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Hydroclimate in Africa during the Medieval Climate Anomaly

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ABSTRACT

The Medieval Climate Anomaly (MCA) is a recognized period of distinct pre-industrial climate change, with a core period of 1000–1200 CE. The field of palaeoclimatology has made major progress over the past 15 years during which a great number of high- and medium-resolution case studies were published, reconstructing climate change of the past millennia. In many parts of the world, regional data coverage has now reached a point which allows compiling palaeoclimate maps for well-defined time intervals. Here we present hydroclimatic trend maps for the MCA in Africa based on 99 published study locations. Key hydroclimatic proxy curves are visualized and compared in a series of 16 correlation panels. Proxy types are described and possible issues discussed. Based on the combined MCA dataset, temporal and spatial trends are interpreted and mapped out. Three areas have been identified in Africa in which rainfall seems to have increased during the MCA, namely Tunisia, western Sahel and the majority of southern Africa. At the same time, a reduction in precipitation occurred in the rest of Africa, comprising of NW and NE Africa, West Africa, Eastern Africa and the Winter Rainfall Zone of South Africa. MCA hydroclimate change in Africa appears to have been associated with characteristic phases of ocean cycles, as also supported by modern climate observations. Aridity in Morocco typically coincides with the positive phase of the North Atlantic Oscillation (NAO), whilst increased rainfall in the western Sahel is often coupled to the positive phase of the Atlantic Multidecadal Oscillation (AMO). Reduction in rainfall in the region Gulf of Aden/southern Red Sea to Eastern Africa could be linked to a negative Indian Ocean Dipole (IOD) or a derived long-term equivalent Indian Ocean cycle parameter. The Intertropical Convergence Zone (ITCZ) appears to have been shifted pole-wards during the MCA, for both the January and July positions. MCA hydroclimate mapping revealed major data gaps in the Sahara, South Sudan, Somalia, Central African Republic, Democratic Republic of Congo, Angola, northern Mozambique, Zambia and Zimbabwe. Special efforts are needed to fill these gaps, e.g. through a dedicated structured research program in which new multiproxy datasets are created, based on the learnings from previous African MCA studies.

1. Introduction

Large parts of Africa depend on seasonal rainfall which supplies drinking water and forms the basis for agriculture and food production. Observational precipitation data collected over the past 100 years indicates that African rainfall shows significant variability on year-to-year to decadal time-scales. For example, after rather dry years in the 1980s and 1990s, the Maghreb has now returned to wetter conditions (Nouaceur and Murarescu, 2016). West Africa and the Sahel experienced severe drought during the 1970s and 1980s with a regime shift towards increased rainfall around 1992 (Badou et al., 2017; Park et al., 2016). Precipitation in South Africa is particularly influenced by multi-year variations without any detectable major regionally aggregated trends in total rainfall (MacKellar et al., 2014). Droughts have been steadily increasing in the Greater Horn of Africa over the past three decades (Rowell et al., 2015), whilst the general development in equatorial eastern Africa is complex, yielding differences in trends for the short and long rainfall seasons (Gitau et al., 2017). In many cases, climate models are unfortunately not yet able to robustly capture the observed trends (e.g. MacKellar et al., 2014; Masih et al., 2014;

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Nouaceur and Muraréscu, 2016; Rowell et al., 2015). Only recently has it become clear that a significant part of the African rainfall variability is associated with multi-decadal large-scale climate modes of the global oceans (e.g. Masih et al., 2014; Nash et al., 2016; Taye and Willems, 2012; Tierney et al., 2013; Verdon-Kidd and Kiem, 2014). Full integration of such ocean cycles into the models is likely to improve the model skill with regards to multi-decadal regional precipitation trends in Africa.

A second key challenge for hydroclimate simulations is the correct reproduction of centennial-scale trends in African rainfall. African palaeoclimate reconstructions have identified major hydroclimatic trends over the past 2000 years which form important calibration data sets for model hindcast tests (e.g. Chase et al., 2013; Maley and Vernet, 2015; Nash et al., 2016; Stager et al., 2012b; Tierney et al., 2015). Modern African climate variability is a mixture of anthropogenic and natural drivers. A robust understanding of pre-industrial hydroclimate change and possible forcings is needed to be able to distinguish between natural and anthropogenic contributions in modern African rainfall.

Here we are presenting an analysis of centennial-scale hydroclimatic change in Africa for the Medieval Climate Anomaly (MCA), a recognized phase of natural pre-industrial climate change associated with marked temperature and hydroclimatic variability in many parts of the world. The anomaly was first described by Lamb (1965) as 'Early Medieval Warm Epoch', which subsequently changed in the literature to 'Medieval Warm Period' (MWP). It is generally agreed today that the core period of the MCA comprises ca. 1000–1200 CE, even though different time schemes and durations have historically been used in the literature (e.g. Crowley and Lowery, 2000; Esper and Frank, 2009; Mann et al., 2009). The few existing land temperature reconstructions from Africa with adequate resolution in the last 2000 years suggest a generally warm MCA, but do not allow comprehensive assessment of the continent's temperature variability during this period (Lüning et al., 2017; Nash et al., 2016; PAGES 2k Consortium, 2013).

In contrast, hydroclimate reconstructions covering the MCA in Africa are more widely available which enabled the PAGES2k Africa group to compile an invaluable hydroclimate synthesis for the past 2000 years based on selected high-resolution datasets (Nash et al., 2016). The group identified several major hydroclimatic trends across the MCA which they reported as general observations in the text, but not in map form. A trend towards increased rainfall is reported for the Sahel, Namibia and the majority of South Africa, whilst drier-than-usual conditions are described for the MCA in the area immediately south of the Sahel, Eastern Africa and the Winter Rainfall Zone of South Africa. No trend information was available for North Africa, Angola, Congo Kinshasa and Madagascar. The group proposed ocean cycles such as Atlantic multi-decadal variability, Indian Ocean Dipole and El Niño–-Southern Oscillation (ENSO) as main drivers of the pre-industrial hydroclimatic change in Africa.

Here we are building on the results of Nash et al. (2016) as well as other predecessor papers (e.g. Holmgren and Öberg, 2006; Verschuren, 2004) and aim to take the analysis one step further by mapping the MCA hydroclimate trends in detail across the continent. We are enlarging the dataset by adding case studies that were only recently published and post-date the cut-off date of Nash et al. (2016), or which were excluded by the PAGES2k group due to lower resolution nature, yet may offer useful qualitative insight into the African MCA hydroclimate. Based on the enlarged portfolio of case studies, we add the MCA hydroclimate of North Africa, the eastern Sahel and Madagascar into the African-wide picture and attempt to delineate likely borders of the regions sharing similar trends in MCA hydroclimate. Hydroclimatic change in Africa during the MCA followed characteristic regional patterns whereby knowledge of the distributional trends will ultimately help to better understand the respective driving mechanisms behind the change.

The objective of this paper is to provide a *qualitative* description of regional variability, leaving a fully *quantitative* analysis for later, once crucial data gaps have been filled. Hydroclimate is intensely linked to climate change. Rain belts are prone to shift and monsoons can intensify or weaken. The analysis of MCA temperature trends in Africa is not part of this study and was documented in a separate contribution (Lüning et al., 2017).

2. Modern hydroclimate elements of Africa

According to the Köppen-Geiger climate classification (e.g. Köppen, 1918), Africa can be grouped into several sub-tropical to tropical climate zones. These include for example the Mediterranean climate of the northern Maghreb, the warm desert climate of the Sahara and Namib deserts, the warm semi-arid climate of the Sahel, the tropical savannah climate of the equator region, the humid subtropical climate of Angola and Zambia, the warm semi-arid climate of Namibia and Zimbabwe, as well as the cold semi-arid and desert climates of South Africa.

African monsoon rains are generally controlled by the seasonal shift of the Intertropical Convergence Zone (ITCZ) where the northeast and southeast trade winds converge, triggering the rise of moisture-laden air which then results in heavy precipitation. The general mechanism brings rain to the Sahel Zone in northern hemisphere summer and to southern Africa in southern hemisphere summer. Nevertheless, the processes are more complex when looked at in detail. In part of the area the rainy season appears to be controlled by migrating mesoscale features associated with jet streams such as the African Easterly Jet and the Turkana Jet (Nash et al., 2016; Nicholson, 2016). In some areas bimodal rainfall occurs, i.e. two rainy seasons. Following the Hadley cell circulation, dry air descends over the arid subtropics, namely the Sahara Desert in the north and the Namib Desert in the south. Case studies suggest that climatic temperature changes influence both the location and width of the ITCZ (Byrne and Schneider, 2016; Sachs et al., 2009; Schneider et al., 2014). Most of South Africa receives summer rain, whilst only the Western Cape area lies in the winter rainfall zone.

Other important hydroclimatic elements are the African Easterly Jet in the western Sahel Zone, the West Africa rainfall dipole, the Congo Air Boundary (CAB), South Atlantic Anticyclone (SAA), South Indian Ocean Anticyclone (SIA) and the South African Winter and Summer Rainfall Zones (WRZ, SRZ). The location and significance for the MCA hydroclimate will be elaborated in detail in the Discussion part of this paper. More detailed descriptions of African modern hydroclimate elements can be found in Nicholson (2000) and Nash et al. (2016).

3. Material and methods

3.1. Literature review

The mapping project is based on an intense iterative literature screening process during which a large number of published African palaeohydroclimate case studies were evaluated towards their temporal coverage, types of climate information and data resolution. Suitable papers including the MCA core period 1000–1200 CE were earmarked for a thorough analysis. A total of 99 African localities with one or more MCA palaeoclimate proxy curves were identified (Fig. 1, Table 1).

3.2. Palaeoclimate archives and data types

MCA climate reconstructions of the high-graded publications comprised of a wide spectrum of natural archives, namely (1) sediment cores from offshore marine, lakes, swamps, peatlands, lagoons and sebkhas, (2) ice cores from ice caps (e.g. Kilimanjaro), (3) cave speleothems, (4) tree rings, (5) fossilized rock hyrax middens, (6) historical river gauge records (e.g. Nilometer), (7) archaeology and (8) age dating of fluvial deposits and geomorphological features. Data types include (a) palaeontology (pollen, diatoms, ostracods, planktonic and benthic foraminifera), (b) inorganic and organic geochemistry (carbon, oxygen, nitrogen and deuterium isotopes; elemental sediment composition; salt