

We thank Referee #1 for the constructive review of our manuscript. To facilitate the discussion, we have copied his/her comments below in black and inserted our responses in green.

This is an interesting manuscript presenting two high-resolution planktic $\delta^{13}\text{C}$ records from the Brazilian coast covering HS3 and HS2. It is worth publishing in *Climate of the Past* if the “Discussion” section is completely rewritten and therefore the interpretation of the results re-assessed.

The authors have not shown that the planktic $\delta^{13}\text{C}$ decrease measured in their core was due to stronger Southern Ocean upwelling. This is just an hypothesis.

Comment #1 - We agree that it is a hypothesis and have now treated it accordingly by rephrasing specific parts of the revised version of our manuscript.

Considering this comment and the similar suggestions from Referee #2 and Dr. Schmittner, we also incorporated two additional hypotheses (see below) in the revised manuscript, in order to have a more thorough and balanced discussion:

i. AMOC-induced weakening of the biological pump

As shown by model experiments (e.g., Schmittner and Galbraith, 2008; Schmittner and Lund, 2015), AMOC slowdown events may cause a decrease in the global efficiency of the oceanic biological pump, being an important driver for the oceanic CO_2 outgassing during the last deglaciation, i.e., HS1 (but most likely also during other HS, e.g., HS3 and HS2). Two factors acting in conjunction are claimed to be responsible for the simulated weakening of the efficiency of the biological pump (Schmittner and Galbraith, 2008). First, the reduction in North Atlantic Deep Water (NADW) formation decreases the input of low preformed nutrient (high $\delta^{13}\text{C}_{\text{DIC}}$ values) waters to the interior ocean which becomes more dominated by the high preformed nutrient southern component (low $\delta^{13}\text{C}_{\text{DIC}}$ values) waters (e.g., Antarctic Bottom Water and Antarctic Intermediate Water). Second, the reduction of the Southern Ocean stratification induced by the decrease of salt input via NADW formation promotes the strengthening of the upwelling and subsequent sinking of high preformed nutrient (low $\delta^{13}\text{C}_{\text{DIC}}$ values) waters to the interior ocean, thus reducing the capacity of those unutilized nutrients to sequester carbon via the biological pump.

The weakening of the biological pump would promote the accumulation of isotopically light organic carbon in the upper water column of the South Atlantic and the negative anomaly of the $\delta^{13}\text{C}_{\text{DIC}}$ as well as of the $\delta^{13}\text{CO}_{2\text{atm}}$ (Schmittner and Lund, 2015). This $\delta^{13}\text{C}_{\text{DIC}}$ anomaly should be captured by the tests of planktonic foraminifera $\delta^{13}\text{C}$ because they incorporate $\delta^{13}\text{C}_{\text{DIC}}$ during calcification (Spero and Lea, 1996; Bemis et al., 2000). Our planktonic foraminifera $\delta^{13}\text{C}$ records agree with this hypothesis by showing negative anomalies during HS3 and HS2. Additionally, this mechanism also provides a possible explanation for the larger negative $\delta^{13}\text{C}$ anomaly in *G. ruber* w

(mixed layer–dwelling) relative to the anomaly in *G. inflata* (permanent thermocline–dwelling).

ii. the role of air–sea gas exchange

In the original version of our manuscript (page 7, line 13) we briefly mentioned the role of air–sea gas exchange. However, we see the need to further expand this topic in order to have a more thorough and balanced discussion.

We are aware that the $\delta^{13}\text{C}_{\text{DIC}}$ of the surface ocean can be affected by air–sea gas exchange (Oppo and Fairbanks, 1989; Charles and Fairbanks, 1990; Lynch-Stieglitz et al., 1995). Therefore, we cannot exclude the possibility that the likely decrease in $\delta^{13}\text{CO}_{2\text{atm}}$ during AMOC slowdown events (Eggleston et al., 2016) (e.g., HS3 and HS2) could have affected the $\delta^{13}\text{CO}_{2\text{DIC}}$ via air–sea gas exchange, especially in regions of water mass formation. The formation regions of South Atlantic Central Water and Tropical Water are areas of major ocean CO_2 uptake and may contribute to the $\delta^{13}\text{C}$ anomalies observed in our records. Additionally, since the isotopic fractionation during air–sea exchange is temperature–dependent, the weakening of the AMOC and subsequent warming of the upper subtropical South Atlantic (Barker et al. 2009; Chiessi et al. 2015) could also have contributed to the observed $\delta^{13}\text{C}$ anomalies in our records (as suggested by Referee #2).

However, for the reasons stated below we still consider the possible role played by changes in Southern Ocean ventilation in producing our $\delta^{13}\text{C}$ anomalies:

- i. the mechanisms that invoke the Southern Ocean as one of the $\text{CO}_{2\text{atm}}$ –sources during the last deglaciation are based on reconstructions as well as conceptual and numerical models that, to our understanding, have not yet been negated (Toggweiler et al., 2006; Anderson et al., 2009; Sigman et al., 2010; Tschumi et al., 2011; Lee et al., 2011; Burke and Robinson, 2012);
- ii. model experiments that question the role of the Southern Ocean (e.g., Schmittner and Lund, 2015) were performed under preindustrial boundary conditions, which can significantly influence the results (e.g., Menviel et al., 2008), and do not constitute a firm negation of the Southern Ocean hypothesis.

Planktic $\delta^{13}\text{C}$ is influenced by several factors such as changes in oceanic circulation, mixing, SST, export production: : : (see Charles et al. 1993, Lynch-Stieglitz et al. 1995, Menviel et al. 2015: : :).

Comment #2 - We agree that planktonic foraminiferal $\delta^{13}\text{C}$ can be affected by several factors and that some of them were not thoroughly considered in the original version of our manuscript. To account for these different factors we have inserted two new sections (i.e., (i) AMOC–induced weakening of the biological pump, and (ii) the role of air–sea gas exchange) in our manuscript (please see our Comment #1 above) and clearly refer to the complexity of the proxy.

Additionally, by analyzing two different species of planktonic foraminifera, i.e., *G. ruber* w that is a symbiont-bearing species, and *G. inflata* that is a symbiont-facultative species (e.g., Hemleben et al., 1989), we have excluded the potential bias in our records related to changing symbiont activity (e.g., Spero and Lea, 1993; Spero et al., 1997; Bemis et al., 2000). Since the $\delta^{13}\text{C}$ record of both species show a similar pattern, changing symbiont activity can be disregarded as a potential bias to our results.

An AMOC decrease will lead to significant surface ocean $\delta^{13}\text{C}$ changes. Changes in Southern Ocean upwelling are not the only solution.

Comment #3 - Agreed. As mentioned in our Comment #1 (please see above) we have revised our manuscript accordingly by incorporating two additional mechanisms (i.e., (i) AMOC-induced weakening of the biological pump, and (ii) the role of air-sea gas exchange) that could account for the $\delta^{13}\text{C}$ changes in our records.

In addition, it has been shown that during calcification temperature and carbonate ion content could have an impact on calcite $\delta^{13}\text{C}$ in planktic species (see Spero et al. 1997, Bemis et al. 2000: : :).

Comment #4 - Experiments with *O. universa* (a symbiont-bearing species) and *G. bulloides* (a non-symbiont species) suggest that under higher temperatures the first species presents higher $\delta^{13}\text{C}$ values whereas the second species presents lower $\delta^{13}\text{C}$ values (Bemis et al., 2000). These opposed $\delta^{13}\text{C}$ responses were related to the presence (i.e., *O. universa*) or absence (i.e., *G. bulloides*) of symbionts. We analyzed a symbiont-bearing and a facultative-symbiont species (i.e., *G. ruber* w and *G. inflata*, respectively), but both records showed a similar behavior. During HS, we would expect warmer temperatures in the upper water column of the western South Atlantic (Barker et al. 2009; Chiessi et al. 2015) and an increase in $\delta^{13}\text{C}$ values of our symbiont-bearing species if calcification temperature would dominate the $\delta^{13}\text{C}$ signal. Since *G. ruber* w $\delta^{13}\text{C}$ also showed a negative anomaly, we do not see the need to consider changes in calcification temperatures as a relevant driver for our $\delta^{13}\text{C}$ anomalies. We briefly refer to this issue in the revised version of our manuscript.

Regarding the possible effect of changes in carbonate ion concentration, we are aware that changes in the seawater $[\text{CO}_3^{2-}]$ can impact planktonic foraminiferal $\delta^{13}\text{C}$ in an inverse way (i.e., higher (lower) $[\text{CO}_3^{2-}]$ decreases (increases) planktonic foraminiferal $\delta^{13}\text{C}$) (Spero et al., 1997). Given the lack of regional upper ocean reconstructions for $[\text{CO}_3^{2-}]$, we assumed that increased $\text{CO}_{2\text{atm}}$ would be accompanied by a decrease in sea surface $[\text{CO}_3^{2-}]$ (Broecker and Peng, 1993). This would promote an increase in the $\delta^{13}\text{C}_{\text{DIC}}$. HS are frequently associated with an increase in $\text{CO}_{2\text{atm}}$ (Ahn and Brook, 2008; Ahn and Brook, 2014) but our records show a negative $\delta^{13}\text{C}$ anomaly, suggesting that changes in $[\text{CO}_3^{2-}]$ are not the dominant driver of our $\delta^{13}\text{C}$ anomalies. We briefly refer to this issue in the revised version of our manuscript.

Moreover, the authors suggest that increased runoff from the Plata river drainage basin led to increased sediment rate. It is an interesting result, which nicely fits with a southward shift of the ITCZ during that time, however river runoff might potentially have a fairly low $\delta^{13}\text{C}$ signature, thus potentially also influencing surface $\delta^{13}\text{C}$ at the core location?

Comment #5 - Abrupt millennial-scale climate events of the last glacial period have been associated with increased precipitation over tropical and subtropical South America to the east of the Andes (e.g., Arz et al., 1998; Wang et al., 2007; Kanner et al., 2012; Strikis et al., 2015). During HS1, however, the millennial-scale signal of $\delta^{18}\text{O}_{\text{IVC-sw}}$ from the upper water column of our core site indicates an increase in salinity (Chiessi et al., 2015). Thus, the upper water column of our core site was not affected by an increase in freshwater discharge from the Plata River at millennial-scale. Since the anomaly of precipitation during HS1 was stronger than during HS3 and HS2 in the Plata River drainage basin (Wang et al., 2007), it is unlikely that weaker precipitation anomalies in the Plata River drainage basin (i.e., HS3 and HS2) affected the upper water column of our core site more intensely than during HS1. This suggests that changes in the discharge of the Plata River drainage basin at millennial-scale are not a relevant driver of our $\delta^{13}\text{C}$ anomalies.

Please note that: 1) the ice core data (Ahn and Brook 2014) do not support any atmospheric CO_2 increase during HS2 and HS3.

Comment #6 - We cannot agree with this point. The best resolved $\text{CO}_{2\text{atm}}$ record available (Ahn and Brook, 2014) shows an increase in CO_2 during HS3 and HS2 that is highlighted by red arrows in the original publication (please see Fig. 1c from Ahn and Brook (2014)). The slight offset between the increase in $\text{CO}_{2\text{atm}}$ and the HS3 and HS2 intervals used in our manuscript can be accommodated by age model uncertainties.

2) $\delta^{13}\text{C}_{\text{CO}_2}$ can't really be used due to poor resolution and most likely issues with age model.

Comment #7 - We agree that the resolution of the $\delta^{13}\text{C}_{\text{CO}_{2\text{atm}}}$ curve is still suboptimal to resolve changes during HS2, and we have removed this curve from Fig. 5 of the revised version of our manuscript. We are aware of Eggleston et al.'s (2016) new $\delta^{13}\text{C}_{\text{CO}_{2\text{atm}}}$ data. However, despite their reference to a reduction in $\delta^{13}\text{C}_{\text{CO}_{2\text{atm}}}$ during HS2, their record also lacks the necessary temporal resolution to allow an appropriate comparison to our records.

3) The link between changes in southern hemispheric westerlies and AMOC changes is still poorly documented.

Comment #8 - Despite the existence of some open issues, several publications (e.g., Lee et al., 2003; Anderson et al., 2009; Toggweiler et al., 2006; Tschumi et al., 2008; d'Orgeville et al., 2010; Laurantou et al., 2010; Sigman et al., 2010; Tschumi et al.,

2011; Lee et al., 2011; Voigt et al., 2015) describe links between changes in AMOC and the Southern Hemisphere westerlies.

4) the opal flux in the Southern Ocean (Anderson et al. 2009) does not increase during HS2 and HS3.

Comment #9 - We are aware that Anderson et al.'s (2009) opal flux data (a proxy for the strength of Southern Ocean upwelling) did not change during the HS3 and HS2. However, this could be a temporal resolution issue. In core TN057-13-4PC, opal measurements show a mean temporal resolution of ca. 310 yr for HS1, but ca. 1550 yr for HS2 (this core does not reach HS3). In core E27-23, the mean temporal resolution of HS1 measurements is ca. 686 yr, but ca. 1550 yr for HS2, and ca. 1850 yr for HS3. HS1 opal measurements in core NBP9802-6PC have a mean temporal resolution of ca. 1715 yr, while HS2 measurements have a mean temporal resolution of ca. 3100 yr (this core does not reach HS3). Additionally, Anderson et al. (2009) suggest that such mechanism may be a common feature for other HS of the last glacial period.

As such the whole discussion section, as well as conclusion and abstract need to be rewritten.

Comment #10 - To account for the main topics raised by Referee #1 (but also Referee #2 and Dr. Schmittner) we have revised the necessary sections of our manuscript accordingly (please see above).

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