*Interactive comment on*

# A model study of warming-induced phosphorus-oxygen feedbacks in open-ocean oxygen minimum zones on millennial timescales

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**Responses to Reviewer#2**

We would like to thank the reviewer for their time and expertise. We have replied and acted on all their thoughtful and constructive comments and advice (Reviewer's comments in blue).

Using the UVic Earth System Model the authors describe a feedback loop between expanding oxygen minimum zones (OMZ's) and the availability of dissolved inorganic phosphorus (DIP). A warming climate stimulates weathering processes on land leading to an eutrophication of the oceans. The excess nutrients are taken up by marine phytoplankton which decays due to bacterial decomposition while it sinks out of the euphotic zone, thereby consuming extra oxygen. Increasing benthic oxygen depletion stimulates the redox dependent phosphorus fluxes from sediments, further elevating the concentration levels of DIP, leading to an even larger spread of OMZ's.

General comments:

The paper provides an interesting contribution to the actual discussion of the trends of oxygen concentrations under the impact of anthropogenic green house gas emissions. It discusses at the first time the very relevant issue of the threat of an accelerated expansion of OMZ's due to a warming- induced phosphorus-oxygen feedback. The paper is nicely written and I recommend it - subject to minor revisions - for publication in the journal "Earth System Dynamics".

Specific comments

The authors report an increase of ocean net primary production (ONPP) between preindustrial times and year 3005 from 43.8 Tmol P $a^{-1}$ to 65 Tmol P $a^{-1}$ even for their reference model run (REF). Usually, global warming is thought to cause a decline in chlorophyll_a concentrations and NPP owing to a strengthening of ocean stratification (see references below).

Gregg W W, Casey N W and McClain C R 2005 Recent trends in global ocean chlorophyll Geophys. Res. Lett. 32 L03606

Boyce D G, Lewis M R and Worm B 2010 Global phytoplankton decline over the past century Nature 466 591–6

The authors should provide a short discussion of how this increase in ONPP, notably in the tropical ocean of their model, can be explained.

Thank you for this very important comment. In the revised version of the manuscript we will add a discussion about processes altering ONPP under climate change projection as the correlation between temperature and ONPP is still unclear. GREGG ET AL. (2005) and BOYCE ET AL. (2010) suggest a decrease of ONPP under climate change conditions based on enhanced stratification. However, SARMIENTO ET AL. (2004) argued that the temperature sensitivity of ONPP could be the main cause for an increase in ONPP. TAUCHER & OSCHLIES (2011) also highlighted in their study with the UVic-ESCM that simulated future changes in ONPP are very sensitive to the assumed temperature effects on metabolic rates. Furthermore, KVALE ET AL. (2015) found a near-linear relationship between both parameters. Consequently, it can be assumed that the direction of ONPP change depends on the strength of temperature effect versus stratification effect. In our model the direct effect of temperature on metabolic rates overcompensates the stratification effect and thus leads to a net increase in ONPP under global warming.

The volume of OMZ’s in UVic under present day conditions is drastically underestimated in comparison with observational data ($15.8x10^6$ $km^3$ vs. $102x10^6$ $km^3$). The authors should discuss this flaw more in detail, notably if and how it could influence their conclusions. I would like to see the oxygen concentration map not only in 300 m depth (as shown in Figure 5) but also at depth of 900 m.

Because of still relatively poor data coverage and heavy reliance on inter- and extrapolation routines, the data-based estimates for the volumes of OMZs vary widely and the definitions are not yet uniform. Using 20 mmol $m^{-3}$ as threshold for OMZs and comparing our results ($WB_{2005}$ = $1.58*10^7$ $km^3$) with results of the WOA ($WOA_{2005}$=$4.12*10^5$ $km^3$), Paulmier et al. ($Paulmier_{2009}$ = 102*106 ± $15*10^6$ $km^3$) or Bianchi et al. ($Bianchi_{2012}$ = $2.28\text{-}2.78*10^6$ $km^3$) it seems that the volume of OMZs are difficult to validate. Our result is within the wide range of these estimates. Looking at the feedbacks described in the manuscript, the suboxic sediment area is more important for the benthic release feedback than the suboxic volume in the water column, which does not necessarily reach the seafloor. In our study we calculated a suboxic sediment area of $WB_{2005}$ = $3.8*10^5$ $km^2$, which fits well with data of the $WOA_{2005}$ = $2.48*10^5$ $km^2$. We will add this discussion to our revised manuscript.

We have also added an oxygen concentration map at a depth of 900 m to the supplement (see Figure S 2 and below).

Technical corrections

In the abstract the sentence ending with: " ... due to increased alkalinity, which, in turn, got there through weathering.“ sounds awkward. Please rephrase.

Corrected.

Page 6 line 19 please replace Tol P $a^{-1}$ by Tmol P $a^{-1}$

Corrected.

Figures:

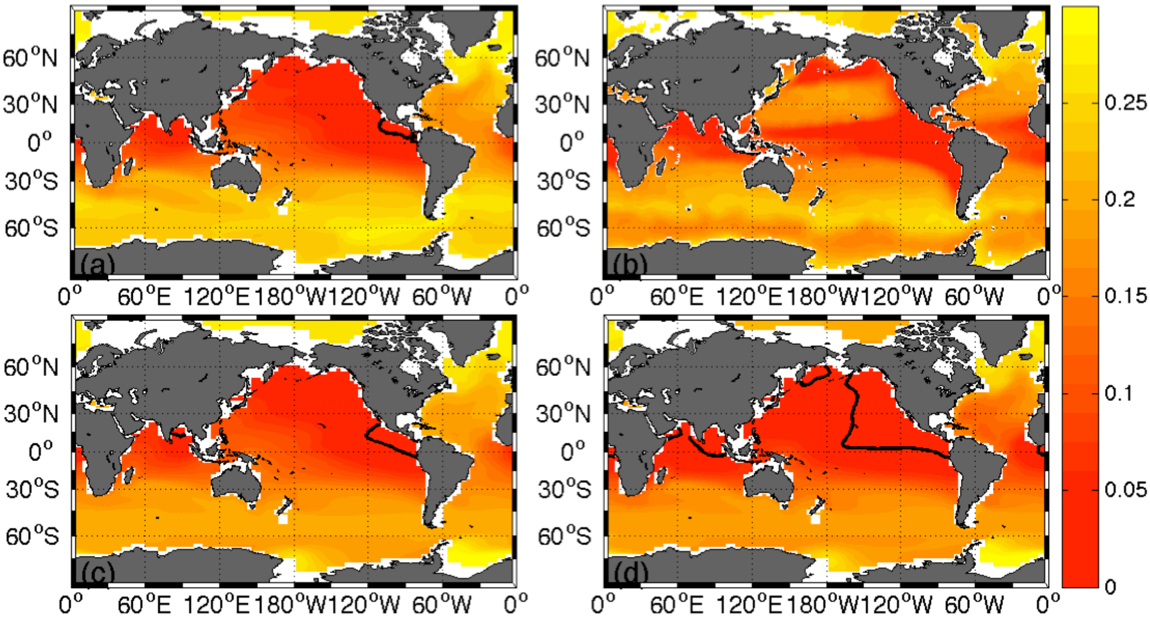


**Figure S 2: Oxygen concentration in mol $O_2$ m$^{-3}$ at 900m depth simulated by the (a) control simulation at year 1775 (representative for both REF and WB model runs in year 1775), (b) the World Ocean Atlas in 2009, (c) the control simulation at year 3005 and (d) simulation WB at year 3005. The black isoclines at 0.005 mol m$^{-3}$ highlight the oxygen minimum zones (OMZs).**