Response to Anonymous Referee #2

First, we would like to thank the referee 2 for its comments which will help to improve the revised version. Below we address the remarks of the referee.

Major comments:

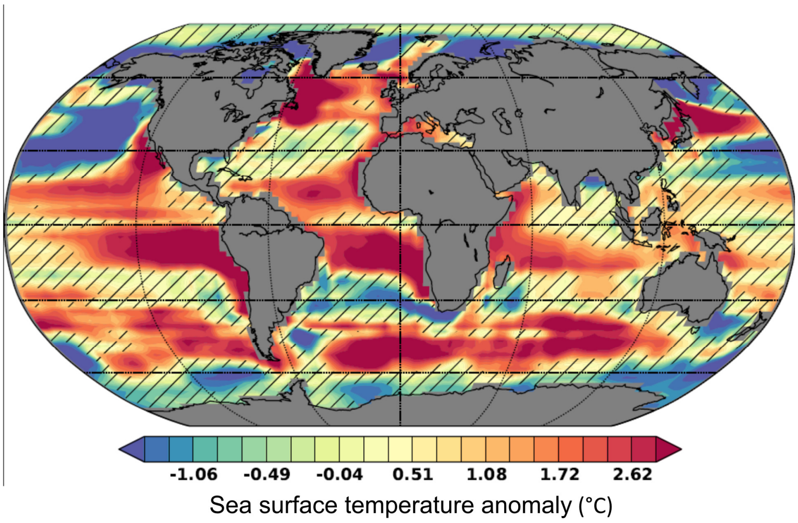
1. From the viewpoint of a reader, it would be more convenient to merge the three parts to one, or at least the first and the second part, if the third part can be conveincingly expanded to become an article in its own right. This has the advantage that the merged paper would contain only one common Introduction section, and that one could refer to, for example, a single Methods section. Indeed, any presentation of a new model should contain a model-data comparison as an integral part, at least with respect to current observations, maybe less so for paleo-data. To restrict the model „verification" to just delta O-18-salinity relationship is not sufficient from my point of view.

We agree with the referee that the part one and two could have been merged in principle, less so for the part three that has a rather different perspective. However, given the manuscripts types in Geoscientific Model Development, it is not really possible to describe the implementation of the model and do the verification and validation in the same manuscripts. "Model description papers" as the part 1 of the present study aims at the actual description of the equations and methods employed and "Model evaluation papers" such as part 2 and 3 aim at in-depth analysis of already published models. Clearly, part 1 cannot fit in the latter manuscript type.

2. Because the O-18 of carbonate critically depends on temperature, the modeled temperature should be assessed as well and ideally compared to a "Late Holocene" temperature reconstruction, to rule out that errors in the modeled temperature and water isotope distributions compensate each other. Indeed, the authors touch on the effect of a temperature bias in the deep ocean, but they may miss a similar effect in the near-surface ocean.

Unfortunately, there is no database for "Late Holocene" temperature reconstruction available in the literature. The MARGO project has realized this compilation for the LGM, but the anomaly with present day is calculated from World Ocean Atlas (WOA) temperature measurements (MARGO Project Members, 2009).
We added a figure of comparison between the Levitus and Boyer (1994) data and model results in the revised version to assess the modelled temperature. We added in the text: "*From this comparison it appears that sea surface temperature (SST) in the model are in good agreement with data (overall, less than 1°C of differences is observed) (Fig. 4) and therefore can't lead to important bias on the calcite δ18O signal. We focus on regions where SSTs are significantly warmer or colder in the model in comparison to data and where some notable discrepancies between the modelled distribution and data for the δ18Osw have been observed (Roche and Caley, 2013).*
*The main differences for the δ18Osw are in the Atlantic and Indian subtropical Ocean and offshore California (Roche and Caley, 2013). These regions are all marked by warmer SST in the model (Fig. 4). The δ18Osw in the model is slightly depleted in the Atlantic Ocean and even more depleted in the North India Ocean in comparison to data (Roche and Caley, 2013). These two effects (warmer SST and more depleted δ18Osw) produce both a weak*

*supplementary decrease of the δ18O calcite signal but no compensation effect. Concerning the region offshore California, the warmer SST and more enriched δ18Osw could compensate each other but the modelled signal is compared to only two calcite δ18O points of our dataset (Fig. 5). Therefore, the δ18O calcite signal of the model can be compared with data with a good accuracy because slight errors in the modelled temperature and water isotope distributions do not compensate each other. Also note that this problem do not applies when anomaly with past climates will be calculated (for example the last glacial maximum).*"




New Figure 4

3. The paleo-temperature equation by Shackleton (1974) was derived for inorganic precipitates. As shown by Mulitza et al. (2003) and Mulitza et al. (2004), it is more appropriate to use a paleo-temperature equation derived for living planktonic foraminifera, even taking into account differences between the different species.

Mulitza et al., 2003 demonstrate that over the oceanic temperature range, the slopes of the equations derived for living species agree with the slopes obtained from inorganic precipitates and are nearly identical to the paleotemperature equation of Shackleton (1974). Therefore, we choose to conserve the equation of Shackleton (1974) to realize the global comparison (mix of different species). However, we agree that when individual species are considered, the use of the equations of Mulitza et al., 2003-2004 could refine our conclusions. We therefore use these equations and compare the results with the results obtained with the equation of Shackleton (1974) in a new table 1.

| Foraminiferal specie | Depth habitat estimation (m) | Paleo-temperature equation by Shackleton (1974) | Data-model $R^2$ | Paleo-temperature equations by Mulitza et al., 2003 | Data-model $R^2$ |
|---|---|---|---|---|---|
| *G. ruber white* | 0-50 | T=16,9-4,38(δc-δw)+0,1(δc-δw)2 | 0.76 | T=-4.44(δc-δw)+14.20 | 0.76 |
| *G. ruber pink* | 0-25 | T=16,9-4,38(δc-δw)+0,1(δc-δw)2 | 0.51 | T=-4.44(δc-δw)+14.20* | 0.51 |
| *G. sacculifer* | 0-50 | T=16,9-4,38(δc-δw)+0,1(δc-δw)2 | 0.63 | T=-4.35(δc-δw)+14.91 | 0.63 |
| *G. bulloides* | 0-50 | T=16,9-4,38(δc-δw)+0,1(δc-δw)2 | 0.73 | T=-4.70(δc-δw)+14.62 | 0.72 |
| *N. Pachyderma dextral* | 0-75 | T=16,9-4,38(δc-δw)+0,1(δc-δw)2 | 0.5 | T=-3.55(δc-δw)+12.69 | 0.48 |
| *N. Pachyderma sinistral* | 0-150 | T=16,9-4,38(δc-δw)+0,1(δc-δw)2 | 0.11 | T=-3.55(δc-δw)+12.69 | 0.11 |

New Table 1

The results indicate no differences with the different equations, confirming that over the oceanic temperature range, the slopes of the equations derived for living species agree with the slopes obtained from inorganic precipitates.
We added in the revised version: *"We then realized a data-model comparison for the calcite δ18O signal for individual species (Fig. 7). For this comparison, the use of paleo-temperature equations derived for living planktonic foraminifera (Mulitza et al., 2003) could be more appropriated than the paleo-temperature equation derived for inorganic precipitates (Shackleton, 1974). We test this possibility but the results indicate no differences with the different equations (Table 1), confirming that over the oceanic temperature range, the slopes of the equations derived for living species agree with the slopes obtained from inorganic precipitates (Mulitza et al., 2003)."*
We also list the various habitat depths and correlation factor between data and model results as suggested by the reviewer (see new table 1).

Minor comments:

Note that the results by Telford et al. (2013) suggest that changes in habitat depth with time (from the present to the past) may have a significant effect. Similarly, any salinity-temperature relationship may change with time, as well as the temperature and salinity that happen to coincide with a (modern) oceanic front that should be really defined by strong horizontal gradients in temperature and other hydrographic quantities.

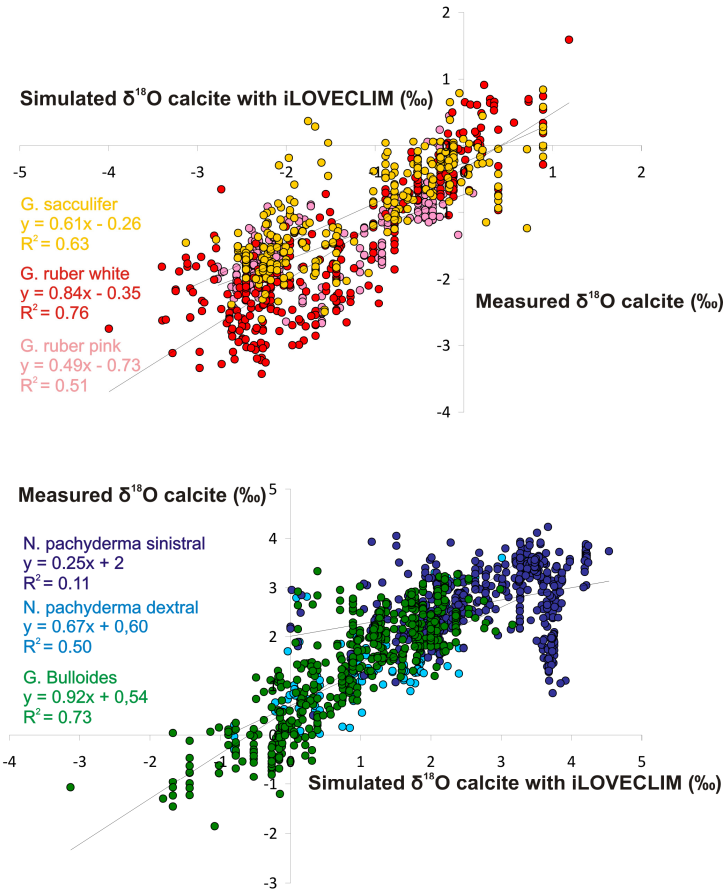
We mention these points in the revised version : "Applying this data-model comparison for calcite δ18O in past climate could constitute an interesting tool for mapping the potential shifts of the frontal systems and circulation changes through time, *assuming that changes in foraminiferal habitat depth (Telford et al., 2013) and salinity-temperature relationship in oceanic fronts stay relatively stable with time*. Previous data studies on the amplitude of the calcite δ18O have documented hydrographic changes during the 8.2 kyr event, the Younger Dryas event, Heinrich events and the Last Glacial Maximum (LGM) (Cortijo et al., 2005; Eynaud et al., 2009).

Changes in habitat depth and seasonality are also at the heart of the forward models of planktonic foraminifera, for example, by Schmidt and Mulitza (2002), Fraile et al. (2007, 2008). It comes as a surprise that their effects should only be of second order. Indeed, the correlation between modeled and reconstructed calcite O-18 may be deceiving – it may only be relatively large ($R^2$ = 0.85) because various species are lumped together (Fig. 5). When individual species are considered, the correlation is considerably weaker (Fig. 7 – the numbers are hard to read and warrant a table). The correlation for individual species may be well influenced by factors such as species-specific habitat depth and seasonality.

It is true that the correlation regressions are less significant when individual species are considered and it may be the influence of factors such as species-specific habitat depth and seasonality. We mention this point in the revised version:
In the abstract: "Our results indicate that temperature and the isotopic composition of the seawater are the main control on the fossil δ18O signal recorded in foraminifer shells at the global and regional scales *when all species are grouped together*. *Depth habitat, seasonality and other ecological effects play a more significant role when individual species are considered."*
In the text: *"We also note that when individual species are considered, the correlation is weaker compared to when species as grouped together (Table 1 and Fig. 7). This probably reflects the stronger influence of species-specific habitat depth, seasonality and other ecological effects (Bemis et al., 1998; Schmidt and Mulitza, 2002; Fraile et al., 2007; 2008). In addition, biases linked to sedimentation and post-deposit effects such as bioturbation or dissolution (Waelbroeck et al., 2005) can also play a role."*
In the conclusion: "Our results indicate that temperature and the isotopic composition of the seawater are the main control on the fossil δ18O signal recorded in foraminifer's shells at the global and regional scale. *Nonetheless, depth life, seasonality and other ecological effects play also a role and are more expressed when individual species are considered. Further works with more sophisticated ecological models are needed to refine these conclusions and increase the quantitative match of the modelled calcite δ18O results with data."*

In this connection, listing the various habitat depths is useful, but may be better presented in a table. Fig. 7 in particular should be enlarged and all font sizes increased to make it readable. The manuscript also requires slight proof-reading with respect to wording and spelling.

We list the various depths habitat in a new table 1. Fig. 7 has been enlarged (three regression on one graph) and all font sizes increased to make it readable. We also realize slight proof-reading with respect to wording and spelling as recommended by the reviewer 2.




New Figure 7

Apparently, the effect of a temperature bias in the deep ocean was also described by Paul et al. (1999). These authors relate a warm bias to the representation of vertical (isopycnal) mixing. The authors of the present manuscript should similarly analyze the source of their cold bias.

We were not aware of the cold bias before computing d18O calcite in the model. We are investigating the source of the cold bias, but so far it remains difficult to remedy. It is apparently linked to the deep southern-sourced water masses and might be related to the brines rejection and deep water formation. It is beyond the scope of the present study to solve this issue but is a clear case of the advantage of water isotopes to decipher model-data mismatches where temperature measurements are scarce.
We added in the revised version: "*The caveat for the deep ocean temperature with the model is unclear so far and would be the matter of future investigation. We hypothesize that it is link to the deep water formation in the Southern Ocean since it shows a marked underestimation in that region.*"

To my knowledge, the correct citation of the MARGO synthesis of SST reconstructions for the LGM should be MARGO Project Members (2009), as opposed to Waelbroeck et al. (2009) (this usage would be similar to the citation of the older CLIMAP synthesis of SST reconstructions for the LGM).
We cite MARGO Project Members (2009) in the revised version.