Reply to the Referee #1

We would like to thank the reviewer for the thoughtful and constructive comments.

<< About the major comments >>

Q1a: Large differences in sediment contents between two experiments

The paper shows the diagnosed sediment contents of opal and organic carbon are very different in the coupled (EXCPL) and uncoupled (EXOGR) ocean-sediment system (Figs. 5a,c and 6b--c). Why is the difference so large between the two experiments? I expect that the sediment contents should be relatively similar in two experiments, as shown by the relative similarity in CaCO3 sediments (Figs. 2a and 6a), because the sedimentation feedback seems to be small in the broad ocean expect the North Atlantic (Fig 7).

A1a: Burial ratios (the ratios of burial amount to the flux to the ocean bottom) of OM and opal calculated by MEDUSA in EXCPL are remarkably different from those given by the highly simplified parameterization in the original CESM (Fig. 1). In particular, the ratios in EXCPL are significantly lower in low-flux locations, which means that the difference will be larger in the open ocean. Depending on whether OM or opal forms the major part of the total particulate flux (e.g., opal in the Southern Ocean), the difference in burial ratios will lead to substantial discrepancies in terms of the weight fraction. In this regard, we will add two figures and an associated discussion to Section 3.2 in the manuscript.

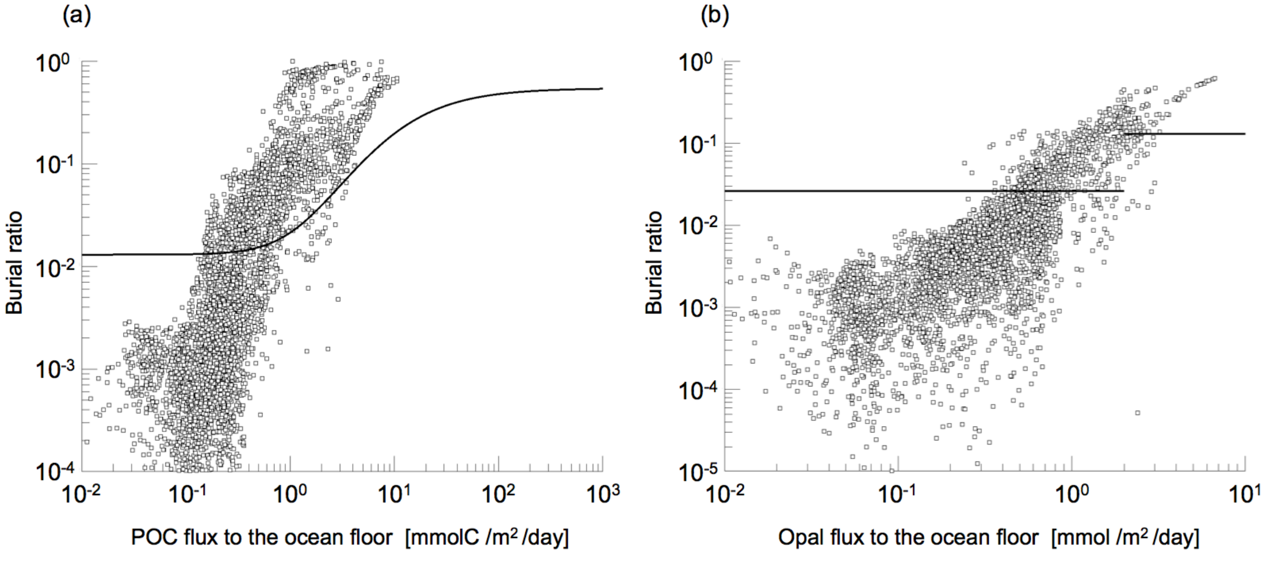

Figure 1. Sediment burial ratios versus the particulate flux to the ocean floor for (a) OC and (b) opal. The dots show the ratio at each grid cell obtained in the last MEDUSA run for EXCPL. The solid lines indicate those given by the parameterized models in the original CESM(BEC) based on Dunne et al. (2007) for OC and Ragueneau et al. (2000) for opal.

Q1b: I wonder whether the total concentrations of silicate and nutrient are conserved in EXCPL. It may be helpful to provide a table that presents the global integrated deposition fluxes of opal, CaCO3 and OC and the global integrated concentrations of DIC, ALK, SiO3 or PO4 in two experiments.

A1b: We will add the following two tables including those globally integrated quantities to Section 3.2 to show that the two experiments are comparable in terms of globally-integrated quantities except for the burial flux.

Table 1. Globally-integrated annual mean deposition flux of particulate matter to the sediment and their burial flux (in parentheses) at the end of EXCPL and EXORG.

	EXCPL	EXORG
POC (GtC/y)	0.57 (0.091)	0.51 (0.12)
$CaCO_3$ (GtC/y)	0.39 (0.082)	0.38 (0.14)
Opal (Tmol/y)	46 (0.72)	45 (3.4)

Table 2. Total inventories in the global ocean of DIC, ALK, and PO_4 in EXCPL and EXORG. Values averaged over the last CESM run (10 surface years) are shown.

	EXCPL	EXORG
DIC (GtC)	3.660×10^4	3.657×10^4
ALK (Peq)	3.201×10^3	3.201×10^3
PO_4 (Pmol)	2.948	2.923

Q1c: I also recommend to add the description how the model treats the riverine inflow and sediment outflow fluxes in Section 2.2. That information is key to understand the experimental design of EXCPL. For example, we can understand whether EXCPL is designed for an open or closed system in the atmosphere, ocean and sediment reservoirs.

A1c: Both EXCPL and EXORG are designed as an "open" system. Both experiments have a common riverine-inflow field corresponding to the modern nutrient exports based on Seitzinger et al. (2010) and

Mayorga et al. (2010). On the other hand, the net flux of matter through the lower boundary of the ocean domain is calculated by MEDUSA in EXCPL and by the parameterized burial treatment of BEC in EXORG. We will add a description regarding the open-system configuration to Section 2.1 rather than 2.2 because it is a common framework to EXCPL and EXORG.

Q2: The impact of all dissolution of CaCO3 below 3300m depth

The BEC model is coordinated by all dissolution of particulate CaCO3 in the ocean below 3300 m depth, which probably causes less calcite preservation particularly in the Pacific and Indian Ocean. It would be helpful to discuss the impact of this "fixed lysocline depth" setting to the model performance and behaviors in more details. Does this setting affect excess accumulation of organic matter in the equatorial Pacific? I suspect that less CaCO3 burial maybe cause slower sedimentation rate, which may expose OC at the upper sediments on longer timescale and thus accelerate the decomposition of OC in sediments.

A2:

The difference between the prescribed fixed-depth of $CaCO_3$ dissolution and the actual depth of lysocline is larger in the Atlantic Ocean than in the Pacific and Indian Oceans. In EXORG, therefore, the influence of the fixed depth on the $CaCO_3$ weight fraction is more noticeable in the Atlantic when compared to the observation-based data, as mentioned in the manuscript (p.7, l.32)

As to the excess accumulation of OM in the equatorial Pacific in EXORG, we find that the effect of the simplified OM dissolution scheme dominates over the reduced burial of $CaCO_3$ (see our answer A1a to question Q1a) because such an excess accumulation of OM is not observed in EXCPL where there is hardly any $CaCO_3$ burial in that region as in EXORG.

However, the reviewer's argument applies to EXCPL and explains the underestimation of the OC weight fraction in the eastern South Pacific (around 110°W, 25°S) and the correlation between the patterns in the OC and $CaCO_3$ weight fractions in that region. We will add the following sentence to the 6th paragraph of Section 3.1: “In some regions, for example in the eastern South Pacific (around 110°W, 25°S), the simulated OC weight fraction is lower than the observed OC fraction. This correlates with the underestimation of the calcite weight fraction, which implies that less calcite burial may cause a slower sedimentation rate, leading to a longer exposure of OC to the pore water in the upper sediment and thus facilitating its respiration.”

Q3: What is the difference of sediment coupling with the state-of-the-art earth system model with previous studies with intermediate complexity models? I think it is helpful to discuss the advantage using the state-of-the-art earth system model. What is a large difference in simulations between CESM-MESUDA and for example, GENIE? What does this development help our better understanding?

A3:
We consider that the advantage of using state-of-the-art comprehensive models over using Earth system models of intermediate complexity (EMICs) is (at least) threefold:

First, EMICs typically use more empirical parameterizations than process-based representations of physical (and other) phenomena in their model components to realize a more efficient computation. For many EMICs, this applies in particular to the atmosphere component. Such model representations cannot properly capture the feedback from variations in model input if it is beyond the range of the underlying empirical relationship. From this viewpoint, comprehensive models would be more advantageous to simulate the response of the atmosphere or the ocean to the variation in the sediment component in a long-term transient "paleo" simulation that explores climate states very different from the present-day.

Second, the ocean component of some EMICs is of lower dimension and/or coarser spatial resolution. For example, the ocean component of CLIMBER-2 is based on zonally-averaged equations for three ocean basins with a meridional resolution of 5°, while the ocean component of cGENIE is three-dimensional but of a similar coarse horizontal resolution and using simplified ("frictional") physics. Using primitive equations in the atmosphere and ocean combined with a higher spatial resolution is a clear advantage in comparing model results to local observations because it reduces the uncertainty introduced by the mapping, averaging or interpolation of either model output or data.

Third, as an indirect merit, it enables us to evaluate the performance of comprehensive CMIP5-level climate models with respect to additional observational data sets from a new archive (i.e., ocean sediments), which is a significant benefit, considering that the assessment of model performance is a crucial task in the global-climate-projection context (e.g., Flato et al., 2013).

We will add a similar discussion to Section 4 in the manuscript.

<< About the minor comments >>
Q4: Table1: This table is very good and informative to provide the model's capability from the model-data comparison. It may be also helpful to add the deposition and burial fluxes, as described above in my comment (1).

A4: We will add the burial fluxes to the table mentioned in A1b above.

Q5: Page 3 L31--33: This description is unclear. Does it mean that all burial fluxes return to the bottom water as dissolved properties? Please rewrite the description.

A5: No, the burial fluxes do not return to the bottom water as dissolved properties. The description is about the stack layers below the top reactive layer storing old deposits that are not reactive any longer in the model. The thickness of the reactive layer is always kept at 10 cm, and in case the net budget of solid material reduces the thickness to below 10 cm, some old material from the stack layers will be "revived" to compensate for the loss in the reactive layer and to keep the 10-cm thickness. We will rephrase the relevant description to clarify that.

Q6: Page 8 L5--6: This sentence is also unclear. Do you want to say that the ocean-sediment coupling is important to simulate the water properties? Please rephrase it to present your argument more clearly.

A6: We will rephrase the sentence as follows: “Such large model errors would complicate the model–data comparison for the upper sediment composition. Therefore, the coupling of a more reliable sediment model like MEDUSA to CESM is essential for a more straightforward comparison between model results and observations.”
(We assumed the reviewer had referred to P.8, L4--5)

Q7: Page 9 Line29: "over large areas" maybe mislead readers. In this paper, the sediment feedback is apparent in some regions, such as along the east coast of the equatorial Pacific, along the west coast of the Pacific, in the Arctic and Hudson Bay. Rather, the large difference in d13C in the North Atlantic arises from the model's bias in relation to AMOC or ocean mixing variability, which should be excluded from the sediment contributions to the bottom-water properties.

A7: We will delete the phrase “over large areas” from the sentence and will modify it as follows. “In this study, the MEDUSA coupling produces $\delta^{13}C_{DIC}$ differences up to 0.2‰ compared to the original BEC method through direct influence from the sediment and through feedbacks from the ocean physics leading to the water mass displacement as well.”

Q8: Page 10 L29: provides -> provide

A8: It will be corrected.