Palaeogeography, Palaeoclimatology, Palaeoecology 415 (2014) 21–27

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

South Tropical Atlantic anti-phase response to Holocene Bond Events

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ARTICLE INFO

Article history:
Received 1 August 2013
Received in revised form 14 July 2014
Accepted 19 July 2014
Available online 31 July 2014

Keywords:
Bond cycles
Atlantic overturning
South Atlantic
Holocene
Alkenone

ABSTRACT

Records of the climatic impacts of the North Atlantic Bond cycles over the subtropical Southern Hemisphere remain scarce, and their mechanism is a topic of active discussion. We present here an alkenone-based reconstructed sea surface temperature (SST) of a sediment core retrieved from the Brazilian Southwestern Tropical Atlantic (SWTA), Rio de Janeiro, together with a sediment SST record from the Cariaco Basin. The sediment cores span the period 2,100 B.P. – 11,100 B.P. Morlet-wavelet analysis detected marked periodic signals of ~0.8, ~1.7 and ~2.2 kyr, very similar and with comparable phases to the hematite-stained-grain time series from the Northern North Atlantic in which the cyclic pattern was recognized as Bond cycles. Our result corroborates the modeled surface ocean anti-phase thermal relation between the North and the South Atlantic. We attribute this behavior to the slowing of the Atlantic Meridional Overturning Circulation. The relative SST warming at Rio de Janeiro and the relative cooling at Cariaco were comparatively more pronounced during the early Holocene (from 11 to 5 kyr B.P.) than in more recent time.

1. Introduction

The Atlantic Meridional Overturning Circulation (AMOC) is considered to be the primary ocean process in which heat is delivered meridionally between the two hemispheres through the Atlantic Ocean. It carries warm surface waters towards the North Atlantic, where they cool and sink. It is estimated that the AMOC redistributes as much as ~25% of the global combined atmosphere–ocean heat flux (Cunningham et al., 2010) and that it explains the mild climate conditions observed at the Eastern North Atlantic Ocean sector. It has been speculated that a weakening of the AMOC is likely to occur in the near future due to the effects of anthropogenic greenhouse gas emissions (Cubasch et al., 2001; Bryden et al., 2005; Meehl et al., 2007). This weakening would result in excess melt-water influx from the Arctic and Greenland, which in turn would trigger further climate changes. Nevertheless, the additional meltwater influx is probably not the only cause for AMOC weakening. Results from modeling experiments of Gregory et al. (2005) have indicated that weakening would be caused more by changes in ocean surface heat flux than by changes in surface water flux. In all of the 11 climate models investigated by their work, the AMOC does not collapse strongly despite the final concentrations of CO_2 reaching 4 times modern values.

During the last glacial, rapid air temperature increases followed by intense cooling are clearly evident in NGRIP Greenland ice core (Andersen et al., 2007), North Atlantic sediment cores (Clement and Peterson, 2008) and Northern Hemisphere palynology (Correa-Metrio et al., 2012). These events were named Dansgaard-Oeschger (D-O) and Heinrich events. They were attributed to influx of meltwater that promoted significant reduction in the strength of AMOC in which effects were globally synchronous. It has been proposed that D-O events were pretty regular with cyclicity around 1470 years (Rahmstorf, 2003). Although much less intense, an apparently analogous climate fluctuation during the Holocene was also recorded from petrologic tracers present in sediment cores from the North Atlantic with a cyclicity of ~1470 ± 500 years and named Bond cycles (Bond et al., 1997). The same cyclicity was found by Bianchi and McCave (1999) using sediment grain-size data that they employed as a proxy of the deep-water flow, an important component of the thermohaline circulation in the Iceland basin. Their grain-size data indicated increased water speeds when the climate of Northern Europe was warmer.

During the last 12 kyr, eight occurrences of hematite-stained-grain (HSG) peaks were recognized as ice-rafted debris. Significant correlations obtained between the stacked marine records and cosmogenic

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http://dx.doi.org/10.1016/j.palaeo.2014.07.019
0031-0182/

radionuclides, whose activity concentrations are thought to be modulated by the solar-terrestrial geomagnetic activity, suggested originally that changes in solar activity could be the major forcing agent of these events (Bond et al., 2001). A later study conducted on the cyclicity pattern of the time series using spectral wavelet analysis was able to distinguish between the solar forcing and the oceanic forcing to show that the 1500-year cycle was basically an ocean-related climate phenomenon (Debret et al., 2007).

The consensus is that the influx of excess meltwater into the Northern North Atlantic, whether forced by anthropogenic causes or due to natural forcings like the Bond events, would have important implications to the regional ocean circulation dynamics. It is proposed that if the AMOC collapses, it would reduce the inter-hemispheric northward heat transport and consequently induce a positive temperature anomaly in the tropical Southern Ocean and induce a bipolar see-saw pattern characterized by a cooling of the northern Atlantic Ocean and warming of the South Atlantic (Crowley, 1992). Nevertheless, no robust experimental evidence from marine records from the Southern Atlantic Ocean exists to show this north–south synchronicity in ocean heat transport. In this work we present reconstructed SST record from Rio de Janeiro that may help to clarify the South Hemisphere response to Holocene Bond cyclicity and that extends our knowledge of the global impact of the Pleistocene ~1500 yr cyclicity.

2. Methods

2.1. Site description

The oceanographic system at the coring site has two main components: (1) the prevailing action of the Brazil and the North Brazil Currents (BC and NBC) that constitute low density tropical waters flowing south/southwest along the Brazilian coast partially over and mostly off the continental shelf; and (2) the South Atlantic Central Water (SACW) that rises at the coast coming from the west, which is most pronounced during austral spring and summer seasons (Coelho-Souza et al., 2012; (Fig. 1). The SACW component is responsible for an important quasi-seasonal upwelling phenomenon that occurs in Cabo Frio at around latitude 23°S. The upwelling itself occurs when a prevailing northeasterly trade wind dominates in the region (Calado et al., 2008) as a result of a north–south to east–west change in the orientation of the South American shoreline. The intense and constant flow of the BC and NBC waters, accompanied by a relatively low volume of regional fluvial terrigenous sediment delivery, makes the Southwestern Atlantic coast a region of low sedimentation rates (Mahiques et al., 2005). Along the Southwestern Brazilian coast the BC occupies the top 200 m of the water column. The SACW is located just below it to the domain of the Antarctic Intermediary Waters. The sediment core was retrieved on the continental shelf, which is the domain of the Plataform Waters (mostly confined near shore) that is fed by meanders of the BC and is seasonally influenced by the oligotrophic waters of the SACW.

2.2. Sediment core recovery

The sediment core (ID: CF02-02A) used in the study was collected by the PSV Astro Garoupa Vessel (Astromarítima/PETROBRAS), on 15th August 2002, at 124 m water depth (23°16′00″S, 41°48′02″W). A Kullenberg piston corer was used to recover 228 cm of sediment from a shelf mud patch made up of grayish hemipelagic mud. The core was sub-sampled continuously at 1 cm intervals; the sub-samples were oven dried at <50 °C and ground in an agate mortar. Core X ray stratigraphy was performed by the SCOPIX method (Migeon et al., 1999).

2.3. Sea surface temperature (SST) reconstruction method

Past SSTs were obtained from the unsaturations ratio of long-chain C_{37} alkenones: the alkenone unsaturation index, $U^{K'}_{37}$. These compounds are biosynthesised exclusively by a group of prymnesiophyte algae, principally the coccolithophorid *Emiliania huxleyi* (Prahl et al., 1988; Marlowe et al., 1990; Volkman et al., 1995). Because of the presence of a natural compound in the samples with the same retention time as the 5-α-cholestane employed as a quantitative standard and in order to avoid quantification problems, $U^{K'}_{37}$ was calculated using the peak areas of $C_{37:2}$ and $C_{37:3}$ instead of their absolute concentrations—therefore, $U^{K'}_{37} = (C_{37:2}$ peak area) ÷ ($C_{37:2}$ peak area + $C_{37:3}$ peak

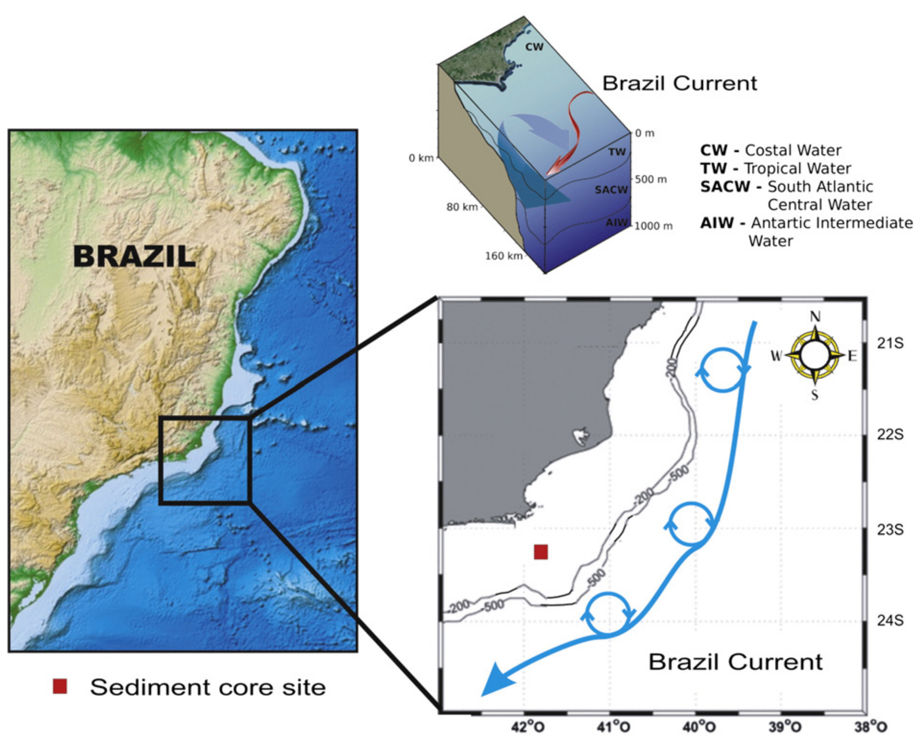

Fig. 1. Main oceanographic features and marine currents at Rio de Janeiro core site. The 500 m isoline limits the continental shelf.