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Influence of continental shelf processes in the water mass balance and productivity from stable isotope data on the Southeastern Brazilian coast

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ABSTRACT

Stable isotopic composition ($\delta^{18}O$ and δD of water, $\delta^{13}C_{DIC}$) of the water column in the open ocean is related to the origin of water masses. Due to the recent increase of paleoceanographic studies on continental shelves, it is also important to understand their distribution and variability in those systems. To examine the influence of continental shelves internal processes on isotopic composition of water masses, we present data of stable isotopes and phosphate content from a western boundary upwelling system located on the Southeastern Brazilian coast and compare them with offshore observations. High mixing of the main water masses (SSW, TW and SACW) was observed in the majority of the samples collected during different seasons in 2011 and 2012. A mixing triangle approach was used to separate the water masses contribution and characterize their isotopic composition. In addition, an isotopic three end-member model was established, proposing it as a paleoceanographic tool to reconstruct relative contribution of these water masses in sediment records. Variations of $\delta^{18}O$ values are linked to oceanographic dynamics, mixing, continental runoff and upwelling processes on the shelf. Differently the $\delta^{13}C_{DIC}$ variations in the middle and inner parts of the shelf are related to the productivity of the upwelling system. Seasonal variability of the $\delta^{13}C_{DIC}$ values may be also related to changes in the upwelling intensity.
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1. Introduction

The oceans are an important redistribution agent for the constituents of the Earth's climate system, as heat, fresh water and carbon dioxide. Variations of these constituents affect the climate and leave imprints that can be tracked by geochemical tracers. One of these tracers is the isotopic composition of water masses. The relevance of this specific tracer lies on the fact that biogenic carbonate is assumed to be in isotopic equilibrium with water. As a consequence isotopic composition of foraminifera has been one of the most widely used tools to reconstruct both the variations in sea surface temperature and salinity ($\delta^{18}O$) and paleoproductivity ($\delta^{13}C$) in marine cores (Ganssen et al, 2011; Morley et al, 2011; Piotrowski et al, 2009; Thornalley et al, 2010). The establishment of isotopic equilibrium functions, based on culture experiments (Bemis et al, 1998; Erez and Luz, 1983; Kim and O'Neil, 1997) and calibrated by studies with tops cores (Grauel and Bernasconi, 2010; Steph et al, 2009), trawled plankton nets (Mulitza et al, 2003) and sediment traps (Sautter and Thunell, 1991; Wejnert et al, 2010), make possible to reconstruct the variations of temperature (SST) and salinity (SSS) in sea surface water in paleoceanographic studies. However, the accuracy of these SST–SSS reconstructions still depends primarily on assumed values for the $\delta^{18}O$ of seawater, which despite being considered conservative and near the standard VSMOW (Vienna Standard Mean Ocean Water) for the open ocean, can suffer large variations on the continental margins resulting from the action of oceanic and shelf water mixing including continental water contribution, the balance of precipitation–evaporation (P:E) which is distinct between west and east ocean boundaries, or even coastal upwelling, bypassing thus the average signal of global scale (Bigg and Rohling, 2000; Mackensen, 2001; Meredith et al, 1999).

Moreover, searching high resolution records, especially for the Holocene, many studies have used marine sediments deposited on the continental shelf (Limmer et al, 2012; Mendes et al, 2010; Nizou et al, 2011) whose dynamics results from interactions of shelf processes such as mixing, continental runoff and coastal upwelling, and the mesoscale boundary processes, which contains much of the climatic oscillations of the boundary currents. Under these conditions the oxygen isotopic composition of seawater ($\delta^{18}Ow$) deviates from the values of open ocean waters, and imprints significantly the oxygen isotopic composition of the carbonate ($\delta^{18}Oc$) used to reconstruct paleotemperatures of calcification. Therefore, an assessment of the degree of mixing of

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the shelf waters is critical to propose accurate paleotemperature reconstructions based on the oxygen isotopic composition of carbonate shells of foraminifers of sediments from the continental shelf.

Continental margins also represent the main productive compartment of the oceans. The potential fertilization of coastal waters arising from runoff and aeolian inputs and from upwelling of deeper and colder nutrient rich waters alters the carbon isotopic composition of the dissolved inorganic carbon ($\delta^{13}C_{DIC}$), which is recorded in the $\delta^{13}C$ values of biogenic carbonates, thus influencing, the understanding of the variance of paleoproductivity signal (Eberwein and Mackensen, 2008; Lückge et al, 2009). This is especially valid on the western boundary of the oceans where the signal of local upwelling systems may vary significantly from the paleoproductivity of boundary current waters (Bickert and Wefer, 1999).

On the Southwestern Atlantic, the only study that addresses the isotopic composition of seawater was conducted by Pierre et al. (1991), that through the pair $\delta^{13}C_{DIC}$ and $\delta^{18}Ow$ showed a clear distinction between the main water masses carried by the main Western Boundary Current, the Brazil Current: TW (Tropical Water), SACW (South Atlantic Central Water), and the waters on intermediate depths carried by less organized deep currents AAIW (Antarctic Intermediate Water), NADW (North Atlantic Deep Water) and AABW (Antarctic Bottom Water). However, the oceanographic regime of the open ocean is distinct from the continental shelf, which can lead to differences in the isotopic composition of the water masses of the Brazil Current (TW and SACW). Albuquerque et al (2014) and Belem et al (2013) showed that, in the Eastern Brazilian Continental Shelf (EBS), multiple oceanographic processes act together to control shelf temperature variability near the shelf break and inshore of the western boundary current, and the isotopic composition of these shelf water masses will thus reflect in part these processes. Starting from these pioneering results, this study aims to understand how the typical processes of dynamic shelf influence the isotopic compositions ($\delta^{18}Ow$, δ Dw and $\delta^{13}C_{DIC}$) of water masses of the Brazil Current and the EBS to improve the accuracy of paleoceanographic reconstructions from sedimentary cores of the continental shelf.

2. Oceanographic setting

The continental shelf of southeastern Brazil, especially between the parallels 21°S and 25°S (Fig. 1), is widely studied due to the upwelling system in the area of Cabo Frio (e.g. Castelao, 2012; Castelao and Barth, 2006; Castro and Miranda, 1998; Ikeda et al., 1974; Matsuura, 1996; Rodrigues and Lorenzzetti, 2001; Diaz et al, 2012). The Brazil Current (BC) flows southward along the shelf break and slope, as a component of South Atlantic Subtropical Gyre and gains integrity and velocity south of Abrolhos bank (Campos et al., 2000). However, around 23°S the continental margin changes orientation from NE–SW sharply to E–W. Instability in the BC flow associated with prevailing NE trade winds and a wind divergent on the midshelf (Castelao and Barth, 2006) causes an enhanced pumping of SACW on the shelf and the formation of an Upwelling System which controls the local oceanography and production in the area (Belem et al, 2013). Moreover, this boundary current carries the Tropical Water (TW) in the upper layer and the South Atlantic Central Water (SACW) in a more intermediate depth southward (Stramma and England, 1999). The TW and the SACW, additionally to the Coastal Water (CW), are the main water masses in this region (Castro and Miranda, 1998).

These three different water masses are characterized by their temperature and salinity patterns (Fig. 1). The TW is associated with temperatures higher than 20 °C and salinities above 36.4. The CW and TW have the same temperature range but the CW is characterized by lower salinities than the TW, as a result from the mixing of shelf waters and continental drainage (Castro and Miranda, 1998) although the contribution of river discharge is minor (Oliveira et al, 2006). However some studies also define the CW as Subtropical Shelf Water (SSW) (Piola et al, 2000) and we decided to adopt the term SSW in this study. Finally, the presence of SACW on the shelf is characterized by temperatures below 20 °C and salinities lower than those of TW (Castro and Miranda, 1998; Silveira et al., 2000). The SACW can be found at the surface near the coast characterizing the costal upwelling of Cabo Frio that is most associated with the persistence of intense NE winds and is also explained by bottom topography, coastline geometry and wind stress curl (Castelao and Barth, 2006; Rodrigues and Lorenzzetti, 2001). In the inner shelf, upwelling is enhanced during austral spring and summer and is seasonally modulated by NE winds (Cerda and Castro, 2013). However in the mid-shelf, Belem et al. (2013) and Albuquerque et al. (2014) pointed out that SACW intrusions in the euphotic zone (sub-surface upwelling) are intermittent all over the year. This Western Boundary Upwelling System (WBUS) is considered unique due to its configuration in a mosaic of oceanographic systems, which acts synergetically in biogeochemical processes on the shelf (Albuquerque et al, 2014). Typically, the region is defined as oligotrophic due to the TW characteristics but with enhanced local productivity due to the upwelling.

We emphasize that, although the SACW outcrops at the surface in the coastal region, producing an upwelling in its sensu strict definition, it

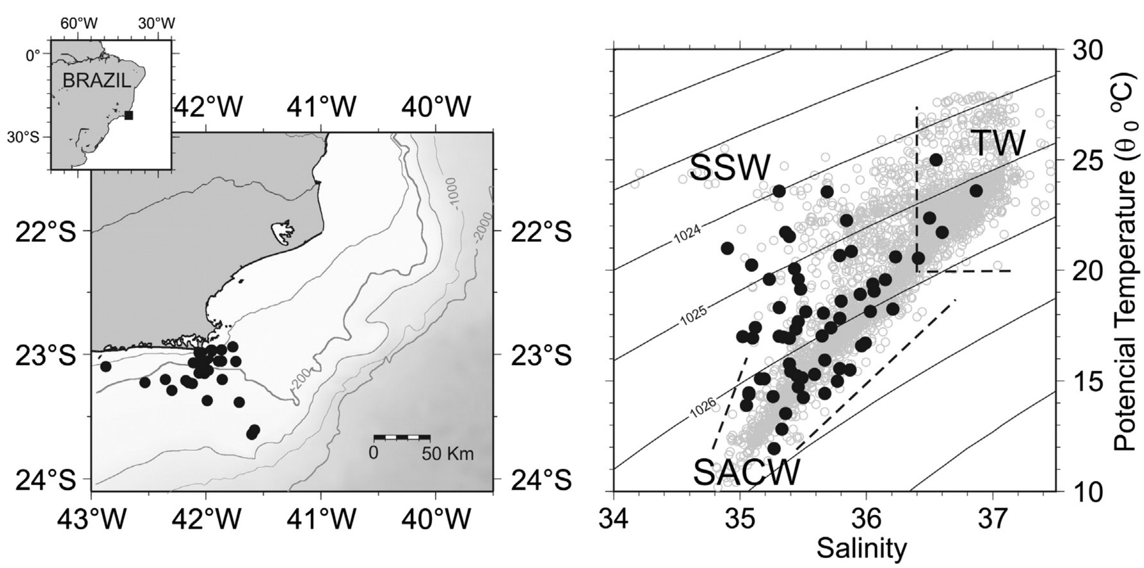

Fig. 1. Location of oceanographic stations and regional T–S diagram. The gray dots represent T–S extracted from NODC database for the region and the black dots represent the data collected in this study.

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