

2. Data and Methods

[7] *Rasmusson and Carpenter* [1982] first identified the El Niño–Southern Oscillation phenomenon with anomalous Christmas-time SST warming off the coast of Peru and

[1]PNW Research Station, U.S. Forest Service, U.S. Department of Agriculture, Seattle, Washington, USA.
[2]Pacific Marine Environmental Laboratory, NOAA, Seattle, Washington, USA.
[3]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington, USA.

Table 1. Years in Which "Conventional" or "Dateline" El Niño Conditions Are Present During Autumn and/or Winter[a]

Conventional	Dateline/ NOAA Definition	Dateline/ CPC Definition
1951		
1957		
	1963	1963
1965		
	1968[b]	1968[b]
1969		
1972		
1976		
	1977	1977
	1979[b]	
1982		
	1986	1986
1987		
	1990[b]	
1991		
	1994	1994
1997		
2002		
	2003[c]	

[a]See section 2 for explanation.
[b]Winter only.
[c]Autumn only.

periods of negative values of the Southern Oscillation Index. Since this seminal work, many additional studies have used a variety of indices to identify El Niño events [e.g., *Trenberth*, 1997]. Most studies have selected 1951, 1957, 1965, 1969, 1972, 1976, 1982, 1987, 1991 as El Niño years [e.g., *Rasmusson and Carpenter*, 1982; *Kiladis and Diaz*, 1989; *Deser and Wallace*, 1990; *Hoerling et al.*, 1997; *Harrison and Larkin*, 1998a]. We identify these years with the addition of 1997 and 2002 as the "Conventional" El Niños (Table 1) having El Niño autumn and winter seasons. (Note that, e.g., winter 1951 is here taken to be Dec 1951–Feb 1952.) The conclusions presented here are not sensitive to minor changes to this list.

[8] Use of the NOAA definition identifies 5 additional autumns (1963, 1977, 1986, 1994, 2003) and 7 additional winters (1963, 1968, 1977, 1979, 1986, 1990, 1994) as having El Niño conditions as compared with the "Conventional" El Niño autumns and winters (Table 1). Use of NOAA CPC's 5-month criterion results in a slightly reduced list of seasons with only 4 additional autumns (2003 is omitted) and 5 additional winters (1979 and 1990 are omitted, Table 1). We here show results for the NOAA CPC definition because NOAA seasonal forecasts make use of the presence of El Niño in this manner. The main conclusions offered here are not affected by the choice of either of these definitions.

[9] To compute the U.S. seasonal anomaly associations, we use the NCDC climate division data set [*NCDC*, 1994] and follow the methodology of HL98b. U.S. temperature and precipitation anomalies are computed as deviations from the 1950–1995 average value. Seasonal average composites are done by calendar month over a 3-month period using data from S-O-N (D-J-F) for the Autumn (Winter) season. Statistical significance of the average anomalies is done using a bootstrap technique (resample with replacement, $N = 30{,}000$ [*Efron and Tibishrani*, 1991]) to determine the likelihood of the value occurring by chance. Extreme seasonal anomalies are defined as those in the upper quintile with the same sign as the average anomaly. The statistical significance of the occurrence of extreme seasonal anomalies is computed by counting the number of extreme seasonal anomalies found during the set of El Niño years ("Conventional" or additional "Dateline"), and comparing with the probability of this frequency of extreme seasonal anomalies occurring by chance.

3. Results

[10] Figure 1 shows the Autumn and Winter U.S. temperature anomalies computed for the "Conventional" and additional "Dateline" sets of El Niño seasons. For the

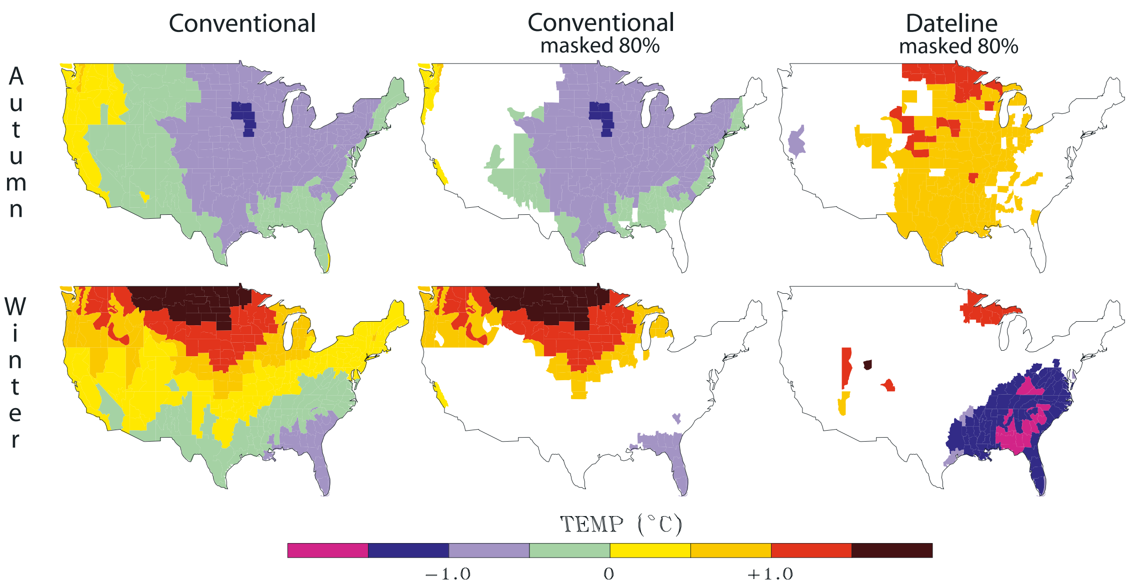

Figure 1. El Niño-Seasonal Average U.S. Temperature Anomaly Associations for Autumn(SON) and Winter(DJF). The left two columns are based on the "Conventional" 1950–2003 El Niño seasons; the right column is based on the "Dateline" El Niños. The right two columns are masked for 80% statistical significance. See text for details.

Table 2. Net Correlation Between Statistically Significant Anomalies Associated With "Conventional" and "Dateline" El Niño Years[a]

	Temp	Precip
Autumn	−0.77	−0.07
Winter	0.14	0.36

[a]Correlations are computed across climate divisions with no area weighting. See text for details.

"Conventional" set, the unmasked average anomalies are presented along with the same anomalies masked for 80% (p = 0.2) statistical significance. Only the masked "Dateline" El Niño anomalies are presented.

[11] First note that the "Conventional" composites are very similar to those of HL98b even though 1997 and 2002 are added. The addition of these 2 periods, including the very strong 1997 El Niño event, only introduces some spatial broadening and minor increase in amplitude of the Winter north-central U.S. warm anomaly. Detail changes are introduced in the results for other anomalies, but no widespread differences appear.

[12] The seasonal temperature anomalies associated with the additional "Dateline" El Niño seasons are shown in the third column of Figure 1. In general the statistically significant "Dateline" temperature anomalies either are of the opposite sign or do not overlap the "Conventional" anomalies spatially. One way to summarize the extent of these differences is via the spatial correlation statistics between the "Dateline" and "Conventional" statistically significant anomalies (zeroing non-significant anomalies, Table 2).

[13] Figure 2 presents the seasonal average precipitation anomalies in the same format. While more spatially complex than the temperature anomalies, a substantial mismatch of patterns again exists between the "Conventional" and "Dateline" seasons. Autumn precipitation anomalies are different, and have a near zero correlation (Table 2). Winter anomalies along the central and southern California coast and from Florida through N. Carolina are similar, but there are large differences over the rest of the U.S.

[14] Figure 3 details where the likelihood of extreme seasonal anomalies is statistically significantly increased. The "Conventional" seasons have an enhanced occurrence of seasonal extremes over much of the country centered in the regions where the anomalies are greatest. In both temperature and precipitation the "Dateline" seasons are weaker overall. Use of the official NOAA definition as opposed to the CPC working definition leads to even weaker extreme associations.

4. Discussion

[15] The autumn and winter seasonal temperature and precipitation anomalies over the U.S. during "Conventional" El Niño seasons, when tropical Pacific SST warms from near the International Dateline to the S. American coast, have become familiar. They provide a foundation for statistical forecasts, and are made use of by many user communities. The statistically significant parts of these patterns are not sensitive to modest differences in the make up of the list of conventional El Niño seasons.

[16] The new NOAA definition focuses only on central tropical Pacific SST warming, thereby introducing a number of additional El Niño seasons when warming did not extend into the eastern Equatorial Pacific. The seasonal weather anomalies associated with these additional "Dateline" El Niño seasons are substantially different from the conventional anomalies. While some regions experience similar anomalies, overall patterns are different in amplitude, percent of the US covered and, often, in sign. Different regions experience an increased chance of extreme seasons, altering the application to many user communities. This result holds whether the official NOAA definition or the modified CPC working definition of El Niño is used.

[17] This work raises many additional questions: should "Dateline" El Niño periods be identified as a separate

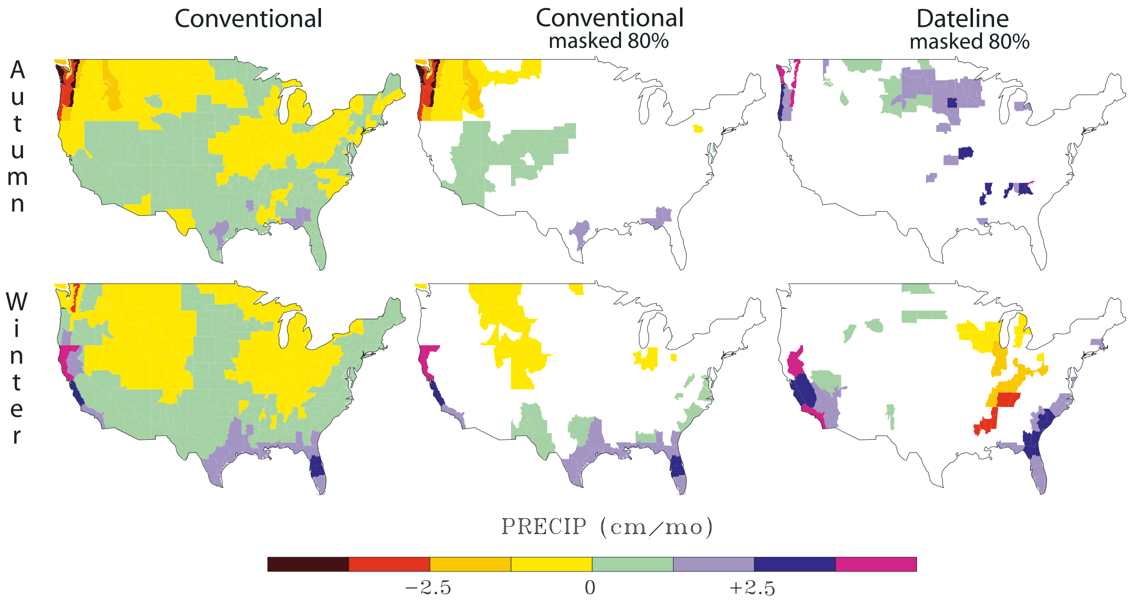

Figure 2. El Niño-Seasonal Average U.S. Precipitation Anomaly Associations. Shown as in Figure 1.

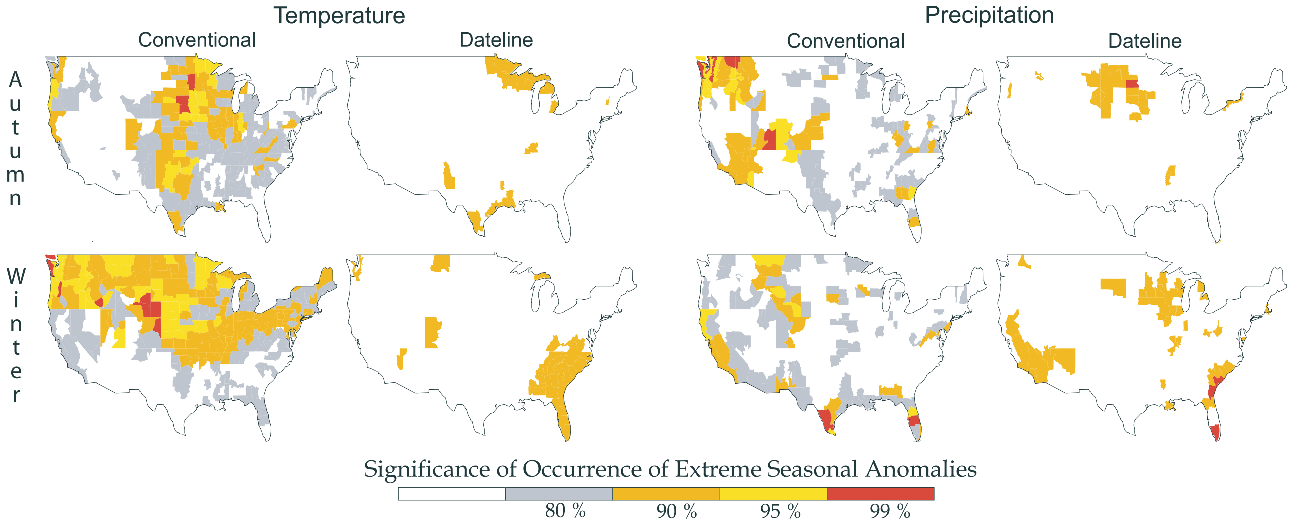

Figure 3. Regions in which the frequency of occurrence of extreme (upper quintile) seasonal anomalies during El Niño conditions is statistically significant (at 80%, 90%, 95%, 99%). Temperature anomaly results on the left; precipitation on the right. Columns 1 and 3 for "Conventional" El Niño seasons, and columns 2 and 4 for "Dateline" El Niño seasons.

entity; is the "Conventional" and "Dateline" distinction optimal for seasonal forecasting; which indices are most appropriate to characterize El Niño for U.S. impacts; what mechanisms control the U.S. middle latitude response to different tropical Pacific warming patterns; is the global response as sensitive to these differences? Our core point is that the new NOAA definition has identified as El Niño a number of seasons that have substantially different U.S. seasonal weather impacts from those conventionally identified. Lumping these periods together with the conventionally identified El Niño periods both reduces the statistical power of the U.S associations and obscures more robust impacts. This result suggests that all of the familiar regional El Niño associations should be reexamined using the NOAA definition, both globally as well as in the U.S. Until such reexamination is complete, it is best not to expect the conventional associations to apply when El Niño SST warming is concentrated near the International Dateline.

[18] **Acknowledgments.** The authors thank David Enfield, Nick Bond, and Philip Mote for their assistance. This is USFS PNW paper #05-174J and NOAA PMEL paper #2735. DEH acknowledges support from NOAA/PMEL, NOAA Climate Office and NOAA Office of Climate Observations. This work made use of the freely available FERRET analysis system (http://www.ferret.noaa.gov). This is contribution 2735 from NOAA/Pacific Marine Environmental Laboratory.

References

Deser, C., and J. M. Wallace (1990), Large-scale atmospheric circulation features of warm and cold episodes in the tropical Pacific, *J. Clim.*, *3*, 1254–1281.

Efron, B., and R. Tibishrani (1991), Statistical data analysis in the computer age, *Science*, *253*, 390–395.

Harrison, D. E., and N. K. Larkin (1998a), El Niño–Southern Oscillation sea surface temperature and wind anomalies, 1946–1993, *Rev. Geophys.*, *36*(3), 353–400.

Harrison, D. E., and N. K. Larkin (1998b), Seasonal U.S. temperature and precipitation anomalies associated with El Niño: Historical results and comparison with 1997–98, *Geophys. Res. Lett.*, *25*(21), 3959–3962.

Hoerling, M. P., A. Kumar, and M. Zhong (1997), El Niño, La Nina, and the non-linearity of their teleconnections, *J. Clim.*, *10*, 1769–1786.

Kiladis, G. N., and H. F. Diaz (1989), Global climatic anomalies associated with extremes in the Southern Oscillation, *J. Clim.*, *2*, 1069–1090.

National Climatic Data Center (NCDC) (1994), Time bias corrected divisional temperature-precipitation-drought index: Documentation for dataset TD-9640, http://www.cdc.noaa.gov/USclimate/Data/, Asheville, N. C.

Rasmusson, E. M., and T. H. Carpenter (1982), Variation in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño, *Mon. Weather Rev.*, *110*, 354–384.

Ropelewski, C. F., and M. S. Halpert (1987), Global and regional scale temperature patterns associated with the El Niño/Southern Oscillation, *Mon. Weather Rev.*, *115*, 1606–1626.

Ropelewski, C. F., and M. S. Halpert (1996), Quantifying Southern Oscillation–precipitation relationships, *J. Clim.*, *9*, 1043–1059.

Smith, S. R., D. M. Legler, M. J. Remigio, and J. J. O'Brien (1999), Comparison of 1997–98 U.S. temperature and precipitation anomalies to historical ENSO warm phases, *J. Clim.*, *12*, 3507–3515.

Trenberth, K. E. (1997), The definition of El Niño, *Bull. Am. Meteorol. Soc.*, *78*, 2771–2777.

Trenberth, K. E., and J. M. Caron (2000), The Southern Oscillation revisited: Sea level pressures, surface temperatures and precipitation, *J. Clim.*, *13*, 4358–4365.

D. E. Harrison, Pacific Marine Environmental Laboratory, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, USA.

N. K. Larkin, Forest Service, USDA, 400 N. 34th St. #201, Seattle, WA 98103, USA. (larkin@fs.fed.us)