Key:
Black= Reviewers' comments
Blue= Authors' responses
Green = Modified text in the manuscript
Please note that all line numbers pertain to the first version of the manuscript.

We thank the Reviewer for their helpful comments. Please see below for the specific modifications to the manuscript and our response.

This paper describes a data compilation of benthic δ 13C data from the Last Interglacial (LIG), consisting of already publöished data. The authors compile material from two previous δ 13C compilations (Lisiecki and Stern 2016, Oliver et al 2010), and also add a few other cores. They compare their findings with benthic δ 13C from the mid-Holocene (HOL) and discuss 3 different hypothesis, which they suggest are the only possible ones to explain the observed LIG-HOL offset. They conclude, that AMOC change was probably not the reason for their findings, but changes in the balance of weathering and sedimentation. The paper in principle covers a nice piece of work, however, I believe it is a bit loosely constrained at certain points and misses some of the already available / published literature. I suggest a major overhaul following replies and response to the points given below.

1. Definition of analysed data: Some data analysis covers the whole LIG, some 125-120 ka, some all available data including part of Termination II and of the glacial inception. Similarly for the HOL, with which they compare. This needs to be focused. Define your time interval, but also give reasons for your chosen definition. So far, it is said, that 125-120 ka and 7-4 ka are chosen because δ 13C is stable. Looking at figure 4c (Pacific in HOL), this does not seemed to be the case, here 5-2 ka is much more stable. Maybe use as has been done in Peterson et al. (2014) the late Holocene 6-0 ka. I also believe taking two time windows which are of the same length might be a valid idea. Furthermore, check on the definition of interglacials (Past Interglacials Working Group of PAGES, 2016) when the community thinks Termination I or II was over and when the last glacial inception started. Please discuss your choice based on such literature widely. Also: I believe somewhere it was written, that only data below 2500m water depth are analysed. Is this always the case? If not, please specify in each and every section, which water depth is considered, also add this information in the figure caption, if this info is not popping up from the figure itself.

We would like to thank the Reviewer for these suggestions. We agree that both the definition of the time periods selected and the explanation on why we decided on these definitions needed to be improved. The two periods were defined based on the following criteria: that data associated with glaciations/deglaciations are excluded, and that data from periods of known instability are avoided. Following the Reviewer's comment, we have now modified the Holocene period such that the lengths of the time periods considered during the LIG and the Holocene are the same. Based on this, we are now using the time period 7-2 ka BP for the Holocene. The LIG period used is still 125-120 ka BP. We are now providing the following explanation in the manuscript:

We then define the time periods within the LIG and the Holocene to perform our analyses. For the Holocene, as most of the available data is dated prior to 2 ka BP, we define the end of our Holocene time period as 2 ka BP. To capture as much of the Holocene data as possible, we include data back to 7 ka BP, ensuring that we do not include instability associated with the 8.2 kiloyear event (Alley et a., 2005; Thomas et al., 2007). This provides a time span of 5 ka of data that we will consider for our analysis of the Holocene.

For the LIG, we seek to avoid data associated with the end of the penultimate deglaciation, which is characterised by a benthic d13C increase in the Atlantic until ~128 ka BP (Govin et al., (2015); Menviel et al. (2019); Oliver et al. (2010), Fig. 3). In addition, a millennial-scale event has been identified in the North Atlantic between ~127 and 126 ka BP (Galaasen et al., 2014, Tzedakis et al., 2018). Considering the typical dating uncertainties associated with the LIG data (2 ka), we thus decide to start our LIG time period at 125 ka BP. To ensure that the two time periods are of same length (5 ka BP), we define the LIG period for our analysis to be 125-120 ka BP. We note that our definition should also avoid data associated with the glacial inception (Govin et al. (2015); Past Interglacial Working Group of PAGES, 2016). We verify that the LIG time period has sufficient data across the four selected regions, noting that the highest density of data falls within the 125-120 ka BP time period---particularly in the equatorial Atlantic and southeast Atlantic (Fig. 3b, c).

To test the impact of the time period studied during the LIG, we are now also comparing the results of the "early LIG", defined as the period 128 ka to 123 ka, and the "late LIG" (123 ka to 118 ka), compared to the results of the 125 to 120 ka time period. This comparison is now shown on a new figure (Figure 4). This figure shows that the results are not statistically different across the 3 LIG periods defined above. However, the spread in between the 1st and 3rd quartiles is much larger for the early LIG than the LIG, confirming that the time period principally used in this study is appropriate.

Our analysis is restricted to cores that were recovered from depths greater than 1,000 m. However, given the strong vertical d13C gradient due to oceanic circulation, we also split the cores by depth for some specific analyses. We have thus made changes throughout the text to ensure that this has been clarified at all points in the paper where a depth restriction has been placed on the visualisation and analysis:

L174-175: The average δ13C anomaly between the LIG and mid-Holocene stable periods for cores deeper than 2,500 m is consistent across the different regions despite their geographic separation.

Table 2 caption: Regional breakdown of δ13C data for all depths during the Holocene (7–2 ka BP) and LIG (125–120 ka BP) averaged across the 1 ka timeslices…

Figure 4 caption: Comparison of volume-weighted δ13C for the Atlantic (red) and Pacific (blue) for the LIG and Holocene, calculated using the regions from Peterson et al. (2014) from data covering all depths...

2. You are missing one important review on simulating LIG vs HOL carbon cycle, which is Brovkin et al. (2016), which also deals with δ 13C. Discuss your potential explanations within the framework of that study, which contained results from different models, and which finds some explanations for the carbon cycle in the HOL, but not for the LIG. You might also note, that during the end of LIG / during glacial inception CO2 and sea level / land ice volume / temperature was decoupled on a multi-millennial timescale, which might indicate towards some processes that are important here (Barnola et al., 1987; Hasenclever et al., 2017; Köhler et al., 2018).

We apologise for not including Brovkin et al. 2016 in our review of the literature. We have now included extra information regarding the mechanisms that are presented in Brovkin et al. 2016.

For example, we have included the findings of the simulations in Brovkin et al. 2016 in references to aspects that need stronger constraint during the LIG in L56-57:

In particular, stronger constraints are needed on the extent of Greenland and Antarctic ice sheets, on ocean circulation and the global carbon cycle, including $CaCO_3$ accumulation in shallow waters, and peat and permafrost carbon storage changes (Brovkin et al., 2016).

We have expanded L71 to include more details of different carbon stores on land:

Organic matter on land includes the terrestrial biosphere, as well as carbon stored in soils, such as in peats and permafrosts.

We have generalised L77-79 slightly to encompass other mechanisms that are discussed in Brovkin et al., 2016:

Thus, atmospheric $\delta^{13}CO_2$ during the LIG (Fig. 1d) is influenced by the cycling of organic carbon within the ocean, changes in the amount of carbon stored in vegetation and soils, temperature-dependent air-sea flux fractionation (Lynch-Stieglitz et al., 1995; Zhang et al., 1995), and, on longer time scales, by interactions with the lithosphere (Tschumi et al., 2011).

We have also broken down the exchanges with the lithosphere further on L91-92 in line with the element discussed in Brovkin et al. 2016:

However, on longer time scales, exchanges with the lithosphere including volcanic outgassing (Hasenclever et al., 2017; Huybers and Langmuir 2009), $CaCO_3$ burial in sediments and weathering, release of carbon from methane clathrates, and the net burial of organic carbon also influences the global mean d13C.

We have also rephrased significant portions of the discussion, including a paragraph where we explore the mechanisms presented in Brovkin et al. 2016 in more detail:

In addition, due to the warmer conditions at the LIG than during the Holocene, there could have been a release of methane clathrates which would have added isotopically light carbon ($\delta^{13}C$: ~-47 ‰) to the ocean-atmosphere system. However, available evidence suggests that geological CH_4 sources are rather small (Bock et al., 2017; Hmiel et al., 2020; Petrenko et al., 2017; 320 Saunois et al., 2020) making this explanation unlikely, although we cannot completely exclude the possibility that the geological CH_4 source was larger at the LIG than the Holocene. Similarly, since the $\delta^{13}C$ value of CO_2 from volcanic outgassing is close to zero (Brovkin et al., 2016) and modelling suggests volcanic outgassing likely only had a minor impact on $\delta^{13}CO_2$ (Roth and Joos, 2012), it is unlikely that volcanic outgassing of CO_2 played a significant role in influencing the mean oceanic $\delta^{13}C$.

3. line 13: PI is NOT 0.7K cooler than the peak Holocene, this differences in Marcott et al 2013 compares peak Holocene with the Little Ice Age. The PI-peak-HOL difference is about 0.4K. The maximum Holocene peak is also not at 5 ka, but early, check the Marcott paper for details.

We apologise for the error. 0.7K in L18 has been changed to 0.4K and the time frame has been changed to 10-5 ka BP in L18 as suggested by Marcott et al (2013).

4. line 25: CO2 in the Holocene rose by maybe 18 ppm, but not by 28 ppm.

We have corrected this typo in L25. It now reads 18 p.p.m.

5. line 27: The details on CH4 need to condense.

L26-27 now read:

CH4 reached ~700 p.p.b and ~675 p.p.b during the LIG and the Holocene, respectively, and N2O peaked at ~267 p.p.b during both periods (Flückiger et al., 2002; Petit et al., 1999; Spahni et al., 2005).

6. line 28: The given warming on Greenland is for the NEEM site, not for the whole of Greeland. Please revise.

This line has been removed during the revision process.

7. line 38; SST record were 0.5K WARMER (not higher)

This has been changed to warmer.

8. All-in-all, the introduction on climate changes in the LIG needs some revision. Please focus on already existing stacks (which also have regional subdivions), that should also be plotted in Fig 1, e.g. Hoffman et al 2017, cited here.

We thank the Reviewer for their comments on the introduction. Based on the suggested changes to Fig. 1, we have changed our exploration of LIG-Holocene temperature differences. Lines 32-44 now read:

Strong polar warming is supported by terrestrial and marine temperature reconstructions. A global analysis of SST records suggests that the mean surface ocean was 0.5±0.3◦C warmer during the LIG compared to 1870–1889 (Hoffman et al., 2017), similar to another global reconstruction estimate of 0.7±0.6◦C higher SSTs during the LIG compared to the late Holocene (McKay et al., 2011). However, there were differences in the timing of these SST peaks in different regions compared to the 1870–1889 mean: North Atlantic SST peaked at +0.6±0.5◦C at 125 ka BP (e.g. Fig. 1b) and Southern Hemisphere extratropical SSTs peaked at +1.1±0.5◦C at 129 ka BP (Hoffman et al., 2017). On land, proxy records from mid to high latitudes indicate higher temperatures during the LIG compared to PI, particularly in North America (Anderson et al., 2014; Axford et al., 2011; Montero-Serrano et al., 2011). Similarly, the EPICA DOME C record suggests that the highest Antarctic temperatures from the last 800 ka occurred during the LIG (Masson-Delmotte et al.,2010) (Fig. 1c).

9. Revise Figure 1: Consider using splines including uncertainites instead of single lines, e.g. CO2 from Köhler et al. (2017), temperature (should be SST) from Hoffman et al. (2017) and Marcott et al. (2013), atmospheric δ 13C from Eggleston et al. (2016), which also closes the gap at the onset of the Holocene (no data so far). In Eggleston et al. (2016); Köhler et al. (2017) the newest ice core age model AICC2012 is already included, which might not have been the case in the plotted data. Mark which time windows you analyse in this figure. If you do not use the suggested splines, please include data uncertainties in the plotting, and explain the chosen time series in more detail, e.g which age model, b is tempertature change in certain ice cores (which cores). Subfigure (c) would need a further motivation (why

plotting a mediterranean SST here?). The legend is not useful, since all records are plotted on individual subfigures and explained in the caption.

Thank you for the suggestions on data to present in Figure 1. We have removed the redundant legend and are now more selective in the data that we present, with the subplots now showing the following (NB: subplots b and c have been swapped):

a) CO2 from Köhler et al. (2017) as suggested.
b) We were unable to find an SST stack that covers the same region during both the LIG and the Holocene. For this reason, we have chosen to use reconstructions from individual cores. However, we have now selected data from a region which is more relevant to our study, presenting two cores, one from the Iberian Margin, and the other from the North Atlantic.
c) We have now also provided the deuterium measurements from which surface air temperature was calculated.
d) For the Holocene, we have changed the atmospheric d13C to be the spline from the suggested reference (Eggleston et al., 2016). However, for the LIG we have decided to use the Monte Carlo average from Schneider et al. (2013) since the spline during the time period plotted (132-116 ka BP) from Eggleston et al. (2016) is only based on three data points.

The new figure caption reflects the changes in the data and now provides more details about the corresponding age models.

10. line 78: I do not understand how atmospheric δ 13C is influenced be the total amount of carbon in vegetation and soil, please expend.

Apologies, the sentence was misleading the way it was written. L77-80 now read:

Thus, atmospheric $\delta^{13}CO_2$ during the LIG (Fig. 1d) is influenced by plant type, the cycling of organic carbon within the ocean, changes in the amount of carbon stored in vegetation and soils, temperature-dependent air-sea flux fractionation (Lynch-Stieglitz et al., 1995; Zhang et al., 1995), and, on longer time scales, by interactions with the lithosphere.

11. line 80: If you compare atmospheric δ 13C with modern values you need to include a sentence on the contribution of the 13C Suess effect. Either extend or rewrite to a comparison of the pre-Suess effect values.

Sorry, we meant to refer to PI and not to today. L80 now reads:

During PI, the mean surface DIC is thereby enriched by ~8.5 ‰ compared to the atmosphere due to fractionation during air-sea gas exchange (Menviel et al., 2015; Schmittner et al., 2013).

12. Introduction: I believe the subsections are not necessary here.

The subsection headings have now been removed.

13. line 123 and 133 (maybe elsewhere): Uncertainties are typically going symetrically in both direction, so "±" is not necessary. Also, please state, what these uncertainties are, is this 1σ?

The plus/minus signs in lines L119, L123, L131, L133, L271 have been removed. The age model uncertainties are based on 2σ. We have added this clarification L119:

The estimated age model uncertainty (2σ) for this group of cores is 2 ka.

14. Table 1 and Fig 3: Please use error propagation and also include an uncertainty in the calculated anomaly Δδ 13C.

We have added the standard deviation in Δδ13C using error propagation to Table 1.

15. section 3.1. Use the same time window for analysis throughout, here 130-118 ka instead of 125-120 ka has been used.

We have adjusted the analysis in Section 3.1 to use the same time periods used elsewhere (125-120 ka BP, and 7-2 ka BP), and we have adjusted Fig. 1 accordingly.

16. lines 172ff. As said in #1, 7-4 ka is not a constant period. Please redefine.

The periods have been redefined as per our response to comment #1.

17. Fig 3: If I got it right these are only benthic forams from deep sedimemt cores from below 2500 m water depth, please say so. Revise the x-axis label: You have your mean times at full kiloyears, but the labels partly at half kiloyears.

We have revised the x-axis labels as per your comment.
The cores are indeed from depths below 2,500 m as written in the caption. We have added this clarification to the main text to improve clarity. L181 now reads:

Figure 3 suggests that the difficulty in determining significance in this region for cores deeper than 2,500 m might be due to a singular...

18. line 192: It is not clear that the mentioned Fig A1 is from this paper, I thought it was from Peterson et al 2014.

We have modified the text in the main body and the figure caption to make this clearer. The text in the main body now reads:

We define our regional boundaries based on the regions described in (Peterson et al, 2014), however we only include the regions where there is enough data to justify an analysis. For all the data in each of these regions, we calculate a mean value by taking the direct averages of all data. We divide the ocean basins into eight regions (Table 4, shown in Fig. 2) and calculate the volume-weighted averages d13C for each of these regions.

This figure was also combined with figure 2. The figure caption now includes the following line:

Regional boundaries used to calculate the global volume-weighted mean δ13C (Sect. 3.2) are indicated by dotted black lines as defined in Peterson et al., (2014).

19. line 215, 222: 3 possible explanations. Maybe there are others which you did not think of so far (e.g. decoupling of CO2 with other climate records at the end of LIG, see #2). Also,

you only in detail investigate AMOC changes, and briefly discuss the others. This should be a bit better balanced. I therefore suggest to move section 3.3 to the discussion, and also ask for some more thoughts on the alternative explanations.

We fully agree with the Reviewer that the discussion on land biosphere changes and on weathering-sediment fluxes belongs into the discussion section. These two issues are now discussed in section 4.

We also agree that the numbering of reasons for the difference may be misleading for some readers; we do not intend to exclude other explanations. We do not provide numbers anymore.

We consider the assessment of potential biases in our results and the tests presented in section 3.3 as an integral part of the result section and prefer to keep this text in section 3.3 We shortened the text on L214 to L222 to read:

Both the regional analysis of our new database and our volume-weighted estimate indicate that the global mean d13C was about 0.2 ‰ lower during the LIG than during the mid-Holocene. We further test the robustness of this result in the next section.

As far as other possible reasons are concerned, we now discuss explicitly the processes mentioned by Brovkin et al., 2016.

We now mention explicitly volcanic CO2 outgassing. We consider this to be an intrinsic part of the slow carbon cycle from the lithosphere (weathering, volcanic CO2 outgassing and sediment burial). We note that the impacts of volcanic outgassing on atmospheric d13C is simulated to be low (Roth, R., F. Joos, "Model limits on the role of volcanic carbon emissions in regulating glacial-interglacial CO2 variations", Earth and Planetary Science Letters, 329-330, 141-149,2012).

We also mention the possibility of CH4 release from clathrates. However, the available evidence suggests a small role for such a release (Bock et al., 2017; Hmiel et al., 2020; Petrenko et al., 2017; Saunois et al., 2020).

The discussion regarding volcanic outgassing and CH4 release from clathrates now reads:

In addition, due to the warmer conditions at the LIG than during the Holocene, there could have been a release of methane clathrates which would have added isotopically light carbon (δ 13C: ~-47 ‰) to the ocean-atmosphere system. However, available evidence suggests that geological CH4 sources are rather small (Bock et al., 2017; Hmiel et al., 2020; Petrenko et al., 2017; 320 Saunois et al., 2020) making this explanation unlikely, although we cannot completely exclude the possibility that the geological CH4 source was larger at the LIG than the Holocene. Similarly, since the δ 13C value of CO2 from volcanic outgassing is close to zero (Brovkin et al., 2016) and modelling suggests volcanic outgassing likely only had a minor impact on δ13CO2 (Roth and Joos, 2012), it is unlikely that volcanic outgassing of CO2 played a significant role in influencing the mean oceanic δ13C.

20. Fig 4: Again, revise your calculated offset in δ 13C based on a revised definition of time windows and include uncertainties in it.

The periods have been redefined as per our response to #1, and figure 4 modified accordingly. We have added the propagated sample standard deviations to the anomaly value in the figure.

21. Fig 5: I do not understand the backgorund shading which is labels as “reconstructed δ 13C. Reconstructed by what? Is this a model result or an interpolation.

We’re sorry that the figure caption was not clear. The caption has been revised to include the following line:

Background shading shows the reconstructed d13C using a quadratic statistical regression of the proxy data following the method described in Bengtson et al. (2019).

22. line 310: It could be that not only weathering and sedimentation but also volcanic CO2 might add to this mentioned imbalance.

Thank you for highlighting this factor. In light of your comment, we have added the following consideration to the discussion:

Similarly, since the d13C value of CO2 from volcanic outgassing is close to zero (Brovkin et al., 2016) and modelling suggests volcanic outgassing likely only had a minor impact on d13CO2 (Roth and Joos, 2012), it is unlikely that volcanic outgassing of CO2 played a significant role in influencing the mean oceanic d13C.

23. No data availability is given. Please upload your data base to a repository, e.g. PANGAEA.

The database has now been published. We have added the following link to the data availability section:

The data is published on Research Data Australia at DOI https://doi.org/10.26190/5efe841541f3b.

24. The SI reference list of cores should be contained in the main text.

The lists of cores for the LIG the Holocene have been inserted into the text (Table 1 and Table 2, respectively). The reference in the text at the end of L111 has been changed to:

The full core lists are provided in Tables 1 and 2 for the LIG and the Holocene, respectively.