Response to reviewer 1

We are grateful for the constructive feedback provided by the reviewer 1 that help to significantly improve our manuscript. Below, we present a point-by-point response to the individual comments raised. A final version of our point-by-point response will be given at the end of the discussion phase with responses to all reviewers' comments.

Reviewer comments are shown in red color, with our responses in black.

Caley et al. calibrate planktic $\delta^{18}O$ from core tops to surface density and assess the uncertainty via Bayesian modelling. The authors test the calibration with the results of isotope enabled models and apply the method to foraminiferal $\delta^{18}O$ values from the Last Glacial Maximum and the late Holocene. The attempt to translate $\delta^{18}O$ directly into density is certainly worthwhile since we have probably an order of magnitude more $\delta^{18}O$ data available compared to combined $\delta^{18}O$/temperature reconstructions. However, the paper has methodological and transparency issues that need to be addressed.

1. Representation of mean ocean density. There are surface density changes related to local/regional SST and SSS changes and mean ocean density changes related to ocean volume. Part of the local/regional density changes will be related to mean ocean salinity due to volume changes with sea level. For example, Duplessy et al. (1991) estimated that the smaller LGM ocean volume led to ~1 psu higher salinity (and hence a significantly higher global ocean LGM density). In principle, foraminiferal $\delta^{18}O$ contains information on sea level via the ice effect (albeit with a higher slope as usual evaporation -precipitation changes). The $\delta^{18}O$ ice effect, however, is removed before the LGM density reconstruction. Can the LGM reconstructions really reflect absolute density or have the authors rather reconstructed the density changes due to local/regional changes in SST and SSS? Perhaps I am missing something here, but in my view the mean ocean density changes corresponding to mean ocean salinity changes due to ice/ocean volume changes have to be added to the LGM values since the used foraminiferal isotope data do not contain this information and the method does not account for it. This point requires further clarification.

We thank the reviewer for this thoughtful comment and we agree with the reviewer that this point requires further clarification in our paper. What we reconstructed are indeed the density changes due to the hydrographic changes in SST and SSS (the local/regional SST and SSS changes mentioned by the reviewer). To determine mean ocean density changes related to ocean volume we used model simulations results (ECHAM/MPI-OM and iLOVECLIM) and added or removed 1 psu salinity in global salinity outputs. Note that adding or removing 1 psu of salinity at LGM in climate model simulations have only small effects on ocean dynamic. Indeed, the effect is due to the small non-linearity in the sea-ice freezing, hence generating small differences in regions of sea ice and deep water formation. We have tested it in new simulations performed with the iLOVECLIM model and found the dynamical effect of that 1 psu in the regions we are analyzing to be very small (not shown). We also added or removed 1 ‰ in the ocean $\delta^{18}O_{sw}$ reflecting the global mean ice-sheets contribution.

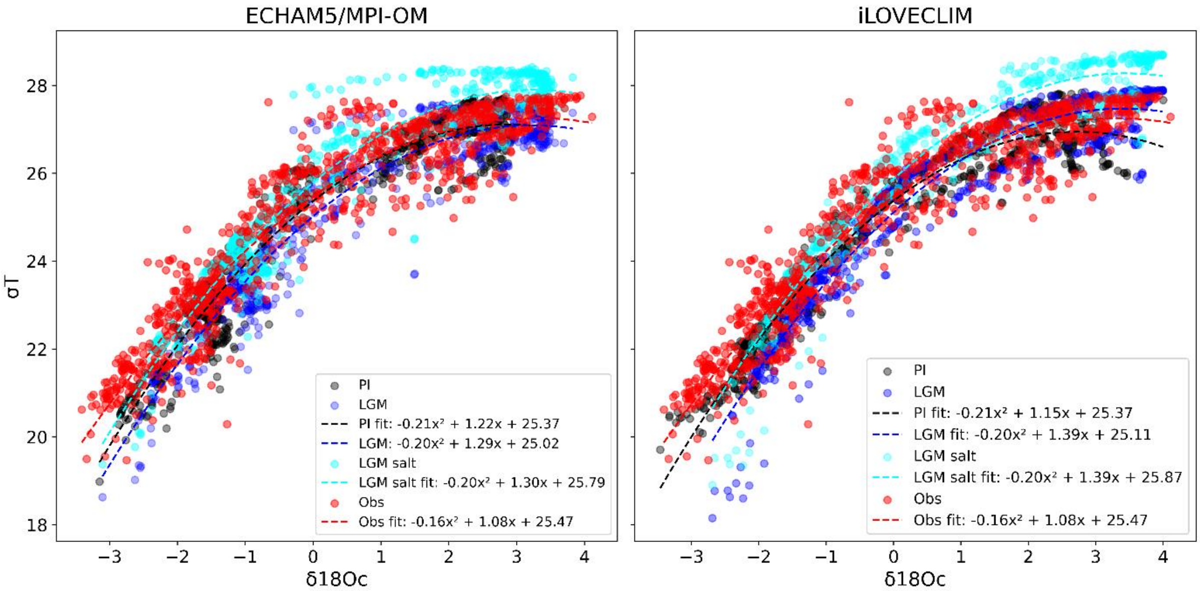


Figure a1: δ^{18}Oc-density relation based on observations (red), PI (grey) and LGM without (blue) and with + 1 psu in salinity (cyan) in model simulations.

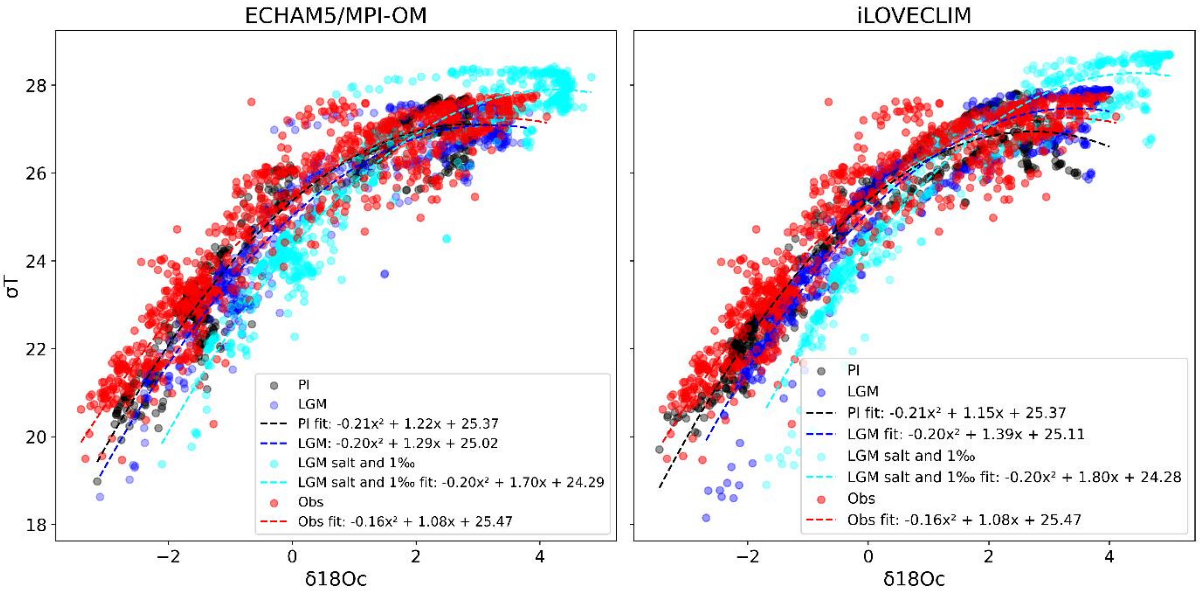


Figure a2: idem than Figure a1 but cyan color indicates with + 1 psu salinity and +1 ‰ δ^{18}Osw in model simulations.

In Figure a1 we observe how a change in + 1 (cyan color) or – 1 (blue color) psu salinity in model simulations affect the surface density at the LGM and so the δ^{18}Oc-density relation. In Figure a2, the cyan colour data show the δ^{18}Oc-density relation at the LGM (with + 1 psu salinity and +1 ‰ δ^{18}Osw) contrary to Figure a1 that only contain + 1 or – 1 psu salinity in model simulations. The δ^{18}Oc-density relation at the LGM (with + 1 psu salinity and +1 ‰ δ^{18}Osw, cyan colour) can be used to estimate LGM density. To reconstruct absolute density at the LGM with the observed relation (red color on Figures a1 and a2), we can remove the δ^{18}O ice effect (1‰) but need to add mean ocean density changes corresponding to mean ocean salinity changes due to ocean volume changes (Figure a1). If not added, we indeed reconstruct the density changes due to hydrographic changes in SST and SSS (the local/regional SST and SSS changes mentioned by the reviewer).

We calculated mean ocean density changes corresponding to mean ocean salinity changes due to ocean volume changes by adding or removing +1 psu of salinity during the LGM in model simulations (Figure b).

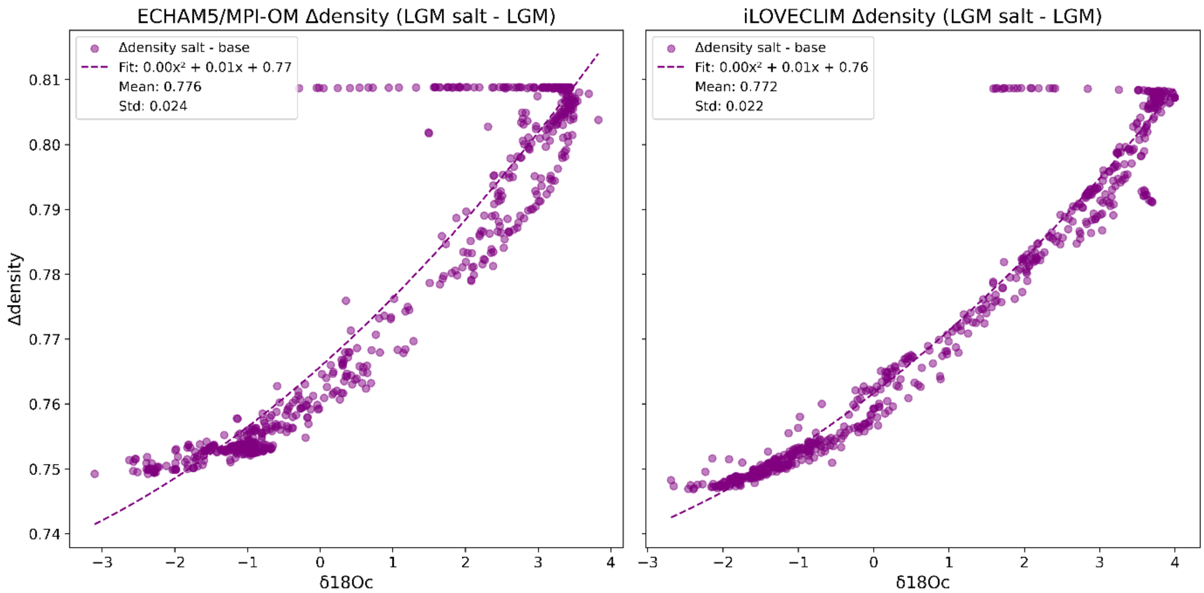


Figure b: surface ocean anomaly of density when +1 psu is added or removed during the LGM at the location of our core top observations used in our calibration

Figure b shows the surface anomaly of density when +1 psu is added or removed during the LGM at the location of our core top observations used in our calibration. Both model simulations agree and yield a mean ocean salinity effect on density of 0.776 ($\sigma = 0.02$) for ECHAM/MPI-OM and 0.772 ($\sigma = 0.02$) for iLOVECLIM.

We also performed a calculation to estimate this effect based on observation (reference state based on present day observation and LGM state based on Tierney et al., 2020 for SST and Duplessy et al., 1991 for SSS). To calculate uncertainties, we uses a bootstrap simulation approach (uncertainties of ± 0.1 g/kg for salinity and of ± 0.2 °C for temperature) to estimate the isolated effect of increased salinity on surface seawater density under Last Glacial Maximum (LGM) conditions (10,000 samples of temperature and salinity anomalies are randomly drawn using a uniform distribution to reflect plausible variability).

Reference State Definition: Modern ocean conditions are used as a baseline: surface salinity of 34.7 g/kg and temperature of 13.85 °C.

Perturbation Parameters: A salinity anomaly of +1 g/kg ± 0.1 is applied (Duplessy et al., 1991). A surface temperature anomaly of −2.9 °C ± 0.2 simulates cooler LGM conditions (Tierney et al., 2020).

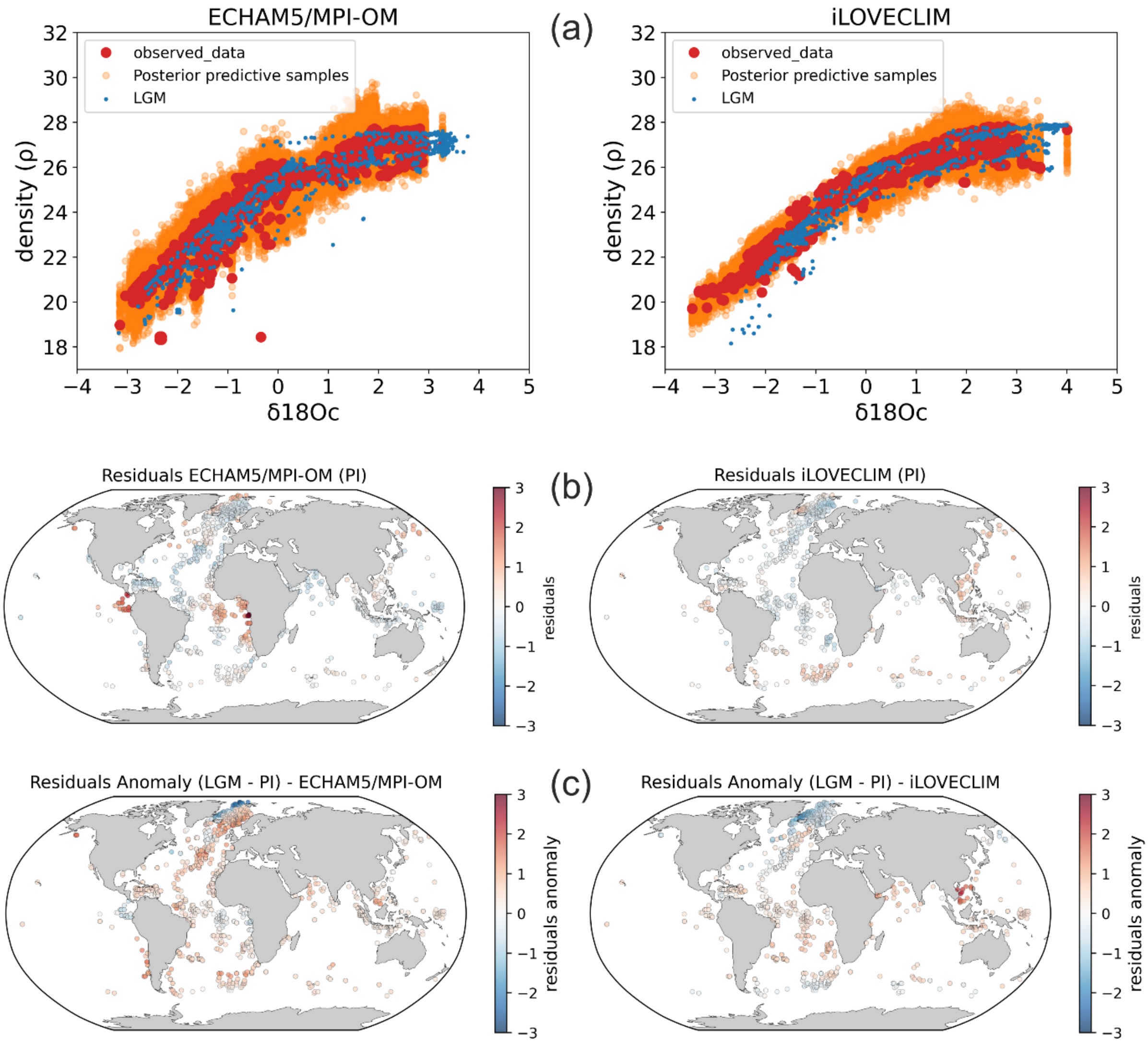
Results of mean surface density anomaly corresponding to mean ocean salinity changes due to ocean volume changes (LGM context): 0.772 kg/m³ 95% confidence interval: (0.698 to 0.845) kg/m³.

Results and uncertainties are in very good agreement with model simulations results (Figure b).

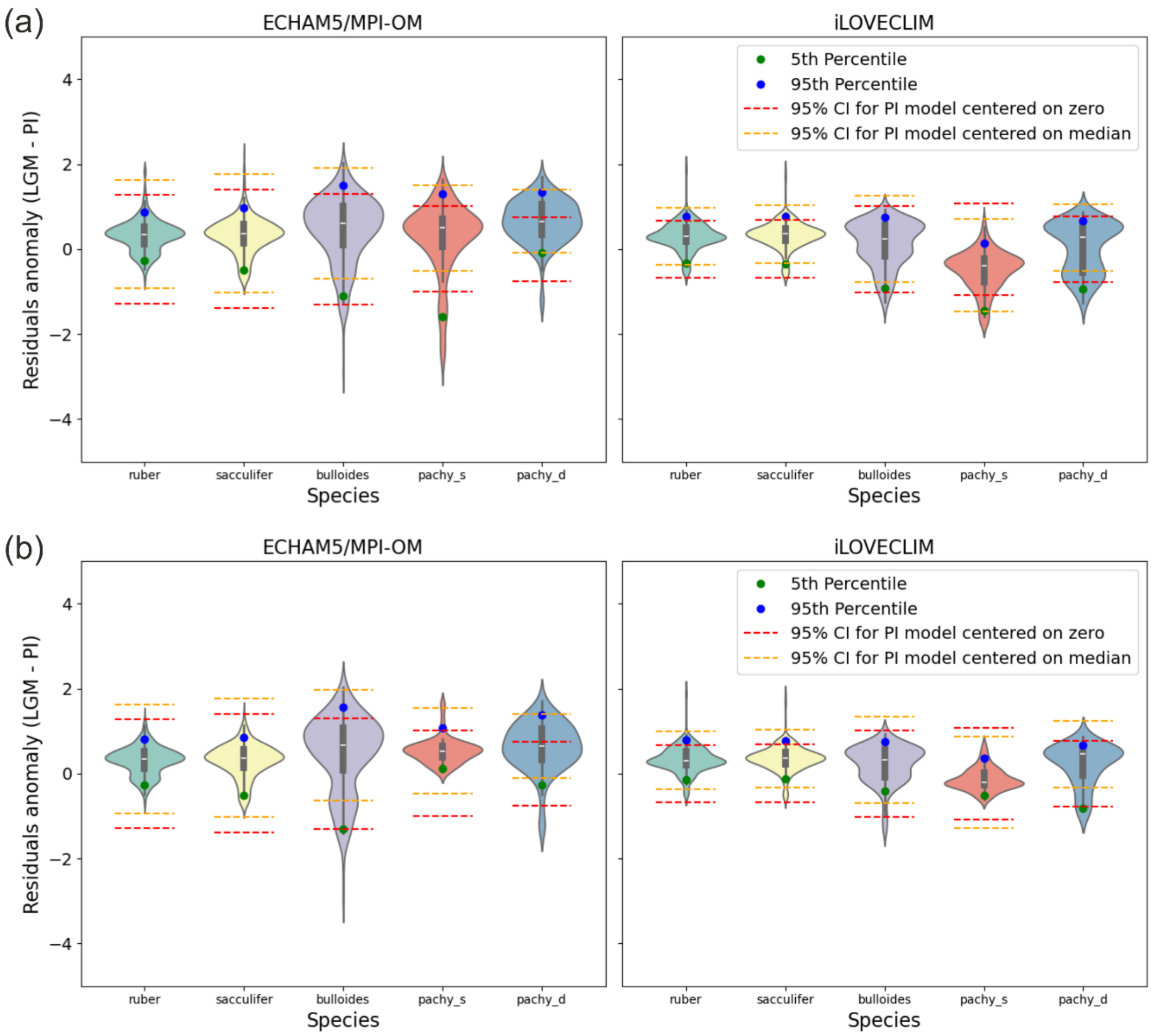
Therefore, depending of what we want to reconstruct, absolute density or density changes linked to hydrographic changes in SST and SSS (the local/regional SST and SSS changes mentioned by the reviewer), we need or not to have an additional correction. For absolute density, an additional correction is necessary, estimated to be equal to 0.77.

We will therefore add a new section “Reconstruction of absolute density” to the text before section “3.2 LGM annual surface density reconstruction” in which we will explain that around +0.77 needs to be added to obtain absolute surface density values.

In part 3.2 we will propose the reconstruction of absolute density together with the density changes due to hydrographic changes in SST and SSS (the local/regional SST and SSS changes mentioned by the reviewer) for comparison and discussion (including a revised version of Figure 7).



Revised Figure 5: Stability of foraminifera δ^{18}Oc-density relations between PI and the LGM calculated with FAME and forced by global ECHAM5/MPI-OM (left panels, Werner et al., 2016) and iLOVECLIM (right panels, Caley et al., 2014) hydrographic data. (a) PI Bayesian regression models between foraminifera δ^{18}Oc and annual surface density. Data in the PI experiments have been selected at the same locations as observations (Fig. 1). Posterior predictive samples and LGM density prediction are visible. (b) Density residuals (predicted - observed) for the PI experiments. (c) Density residuals anomaly between LGM and PI. Results for the Mediterranean Sea have been excluded because of its difficulty to be simulated and inconsistency between the two model simulations because of their different grid resolutions. Annual mean temperature and δ^{18}Osw were used for the iLOVECLIM experiment whereas monthly temperature and δ^{18}Osw were used for the ECHAM5/MPI-OM experiment.



Revised Figure 6: probability distributions of surface density residuals anomaly (LGM - PI). (a) global data and (b) without Nordic Seas (north of 40°N). North Indian Ocean data for iLOVECLIM have been removed in both cases.

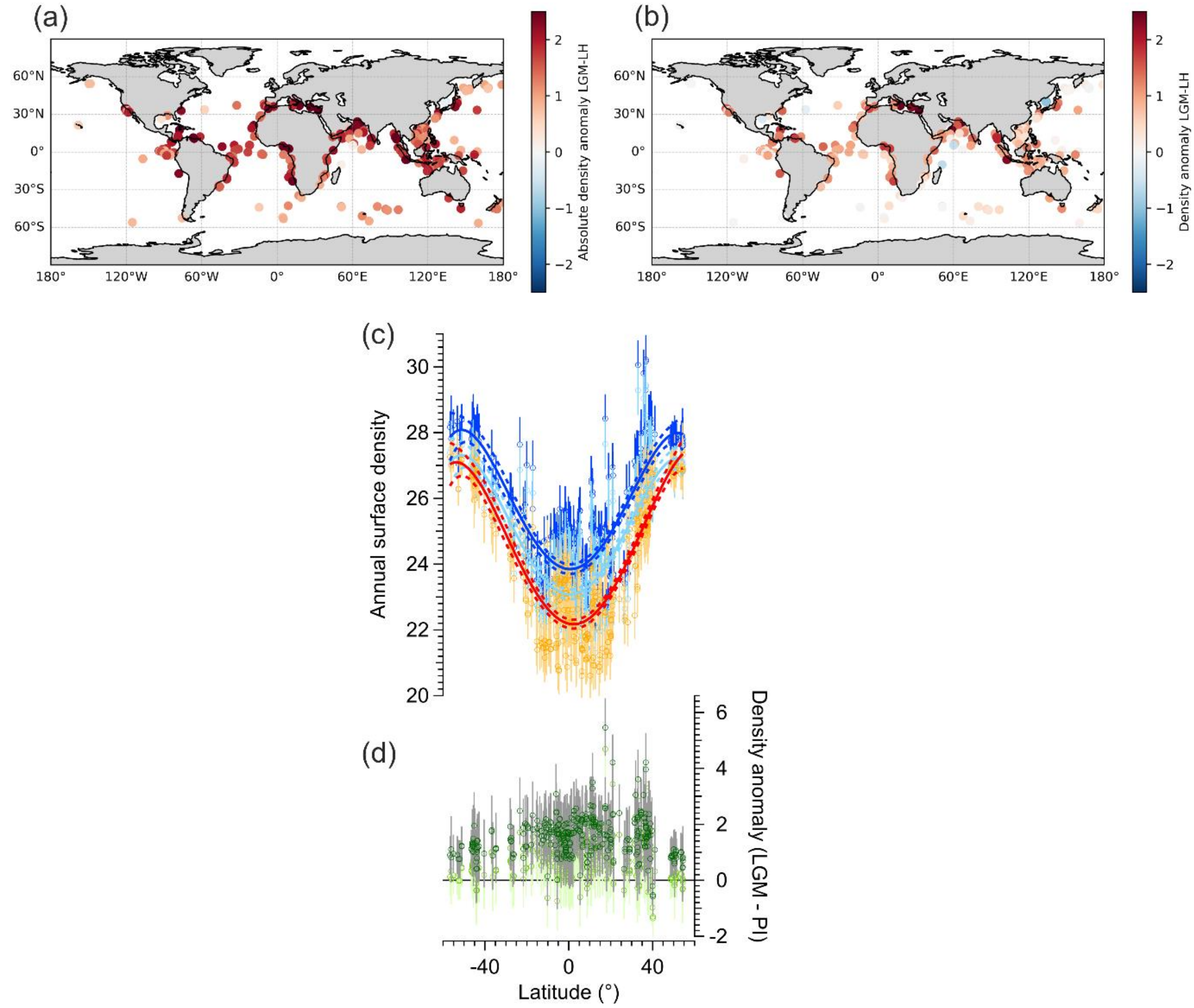


Figure 7 revised: reconstructions of LGM and LH annual surface ocean density from foraminifera δ^{18}Oc. (a) Spatial distribution of the LGM - LH absolute density anomaly. (b) Spatial distribution of the LGM - LH density changes due to hydrographic changes in SST and SSS. (c) Meridional gradient of reconstructed surface annual LGM density (absolute density in dark blue, density due to hydrographic changes in light blue) and comparison with LH reconstructions (red and orange colors). Error bars for each data point represent the 68 % C.I. A polynomial fit (5th degree) and associated 95% confidence bands are shown as solid resp. dashed lines. (c) Meridional gradient of reconstructed density anomaly (LGM - LH) for absolute density in dark green and density due to hydrographic changes in light green and associated 68 % C.I (grey lines).

2. Uncertainty of density reconstruction. With respect to the previous point, the uncertainty in the density reconstruction due to ocean volume changes should be implemented into the error analysis.

Based on our new analyses this uncertainty is very small (**less than 0.1 in observations and model simulations,** see discussion before and Figure b) in comparison to uncertainties in the Bayesian calibration (see Figure 2 of our paper). We performed a sensitivity test based on our LGM database for three different foraminifera species. We used a method for propagating uncertainty in density estimates through bootstrapping. It allows for the calculation of confidence intervals (CIs) that account for this additional uncertainty (estimated here to be 0.1), resulting in updated confidence intervals for the uncertainties of absolute densities (Tables 1 and 2).

Species	**Mean density (ρ)**	**CI Low 80%**	**CI High 80%**	**CI Low 95%**	**CI High 95%**
pachy_s	25.72	25.11	26.35	24.78	26.68
ruber	24.19	23.25	25.13	22.74	25.67
bulloides	26.18	25.08	27.31	24.47	27.90

Table 1: initial density prediction and uncertainties for an example of three different foraminifera species.

Species	**Mean density (ρ)**	**CI Low 80%**	**CI High 80%**	**CI Low 95%**	**CI High 95%**
pachy_s	25.72	25.09	26.36	24.75	26.72
ruber	24.19	23.21	25.16	22.71	25.69
bulloides	26.18	25.04	27.30	24.45	27.88

Table 2: density prediction and uncertainties for the same example of three different foraminifera species but adding the uncertainty in the density reconstruction due to ocean volume changes.

Our sensitivity test of uncertainties propagation through bootstrapping indicates that the uncertainties in the density reconstruction due to ocean volume changes can be neglected.

With respect to the uncertainty of $\delta^{18}O$ seawater reconstructions (line 72-75), I recommend citing the work of Schmidt (1999), because this author provides a reliable error estimate for $\delta^{18}O$ sea water reconstructions.

Ok, done

Also, I miss an assessment if the total error of the method is small enough to distinguish glacial densities from the modern ones, particularly if the global warming bias in the modern reference data is considered.

Uncertainties given in Figure 2 of our paper (uncertainties at 1 sigma) can be compared to changes in density in our submitted or revised Figure 7. It is dependent on the species considered but is comprised between around 0.48 and 0.86 (at 1 sigma), for reconstructed density changes due to hydrographic changes in SST and SSS (the local/regional SST and SSS changes mentioned by the reviewer) that vary between around 0 and 3 and absolute density changes between around 0.8 and 3.8 (see revised Figure 7). Note that when absolute density is considered, the signal/noise ratio increases because density increases at the LGM (by around 0.77) but the uncertainties is similar (see our estimation discussed before). **So yes, the total error of the method is small enough to distinguish absolute glacial densities from the modern ones.**

Regarding a potential global warming bias in the modern reference data.

For the Multi Observation Global Ocean Sea Surface density product (Droghei et al., 2016; 2018, cmems), we used the period 1993-2003 for our calibration but the temporal extent is only from 1993 to 2025 so we cannot investigate if older historical period can lead to different densities compare to a period more affected by the global warming. As suggested by the reviewer in point "**8. Global warming in modern hydrography**", There might be products like the World Ocean Atlas that integrate over longer time periods and therefore contain less global warming signals. We therefore investigate WOA18 observations and compare the available periods 1995-2004 (closest period to the one we use for the calibration) and the period 1955-1964, the oldest one proposed for WOA18 and susceptible to be less affected by global warming effect (Figure c).

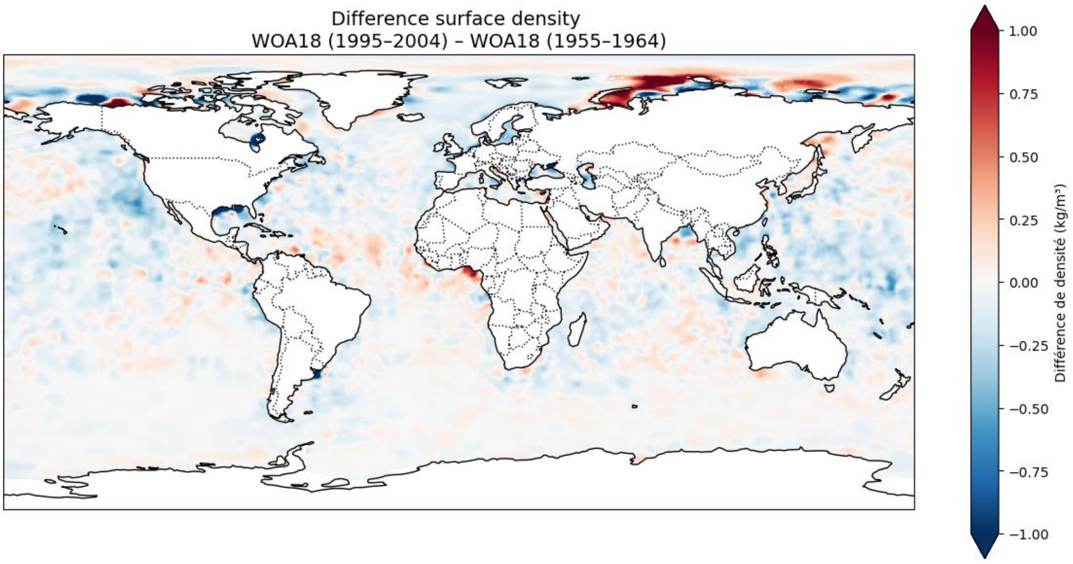


Figure c: difference in surface density (WOA18 1995-2004 – WOA18 1955-1964)

Results highlights no clear effect of the global warming bias, it seems more related to uncertainties in the density product (quality and number of observations) than the global warming bias.

At observation locations (Figure d), the effect of the global warming is very week, except maybe in the equatorial East Atlantic but again this could be related to uncertainties in the density product rather than a global warming effect, as highlighted in Figure e for this region.

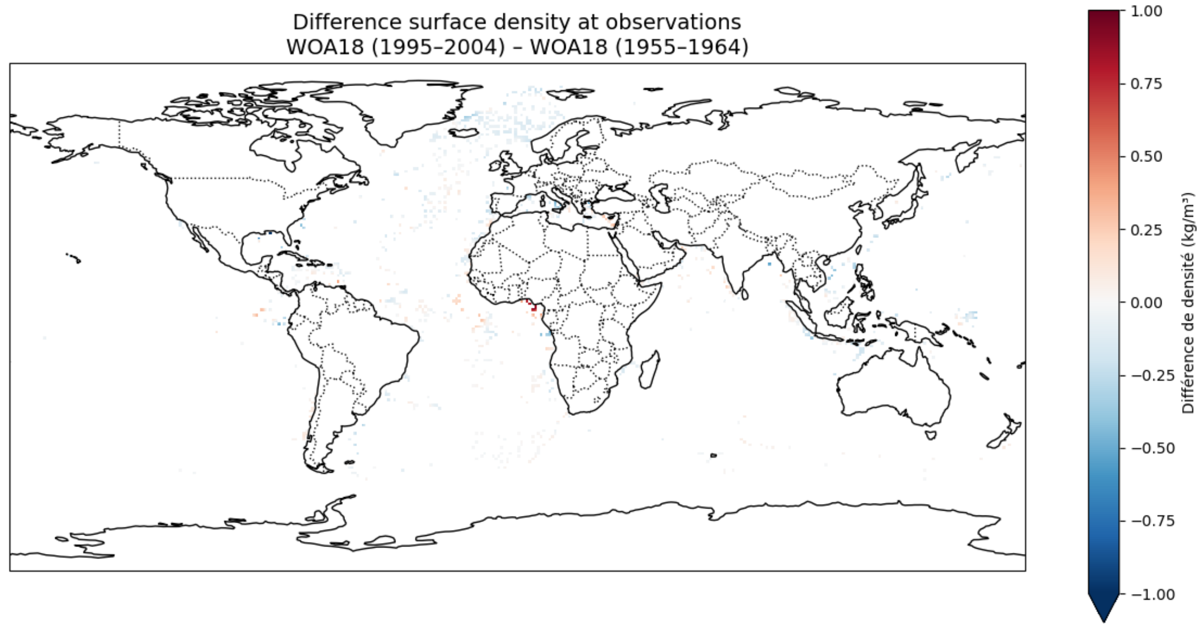


Figure d: difference in surface density (WOA18 1995-2004 – WOA18 1955-1964) at observation sites.

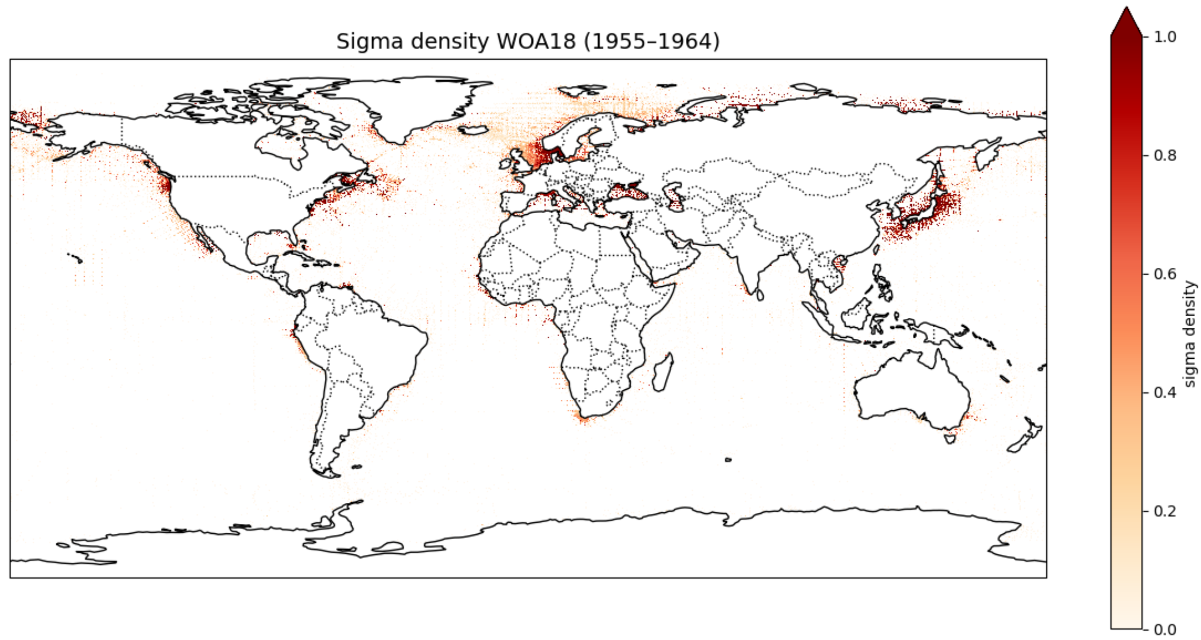


Figure e: The standard deviation about the statistical mean of surface density in each grid-square (WOA18 1955-1964).

To clearly demonstrate that a potential global warming bias in the modern reference data has no significant influence on our final density prediction, we realized a new Bayesian calibration with WOA18 (period 1955-1964) as the modern reference data and compared it with our previous calibration (cmems, period 1993-2003) (Figures f and g).

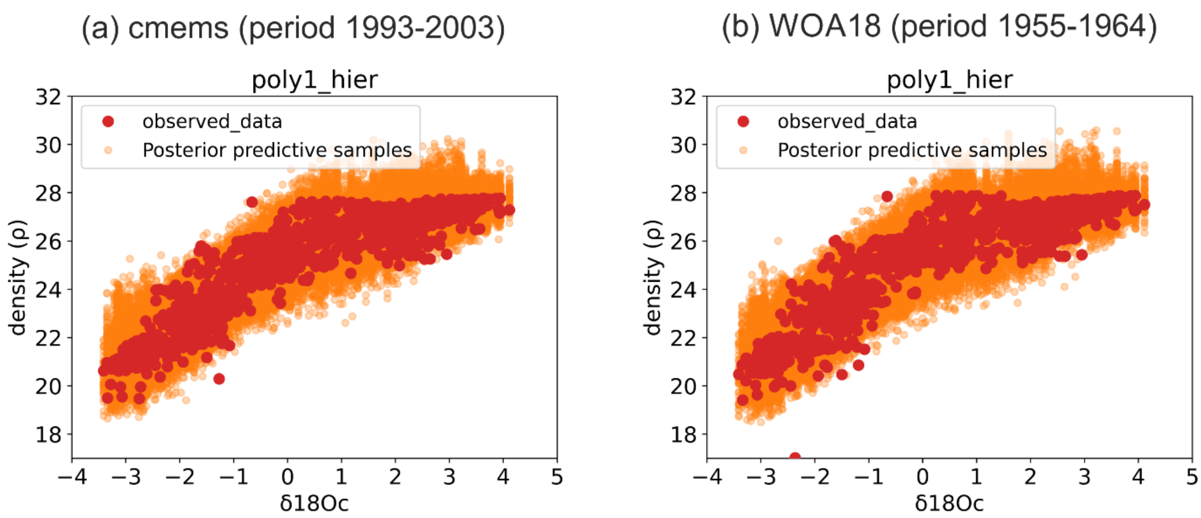


Figure f: Bayesian calibrations with (a) cmems density observations (period 1993-2003) and (b) with WOA18 density observations (period 1955-1964).

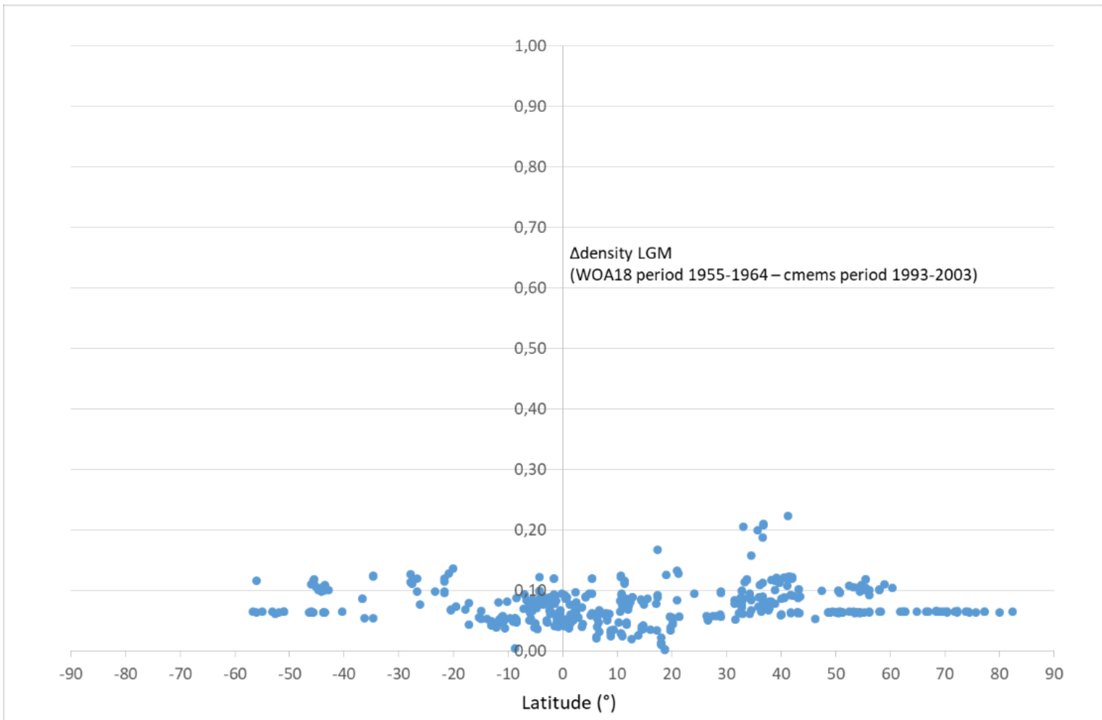


Figure g: Difference in density at LGM predicted using WOA18 (period 1955-1964) observations for the calibration – predictions using cmems observations for the calibration (period 1993-2003).

We observe (Figures f and g) differences that are generally lower than 0.1 and of maximum 0.2 kg/m³. Similar results are obtained for the confidence interval calculated. As already demonstrated in response to point 2 of the reviewer, these differences can be considered as uncertainties that can be neglected.

Therefore, the type of density product (WOA18 versus cmems observations) and the time period considered (period 1955-1964 versus 1993-2003) have no significant impact on our Bayesian calibration models and associated LGM density predictions within the estimated uncertainty.

3. Ice effect correction. The authors cite an ice effect correction of either 1.0 (line 365) or 1.05 (line 421). Please clarify why different numbers have been used or correct. I also find it appropriate to cite Labeyrie et al. (1987) (see their Fig. 5) in this context, as they for the first time provided robust evidence for an ice effect on the order of 1 o/oo.

Yes, we keep 1.0 ‰ and we added references of Schrag et al., 2002 and Labeyrie et al. (1987).

4. Transparency. The documentation of the data sources is not sufficient. For the LGM compilation the authors mention „additional data“ which are not specified anywhere in the paper. In the „Code and data availability“ section, it is stated that „The additional LGM and δ18Oc dataset will be available as a supplement“. Unfortunately, the supplement is not available to me. The „Obligations to authors“ states that „ A paper should contain sufficient detail and references to public sources of information to permit the author's peers to replicate the work.“ As a reviewer, I am unable to replicate the work because neither the data/supplement nor all the sources are available to me. Also, „Copernicus Publications requests depositing data that correspond to journal articles in reliable (public) data repositories, assigning digital object identifiers, and properly citing data sets as individual contributions“ (from https://www.climate-of-the-past.net/policies/data_policy.html). I strongly suggest that the authors adhere to this policy.

All the data and the code for the Bayesian calibrations will be available after publication. We refrained to share these data at the stage of the preprint because the data will be publicly available but still not validated and accepted for publication. We understand and agree that the reviewers should have access to these data before publication, so we will propose a link that will be shared with the editor if the reviewers want to have access to the code and data.

5. Transport of foraminiferal shells with currents. Currents can transport foraminiferal shells and the isotope signals they carry over relatively large distances. Based on typical current speeds, it can be estimated that planktic foraminifera may be transported several degrees latitude within their lifetime. While one can argue that the effects will be minimal because the ambient water mass is transported with the shells, discrepancies between recorded $\delta^{18}O$ and calculated $\delta^{18}O$ may occur if foraminifera/water masses are subducted, if water masses are mixed or in the vicinity of fronts, with the filaments from upwelling regions or close to freshwater plumes. I suggest that the authors consider and discuss shell transport/expatriation in addition to seasonality and vertical migration.

We agree that transport of foraminifera shells by currents is one additional process that can potentially lead to discrepancies between recorded $\delta^{18}O$ and calculated $\delta^{18}O$ or hydrographic data. However, as mentioned by the reviewer, one can argue that the effects will be minimal because the ambient water mass is transported with the shells. Indeed, our comparison between simulated $\delta^{18}Oc$ and core tops observations (Figure 4) indicates that this effect would be weak.

In addition, this effect is implicitly included in the uncertainty. We assume here that this is a stochastic process that will lead sometimes to a positive and sometimes to a negative error, which accordingly inflates the credible intervals of our predictions.

We propose to add few sentences to explain this potential additional effect in the paragraph dealing with all potential influences on the $\delta^{18}Oc$ signal in addition to temperature and $\delta^{18}Osw$ (lines 88-99).

6. Abstract. „We developed the use of the $\delta^{18}Oc$ of planktonic foraminifera as a surface paleodensity proxy for the whole ocean...“. As the authors show obviously not for the Nordic Seas and hence not for the global ocean surface.

Ok, we changed this for "We developed the use of the $\delta^{18}Oc$ of planktonic foraminifera as a surface paleodensity proxy using Bayesian regression models calibrated to annual surface density".

7. Effect of mixing/bioturbation (line 91-95). The paper by Köhler and Mulitza (2024) mainly deals with the detection of the carbon ion effect, not with bioturbation. Bioturbation will have a significant effect on most core tops used in this study. At typical mixed layer depths of 5-10 cm, deglacial/glacial material will be mixed with the Holocene layer below a sedimentation rate threshold of about 2 cm/kyr (see for example Broecker, 1986), mid-Holocene material (including monsoonal related salinity/density changes) at even higher sedimentation rates. For most of the MARGO core tops, there seams to be a weak stratigraphic control.

This is an issue that affects all core-top calibrations (see for example Malevich et al., 2019). However, our comparison between simulated $\delta^{18}Oc$ and core tops observations (Figure 4) indicates that this effect should be weak. If mixing/bioturbation effect was dominant, since there is no bioturbation in model simulations, we would expect no agreement on Figure 4 ($R^2 = 0.9$).

In addition, this effect is implicitly included in the uncertainty. We assume here that this is a stochastic process that will lead sometimes to a positive and sometimes to a negative error, which accordingly inflates the confidence intervals of our predictions.

Moreover, the MARGO core top data set only contains cores for which bioturbation is not severe. In low sedimentation cores, bioturbation would lead to the mixing of glacial and interglacial shells which would in turn lead to abnormally heavy Holocene $\delta^{18}Oc$. In the MARGO data set, sediment cores with sedimentation rates lower than 5 cm/ky were discarded when planktonic $\delta^{18}Oc$ values were heavier than the SST vs ($\delta^{18}Oc$ - $\delta^{18}Ow$) regression value + 1 root mean square error (Waelbroeck et al., 2005).

8. Global warming in modern hydrography. The fact that all core top calibrations are affected by global warming (line 140) is not a good justification for its use. There might be products like the World Ocean Atlas that integrate over longer time periods and therefore contain less global warming signals. This issue should at least be discussed, since global ocean warming approaches the magnitude of the deglacial warming and the bias can be considerable.

This is a potential issue that affects all core-top calibrations (see for example Malevich et al., 2019, Tierney et al., 2019). But see our response to point 2. To clearly demonstrate that a potential global warming bias in the modern reference data has no influence on our final density prediction, we realized a new Bayesian calibration with WOA18 (period 1955-1964) as the modern reference data and compare with our previous calibration (cmems, period 1993-2003) (Figures f and g).

Therefore, the type of density product (WOA18 versus cmems observations) and the time period considered (period 1955-1964 versus 1993-2003) have no significant impact on our Bayesian calibration models and associated LGM density predictions within the estimated uncertainty.

9. Stability of the δ^{18}Ow salinity relationship. The authors have tested the stability of the δ^{18}O/salinity relationships with the results of model simulations for the LGM. I find the choice of the time slice not ideal. In the tropics and subtropics (the majority of the ocean area), the strongest precipitation changes (and hence changes in surface δ^{18}O and salinity) occur in the early to mid-Holocene with the strengthening of the Monsoon (see for example Weldeab et al. 2007). This is the time when I would expect changes in δ^{18}O of the freshwater endmember for example due to the amount effect and hence a potential instability of the δ^{18}O/Salinity relation. The authors should have access to isotope-enabled model runs representing the mid-Holocene (e.g., Shi et al. 2023, co-authored by M. Werner).

Our work is really focus on the LGM and so testing the stability of the δ^{18}O/salinity relationships for the MH and its potential effect on density predictions is rather out of the scope of this paper. We agree that it is interesting to put into context our results regarding other climate periods. Detailed analyses and work on other period such as the MH will be for the future. Nonetheless, we conducted some preliminary tests using isotope-enabled model runs representing the mid-Holocene (e.g., Shi et al. 2023) in order to demonstrate that additional uncertainties due to the evolution of the $\delta^{18}O_c$-density relationship with time are globally weak and that the new calibration has great potential to be applied to other past periods and to reconstruct the past temporal evolution of ocean surface density.

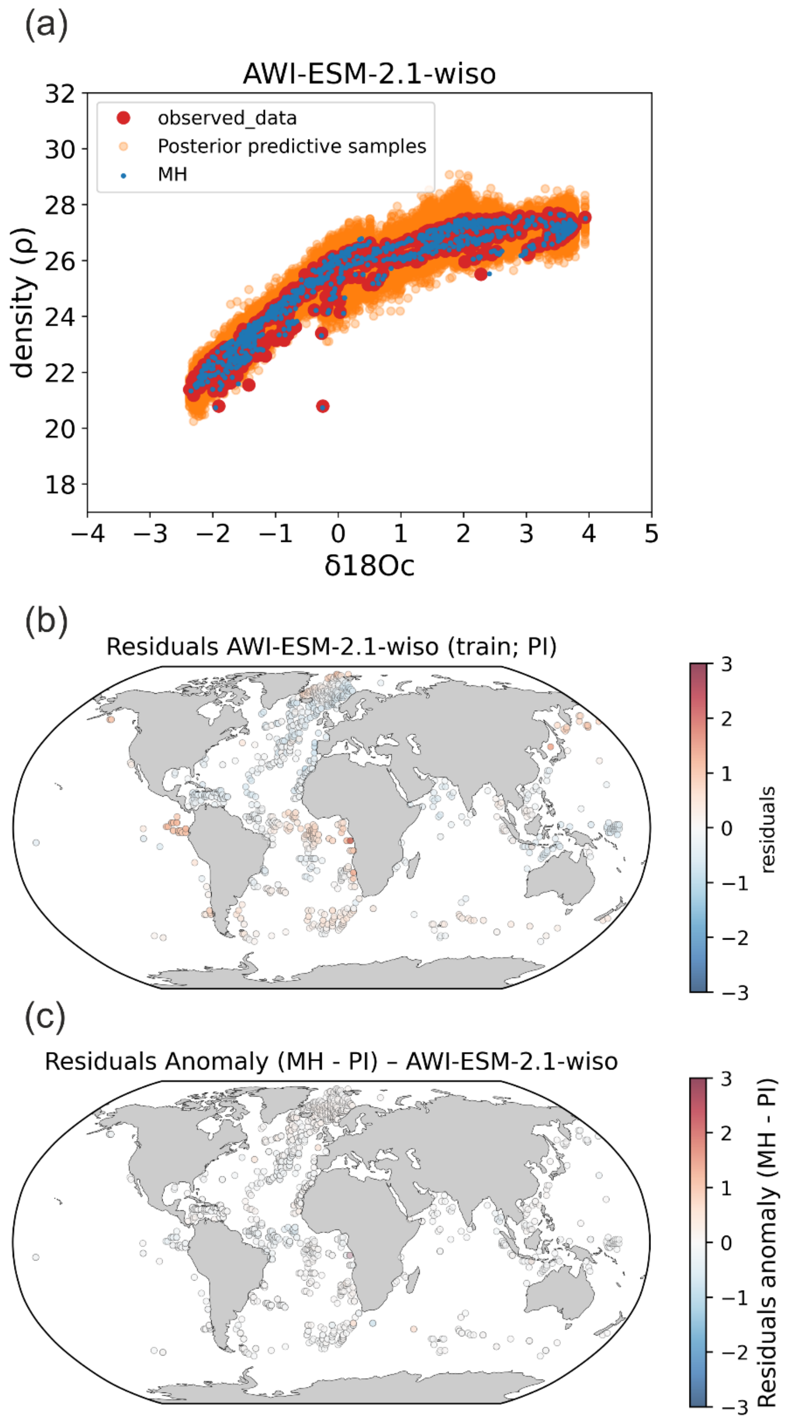


Figure h: Stability of foraminifera δ^{18}Oc-density relations between PI and the MH calculated with FAME and forced by global AWI-ESM-2.1-wiso (Shi et al., 2023) hydrographic data. (a) PI Bayesian regression models between foraminifera δ^{18}Oc and annual surface density. Posterior predictive samples and MH density are visible. (b) Density residuals (predicted - observed) for the PI experiments. (c) Density residuals anomaly between MH and PI.

Results of the Figure h clearly indicates a strong stability of foraminifera δ^{18}Oc-density relations between MH and the PI and so very weak influence of δ^{18}O/Salinity relation instability on final density predictions.

10. Direct comparison to modelled LGM density. Why has the LGM foraminiferal-based density reconstruction not directly been compared to modelled LGM density? The models are considered good enough to test the stability of the $\delta^{18}O$ salinity relation, why are they not good enough to compare with the density reconstruction directly?

This will be the focus of a detailed paper submitted very soon Barathieu et al.,. As mentioned in our paper in line 439-440: "Further regional analyses of ocean surface density and comparison with numerical climate models are presented in Barathieu et al. in prep."

We think that it would be interesting to have this detailed data-model comparison paper as a companion paper of our paper in CP if the editor agrees.

Broecker, W. S.: Oxygen Isotope Constraints on Surface Ocean Temperatures, Quat. res., 26, 121–134, https://doi.org/10.1016/0033-5894(86)90087-6, 1986.

Duplessy, J.-C., Labeyrie, L., Anne, Maitre, F., Duprat, J., and Sarnthein, M.: Surface salinity reconstruction of the North Atlantic Ocean during the LGM, Oceanologica Acta, 14, 311–324, 1991.

Labeyrie, L. D., Duplessy, J. C., and Blanc, P. L.: Variations in mode of formation and temperature of oceanic deep waters over the past 125,000 years, Nature, 327, 477–482, https://doi.org/10.1038/327477a0, 1987.

Köhler, P. and Mulitza, S.: No detectable influence of the carbonate ion effect on changes in stable carbon isotope ratios ($\delta^{13}C$) of shallow dwelling planktic foraminifera over the past 160 kyr, Clim. Past, 20, 991–1015, https://doi.org/10.5194/cp-20-991-2024, 2024.

Schmidt, G. A.: Error analysis of paleosalinity calculations, Paleoceanography, 14, 422–429, https://doi.org/10.1029/1999PA900008, 1999.

Shi, X., Cauquoin, A., Lohmann, G., Jonkers, L., Wang, Q., Yang, H., Sun, Y., and Werner, M.: Simulated stable water isotopes during the mid-Holocene and pre-industrial periods using AWI-ESM-2.1-wiso, Geosci. Model Dev., 16, 5153–5178, https://doi.org/10.5194/gmd-16-5153-2023, 2023.

Weldeab, S., Lea, D. W., Schneider, R. R., and Andersen, N.: 155,000 years of West African monsoon and ocean thermal evolution, Science (New York, N.Y.), 316, 1303–1307, https://doi.org/10.1126/science.1140461, 2007.

References:

Droghei, R., Nardelli, B. B., and Santoleri, R.: Combining In Situ and Satellite Observations to Retrieve Salinity and Density at the Ocean Surface, J. Atmos. Ocean. Tech., 33, 1211–1223, https://doi.org/10.1175/JTECH-D-15-0194.1, 2016.

Droghei, R., Buongiorno Nardelli, B., and Santoleri, R.: A new global sea surface salinity and density dataset from multivariate observations (1993–2016), Frontiers in Marine Science, 5, https://doi.org/10.3389/fmars.2018.00084, 2018.

Malevich, S. B., Vetter, L., and Tierney, J. E.: Global core top calibration of $\delta^{18}O$ in planktic foraminifera to sea surface temperature, Paleoceanogr. Paleoclimatol., 34, 1292–1315, 2019.

Schrag, D. P., Adkins, J. F., McIntyre, K., Alexander, J. L., Hodell, D. A., Charles, C. D., & McManus, J. F. (2002). The oxygen isotopic composition of seawater during the Last Glacial Maximum. *Quaternary Science Reviews*, *21*(1-3), 331-342.

Tierney, J. E., Malevich, S. B., Gray, W., Vetter, L., & Thirumalai, K. (2019). Bayesian calibration of the Mg/Ca paleothermometer in planktic foraminifera. *Paleoceanography and Paleoclimatology*, *34*(12), 2005-2030.

Tierney, J. E., Zhu, J., King, J., Malevich, S. B., Hakim, G. J., & Poulsen, C. J. (2020). Glacial cooling and climate sensitivity revisited. *Nature*, *584*(7822), 569-573.

Waelbroeck, C., Mulitza, S., Spero, H., Dokken, T., Kiefer, T., and Cortijo, E.: A global compilation of Late Holocene planktic foraminiferal $\delta^{18}O$: Relationship between surface water temperature and $\delta^{18}O$, Quaternary Sci. Rev. 24, 853–878, 2005.