

## ***Interactive comment on “Late Pleistocene Glacial–Interglacial related shell size isotope variability in planktonic foraminifera as a function of local hydrology” by B. Metcalfe et al.***

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Received and published: 2 April 2015

Comments in response to Referee 1

B.Metcalfe

We thank you for the careful consideration of our manuscript. Please find outlined below our response to your reviewer comments and corrections of the manuscript, "Late Pleistocene Glacial-Interglacial related shell size isotope variability in planktonic foraminifera as a function of local hydrology.", submitted to Biogeosciences. We have split the referee comments into those that merit a longer discussion, from those that can be answered with a short comment (i.e. we agree to change the text).

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Specific comments:

Page 136, line 21-23. 'Seasonal insolation patterns' – What is the sedimentation rate of the core of interest? I am assuming it is relatively low to moderate and I would not expect to records/data to be able to resolve 'seasonality'? I suppose the authors are attributing the overlap (or spread of  $\delta^{18}\text{O}$ ) for *G. bulloides*  $\delta^{18}\text{O}$  to represent forams tests that have live/grown in different seasons.

The core has a sedimentation rate of between 1.7 and 3.1 cm per kyr during this core interval, based upon the age control points of Huybers (2007) as discussed in Feldmeijer et al.(2015). Whilst this sedimentation is not varve like, if you consider that there is some degree of symmetry in the insolation pattern of a given period then whilst we may not record autumn with a given species (i.e. *G. bulloides*), as its main flux is in Spring, the information gathered on only a few seasons can give us information on the remainder. If for example you look at Figure 3 D you will see there are periods (indicated by arrows) when the annual insolation budget changes. Factoring in the offset that occurs annually between actual insolation change and changes in the ocean, you'd expect that the growing season of a cold species would be longer when the relatively high insolation has contracted.

Page 137, line 12. The  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  of foraminiferal calcite is also a function of carbonate content (e.g. Spero et al., 1997), temperature (e.g. Bemis et al., 2000) and dissolution (e.g. Lohmann, 1995, Rosenthal et al. 2000). These impacts on foraminiferal  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  should also be mentioned in the text.

A short sentence has been included: "The isotopic composition has been shown to be a function of the ambient carbonate ion concentration ( $[\text{CO}_3^{2-}]$ , e.g. Spero et al., 1997), temperature (e.g. Bemis et al., 2000) and post-mortem effects (e.g. Lohmann, 1995; Rosenthal et al., 2000)."

Page 137, line 24. Shell size – What about shell mass (e.g. shell weight)? How does shell mass affect isotopic values? I suppose shell mass may reflect a direct

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relationship of environmental stimuli in both growth/environmental conditions and/or post depositional conditions. Page 138, line 4. 'hence large sizes' – Is there any correlation of these studies with shell size and mass?

Shell mass is a byproduct of number of chambers, wall thickness and the porosity of the shell all of which can be influenced by growth and environmental conditions. Whilst, the mass was determined for these specimens we have chosen not to discuss this dataset because: (1) there is no relationship between isotope and shell weight for this dataset and (2) studies that focus on shell size vs. isotopic composition do not use it. Our shell mass for these species do however show that *G. bulloides* and *G. inflata* follow a similar pattern as the pCO<sub>2</sub> curve from Vostok.

Page 139, line 9. T90-9p location. Please include 'water depth' for the core location. I am assuming APNAP core T90-9p was collected well above the modern calcite saturation horizon? Hence, what about post depositional effects of foraminiferal stable isotopic composition over time at this site? Can these post depositional effects on foraminiferal isotopes be excluded from the isotope results presented here?

Water depth of the core is 2934 m, the average modern CCD in the North Atlantic is considerably deeper. Post depositional effects are dealt with in Feldmeijer et al. (2015), bioturbation has been ruled out given the abundance counts, coiling direction of *G. truncatulinoides* and XRF records. Whilst, the core lies well above the modern CCD there was a glacial shift in the preservation potential in the North Atlantic. A visual inspection, plus the shell weight signal would indicate that dissolution is minimal.

Page 141, line 12. 'following ultrasonic cleaning in ethanol' – Ethanol? We typically use methanol for cleaning foram tests prior to analysis. I suppose each laboratory has a preference for a cleaning media during sonication just as long as there is no isotopic effect on the foraminiferal d18O and d13C during the cleaning process.

There was no active decision to use ethanol over methanol, we pick foraminifera with ethanol as it dries under microscope lights faster than water and therefore it is the

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'closest thing to hand'. It is unlikely that using ethanol would lead to an alteration of the isotopic signature.

Page 148, line 6-26. What about the effects/influences of the 'carbonate ion effect, temperature and dissolution' of foraminiferal d18O and d13C?

The effect of temperature, dissolution and carbonate ion could influence our signal. Like d18O<sub>sw</sub> we can assume that within sample the SST and [CO<sub>3</sub><sup>2-</sup>] should remain the same (albeit with depth related changes) and are different between samples. Therefore We do discuss the carbonate ion concentration in the carbon section of the discussion.

Page 148, line 25-26. '..is a progressive enrichment in 13C for increasing size.' Could this observation be due to changing sea water temperature or carbonate ion concentration during TIII?

It could be both, Bemis et al., 2000 suggested that the d13 of DIC of the surface ocean during the glacial would have to increase by 0.3 to 0.4 per mil to account for changes in sea surface temperature and alkalinity. A similar figure was estimated by Broecker and Henderson (1998), at 0.35 per mil, although they considered that it should be as a response to an enhanced biological pump drawing down CO<sub>2</sub>. A conservative estimate, given the poorly constrained alkalinity inventory, of 60 umol kg<sup>-1</sup> change in [CO<sub>3</sub><sup>2-</sup>] at the LGM would have decreased the d13C of *G. bulloides* by 0.72 per mil. Given that the pCO<sub>2</sub> of MIS8 never reaches the lower boundary of 180 ppm it is likely that this value is lower for the period of study. If we use shell weight from this core section as a rough predictor then a change of only 25 umol kg<sup>-1</sup> in [CO<sub>3</sub><sup>2-</sup>] would have occurred (but this is full of caveats). Page 159 outlines the differences between the temperature and carbonate ion effect, the problem is unravelling the dominant influence. Our data is further complicated by the fact that if we use the d18o to estimate the calcification depth then they do not fit the d13c profiles. Shackleton (1978) pointed out that trying to estimate the carbon isotope composition of the surface ocean is particularly tenuous

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given the gradient in carbon isotope values is steepest at the surface when couple with the limitations and uncertainties regarding the precise depth of calcification.

Page 154, line 1-25. 'Seasonality' – Are there any sediment trap foraminiferal studies in this region on foraminiferal flux, size, mass, isotopes (d<sub>18</sub>O and d<sub>13</sub>C). I suppose a comparison of what might be seen in sediment trap data may provide further insights into the 'mixed' isotope values that are seen in the figures?

We agree and are looking into such an effort, however in this instance the use of glacial-interglacial transition between MIS7 and MIS8 complicates matters. Numerous papers have commented on the fact that Heinrich events, glacial and interglacial periods should be considered separately in respect to overall conditions. Therefore we haven't gone into detail with sediment trap studies in the region. With respect to 'mixed' isotope values, we believe that if one is referring to the large spread in small specimens which could represent a shallower depth habitat, with a larger range in temperature (see Figure 11), this 'mixed' signal could just relate to normal conditions.

Page 157, line 16-19. The sentence 'Given the seasonal flux: : .:large scale transport.' It would be interesting to see if there any data (e.g. foram isotopes, flux weight info, size fractions) for the NABE48 sediment. The spread of this seasonal information could be averaged, computed to see if it fits the observations seen in the results presented here?

We agree, and such a study with modern coretop samples has been compiled as the change between glacial and interglacial may complicate these matters, however NABE 48 does not have size fraction or isotope data.

Detailed comments:

The following outlines our comments that involve small changes to the manuscript:

Consider changing the title from "Late Pleistocene Glacial-Interglacial related shell size isotope variability in planktonic foraminifera as a function of local hydrology" to "Late

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Pleistocene Glacial-Interglacial shell size isotope variability in planktonic foraminifera"

'Related' removed from title

Page 136, line 4; Consider changing 'foraminifer shells hamper' to 'foraminifer shells that hamper'

Changed

Page 136, line 12; What do the authors mean by 'dynamic size range'?

Altered to provide clarity

Page 136, line 13; Change 'G. inflata' to 'Globorotalia inflata' as this is the first time it is mentioned. Likewise, change 'G. truncatulinoides' (line 14) and G. bulloides (line 19).

Changed

Page 137, line 17. Added to this is the complication is the shell-size dependency of isotopic offsets from dissolved carbonates (e.g. Kahn, 1979, Curry & Mathews 1981, Kahn & Williams 1981, Oppo & Fairbanks 1989, Oppo et al., 1990, Elderfield et al., 2002, Hillaire-Marcel et al., 2004.)

Changed

Page 138, line 28. 'Subsequent investigations: : ..single depth in core or core top,: : .:' Studies like King and Howard 2004, 2005 examined the offsets in 'planktonic foraminiferal isotope values' and then looked at the isotopic values in sediment trap and sediment core tops etc.

Our point here is to highlight that very few studies have tested the size isotope relationship over a glacial or interglacial period.

Page 139, line 4. Consider changing 'We here test' to 'Here we test..'

Changed

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Page 139, line 5. Expand 'TIII' to 'Termination III' as this is the first time it is mentioned.

Expanded

It would also be an idea to let readers know the 'sedimentation rate' at this site? Is this site a low, moderate, high sedimentation rate site where past seasonality climate signals can be resolved?

We can make a point of adding this to the text, although readers can easily calculate this given that the samples were taken evenly spaced at 4cm intervals.

Page 140, line 6. Change '(Termination III)' to '(TIII)'

Changed

Page 140, line 16. '2.1 Calculation of average size and weight'. This following section does not provide any information on 'weight' calculations. The text provides information on 'foraminiferal abundances (e.g. numbers per gram)'.

Shell weight has been removed

Page 140, line 20. 'into small aliquots approximately' – Did the authors 'split into small aliquots where 200 forams were collected/picked' or do they mean '\_200 particles collected – including forams (all species), particles etc'?

200 particles, given that most abundance counts are performed on two size fractions: 125-250  $\mu\text{m}$  and  $>250 \mu\text{m}$  whereas here we count from four size fractions we felt that this was sufficient to provide an estimate of the abundance.

Page 140, line 22-23. 'numbers per gram' – the numbers per gram was calculated per Peeters et al. 1999. Did the authors consider calculating the shell normalised weight (mass) for each of the foram species during this step to obtain an average weight?

The shell normalized weight for each foram species has been determined but we decided not to publish it in this instance as it does not add to the manuscript.

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Page 140, line 20-24. With the dried residual – did the authors consider further cleaning of the 200 foraminiferal species to remove any nanno fossil or carbonate particles contained within the foram tests prior to other analysis? E.g. for the stable isotopic measurements – the authors sonicated in ethanol to remove any foreign calcite/carbonate not from the foram tests for single foram isotope analysis.

Specimens were sonicated in ethanol. We did not do any further pre-treatment as we have shown that this has little impact on a number of proxies, see Feldmeijer, Metcalfe, Scussolini, Arthur, 2013. G3

Page 141, line 2. 'Bulk measurements routinely consist of between 8-40 specimens'. Were the bulk measures ultrasonically cleaned in methanol/ethanol?

Here we are not referring to our own work but to the general isotope methodology applied to palaeoceanography.

Page 144, line 8. 'Faunal abundance counts and size' – the methodology section has the subtitle 'Calculation of average size and weight'. In this section I assumed 'weight' was actually faunal abundance. Please clarify this in the text.

Weight has been removed, faunal abundance was added

Page 144, line 9. I am assuming the percentage (%) values after each species is the abundance (in %)? From looking at the figures, there are large changes in the abundances for *G. bulloides* and *G. inflata*. I suppose these large difference or at least the time periods when these changes occur should be mentioned. Consider changing these first sentences to: "Over the time period of interest *G. truncatulinoides* abundance is generally <10% (Fig. 3.). Faunal abundance for *G. inflata* ranges between 10 to 40% with higher abundance corresponding with warmer interval MIS73 and the lower abundances preceding cold interval MIS8. The abundance for *G. bulloides* ranges between \_10 to 35%.....".

Changed

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Page 144, line 14. 'The calculated average size' – I am assuming 'the average size is a SFD'?

It is the average size based upon a SFD

Page 144, line 20. I am assuming the 'Foraminiferal stable isotope values (d18O and d13C)' are for single test measurements. Consider changing from 'The oxygen isotope: : :.' to 'Single foraminiferal test oxygen isotope: : :.'

Changed

Page 150, line 1-6. It would have been interesting to know the shell normalised mass (weight) of forams between the different size fractions.

Weight, whilst measured will be dealt with elsewhere as it does not link to the current understanding in this paper.

Page 154, line 7. Consider changing 'Given the overlap of the larger than >250um: : :.' to 'Given the overlap of the >250um: : :.'

Changed

Page 160, line 16. Consider changing 'This depletion' to 'The depletion for globorotalia species.'

Changed

Page 161, line 2. 'how this size-isotope relationship varies: : :.' Consider including 'shell mass' as well?

Unchanged

Page 174, Table 2. Consider changing caption to include information of size fractions. Eg. 'Smallest (212 – 250um) and largest (300-355um) size fraction : : :..'

Changed

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Page 176. Table 4. There is a typo in table 4. I think 'G. inflata' should be G. bulloides?

Changed

Page 178. Figure 1. Consider adding some information on the colour coding for relative temperatures? Eg. Is blue – cold, Orange – intermediate temp, Red – warm? Or at provide information on the temperature range for the colour codes.

Changed

Page 180. Figure 3. Consider having (A) – G. bulloides single d18O values in a separate figure. There is lots of information in Figure 3 as it is. Also, the title of the figure caption should also be changed. Consider 'Figure 3. Relative abundance and average size of G. bulloides (blue), G. inflata (red) and G. truncatulinoides (green): : :: : :.etc.

Changed caption however we felt it is better to keep (A) in the figure as it gives the position of isotope changes that can be used to compare the abundance and insolation patterns.

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Interactive comment on Biogeosciences Discuss., 12, 135, 2015.

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