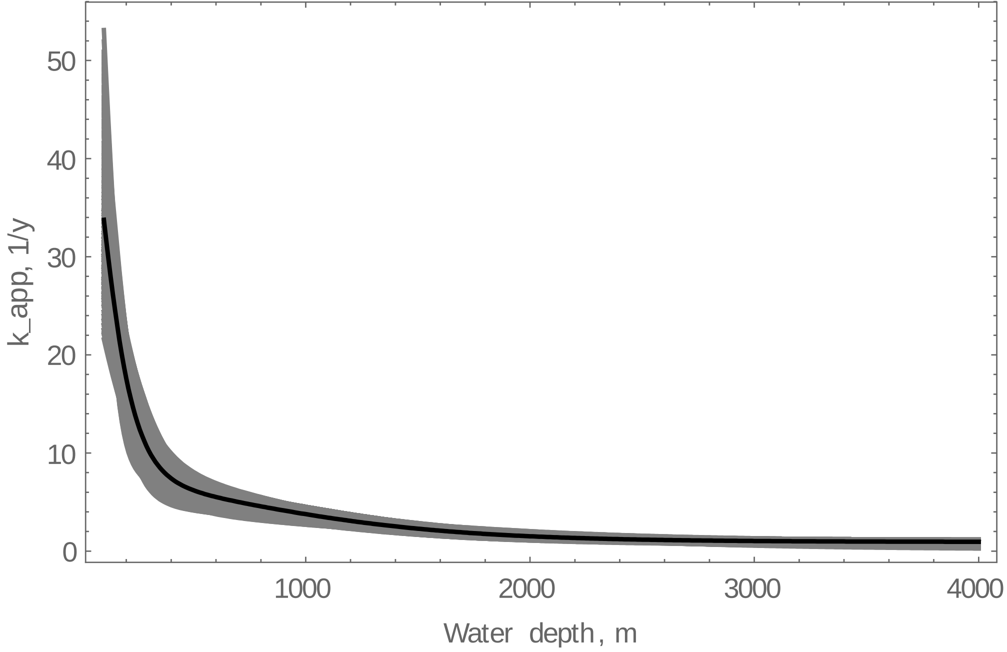
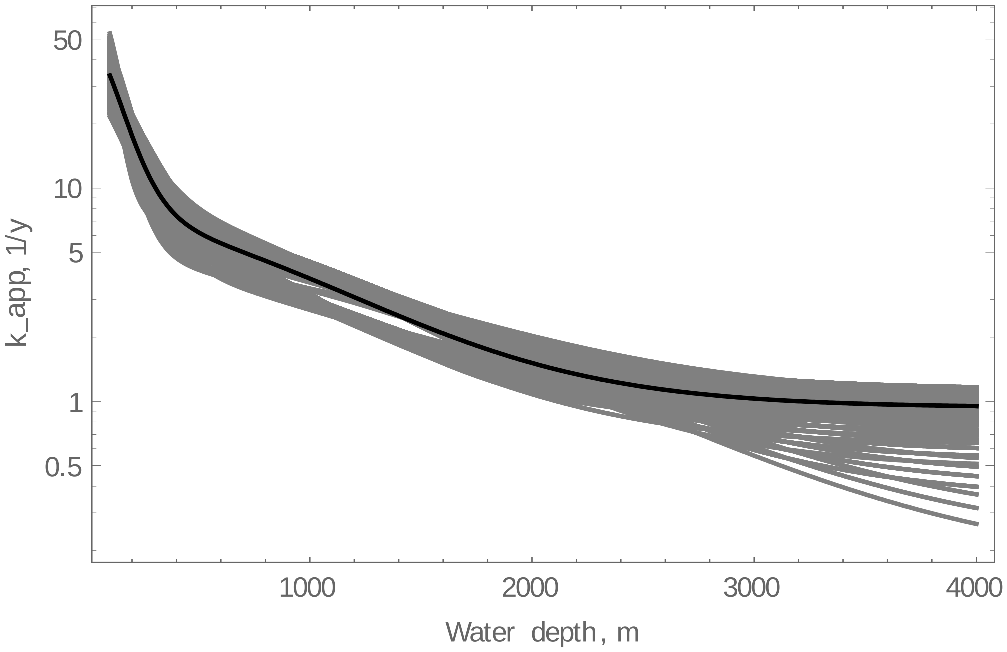
Reviewer 3

It is unclear how sensitive the results are to the value of b (the paper makes the case that b=0.86 matches the data but it doesn't address the sensitivity to this parameter and papers such as the one cited by Buesseler et al. illustrate the wide range of values for b) - the burial efficiency relationship reported in Dunne et al. is used to estimate the proportion of the refractory POC pool and to constrain the rate constants. This estimate of the CBE is applied at 10 cm, presumably well above the depth at which mineralization becomes negligible (which clashes with the choice of no gradient lower boundary conditions at 10cm for POC and mineralization products). Furthermore, the CBE estimate of Dunne et al. is off by about 80% (the average of (estimated-true burial eff.)/true burial efficiency for the data shown in Figure 2 of Dunne et al.). A central benefit of the work presented here relates to its applicability across a wide range of oceanic conditions. I suggest that the authors quantify and show the impact of the considerable uncertainties in the fundamental input variables b and CBE.

We thank the review for his/her constructive comments on our manuscript. The sensitivity of the apparent reactivity (k_{app}) to a ±20 % change in *b* is shown below on linear and log scales. More negative values of *b* lead to a greater attenuation (loss) of POC with water depth:





This difference in apparent reactivity leads to minor (within 50% error) changes in flux, thus for station 1 from Figure 4 (114 m) the flux of oxygen calculated with *b* = –0.69 differs from the one calculated with *b* = –1.032 by 14% and nitrate by 13.5%; and for station 5 (3073 m) by 0.02% and 0.13% respectively.

With regard to the CBE algorithm, we recognize that the Dunne relationship is not perfect at the global scale. However, it is broadly consistent with global modeling studies (see Fig. 1 in Kriest and Oschlies, 2013) as well as data evaluations of CBE versus rain rate by Flögel et al. (2011) and serves as a basis for correcting the POC rain rate for C burial. We agree that defining the CBE horizon is somewhat ambiguous, but we refer to the point made to Reviewer #1 and #2 that the bulk of OM is mineralized in surface sediments. Improvements could be easily made as and when new data becomes available.

Kriest, I. and Oschlies, A. (2013) Swept under the carpet: organic matter burial decreases global ocean biogeochemical model sensitivity to remineralization length scale. *Biogeosciences*, 10, 8401-8422. *doi* 10.5194/bg-10-8401-2013.

As the authors state, the choice of two particle size classes with distinct sinking velocities is a tremendous simplification. Furthermore, the assumption is then made that the ratio of the rate constants for small and large particles of the same POC pool *i* match the ratio of the settling velocities (equation 4). I simply don’t understand the rationale for this particular choice (e.g., if the POC was the same in the small and large fraction of pool i, then one may expect the rate constants to be the same, resulting in a more pronounced removal of slow settling small particles, which is not what is implemented here). If there is compelling evidence for such a scaling of rate constants, then this needs to be presented, or the relevant literature needs to be cited. Else, the consequences of such an assumption need to be quantified, or the assumption revisited.

As the reviewer correctly noted, very simple representation of sinking particles (their reactivity and sinking speed) was used. The rationale for this particular choice is based on i) the assumption that small particles are settling from the very top of the water column and not originated from disintegrated large particles (aggregation/disaggregation is poorly constrained and thus not considered here) and on ii) observations proving that the contribution of POC bound in the fine fraction to the total POC concentration in the water column does not decrease with water depth (Aumont 2017, Fig. 5). To maintain this constant contribution, POC in small particles (POC_{small}) must be less reactive than POC in large particles (POC_{large}) because the reduced sinking speed of small particles would otherwise induce a systematic decrease in the POC_{small}/ POC_{large} ratio with water depth.

The rate of POC degradation is said to be continuous between sediment and water (page 5, line 14). This presumably is not true for volumetric rates, as POC concentrations change drastically at this interface. On line 20, it then says that k_{app} is continuous across the sediment-water interface. However, first order rate constants intrinsically reflect the abundance and activity of microbes involved in the breakdown of organic matter, which surely varies across this interface. What data is there to support this approach?

Here we repeat the answer given to Reviewer #2. It is true that the specific nature of sedimentary environments is vastly different from the bottom water, and other uncertainties were listed at the beginning of section 4.2. However, the reactivity of the bulk material does appear to be broadly consistent with the water column reactivity (Fig. 3 to 6) and it is likely that the abundance and activity of microbes is largely controlled by the flux and the reactivity of organic matter raining to the seafloor. We are still at a very early stage of understanding the relationship between the continuity of POC reactivity at the sediment water interface, not least because the reactivity of material in the lower water column is probably even less well understood than in the sediments. The assumptions made provide a basis for further research on this topic.

The 3G model is parameterized to essentially match the OC mineralization integrated over the top 10 cm (input from Martin, burial from Dunne), while parameters were optimized in the power function approach of Stolpovsky et al. 2015 to match the fluxes. Hence, it is not a big surprise that the O2 fluxes match closely, though it is not immediately evident what motivates the use of a 3G approach over the continuum approach the authors presented previously. And what about the 2G model? Can the reason it performs worse be linked to the parameterization (eq. 21; what is mk? summation over k?), in which the less reactive fraction of the 2G model is set to be equal to the refractory pool in the 3G model?

Reviewer #1 and #2 made the same comment concerning the advantages of the 3G versus continuum model. The major advantage of G-type models is that they can be applied to non-steady state situations where temporal storage of POC and solutes in the sediment may be important. POC degradation in the continuum model is a function of RRPOC and therefore RPOC over the whole sediment profile responds instantaneously to changes in RRPOC. We omitted this information from the final version of the paper (for length consideration) but now recognize its relevance and will include it in the revised manuscript.

For the 2G model, the less reactive fraction was set to be equal to the refractory pool in the 3G model in order to maintain consistency with the global CBEs. The reason why the 2G model perform worse than the 3G one is that the highly reactive fraction that is degraded over the top millimeter(s) of sediments is lacking. *mk* is in fact k_{app}; a typo that will be corrected.

Benthic exchange fluxes reported in Figure 4 seem to be similar for profiles with similar gradients at the sediment-water interface but differ vastly below that (some have subsurface maxima). Are irrigation fluxes not important for the overall exchange, even at the shallower stations?

Indeed, bioirrigation plays an important role in solutes transport especially at the shallower stations. However, the subsurface maxima do not play important role as POC degradation rate at that depth is very low compared to the one at sediment-water interface. The benthic flux is mostly driven by oxidation of labile POC fraction within the top millimeter(s) of sediments whereas deeper down the electron acceptors are mostly reduced with the reactive POC.

Equation (2): what does w_j represent?

w_j represents the sinking speed, and will be clarified in the manuscript.