

REVIEWER 2

Kvale et al. – The open uncertainty window in ocean biogeochemical responses to fossil carbon emissions.

Summary.

Kvale and colleagues explore how slight variations in how an ocean model is calibrated under pre-industrial or historical conditions can lead to a divergence in the transient response under greenhouse warming.

To do so, they use the UVIC ESM. They set up three independent physical states by using 3 different vertical mixing regimes - BL, TID and CON – which they tune manually so that each is as similar as possible. Similarity is measured in terms of AMOC, AABW, ACC and CDW overturning strengths and these 3 independent physical states are run for 10,000 years. They feed these equilibrated physical circulations into a transport tracer matrix (TTM) and follow a useful method for simultaneous parameter optimisation of 6 key ocean BGC model parameters. Thus, they arrive at 3 different physical and biogeochemical ocean states that nonetheless near-equally represent the ocean and BGC state relative to modern day observations. Following this achievement, the authors then force the ESM with these 3 ocean states with increasing atmospheric CO₂ and describe the differences and similarities in the transient response.

The authors find divergent responses in key biogeochemical properties of interest, like net primary production, showing that how we set-up our ocean models can have a real influence on our projections. Their results highlight how even very similar model states tuned to reproduce modern day conditions can result in different projected states in the future and this is a major challenge in our work.

Comments.

The authors do a good job of assessing their model states and addressing biases at each stage of their approach. The paper is well presented and I find no major problems or concerns with it. I have some minor comments below that I hope the authors can address.

We thank the Reviewer for their careful assessment of our manuscript. Please find our responses provided in blue. Modifications to the manuscript text are shown in red.

Line 149 – sentence needs rephrasing.

Thank you for the correction- “later” was supposed to read “alter”

Line 297 – the authors state: “All three model configurations retain similar biases in pre-industrial nutrient and carbon distributions in all ocean basins (Fig. 7) despite calibration, which result from shared biases in the general circulation.” Can the authors

show this? At present, this statement has no clear evidence behind it and appears to be an assertion. Isn't it possible that the BGC model, which is simple as far as BGC models go, has an upper ceiling in its process representation that sets a limit to how well the model can represent nutrient and oxygen fields?

Figure 7 shows these shared biases, in the sense that e.g. DIC, PO₄, and NO₃ concentrations are too low at mid-depth and too high in the deep ocean, despite model calibration. This assertion is based on the circulation sensitivity study of Kriest et al. 2020, which is cited in the next sentence. For clarity, this citation is also moved to the sentence in question.

Correlation metrics - Isn't it a bit dishonest to present the correlation statistics when these are actually based on only 3 points? Noting that you've done a lot of work to get those three points, I think a different way of presenting this information would be good. Instead of large monotone boxes, couldn't you have individual panels with the three points and a line, which would be honest about the fact that these correlations are created from 3 points.

The application of the color matrices was a decision based on the need to show a lot of interrelated and complex information in a compact way. We acknowledge the limitation of using only 3 models in the conclusions. Individual panels of line plots are more difficult to assess holistically, especially for e.g. Fig. 9 showing how absolute metric vs. a change in metric affects the relationships. However, we have now added these as a supplement. The text has now been edited to emphasize the limited data points and the motivation for showing correlations:

Line 243 It is important to note that our small sample size of only three points increases the uncertainty in our analysis, and we furthermore do not account for covariance, nor do we attempt to identify causal links. These correlations are provided as a means to explore systematic relationships between optimal biogeochemical parameter sets and minimum misfit with the models' physical circulation metrics, which could suggest some physical-biogeochemical parameter compensation.

Discussion Lines 503 - 518: I was unsure of your point. Consider rephrasing or separating this paragraph into distinct arguments.

The paragraph has been separated into 2 to clarify that two distinct points are made. The language is also edited to clarify the points and to reflect concerns of Reviewer 1.

Line 520 - I disagree that the parameter optimisation is rigorous if it can only address 6 parameters. Suggest rephrasing.

"rigorous" is changed to "objective"

Line 525 - Which processes? Can you give a concrete example? Without one it becomes too abstract and hard to follow.

The sentence is somewhat redundant and is now removed. The following sentence is revised for greater clarity.

The discussion in general feels a bit thin while the results section is overwhelming with detail. Consider re-prioritizing.

We agree that there is a lot of detail in the results section. Calibration analyses are always difficult to write clearly and in a way that does not exhaust or lose the reader, which is why there is quite a bit of discussion interwoven into the results sections, making them long. In earlier versions we had more strictly separated results and discussion and found this was confusing readers. Internal feedback also showed that flow benefitted from additional “summary and discussion” sections to provide a succinct overview of the section results, which may be what the Reviewer is judging to be thin?

Thank you for considering my input to your research.