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Interactive comment on "On the validity of foraminifera-based ENSO reconstructions" *by* Brett Metcalfe et al.

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Dear Dr. Kaustubh Thirumalai, Thank you for taking the time to make known your opinion of our paper and for volunteering your comments. We addressed many of these issues in the reply to reviewer 1, reply to reviewer 2, reply to reviewer 3 and the general reply to all reviewers. However, we will gladly address your points here. We must stress, as we have done so in the previous replies, that we are modelling foraminifera populations in the water, and not in the sediment archive.

COMMENT: "Regardless of using Anderson-Darling statistical tests to assess whether subsampling occurs from their forward-modeled δ18O and temperature histograms, their analyses completely discount that ENSO events are seasonally synchronized to

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the annual cycle, and much of the variance of subsampled IFA distributions across the Pacific Ocean represents this power. Foraminiferal reconstructions are sensitive to absolute temperatures and NOT to monthly anomalies of temperature."

- By forcing the model with 65 years of monthly ocean reanalysis temperature and salinity data we are not discounting seasonality (an odd suggestion), it is exactly why we chose such a dataset to run the analysis rather than producing a theoretical or hypothetical temperature distribution to which to produce FAME modulated signals. We produce 696 values (1 for each month) of d18O and Tc, that are then pooled into their respective climatological states (using a modified definition). Naturally this has repercussions. We use absolute temperature (FAME requires absolute temperature, see Roche et al., 2018) and not monthly anomalies for calculation (ONI – the definition of events is however a monthly anomaly).

- If the suggestion from this comment is that we should be more flexible with our definition of El Nino, or how we pool such values, we refer to the arguments of reviewers' 1-3 against such flexibility.

- We do not use " Anderson-Darling statistical tests to assess whether subsampling occurs from their forward-modeled δ18O and temperature histograms" but to determine whether the different climate states could be considered statistically different (i.e., if foraminifera populations from event A and event B can be considered to be statistically different or not). The commentator's interpretation of the Anderson-Darling test does not reflect what we did (or stated). If the commentator is suggesting that second order variability (short -term changes in the seasonal cycle) should be included, then it implicitly implies that foraminifera don't record El Nino events.

COMMENT: "If the authors want to comment on ENSO and foraminifera (as in their title), they MUST incorporate subsampling uncertainties and how this interacts with the seasonal cycle."

- As we made clear in the reply to reviewer 1, reply to reviewer 2, reply to reviewer

3 and our general reply to all reviewers, we are using FAME, driven by six decades of monthly observed climate data, to model foraminifera populations in the water. We are not modelling foraminifera retrieved from the sediment archive, so we therefore do not model processes such as bioturbation, fabric disturbance during core retrieval, species misidentification, machine error, subsampling-induced noise, sample vial mislabelling, or indeed anything else pertaining to the generation of palaeodata in a practical sense. We seek to understand whether or not foraminifera populations in the water are intrinsically capable of recording ENSO dynamics, and at which locations. We consider this to be the most fundamental consideration for foraminifera-based ENSO studies, and therefore, we fail to see how our title is inappropriate. Assessment of sediment/laboratory processes essentially becomes a moot point if the events to be reconstructed are not recorded by foraminifera in the water.

- Further studies should address whether or not the signal produced is an artefact of subsampling (i.e., that the signal is introduced because of picking and not a real climatological signal) – a point we suggest in the text, that should definitely be of concern for palaeoreconstructions, as the commentator is aware of.

COMMENT: “By definition, the authors state that "FAME uses the associated temperature and δ18Oeq at each grid cell to compute a time averaged δ18Oc and Tc for a given species". In other words, the authors have shown in their analyses that ENSO events strongly alter the temperature and δ18O in much of the tropical Pacific and that foraminiferal histograms (or foraminiferal distributions) are able to capture mean state conditions by sampling from these altered distributions (i.e., based on the utility of the Anderson-Darling test to account for histogram subsampling). Both of these aspects are well known. This, by no means, demonstrates a calculation of skill or validity of IFA-based ENSO reconstructions. Thus, the title of the manuscript is inaccurate and misleading.”

- We were testing whether it is possible for foraminifera in the water to record ENSO. The skill or validity of IFA-based ENSO reconstructions has been studied before (we

have made this point previously to more than one reviewer). Here we are testing whether (in a perfect world) the foraminifera population in the water detect ENSO dynamics.

- 'Thus the title of the manuscript is inaccurate and misleading' – we broke down the title in our response to reviewer 3 as follows: If we break down the title: Validity – is the quality or state of something being valid (valid - being logically correct or well-grounded/justifiable). We are testing whether the distributions of different climate events are statistically different (this is a fundamental test) Foraminifera-based – we use a foraminiferal model. An alternative could include the word "populations" here, as in "foraminiferal populations". ENSO reconstructions - The reviewer, we assume, is arguing that as we say ENSO reconstructions, and judging from their previous point ("as it focuses on determining whether ENSO events (El Niño, La Niña) and neutral conditions have distinct distributions (forward modeling) rather than on how one could detect ENSO change (inverse modeling).") that we haven't focused on the 'how one could detect', yet we are testing whether the foraminiferal distributions of different climate events are statistically different, hence we have carried out a test on a more fundamental level (i.e. foraminifera in the water, before they are incorporated in the sediment archive)." We do not think that we are being misleading or inaccurate.

COMMENT: "In other words, the authors have shown in their analyses that ENSO events strongly alter the temperature and δ18O in much of the tropical Pacific and that foraminiferal histograms (or foraminiferal distributions) are able to capture mean state conditions by sampling from these altered distributions (i.e., based on the utility of the Anderson-Darling test to account for histogram subsampling)."

-The first half of this is correct, the signal will be modulated in response to water column conditions (and potential depth habitat or growth related changes). However, we are not referring to mean state conditions, we are testing whether the El Nino foraminifera population is statistically different from the foraminifera population for other climate states. The comment keeps referring to 'histogram subsampling' which is not

at Anderson-Darling test does. The A-D test compares two probability distribution functions for (dis)similarity.

COMMENT: “For a demonstration of calculating ENSO skill in reconstructions, please read the literature: Carré et al. 2013, Emile-Geay and Tingly, 2017, Ford et al., 2014, Hereid et al. 2013, Khider et al. 2011, Tindall et al. 2017, Thirumalai et al. 2013, and so forth (only two of which are cited and not discussed).”

- We will endeavour to incorporate those papers we feel match our discussion, however, as pointed out to Reviewer 3, we did mention that our ’validity’ is referring to a fundamental validity of foraminifera populations in the water to record ENSO dynamics, and not a test of the skill of sediment-based reconstructions.

COMMENT: “The manuscript mischaracterizes Thirumalai et al. 2013 and does not refer to the advances contained therein appropriately” - We have already mentioned rephrasing this section in the replies. We apologise for mischaracterisation.

COMMENT: “ Firstly, considering that their analyses do not account for sampling uncertainty or ENSO skill in IFA-based reconstructions due to the lack of separation from the seasonal cycle as well as decadal and higher forms variability, their conclusion is not supported by their findings.”

- Although our results are condensed into a simple binary 0 and 1, that is an aid to the reader, such simplicity does not reflect a lack of complexity. As we point out above, we have utilised over six decades of monthly ocean reanalysis data, which means that for every grid cell we produce 696 monthly values and divided them into their various climatological states. That means the low and high orders of variability are intrinsically included in our approach. However, foraminifera are a filter of the signal, which means that much of this variability will be altered (e.g., changes in flux, the growth weighting or even the depth habitat). This is why we decided to use a simple foraminiferal module to produce our time series.

-Separating out seasonal and annual values would be unrealistic, as foraminifera are pooled in the sediment, therefore it would be a falsifiable test. Separation also implies that it is possible to reconstruct seasonal or decadal time series within the sediment, which is not possible.

Finally, we would like to raise an important point, reviewer 1, 2 and 3 have stressed repeatedly that our study fails to address the inverse problem instead using a forward model, to which we have in our replies to reviewers 1, 2 and 3 repeatedly had to discuss inverse modelling. But it is worth noting that here you state ("according to forward-modeled IFA (with uncertainty)") that your previous research (Thirumalai et al., 2013) is also in part based upon a forward model - which suggests the reviewers have not appreciated this fact.

Kind regards,

dr. Brett Metcalfe

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