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Comment on bg-2021-14

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Referee comment on "Oceanic primary production decline halved in eddy-resolving simulations of global warming" by Damien Couespel et al., Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-14-RC1, 2021

Oceanic primary production decline halved in eddy-resolving simulations of global warming
Damien Couespel, Marina Lévy, and Laurent Bopp
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The manuscript is well constructed in terms of the scientific numerical experiments, analysis and interpretation of the model output, and presentation. The scientific topic is importance and broadly relevant to the ocean biophysical and biogeochemical research communities. Below, I describe a few areas where the text could be amplified or clarified as well as a few minor specific issues. Overall this is an excellent contribution and should be published after minor revisions.

The manuscript brings together two important current lines of ocean science modeling: 1) quantifying the response of ocean productivity to climate change, and 2) characterizing the influence of mesoscale dynamics on phytoplankton growth. The Earth System Models used to project future climate change impacts on marine plankton ecosystems and biogeochemistry are limited computationally to relatively coarse spatial resolution that do not capture mesoscale dynamics. These simulations indicate the decline in global marine primary production, though with considerable cancellation of regional patterns of positive and negative trends and variations across current generation models. The decline in primary production has important implications for marine fisheries and conservation.

Previous modeling and field studies indicate the mesoscale features can enhance nutrient supplies in many ocean regions and are thus important for correctly simulating primary production rates and patterns. The lack of these mesoscale biophysical process could bias future climate change projections. The authors of this study conduct novel climate experiments varying spatial resolution in an ocean model with idealized, two-gyre geometry. The model is integrated at eddy-resolving through to eddy-parameterized resolution, with several different versions of the eddy-parameterized simulation using different combinations of horizontal diffusivity in the Gent-McWilliams parameterization.

The model description and experimental design subsections of the methodology are solid, detailed and informative, with sufficient details provided for other researchers to replicate the basics of the study. The experimental design includes description of the control simulation, model spin-up for the different experimental cases, and the pre-industrial and climate change integrations.

The model analysis is framed the changes in net primary production (NPP) and on a budget of the various physical advective transport and mixing terms regulating the nutrient (nitrate) supply to the surface waters of the subpolar gyre. The nitrate budget analysis is solidly based, building on a number of previous studies analyzing time mean and variability (Reynolds decomposition) of the North Atlantic nitrate budget from the perspective of both vertical and lateral nutient supply terms (e.g., McGillicuddy et al., Global Biogeochemical Cycles, 2003, doi:10.1029/2002GB001987).

The climate change simulations in the simplified geometry model exhibit a decline in NPP in the subpolar gyre similar the the results seen Earth System Models for the North Atlantic (e.g., Bopp et al., 2013; Kwiatkowski et al., 2020). The NPP decline is stronger in absolute and fractional terms for the coarse resolution model, and the analysis links those declines to a reduction in nitrate supply. Similar to previous coarse resolution simulations, the model shows declines in nutrient supply both due to increased stratification (reduced supply vertical mixing) and decline in nitrate in the thermocline linked to lateral processes.

One issue that would be good to address in a little more detail is the difference between the response of new and regenerated production (around Line 210). In the chosen model, ~2/3rds of the NPP decline is due to new production that is directly linked to nitrate supply; previous model studies have indicated substantial variations across models in the temperature sensitivity of NPP under climate warming scenarios that can reflect direct phytoplankton physiological effects as well as changes in the efficiency of nutrient recycling and export (e.g., Laufkötter et al., 2015, doi:10.5194/bg-12-6955-2015; Laufkötter et al. 2016, Biogeosciences, doi:10.5194/bg-13-4023-2016). It would be useful to know the temperature sensitivity of some of the biological terms in the model, for example. It would also be useful to present briefly some results on the baseline f-ratio in the control simulations and change in f-ratio across the climate change scenario.

The Results section continues with an analysis of the physical transport differences in the climate response across resolution, linking back to nutrient supply. The issue of changes in circulation is an important aspect of the results. In the discussion of the meridional overturning circulation (MOC) (around line 275) it would be good to clarify the differences in the MOC in this simplified geometry model versus more realistic simulations of the North Atlantic. While the simplified geometry model does include some deep convection at the northern boundary, the overturning circulation is shallow (<1000 m) and weak (only a few Sv in control simulation). Also, in full ESMs, the North Atlantic deep water formation rate and MOC are affected by freshwater export from the Arctic, a process not captured in the simplified model. It would be good to clarify what can be done with the simplified model versus those processes that would require investigation in a more detailed model. A more minor point is that the experiments appear to assume that the seasonal wind stress patterns are constant under climate change, a topic perhaps worth noting in the discussion.

Specific issues in text.

Line 177
"u cot N ds"
The "cot" probably used be the command "\cdot" in Latex.

Line 190
In Equation 4, the second N_CC probably should be N_CTL

Line 298
"eddy parameterization coefficients (kredi and kgm)."
I think there is a formatting issue here with the subscript. Also, would be good to relate back to terms such as "isopycnal" and "bolus" diffusivity that may be more understandable to the reader rather than model coefficient names, since the specific GM parameterization equations were note presented.