Quaternary Science Reviews 154 (2016) 1–22

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Invited review

African hydroclimatic variability during the last 2000 years

David J. Nash [a, b, *], Gijs De Cort [c, d], Brian M. Chase [e], Dirk Verschuren [d], Sharon E. Nicholson [f], Timothy M. Shanahan [g], Asfawossen Asrat [h], Anne-Marie Lézine [i], Stefan W. Grab [b]

[a] School of Environment and Technology, University of Brighton, Lewes Road, Brighton BN2 4GJ, United Kingdom
[b] School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Private Bag 3, Wits 2050, South Africa
[c] Department of Earth Sciences, Royal Museum for Central Africa, Leuvensesteenweg 13, 3080 Tervuren, Belgium
[d] Limnology Unit, Department of Biology, Ghent University, K.L. Ledeganckstraat 35, 9000 Ghent, Belgium
[e] Centre National de Recherche Scientifique, UMR 5554, Institut des Sciences de l'Evolution de Montpellier, Université Montpellier, Bat.22, CC061, Place Eugène Bataillon, 34095 Montpellier, cedex5, France
[f] Department of Earth, Ocean and Atmospheric Science, Florida State University, Tallahassee, P.O. Box 3064520, FL FL32306-4520, USA
[g] Department of Geological Sciences, University of Texas at Austin, EPS RM 1.130, 1 University Station C9000, Austin, TX TX78712-0254, USA
[h] School of Earth Sciences, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia
[i] Sorbonne Universités, UPMC, University Paris 06, CNRS-IRD-MNHN, LOCEAN/IPSL Laboratory, 4 Place Jussieu, 75005 Paris, France

ARTICLE INFO

Article history:
Received 14 July 2016
Received in revised form
18 October 2016
Accepted 21 October 2016

Keywords:
Africa
Holocene
Palaeoclimatology
Little Ice Age
Medieval Climate Anomaly

ABSTRACT

The African continent is characterised by a wide range of hydroclimate regimes, ranging from humid equatorial West Africa to the arid deserts in the northern and southern subtropics. The livelihoods of much of its population are also vulnerable to future climate change, mainly through variability in rainfall affecting water resource availability. A growing number of data sources indicate that such hydroclimatic variability is an intrinsic component of Africa's natural environment. This paper, co-authored by members of the PAGES Africa 2k Working Group, presents an extensive assessment and discussion of proxy, historical and instrumental evidence for hydroclimatic variability across the African continent, spanning the last two millennia. While the African palaeoenvironmental record is characterised by spatially disjunctive datasets, with often less-than-optimal temporal resolution and chronological control, the available evidence allows the assessment of prominent spatial patterns of palaeomoisture variability through time. In this study, we focus sequentially on data for six major time windows: the first millennium CE, the Medieval Climate Anomaly (900–1250 CE), the Little Ice Age (1250–1750 CE), the end of the LIA (1750–1850 CE), the Early Modern Period (1850–1950), and the period of recent warming (1950 onwards). This results in a continent-wide synthesis of regional moisture-balance trends through history, allowing consideration of possible driving mechanisms, and suggestions for future research.

1. Introduction

From humid equatorial West Africa to the arid deserts in the northern and southern subtropics, the African continent is characterised by a wide range of hydroclimate regimes (Fig. 1). Determining the full range of natural climate variability on temporal and spatial scales relevant to ecosystem functioning and human well-being is of utmost importance to anticipate the impact of, and improve the preparedness of communities to, future climate change. Efforts to synthesise continent-specific patterns of climate change over the past two millennia have made good progress (mainly focused on temperature, e.g. Nicholson et al., 2013; PAGES 2k Consortium, 2013, 2015). However, regional to continent-scale patterns of past hydroclimate variability remain less well documented, especially for the tropics and the Southern Hemisphere.

Africa is cited by the Intergovernmental Panel on Climate Change as a continent where proxy-based climate reconstructions are currently too limited to support regional climate change assessments (Masson-Delmotte et al., 2013). Indeed, time series of temperature- or moisture-related climate variables spanning (a significant portion of) the last two millennia with adequate temporal resolution and age control remain sparse (see Neukom and

* Corresponding author. School of Environment and Technology, University of Brighton, Lewes Road, Brighton BN2 4GJ, United Kingdom.
E-mail address: d.j.nash@brighton.ac.uk (D.J. Nash).

http://dx.doi.org/10.1016/j.quascirev.2016.10.012
0277-3791/

Gergis, 2012; Nicholson et al., 2013; PAGES 2k Consortium, 2013), and display a highly uneven spatial distribution (Verschuren, 2004). This is partly because the classic high-resolution archives of tree rings and ice cores are mostly lacking. Tree species suitable for dendroclimatological reconstruction are few, because many local climates fail to drive the strong seasonal variation in wood growth required to produce reliable annual rings, and because trees which do grow annual rings most often do not preserve long after death (Dunbar and Cole, 1999). The potential of continuous and reliably dated ice core records is also limited, given that the only centres of glaciation (Mt Kilimanjaro, Mt Kenya, the Rwenzori range) are small and rapidly shrinking (e.g. Thompson et al., 2002).

Across much of Africa, lake-sediment records are the most important source of evidence on past climate change. However, only a small sub-set of those studied combine adequate hydrological sensitivity with demonstrably continuous sediment accumulation over the past 2000 years (Verschuren, 2003). Frequently, the timing and duration of successive wet and dry episodes is uncertain because desiccation horizons, cryptic hiatuses and large changes in sedimentation rate modify the depth-time relationship beyond what can be constrained by ^{14}C dating (Verschuren and Russell, 2009). In a large swathe of western tropical Africa, lake-based climate-proxy records with high temporal resolution are scarce because the shallow ponds and marshes dotting the region dried out during sub-recent drought episodes, while depositional environments along rivers are too dynamic to have preserved high-quality sediment records. Hence, there are currently still only a handful of well-dated records spanning the last 2000 years with robust climate signals at inter-annual to decade-scale resolution.

In southern Africa, where there is limited potential for high-quality lake-sediment records, a diverse range of other climate archives, including speleothems (e.g. Holmgren et al., 2003) and more recently hyrax middens (e.g. Chase et al., 2012), have been explored. Pollen records of past vegetation change extracted from lake and swamp sediments are often poorly dated with low temporal resolution, and the complex nature of the region's flora can create fossil pollen assemblages that are difficult to interpret in terms of past shifts in climate regimes (e.g. Nash et al., 2006; Meadows et al., 2010; Chase et al., 2015). Previous reviews of climate change in southern Africa during the last few millennia (e.g. Tyson and Lindesay, 1992; Tyson et al., 2000) have drawn heavily on stable carbon and oxygen ratios ($\delta^{13}C$, $\delta^{18}O$) from speleothems. However, these data also prove difficult to interpret, as the records reflect multi-factorial influences that hinder clear palaeoclimatic reconstructions (see below).

The above-mentioned continental climate archives are supplemented by a small number of marine sediment cores and shell middens (e.g. Holz et al., 2007). Altogether, the spatial coverage of African palaeoclimate records remains at least an order of magnitude less than that in Europe or North America (Fig. 1). With instrumental weather data beginning only in the late 19th or early 20th century for much of the continent (Nicholson et al., 2012a, 2012b), climate-related information gleaned from documentary sources covering the last 2–3 centuries constitutes a crucial bridge between instrumental and palaeodata concerning hydroclimate variability at (multi-)decadal timescales.

This paper represents the concerted effort by members of the PAGES (Past Global Changes) Africa 2k Working Group to (a) compile, and assess the quality of, currently available high-resolution datasets on hydroclimatic variability from across the African continent spanning the last 2000 years, and (b) combine them into a pan-African synthesis. Where possible, we direct our attention to reconstructions displaying the highest degree of continuity and most robust signatures of past hydroclimate change in well-understood climate indicators (proxies). While the currently available data have shortcomings in terms of quality and geographical coverage (we note, for example, an absence of high resolution records for Madagascar spanning the last two millennium), they exhibit sufficient spatial coherence to justify exploration of the synchrony of temporal patterns between Africa's major climate regions.

In the synthesis below (section 4), we focus sequentially on evidence pertaining to each of six major time windows recognised within the last 2000 years: the first millennium CE, the Medieval Climate Anomaly (MCA; 900–1250 CE), the Little Ice Age (LIA; 1250–1750 CE), the end of the LIA (1750–1850 CE), the Early Modern Period (1850–1950 CE), and the period of recent warming (from 1950 CE onwards). In the time periods since the end of the LIA, an increasing proportion of evidence on past hydroclimate variability is derived from historical documents and instrumental time series.

2. Regional climate dynamics of the African continent

Africa spans some 70° of latitude, so that both mid-latitude and tropical meteorological regimes prevail in various parts of the continent. At the warm-temperate northern and southern extremes, rainfall is mainly linked to the frontal systems of the mid-latitude westerlies, which reach Africa in the winter of the respective hemisphere (Fig. 1). In tropical areas, a broad region of rainfall shifts latitudinally throughout the year, trailing the zone of maximum solar insolation. This rain belt reaches its poleward extremes during the summer of the respective hemisphere, passing twice through the equatorial latitudes (Fig. 1, bottom). Consequently, the seasonal cycle of rainfall tends to be unimodal (with a single peak in the summer) in the outer-tropical latitudes, and bimodal (with peaks during the two transition seasons) near the equator. In between the mid-latitude and tropical regimes, deserts or semi-arid regions prevail. In addition to these general climate mechanisms, factors such as topography and maritime influences create complex patterns of regional rainfall, controlled by diverse dynamic causes (Nicholson, 2000). Much rainfall in the subtropical latitudes is associated with systems that develop from the interaction of the tropical and mid-latitude regimes, diagonal cloud bands, and cutoff lows (van Heerden and Taljaard, 1998; Todd and Washington, 1999; Knippertz and Martin, 2005, 2007; Hart et al., 2010). These often bring rainfall to West and North Africa during what is usually the dry season, and are also responsible for much of the austral summer rainfall over southern Africa.

The tropical rain belt was traditionally referred to as the Intertropical Convergence Zone (ITCZ); however, the rainfall maximum is not necessarily linked to this zone of surface convergence (Zhang et al., 2006; Nicholson, 2009). This is particularly true over West Africa, where the rainy season is a consequence primarily of large, westward migrating mesoscale features associated with the African Easterly Jet of the mid-troposphere (Mohr and Thorncroft, 2006). Over equatorial Africa, orography exerts a major influence, with the terrain-induced low-level Turkana Jet playing a significant role in the relative dryness of eastern areas (Obwang et al., 2014; Nicholson, 2015). Over the Congo Basin, mesoscale disturbances related to the terrain-induced diurnal cycle of wind are the dominant rain-producing system (Nesbitt et al., 2000; Zipser et al., 2006), and are likewise influenced by a mid-level easterly jet stream (Jackson et al., 2009). As such, we recommend that the interchangeable use of the ITCZ for the tropical rain belt in Africa be discontinued.

Over West Africa, rainfall is part of a monsoon system created largely by the thermal contrast between the Sahara and the cooler Atlantic to the south (Thorncroft et al., 2011). This system connects the Sahel, with its unimodal seasonality, and the Guinea Coast,