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Biogeosciences
Discussions

Interactive comment on "Shelf erosion and submarine river canyons: implications for deep-sea oxygenation and ocean productivity during glaciation" *by* I. Tsandev et al.

I. Tsandev et al.

tsandev@geo.uu.nl

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We would like to thank Dr. Föllmi and Dr. Filippelli for their constructive comments on the manuscript. Below is a point by point reply to the questions raised during the review process.

Sincerely,

The authors

Reviewer: G. Filippelli

1. Why the P cycle shows so little variation, at least in terms of P burial on glacial

timescales?:

a) Deep marine sediments contain very little redox sensitive P, roughly 20% of total reactive P is in a redox sensitive form in deep sea sediments (Delaney, 1998), and this fraction is likely comprised largely of oxides conducive to dissolution only under truly anoxic conditions . . .

response: The article cited (Delaney, 1998) explains that the dominant reactive P flux to the sediment water interface is in the form of particulate organic P and further states that the majority of particulate organic P delivered to the sediment is regenerated back into the water column through organic matter degradation. It is well known that the preferential regeneration of P from organic matter is a redox-sensitive process (see, for example, references in Slomp and Van Cappellen (2007)). Thus the statement that only 20% of reactive P is redox sensitive, based on the iron oxide sorbed phosphorus fraction, omits an important redox sensitive P reservoir, namely organic P. Furthermore, as explained in Tsandev and Slomp (2009), the formation of authigenic phosphate is also redox sensitive, as the shallowness of the redox front in the sediment determines the likelihood of dissolved pore water phosphate re-precipitating into authigenic form in the sediment vs. diffusing out into the overlying water column. Therefore, while the redox-sensitive oxide bound/incorporated fraction of P may indeed be a small percentage of sedimentary reactive phosphate it does not encompass all the forms of sedimentary phosphate which can be affected/recycled under changing redox conditions. When the collective redox sensitivity of the three main reactive P phases is taken into account (iron bound, organic and authigenic) the net redox sensitivity of sedimentary phosphate is greater and the P recycling capacity of deep-sea sediments becomes more important.

Given the uncertainty in the quantitative response of the burial of organic and authigenic Ca-P in marine sediments to changes in redox conditions, we explicitly test three different model settings for redox dependent burial of5 organic and authigenic phosphorus: 1) no redox dependent burial of organic or authigenic P; 2) moderately redox dependent burial 3) highly redox dependent P burial. This is explained on page 884 and the findings are reported in Figure 2.

b) Simple mass balance calculations predict a transfer of a significant portion of the shelf P sink to the deep sea during glacial . . . all other factors being equal, [] a significant shift in deposition of P to the deep sea sink must occur. . . Filippelli et al. (2007), [] found that deep sea burial increases by up to 100% in high productivity areas . . . thus the physical record seems to indicate that burial corresponds to production.

response: We agree with the statement that mass balance requires that the P inventory of the decreasing shelf sink must be transferred to the open ocean. The argument of this paper is however, that this inventory is transferred to the open ocean's water column rather than the sediments due to the recycling conditions imposed by low oxygen levels. The findings of Filippelli (2007) that high production areas see an increase in P burial are very possible, as more particulate organic matter rain onto the sediment is bound to increase burial. However, looking at a total ocean average, as was done in this study, we find the net productivity of the whole ocean is not greater during glaciation. Thus on average, the deep sea is not overlain by a high productivity environment. This is because the water column has great capacity to absorb the P inventory imparted to it from the shrinking shelves and the slow down of circulation helps ensure that P is sequestered primarily in deep waters (vs. surface waters) thus does not participate in primary production. Under these circumstances, it is therefore not necessary to assume that the P previously buried on shelf sediments needs to be transferred to the deep sea sediment in its entirety; instead it is sequestered in deep sea waters.

Furthermore, based on Filippelli et al. (2007), the increased P burial at glacial terminations is not obvious (i.e. not displayed for all sites) thus it is not clear that P burial should necessarily follow that trend for the total ocean simply based on Southern Ocean results. Another study (Tamburini and Föllmi, 2009) shows that increased P burial is not always seen in the glacial period (also see comment of other referee).

We have now included a reference to the work of both Filippelli et al. (2007) and Tamburini and Follmi (2009) in our discussion of the P burial results on page 891: "Therefore the fertilization of the ocean by labile organic material from land and coast goes unrecorded in the buried P record. Our finding that P burial records do not change significantly over glacial time scales is in accordance with observations for sediments from various ocean regions published by Tamburini and Follmi (2009). In contrast, Filippelli (2007) finds increased P burial at several high production sites in the Southern Ocean. Note, however, that our box model results refer to a total ocean average where productivity was not greater during glaciation and direct comparison to specific sites is difficult as local parameters often influence behaviour. Our finding that phosphorus burial cannot be readily used as a proxy for ocean productivity or organic matter flux to the seafloor is an important one;. . ." .

c) I suggest that some aspect of the recycling efficiency assumed for P is not correct in the model, as the geologic record in the standard to which the model should compare.

response: For some of the reasons listed above, we do not believe that the geological record exclusively predicts increased P burial during glacial periods, and therefore do not agree that the geological record is at odds with our model results. It is important to stress that we look only at total ocean averages in this study and therefore direct comparison to specific sites is difficult as local parameters often influence behavior (as now included in the text: see response to previous comment). In Tsandev et al. (2008) we include some geological record discussion which corroborates our model findings for a glacial-interglacial scenario, including P burial trends based on the work of Tamburini (2001). It would of course be possible to find ocean environments where this average behavior is not observed, but outlining the heterogeneity of the sea-floor is beyond the scope of our study and beyond the capacity of the box-model.

Furthermore, we explicitly test the role of the P recycling efficiency on our model results in the study. We do this precisely because the mechanisms for P recycling are still poorly quantified and this mechanism plays a potentially important role in determining the oceanic sedimentary and water column inventory. We also highlight in the conclusions section on page 894 that “It is therefore paramount that more investigations are done on the mechanisms by which P is recycled from sediments under changing redox conditions and a better quantitative relationship be established between oxygen in overlying waters and reactive P burial.”.

Reviewer: K. Föllmi

1. Do we have direct evidence for the importance of erosional processes on freshly emerged shelves during late stages of glaciations?

response: We do indeed identify some studies recognizing the erosion of unconsolidated shelf sediment during glacial periods (Broecker, 1982; Damuth, 1977; Hay, 1994; Pollock, 1997) on lines 10-11 on page 883 of the manuscript.

We have now expanded this sentence in the revised manuscript to make more clear that this is based on observations in the sediment record:“ Erosion of unconsolidated shelf sediment during glacial periods has long been recognised and is based on observations of glacial sediments (Broecker, 1982; Damuth, 1977; Hay, 1994; Pollock, 1997).”

2. Do we have evidence for increased burial rates of refractory organic carbon of continental origin in deep-water sediments during glaciations as is postulated by the authors (page 891, line 20 onwards)?

response: Observations of elevated total OM buried in glacial sediments have been made for the Amazon Fan (Goñi, 1997) and the Gulf of Mexico (Newmann, 1973). OM accumulation was also higher during the LGM than during the mid-Holocene along the continental margins of Africa and South America (Mollenhauer et al. 2004). Buridige (2005) stipulates that this is because during sea-level low stands (glacials), in the absence of shelves, continental POM escapes remineralization (which is less efficient for terrestrial OM than marine OM) and is buried in deep-sea sediments.

We have now expanded this section in the manuscript to make more clear that our model results are supported by observations: “Therefore, most of the carbon arriving from the continent is buried in ocean sediments, which helps explain why ocean productivity can remain relatively low despite high loads of labile organic material. These model results are supported by observations of elevated organic matter burial in glacial sediments for various locations, including the Amazon fan (Goni, 1997), the Gulf of Mexico (Newmann, 1973) and the continental margins of Africa and South America (Mollenhauser et al., 2004).”

3. Which portion of the total amount of particulate organic matter transferred into the deep sea is assumed to have been remineralized in this model? a) this is not very clearly stated in the manuscript and some contradiction seems present: the authors assume that “ particulate material is assumed to mineralize (into dissolved nutrients) or get buried as proximal sediment” (page 884, line 18) without specifying the ratio between the two processes.

response: With regards to the parameterisation of remineralization in the model we refer to the original model description given in Slomp and Van Cappellen (2007) and the changes for the 13-kyr residence time version given by Tsandev et al. (2008). The former paper specifically addresses the differences in recycling efficiency of organic matter in the coastal and open ocean, and states that the recycling efficiency of P is higher in the open ocean than on the coast, i.e. the same supply of reactive P to the open ocean would yield a higher SRP release into the water column and less burial into sediments.

The cited section refers to the way nutrient loading from the continents is implemented in the original formulation of the box model (Slomp and Van Cappellen, 2007). The supply of reactive P to the proximal zone is calculated based on the sum of the soluble reactive P and the particulate reactive P arriving from the continents being solubilized into SRP (Berner and Rao, 1994; Howarth et al., 1995). Thus there is only a reactive dissolved P flux from rivers and the incoming and burial flux of particulate matter in the proximal zone are not explicitly modeled.

We have modified the text to make more clear how the reactive P flux from the continents is implemented in the original version of the model:“ However, particulate material is assumed to mineralize (into dissolved nutrients) or get buried as proximal sediment. In the original formulation of the model by Slomp and Van Cappellen (2007) these processes that occur in the proximal zone are not explicitly modeled and only a dissolved nutrient (P) flux (flux (1) in Fig. 1) from the continents is implemented.”

b) In the first part of the manuscript, one may get the impression that most particulate material is mineralized: “allows the deep-sea nutrient supply to increase significantly” (page 889, line 11); “The net effect of all the mechanisms is some ocean fertilization. Dissolved reactive P (SRP) increases in the deep-sea and correspondingly so does primary production” (page 890 – 891) . . . Later on, the authors state, however that “The variable most affected by river canyons and the particulate load from the continents and shelves is organic carbon burial in the deep-sea which increases twice as much as the dissolved phosphate reservoir. Therefore, most of the carbon arriving from the continent is buried in ocean sediments, which helps explain why ocean productivity can remain relatively low despite high loads of labile organic material” (page 891, line 20 onwards).

response: Indeed we observe that as the nutrients from the continents and the exposed shelf are delivered directly to the deep sea there is an increase in deep water nutrient inventory and thus some ocean fertilization (page 889 – 891).

However, we also observe that this increase is not as high as would be expected because much of the material sediments to the deep sea floor thus quenching the effect of increased nutrient supply (page 891, line 22-24). And, as mentioned elsewhere in the manuscript (page 891, lines 5-8), the ocean fertilization which is observed in fact only brings primary production levels close to interglacial values since production is generally lower during glaciations due to reduced ocean mixing.

Thus the two observations are not contradictory but merely an assessment of the degree to which shelf nutrients and their rerouting affect the open ocean’s fertility.

4. The authors assume that the ocean productivity rates were generally lower during glacials, thereby using the results of an earlier model . . . the authors may devote a paragraph or two in discussing why they keep overall glacial ocean productivity rates on the same low level as was identified in the 2008 publication.

response: We do not assume ocean productivity to be lower during glacials nor do we impose the results of our earlier study in Tsandev et al. (2008) on the current work. Low ocean productivity during glacial time is a result of the model (a system response), not an imposed parameter. Therefore, we make no assumptions about productivity but allow it to vary with the model’s glacial forcings. While it is true that our earlier work on glacial-interglacial transitions also finds ocean productivity to be generally lower during glaciations, this result is not imposed on the current study. The productivity of the ocean responds to the imposed forcings in both studies and in both cases we find productivity to be lower during glaciations relative to the interglacial periods.

We have revised the manuscript to explicitly state that we do not assume ocean productivity values but allow them to vary dynamically with changing parameters. After the sentence on line 26 -28 on page 885 “We represent these end member situations, though in reality the global coast-line may have been comprised of a combination of such settings.” we have added the following sentence: ”The 6 environmental variables outlined are therefore the only parameters imposed on the box model. All other variables are allowed to vary dynamically and are considered as part of the system’s response.”

5. . . . changes in continental weathering and corresponding changes in nutrient fluxes from the continent to the ocean are not considered.

response: As part of the environmental forcings applied to the global ocean in this study we do consider the change in river discharge of reactive P from the continents to the ocean. In our earlier study on glacial-interglacial transitions (Tsandev et al., 2008) we researched how continental runoff likely changed during glaciations (10% decrease in riverine reactive P supply) and incorporated that into a glacial perturbation scenario. In the current study, we start from the same glacial perturbation scenario as in Tsandev et al. (2008) and augment that with shelf erosion and river re-routing fluxes. Therefore we do indeed consider changes in continental weathering and corresponding changes in nutrient fluxes to the ocean as part of our overall glaciation scenario.

To clarify this point in the manuscript we have added some text which clearly identifies all the glacial forcing factors applied to our global ocean model. We have replaced the sentence “The shelf nutrient and river canyon mechanisms discussed earlier are then applied to the equilibrated model as illustrated in Fig. 1.” (p. 885, line 15-16) with “The shelf nutrient loading and river canyon rerouting (illustrated in Figure 1) were then added to the other glacial forcings outlined above; for a total of 6 environmental parameters perturbed during a glacial transition: ocean mixing, continental nutrient flux, surface water temperature, sea level, shelf erosion and river canyon rerouting comprised the new augmented glacial perturbation scenario.”

References:

Berner, R. A. and Rao, J. L.: Phosphorus in sediments of the Amazon River and estuary: implications for the global flux of phosphorus to the sea, Geochim. Cosmochim. Acta, 58, 2333–2340, 1994.

Broecker, W. S.: Glacial to interglacial changes in ocean chemistry, Prog. Oceanogr., 11, 151–197, 1982.

Burdige, D. J.: Burial of terrestrial organic matter in marine sediments: A re-assessment, Global Biogeochem Cy., 19(4), GB4011, 2005.

Damuth, J. E.: Late Quaternary sedimentation in the western equatorial Atlantic, Geol. Soc. Am. Bull., 88, 695–710, 1977.

Delaney, M. L.: Phosphorus accumulation in marine sediments and the oceanic phosphorus cycle, Global Biogeochemical Cycles, 12, 563 – 572, 1998.

Filippelli, G. M., Latimer J.C., Murray, R. W., and Flores J.A.: Productivity records from the Southern Ocean and the equatorial Pacific Ocean: Testing the glacial Shelf-Nutrient Hypothesis, Deep Sea Res II, 54, 2443 – 2452, 2007.

Goñi, M. A.: Records of terrestrial organic matter composition in Amazon Fan sediments, in Proceedings of the Ocean Drilling Program, Scientific Results, vol. 155, edited by R. D. Flood, D. J. W. Piper, and L. C. Peterson, pp. 519–530, Ocean Drill. Program, College Station, Texas, 1997.

Hay, W.: Pleistocene-Holocene fluxes are not the Earth’s norm, in: Material fluxes on the surface of the Earth, National Academy Press, Washington, D. C., 15–27, 1994.

Howarth, R. W., Jensen, H. S., Marino, R., and Postma, H.: Transport to and processing of P in near-shore and oceanic waters, in: Phosphorus in the global environment, edited by: Tiessen, H., Transfers, cycles and Management, SCOPE 54, Wiley, 323–345, 1995.

Mollenhauer, G., Schneider, R.R., Jennerjahn, T., Muller, P.J., Wefer, G.: Organic carbon accumulation in the South Atlantic Ocean: its modem, mid-Holocene and last glacial distribution, Global and Planet. Ch., 40(3-4), 249-266, 2004.

Newman, J. W., P. L. Parker, and E. W. Behrens: Organic carbon ratios in Quaternary cores from the Gulf of Mexico, Geochim. Cosmochim. Acta, 37, 225–238, 1973.

Pollock, D. E.: The role of diatoms, dissolved silicate and Antarctic glacial/interglacial climatic change: A hypothesis, Global Planet. Change, 14(3–4), 113–125, 1997.

Slomp, C. P. and Van Cappellen, P.: The global marine phosphorus cycle: sensitivity to oceanic circulation, Biogeosciences, 4, 155–171, 2007.

Tamburini, F. and Föllmi, K. B: Phosphorus burial in the ocean over glacial-interglacial time scales, Biogeosciences 5, 5133-5162, 2008.

Tamburini, F.: Phosphorus in marine sediments during the past 150000 years: Exploring relationships between continental weathering, productivity, and climate, Ph.D. thesis, 217 pp., Univ. de Neuchatel, Neuchatel, France, 2001.

Tsandev, I., Slomp, C. P., and Van Cappellen, P.: Glacial-interglacial variations in marine phosphorus cycling: Implications for ocean productivity, Global Biogeochem. Cy., 22(4), GB4004, doi:10.1029/2007GB003054, 2008.

Tsandev, I. and Slomp, C. P.: Modeling phosphorus cycling and carbon burial during Cretaceous Oceanic Anoxic Events, Earth Planet. Sc. Lett., 286, 71–79, doi:10.1016/j.epsl.2009.06.016, 2009.

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