Interactive Comment on McKay et al., 2020 ESDD "Resolving ecological feedbacks on the ocean carbon sink in Earth system models"

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We appreciate this submission of a sensitivity study exploring the isolated and combined effects of temperature dependent remineralization and ecological dynamics on the ocean's changing biological pump in the recently updated EcoGENIE EMIC. We agree with the authors that the topic of ecological model complexity and its relevance for biogeochemistry and eventually climate represents an important, and as yet unresolved, scientific challenge. We also appreciate the careful design and analysis of the numerical experiments. The analysis, however, over-emphasizes the role of the biological processes for model-model differences in the oceanic CO2 uptake while neglecting the importance of model-model differences in the buffer factor due to differences in the surface carbon chemistry at the end of the spin-up of the different versions. The manuscript makes a number of strong statements that are not justified by the material presented and, we feel, need a careful scientific reassessment.

Conceptual issues:

Page 3, Line 69:
…up to 4-12 GtCy-1 of POC reaches the deep ocean where it becomes part of the long-term carbon sink on centennial-to-millennial timescales

We suggest rephrasing as this is not the marine carbon sink of anthropogenic CO2 mentioned earlier in the text. In fact, the biological pump is, in steady state, neither a carbon sink nor source as it fluxes as much (organic) carbon to depth as is transported back in inorganic form to the surface ocean. The timescale describes how long it take one carbon atom to take a full loop, but it does not say anything about a timescale of a possible sink or source of carbon.

Page 9, Lines 259-266:
In our simulations, the relative strengthening of the biological pump when TDR is included actually leads to a net decrease in the ocean carbon sink capacity during the 21st century (Table 2). Conversely, the relative weakening of the biological pump with ECOGEM activated instead (ECO+FPR) is associated with a net increase in the ocean carbon sink capacity. Combining both ECOGEM and TDR (ECO+TDR) results in a smaller overall relative weakening of the biological pump compared to default, and a marginal net decrease in the ocean carbon sink capacity of ~0.4 GtC (~2.4 GtC under RCP8p5) over the 21st Century. Including trait-based ecology using size classes largely but not entirely offsets the impact on the ocean carbon sink of also including TDR in this model. The model thus suggests that ecological dynamics increases the resilience of plankton ecosystem functioning against the pressures of climate change.

We believe this interpretation needs to be revisited. The overwhelming contribution to the ocean's uptake of anthropogenic CO2 is from the solubility pump. Though your models share the same physics, surface ocean DIC and ALK are only ‘calibrated’ to be similar (lines 188-190). Table S1 indicates that at least BIO+TDR has a considerably smaller surface carbonate ion concentration compared to BIO+FPR, indicating that the carbonate buffer is reduced compared to BIO, suggesting that in that model run the solubility pump should be weaker. It is actually this pair of model experiments, which shows by far the strongest difference in marine CO2 uptake (Table 2). BIO+TDR has lower CO2 uptake, consistent with the lower initial buffer, but inconsistent with the higher POC-export response.

In the follow-up paragraph (lines 268ff) this is being discussed somehow, but still analyzed as an effect of differences of biological pump representations. However, the different marine CO2 uptake seems in fact to result from different surface DIC and ALK concentrations at the end of the respective model spin-ups. If the models were calibrated to have identical surface DIC and ALK values, buffer factors and the responses of the solubility pump to increasing atmospheric CO2 would be similar, allowing a more straightforward identification of biological effects on the oceanic CO2 uptake.

Page 10, Line 289:
Other processes that are not resolved in this configuration of ecoGEnIE could also substantially affect the biological pump though, such as ballasting, calcifier-silicifier trade-offs, and deep chlorophyll maxima (discussed more fully below), and further work is required to assess their impact on our estimates

Recent work has also demonstrated the importance of representing interacting N-cycle processes (such as N2 fixation and water column and benthic denitrification) to capture important feedback processes that affect biological export production (Somes et al., 2016; Landolfi et al., 2017) and potentially air-sea CO2 exchange (Buchanan et al., 2019) and ecosystem restructuring (Dutkiewicz et al., 2013). Also, redox-dependent feedbacks in nutrient cycles are not included in most current models, but may be relevant even on centennial timescales and will require an adequate representation of marine oxygen distributions (Watson, 2016, Niemeyer et al., 2017).

Unjustified statements:

Page 1, Line 22 (Abstract) and, similarly, p 10, Line 282:
These results clearly illustrate the substantial degree to which ecological dynamics and biodiversity modulate the strength of climate-biosphere feedbacks, and demonstrate that Earth system models need to incorporate more ecological complexity in order to resolve carbon sink weakening.

The last column of Table 2 shows that the addition of ecological complexity results in a maximum weakening of the ocean carbon sink capacity of 2.39 GtC over a 100 year period (a 0.4% weakening). If ecological complexity is removed and only temperature dependent remineralization is considered, the maximum weakening is still only 0.9%. These differences in marine carbon uptake, even if buffer factors were similar and effects were caused predominantly by differences in the representation of biological processes, do not strongly demonstrate the need for additional model complexity. Instead, if the same metric is applied, one might even argue that uncertainties can probably be reduced by a far larger amount by investigating better representations of, for example, physical processes.

Page 10, Line 297:
To date, gains in computational power have largely been allocated to improved resolution and physical process representation. This study suggests that it is timely for the research community to debate again where future gains should be focused …

While we agree that such a debate is important and should always be encouraged, this statement makes the misleading impression that this paper is the first to propose potential gains from shifting some resources from even higher ocean resolution to more complex bgc models. However, what has been hindering the application of more complex biogeochemical models is not necessarily computation-power issues related to performing simulations, but the uncertainty in biogeochemical model parameters and the associated computational costs in properly calibrating these parameters. Fortunately, since a few years, biogeochemical and ecological parameter optimization has emerged as a very active field of research that exploits recent gains in computational power. Please see Frants et al. (2016), Chien et al. (2020), Schartau et al. (2017), Kriest et al. (2020), Kriest 2017, Niemeyer et al. (2019), Sauerland et al. (2019), Yao et al. (2019), to name just a few. So far most of this work has not been carried out with 'proper' ESMs, but with EMICS. To pose all discussion of ocean carbon cycle dynamics research in the framework of CMIP is misleading. Actually, including poorly calibrated more complex bgc models in high resolution ESMs is likely not in favor of more reliable marine CO2 uptake predictions. Since such calibration can be done on the EMIC level, it is rather more important to propose studies with well calibrated models to better understand the relationship between bgc complexity and marine CO2 uptake.

Page 11, Line 318:
Empirical observations have suggested that the ballasting effect is weaker than hypothesized (Wilson et al., 2012), making ballasting unlikely to substantially alter our findings, but it would likely result in greater surface layer remineralization in scenarios with reduced PIC production

Please see Kvale et al. (2015, 2019) for 2 explorations of how ballasting can affect export in a temperature-dependent remineralization model (EMIC) over long-term simulations. Depending on how you choose to represent calcification, the ballasting effect can alter the pathway to the long-term response of your model via modification of suboxic volumes, which regulate denitrification, nitrate availability, and hence primary and export production.

In summary, this manuscript could be improved on two fronts. The first is stylistic, in which the introduction and discussion of the state-of-the art should include references to the recent ecology and biological pump work happening with both EMICs and ESMs. This is important for giving proper context to the present study. The second is technical, in which the major conclusions must be shown to be independent of different states of the carbon chemistry at the end of the spin up of the respective models. This can be demonstrated, for example, by carbon separation techniques (e.g., Koeve et al., 2014) or a better model calibration that adequately controls for buffer chemistry. On technical aspects we are always happy to offer advice, and invite the manuscript authors to contact us for further discussion.

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