Coupling of equatorial Atlantic surface stratification to glacial shifts in the tropical rainbelt

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Introduction

The Intertropical Convergence Zone (ITCZ) can be defined as a narrow belt of maximum tropical precipitation associated with the ascending branch of the Hadley circulation (Schneider et al., 2014). Primarily because of the meridional ocean–atmospheric energy transport, the annual average position of the ITCZ is not located at the equator, but north of it (Fig. 1a) (Donohoe et al., 2013; Frierson et al., 2013). At the tropical Atlantic surface, the position of the ITCZ is marked not only by a low-salinity belt (Fig. 1a) but also by a prominent change in water column structure with a pronounced shallow mixed layer between 5° N–12° N (Fig. 1b), which is considered to be the oceanic counterpart of the ITCZ. The resulting shallow tropical mixed layer is recorded in the composition of planktonic foraminifera faunas in the seafloor sediments below, which could be used to track the mean position of the oceanic counterpart of the ITCZ in the equatorial Atlantic (i.e., the Atlantic ITCZ). Here we provide a new proxy for the mixed layer depth based on the relative abundance of three planktonic foraminifera species and apply it to track the position of the Atlantic ITCZ during the last 30 cal ka BP in high-temporal resolution.

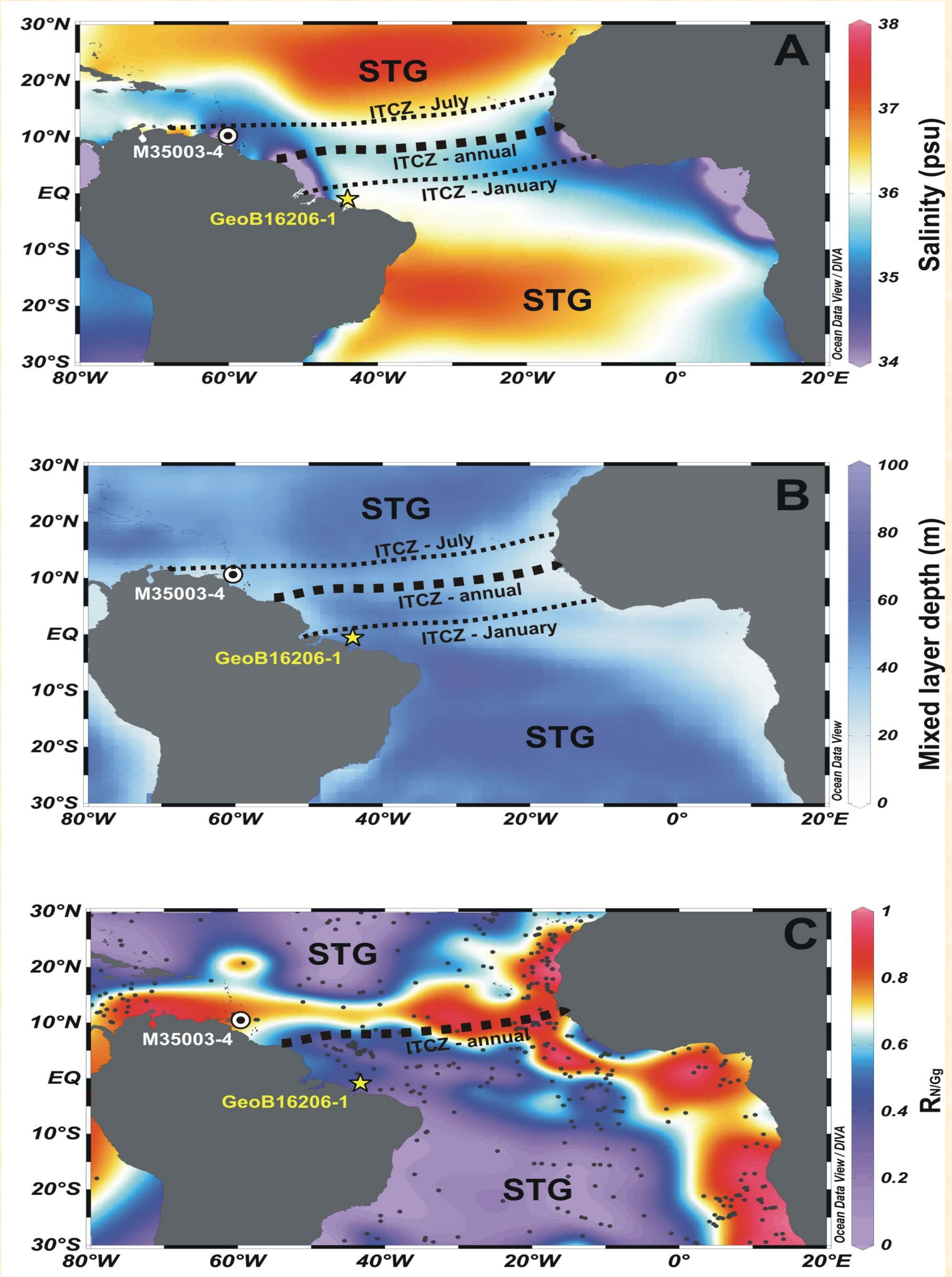

Figure 1: Tropical Atlantic Ocean maps with location of the investigated cores, upper water column properties and modern planktonic foraminifera response to the mean annual mixed layer depth. (a) Mean annual surface salinity (WOA 2009; Antonov et al., 2010) and location of cores GeoB16206-1 (1° 34.75'S, 43° 01.42'W) and M35003-4 (12° 5.4'N, 61° 14.6'W). The black dashed lines indicate the mean annual (thick) and seasonal (thin) position of the Intertropical Convergence Zone (ITCZ). (b) Mean annual mixed layer depth. (c) Distribution of the $R_{N/Gg}$ ratio. Black dots represent the location of the 407 surface sediment samples (Kucera et al., 2005).

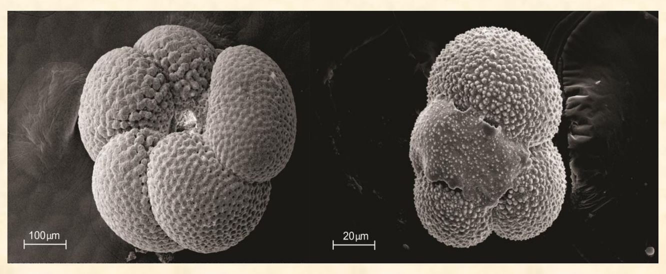

Figure 2: Key species of planktonic foraminifera used to track the Atlantic ITCZ. *Neogloboquadrina dutertrei* (Left) and *Globigerina glutinata* (right).

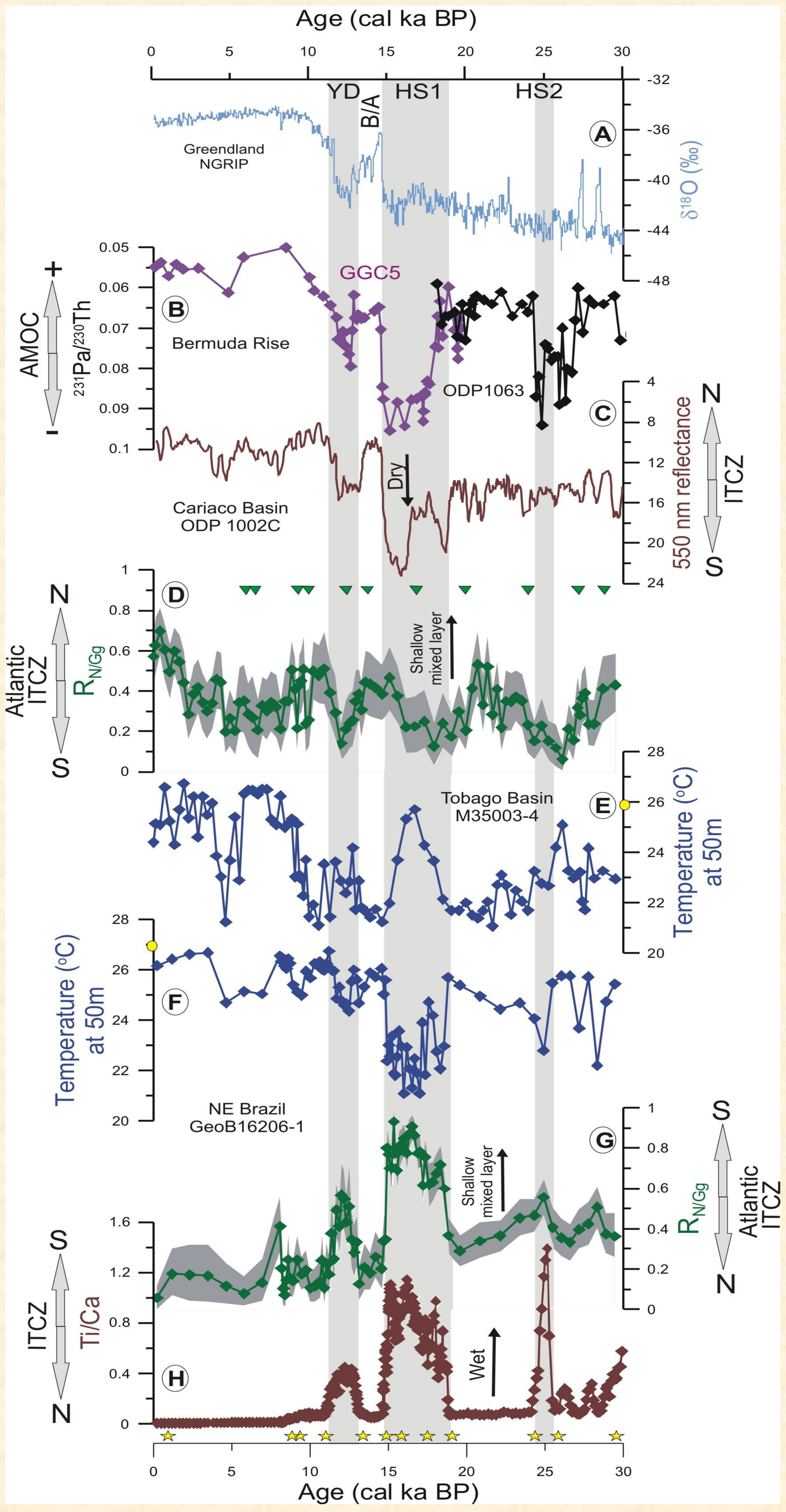

Figure 3: Antiphase relationship of the upper water column off NE-Brazil and at the Tobago Basin over the last 30 cal ka BP. (a) Greenland $\delta^{18}O$ record (Andersem et al., 2004); (b) Bermuda Rise cores GGC5 (purple) and ODP1063 (black) $^{231}Pa/^{230}Th$ as a proxy for the strength of the Atlantic Meridional Overturning Circulation (AMOC) (MacManus et al., 2004; Lippold et al., 2009); (c) Cariaco Basin core ODP1002C reflectance showing wet/dry conditions linked to meridional shifts of the Intertropical Convergence Zone (ITCZ) (Peterson et al., 2000); $R_{N/Gg}$ ratio as a proxy for the position of the Atlantic ITCZ in the (d) Tobago Basin core M35003-4 and in the (g) NE Brazil core GeoB16206-1; Modern Analog Technique-based temperature at 50 m water depth in the (e) Tobago Basin and (f) off NE Brazil; (h) Ti/Ca ratio as a proxy for precipitation over NE Brazil. Grey shading in (d) and (g) indicates the 95% confidence interval.

MATERIAL AND METHODS

The new mixed layer proxy

Comparing the modern distribution of planktonic foraminifera in surface sediments from the Atlantic Ocean between 30° N and 30° S with the water mass distribution we identified *Neogloboquadrina dutertrei*, *Neogloboquadrina incompta* and *Globigerina glutinata* (Fig. 2) as key species to track the modern position of the Atlantic ITCZ

We propose that the ratio **$R_{N/Gg}$ = %*Neogloboquadrina* / (%*Neogloboquadrina* + %*G. glutinata*)** can be used as a proxy for the modern position of the shallowest mixed layer associated with the Atlantic ITCZ (Fig.1c).

Past position of the Atlantic ITCZ over the last 30 kyr.

To reconstruct the variability of the Atlantic ITCZ over time, we applied the $R_{N/Gg}$ ratio to two sediment cores located on opposite sides of the modern seasonal range of the Atlantic ITCZ (Fig. 1a). Core GeoB16206–1 (1° 34.75'S / 43° 01.42'W / 1367 m water depth) was raised off NE Brazil and core M35003–4 (12° 5.4'N / 61° 14.6'W / 1300 m water depth) from the Tobago Basin (Fig. 1) The subsurface temperatures were reconstructed at both sites using a planktonic foraminifera–based Modern Analogue Technique (MAT). We also analyzed the Ti/Ca ratio in GeoB16206–1 to infer millennial-scale increases in river runoff associated with pulses of ITCZ-related rainfall over NE Brazil. Additionally, we used the output from a transient simulation of the last deglaciation (provided by the TraCE-21ka project (www.cgd.ucar.edu/ccr/TraCE/) (He, 2011) using a comprehensive coupled atmosphere-ocean general circulation model (Liu et al., 2009) to assess the effects of the AMOC slowdown during HS1 on the meridional displacement of the ITCZ and on the mixed layer depth of the tropical Atlantic.

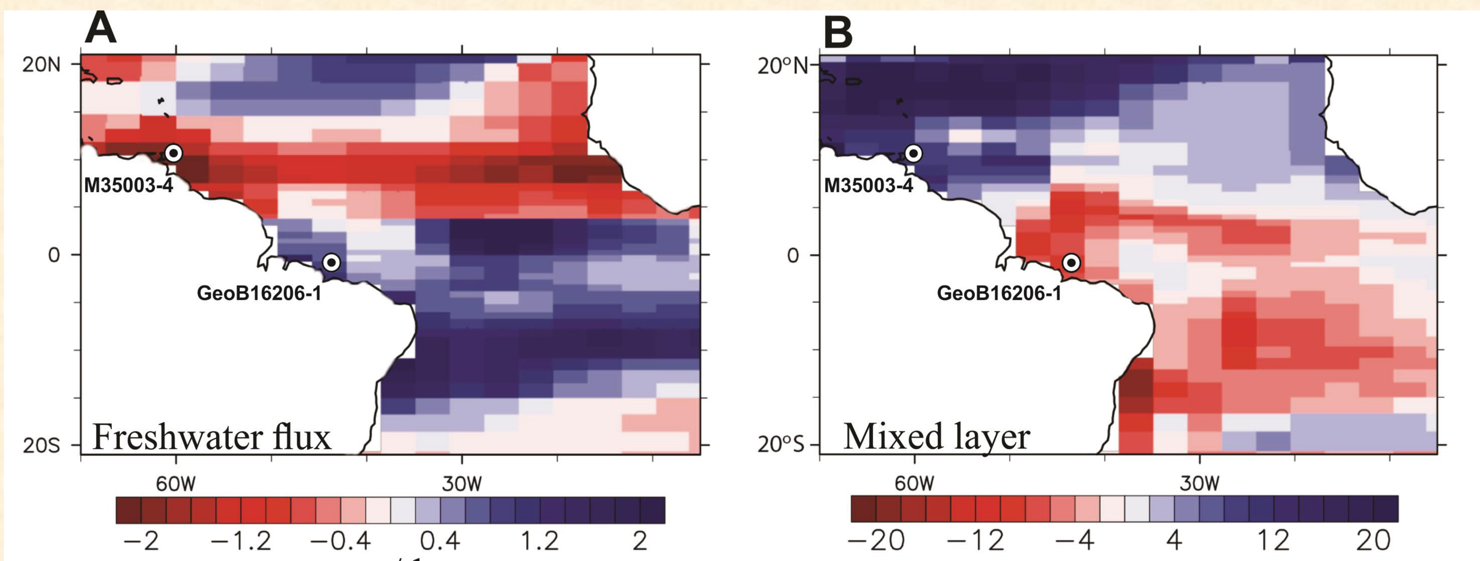

Figure 4: Simulated response of tropical Atlantic Ocean surface freshwater flux and mixed layer depth to a slowdown of the Atlantic Meridional Overturning Circulation. Shown are the long-term mean (a) surface freshwater flux (precipitation plus continental runoff minus evaporation) and (b) mixed layer depth anomalies during Heinrich Stadial 1 (18–15 ka average) relative to the Last Glacial Maximum (LGM) (22–19 ka average) from the transient TraCE-21ka deglacial simulation (Liu et al., 2009).

RESULTS

A clear antiphase relationship is observed in both the $R_{N/Gg}$ and subsurface temperature records off NE Brazil and the Tobago Basin (Figs. 2d-g). Elevated values of $R_{N/Gg}$ and cooler subsurface waters off NE Brazil occurred simultaneously (i.e., within age model uncertainties) with decreased $R_{N/Gg}$ values (deeper mixed layer) and warmer subsurface waters (partly due to enhanced turbulent downward mixing of heat) in the Tobago Basin during HS2–1 and the YD. The deglacial antiphase strongly suggests that the meridional movements of the Atlantic ITCZ influenced both sites during millennial–scale climate oscillations with a southward shift during HS2–1 and the YD (Fig. 2). Our paleorecords is supported by the TraCE-21k coupled atmosphere-ocean transient simulation that also shows a clear deglacial antiphase pattern between the region off NE Brazil and the Tobago Basin for both the mixed layer depth and the annual mean surface ocean freshwater flux in response to a slowdown of the AMOC (Fig. 4).

Conclusions

1) The western Atlantic ITCZ was located at ca. 1ºS (5º from its modern position) during HS1;
2) Physical and ecological changes in the upper tropical Atlantic followed the southward displacements of the ITCZ;
3) Our results support the model's hypothesis of an ITCZ position to the south of the equator under reduced cross-equatorial (AMOC) oceanic heat transport

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Support: