# Comment on bg-2020-479

Anonymous Referee #1

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Referee comment on "Sensitivity of 21st-century projected ocean new production changes to idealized biogeochemical model structure" by Genevieve Jay Brett et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-479-RC1, 2021

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This manuscript examines the effects of the choice of biological parameters on changes in the biological carbon pump. The authors make use of an elegant simple model and demonstrate that it is a very powerful tool. They demonstrate that the simplified model is a useful minimal model that yields insight into regional and seasonal differences in the mechanisms that drive changes in the biological pump. This is an important and insightful contribution. However, I think that there are a few conceptual gaps and methodological issues that should be clarified or addressed before this paper is published.

**Major comments**
1. Section 2.3

This decomposition is a clever analysis technique, however there are some unaddressed issues that make the interpretation of the results questionable.

- There is an error in equation 6, which forms the foundation for much of the analysis. Specifically, there is a sign error and the cross term between the changes in light and nutrients should be negative rather than positive. The equation should be $\Delta(QL) = Q\Delta L + L\Delta Q - \Delta Q\Delta L$. Because the components in the figures (e.g. Figure 6) look like they sum to the total, it is possible that this is only a typo and does not affect the results that are presented in this manuscript, but I would ask the authors to verify the nature of this error. This difference in sign may help the reader to understand why this term has a negative covariance with the total change.
- The change in light is calculated from R and Q instead of being calculated independently from equation 3. In fact, based on equation 3 the light would not change at all under

climate change. Instead, the change in L seems to combine changes in mixed layer depth (because light is averaged over the mixed layer) and changes in the vertical structure of nutrients (and particularly covariance of light and nutrients). Which of these factors is most important? Which is most important in regions where \Delta L \Delta Q cancels L\Delta Q and which is most important in regions where \Delta L \Delta Q largely cancels Q\Delta L?This should be made more explicit in the presentation of the methods, the results, and the discussion.

- It may help the reader if equation 6 is written out more explicitly (i.e. (Q_2100-Q_2000) rather than $\Delta$Q) to show which differences are being presented. One reason this is helpful is that it may not be immediately obvious to the reader that L and Q on the right hand side are the values at the later time and that this is a difference, not a product rule derivative.

2. Section 3.1

One of the main quantitative metrics used in this study is pattern correlations. The correlation coefficients are presented but there is no assessment of the statistical significance of these correlations. The authors should compute the statistical significance or provide another context in which these correlations should be interpreted. The values of the pattern correlations are difficult to assess in isolation. Moreover, there is an over-reliance on pattern correlation in some sections. This is particularly true when discussion the \Delta L \Delta Q term (line 309), which has a small correlation with \Delta (QL) but can be a large contributor in some locations.
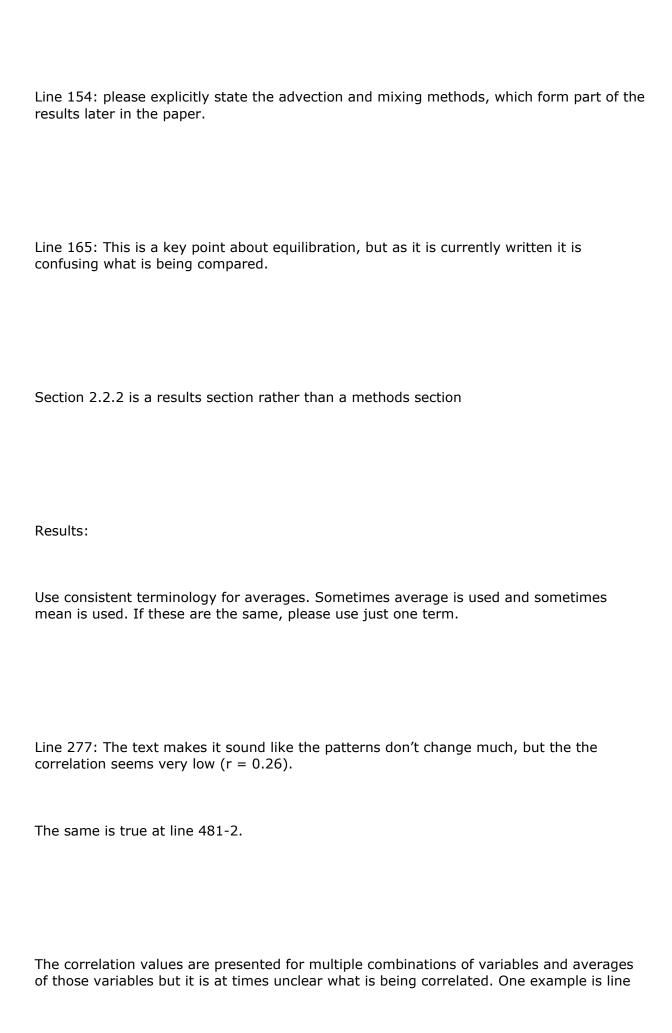
3. Section 3.2

This section concludes that there are different mechanisms that govern changes in the seasonal cycle of production than that govern changes in the annual average of production. However, I remain unconvinced by this conclusion. The results shown seem to be driven more by regional differences than by seasonality. The largest seasonal cycles are in the high latitudes while the low latitudes have weak seasonality. The results show that changes in the seasonal cycle and the mechanisms driving those changes are similar to the arctic and sub polar North Atlantic, perhaps with more influence from the Southern Ocean in the slow timescale case.

Furthermore, the statement in lines 344-346 is only true for the fast case but not the slow case, again likely due to different responses in the high latitudes with each of the timescales.

4. Methods: How effectively is the nutrient mixed within the mixed layer? The light is averaged over the mixed layer, however there is a comment about productivity being enhanced below the mixed layer depth (line 469). Does this mean that light is more effectively homogenized than nutrients due to the mixed layer not being an actively mixing layer? How does this affect the results about the mechanisms that drive changes in productivity?

5. I am concerned about the low deep nutrient concentration and the implications that has on the high latitudes, particularly the Southern Ocean. Some of the largest changes are in the high latitudes and especially the Southern Ocean. The authors state that the model is a very poor fit in these regions due to the low nutrient concentrations in these regions, which would otherwise be larger than the 20 uM deep nutrient concentration used in this model. Could the authors justify this choice and make the implications of this choice more clear? Would the global average statistics differ if the Southern Ocean were excluded? How do these results then relate to mechanisms for changes in primary production such as Southern Ocean nutrient trapping and the predominance of the Southern Ocean is global carbon export?

**Minor comments**

Introduction:

Paragraph at line 30: it is unclear what is meant by "essential properties" here although the phrase is repeated multiple times in this paragraph

Line 65: add citations to the specific prior work to which you are referring

This study is not the first to use simplified models to discuss biophysical coupling. The introduction should cite more of the relevant theoretical literature such as:

Smith, K. M., Hamlington, P. E., & Fox‐Kemper, B. (2016). Effects of submesoscale turbulence on ocean tracers. *Journal of Geophysical Research: Oceans*, *121*(1), 908-933.

Pasquero, C., Bracco, A., & Provenzale, A. (2005). Impact of the spatiotemporal variability of the nutrient flux on primary productivity in the ocean. *Journal of Geophysical Research: Oceans*, *110*(C7).

Methods:

Line 95: Are the tracers initialized in the model at the beginning of the spin up or only at the beginning of the 10 year timeslice? What is the tracer initial condition?

Line 111: Figure 1 shows more changes than are outlined briefly in this section. There are some prominent changes like a speeding up of the ACC that are not mentioned.

Equation 1: what is the functional form of the restoring S? Is there a parameter that relates to the nutrient restoring rate?

Line 154: please explicitly state the advection and mixing methods, which form part of the results later in the paper.

Line 165: This is a key point about equilibration, but as it is currently written it is confusing what is being compared.

Section 2.2.2 is a results section rather than a methods section

Results:

Use consistent terminology for averages. Sometimes average is used and sometimes mean is used. If these are the same, please use just one term.

Line 277: The text makes it sound like the patterns don't change much, but the the correlation seems very low (r = 0.26).

The same is true at line 481-2.

The correlation values are presented for multiple combinations of variables and averages of those variables but it is at times unclear what is being correlated. One example is line

293.

Line 305: this sentence has confusing wording

Line 330: do you mean to repeat qualitative twice in this sentence?

Line 403: Is the Arctic region defined using two criteria or are these two criteria equivalent?

Conclusions:

Line 466: "other processes" is confusing because the next sentence discusses productivity processes that were not included.

An overall note on the grammar is that the sentence structures can be repetitive with a few sentences in a row beginning with the same clauses (e.g. "here").

Figures:

Figure 5 caption: Expand on what is meant by "Annual and 100m mean nutrient concentration." Is this an integral over the upper 100 meters? Include all information in the caption (what is shown in panels a, b, c, d).

Figure 6: the color scales appear to be saturated. Could the minimum and maximum values be includes as annotations on the figures?

What is meant by 100m average? Is that an integral over the upper 100 meters?

Figure 7: This figure would be easier to interpret if panels c and d were both underneath b.

Figure 9: Over what depth range are these values averaged?