

Clim. Past Discuss., referee comment RC2
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Comment on cp-2021-98

Anonymous Referee #2

Referee comment on "Marine carbon cycle response to a warmer Southern Ocean: the case of the last interglacial" by Dipayan Choudhury et al., *Clim. Past Discuss.*, <https://doi.org/10.5194/cp-2021-98-RC2>, 2021

A review of "Marine carbon cycle response to a warmer Southern Ocean: the case of the Last Interglacial" by Choudhury et al.

The authors present the ocean carbon cycle response to a warmer climate, as simulated by an Earth System Model with the last interglacial (LIG) radiative forcing. The authors compared the Southern Ocean air-sea CO₂ exchanges between the LIG and the pre-industrial (PI), and attributed the difference to changes in SST, SSS, DIC, and alkalinity using a decomposition method. A major finding includes a greater CO₂ outgassing during the LIG compared to the PI, caused by warmer SST overwhelming the effects of surface DIC decreases. As the authors noted, exploring the Southern Ocean carbon cycle sensitivity to a warmer climate is an important research topic. The analyses/interpretations of the model results are also convincing. However, I have a few comments that might help improve this study.

- Although this study focuses on the potential changes in the Southern Ocean carbon cycle during the LIG, there are no discussions of how the simulated changes are compared with other observation or model based studies. The authors discussed it for some physical variables such as SST and sea ice extent, but no discussions regarding biogeochemical properties (which are the focus of this work).
- There are no validations of the model SST, SSS, DIC, and alkalinity against observations. Climatological mean DIC and alkalinity data are available through the GLODAP project where the authors can download observation-based estimates for the preindustrial period. The validation could be important because the simulated depth gradients of DIC and alkalinity can affect their redistributions during the LIG, which in turn control ocean surface pCO₂ changes through their surface changes. Of course, the model would not be perfect, but potential biases due to the model deficiencies need to be discussed.
- I am not sure how the inference of future carbon cycle change would be useful based on the simulated steady-state response during the LIG. What are the logics behind the linkage?
- The authors focused on the Southern Ocean carbon cycle responses to a global scale

climate change. In such a steady-state model setup, the globally integrated air-sea CO₂ exchange should be close to zero unless there are imbalances caused by riverine input and sedimentary burial. The excess CO₂ outgassed through the Southern Ocean needs to be taken up elsewhere. Where and how does this uptake occur? A discussion of this would be useful.

Specific comments

Line 10: "changes in sea ice exert a minor control" Is this also true on regional scales?

Line 11-12: what are the logics behind the linkage between the simulated LIG steady-state response and future transient responses in the coming century?

Line 18: 25% each or together?

Line 100: 275 ppm for radiative forcing only? The authors earlier stated that they used 280 ppm.

Line 110 and elsewhere: To my best understanding, the Revelle factor refers to a sensitivity of pCO₂ with respect to DIC only, not to SST, SSS and ALK.

Line 169: could the increased uptake south of 62S be due to reduced sea ice? Reduced convection in the bottom water formation regions should decrease CO₂ uptake.

Line 188-202: The net change in pCO₂ is really small at 1.2 uatm due to compensating effects of SST and DIC+ALK on pCO₂ change. Perhaps this might be smaller than measurement or PI pCO₂ uncertainties? When averaged over the Southern Ocean, it is true that SST is a dominant factor. However, the dominating factors would be different regionally because the contributions from SST, DIC, and ALK seem to be highly variable in space. The authors discussed the zonally averaged contributions, but the contributions seem to be also variable in a longitudinal direction as well. Would it be useful to provide a spatial map to identify the dominant factor at each grid cell? For example, SST dominance in red, DIC dominance in yellow, ALK dominance in blue, and SSS dominance in green?

Line 206-207: negative? The red line seems to suggest positive values south of 75S in Fig. 3g.

Line 218: It is interesting to see the larger SST increases over the Southern Ocean compared to other ocean surfaces, which is responsible for the net increase in oceanic pCO₂ over the Southern Ocean during the LIG compared to the PI. Perhaps, it would be useful to discuss why the SST increase is larger over the Southern Ocean than the global average during the LIG?

Line 228-230: why does the northward shift of AAIW lead to lower O₂ and higher DIC and PO₄? If it is the shift that causes the changes, we might expect some dipole patterns?

Line 283: The role of sea ice cover change can be tested offline. You can calculate air-sea CO₂ fluxes based the simulated air-sea pCO₂ difference with and without the sea ice cover changes.

Line 301: There is a study suggesting an increase in surface productivity over the Southern Ocean in a warming climate (e.g., Kwiatkowski et al. (2020)).

Figures: please add latitude and longitude labels to maps

References

Kwiatkowski, L., Torres, O., Bopp, L., Aumont, O., Chamberlain, M., Christian, J. R., Dunne, J. P., Gehlen, M., Ilyina, T., John, J. G., Lenton, A., LI, H., Lovenduski, N. S., Orr, J. C., Palmieri, J., & Santana-Falcón, Y. (2020). Twenty-first century ocean warming, acidification, deoxygenation, and upper-ocean nutrient and primary production decline from CMIP6 model projections. *Biogeosciences*, *17*, 3439-3470.
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