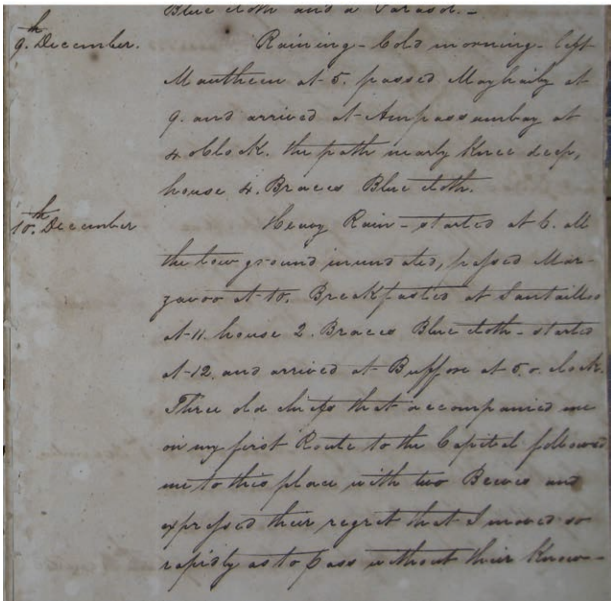
RECENT ADVANCES IN THE HISTORICAL CLIMATOLOGY OF THE TROPICS AND SUBTROPICS

BY DAVID J. NASH AND GEORGE C. D. ADAMSON

Historical documents from tropical regions contain weather information that can be used to reconstruct past climate variability, the occurrence of tropical storms, and El Niño and La Niña episodes.

In comparison with the Northern Hemisphere midlatitudes, the nature of long-term climatic variability in the tropics and subtropics is poorly understood. This is due primarily to a lack of meteorological data. Few tropical countries have continuous records extending back much further than the late nineteenth century. Within Africa, for example, records become plentiful for Algeria in the 1860s and for South Africa in the 1880s (Nicholson et al. 2012a,b). In India, a network of gauging stations was established by the 1870s (Sontakke et al. 2008). However, despite the deliberations of the Vienna Meteorological Congress of 1873, for many other nations, systematic meteorological data collection began only in the very late nineteenth or early twentieth century.

To reconstruct climate parameters for years prior to the instrumental period, it is necessary to use proxy indicators, either "manmade" or natural. The most important of these for the recent historical past are documents such as weather diaries (Fig. 1), newspapers (Fig. 2), personal correspondence, government records, and ships' logs (Bradley 1999; Carey 2012). These materials, often housed in archival collections, are unique sources of climate information. They may include very early instrumental observations, which, if extensive and of national or regional significance, may require data rescue efforts. More commonly, they contain first-hand descriptions of weather conditions and/or accounts of weather-dependent natural phenomena. Such *descriptive documentary data* (Brázdil et al. 2005) require careful



Blue cloth and a Parasol.–

9th December. Raining – Cold morning – left Mauthem at 5. passed Mayhaily at 9. and arrived at Ampassambay at 4 oclock. the path nearly Knee deep, house 4. Braces Blue cloth.

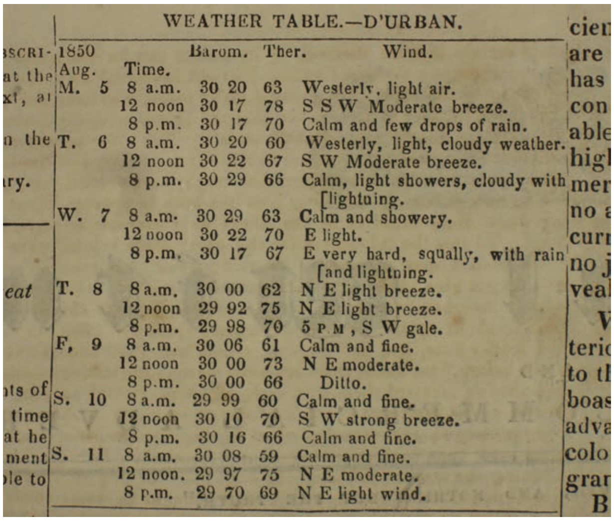
10th December Heavy Rain – started at 6. all the low ground inundated, passed Marzavoo at 10. Breakfasted at Sautailles at 11. house 2. Braces Blue cloth – started at 12. and arrived at Buffore at 5 o clock. Three old Chiefs that accompanied me on my first Route to the Capital followed me to this place with two Beeves and expressed their regret that I moved so rapidly as to pass without their Know–

FIG. 1. Personal journal entry describing heavy rain and cold conditions in coastal eastern Madagascar on 9 and 10 Dec 1817, written by the British Agent to Madagascar, Mr. James Hastie (Mauritius National Archive HB 10-01, Journal of Mr Hastie, from 14 Nov 1817 to 26 May 1818).

interpretation (Table 1) but can, through the application of methods such as content analysis, be used to reconstruct climatic variability. Significantly, they describe short-term (high frequency) fluctuations (Bradley 1999) and are the only source through which direct evidence of the impacts of climate upon individuals and societies can be obtained (Brázdil et al. 2005).

Research exploring historical documents and employing the methodologies of both climatology and history to reconstruct past weather conditions is referred to as *historical climatology* (Pfister et al. 2001). The subdiscipline has three main objectives: 1) the reconstruction of spatial and temporal climatic patterns, 2) the investigation of the vulnerability of past societies to climate variations, and 3) the exploration of past discourses and social representations of climate (Brázdil et al. 2005). Given this breadth of mission, historical climatology is uniquely placed to both generate extended datasets for climate modelers and engineers, and to provide empirical evidence to further our understanding of the changing nature of climate–society relationships over time (see Jones et al. 2009).

The majority of historical climatology research has focused on Europe, North America, and, more recently, parts of China, all regions for which well-preserved collections of historical documents exist. However, the start of this century has also seen major advances in our understanding of the historical climatology of the tropics and subtropics. Studies have ranged from the world's first measurement of atmospheric pressure within the circulation of a hurricane, near Barbados in 1680 (Chenoweth et al. 2007), to the reconstruction of rainfall variability over the African continent during the nineteenth century using descriptive documentary and gauge data (Nicholson et al. 2012b). The aim of this paper is to present a critical review of these advances, highlight recent methodological developments, and suggest productive avenues for future research.



WEATHER TABLE.—D'URBAN.

1850 Aug.	Time.	Barom.	Ther.	Wind.
M. 5	8 a.m.	30 20	63	Westerly, light air.
	12 noon	30 17	78	S S W Moderate breeze.
	8 p.m.	30 17	70	Calm and few drops of rain.
T. 6	8 a.m.	30 20	60	Westerly, light, cloudy weather.
	12 noon	30 22	67	S W Moderate breeze.
	8 p.m.	30 29	66	Calm, light showers, cloudy with [lightuing.
W. 7	8 a.m.	30 29	63	Calm and showery.
	12 noon	30 22	70	E light.
	8 p.m.	30 17	67	E very hard, squally, with rain [and lightning.
T. 8	8 a.m.	30 00	62	N E light breeze.
	12 noon	29 92	75	N E light breeze.
	8 p.m.	29 98	70	5 P M , S W gale.
F, 9	8 a.m.	30 06	61	Calm and fine.
	12 noon	30 00	73	N E moderate.
	8 p.m.	30 00	66	Ditto.
S. 10	8 a.m.	29 99	60	Calm and fine.
	12 noon	30 10	70	S W strong breeze.
	8 p.m.	30 16	66	Calm and fine.
S. 11	8 a.m.	30 08	59	Calm and fine.
	12 noon.	29 97	75	N E moderate.
	8 p.m.	29 70	69	N E light wind.

Fig. 2. Early instrumental data and related weather observations for Durban, published in South Africa's longest continually running newspaper, the *Natal Witness*, on Friday 16 Aug 1850.

Our review focuses on studies that have attempted to reconstruct spatial and temporal climate patterns, using both early instrumental and descriptive documentary data, since these dominate the recent literature. It is divided into five sections. We first consider the ways in which historical sources have been used to reconstruct past 1) temperature and 2) rainfall variability in the tropics and subtropics, and 3) the occurrence and severity of tropical cyclones. We then review 4) the ways in which written materials have contributed to reconstructions of the El Niño–Southern Oscillation (ENSO), before concluding with 5) some suggestions for future research. All time periods described are in years A.D. unless otherwise stated.

HISTORICAL TEMPERATURE RECONSTRUCTIONS.

Debates about recent global warming fundamentally hinge upon the availability of instrumental surface data from which temperature trends can be identified. Several compilations provide gridded monthly mean estimates of temperatures back to the mid-nineteenth century [see Jones and Mann (2004) for a review], but coverage becomes increasingly sparse during earlier decades,

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Table 1. Advantages and limitations of descriptive documentary evidence for the reconstruction of past climates (after Pfister et al. 1999; Brázdil et al. 2005).

Advantages	Limitations
Excellent dating control and high temporal resolution.	Discontinuous nature of many records (e.g., due to partial preservation of material or the death of observers).
Clear identification of different meteorological elements (e.g., temperature, precipitation, snow cover, wind).	Positionality of individual observers may influence their attitudes, biases, and environmental awareness.
Emphasis of observations on climate anomalies and natural disasters.	Emphasis of observations is often short-term, so long-term trends may go unrecognized.
Generally good coverage of months and seasons (although evidence may be biased toward months of sowing and harvest).	Mathematical analysis is simple but robust (although this may be a drawback for the acceptance of results by the scientific community).
Descriptions of conditions are often accompanied by accounts of associated impacts.	Geographical coverage of evidence is often incomplete, as it depends upon (a) the sedentary presence of literate individuals, (b) a tradition of recording eyewitness accounts of extraordinary events, and (c) the existence of appropriate institutional and cultural frameworks to preserve documents.

and particularly so in tropical and subtropical regions. In Europe, it has been possible to use historical sources to extend the instrumental record and undertake detailed continent-wide reconstructions of temperature variability over many centuries (e.g., Luterbacher et al. 2004). However, few equivalent accounts have been published for the tropics and subtropics. Those studies that are available use descriptions of conditions during winter months (e.g., frosts, snow falls, ice thickness) to reconstruct average cold season temperatures.

Of all the categories of descriptive documentary data, cold climate indicators are the most straightforward to interpret, since accounts of, for example, extensive frost over several days are unequivocal evidence of temperatures falling close to or below freezing (see Bradley 1999). Counts of the number of frost days recorded within historical sources, coupled with information about the frequency of snowfall events and persistence of snow cover, provide an effective proxy for winter severity and lend themselves well to the development of transfer functions. There are, however, limitations; studies are usually restricted to higher-altitude regions of the tropics and the extent to which temperature reconstructions can be extrapolated (both spatially and to other seasons) is debatable.

In the Northern Hemisphere tropics, some of the longest reconstructions have been reported from China. Here the earliest known writing, in the form of text inscribed onto pieces of bone, dates back to the Shang dynasty (some 3700–3100 years ago; Bradley 1999). The meteorologist Zhu Kezhen pioneered the use of such “oracle stones” and other sources (Fig. 3) in the early 1970s to conclude that the period 3000 to 1000 BC was generally warmer than the twentieth century (Endfield and Marks 2012).

Recent research has built on this seminal work to reconstruct temperature variability at a resolution of 10 yr or less. Most studies focus upon areas north of the Yangtze River, but a number of investigations concern the subtropical regions of southern China. Zheng et al. (2012), for example, have used available instrumental data and reports of snow and ice events within local gazettes to reconstruct a chronology of extreme cold winter events for southern China. The study identifies that extreme cold winter events were particularly intense or frequent from 1650 to the end of the seventeenth century and from the end of the eighteenth century to the beginning of the twentieth (Table 2). These results compare well with work by Ge et al. (2010), who reconstructed temperature variations in southeast China over the last 600 years through a meta-analysis of several documentary time series. Their results suggest that maximum temperatures occurred in the 1490s, 1620s, 1670s, and 1930s, with minima in the 1650s and 1830s.

The growth of investigations into the historical climatology of China has allowed for the impact of a concern about the use of documentary evidence to be assessed—namely, that climate descriptions within historical sources are subjective and require careful interpretation to obtain their precise meaning (Pfister and Wanner 2002). Discrepancies in results have been identified between different Chinese regional temperature series, which have raised doubts about their quality and even the value of using historical documents as data sources (Ge et al. 2008). Some studies (e.g., Wang and Gong 2000) have suggested

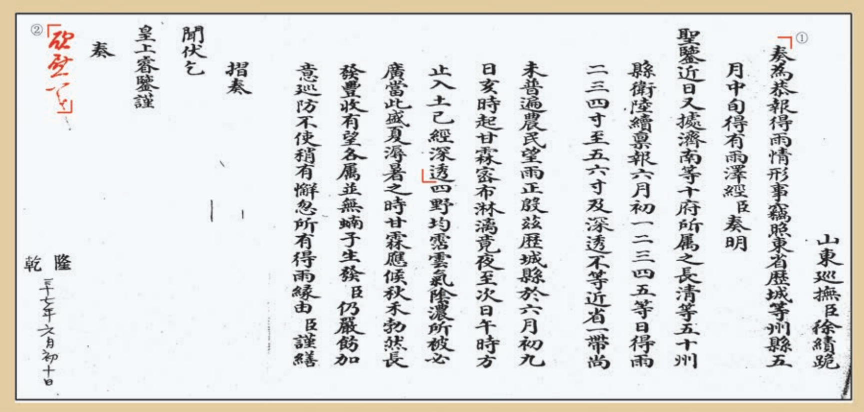
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Fig. 3. An example of the qualitative description of rainfall reported in a rainfall memo by Xu Ji, Governor General of Shandong province, on the 10th day of the sixth month in the Chinese lunar calendar on the 37th year of the Qianlong Reign (i.e., 10 Jul 1772). The text labeled (1) translates as: "Some counties such as Licheng received rain in the middle of the fifth month, which was reported by me before. Recently, more than 50 counties of ten-Fus, such as Changqing county, had rain again with 2, 3, 4, to 5, 6 cuns and up to Shentou [enough depth into the soil from the 1st to 5th day on the sixth month in lunar calendar (1–5 July)]. But in the nearby Licheng county of Ji'nan Fu, the rain is not enough, and the farmers were expecting rainfall. Now, in the 9th day of the sixth month (9 July), the rain started from HaiShi (Chinese ancient time, 9:00–11:00 p.m.) to the next WuShi (11:00 am–1:00 pm) in Licheng county; it was in time and has penetrated into the arable soil." The text labeled (2) is a comment by the emperor: "It's great to hear about this report." Image courtesy of Zhixin Hao.

that China experienced only moderately warm conditions during the Medieval Climate Anomaly when compared to the late twentieth century, while others (e.g., Ge et al. 2003) have concluded that it was markedly warmer. To assess the cause of this difference, Ge et al. (2008) analyzed 14 published temperature series, including several from subtropical southern China (e.g., Zhang 1980; Wang et al. 1998), for coherence and mutual consistency using correlation and cluster analyses. The authors concluded that there were significant correlations among the 14 series, and that discrepancies between the reconstructions could be accounted for by regional climatic variability rather than differences in interpretation. Ge et al. (2008) also identified that cold/warm stages of 50–100-yr duration derived from documentary records varied coherently with reconstructions based on natural proxies (including data from tree rings, ice cores, and lake sediments), suggesting robustness in the document-derived chronologies.

For the Southern Hemisphere, Prieto and García Herrera (2009) have presented a preliminary synthesis of the wealth of temperature-related historical investigations emerging from Ecuador, Peru, Bolivia, Chile, and Argentina. These use a range of cold climate indicators within historical documents to reveal that areas of subtropical South America experienced cold conditions during the late sixteenth to early seventeenth century, with extreme frost events recorded in northwestern Argentina from 1583 to 1605. Prieto et al. (1999), for example, identified reductions in flow within the Mendoza River between 1600 and 1670, which they attributed to a decline in summer snowmelt in the Andes during the Little Ice Age. Severe, cold summers and early frosts also appear to have been more common in the period 1630–60.

In southern Africa, Grab and Nash (2010) have used a variety of English-, French- and Sesotho-language missionary and colonial sources to identify annually resolved variations in cold season extremes in the highlands of Lesotho during the nineteenth century. The study identifies a longer frost season and more severe and snow-rich winters during the early part of the nineteenth century (Fig. 4). The late 1800s were associated with generally milder cold seasons, with the exception of the 1880s when a run of winters with heavy snowfall occurred in the years following the 1883 eruption of Krakatoa. The study identifies a possible link between major tropical and Southern Hemisphere volcanic eruptions and severe to very severe cold seasons in southern Africa,

Table 2. The frequency of extreme cold winter events in southern China during each half-century of the period 1650–2000 (Zheng et al. 2012).

Period	1650–99	1700–49	1750–99	1800–49	1850–99	1900–49	1950–99
Frequency	11	5	5	10	11	8	5

which warrants further investigation.

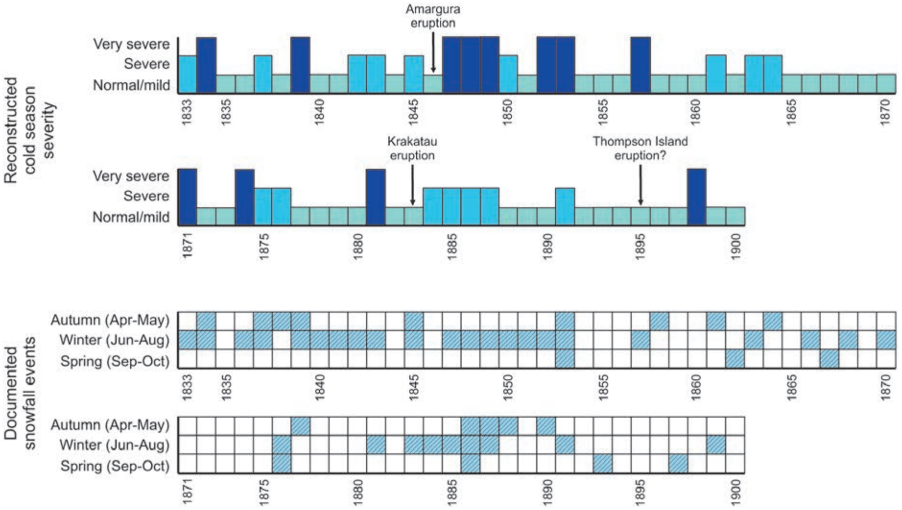

Fig. 4. (top) Cold season chronology for Lesotho and surrounding areas of South Africa (1833–1900) reconstructed through the analysis of missionary and colonial records. (bottom) Documented snowfall events identified from the same sources (data from Grab and Nash 2010).

Four recent studies include examples of instrumental temperature data uncovered from historical documents. Cruz Gallego et al. (2011) describe one of the oldest meteorological datasets known for central Africa, recorded by the sisters Isabel and Juliana Urquiola at Little Elobey in Equatorial Guinea. The maximum monthly temperatures recorded from July to December 1875 show good agreement with contemporary data from the nearby Cocobeach meteorological station, although there are discrepancies in minimum temperature that may be due to either instrumental problems or microclimatological differences between the recording sites. Grab and Nash (2010) used homogenous historical temperature observations from Maseru to calibrate their Lesotho cold season chronology, while Gergis et al. (2009) have analyzed daily observations recorded by William Dawes and William Bradley to reconstruct temperature variability in Sydney, Australia, for 1788–91. The daily, seasonal, and interannual temperature fluctuations revealed in the early Australian observations are directly comparable with modern day series recorded at Sydney Observatory Hill. Perhaps the single most impressive set of recorded observations is that compiled by the Jamaican colonist Thomas Thistlewood, which includes high-quality daily observations spanning more than 35 years (1750–86) (Chenoweth 2003). Comparison of Thistlewood's records with modern weather data indicates that eighteenth-century Jamaica was a much cooler and wetter place than the present day.

HISTORICAL RAINFALL RECONSTRUCTIONS.

Flooding and drought-related starvation are two of the greatest causes of contemporary mortality in tropical and subtropical regions and have a disproportionate impact on poor rural households (GAR 2011). Extensive data are required to ensure weather forecasts have a high level of accuracy, and to allow scientists to identify particularly hazard-prone areas and develop appropriate warning systems. Floods and droughts were equally, if not more, significant for the lives of agriculture-dependent communities in the past. As a result, accounts of variations in the timing and intensity of rainfall and of related weather-dependent phenomena feature prominently in documentary records from the tropics and subtropics. These provide data for a large number of historical rainfall reconstructions. Most studies are essentially seasonal chronologies, but where the density of information within documents permits, monthly reconstructions and the identification of the date of rainy season onset are also possible.

In comparison with cold climate indicators, descriptions of relative rainfall are much more difficult to interpret and categorize. Individual observers can describe rainfall levels for a specific time and place very differently (Duncan and Gregory 1999). This may depend, at least in part, upon factors such as their nationality and background, as well as their intended audience (Nash and Grab 2010). Sometimes authors, particularly recent arrivals to an area, lack knowledge of the "typical" climate and may (often unwittingly) exaggerate certain climatic conditions (Kelso and Vogel 2007). These subjectivities can be overcome through triangulation between observers, where possible, but much care is needed in interpretation. Descriptions of "floods" are much less equivocal, but even here it is often difficult to assess the magnitude of flooding unless associated impacts are reported. Most rainfall reconstructions have been produced for regions with strongly seasonal climates. This is unsurprising, since rainfall variability in these areas is more likely to have had an impact upon everyday lives and hence be noted. It is unlikely that historical sources would permit the identification of more subtle seasonal variations in precipitation such as those that occur in year-round tropical rainfall zones.

At a regional scale, a number of studies focus on southern Africa, where nineteenth-century rainfall series have been published for the Kalahari (Nash and Endfield 2002a,b, 2008), Lesotho (Nash and Grab 2010), Namaqualand (Kelso and Vogel 2007), and the southern and eastern Cape (Vogel 1989). These reconstructions are based on a variety of types of historical source, which have varying degrees of reliability. The studies from Namaqualand and the Cape draw heavily upon published monographs, reports, and colonial government "Blue Books." Although sometimes derived from eyewitness descriptions, these sources comprise mainly summarized secondhand accounts and lack the temporal resolution of primary materials (see Pfister 1992). The series for the Kalahari and Lesotho, in contrast, derive their data predominantly from unpublished collections of primary British and French missionary materials, which permit more detailed reconstructions (see Nash and Endfield 2008). Regardless of source, the rainfall series show strong interannual coherence (Fig. 5) and reveal subcontinent-wide drought episodes in 1820–21, 1825–27, 1834, 1861–62, 1874–75, 1880–83, and 1894–96 (Kelso and Vogel 2007). The documentary rainfall series also show good agreement with a tree-ring-based November–February precipitation reconstruction for Zimbabwe (Therrell et al. 2006), which identifies protracted droughts in the 1840s and from 1859–68 and 1882–96.

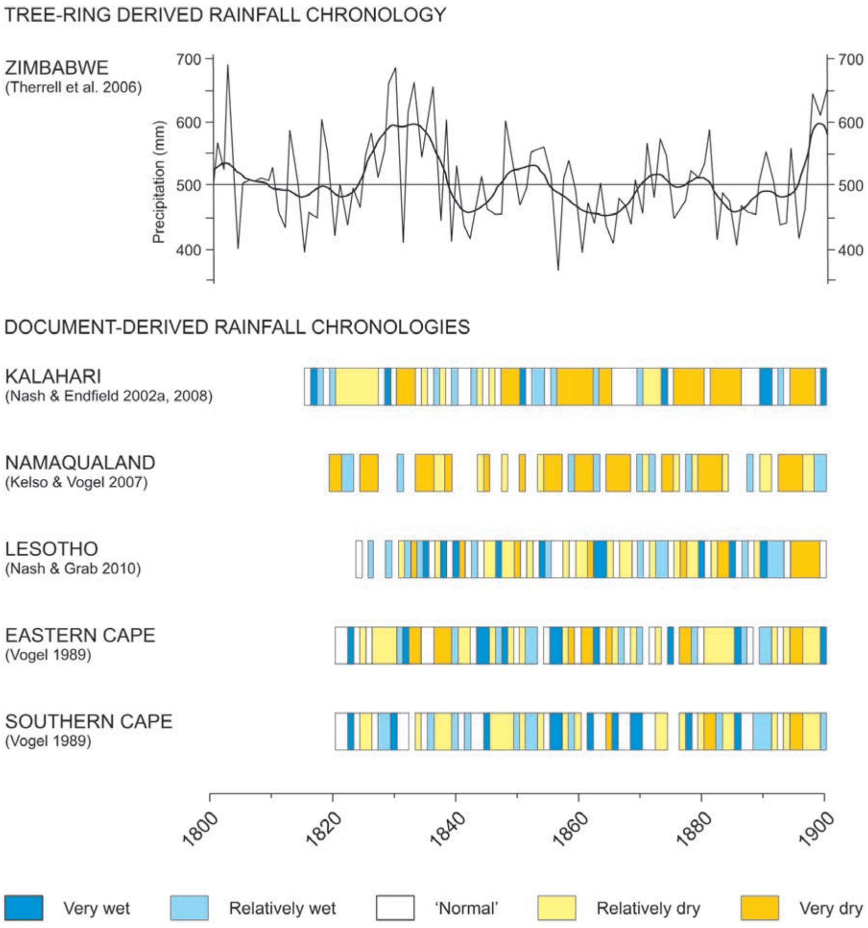

Fig. 5. High-resolution document-derived rainfall chronologies for the southern Kalahari Desert and surrounding hardveld (Nash and Endfield 2002a), Namaqualand (Kelso and Vogel 2007), the southern and eastern Cape regions (Vogel 1989), and Lesotho (Nash and Grab 2010) in southern Africa. Also shown is a tree-ring reconstructed rainfall record for Zimbabwe (Therrell et al. 2006), including both the annual (thin line) and 10-yr smoothing spline (heavy line) values of reconstructed November–February rainfall. Gaps in the chronologies correspond to either missing data (tree-ring record) or unclassified years (documentary records). The widespread drought episodes identified by Kelso and Vogel (2007) span the years 1820–21, 1825–27, 1834, 1861–62, 1874–75, 1880–83, and 1894–96, with an additional dry period from the early to mid-1840s affecting the Kalahari and Zimbabwe only.

In addition to their value for understanding long-term rainfall variability, the various studies from southern Africa illustrate the increasing methodological transparency adopted during the compilation of climate series. The studies by Vogel (1989) and Nash and Endfield (2002a) simply present rainfall chronologies with little indication of the reliability of the reconstruction for individual years. However, it is very apparent that data are sparse for earlier parts of both reconstructions. To improve the transparency of their reconstruction process, Kelso and Vogel (2007) gave each year in their rainfall series a "confidence rating," whereby a rating of 1 (low confidence) was awarded for years where only a very limited number of sources refer to a climatic condition, and 3 (high confidence) where multiple date- and place-specific observations are available. This approach was used subsequently by Nash and Grab (2010). Efforts such as this should, where possible, be applied in future investigations.

Seasonal rainfall reconstructions are also available at a continental scale for 90 climatically homogenous geographical regions of the African mainland (Nicholson et al. 2012a,b). These studies represent the culmination of many decades of work (e.g., Nicholson 1981, 1996) collecting early gauge data and accounts of rainfall variability and lake level status from mainly published historical sources [see Nicholson (2001) for a description of the dataset]. The major advance in Nicholson's most recent work is through the application of variants of statistical techniques used in modern climate reconstruction to address the fragmentary nature of documentary availability. Her Africa-wide "wetness" reconstruction (Nicholson et al. 2012b), for example, reveals decade-long wetter and drier periods over the last 200 years (Fig. 6) but is based on annual series for which empirical data make up less than 25%. A portion of the remaining series was inferred between regions that covary with respect to precipitation (Nicholson 2001), with the remainder calculated using spatial reconstruction, devised from principal component analysis of twentieth-century data. This generated reliable data for the entire continent after 1820, with the exception of the eastern Sahara and central equatorial Africa.

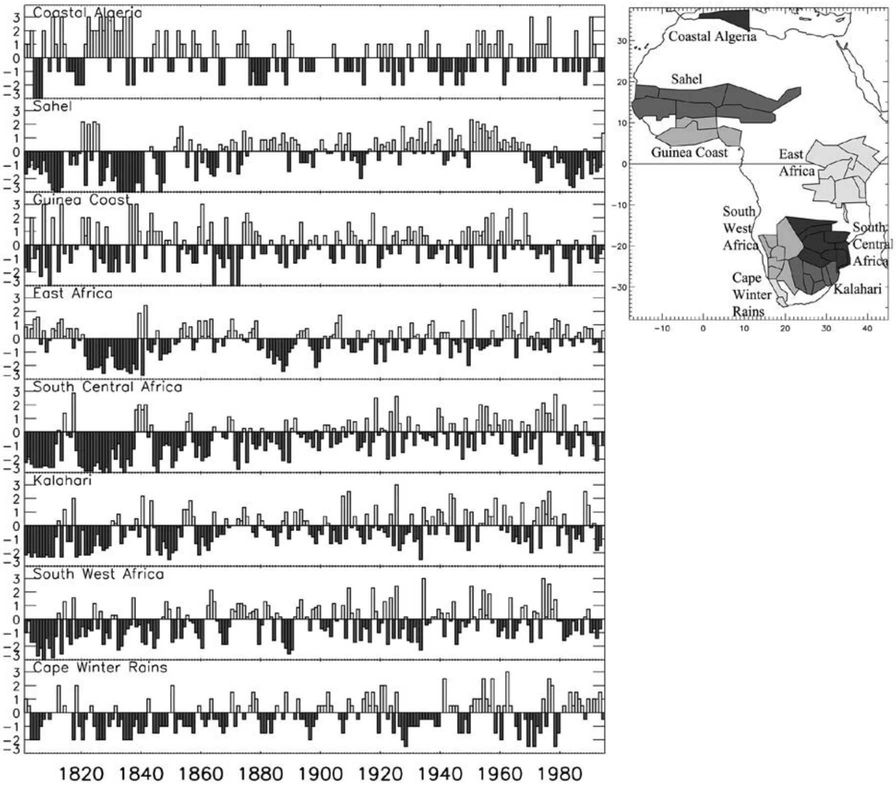

Fig. 6. Select multiregion time series of "wetness" from 1801 to 1998 produced by Nicholson et al. (2012b) using documentary and gauge data for eight geographical sectors of Africa (location shown in the inset map).

Comparison of the Nicholson et al. (2012b) record with the chronologies for southern Africa shown in Fig. 5 suggests generally good agreement, although the early part of the nineteenth century appears to be significantly drier in Nicholson's reconstruction. This may be a product of the different types of documentary evidence employed in the respective studies, or the methodologies adopted, and requires further analysis. Nicholson's approach also requires verification through the generation of new time series for regions where statistical inference was used.

Precipitation and streamflow time series for subtropical South America dating back to the early 1500s have been summarized by Prieto and García Herrera (2009). Historical documents from northwest Argentina, for example, reveal a protracted dry period from 1580 to 1641, including severe droughts around 1610 and in the period leading up to 1641. In contrast, the adjacent lowlands around Mendoza were comparatively wet during the seventeenth century. The eighteenth century saw much more variable climatic oscillations, trending toward drier conditions in the subtropical Andes and lowlands by the end of the century.

Neukom et al. (2009) have applied state-of-the-art statistical techniques to these South American documentary series and twentieth-century instrumental data to generate a precipitation reconstruction spanning the period 1600–2006. Their study uses

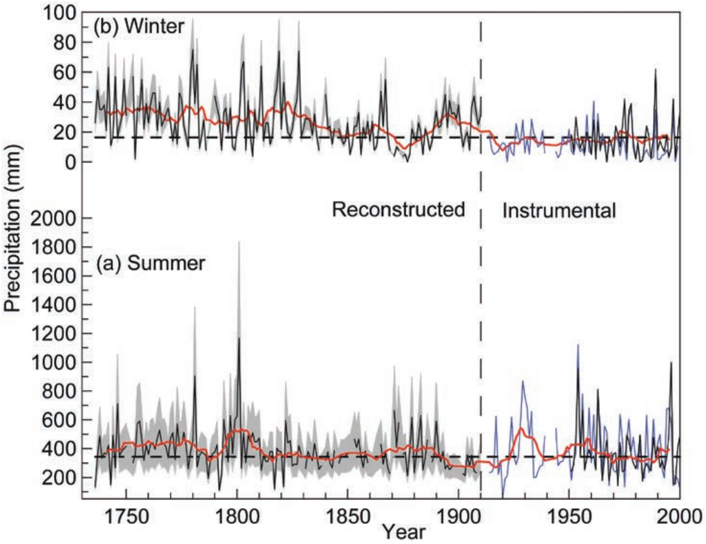

Fig. 7. Reconstructed (1736–1911) and instrument-measured (1951–2000) summer and winter precipitation (mm, black line) at Shijiazhuang, southern China (Ge et al. 2005). The red line represents the 11-yr running mean, while the horizontal dashed line is the mean annual value for 1961–90. Grey shading represents the 95% confidence interval. Seasonal instrumental precipitation measurements from the neighboring city, Baoding (located 125 km northeast of Shijiazhuang; blue line), are used to fill the data gap between 1911 and 1950. The 11-yr running mean values from 1911 to 1950 are based on the precipitation measurements from Baoding.

the pseudoproxy approach, first devised by Mann and Rutherford (2002). This approach accepts the inherent uncertainty within proxy reconstructions and seeks instead to apply a proportional uncertainty to the instrumental data so that statistically robust comparisons can be made. "Pseudo-documentary" time series were created by degrading twentieth-century instrumental data into classes equivalent to the documentary series and adding white noise. The amount of white noise was determined by the correlation between the reconstruction and instrumental data during an overlap period. This study introduces an important new approach for quantifying otherwise semi-quantitative documentary reconstructions, and reveals that prevailing dry (wet) periods in the first (second) half of the twentieth century at Mendoza were extraordinary in the context of the last 400 years. The one weakness in this approach is that it is reliant upon the accuracy of the rainfall reconstruction during the overlap period; outliers or problematic years in terms of the amount or coherence of the available documentary information can influence significantly the amount of white noise added.

Only one extensive documentary-derived rainfall chronology exists for the central Americas, namely the record for Antigua produced by Berland et al. (2013). This was constructed through the analysis of unpublished (mainly first-hand) sugar plantation, missionary, and government records. Over 13,000 documents were consulted to produce the rainfall reconstruction, using a method similar to that of Nash and Endfield (2002a), which reveals nine significant dry phases (1775–80, 1788–91, 1820–22, 1834–37, 1844–45, 1859–60, 1862–64, 1870–74, and 1881–82) and six wet phases (1771–74, 1833–34, 1837–38, 1841–44, 1845–46, and 1878–81) during the late eighteenth to late nineteenth centuries.

In China, Ge et al. (2005) have used "Memos-to-Emperor" (documents reporting daily administrative activities sent by provincial and local government officials to the Emperor) during the Qing Dynasty to reconstruct variations in summer and winter precipitation for the period 1736–1911 (Fig. 7). These documents also reveal an extreme drought in 1792, which affected large areas of China, including Beijing, and extremely heavy rainfall and flooding in 1801.

Aspects of the climate of the Chennai region of southeast India have been assessed by Walsh et al. (1999) using German-Danish historical sources, including weather diaries (one of the most reliable sources for historical climate reconstruction), annual reports, and letters. Rather than reconstructing a single long chronology, these documents have been used to identify rain days and wind directional frequencies for the periods 1732–37 and 1789–91, from which variations in the strength of the summer and winter monsoon have been inferred. The study identifies that lower than average (compared with the period 1813–1991) levels of rainfall fell in Madras during the 1730s, with very low winter monsoon and near-average summer monsoon rainfall. The period 1789–91 was associated with near-average rainfall but reduced summer and above-average winter monsoon rains.

More recent work by Adamson and Nash (2013) has used the extensive records of the British East India Company, combined with newspapers and missionary sources, to reconstruct variations in the summer monsoon over western India for the period 1781–1878. Such is the richness of the documentary material that it has been possible to reconstruct the date of rainy season onset (Fig. 8), the first occasion that this has been achieved for a tropical region, thereby extending the existing record of monsoon onset by 97 years. The longer-term perspective provided by this investigation suggests that the climate regime that controls monsoon onset over this region did not change from 1781 to around 1955, but that the date of onset over Mumbai has shifted later since this time.

RECONSTRUCTION OF TROPICAL CYCLONES. A common criticism of historical sources is that the information they contain is biased toward extreme events (Bradley 1999). This is, however, a major advantage for fields such as paleotempestology (the study of past tropical cyclone activity), where documentary sources can be used to reconstruct historical cyclone frequency, pathways, and impacts with high precision. It is important to understand cyclone histories because of the potential cost of damage repair and the time needed to recover from major events. In some cases, reconstructions of historical storms have revealed potential "worst-case scenarios" that would be considered unprecedented from an examination of the modern record alone (see Chenoweth and Landsea 2004). Recent advances have been documented in the edited volumes *Hurricanes and Typhoons: Past, Present, and Future* (Murnane and Liu 2004) and *Historical Climate Variability and Impacts in North America* (Dupigny-Giroux and Mock 2009). Methodological advances have also been made through the content analysis of wind force terms and the assessment of damage reports to reconstruct historical tropical cyclone intensity (see Boose 2004; Chenoweth 2007) (Table 3).

There is a growing understanding of historical cyclone occurrence for a number of tropical and subtropical regions. Liu et al. (2001), for example, have published a 1,000-yr chronology of typhoon landfalls in southern China through the analysis of descriptions of natural disasters within semi-official local gazettes. A total of 571 typhoons are identified in the historical data. This probably underrepresents the actual number, as the authors acknowledge that record-keeping (and possibly preservation) was sporadic for the centuries prior to the year 1400. The years 1660–80 and 1850–80, coinciding with two of the driest and coolest periods of the Little Ice Age in China (see above), appear to have been the most active on record. Ribera et al. (2008) have explored the *Catalogue of Typhoons 1348–1934* (produced by the Spanish Jesuit Miguel Selga in the early twentieth century from an analysis of old chronicles) to identify the deadliest typhoons to affect the Philippines (Table 4). The most deadly was the storm that passed to the north of Manila between 20 and 26 September 1867 [at the heart of the period of enhanced Chinese typhoon activity identified by Liu et al. (2001)] in which more than 1800 people died as a result of catastrophic flooding of the Abra River. Care is needed in interpreting secondary records of this type, hence the focus of the study on the most severe storms (i.e., the ones most likely to have been reported by historical observers).

The greatest number of studies of historical cyclone activity emanate from the Caribbean and tropical Atlantic. Chenoweth and Divine (2008), for example, used accounts of major storms within British ships' logs, newspapers, and official colonial correspondence to construct a 318-yr series of cyclone activity in the Lesser Antilles, and identify

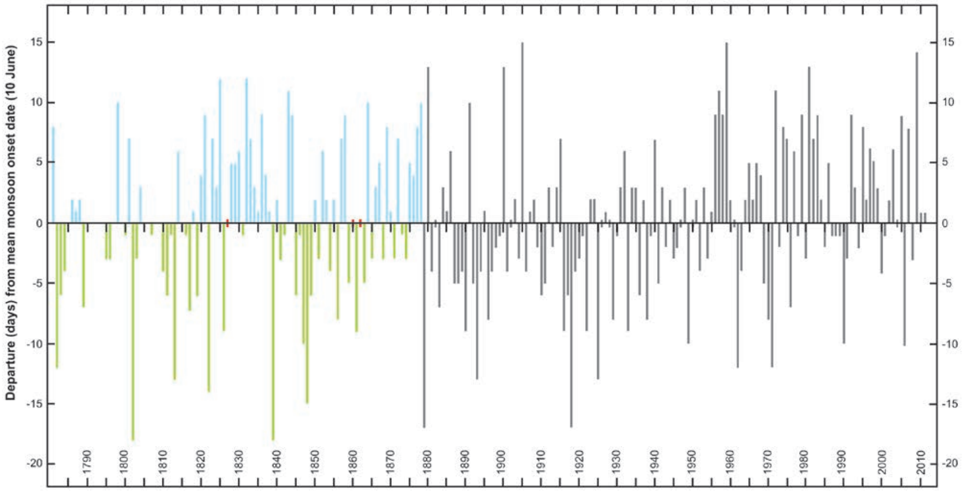

Fig. 8. Date of monsoon onset over western India from 1781 to 2011 (Adamson and Nash 2013). Onset dates for 1781–1878 (blue and green bars) are derived from the analysis of colonial documents. Onset dates for 1879–2011 (grey bars) are from Indian Meteorological Department weather reports and declared during the operational phase of the monsoon. Data are expressed as a departure (in number of days) from the average onset date of 10 June between 1781 and 2011. Positive values indicate a later date of monsoon onset.

Table 3. Common wind force terms used in newspapers referring to the Lesser Antilles between 1795 and 1879 and their associated tropical cyclone category (Chenoweth 2007).

Tropical depression	Tropical storm	Hurricane
blew pretty fresh	blew severely, fierce gusts	blew with great and destructive fury
blew rather heavily	fearful gale, frequent gusts	blew with indescribable violence
blew heavy (hard)	furious gale, hard squalls	fierce roaring
blowing half a gale	gale, heavy gusts	hurricane
brisk wind	heavy gale, severe blasts	indescribable force
inclining to a gale	heavy storm, severe gusts	mere hurricane
nearly a gale	not a hurricane, severe squalls	roared and howled most terribly
stiff breeze	regular gale, strong blasts	terrific hurricane
strong breeze (wind)	severe gale, strong puffs	violent hurricane
very fresh and variable	smart gale, strong squalls	
wind whistled loudly	stormy, tremendous gusts	
wind unsteady	strong gale, violent gusts	
(very) high wind	violent gale, wind raged	

Table 4. Typhoons in the Philippines resulting in more than 100 deaths, identified by Ribera et al. (2008) using the typhoon chronology produced by the Spanish Jesuit Miguel Selga.

Date	Deaths	Description	Location
20 Sep 1867	1800	Inundation and destruction plus a shipwreck (victims not included in the 1800 deaths)	Luzon
7 Oct 1897	1500	Destruction and tsunami	Samar, Leyte, and Mindoro
10 Oct 1617	1000	Shipwreck	Marinduque
5 Aug 1639	750	Shipwreck	Luzon
23 Oct 1767	500	Inundation and destruction	Luzon
3 Jul 1694	400	Shipwreck	Luban
5 Oct 1649	200	Shipwreck	Luzon and Samar
22 Oct 1831	150	Inundation and destruction	Luzon
25 Nov 1876	150	Destruction	Mindanao, Visayas, Bohol, Cebu, Panay, Negros, and Calamianes

that there has been no significant change in the frequency of tropical storms and hurricanes over the period of record. Chenoweth and Divine (2012) built upon this work and report a ~50–70-yr variability in the energy of cyclones affecting the Lesser Antilles between 18° and 25°N, which they attribute to variations in North Atlantic sea surface temperatures (SSTs). García Herrera et al. (2004) document a collection of historical materials describing various parts of the Caribbean. Using these sources, García Herrera et al. (2005) identified 134 hurricanes and 403 severe storms and suggested that the seventeenth century may have seen less hurricane activity than the sixteenth and eighteenth centuries. Reconstructions of cyclone chronologies (Mock 2004), storm seasons (Fig. 9; Dodds et al. 2009; Glenn and Mayes 2009), and even individual events (Chenoweth and Landsea 2004; Glenn and Mayes 2009; Mock and Dodds 2009; Mock et al. 2010) have also been undertaken for extratropical regions, but space precludes their detailed discussion.

RECONSTRUCTION OF EL NIÑO/LA NIÑA EVENTS. Extension of the instrumental El Niño–Southern Oscillation record is a key research goal, especially given the importance of ENSO for global precipitation variability (Diaz et al. 2001). Three new documentary ENSO reconstructions have been published in recent years. The first (Ortlieb 2000) is an update of Quinn and Neal's (1992) seminal El Niño series for 1525–1987, which used mostly historical documents from northern Peru. Ortlieb reanalyzed the data used by Quinn and Neal, finding issues in the dating and transcription of sources and the

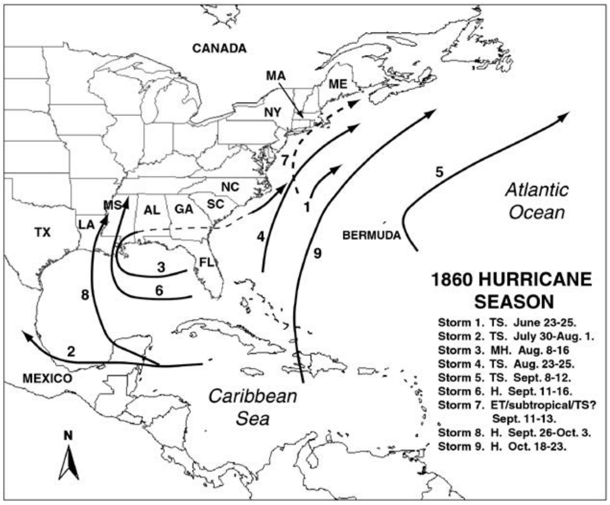

Fig. 9. Tracks of Atlantic tropical cyclones in 1860 (Dodds et al. 2009); MH = major hurricane, H = hurricane, TS = tropical storm, and ET = extratropical cyclone. Dashed lines indicate times when the tropical cyclone dropped below tropical storm strength or had extratropical characteristics.

interpretation of El Niño–ascribed events. He also concluded that Quinn and Neal had incorporated two potentially dubious proxies in their reconstruction: flooding of the Rímac River (not associated with El Niño in instrumental records; Minaya 1994) and rainfall in southeastern Peru (indicative of La Niña episodes). This reanalysis resulted in the elimination of 25 El Niño events from Quinn and Neal's chronology, the classification of 17 more cases as doubtful, and the addition of a further seven events (Ortlieb 2000).

García Herrera et al. (2008) have argued that both the Quinn and Neal (1992) and Ortlieb (2000) chronologies have inherent issues with dating and reliability due to their reliance on secondary sources. These authors devised a new El Niño series using primary documents from Trujillo, a coastal town in northern Peru whose precipitation is one of most sensitive in South America to instrumental ENSO indicators. Two proxies—failures of fisheries and coastal rain—were selected as "principal evidence," with others (including flooding, damage to infrastructure, changes in agriculture, and disease incidence) classed as "suggestive of El Niño." The study found significantly fewer El Niño events from 1550–1900 than Quinn and Neal (1992), but also recorded 10 more events than Ortlieb (2000).

A reconstruction of El Niño and La Niña events from 1525 has been published by Gergis and Fowler (2009). This utilizes documentary and natural proxy series, from both the central Pacific and global ENSO teleconnection regions (Fig. 10). Proxies were selected for inclusion in the reconstruction by generating a "proxy performance score," based on the ability of each to capture ENSO-type events suggested by twentieth-century Pacific SST anomalies and Southern Oscillation index values. Three strong documentary ENSO proxies were identified: the Quinn and Neal (1992) record and an Indian drought chronology (Whetton and Rutherford 1994) for El Niño, and the Nile flood

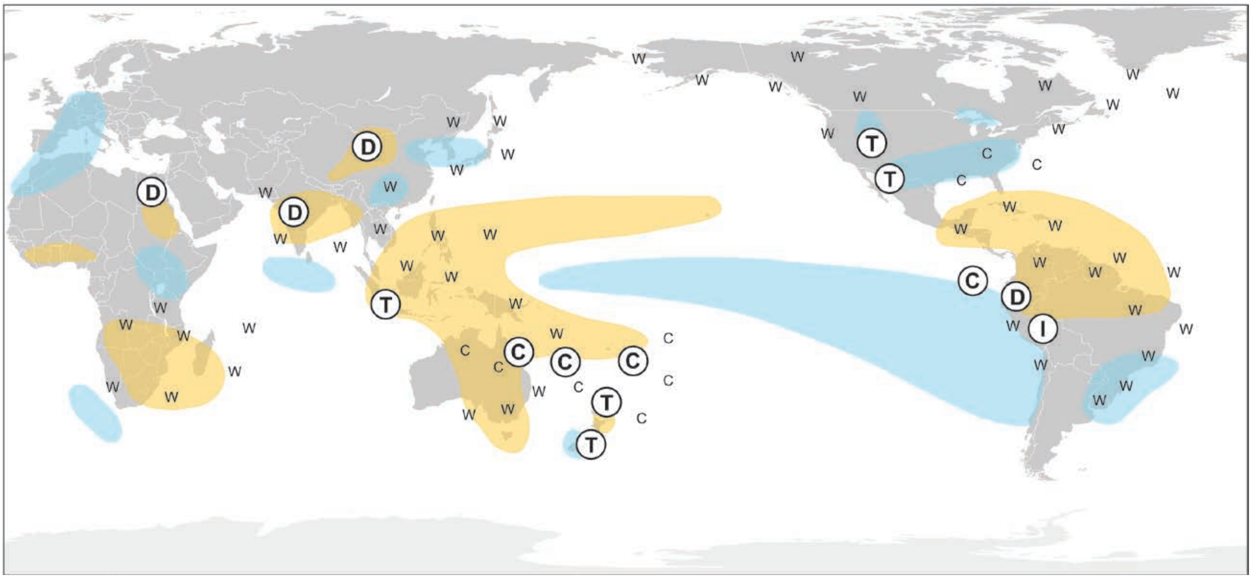

Fig. 10. Location of proxy records used by Gergis and Fowler (2009) to reconstruct historical El Niño and La Niña events superimposed onto a map of ENSO teleconnection characteristics (adapted from Allan et al. 1996). Rainfall anomalies associated with El Niño episodes are represented by orange (dry) and blue shading (wet). Temperature anomalies are indicated by c (cool) and w (warm) annotations; D denotes documentary records of droughts or floods, T tree-ring chronologies, C coral sequences, and I ice-core data.

record (Hassan 1981, 2007, 2011) for La Niña. El Niño and La Niña episodes were assigned a five-category classification (weak to extreme) based on the number of proxies recording an event and their reconstruction skill. This approach identified 16 fewer El Niño events than Ortlieb (2000) [incorporating Quinn and Neal (1992) after 1900], suggesting that some events within the Ortlieb chronology were only local in nature. It also identified 24 (26) protracted El Niño (La Niña) events from 1825 to 2002 (Table 5).

The discrepancies between the Quinn and Neal (1992) and Ortlieb (2000) series highlight the wider issue of researcher interpretation within documentary reconstruction noted above. As the sources used in these studies are secondary, and by their nature less reliable, it could be argued that Quinn and Neal should be superseded by García Herrera et al. (2008) as the "standard" El Niño series. The García Herrera et al. record is based on primary documents from Peru, now regarded as providing the best indication of ENSO conditions (Gergis et al. 2006). It is also a discrete proxy; series of this type exhibit very high correlations with Niño-3.4 SSTs at interannual time scales (Gergis and Fowler 2009), although correlation may be poor at the decadal scale (Neukom and Gergis 2012). Reconstructions based on wider teleconnections (e.g., Gergis and Fowler 2009) also produce a strong replication of ENSO events during the instrumental period, but do not permit the analysis of changes in teleconnection patterns over time. It is unfortunate that García Herrera et al. (2008) was not published until after Gergis and Fowler (2009) entered the review process, as it would have been useful to compare its "performance score" against other proxies.

Table 5. Protracted ENSO events reconstructed by Gergis and Fowler (2009) since 1525 using a combination of documentary and other proxy data (see Fig. 10).

Reconstructed protracted events	Duration (yr)	Reconstructed protracted events	Duration (yr)
El Niño episodes			
1525–27	3	1814–17	4
1585–83	3	1844–48	5
1607–09	3	1856–58	3
1618–21	4	1864–66	3
1650–52	3	1876–78	3
1659–61	3	1900–06	7
1712–14	3	1911–15	5
1718–24	7	1918–20	3
1746–48	3	1924–26	3
1768–71	4	1937–42	6
1782–84	3	1957–59	3
1791–94	4	1964–69	6
La Niña episodes			
1531–33	3	1847–51	5
1540–42	3	1860–64	5
1571–73	3	1866–68	3
1576–81	6	1870–75	6
1600–05	6	1878–80	3
1622–32	11	1890–94	5
1637–39	3	1907–10	4
1730–33	4	1916–18	3
1739–43	5	1921–23	3
1750–58	9	1955–60	6
1778–80	3	1970–75	6
1785–90	6	1984–86	3
1808–11	4	1988–90	3

LEARNING FROM THE PAST: FUTURE DIRECTIONS.

The preceding sections have summarized the major advances in our understanding of the historical climatology of the tropics and subtropics since the start of this century. However, they also highlight several challenges and opportunities for future research. Some of this work, particularly in the area of "data rescue," is being coordinated through global programs such as ACRE (Atmospheric Circulation Reconstructions for the Earth; www.met-acre.org), IEDRO (International Environmental Data Rescue Organization; www.iedro.org), the International Surface Temperature Initiative (www.surfacetemperatures.org), and Old Weather (www.oldweather.org). Other projects, such as the "Collaborative research on the meteorological and botanical history of the Indian Ocean, 1600–1900" network (www.sussex.ac.uk/cweh/), focus more on the identification and digitization of descriptive documentary data. There is, however, a daunting amount of material awaiting rescue. The authors know, for example, of a large collection of daily instrumental records with accompanying commentary held by the Mauritius Meteorological Services (and in urgent need of preservation) that would be invaluable in extending nineteenth-century datasets for the southwest Indian Ocean.

During the course of exploring the scientific and historical literature for this review, we became acutely aware of lacunae in the geographical coverage of climate reconstructions for the tropics and subtropics. The continent-wide rainfall reconstruction for Africa by Nicholson et al. (2012b), for example, identifies major gaps for equatorial and hyperarid areas. A similar situation exists in South America, with documentary reconstruction limited predominantly to western regions (Prieto and García Herrera 2009). Many of these gaps could be filled through targeted research using missionary and other historical sources. With the exception of their use in cyclone reconstruction, resources from the Spanish-speaking Caribbean and Central America remain largely unexploited. The authors are aware of no work being undertaken in Southeast Asia and Indonesia, and historical documents relating to the Pacific Islands, including several large collections of missionary materials, also constitute a substantial untapped resource. A more complete picture of past ENSO variability may be possible using information contained within historical ships' log entries for the central Pacific, but we are not aware of such analyses being undertaken.

Arabic-language manuscripts (Fig. 11) offer considerable potential for climate reconstruction, and have already been used to produce preliminary assessments of variations in rainfall (Vogt et al. 2011) and winter severity (Domínguez-Castro et al. 2012) for parts of the Middle East during the medieval period. The analysis of collections of Arabic-language manuscripts in various cities across the Sahel (including Timbuktu) would permit the reconstruction of long-term rainfall variability along the southern margin of the Sahara, and bridge the gap between lake sediment and instrumental records.

A number of options are open to researchers wishing to explore whether collections of historical documents are available for specific regions. Obvious starting points are the websites of individual national archives and major universities. The web portal Mundus (www.mundus.ac.uk) provides comprehensive details of British missionary collections plus links to missionary archives around the world. The *World Missionary Atlas* (Beach and Fahs 1925) and *Katholischer Missions-Atlas* (Werner 1885) are also invaluable for locating areas of eighteenth- to early twentieth-century Protestant and Catholic missionary activity, respectively.

Fig. 11. Facsimile of a page from a late fifteenth-century (1480–1509) autograph diary from Damascus. The writer, Ibn Tawq, took note of many aspects of his daily life, including weather observations. The page shown is from the very beginning of the diary. The entry dated Shawwāl 9, 885 AH (12 Dec 1480) describes, among other things, the end of autumn and the beginning of the winter season. Image courtesy of Steffen Vogt.

This review has highlighted two methodological advances that offer real potential for pushing forward historical climatology as a research field and could be applied in a wider range of studies. The first is the novel statistical approach used by Nicholson et al. (2012b), which will permit the development of regional- to continental-scale historical rainfall reconstructions, even where documentary evidence is fragmented. The second is the statistical procedure used by Neukom et al. (2009), which can be employed to extend and quantify documentary series, even within regions where few series have a suitable instrumental crossover period.

More work is needed, however, to understand the nature of uncertainties in documentary reconstruction. Moves toward the quantification of data reliability and reconstruction skill—such as the "confidence ratings" used by Kelso and Vogel (2007) and the "proxy skill" scores assigned by Gergis and Fowler (2009)—are to be commended and should be developed further in future analyses. Yet an issue still exists with regard to the interpretation of descriptive documentary data. The analysis by Ge et al. (2008) suggests that the problem may not be as large as previously feared. However, greater efforts are needed to explore the causes and implications of differences in the interpretation of sources between researchers. Targeted research may allow uncertainties to be quantified and lead to the standardization of reconstruction procedures. This would permit documentary chronologies to be better integrated into reconstructions using natural proxies, increasing our understanding of long-term climate variability in the tropics, subtropics, and elsewhere.

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