A Chronology of El Niño Events from Primary Documentary Sources in Northern Peru*

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ABSTRACT

The authors present a chronology of El Niño (EN) events based on documentary records from northern Peru. The chronology, which covers the period 1550–1900, is constructed mainly from primary sources from the city of Trujillo (Peru), the Archivo General de Indias in Seville (Spain), and the Archivo General de la Nación in Lima (Peru), supplemented by a reassessment of documentary evidence included in previously published literature. The archive in Trujillo has never been systematically evaluated for information related to the occurrence of El Niño–Southern Oscillation (ENSO). Abundant rainfall and river discharge correlate well with EN events in the area around Trujillo, which is very dry during most other years. Thus, rain and flooding descriptors, together with reports of failure of the local fishery, are the main indicators of EN occurrence that the authors have searched for in the documents. A total of 59 EN years are identified in this work. This chronology is compared with the two main previous documentary EN chronologies and with ENSO indicators derived from proxy data other than documentary sources. Overall, the seventeenth century appears to be the least active EN period, while the 1620s, 1720s, 1810s, and 1870s are the most active decades. The results herein reveal long-term fluctuations in warm ENSO activity that compare reasonably well with low-frequency variability deduced from other proxy data.

1. Introduction

ENSO is a coupled atmosphere–ocean phenomenon and the largest source of interannual climatic variability on a global scale. It is characterized by a large-scale fluctuation of atmospheric mass, which is best detected as a "seesaw" of sea level pressure between the southeastern tropical Pacific and the Australian–Indonesian region, the so-called Southern Oscillation (SO). Associated with this global-scale atmospheric phenomenon, there are marked changes in tropical Pacific sea surface temperatures (SST), particularly along the eastern equatorial Pacific upwelling zone and off the coast of Peru, including changes in the warm, nearshore current known as El Niño, whence the phenomenon takes its local name.

Coastal northern Peru and southern Ecuador are the areas most directly impacted by the rise in SST during EN events. Under normal conditions, SST along the western coast of South America, and along the equator in the central and eastern Pacific, are cold because of strong oceanic upwelling associated with the trade winds. The cool water stabilizes the lower atmosphere, inhibiting convection and giving rise to the hyperarid climate of coastal Peru. However, the relationship between the global and the local manifestations of ENSO is not always direct (Diaz and Kiladis 1992; Hoerling and Kumar 2000; Diaz et al. 2001). Changes in ENSO and in the background state of the atmospheric circulation over time can result in high event-to-event variability, and hence ENSO impacts—floods or drought—

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will also experience changes over time. Such inherent variability should be carefully considered when interpreting ENSO indices and proxies, especially in the absence of corroborating information (e.g., Gergis et al. 2006).

The first instrumental observations of ENSO start in the last half of the nineteenth century, which yields too short a record to characterize properly all the time scales involved in its variability. For this reason numerous proxy records of ENSO have been developed over the past few decades, including tree rings, tropical corals, tropical ice cores, and documents reporting unusual rainfall or other disturbed conditions along the northern coast of Peru. Many of these proxies have been described and summarized in Diaz and Markgraf (1992, 2000) and Markgraf (2001). Among them, documentary chronologies of El Niño (EN) based upon historical documents are considered a proxy for warm ENSO phases since they report heavy rainfall or other indicators of EN conditions in the coastal region of northern Peru. Nevertheless, we also refer to these as ENSO chronologies in what follows, with the understanding that they document only the warm phase of ENSO.

While natural proxy records have been widely explored, documentary chronologies of EN are scarce and subject to a certain degree of ambiguity. Perhaps the first historical analysis of EN based upon documentary sources was made by the Peruvian geographer Eguigúren (1894), who analyzed reports of rains in northern Peru and provided an intensity index of these events for the period 1791–1890. Eguigúren worked with a variety of primary and secondary sources, including eyewitness accounts of the conquest of Peru, histories and geographies of the New World written by Spanish colonists and scholars, and contemporary descriptions of the coastal areas of northern Peru. Thus, his intensity index was subjective, being based upon the perceived severity and persistence of rainfall in those years mentioned in the sources available to him. Nonetheless, Eguigúren's was a pioneering paper, anticipating a number of important ideas and methods developed many years later. Aside from his attempt to rank rainfall, Eguigúren also suggested a connection between rainfall and the warm El Niño current [the existence of the current was well known to local fishermen, and was formally documented by the Peruvian naval officer, Carrillo (1892), whose report is quoted by Eguigúren].

The most widely referenced EN documentary chronologies are those published by Quinn and colleagues (Quinn et al. 1978, 1987; Quinn and Neal 1983, 1992; Quinn 1992, hereafter QU). Quinn's chronologies record years beginning in 1520 that are associated with unusual climatic events in the South American region according to two types of indicator. The first type includes the occurrence of floods, droughts, crop losses, pests, migration of fisheries, and so on, in northern Peru, and is therefore a local indicator of EN. The second type includes information from other areas of South America, such as southern Peru, Bolivia, and Brazil, where the impact of ENSO is through teleconnections, and may be weak or even controversial in some cases. In both cases, the indicators were compiled from secondary documentary sources (i.e., secondhand accounts), which introduces a certain degree of ambiguity in the results because of the use of documents not written by direct witnesses. In one of his last papers, QU (his Table 6.2) reported 93 events over the period 1500–1900, providing date of occurrence, an index of intensity (from weak to very strong), and a reliability or confidence index.

Hamilton and Garcia (1986), following Quinn's early work, identified several additional possibilities for strong EN events. They also showed that, in many instances, these events also appeared to be recorded in teleconnection patterns at remote locations of the Northern Hemisphere. More recently Ortlieb (2000, hereafter OR) has revised Quinn's chronology,[1] mainly by reinterpreting the South American sources used by Quinn and reassessing the reliability of the reports, the intensity of the events, and the data quality and its significance. Ortlieb detected some significant sources of uncertainty in Quinn's work: some events had been reconstructed only from floods in the Rimac River, in Lima, which are not reliably associated with EN events. Quinn also associates precipitation anomalies in southern Peru with EN, although in modern data they are more closely related to La Niña events. Ortlieb classified 42 of Quinn's EN events as doubtful, among which are some 25 cases that Ortlieb suggests should be eliminated from the chronology. On the other hand, Ortlieb added seven EN events not reported by Quinn. For the purposes of the present work, we take Ortlieb's chronology to include only events not considered doubtful by Ortlieb, plus the seven additional events identified by him, as listed in Table 1 of OR. Because the number of events rejected as doubtful is much larger than the number of new events added, Ortlieb's chronology is,

[1] More precisely, Ortlieb revised a composite of Quinn's work, including Quinn et al. (1987), Quinn and Neal (1983, 1992), and QU, as explained by OR. In the present work, we take Quinn's chronology to be the one presented in QU, which agrees closely, but not precisely, with the chronology that appears in Table 1 of OR.

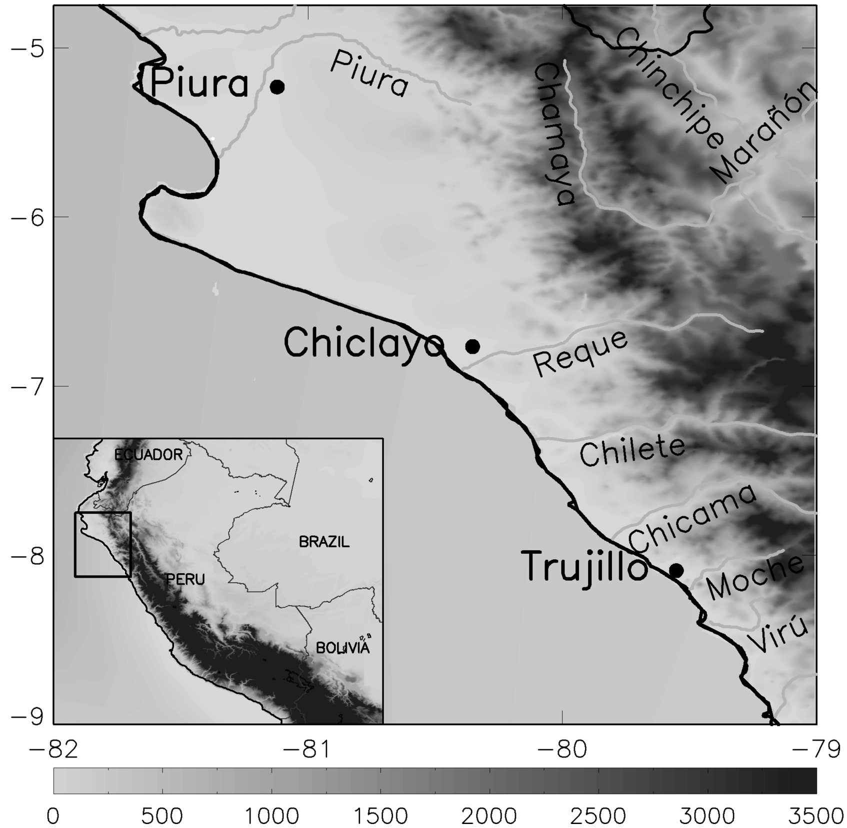

FIG. 1. Map of northern Peru. The map shows the location of Trujillo and the nearby cities of Chiclayo and Piura, as well as the major rivers in the region.

for all practical purposes, a subset of Quinn's. Insofar as these reconstructions were compiled mainly from secondary documentary sources, the dating of EN events may be imprecise.

The aim of the present paper is to develop a new historical chronology of EN events for the period of 1550–1900 based on documentary records from northern Peru. This EN chronology has been constructed in two steps. First, we have compiled new, hitherto unpublished evidence from primary, well-dated documents from the archives of the city of Trujillo, complemented by information from the Archivo General de Indias in Seville (Spain) and the Archivo General de la Nación in Lima (Peru). These data have been combined with additional sources from northern Peru reported in previous studies.

In what follows, we describe the impact of ENSO in the region surrounding Trujillo, provide some details of the archival sources in the area, and describe and illustrate the methodology used to build the EN chronology for the period 1550–1990. The results are compared with the chronologies of OR and QU and other proxy indicators of warm ENSO occurrence.

2. The ENSO signal in the precipitation record of northern Peru

In a couple of recent papers, Rossel et al. (1998) and Lagos et al. (2004) have analyzed the relationship between the occurrence of warm ENSO events and precipitation in northern Peru, and concluded that the region around the city of Trujillo experiences some of the strongest EN signals along the northwest coast of South America, with increases in rainfall over climatology typically exceeding 40%. Lagos et al. (2004) showed high regional correlations with the Niño-3.4 index (N3.4), with values between 0.58 and 0.78, peaking in November–December in Trujillo, December–January in Chiclayo, and December–March in Piura. According to these results, these three locations should show a similar coastal precipitation pattern under warm ENSO conditions.

To obtain a clearer view of the relationship between EN in northern Peru and ENSO, we have examined monthly precipitation records over the period 1955–2003 for the city of Trujillo and the airports of Chiclayo and Piura, whose locations are shown in Fig. 1. Data

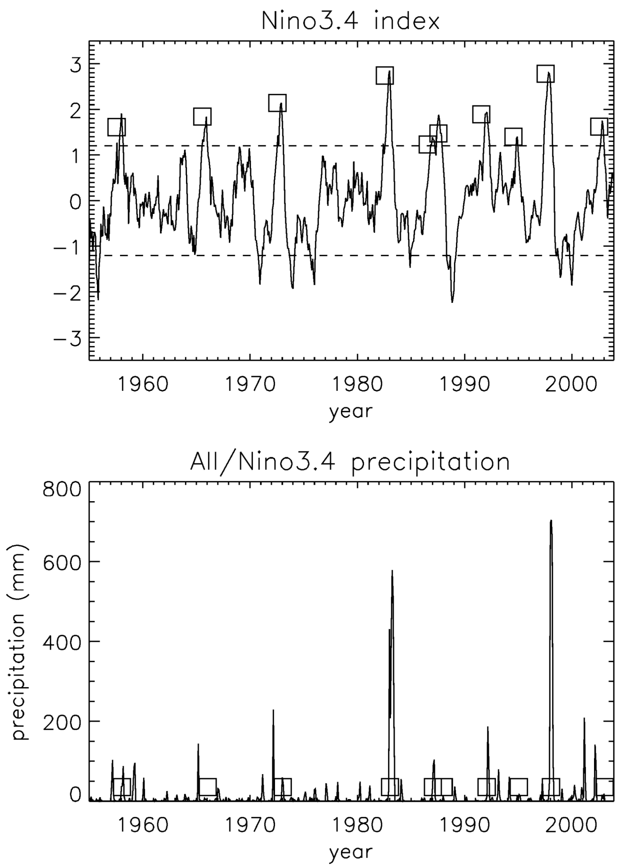

FIG. 2. Warm ENSO events and regional precipitation in northern Peru. (top) Time series of the standardized N3.4 for the period 1955–2003. Years when N3.4 exceeded 1.2 are denoted by the squares. (bottom) Combined monthly precipitation time series for Chiclayo, Piura, and Trujillo for the same period. The squares denote the rainy season beginning during the maximum of N3.4.

were provided by the National Office for Evaluation of Natural Risks of Peru (abbreviated as ONERN in Spanish). Figure 2 compares the combined rainfall time series for these cities during the rainy season with a monthly series of standardized N3.4 index, derived from the average sea surface temperature in the area bounded by 5°S–5°N and 170°E–120°W. The N3.4 data were obtained from the Climate Prediction Center (CPC) of the U.S. National Oceanic and Atmospheric Administration (NOAA; http://www.cpc.ncep.noaa.gov/data/indices/). If we define warm ENSO events as those for which N3.4 $\geq$ 1.2 (which captures major events since 1955), it is clear from Fig. 2 that almost all of these events are associated with excess rainfall in northern Peru, although the timing when N3.4 reaches its maximum value does not always coincide precisely with the local rainy season (November–April). For example, while N3.4 reaches a local maximum in late 1965 and 1972, an enhanced precipitation signal did not occur in 1965/66 or 1972/73; instead, precipitation was anomalously high in the preceding rainy seasons, 1964/65 and 1971/72, respectively. During 1986/87, N3.4 remained above 1.2 from mid-1986 through late 1987; however, this event is associated with a large precipitation signal in 1986/87 but not in 1987/88. Examination of the relationship between precipitation and the Niño-1.2 index (not shown), which reflects SST adjacent to the coast of northern Peru (0°–10°S, 90°–100°W), indicates that coastal SST often warm up well in advance of the maximum in N3.4. This finding is consistent with the occurrence of excess rainfall in the rainy season preceding the maximum in N3.4, as noted in previous studies (Deser and Wallace 1987; Quinn and Neal 1992).

Figure 3 displays the seasonal evolution of combined monthly rainfall totals for Trujillo, Piura, and Chiclayo during the strongest EN events of 1955–2003 defined, as before, by values of N3.4 $\geq$ 1.2. Precipitation values are shown for two years, encompassing the rainy season preceding the maximum on N3.4 as well as the following rainy season, when the maximum of N3.4 usually occurs. If we let year_0 denote the year of maximum N3.4, then the rainy seasons shown in Fig. 3 are those straddling year_{-1}–year_0 and year_0–year_1. For comparison, we also plot the mean monthly precipitation in non-EN years. The EN signal is readily apparent, usually exceeding several times the mean value for non-EN years, although it is not always present in the rainy season of year_0–year_1. The only exception is the relatively weak EN event of 1994/95, when precipitation was not anomalous compared to non-EN years. On the other hand, the most intense ENSO events of the period in question (1982/83 and 1997/98) are marked by spectacular increases in precipitation (600–700 mm, compared to an average of less than 40 mm in non-EN years). In view of these results, we conclude that northern Peru exhibits a robust ENSO signal, with anomalous rainfall recorded during all but one of the major warm ENSO events of 1955–2003. As a consequence, although our EN chronology strictly reports EN events in northern Peru, it is nonetheless a valuable indicator of past ENSO behavior (warm ENSO events).

3. Description of the documentary sources

We made an assessment of the availability of documentary records for selected locations in northern Peru, which have not been fully explored previously. The main historical archives in this region are in Piura and Trujillo. Piura has a smaller and incomplete collection because it belonged to the administrative district of Trujillo until the early years of the eighteenth century,

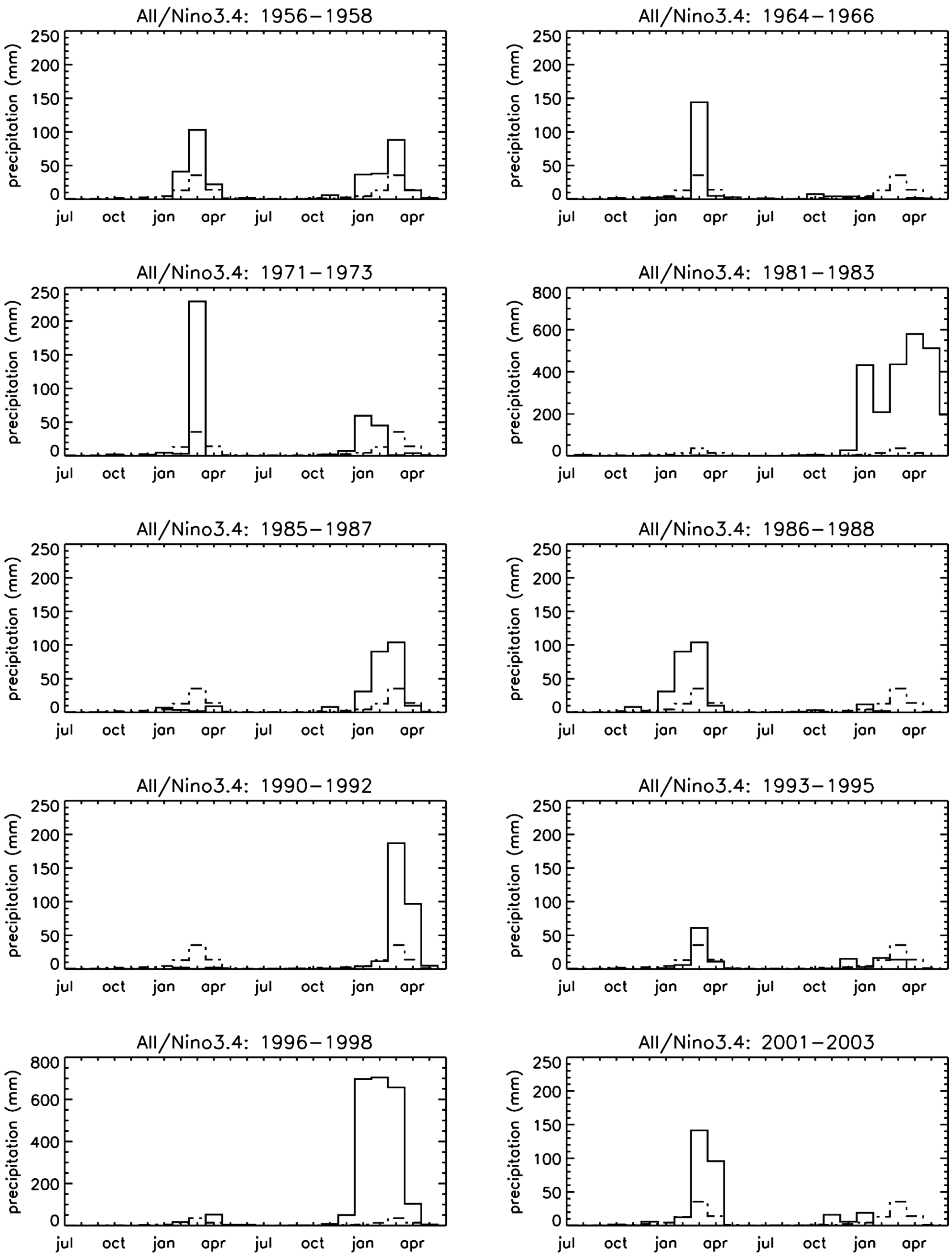

FIG. 3. ENSO impact in northern Peru precipitation. Seasonal evolution of monthly combined precipitation for Chiclayo, Piura, and Trujillo for major warm ENSO events (defined as in Fig. 2; histograms). Precipitation is shown for the rainy season preceding the maximum in N3.4, and for the season when maximum N3.4 occurs. Mean precipitation values for non-ENSO years are shown by dashed lines. Note different scale for the ENSO events of 1982/83 and 1997/98.

so many documents were actually kept at the Trujillo archive. Additionally, documents have been damaged or even lost because of the heavy rains that fall in Piura. Thus we have used three documentary collections in this paper. The most important one is the collection of primary documents in the Archivo Departamental de la Libertad, in Trujillo, which was created in 1970 and contains the documentary legacy of the city of Trujillo

TABLE 1. Description of the sources used in this study. The first column provides the name of the general historical archive, its location, and the number of manuscripts consulted in this source (in brackets). The last two columns indicate those primary documents examined, corresponding to the Colonial and Republican periods, respectively. The general archives are classified into sections (bold italic), which are themselves divided into subsections (italic) containing series, subseries, and manuscript bundles.

Archive	Colonial period [1534–1850]	Republican period [1850–]
Archivo Regional de La Libertad (Regional Archive of La Libertad), Trujillo (Peru) [147 manuscripts and 41 city council books]	***Notarial*** (Notary), 1539–2000: *Indiferente* (Miscellaneous)	
	Judicial (Judicial) 1537–1850: *Cabildo* (City Council) *Real Hacienda* (Royal Treasury) *Corregimiento* (Litigation) *Intendencia* (Administration)	***Judicial*** (Judicial) 1850–1998: *Cabildo* and *Presidencia* (City Council) *Prefectura* (Prefecture) *Corte Suprema* (High Court) ***Gobierno Regional*** (Regional Government), 1873–1982: *Intendencia de Policía* (Police Administration)
	Empresas Privadas (Private Businesses), 1771–1995	
	Gobierno Local (Local Government), 1549–1987: *Municipalidad Provincial de Trujillo* (Province of Trujillo) *Alcaldía* (Mayoralty), including *Actas Capitulares* (City Council records)	
Archivo General de la Nación (National General Archive), Lima (Peru) [241 manuscripts]	***Derecho Indígena*** (Indian Laws), 1552–1842 ***Juzgado Privativo de Aguas*** (Water Court), 1557–1825 ***Tierras de Comunidades*** (Communal Lands), 1702–1847 ***Administración de Correos*** (Mail Administration), Trujillo, 1804–18 ***Cajas Reales*** (Royal Cashier), Trujillo, 1616–1820 and Saña, 1661–1769 ***Libros de cuentas*** (Account books), Alcabalas, Lambayeque, 1790–1821 ***Tabacos*** (Tobacco), Trujillo, Lambayeque, Chiclayo, 1765–79 ***Estancos*** (Tobacco Concessions), Trujillo, 1751–1823 ***Administración Aduana Real*** (Royal Customs Administration), Trujillo, 1774–1826	***Prefectura*** (Prefecture), La Libertad, 1856–79 ***Correos*** (Mail), Trujillo, 1850–51
Archivo General de Indias (General Archive of Indies), Seville (Spain) [102 manuscripts]	***Gobierno*** (Government), 1492–1870 ***Indiferente General*** (General Miscellaneous), 1758–1898 ***Estado*** (State), 1683–1860 ***Manuscritos*** (Manuscripts), 1500–1899 ***Contaduría*** (Accounts), 1514–1782 ***Correos*** (Mail), 1752–1846 ***Escribanía*** (Records), 1525–1778 ***Justicia*** (Justice), Lima, 1515–1617 ***Patronato*** (Royal Patronage) and ***Quito***, 1480–1801	

and the area under its administrative purview, currently the Department of La Libertad. Additional primary sources related to the area of Trujillo are also found at Archivo General de la Nación in Lima regarding documents on the administration of the Trujillo area. Finally, the Archivo General de Indias, in Seville, contains documents relating to the administration of the Spanish colonies in South America, including Peru [further information about the use of this archive can be found in Garcia et al. (2001) and Garcia-Herrera et al. (2003)]. Each of these sources is described in detail in Table 1. In total, more than 250 000 pages of primary sources were examined to construct the EN chronology. In addition, we also consulted the sources cited in the papers of Quinn et al. (1987), OR, Mabres et al. (1993), Macharé and Ortlieb (1993), and Huertas Vallejos (1993, 2001).

4. Description of Trujillo and its environs

The city of Trujillo, Peru, was founded in 1534 at the site of a previous settlement of the prehispanic Moche

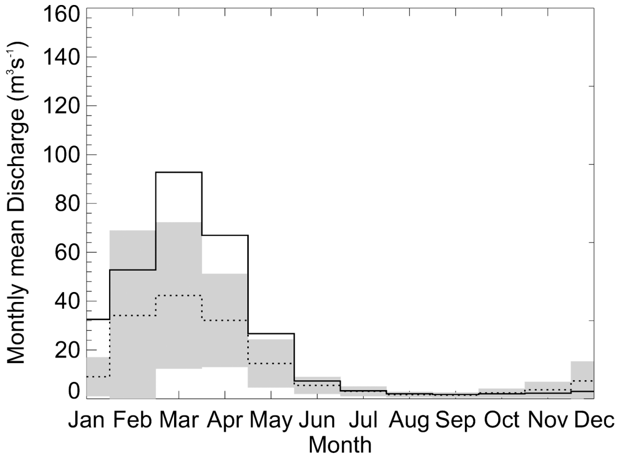

FIG. 4. ENSO impact in northern Peru river flow. Composite of the combined seasonal cycle of river flow for the Moche, Chicama, and Virú Rivers for ENSO (solid line) and non-ENSO (dashed line) years, defined as in Fig. 2, in the period 1983–2002. Shaded areas indicate $\pm 1\ \sigma$ level (where σ denotes the standard deviation for the non-ENSO years).

and Chimu cultures. The city center, *Plaza de Armas*, is at 8°6′3″S, 79°1′34″W, with an altitude above mean sea level (MSL) of 31 m. Trujillo is the capital of the Department of La Libertad, which covers an area of about 25 500 km^2. Three main regions may be identified: coastal, mountain (above 2000 m), and Amazonian. Despite its aridity, the coast is the most densely populated part; Trujillo is located in the wide valley of Santa Catalina, surrounded to the east by the Andes and by hilly terrain elsewhere. The Río Seco, a seasonal river, flows to the north of the city. The river is part of a complex network of brooks, mostly dry except during ENSO episodes, at which time they can become dangerous streams. However, the most important river of the region is the Moche, with a watershed of 2708 km^2, and a length of 104 km from its source in the Andes, at 4000 m MSL, to its mouth in the Pacific Ocean, in the vicinity of the city of Trujillo. Figure 4 shows the combined monthly flow for the main rivers in the area (Moche, Chicama, and Virú, all identified in Fig. 1). A clear seasonal cycle is evident, with maximum flow between March and May, consistent with the seasonal evolution of precipitation shown in Fig. 3. The impact of warm ENSO events is also evident, especially in the months with peak flow. Most of the contribution to these rivers comes from the wetter part of basin, which is located above 1500 m with an annual average precipitation ranging between 200 and 1200 mm. Apart from earthquakes, the main natural hazard in the city of Trujillo is flooding associated with EN conditions, particularly when rain occurs below 1800 m MSL. These rains give rise to sudden flows and rapidly rising water level in rivers, ditches, and gorges. Under these conditions heavy rock masses and mudflows, locally known as *huaycos*, are carried by the river, and pose a special risk for certain city districts. The city can be flooded when the capacity of the Moche bed is surpassed and the gorges are activated. Because of the geomorphology of the basin, this response to heavy rains is very fast. As an example, the historical maximum annual discharge in the Moche River (213 068 m^3 s^{-1}) occurred in 1998, and the maximum daily peak flow (1000 m^3 s^{-1}) on 13 March of the same year was clearly associated with the strong EN event of 1997/98. During the 1998 EN event, the floods damaged the Pan-American Highway, several city sectors, the airport, farming lands south of the city, and even old historical walls in the area.

5. Construction of the chronology

a. New EN evidence

Given the extensive historical information available from the city of Trujillo, we relied primarily on reports of anomalous rainfall and related phenomena from the Archivo Departamental de la Libertad to reconstruct an EN chronology since the mid-sixteenth century. Note that this approach cannot detect cold (La Niña) events because of the extreme aridity that prevails in the area during non-EN years, regardless of whether they are normal or La Niña years. Another limitation is that EN events are not always recorded in the city of Trujillo itself, although they may be apparent in the surrounding region. This was the case, for example, in 1957–58, when Trujillo did not report anomalous rainfall (although Chiclayo and Piura did). However, as noted in section 3, historical documents found in Trujillo often describe conditions found over a much wider area surrounding the city.

After considering the climatic impact of ENSO and the environmental setting of Trujillo and northern Peru (geography, hydrology, geomorphology, and socioeconomic setting, outlined in section 4), we compiled a set of indicators that could reflect the occurrence of an EN event in that area. Since, as described in section 2, the occurrence of rainfall in Trujillo is rare and is mostly associated with warm ENSO events, occurrence of anomalous rainfall was the main indicator, followed by its characteristic impacts on the most sensitive/vulnerable activities of the area. At this initial stage, we were interested in capturing all the potential events, so the list of indicators (shown in Table 2) was as extensive as possible. The first three indicators listed in Table 2 cover the most direct EN impacts: rain, failure of fisheries, and high temperatures. The impacts of

Table 2. Type of indicators. List of indicators and terms used in interpreting the documentary information relevant to El Niño in the Trujillo area.

Number	Indicator
1	Rain
2	Failure of fisheries
3	High temperature
4	River flooding
5	River rises
6	Swamps or lagoons
7	Change in river course
8	Damage to ditches
9	Problems with water supply
10	Bridge damage
11	Road damage
12	Flooding of land
13	Building damage
14	Increase of grass
15	Increase of livestock
16	Lack of products
17	Shortage of grass
18	Famine
19	Death of livestock
20	Loss of crops
21	Pests
22	Damage to cultivated lands
23	Change of prices
24	Epidemics

heavy rains on rivers, buildings, ditches, bridges, and other public infrastructure are included as items 4–13. Indicators 14–23 comprise the expected impacts on farming and agriculture, while indicator 24 is associated with the possible occurrence of epidemics. Thus, a given EN event can be traced from reports containing a diversity of indicators, which helps to overcome some of the problems encountered when a single variable is used. For example, EN events not reflected as heavy rain in the area can be recorded as a period of poor fishery, or of widespread river floods. In this sense, the use of the additional indicators adds robustness and reliability to our assessment.

We then built a database containing transcriptions of all the documents wherein any of these indicators were found. The information is organized in two blocks. The first identifies the data: archive, documentary reference, and date of the document. The second refers to the events described: initial and final date, city and location where the event occurred, type of event according to the classification of Table 2, and the textual copy of the original document. Each record was carefully evaluated in context, taking into account the type and detail of the information provided, the person and/or institution providing the information, and the value of the information as an EN indicator. A total of 3248 records were finally included in the database, of which about 40% were considered as potentially useful. The records selected as potentially useful were analyzed to identify candidates for EN events.

After careful study of these records, we have considered as "principal evidence" of EN just two indicators: failure of fisheries and coastal rain. Other important indicators (crops, flooding, road or bridge damage) are often ambiguous. For example, flooding can occur because of EN or as part of the seasonal cycle, or because of poorly maintained reservoirs and ditches; road and bridge damage, unless noted to be widespread, can be due to causes extraneous to EN; crops can be abundant under EN because of abundant water for irrigation, or they can be poor because of severe flooding or insect infestations; and so on. All EN indicators other than failure of fisheries and coastal rain where considered "other evidence"; that is, they are suggestive, but not definitive, markers of EN events.

b. *Reassessment of previous evidence*

Next we examined the evidence of EN events provided in Quinn et al. (1987), OR, Macharé and Ortlieb (1993), Huertas Vallejos (1993, 2001), and Mabres et al. (1993). Although many mentions of EN conditions from these studies come from secondhand sources, there are also primary sources of information and official archives from northern Peru (especially Piura) that provide evidence of EN conditions. From these studies we added to our chronology those events not reported in our sources that were identified in reports from northern Peru (mostly Piura) for which the evidence was unambiguous according to the criteria previously defined. In the case of conflicting evidence, we gave primacy to our primary sources. In the absence of any contradictory or supporting evidence from our archives, we included those events for which there was firsthand information from primary archives of Northern Peru or reliable secondary sources. We did not include those years when secondary sources provided contradictory or questionable indications. This resulted in the addition of seven new events to our chronology.

c. *Classification of events*

For the final evaluation, we classified each year for which relevant evidence exists according to the following scheme:

- Non-EN years: Cases where no "principal" or "other evidence" of EN was found from our archives, or when contradictory, doubtful, or no evidence of EN occurrence was reported in "previous studies."

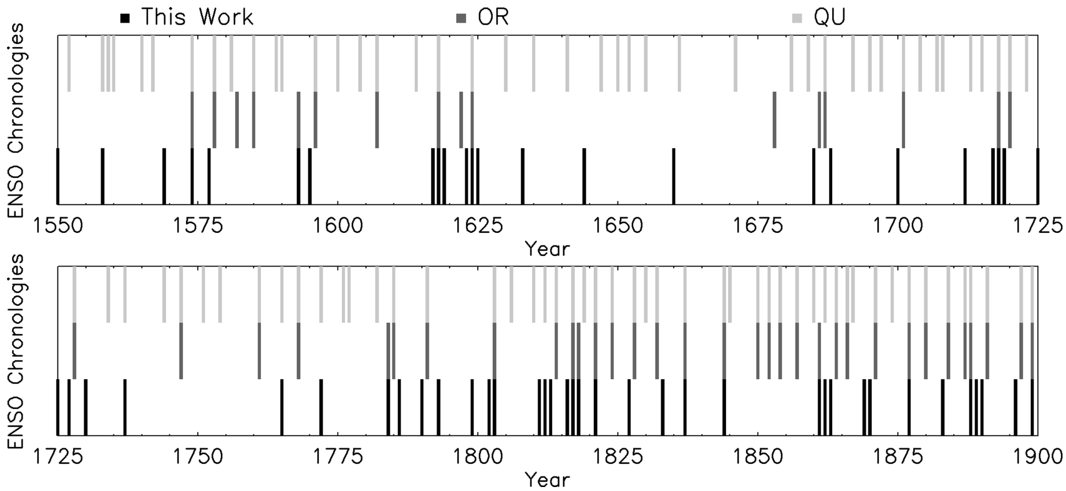

FIG. 5. EN chronologies in the 1550–1900 period. Comparison of EN years in (top) QU, (middle) OR, and (bottom) the present chronology. Bars indicate $year_0$ of the EN events.

- Possible EN years: Cases where either one item of "principal evidence," several internally consistent items of "other evidence," or clear evidence from "previous studies" were found.
- Probable EN years: Cases with multiple items of "principal evidence" or one item of "primary evidence" plus additional, self-consistent items of "other evidence."

When identifying EN years, we have looked for "climatological consistency" in the sources. Thus, principal or other evidence in the rainy season encompassing November of one year ($year_0$) through April of the next year ($year_{+1}$) suggests an EN event in $year_0$–$year_{+1}$. We have considered sources dated at other times of the year to be less indicative of EN. Note that, as shown in section 2a, increased rainfall can also occur in the rainy season of $year_{-1}$–$year_0$. Thus, there is some of ambiguity in the identification of $year_0$ of a warm ENSO event from documentary sources in coastal northern Peru, such that what we identify as $year_0$ of an EN event could actually be $year_{-1}$ of a warm ENSO event. We take this ambiguity into account in the comparisons presented in section 6.

Evaluations of all the EN events identified in this study are available in table format in the supplementary information, Table S1, which summarizes the relevant information for each year, including short excerpts from the original documents and our evaluation thereof. In addition, all database materials, including transcripts of the relevant original documents are being made available through the NOAA/National Climatic Data Center (NCDC) Paleodata Center.

6. EN chronology in comparison with previous work

Figure 5 shows the time distribution of the EN events identified in the present study, together with those identified in the chronologies of QU and OR. EN events are denoted by bars, intensity coded for each chronology, so that matches among the chronologies are readily apparent. Table 3 complements Fig. 6 by

TABLE 3. Frequency of EN years and matches with other chronologies. The first four columns show the number of EN years identified in our chronology, and those of QU, OR, and GF for different periods between 1550 and 1900. The last two columns show the number of same-year matches between our chronology and the other three and (in parentheses) the number of matches that occur on the same year or the year following our EN dates.

	EN events				Matches with this chronology		
Period	This chronology	QU	OR	GF	With QU	With OR	With GF
1550–99	7	13	6	5	2 (4)	2 (4)	1 (2)
1600–99	11	21	7	5	2 (3)	2 (3)	2 (2)
1700–99	16	25	10	5	4 (10)	2 (6)	2 (3)
1800–99	25	34	26	9	10 (18)	10 (18)	2 (5)
Total	59	93	49	24	18 (35)	16 (31)	7 (12)

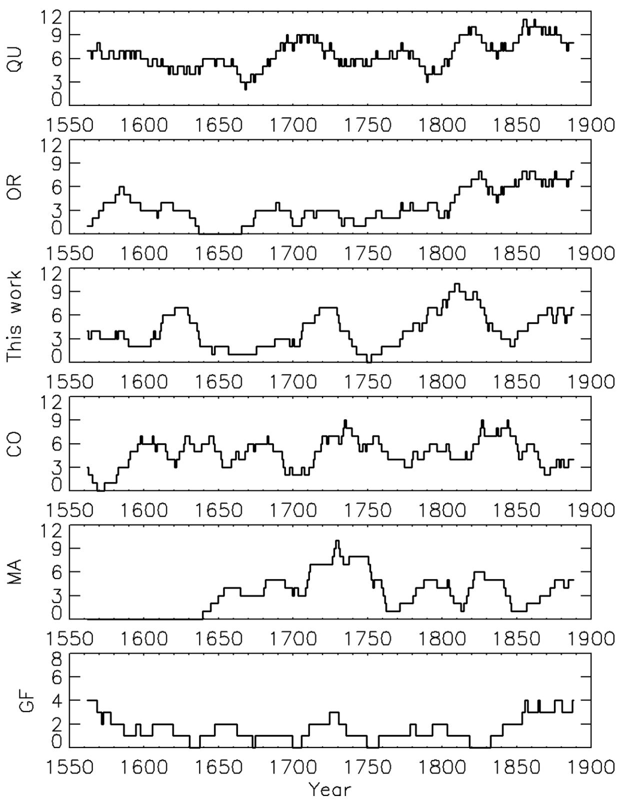

FIG. 6. Long-term variability of El Niño/warm ENSO events. Comparison of 25-yr running means of El Niño/warm ENSO events in (from top to bottom) QU, OR, our chronology, CO, MA, and GF. The value shown for a given year represents the frequency associated with the interval centered in that year. See text for details.

showing the distribution of events during each century in the three chronologies, and the number of matches between our chronology and those of QU and OR. We do not list simultaneous matches among all three chronologies because OR chronology is to a large extent a subset of QU, as noted previously; that is, the chronologies of QU and OR are not independent.

For the entire period included in this chronology (1550–1900), Quinn identified 93 EN event years and Ortlieb 49, in comparison with our 59. Aside from these general considerations, the following features are evident from the comparisons shown in Fig. 5 and Table 3:

- Relative to our chronology, QU overestimates the occurrence of EN, presumably because of the problems described by OR, including inappropriate interpretation of some of the documents, and the inclusion of reports from areas where ENSO teleconnections are questionable.
- On the other hand, OR underestimates the frequency of EN years prior to 1800 relative to our chronology. Possible reasons include the lower availability and reliability of the secondary sources used in the earlier period. In fact, there is a large increase in EN years reported by OR in the nineteenth century.

Discrepancies between our chronology and those of QU and OR may be due to a number of reasons: 1) different criteria were used in the definition of EN versus ENSO; 2) we have restricted our search to northern Peru, while QU includes a wider region of South America, including (sometimes questionable) teleconnections, and OR considers evidences from northern Peru and southern Ecuador; and 3) we use mostly primary sources, while QU and OR use some secondary sources. We believe that the use of primary sources restricted to the area of northern Peru, which has the most robust association with EN, should yield a more reliable chronology.

As regards the correspondence among the chronologies, the level of agreement is low when only exact matches are considered, as shown in the last two columns of Table 3. However, whereas our chronology is based exclusively on documentary sources from northern Peru, QU use both local indicators of EN and remote indicators from ENSO teleconnections, and OR includes some questionable evidence, although he notes the associated uncertainty. As shown in section 2a, rainfall anomalies associated with EN years in northern Peru can occur during the rainy season preceding or coinciding with the maximum development of ENSO, but QU uses local and remote indicators indistinctly, and both QU and OR chronologies rely mainly on secondary sources. This introduces a degree of ambiguity in the chronologies depending on whether these sources record a local EN year or an ENSO episode as well as on the reliability of the secondary source. This should be taken into account when comparing our chronology with QU and OR. Thus, what we identify as an EN event could have been dated as occurring in the following year by QU and OR if their identification was based on a remote indicator of ENSO. The values in parentheses in the last two columns of Table 3 are the number of matches obtained when EN events in QU or OR occur in the same year or in the year following EN events in our chronology. This number is considerably greater than the number of exact matches, although it constitutes an upper limit, since some of the EN identifications by QU and OR were made on the basis of local rather than remote evidence of ENSO. It is also clear that the number of matches between our chronology and those of QU and OR is similar for almost all periods shown in the table, even though QU lists almost twice as many events as OR. This suggests that rejection by OR of doubtful events in QU has indeed succeeded in eliminating many spurious cases.

Given the disagreements in detail between our chronology and those of QU and OR, we might ask whether the number of matches shown in Table 3 is statistically significant. If only exact matches are allowed, the probability of N matches in the 350 yr spanned by the chronologies is governed by the binomial distribution. The number of exact matches between our chronology and those of QU and OR is $N = 18$ and $N = 16$, respectively; the first of these figures is not significant, even at the 90% level, but the second is significant at better than 95%. If, on the other hand, matches occurring on the same or the following year as EN events in our chronology are considered, the agreement between pairs of chronologies is highly significant. In this case, the binomial distribution does not apply, so the statistical significance was determined from the following Monte Carlo test: each EN series was shuffled 5000 times to randomize the order of the EN occurrences, and the number of matches within (0, +1) years of EN events in the present chronology was counted. The shuffling was carried out in 50-yr blocks to take into account the fact that the statistical properties of the series may not be uniform in time. From the probability distribution of matches obtained by this procedure, the 35 matches found between our chronology and QU and the 31 matches between our chronology and OR are both significant at the 99% level.

Using the same methodology, we have also compared our chronology with the series of strong EN events proposed by Gergis and Fowler (2006, hereafter GF). This is a reconstruction of very strong EN events derived from the 70th percentile of a multiproxy index constructed from tree rings, corals, ice cores, and documentary paleoarchives (QU; OR). The number of exact matches (7) is significant at the 95% level, while the matches within (0, +1) years (12) are significant at the 99% level.

7. Interdecadal variability of warm ENSO events

We examined the interdecadal variability of EN events in our chronology and those of QU and OR. The top three panels of Fig. 6 show 25-yr running means of EN frequency for each chronology. The following features are evident:

- The chronologies of QU and, especially, OR exhibit increasing frequency of events with time, presumably because of the increasing availability of their documentary sources in the more recent past (cf. Table 3). Our series, on the other hand, displays a somewhat more balanced century-scale distribution and a smaller temporal trend in the number of events (note that the sixteenth century is really half a century, 1550–99, in our chronology; thus, there could be 14 events in that century if the event frequency is the same in the first and second halves).
- Although certain previous studies have suggested little long-term variation in ENSO frequency, especially in the period 1500–1800 (Lough and Fritts 1989; Enfield and Cid-Serrano 1991; Quinn and Neal 1992), the present chronology displays large interdecadal oscillations. In our chronology, periods of high EN activity occur around 1625, 1725, 1810, and 1890, while periods of reduced EN frequency are found around 1675, 1750, and 1850. Such marked long-period fluctuations are not as apparent in the other two chronologies. Our results are consistent with previous studies using tree rings from North America as a proxy for ENSO activity, which found fluctuations of about 80–100 yr in the amplitude and frequency of ENSO since 1570 (Michaelsen 1989).
- The first half of the eighteenth century was one of the most active intervals in the present chronology, a feature that is absent in OR and indistinct in QU. Another remarkable difference is the relative minimum of ENSO activity in the mid-nineteenth century in our chronology, contrasting with high frequency of events in QU and OR. Previous studies, using proxy records of sea surface temperature from the Galapagos Islands have also suggested that ENSO frequency was rather low in the mid-nineteenth century (Enfield 1989). These long-term changes in the frequency of warm ENSO events have also been reported to occur from instrumental records of the twentieth century (Trenberth and Shea 1987; Allan et al. 1996; Diaz et al. 2001). The well-known climate shift of the 1970s decade has been related to changes in the type of fishery of northern Peru (Chavez et al. 2003). Thus, an "anchovy regime" seems to be prominent under cooler conditions and lower frequency of warm ENSO events, while a "sardine regime" is associated with warmer conditions and higher frequency of warm ENSO activity. A similar change of preferred anchoveta-to-sardine fishery pattern has been documented in 1500 (Sandweiss et al. 2004).

We next explore the question whether the long-period variability in our chronology is consistent with previously published ENSO proxy series constructed using other proxy data, namely, the series of Niño-3 index (N3) index developed by Cook (2000, hereafter CO) and Mann et al. (2000, hereafter MA), and the chronology of GF described in section 6. The CO series is a reconstruction of N3 derived from southwestern North America and northern Mexico tree rings, while MA is a multiproxy reconstruction. To derive chronologies of warm ENSO events from these proxy series we calibrated them against the longest instrumental record of the Southern Oscillation index (SOI) reported in the literature, which spans the period 1866–2005 (Ropelewski and Jones 1987) and is well correlated with N3 (Jones et al. 2001). Warm ENSO events are assumed to occur when SOI < -1.2, which captures all of the major events in the interval 1955–2003. The CO and MA series are then standardized relative to 1866–2005, and an appropriate threshold is chosen in each case to match the number of warm events given by the SOI. These thresholds are used to define warm ENSO events in CO and MA series.

The lower three panels of Fig. 6 show 25-yr running means of warm ENSO frequency derived from the CO, MA, and GF reconstructions. All three series show large multidecadal variability throughout their respective periods of record. Similar features are present, such as higher frequencies during the first half of the eighteenth and nineteenth centuries in CO and MA, and minima near 1825 in GF, 1850 in MA, and 1875 in CO are also observed. These features are reasonably consistent with our chronology, and there is also good agreement between our chronology and those of QU and OR, especially after 1800. Our results are also consistent with other previous warm ENSO chronologies reconstructed from different natural proxies. Thus, Evans et al. (2002) applied the technique of reduced space objective analysis to reconstruct gridded Pacific SSTs and the leading modes of large-scale variability from sparse observational networks of coral stable isotope ($\delta^{18}O$) data for the period 1607–1990. They found periods with vigorous ENSO activity in 1600–50, at the beginning of the eighteenth century, in the first half of the nineteenth century, at the end of the nineteenth century, and at the beginning of the twentieth century (see their Fig. 11). These periods alternated with relatively low frequency in warm ENSO activity, especially remarkable during 1650–75, 1725–1800. These results suggest that our ENSO chronology provides a more consistent reconstruction than previous proxies of ENSO from documentary sources.

To highlight the periodic oscillations in our EN chronology, a wavelet spectrum was computed for the EN series (Fig. 7). Significance was tested against a red noise process designed to allow for autocorrelation in the series. As shown in the figure, variance is concentrated in decadal and interdecadal frequency bands, with much of the variance occurring near a period of 100 yr. The other proxy series of warm ENSO events

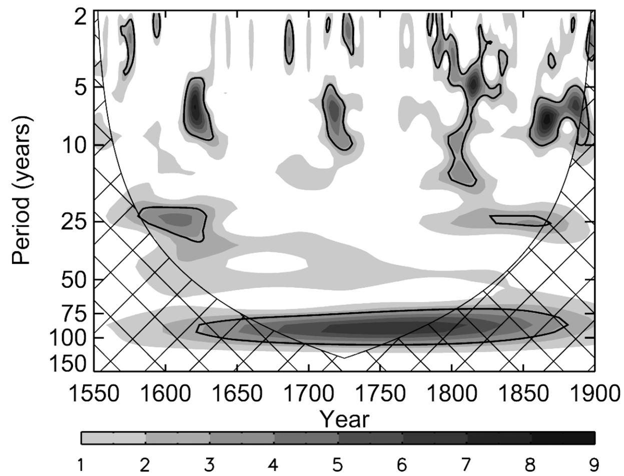

FIG. 7. Periodicity of EN years. Morlet-type wavelet spectrum of the EN chronology. Shaded areas indicate the power/variance. Dashed lines denote the cone of influence. Solid lines reflect significant oscillations at $p < 0.1$ level.

contain similar features, but with generally less power near the century band (figures not shown).

8. A statistical test of consistency between our chronology with other ENSO indicators

In the previous section we have shown that warm ENSO events as derived from ENSO proxies have signatures in the long-term behavior similar to those in our chronology. Here we assess this relationship in the inverse sense, that is, whether our EN events are reflected as anomalies in proxy indicators of ENSO teleconnection patterns. To explore this linkage we constructed the following variable:

$$P=\frac{1}{N}\sum_{i=1}^{N} p_i\,, \qquad (1)$$

where p_i is the value of the proxy for the ith year, and the summation ranges over the set $i = 1, N$ of EN years identified by our chronology. The expectation is that P will attain anomalously large values if there are significant teleconnection effects in the EN years identified in the chronology. To accommodate the uncertainty in the dating of EN events discussed in section 2a, the value of p_i corresponding to the ith year of the chronology is actually chosen to be the largest (absolute) value of p_i and p_{i+1}. To concentrate on ENSO variability on subdecadal time scales we prewhitened each series p by high passing it with a filter that eliminated variability at periods longer than 10 yr. The statistical significance of P is determined from a Monte Carlo test wherein the series p is randomly shuffled 1000 times,

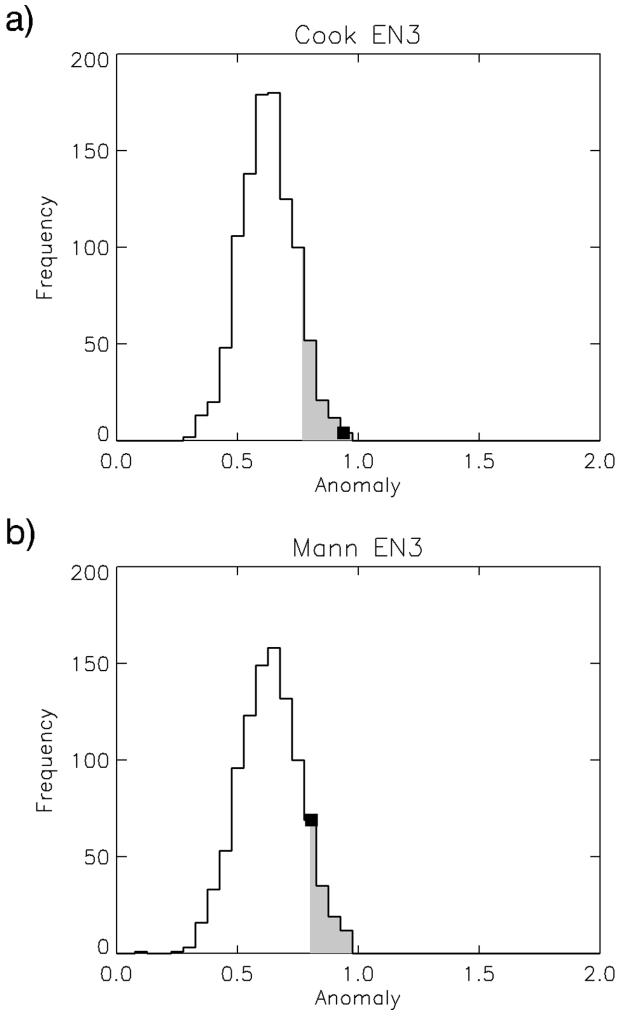

FIG. 8. Composite of ENSO proxy anomalies for EN years. Monte Carlo probability distribution histogram of the proxy composite for EN years after 1000 randomized realizations of the prewhitened proxy series. The shaded area indicates the (one tailed) 90th percentile of the distribution, while the black square denotes the observed proxy composite value in (a) CO and (b) MA. See text for further details.

P is computed as described above for each member of the resulting ensemble, and a probability distribution is constructed from the resulting values of P. This distribution has a mean $\overline{P}_{MC}$ and a value $P_{90} > \overline{P}_{MC}$ such that $<10\%$ of the members of the distribution lie at values larger than P_{90}. That is, P_{90} is the (one tailed) 90% confidence limit for the Monte Carlo distribution; it identifies values of P whose likelihood of occurring by chance is $\leq 10\%$.

The results of these Monte Carlo tests are shown for the CO and MA series in Fig. 8. Both series exhibit the expected relationship with EN. That is, P computed using our EN chronology is usually larger than $\overline{P}_{MC}$. Note, by the way, that $\overline{P}_{MC} > 0$ in all cases; this is a result of the selection procedure for the values p_i, which allows for the 1-yr uncertainty in dating ENSO events from Peruvian sources mentioned above. The procedure in effect biases P so that its expected value is no longer zero. Nonetheless, it can be seen that in both cases there is a significant relationship between the ENSO proxies and our EN chronology, which is more robust for CO ($p < 0.01$) than for MA ($p < 0.1$). The same analysis for the OR series show significant results at the $p < 0.1$ level (for both MA and CO), while only the MA series reveals a significant response to the chronology of QU ($p < 0.1$).

9. Concluding remarks

Previous documentary chronologies of warm ENSO events are subject to uncertainties arising from the use of secondary sources and both local and remote indicators of ENSO. Here we have presented a new historical reconstruction for the period 1550–1900 based mostly on primary documentary records from northern Peru, which experiences the largest EN signal along the western coast of South America. The primary sources have been well preserved for the entire period under consideration, providing a robust chronology and a more a reliable indicator of past ENSO behavior than previous efforts. Diaz et al. (2001) examined temporal changes in the strength of the correlation between standard ENSO indices and precipitation in various parts of the world based on instrumental records. Many of these teleconnections were shown to change substantially over time, so it may also be expected that the strength of the teleconnections would vary substantially over centuries. Nevertheless, the signal of EN in northern Peru is considered among the most robust, as it is located in a primary zone of climatic variability in response to ENSO. Thus, this chronology is expected to provide higher reliability than previous EN reconstructions because of the use of primary sources restricted to the area with strongest association with ENSO.

A total of 59 EN years were identified in the present study. To a greater degree than previous EN chronologies, the present reconstruction reveals nonstationary behavior in warm ENSO occurrence during the last few centuries, with alternating periods of high and low activity lasting as long as 50 yr. Accordingly, the beginning of the seventeenth, eighteenth, and nineteenth centuries presented active periods of warm ENSO activity, while the mid-seventeenth century seems to be the least active EN period. Such strong long-term variability has not been reported in previous EN chronologies based upon documentary records.

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REFERENCES

Allan, R. J., J. Lindesay, and D. Parker, 1996: *El Niño: Southern Oscillation & Climatic Variability.* CSIRO, 405 pp.

Carrillo, C., 1892: Hidrografía oceánica. *Bol. Soc. Geogr. Lima,* **1,** 72–111.

Chavez, F. P., J. Ryan, S. E. Lluch-Cota, and M. Ñiquen C., 2003: From anchovies to sardines and back: Multidecadal change in the Pacific Ocean. *Science,* **299,** 217–221.

Cook, E. R., 2000: Niño 3 index reconstruction. International Tree-Ring Data Bank, IGBP PAGES/World Data Center-A for Paleoclimatology. NOAA/NGDC Paleoclimatology Program, Data Contribution Series 2000-052.

Deser, C., and J. M. Wallace, 1987: El Niño events and their relation to the Southern Oscillation: 1925–1986. *J. Geophys. Res.,* **92,** 14 189–14 196.

Diaz, H. F., and G. N. Kiladis, 1992: Atmospheric teleconnections associated with the extreme phases of the Southern Oscillation. *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation,* H. F. Diaz and V. Markgraf, Eds., Cambridge University Press, 7–28.

——, and V. Markgraf, Eds., 1992: *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation*. Cambridge University Press, 476 pp.

——, and ——, Eds., 2000: *El Niño and the Southern Oscillation: Multiscale Variability and Global and Regional Impacts*. Cambridge University Press, 496 pp.

——, M. P. Hoerling, and J. K. Eischeid, 2001: ENSO variability, teleconnections, and climate change. *Int. J. Climatol.,* **21,** 1845–1862.

Eguigúren, V., 1894: Las lluvias en Piura. *Bol. Soc. Geogr. Lima,* **4,** 241–258.

Enfield, D. B., 1989: El Niño, past and present. *Rev. Geophys.,* **27,** 159–187.

——, and L. Cid-Serrano., 1991: Low-frequency changes in El Niño–Southern Oscillation. *J. Climate,* **4,** 1137–1146.

Evans, M. N., A. Kaplan, and M. A. Cane, 2002: Pacific sea surface temperature field reconstruction from coral $\delta^{18}O$ data using reduced space objective analysis. *Paleoceanography,* **17,** 1007, doi:10.1029/2000PA000590.

Garcia, R. R., and Coauthors, 2001: Atmospheric circulation changes in the tropical Pacific inferred from the voyages of the Manila Galleons in the sixteenth–eighteenth centuries. *Bull. Amer. Meteor. Soc.,* **82,** 2435–2455.

Garcia-Herrera, R., R. R. Garcia, M. Rosario Prieto, E. Hernandez, L. Gimeno, and H. F. Diaz, 2003: The use of Spanish historical archives to reconstruct climate variability. *Bull. Amer. Meteor. Soc.,* **84,** 1025–1035.

Gergis, J. L., and A. M. Fowler, 2006: How unusual was late 20th century El Niño–Southern Oscillation (ENSO)? Assessing evidence from tree-ring, coral, ice-core and documentary palaeoarchives, A.D. 1525–2002. *Advances in Geoscience,* Vol. 6**,** Academic Press, 173–179.

——, K. Braganza, A. M. Fowler, S. Mooney, and J. Risbey, 2006: Reconstructing El Niño–Southern Oscillation (ENSO) from high-resolution palaeoarchives. *J. Quat. Sci.,* **21,** 707–722.

Hamilton, K. P., and R. R. Garcia, 1986: El Niño/Southern Oscillation events and their associated midlatitude teleconnections 1531–1841. *Bull. Amer. Meteor. Soc.,* **67,** 1354–1361.

Hoerling, M. P., and A. Kumar, 2000: Understanding and predicting extratropical teleconnections related to ENSO. *El Niño and the Southern Oscillation: Multiscale Variability and Global and Regional Impacts,* H. F. Díaz and V. Markgraf, Eds., Cambridge University Press, 57–88.

Huertas Vallejos, L., 1993: Anomalías cíclicas de la naturaleza y su impacto en la sociedad: "El fenómeno El Niño." *Bull. Inst. Fr. Ét. Andines,* **22,** 345–393.

——, 2001: *Diluvios Andinos: A Través de las Fuentes Documentales.* Pontificia Universidad Católica del Perú, 390 pp.

Jones, P. D., T. J. Osborn, and K. R. Briffa, 2001: The evolution of climate over the last millennium. *Science,* **292,** 662–667.

Lagos, P., Y. Silva, and E. Nickl, 2004: El Niño y la Precipitación en los Andes del Perú. *Proc. III Encuentro RUPSUR* "*Impactos Biofísicos y Socieconómicos de El Niño en Ecosistemas Marinos y Terrestres,*" Santiago, Chile, Instituto Geofísico del Peru, 22 pp.

Lough, J. M., and H. C. Fritts, 1989: Historical aspects of the El Niño/Southern Oscillation—Information from tree rings. *Global Ecological Consequences of the 1982–83 El Niño–Southern Oscillation,* P. W. Glynn, Ed., Elsevier, 285–321.

Mabres, A., R. Woodman, and R. Zeta, 1993: Algunos apuntes adicionales sobre la cronología de El Niño. *Bull. Inst. Fr. Ét. Andines,* **22,** 395–406.

Macharé, J., and L. Ortlieb, 1993: Registros del fenómeno El Niño en el Perú. *Bull. Inst. Fr. Ét. Andines,* **22,** 35–52.

Mann, M. E., E. P. Gille, R. S. Bradley, M. K. Hughes, J. T. Overpeck, F. T. Keimig, and W. S. Gross, 2000: Global temperature patterns in past centuries: An interactive presentation. *Earth Interactions,* **4**. [Available online at http://EarthInteractions.org.]

Markgraf, V., Ed., 2001: *Interhemispheric Climate Linkages*. Academic Press, 454 pp.

Michaelsen, J., 1989: Long-period fluctuations in El Niño amplitude and frequency reconstructed from tree-rings. *Aspects of Climate Variability in the Pacific and the Western Americas, Geophys. Mongr.,* Vol. 55, Amer. Geophys. Union, 69–74.

Ortlieb, L., 2000: The documentary historical record of El Niño events in Peru: An update of the Quinn record. *El Niño and the Southern Oscillation: Multiscale Variability and Global and Regional Impacts,* H. F. Diaz and V. Markgraf, Eds., Cambridge University Press, 207–297.

Quinn, W. H., 1992: A study of Southern Oscillation-related climatic activity for A.D. 622–1900 incorporating Nile River flood data. *Historical and Paleoclimatic Aspects of the Southern Oscillation,* H. F. Diaz and V. Markgraf, Eds., Cambridge University Press, 120–149.

——, and V. T. Neal, 1983: Long-term variations in the Southern Oscillation, El Niño, and Chilean subtropical rainfall. *Fish. Bull.,* **81,** 363–374.

——, and ——, 1992: The historical record of El Niño events. *Climate Since A.D. 1500,* R. S. Bradley and P. D. Jones, Eds., Routledge, 623–648.

——, D. O. Zorf, K. S. Short, and R. T. W. Kao Yang, 1978: Historical trends and statistics of the Southern Oscillation, El Niño, and Indonesian droughts. *Fish. Bull.,* **76,** 663–678.

——, V. T. Neal, and S. E. Antúnez de Mayolo, 1987: El Niño occurrences over the past four and a half centuries. *J. Geophys. Res.,* **92** (C13), 14 449–14 461.

Ropelewski, C. F., and P. D. Jones, 1987: An extension of the Tahiti–Darwin Southern Oscillation index. *Mon. Wea. Rev.,* **115,** 2161–2165.

Rossel, F., R. Mejia, G. Ontaneda, R. Pombosa, J. Roura, P. Le Goulven, E. Cadier, and R. Calvez, 1998. Regionalization of El Niño influence on rainfall in Ecuador (in French). *Bull. Inst. Fr. Ét. Andines,* **27,** 643–654.

Sandweiss, D. H., K. A. Maasch, F. Chai, C. F. T. Andrus, and E. J. Reitz, 2004: Geoarchaeological evidence for multidecadal natural climatic variability and ancient Peruvian fisheries. *Quat. Res.,* **61,** 330–334.

Trenberth, K. E., and D. J. Shea, 1987: On the evolution of the Southern Oscillation. *Mon. Wea. Rev.,* **115,** 3078–3096.