Quaternary Science Reviews 164 (2017) 68–76

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Timing of the southward retreat of the ITCZ at the end of the Holocene Humid Period in Southern Arabia: Data-model comparison

Anne-Marie Lézine [a,*], Sarah J. Ivory [b], Pascale Braconnot [c], Olivier Marti [c]

[a] Sorbonne Universités, UPMC, Univ Paris 06, CNRS-IRD-MNHN, LOCEAN/IPSL Laboratory, 4 place Jussieu, 75005, Paris, France
[b] Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI, 02912, USA
[c] Laboratoire des Sciences du Climat et de l'Environnement/IPSL, CEA-CNRS-UVSQ – UMR8212, CE Saclay, l'Orme des Merisiers, 91191, Gif-sur-Yvette Cedex, France

ARTICLE INFO

Article history:
Received 6 September 2016
Received in revised form
28 December 2016
Accepted 20 March 2017

Keywords:
Pollen
Climate simulations
IPSL model
Oman
ITCZ
End of the Holocene Humid Period

ABSTRACT

New pollen data from Omani mangroves (Kwar-al-Jaramah [22.49° N - 59.76° E] and Filim [20.61° N - 58.17° E]), in addition to previously published paleohydrological records from Southern Arabia improve our understanding of the timing and amplitude of the southward retreat of the Indian monsoon influence in Southern Arabia along a north-south transect. Comparison with simulations performed with the IPSL climate model, considering both snapshot experiments and transient simulations from 6000 cal yr BP to the present, confirm the latitudinally time-transgressive nature of the humid-arid transition at the end of the Holocene Humid Period. This occurred in two steps, respectively dated at around 5000 and 2700 cal yr BP. At around 5000 cal yr BP, the southward ITCZ shift was orbitally-driven and led to the abrupt aridification at Kwar-al-Jaramah and the progressive increase of dryness at Filim as the mean position of the ITCZ was centered ca 22.30°N. At 2700 cal yr BP, aridity was fully in place over all of southern Arabia due to increased climate variability. More intense rainy events during the last millennium, however, may have contributed to the discrete hydrological improvement without any impact on the regional vegetation which has remained desert to the present day.

1. Introduction

The timing and amplitude of the end of the Holocene Humid Period and the transition toward the present day arid/semi-arid conditions in the northern tropics has been the subject of multiple debates involving numerous scientists from both the model (e.g., Claussen and Gayler, 1997; Claussen et al., 2003; Liu et al., 2007) and data communities (e.g., deMenocal et al., 2000; Kröpelin et al., 2008a, b, Bayon et al., 2012). Several scenarios have been developed to discuss the abrupt or gradual character of this period and to identify the forcings at work (e.g., Brovkin et al., 2002; Rensen et al., 2006). These debates have mostly focused on regions under the Atlantic monsoon influence, with a specific emphasis on the iconic "Green Sahara". This region is well known to have hosted flourishing prehistoric cultures evidenced by widespread archaeological remains (e.g., Kuper and Kröpelin, 2006; Manning and Timpson, 2014), rock paintings and carvings (Le Quellec, 2013), and abundant tropical faunas (e.g., Jousse and Escarguel, 2006) during the Holocene. Based on paleohydrological (Lézine et al., 2011) and archaeological (Kuper and Kröpelin, 2006) evidence, it has been shown that the end of the "Green Sahara" period in northern tropical Africa and the start of present day arid conditions has been latitudinally time-transgressive, with the lake phase ending from 6500 cal yr BP between 26° and 28°N to 3500 cal yr BP between 16° and 20° N. In this region, however, the response time of the systems (hydrology, vegetation), involving aquifer recharge or surficial runoff from distant origin and/or from the Saharan highlands make the evaluation of the precise timing of the climate signal alone difficult (Gasse, 2000; Lézine et al., 2011; Hély and Lézine, 2014).

The end of the Holocene Humid Period is also recorded in regions under the Asian summer monsoon influence by a dramatic weakening of rainfall ca 5000-4000 cal yr BP (e.g., Morrill et al., 2003), particularly in its western part (e.g., Ivory and Lézine, 2009; Lézine et al., 2014). Here also dramatic impact of changing climate on past Harappan culture in the Indus Valley has been evoked (Farooki et al., 2013). In this paper, we focus our attention on southern Arabia, a region particularly suitable for investigating

* Corresponding author.
E-mail address: anne-marie.lezine@locean-ipsl.upmc.fr (A.-M. Lézine).

http://dx.doi.org/10.1016/j.quascirev.2017.03.019
0277-3791/

the late Holocene period owing to the quality of the available high-resolution records. Paleolakes are particularly scarce and poorly preserved due to the exceptionally arid conditions which prevail in the Rub-al-Khali desert today (e.g., Lézine et al., 2007, 2014). However, speleothems records in South-Eastern Arabia have led to observation of changing rainfall amounts at the study sites as well as changes in the origin of the rains (Neff et al., 2001; Fleitmann et al., 2003, 2007). In addition, specific geomorphological and ecological features in coastal areas favor the preservation of mangroves whose floristic composition is closely dependent on rainfall amount and distribution (Spalding et al., 1997). These sedimentary environments also have the advantage of rapid depositional rates and good preservation of the organic matter, and thus are powerful tools to trace fluctuations of the rain belt associated with past monsoon circulation and changes in the location of the Intertropical Convergence Zone (ITCZ) through time (Lézine et al., 2002; Berger et al., 2013).

We consider here new pollen data from Omani mangroves and compare the chronology of events with those deduced from the isotopic composition of speleothems and the extension of lakes and wetlands. Our aim is to discuss the timing and amplitude of the southward retreat of the Indian monsoon influence in Southern Arabia along a north-south transect from 23° to 17°N. The results of these new data are compared with results of simulations with the IPSL climate model (Dufresne et al., 2013), considering both snapshot experiments for key Holocene periods and a suite of transient simulations. This allows us to discuss the changes induced by long term alterations to Earth's orbit and provide an indication of the possible role of insolation in triggering some of the rapid changes observed in the pollen records. The remainder of the manuscript is organized as follows: section 2 presents the new records and the climate simulations, whereas section 3 discusses the timing of the environmental changes over the region of interest and their relationship to the southward shift of the ITCZ from the mid-Holocene to today. A conclusion is provided in section 4.

2. Mid to late Holocene pollen records and climate simulations

2.1. Regional climate features

Oman is situated at the present northern limit of the annual migration of the ITCZ and the associated rainfall belt. In summer, southwesterly surface winds carry moisture from the southern Indian Ocean along the Arabian coast but do not penetrate far north- and eastwards into Southern Arabia (Fig. 1). The mean annual rainfall rapidly decreases from the southernmost part of the peninsula (the mountains of Yemen) to the Dhofar region in South Oman to the east, where the coastal station of Salalah records about 83 mm of annual rainfall. SW monsoon fluxes barely penetrate the Gulf of Oman, and rains only rarely occur in the lowlands where dry conditions occur year round. In winter, the southward penetration of Mediterranean cyclonic depressions follows the topographic corridor of the Arabo-Persian Gulf bounded by the Zagros Mountains, Iran, to the north-east and the Jebel-al-Akhdar range, Oman, to the southwest. Winter rainfall averages 90 mm along the coast and reaches up to 350 mm in the Jebel-al-Akhdar, where snow may also occur. Mean annual temperature varies from about 26 °C at Salalah to 35 °C at Muscat along the Gulf of Oman, with temperature falling with altitude from about 0.6 °C per 100 m elevation in the Jebel-al-Akhdar (Ghazanfar and Fisher, 1998).

2.2. Sediment cores

Two cores were collected at Kwar-al-Jaramah (KAJ) in the Gulf of Oman (22.49°N - 59.76°E) and at Filim at the Indian Ocean shore (20.61°N - 58.17°E) (Figs. 1 and 2). Both were recovered behind the forest remnants of *Avicennia marina*-dominated mangrove populations. Kwar-al-Jaramah (Lézine, 2009) is a sheltered creek fed by local wadis originating from the foothills of the Jebel al Akhdar (El-Baz, 2002). Filim is a bay located west of the Barr al Hikmân peninsula facing the Masirah island. It is fed by the wadi Halfayn/wadi Andam system originating from the Jebel al Akhdar, located several hundreds of kilometers to the north. The regional environment is of desert type at both sites, and the mangrove is only represented by a single species, *Avicennia marina,* which is particularly adapted to highly saline environments (Spalding et al., 1997).

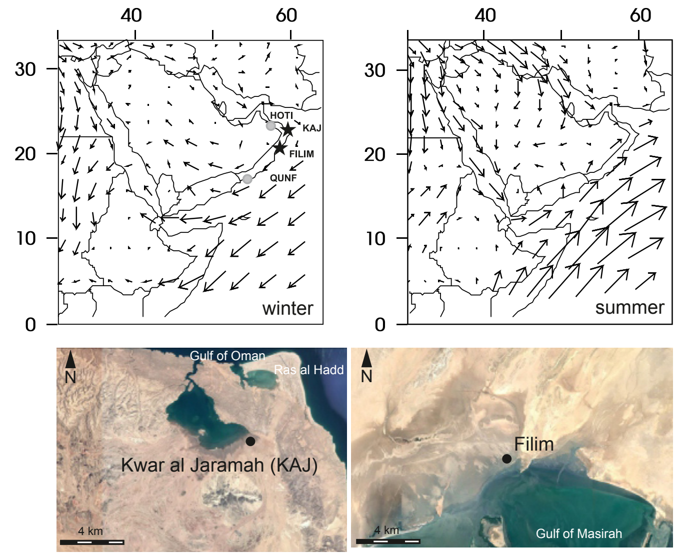

Fig. 1. Modern surface winds at 925 hP for summer and winter months (NCEP-DOE AMIP-II Reanalysis) and location of the sites in the text: Kwar-al-Jaramah (KAJ) and Filim: pollen, this study; Qunf and Hoti: speleothems, Neff et al., 2001; Fleitmann et al., 2003, 2007. Aerial views from El-Baz (2002).

The sedimentary columns are 440 cm long at both sites and consist of homogenous sandy mud with rare shell fragments. Chronologies are based on seven AMS ^{14}C ages on carbonates at Kwar-al-Jaramah and eight at Filim. Raw radiocarbon dates were reservoir-corrected (Saliège et al., 2005) and converted to calibrated ages using CALIB Radiocarbon Calibration software (Reimer et al., 2009). Then, a time scale was obtained by linear interpolation between two ages taking into account the highly variable sedimentation rate in such a littoral environments undergoing sea level fluctuations (Lambeck, 1996) (Table 1a and b).

2.3. Pollen analysis

Ninety seven samples (each 1.5–3 cm^3) were taken for pollen analyses. Samples were processed according to standard procedures (chemical treatment with HCL and HF; sieving at 5 μm) (Faegri and Iversen, 1975). They yielded an abundant microflora of 163 pollen taxa for pollen counts ranging between 299 and 463 at KAJ and 82 to 405 at Filim. Pollen grains were determined using pollen flora of Qatar (El-Ghazali, 1991), Chad (Maley, 1970), and East Africa (Bonnefille and Riollet, 1980). Littoral mangrove pollen percentages (*Rhizophora* and *Avicennia*) were calculated against the sum of all the pollen grains and fern spores counted. As usual in tropical marine and littoral palynology, these taxa were excluded from the pollen sum for the calculation of the percentages of the other pollen taxa originating from inland vegetation types in order to better represent the regional flora (Fig. 3).