This is a detailed point-by-point response to all comments from the Referees and the Editor. The response include the comments from Referees and Editor in **black**, our responses in blue, and the changes performed in the manuscript in **red** (page and line numbers refer to the revised version of the marked-up manuscript).

Referee #1 - Dr. L. Barbara

We thank Dr. L. Barbara (Referee #1) for his constructive review of our manuscript.

The manuscript by Chiessi and colleagues seeks to reconstruct oceanic and atmospheric thermal conditions in the southeastern South America region, as evidence for changing climate during Termination 1. In general the manuscript is well presented, well-written, and with comprehensive literature support. The finding that the marine temperature appear to be associated with AMOC strength, and that changes in the continental temperature in this region are synchronous with atmospheric CO2, are interesting. In general, I am very much in favor of this paper which is within the scope of Climate of the Past. Before publication, however, I would like the authors to consider these 2 major points listed below.

 My overall concern is that the results and discussion sections are brief and could be more informative. Chiessi et al. present a really interesting high-resolution data set of the Termination 1. However the authors discuss only the (multi-)millennial scale variability when the data show interesting multicentennial scale variability. I would like the authors to complete the results and discussion sections in term of centennial scale variability, particularly the opposite centennial trend between SST and MAT during the HS1: For example, high SST occur when minima in MAT occur at 16.5 and 15 cal ka BP. SST drop Vs MAP sharp increase at 15.5 cal ka BP. How the authors can explain this opposite thermal evolution during HS1 between the continent and the BC? In this way, I would like the author to give more details about regional ocean-atmosphere interactions at millennial and centennial time scale.

Uncertainties intrinsic to (i) radiocarbon based age models, and (ii) our sea surface temperature and mean air temperature proxies call for caution while interpreting and correlating multi-centennial-scale variability to other records. Thus, we prefer to limit our interpretation to the main features present in our records that are robustly supported. This is the case, for instance, of the marked negative anomaly in our sea surface temperature record around 15.5 cal ka BP. It has been described in the results but not appropriately addressed in the discussion. We agree that giving more attention to it in the discussion will improve our manuscript, particularly considering new high temporal resolution records like Martrat et al. (2014. Quaternary Science Reviews). Accordingly, we implemented the following sentences to the revised version of our manuscript (section 5.1, page 11, lines 25-30):

Moreover, the marked drop in our SST record reaching minimum values at ca. 15.5 cal ka BP could be related to an intervening warm spell registered within HS1 in the North Atlantic mid-

latitudes (Martrat et al., 2014). We hypothesize that not only millennial-scale changes associated to Termination 1 (e.g., HS1) affected the BC, but also centennial-scale fluctuations (e.g., internal structure of HS1) were registered. However, we primarily discuss the millennial-scale events because of age model uncertainties.

We examined a putative anti-phased behavior between our sea surface temperature and mean air temperature records. Since a scatter plot between both records shows no inverse correlation (Fig. 1) we do not have support to discuss this topic in more detail.



Fig. 1. GeoB6211-2 Methylation Branched Tetraether (MBT') and Cyclisation Branched Tetraether (CBT) based mean air temperature (MAT) vs. GeoB6211-2 *Globigerinoides ruber* (white) Mg/Ca based sea surface temperatures (SST) from 18.8 until 14.1 cal ka BP (the time window for which both datasets show similar temporal resolution). Before plotting, both datasets were linearly interpolated with a step of 65 years starting at 14.1 cal ka BP.

2. Following the previous studies, the slowdown of the AMOC during HS1 has been presented as responsible of the heat retention in the Southern Hemisphere. This is not strictly the case as explained by Mayewski el al., 2009. Those authors describe that changes in the Antarctic ice sheet, sea ice extent, and Antarctic Circumpolar Current (ACC) position can also affect Southern Hemisphere heat retention and ocean circulation. The Brazil-Malvinas Confluence is connected with the ACC. Several studies in Antarctic Peninsula have shown that the winter sea ice edge, cold fresh water discharged, Iceberg runoff would have driven the latitudinal position of the ACC in the South Atlantic Ocean during the Termination 1. In this way, a change in ACC position would have affected the latitudinal position of the Brazil-Malvinas Confluence and affected the SST of the BC. I suggest that the teleconnection between the high latitude and the mid-latitude should have to be taken on board during this period. I would like to ask the authors to consider their interpretations of the SST changes in light of the studies about the ACC evolution during the Termination 1. Maybe the authors could compare their results with the SST reconstruction of Bianchi et al., 2004 (EPSL) or the Icebergs discharge reconstruction of Weber et al., 2014 (Nature).

The paleoclimatic section from Mayewski et al. (2009. Reviews of Geophysics) rather deals with the Holocene. However, in the introductory section "1. Prelude to recent climate", the authors briefly discuss millennial-scale changes of the last glacial/deglaciation. More specifically, the authors suggest, "The cause(s) of these millennial-scale climate events are not fully understood, but slowing of the MOC has been attributed to North Atlantic meltwater flood events and/or to massive iceberg discharges (Heinrich events) that slow the formation of North Atlantic Deep Water. Changes in the Antarctic ice sheet and sea ice extent can also affect Southern Ocean heat retention and ocean circulation [Stocker and Wright, 1991; Knorr and Lohman, 2003]." Although we see no fundamental contradiction to our view of HS1, we agree that encompassing the potential influence that changes in the Southern Ocean may have over our records (see below) will strengthens the manuscript.

The Brazil-Malvinas Confluence is a major barrier for planktonic foraminifera (Boltovskoy et al., 1996. Marine Micropaleontology; 2000. Journal of the Marine Biological Association of the United Kingdom). To the north of the Brazil-Malvinas Confluence, subtropical species like Globigerinoides ruber and Globigerinoides sacculifer dominate the mixed layer of the warm and salty Brazil Current. To the south of the Brazil-Malvinas Confluence, the uppermost water column is dominated by transitional species like Globigerina bulloides and Turborotalita quinqueloba. The presence of G. ruber throughout Termination 1 is an indicator that the Brazil Current always bathed our core site. Moreover, *Globorotalia inflata* δ^{18} O shows a ca. 2 ‰ change across the Brazil-Malvinas Confluence (Chiessi et al., 2007. Marine Micropaleontology; Voigt et al., 2015. Paleoceanography). In our core, *G* inflata δ^{18} O never reach the heavy values typical of the Malvinas Current during Termination 1 (Chiessi et al., 2008. Geology), if changes in global sea level are taken into account. Thus, we exclude a direct influence of the Brazil-Malvinas Confluence over our core site during Termination 1. Still, the Southern Ocean could indirectly affect our core site through the Benguela and South Equatorial Currents, with the signal eventually reaching the Brazil Current. In addition, as discussed below, the Southern Ocean may have influenced mean air temperatures over the La Plata River drainage basin through an atmospheric teleconnection.

Because of the higher temporal resolution, we prefer to compare our results to Weber et al. (2014. Nature) instead of to Bianchi and Gersonde (2004. Earth and Planetary Science Letters).

Regarding mean air temperatures, the multi-model experiment from Weber et al. (2014. Nature) suggests a cooling over southern South America (i.e., to the south of 30°S) as a response to an Antarctic meltwater pulse. The cooling amounts to ca. 1.0°C over the southernmost portion of the La Plata River drainage basin, whereas the temperature anomaly over the rest of the basin is not shown. As mentioned in section 3.5 of our manuscript, we expect our mean annual temperature record to represent an integrated signal over the La Plata River drainage basin with a predominant contribution from its northwestern domain. The absence of most of the La Plata River drainage basin, including its northwestern domain, on the modelling results from Weber et al. (2014. Nature) hampers a direct evaluation of the impact that an Antarctic meltwater pulse may have had over our mean air temperature record. However, the two most prominent events of increased flux of iceberg-rafted debris at the Scotia Sea (a proxy for Antarctica meltwater pulse) recorded during Termination 1 (Weber et al., 2014. Nature) (i.e., Antarctic Ice Sheet discharge (AID) event 7 between 16.91 and 15.75 cal ka BP, and AID6 between 14.86 and 13.94 cal ka BP) partially correlate with negative anomalies in our mean air temperature record, given age model uncertainties (Fig. 2).



Fig. 2. Millennial-scale variability of the sea surface temperatures of the Brazil Current and mean air temperatures of southeastern South America spanning Termination 1 compared to selected circum-Atlantic records. (a) North Greenland Ice Core Project (NGRIP members, 2004. Nature) δ^{18} O plotted vs. the Greenland Ice Core Chronology 2005 (GICC05) (Rasmussen et al., 2006. Journal of Geophysical Research). (b) GeoB6211-2 *Globigerinoides ruber* (white) Mg/Ca and Mg/Ca based sea surface temperatures (SST). (c) GeoB6211-2 Methylation Branched Tetraether (MBT') and Cyclisation Branched Tetraether (CBT) based mean air temperature (MAT). (d) Stacked iceberg-rafted debris (IBRD) flux record from the Scotia Sea (Weber et al., 2014. Nature). (e) EPICA Dronning Maud Land (EPICA Community Members, 2006. Nature) δ^{18} O plotted vs. its original chronology. Black symbols at the bottom of the panel depict calibrated radiocarbon ages used to produce the age model for GeoB6211-2.Grey vertical bars depict Heinrich Stadial 1 (HS1) (Sarnthein et al., 2001) and the Younger Dryas (YD) (Rasmussen et al., 2006). BA: Bølling–Allerød; EH: early Holocene.

Accordingly, we implemented the following sentences to the revised version of our manuscript (section 5.2, page 15, lines 6-12):

Additionally, Antarctic meltwater pulses may have decreased MAT over southeastern South America (Weber et al., 2014). The modeled cooling amounts to ca. 1.0°C over the southernmost portion of the LPRDB. Given age model uncertainties, the two most prominent events of increased flux of iceberg-rafted debris at the Scotia Sea (i.e., AID7 and AID6; Weber et al., 2014) partially correlate with negative anomalies in our MAT record (Chiessi et al., 2015a). Thus, Antarctic meltwater pulses may have contributed to the variability of MAT over the LPRDB in addition to changes in atmospheric CO₂ concentration.

Regarding sea surface temperatures, the multi-model experiment from Weber et al. (2014. Nature) also suggests a cooling for the uppermost ca. 1000 m of the water column of the subtropical South Atlantic as a response to an Antarctic meltwater pulse. The cooling amounts to ca. 0.5°C at the uppermost water column, where we expect our sea surface temperature signal to come from. Indeed, our sea surface temperature record shows minor (i.e., ca. 0.5°C) decreases around peak iceberg-rafted debris fluxes within AID7 and AID6. Thus, Antarctic meltwater pulses may have contributed to the variability of sea surface temperatures of the subtropical domain of the Brazil Current on top of the mechanisms described in our manuscript. Accordingly, we implemented the following sentences to the revised version of our manuscript (section 5.1, page 14, lines 17-24):

Recently, Weber et al. (2014) suggested that Antarctic meltwater pulses may have cooled the upper water column of the South Atlantic. Indeed, our sea surface temperature record shows minor (i.e., ca. 0.5°C) decreases around two most prominent events of increased flux of iceberg-rafted debris at the Scotia Sea (a proxy for Antarctic meltwater pulses) recorded during Termination 1 (i.e., Antarctic Ice Sheet discharge (AID) event 7 between 16.91 and 15.75 cal ka BP, and event AID6 between 14.86 and 13.94 cal ka BP) (Chiessi et al., 2015a). Thus, Antarctic meltwater pulses may have contributed to the variability of SST from the subtropical domain of the Brazil Current on top of the mechanisms already described.

However, the ocean temperature modelling results shown by Weber et al. (2014) relate to a zonally averaged meridional transect, and has to be compared with caution with our sea surface temperature record that comes from the westernmost portion of the subtropical South Atlantic.

Referee #2 - Anonymous

We thank anonymous Referee #2 for his constructive review of our manuscript.

The paper by Chiessi and colleagues present a high-resolution, high-quality record of the termination 1 SST and SAT from the adjacent landmass from a core collected North of the La Plata river mouth. I am very much in favor of publishing this study. I however suggest some minor to moderate revisions prior to publication, as I feel the results and discussion can be improved.

First, I just had a look at Loic Barbara's comment. Before starting my own review I want to strongly emphasize that I couldn't agree more with him on the two points, especially on point 1. The authors present a very high quality paleo-record at unprecedented resolution for this

area, but instead of commenting the extremely interesting music found in their records they comment on the H1 anomaly, as if it was the only interesting feature in their high-resolution record. Why? Such an analysis MUST be more descriptive, if the authors want their record being a reference record for the region. Instead, they try to make their own record fitting to other ones - sometimes of worse quality – and I sometimes have the sad feeling that the authors try to avoid commenting on their high-quality record (because it is complex?).

This observation is very similar to comment #1 from Dr. L. Barbara (Referee #1). Since we already answered that comment we do not see the need to repeat it here, and we kindly remit Referee #2 to our answer to comment #1 from Dr. L. Barbara (see above).

This being said, I have a few major and minor comments that I list below, hopefully from the most to the least important to consider.

1. Chapter 5.2 should be reconsidered / rewritten. Again, the MAT record acrobatically tries to fit to westerlies, to CO2, Antarctica, etc. The only regional record to which the MAT has been compared here is the Lake Consuelo pollen record. But you can't write the MAT bears "close resemblance" with it! The only thing one can say about the pollen record is that there might have been an overall temperature increase of about 3°C between the LGM and the early Holocene. The MAT record during the H1 is indeed impressive, and the authors just forgot to discuss some interesting connections between the MAT and the seawater d180! What can been told about the internal complexity of H1? What can be told about land-sea interactions? What can be told about some apparent anti phasing between the SST and MAT records?

Continuing on the MAT, how the authors can be sure that there is no contribution from marine temperature? I am not familiar with GDGT but suspect that some membrane lipids from marine algae are used in the MBT/CBT proxy? As for TEX, it is usual to show the BIT to invoke that there are no marine vs. continental source, but the authors just don't show it. Why? Did I miss an important technical point here? This would be much more convincing than invoking Nd isotopes or the origin of particulate organic matter if the authors could show that none of the molecules of the MBT/CBT proxy are of marine origin by using the same armada of GDGTs or whatever other membrane molecules. If I'm technically wrong about the GDGTs (meaning any of the molecules used in the MBT/CBT are not used either for the TEX), then some easy-to-understand explanation of why it is pointless to show the BIT might be useful to non-specialists of the GDGTs proxies like me.

Finishing on the MAT, the first sentence "Most of the warming in our step-like structured MAT record takes place during the second half of HS1 and during the YD, whereas little or no warming characterizes the LGM, the BA and the early Holocene" should be deeply rethought. The truth is that the resolution is not sufficient to write such a sentence (no data for the LGM, only few points at the very beginning of the B/A, two points in the YD, 4 points during the early Holocene. Again, you really should deal with internal variability during the H1 there. In any case, no data = no variability to comment on.

We agree that the wording used to characterize the similarity of our mean air temperature record and the temperature record from Bush et al. (2004. Science) was not appropriate. Thus,

we rewrote part of the second paragraph of section 5.2 (the main paragraph dealing with the comparison of our MAT record to the temperature record from Bush et al., 2004. Science) to (section 5.2, page 15, lines 20-27):

Nevertheless, the comparison of our MAT record to other continental temperature records with relatively lower temporal resolution allows evaluating the spatial variability of MAT. Our MAT record, for instance, bears some resemblance with a pollen-derived temperature record from eastern Peru (Lake Consuelo) collected at 13.95°S (Fig. 6B, C) (Bush et al., 2004). The linkage of MAT in the LPRDB to low latitude temperature evolution is supported by modern observations of a relatively flat MAT profile in tropical to subtropical South America between 10°N and 20°S (Fig. 1B) (Legates and Willmott, 1990).

Also, the first sentence of the third paragraph of section 5.2 that also referred to the comparison of our MAT record to the temperature record from Bush et al. (2004. Science) was changed to (page 15, lines 28-31):

The general agreement between our MAT and eastern Peru temperatures (Bush et al., 2004) taken together with the rise in atmospheric CO_2 content (Monnin et al., 2004) (Fig. 6B, C, D) suggests that greenhouse gas concentrations exerted a strong control on South American MAT during Termination 1.

Still, we are not aware of other quantitative mean air temperature records from (sub)tropical South America to the east of the Andes that is continuous for most of Termination 1 and shows the necessary high temporal resolution (Shakun et al., 2012. Nature). We added this information to the revised version of our manuscript as mentioned below, in order to justify the comparison to the record from Bush et al. (2004. Science) (section 5.2, page 15, lines 18-20):

High temporal resolution and continuous MAT records from tropical South America to the east of the Andes spanning most of Termination 1 are, to our knowledge, still absent (Shakun et al., 2012).

We also agree on the apparent connection between our mean air temperature and δ^{18} Oivc-ssw records (i.e., higher mean air temperatures associated to lower δ^{18} Oivc-ssw). However, since this relationship does not hold for the whole investigated period (e.g., from 19 until 18 cal ka BP the mean air temperature record remains stable while the δ^{18} Oivc-ssw record increases) we do not feel confident enough to include this into the revised version of the manuscript.

Regarding the internal complexity and apparent anti-phasing between our sea surface temperature and mean air temperature records, please see our answer to comment #1 from Dr. L. Barbara (Referee #1) above.

The referee is right in pointing out that there might be some complicating processes when applying the mean air temperature proxy. The most widely discussed issue with this proxy in marine sediments is the in-situ production of the branched glycerol dialkyl glycerol tetraethers (brGDGTs) by some uncharacterized microbial community in sediments. There are a few studies describing this effect (e.g., Peterse et al., 2009. Organic Geochemistry; Zhu et al., 2011. Organic Geochemistry). In these studies, the authors consistently find an increase in the relative abundance of those brGDGTs containing cyclopentane moieties (e.g., brGDGT Ic and brGDGT IIc) as well as a decrease in the relative abundance of the compounds brGDGT I and brGDGT II. We examined our data set for indications of marine in-situ production, which was not present (Fig. 3). Accordingly, we added the following sentences to the revised version of our manuscript (section 3.5, page 8, lines 15-20):

The production of GDGTs by some uncharacterized microbial community in marine sediments has gained recent attention (e.g., Zhu et al., 2011). For in situ production in the marine realm, the authors consistently describe an increase in the relative abundance of those GDGTs containing cyclopentane moieties (e.g., GDGT Ic and GDGT IIc) as well as a decrease in the relative abundance of the compounds GDGT Ia and GDGT IIa. We carefully screened our results for a similar behavior.

And (section 4.4, page 10, lines 10-13):

We first examined our data set for indications of marine in-situ production of GDGTs as described in section 3.5, which was not the case (Chiessi et al., 2015b). Then, we calculated continental MAT values that range from 11.5°C at 18.0 cal ka BP to 14.9°C at 11.5 cal ka BP (Fig. 4E).

Furthermore, Referee #2 suggests presenting a branched and isoprenoid tetraether (BIT) index record along with the mean air temperature estimates to illustrate unchanged continental sources. Our BIT record is indeed rather constant over the time interval discussed here. However, as this quantifies the relative contributions of brGDGTs and isoGDGTs derived from aquatic archaea, and the latter are not considered at all in the MBT'/CBT indices, we do not think that much can be gained from the BIT record.

We agree that rewording the sentence "Most of the warming..." taking into consideration the comment from Referee #2 will improve the manuscript. More specifically, we are not able to make a statement about the Last Glacial Maximum, and have to be more careful on the second half of the Bølling-Allerød, Younger Dryas and early Holocene due to the low temporal resolution of our record for that specific period. Accordingly, in the revised version of our manuscript we added one sentence to section 4.4, and changed the first sentence of the first paragraph of section 5.2 as follows (section 4.4, page 10, lines 18-21):

The marked decrease in the mean temporal resolution of our MAT record after 14.1 cal ka BP that shifts from ca. 70 years to ca. 555 years is worthy of note. This has to be considered while interpreting the MAT trends described for the period after 14.1 cal ka BP.

And (section 5.2, page 14, lines 27-31):

Most of the warming in our step-like structured MAT record takes place during the second half of HS1 and during the YD, but due to the marked decrease in temporal resolution of our MAT record after 14.1 cal ka BP we raise a note of caution while interpreting changes in continental temperature during the YD (Fig. 4E) (Sarnthein et al., 2001; Rasmussen et al., 2006).



Fig. 3. (a) Mean air temperatures (MAT) based on branched glycerol dialkyl glycerol tetraethers (GDGTs), and (b) fractional abundance of the branched glycerol dialkyl glycerol tetraethers (GDGTs) from core GeoB6211-2. For the estimation of mean air temperatures molecules IIIb and IIIc are not used (Peterse et al., 2012. Geochimica et Cosmochimica Acta). Note that (a) and (b) are plotted against core depth.

2. The data "shows very similar patterns" with Weldeab. This is true if, again, you just deal with the LGM/H1/B-A broad shifts. But the resolution of each core contains much more than that, and interesting differences should be commented. When Weldeab starts warming, your data

already reached its SST maximum. At the end of th H1 you barely comment, in the result chapter, the very most prominent shift in SST at around 15.5 ka which is not seen in Weldeab, etc. Without going too far in the details you should spot those prominent features, so that people interested in the curve zigzags such as the famous "W" recorded in some tropical rainfall records can be more interested in your data. So the "in phase" behavior is, in the end, very sketchy given the golden piece of dataset you have in hands.

We agree that giving more attention to the marked negative anomaly in our sea surface temperature record around 15.5 cal ka BP will improve the discussion of our manuscript, particularly considering new high temporal resolution records like Martrat et al. (2014. Quaternary Science Reviews). This negative anomaly has been described in the results but not appropriately addressed in the discussion of our manuscript.). Accordingly, we implemented the following sentences to the revised version of our manuscript (section 5.1, page 11, lines 25-30; already mentioned above):

Moreover, the marked drop in our SST record reaching minimum value at ca. 15.5 cal ka BP could be related to an intervening warm spell registered within HS1 in the North Atlantic midlatitudes (Martrat et al., 2014). We hypothesize that not only millennial-scale changes associated to Termination 1 (e.g., HS1) affected the BC, but also centennial-scale fluctuations (e.g., internal structure of HS1) were registered. However, we primarily discuss the millennial-scale events because of age model uncertainties.

However, uncertainties intrinsic to (i) radiocarbon based age models, and (ii) our sea surface temperature proxy call for caution while interpreting and correlating multi-centennial-scale variability to other records. We prefer to limit our interpretation to the main features present in our records that are robustly supported. Still, we toned down the statements that our sea surface record and the one from Weldeab et al. (2006. Earth and Planetary Science Letters) are "in-phase" in the second paragraph of section 5.1 of the revised version of our manuscript in the following way (section 5.1, from page 11 line 31 until page 12 line 9):

Interestingly, the other high temporal resolution Mg/Ca based SST record from the western South Atlantic covering Termination 1 shows similar changes in SST during HS1 (Figs. 1A, 5C) (Weldeab et al., 2006). This core (i.e., GeoB3129-1/3911-3) was collected off NE Brazil at 4.61°S, thus under the influence of the NBC. The similarity in SST between both western South Atlantic records goes beyond HS1, and is also valid for the SST drop with minimum values at ca. 14 cal ka BP, and peak SST at ca. 13 cal ka BP, during the Bølling-Allerød (BA). Thus, our SST record (from the BC) together with the SST record from Weldeab et al. (2006) (from the NBC) suggest a generally in-phase behavior of the BC and the NBC regions during HS1 and the BA. This is contradicts the BC-NBC anti-phase relationship suggested by Arz et al. (1999), at least concerning SST since we have proxy to assess current strength. Additionally, we substituted the second sentence of the fifth paragraph of section 5.1 by (section 5.1, page 12, lines 3-6):

However, the thermal response of the surface layer of the western South Atlantic cannot be described as an anti-phase in SST between the BC and the NBC regions (Arz et al., 1999), but rather as a widespread and in-phase increase in SST.

3. What exactly your proxies mean, and what is the implication of that? You rapidly deal with seasonality of G. ruber at your core site, but does it apply also at theWeldeab site? What would happen if instead of Mg/Ca you used alkenones? What would be the final overall interpretation? Of course I don't want to push you measuring alkenones, but you might have opted also for the SST record of Jaeschke (2007, paleoceanography) while attempting to compare you record to a SST record form the NBC branch. The Jaeschke, at almost the same site than Weldeab, shows a more Greenland-like SST record (!), definitely different from that of Weldeab. I feel there is more to dig here in terms of rapid climate changes/seasonality during the deglaciation.

In section 3.3 of our manuscript, we state that our Mg/Ca based sea surface temperature record reflects southern hemisphere summer conditions. As suggested by Steinke et al. (2008. Quaternary Science Reviews) and Leduc et al. (2010. Quaternary Science Reviews) different sea surface temperature proxies may record different seasons. This is one of the reasons that compelled us to compare our Mg/Ca based sea surface temperature record to other Mg/Ca based records like Weldeab et al. (2006. Earth and Planetary Science Letters) and Barker et al. (2009. Nature). Moreover, many water hosing model experiments (e.g., Stouffer et al., 2006. Journal of Climate) place a change in sign of sea surface temperature anomaly in the tropical Atlantic off northeastern South America. To the north of this boundary, the sea surface temperature anomaly is negative under a weak Atlantic meridional overturning circulation, and to the south of it the anomaly is positive. This boundary may have shown seasonal meridional migrations producing different signals in different proxies from nearby cores, as it seems to be the case in Weldeab et al. (2006. Earth and Planetary Science Letters) and Jaeschke et al. (2007. Paleoceanography).

Other minor comments:

-Chapter 2.2, last paragraph, I just don't get what you want to say.

This paragraph was rephrased in the revised version of our manuscript as follows (section 2.2, page 4, lines 14-19):

Air temperatures at low atmospheric levels over South America are dominated by the equatorto-pole thermal gradient (Fig. 1B) (Garreaud et al., 2009). The meridional temperature profile is rather flat between the equator and 20°S, amounting to ca. 20°C. To the south of 20°S, temperatures gradually decrease to 0°C over the southern tip of the continent. Zonal departures from this meridional gradient are relatively small to the east of the Andes, as is the case for the LPRDB.

-As for the H1, the B/A variability in both your and Weldeab's records is quite interesting, why not developing this a little more, as already suggested for the H1? There is the Bolling, the older dryas, the early allerod, the intra-allerod cold reversal, the late allered etc. already documented in the north atlantic and in greenland, I feel you also miss some interesting comments on that time window.

Again, we claim that uncertainties intrinsic to (i) radiocarbon based age models, and (ii) our sea surface temperature proxy call for caution while interpreting and correlating multi-centennial-scale variability to other records. The negative anomaly of our sea surface temperature record centered around 14 cal ka BP and the gradual increase in sea surface temperatures from 14 until 13 cal ka BP that seem to be reliable features have already been described in section 4.2 and discussed in section 5.1 of our manuscript. At this stage, we do not feel confident to interpret additional minor features that characterize our record during the Bølling-Allerød.

-The chapter 5.3 says all and nothing. Please try to hierarchize the information and interpretation you want to convey instead of having a shopping list of all the Science and Nature paper you might want to consider.

According to the comment from Reviewer #2, we agree that the first paragraph of section 5.3 needed substantial changes. Thus, we substituted the first paragraph of section 5.3 by (section 5.3, page 16, lines 16-27):

Our SST record suggests that the South Atlantic and the BC more specifically, was of paramount importance for the southward propagation of the thermal bipolar seesaw signal of HS1 (Fig. 5). Indeed, the western South Atlantic was more sensitive to AMOC forcing than lowland South America, which appears to be more susceptible to atmospheric CO2 changes (Figs. 5 and 6). Thus, our SST and MAT records sum up to other lines of evidence supporting the notion that global continental air temperature closely tracked the increase in atmospheric CO2 concentration during Termination 1, and that variations in the AMOC caused a seesawing of heat between the hemispheres mainly impacting the oceans in the Southern Hemisphere (Shakun et al., 2012).

-The "no reservoir age"... I am OK, but if the authors decide to re-focus a little on the centennial-scale features they may deal with that issue a little more lengthy. Further South of their core, there are some samples along the argentinian coast with reservoir ages of more than 1000 years (one sample has a 2800 years reservoir age!) As Loic Barbara points out, any change in the Antarctic circumpolar current is likely, and might also affect the latitude of the

Malvinas/Brazil confluence and input some old carbon into surface waters, obscuring the timing of the high-resolution climate records.

Because we exclude a direct influence of the Brazil-Malvinas Confluence over our core site (for a thorough rationale, please see the second paragraph of our answer to comment #2 from Dr. L. Barbara (Referee #1) we have no reason to use an additional ΔR .

I sincerely wish very good luck to the authors for the review process and very warmly encourage them to re-submit an article that is not shy to present an awesome reference curve from the region!

Editor – Dr. J.P. Bernal

We thank Dr. J.P. Bernal (Editor) for his constructive comments to our manuscript.

Two referees have commented on your recently submitted paper entitled "Thermal evolution of the western South Atlantic and the adjacent continent during Termination 1" in which you are the lead author.

I have read the manuscript as well as the referees comments posted on-line and I agree with their comments and suggestions. Both referees agree that the record presented in the manuscript is of extremely high quality and reveals an interesting story on the multimillennia time-scale and the tele-connections that may be driving them. However, they also agree that the high-resolution sampling of the core permits further interpretations into the centennial-scale processes taking place, particularly during HS-1.

Another common issue found by the reviewers encourages you to include other records from the area, as well as to enhance the discussion regarding the significance of the selected proxies as well as potential lags and leads between such records.

Consequently, I encourage you to answer to the questions/issues raised by the referees and I look forward to read the corrected version of the manuscript.

The comments from Dr. J.P. Bernal (Editor) exclusively refer to topics raised by Dr. L. Barbara (Referee #1) and anonymous Referee #2. We kindly remit Dr. J.P. Bernal to our thorough answers to Dr. L. Barbara and Referee #2 above.

Additional changes made to improve the readability or comprehensiveness of the text and figures

Page 1, line 22: Added "so far".

Page 1, lines 22-23: Deleted "and a compelling record of the BC-NBC antiphase behavior remains elusive".

Page 1, line 27: Substituted "existing NBC record" by "existing SST record from the NBC".

Page 2, line 9: Added "Stocker, 1998".

Page 2, line 9 (and further occurrences): Added a space between adjacent citations.

Page 2, line 13: Substituted "collapse" by "reduction".

Page 2, line 19: Substituted "lack of a high temporal resolution record" by "lack of high temporal resolution records".

Page 4, line 11: Substituted "minima" by "minimum".

Page 6, line 16: Deleted "ratios".

Page 6, line 27: Substituted "record austral hemisphere summer conditions in our" by "records austral hemisphere summer conditions at our".

Page 7, line 13 (and further occurrences): Formatted all suffixes to δ^{18} O (i.e., "ivc-ssw", "sw", "ssw", "G. ruber") as subscripts.

Page 9, line 10: Substituted "cal kyr BP" by "cal ka BP".

Page 9, line 21: Deleted "ratios".

Page 10, lines 27-28: Substituted "During the LGM sea-level lowstand shifted" by "The sea-level drop preceding the LGM shifted".

Page 11, line 4: Substituted "in the" by "on the".

Page 11, lines 15-16: Added "(Fig. 5A) (Bard et al., 2000)".

Page 13, line 12: Added "EPICA Community Members, 2006".

Page 13, line 13: Substituted "oceans" by "South Atlantic".

Pages 15 and 16, lines 31 (page 15) – 5 (page 16): Deleted "Considering equilibrium climate sensitivity to changes in atmospheric CO₂ concentration to be within the range 1.5 to 4.5° C (Bindoff et al., 2013), the deglacial temperature increase exclusively due to CO₂ rise would range from 0.9 to 2.7°C. Thus, the deglacial temperature rise in our MAT record (i.e., 2.5°C) may largely be explained by the deglacial atmospheric CO₂ increase. Nevertheless, this attribution hypothesis has to be considered with caution since deglacial equilibrium climate sensitivity may have differed from the modern one (Crucifix, 2006).".

Page 17, line 3: Substituted "duration of the stadials of the last deglaciation was" by "duration of last deglaciation stadials was".

Page 18, lines 17-18: Added ", and L. Barbara (reviewer), one anonymous reviewer and J.P. Bernal (editor) for constructive comments".

Pages 19-27: References were updated.

Page 29, line 13: Substituted "and mean annual low-level (925 hPA) atmospheric" by "and annual mean low-level atmospheric".

Page 29, line 21: Substituted "number 1 in the central panel indicate the" by "number "1" in the central panel indicates the".

Page 30, line 10: Deleted "the".

Figure 4: Formatted "ivc-ssw" (y-axis title of panel D) as a subscript.

Thermal evolution of the western South Atlantic and the adjacent continent during Termination 1

- 3
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13 Abstract

14 During Termination 1, millennial-scale weakening events of the Atlantic meridional 15 overturning circulation (AMOC) supposedly produced major changes in sea surface temperatures (SST) of the western South Atlantic, and in mean air temperatures (MAT) over 16 17 southeastern South America. It was suggested, for instance, that the Brazil Current (BC) 18 would strengthen (weaken) and the North Brazil Current (NBC) would weaken (strengthen) 19 during slowdown (speed-up) events of the AMOC. This anti-phase pattern was claimed to be 20 a necessary response to the decreased North Atlantic heat piracy during periods of weak 21 AMOC. However, the thermal evolution of the western South Atlantic and the adjacent 22 continent is so far largely unknown-and a compelling record of the BC-NBC anti-phase 23 behavior remains elusive. Here we address this issue, presenting high temporal resolution SST 24 and MAT records from the BC and southeastern South America, respectively. We identify a 25 warming in the western South Atlantic during Heinrich Stadial 1 (HS1), which is followed 26 first by a drop and then by increasing temperatures during the Bølling-Allerød, in-phase with 27 an existing <u>SSTNBC</u> record from the NBC. Additionally, a similar SST evolution is shown by 28 a southernmost eastern South Atlantic record, suggesting a South Atlantic-wide pattern in 29 SST evolution during most of Termination 1. Over southeastern South America, our MAT

 $1 \quad \ \ record \ shows \ a \ two-step \ increase \ during \ Termination \ 1, \ synchronous \ with \ atmospheric \ CO_2$

rise (i.e., during the second half of HS1 and during the Younger Dryas), and lagging abrupt
SST changes by several thousand years. This delay corroborates the notion that the long

- 4 duration of HS1 was fundamental to drive the Earth out of the last glacial.
- 5

6 1 Introduction

7 The thermal bipolar seesaw describes the warming occurring in the Southern Hemisphere due 8 to diminished northward heat transport within the Atlantic Ocean when the Atlantic 9 meridional overturning circulation (AMOC) is weakened (Mix et al., 1986; Stocker, 1998). 10 This mechanism is particularly efficient for perturbations of the AMOC through positive 11 anomalous freshwater fluxes in the high latitudes of the North Atlantic (Crowley, 1992; 12 Manabe and Stouffer, 1988). Heinrich Stadial 1 (HS1) is probably the best example for a 13 freshwater-forced AMOC collapse reduction (McManus et al., 2004). It has been suggested 14 that the southward flowing Brazil Current (BC) might redirect the excess heat to the South 15 Atlantic during times of AMOC slowdown (Crowley, 2011; Maier-Reimer et al., 1990). Yet, 16 little is known about the thermal evolution of the western South Atlantic and the adjacent 17 continent during Termination 1. The few available oceanic (e.g., Carlson et al., 2008) and 18 continental (e.g., Bush et al., 2004) records do not show the necessary temporal resolution to 19 appropriately resolve HS1. The lack of a high temporal resolution records from the BC (Clark 20 et al., 2012), for instance, hinders the evaluation of the previously hypothesized anti-phase 21 behavior between the BC and the North Brazil Current (NBC) during periods of a stalled 22 AMOC (Arz et al., 1999; Schmidt et al., 2012; Chiang et al., 2008).

Here we address this issue using an oceanic and a continental temperature record based on Mg/Ca analyses in planktonic foraminifera and lipid analyses in continentally-derived organic matter, respectively. Our records come from a single marine sediment core collected off southeastern South America under the influence of the BC and spanning Termination 1 with high temporal resolution. Our data provide evidence for millennial-scale fluctuations in the oceanic temperature record associated to changes in AMOC strength, and a two-step increase in the continental temperature record associated to changes in atmospheric CO₂.

30

1 2 Regional setting

2 2.1 Western South Atlantic

3 Upper level circulation in the subtropical western South Atlantic is dominated by the 4 southward-flowing BC (Fig. 1A) (Peterson and Stramma, 1991; Stramma and England, 1999). 5 The BC originates between 10 and 15°S from the bifurcation of the Southern South Equatorial Current (SSEC). At the bifurcation, the SSEC feeds both the BC and the northward flowing 6 7 NBC (also termed the North Brazil Undercurrent (Stramma et al., 1995) between the 8 bifurcation and ca. 5°S). Around 37°S the BC converges with the northward-flowing Malvinas 9 Current (Olson et al., 1988), where both currents turn southeastward and flow offshore as the 10 South Atlantic Current and the northern branch of the Antarctic Circumpolar Current, 11 respectively. The position of the Brazil-Malvinas Confluence varies seasonally between ca. 12 34 and 40°S, with a northward penetration of the Malvinas Current during austral winter and 13 early spring and a southward shift of the BC during austral summer and early autumn (Olson 14 et al., 1988). In its uppermost 100 m, the BC transports Tropical Water (>20 °C and >36 psu) 15 in the mixed layer, and from ca. 100 until 600 m the BC transports South Atlantic Central 16 Water (6-20°C and 34.6-36 psu) in the permanent thermocline (Locarnini et al., 2010; 17 Antonov et al., 2010).

18 The deficit in the southward BC transport relative to what would be expected from the wind 19 field is a consequence of the northward-directed upper branch of the thermohaline circulation 20 (Stommel, 1957; Peterson and Stramma, 1991). The formation of North Atlantic Deep Water 21 in the high latitudes of the North Atlantic requires a net transfer of thermocline water from the 22 South Atlantic to the North Atlantic together with net northward fluxes of intermediate and 23 bottom waters (Rintoul, 1991; Peterson and Stramma, 1991). Thus, under modern conditions 24 the NBC receives the larger portion (ca. 12 Sv) of the SSEC volume transport if compared to 25 the BC (ca. 4 Sv) (e.g., Stramma et al., 1990).

26 2.2 Southeastern South America

Throughout the year atmospheric circulation over southeastern South America is dominated by northerly winds (Fig. 1B) (Kalnay et al., 1996). During Southern Hemisphere summer, the South Atlantic Convergence Zone, a northwest-southeast-oriented convective band along the northeastern boundary of the La Plata River drainage basin (LPRDB), and the South

1 American Low-Level Jet, a northwesterly low-level flow that transports moisture from the 2 western Amazon to the LPRDB, are key features of the South American summer monsoon 3 (Carvalho et al., 2004; Zhou and Lau, 1998). During Southern Hemisphere winter, 4 equatorward incursions of mid-latitude cold dry air result in cyclonic storms (Vera et al., 5 2002). Precipitation in the LPRDB is dominated by Southern Hemisphere summer rainfall 6 associated to the South American summer monsoon (Fig. 2) (Zhou and Lau, 1998; Xie and 7 Arkin, 1997). Correspondingly, maximum La Plata River discharge occurs in late Southern 8 Hemisphere summer (Fig. 2). Winter precipitation triggered by occasional northward 9 migration of extratropical cyclones results in less pronounced rainfall (Vera et al., 2002). 10 Histograms of long--term mean average monthly precipitation display a strong Southern 11 Hemisphere winter minimuma (Fig. 2), particularly in the north-western sector of the 12 LPRDB, which supplies most of the particulate load of the La Plata River (Depetris and Kempe, 1993; Depetris et al., 2003). 13

Low level_<u>Aa</u>ir temperatures <u>at low atmospheric levels</u> over South America are dominated by the equator-to-pole thermal gradient (Fig. 1B) (Garreaud et al., 2009). The meridional temperature profile is rather flat at ca. 20°C-between 20°N-the equator and 20°S, centered around 20°C. To the south of 20°S, temperatures gradually decrease to 0°C over the southern tip of the continent. Zonal departures from this meridional gradient are relatively small to the east of the Andes, as is the case for the LPRDB.

20

21 3 Material and methods

22 3.1 Marine sediment core

We investigated sediment core GeoB6211-2 (Schulz et al., 2001; Wefer et al., 2001) collected from the continental slope off southeastern South America (32.51°S / 50.24°W / 657 m water depth / 774 cm long) (Figs. 1A, 2). The gravity core was raised at the Rio Grande Cone, a major sedimentary feature in the western Argentine Basin (Schulz et al., 2001). Because our focus here is Termination 1 we analyzed the section from 86 until 583 cm core depth that corresponds to the period from 10.2 until 19.3 cal ka BP (see Section 4.1 below).

29 One meter long sections of core GeoB6211-2 were longitudinally split and described onboard,

30 and then stored at 4°C. Visual inspection of core GeoB6211-2 does not provide evidence for

31 depositional or erosive disturbance (Wefer et al., 2001). Onshore, the last deglaciation section

1 of the core was sampled at 1 cm intervals. Samples for radiocarbon, Mg/Ca and stable oxygen

4 under a binocular microscope. Samples for lipid analyses were stored at 4°C until processing.

5 3.2 Radiocarbon analyses and age model

6 The age model of core GeoB6211-2 is based on nine accelerator mass spectrometry 7 radiocarbon ages (Table 1, Fig. 3). Five ages are based on tests of shallow dwelling 8 planktonic foraminifera Globigerinoides ruber (pink and white) and Globigerinoides 9 sacculifer, while the remaining four ages are based either on mixed planktonic foraminifera 10 (i.e., two ages) or epibenthic bivalve shells (i.e., two ages). Apart from the age obtained at 11 315 cm core depth, all ages were previously published by Chiessi et al. (2008) and Razik et al. 12 (2013). For each sample, we collected around 10 mg of $CaCO_3$ from the sediment fraction 13 larger than 150 µm. One of the samples was measured at the National Ocean Sciences 14 Accelerator Mass Spectrometry Facility at Woods Hole (USA), while the other eight were 15 measured at the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research at 16 Kiel (Germany). All radiocarbon ages were calibrated with the calibration curve Marine13 17 (Reimer et al., 2013) with the software Calib 7.0 (Stuiver and Reimer, 1993). Following the 18 arguments from Chiessi et al. (2008) we decided not to use a specific reservoir age to the 19 radiocarbon ages based on epibenthic bivalve shells. Also, no additional marine reservoir 20 correction was applied because our core site is located far from upwelling zones and 21 significantly to the north of the Brazil-Malvinas Confluence, both being places where 22 corrections are typically necessary (Reimer and Reimer, 2001). All ages are indicated as 23 calibrated years before present (cal a BP; present is 1950 AD), except where noted otherwise. 24 To construct the age model, we linearly interpolated the calibrated ages. For each dated depth 25 we used in the interpolation the mean value from the 1σ range of the calibrated age.

26 3.3 Mg/Ca analyses and sea surface temperatures

Around 40 tests of *G. ruber* (white, sensu stricto according to Wang (2000)) within the size range 250–350 µm were used for Mg/Ca analyses. Analyses were performed at approximately every cm between 86 and 123 cm core depth, and at approximately every four cm below 123 cm core depth. Different spacing was applied to compensate for the lower sedimentation rates in the section 86-123 cm core depth as compared to the section 123-583 cm core depth (see

Section 4.1 below). After gently crushing the tests, shell fragments were cleaned according to 1 2 the standard cleaning protocol for foraminiferal Mg/Ca analyses suggested by Barker et al. 3 (2003) and slightly modified by Groeneveld and Chiessi (2011). Before dilution, samples 4 were centrifuged for 10 min (6000 rpm) to exclude any remaining insoluble particles from the 5 analyses. Samples were diluted with Seralpur water before analysis with an inductively coupled plasma - optical emission spectrometer (ICP-OES) (Agilent Technologies, 700 6 7 Series with autosampler (ASX-520 Cetac) and micro-nebulizer) at the MARUM - Center for 8 Marine Environmental Sciences, University of Bremen, Germany. Instrumental precision of 9 the ICP- OES was monitored by analysis of an in- house standard solution with a Mg/Ca of 10 2.93 mmol mol⁻¹ after every five samples (long--term standard deviation of 0.026 mmol mol⁻¹ 11 or 0.91 %). To allow inter-laboratory comparison we analyzed an international limestone 12 standard (ECRM752-1) with a reported Mg/Ca of 3.75 mmol mol⁻¹ (Greaves et al., 2008). The long-term average of the ECRM752-1 standard, which was routinely analyzed twice 13 14 before each batch of 50 samples in every session, is 3.78 mmol mol⁻¹ ($1\sigma = 0.066$ mmol mol⁻ 15 ¹). Analytical error based on three replicate measurements of each sample for G. ruber was 16 0.14 % ($1\sigma = 0.004$ mmol mol⁻¹) for Mg/Ca. To convert Mg/Ca-ratios into sea surface 17 temperatures (SST) we used the calibration equation of Anand et al. (2003) for G. ruber 18 (white) in the size range 250-350 µm with no pre-assumed exponential constant:

19 $Mg/Ca = 0.34\exp(0.102*SST)$ (1)

- 20 The propagation of uncertainties typically results in 1σ error of about 1°C for SST (Mohtadi 21 et al., 2014).
- According to Hönisch et al. (2013), the small sensitivity of *G. ruber* Mg/Ca to changes in
 salinity (i.e., 3.3 +/- 1.7 % per salinity unit) supports the use of this paleotemperature proxy
 given the range of salinity change in our study area (see Section 4.3 below).

25 We measured Mg/Ca in tests of G. ruber (white) because it dwells in the uppermost water 26 column and reflects mixed layer conditions (Chiessi et al., 2007). Moreover, G. ruber (white) 27 records austral hemisphere summer conditions in-at our core site (Fraile et al., 2009a; 28 Lombard et al., 2011), with no significant change in seasonal preference during the Last 29 Glacial Maximum (LGM) (Fraile et al., 2009b). Furthermore, the mean Mg/Ca based SST 30 (i.e., 23.1°C) obtained for the uppermost two samples of multicore GeoB6211-1 (collected in 31 the same site as gravity core GeoB6211-2) compares favorably with the modern mean summer SST in the top 20 m of the local water column (i.e., 24.1°C) and differs considerably 32

1 from modern mean winter SST (i.e., 17.8°C), corroborating the austral hemisphere summer

2 signal recorded by *G. ruber* (white) (Chiessi et al., 2014).

3 3.4 Stable oxygen isotope analyses and sea surface salinities

4 Ten hand-picked tests of G. ruber (white, sensu stricto according to Wang (2000)) within the size-range 250-350 µm from approximately every cm of core GeoB6211-2 were used for 5 δ^{18} O analyses. Results between 448 and 123 cm core depth were previously published by 6 7 Chiessi et al. (2009). Stable oxygen isotope analyses were performed on a Finnigan MAT 252 8 mass spectrometer equipped with an automatic carbonate preparation device at the MARUM -9 Center for Marine Environmental Sciences, University of Bremen, Germany. Isotopic results 10 were calibrated relative to the Vienna Peedee belemnite (VPDB) using the NBS19 standard. The standard deviation of the laboratory standard was lower than 0.07 ‰ for the measuring 11 12 period.

13 To calculate the δ^{18} O of continental-ice-volume-corrected surface sea water (δ^{18} O_{ivc-ssw}), a

14 proxy for relative sea surface salinity, we used: (i) our *G. ruber* Mg/Ca SST and δ^{18} O; (ii) the

15 paleotemperature equation from Mulitza et al. (2003) for *G. ruber* (white):

16
$$SST(^{\circ}C) = -4.44 * (\delta^{18}O_{G ruber} - \delta^{18}O_{rub}) + 14.20$$

17 (iii) the VPDB to Vienna Standard Mean Ocean Water conversion factor from Hut (1987);

18 (iv) the sea level curve from Lambeck and Chappell (2001); and (v) the global average change

19 in $\delta^{18}O_{sw}$ since the LGM from Schrag et al. (2002). The sea level curve from Lambeck and

20 Chappell (2001) is consistent with the timing of meltwater pulse 1A reported by Deschamps

21 et al. (2012) (14.5 and 14.6 cal ka BP, respectively). The propagation of uncertainties

22 typically results in 1σ error of about 0.3 % for $\delta^{18}O_{ivc-ssw}$ (Mohtadi et al., 2014).

23 3.5 Lipid analyses and continental mean air temperatures

Lipid analyses were performed at approximately every 6 cm. Lipid extraction of freeze-dried powdered samples was performed by the use of ultrasonic probes. Extracts were saponified and further separated on Bond-Elut SiO₂ columns. Polar fractions containing glycerol dialkyl glycerol tetraethers (GDGTs) were eluted with 2 mL MeOH. Prior to analysis by high performance liquid chromatography / atmospheric pressure chemical ionization – mass spectrometry (HPLC/APCI-MS), samples were filtered through a 4 μm pore size PTFE filter Formatado: Subscrito

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7

(2)

and dissolved in hexane/isopropanol (99:1; v/v). An Agilent 1200 series HPLC/APCI-MS 1

2

()

system equipped with a Grace Prevail Cyano column (150 mm x 2.1 mm; 3 µm) was used, 3 and separation was achieved in normal phase using the method described by Hopmans et al. 4 (2004).

5 Mean air temperature (MAT) was estimated according to Peterse et al. (2012). GDGTs with the following protonated molecular ion masses were quantified: 1022 (Ia), 1020 (Ib), 1018 6 7 (Ic); 1036 (IIa), 1034 (IIb), 1032 (IIc); 1050 (IIIa). Ratios of peak areas were used to calculate 8 the Methylation Branched Tetraether (MBT') and Cyclisation Branched Tetraether (CBT) 9 indices as follow:

10
$$MBT' = \frac{(Ia + Ib + Ic)}{(Ia + Ib + Ic + IIa + IIb + IIc + IIIa)}$$
(3)

11
$$CBT = -\log\left[\left(\frac{Ib + IIb}{Ia + IIa}\right)\right]$$
 (4)

12 Index values calculated using equations (3) and (4) were subsequently converted to MAT 13 estimates according to:

14
$$MAT(^{\circ}C) = 0.81 - 5.67 * CBT + 31.0 * MBT'$$
 (5)

15 The production of GDGTs by some uncharacterized microbial community in marine 16 sediments has gained recent attention (e.g., Zhu et al., 2011). For in situ production in the 17 marine realm, the authors consistently describe an increase in the relative abundance of those 18 GDGTs containing cyclopentane moieties (e.g., GDGT Ic and GDGT IIc) as well as a 19 decrease in the relative abundance of the compounds GDGT Ia and GDGT IIa. We carefully 20 screened our results for a similar behavior.

21 Temperature estimates are thought to reflect mean annual air temperature (Peterse et al., 22 2012). During Termination 1, our core site received terrigenous material discharged from the La Plata River drainage basin (LPRDB) as attested by Nd isotopes (Lantzsch et al., 2014). 23 Within the LPRDB, most of the suspended load (Depetris et al., 2003) and particulate organic 24 25 matter (Depetris and Kempe, 1993) originates from the Bermejo River sub-basin, located in 26 the northwest domain. The amount of river suspended load corresponds to the discharge 27 (Depetris et al., 2003), and most of the particulate organic matter is soil-derived (Depetris and 28 Kempe, 1993). Thus, we expect our MAT record to represent a LPRDB-integrated signal with 29 a predominant contribution from its north-western domain.

1

2 4 Results

3 4.1 Radiocarbon analyses and age model

The investigated section (i.e., 86-583 cm core depth) of core GeoB6211-2 recorded the period between 10.2 and 19.3 cal ka BP (Table 1, Fig. 3). The Marine13 calibration curve produced very similar ages (i.e., difference smaller than 0.2 kyr) if compared to the previously published values (Chiessi et al., 2008; Razik et al., 2013) calibrated with Marine04 (Hughen et al., 2004) and Marine09 (Reimer et al., 2009). Thus, the age model used here is very similar to the age models published by Chiessi et al. (2008) between 19.3 and 14.1 cal ka BP, and by Razik et al. (2013) between 14.1 and 10.2 cal kayr BP.

11 Sedimentation rates of the investigated section of core GeoB6211-2 show a two-step decrease

12 from the LGM to the early Holocene (Fig. 3). Mean values decrease from ca. 160 to 80 cm

13 kyr⁻¹ at 18.45 cal ka BP, and from ca. 80 to 10 cm kyr⁻¹ at 14.1 cal ka BP.

14 Considering the sampling strategy and the sedimentation rates for core GeoB6211-2, the

15 mean temporal resolution is ca. 30 yr for Mg/Ca analyses, ca. 10 yr for δ^{18} O analyses, and ca.

16 80 yr for lipid analyses for the period before 18.45 cal ka BP, ca. 60 yr for Mg/Ca analyses,

- 17 ca. 15 yr for δ^{18} O analyses, and ca. 70 yr for lipid analyses for the period between 18.45 and
- 18 14.1 cal ka BP, and ca. 120 yr for Mg/Ca analyses, ca. 105 yr for δ^{18} O analyses, and ca. 555
- 19 yr for lipid analyses for the period after 14.1 cal ka BP.

20 4.2 Mg/Ca analyses and sea surface temperatures

21 Mg/Ca ratios_from G. ruber range from 2.50 to 3.60 mmol mol⁻¹ and are equivalent to 19.5 22 and 23.1 °C, respectively (Fig. 4B). Reconstructed SST increase since the LGM (averaging 23 20.6°C) until ca. 18 cal ka BP, remaining roughly constant (averaging 21.9°C) until ca. 16 cal 24 ka BP. A marked SST drop reaching minimum value (20.4°C) at ca. 15.5 cal ka BP ends the 25 period of relatively stable SST. A double-peak structure culminating at ca. 15 cal ka BP 26 (23.0°C) and ca. 13 cal ka BP (22.9°C) was followed by low temperatures (averaging 21.7°C) 27 until ca. 11.9 cal ka BP. After that, the record is characterized by oscillating SST (averaging 28 22.2°C) SST. Thus, the deglacial SST rise is ca. 1.6°C.

1 4.3 Stable oxygen isotope analyses and sea surface salinities

2 Values of G. ruber δ^{18} O show a stepwise decrease from 0.75 ‰ during the LGM to -0.06 ‰

3 during the early Holocene (Fig. 4C). There are three major steps and they occurred at ca. 15.5,

4 13.5 and 11.5 cal ka BP.

5 Ice-volume corrected $\delta^{18}O_{ssw}$ values range from 0.88 to 2.15 ‰ (Fig. 4D). From the LGM

6 until ca. 14 cal ka BP, temporal changes in $\delta^{18}O_{ivc-ssw}$ are similar to the changes described for

7 SST. After that, the record is marked by roughly constant values (averaging 1.65 ‰) until

8 11.5 cal ka BP and a rather large variability around 1.47 ‰ during the early Holocene.

9 4.4 Lipid analyses and continental mean air temperatures

10 We first examined our data set for indications of marine in-situ production of GDGTs as described in section 3.5, which was not the case (Chiessi et al., 2015b). Then, we calculated 11 12 cContinental MAT values that range from 11.5°C at 18.0 cal ka BP to 14.9°C at 11.5 cal ka 13 BP (Fig. 4E). Reconstructed MAT show a small gradual increase from the base of the record 14 until ca. 16.5 cal ka BP when a sharp increase of ca. 1.1°C takes place. Temperatures remain 15 relatively stable until ca. 12.5 cal ka BP when an increase of ca. 1.0°C within ca. 1 kyr was 16 recorded. After that, stable MAT characterize the record until the early Holocene. Although 17 our MAT record does not cover the LGM, the deglacial MAT rise calculated using the 18 averaged value for the oldest and youngest 500 yr values of our time series is 2.5°C. The 19 marked decrease in the mean temporal resolution of our MAT record after 14.1 cal ka BP that 20 shifts from ca. 70 years to ca. 555 years is worthy of note. This has to be considered while 21 interpreting the MAT trends described for the period after 14.1 cal ka BP.

22

23 5 Discussion

The two major decreases in sedimentation rates found in GeoB6211-2 are remarkably synchronous (within age model uncertainties) with outstanding events of sea-level rise related to meltwater pulses that occurred at ca. 19 and 14.6 cal ka BP (Deschamps et al., 2012; Yokoyama et al., 2000). <u>The sea-level drop preceding During</u> the LGM, sea level lowstand shifted the coastline towards our core site. With the resulting narrow continental shelf, the large sediment supply of the La Plata River was directed to the Rio Grande Cone via the La Plata paleo-valley, that was responsible for the high sedimentation rates typical for the Formatado: Subscrito
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lowermost section of core GeoB6211-2 (Fig. 3) (Chiessi et al., 2008; Lantzsch et al., 2014).
 The stepwise rise in sea-level following the LGM caused abrupt displacements of the
 coastline towards the continent trapping a large amount of the La Plata River sediment supply
 in-on_the shelf and controlling the stepwise decrease in sedimentation rate at our site (Chiessi
 et al., 2008; Lantzsch et al., 2014). Because of the high sedimentation rates (i.e., ca. 100 cm
 kyr⁻¹) found between the LGM and 14.1 cal ka BP, core GeoB6211-2 is particularly well
 suited to investigate HS1.

5.1 Sea surface temperatures and salinities of the western South Atlantic 9 during Termination 1

10 The high SST reconstructed for our western South Atlantic site between 18 and 16 cal ka BP 11 as well as the peak in SST at ca. 15 cal ka BP (Fig. 4B) fall within HS1, as defined by 12 Sarnthein et al. (2001). It has been suggested that during HS1 a strong slowdown of the 13 AMOC (Fig. 5B) (McManus et al., 2004) produced by a positive anomalous freshwater 14 discharge into the high latitudes of the North Atlantic (Bond et al., 1992) would have been 15 responsible for a decreased cross equatorial heat transport in the Atlantic (Fig. 5A) (Bard et 16 al., 2000). Under a sluggish AMOC, the residual heat not transported to the North Atlantic 17 would be trapped in the Southern Hemisphere (Broecker, 1998; Crowley, 1992). Many water 18 hosing model experiments that show a strong decrease in AMOC strength suggested that the 19 Southern Hemisphere warming should have affected the surface layer of the BC (Kageyama 20 et al., 2013; Stouffer et al., 2006). This warming has been suggested for experiments under 21 both LGM and pre-industrial boundary conditions. Here we show the first record that 22 corroborates this suggestion (Fig. 4B). We propose that the surface layer of the BC acted as a 23 conduit and storage volume for part of the heat not transported to the North Atlantic during HS1 that was eventually shunted towards higher latitudes in the South Atlantic (Barker et al., 24 25 2009; Anderson et al., 2009). Moreover, the marked drop in our SST record reaching 26 minimum values at ca. 15.5 cal ka BP could be related to an intervening warm spell registered 27 within HS1 in the North Atlantic mid-latitudes (Martrat et al., 2014). We hypothesize that not 28 only millennial-scale changes associated to Termination 1 (e.g., HS1) affected the BC, but 29 also centennial-scale fluctuations (e.g., internal structure of HS1) were registered. However, 30 we primarily discuss the millennial-scale events because of age model uncertainties.

31 Interestingly, the other high temporal resolution Mg/Ca based SST record from the western

32 South Atlantic covering Termination 1 shows very similar changes in SST during HS1 (Figs.

1A, 5C) (Weldeab et al., 2006). This core (i.e., GeoB3129-1/3911-3) was collected off NE 1 2 Brazil at 4.61°S, thus under the influence of the NBC. The marked-similarity in SST between 3 both western South Atlantic records goes beyond HS1, and is also valid for the SST drop with 4 minimum values at ca. 14 cal ka BP, and peak SST at ca. 13 cal ka BP, during the Bølling-5 Allerød (BA). Thus, our SST record (from the BC) together with the SST record from 6 Weldeab et al. (2006) (from the NBC) suggest an generally in-phase behavior of the BC and the NBC regions during HS1 and the BA. This contradicts , in contradiction with the BC-7 8 NBC anti-phase relationship suggested by Arz et al. (1999), at least concerning SST since we 9 have no proxy to assess current strength.

It is worthy of note that Arz et al. (1999) based their suggestion exclusively on δ^{18} O records 10 of planktonic foraminifera. The more negative excursion in foraminiferal δ^{18} O that those 11 12 authors reported during HS1 for the cores collected under the influence of the BC (i.e., 13 GeoB3229-2, GeoB3202-1) if compared to the less negative excursion reported for the cores 14 under the influence of the NBC (i.e., GeoB3104-1, GeoB3117-1, GeoB3129-1/3911-3, 15 GeoB3176-1) supported the notion that the sluggish AMOC would have triggered a weakening in the NBC and a strengthening in the BC (Fig. 1A). This would have been 16 17 responsible for the low HS1 meridional gradient in the δ^{18} O records published by Arz et al. 18 (1999).

19 Based on absolute SST and $\delta^{18}O_{ivc-ssw}$ values from the NBC (Weldeab et al., 2006) and the 20 BC (this study) we are now able to show that the HS1-LGM SST ($\delta^{18}O_{ivc-ssw}$) anomaly at the NBC site amounts to ca. 2.5°C and 0.5 ‰ respectively, while at our BC site it is limited to ca. 21 1.3°C and 0.3 % respectively. Thus, the NBC showed larger SST and $\delta^{18}O_{ivc-ssw}$ increases if 22 23 compared to the BC during HS1. Since temperature and $\delta^{18}O_{sw}$ influence for a miniferal $\delta^{18}O_{sw}$ 24 in opposite directions, the signal of the stronger warming at the NBC was dampened by the larger increase in $\delta^{18}O_{ivc-ssw}$, preventing the $\delta^{18}O$ signal in *G. ruber* to change (assuming a 0.2 25 26 % °C-1; (Mulitza et al., 2003)). So far, this stands for no BC-NBC anomaly in foraminiferal δ^{18} O during HS1. Nevertheless, our BC site is located ca. 12° downstream the sites 27 28 investigated by Arz et al. (1999) in the BC. Because the N-S SST gradient in the western 29 South Atlantic was larger than the one for $\delta^{18}O_{ivc-ssw}$ during HS1, it is expected that a larger 30 warming at the southern sites studied by Arz et al. (1999) overprinted the $\delta^{18}O_{ivc-ssw}$ effect, and produced the reported negative excursion in foraminiferal δ^{18} O. 31

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Together with the NBC record, our SST reconstruction provides evidence that the western South Atlantic was indeed affected by Northern Hemisphere rapid climate change during Termination 1. However, the <u>thermal</u> response of the surface layer of the western South Atlantic cannot be described as an anti-phase in SST between the BC and the NBC regions as suggested from a weakening (strengthening) of the northern (southern) branch of the SSEC bifurcation (Arz et al., 1999), but rather as a widespread and in-phase increase in SST.

7 The low SST from our record during the Younger Dryas (YD) do not agree with the high 8 temperatures reported by Weldeab et al. (2006) for the same event (Fig. 5C, D). The 9 inconsistency of the YD SST signal in the western South Atlantic may be due to: (i) the 10 smaller amplitude of the AMOC slowdown that characterized the YD if compared to HS1 11 (McManus et al., 2004; Ritz et al., 2013); (ii) the shorter duration of the YD if compared to 12 HS1 (EPICA Community Members, 2006; Rasmussen et al., 2006; Sarnthein et al., 2001) 13 related to the time needed for the oceans-South Atlantic to equilibrate after an anomalous 14 freshwater pulse in the high latitudes of the North Atlantic; and (iii) the different boundary 15 conditions of the YD if compared to those present during HS1 (Clark et al., 2012). Numerical 16 model experiments provide key insights to these three non-exclusive possibilities. First, water 17 hosing model experiments that retain an active and relatively strong AMOC indeed showed a 18 much weaker expression of the bipolar seesaw, if compared to simulations in which the 19 AMOC strongly decreases (Kageyama et al., 2013; Otto-Bliesner and Brady, 2010). Second, 20 the reduction of the AMOC intensity due to freshwater perturbation increases with increasing 21 duration and amount of the freshwater perturbation (Rind et al., 2001; Prange et al., 2002). 22 Third, freshwater discharge to different geographic regions in the North Atlantic has been 23 shown to trigger different responses in the AMOC (Roche et al., 2009; Otto-Bliesner and 24 Brady, 2010). Thus, all three possibilities may have acted together or independently 25 producing a different response of the western South Atlantic during the YD and HS1.

In addition to the bipolar seesaw, another mechanism that acts to cool the western South Atlantic during specific slowdown events of the AMOC seems to exist. This mechanism may be related to a change in the wind field, more precisely to a weakening of the subtropical high pressure cell (Prange and Schulz, 2004). Based on climate model results and proxy records from the Benguela upwelling region, Prange and Schulz (2004) suggested a weakening of the South Atlantic subtropical anticyclone in response to a reduced cross-equatorial Atlantic Ocean heat transport. This would result in a weakening of the BC and its associated heat

1 transport from the tropics and hence a cooling at our core site. Which mechanism dominates

2 (i.e., bipolar seesaw or wind field) may depend on boundary conditions and freshwater 3 forcing function.

A similar thermal evolution spanning most of Termination 1 (i.e., HS1 and BA) is not only a 4 5 pervasive feature of the western South Atlantic (this study; Weldeab et al., 2006), but also includes the southernmost eastern South Atlantic, as reconstructed from a core raised at 6 7 41.10°S / 7.80°E / 4981 m water depth (Fig. 5E) (Barker et al., 2009). The high temporal 8 resolution Mg/Ca based SST record from the southernmost eastern South Atlantic also 9 presents high SST during HS1 that is followed by a marked drop at ca. 14 cal ka BP and 10 increasing temperatures towards the onset of the YD (Barker et al., 2009). The striking 11 similarity of the three high temporal resolution (i.e., 150 yr or less between adjacent samples) 12 Mg/Ca based SST records from the South Atlantic (this study; Weldeab et al., 2006; Barker et 13 al., 2009) not influenced by continental margin upwelling (Farmer et al., 2005) or continental 14 freshwater discharge (Weldeab et al., 2007) suggest an emerging South Atlantic-wide pattern 15 in SST evolution during most of Termination 1. Still, the view of the YD as a replicate of HS1 16 seems not to hold for the western South Atlantic. 17

Recently, Weber et al. (2014) suggested that Antarctic meltwater pulses may have cooled the

18 upper water column of the South Atlantic. Indeed, our sea surface temperature record shows 19

minor (i.e., ca. 0.5°C) decreases around the two most prominent events of increased flux of

20 iceberg-rafted debris at the Scotia Sea (a proxy for Antarctic meltwater pulses) recorded

21 during Termination 1 (i.e., Antarctic Ice Sheet discharge (AID) events 7 between 16.91 and

22 15.75 cal ka BP, and event AID6 between 14.86 and 13.94 cal ka BP) (Chiessi et al., 2015a).

23 Thus, Antarctic meltwater pulses may have contributed to the variability of SST from the

24 subtropical domain of the Brazil Current on top of the mechanisms already described.

25 5.2 Continental mean air temperatures over southeastern South America during Termination 1 26

27 Most of the warming in our step-like structured MAT record takes place during the second 28 half of HS1 and during the YD, but due to the marked decrease in temporal resolution of our 29 MAT record after 14.1 cal ka BP we raise a note of caution while interpreting the temperature 30 rise during the YD, whereas little or no warming characterizes the LGM, the BA and the

31 early Holocene (Fig. 4E) (Sarnthein et al., 2001; Rasmussen et al., 2006). Our MAT record is

1 remarkably similar to deglacial rise in atmospheric CO₂ and Antarctic temperatures (Fig. 6C, 2 D, E) (EPICA Community Members, 2006; Monnin et al., 2004). Not only the timing of the 3 two pulses of MAT increase in our record (i.e., ca. 16.5 and 12.5 cal ka BP) is synchronous 4 with intervals of marked increases in global atmospheric CO₂ and Antarctic temperatures, but 5 also the periods of relatively stable MAT are contemporaneous with periods of a small rate of global atmospheric CO₂ and Antarctic temperature increase. The two pulses of sharp increase 6 7 in deglacial atmospheric CO2 also occurred simultaneously with increased upwelling in the 8 Southern Ocean (Anderson et al., 2009). As suggested by Toggweiler et al. (2006), warming 9 around Antarctica may have increased upwelling through a poleward shift in the Southern 10 Westerlies and a corresponding increase in northward Ekman transport of surface waters. 11 Still, the trigger for the changes in upwelling in the Southern Ocean probably resided in the 12 high latitudes of the North Atlantic (i.e., HS1 and the YD) and was transmitted to the Southern Hemisphere via changes in atmospheric (Lee et al., 2011) or oceanic (Knutti et al., 13 14 2004) circulation.

15 Since atmospheric circulation in the LPRDB is dominated by northerly winds (Fig. 1B) 16 (Kalnay et al., 1996), deglacial evolution of continental surface air temperature in the region 17 is also expected to follow the mean warming trend of low latitude regions in South America. 18 High temporal resolution and continuous MAT records from tropical South America to the 19 east of the Andes spanning most of Termination 1 are, to our knowledge, still absent (Shakun 20 et al., 2012). Nevertheless, the comparison of our MAT record to other continental 21 temperature records with relatively lower temporal resolution allows evaluating the spatial 22 variability of MAT. Indeed, Oour MAT record, for instance, bears close some resemblance 23 with a pollen-derived temperature record from eastern Peru (Lake Consuelo) collected at 24 13.95°S (Fig. 6B, C) (Bush et al., 2004). A strong The linkage of MAT in the LPRDB to low 25 latitude temperature evolution is supported by modern observations of a relatively flat MAT 26 profile in tropical to subtropical South America between 10°N and 20°S (Fig. 1B) (Legates 27 and Willmott, 1990).

The <u>good temporalgeneral</u> agreement between our MAT and eastern Peru temperatures (Bush et al., 2004) taken together with the rise in atmospheric CO₂ content (Monnin et al., 2004) (Fig. 6B, C, D) suggests that greenhouse gas concentrations exerted a strong control on South American <u>surface temperaturesMAT</u> during Termination 1. <u>Considering equilibrium climate</u> <u>sensitivity to changes in atmospheric CO₂ concentration to be within the range 1.5 to 4.5°C</u>,

the deglacial temperature increase exclusively due to CO₂ rise would range from 0.9 to 2.7°C.
 Thus, the deglacial temperature rise in our MAT record (i.e., 2.5°C) may largely be explained
 by the deglacial atmospheric CO₂ increase. Nevertheless, this attribution hypothesis has to be
 considered with caution since deglacial equilibrium climate sensitivity may have differed
 from the modern one (Crucifix, 2006).
 Additionally, Antarctic meltwater pulses may have decreased MAT over southeastern South

- America (Weber et al., 2014). The modeled cooling amounts to ca. 1.0°C over the
 southernmost portion of the LPRDB. Given age model uncertainties, the two most prominent
 events of increased flux of iceberg-rafted debris at the Scotia Sea (i.e., AID7 and AID6;
 Weber et al., 2014) partially correlate with negative anomalies in our MAT record (Chiessi et
- 11 al., 2015a). Thus, Antarctic meltwater pulses may have contributed to the variability of MAT
- 12 over the LPRDB in addition to changes in atmospheric CO₂ concentration.

5.3 Combining sea surface temperatures in the western South Atlantic and continental mean air temperatures on the adjacent continent during Termination 1

16 Taken together with other temperature reconstructions from the western South Atlantic and 17 the adjacent continent as well as global compilations (Figs. 5, 6) (e.g., Bush et al., 18 2004;Weldeab et al., 2006;Shakun et al., 2012;Clark et al., 2012), Oour SST records suggests 19 that the South Atlantic, and the BC more specifically, was of paramount importance for the 20 southward propagation of the thermal bipolar seesaw signal of HS1 (Fig. 5). Indeed, the 21 western South Atlantic was more sensitive to AMOC forcing than lowland South America, 22 which appears to be more susceptible to atmospheric CO₂ changes (Figs. 5 and 6). Thus, oOur 23 SST and MAT records sum up to other lines of evidence supporting the notion that global 24 continental air temperature closely tracked the increase in atmospheric CO₂ concentration 25 during Termination 1, and that variations in the AMOC caused a seesawing of heat between 26 the hemispheres mainly impacting the oceans in the Southern Hemisphere (Shakun et al., 27 2012).

Assuming no significant delay in the transport of the continental temperature signal to our core site (Weijers et al., 2007;_Schefuss et al., 2011), our records allow establishing a phase relationship between changes in AMOC strength related to the onset of HS1 and the rise in atmospheric CO₂. According to our records, the decrease in AMOC strength already impacted

SST in the western South Atlantic as early as ca. 19 cal ka BP, while the rise in atmospheric CO₂ only affected MAT at ca. 16.5 cal ka BP. As suggested by Denton et al. (2010), the long duration of <u>last deglaciation the</u> stadials of the last deglaciation was of fundamental importance to produce the necessary large oceanic CO₂ release via the Southern Ocean (Anderson et al., 2009). Thus, increasing Northern Hemisphere summer insolation alone was insufficient to terminate the last glaciation, and the impact of rising atmospheric CO₂ was a key factor to complete the last deglaciation (Denton et al., 2010; Shakun et al., 2012).

8 Interestingly_a our SST and MAT records present different amplitudes in deglacial temperature 9 rise. Similarly to the oceanic and continental temperature records reported by Weijers et al. 10 (2007), our oceanic temperatures (i.e., 1.6°C) showed a smaller amplitude if compared to our 11 continental temperatures (i.e., 2.5°C) (Fig. 4B, E). The deglacial amplitude of our SST record 12 is very similar to global compilations (i.e., 1-2°C) (e.g., MARGO Project Members, 2009) and 13 regional reconstructions (i.e., 1-2°C) (Carlson et al., 2008;_Toledo et al., 2007), even 14 considering the lower temporal resolution of those reconstructions if compared to our record.

On the other hand, the deglacial amplitude of our MAT record is remarkably smaller than the amplitude of the few other available continental records for tropical South America, namely 5-7°C from Behling (2002) and 5-9°C from Bush et al. (2004). Nevertheless, pollen-based tropical and subtropical temperature reconstructions should be interpreted with caution since changes in moisture availability may also impact the recorded signal.

The difference between oceanic and continental warming during Termination 1 reported in this study agrees with climate model simulations that suggest an average continental deglacial warming in the tropics ca. 1.5 times higher than the deglacial warming of the tropical oceans (Otto-Bliesner et al., 2006; Braconnot et al., 2012). The land/sea warming ratio is usually explained through differences in evaporation between land and ocean, and through landsurface feedbacks (Braconnot et al., 2012).

26

27 6 Conclusions

Our SST record from the BC in the western South Atlantic shows a marked positive anomaly during HS1. This is the first record that corroborates model suggestions that the surface layer of the BC acted as an important conduit and storage volume for part of the heat not

transported to the North Atlantic under a sluggish AMOC. Thus, the BC was of paramount 1 2 importance in propagating southwards the thermal bipolar seesaw signal of HS1. Moreover, 3 the marked similarity to a SST record from the NBC suggests an in-phase thermal evolution 4 of the BC and the NBC during HS1 (and the BA), contradicting previous assumptions of a 5 BC-NBC anti-phase. Similar changes in SST are not only a pervasive feature of the western 6 South Atlantic but also include the southernmost eastern South Atlantic, suggesting a South 7 Atlantic-wide pattern in SST evolution during most of Termination 1. Over southeastern 8 South America, our MAT record shows that most of the deglacial warming occurred during 9 the second half of HS1 and during the YD. Changes in MAT are remarkably synchronous 10 with atmospheric CO₂ rise, suggesting that greenhouse gas concentrations exerted a strong 11 control on South American surface temperatures during Termination 1. The ca. 2.5 kyr lag of 12 MAT rise if compared to SST rise after the LGM corroborates the notion that the long duration of HS1 was fundamental to drive the Earth out of the last glacial. 13

14

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1	Table 1.	Accelerator	mass	spectrometer	radiocarbon	ages	and	calibrated	ages	used	to
2	construct	the age mode	l of co	re GeoB6211-	2.						

Lab ID	Core Species	Radiocarbon	1 σ	Calibrated	Additional	References
	depth	age $\pm 1 \sigma$	calibrated	age (cal	age used	
	(cm)	error (yr BP)	age range	ka BP)	in the age	
			(cal ka BP)		model (cal	

				(cal ka BP)		model (cal ka BP)	
NOSAMS75186	86	G. ruber and G. sacculifer	9370 ± 40	10.234 - 10.168	10.2		Razik et al. (2013)
KIA35163	95	G. ruber and G. sacculifer	9920 ± 70	10.997 - 10.762	10.9		Razik et al. (2013)
	98					10.85 ^a	Razik et al. (2013)
KIA35162	101	G. ruber and G. sacculifer	9810 ± 110	10.891 - 10.582	10.75		Razik et al. (2013)
KIA30526	123	G. ruber and G. sacculifer	12600 ± 70	14.180 - 13.985	14.1		Chiessi et al. (2008)
KIA30525	218	G. ruber and G. sacculifer	13340 ± 80	15.599 - 15.306	15.45		Chiessi et al. (2008)
KIA35159	315	Mixed planktonic foraminifera ^b	14520 ± 30	17.388 - 16.985	17.2		This study
KIA30524	358	Mixed planktonic foraminifera ^b	14860 ± 90	17.750 - 17.484	17.6		Chiessi et al. (2008)
KIA30531	448	Yoldia riograndensis	15590 ± 100	18.576 - 18.333	18.45		Chiessi et al. (2008)
KIA30530	583	Yoldia riograndensis	16400 ± 120	19.479 - 19.143	19.3		Chiessi et al. (2008)

3 $^{\mathrm{a}}$ Interpolated value between the calibrated radiocarbon ages at 95 and 101 cm depth.

4 ^bMixed planktonic foraminifera contained G. ruber (pink and white), G. sacculifer, G. bulloides, G. siphonifera, T.

5 quinqueloba, G. glutinata, G. uvula, G. conglobatus, and G. falconensis.

6

1	Figure 1. Location of the marine sediment core investigated in this study and other archives
2	discussed in the text. (A) Annual mean sea surface temperatures (color shading, °C)
3	(Locarnini et al., 2010), and main annual mean surface ocean currents in the western South
4	Atlantic (black arrows) (Peterson and Stramma, 1991; Stramma and England, 1999). Thin
5	white lines depict the main tributaries of the La Plata River. Numbers indicate the locations of
6	the following archives: (1) GeoB3104-1 and GeoB3117-1 (Arz et al., 1999); (2) GeoB3129-
7	1/3911-3 (Arz et al., 1999; Weldeab et al., 2006); (3) Lake Consuelo (Bush et al., 2004); (4)
8	GeoB3202-1 and GeoB3229-2 (Arz et al., 1999); (5) mean location of the sites described by
9	Behling (2002); (6) SAN76 (Toledo et al., 2007); (7) KNR159-5-36GGC (Carlson et al.,
10	2008); (8) GeoB6211-2 (this study). ACC: Antarctic Circumpolar Current; BC: Brazil
11	Current; MC: Malvinas Current; NBC: North Brazil Current; SAC: South Atlantic Current;
12	SSEC: Southern South Equatorial Current. (B) Annual mean air temperature (color shading,
13	°C) (Legates and Willmott, 1990), and <u>annual</u> mean annual low-level (925 hPa) -atmospheric
14	circulation (black arrows) (Kalnay et al., 1996). Dashed black line depicts the La Plata River
15	drainage basin. This figure was partly produced with Ocean Data View (Schlitzer, 2014).
16	

Figure 2. Histograms of the mean annual cycle of precipitation at selected stations in the La Plata River drainage basin (Xie and Arkin, 1997), and mean annual cycle of the La Plata River discharge on the lower right panel (Berbery and Barros, 2002). The color shading in the central panel depicts annual mean sea surface temperatures (°C) (Locarnini et al., 2010). The number <u>"1"</u> in the central panel indicates the location of marine sediment core GeoB6211-2 (this study). This figure was partly produced with Ocean Data View (Schlitzer, 2014).

23

Figure 3. Age model and sedimentation rates for marine sediment core GeoB6211-2.

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Figure 4. Proxy records for the western South Atlantic and southeastern South America
spanning Termination 1 based on marine sediment core GeoB6211-2 together with ice core
temperature records. (A) North Greenland Ice Core Project (NGRIP members, 2004) δ¹⁸O
plotted versus the Greenland Ice Core Chronology 2005 (GICC05) (Rasmussen et al., 2006).
(B) GeoB6211-2 *Globigerinoides ruber* (white) Mg/Ca and Mg/Ca based sea surface
temperatures. (C) GeoB6211-2 *Globigerinoides ruber* (white) stable oxygen isotope (δ¹⁸O)

(partially from Chiessi et al. (2009)). (D) GeoB6211-2 continental-ice-volume-corrected 1 oxygen isotopic composition of surface sea water ($\delta^{18}O_{ivc-ssw}$), a proxy for salinity. (E) 2 3 GeoB6211-2 Methylation Branched Tetraether (MBT') and Cyclisation Branched Tetraether (CBT) based mean air temperature (MAT). (F) EPICA Dronning Maud Land (EPICA 4 Community Members, 2006) δ^{18} O plotted versus its original chronology. Black symbols at 5 6 the bottom of the panel depict calibrated radiocarbon ages used to produce the age model for 7 GeoB6211-2. Grey vertical bars depict Heinrich Stadial 1 (HS1) (Sarnthein et al., 2001) and 8 the Younger Dryas (YD) (Rasmussen et al., 2006). BA: Bølling-Allerød; EH: early Holocene.

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10 Figure 5. Millennial-scale variability of the sea surface temperatures of the Brazil Current 11 spanning Termination 1 compared to available circum-Atlantic records. (A) SU8118 UK₃₇ 12 based sea surface temperatures (Bard, 2000). (B) OCE326-GGC5 ²³¹Pa/²³⁰Th based record of 13 the strength of the Atlantic meridional overturning circulation (McManus et al., 2004). (C) 14 GeoB3129-1/3911-3 Globigerinoides ruber (white) Mg/Ca based sea surface temperatures 15 (Weldeab et al., 2006). (D) GeoB6211-2 Globigerinoides ruber (white) Mg/Ca based sea 16 surface temperatures. (E) TN057-21 Globigerina bulloides Mg/Ca based sea surface 17 temperatures (Barker et al., 2009). (F) Southern Hemisphere proxy temperature stack (Shakun 18 et al., 2012). Grey vertical bars depict Heinrich Stadial 1 (HS1) (Sarnthein et al., 2001) and 19 the Younger Dryas (YD) (Rasmussen et al., 2006). BA: Bølling-Allerød; EH: early Holocene.

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Figure 6. Millennial-scale variability of the mean air temperature of southeastern South 21 22 America spanning Termination 1 compared to selected available records. (A) Southern 23 Hemisphere proxy temperature stack (Shakun et al., 2012). (B) Consuelo Lake pollen based 24 temperature anomalies relative to modern (Bush et al., 2004). (C) GeoB6211-2 Methylation 25 Branched Tetraether (MBT) and Cyclisation Branched Tetraether (CBT) based mean air 26 temperature (MAT). (D) EPICA Dome C (Monnin et al., 2004) atmospheric CO₂ plotted 27 versus its original chronology. (E) EPICA Dronning Maud Land (EPICA Community Members, 2006) δ^{18} O plotted versus its original chronology. Grey vertical bars depict 28 Heinrich Stadial 1 (HS1) (Sarnthein et al., 2001) and the Younger Dryas (YD) (Rasmussen et 29 30 al., 2006). BA: Bølling-Allerød; EH: early Holocene.

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