

Response to Referee #2:

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., $\sim 3^\circ$) 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., $\sim 1^\circ$) 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 #2 comments:

The authors use existing sediment trap and plankton tow data to add seasonal and depth habitat information to the PLAFOM2.0 model. The authors then compare model results to modern data, concluding that they find a reasonable agreement between simulated and observed results for species-specific flux timing and depth habitat. The manuscript is well written, and the discussion of global trends in depth habitat is fantastic and alone an important contribution to the literature. Moreover, in light of an increasing understanding of the consequences of foraminifera habitat tracking for proxy data interpretation, the development of such a modeling tool is potentially quite useful.

The manuscript is successful in modeling modern depth preferences from unfortunately sparse observational data. While the model seems to reproduce broad trends (spinose species in near-

surface waters) and earlier-when-warmer seasonality in some environments, figures 6-7 and the supplemental figures often show a strikingly poor fit between modeled and observed timing and depth preferences at specific sites. As the authors point out, the model tends to underestimate both amplitude of seasonal changes and potentially depth stratification. The authors should consider explicitly discussing why the model might be insensitive in replicating observed variability and how this would be likely to effect modeling of different climate inputs.

This is a good point and we will extend the discussion in this regard especially by bearing in mind that the coarse 3° ocean model is not fully able to represent the ocean's physics properly. Apart from the uncertainty in the observational data (see section 4.2), it is due to the model complexity not trivial to determine which model component (i.e., POP2, BEC or PLAFOM2.0) contributes to what extent to the model-data-mismatch. Determining this would require a suite of sensitivity experiments with each model component. Whilst we agree that these would be useful – and will consider this for future work – we think that the model as it is already presents a useful contribution to improve the interpretation of foraminifera-based proxy records.

Nevertheless, we will expand the discussion on the model uncertainty in section 4.2 after evaluation of the new model run. We will specifically address the dependence of the results on the individual model components. The inferred importance of temperature and food availability (provided by POP2 and BEC, respectively) on the distribution of foraminifera implies that each model component is important for an accurate representation of foraminifera distribution. Hence, we expect the higher resolution ocean model to provide a more realistic representation of ocean physics, which will cascade through the model hierarchy leading to an improved overall model skill. Nevertheless, sub-grid processes and known POP2 and BEC model issues (see, e.g., Danabasoglu et al., 2012, 2014; Moore et al., 2013) will remain. These will contribute to the model-data mismatch, but will not provide information/constraints on the planktonic foraminifera model per se.

When the authors discuss relative abundance of species, are they referring to relative abundance with respect to just modeled species or all foraminifera? Is this consistent throughout? It might be worth clarifying this point.

When we are discussing species relative abundances for the core-top data, we always refer to relative abundances with respect to only the five modeled species. We mention this in section 2.5.1 (page 7, line 17) and also in the caption of Figure 2. To avoid confusion, we will repeat this point also in section 4.1.1 in the beginning of the first paragraph:

“Note that the relative abundances for the core-top data have been calculated with respect to just the

five modeled species and not to the whole faunal assemblage.”

Why have the authors chosen not to include sediment trap based habitat depth based assessments? Since sediment traps provide export flux rates, which are not modeled here, and thus do not provide information about depth habitat, a sediment trap based depth habitat assessment is simply not possible. However, there exist calcification depth estimates based on chemical properties of foraminifera from sediment traps, but calcification depth is not identical to habitat depth. Therefore, we only use plankton tow data for a meaningful depth habitat assessment.

p8/l23 (and throughout) – Do the authors really mean differences in biomass as opposed to species abundances? If so, is the biomass different in different species and how is this accounted for? And how does this metric compare to species abundances, as presumably used in the modern data to which the model is compared?

PLAFOM2.0 calculates the foraminiferal abundance of each species via carbon biomass to be consistent with the ecosystem model (see section 2.3 in the manuscript and Fraile et al., 2008). In the manuscript we prefer to use this unit, rather than foraminifera abundance, since conversion to abundance requires, as the reviewer rightly points out, another step.

However, this conversion of biomass to abundance is only of importance for the comparison of the modeled and observed assemblages. For the global comparison with the core-top data, we are not interested in assessing absolute abundances and, therefore, calculate species' relative abundances. For this comparison, however, we will now account for the different sizes of each species by using a mean size for each species based on the results of Schmidt et al. (2004) and will recalculate the modeled relative abundances accordingly. This allows for a sound comparison with the core-top data, which will, i.a., likely be evident in the newly introduced and considered Bray-Curtis similarity measure. We will add this similarity analysis to the manuscript (i.e., to sections 3.1 and 4.1.1) to provide a thorough model-data-comparison.

We would like to emphasize that the patterns of vertical and/or seasonal abundance are independent of the amount of carbon per shell (as long as there is no significant and systematic size variability). This allows us to directly compare modeled and observed data.

p9/l18 (and throughout this section) – I'm not sure it makes sense for “maximum production” to be “year-round.” Could you clarify?

That is a very good point. Here, we actually wanted to say that uniform and/or constant species

fluxes occur year-round, thus no seasonal peak is evident in the species production. We will change the wording throughout this section accordingly.

section 3.3 – might be helpful to define what you mean by “surface” and “subsurface” as these are pretty general terms but are being used as if the authors have a fairly specific depth range in mind.

Thank you for pointing this out. We will provide more precise depth ranges throughout section 3.3 and will avoid especially the general term “subsurface”. The surface is in general defined from 0 to 10m water depth, which corresponds to the first vertical layer of the used model configuration.

p12/l30 – “prefer thriving” -> “thrive”

Done.

p12/l35 – delete "largely"

Done.

p14/l4 – delete "among each other"

Done.

p14/l11 – delete "preferably"

Done.

p14/l31 – “cold to transitional” compares a temperature to a zonation

We will change “transitional” to “temperate” to be consistent in the wording.

p15/l22 – a -> the

Done.

p17/l2 – might be better to describe these as short time series as compared to plankton tows which really are “snapshots”

We agree and will now describe sediment trap time series as short time series rather than snapshots: “[...] span at most a few years and, hence, represent short time series that [...] plankton tow samples represent snapshots (of one particular day) [...]”

p17/l18 – or genotypes or phenotypes?

We agree that genotype is a more suitable term in this regard and will change the wording accordingly.

p17/l26 “a few”?

Done.

Figure 6 is extremely difficult to read given the mix of opacity and multiple symbols and colors. Is there a better way to present this data?

We agree and will try to find a better solution to present the data when evaluating the new results.

Figures 6 and 7 (a-c) suggest a quite poor fit of modeled data to sediment trap observations. i.e. 7c shows the model completing missing the flux timing of bulloides in JGOFS34. The authors include an overview or why there might be some data-model mismatch, but I think a wider discussion of why and how this could impact or limit interpretation of model results is warranted.

Please refer to our response to your first comment, where you address the same issues.

References:

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- 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.
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- 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.