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Comment on cp-2022-8

Anonymous Referee #1

Referee comment on "Glacial state of the global carbon cycle: time-slice simulations for the last glacial maximum with an Earth-system model" by Takasumi Kurahashi-Nakamura et al., Clim. Past Discuss., https://doi.org/10.5194/cp-2022-8-RC1, 2022

Review of cp-2022-8

Glacial state of the global carbon cycle: time-slice simulations for the last glacial maximum with an Earth-system model

by T. Kurahashi-Nakamura, A. Paul, U. Merkel, and M. Schulz

This manuscript addresses changes in the inventory and distribution of biogeochemical tracers during glacial periods using an Earth system model. The authors present the impacts of glacial-interglacial sea-level changes and associated changes in oceanic inventory of biogeochemical tracers on ocean biogeochemical cycles. The paper is novel in its approach. Of particular significance is their use of a sedimentation model in combination with the ESM to demonstrate the mass accumulation rate (MAR) of carbonate sediments and their discussion of AMOC changes in comparison with MAR observations. On the other hand, although I am familiar with the topic of this paper, I found some of the authors' explanations difficult to follow.

General comments:

In the introduction, the authors emphasized the importance of transiency to explain the glacial-interglacial carbon cycle. I would like to see more discussion of the time scale of the response of the carbon cycle. How fast do carbonate sediments change in response to changes in sea level? How do the time scales of carbonate sediment expansion and contraction differ from other processes that consist of the ocean carbon cycle (solubility, biological pumps, and ocean circulation)?

Although the authors focus on shallow-water carbonate sediments, carbonate is thought to be equally buried in the deep ocean (Cartapanis et al., 2018). I would like to see a clearer separation of these two contributions in the discussion.

In the LGM experiments, whole ocean alkalinity is increased to adjust the atmospheric CO2 concentration to the ice core data. The magnitude of this increase does not seem to be explicitly stated (not shown in Table 2), but is it appropriate? In section 4.1, the authors explained the change in alkalinity is related to the changes in shallow-water coral reefs but is it necessary to consider the effect of carbonate compensation, including deep-sea carbonate sediments (e.g., Brovkin et al., 2012; Ganopolski and Brovkin, 2017; Kobayashi et al., 2021)?

It is reported that PMIP models tend to simulate lower ocean carbon sequestration and higher atmospheric CO2 if they had a lower ocean volume at the LGM (Lhardy et al., 2021). Do the ocean bathymetry and volume change in this study?ã□□It is expected that a greater change in alkalinity would be required if a lower ocean volume is adopted.

Specific comments:

P1/L6: "The increase…"ã□□I am not convinced by this statement because of the lack of information on the inventory change in alkalinity.

P2/L15: How much carbon (PgC) does the change in DIC in the deep ocean (μmol/kg) between the LGM and the present day correspond to?

P2/L16: I would like to know more about the coral reef hypothesis and the subsequent study's discussion of the impact of changes in shallow-water carbonate sedimentation on global carbon cycle changes.

P2/L20: I would like to know the explicit statement about the impact of changes in DIC and alkalinity on atmospheric CO2 concentrations. In other words, the increase in DIC in the deep ocean during glacial periods and the increase in alkalinity throughout the ocean both contribute to a decrease in atmospheric CO2.

P3/L21: Would you explain a little more about the advantages of using SolveSAPHE?

P3/L30: Changes in carbonate sediment burial result in changes in whole ocean alkalinity (Kobayashi et al., 2021). Is it difficult to investigate the changes in carbonate burial by

using the sediment model?

P3/L30: I would like to see information on carbonate burial fluxes and sediment distribution throughout the ocean as calculated by the sediment model in expPI. p7/L8 includes a brief description, but I do not think it is sufficient.

P4/L13: Would you cite a reference for the Ruddiman belt?

P4/L15: Why did you choose 0.25 Sv for the freshwater input to the Southern Ocean?

P4/L34: What is the total change in alkalinity adjusted for "second-guess"? Would you add the information to Table 1?

P5/L14: Would you consider showing the stream function as well?

P5/L19: From my understanding, LGMss was an experiment in which freshwater was removed from the LGM in the North Atlantic and fresh water was added in the Southern Ocean, resulting in a stronger north-south density gradient at the sea surface. However, why do we see a somewhat weaker AMOC relative to the LGM?

P5/26: How about comparing the modeled deep-sea salinity to paleo records (e.g., Adkins et al., 2002; Insua et al., 2014; Homola et al., 2021ï¼□?

P6/L9: Can we assume that this change is consistent with estimates of changes in terrestrial carbon storage (e.g., Peterson et al., 2014; Jeltsch-Thömmes et al., 2019)?

P6/L9: Is the total amount of carbon in the atmosphere, ocean, and terrestrial reservoir the same for all experiments? It is difficult for me to understand the experimental design.

P6/L14: Would you show us d13C paleo records (e.g., Peterson et al., 2014) in the figure? It would make comparisons with other studies easier.

P6/L22: The impact of changes in the distribution of export production on nutrients and AOUs should also be considered. How about conducting sensitivity experiments with fixed

biological fluxes?

P6/L25: The decrease in ideal age in the Southern Ocean in Fig. 4 is caused by changes in AABW flow or changes in local convective mixing. Please describe.

P6/L26: Some studies have reconstructed carbonate ions from B/Ca (e.g., Rickaby et al., 2010; Yu et al., 2013, 2020). Would you compare your modeling results with them? As stated in the discussion, the increase in alkalinity seems to be overestimated in the current setting.

P6/L31: How about showing the reconstructed changes in export production (Kohfeld et al., 2005)? The characteristics of the changes appear to be well reproduced in the model. Also, I would like to see a discussion of the effects of sea ice distribution and iron fertilization on export production.

P7/L12: Would it make sense to compare this model-data comparison of CaCO3 MAR for other ocean regions (the Southern Ocean and the Pacific Ocean)? It makes the model validity and shortcomings clearer.

P8/L15: The pyrite oxidation showed here as negative feedback on atmospheric CO2, but was insufficiently studied to constrain its quantitative contribution to the glacial-scale carbon cycle. Is my understanding of this correct?

P8/L32: A recent modeling study of Kobayashi et al. (2021) also used d13C to constrain their ocean carbon cycle fields in the LGM.

P9/L32: I asked a similar question about the export production, but does the change in sea ice coverage affect the sinking flux of CaCO3 in this region?

P10/L7 Typo? The references are not listed correctly.

P10/L13: The maximum values of ideal age in the Pacific appear to be getting younger in expPI, expLGM, and expLGMss (expLGMws). Is this related to the increased AABW-related deep-water flow?

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