

## Interactive comment on "BPOP-v1 model: exploring the impact of changes in the biological pump on the shelf sea and ocean nutrient and redox state" by Elisa Lovecchio and Timothy M. Lenton

## Anonymous Referee #2

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This paper describes a new box model of phosphorus and oxygen cycling in the ocean and its sediments, with the oxygen in the ocean coupled to oxygen in the atmosphere through air-sea gas exchange. The model resolves shelf and open ocean environments separately. A novel aspect of the model is the separation of the particle export flux into export by small and export by large particles. This separation makes the model a potentially useful tool for investigating the impacts of the evolution of eukaryotic phytoplankton, which generally produce larger particles which remineralise deeper in the ocean on average. The transition back in geological time from an ocean dominated by

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the microbial loop (intense recycling) to an ocean with more efficient export can thus be studied.

This paper is well written and the motivation for its construction is clearly articulated in the introduction to the paper. The scientific rationale for this study is convincing and the overall design of the model is appropriate for the scientific questions that it hopes to address. However, there appear to be some deficiencies in the mechanics of the model such that it is not at all clear that the model, as presently formulated, is working correctly. This review therefore concentrates on providing comments on the details of the model and its equations, because it is premature to give detailed consideration of the model results at a time when the model needs further development.

It is stated on line 10 of page 4 that any organic matter that does not reach the sediments is instantaneously remineralised. This decision seems quite reasonable, but it is contradicted by the equations, in which organic matter is not only remineralised but is also advected and mixed. I recommend to do either one thing or the other but not both. If suspended particles are going to be mixed around in the model then they should have their own separate ordinary differential equations and state variables. Alternatively, if particle flux and remineralisation are made instantaneous, as stated in the manuscript, then there should be no mixing or advection of particulate organic matter. Whichever way it is done, the descriptions in the text need to be made consistent with the equations.

Tables 1 to 3 are very helpful. Another table needs to be added, listing the state variables in the model and stating their units. In addition, the units of all equations (the left-hand side) should also be stated, if they are not already given in the tables.

Too many of the equations in the model are dimensionally inconsistent. That is to say, the units on the left-hand side of the equation do not match the units on the right-hand side of the equation when the different terms are combined together. As an example, equation 4 on page 4 is an equation for the rate of organic matter production in units of

phosphorus. This is a flux (rate of transfer), and therefore has to be in units of Moles y-1 or mmol m-3 y-1 or similar. Because this is an ongoing flux rather than a one-off transfer, it must be expressed as a rate of transfer per unit time. However, none of the terms on the right-hand side of the equation have time anywhere in their units. The equation is formulated in such a way that it appears to be aimed at converting a fraction of the surface phosphorus concentration into production at each timestep, but the way it is actually formulated means that the rate of conversion of surface phosphate into production (organic matter) will depend on the timestep used. Shorter time steps will convert phosphate to organic matter more rapidly than longer timesteps whereas ODE equations should be timestep-independent. Equation 5 is another example, where, according to the equation, 'Coag' must have units of organic matter concentration squared per year, which makes no sense. Before resubmission, I recommend that every equation in the model is checked for dimensional (units) consistency: multiplying through the units of the terms on the right-hand side should produce the units of the terms on the left-hand side.

I did not notice a statement anywhere that conservation of mass (or, more properly, conservation of total inventories of elements) has been checked and found to be stable. This is easy to do for a box model, whether it is closed or open. Obviously for a closed model, if there are no errors in the equations, the total sum of atoms of a given element should be constant over time. For an open model, the changes in the total inventory over time should exactly match the sum of external inputs over time minus the sum of the outputs from the system over time (i.e.  $\Delta Inv= -$ ). This can easily be checked by adding two extra differential equations to the model: one to track the sum of the system and another to keep track of the sum of the losses from the system as a whole.

From the model equations, I suspect that the model does not properly conserve phosphorus and oxygen but rather there is some (unintended) cumulative creation/destruction over time. This will interfere with the ability of the model to be run

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over long timescales to address the geological timescale questions of interest. It is a little bit unclear, but it appears that the amount of phosphate removed per unit time from the surface box as particle export is not identical to the amounts of phosphate added per unit time to the deep box and sediments combined. The euphotic zone depth appears in the equation for the former but not the latter, for instance, whereas if it appears in one then it should also appear in the other. Again, checks can be made by adding extra (book-keeping) ODEs to the model. For this example, one extra ODE could tally up the cumulative export from the surface box and another extra ODE could tally up the sum of the cumulative inputs to the deep and sediment boxes. At the end of each model run, a quick numerical check can be made to ensure that the tallies are identical within the precision of numerical rounding errors.

These checks should be made before the manuscript is resubmitted, and a statement added to the manuscript to confirm that mass balance checks have been made, with satisfactory results.

Specific comments:

Key paper not cited: Reinhard CT., Planavsky NJ et al. "Evolution of the global phosphorus cycle." Nature 541, no. 7637 (2017): 386.

Equations 14 & 17: AirSea should appear the same in both

Equation 17: why does anaerobic remineralisation remove oxygen?

Line 5 of page 7: anaerobic remineralisation of organic matter also releases phosphorus (in fact oxygen-depleted sediments are stronger sources of phosphorus to the overlying water column).

Table 1: moles of air or moles of oxygen in the atmospheric box?

Table 2: the Redfield ratio of oxygen to phosphorus (-O2:P) is  $\sim$ 150:1 not 106:1 (see for instance: Anderson, L.A. and Sarmiento, J.L., 1994. Redfield ratios of remineralization determined by nutrient data analysis. Global biogeochemical cycles, 8(1),

pp.65-80; Thomas, H., 2002. Remineralization ratios of carbon, nutrients, and oxygen in the North Atlantic Ocean: A field databased assessment. Global biogeochemical cycles, 16(3)). W0 is a baseline flux (line 3 of page 4), hence cannot have units of mmol if equation 3 is to be dimensionally plausible.

Interactive comment on Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-182, 2019.

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