Climate driven shifts in Southern Ocean primary producers and biogeochemistry in CMIP6 models.

Fisher et al.,

Review Response: Round 2

Reviewer 1

I acknowledge the authors' efforts in addressing the first round of revisions. The manuscript is now more understandable, and the connection between the figures and the text is clearer. While I don't have many specific suggestions (except for the two listed below), I believe there is still room for improvement in the linkage between the figures and the text. This may be because much of the CMIP6-related analysis provided by the authors is either buried within the discussion of existing literature or lacks direct support, as some diagnostics (e.g., freshwater flux) do not have output from the CMIP6 models.

We thank the reviewer for their comments. As the reviewer acknowledges, a key struggle is that some parameters are missing from CMIP6 models, we have made an effort to be explicit about which parameters are absent from the models and hope this paper can be used as a basis for increasing the representation of biogeochemically important processes in future generations of CMIP.

I have two additional suggestions/corrections:

1. Figure 1 is not fully described in the manuscript. It is referred only in line 67 when the authors says which change is unknown. A more detailed caption would help the reader. The authors attempt to link Figure 1 with Table S1, but either the references are incomplete or some values (e.g., pH) do not match in table and figure, or certain values (like IPAR) are missing in the table. It is important to clarify where these numbers are coming from, as it is difficult to follow. For example, pco2 row "pCO2 +200% Increase from ~500 µatm (GLODAP) to ~1000 µatm under RCP8.5" Isn't it the increase is 100%? Also if GLODAP is referred, it is needed to be in the references.

We have expanded the figure caption to make clear which parameters in Figure 1 result from CMIP6 values derived in this study compared to those which come from literature values.

"Figure 1: Schematic diagram of Southern Ocean pressures associated with climate change and the downstream biogeochemical consequences for ecosystem productivity. Values shown for surface warming, surface insolation and pH are 100 year mean changes to 2100 under the SSP5-8.5 scenario south of 65°S and are taken from CMIP6 models. Literature values are used for changes in pCO_2, stratification, and shelf warming at depth for the same time period and climate trajectory (Kawaguchi et al., 2013;Hauck et al., 2015;Purich and England, 2021) (see Table S1 for a full description). Question marks indicate key processes which drive biogeochemical change but are not currently included in CMIP models and therefore estimations of change do not currently exist."

We have made clearer reference to Figure 1 in the text, adding in another reference to this Figure in reference to IPAR.

Line 67: "This increase in ocean surface area available for light transmission is offset by decreased insolation (-8.3%, Figure 1) associated with a greater degree of cloud cover."

We have updated Figure 1 to correct the pCO_2 change to 100%

We are not directly referencing GLODAP data, but we are obtaining the pCO_2 value from Kawaguchi et al., (2013) which performs an analysis of GLODAP data. We have added the Kawaguchi et al (2013) reference to the Figure 1 caption.

We have checked Table S1 to make sure the values are consistent with the Figure 1 and added a description of the IPAR data to this.

2. Figure 2A: The label for Subantarctic zone is incorrect; it is written as "Subtropical." This needs to be corrected.

Thank you, we have corrected this label.

Reviewer 2

This is the third time authors submit this paper. I again acknowledge that most of the introduction stays. Results and discussion section has been further simplified, which is something I acknowledge as well. I criticized the old versions mostly because I think that original results presented in the text were diluted within a review, instead of highlighting the relevance of the present work. I am happy to say that this version further improves this issue. I still think that Table 1 can be presented as supplementary material. I acknowledge as well the inclusion of some discussion on the effect of zooplankton grazing. I think the paper has benefited from the changes made in the previous two iterations.

We thank the reviewer for the comments on improvements we have made to the paper. Regarding Table 1, the editorial opinion was to leave this in the main text.

Specific comments about the text and figures:

Line 46-47: “As the ocean's buffering capacity increases, atmospheric CO2 concentrations weaken (Jiang et al., 2019), and the role of pelagic ecosystems is expected to become more important in the Southern Ocean's carbon uptake. (Henley et al., 2020)”.

This isn’t correct, the point is that the buffering capacity of the ocean is decreasing not increasing. We have changed the original statement to be clearer

“As the Ocean’s buffering capacity for increasing concentrations of atmospheric CO_2 reduces….”

Line 58: I will remove “across the Southern Ocean”, as it is not the only place were phyto fuels ecosystems.

Removed

Line 60: I would say something like: “which is the scenario that comes closest to representing the current climate trajectory”.

Changed

Line 96-100: I think this can be removed.

This sentence refers to the fact that surface chlorophyll representation has not improved between CMIP5 and CMIP6, based on benchmarking studies. Given that our paper is arguing for improved representation of biogeochemical processes linked to productivity, we feel this is an essential part of the introduction, providing the rationale for the study which should be retained.

Line 125: we?

Yes, we have used we consistently throughout the manuscript.

Line 184: May acronyms be defined for these parameters.

It is unclear what this comment is referring to, there are no acronyms on line 184 or even in the subsequent paragraph. All acronyms are defined in the text and Table 1 for the parameters.

Line 275: "...where iron-manganese…" can be removed, and "yet only iron…" joined with precedent sentence.

Changed

Line 334: I think authors mean that changes in phytoplankton growth don't result from acidification in CMIP6 results, as they explain after how these effects have impacts.

Correct, we are saying the phytoplankton growth doesn't result from acidification in CMIP6.

Line 390: Why these numbers have been corrected?

There was a minor piece of reanalysis performed in an early round of revisions to change the y axis units from seconds to days, removing exponentials, which changed a couple of the slope values by ~2% points, but this had not been carried forward in to the text. This revision ensured consistency between the figures and the text, the minor change in numbers does not impact any of the analysis or conclusions.