

***Interactive comment on* “Quantifying the impact of ocean acidification on our future climate” by R. J. Matear and A. Lenton**

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Reviewer 1 (C7562)

The aim of the study by Matear and Lenton is to quantify the impact of ocean acidification on future climate. On the basis of an Earth system model they performed a set of sensitivity studies whereby most of the tested assumptions have already been investigated by other research groups. The new aspect of this manuscript is the focus on the OA impact on climate. This is an interesting scientific question which would be relevant to the scope of the Biogeosciences journal.

However, the insufficient description of the model set up creates rather confusion than new insights. Appendix A gives some rudimentary information in an unstructured way.

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Only the fallback to the original paper by Matear and Hirst (2003) could improve the reader's understanding.

While the key model equations were provided in Appendix A, we have extend this at the reviewers request to provide a more complete description of the model that will assist the reader in understanding how the model was configured and how it was modified to investigate the ocean acidification impacts in this study. By providing additional model equations on how the BGC is implemented in the tracer equation, confusion on the sign of some of the terms will be rectified.

Sparse information is also given in the discussion of the results; e.g. the authors describe in section 4.2.5 the changing dissolved oxygen cycle, which is currently one of the most interesting questions of the climate change impact, without mentioning that their model includes an implicit formulation of unlimited denitrification. Enhanced export production, as assumed in 3 out of 4 sensitivity studies, might therefore have only a limited affect on the oxygen concentration at depth.

The reviewer is correct that we have not included a limit on denitrification in paper, to address this point we have add a discussion of the consequence of prescribing the POC depth remineralization profile with unlimited denitrification on oxygen consumption, by POC remineralization. In the text we will added: By prescribing the POC depth profile in our model formulation, POC will be remineralized without consuming oxygen, which implies unconstrained denitrification. By having unlimited denitrification the consumption of oxygen may be under-estimated when POC export increases because POC remineralisation is occurring by denitrification rather than by oxygen consumption. Thus, the simulated response of the thickness of suboxic water to increasing POC export, as in the EP+ and COMB simulations, may be under-estimated. The large uncertainty in the potential changes in POC export and remineralisation with OA, at present make it difficult to project the potential consequences of OA on dissolved oxygen levels with confidence, and this makes it a critical issue for further investigation. The response of denitrification to increases in POC export adds another uncertainty to

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projecting the future interior oxygen levels with OA that needs further study. .

The major part of the section “summary and perspectives” is just a listing of other potential OA feedback mechanisms by referring to the work of others. This paragraph could be drastically shortened as there is no additional information related to the presented study.

While we agree that much of the material present is a review of existing research, we do believe that this information aids in placing our study in the context of previous work. Therefore, as we think it is appropriate and important to have such a discussion, we have retained most of the material in this section.

Special remarks:

The impact of OA is in the focus of this ms and inorganic carbon and alkalinity are prognostic tracers of the model: So why seems the dissolution of PIC not to be a function of the aragonite/carbonate saturation state (page 17704, line 4-10, A 11)?

Our choice of PIC remineralization keeps the model simple and allows the present-day alkalinity field to be reproduced ($r=0.92$ with new figures in Appendix A and additional points in the Taylor Diagram to assess both DIC and ALK, added). Like POC, we have simplified the PIC dissolution by prescribing it depth profile for several reasons: 1) PIC dissolution may occur above the lysocline in micro-environments (e.g. gut of a fish); 2) the composition of the export calcium carbonate may contain a mixture of high Mg calcite, aragonite and calcite which makes it difficult to explicitly model calcium carbonate with just one calcium carbonate saturation state. Furthermore, recent studies show just using the calcite saturation state for calcium carbonate dissolution tends to under-estimate dissolution in the upper ocean and produce too little alkalinity in the upper ocean (e.g. Regenberg et al 2014 BGD).

Oxygen cycle: please add more details on denitrification and its changing magnitude in the different sensitivity studies does the oxygen consumption change during reminer-

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alisation in the sensitivity studies with increased C/P ratio?

We have added more discussion of the impact of our formulation of denitrification to the paper by adding to this section a discussion on the potential impact of our denitrification formulation on the simulated dissolved oxygen levels in the ocean interior (see above comments). Regards the variable C/P ratio experiment the C/O ratio is fixed – we have now clearly stated this in the model discussion. The consequence OA on the interior oxygen levels is a key future issue to address and the role of denitrification is another mechanism that would contribute to uncertainty in projection the future oxygen levels in the ocean.

The change in alkalinity due to aerobic remineralisation of org. matter is very different than due to denitrification (see Paulmier et al. Biogeosciences, 6, 923–935, 2009). Is this considered?

We now clearly state how we handle changes in alkalinity with denitrification. In the simulations denitrification has the same impact on alkalinity as aerobic respiration. Our formulation also ensures we conserved alkalinity. We cite Paulmier et al. (2009), which shows this is inconsistent with the chemistry changes associated with denitrification. From the amount of denitrification that occurs in the model, the impact of the simulated alkalinity changes in denitrification regions on the future uptake of carbon dioxide is small compare to the changes implemented in our sensitivity experiments. For example, even with a doubling of the POC export with unlimited denitrification the impact is much less than the impact of reducing the length scale of PIC remineralization.

For what reason is exp. CTRL included in the ms.? There is no discussion on CTRL. In Fig. 8 and 9 panel a and b could refer to REF 1850

We agree with this comment and consequently we have removed the CTRL experiment from the paper and replace it with REF 1850.

page 17684, line 23-25 : it is not the pH that changes by 30 % but the H⁺ concentration;

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what is a 100 % change in pH in 2100 – again here the authors must refer to H⁺

Correct, we will replace pH change with H⁺ change

page 17686, line 21 : “. . . provide a negative feedback to climate change” replace “change” by “warming”

Corrected

page 17690, line 13 , replace 2006 by 2005

Corrected

page 17690, line 25 – give value of F(o) for 2100 for completeness

We now state that by 2100 pco₂ equals 1010 and F(o) equals 1.31

page 17691, line 20 delete a in “ have a prescribed depth profiles”

Deleted

page 17693, line 27 replace “water” by “layer” in “that the suboxic water is too thick”

Replaced

page 17694, line 5 please add the mean atmospheric pCO₂ in 2100 of REF for better understanding page 17695, line 7 incomplete sentence . . .“level of saturation state that historically corals are not found “

We have added the pCO₂ value at 2100. At 2100, the REF simulation has an atmospheric CO₂ value of 1026 ppm.

Changed sentence to: which is a saturation state level that historically no living corals are observed

page 17697, line 17 add Fig 10a

Added

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page 17699, line, 4-6 “While the differences that occur by including OA impacts on biogeochemistry are small, we emphasize with the RCP8.5 scenario by 2100 there will be significant changes in ocean acidification, that will impact the marine ecosystem.” I do not understand this sentence. What do the authors mean by “biogeochemistry” and what by “marine ecosystem”?

We have clarified our comments, the text now states :

Consistent with both the small impact on carbon storage in the ocean and on global warming, the inclusion of OA impacts did not significantly alter the projected trajectory of future ocean acidification (e.g. surface aragonite state and lysocline depth). However, we emphasize that with the RCP8.5 scenario by 2100 all simulations project significant changes in ocean acidification. All polar surface waters will be under-saturated with respect to aragonite, and the maximum surface aragonite saturation state in the tropics will be less than 2.75, a value below which coral reefs are not historically found. Such changes could have profound impacts on marine ecosystems.

page 17699, line 20 infinitive “address” or “to be addressed”

Corrected

page 17702, line 13 delete “the” in “. . .summarises the how the BGC processes”

Deleted

page 17704, line 7-10 please rephrase, this is confusing

changed to: The POC and PIC produced in the photic zone, E_{POC} and E_{PIC} respectively, were exported from the photic zone and instantaneously remineralised in the ocean interior above where they were produced according to the following equations:

page 17703, A6 why has the O:P Redfield ratio changed from 138 (Matear & Hirst, 2003) to 136

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Thank you this was an error it has been changed to 136

page 17704 , line 7-8 and A 10 and A11 : please do not use POC and POC(z) for very different expressions => POC is defined as export flux of POC and POC(z) is a dimensionless function (PIC,PIC(z) resp.)

Corrected, the notation has been now been changed to reflect these changes.

page 17704 A12 and A13 : why are these equations negative? C(o) is the remineralization of POC should be added to the inorganic carbon.

We agree the sign is confusing and in the revised appendix we give the tracer equation with all the terms so it is clear how we implemented the terms discussed.

Table 1: "positive value reflecting greater climate change", replace "change" by "warming"

Changed to warming

Figure 1: could be reduced to only 1a

Figure 1b has been deleted.

Figure 4 : Why are the lines in panel b and c not given as changes relative to REF as in panel a and d. Please unify the presented information.

We have kept panels b and c as they are because we think it is useful to provide the actual land and ocean uptake rather than just the change relative to the REF simulation.

â&C

Please also note the supplement to this comment:

<http://www.biogeosciences-discuss.net/10/C9258/2014/bgd-10-C9258-2014-supplement.pdf>

Interactive comment on Biogeosciences Discuss., 10, 17683, 2013.

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