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Reply on RC1

Genevieve Jay Brett et al.

Author 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-AC1, 2021

Partial response to Reviewer 1

In the interest of contributing to a conversation which will allow for the best revisions of this paper, this response to RC1 is partial, focusing on the major comments, and does not include the associated revisions. Minor comments and all revisions will be fully addressed after the public discussion period. Below, we respond to each major point. Portions of the original comment included here are in *italics*.

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.

Thank you for checking the math here. Indeed, we formulated this equation differently than you assumed, so we will write it out more explicitly in the final manuscript. The existing equation is:

$d(QL)=QdL + LdQ + dQdL = Q0(L1-L0) + L0(Q1-Q0) + (Q1-Q0)(L1-L0)$

where d is used rather than delta, Q0 is Q in 2000s, L1 is L in 2100s, and so on. The alternate formulation which you expected is:

$d(QL)=QdL + LdQ + dQdL = Q1(L1-L0) + L1(Q1-Q0) - (Q1-Q0)(L1-L0)$.

The pattern correlations coefficients are similar but not quite the same for these different formulations; we do not see qualitative changes. In the below table, dQdL in the new equation is - (Q1-Q0)(L1-L0).

Correlations with d(QL)	Slow	Fast	Slow, new eqn.	Fast, new eqn.
LdQ	0.73	0.64	0.78	0.52
QdL	0.44	0.19	0.37	0.17
dQdL	-0.035	-0.058	0.035	0.058

As for the computation of L, our climate change scenario directly impacts the incoming radiation and the sea-ice coverage of the ocean, changing the light incident at the sea surface. See Fig 1a, which shows changes in the minimum incoming short-wave radiation of 10-25W/m2 over most of the ocean. Then the mixed layer depth changes further impact the light availability through the averaging you noted. The reason for computing L from production rate and Q(N) is that the mixed layer depth, and thus L, can change rapidly. Production rate and N are averaged on-line in our model, and thus computing L from them allows us to have an accurate time-averaged L that would not be possible to compute from the time-averaged mixed layer depth and incoming radiation. For future development of models, it is a good idea to have as output an online-average of nonlinear functions like L and Q.

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.

Determining statistical significances for ocean pattern correlations was not originally attempted because the Q and L functions and their differences are not distributed similarly to a standard statistical distribution. If we treat these terms as normally distributed, there is the challenge of deciding on an appropriate estimate of the degrees of freedom in the model global ocean. There are 82,565 ocean gridcells used in these correlations, but these are not independent. If we suppose a moderate correlation lengthscale of about 10 gridcells in both directions, which will be about 6-9 degrees of longitude and latitude depending on location, we have perhaps 825 degrees of freedom and $p<0.01$ for $r>0.09$. Empirically, the lagged autocorrelation of d(QL) drops from 1 to ½ after 18 gridcells (slow case, longer), which suggests a single-direction 36 gridcell correlation lengthscale, 2294 degrees of freedom, and $p<0.01$ for $r>0.06$. We welcome further input on best practices for significance in this situation.

When editing the manuscript, we will add in appropriate places that small pattern correlations, like those of dQdL with d(QL), are insignificant. We will also collect our correlations into a table as requested in the second reviewer comment and note those which are significant under what assumptions.

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.

Global annual-average production is reduced in the warmer climate mainly due to reduced nutrient availability (LdQ). Looking at the seasonal cycle, production is reduced mainly in latter half of the growth season, which is shortened. In both cases considered, reduced nutrient availability contributes to the reduced production during this period, which is consistent with the annual-average results. The two cases have different contributions from light availability and light-nutrient covariance during the latter half of the growth season. We will rewrite the final paragraph of this section to make these points clearer, including the fact that the noted statement is only in regards to the fast case.

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?*

Line 469 should read "enhances production in the lower portions of the mixed layer"; the averaged light enhances light availability, and thus production, in the deeper parts of the mixed layer.

The extent to which nutrient is mixed within the mixed layer is a very good question. Looking at the values of monthly-mean N, we computed the range and mean across the shallower of the mixed layer depth or the top 100m, as analyses in the text are limited to the top 100m. The median range of N and of range(N)/mean(N) are in the table below. Broadly speaking, there is a gradient of N within the mixed layer which is larger in the summer, near the equator, and in the present climate. The range of N is usually smaller than the mean N, but these are more similar in the fast case.

	Slow 2000	Slow 2100	Fast 2000	Fast 2100
Median range(N)	0.0151	0.0125	6.39 10^-6	1.29 10^-6
Median range(N)/ mean(N)	0.119	0.145	0.447	0.447

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?*

The choice of value for the deep nutrient concentration was based on global observed deep nitrate values. The observed concentrations of nitrate at depth varies considerably, from about 13mmol/m3 in the Arctic to about 38mmol/m3 in the South Pacific, so 20mmol/m3 is within the range of observations. The deep nutrient pool is likely to change with the climate and associated shifts in deep water formation and ventilation. Our focus is on the upper ocean where new production occurs, and so we chose a constant value of nutrient at depth across space and time.

With regards to the Southern Ocean, we note that modeling production here requires the inclusion of iron. While one could imagine interpreting our single nutrient as iron, the deep concentration and half-saturation coefficient would need to change. The production in the Southern Ocean is close to half the global annual production (see appendix of the original manuscript). The reductions in global annual production are 8.5-11% without the Southern Ocean, as opposed to 9.5-19.5% when it is included. The causes for reduction remain mainly reduced nutrient availability. We have similar results in the pattern correlations between d(QL) and its components regardless of including the Southern Ocean (table below).

Correlations with	Slow	Fast	Slow, no SO	Fast, no SO

d(QL)				
LdQ	0.73	0.64	0.66	0.52
QdL	0.44	0.19	0.45	0.14
dQdL	-0.035	-0.058	-0.016	0.016