Climatic Change (2009) 92:389–416
DOI 10.1007/s10584-008-9470-5

The 1877–1878 El Niño episode: associated impacts in South America

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Received: 24 April 2007 / Accepted: 12 May 2008 / Published online: 10 September 2008

Abstract At times when attention on climate issues is strongly focused on the assessment of potential impacts of future climate change due to the intensification of the planetary greenhouse effect, it is perhaps pertinent to look back and explore the consequences of past climate variability. In this article we examine a large disruption in global climate that occurred during 1877–1878, when human influence was negligible. The mechanisms explaining this global disturbance are not well established, but there is considerable evidence that the major El Niño episode that started by the end of 1876 and peaked during the 1877–1878 boreal winter contributed significantly to it. The associated regional climate anomalies were extremely destructive, particularly in the Northern Hemisphere, where starvation due to intense droughts in Asia, South-East Asia and Africa took the lives of more than 20 million people. In South America regional precipitation anomalies were typical of El Niño events, with rainfall deficit and droughts in the northern portion of the continent as well as in northeast Brazil and the highlands of the central Andes (Altiplano). In contrast, anomalously intense rainfall and flooding episodes were reported for the coastal

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areas of southern Ecuador and Northern Perú, as well as along the extratropical West coast of the continent (central Chile, 30° S–40° S), and in the Paraná basin in the southeast region. By far the most devastating impacts in terms of suffering and loss of life occurred in the semiarid region of northeast Brazil where several hundreds of thousands of people died from starvation and diseases during the drought that started in 1877.

1 Introduction

A shift of the Southern Oscillation (SO) toward its low/warm phase in late 1876 marked the starting point for a major El Niño episode during 1877–1878 (Kiladis and Diaz 1986; Quinn et al. 1987; Ortlieb 2000). The associated changes in the planetary atmospheric circulation led to intense weather and climate anomalies in many regions of the world, with enormous socio-economic impacts. The description of those occurring in South America is the main objective of this paper. We use in this paper the term El Niño and El Niño/Southern Oscillation (ENSO) to refer indistinctly to periods characterized by anomalously high sea surface temperature and weakened trade winds in the equatorial Pacific during the low/warm phase of the SO.

In Section 3 to Section 8 a detailed analysis is presented of the regional rainfall anomalies in South America during 1877 and 1878 that can be linked to ENSO-related changes in the atmospheric circulation. Particular emphasis is given to those regions where El Niño is recognized as a significant factor influencing interannual climate variability. These include the far north (Colombia, Venezuela and Guyana), north-eastern Brazil, the coastal areas of southern Ecuador and northern Peru, the highlands of the central Andes (Altiplano), the southeast portion of the continent (Northern Argentina, Paraguay and Southern Brazil), and the extratropical west coast (central Chile).

Whenever possible, the analysis was based on instrumental rainfall records. In 1877 meteorological networks were at a very early stage of development in Argentina and Chile while only isolated observatories were operating in other South American countries. Stations with available monthly rainfall data for 1877 and 1878 are indicated in Table 1 and Fig. 1. For regions where rainfall records were not available, description of rainfall anomalies was based on careful scrutiny of various documentary sources, including historical reports, newspapers and government records. This was the case for the coastal areas of northern Peru and southern Ecuador, and for the central Andes (Altiplano).

2 Background

The ocean–atmosphere system in the central equatorial Pacific evolved from a condition characterized by the positive phase of the SO including negative sea surface temperature (SST) anomalies during early 1876, to intense El Niño conditions in 1877 and early 1878 (Fig. 2a). Positive sea level pressure (SLP) anomalies prevailed at Darwin during the second semester of 1877 and early 1878 (Fig. 2b), while negative anomalies characterized the SLP regime at Tahiti from late 1876 to mid-1878. The SST anomalies in the central equatorial Pacific increased steadily from a value close

Table 1 Stations with available monthly rainfall data during 1877 and 1878

Station	Lat (° S)	Lon (° W)	Period
San José	9.7° N	84.0	1866–1900
Demarara	6.8° N	58.2	1874–1900
Medellín	6.3° N	75.6	1875–1878
Bogotá	4.6° N	74.1	1866–1900
Fortaleza	3.7° S	38.5	1849–1900
Rio de Janeiro	22.0° S	42.5	1851–1900
Corrientes	27.5° S	58.8	1876–1900
Goya	29.1° S	59.3	1877–1900
La Serena	29.9° S	71.3	1869–1900
Córdoba	32.0° S	64.0	1873–1900
Valparaiso	33.0° S	71.6	1876–1900
Santiago	33.5° S	70.7	1866–1900
Buenos Aires	34.6° S	58.5	1861–1900
Concepción	36.8° S	73.0	1876–1900
Bahía Blanca	38.7° S	62.3	1860–1900
Valdivia	39.8° S	73.2	1853–1879

The period used to calculate climatological means is indicated for each station

to −1.0°C in MAM 1876 up to a maximum of 2.7°C during the 1877–1878 austral summer. The latter value is slightly lower than those observed during the major 1982–1983 and 1997–1998 El Niño events when a SST anomaly larger than +3.0°C was observed in region Niño 3 (NWS/CPC 2007).

The demise of SLP anomalies associated with the 1877–1878 El Niño episode was relatively abrupt. By MAM 1878 SLP at Darwin was near its climatological mean and during the following season (JJA) the SO had already switched to the positive phase (Fig. 2b). In contrast, the positive SST anomalies in the central equatorial Pacific declined much more slowly during 1878. Nonetheless, weak negative SST anomalies were established by OND 1878 and persisted throughout 1879.

Figure 3 shows the evolution of annual mean atmospheric pressure anomalies at several stations where the influence of the SO is significant. In the western Pacific and southeast (SE) Asia the 1877 SLP anomaly was the largest during the period 1870–1900, suggesting that ENSO related climate anomalies were most intense during the 1877–1878 El Niño event as compared with others during the same period, including the major event of 1899. On the other hand, the 1877 SLP anomalies in South America were relatively weak, and much lower than those during the 1899 El Niño episode.

The seasonal evolution of global SST and sea level pressure anomaly fields throughout the 1877–1878 El Niño episode was analyzed using the HadISST (Rayner et al. 2003) and HadSLP2 (Allan and Ansell 2006) data sets of the UK Met Office Hadley Centre. Monthly SST and SLP anomaly maps analyzed by Allan et al. (1996) were also considered. By October 1876 weak positive SST anomalies prevailed off the Pacific coast of South America and along the eastern equatorial Pacific while negative anomalies predominated over the maritime continent and the Indian Ocean. Positive SST anomalies spread and intensified throughout the tropical Pacific during 1877. By October 1877 the SLP was above average over a vast region including most of Africa, southern Europe, most of Asia, the Indian Ocean northward from 30° S, the maritime continent and Australia. In contrast, below average SLP prevailed over most of the eastern Pacific Ocean and the Americas. The shape of SLP and SST

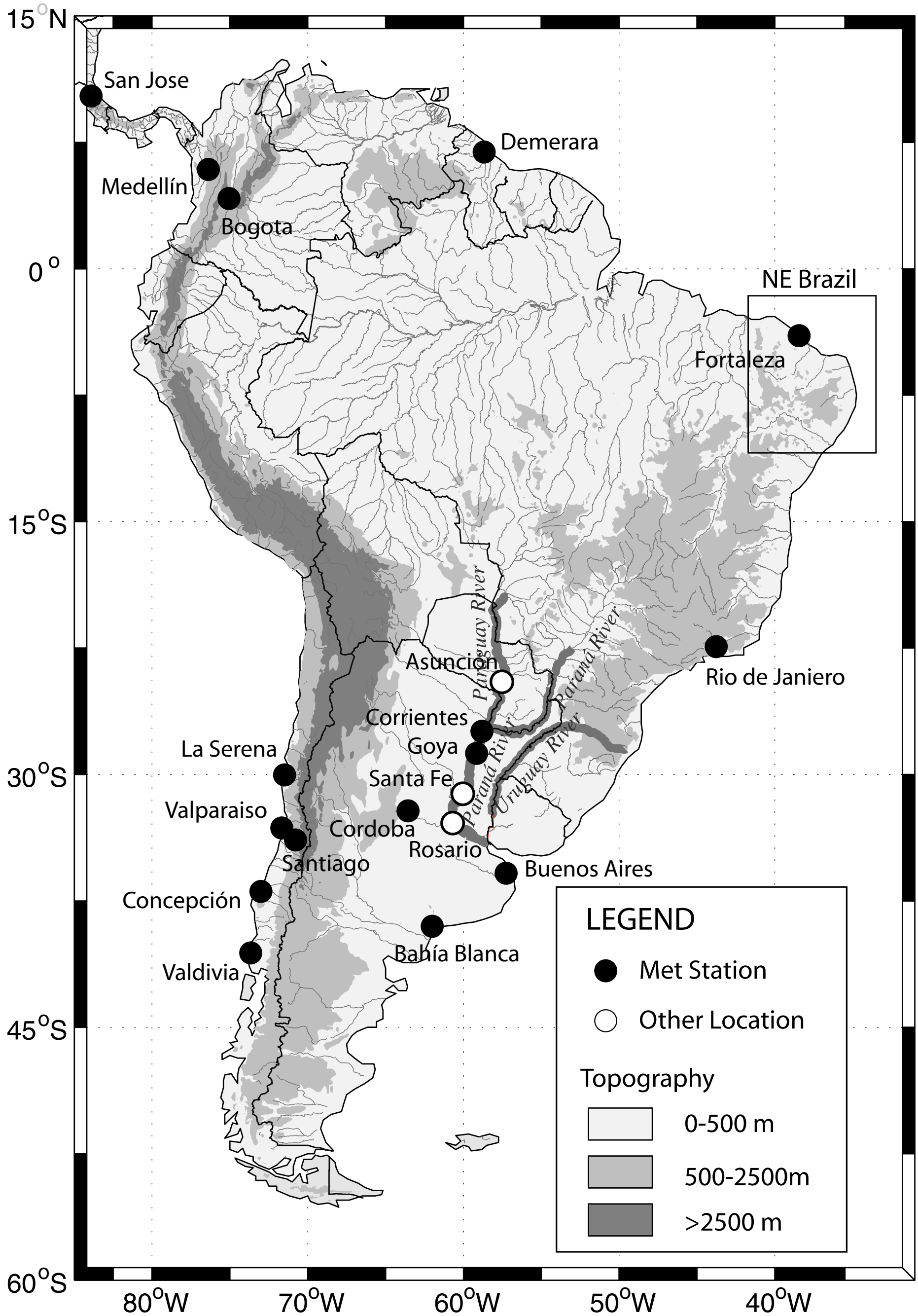

Fig. 1 Meteorological stations with available monthly rainfall data for 1877 and 1878 (*black dots*)

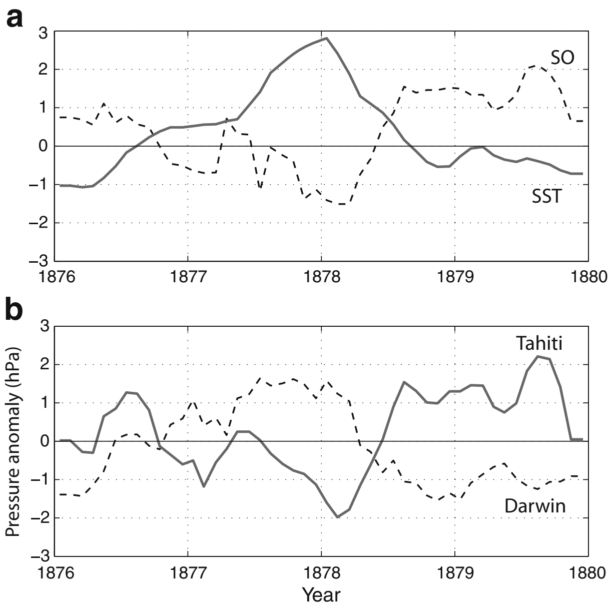

Fig. 2 Three-month averages of the Southern Oscillation Index, sea surface temperature (*SST*) anomaly in region Niño 3, and sea level pressure anomalies at Tahiti and Darwin, during 1876–1879: **a** standardized value of SOI (*dashed line*) and SST anomaly (°C, *continuous line*); **b** SLP anomaly at Darwin (*dashed line*) and Tahiti (*continuous line*). Sources: SLP and SOI data: NCC–Bureau of Meteorology–Australia; SST data: Hadley Center HadSST1 data set (Rayner et al. 2003)

anomaly fields did not change much over the tropics in January 1878 when the El Niño episode reached its maximum strength (Fig. 4). However, by April 1878 the negative SLP anomalies along the west coast of South America had weakened considerably and 3 months later, the positive SLP anomalies that prevailed during El Niño phenomenon on the western tropical Pacific and Indian oceans had mostly disappeared, reflecting the evolution toward the positive phase of the SO that eventually became firmly established by October 1878, when negative SST anomalies prevailed along the equatorial Pacific. As mentioned earlier, the SST anomalies associated with the 1877–1878 El Niño episode persisted longer than the SLP anomalies, such that in July 1878 warmer than normal conditions still prevailed in the tropical Pacific.

The magnitude of the disruption of global climate during 1877–1878 is demonstrated in Fig. 5 showing the evolution of global October–March near-surface temperature anomaly (with respect to the 1961–1990 mean value), after removing the long-term trend by subtracting a centered 31-year moving average. Although there is considerable uncertainty associated with estimates of global temperature anomalies during the second half of the nineteenth century, it is nonetheless remarkable that the magnitude of the 1877–1878 warm pulse, superimposed on the long-term trend, almost doubles the next largest in magnitude over the entire record.

The most dramatic impacts of climate anomalies during 1877–1878 were associated with intense and long-lasting droughts in many regions along the western center of the SO, whose effects were aggravated by the failure of the monsoonal rainfall in India and northern China during the 1876 season previous to the onset of El Niño. According to Kiladis and Diaz (1986), the 1877 precipitation was about three standard deviations below normal for the Indian subcontinent as a whole. Davis (2001) estimated that some 15 to 25 million people, mostly peasants and rural

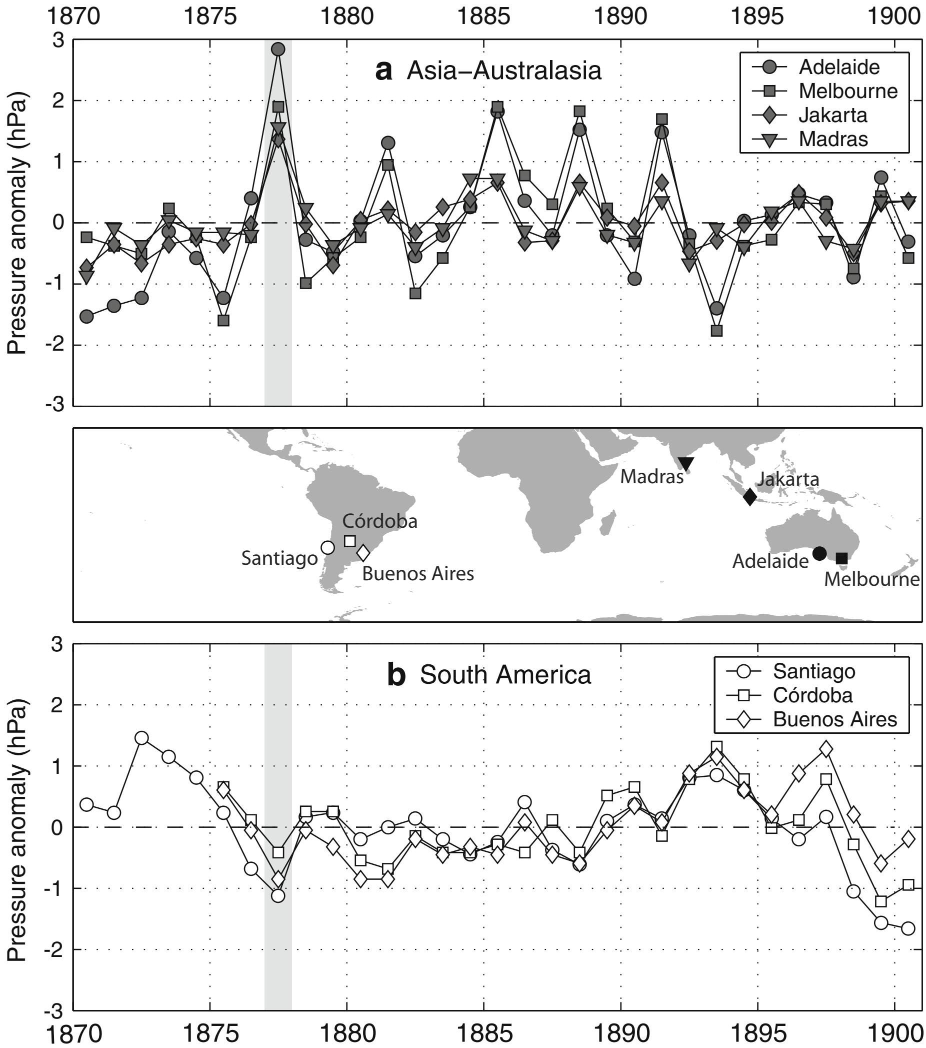

Fig. 3 Annual mean pressure anomalies (hPa) at indicated stations during 1870–1900: **a** Adelaide, Melbourne, Batavia (Jakarta) and Madras, adapted from Lockyer (1906); **b** Santiago, Córdoba and Buenos Aires, adapted from Lockyer (1906) and Mossman (1923)

workers, died in India and northern China during 1876–1879 as result of famine and drought-related diseases. It is interesting to notice that this drought episode gave a considerable impulse to the development of a large surface meteorological station network in India and was a major catalyst in the initiation of tropical climate prediction research (Hastenrath 1991, pp. 383–384). Furthermore, a severe drought hit Indonesia and the Philippines, as convective cloudiness shifted eastward toward the central equatorial Pacific. Jakarta (Indonesia) received less than one third of its normal rainfall from May 1877 through February 1878 (Kiladis and Diaz 1986), based on information included in Berlage (1957). The drought was also detected in tree

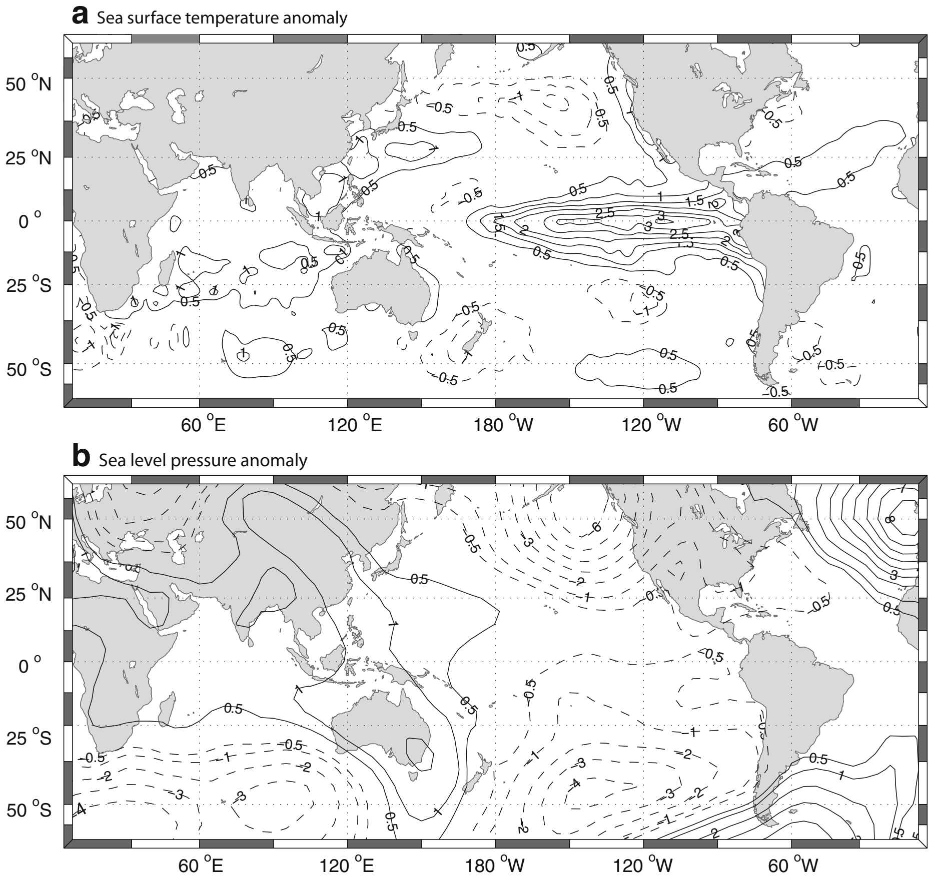

Fig. 4 Sea level pressure and sea surface temperature anomaly maps for January 1878, when the 1877–1878 ENSO reached its maximum strength. Anomalies were calculated with respect to the 1870–1900 mean values, from the HadISST and HadSLP2 data sets, with 1° and 5° latitude–longitude grids, respectively. *Continuous* (*dashed*) *isolines* indicate *positive* (*negative*) anomalies (no 0 isoline) every 0.5° C and 1.0 hPa. Isolines corresponding to ±0.5 hPa are also indicated

ring data from central Java (Berlage 1966), and references to famine, forest fires and vegetation depletion are mentioned in Goldammer and Seibert (1990). These rainfall anomalies are consistent with a slack zonal pressure gradient and extremely weak westerlies during 1877 along the equatorial Indian ocean during 1877 (Hastenrath 2001).

Droughts also plagued Africa during 1877 and 1878. The level of Nile River was anomalously low in 1877 (Mossman 1914) and references to food shortage in Egypt during that year coincide with reports of a severe drought in Sudan during 1877 and 1878 that decimated the population.[1] Consistent with regional rainfall anomaly patterns during El Niño episodes, drought hit southern Africa in 1877, along with

[1] Biography of Saint Daniel Comboni, Vatican document (http://www.vatican.va/news_services).

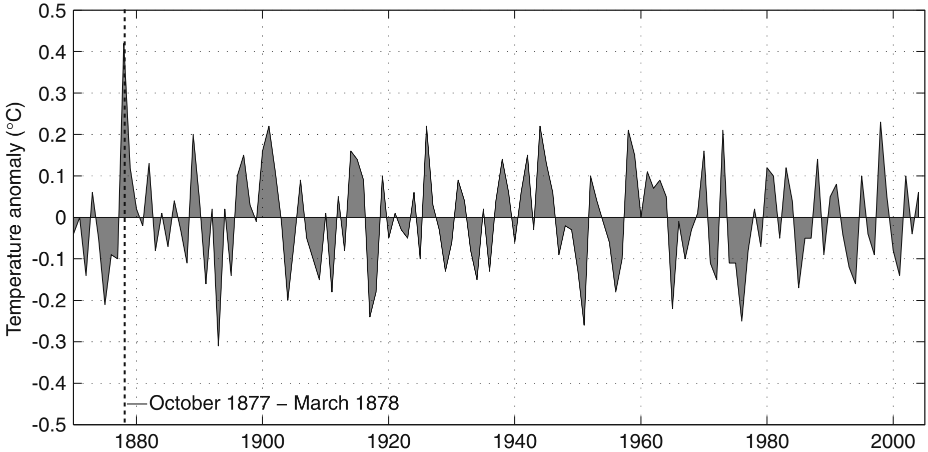

Fig. 5 Global near-surface temperature anomaly during October–March, with respect to the 1961–1990 mean, after a centered 31-year moving average has been subtracted. Source: Climate Research Unit, University of East Anglia

other regions whose rainfall regimes are not modulated by ENSO, including northern Africa and some regions in Mediterranean Europe. According to Davis (2001) half of the grain harvest was lost in Algeria in 1877 and vast tracts of the interior and southern Morocco were virtually depopulated during the summer of 1878. There is also evidence of severe droughts in Canary islands during 1877[2] and in south eastern France (Languedoc region) during the 1877–1878 boreal winter.[3] Furthermore, the 160.1 mm of rainfall registered at Barcelona (NE Spain) from September 1877 to April 1878 was the third lowest value for the period 1786–2005.[4]

Large climate disruptions were also reported for the Americas. In comparing the regional circulation anomalies during the 1877–1878 ENSO with those in 1982–1983, Kiladis and Diaz (1986) noted some remarkable similarities in several climate anomaly patterns, such as a southward displacement of the Aleutian low that led to enhanced storm activity along the west coast of North America. The anomalously mild 1877–1878 winter in the upper Midwest and southern central Canada is another feature typical of major El Niño episodes. The +8.7°C mean temperature anomaly at Winnipeg (49.9° N, 97.2° W) and +7.3°C at Minneapolis (45.0° N, 93.2° W) from Dec. 1877 to Feb. 1878 exceeded that during the 1982–1983 El Niño, and were the largest ever recorded during the instrumental era (Kiladis and Diaz 1986). Furthermore, the anomalously low pressure and above normal rainfall in the southeast of North America (Allan et al. 1996; Allan and Ansell 2006) during the 1877–1878 El Niño event are also consistent with the climate anomalies that typically occur during ENSO episodes.

[2]Personal communication Ms. Carmen J. Hernández, Universidad de la Laguna, Canary Island, Spain.

[3]Meteo-France.

[4]Barrera A. and M. del C. Llasat. Nota sobre la evaluación de la situación de sequía en España (Septiembre de 2004–Mayo de 2005). RAM, N°33, Sep. 2005. (http://www.meteored.com/ram/numero33).

3 Northern South America

The rainfall regime in northern South America, including Colombia, Venezuela, Guyana, Suriname, French Guyana and adjacent territories in Brazil, is significantly modulated by ENSO with a tendency for anomalously dry (wet) conditions when positive (negative) SST anomalies prevail in the equatorial Pacific (Ropelewski and Halpert 1987, 1989, 1996; Aceituno 1988; Rogers 1988; Kiladis and Diaz 1989; Poveda and Mesa 1997). The coastal areas of the eastern territories of Venezuela, Guyana, Suriname and French Guyana experience a semi-annual cycle in the rainfall regime characterized by relatively dry conditions during August to October and February–March, principally related to the seasonal N–S displacement of the intertropical convergence zone. A similar cycle is observed in the Andean region of Colombia, associated with the seasonal displacement of the centre of convective cloudiness from the border between Central and South America in the austral winter, to the southern Amazonian basin in the austral summer.

A set of complex physical mechanisms control the hydro-climatic anomalies over northern South America during El Niño episodes (Poveda et al. 2006). Specifically, the reduced SST gradient in the eastern Pacific weakens the Choco jet (centered at 5° N) and decreases moisture transport inland (Poveda and Mesa 2000; Poveda et al. 2001), with an associated reduction in the intensity and number of mesoscale convective complexes (Velasco and Frisch 1987; Poveda et al. 2006).

The evolution of monthly rainfall during 1877 and 1878 at San José (Costa Rica), Demerara (Guyana), and Medellín and Bogotá (Colombia) is presented in Fig. 6. Drier than average conditions prevailed at San José (Costa Rica) during the second half of the 1877 rainy season and the first half of 1878 (Fig. 6a), with just 61% of

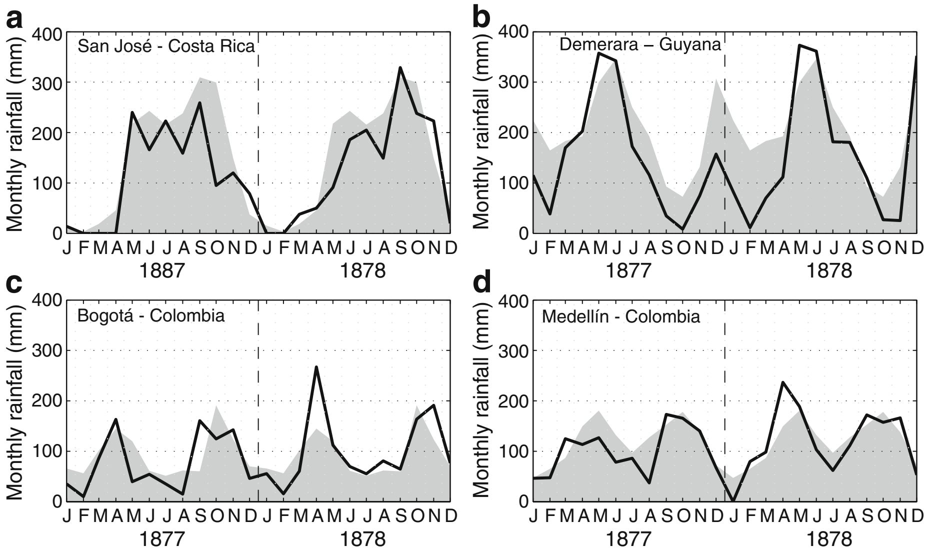

Fig. 6 a–d Monthly rainfall at indicated stations during 1877–1878. Mean climatological values are indicated as shaded areas. For station locations see Fig. 1 and Table 1 the 1866–1900 climatological mean measured during the 1877 rainy season (ASO) while a rainfall deficit of nearly 30% occurred from May to August 1878. On the Atlantic coast, the rainfall record at Demerara (near Georgetown—Guyana) shows that although the 1877 wet season was normal, anomalously dry conditions prevailed during the rest of the year. On the whole, the 1877–1878 period was especially dry, with the 1877 (1878) annual rainfall being the third (fourth) lowest during the period 1874–1903. Drought was particularly intense from September 1877 to April 1878, when accumulated rainfall was around 40% of the climatological mean (Fig. 6b). Berlage (1966) also documents a serious drought in Suriname and Guyana during this time.

In the Colombian Andes, the 913 mm recorded at Bogotá during 1877 was the sixth lowest for the period 1866–1900, due to significant rainfall deficits during January–February and May–August (Fig. 6c). Precipitation was also significantly below the climatological mean from December 1877 to March 1878 (deficit of −39%), when the 1877–1878 El Niño episode peaked. Apparently drought was less severe at Medellín, where rainfall deficit was confined to the period from April to August 1877 (Fig. 6d). Nonetheless, a lack of rainfall in 1877 and 1878 and a severe locust invasion in 1878 affected corn, banana, cocoa crops in SW Colombia (Valle del Cauca district), where starvation and migration to the cities was reported.[5]

The drought in northern South America at the height the El Niño episode in January–February 1878 contrasted with extremely wet conditions in the northern part of the Gulf of Mexico, where the accumulated rainfall at La Habana (376 mm) and Nassau—Bahamas (310 mm) were nearly three-times the climatological mean. These wet conditions are likely to be associated with the enhanced baroclinicity and intensified westerlies in this region during the negative phase of the Southern Oscillation (Aceituno 1989).

4 Northeast Brazil

The extraordinary drought that started in 1877 in the Brazilian Nordeste was the most destructive consequence of the 1877–1878 El Niño in South America. The rainfall regime in this region exhibits a pronounced annual cycle, the rainy season (February–May) occurring when the Atlantic inter-tropical convergence zone (ITCZ) and the associated band of maximum sea surface temperature reach their southernmost position. The semi-arid climate of the inland parts of this region (the *Sertão*) is particularly surprising considering its location a few degrees south of the Equator.

The relatively large interannual rainfall variability in NE Brazil is modulated by changes in the latitudinal position of the Atlantic ITCZ, and in the frequency of extratropical fronts reaching the area (Kousky 1979). Several studies have described the regional anomaly circulation patterns over the tropical Atlantic associated with drought in NE Brazil (see for example Hastenrath and Heller 1977 and Moura and Shukla 1981). A combination of positive (negative) SST anomalies in the

[5]Colombia: País de regiones. Vol. 3. Centro de Investigación y Educación Popular. Santafé de Bogotá: CINEP COLCIENCIAS, 1998. Ed. F. Zambrano.

north (south) tropical Atlantic during the rainy season favors an anomalously weak North Atlantic subtropical anticyclone and a strengthened counterpart in the South Atlantic. The relatively weak (strong) north (south) trade winds are thus conducive to a northward displacement of the ITCZ and consequently to rainfall deficit over the Brazilian Nordeste.

While the tendency for drought in NE Brazil during El Niño episodes has been recognized since the early 1970s (Caviedes 1973), it is generally acknowledged that ENSO is not the main factor determining the interannual rainfall variability in this region. The negative correlation between a SO index and SST along the Caribbean and the northern tropical Atlantic during the rainy season (Hastenrath et al. 1987; Aceituno 1988) points to the link between the *Secas* (droughts) and El Niño: During the negative SO phase anomalously warm conditions tend to prevail in the northern tropical Atlantic favoring a relatively weak north Atlantic subtropical anticyclone and associated trade winds and consequently, a northward displacement of the Atlantic ITCZ.

After a sequence of at least 6 years of average to above average rainfall, drought began in 1877 when only 468 mm were measured at Fortaleza, corresponding to only 33% of the 1871–1900 climatological mean (Fig. 7). The situation did not improve during the following rainy season as the El Niño episode peaked and began its demise. Rainfall in 1878 was just 35% of the climatological mean. Although by the beginning of 1879 the El Niño episode was already over, the drought persisted and the rainy season ended with a rainfall deficit close to 60% as SST and SLP anomalies in the tropical Atlantic contributed to keep the ITCZ northward of its normal position (Allan et al. 1996, pp. 174–175).

The impacts of the drought of 1877–1879 in NE Brazil were devastating and shaped the political and economical future of that region that, at the time, contained

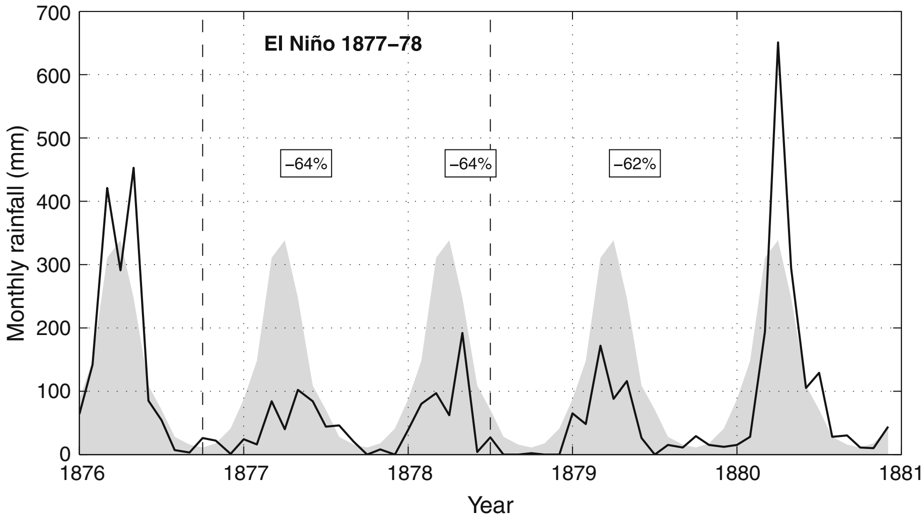

Fig. 7 Monthly rainfall at Fortaleza (3.7° S, 38.5° W) during 1876–1880. Mean climatological values for the available period before 1900 are indicated as *shaded areas*. Rainfall deficit (%) are indicated for 1877, 1878 and 1879

around 48% of the Brazilian population (Villa 2000). After the harvest failure in 1877 the threat of famine forced mass migration that depopulated the *Sertão*. By the end of the year around two million displaced people (*retirantes* or *flagelados*) packed the coastal cities, where deplorable sanitary conditions led to the onset of a smallpox epidemic that killed thousands (Costa 2004). Tens of thousands of *retirantes* chose (or were forced) to migrate to the Amazonia in search of work in the emerging rubber industry, while many others sought a better future in the southern states of the country. Accurate mortality statistics are not available but estimates of the drought related death toll range from 200,000 to 500,000 (Villa 2000; Davis 2001; Greenfield 2001). There is no doubt that the drought of 1877–1879 in NE Brazil constitutes one of the largest environmental disasters in South America in recorded history.

5 Coastal region in northern Perú and southern Ecuador

Abnormal rainfall and flooding episodes were observed in 1877 and 1878 along the coastal region in northern Peru and southern Ecuador. It is in this region where the term El Niño was first used to refer to a weak and warm oceanic current that develops almost annually by the end of the year (Carrillo 1892). Although the concomitant floods, anomalously high sea surface temperature and associated environmental changes that occur there every few years were first considered the result of an anomalously intense and warm El Niño current (Carranza 1892; Eguiguren 1894a), eventually it became clear that the anomalies were part of a large-scale shift of the ocean–atmosphere system in the tropical Pacific toward the negative phase of the Southern Oscillation (Bjerknes 1966, 1969; Rasmusson and Carpenter 1982).

In normal years, rainfall in this arid coast a few degrees south from the Equator is concentrated during February to April, when the ITCZ reaches its southernmost position along the eastern Pacific. The situation changes dramatically during El Niño episodes when rainfall may increase by several orders of magnitude. Rainfall episodes are associated with the development of deep convection within an unstable environment characterized by anomalously high coastal ocean temperatures (Horel and Cornejo-Garrido 1986). According to Takahashi (2004) the intense rainfall during El Niño events is related to an enhanced low-level westerly flow that favors orographic lifting and the subsequent triggering of convection over the western slope of the Andes. El Niño episodes are often extremely damaging, with the fishing industry affected by changes in the marine ecosystem, and agriculture, housing and public infrastructure by intense precipitation and flooding.

Although meteorological data are not available for the coast of northern Peru during 1877–1878, considerable evidence has been gathered indicating that climate anomalies typical of El Niño occurred. Specifically, numerous studies document the fact that anomalously intense rainfall was observed during the wet season both in 1877 and 1878 (Eguiguren 1894a; Quinn et al. 1978; Hocquenghem and Ortlieb 1992; Mabres et al. 1993). Other studies referring to these anomalies are mentioned in the historical chronology of El Niño event prepared by Ortlieb (2000). Flooding and anomalously high temperatures led to deteriorated sanitary conditions, the spread of disease and an increased mortality rate (Eguiguren 1894b). In the chronology of ENSO impacts along the coastal area of southern Ecuador prepared by Arteaga et al. (2006) it is mentioned that the dry season during 1877 lasted only 2 months

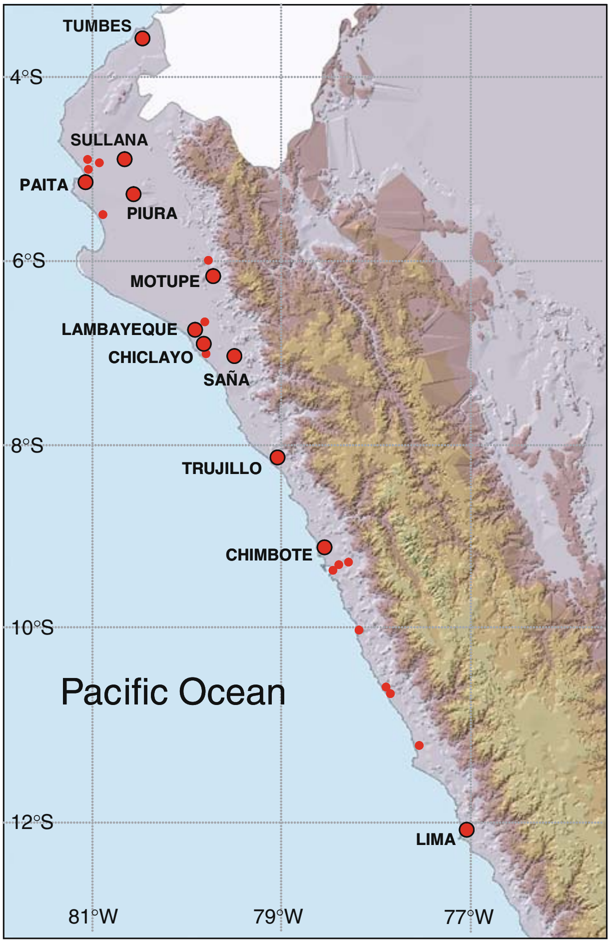

Fig. 8 Cities (*large dots*) and towns (*small dots*) along the arid coast of northern Peru for which flooding and associated damages were reported in the press during 1877 and 1878

(Wolf 1892). There are also references to the outbreak of yellow fever during the 1877–1878 rainy season (Hamerly 1987), and to the accumulation of sediments in the Guayas River after 15 months of rain during 1877–1878 that affected the supply of fresh-water to the city of Guayaquil (Carbo 1881).

The following description of anomalous weather conditions along the coastal northern Peru during 1877 and 1878 is based on information compiled from newspapers published in Lima (*La Patria*, *El Comercio* and *El Peruano*). Locations mentioned in the text are indicated in Fig. 8.

Rainfall episodes were reported by early 1877. Heavy rainfall on March 8th produced considerable damages in the city of Piura.[6] However, most intense precipitation started on March 26 leading to a large flood that on 29 March caused

[6] *La Patria*, Lima, N° 1737, 23 March 1877, section "Crónica de las provincias" under the title "Piura".

considerable damage and isolated many towns and cities.[7] By the beginning of May the discharge of the Chira River increased considerably[8] indicating that the rainy season was still active. After a dry spell that lasted most of the second semester of 1877, heavy rainfall and flooding were again reported along the northern coast of Peru by the end of the year and January 1878, with negative impacts on agriculture, particularly on the cotton crop. During this month the Chira River flooded several cities including Paita and Sullana[9] and the destruction of roads and railroads left many people without access to drinking water. The effects of rainfall and associated floods were also felt in Tumbes. The situation worsened in February when intense precipitation caused floods in several cities (e.g., Chiclayo, Motupe and Chimbote). Hundreds of houses were swept away in Lambayeque[10] and the city of Saña was completely destroyed, as it had been in previous El Niño events (Huertas 2001). Rainfall episodes and flooding also affected the normally arid coast of central Perú during February 1878[11] producing extensive damage to railroads.[12] At Lima, newspapers drew attention to the particularly mild conditions during the 1877 winter and to the unusually warm 1877–1878 summer.[13] Uncharacteristic summertime rainfall episodes at Lima (31 Dec. 1877, 24–25 January and 9–10 March 1878) were also reported by the local press.

Although there is no doubt that the impacts of the 1877–1878 ENSO episodes were very severe along the coast of northern Peru, there is evidence indicating that positive rainfall anomalies and associated impacts were larger during 1891 (Ortlieb 2000). It is worthwhile mentioning that this particular episode, which pushed Carrillo (1892) to postulate for the first time the concept of the El Niño oceanic current, occurred during the transition period from a relatively intense cold episode to a weak warm event in the central equatorial Pacific that reached maximum strength (+0.5° C in region Niño 3.4) in June 1891 (Trenberth and Stepaniak 2001).

[7] *El Comercio*, Lima, 4 April 1877, section "La Tarde", under the title "Inundación en el Norte"; *El Comercio*, Lima, 11 April 1877, section "Interior", under the title "Eten"; *El Comercio*, Lima, 12 April 1877, section "Comunicados", under the title "Gratitud de Lambayeque a Chiclayo".

[8] *El Comercio*, Lima, 22 May 1877. Section "Interior", under the title "Paita".

[9] *El Comercio*, Lima, 26 January 1878, section "Interior", under the title "Paita"; *El Comercio*, Lima, 5 February 1878, section "La Tarde", under the title "Inundación en Paita"; *El Comercio*, 28 February 1878, section "La Tarde", under the title "Efectos de la Inundación en Paita"

[10] *El Peruano*, Lima, 14 March 1878, pp 333–334. Also published in *El Comercio*, Lima, 15 March 1878, section "La Mañana", under the title "Las inundaciones en el Norte".

[11] *El Comercio*, 25 February 1878, section "La Tarde", under the title "Supe, Casma, Huarmey y Barranca inundados"; *El Comercio*, 16 March 1878, section "Crónica", under the title "Inundación de Chancay".

[12] Report by D.L. Folkierski about damages to the railroad in Trujillo caused by the floodings in 1878. Lima, 8 July 1878. Anales de las Obras Públicas del Perú. Ed. Imprenta de Lima, 1884.

[13] *El Comercio*, 2 January 1878, section "Crónica", under the title "A propósito de la tempestad"; *El Comercio*, 3 January 1878, section "Inserciones", under the title "Fenómenos Meteorológicos"; *El Comercio*, 17 January 1878, section "Crónica", under the title "¡Que calor!"; *El Comercio*, 25 January 1878, section "Crónica", under the title "Lluvia"; *El Comercio*, 6 February 1878, section "Inserciones", under the title "El calor".

6 Central Andes (Altiplano)

Coinciding with the onset of the 1877–1878 El Niño episode a severe drought started in late 1876 in the highland region of the central Andes known as Altiplano (15° S–22° S). Although this area is often omitted in maps depicting regions where climate variability is significantly modulated by ENSO (see for example Ropelewsky and Halpert 1987), several studies have documented the occurrence of rainfall deficit or drought in the Altiplano during El Niño events (Francou and Pizarro 1985; Ronchail 1995; Aceituno and Garreaud 1995; Vuille et al. 2000; Garreaud and Aceituno 2001). Rainfall in the Altiplano is concentrated during the austral summer (Oct–Mar), associated with afternoon convection that develops when the regional circulation favors the advection of moist air from the lowlands to the east (Garreaud 1999). The warming of the troposphere over the tropics during El Niño episodes increases the meridional temperature gradient over the Altiplano, favoring an intensification and southward displacement of the dry subtropical westerlies (Garreaud and Aceituno 2001). Unfortunately no direct meteorological information is available to describe the timing and intensity of the rainfall deficit in the Altiplano during the 1877–1878 El Niño episode, and all the following information was obtained from the analysis of newspapers and historical reports.

According to a newspaper report, anomalously dry conditions and elevated temperatures prevailed at Puno in the northern Altiplano during January 1877.[14] Another report, published by the end of the wet season in April 1877, commented on the severe crop damages brought about by the lack of rainfall and freezing episodes, anticipating food shortages and high livestock mortality.[15] By the end of 1877 a disastrous economical situation was reported in Puno, associated with persistent drought and anomalously high temperatures that continued during January and part of February 1878.[16] Rainfall episodes by the end of February brought some relief,[17] but reports of social unrest due to water shortages near Lake Titicaca, published in March and April 1878, reveal that by the end of the rainy season drought had returned to the northern Altiplano (refer to footnote 17).[18]

The harvest failure during the 1877–1878 rainy season brought a considerable increase in the price of basic foodstuffs, as illustrated in Fig. 9. Revolts and looting of food markets were reported in Tarata, Sucre and Cochabamba during 1878 (Pentimalli and Rodríguez 1988; Gioda and Prieto 1999) while monthly records show that mortality rates at Cochabamba were greatly above normal during 1877 and 1878 due to starvation and drought-related diseases (Fig. 10). References to deaths by starvation in Cochabamba, Sucre and Potosi are also mentioned by Basadre (1969, pp. 117). The impacts of the drought were particularly severe during 1878 in the southern Altiplano and the lower-lying areas to the east. Drought persisted in the

[14] *El Comercio*, Lima, 11 January 1877. Section "Interior" under the title "Puno".

[15] *El Comercio*, Lima, 5 April 1877. Section "Interior" under the title "Puno".

[16] *El Comercio*, Lima, 2 January 1878. Section "Interior" under the title "Puno".

[17] *La Patria*, Lima, 18 March 1878, under the title "Puno". *El Comercio*, Lima, 18 February 1878. Section "Interior" under the title "Puno".

[18] *El Comercio*, Lima, 20 March 1878. Section "Interior" under the title "Puno".

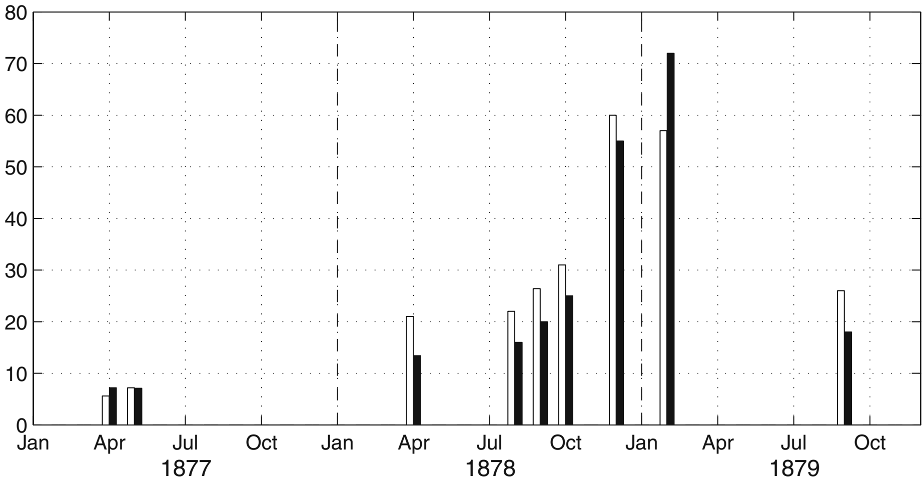

Fig. 9 Price or cereals (pesos/fanegas) at Cochabamba—Bolivia during 1877 and 1878. Source: newspaper *El Heraldo*—Cochabamba (cited by Pentimalli and Rodríguez 1988)

1878–1879 rainy season (Gioda and Prieto 1999), although this is unlikely to be associated with El Niño as the event was over by mid-1878.

Finally, it is interesting to mention the possible link between the 1877–1879 drought in the Bolivian Altiplano and the War of the Pacific that started in February 1879 between Chile and the Bolivia–Peru alliance. According to Bolivian historians, the tax imposed by the Bolivian government in 1878 on companies extracting and exporting nitrate in the then Bolivian territories along the Pacific coast was to a large

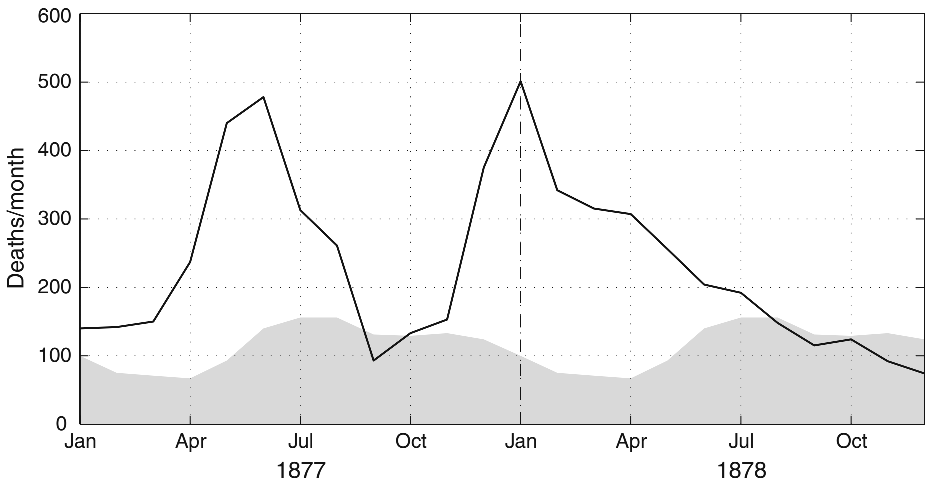

Fig. 10 Monthly mortality rate at Cochabamba—Bolivia during 1877 and 1878. *Shaded area* indicate average mortality rate during 1875–1877. Source: newspaper El Heraldo—Cochabamba, 12 Dec. 1879 (cited by Pentimalli and Rodríguez 1988)

extent motivated by the economical crisis generated by the drought.[19] War began after Chile, who had major mining interests in the region, declared the tax illegal, and occupied the city of Antofagasta in February 1879 to prevent the auction of one nitrate mining company.

7 Southeastern South America

Anomalously wet conditions prevailed in southeastern South America (SESA: southern Brazil, Uruguay, Paraguay and northeastern Argentina) during the 1877–1878 El Niño. The wet conditions and floods in this region during El Niño years were initially documented during the 1980s. Kousky et al. (1984) noted the above average discharge of the Paraná River during El Niño episodes, based on gauge measurements (1884–1916) reported in Mossman (1923). Furthermore, relatively wet conditions in the region have been associated with the negative phase of the Southern Oscillation (Ropelewski and Halpert 1987; Aceituno 1988). The ENSO influence on rainfall and hydrological regimes has been extensively documented, with the general conclusion that the ENSO–rainfall relationship is strongest during the austral spring (Pisciottano et al. 1994; Grimm et al. 2000; Montecinos et al. 2000; Camilloni and Barros 2000). The regional circulation pattern during wet periods in the austral summer is characterized by warm anticyclonic anomalies over southern Brazil and the adjacent Atlantic ocean that favour the advection of warm and moist air masses from the Amazon basin (Fig. 11). This anomalous feature, combined with the occurrence of cold cyclonic circulation anomalies in the southern portion of the continent, is consistent with an intensified subtropical jet stream and the blocking of northward propagating extratropical fronts that tend to stall over SESA (Kousky et al. 1984).

The impacts of anomalously wet conditions and flooding during El Niño episodes are particularly severe on the lowland areas along the rivers Parana, Uruguay and Paraguay (Fig. 1). The total economic loss due to flooding in this region during the major 1982–1983 El Niño event has been estimated at around 2,600 million US dollars (US$ of 1992; Pochat 1996).

The specific hydro-meteorological conditions in SESA during the 1877–1878 El Niño were analyzed on the basis of available rainfall data from meteorological stations in Argentina, as well as from reports on the impacts of flooding at cities along the Parana River, and other documentary sources. The evolution of monthly rainfall at the cities of Corrientes, Goya, Córdoba and Buenos Aires during 1877 and 1878 is presented in Fig 12. The relatively dry conditions that prevailed between January and March 1877 were sharply interrupted in April when more than three times the average rainfall was measured at Corrientes (3.5 times) and Goya (4.6 times). The impacts of this extraordinary rainfall were reported in the press. On 16 April 1877 the newspaper *El Mercurio de Valparaiso* (Valparaiso—Chile) mentioned the serious losses of livestock due to floods in the province of Cordoba,[20]

[19]"Epoca Republicana (1828–1899)" by Carlos. D. Meza published in the official Web Site of the Bolivian Government (www.bolivia.gov.bo).

[20]*El Mercurio de Valparaiso*—Chile, N°. 14998, 16 April 1877.

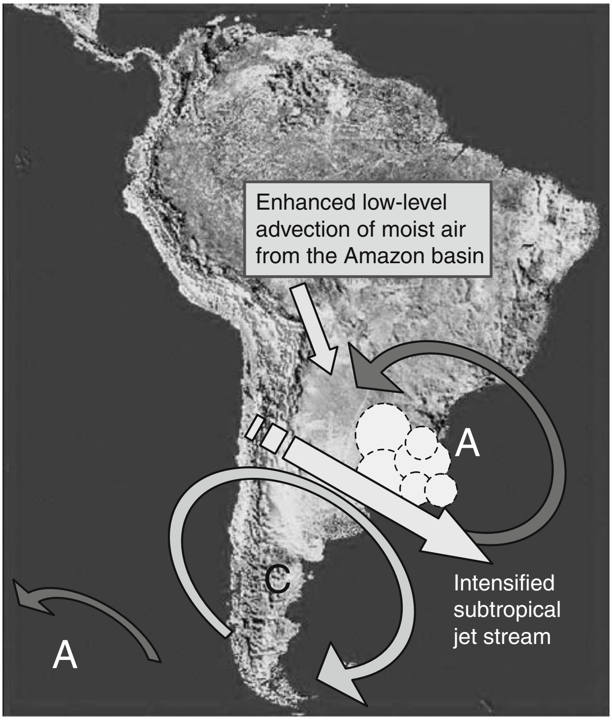

Fig. 11 Anomaly circulation pattern for periods with enhanced convective cloudiness and rainfall in southeastern South America during October–March. Circulation anomalies are labeled as *C* for cyclonic, and *A* for anticyclonic (adapted from Diaz and Aceituno 2003)

and the next day it reported on damage to houses and grain depots due to intense precipitation and flooding in the province of Buenos Aires.[21] Following the rainfall of April 1877 the Parana and Uruguay rivers swelled considerably, leading to flooding during May 1877, particularly along the Uruguay River.[22]

Although little quantitative evidence of anomalously wet conditions could be found for southern Brazil during October–November 1877 (as expected during an El Niño year), at least one newspaper report called the attention in November 1877 to the occurrence of a severe and long-lasting storm that produced severe damage in the southernmost state of Brazil (Rio Grande do Sul).[23]

The information presented in Fig. 12 indicates that very wet conditions prevailed from December 1877 to April 1878, particularly at Corrientes during FMA, Goya during DJFM, Córdoba during DJFMA, and Buenos Aires during DJFM, when the accumulated rainfall was around twice the climatological mean. By the end of March 1878, the Paraná River was reported to be more than 6 m above its average level at the city of Rosario, and the associated floods were labelled as catastrophic.[24]

[21] *El Mercurio de Valparaiso*—Chile, N°. 14999, 17 April 1877.

[22] *El Mercurio de Valparaiso*—Chile, N° 15023, 15 May 1877.

[23] *La Nación*—Buenos Aires, 28 November 1877.

[24] *La Nación*—Buenos Aires, 29 March 1878.

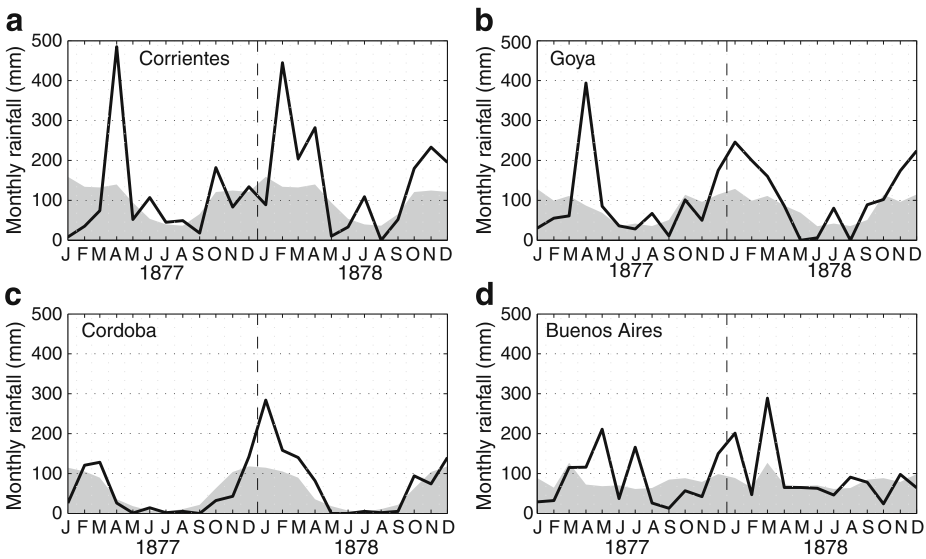

Fig. 12 Monthly rainfall at indicated stations in Argentina during 1877–1878. Mean climatological values are indicated as *shaded areas*. For station locations see Fig. 1 and Table 1

During the forthcoming weeks a series of reports described the impacts of floods in several cities along the Paraná River (Corrientes, Goya, Santa Fe, Rosario, etc.).[25,26] The river Paraguay also swelled considerably, and in May 1878 caused flooding in several parts of Paraguay, particularly in the city of Asunción (refer to footnote 26). In agreement with the tendency for a dipolar structure in the rainfall anomaly field that has been described for the eastern coast of subtropical South America (see for example Diaz and Aceituno 2003), rainfall was below the average at Rio de Janeiro, with deficits of −32% in 1877 and −15% in 1878, with respect to the 1871–1900 average. At the seasonal scale, drought was particularly severe from January to July 1877, and from Dec. 1877 to Mar. 1878, when accumulated rainfall was 43.4% and 53.1% of the long-term average, respectively.

From estimations of the highest water level of the Paraná River at Corrientes (for location see Fig. 1) during major floods during the nineteenth century obtained from old marks in buildings and newspaper reports (Aiskis 1984) and from direct measurements afterwards (Paoli and Cacik 2000; Depettris and Rohrmann 1998) it is concluded that the maximum water level during the 1878 flooding episode (8.65 m) was the fourth highest after those in 1812, 1858 and 1983. Furthermore, the flood of 1878 is considered one of the three largest affecting the city of Rosario (location in Fig. 13) during a period 1875–1978 (Motor Columbus y Asociados 1979). According to this study, during the 1878 flooding episode the Paraná River reached its

[25] *La Nación*—Buenos Aires, 3 April 1878.

[26] *La Nación*—Buenos Aires, 21 May 1878.

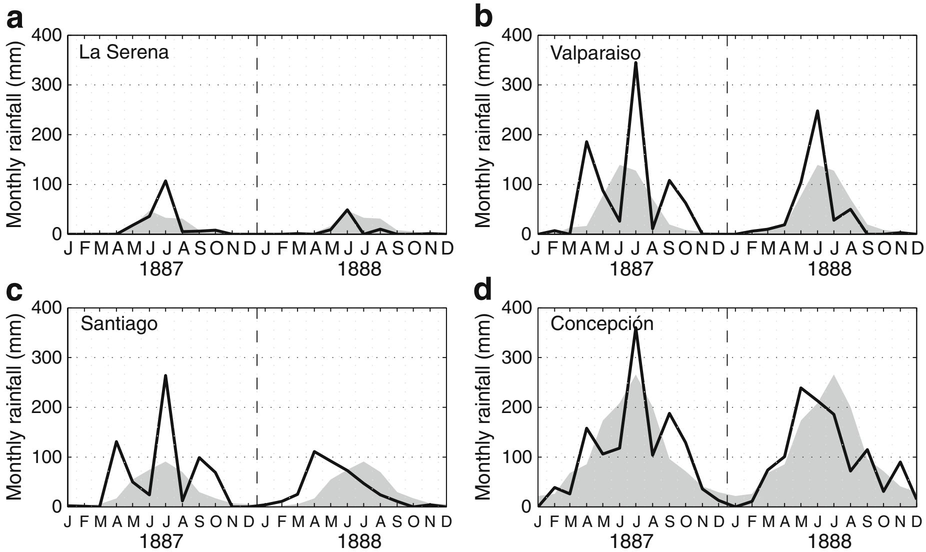

Fig. 13 Monthly rainfall at indicated stations in central Chile during 1877–1878. Mean climatological values are indicated as *shaded areas*. For station locations see Fig. 1 and Table 1

highest level on 18 May, remaining around 6 months above the flooding level (from 12 February to 13 August).

8 Extratropical West Coast (Central Chile)

Anomalously wet conditions prevailed in central Chile (30° S–40° S) during the 1877 rainy season (Vicuña-Mackenna 1877; Taulis 1934). This climate anomaly has been also mentioned in historical chronologies of El Niño events (Quinn and Neal 1992; Ortlieb 2000) and in studies documenting the ENSO influence on rainfall variability in Central Chile during the nineteenth century (Ortlieb 1994).

The rainy season in central Chile occurs during the austral winter semester (April–September) when the subtropical SE Pacific anticyclone is at its northernmost latitude. Mean annual rainfall increases southward from the almost permanently dry conditions in the Atacama Desert (25° S) to more than 3,000 mm in southern Chile (40° S–50° S). Most of precipitation is associated with extratropical fronts that produce rainfall at low elevations and snowfall over the Andes cordillera.

Although the influence of the Southern Oscillation on interannual rainfall variability in central Chile has been long recognized (Walker and Bliss 1932), a general awareness of the impacts of El Niño phenomenon in this region emerged only after the occurrence of large floods in 1982, 1987 and 1997. A higher than normal frequency of atmospheric blocking episodes at mid-latitudes in the SE Pacific is generally accepted as the main factor explaining the increased winter and spring rainfall in central Chile during El Niño episodes (Karoly 1989; Rutllant and Fuenzalida 1991; Montecinos and Aceituno 2003), as they tend to shift migratory low pressure systems and their associated fronts to the north as they approach the South American coast from the SE Pacific. Concurrent with the increased rainfall during El Niño episodes, above average snow accumulation occurs over the Andes, which in turn leads to increased river discharges from Andean watersheds in Chile and Argentina during the snow melt season of spring and summer (Aceituno and Vidal 1990; Compagnucci and Vargas 1993; Aceituno and Garreaud 1995; Escobar and Aceituno 1998; Prieto et al. 1999, 2001).

The rainfall anomalies associated with the 1877–1878 El Niño event in central Chile and neighboring regions in Argentina were analyzed using rainfall information from five Chilean stations between 30° S to 40° S (Table 1 and Fig. 1). Furthermore, a detailed survey was conducted of articles pertaining to weather and climate published by one of the most important Chilean newspapers at the time (*El Mercurio de Valparaiso*, EMV) during 1877 and the first semester of 1878. Other documentary sources were also examined, including the Archives of the Ministry of Public Works and Memoirs of the Ministry of Interior, in Chile, and the Historical Archive of Mendoza, the Memoirs of War, the newspaper *El Constitucional* (Mendoza), and travel reports, in Argentina.

In the northern part of central Chile (30° S–35° S), rainfall had been relatively low during the 8 years preceding 1877, with the deficit being particularly severe during 1874, 1875 and 1876. Similar to the major 1982–1983 and 1997–1998 El Niño episodes, above average rainfall fell in 1877 during the onset stage of the event (Fig. 13). The rainfall surplus above the climatological mean during 1877 austral winter (JJA) was 22% at La Serena (30° S), and near 70% at Santiago and Valparaiso (33° S). To the south, winter rainfall was slightly below average in Concepción (36.8° S) and Valdivia (38.7° S). The anomalously wet conditions in central Chile during 1877 were not continuous throughout the rainy season, as it also has been described for recent El Niño episodes (Rutllant and Fuenzalida 1991). Figure 13 shows that well above average precipitation occurred in April, July, September and October 1877, while relatively dry conditions prevailed in June and August. The 1878 rainy season was characterized by normal to above normal during the first half of the year followed by relatively dry conditions after June, when the El Niño episode was in its demise.

According to newspaper reports unusual weather conditions occurred early in 1877, beginning with an extratropical front that reached central Chile at the height of the dry season leaving near 10 mm of rainfall at Santiago (33° S) on 9 February.[27] Several storms affected central Chile in April indicating that the 1877 rainy season started much earlier than usual. The most intense one moved northward to around 28° S at the beginning of May, producing extensive flooding, destroying roads, railroads and bridges, and severely damaging agriculture (Vicuña-Mackenna 1877, pp 425–428).[28] Although near-to below average conditions prevailed in central Chile during June 1877 references can be found to a rainfall episode that affected the southern border of the Atacama Desert during that month,[29] probably associated with a cut-off low pressure system.

[27] *El Mercurio de Valparaíso* (EMV), N° 14951, 16 Feb. 1877.

[28] *El Mercurio de Valparaiso*, N° 1510, 30 April 1877; N° 15011, 1 May; N° 15012, 2 May; N° 15013, 3 May; N° 15015, 5 May; N° 15016, 7 May; N° 15017, 8 May; N° 15020, 11 May 1877.

[29] *El Mercurio de Valparaiso*, N° 15048, 13 June 1877; N° 15050 15 June; N° 15051, 16 June 1877.

Extraordinary precipitation occurred in July 1877 when accumulated rainfall at La Serena, Santiago and Valparaiso was near three times the climatological mean (Fig. 13). The intense storms that affected central Chile during that month caused dozens of fatalities along with extensive damage to infrastructure.[30] A detailed description of the flooding in Santiago associated with the storm that hit central Chile from 12 to 18 July is presented in Vicuña-Mackenna (1877) and Ortega (1999). The above average rainfall values for Valparaiso, Santiago and Concepción during September and October 1877 (Fig. 13) coincide with newspaper reports documenting the impacts of heavy rainfall and swollen rivers from mid-September.[31] through the first half of October.[32]

As is usually the case during abnormally wet winters in central Chile, snowfall accumulation in the Andes was greatly above average during 1877 and trans-Andean roads were forced to be closed much longer than usual, seriously affecting commercial exchange between Chile and Argentina. A major road crossing the Andes at 33° S was closed by the end of March 1877, 2 months before normal (Barra de Cobo 1878), and by mid January 1878, at the height of the following summer, traffic remained interrupted.[33] Mining activities were also impeded by the large snow accumulation during 1877.[34] Furthermore, the Andean rivers in Chile became swollen during the subsequent snow melt season and overflowed on several occasions from October 1877 to February 1878.[35] On the eastern side of the Andes the increased discharge of the Mendoza River destroyed bridges in early November 1877, interrupting the traffic along the routes from Mendoza to Buenos Aires and across the Andes.[36] Flooding during the snow melt season was also reported for Andean rivers in Argentina from February to April 1878.[37]

9 Discussion

We have analyzed the rainfall anomalies during the 1877–1878 ENSO episode in different regions of South America for which there is consistent evidence from several studies that this phenomenon is a relevant factor modulating the interannual climate variability. The relative intensity of this particular warm episode in the equatorial Pacific and the associated regional climate anomalies depends on the index used to assess its magnitude, and the region that is considered. The difference

[30] There are many references in the *El Mercurio de Valparaiso* during July 1877 to the intensity of the storms and the associated impacts, including destruction of bridges, roads and railroads, sunken ships, mudflow episodes, overflow of rivers, etc.

[31] *El Mercurio de Valparaiso*, N° 15131, 21 Sep. 1877; N° 15132, 22 Sep. 1877.

[32] *El Mercurio de Valparaiso*, N° 15153, 17 Oct. 1877.

[33] Historical Archive of Mendoza, carpeta 389.

[34] Historical Archive of Mendoza, carpeta 391, documento 80.

[35] *El Mercurio de Valparaiso* in 1877: N° 15152, 16 Oct.; N° 15185, 23 Nov.; N°15186, 24 Nov.; N° 15205, 17 Dec.; N° 15210, 22 Dec.; N° 15212, 24 Dec. In 1878: N° 15224, 8 Jan.; N° 15226, 9 Jan.; N° 15228, 11 Jan; N° 15243, 30 Jan.

[36] *El Constitucional*, Mendoza, 3 Nov. and 15. Dec., 1877

[37] Memoirs of War—Argentina, 1878, pp.179.

in normalized sea level pressure between Tahiti and Darwin is the most frequently used Southern Oscillation Index (SOI). The intensity and duration of periods with negative SOI can be used to characterized the strength of ENSO episodes. According to Allan and Ansell (2006) the minimum value of the SOI during the 1877–1878 event was significantly weaker in comparison with that reached during other major ENSO events (i.e. 1940–1941, 1982–1983). This is explained by the fact that during the 1877–1878 episode the magnitude of the positive pressure anomaly over the western core of the SO was considerably larger than that of the negative anomaly over the eastern core (Fig. 3). Regarding the intensity of the concurrent positive SST anomalies in the central equatorial Pacific, the monthly SST index for region Niño 3.4 (5° N–5° S, 170° W–120° W), prepared by Trenberth and Stepaniak (2001) from the Hadley Center HADISST data set for 1871–1981 and optimum interpolation SST analysis of the NCEP-CPC-NOAA, for 1982–2000, the intensity of the 1877–1878 El Niño event is slightly weaker than that of the strong 1982–1983 and 1997–1998 ENSO episodes. Based on the analysis of SST and station pressure in the tropics, sea level pressure in North America and the North Atlantic, temperature in North America and precipitation in key areas around the globe, Kiladis and Diaz (1986) concluded that the 1877–1878 and 1982–1983 ENSO episodes were comparable in magnitude. We reached the same conclusion regarding the rainfall anomalies in South America, although the loss of human lives during the 1982–1983 episode was considerably less than in comparison with the 1877–1878 event, resulting from an improved management of the impacts of natural disasters. A detailed comparison of global and regional climate anomalies during 1877–1878 with those during the strong 1997–1998 ENSO episodes is beyond the scope of this article, but a quick review of seasonal rainfall anomalies in South America during the 1997–1998 episode reveals that some of the expected anomalies were relatively weak (i.e. drought in NE Brazil) or did not occurred (i.e. drought in the central Andes Altiplano). This calls attention to the fact that regional climate anomalies associated ENSO events, are highly variable depending on the region, and that the magnitude of such climate disturbances does not necessarily follow the intensity of the SST anomalies in the equatorial Pacific. This is particularly the case for regions where ENSO-related climate anomalies are linked to atmospheric teleconnection patterns triggered by the anomalous conditions in the equatorial Pacific. Such is the case, for example, for the ENSO-related rainfall anomalies in central Chile during austral winter (Rutllant and Fuenzalida 1991). Moreover, this situation is clearly apparent from the maps of regional climate anomalies during major ENSO events presented in Allan et al. (1996). Thus, the extraordinary drought described here for the northern coast of Africa and SW Europe during the 1877–1878 event is not a recurrent climate anomaly during ENSO episodes, as relatively wet conditions or no significant rainfall anomalies are reported in that publication for several ENSO episodes.

The large impact of the climate anomalies during 1877–1878 on the evolution of global temperature indicated in Fig. 5, and the fact that some of them persisted beyond that period (i.e. droughts in NE Brazil and the Altiplano of the central Andes) make this period unique and suggest that other factors apart from ENSO may have been involved. Further research is needed regarding this matter but it should be remained that many of the ENSO-related climate anomalies are determined by teleconnection mechanisms that may interplay in a complex way with other low-frequency modes of atmospheric variability.

10 Summary and conclusions

Based on the compilation of relatively scarce instrumental data and the analysis of documentary information from several sources, a complete description of rainfall anomalies in South America during the strong 1877–1878 ENSO event was performed. Those followed a canonical regional pattern, characterized by rainfall deficit and drought along the northern portion of the continent, in northeastern Brazil and in the central Andean highlands (Altiplano), and abundant rainfall and floods along the coastal areas of southern Ecuador and Northern Peru, central Chile (30° S–40° S) and the Paraná basin in the southeastern part of the continent.

In the north of the continent, the rainfall records for San José (Costa Rica), Bogotá and Medellín in the Andean region of Colombia, show predominantly negative rainfall anomalies during 1877 and 1878, while the rainfall record at Demerara near the Atlantic coast in Guyana indicates drought during the 1877–1878 boreal winter.

Intense rainfall and damaging floods were reported for the coastal areas of southern Ecuador and northern Peru during the rainy seasons in 1877, at the initial stage of development of the 1877–1878 El Niño event, and in 1878, after the episode peaked and began to decline. In contrast, there is considerable evidence that severe drought affected the highland region of the central Andes in Peru and Bolivia (Altiplano) from 1877 to 1879. The impacts of the drought were most extreme along the southeastern portion of the Altiplano, where famine, disease and starvation were reported.

Anomalously wet conditions affected the extratropical west coast of the continent (central Chile) during 1877, in agreement with the well documented tendency for above average rainfall in this region during El Niño episodes. Associated with an anomalously weak subtropical anticyclone in the SE Pacific, extratropical fronts reached this region earlier than normal in the annual cycle and intense rainfall episodes continued to be reported by the beginning of the dry season in the austral spring. The associated flooding took a severe toll in terms of loss of lives, property and infrastructure, and unprecedented snowfall accumulation in the Andes seriously hampered transportation and the exchange of goods between Chile and Argentina. Furthermore, the subsequent snowmelt during spring and summer increased river discharges and led to destructive floods on both sides of the Andes.

Floods also affected the low-land areas in southeastern South America, particularly during the first semester of 1878. Meteorological stations such as Corrientes, Goya, Córdoba and Buenos Aires registered greatly above average rainfall during April 1877 (apparently associated with a potent storm that also caused destruction in Chile), and from December 1877 to March 1878. As during recent major El Niño episodes, severe floods were reported for all major rivers in the region such as the Paraná, Uruguay and Paraguay. According to hydrological reports the flood of the Paraná River during 1878 was the fourth largest since the beginning of the 19th century, behind those in 1858, 1983, and 1812.

By far the most tragic impacts of the 1877–1878 El Niño episode in South America occurred in the semiarid region of the Brazilian *Nordeste,* where three consecutive years of drought (1877–1879) left several hundreds of thousands of people dead by starvation and related disease, and the regional economy in ruins. Although the droughts in 1877 and 1878 can be linked to changes in the regional circulation modulated by the anomalous El Niño conditions in the equatorial Pacific, the severe rainfall deficit in 1879 occurred when the warm episode was over, suggesting that other factors were also responsible.

In summary, as in the Northern Hemisphere, intense climate anomalies affected South America during 1877 and 1878, leaving behind a trail of suffering and destruction. There was a very extreme global climatic disaster that was the result of natural variability unrelated to human activity. Considering the magnitude of the interannual climate variability at a planetary scale during these years and the fact that some of climate anomalies persisted beyond that period, it is plausible that other factors, apart from ENSO, were involved. Nevertheless, this episode is a remainder of how powerful the natural forces shaping global climate variability can be. Such occurrences seem to be forgotten at times when the human intervention is perceived by many people as the main cause of present and future natural disasters.

Acknowledgements Many people contributed valuable information for this study. We gratefully acknowledge the collaboration of Dr. Antonio Mabres, Universidad de Piura, Perú; Prof. Norberto García, Universidad Nacional del Litoral, Argentina; Ing. Luis Marcelo Cardinali, Entidad Binacional Yacyretá, Argentina; Prof. Peter Waylen, University of Florida, USA; Ing. Carlos A. Depettris, Universidad Nacional del Nordeste, Argentina; Prof. Rodolfo Rodríguez, Universidad de Piura, Peru; Prof. Ricardo A. Smith, Universidad Nacional de Colombia, Medellín; and Dr. Alain Gioda, IRD, Montpellier, France. Careful reviews and suggestions to the original manuscript by Chet Ropelewsky and Stefan Hastenrath are greatly appreciated. We also acknowledge the valuable comments and suggestions of Dr. Luc Ortlieb and one anonymous reviewer, which contributed to improve a previous version of this paper. This research was sponsored in Chile by Conicyt research grants Fondecyt N° 1000445 and N° 1040326, and ACT-19. We thank the U.K. Met. Office for use of the HadISST and HadSLP2 data sets.

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