

## ***Interactive comment on “<sup>231</sup>Pa and <sup>230</sup>Th in the ocean model of the Community Earth System Model (CESM1.3)” by Sifan Gu and Zhengyu Liu***

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We thank the reviewer for his/her time for constructing the comments.

In the following, we have addressed all comments, with the original review text underlined in italics and red.

“The main point of criticism I have here is their comparison to observational data, which I find is too nebulous and not supported by newer data. There is an obvious lack of consideration of recent papers. More recent studies would provide a much better basis for comparison and reality-checks of the model. The references for the observational data given in the MS are quite old holding mostly data obtained by the noisy counting-method resulting in large analytical uncertainties. Instead the model should be cross-

C1

checked with newer sedimentary and water column data. I don't see much benefit from comparing “biotic” against “abiotic” <sup>231</sup>Pa and <sup>230</sup>Th particle-fluxes (Fig. 2), as long as the absolute values have not been tested against new observational data. The authors urgently need to test the output of the model versus recent sedimentary data (e.g. (Böhm et al., 2015; Bradtmiller et al., 2014; Burckel et al., 2016; Henry et al., 2016; Hoffmann et al., 2013; Jonkers et al., 2015; Lippold et al., 2011; Lippold et al., 2016; Lippold et al., 2012; Luo et al., 2015; Negre et al., 2010; Roberts et al., 2014; Rutgers van der Loeff et al., 2016)), water data (e.g. (Deng et al., 2014; Hayes et al., 2014; Hayes et al., 2013; Hayes et al., 2015a; Hayes et al., 2015b; Kretschmer et al., 2011)) and most importantly other modelling studies (e.g. (Dutay et al., 2015; Lippold et al., 2011; Rempfer et al., 2017)).”

Thanks for pointing recent available observations. We have updated our analysis with more complete data. The references for observations are listed in Table 3, which includes all the references used for model data comparison in Rempfer et al., (2017). Unfortunately, there is no intercalibrated dataset available.

In the revised manuscript, we replace the zonal mean figure with the GEOTRACE transects (Fig. 2 and 3), which seems to be more appropriate for direct model-data comparison. These two GEOTRACES transects are also shown in Rempfer et al. 2017. Our modelling scheme is essentially the same as Siddall et al., (2005) and the experiment Re3d in Rempfer et al., (2017), which does not include boundary scavenging and sediment resuspensions. Our results along the two GEOTRACES transects are similar to the Re3d in Rempfer et al., (2017). For dissolved <sup>231</sup>Pa and <sup>230</sup>Th, our model can simulate the right magnitude as in observations (Fig. 2 and 3) except in the abyssal. The larger values in the abyssal compared with observations is because we do not include boundary scavenging and sediment resuspensions in our model. As shown in Rempfer et al., (2017), if boundary scavenging and sediment resuspensions are added, the model performance in simulating the dissolved <sup>231</sup>Pa and <sup>230</sup>Th will be much improved (their Fig. 2 and 3 top and bottom row). This is discussed in the

C2

revised manuscript (Line 255-263).

Rempfer et al., (2017) suggests that boundary scavenging and sediment resuspensions are unimportant for particulate  $^{231}\text{Pa}/^{230}\text{Th}$ . Our particulate  $^{231}\text{Pa}/^{230}\text{Th}$  (Fig. 2c and Fig. 3c) in the Atlantic show similar results as Rempfer et al., (2017). Most importantly, our sediment  $^{231}\text{Pa}/^{230}\text{Th}$  compares well with available observations (Fig. 4): low values in North Atlantic and high values in the Southern Ocean; high values in high productivity regions (Line 281-296). In addition, we show side by side comparison between “abiotic” and “biotic” version in revised Fig. 2, 3 and 4 to directly show that the two versions give identical results in CTRL (Line 237-246). Although these two are similar in CTRL, they do vary differently in the HOSING experiment. Therefore, we find it may be clearer for readers to directly see the comparison between the two version in both CTRL and HOSING.

“I find the terms “biotic  $^{231}\text{Pa}/^{230}\text{Th}$ ” and “abiotic  $^{231}\text{Pa}/^{230}\text{Th}$ ” quite confusing. Since there is no biotic  $^{231}\text{Pa}$  and  $^{230}\text{Th}$  these terms should be used only to distinguish between the usage of particle fields in the model.”

Thanks for pointing out this inappropriate usage. We have renamed the version which is coupled to the ecosystem model as “p-coupled” and the version which uses prescribed particle fields as “p-fixed” as suggested.

“Given that (Rempfer et al., 2017) recently provided insights into an upgraded approach by (Siddall et al., 2005) and (Siddall et al., 2007), including a bio-geochemical-module in the model, I do not see much advance provided by the here presented MS. I did not find a reference to (Rempfer et al., 2017), maybe because this is a very recent publication, but I don’t think the authors should neglect this paper in a new version.”

Thanks for referring to Rempfer et al., (2017). We add comparison with their results in the revised manuscript. In CTRL, our water column dissolved  $^{231}\text{Pa}$  and  $^{230}\text{Th}$  is similar as Re3d in Rempfer et al., (2017) which do not include boundary scavenging and sediment resuspensions. The particulate  $^{231}\text{Pa}/^{230}\text{Th}$  in the Atlantic is also simi-

C3

lar to Rempfer et al., (2017). In the hosing experiment, our model produces the similar spatial dependence of particulate  $^{231}\text{Pa}/^{230}\text{Th}$  in the Atlantic (our Fig. 12 and their Fig.8). The text referring to Rempfer et al., 2017 are in line 86-89, 202-207, 255-263, 423-444.

“Although I welcome very much the provision of the Fortran code the reader is left alone with the comparison between model and observations (Fig.3) without sufficient information about the values, observational error bars and references. The color code in Fig. 3 may hold some information about the water depths, but since (already) older publications demandingly have shown, that the correlation of  $^{231}\text{Pa}/^{230}\text{Th}$  with water-depth seems to be a manifested pattern of AMOC in the  $^{231}\text{Pa}/^{230}\text{Th}$  distribution (Burckel et al., 2016; Gherardi et al., 2009; Gherardi et al., 2010; Hoffmann et al., 2013; Luo et al., 2010; Luo et al., 2015) this feature is required to be reproduced by a meaningful model. But I’m not able to see this from the provided figures.”

Thanks for pointing out the important depth dependence of  $^{231}\text{Pa}/^{230}\text{Th}$ . In our revised Fig. 2 and 3, particulate  $^{231}\text{Pa}/^{230}\text{Th}$  in the Atlantic transects are shown.  $^{231}\text{Pa}/^{230}\text{Th}$  increases with depth as suggested by previous studies (Line 277-280). We also show North Atlantic average particulate  $^{231}\text{Pa}/^{230}\text{Th}$  profile in Fig.12. We further discuss this depth dependence in the HOSING experiment (Line 423-444). Our results supports the argument that this depth dependence is caused by the lateral transport of  $^{231}\text{Pa}$  by ocean circulation (Gherardi et al., 2009; Lippold et al., 2011, 2012; Luo et al., 2010).

“By the way, the diagrams are way too detailed (in terms of graphic resolution) demanding a lot of computer resources and slowing down even my reasonably new computer just by scrolling down.”

Sorry the resolution of figure is too large. We have compress this figure in the revised manuscript.

“The table for the K values (Table 1) needs to be accompanied by references, because

C4

these values vary within a wide range according to the studies by (Chase et al., 2002, 2004; Hayes et al., 2013; Hayes et al., 2015b; Kretschmer et al., 2011; Kretschmer et al., 2008; Luo et al., 1999, 2003, 2004) and others. I think, a well selected digest of values can be found at the new study by (Rempfer et al., 2017)."

The K values used in our control experiment are the same as what used in Siddall et al., (2005), which is from Chase et al., (2002). We have added these references in the Table 2 (originally Table 1) caption in the revised manuscript.

"Besides the shortcomings of the MS regarding the observational data, I also find patterns in the model output, which are not observed in reality to my knowledge. E.g. the appearance of a high opal/POC field in the NW-Atlantic. Further, I see an obvious mismatch of model and observations in Fig. 5, which is not explained."

The particle fields are produced by the marine ecosystem module in CESM. This ecosystem module is have been discussed in many previous studies (e.g. Doney et al., 2009; Long et al., 2013; Moore et al., 2002, 2004; Moore and Braucher, 2008) (Line 122-123). The general pattern globally is similar to the satellite observations (Sarmiento and Gruber 2006). For example, low production in subtropical gyre; high opal in the Southern Ocean. Regionally, the mismatch can be caused by many different aspects, such as modelling scheme, model resolution and biases in boundary conditions. How to improve the performance of the marine ecosystem module is beyond the scope this study.

The Fig. 6 (originally Fig. 5) shows the results of sensitivity experiments. The discussion is in line 303-310. The mismatch of model and observation is reasonable since we change the partition coefficients K in these two experiments. Take EXP\_1 for example, the simulated dissolved  $^{231}\text{Pa}$  and  $^{230}\text{Th}$  (Fig. 6 and b) are much larger than observations because in EXP\_1, K is decreased from CTRL by a factor of 5. Smaller K means smaller sink for  $^{231}\text{Pa}$  and  $^{230}\text{Th}$ , with the source kept the same, dissolved  $^{231}\text{Pa}$  and  $^{230}\text{Th}$  will increase. The mismatch of model and observations also suggest

C5

that K is in the correct magnitude in CTRL.

"In summary, it is hard for me to see that the here presented model approach provides any new insights on the  $^{231}\text{Pa}/^{230}\text{Th}$  method. Due to the lack of information about the model-data comparison it is not possible to assess the quality of the model and the applied parameters. Consequently I suggest revising both the model runs and the MS thoroughly before publication can be considered."

In our revised manuscript, we compare our model results with new GEOTRACES data and also compare with the recent modelling study by Rempfer et al., (2017). Overall, our model can simulate the general features in water column  $^{231}\text{Pa}$  and  $^{230}\text{Th}$  and sediment  $^{231}\text{Pa}/^{230}\text{Th}$ . Different from Rempfer et al., (2017), we have two versions of  $^{231}\text{Pa}$  and  $^{230}\text{Th}$ : p-fixed and p-coupled, which have the advantage to detangle the circulation effect and particle effect in controlling sediment  $^{231}\text{Pa}/^{230}\text{Th}$ . In our hosting experiment, these two version of  $^{231}\text{Pa}$  and  $^{230}\text{Th}$  do show different responses. Therefore, our model is a useful tool to improve the interpretations of  $^{231}\text{Pa}/^{230}\text{Th}$  reconstructions.

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C6