

We would like to thank the two reviewers and Julien Emile-Geay for their feedback on our manuscript, which we have revised accordingly. Below we pasted the comments by the reviewers and provided our response in orange and proposed changes in italics. Line numbers below refer to the version with tracked changes.

Reply to reviewer 1

Jonkers and co-authors give an update on the PALMOD data base of marine paleotracers for the last 130 k. This is a necessary and significant update for the PALMOD data base. The previous version was limited to $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ from benthic foraminifera, Jonkers et al. now include planktic foraminifera stable isotopes, and other proxies such as Mg/Ca and carbonate and biogenic silica content. They also include temperature reconstructions for each of the sites. The authors claim to have merged age models with proxy data, assigning an age value to each downcore sample. This is a useful update, which saves users from the necessity to interpolate the age models to the data depth scales.

We would like to thank the reviewer for their positive evaluation of version 2 of the database.

I am worried by the presentation of the data. The authors choose two formats: R and LiPD files. However, the way they have structured the data makes it very hard to look at it at a glance. For R (.RDS) files R needs to be used. I am an advanced python programmer, and I wasn't able to quickly access the data. Both in R and LiPD the data sets of each coring sites were saved without column names, and I find no easy way to see a depth,age,proxy list on screen. I thought LiPD would be easier, since I know that inside a LiPD folder the data are saved as .csv, however, the problem is the same: There is no reference at each file to know what I am seeing. Of course, it could be that I am not knowledgeable enough to open these files. But I am myself a data person, so if I had a problem accessing the data base, it is reasonable to think that many other users will have issues too.

Thank you for this important feedback. From experience with the previous version of the database we learned that our prime user base works with R, but we acknowledge that this limits the use of the data with different softwares. For that reason, we also provide a LiPD version of the database that can be read using a wide range of softwares (including Python).

Palaeo(climate) data are inherently complex given the high demands on metadata and contextual information and the need for age-depth models (which are both uncertain and likely to change in the future). We fully acknowledge that this complexity may render reading the data somewhat difficult or non-intuitive. For this reason, we paid special attention to clearly describe the data structure and we provided links to online resources to facilitate reading and using the data. In the revised version we will update the links following the comment by Julien Emile-Geay and add additional detail in the text (L505–516).

Perhaps the issues with reading the data arose because of conversion from the specific R format to a Python readable format or failure to make use of the python utilities to access the

LiPD files. Both formats are structured similarly and the data are provided separate from the metadata (analogous to a netcdf file where the variable information is provided separately from the data and separate commands need to be used to access the metadata and the data). Importantly, the R-formatted data do contain column names (see screenshot below).

```

R 4.5.1 ~ /UniNextCloud/PalMod/R_database/database_scripts/PALMOD/
> site <- "GeoB3359_3"
> dat <- readRDS(paste0("~/Users/lukas/UniNextcloud/PalMod/PalMod_data_QC/PALMOD_v2_RDS_with_age/", site, "_age.RDS"))
> head(dat$data)
  meanAge_kaBP Age_kaBP_2.5percentile medianAge_kaBP Age_kaBP_97.5percentile depth_merged Age_ka_BP CaC03_percent TOC_percent bSi02_percent
1          NA                NA                NA                NA                NA          0.03      7.156          1.40          1.967          4.8
2          NA                NA                NA                NA                NA          0.08      7.400          1.50          1.892          NA
3          NA                NA                NA                NA                NA          0.13      7.644          1.27          1.895          5.1
4          NA                NA                NA                NA                NA          0.18      7.889          1.84          1.809          NA
5          NA                NA                NA                NA                NA          0.23      8.133          1.06          1.853          5.4
6          NA                NA                NA                NA                NA          0.28      8.378          1.25          1.678          NA

  SST_1_12_degC UK37_prime recal_UKSST_2.5 recal_UKSST_50 recal_UKSST_97.5
1          17.5      0.6215      14.08580      16.77813      19.57781
2          17.4      0.6182      13.96192      16.71961      19.47067
3          17.5      0.6215      14.01745      16.77948      19.56596
4          17.6      0.6248      14.14173      16.89350      19.62375
5          17.6      0.6248      14.17981      16.90338      19.63713
6          17.7      0.6281      14.30275      17.00807      19.76461
>

```

I recommend the authors to re-include netcdf files of each coring sites as part of the data base (they were included in the first version of the PALMOD database). These files are more universal than LiPD and R files, and readable by different software types. In addition, I recommend the authors to produce a more human-readable version of the data base. These could just be the csv files inside the LiPD directories, if we have in each file explicit information of what each column is. Otherwise, I am sad to say that this important data product will be useful for just a very few R and LiPD experts.

We appreciate the reviewers' concern about the complexity of the data, but unfortunately inclusions of rich metadata, chronological information, documentation of the age-depth modelling approach and posterior age-depth models and seawater temperature estimates render some complexity unavoidable. From our experience with version 1, we are confident that, with the documentation in the article and the online resources, the data synthesis is useful for a wide audience.

In the original manuscript we did not mention that the palaeodata and chronological information can be downloaded as human readable csv files on the lipdverse website. We made this clear in the revision and we hope that this addresses the concerns of the reviewer (L391–393).

The netcdf format is not specifically intended to accommodate the complexity of palaeodata and conversion to this format leads to loss of information (also mentioned in Jonkers et al. (2020)). In particular, the metadata won't be as easily queryable and there is no standard way to include the seawater temperature ensembles. The reason why netcdf files were included in version 1 was to ensure readability with the custom made software PDV (Langner and Mulitza 2019), but PDV is no longer actively maintained and as of yet no longer works on all platforms. Thus, given

the availability of the data in the universally readable json (lipd) format as well as existing online resources to interact with the data, we see no reason to offer a netcdf version of the synthesis too.

Comment from Julien Emile-Geay

Re: LiPD, perhaps this would help? <https://pylipd.readthedocs.io/en/latest/>. Also see examples of how to load the data into Pyleoclim for analysis here: https://linked.earth/PyleoTutorials/notebooks/L0_loading_to_series.html#loading-a-single-lipd-file

If, as you contend, the data tables are not properly formatted, then it might not. But otherwise, this will save all Python users a lot of trouble with this dataset.

Best,

J.E.G.

We would like to thank Julien Emile-Geay for pointing us to the new online documentation on how to handle LiPD files using Python. We updated the manuscript accordingly (L505–516).

Reply to reviewer 2

The article presents a major update to the first PALMOD synthesis, including many primary data compiled here for the first time. The manuscript is very well structured and the figures are very informative. I recommend publication after the following comments have been addressed.

Thank you for your positive evaluation of our manuscript and for the helpful suggestions for improvement.

Major Comment:

For the purpose of uncertainty propagation, it is tremendously useful that PALMOD 2 includes age-model ensembles, as well as “1000 ensemble time series of seawater temperature” whenever possible. However, a question arises as to how these two sources of uncertainty should be combined. Are all paths through the depth-age-SST space physically realizable, or do some result in unrealistically abrupt SST changes, or even reversals compared to what is observed in the raw data (for instance, Mg/Ca vs depth)? I do not know of a standard solution to this problem, but there are existing strategies to address it (e.g. Khider et al, 2017; doi:10.1002/2016PA003057); I believe it is worth raising here to ensure the best possible use of the data. It would be useful to add a figure showing the reconstructed SST history in one core, displaying quantiles of its distribution (e.g. 5%, 25%, 50%, 75%, 95%) through time, and sharing the associated code so that users can easily repeat this relatively rare analysis.

Thank you for pointing this out. We will include an example of such a joint uncertainty estimation following previous work (Cartapanis et al. 2022), but thank you for pointing us to the earlier paper by Khider et al.

We propose the following addition (starting L476):

The availability of age and nSST ensembles offers the possibility to estimate the joint chronological and calibration uncertainty of the seawater temperature estimates. A possible way to do so is through combining the age and nSST ensembles in a Markov Chain Monte Carlo approach (Cartapanis et al. 2022; Khider et al. 2017), by randomly joining ensembles (Fig. 8a). However, the large number of ensembles potentially renders this approach excessive and computationally expensive as 10^6 unique combinations of the ensembles are possible. A preliminary analysis suggests that 500 – 1,000 random combinations of age and nSST ensembles are sufficient to capture the combined age and calibration uncertainty (Fig. 8b). We caution however against universal application of this number as the distributions of age and calibration uncertainty likely vary by time series and different research questions may require different approaches. We hence encourage users to carefully consider the chosen number of ensemble combinations. Alternatively, the joint uncertainty may be quantified analytically, but such an approach needs to consider the potential complexity in the probability density distributions of chronological and calibration uncertainty.

We have added example code to the github page with PALMOD utilities and will mention this in the manuscript too so users can repeat the analysis.

As to the question whether all (joint) temperature trajectories are physically plausible, we think that in particular the temperature estimates may represent an overly pessimistic view of the associated uncertainty because both BaySPLINE and MgCaRB ignore the potential for temporal autocorrelation in temperature and in its uncertainty. We have flagged this issue in line 435 (*“It is important to note that the range of possible nSST trajectories may be overestimated as temporal autocorrelation in the temperature and its uncertainty are ignored in the calibration. Whether such autocorrelation would be preserved in sedimentary time series and how large the effect would be, remains to be investigated.”*), but note that both calibration schemes represent the current state of the art and we deem a revision of calibrations to be beyond the scope of this data descriptor article.

Minor Comments:

L113: “the updated radiocarbon curve”. We learn later in the text that it is IntCal20; it would be logical to cite it here.

We included this information in the revised version (L116–117).

L140: “estimates of their uncertainty” → estimates of uncertainty
Changed.

L227: “associated manuscript” → original publications (there may be more than one, and “manuscript” typically refers to a pre-publication form)
Changed..

L249: the reference to “convergence” will be unfamiliar to many readers; it may be worth explaining in more detail.
We added an explanation.

Table 1:

- “standardised parameter name” → what standard vocabulary was used here? If none was available or relevant, how did the authors choose to standardise?
For consistency we kept the vocabulary introduced in version 1.

- “CalibrationUncertainty”: does this refer to 1sigma, 2sigma, or something else?
This field has not been standardised and is provided as in the original publication (when available). We added this information and mention that it is, for nSST, superseded by the ensembles.

L273: “priority climate-relevant variables” → who decided on such priorities?

This is a good point and even though the selection approach is described in the data descriptor of version 1, we will briefly repeat it here. We propose to do so right at the start in the introduction. We added the following (L98–101):

These parameters were selected following discussions within the PALMOD project. They include physically and biogeochemically relevant parameters that can be directly compared with climate model simulations and for which reasonable spatiotemporal coverage could be achieved.

We have, for clarity, also removed “priority” in this context.

L329: “14 time series shorter than 1 kyr are not shown.” —> why are such series included at all? Is there any scientific use to be made of them in the context of this compilation?

Fair point. These time series can be considered a bycatch of the synthesis approach and are unlikely to be relevant for the evaluation of long transient climate model simulations. However, we chose not to impose any restrictions on length or resolution (see Jonkers et al (2020)) and leave it up to the user to define criteria for time series selection.

L359: “The majority ... is based” -> The majority ... ARE based
Both singular and plural are correct. Happy to change if needed.

L363: “LDI” this is a new acronym to me. Would it be useful including a citation?
We replaced LDI by “long chain diol index” and added a citation (L373).

L376: “Data is freely available” —> Data ARE freely available.
We have changed the wording.

L378/9: “We explicitly encourage users to also cite the original data when using this data product. “ Please provide an explicit example or two here, as I am not sure everyone would get the hint otherwise.
We added an example (L393–400).

L412/3: “To allow ..” -> this sentence is incomplete. It implies a second clause that never comes. Please rewrite.
Thank you for catching this omission. We rewrote the sentence.

L414: “different calibration (schemes)” -> please remove parentheses.
Done.

L418: “only in the form as reported” -> only in the form reported (no “as”)
We deleted “as”.

L444: “modelling strategies like for instance done in the “ -> modelling strategies like for instance used for the ...

The SISAL data product provides an example of such a comparison of different age-depth modelling strategies. We would like to highlight this aspect, not suggest that the same modelling strategies should be used. We have changed to text to make this point clearer (L474).

L451/2: Note that the for Python users, the relevant resource is now the PyLiPD package (<https://pylipd.readthedocs.io/en/latest/>), and associated tutorials (<https://linked.earth/pylipdTutorials/intro.html>).

Thank you for mentioning this, we updated the text accordingly (L505–516).

L456/7: “Users are encouraged to report those to the lead author so they can be corrected”. Can you perhaps add a line about the process for reporting errors (github issues?), the versioning scheme for corrections, and how they will be released?

We added the following (L521–523):

Users are encouraged to report those to the lead author by email so they can be corrected. Updates to the data synthesis will be published on PANGAEA and linked to the current version. Minor updates with corrections only will not be associated with a new data descriptor. The updating and versioning strategy is described in detail in Jonkers et al. (2020).

Question for the editor: does ESSD have a mechanism for issuing dataset corrections distinct from the standard Copernicus author correction?

L464: “metadata and chronology data is” -> metadata and chronology data are

We changed the wording.

L474: “invariantly” -> invariably

We changed the wording.

L481: “The lack of a standardised vocabulary and consistent ontology” -> what about the LinkedEarth ontology (<https://linked.earth/ontology/>), which is aligned to the LiPD scheme?

Re: “The lack of a standardised vocabulary”, the PaST Thesaurus qualifies in my book as a “standardised vocabulary”. Perhaps the authors mean that the two major data repositories (WDS-Paleo and PANGAEA) have yet to adopt the same vocabulary? If so, I agree that it is worth calling out, in hopes that they work more closely together (and the rest of the community) to make that happen.

Thank you for raising this point. We propose to replace the paragraph with the following (L553–564):

With the National Climate Data Center (NCDC) at NOAA and PANGAEA the palaeoclimate community has access to at least two dedicated data repositories that enforce standardisation and perform data curation. This is a tremendously advantageous position to facilitate the

reusability of palaeoclimate data and we explicitly encourage data generators to continue sharing their data through these recognised and specific data repositories. Nevertheless and despite the existence of the LinkedEarth ontology (<https://linked.earth/ontology/>, last access 20 January 2026) and the PaST thesaurus (Morrill et al., 2021), the lack of adaptation of a single standardised vocabulary and consistent ontology across the repositories also remains a consistent hurdle to reusability. The PaST thesaurus is used at NCDC (Morrill et al., 2021), but standardisation is only performed under the hood at PANGAE (Felden et al., 2023), where structured and standardised data can be accessed in xml format. Future synthesis efforts can benefit from such standardisation, but increased harmonisation across the repositories, or tools to do so, would further facilitate synthesis efforts and increase the reusability of data even more.

- Cartapanis, Olivier, Lukas Jonkers, Paola Moffa-Sanchez, Samuel L. Jaccard, and Anne de Vernal. 2022. "Complex Spatio-Temporal Structure of the Holocene Thermal Maximum." *Nature Communications* 13 (1): 1–11.
- Jonkers, L., O. Cartapanis, M. Langner, et al. 2020. "Integrating Palaeoclimate Time Series with Rich Metadata for Uncertainty Modelling: Strategy and Documentation of the PalMod 130k Marine Palaeoclimate Data Synthesis." *Earth System Science Data* 12 (2): 1053–1081.
- Langner, M., and S. Mulitza. 2019. "Technical Note: PaleoDataView -- a Software Toolbox for the Collection, Homogenization and Visualization of Marine Proxy Data." *Climate of the Past* 15 (6): 2067–2072.