Response to Referee #4:

Ref.: Ms. No. bg-2017-429

Title: Modeling seasonal and vertical habitats of planktonic foraminifera on a global scale

We would like to thank the reviewer for the constructive comments and suggestions, which will help us to greatly improve our manuscript. Based on the comments of all four reviewers we will prepare a new version of our manuscript as outlined below.

However, during the review process, we discovered an error in the underlying ocean model. Unfortunately, the ocean circulation is not correctly represented in the used coarse resolution (i.e., ~3°) model configuration. For a correct representation of the ocean and to yield scientifically consistent results, we had to perform a new model run with a higher horizontal resolution (i.e., ~1°) on a supercomputing system. This model run takes ca. 5 weeks and is currently in the final production phase. At a first glance, the new results will not differ that much from our previous results as the representation of the upper ocean, where the analyzed foraminiferal species live, was actually reasonably well simulated in the coarse resolution model configuration compared to, e.g., the World Ocean Atlas 2013. We expect that the distribution of only a few species might be affected, when using the higher resolution model configuration with a more realistic representation of the ocean physics. Since we have not yet obtained the final results, we were not always able to provide detailed answers to your comments and had to keep our responses rather general.

Please find, in the following, the original comments in black and our responses in light blue; the indicated page and line numbers refer to the previously submitted manuscript.

Referee #4 comments:

This paper builds upon preexisting work modeling planktonic foram distributions in the global oceans via a coupling to CESM's ocean model. The goal is to better understand how the vertical distribution of foraminifera species varies seasonally and throughout larger climatic changes in the ocean. The paper is generally well written, clear, and broadly does a fine job demonstrating the usefulness of the model. It is also very thorough in its examination of the model's performance against available data. The methods seem robust and I can recommend that with some minor revisions (mostly grammar and clarity) the paper be published in Biogeosciences.

I must acknowledge that I am not an expert on the biogeochemistry of planktonic forams in any way and hope the other reviewers can address the methods and parameterizations employed in this

paper in particular. I can instead comment on the benefit of this work and the need for such proxy system models for the robust interpretation of paleoceanographic records via the use of PLAFOM2.0 + CESM1.2. To that end, my first major comment is that the authors can focus more in the introduction and conclusion on the body of literature developing forward models, or proxy system models, for understanding paleoclimate proxies and introduce this work as a part of this group of literature. A major effort has been underway to build proxy system models, link them with GCMs, and make these models publicly available, and this paper is absolutely in this category and should make as much clear.

See for example:

- Dee, S., et al. "PRYSM: An open-source framework for PRoxY System Modeling, with applications to oxygen-isotope systems." Journal of Advances in Modeling Earth Systems 7.3 (2015): 1220-1247.
- Evans, Michael N., et al. "Applications of proxy system modeling in high resolution paleoclimatology." *Quaternary Science Reviews* 76 (2013): 16-28.
- Schmidt, Gavin A. "Forward modeling of carbonate proxy data from planktonic foraminifera using oxygen isotope tracers in a global ocean model." *Paleoceanography* 14.4 (1999): 482-497.

We agree that over the last decades proxy system/formation models have become more and more important for understanding paleoclimate proxies and that PLAFOM2.0 belongs to a series of different proxy system/formation models. We will briefly introduce PLAFOM2.0 as part of this large group of proxy system models in section 2.1 (page 3, line 24):

"Thus, PLAFOM2.0, as belonging to a suite of proxy system models (e.g., Pollard and Schulz, 1994; Schmidt, 1999; Fraile et al., 2008; Evans et al., 2013; Dee et al., 2015; Völpel et al., 2017), might add to the improvement of interpreting paleoclimate reconstructions."

You might also consider mentioning (in the intro or discussion) the potential for PLAFOM to assist in data assimilation exercises for periods extending back further than the last millennium, for example. A number of papers look at the impacts of using process-based models in the DA framework and this is another application of your model. See work of Hugues Goosse's lab (e.g. Goosse, Hugues, et al. "Reconstructing surface temperature changes over the past 600 years using climate model simulations with data assimilation." *Journal of Geophysical Research: Atmospheres* 115.D9 (2010)), as well as:

- Steiger, Nathan J., et al. "Assimilation of time-averaged pseudoproxies for climate

reconstruction." *Journal of Climate* 27.1 (2014): 426-441.

- Dee, Sylvia G., et al. "On the utility of proxy system models for estimating climate states over the common era." *Journal of Advances in Modeling Earth Systems* 8.3 (2016):
- Hakim, Gregory J., et al. "The last millennium climate reanalysis project: Framework and first results." *Journal of Geophysical Research: Atmospheres* 121.12 (2016): 6745-6764

Thank you for pointing this out. We agree that PLAFOM2.0 has the potential to be used in the data assimilation framework and we will add a statement in this regard to section 2.1:
"In addition, PLAFOM2.0 has the potential to be used in the paleoclimate data assimilation framework, which provides a promising technique to estimate past climates (see, e.g., Dee et al., 2016; Goosse et al., 2010; Hakim et al., 2016; Steiger et al., 2014)."

In Section 4, it would be nice if the authors could provide a more quantitative data-model comparison technique—you identify areas where the model does not well simulate the observations and Figure 2 summarizes this to some extent, but perhaps you could include an additional table or figure or even compute something like the RMSE for each oceanic province? Or the mean RMSE for each species over all of the locations where core-top data exist?
Please refer to our response to a similar comment by reviewer #1 regarding a more quantitative model-data-comparison.

Finally, in the discussion, you assert (correctly) that your new model is a powerful tool for separating the independent influences of habitat and climate on foram reconstructions. I think this paper would be greatly strengthened by a demonstration of this. Can you take a well-known and vetted reconstruction and apply this model in a meaningful way to reassess the climatic interpretation? I think this would show the power of forward modeling in this field to make more robust assessments of uncertainties in oceanic climate changes... And I think having this demonstration would add weight to the assertions you make in your Discussion section.
This is a good point and we agree that such a demonstration would add to a better understanding of climate change. In a next study, we plan on performing a model run with, e.g., Last Glacial Maximum climate conditions to test the applicability of our modeling approach. Here, in this study we simply wanted to test if the existing planktonic foraminifera model is able to reproduce species-specific habitats when combined with a model configuration that resolves the vertical.

Minor / Line by Line comments: (Page-Line)

2-10 awkward paragraph break, consider revising

We agree and will delete the paragraph break.

2-13 comma after perspective,

Done.

2-20 Have you investigated/reviewed Schmidt et al., 1998, 1999? These papers I believe address vertical migration of foram species in the water column—worth checking/citing if appropriate.

- Schmidt, Gavin A. "Oxygen-18 variations in a global ocean model." *GRL* 25.8 (1998): 1201-1204.
- Schmidt, Gavin A. "Forward modeling of carbonate proxy data from planktonic foraminifera using oxygen isotope tracers in a global ocean model." *Paleoceanography* 14.4 (1999): 482-497.

Thank you for referring to those two studies. In both studies, Schmidt does unfortunately not address the vertical migration of foraminifera. Schmidt (1998, 1999) investigates the distribution of oxygen isotopes in seawater and subsequently calculates equilibrium calcite values based on different temperature equations. This, however, is beyond the scope of our present study and, hence, citing those studies is not appropriate.

2-26 need comma after behavior.

Done.

Check for needed commas and small grammatical errors throughout text.

Done.

3-6 comma after estimate,

Done.

3-13 this phrase is awkward, revise ("with the biogeochemical model being enabled")

We will revise the phrase as follows:

"[…] as an off-line module into the ocean component of the Community Earth System Model, version 1.2.2 (CESM1.2; Hurrell et al., 2013), with active ocean biogeochemistry (which is denoted as

CESM1.2(BGC) configuration).”

3-15 change “aimed for” to ‘aimed to’

Done.

3-16 change “at geologic timescales” to “ON geologic timescales”

Done.

Check for similar awkward language throughout.

Done.

3-23 comma after configuration,

Done.

3-30 no paragraph break.

Done.

4-9 what do you mean by ‘data models’ for the atmosphere, etc.? Are you not using the fully coupled simulations and using some kind of statistical representation of the other components?

The CESM data models are “non-active” model components that read external data, modify that data (e.g., interpolate that data in time and space), and subsequently return the final data fields to the coupler. In this study, we did not perform a fully coupled simulation. Here we analyze an ocean-ice-only simulation with active ocean biogeochemistry coupled to data models for the atmosphere, land, and river routing. Since “data model” is a common term in the CESM model community, we also used it to be consistent with other publications using the CESM1.2(BGC) configuration. However, for a better understanding, we will revise the sentence as follows:

“Here we performed an ocean-ice-only simulation with active ocean biogeochemistry, whereby the ocean model is coupled to both the sea ice model and data models for the atmosphere, land, and river routing, which provide the respective input data for the considered simulation.”

Heading 2.4 consider changing this to “Coupled GCM Setup” ?

Since our results are based on an ocean-ice-only simulation, a heading change to “Coupled GCM setup” is not appropriate. Nevertheless, we will change heading 2.4 to “Model simulation”, which is

more accurately describing this section.

7-15 missing space before new sentence.

Done.

8-21 comma after ‘life cycle,’

Done.

Throughout section 3, be extremely clear about whether you are referring to observations vs. the model simulation of foram distributions/abundances etc. The reader gets a bit lost in the data-model comparison here unless that’s super clear.

In section 3, we actually just describe model results and do not provide a model-data-comparison. To be more concise and clear about that, we will revise this section accordingly. In addition, we will also revise section 4 to be more clear about when we refer to observations and/or model output.

16-29 no comma after ‘data’

Done.

16-30 this is a run-on sentence—consider shortening/rewriting

We will revise this run-on sentence by splitting it into two parts:

“The emergence of seasonal and vertical habitat patterns consistent with observational data provides important support for our modeling approach. Nevertheless, a more detailed comparison with observations is warranted to gain further insight into the model behavior.”

I appreciate the thorough discussion of the model – data comparison limitations on page 17.

Thank you!

Figure 5 has some strange cropping issues along top margin.

Thank you for pointing this out. We will check for this and will adjust Figure 5 accordingly after obtaining our final results.

References:

- Fraile, I., M. Schulz, S. Mulitza, and M. Kucera (2008), Predicting the global distribution of

planktonic foraminifera using a dynamic ecosystem model, *Biogeosciences*, *5*, 891-911.

- Pollard, D. and M. Schulz (1994), A model for the potential locations of Triassic evaporite basins driven by paleoclimatic GCM simulations, *Global and Planetary Change*, *9*, 233-249.
- Schmidt, D. N., S. Renaud, J. Bollmann, R. Schiebel, and H. R. Thierstein (2004), Size distribution of Holocene planktic foraminifer assemblages: biogeography, ecology and adaptation, *Marine Micropaleontology*, *50*, 319-338.
- Völpel, R., A. Paul, A. Krandick, S. Mulitza, and M. Schulz (2017), Stable water isotopes in the MITgcm, *Geosci. Model Dev.*, *10*, 3125-3144.