Modern-day African rainbelt

The African rainbelt is closely associated with the Inter Tropical Convergence Zone (ITCZ). Both oscillate seasonally between ~20°N in July and ~20°S in January (Supplementary Fig. S1a,b) following the seasonal movement of the insolation maximum. Over West Africa, rainfall is generated by a band of ascending air located between the mid-level African Easterly Jet and the upper-level Tropical Easterly Jet. Over the Congo basin region, rainfall is associated with the Congolan Air Boundary. The generation of rainfall and seasonal oscillation of the rainbelt in Africa are also closely linked to the monsoon system, the seasonal reversal of the atmospheric circulation which brings warm moist air on land during the summer.

Supplementary Figure S1. Modern-day seasonal extremes of the rainbelt. a, Mean Jun-Jul-Aug precipitation, (cm month$^{-1}$) for the period 1950-1999 (University of Delaware dataset, http://climate.geog.udel.edu/~climate/). b, As (a) but for Dec-Jan-Feb.
Estimating wet season length, mean annual rainfall and wet season intensity from vegetation type

In modern-day tropical Africa, mean annual rainfall is controlled by wet season length and wet season intensity. Modern-day %C$_3$ vegetation is positively correlated with wet season length (Supplementary Fig. S2a), since trees cannot survive when the wet season becomes too short$^{55}$. Modern-day %C$_3$ vegetation is also correlated with mean annual rainfall (Supplementary Fig. S2b), owing to the dominance of the spatial distribution of wet season length on the spatial distribution of mean annual rainfall (Fig. 1a,b). Modern-day %C$_3$ vegetation is weakly correlated with wet season intensity (Supplementary Fig. S2c), suggesting that wet season intensity only exerts a small control on vegetation type.

Since temperature conditions in Africa do not favour the growth of C$_3$ grasses$^{56}$, changes between C$_3$ and C$_4$ vegetation over time represent shifts between trees and grasses and thus represent changes in hydrological conditions, rather than changes in atmospheric CO$_2$ concentration. Moreover, the large difference in C$_3$ and C$_4$ vegetation distribution between the mid-Holocene and late Holocene, when atmospheric CO$_2$ levels were broadly similar, further emphasises the dominance of hydrological changes (that is changes in wet season length) on changes in C$_3$ and C$_4$ vegetation distribution in Africa, rather than changes in atmospheric CO$_2$ concentration.
Supplementary Figure S2. %C₃ vegetation as a recorder of wet season length, mean annual rainfall and wet season intensity. a, %C₃ vegetation vs. wet season length. Each data point represents the mean value of 1° grid squares for an area extending from the west coast to 20°E, between the latitudes of 20°N to 20°S, for 5%<C₃<95%. The solid line represents a robust linear regression between %C₃ vegetation and wet season length (90% confidence interval is approximately ± 0.1 months). The correlation ($r^2$) is 0.65 ($p<0.001$). Dashed lines represent the 90% prediction interval. The predictive uncertainty on the regression relationship is ± 2 months. Mean monthly rainfall is based on the University of Delaware dataset, while vegetation type data is based on ref. S7. b, As (a) but for %C₃ vegetation vs. mean annual rainfall (90% confidence interval is approximately ± 0.2 cm month⁻¹). The correlation ($r^2$) is 0.57 ($p<0.001$). The predictive uncertainty on the values is ± 4 cm month⁻¹. c, As (a) but for %C₃ vegetation vs. wet season intensity (90% confidence interval is approximately ± 0.3 cm month⁻¹). The correlation ($r^2$) is 0.18 ($p<0.001$). The predictive uncertainty on the values is ± 5 cm month⁻¹.
**Transport mechanisms and source areas of material**

Most cores receive both river suspended sediment and wind blown dust, although the core at 21°N receives little river material (Fig. 1a), and the cores at 6°S and 12°S receive little dust (Supplementary Fig. S4a). However, the exact location of dust sources are not well known⁸ and neither are the exact areas within river catchments from where cores receive material.

Nonetheless, it is thought that dust storms from the Saharan and Namibian deserts and the Sahel savanna generally follow a westward trajectory⁸,⁹. Apart from the Niger and Congo rivers, major rivers also generally transport material in a westward direction (Fig. 1a). Moreover, during transport and entrainment of a dust storm, the \( n \)-alkane isotopic composition of the dust source is overprinted with the isotopic composition of the vegetation along the transport pathway¹⁰, and thus the sediment cores record mostly local vegetation type rather than distal vegetation type. This ‘overprinting’ by the latest vegetation type is also applicable to material that is transported as river suspended sediment¹¹. Therefore, we assume that the cores at 21-9°N and 12-17°S are receiving their dust and river material from a source area located on the continent approximately eastward of the core site. We assume that the core at 2°30´N receives material mainly from the Sanaga river catchment¹² and also dust from the Bodelé depression to the north of the core site¹³, while the core at 6°S receives material from the Congo river catchment¹⁴ (see Fig. 1).

In order to test this assumption of the source areas, we compare the modern-day mean vegetation type (from a satellite-based dataset; ref. S7) of the assumed source areas to the late Holocene vegetation type estimated from the sediment cores. For the cores at 21°N, 15°N, 12°N, 9°N, 12°S, 17°N we calculate the vegetation type from the satellite data for a source area that we designate to be the region 5° of...
latitude to the north and south of each core site. A value of 5° is used because the core at 21°N receives material from a region ~5° to the south (there is no vegetation on the adjacent continent; Fig. 1d). Also the latitudinal transport of the Senegal, Balombo, Cunene rivers and any other smaller rivers equates to approximately 5° latitude: therefore the rivers are averaging material from a region 5° to the north and south of the core site. We designate the source area to extend eastwards to 5°W for the cores at 21°N, 15°N, 12°N and 9°N and to 20°E for cores at 12°S and 17°S. For the core at 2°30´N, we designate the source area to be between 15°N and the core site, and between 10°E and 20°E. For the core at 6°S, we designate the Congo River catchment as the area between 5°N and 10°S and between the west coast and 30°E.

In general, the calculated mean %C₃ vegetation for the above designated catchments compares well to the n-alkane-derived %C₃ vegetation estimation from the cores for the late Holocene timeslice (Supplementary Fig. S3) and thus implies that this assumption of the source areas is reasonable. Importantly, our source area estimation illustrates that although the source areas are not necessarily centred at the same latitude as the core sites, the combined source area of the whole transect covers the entire latitudinal range of the rainbelt.
Supplementary Figure S3. Sediment core %C\textsubscript{3} vegetation values compared with estimated continental source area %C\textsubscript{3} vegetation values. Black line represents %C\textsubscript{3} vegetation determined from \textit{n}-alkanes for the late Holocene timeslice of each sediment core, plotted against core site latitude. Red line represents %C\textsubscript{3} vegetation values from the estimated source areas (based on satellite data\textsuperscript{57}) of each core.
Lake Bosumtwi and the ‘Dahomey Gap’

Modern-day mean annual rainfall is focussed in the Guinea–Liberia and Cameroon regions, especially in terms of wet season intensity (Fig. 1c) and this is partly related to topography\textsuperscript{15}. In between these two regions lies a savanna corridor known as the ‘Dahomey Gap’ (Fig. 1d). This is a comparatively dry area (Fig. 1a), in terms of both shorter wet season length (Fig. 1b) and lower wet season intensity (Fig. 1c). These conditions are thought to result from the coastal upwelling of cold waters and the parallel orientation of the south-westerly winds with the coast, which both act to stabilise the lower troposphere and thus reduce rainfall\textsuperscript{16,17}. Lake Bosumtwi (6°N), which is located adjacent to the Dahomey Gap area, displays low lake levels during the LGM and HS1 relative to today\textsuperscript{18}. This is in contrast to our cores at 9°N (Guinea–Liberia region) and 2°30´N (Cameroon region) which record the same and wetter conditions, respectively. This seems to indicate that the Dahomey Gap region responded differently to the Guinea-Liberia and Cameroon regions during the LGM and HS1.
Dust and river proportion

In general, dust is mobilised in arid areas (Supplementary Fig. S4a) and is hence derived from less weathered soils such as Arenosols and Sand dunes\textsuperscript{19} (Supplementary Fig. S4b). Conversely, rivers originate in wet areas (Fig. 1a) and thus derive their material from more heavily weathered soils such as Ferralsols, Nitisols, Acrisols, Plinthosols and Lixisols (Supplementary Fig. S4b). Chemical weathering acts to remove mobile elements such as K and Si\textsuperscript{20}, while leaving behind more immobile elements such as Al and Ti\textsuperscript{21-23}. Therefore, based on the major element composition of the sediment core and of dust, river suspended sediment and marine sediment end-members, we apply an unmixing model to determine the relative proportions of these three components in the sediment\textsuperscript{24}. For the sediment core, samples were measured for major element composition using EDP-XRF analysis. For the end-members, we used 28 values for the major element composition of dust end-members from the northern hemisphere\textsuperscript{20,25-29}, 9 values for dust from the southern hemisphere\textsuperscript{30} and 13 values for river suspended sediment from the Senegal, Niger and Congo Rivers\textsuperscript{23,31-33}. The marine end member was constructed using the same assumptions as in ref. S24.
Supplementary Figure S4a. Modern-day average dust deposition across Africa\textsuperscript{S34,S35} (g/m\textsuperscript{2}/yr). A large amount dust is transported to the west from the Sahara-Sahel region and a smaller amount from the Namib/Kalahari deserts. \textbf{b, Major soil groups across Africa}\textsuperscript{S36}. Heavily weathered soils include Ferralsols, Nitisols, Acrisols, Plinthosols and Lixisols. Less weathered soil groups include Arenosols and Sand dunes. Soil groups not given in the key are those that are defined on properties not linked to climate.

The bootstrapping method used in the unmixing analysis incorporates some of the uncertainty in possible end member composition into the final unmixing model\textsuperscript{S24}. However, the limited availability of both dust and river end members, particularly for the southern hemisphere, restricts the ability of the model to fully characterise the end member composition of each source area and thus to quantitatively determine the amount of each component in each core. Nonetheless, we are still able to qualitatively estimate relative changes in dust/river ratio between each timeslice.

We present the results as dust proportion divided by river proportion (Supplementary Fig. S5). The dust flux to the core site is thought to be dependent on aridity\textsuperscript{S24} and also wind strength\textsuperscript{S37}. River flux is mostly dependant on continental aridity, since total suspended sediment discharge increases with annual water
The magnitude of the increase in dust/river at the LGM and HS1 is much greater in the 21-12°N region than in other regions (Supplementary Fig. S5). This perhaps reflects a greater potential for dust mobilisation in the Sahara-Sahel region than in central and southern Africa.

**Supplementary Figure S5.** Latitudinal distribution of dust/river ratio for modern and past climate states. Dust proportion divided by river proportion plotted against core-site latitude for the LGM (19-23ka), HS1 (16-19ka), mid-Holocene (6-8ka) and late Holocene (0-2ka). Each data point is the median value of the unmixing iterations for each sample from each timeslice. Error bars are nonparametric 95% confidence intervals, and represent the variation between each of the unmixing iterations for each sample as well as the variability between samples within any given timeslice.
**Seasonal oscillation, latitudinal width and intensity of the rainbelt**

In terms of rainbelt dynamics, the distribution of wet season length on the continent is controlled by the latitudinal extent of the seasonal oscillation of the rainbelt, and also by the latitudinal width of the rainbelt (that is the width of the band of rain during a given part of the year). A reduction in seasonal oscillation would produce a contraction of the rainbelt, while a reduction in the latitudinal width of the rainbelt would result in a reduction in wet season length across all latitudes. In addition, although the correlation is poor (Supplementary Fig. S2c), the intensity of the rainbelt (that is the wet season intensity) may also exert some control on vegetation type: for example there may be a lower limit of wet season intensity that is required to sustain rainforest. A reduction in wet season intensity would result in a reduction in mean annual rainfall across all latitudes.

**Chronology**

Age models for GeoB9508-5, GeoB9526-4/5, GeoB4905-4, GeoB6518-1, ODP1078C and GeoB1023-5 are based on published chronologies S12,S14,S39-S44. The age models for GeoB7920-2 and GeoB9535-4 are based on new AMS $^{14}$C ages (Supplementary Table S1). Calibration was performed with the ‘Fairbanks 0107’ calibration curve S45, using a reservoir age of 400 yrs.
**Supplementary Table S1:** ^14^C-AMS Dates used for chronology of GeoB7920-2 and GeoB9535-4

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†Measured at Peking University, all others measured at Kiel University
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SUPPLEMENTARY INFORMATION

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