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Interactive comment on "Climate change and ocean acidification impacts on lower trophic levels and the export of organic carbon to the deep ocean" *by* A. Yool et al.

Anonymous Referee #2

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The ocean presently takes up a large fraction of the anthropogenic emissions of carbon dioxide, mainly by the so-called physical carbon pump. The biological carbon pumps (both the direct pump connected to the sinking of particulate organic material and the carbonate counter pump) in contrast are believed not to have changed much since pre-industrial times. It is of major interest whether the role of the ocean as carbon sink that moderates the increase of CO_2 in the atmosphere will change under projected climate change.

The manuscript by Yool, Popova, Coward, Bernie and Anderson analyzes changes in the biogeochemical cycling of carbon in the ocean under two different climate change scenarios, by comparing it to the present state. To do so, the authors have used a relatively new ocean ecosystem and biogeochemistry model, Medusa 2.0, to perform ocean-only model runs forced by output from CMIP5 coupled ocean-atmosphere scenario runs. One of the possible feedbacks that is interesting in the question of the evolution of the biological pump is that the increase in dissolved carbon dioxide and the concomitant decrease in pH can affect the formation of calcium carbonate by phytoplankton. This decrease can affect carbon fluxes directly, but also indirectly by affecting the sinking speed and remineralization rate of sinking organic particulate matter.

The model that the authors use here allows to investigate this question because it includes parameterizations of both, how pH affects calcification, and how the calcium carbonate fraction of sinking particles affects the remineralization of their organic content. Another interesting difference of the model used here to other biogeochemical models is that it takes into account that the average carbon:nitrogen stoichiometry of zooplankton differs from that of phytoplankton.

The authors find a general decrease in primary production by approximately -6% globally under the high-emission scenario, with a much larger decrease in the North Atlantic, in line with findings by Bopp et al., 2013 from an analysis of a suite of CMIP5 scenario runs. They find a much more pronounced decrease of planktonic calcification (-50%), which is mostly due to the decreased pH. This has knock-on effects on how deep organic particles sink before getting remineralized by bacteria: While the export at 100 m depth sinks roughly in accordance with primary production, the export over 1000 m depth decreases by more than -40% and the flux to the benthic layer decreases even further. If this prediction would hold true it would have very large consequences for the ecosystems in the deep sea and the benthos.

General comments

Predictions of the magnitude and sometimes even sign of the biogeochemical feedbacks of the ocean carbon cycle to climate change differ between different biogeochemical models, see e.g. Bopp et al., 2013. While there is some agreement between

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models that primary production will likely decrease in a warmer climate, there is much less confidence in predictions of community composition or export efficiency. This reflects that presently marine ecosystem models still contain a large number of hypotheses and parameterizations on what determines elemental fluxes that are based on isolated lab experiments and our limited understanding of the marine ecosystem as a whole. Even the agreement between models therefore not necessarily implies confidence, as most models have been tuned to reproduce the present-day observations of phytoplankton chlorophyll. It may for example well be that our present model perspective is much too biased towards a bottom-up control of primary production.

In this state of things, it is necessary that a multitude of models with different assumptions are all analyzed for their response to climate change, as done in the ongoing Marine Ecosystem Model Intercomparison Project MAREMIP. The present paper is a good contribution to this goal. It is also necessary that the model results obtained are critically evaluated with respect to how the inherent assumptions and parameterizations in the model affect the outcome of the climate change model experiments. I feel that in this latter respect the authors could have done a bit more. The authors freely admit that their predictions of the decrease of calcification and of the changes in deep export critically depend on the chosen parameterization of the pH-dependent $CaCO_3$ production and on the assumption of a strong regulatory role of biominerals for the fate of organic carbon (p. 3479 and 3480). The role of the first parameterization is explored by a control experiment without pH-induced changes in $CaCO_3$-production. The influence of the second parameterization is not really explored. I guess it would be overly difficult to design another control experiment to isolate the effect of this parameterization without changing the present-day model results, but the authors could have provided a bit more information, e.g. on

- how much does the remineralization rate or length scale change through the reduced $CaCO_3$ content and how does that compare with present-day variability in the length scale (or Martin-curve k)?

- is the reduction in $CaCO_3$ production the dominating effect for the reduction in export, or is there also a contribution from changing water-column dissolution in the upper ocean?
- the authors mention changes in the opal production also: How much does that contribute to the changes in export production?

The authors also mention at least two other effects that contribute to the feedbacks, but without further discussion, namely that in their scenario runs the Si:N ratio of diatoms changes, and that the increasing temperature increases metabolic rates. In both cases, not even the way that these effects are parameterized is presented in the paper and the reader is referred to a companion discussion paper. Given that the paper is on feedback effects, it would have been nice to discuss the parameterizations and to show briefly whther they are not that important for the effects discussed here. Also, the authors state that the physical circulation field has some important deficiencies, such as a much too strong Antarctic Circumpolar Current, but just mention this as a caveat without further discussion on *how* this might affect model outcomes. I find it a pity that the effects of one of the really innovative characteristics of Medusa, namely the different C:N ratios in different trophic levels are not explored at all.

Specific comments

p. 3457, l. 28: That PP in the ocean is limited by nutrients is probably one of the important mechanisms, the other being top-down control by grazers; I would argue that it is probably the interplay between both. Also, on land, a large role is played by water, and the CO_2-effect is related to better economies of water usage, if I am not mistaken.

p. 3458, l. 24ff: perhaps one could already mention the different isomorphs of $CaCO_3$ here? I would hesitate to call $CaCO_3$ a biomineral without mentioning its crystal form(s).

p. 3460ff: It would be helpful to mention which processes in Medusa are directly

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temperature-dependent.

p. 3467, l. 25: Why compare against an average of the three PP algorithms?

p. 3468, l. 1: Is that an indication of deficits in the modeled iron distribution?

p. 3468, l. 15: Does the model include riverine inflow of carbon? If I understood it correctly, the uptake of 1.35 Pg C (which btw. is the SI unit, not Gt) is the sum of 2 Pg C uptake of anthropogenic carbon and 0.6 PgC outgassing of river-derived carbon.

p. 3470, l. 15ff: If the changing iron distribution has a major effect on the changes in primary and export production then it would be helpful to have at least some information how iron is modeled (how is the benthic source parameterized, what is the assumed scavenging rate etc.).

p. 3471, l. 28-29: It is indeed likely that the decrease in PP is due to the nutrient changes shown. But what is the role of compensating effects, such as higher temperature or higher mixed layer irradiance in high latitudes?

p. 3472, l. 20-24: How is the change in diatom Si:N ratio described in the model, as a pre-set function of iron limitation? Si:N racts also to nitrogen limitation, see e.g. Claquin et al. 2002.

p. 3477, l. 4-6: If this is an important effect, then why is it not really shown/discussed before?

p. 3477, l. 9: What do the percentages stand for?

Finally a brief note on one comment by reviewer #1: He/she asks (p. wC2080 line 1) why some equations use the "partial" symbol and others use the "d". This is actually correct, since the equations that use the "d" symbol are those for the benthic layer, where in the model no advection or diffusion takes place.

Technical corrections

p. 3466, l. 7: perhaps insert 'globally averaged' before SST?

page 3458, line 27: pterpods → pteropods

References

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Claquin, P., Martin-Jèzequel, V., Kromkamp, J.C., Veldhuis, M.J.W. and Kraay, G.W.: Uncoupling of silicon compared with carbon and nitrogen metabolisms and the role of the cell cycle in continuous cultures of Thalassiosira pseudonana (Bacillariophyceae) under light, nitrogen, and phosphorus control, Journal of Phycology, 38, 922-930, 2012.

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