



High- and low-latitude forcing of the Nile River regime during the Holocene inferred from laminated sediments of the Nile deep-sea fan

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ABSTRACT

Sediments deposited on deep-sea fans are an excellent geological archive to reconstruct past changes in fluvial discharge. Here we present a reconstruction of changes in the regime of the Nile River during the Holocene obtained using bulk elemental composition, grain-size analyses and radiogenic strontium (Sr) and neodymium (Nd) isotopes from a sediment core collected on the Nile deep-sea fan. This 6-m long core was retrieved at ~700 m water-depth and is characterized by the presence of a 5-m thick section of finely laminated sediments, which were deposited between 9.5 and 7.3 ka BP and correspond to the African Humid Period (AHP). The data show distinct changes in eolian dust inputs as well as variations in discharge of the Blue Nile and White Nile. Sedimentation was mainly controlled by changes in fluvial discharge during the Holocene, which was predominantly forced by low-latitude summer insolation and by the location of the eastern African Rain Belt. The changes in relative contribution from the Blue Nile and White Nile followed changes in low-latitude spring/autumn insolation, which highlights the role of changes in seasonality of the precipitation on the Nile River regime. The relative intensity of the Blue Nile discharge was enhanced during the early and late Holocene at times of higher spring insolation (with massive erosion and runoff during the AHP at times of high summer insolation), while it was reduced between 8 and 4 ka at times of high autumn insolation. The gradual insolation-paced changes in fluvial regime were interrupted by a short-term arid event at 8.5–7.3 ka BP (also associated with rejuvenation of bottom-water ventilation above the Nile fan), which was likely related to northern hemisphere cooling events. Another arid event at 4.5–3.7 ka BP occurred as the apex of a gradually drier phase in NE Africa and marks the end of the AHP.

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1. Introduction

Due to the fact that atmospheric temperatures remained near constant during the Holocene (last 10 kyr), this interval is generally considered as climatically stable as compared to the rest of the Quaternary (Groote et al., 1993). However, environmental and hydrological reconstructions have revealed that subtropical regions have drastically changed during the course of the Holocene (Haug et al., 2001; Ruddiman, 2003). In particular, the progressive drying of North Africa led to the retreat of the vegetation cover and of human

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populations from the so-called 'Green Sahara' (Gasse, 2000; Kuper and Kröpelin, 2006). Paleoenvironmental and archeological studies documented the occurrence of a very wet phase in North Africa between 10 and 6 ka BP, which led to the development of extensive lake and river systems and of a savannah-type of vegetation within what is nowadays one of the most arid areas on Earth (Drake et al., 2011). This pronounced Holocene wet phase is known as the African Humid Period (AHP) and favored the settlement of Neolithic human populations within the present-day Saharan Desert (Kuper and Kröpelin, 2006). Additionally, the highly increased Nile River runoff had a major impact on the marine environment in the Eastern Mediterranean, as evidenced by the deposition of organic-rich sapropel layers (Rossignol-Strick et al., 1982). Stratification of the water column and high primary productivity in the surface waters induced oxygen depletion of the bottom waters in the Eastern Mediterranean basin, which stimulated the accumulation and preservation of organic matter in the sediments (De Lange et al., 2008).

The termination of the AHP was marked by a southward shift of the African monsoon and associated rainfall belts causing a retreat of the extensive Saharan grassland and the desiccation of vast system of lakes and rivers within the Sahara (Pachur and Kröpelin, 1987; Lézine et al., 2011). The primary forcing for this wet/arid transition is thought to be the precession-forced low latitude insolation, which gradually decreased between 8 and 4 ka BP (Rossignol-Strick, 1983). However, the rate of the paleoenvironmental changes appears to be highly variable depending on the archives and on the studied area (Lézine et al., 2011). Consequently, the response of continental environments and ecosystems to a gradual orbital forcing is still under debate. Some authors reported a gradual transition, which implies a linear response of the ecosystem to the orbital forcing (Brovkin et al., 2002; Fleitmann et al., 2003; Renssen et al., 2003; Kröpelin et al., 2008), whereas others reported a more abrupt transition, which suggests the existence of complicated feedback processes and threshold responses between the ecosystem and the climate (Gasse and Van Campo, 1994; Claussen et al., 1999; deMenocal et al., 2000a; Liu et al., 2007).

Here we focus on changes in the regime of the Nile River during the Holocene by investigating a laminated sediment sequence corresponding to the youngest sapropel layer (S1) from the Nile deep-sea fan, which provides a very detailed record of the AHP and its termination. The changes in river runoff and main sources of the river waters have been previously investigated using sediment cores (Krom et al., 2002; Revel et al., 2010; Marriner et al., 2012),

geomorphology (Adamson et al., 1980; Williams, 2009) and lake levels (Gasse, 2000; Stager et al., 2003; Garcin et al., 2009, 2012; Marshall et al., 2011). However, these reconstructions only provide a fragmentary and/or low-resolution picture of the changes in river regime that prevents their comparison and does not allow assessing the response of the Nile River system to changes in orbital configuration and in seasonality. We thus aim at providing an integrated reconstruction of changes in Nile River runoff and freshwater source at high temporal resolution during the past 9.5 kyr from a single sediment archive. This will help evaluating the impact and the response of the Nile River system to changes in orbital parameters as well as to more abrupt climatic events previously recognized in North Africa (Gasse, 2000; Thompson et al., 2002; Kim et al., 2007). Finally, we aim at evaluating the impact of changes in the hydrological regime of Nile River on the marine environment (especially on the bottom-water oxygenation).

2. Regional settings

The drainage area of the Nile River extends from $\sim 4^{\circ}\text{S}$ to $\sim 30^{\circ}\text{N}$ and from 20°E to 40°E and the river flows northward over a total length of over 6700 km (Fig. 1). The main stream integrates contributions from four main tributaries, which are from South to North: the White Nile, the Sobat, the Blue Nile and the Atbara (Fig. 1a and b). The White Nile originates from the equatorial

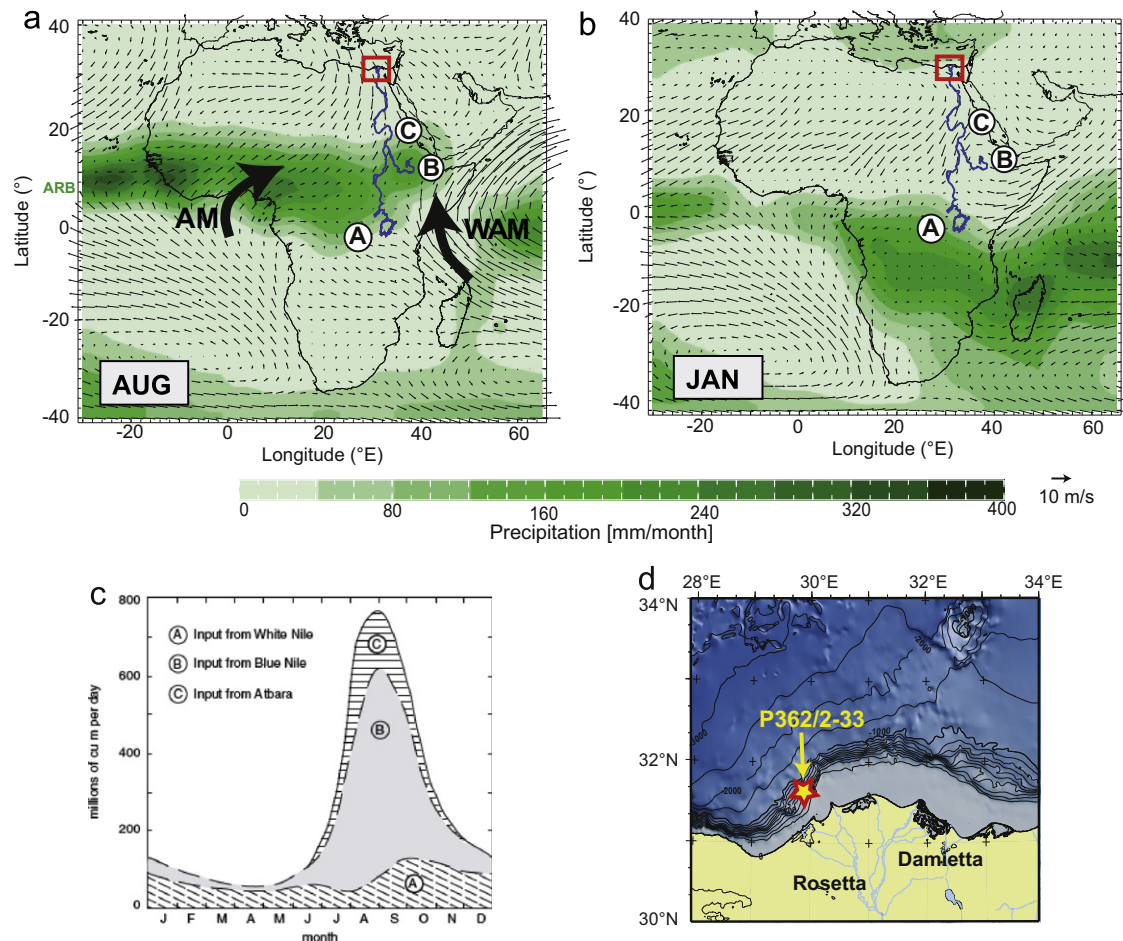


Fig. 1. Climate and regional settings. (a) and (b) Seasonal climatic patterns over Africa, with precipitation rates (green shading) and wind fields in August (a) and January (b). ARB: African Rain Belt, AM: African Monsoon, WAM: Western Asian Monsoon. A, B and C refer to the White Nile, Blue Nile and Atbara sources, respectively. (c) Relative contribution from the White Nile (A), the Blue Nile (B) and the Atbara (C) throughout the year. Redrawn from Williams et al. (2006), with permission from Elsevier. (d) Blow-up from the red squares in (a) and (b) and showing the location of core P362/2-33 on the Nile deep-sea fan (star). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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