We thank Referees #1 and #2 as well as the Editor (Prof. Dr. Arne M.E. Winguth) for the very constructive reviews of our manuscript. We worked extensively to address all comments and suggestions. Below, we provide a point-by-point response together with a description of all relevant changes performed to the revised version of the manuscript. To facilitate the discussion, we copied the comments and suggestions from Referees #1 and #2 in black and inserted our responses in blue.

Anonymous Referee #1

The manuscript represents an important contribution for the paleoceanographic and paleoclimatic reconstruction of the Southwest South Atlantic, addressing relevant scientific questions within the scope of CP. It analyzes the relative abundance of some species of planktonic foraminifera and 100m-temperature reconstructions from the uppermost 350 cm of a sediment core extracted from the southern Brazilian margin. Despite it does not contribute with new concepts or substantial data, it intends to elucidate the mechanisms behind the high glacial productivity recorded in the region, and consequently, interesting conclusions are reached. In general terms the manuscript is well written and it is easy to follow the reasoning proposed by the authors. The title clearly reflects the contents, the abstract is concise and complete, the overall presentation is clear and correctly structured, and the references are correct. The language is fluent and precise; I did only some minor comments in the PDF about it.

Response #1 – We thank Referee #1 for the suggestions made directly in the PDF file. We incorporated all of them in the revised version of our manuscript.

The scientific approach is correct. However, there are methodology aspects that could be improved. Some of the applied methods lack of robustness:
the authors state that the “basic assumption is that temperature of ambient seawater is the primary control of foraminiferal assemblages” (line 139). In a particular region like this, why not considering that the planktonic foraminiferal assemblages could mainly respond to productivity instead of temperature? Did the authors test this option? I suggest them to consider this possibility and evaluate it.

Response #2 – We agree that under specific circumstances, productivity may be the first order stressor controlling planktonic foraminifera assemblage (PFA). Indeed, PFA are controlled by different environmental parameters (e.g. temperature, productivity, mixed layer depth), and productivity has been reported as the first order stressor in eastern boundary upwelling zones (e.g. Salgueiro et al., 2014). In general, however, when MAT is used to reconstruct past temperatures out of eastern boundary upwelling zones, the basic assumption is to consider temperature as the first order stressor (Telford et al., 2013), as performed in our study. This assumption has been extensively tested and is routinely applied in paleoceanographic studies not investigating eastern boundary upwelling zones (e.g. Kucera et al., 2005; Lessa et al., 2017; Niebler & Gersonde, 1998; Portilho-Ramos et al., 2015). Additionally, the Canonical Correspondence Analysis of core-top sediments and water column properties from the Atlantic and Pacific Oceans indicates that PFA is highly correlated (30.4% of faunal variance) to temperature, while only 7.9% of the faunal variance is related to productivity (Morey et al., 2005). The western boundary upwelling zones like those along the Brazilian margin are not as strong and geographically extensive as their eastern boundary counterparts (e.g. off Iberian margin and off NW Africa). In contrast, the Brazilian margin is generally an oligotrophic area bathed by nutrient-poor, warm and salty tropical waters of the Brazil Current (e.g. Peterson and Stramma, 1991; Brandini et al., 2000; Locarnini et al., 2013; Zweng et al., 2013; Garcia et al., 2014) dominated (i.e. ca. 80% of the PFA) by warm tropical water foraminifera species (i.e. *Globigerinoides ruber*, *Globigerinoides trilobus* and *Globigerinella siphonifera*) (e.g. (Boltovskoy et al., 1996, 2000; Kucera et al., 2005; Venancio et al., 2016). In the investigated marine sediment core JPC-17, tropical species are responsible for ca. 70% of PFA. Thus, warm-oligotrophic species largely dominate PFA variance and supports the application of a temperature-based MAT, as performed in our study.

Instead, the authors use 100m-temperature reconstructions derived from MAT following Portillo-Ramos et al. (2015). In that contribution, the authors follow the criteria of Telford et al. (2013). Telford et al. emphasize that the highest performance of a transfer function is the one that should be used and, in 2015, Portillo-Ramos et al. obtained the best performance at 10 m, not 100 m depth. As in this contribution the aim of the authors is to reconstruct the subsurface temperature, I strongly recommend (following Telford et al., 2013) to constrain the training set to a regional scale and try to obtain a better performance at 100 m depth. In fact, they could apply the same criteria of Lessa et al. (2017), who added 161 core tops from upwelling areas such as the Iberian Peninsula and NW Africa to the training set. I see this item important to be addressed.

Response #3 – Indeed, the criteria of Lessa et al. (2017), using the entire Atlantic Ocean dataset from MARGO (Kucera et al., 2005) and including 161 samples from North Atlantic eastern boundary upwelling zones (Salgueiro et al., 2014), improved the MAT performance at 100 m water depth in comparison to Portilho-Ramos et al. (2015). This approach also provides analogs between 5° and 15°C that are otherwise not available when the South Atlantic database is used alone. We now use a similar approach applying the entire Atlantic Ocean dataset from MARGO (Kucera et al., 2005) as well as and including 161 samples from the North Atlantic eastern boundary upwelling zones (Salgueiro et al., 2014) and obtained a R^2 of 0.98 and RMSEP of 0.95 (in the previous version of manuscript we had a R2 of 0.90 and a RMSEP of 1.5 for 100 m water depth). It is worthy of note that the new training set shows the same R2 for 10 and 100 m water depth, thus showing an equally good performance for these two specific water depths. The revised version of our manuscript was changed accordingly.

Finally, I suggest the authors to use the WOA data previous to 2005 in order to avoid the “global warming” signal.

Response #4 – We agree that using earlier versions of the World Ocean Atlas has the advantage of minimizing a possible bias related to “global warming”. However, these earlier versions have the disadvantage of showing a smaller spatial coverage, introducing local biases due to the interpolation of sparse data (Locarnini et al., 2013). Thus, using the 2009 version of the World Ocean Atlas (as performed in this study) represents a compromise between the deleterious effects of “global warming” and sparse data. Indeed, the impact of “global warming” over the temperature output of the World Ocean Atlas 2009 is rather small compared to the impact of “global warming” inherent to the first version of the World Ocean Atlas (Levitus and Boyer, 1994). In the 2009 version of the World Ocean Atlas, temperature is calculated as the average of instrumental data back to 1955 (Locarnini et al., 2009).

The age model is another point of argue. The first meter (which corresponds to the first 23 ka) was already published by Tessin and Lund (2013) and it contains 5 reversals (if we also consider the one obtained by Portillo-Ramos et al. -2014-). The last 2.5 meters have one AMS point from Portillo-Ramos et al. (2014) and two _18O points of control performed in this study. The _18O curve fits correctly with the Stack LS16 and the one obtained for sediment core GL-1090. However, as there are so many reversal points, why not trying a Bayesian model like Santos et al. (2017)? In fact, it would be better for the comparison with core GL-1090. I consider this a major point in the MS and I encourage the authors to check the age model. These issues can be easily improved.

Response #5 – Agree. We improved the age model by applying the R script BACON version 2.2, which uses Bayesian statistics to reconstruct Bayesian accumulation histories for sedimentary deposits (Blaauw and Christeny, 2011). All AMS ^{14}C ages were calibrated using the IntCal13 calibration curve (Reimer et al., 2013) with a reservoir correction age of 400 ±100 yr (1σ error). We estimated the error of the δ^{18}O tie-points similarly to Santos et al. (2017), considering the mean resolution of the JPC-17 benthic δ^{18}O record around the tie-point depth, the mean resolution of the reference curve around the tie-point age, a matching error visually estimated when defining tie-points, and the absolute age error of the time-scale used for the reference record. The chronology of core JPC-17 was additionally verified and supported by regional planktonic foraminifera biostratigraphy (Ericson & Wollin, 1968; Portilho-Ramos et al., 2014).

The new age model does not differ significantly from the previous one (i.e. maximum difference is 3.7 kyr around 56 – 60 cal ka BP), but BACON smoothed the interval with reversed ages (i.e. between16 and 21 cal ka BP). Importantly, the new age model does not change our interpretation or conclusions. Still, Figures 2-4 were updated. The revised version of our manuscript was changed accordingly.

I carefully read the referenced publications from the SBM and revise the results obtained for G. bulloides' relative abundances. When compared the different core's results, glacial abundances of G. bulloides in JPC-17 seem to be a bit higher than in the other cores (<10%). Nowadays, this species is considerably abundant along the Malvinas Current (Boltovskoy et al., 1996) and apparently the modern configuration of the Brazil-Malvinas Confluence would have been established _9 ka ago in response to changes in the strength of the SW-winds (Voigt et al., 2015). If the authors suggest that during the last glacial period there were "prolonged winter-like conditions of prevalent alongshore SW-winds and frequent cold front passages", I think they should consider the Malvinas Current also as a G. bulloides input.

Response #6 – Core JPC-17 (27ºS) is located ca. 10º to the north of the mean position of the Brazil-Malvinas Confluence (BMC) (Combes and Matano, 2014). We argue that a 10º meridional shift of the BMC during the last glacial period seems unrealistic. First, if this would have happened, the stable oxygen isotopic composition of glacial *Globorotalia inflata* (a particularly suited isotopic tracer of the Malvinas Current; Chiessi et al., 2007) from core GeoB6211-1 collected at ca. 32ºS should have registered the presence of the Malvinas Current, which is not the case (Chiessi et al., 2008). Second, one would expect a similar pattern between the abundance of planktonic foraminifera *Globigerina bulloides* and the abundance of dinoflagellate cyst *Brigantedinium* spp. (a particularly suited species to track the Malvinas Current; Zonneveld et al., 2013) from nearby core GeoB2107-3, which is not the case (Gu et al., 2017).

We argue that the slightly different *G. bulloides* abundance between core JPC-17 and nearby cores collected to the north of it (Portilho-Ramos et al., 2015) is rather related to the regional distribution of the species along the Brazilian margin. The high abundance of tropical species (ca. 80% of the PFA at 30º–36ºS) decreases towards higher latitudes along the Brazilian margin (Boltovskoy et al., 1996; Niebler et al., 1998; Boltovskoy et al., 2000; Kucera et al., 2005a; Venancio et al., 2016). For example, in surface sediments from the MARGO database (Kucera et al., 2005a), the abundance of *G. ruber* around the site of core GL-75 (21ºS) ranges between 50 and 60 % but decreases to 30–50% at the site of core JPC-17 (27ºS). The glacial abundance of *G. ruber* (and total tropical species) was 52.4% (84%) in northern core GL-75 and 38% (53%) in JPC-17, while its Holocene abundance was 55% (95%) in GL-75 and 45% (72%). Today, *G. bulloides* is virtually absent from the Brazilian margin, being restricted to surface sediments from the Cabo Frio Upwelling system (10–20 %; Lessa et al., 2014). Thus, we interpret glacial abundances of *G. bulloides* of 8–18 % (JPC-17) and 3–12 % (GL-75) as associated to enhanced upwelling.

Anonymous Referee #2

This paper presents a new record of foraminiferal species abundances, which are used to reconstruct temperature and productivity changes off the Brazilian Margin over the last 70 kyr. In general, I enjoyed reading this paper, which is clearly written and with apparently sound methods (note that the use of MAT isn't my area of expertise) and mostly good interpretations. I have a suggestion for a moderate revision to the manuscript before publication in Climates of the Past, and some minor corrections/ suggestions for the correct use of English. My main comment surrounds the interpretation of the silicic acid leakage hypothesis (SALH). The authors use as evidence for silicon leakage the opal records from sediment core RC13-254 and 259. Whilst these do show a change in opal burial from the glacial into the Holocene, this change in burial is most likely a result in the shift of location of opal production (due to movement of frontal zones), rather than an overall net change in opal accumulation in the Atlantic Sector and leakage of DSi (see papers by Kumar et al., 1995 and Frank et al., 2000). [In contrast to the Atlantic, the Pacific Sector may have experienced not only a shift in opal burial location, but also a net decline across the glacial termination (Chase et al., 2003)]. Although there is some evidence that there was a net decrease in opal burial in the Equatorial Atlantic over this time period (Bradtmiller et al., 2007), opal records from the Atlantic Ocean north of the APF are variable and paint an inconsistent story. There are also AAIW DSi reconstructions available for the Western Atlantic available for comparison, including from GeoB2107- 3 (Hendry et al,. 2012; Griffiths et al., 2013). In summary, I think the authors should make a more nuanced discussion of the evidence for Atlantic ∆Si leakage changes on glacial-interglacial timescales taking all of the evidence into account.

Response #1 – We agree that a more nuanced discussion about the Atlantic silicic acid leakage hypothesis (SALH) would be beneficial to the manuscript. We now discuss the evidences for the SALH in the South Atlantic. This includes the Antarctic Intermediate Water silicic acid content from nearby core GeoB2107- 3 (Hendry et al., 2012) and from equatorial Atlantic cores RC24-01, RC24-07 and MD99-2198 (Bradtmiller et al., 2007; Griffiths et al., 2013). Importantly, South Atlantic Central Water is highlighted as the major conduit for sub-Antarctic thermocline waters involved in the SALH (Sarmiento et al., 2004) that has great potential to boost primary production in the southern Brazilian margin (Campos et al., 2000). We also improved Figure 4 by adding biogenic opal records from cores RC24-01 and RC24-07 from the equatorial upwelling off NW Africa (Bradtmiller et al., 2007). The revised version of our manuscript was changed accordingly in lines 310 – 322, lines 326 – 330 and lines 355 – 356, and Figure 4.

Minor suggestions/corrections:

Line 18: The first sentence of the abstract would read better if merged with the second sentence: “This study explores the mechanisms behind the high glacial productivity in the southern Brazilian margin during the last 70 kyr, using planktonic foraminifera:

Line 49: Avoid phrases such as “On the other hand” e.g. use “Opposing this drawdown, the upwelling:

Line 79: Change “mechanisms” to “mechanism”

Line 94: What is meant by “besides other oceanographic processes”? Perhaps just remove this phrase as I don’t think it adds anything

Line 101: Change “vicinities” to “vicinity”

Line 110: Change “vicinities” to “vicinity”

Line 120: Change “limestone” to “sediments” Line 153: Change “where” to “were”

Line 157: Change “decide” to “decided”

Line 180: Change “by” to “of”

Line 204: Change “has” to “have”

Line 214: Change “like” to “such as”

Line 237: I find the references to G. bulloides vs. dinocyst deposition showing different seasonal changes rather repetitive as it appears a number of times throughout the text. As a suggestion, perhaps remove reference to it at this point, leaving the explanation of the interpretation to the next section.

Line 248: Remove “On the other hand”

Line 256: Change “to” to “with”

Line 259 (and elsewhere): I find the use of the phrase “eutrophic environmental dinocysts” a little unclear. As a suggestion, perhaps replace with “dinocysts characteristic of eutrophic conditions”, and then subsequently just refer to “dinocysts”?

Line 286: Change “do” to “does”

Line 288: This sentence could do with restructuring. Perhaps “dinocyst record from core GeoB2107-3 matches austral winter (June) insolation at 65oS very well over the past: : :”

Line 301: This sentence could do with restructuring. Perhaps “We suggest that, rather than being driven by changes in upwelling intensity: : :, the increased productivity may have been a result of increased silicic acid content: : :” (this sentence appears in a similar form in the conclusions, and so should also be rephrased)

Line 324: Change “benefited the” to “benefited from the”

Line 337: Change “decrease” to “decreased”

Line 338: Change “Oligotrophic conditions is” to (e.g.) “The presence of oligotrophic conditions is”

Response #2 – We thank Referee #2 for the corrections. We incorporated all of them in the revised version of our manuscript.

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Understanding the mechanisms behind high glacial productivity in the southern Brazilian margin

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Abstract. This study explores the mechanisms behind the high glacial productivity in the southern Brazilian margin during the last 70 kyr~~. Therefore, we use~~ using planktonic foraminifera assemblage and subsurface temperatures derived through the Modern Analogue Technique. We show that enhanced glacial productivity was driven by the synergy of two mechanisms operating in different seasons: (i) ~~high~~an enhanced productivity in the upwelling region during short austral summer events; and (ii) the persistent presence of the Plata Plume Water due to prolonged austral winter conditions. We suggest that the upwelling systems in the southern Brazilian margin were more productive during the last glacial period due to the enhanced Si supply for diatom production through high-Si thermocline waters preformed in the Southern Ocean. We hypothesize that orbital forcing did not have a major influence on changes in upwelling during the last glacial period. However, the more frequent northward intrusions of the Plata Plume Water were modulated by austral winter insolation at ~~65°S~~60°S through changes in the strength of alongshore SW-winds. After the Last Glacial Maximum, the reduced Si content of thermocline waters decreased upwelling productivity, while lower austral winter insolation decreased the influence of the Plata Plume Water over the southern Brazilian margin, reducing regional productivity.

1. Introduction

Continental margins are regions of relatively high biological productivity and long-term carbon storage due to high nutrient flux (i.e. continental discharge and upwelling) and shallow seafloor depths (i.e. interception of sinking particulate organic matter) (Abrantes et al., 2016; Bianchi et al., 2005; Brandini et al., 2018; Ito et al., 2016; Wang et al., 2015). The high biological productivity and exportation of particulate organic carbon to the seafloor, the so-called "biological pump" (Turner, 2015), play a paramount role in removing CO_2 from the atmosphere (Bianchi et al.,2005; Muller-Karger et al., 2005). It is estimated that ca. 0.06Pg C yr^{-1} is buried in continental margins accounting for >40% of the carbon storage in the oceans (Muller-Karger et al., 2005). Opposing to this drawdown, the upwelling of CO_2-rich thermocline waters along continental margins can release CO_2 to the atmosphere (Bianchi et al., 2005; Ito et al., 2016). Thus, continental margins have a great potential to modulate the drawdown and emission of atmospheric CO_2, influencing the Earth's climate system.

The southwestern Atlantic (southern Brazilian margin – SBM) is generally an oligotrophic area bathed by nutrient-poor, warm and salty tropical waters of the Brazil Current (BC) (Fig. 1). However, upwelling zones and riverine discharge inject nutrients into the photic zone (Brandini et al., 2018; Campos et al., 2000, 2013; Garcia and Garcia, 2008; Möller et al., 2008) resulting in confined areas and seasons with higher concentration of phyto-zooplankton biomass (Brandini et al., 2014; Rodrigues et al., 2014). During austral summer, upwelling zones are intensified due to the prevailing alongshore northeasterly winds and the cyclonic meanders of the BC induced by the interaction of the current with the morphology of the continental margin (Aguiar et al., 2014; Campos et al., 2000; Castelao et al., 2004). Winter conditions of vigorous alongshore SW-winds and a relatively weakened BC, allow the northward intrusion of low-salinity waters from the Plata River along the SBM (Garcia and Garcia, 2008; Möller et al., 2008). Both processes increase local productivity and lead to distinct changes in planktonic community (Brandini et al., 2014; Rodrigues et al., 2014), that are preserved in sea-floor sediments and can be used to reconstruct changes in productivity in the SBM over time (Gu et al., 2017; Lessa et al., 2017; Portilho-Ramos et al., 2015).

Previous paleoceanographic studies provide evidence for an extremely intense primary productivity in the SBM probably related to an upwelling system during part of Marine Isotope Stage 5 (~90 – 130 kyr) forced by strengthened NE-winds and BC (Lessa et al., 2017; Portilho-Ramos et al., 2015). During the last glacial period (Marine Isotope Stages 2-4, ~11.7 – 71 kyr), primary productivity weakened but was still significantly higher than the one occurring in the Holocene (Portilho-Ramos et al., 2015). It has been suggested that the upwelling systems of the SBM were reduced during the last glacial period, and may have been limited to short intervals of the austral summer due the prolonged winter-like conditions of prevalent alongshore SW-winds and frequent cold front passages (Portilho-Ramos et al., 2015). However, high abundance of eutrophic dinoflagellate cysts suggests increased primary productivity in the SBM during specific intervals of the last glacial period (Gu et al., 2017). These high productivity periods would be triggered by the input of local (i.e. Itajaí River) and remote riverine nutrient-rich freshwater (i.e. Plata River plume) (Gu et al., 2017). Additionally, a recent study proposed that the periods of expansion and contraction of the upwelling zones of the SBM are modulated by eccentricity (Lessa et al., 2017), providing yet another mechanism to explain the evolution of primary productivity in the SBM. In summary, these studies show that different oceanographic mechanisms may have triggered high primary productivity in the SBM over time. These mechanism~~s~~ are, however, poorly understood.

Here we used records of planktonic foraminifera assemblage and associated subsurface temperature reconstructions derived by the Modern Analogue ~~technic~~Technique (MAT) from piston core JPC-17 (27°52.73'S, 46°55.25'W) to understand the paleoceanographic processes controlling changes in biological productivity in the SBM over the last 70 kyr. The comparison of our results to previously published records from the SBM allowed us to recognize two different mechanisms modulating past productivity changes over the last glacial-interglacial cycle.

2. Regional setting

The SBM is an oligotrophic margin under the influence of warm (≥ 25ºC) and salty (≥ 35psu) Tropical Water that flows southward within the BC (Fig. 1). Interactions of the BC with the morphology of the margin (i.e. changes in the orientation of the margin and the presence of a barrier represented by the Abrolhos Bank)~~, besides other oceanographic processes,~~ generates cyclonic meanders and eddies that bring cold (≤20ºC) and nutrient-rich thermocline waters (South Atlantic Central Waters (SACW) to shallower depths where they are subjected to alongshore NE-winds (Aguiar et al., 2014; Campos et al., 2000; Castelao et al., 2004; Rodrigues and Lorenzzetti, 2001). Once over the shelf, wind stress and the Ekman dynamics brings the SACW to the surface creating mature upwelling zones in the SBM (Aguiar et al., 2014; Castelao et al., 2004). These processes boost biological productivity in specific portions of the SBM such as off Vitória (~18ºS), Cabo Frio (22º–23ºS) and Cape Santa Marta (27º–29ºS) during the austral summer (Fig. 1). Marine sediment core JPC-17 investigated in this study was collected off Cape Santa Marta (Fig. 1).

In the ~~vicinities~~ vicinity of Cape Santa Marta, local productivity is also enhanced by the injection of nutrients from freshwater discharge of local (i.e. Itajaí River) and remote (i.e. Plata River and Patos/Mirim Lagoon complex) sources (Garcia and Garcia, 2008; Möller et al., 2008). During the summer (Fig. 1A), the upwelling favorable NE-winds and the strong BC block the northward penetration of the Plata Plume Water (PPW) (at ca. 32ºS) (Campos et al. 2013; Möller et al. 2008). During austral winter (Fig. 1B), the weakened BC and the prevailing alongshore SW-winds increase the northward intrusion (up to ca. 27ºS) of the nutrient-rich, cold (≤18ºC) and low salinity (≤ 33.5psu) PPW (Campos et al. 2013; Möller et al. 2008).

Both upwelling and freshwater inject large amounts of nutrients into the oligotrophic SBM, modulating seasonally the biological productivity as well as plankton community in the region (Garcia and Garcia, 2008; Rodrigues et al., 2014). In the ~~vicinities~~ vicinity of the Cape Santa Marta, diatoms are the dominant group of phytoplankton, accounting for 29–90% of phytoplankton and 31–90% of the carbon biomass during the summer upwelling, while dinoflagellates dominates the phytoplankton during the winter intrusion of the PPW (Brandini et al., 2014).

3. Material and methods

Piston core KNR159-5-17JPC (27°52,73'S and 46°55,25'W) recovered 15 m from which the uppermost 350 cm were investigated in this study. The core was raised from 1627 m water depth during R/V KNORR cruise 159-5 from Woods Hole Oceanographic Institution (WHOI, USA) (Fig. 1). The upper 350 cm of the core consist in dark gray carbonate ~~limestone~~sediments. This section was sampled continuously every 10 cm and 2 g of sediment per sample were washed in 62 µm sieves.

3.1. Planktonic foraminifera assemblage

Planktonic foraminifera from core JPC-17 were dry picked from >150 µm size fraction and quantified in relative abundances from splits containing more than 300 specimens per sample. The taxonomy was based on Stainforth et al., (1975). We assumed the effect of dissolution in our planktonic foraminiferal faunal composition to be negligible since core JPC-17 was collected at 1627 m water depth, well above the modern and glacial lysocline (Volbers and Henrich, 2004). Here we do not distinguish between *Globigerinoides ruber* white and pink variety, and also counted *Globigerinoides sacculifer* and *Globigerinoides trilobus* together as *G. sacculifer* since they are genetically the same species (André et al., 2013). Considering the taxonomic ambiguity in distinguishing the small-sized (i.e. ≤250 µm) specimens of *Globigerinella calida* and *Globigerinella siphonifera* (Vargas et al., 2002) we counted them together as *G. siphonifera*.

3.2. Subsurface temperature reconstruction

We reconstructed subsurface temperatures at 100 m water depth using the modern analog technique (MAT) following Portilho-Ramos et al. (2015). The MAT was performed on the software C2 (Juggins, 2007) and the basic assumption is that temperature of ambient seawater is the primary control of the foraminiferal assemblage (Morey et al., 2005). The planktonic foraminiferal calibration dataset used here comprises 1052 surface samples from the Atlantic Ocean, from which 891 samples were previously published in Kucera et al. (2005a) and 161 samples from North Atlantic eastern boundary upwelling zones previously published in Salgueiro et al. (2014). The modern annual temperature values at 100 m water depth from WOA 2009 (Locarnini et al., 2010) were extracted and used to calibrate the MAT. For the MAT transfer function, the squared chord distance was applied as similarity measure. Additionally, when reconstruction results were evaluated, the weighted mean of the best 10 modern analogs was used (Kucera et al., 2005b). Using the leave-one-out cross-validation method, the root mean square error of prediction of the transfer function is 0.95°C ($R^2 = 0.98$).

3.3. Age model

An age model for core JPC-17 has been previously published on the basis of calibrated radiocarbon AMS ^{14}C ages, $\delta^{18}O$ in both planktonic and benthic foraminifera as well as regional planktonic foraminifera biostratigraphy (Portilho-Ramos et al., 2014a; Tessin and Lund, 2013). Reversals in radiocarbon ages from ca. 16 to 21 calibrated kiloannum before present (i.e. 1950 AD) (cal ka BP) ~~where~~ were detected by Tessin and Lund (2013). These authors excluded four radiocarbon ages (i.e. 50, 54, 58 and 82 cm core depth) out of 17 dated samples from core JPC-17 because of reversals (Table 1). The radiocarbon age obtained at 56 cm from Portilho-Ramos et al., 2014a) is placed within this interval and also seems to be reversed. Considering these age reversals, the chronology of the JPC-17 was improved using the R script BACON version 2.2, which uses Bayesian statistics to reconstruct accumulation histories for sedimentary deposits and considers a Student-t model to address outlying (reversed) ages (Blaauw and Christen, 2011). Thus, as explained by Blaauw and Christen (2011), BACON version 2.2 is not affected by outlying ages. For the upper 190 cm of core JPC-17, all AMS ^{14}C ages (Table 1) were calibrated using the IntCal13 calibration curve (Reimer et al., 2013) with a reservoir correction age of 400 ±100 yr (1σ error). For the core section that extrapolates the radiocarbon range (i.e. 191 - 350 cm), two additional tie-points (Table 1) were obtained by aligning the benthic foraminifera stable oxygen isotopes ($\delta^{18}O$) record from JPC-17 to benthic $\delta^{18}O$ of nearby core GL-1090 (Santos et al., 2017) (Fig. 1) and to the intermediate-depth South Atlantic benthic $\delta^{18}O$ stack LS16 (Lisiecki and Stern, 2016) using the Analyseries 2.0.5.2 software (Paillard et al., 1996) (Fig. 2). The benthic $\delta^{18}O$ curve from JPC-17 is a combination of published *Cibicidoides* spp. (Tessin and Lund, 2013) and unpublished *Cibicidoides* spp. $\delta^{18}O$ provided by WHOI (Fig. 2). The latest follow the methodology applied in (Curry and Oppo, 2005). Error estimations of the $\delta^{18}O$ tie-points followed Santos et al. (2017), which take into account the mean resolution of the JPC-17 benthic $\delta^{18}O$ record around the tie-point depth, the mean resolution of the reference curve around the tie-point age, a matching error visually estimated when defining tie-points and the absolute age error of the time-scale used for the reference record. Beside the default parameters of the software, the following settings were used: mem.mean = 0.4, acc.shape = 0.5. and t.a =9/t.b =10. A total of 10,000 age-depth realizations have been used to calculate the median age and the 1σ analytical uncertainty at 5 mm resolution (Fig. 2B). The chronology of core JPC-17 was additionally supported by planktonic foraminifera biostratigraphy (Ericson and Wollin, 1968; Portilho-Ramos et al., 2014b), where the presence of *Globorotalia menardii* and the low abundance of *Globorotalia inflata* indicate Biozone Z (Holocene), while the absence of *G. menardii* and the high abundance of *G. inflata* characterize the glacial Biozone Y (last glacial period) (Fig. 2).

4. Results

In contrast to a previous chronology (Portilho-Ramos et al., 2014a), the new age model for the upper 350cm of core JPC-17 spans the last ca. 70 cal ka BP (Fig. 2). The benthic oxygen isotope records from core JPC-17 display a clear glacial-interglacial pattern, comparable to the benthic $\delta^{18}O$ record of nearby core GL-1090 as well as that of the intermediate-depth South Atlantic benthic $\delta^{18}O$ stack LS16 (Lisiecki and Stern, 2016) (Fig. 2).

Planktonic foraminifera assemblage is composed ~~by~~ of 28 species and subspecies. The following six species accounted for more than 70% of total planktonic assemblage: *G. ruber* (39%); *Globigerina glutinata* (13%); *G. bulloides* (11.2%); *G. inflata* (8.8%); *G. sacculifer* (5%); and *G. siphonifera* (2.5%). The abundance of *G. menardii* (0.7%), *Pulleniatina obliquiloculata* (0.3%), *Orbulina universa* (0.3%), *Globorotalia crassaformis* (0.3%), *Neogloboquadrina dutertrei* (5.5%) and *Globorotalia truncatulinoides* (3.9%) were published in Portilho-Ramos et al., (2014a).

In general, the distribution of the most abundant species follows the glacial-interglacial pattern over the last 70 kyr (Fig. 3). The abundance of the non-spinose species *G. bulloides* and *G. inflata* were higher during the last glacial period (mean of 12% and 9.6%, respectively) and lower during the Holocene (mean of 4.6% and ~2%, respectively) (Fig. 3A, 3B, respectively). In contrast, the abundance of spinose species displayed the opposite behavior. The abundance of *G. ruber* ranged from 25 to 50% (mean of 39%) during the glacial and increased after 40 cal ka BP towards the Holocene (mean of 47) (Fig. 3C). The abundance of *G. sacculifer* and *G. siphonifera* display similar patterns (Fig. 3D, E, respectively), and ranged between 1.6–10.4% and 0–7.6% (respectively), with higher abundance during the postglacial interval (mean of 7.5 and 6.9%, respectively).

The temperature at 100 m-water depth derived from MAT ranged from ~~17.5~~16ºC to ~~23ºC~~21.3ºC over the last 70 kyr with lower temperatures recorded during the glacial (~~17.5 –~~16º–20.3ºC) in comparison to the Holocene (~~~23ºC~~21ºC) (Fig. 3F). A pronounced warming trend is observed after ~~40~~30 cal ka BP toward the Holocene.

5. Discussion

Planktonic foraminifera *G. bulloides* is a non-spinose surface-dwelling species generally inhabiting regions of cold and high phytoplankton biomass typically associated with upwelling zones (Lessa et al., 2014; Mohtadi et al., 2007; Sautter and Thunell, 1991). Thus, high abundances of *G. bulloides* in marine sediments from regions potentially affected by upwelling ~~has~~ have been widely used as an upwelling indicator (Godad et al., 2011; Peeters et al., 2002), including the SBM upwelling zones (Lessa et al., 2017; Portilho-Ramos et al., 2015). The last glacial abundance of *G. bulloides* in core JPC-17 (8–18%) (Fig. 3A) closely matches those found in surface sediments from the Cabo Frio upwelling (10−20%) (Lessa et al., 2014), suggesting the occurrence of a sustained upwelling off Cape Santa Marta in the SBM. It also closely matches glacial records from cores collected further north at the SBM ~~like~~ such as GL-75 (21°83`S; 40°01`W) (Portilho-Ramos et al., 2015), GL-77 (21º12’S; 40º02’W) (Petró et al., 2016) and SAN 76 (24°26′S; 42°17′W) (Toledo et al., 2007), where *G. bulloides* ranged between 8%–17%, suggesting widespread cooling and elevated productivity at the SBM during the last glacial period relative to the modern oligotrophic conditions (Fig. 4A, B). During the last glacial period, the reduced abundance of non-upwelling species *G. ruber* (25–50%) and other warm and oligotrophic symbiont-bearing species like *G. sacculifer* (2.1–10.4%) and *G. siphonifera* (0.3%–4.3%) (Fig. 3) support the occurrence of cold-productive conditions promoted by upwelling. Simultaneously, lower temperatures at 100 m water depth (≤ 20ºC) suggest that SACW may have been frequently located in the photic zone. The isotherm of 20ºC is used to track the boundary between Tropical Water and SACW (Castelao et al., 2004), and has been used as a proxy for the presence of SACW in the photic zone in the past (Portilho-Ramos et al., 2015; Lessa et al., 2017). It should be highlighted that a relative warming of thermocline waters observed after 30cal ka BP may be related to heat accumulation in the western South Atlantic associated to the glacial reduced mode of the Atlantic meridional overturning circulation (Santos et al., 2017) as well as increased transport of heat from Indian Ocean into South Atlantic through Agulhas Leakage (Martínez-Méndez et al., 2010).

Enhanced glacial productivity in the SBM was recently reported by a 74 kyr-long record of dinoflagellate cysts from adjacent core GeoB2107-3 (27°17'S; 46°45"W) (Gu et al., 2007). The authors provide evidences for increased eutrophic conditions associated to more frequent northward intrusions of the PPW (Fig. 4D) (Gu et al., 2017). However, *G. bulloides* is virtually absent in surface sediments deposited under the influence of the PPW to the north from the Brazil-Malvinas Confluence (Chiessi et al., 2007). Thus, more frequent northward penetrations of the PPW in our study site is unlikely to explain the enhanced glacial abundance of *G. bulloides*. In addition, the abundance of the eutrophic environmental dinocysts and *G. bulloides* show different behavior along the last glacial period (Fig. 4A, D). The dinocysts increased in abundance between 54–74 cal ka BP and 14–40 cal ka BP, suggesting increased productivity related to frequent northward intrusions of the PPW, while the opposite is observed between 40–54 cal ka BP (Fig. 4D), suggesting reduced influence of the PPW and relatively low productivity (Gu et al., 2017). In contrast, the abundance of the *G. bulloides* remained relatively high during the entire glacial with a decrease trend after 30 cal ka BP toward the Holocene (Figs. 3A, 4B). Furthermore, enhanced abundance of *G. bulloides* during the last glacial period is also observed as far north as 21°S (i.e. core GL-75) (Fig. 4A) (Portilho-Ramos et al., 2015), which is unlikely be explained by continuous presence of the PPW (Möller et al., 2008). ~~In summary, enhanced abundance of *G. bulloides* indicates that upwelling systems in the SBM were markedly active during the last glacial and its mismatch with dinoflagellate cysts assemblages suggests that both taxa recorded different seasonal oceanographic processes responsible for boosting primary productivity in the SBM: the Cape Santa Marta upwelling and the more frequent northward intrusions of the PPW.~~

5.1. Modern and past seasonal productivity processes in the SBM

Modern surface productivity in the SBM is seasonally modulated by two different processes that inject nutrients in the photic zone: (i) austral summer coastal and shelf-break upwelling (Campos et al., 2013); and (ii) austral winter northward intrusions of the PPW (Garcia and Garcia, 2008; Möller et al., 2008). During austral summer upwelling events, diatoms are the dominant group of the phytoplankton, accounting for 29–90% of phytoplankton density and 31–90% of the carbon biomass ~~(Brandini et al., 2014). On the other hand~~, while ~~while~~ dinoflagellate is the dominant group during the austral winter associated to northward intrusions of the PPW (Brandini et al., 2014). We suggest that both taxa reveal different seasonal conditions during the last glacial period, with *G. bulloides* recording upwelling events during austral summer and dinoflagellate recording northward intrusions of the PPW during austral winter.

Prolonged winter-like conditions of prevalent alongshore SW-winds and frequent cold front passages during the last glacial period may have limited the SBM upwelling systems to a short period of austral summer-like conditions, as suggested by Portilho-Ramos et al. (2015). Furthermore, increased continental runoff (i.e. Itajaí River, Plata River and Patos/Mirim Lagoon complex~~-~~) associated ~~to~~with enhanced precipitation over SE South America (Cruz et al., 2005; Wang et al., 2007) as well as a vigorous alongshore SW-winds were favorable to the northward penetration of the PPW. These conditions increased the abundance of dinocysts characteristic of eutrophic conditions in the SBM during the glacial (Gu et al., 2017). The lower sea level (Waelbroeck et al., 2002) may have caused offshore displacement of the PPW over to our core site location (Lantzsch et al., 2014).

Importantly, our reconstructed temperature at 100 m water depth indicates that SACW may have reached the photic zone during the last glacial period (Fig. 3F). Modern hydrographic data and model simulations show that shelf-break upwelling in the SBM induced by the interaction of the BC with bottom topography occurs year-long but is modulated by seasonal alongshore-wind direction (Brandini et al., 2018; Campos et al., 2013). Thus, a prolonged presence of the low salinity PPW in the region may have increased the upper water stratification and suppressed the surfacing of SACW, favoring the proliferation of eutrophic ~~environmental~~ dinocysts. In contrast, during short austral summer periods, the strengthening of both the alongshore NE-winds and the BC hampered the northward PPW migration, inducing the upwelling of SACW and creating favorable conditions to the proliferation of *G. bulloides*. Owing to the low resolution of core JPC-17, we cannot rule out an anthiphase between the *G. bulloides* (i.e. core JPC-17) and the ~~eutrophic environmental~~ dinocyst (i.e~~., coe~~. core GeoB2107-3) records that would assign the SW-winds and the associated northward penetration of PPW a key role on controlling the upwelling zones in the SBM during the last glacial period.

5.2. Orbital forcing of SBM upwelling systems

A recent study proposed orbitally forced changes in insolation (eccentricity) as a major mechanism modulating the intensification/deintensification as well as the expansion/contraction dynamics of the SBM upwelling zones (Lessa et al., 2017). In accordance to these authors, eccentricity maximum (≥ 0.03) during MIS5 would have altered the seasonality of the wind regime by controlling the amplitude of austral summer and winter insolation and the South Atlantic subtropical high-pressure position. Thus, prolonged NE-winds during austral summer promoted intensification and expansion (from 24°S to 28°S) of the SE-Brazil upwelling systems during MIS5. On the other hand, eccentricity minimum (≤ 0.02) during the Holocene would result in weak NE-winds and deintensifying and contracting these upwelling systems in comparison to MIS5 (Lessa et al., 2017).

However, the orbital mechanism proposed by Lessa et al. (2017) ~~do~~does not explain the intensified/expanded upwelling in the SBM during the last glacial period, since eccentricity was ≤0.02 during the entire interval (Fig. 4C). Interestingly, the ~~eutrophic environmental~~ dinocyst record from core GeoB2107-3 matches ~~very well~~ austral winter (June) insolation at ~~65°S~~ 60°S very well over the last 70 kyr (Fig. 4D), highlighting the close connection between dinocyst abundance and winter conditions through vigorous alongshore SW-winds and increased presence of the PPW in our core site. Periods of increased austral winter insolation at 65°S may have steeped the thermal gradient between the high and mid latitudes in the Atlantic sector of the Southern Ocean, intensifying the alongshore SW-wind system and the northward incursion of PPW, thereby boosting the eutrophic environmental dinocyst productivity in the SBM.

5.3. The silicic acid leakage hypothesis (SALH)

In sections 5.1 and 5.2, we showed that *G. bulloides* and ~~eutrophic environmental~~ dinocysts record different seasonal productivity processes in the SMB. While austral winter productivity events were triggered by the more frequent northward intrusions of the PPW, it is not clear what could explain the occurrence of austral summer productivity events related to upwelling in the SBM.

We suggest that, rather than being driven by changes in upwelling intensity as observed during interglacial MIS5 (Lessa et al., 2017; Portilho-Ramos et al., 2015), the increased productivity may have been a result of increased silicic acid ($Si(OH)_4$) content supplied by the glacial SACW. Several paleorecords and model experiments addressed the hypothesis of increased export of dissolved $Si(OH)_4$ preformed in the Southern Ocean that have fueled primary diatom productivity in low latitude upwelling zones and continental margins during the last glacial period, the so called "silicic acid leakage hypothesis" (SALH) (Bradtmiller et al., 2007; DeMaster, 2002; Matsumoto et al., 2014; Sarmiento et al., 2004). The SALH postulates that during glacial periods, imposed sea ice around Antarctica displaced the zone of high diatom production to the North of the Antarctic Polar Front (APF), where thermocline waters (i.e. Subantarctic Mode Water, a precursor of SACW and Antarctic Intermediate Water - AAIW) are formed (Abelmann et al., 2015; Bradtmiller et al., 2007; Sarmiento et al., 2004). Thus, (unused) high-Si waters were exported from the Southern Ocean to the low latitude world ocean, where diatom production increased at the expense of other types of phytoplankton (Bradtmiller et al., 2007; Griffiths et al., 2013; Sarmiento et al., 2004). In the Brazilian margin, the silicon isotopic composition ($\delta^{30}Si$) of sponge spicules from nearby core GeoB2107-3 indicates no substantial difference in the $Si(OH)_4$ content of AAIW between the Last Glacial Maximum and the Holocene, which would contradict the SALH (Hendry et al., 2012). However, high $Si(OH)_4$ pulses that occurred during the Younger Dryas and Heinrich Stadials (Hendry et al., 2012) make the $Si(OH)_4$ content of the average last glacial AAIW higher than that of the average Holocene AAIW. Significant increment of $Si(OH)_4$ transported by AAIW was also observed in the western equatorial Atlantic at the onset of the last glacial (40–80 cal ka BP), which was not followed by enhanced surface productivity indicating that AAIW $Si(OH)_4$ did not reach the photic zone (Griffiths et al., 2013). However, equatorial Atlantic upwelling zones are fed by SACW and high glacial opal burial as a consequence of enhanced surface diatoms production due to intense upwelling is considered a direct evidence from the SALH (Bradtmiller et al., 2007). Indeed, SACW is the major conduit for sub-Antarctic thermocline waters involved in SALH (Sarmiento et al., 2004) and bear a great potential to boost primary production in the SBM (Campos et al., 2000).

Currently, diatoms dominate the phytoplankton in the SBM during austral summer SACW upwelling (Brandini et al., 2014) and are an important component of the diet of the symbiotic-barren *G. bulloides*, which can alternatively feed on zooplankton (i.e. copepods) (Sautter and Thunell, 1991; Schiebel and Hemleben, 2017; Thunell and Sautter, 1992). Within age model uncertainties (including also the radiocarbon reversals in our core) and considering the different temporal resolution of the records, the glacial high abundance of *G. bulloides* in core JPC-17 matches well with high biogenic Opal% in cores RC24-01 and RC24-07 from the equatorial upwelling off NW-Africa (Bradtmiller et al., 2007) as well as core RC13-254, to the north of the APF Front (Atlantic sector) (Mortlock et al., 1991) (Fig. 4B, F and G). It is noteworthy that SACW also receives contributions from the Indian Ocean through the Agulhas Leakage (warm water route; Donners and Drijfhout, 2004), where the production of opal (north of the APF) and export of silicic acid remained high over the entire last glaciation (Dezileau et al., 2003). We suggest that *G. bulloides* in the SBM may have benefited the silicic acid-induced diatom blooms by directly feeding diatoms and/or indirectly by preying other zooplankton that also feed on diatoms. Thus, the increased abundance of *G. bulloides* in the SBM during the last glacial period was related to upwelling-driven high productivity during short austral summer periods, as previously suggested in Portilho-Ramos et al. (2015). In contrast, prolonged austral winter conditions with vigorous alongshore SW-winds as well as increased precipitation over SE South America (Cruz et al., 2005; Wang et al., 2007) increased the northward penetration of the PPW leading to enhanced eutrophic environmental dinocyst productivity during the last glaciation (Gu et al., 2017). Taken together, both processes may have boosted biological primary productivity along the year during the last glacial period. This is supported by enhanced abundance of deep-dwelling herbivorous planktonic foraminifera species *Globorotalia inflata* (Schiebel and Hemleben, 2017) that calcifies between 200 and 400 m water depth (Chiessi et al., 2007) and would have benefited by grazing the increased amount of sinking organic particles.

5.4. Post-glacial conditions

After the Last Glacial Maximum, the abundance of *G. bulloides* and eutrophic ~~environmental~~ dinocycts decrease until the onset of the Holocene, suggesting decreased regional productivity and more oligotrophic conditions in comparison to the last glacial period (Fig. 4B, D). The presence of ~~O~~oligotrophic conditions is supported by increased abundance of tropical symbiont-bearing species *G. ruber* (37–52%), *G. sacculifer* (6–8.8%) and *G. siphonifera* (6.3–7.5%) (Fig. 3). The low abundance of *G. inflata* also suggests oligotrophic conditions during the Holocene (Fig. 3B). Despite the favorable conditions for upwelling in the SBM during the Holocene (i.e. occurrence of alongshore NE-winds and a strong BC; Chiessi et al., 2014; Lessa et al., 2017; Portilho-Ramos et al., 2015), upwelling productivity may have been hampered by the reduced export of pre-formed silicic acid through SACW (Fig. 4F, G). This is supported by the substantial decrease of biogenic opal in equatorial upwelling cores RC24-01 and RC24-07 after 15 cal ka BP (Fig. 4F; Bradtmiller et al., 2007). Indeed, the retraction of Antarctic sea ice displaced the zone of enhanced biogenic opal production to the south of the APF, retaining the excess of silicic acid and opal burial in the Southern Ocean (Bradtmiller et al., 2007; Sarmiento et al., 2004) as evidenced by increased Holocene biogenic opal to the South of the APF at core RC13-259 (Fig. 4G; Mortlock et al., 1991). In addition, low austral winter insolation at 65°S and reduced sea ice may have decrease the thermal gradient between the high and mid latitudes in the Atlantic sector of the Southern Ocean and consequently weakened the alongshore SW-winds in the SBM, inhibiting the northward intrusions of the PPW. Simultaneously, the high sea level stand modified the SBM morphology increasing the width of the southern Brazilian shelf and, displacing the core of the upwelling zone to the inner shelf off Cape Santa Marta where it is controlled by local factors such as coastal wind system (Campos et al., 2013; Möller et al., 2008). The high temperatures at 100 m water depth from core JPC-17 (Fig. 3F) support this hypothesis, suggesting that the SACW was not frequently in the photic zone at the core location.

6. Conclusions

In this study we used planktonic foraminifera assemblage and associated 100 m water depth temperatures to discuss changes in productivity in the southern Brazilian margin over the last 70 kyr. The enhanced abundance of upwelling indicator *Globigerina bulloides* (12–16%) together with the reduced abundance of oligotrophic species and subsurface temperatures lower than 20°C suggest the occurrence of upwelling off Cape Santa Marta during the last glacial period. We suggest that rather than being driven by changes in upwelling intensity, the increased productivity may have been a result of increased silicic acid export from the Southern Ocean through South Atlantic Central Water. Our results show that orbital forcing did not have a major influence on changes in upwelling during the last glacial period. We further show that more frequent northward intrusions of Plata Plume Water modulated by austral winter insolation at 65ºS through enhanced alongshore SW-winds boosted austral winter productivity at the SBM. Thus, a productive upwelling during short austral summer events and the prolonged presence of Plata Plume Water during austral winter enhanced the biological productivity year-round in the SBM during the last glacial period relative to modern conditions. After the Last Glacial Maximum, low silicic acid content in thermocline waters decreased the productivity of the upwelling, while lower austral winter insolation at 65ºS and associated weakened SW-winds reduced the presence of the Plata Plume Water in the SBM. In addition, last deglaciation sea level rise may have modified the geomorphology of the SBM limiting the upwelling system to the coast, southern to Cape Santa Marta.

~~The data reported here will be archived in Pangaea~~

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Data availability. The data reported here will be archived in in the World Data Center PANGAEA (www.pangaea.de).

Author contributions

R.C.P.-R. and C.M.C. designed the study. R.C.P.-R. and T.M.L.P. analyzed planktonic foraminifera assemblage. R.C.P.-R and C.M.C. wrote the manuscript. R.C.P.-R. performed the Modern Analogue Technique. R.C.P.-R. and C.F.B performed age modeling. All authors contributed to the interpretation of the data.

Competing interests. The authors declare that they have no conflict of interest.

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Depth (cm)	^{14}C age (yr)	1 sigma error (yr)	Calibrated age (cal ka BP)	1 sigma error (yr)	Notes	δ^{18}O tie-points	Estimated error	Reference
10	4140	80	4228	283				Tessin and Lund (2013)
18	6970	20	7463	201				Tessin and Lund (2013)
26	9895	25	10784	233				Tessin and Lund (2013)
30	10555	25	11795	298				Tessin and Lund (2013)
34	11955	30	13454	195				Tessin and Lund (2013)
38	12870	30	14550	341				Tessin and Lund (2013)
42	13650	35	16001	390				Tessin and Lund (2013)
50	4190	15	4281	264	reversal			Tessin and Lund (2013)
54	14080	35	16569	338				Tessin and Lund (2013)
56	10000	60	10967	147	reversal			Portilho-Ramos et al. (2014)
58	10990	35	12371	273	reversal			Tessin and Lund (2013)
66	10790	25	12091	273	reversal			Tessin and Lund (2013)
74	18010	100	20922	282				Tessin and Lund (2013)
82	16120	80	18994	199	reversal			Tessin and Lund (2013)
90	18100	60	20975	282				Tessin and Lund (2013)
98	19020	70	22074	292				Tessin and Lund (2013)
190	32550	270	37946	312				Portilho-Ramos et al. (2014)
260						57614	3870	This study
350						70000	2260	This study

Table 1: Chronology of core JPC-17 obtained by accelerator mass spectrometry (AMS) ^{14}C dating on planktonic foraminifera shells (Tessin and Lund, 2013; Portilho-Ramos et al., 2014a) and stable oxygen isotope (δ^{18}O) tie-points tuned to the LS16 stack from Lisiecki and Stern (2016).

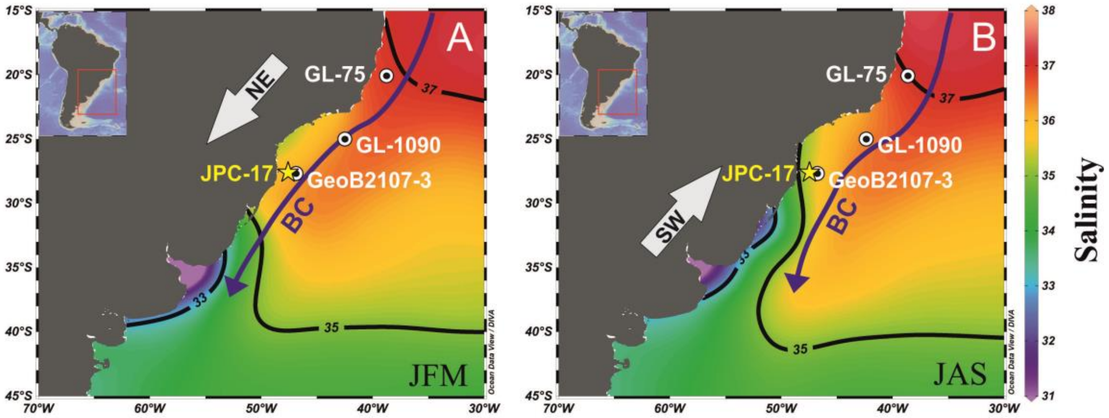

Figure 1: Surface salinity in southwestern Atlantic Ocean (Locarnini et al., 2010) during (**A**) austral summer (December-February, DJF) and (**B**) winter (June-August, JJA) showing the location of cores JPC-17 (this study), GeoB2107-3 (27°17'S; 46°45'W; Gu et al., 2017), GL-1090 (24°92'S; 42°51' W; Santos et al., 2017) and GL-75 (Portilho-Ramos et al., 2015). Blue arrows indicate the western boundary Brazil Current (BC) and the gray arrows show the regional prevailing alongshore wind direction (northeastern – NE and southwestern – SW). Figure created using the Ocean Data View software (ODV - version, 4.7.10., http://odv.awi.de, 2018).

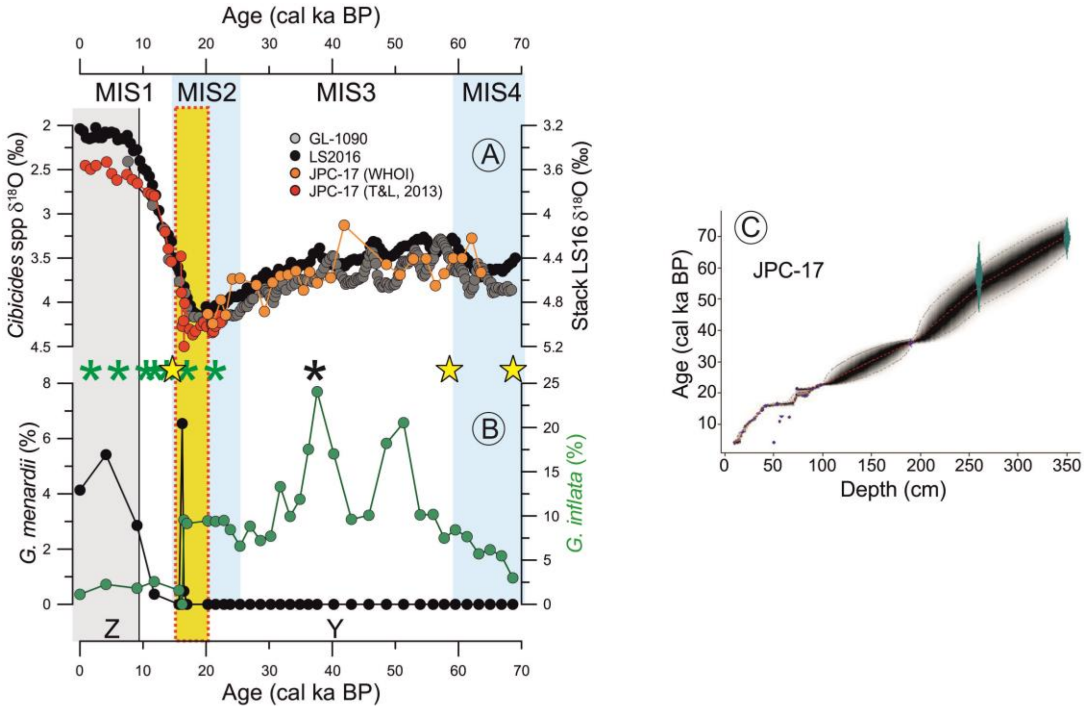

Figure 2: Age model of core JPC-17. (**A**) Comparison between the benthic foraminifera δ^{18}O record of JPC-17 (composed of published *Cibicidoides* spp. (Tessin and Lund, 2013; T&L, 2013) and unpublished *Cibicidoides* spp. data from Woods Hole Oceanographic Institution - WHOI) to the benthic foraminifera δ^{18}O record of core GL-1090 (Santos et al., 2017) as well as to the intermediate-depth South Atlantic benthic δ^{18}O stack LS16 (Lisiecki and Stern, 2016). Asterisks represent the calibrated radiocarbon ages published in (green) Tessin and Lund (2013) and (black) Portilho-Ramos et al. (2014b), while yellow stars represent the δ^{18}O tie-points shown in Table 2. (**B**) Abundance of the main biostratigraphical planktonic foraminifera species *Globorotalia menardii* and *Globorotalia inflata* from core JPC-17. Marine Isotopic Stages 1 to 4 (MIS1–4; MIS 2 and 4 indicated by vertical blue bars) are shown at the top, while letters Z (vertical grey bar) and Y in the bottom correspond to biostratigraphical biozones of Ericson and Wollin (1968). (**C**) Age-depth model based on Bacon v. 2.2 (Blaauw and Christeny, 2011). The symbols represent the positions of the calibrated AMS ^{14}C ages benthic δ^{18}O tie-points listed in Table 1. Error estimations of δ^{18}O tie-points follow Santos et al. (2017) that take into account the mean resolution of the JPC-17 benthic δ^{18}O record around the tie-point depth, the mean resolution of the reference curve around the tie-point age, a matching error visually estimated when defining tie-points and the absolute age error of the time-scale used for the reference record. The vertical yellow bar marks the interval with reversed radiocarbon ages listed in Table 1.

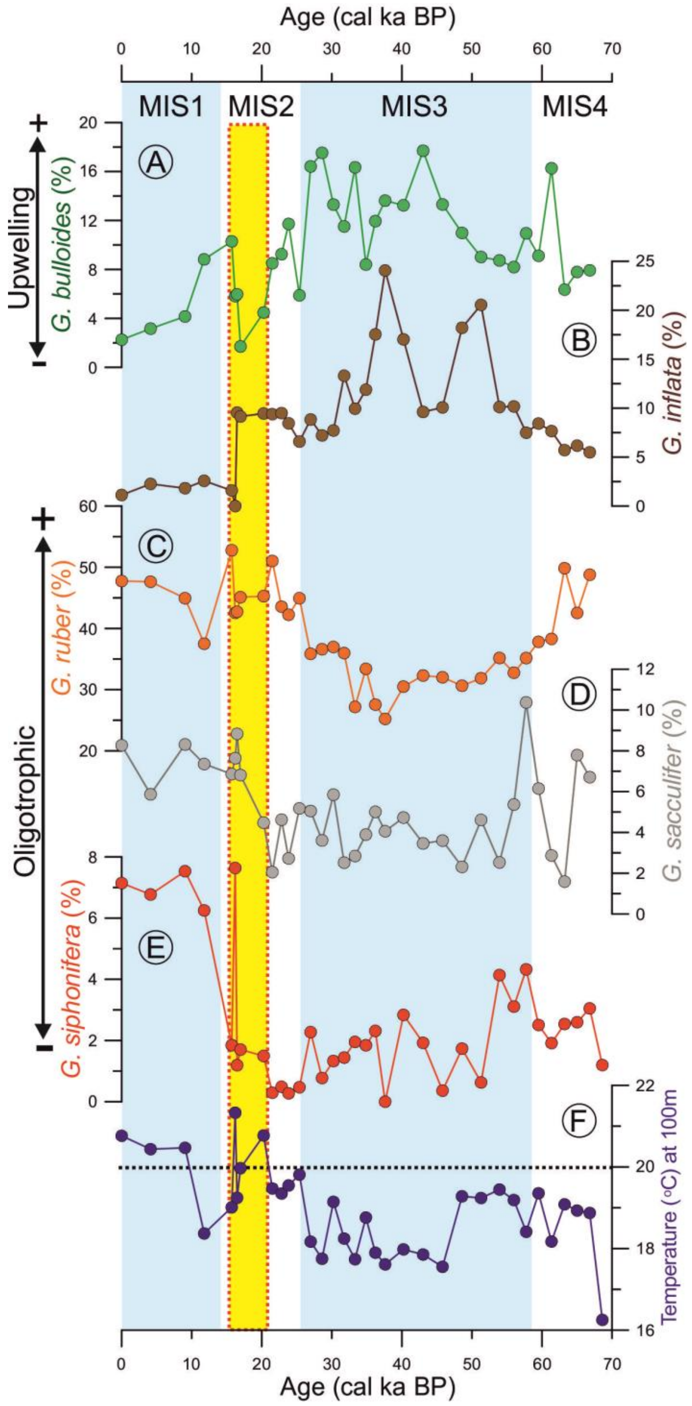

Figure 3: Relative abundance of planktonic foraminifera species and reconstructed subsurface temperature (100 m water depth) from core JPC-17 over the last 70 kyr. (**A**) Relative abundance of *Globigerina bulloides*, (**B**) *Globorotalia inflata*, (**C**) *Globigerinoides ruber*, (**D**) ~~*Glogigerinoides*~~*Globigerinoides sacculifer* and (**E**) *Globigerinella siphonifera*. (**F**) Temperature at 100m water depth. Blue dashed line in (**F**) indicates the 20°C isotherm which defines the modern maximum temperature of South Atlantic Central Water (Castelao et al., 2004), the water mass entering the photic zone in the upwelling sites of the southern Brazilian margin. The vertical yellow bar marks the interval with reversed radiocarbon ages listed in Table 1.

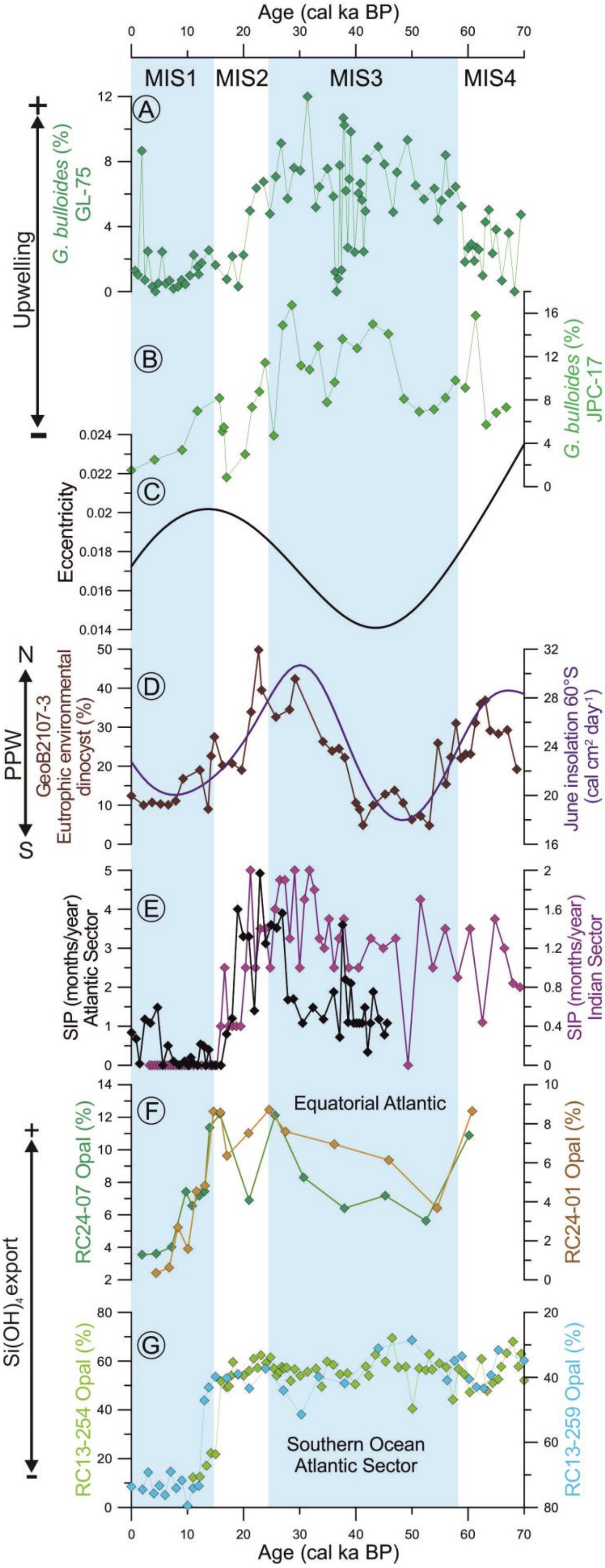
Age (cal ka BP)
0
10
20
30
40
50
60
70
MIS1
MIS2
MIS3
MIS4
Upwelling
+
−
A
G. bulloides (%)
GL-75
12
8
4
0
B
G. bulloides (%)
JPC-17
16
12
8
4
0
C
Eccentricity
0.024
0.022
0.02
0.018
0.016
0.014
D
PPW
N
S
GeoB2107-3
Eutrophic environmental dinocyst (%)
50
40
30
20
10
0
June insolation 60°S
(cal cm² day⁻¹)
32
28
24
20
16
E
SIP (months/year)
Atlantic Sector
5
4
3
2
1
0
SIP (months/year)
Indian Sector
2
1.6
1.2
0.8
0.4
0
F
Equatorial Atlantic
RC24-07 Opal (%)
14
12
10
8
6
4
2
RC24-01 Opal (%)
10
8
6
4
2
0
Si(OH)₄ export
G
RC13-254 Opal (%)
80
60
40
20
0
RC13-259 Opal (%)
20
40
60
80
Southern Ocean
Atlantic Sector
Age (cal ka BP)

Figure 4: Mechanism behind the variability of the productivity in the southern Brazilian margin over the last 70 kyr. Abundance of upwelling indicator species *G. bulloides* from (**A**) core GL-75 (21°S) (Portilho-Ramos et al., 2015) and (**B**) core JPC-17 (27°S) (this study). **C.** Eccentricity and austral summer (January) insolation at 15ºS (Berger and Loutre, 1991). (**D**) Abundance of dinoflagellate cysts from core GeoB2107-3 (27°S) representing the influence of the Plata Plume Water in the southern Brazilian margin (Gu et al., 2017) and austral winter (June) insolation at 65ºS (Berger and Loutre, 1991). (**E**) Antarctic sea ice presence (SIP) in the Atlantic Sector core TN057-13-PC4 (53°20´S; 5º10'W; Shemesh et al 2002) and Indian Sector core SO136-111 (56°40'S; 160º14'W; Crosta et al., 2004) sectors of the Southern Ocean derived from diatoms assemblage. (**F**) ~~Opal content~~Opal content in Equatorial Atlantic upwelling off NW-African cores RC14-01 (0.55°N; 13º65´W) and core RC24-07 (1°33´S; 11º92´W) (Bradtmiller et al., 2007) as well as (**G**) in Atlantic sector of the Southern Ocean cores RC13-254 (48°34´S; 5º34´E) and core RC13-259 (53°53´S; 4º56'W) as a proxy for silicic acid transport toward low latitudes (Mortlock et al., 1991). Core RC13-254 is located to the north of the Antarctic Polar Zone (APZ) while core RC13-254 is located to the south of the APZ. Note the inverted (RC13-259) axis in (**F**).