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Interactive comment on "Was the North Atlantic Ocean well-ventilated during Oceanic Anoxic Event 2 in the mid-Cretaceous?" *by* I. Ruvalcaba-Baroni et al.

Anonymous Referee #1

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This study presents a new biogeochemical model to assess under what conditions the spread of anoxia has developed in the proto-North Atlantic basin during OAE2. The authors look in particular at the role of phosphate inputs, oxygenation in the Pacific Ocean and ocean circulation on sustaining seafloor anoxia in the OAE2 proto-North Atlantic. The model is a multi-box model capturing the biogeochemical cycles of the C, P and O2, using a prescribed ocean circulation of the studied region which is derived from the 3D ocean model of Topper et al. (2011). The main result indicates that an input of phosphorus from rivers and/or the Pacific Ocean relative to pre-OAE2 conditions is required for the widespread development of low oxygen in the proto-North Atlantic during OAE2. The model also shows that anoxia in the proto-North Atlantic is greatly

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influenced by the oxygen concentration of Pacific bottom waters; and that ocean circulation used in the model may be too vigorous and/or that anoxia in the proto-North Atlantic was less widespread than previously thought. Finally, the authors find in their model that bottom water anoxia of the central open ocean in the proto-North Atlantic can only be reached if ocean circulation is reduced.

OAE2 and OAEs in general are fascinating subjects for understanding the state of the ocean biogeochemistry under extreme conditions. Oceanic Anoxic Events are characterised with widespread anoxia of the global ocean driving changes of the carbon cycle and ocean redox on the global scale. There are still a lot of uncertainties associated with the mechanisms responsible for the spread of anoxia during OAEs. This paper provides interesting results on the comparative effect of ocean circulation, ocean biogeochemistry and sediment interactions for the extreme OAE2-like conditions, which one of the most studied OAEs of the Cretaceous. The model is low in resolution but includes a sediment model for C burial and P regeneration and the representation of continental shelves. This is worth consideration for publication in Biogeosciences as it addresses main issue related to the Biogeochemistry and global elemental cycles, and the Earth system sciences and response to global changes and paleoclimate.

Main Points

Observations

- P13237, lines 6-8: There is actually some evidence for seafloor anoxia in the open ocean prior OAE2. DSDP site 105 shows a succession a green claystone and black shales with TOC up to 8% and high HI before OAE2 (see Kuypers, et al., 2004, Figure 4). Kuypers, M. M. M., Lourens, L. J., Rijpstra, W. I. C., Pancost, R. D., Nijenhuis, I. a., & Sinninghe Damsté, J. S. (2004). Orbital forcing of organic carbon burial in the proto-North Atlantic during oceanic anoxic event 2. Earth and Planetary Science Letters, 228, 465–482

- P13232, lines 15-16: In the abstract it is mentioned that the model results are “com-

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pared to ... proxies for photic zone euxinia and bottom water redox conditions". Though the data showing evidence of euxinia are described in section 2.2 (biogeochemistry), there is actually no comparison with the model results, which makes the statement in the abstract misleading.

Model setup

Bathymetry

P13235, line 9: The model which is used in this study, is a box model and does not capture the resolution presented in Figure 1. Instead of "we use" which leads to think that "the model uses", the authors should be more general here describing what is known about the bathymetry and paleogeography reconstruction of the Cenomanian-Turonian period based on the reconstruction of Topper et al. (2011).

Initial conditions:

The authors need to clarify how they setup the initial conditions for the their model experiments. Some of the choices for the pre-OAE2 states are not fully justified and it is not clear if the model ocean biogeochemistry is ran to steady state for the pre-OAE2 condition (see details below). This is important as the model results and the assessment of the conditions for the spread of anoxia rely on the initial conditions and the model setup.

- P13241, lines 5-6: What are the evidence that pre-OAE2 ocean concentrations of POC, SRP and O2 is similar to modern values? This choice should be justified.

- P13241, lines 10-17: More info are needed on how the rates of burial are estimated from the observed TOC content. Also the authors should be more explicit why they choose to prescribe PP for pre-OAE2 conditions but to calculate OAE2 PP in the model experiments. I think using the observed TOC content as a proxy for PP is a really good idea that could be used to constrain the model results for OAE2 as well. Is there a way to include sediment data to constrain the model PP for OAE2 as well as using seafloor

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anoxic conditions?

- P13241, lines 24-27: The distribution of nutrient and oxygen content in the intermediate and deep ocean depends not only on how fast the ocean circulation is, but also where the deep water formation sites are and how strong the biological pump is. The authors should thus provide justification for lower oxygen and higher phosphate in the Pacific by considering also the location of the deep water formation and the strength of the biological pump.

- P13242, lines 1-2: It would be good to add a short discussion about what we know about river input at the Late Cretaceous. There is probably not much out there, but at least saying that we know very little will be instructive and support better why the modern flow distribution and concentrations have been picked.

- It is not specified in the manuscript if the model is ran to steady state for pre-OAE2 conditions. This should be explicitly mentioned and justified if not ran to steady state. - The organisation of this section would gain in clarity if the description of the initial conditions is separated from the model biogeochemistry.

Model biogeochemistry

- This point relates to my previous point about primary production. It is not clear how primary production is calculated in the model for OAE2 relative to pre-OAE2 conditions.

Model results

- P13246, lines 16-17: The fact that PP reduces with OAE2 conditions due to a larger ocean volume might be an artefact of the model configuration. Does the volume of the ocean really increase during OAE2 or is the sea level rise more a result of lifting of the oceanic seafloor due to volcanic activity?

- P13249-13250: Because the Pacific deep water concentrations in oxygen and SRP have a big impact on the proto-North Atlantic anoxia, it is important to add some discussion here about why there might be less oxygen in the Pacific during OAE2 and

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where the extra deep Pacific SRP comes from. Is it related to the river input? One interesting aspect would be to think about if the P input (river+P regeneration ...) can be higher in the Pacific than in the North Atlantic Ocean during OAE2 and if that is enough to fuel the North Atlantic afterwards.

- Can the authors emphasize more on the results in relation to P regeneration? An experiment with and without this process would be interesting for instance to see the effect of P regeneration on the spread of anoxia.

- A discussion about the limitation of the lower spatial resolution would be good. This is a box model and it would be interesting to see what the authors think if their results would hold in a 3D ocean model.

- It would good also to comment on the model results in relation to previous similar modelling studies such as Flogel et al al. (2011) and Monteiro et al. (2012).

Flögel, S., Wallmann, K., & Poulsen, C. J. (2011). Simulating the biogeochemical effects of volcanic CO2 degassing on the oxygen-state of the deep ocean during the Cenomanian/Turonian Anoxic Event (OAE2). Earth and Planetary Science Letters, 305(3-4), 371–384

Monteiro, F. M., Pancost, R. D., Ridgwell, A. J., & Donnadieu, Y. (2012). Nutrients as the dominant control on the spread of anoxia and euxinia across the Cenomanian-Turonian oceanic anoxic event (OAE2): Model-data comparison. Paleoceanography, 27, PA4209. doi:10.1029/2012PA002351

Minor points

P13234, lines 5-7: Add “in the sediments”

P13236, lines 4-6: for meridional or zonal circulation?

P13237, lines 7-8: “in the southern part of the proto-North Atlantic Ocean “

P13237, lines 20-21: Can you be more specific how biomarkers show evidence of

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lower euxinia?

P13238, lines 8-10: Explain how the POC:Ptot ratio can be interpreted.

P13238, line 19: “inflow of nutrient from the Pacific”

P13240, lines 25-27: Constant to what?

P13241, lines 14-17: For which region 13% of primary production is valid?

P13257, line 1: May add quick info on what E6 experiment is here to prevent the reader to look for the info in the table

Table 1:

- Explain what you mean by “where available”

- Add description of the Box in addition to the labels W1-W7 to add clarity (Open ocean, South boundary ...)

Table 2:

- Write proto-North Atlantic differently than the source name, otherwise confusing

Figure 3:

- It would be useful to show also pre-OAE2 vertical flux of Topper et al. 2011) model.

- What are the arrows for the middle of the open ocean box?

Figure 4:

- Mention that the levels of P input relative to standard run are indicated in dashed white lines.

Figure 6:

- x and y labels are not very well positioned. Maybe move River P input slightly higher?

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- Say that the ocean circulation is reduced by x%

Interactive comment on Biogeosciences Discuss., 10, 13231, 2013.