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Variability of the Brazil Current during the late Holocene

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ABSTRACT

Our understanding of the centennial-scale variability of the Brazil Current (BC) during the late Holocene is elusive because of the lack of appropriate records. Here we used the Mg/Ca and oxygen isotopic composition of planktonic foraminifera from two marine sediment cores collected at 27°S and 33°S off southeastern South America to assess the late Holocene variability in the upper water column of the BC. Our results show in phase fluctuations of up to 3 °C in sea surface temperatures (SST), and 0.8‰ in oxygen isotopic composition of surface sea water, a proxy for relative sea surface salinity (SSS). Time-series analyses of our records indicate a cyclicity with a period of ca. 730 yr. We suggest that the observed cyclicity reflects variability in the strength of the BC associated to changes in the Atlantic meridional overturning circulation (AMOC). Positive (negative) SST and SSS anomalies are related to a strong (weak) BC and a weak (strong) AMOC. Moreover, periods of peak strength in the BC occur synchronously to a weak North Brazil Current, negative SST anomalies in the high latitudes of the North Atlantic, and positive (negative) precipitation anomalies over southeastern South America (equatorial Africa), further corroborating our hypothesis. This study shows a tight coupling between the variability of the BC and the high latitudes of the North Atlantic mediated by the AMOC even under late Holocene boundary conditions.

1. Introduction

In many regions of the globe, the Holocene was punctuated by centennial-scale climate variations. Such variations were recorded in different oceans (e.g., Rimbu et al., 2004; Lamy et al., 2006; Hoogakker et al., 2011) and continents (e.g., Russell et al., 2003; Turney et al., 2005; Strikis et al., 2011). But questions still persist on whether or not a unifying theory is able to explain their formation (Wanner et al., 2011). One of the factors that hampered the establishment of a theory is the small number of records from the Southern Hemisphere. The tropical and subtropical western South Atlantic is one such region where records are particularly scarce (Leduc et al., 2010). Despite the lack of studies, the western boundary currents (i.e., the Brazil Current (BC) and the North Brazil Current (NBC)) in the South Atlantic play an important role in the Atlantic meridional overturning circulation (AMOC) (Peterson and Stramma, 1991). It was proposed, for instance, that the strength of the BC and the NBC should be anti-phased during abrupt climate change events (Arz et al., 1999; Crowley, 2011). Although some reconstructions are available for Marine Isotope Stages 2 and 3 (Arz et al., 1999; Carlson et al., 2008), there is so far no study that investigates the late Holocene centennial-scale variability of the BC.

Here we address this issue using planktonic foraminiferal Mg/Ca and stable oxygen isotope ratios ($\delta^{18}O$) from two marine sediment cores collected off southeastern South America. Our data provide evidence for centennial-scale fluctuations in sea surface temperature (SST) and sea surface salinity (SSS) in the BC that are anti-correlated to changes in the strength of the NBC.

2. Regional setting

The upper water column of the study area is bathed by the BC, a weak southward-flowing western boundary current that is associated with the South Atlantic subtropical gyre (Fig. 1) (Peterson and Stramma, 1991; Stramma and England, 1999). The BC originates between 10 and 15°S, where the Southern South Equatorial Current bifurcates while approaching the South American continental margin. At the bifurcation, the SSEC feeds not only the BC but also the northward flowing NBC (also termed the North Brazil Undercurrent (Stramma et al., 1995) between the bifurcation and ca. 5°S). Around 37°S the BC encounters the northward-flowing Malvinas Current (Olson et al., 1988), where both currents turn southeastward and flow offshore as the South Atlantic Current and the northern branch of the Antarctic Circumpolar Current, respectively.

The BC transports Tropical Water (TW) (>20 °C and >36 psu) in the upper ca. 100 m of the water column and South Atlantic Central Water (SACW) (6–20 °C and 34.6–36 psu) from ca. 100 until 600 m water depth. Whereas the TW constitutes the mixed layer, the large

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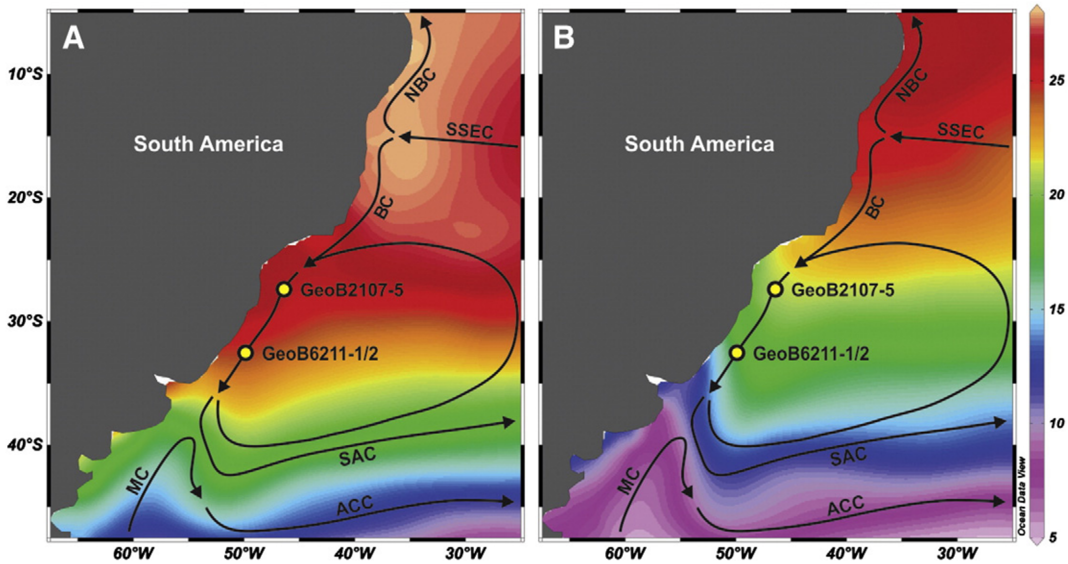

Fig. 1. Location of the marine sediment cores investigated in this study, and mean austral summer (A) and winter (B) sea surface temperatures (SST) (color shading, °C; Locarnini et al., 2010) plotted together with mean annual horizontal circulation at the surface (black arrows; Stramma and England, 1999). During austral summer (winter) the Brazil Current is strengthened (weakened) and our study area experiences higher (lower) SST (Matano et al., 1993; Locarnini et al., 2010). ACC: Antarctic Circumpolar Current; BC: Brazil Current; NBC: North Brazil Current; SAC: South Atlantic Current; SSEC: Southern South Equatorial Current. This figure was partly produced with Ocean Data View (Schlitzer, 2012). See Table 1 for more information about the sediment cores.

temperature and salinity ranges of the SACW characterize the permanent thermocline.

The BC shows a strong annual cycle in SST that increases from the bifurcation of the SSEC (amplitude of ca. 3 °C at 17.5°S/36.5°W) towards the confluence with the MC (amplitude of ca. 5 °C at 33.5°S/45.5°W), with warmer waters prevailing during austral summer (Fig. 1) (Locarnini et al., 2010). On the other hand, changes in SSS show a rather small annual cycle (amplitude of ca. 0.2 psu on both positions along the BC), with slightly higher values during austral winter as compared to austral summer and no clear latitudinal trend (Antonov et al., 2010). Instrumental data and numerical modeling assigned the annual cycle in SST to both the annual cycle in insolation and variations in the transport of the BC (Provost et al., 1992; Matano et al., 1993; Wainer et al., 2000). Increased heat flux from the atmosphere during austral summer evidently occurs synchronously with the peak in mass transport of the BC that is, in turn, related to intensified wind stress forcing (Peterson and Stramma, 1991; Matano et al., 1993).

The deficit in the southward BC transport relative to what would be expected from the wind fields is due to the northward-directed upper branch of the thermohaline circulation (Stommel, 1957; Peterson and Stramma, 1991). Indeed, the formation of North Atlantic Deep Water (NADW) requires a net transfer of thermocline water from the South Atlantic to the North Atlantic together with net northward fluxes of intermediate and bottom waters (Rintoul, 1991; Peterson and Stramma, 1991). Because of this condition, the NBC receives the largest share (ca. 12 Sv) of the SSEC volume transport if compared to the BC (ca. 4 Sv) (e.g., Stramma et al., 1990).

Sea surface temperatures (SST) in the western South Atlantic play an important role in precipitation over southeastern South America (Robertson and Mechoso, 2000; Chaves and Nobre, 2004). Positive SST anomalies have been correlated with increased precipitation over the northern sector of southeastern South America, i.e., to an intensification and northward shift of the South Atlantic Convergence Zone (SACZ). The SACZ is one of the main features of the South American monsoon system (SAMS) during austral summer (Zhou and Lau, 1998; Garreaud et al., 2009). It is an elongated NW-SE convective belt that originates in the Amazon Basin, and it extends above the northern sector of southeastern South America and the adjacent subtropical South Atlantic (Carvalho et al., 2004). It is still debated how far inland SST anomalies in the western South Atlantic are able to influence the position and activity of the continental SACZ (Carvalho et al., 2004; Chaves and Nobre, 2004).

3. Material and methods

3.1. Marine sediment cores

We investigated multi-cores GeoB2107-5 (Bleil et al., 1993) and GeoB6211-1 (Schulz et al., 2001) as well as part of the gravity core GeoB6211-2 (Schulz et al., 2001; Wefer et al., 2001) collected from the continental slope off southeastern South America (Table 1, Fig. 1). Considering that (i) multi-core GeoB6211-1 shows a relatively high sedimentation rate and does not span the whole late Holocene (see Section 4.1. below), (ii) gravity coring frequently disturbs the uppermost centimeters of the sediment column, and (iii) the shallowest AMS ^{14}C age from gravity core GeoB6211-2 was obtained at 18 cm core depth and may not adequately constrain the age of the uppermost 10–15 cm core depth of GeoB6211-2 (see Section 4.1. below), it was necessary to produce a composite record (i.e., GeoB6211-1/2) by assigning the base (i.e., 45 cm core depth) of GeoB6211-1 to 17 cm core depth from GeoB6211-2, based on calibrated accelerator mass spectrometer (AMS) ^{14}C ages from both cores. Further details about the preparation of composite record GeoB6211-1/2 are provided in Table 2 and Fig. 2. Because our focus here is the last 5 kyr, we analyzed the whole GeoB2107-5 and only down to 84 cm core depth from composite core GeoB6211-1/2. Visual core inspection does not provide evidence for disturbance in any of the cores analyzed here (Bleil et al., 1993; Schulz et al., 2001; Wefer et al., 2001).

Multi-cores GeoB2107-5 and GeoB6211-1 were described and then sliced onboard in 1 cm slices, and the samples were stored in plastic vials at 4 °C. One meter sections of gravity core GeoB6211-2 were

Table 1
Marine sediment cores used in this study.

Core ID	Coring device	Latitude (°S)	Longitude (°W)	Water depth (m)	Core length (cm)
GeoB2107-5	Multi-core	27.18	46.46	1052	39
GeoB6211-1	Multi-core	32.51	50.24	654	45
GeoB6211-2	Gravity core	32.51	50.24	657	774