Review round 2 – egusphere-2025-4907

This manuscript demonstrates that uncertainties in model parameters can substantially impact the model's carbon system response to a change in climate. The results are valuable, in particular for the understanding of challenges with modelling palaeoclimate states such as the LGM and the models' ability to reproduce processes involved in ocean drawdown of atmospheric CO_2. They can also inform evaluations of marine CDR methods and their potential. Thus, the manuscript be considered for publication, subject to minor revisions. The updated version of the manuscript takes into account both reviewers' concerns from the previous round regarding the clarity of the text and too high information density, and the authors have successfully worked to increase readability of the manuscript. They have improved the included figures, and moved figures with high information density, that include the full range of results, to supplementary material.

A minor remaining question is whether the PI-to-LGM reduction in sedimentary Fe input is too substantial. The phrasing in the previous version of the manuscript lacked in clarity, but now that the phrasing is clearer (L. 384-390), I find that some further motivation would be helpful for the argument that the reduction of sedimentary Fe input, and the consequences of it, is a lower-range estimate. Specifically, it could be more clearly stated whether it is assumed that the lowered sea level would lead to the same amount of sedimentary input of iron in the LGM regardless of how large the PI input is, or if the loss of input when going from the PI to the LGM scale with the PI input. In the former case, the authors' argumentation that the estimate is in the lower range holds. In the latter case, one could argue that a higher level of PI input that is reduced by 1/5 would lead to a higher amount of available dFe in the LGM c.f. the current experiments, and thus different biogeochemical responses. The paragraph that follows (starting on L. 391) partly addresses effects of different dFe availability, so the two paragraphs could be linked by a clarification of how a higher PI sedimentary Fe release would impact dFe availability in the LGM.

Minor comments

Abstract

L. 14 – Typo. 20x20 does not equal 480. I assume that this should say 24 simulations (i.e. the number of boundary conditions) per parameter set.

Introduction

L. 69: "may have varied during the LGM" – I think you mean "may have differed in the LGM compared to PI" because you are not studying the variability that was occurring during the LGM.

L. 79: "estimating pCO2 changes in the LGM" – Similarly to L. 69, I think you mean difference between PI and LGM.

Materials and Methods

L. 92-97: The new schematic that details the experimental design is very helpful for understanding every step of the modelling approach. The figure is currently mentioned in general terms on L. 149, but it would be more efficient to mention it before describing the details of the design in the text, so that the reader can follow each step. Therefore, it should ideally be referenced already here in the first section that details the performed simulations (Section 2.2), with an explanatory sentence, e.g. "All steps of the experimental design are illustrated in the schematic Figure X, with the model calibration and selection of the best parameter sets described in the left hand column." or similar.

Results

L. 215: “The average NO^{3-} concentration in the ∗_LGMFedep simulations is slightly higher than in ∗_PIallbgc.” – Based on Fig. S3c, it looks like only the LGMatmpi gives a higher concentration for *_LGMFedep. Is the average for the whole set really higher than ∗_PIallbgc?

L. 219-220: “The enhanced N_2 fixation due to the greater phosphate availability in ∗_LGMPO4 and the reduced benthic denitrification in ∗_LGMbdeni […]” - N_2 fixation and denitrification are discussed explicitly in Section 3.3.2, so it would be good to cross-reference it here → add “(see also Section 3.3.2)

L. 222-223: “dFe supply from atmospheric deposition in ∗_LGMallbgc seems to compensate that effect.” – Given that *_LGMPO$_4$ and *_LGMbdeni give much more clearly positive effects on the average NO^{3-} concentration than ∗_LGMFedep, I would expect that these are the ones counteracting the negative effect of ∗_LGMFesed. If this is not the case, this needs to be explained and motivated.

L. 240-241: “The average sPO_4^{3-} in the ∗_LGMFesed simulations is about 62 % higher than in ∗_PIallbgc [...]” – It would be helpful to remind the reader that sedimentary input of Fe is substantially reduced in the LGM. → “The average sPO_4^{3-} in the ∗_LGMFesed simulations, where sedimentary input of Fe is reduced to 1/5 compared to the PI, is about 62 % higher than in ∗_PIallbgc” […]. This is currently mentioned on L. 248 but would be helpful already in this subsection.

L. 241: This is further discussed in Section 3.3.3, specifically on L. 350, so it would be good to add a cross-reference to that section → (See also Section 3.3.3)

L. 264-266: “The ∗_LGMPO4 and ∗_LGMbdeni simulations yield DIC concentrations similar to those of the pre-industrial control. Our LGM simulations yield higher DIC concentrations than the PIctl_∗ simulations throughout the different biogeochemical configurations (Fig. S3o).” – Phrased like this, these two sentences seem somewhat contradictory, first saying that some of the LGM simulations are similar to the pre-industrial control and then saying that they should all yield consistently higher values. Based on Figs. S3g-o, I think the issue is in that you mix talking about the PIallbgc and PIctl physical conditions, but do so in an unclear way by just referring to “pre-industrial control” when you in fact mean PIallbgc. It would be good to clarify this, for example as follows: “The ∗_LGMPO4 and ∗_LGMbdeni simulations yield DIC concentrations similar to those of the *_PIallbgc (Fig. S3g). Our physical LGM configurations yield higher DIC concentrations than the PIctl_∗ simulations throughout the different biogeochemical configurations (Fig. S3o).”

L. 269: “The glacial-interglacial changes in the strength of the solubility pump caused by a reduced temperature […]” - Glacial-interglacial is from LGM to PI, i.e. it would mean an increased temperature → rephrase to interglacial-glacial

L. 274-276: “Switching to LGM Fe fluxes has a relatively strong effect on pCO_2, when compared to the effects of the LGM PO_4^{3-} inventory or benthic denitrification.” – This sentence seems redundant, as the sentence that follows essentially repeats this information but in more detail.

L. 301: “When combined with the biogeochemical conditions” – I think you perhaps mean “With all biogeochemical conditions combined”

L. 305: It could be helpful to add a sentence of the style “In summary, only *_LGMFesed and LGMatmpi_* affect NPP in a substantial way”.

L. 311-312: “Proxy-based studies indicate that changes in export production during the LGM […]” - I think you mean LGM export production compared to PI, not changes during the LGM itself.

L. 317: First use of the acronym WC for water column, so it needs to be defined.

L. 321-322: “In the model, N_2 fixation is the counterpart of WC and benthic denitrification, thus N_2 fixation equals the sum of WC and benthic denitrification at equilibrium.” – To demonstrate that this holds, it might be good to give the actual numbers in Tg N yr^{-1} in parenthesis behind the percentages in the sentences that follow after this one, or give one example.

Discussion

L. 360: “The UVic-ESCM responds to LGM wind stress changes” – Clarify that you mean change from PI to LGM wind stress, not wind stress changes that happened during the LGM itself.

L. 360-365: You only mention the individual effects of wind stress and atmospheric moisture diffusivity on the AMOC. What is the combined effect of all the LGM physical changes on the AMOC?

L. 372 “glacial-interglacial” → interglacial-glacial

L. 384-390: See general comments in the beginning of the review.

Figure 7: The squares with dashes (LGMbdeni) are not visible anywhere in the two subplots, unless they have accidentally been filled with colour. There seems to be a cluster of filled squares close to the origin point that could be these ones, as it is stated in the caption that they should be located around there. It is also possible, based on looking at fig. 8., that they are just clustered so closely that they end up looking as filled squares. In that case, maybe consider changing to a different symbol, e.g. diamonds, and then changing Fig. 8 accordingly, to keep the symbols consistent.

Figure 9: The use of the rainbow colour palette results in an unfortunate combination of red and green dots (no blue) that is inaccessible to people with impaired colour vision. Consider changing to a different colour scheme (e.g. based on red, yellow, blue).