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Changing rainfall patterns in NW Africa since the Younger Dryas

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ABSTRACT

Currently, two climate systems dominate the environmental conditions in NW Africa; the Mediterranean climate, with winter rains in the north, and the NW African monsoonal climate with summer precipitation in the south. These climate regimes are separated by the Saharan Desert. Previous studies indicated past latitudinal movements of the boundary between these climatic systems, causing changes in hydrology over the area. In the arid setting of NW Africa possible future changes in hydrological systematics will have a tremendous impact on the environment and human welfare. Thus, detailed understanding of past wet/dry alterations is of great importance. Here we present new data about the latitudinal shifts of the transition zone between the prevailing NW African rainfall patterns over the last 12 ka. We investigated the terrigenous fraction of marine cores retrieved offshore NW Africa. Grain-size measurements, combined with end-member modeling, show variability in sediment-transport mechanisms. Radiogenic isotopes combined with trace element data show contrasting hydrological conditions in northern versus southern sediment records, indicating a shift of the climate systems during the Holocene. Higher $^{87}Sr/^{86}Sr$ and lower Rb/Sr ratios in the north point to an increased influence of chemical weathering due to the greater impact of the North Atlantic climate system during the Younger Dryas. We propose that the influence of this system reached to at least 26°N 12 ka ago. During the mid-Holocene the boundary shifted further north, possibly reaching as far north as 29°N. In the late Holocene the system evolved to a more southerly position that characterises the present.

1. Introduction

The modern rainfall over NW Africa is influenced by two climate systems, separated by the Saharan Desert (Nicholson, 2000). The northernmost part of the continent is dominated by the Mediterranean climate system, which is related to the North Atlantic climate regime, where the west–east migration of cyclones causes winter rain (Nicholson and Flohn, 1980). South of 20–24°N the NW African monsoonal system provides precipitation during summer (Knippertz et al., 2003). Present-day distribution of rainfall and contrasting rainfall patterns over the year for the northern and southern part of the study area are shown in Fig. 1. The main climatic driver of the region is the tropical rainbelt, which shows a seasonal variability. During boreal winter the core of the rainbelt is located at 5°N, whereas during boreal summer it lies at 20°N, following the seasonal migration of maximum insolation (Nicholson, 2000). It has been shown in various studies that the latitudinal position of the tropical rainbelt has changed over geological time scales, either by latitudinal movements (Gasse et al., 1990; Gasse and Van Campo, 1994) or through expansion and contraction of the rainbelt (Collins et al., 2011) causing variations in the hydrological conditions on land.

Grain-size measurements combined with radiogenic isotope data as well as element intensities indicate that a latitudinal shift of the NW African climate systems may cause changes in hydrological conditions during the Holocene as well as differences in hydrological conditions between the northern and southern part of NW Africa (Meyer et al., 2011; Kuhlmann et al., 2004). In order to gain further information about the detailed extent of the latitudinal shift of the transition zone between the Mediterranean climate system in the north and the monsoonal climate system in the south the existing record was extended in this study by additional sediment cores from offshore Morocco, Western Sahara and Mauritania (Fig. 1). Existing results record a different pattern in continental weathering regime at 29°N compared to results obtained south of 23°N (Meyer et al., 2011). To verify that there was a

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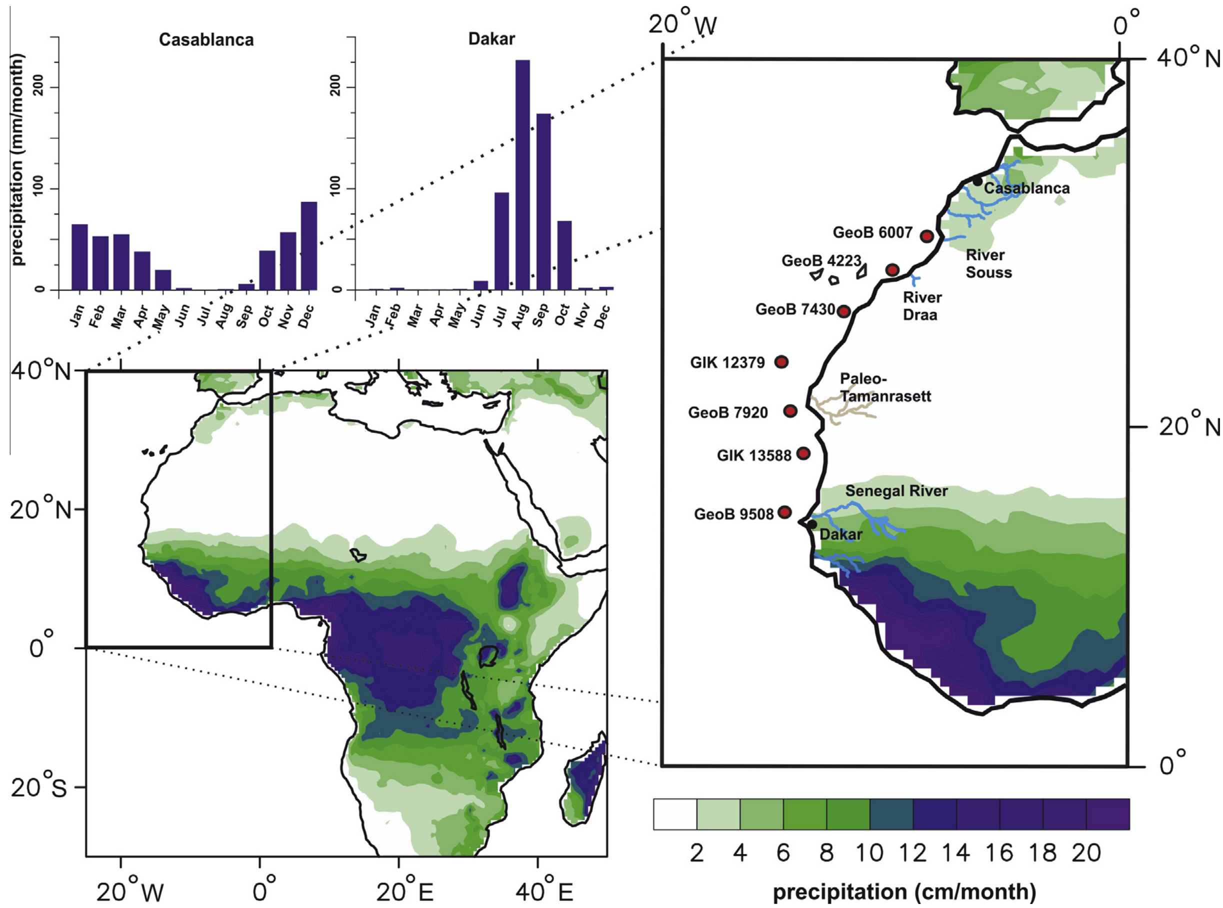

Fig. 1. Present-day mean annual rainfall in cm per month for the period 1950–1999 (University of Delaware data set; modified after Collins et al., 2011). Map show that the modern rainfall in NW Africa is concentrated to winter-rainfall the northern part of the continent (Mediterranean climate system) and to summer-rains in the areas south of 20–24°N (monsoonal climate system). Annual precipitation data from Casablanca and Dakar are obtained from climatemp.info. Investigated deep-sea sediment records (red items) build a coast parallel transect offshore NW African. Furthermore, the most active river systems draining the Atlas Mountains as well as the paleo-river system of the Tamanrasett are indicated. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

systematic change in hydrological conditions, two additional sediment cores were studied from 26° and 31°N. Both sediment cores are located on the continental shelf close to the NW African continent. Therefore both cores are expected to record changes in the contribution of terrestrial material, either dust or fluvial material. Grain-size measurements and end-member modeling of the terrigenous fraction are used in this study to investigate the different sediment-transport mechanisms, which are diagnostic of the input of land-derived sediments into the ocean and can be related to environmental conditions in the sources of the sediments (Prins and Weltje, 1999; Stuut et al., 2002; Weltje and Prins, 2003). Furthermore, to investigate the provenance of the terrigenous fraction and to reconstruct the hydrological changes in the study area, trace element concentrations and the isotopic composition of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ are analyzed in three key time slices of distinct climatic conditions (late Holocene – dry/warm; African Humid Period – wet/warm; Younger Dryas – dry/cold). Measurements are performed on different size fractions representing aeolian sediments (10–40 μm) and fluvial material (0–10 μm). Variations in neodymium (Nd) isotopes are indicative of changing source geology whereas strontium (Sr) isotope systematics are influenced by variations in chemical weathering related to precipitation (Cole et al., 2009; Jung et al., 2004; Meyer et al., 2011; Weldeab et al., 2002). To verify differences in the mineralogical composition between the distinct size fractions presented here, X-ray Diffraction (XRD) measurements are carried out. The combined investigation of the proxies used in this study allows more precise conclusions about the latitudinal position of the different climate system within NW Africa during the Holocene and, in particular, the transition zone between the two dominant climate systems.

1.1. Terrigenous sedimentation offshore NW Africa

The terrigenous fraction deposited in marine sediments consists of a mixture of sedimentary components derived from different sources that are transported to the site of deposition by different sediment transport mechanisms (e.g., Weltje and Prins, 2003). Offshore the Saharan Desert mainly two types of terrigenous matter can be found: first, and most dominant, aeolian input, transported by different wind systems, and second fluvial supply, which can be dominant near the river mouths. Today the Sahara is one of the most arid places in the world and therefore the Earth's largest source of mineral dust (Prospero et al., 2002; Washington et al., 2003). Approximately 50–70% of the global dust emission supplied to the world's oceans is derived from the Saharan Desert (Goudie and Middleton, 2001; Mahowald et al., 2005). Estimations of modern dust output from the Sahara vary from 130 to 460 (Swap et al., 1996) up to 1400×10^6 tons per year (Ginoux et al., 2004). Saharan dust has been observed to travel over enormous distances e.g., in a westerly direction across the Atlantic Ocean and was identified on the Bahamas (Ott et al., 1991), in South America (Prospero et al., 1981), Florida and Barbados (Glaccum and Prospero, 1980; Muhs et al., 1990). Saharan dust also takes a northerly track towards the Mediterranean and sometimes reaches northern Europe (Stuut