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The Marion Dufresne is a research vessel equipped for the collection of long, large-diameter marine sediment cores. Foraminifera and Coccolithophorids preserved within the sediment are used to reconstruct hydrographical and biogeochemical conditions of the paleo-ocean.

Control of West African monsoon precipitation: Insights from the past

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The global monsoon system is the key component in determining hydrological cycles in the low latitudes. Irregularities or anomalies in monsoon rainfall severely affect agricultural production of the most densely populated regions on Earth. Understanding monsoon response to, and interactions with, high latitude and tropical climate oscillations is, therefore, crucial for assessing the impact of future climate changes on the low latitude hydrological cycle. Insights into past abrupt climate changes in the low latitudes can provide a showcase to assess the interplay of climate modes and boundary conditions that control monsoon responses.

Here, I will discuss a centennial- to millennial-scale record from the Gulf of Guinea, eastern equatorial Atlantic (EEA) (Weldeab et al., 2007a, Weldeab et al., 2007b). Mg/Ca, Ba/Ca and oxygen isotope composition in shells of shallow-dwelling planktic foraminifers were analyzed, and Ba/Ca was used as an indicator of changes in fresh water input of both the Niger and Sanaga Rivers, which drain large parts of the West African monsoon area (Fig. 1). Ba is enriched in riverine runoff relative to Ba in seawater. Ba uptake into planktic foraminiferal shells is linearly dependent on the Ba concentration of seawater (Lea and Spero, 1994). Thus, temporal variation of planktic foraminiferal Ba/Ca in sediment of core MD03-2707 (Fig. 1) indicates changes in the amount of riverine runoff, which is directly related to changes in West African monsoon precipitation.

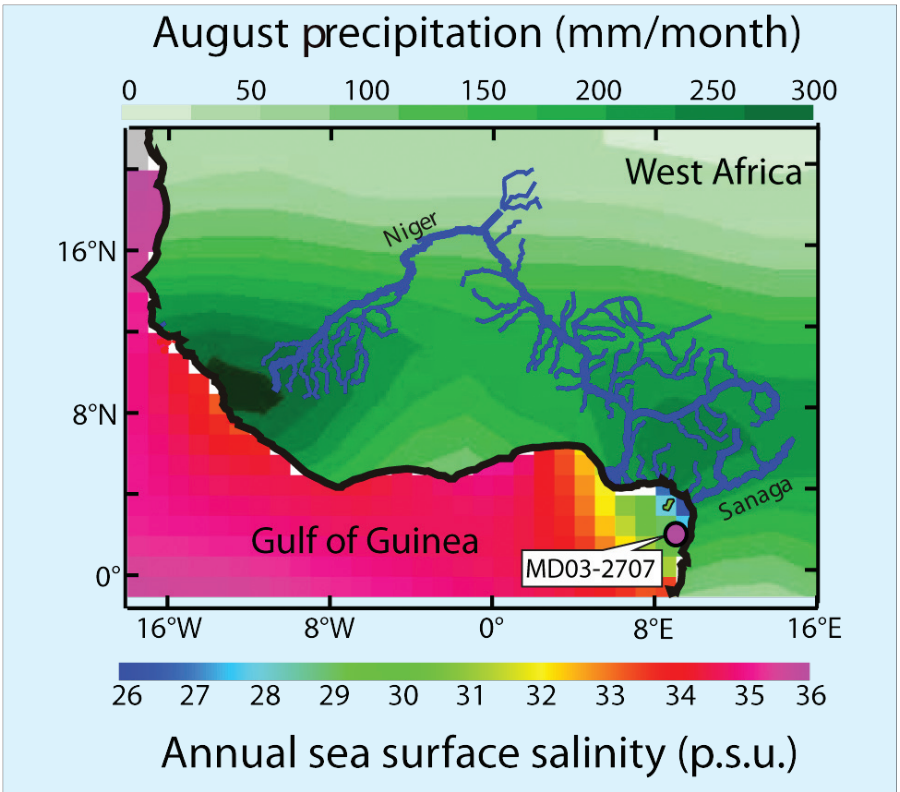

Figure 1: Location of MD03-2707, drainage basin of the Niger and Sanaga Rivers, precipitation in August (the height of West African monsoon precipitation) (Janowiak and Xie, 1999), and annual sea surface salinity in the Gulf of Guinea (Levitus and Boyer, 1994). Note: the drainage basins of the Niger and Sanaga Rivers cover a large part of the West African monsoon, and riverine runoff heavily affects the hydrography over the core site (Weldeab et al., 2007b).

West African monsoon responses to northern high latitude climate

On Milankovitch timescales, the planktic foraminiferal Ba/Ca and oxygen isotope records (Fig. 2) suggest that changes in the West African monsoon precipitation have closely followed the variations in low-latitude insolation and tropical Atlantic sea surface temperature (SST). The Gulf of Guinea records reveal that during interglacials, the West African monsoon was repeatedly punctuated by abrupt centennial- to millennial-scale swings in precipitation that closely correlate with abrupt climate shifts in Greenland (NGRIP members, 2004). Episodes of intensified West African monsoon precipitation coincide with intervals of warm air temperatures over Greenland. Conversely, periods of relatively weak monsoon precipitation during the penultimate interglacial and the last deglaciation tightly correlate with cold events in the Greenland ice core record. Close correspondence between weak monsoon precipitation (Fig. 2b) and early Holocene fresh water discharges into the North Atlantic (Clark et al., 2001) is also evident. These correlations suggest a strong linkage between interglacial West African monsoon conditions and abrupt climate changes in northern high-latitudes. Moreover, because the EEA SST record (see below) does not show fluctuations correlating to the centennial- to millennial-scale changes in West African monsoon precipitation, the West Africa northern high latitude climate linkage appears to have been established via the atmosphere.

Glacial West African monsoon conditions, as reflected by the Ba/Ca and oxygen isotope records, clearly indicate low, stable riverine runoff and do not reveal marked centennial- to millennial-scale oscillations such as those recorded in the Greenland ice cores. This observation suggests that during the last glacial and MIS 3, monsoon precipitation over the Niger and Sanaga drainage basins was fully decoupled from climate fluctuations in the northern high latitudes. We argue that glacial and interglacial boundary conditions and different thermal inertia of the terrestrial and oceanic intertropical convergence zone (ITCZ) have been crucial in determining the response of West African monsoon to climate instabilities in the northern high latitudes. That is, during interglacials, the summer ITCZ lies deep within the African continent and the ITCZ appears to react readily to the abrupt climate changes of the northern high latitudes. During the last glacial, however, the seasonal northward migration of the ITCZ was most likely limited to the region south of the east-west trending West African coast, as suggested by the reconstructed low riverine runoff. I argue that West African monsoon response to glacial millennial-scale northern high latitude climate instabilities was most likely dampened by glacial boundary conditions that kept the ITCZ south of the Niger and Sanaga catchments.

Eastern Equatorial Atlantic SST record

Major changes in eastern equatorial Atlantic SSTs—with increases between 2-3°C—were recorded at glacial-interglacial transitions. The SST record is also in phase with midsummer solar insolation at 15°N, suggesting that the EEA is thermally sensitive to northern hemisphere low-latitude summer radiation, either through a monsoonal feedback or because Mg/Ca-based SST estimates are weighted towards the boreal summer. Major glacial-interglacial SST transitions in the EEA and elsewhere in the tropics are paralleled by large changes in greenhouse gases, as recorded in Antarctic ice cores (Petit et al., 1999). Radiative forcing associated with the increase in greenhouse gases during the glacial-interglacial transition has been estimated to cause an increase of ~2°-3°C in tropical SSTs (Lea, 2004). If this estimate is correct, the EEA SST increase at glacial-interglacial transitions was largely a consequence of radiative forcing corresponding to greenhouse gas increases and orbital insolation changes.

The eastern equatorial Atlantic record does not show SST swings that correlate with millennial-scale ice-sheet instabilities in the northern high latitudes. This observation suggests that the thermal evolution of the eastern equatorial Atlantic over the past 155 kyr was fully decoupled from the Dansgaard Oeschger events, as recorded in Greenland ice cores. This strongly supports the general observation that thermal changes in the tropics primarily reflect greenhouse forcing and orbital insolation changes.

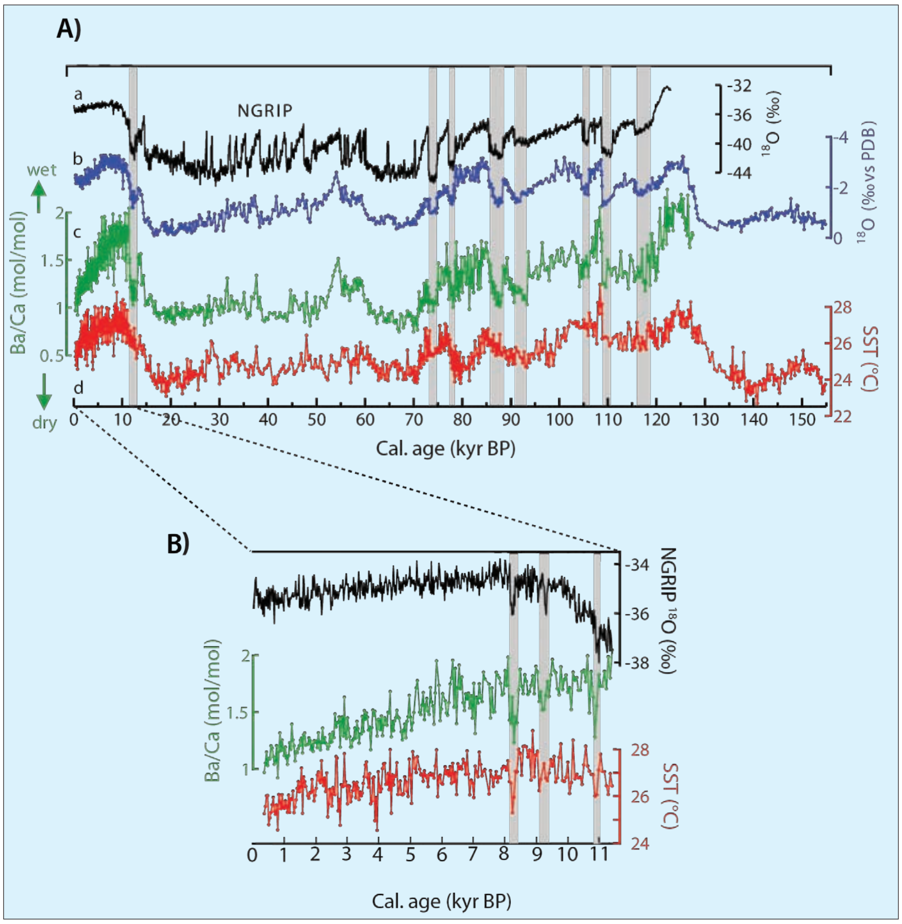

*Figure 2: **A**) Proxy records from shallow-dwelling planktic foraminifers (*Globigerinoides ruber, *pink variety) of core MD03-2707 (b-d) compared (**a**) with isotope composition of Greenland ice core (NGRIP members, 2004). (**b**) oxygen isotope composition, (**c**) Ba/Ca used as indicator of changes in riverine runoff, and (**d**) Mg/Ca-based SST estimate. Gray bars indicate intervals of relatively weak monsoon precipitation that tightly correlate with cold events in the Greenland ice core record (NGRIP). **B**) Enlarged section covering the past 11.5 kyr BP. Gray bars indicate periods of low monsoon precipitation that coincide or overlap with cold air temperature over the northern high latitudes and fresh water discharges into the North Atlantic Ocean (e.g., Clark et al., 2001).*

Hydrological and thermal lead-lag relationships

The Gulf of Guinea record shows that the onset of EEA SST increases during the last and penultimate deglaciation occurred ca. 18 and 136 kyr BP, respectively. Intensification of West African monsoon precipitation during the last and penultimate deglaciations started, however, ~14.5 and 129 kyr BP, respectively, lagging behind EEA warming by ~2.5 kyr during the last deglaciation, and by ~7 kyr during the penultimate deglaciation. This observation suggests that a complex role of tropical SST and low-latitude insolation in rising deglacial monsoon precipitation may exist. The lags may be explained by the following possibilities; 1) Tropical Atlantic SST needed to reach a threshold to push the West African monsoon system from dry, stable glacial to wet deglacial and interglacial conditions, or 2) Deglacial ice sheet instabilities and freshwater discharges into the North Atlantic had a dominant control on the timing of the onset of monsoonal precipitation. The author favors the latter explanation because the impact of millennial-scale northern high latitude climate instabilities on the West African monsoon appears to have overridden the trends set by changes in low latitude insolation and tropical Atlantic SST, as clearly evidenced during the penultimate interglacial and the Younger Dryas.

Conclusions

Superimposed on the glacial-interglacial trend, the Gulf of Guinea record reveals that during interglacial periods the West African monsoon was repeatedly interrupted by centennial- to millennial-scale rapidly decreasing precipitation. These declines in monsoon precipitation tightly correlate with the cold events of the Greenland ice core record. In contrast, during the last glacial, climate instabilities did not have a significant impact on the hydrological cycles over the Niger and Sanaga drainage basins. Thus, glacial-interglacial boundary conditions appear to have been crucial in determining if, and how, West African monsoon precipitation responded to millennial-scale climate instabilities in the northern high latitudes. Furthermore, on centennial- to millennial-timescales, eastern equatorial Atlantic SSTs were fully decoupled from swings in West African monsoon precipitation, suggesting that teleconnections between changes in air temperature over the northern high latitudes and atmospheric changes over West Africa are the dominant control of monsoon precipitation.

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