

Point-by-point response to comments by anonymous Referee #1

I thank the authors for their great and diligent work in revising the paper while taking into account our comments. They did not hesitate to trim down the text quite drastically. I think the manuscript is greatly improved as it makes for a smoother, more focused and therefore more impactful read. I only have minor comments left, most of which related to subideal language.

We thank the reviewer for their positive evaluation of our revisions and the additional comments.

General comments

1. L20, end of result section, end of conclusion : All of these critical parts of the paper end on a rather anecdotic statement. The spin-up strategy is rather a minor part of the study, with (arguably) minor implications. I think the authors could be less humble and find a stronger statement to end on an meaningful note to the community.

We agree that the discussion of the spin up strategy is not the main outcome of the study, so we re-arranged the passages to mention this before the other outcomes. However, we consider the long isotopic drifts in our simulations an important outcome with large implications for the discussion of how to set up and interpret isotope-enabled model simulations as well as $\delta^{13}\text{C}$ records. We added a sentence to our conclusions to express this:

“ These results have implications for model experiment design and the interpretation of $\delta^{13}\text{C}$ proxy data: We showed that the long timescales of ocean-sediment interactions and the weathering burial cycle pose substantial challenges for model spin up because imbalances in the geologic carbon cycle can cause isotopic drifts at the beginning of simulations and which are not present in a control run. Depending on the initial isotopic imbalance, it takes up to 200 kyr for the drift to subside and the signal of the applied forcing to dominate the simulated transient $\delta^{13}\text{C}$ changes. Further studies are needed to test whether $\delta^{13}\text{C}$ can be spun up in more computationally-expensive models by combining them with lower-complexity models. In the absence of such a spin up strategy, open system simulations of glacial $\delta^{13}\text{C}$ are likely strongly affected by these initial drifts severely hampering interpretation of results. These long adjustment timescales also pose challenges for separating long-term from short-term signals in the proxy records.”

2. Statements regarding terrestrial carbon are rather cryptic :

- L51-52 : ‘carbon can also be transferred on land’. It is unclear what is the point of this argument, since this study is not running simulations with a land carbon model.

We made this statement in the introduction for completeness because increased land carbon storage has been discussed as a process lowering glacial atmospheric CO_2 . Here we indeed do not test this hypothesis and only consider the land as a possible C source during glacial phases. We therefore removed this reference to avoid confusion.

- L86 : '(atmosphere-ocean only)'. Same, I don't understand the emphasis on previous modelling studies using atmosphere-ocean system, as many models include a land carbon model.

Our intention here was to point out the lack of dynamic weathering-sediment burial imbalances in many simulations, not comment on the inclusion or exclusion of terrestrial carbon dynamics. We revised our formulation and now mention explicitly that we address the issue of sediment dynamics.

- L388 : I am confused by the mention of the '4-box land biosphere'.

This was a misplaced technical note specific to our model. We removed it.

3. Page 8 : The choices of all physical forcings (+ CO₂T) is justified by a clear link to the processes identified as potential contributors to glacial-interglacial CO₂ changes. This is not the case of the biogeochemical forcings (PO₄, REMI, PIPO). A short but explicit link/scientific reasoning would be welcomed so that this part doesn't read as a list ('we tried that... and that, and that...') without the reader knowing why you tested these specific things.

We added brief reasonings to each forcing as suggested.

4. C, ALK, DIC : Please check that all abbreviations are defined at first instance.

Done

Specific comments

L4 : 'proved the potential'. In my mind (non-native English speaker there), the concept of 'proof' is strong and contrast with 'potential'. I would use a more neutral verb, like 'demonstrate'.

Done

L5 : Please clarify what 'they' refers to. 'These processes' ? 'These glacial conditions'?

Done

L10-11 : This sentence is long and convoluted. First, there is a repetition of 'due to these different forcings' and 'resulting from these forcings' which feels unnecessary. Second, the following proposition 'and the associated isotopic shifts' is missing a verb, and it is unclear whether it is supposed to echo 'assessing' or 'gaining a better understanding of'. Third, the same idea ('transient', 'continuously perturbed' and 'non-equilibrium glacial cycles') is repeated three times, which I think is more than enough for the reader to get it.

We simplified this passage by deleting repetitions.

L44-48 : First, this sentence is too long and hard to follow. Second, why is nitrate not mentioned in addition to phosphate ? Third, the construction of the last part (with 'counteract the effect') makes it difficult to understand the exact effect of 'changes in Southern Ocean dynamics'. It is unclear in which direction these variables are varying, so it could be specified what 'changes' we are talking about, as well as whether the 'effect of colder temperatures' is enhancing or dampening export production.

We split the sentence into two, added a mention of N, and clarified the end.

L51 : 'could have been sequestered in the water column'. Yes, but this is also true of a closed atmosphere-ocean system. I recommend using the phrasing 'in marine sediments as well as/in addition to DIC in the water column' to clarify.

Done as suggested

L63 : 'previous model simulations, that included POC burial, showed that interactive sediments'. Too many commas (very German), a smoother phrasing could be considered ('previous model simulations showed that interactive sediments including POC burial...').

Done as suggested

L81 : 'also'. I don't see the first argument to which 'also' implicitly refers to. This sentence reads to me as a precision of the previous one.

We deleted 'also'.

L97-98 : the in-text question feels a bit convoluted to me. What about : 'which begs the question : what are the effects of the considered processes on glacial-interglacial atmospheric CO₂ and carbon isotopic ratios when the sediments are dynamically calculated?'

Done as suggested.

L183-186 : This sentence is long and convoluted. The verb 'test' is used twice (but with different things following : AMOC changes versus radiative changes resulting to dust changes) and the Adloff 2024 paper is quoted twice. I think that all mentions of the resulting circulation changes could be kept for the next sentence to reduce the weight of this one. It could also be (very briefly) explained why the radiative changes have such an effect on the AMOC, and whether this is a full collapse (as most readers won't look for that information in the quoted paper).

We simplified this passage.

L194 : Why isn't this simulation named 'NUT' if the forcing indirectly encompasses the effects of different nutrient inputs? (I may have not understood this specific experimental design well.)

This is a good point. It is called PO₄ because technically we remove nutrient limitation by adding phosphate, the only export-limiting nutrient in our model set-up. We now clarified this in the text.

L231 : It could be mentioned at the first occurrence of 'weathering input fluxes' that this is what you are calling the 'terrestrial solute supply' made to compensate loss to sedimentary burial in the following. A simple '(thereafter named weathering input)' in Section 2.2 would also do the trick.

Done as suggested.

Fig. 2 : What does the Delta mean ? Maybe the legend is not precise enough, for I was confused in the direction of the signals when reading through the next paragraph. Also, Fig. S10 look identical to Fig. 2 to me, so looking for absolute changes did not help.

We revised the figure caption of Fig. 2 and the following text. Differences between Fig. 2 and Fig. S10 are small because they only differ in whether the small effects of the standard forcing in BASE are subtracted or not.

L241-242 : It could be briefly mentioned why we are observing these variations.

We added this info to the text.

L249 : This sentence looks unnecessary to me.

We removed it.

L255 : 'occurred simultaneously in reality'. The phrasing is not ideal, as we are talking of idealized forcings which did not 'occur in reality'.

We now rephrased this sentence.

L265 : I am confused as to the interpretation of the effects of physical forcings. It is said that 'Reconstructions [...] show that burial rates decreased [...] during glacial inception [...]'. fSOWI shows constant CaCO₃ balance on Fig. 2, so why is it said that 'Physical forcings do not affect burial rates during glacial inception', but later that 'However, the physical forcings fail to decrease burial rates during MIS3 and MIS2'?

Our formulation was wrong. The reconstructions show no global CaCO₃ burial change during glacial inception (before MIS3), which is reproduced by the physical forcings. However, CaCO₃ burial was lower in the reconstructions during MIS3 and MIS2, which is not reproduced by these simulations. We adjusted the text to reflect this.

Fig. 4 legend : It is a bit unclear why the Qin et al (2018) data in particular was chosen for reference. Is this the only core which spans a long enough time interval? Why are you showing the time series for the deep Pacific only (and not e.g. deep Atlantic, especially after the L305-306 mention)?

Yes, to our knowledge, Qin et al (2018) is the only record of that length. We added this to the text. We added a time series of changes in the deep Atlantic to the SI as suggested.

L319-320 : Having mentions to different periods ('during interglacials', 'during glacial phases') in the same sentence is a bit confusing.

We rephrased the sentence.

L375 : It feels like a verb is missing. Do you mean 'required to compensate the prescribed solute fluxes'?

Yes, we corrected the sentence as suggested.

L382 : 'long-term trend of lower atmospheric d13C during the Eemian than the Holocene'. Why use this convoluted phrasing and not simply 'long-term trend of increasing atmospheric d13C during the last glacial cycle'?

We rephrased the sentence as suggested.

Fig. 8 : Since fLAND causes an increase and fPO4 a decrease, I would be curious to see the absolute effect of the BGC simulation, cumulating the two.

We added the results for BGC to the figure.

L563 : 'the buffering impact of this perturbation on the deglacial carbon re-organization'. This phrasing doesn't read easily to me, perhaps because it is unclear what 'this perturbation' refers to.

We clarified the sentence.

Technical comments

L7 : 'of' → 'using' or 'with'

L68 : 'extents' → 'amplitude'

L95-96 : misplaced (

L145 : 'our results section' → using section numbering is better

L149 : Does that mean Section 5 of SI?

Fig 1 legend : typo 'gasses'

L172 and 175 : please use inseparable spaces so that the units appear on the same line.

Page 8 : wall of text. I recommend a line jump between the description of physical and biogeochemical forcings. I also think that replacing 'Next, we tested...' with some type of numbering would make it easier to follow (e.g. 'A third simulation tested...', 'Thirdly, ...')

L191 : missing comma

L228 : 'sediments' → 'sediment fluxes'?

Fig. S9 : typo 'interglacial'

L257 : incomplete sentence without verb or majuscule.

L267 : 'in Fig. 2'. In this instance (and the whole paragraph), it would be quicker for the reader to find where to look at on the graph if the top panels were numbered and you could refer to 'Fig. 2a,b,c,d'.

Fig. 3 legend : References look misplaced to me. They would be better placed after 'reconstructed', with a mention of which is for POC, and which is for CaCO₃.

Fig. S12 and Table S2 : It is unclear what simulation CACO is.

L298 and L302 : extra comma

L304 : unfinished sentence ('but').

L316 : 'causes' → 'cause'

L318 and L443 : typo 'biogeochemical'

Fig. 6 : Since there are mentions in the text of the range of effects in GtC, it could be helpful if a second axis in GtC (on top of the one in ppm) is added. Also, the legend in c) could add the references to the black lines.

L333 : 'Fig. 6' → 'Fig. 6c'

L385 : 'size' → 'amplitude'

L344 : typo majuscule

L392 : typo extra space

L386 : 'geologic' → 'geological'?

L458 : typo 'deglaciations'

L514 : missing space

L544 : 'unlikely' → 'which is unlikely'

L553 : missing comma

We made all the requested changes, except for putting the references for the forcings in Fig. 6 into the figure caption rather than the figure legend due to limited space.