

# 1 The PALMOD 130k marine 2 palaeoclimate data synthesis version 2

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## 9 Abstract

10 Palaeoclimate data hold the unique promise of providing a long-term perspective on climate  
11 change and as such can serve as an important benchmark for climate models. However,  
12 palaeoclimate data have generally been archived with insufficient standardisation and metadata  
13 to allow for transparent and consistent uncertainty assessment in an automated way. Thanks to  
14 improved computation capacity, transient palaeoclimate simulations are now possible, calling for  
15 data products containing multi-parameter time series rather than information on a single  
16 parameter for a single time slice. To confront transient simulations that span the last glacial-  
17 interglacial cycle with palaeoclimate data, we have compiled a multi-parameter marine  
18 palaeoclimate data synthesis that contains time series spanning 0 to 130,000 years ago. In  
19 2020 Jonkers et al. (2020) published the first version of the PALMOD 130k marine  
20 palaeoclimate data synthesis and described our data synthesis strategy and the contents and  
21 format of the data product in detail. Here we present a major update of the data product that  
22 markedly increases both the spatial and temporal coverage. Version 2 of the synthesis contains  
23 2,286 time series of eight palaeoclimate parameters from 475 individual sites, each associated  
24 with rich metadata, age–depth model ensembles, and information to refine and update the  
25 chronologies. Version 2 contains 468 time series of benthic foraminifera  $\delta^{18}\text{O}$ ; 357 of benthic  
26 foraminifera  $\delta^{13}\text{C}$ ; 423 of near sea surface temperature; 482 and 273 of planktonic foraminifera  
27  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$ ; and 128, 111 and 44 of carbonate, organic carbon and biogenic silica content,  
28 respectively. Compared to version 1, all radiocarbon ages have been recalibrated and the age-  
29 depth models updated. In addition, near sea surface temperature estimates based on planktonic

30 foraminifera Mg/Ca and on UK37' have been recalculated using a single calibration thus  
31 ensuring global comparability and comprehensive assessment of their uncertainty. The data  
32 product is available in two formats (R and LiPD) facilitating use across different software and  
33 operating systems and can be downloaded at  
34 <https://doi.pangaea.de/10.1594/PANGAEA.984602> (Jonkers et al., 2025b). This data descriptor  
35 presents our updating methodology and describes the contents and format of the data product  
36 in detail and concludes with recommendations on palaeodata stewardship to increase the  
37 reusability of such data.

## 38 1 Introduction

39 This article describes an update of the PALMOD 130k multiproxy marine palaeoclimate data  
40 synthesis (Jonkers et al., 2020). Palaeoclimate data hold the unique promise to inform about  
41 climate states and climate variability on time scales beyond the instrumental period. As such,  
42 they may help to characterise natural climate variability, shed light on the mechanisms of  
43 climate change and provide analogues for future climate; all crucial insights in a rapidly  
44 changing world. Marine sediments and the compounds and fossils contained in them allow the  
45 reconstructions of largely continuous, long records of past ocean physical and chemical  
46 conditions. Consequently, the multiproxy, global-scale PALMOD 130k synthesis provides a  
47 basis to evaluate the importance of the ocean for regulating Earth's climate and biogeochemical  
48 cycles on a global scale.

49  
50 The synthesis contains palaeoceanographic and sedimentological data from sediment cores  
51 that cover the last glacial–interglacial cycle (up to approximately 130,000 years ago). During  
52 this time Earth has undergone marked changes in climate that involve the atmosphere,  
53 continental ice sheets and the ocean (Jonkers et al., 2023; NGRIP Members, 2004; Waelbroeck  
54 et al., 2002). Up to the influence of humans on global climate, which accelerated around 1950  
55 CE (Steffen et al., 2015), these changes were ultimately controlled by variations in the Earth's  
56 orbit around the Sun (Hays et al., 1976). This orbital forcing triggered a multitude of (non-linear)  
57 feedback mechanisms causing global and regional climate to vary much faster than the forcing.  
58 A large amount of palaeoclimate data that span this period has been collected over the past  
59 decades, rendering the last glacial–interglacial cycle well-suited to study the natural variability of  
60 ocean and climate conditions across timescales and in particular the interaction between the  
61 cryosphere and the rest of the climate system. This is especially relevant given the projected,

62 but uncertain, (partial) disappearance of continental ice-sheets with ongoing anthropogenic  
63 warming. The high-density data availability also makes the period an excellent test-bed for  
64 climate model simulations.

65 Whilst for a long time, palaeoclimate modelling focussed on the simulation of timeslices,  
66 increasing computational power now also enables long transient simulations. For instance, the  
67 paleoclimate modelling intercomparison project (PMIP) now also provides protocols for the  
68 simulation of the last deglaciation (Ivanovic et al., 2016) and several simulations spanning this  
69 period exist (Liu et al., 2009; Mikolajewicz et al., 2025). This development allows investigating  
70 climate dynamics in a new way, but also puts new demands on the (palaeo)observational data  
71 needed for model benchmarking. Specifically, paleoclimate time series need to be associated  
72 with comprehensive and consistent estimates of their (chronological) uncertainty. Moreover, the  
73 stochastic aspects of climate also call for new ways of comparing transient simulations with  
74 observations. For instance, given the uncertainty about whether suborbital abrupt climate  
75 variability is forced or unforced, the observed temporal evolution of climate may represent just  
76 one of many possible trajectories. Therefore, data-model comparison strategies that are  
77 independent of the exact timing of events need to be considered (Weitzel et al., 2024).

78  
79 A particular strength of paleoceanographic data is that by their multiproxy nature. We can hence  
80 gain a more comprehensive insight into the climate system by studying it from a multi-proxy, or  
81 multi-parameter, perspective. Moreover, a multi-parameter approach is also likely to be more  
82 diagnostic for model performance than a single climate parameter approach (Kurahashi-  
83 Nakamura et al., 2017). However, at present, multi-parameter approaches are difficult because  
84 different parameters from the same archive (sediment core) have often been generated in  
85 different studies, and the current poor state of data archiving poses serious challenges to  
86 reuse. These challenges arise mainly from the non-standardised and fragmented way  
87 palaeoceanographic data (and palaeoclimate data in general) are archived and the scarcity of  
88 machine-readable metadata directly included in datafiles. Automated and reproducible analyses  
89 of palaeoceanographic data thus remain time consuming, even though efforts are underway to  
90 alleviate these problems and increase the ease of data reuse (Emile-Geay and Eshleman,  
91 2013; Morrill et al., 2021). Still, such approaches require standardisation and synthesis of raw  
92 and inferred data and of metadata from various sources.

93 The PALMOD 130k marine palaeoclimate data synthesis is an attempt to overcome the  
94 fragmented nature of paleoceanographic data sets and contains multiple climate-relevant  
95 parameters in a single framework. The synthesis combines data on sediment composition

96 (carbonate content, total organic carbon and opal), planktonic and benthic foraminifera stable  
97 oxygen and carbon isotope ratios and estimates of seawater temperature based on various  
98 proxies. These parameters were selected following discussions within the PALMOD project.  
99 They include physically and biogeochemically relevant parameters that can be directly  
100 compared with climate model simulations and for which reasonable spatiotemporal coverage  
101 could be achieved. All data has been compiled on a single depth scale per sediment core  
102 allowing for robust alignment of the various parameters and for reproducible updating and  
103 changing of chronologies. Whenever possible, the synthesis contains raw observational data  
104 together with the inferred data to enable revision of the latter. All data is associated with rich  
105 metadata to facilitate interpretation and for comprehensive uncertainty estimates. The synthesis  
106 is designed to facilitate evaluation of transient climate model simulations, but the data product  
107 can also be used to study climate change over the last glacial–interglacial cycle directly,  
108 independent from climate model simulations. Whilst the intended use of the synthesis has  
109 remained unchanged, version 1 was limited in spatial and temporal coverage, thus warranting  
110 an update to increase its usefulness. This article describes this update of the data synthesis and  
111 complements an earlier description of the data product (Jonkers et al., 2020).

## 112 2 What's new

113 Briefly, version 2 of the PALMOD 130k marine palaeoclimate data synthesis contains 1736  
114 additional time series from 332 individual sites, markedly increasing both the spatial and  
115 temporal coverage of the data. Next, age-depth models presented in version 1 that were based  
116 on radiocarbon ages are revised using calendar ages calculated with the IntCal20 radiocarbon  
117 calibration curve (Hogg et al., 2020; Reimer et al., 2020). In addition, we harmonised seawater  
118 temperature estimates based on geochemical proxies and provide uncertainty estimates that  
119 are consistent and comparable across the different time series. This version also corrects  
120 several errors in the metadata associated with time series included in version 1 and contains  
121 two additional metadata fields to facilitate filtering of the data. Finally, we made slight changes in  
122 the structure of the data to prevent errors during use.

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## 124 3 Methods

### 125 3.1 Data synthesis strategy

126 The synthesis strategy of this version follows that of the previous version (Jonkers et al., 2020).  
127 We compiled time series from marine sediment cores that contained benthic or planktonic  
128 foraminifera stable oxygen and carbon isotope data, estimates of seawater temperature and  
129 information on total organic carbon, opal and carbonate content. As outlined in Jonkers (2020),  
130 we followed a sequential updating strategy guided by the availability of time series with  
131 information needed to develop an age depth model for the sediment cores of interest. Version 1  
132 contained time series dated with radiocarbon and benthic foraminifera  $\delta^{18}\text{O}$ . Version 2  
133 integrates two steps in the update process, it contains time series with any of the parameters of  
134 interest with age control solely based on benthic foraminifera  $\delta^{18}\text{O}$  and it contains time series  
135 that had at least an estimate of seawater temperature and age control based on radiocarbon or  
136 other absolute dates. Data was compiled from public repositories following the two-step  
137 approach of bulk data download and subsequent filtering out of relevant time series as  
138 described in Jonkers (2020). To increase the number of time series from the Indo-Pacific  
139 domain we made 19 previously unpublished datasets available on PANGAEA and included  
140 them here. Given the lack of metadata associated with most data in public repositories,  
141 metadata was in general manually compiled from the publications associated with the datasets.

### 142 3.2 Age-depth modelling

143 All time series in this compilation have updated and harmonised age-depth models with  
144 consistent estimates of uncertainty. The updated age-depth models are based on the most  
145 recent regional benthic foraminifera  $\delta^{18}\text{O}$  stacks and radiocarbon calibration curve, together with  
146 estimates of marine reservoir ages that are globally consistent and physically plausible. We  
147 follow the same hybrid strategy of relying on both absolute age control points (e.g. radiocarbon  
148 ages, tephra horizons) and hypothesis-based age modelling as in version 1.  
149 For this version, benthic foraminifera  $\delta^{18}\text{O}$  were manually aligned to the relevant regional stacks  
150 of Lisiecki and Stern (2016) using mainly the marine isotope stage boundaries as tie points for  
151 consistency among the time series and to avoid inflating the chronological confidence. In  
152 addition, all radiocarbon ages have been recalibrated to calendar years using IntCal20 (Hogg et  
153 al., 2020; Reimer et al., 2020) and model-based estimates of the reservoir age (Butzin et al.,

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155 2017). The age-depth models were constructed using the Bayesian algorithm BACON (Blaauw  
156 and Christen, 2011) implemented in PDV (Langner and Mulitza, 2019) and are presented as  
157 separate elements in the compilation. To avoid extrapolation, we only provide age models for  
158 the core depths bracketed by age control points and the age models presented in the original  
159 studies may extend further to either side. The age-depth information includes mean, median  
160 and the 95% confidence interval of the ages as well as the necessary information to rerun the  
161 age-depth models in BACON and 1,000 posterior age-depth models that can be used for further  
162 analysis.

### 163 3.3 Seawater temperature estimates

164 In order to homogenise seawater temperature estimates and to provide a consistent estimate of  
165 their uncertainty associated with the calibration and, in case of planktonic Mg/Ca ratios, of the  
166 confounding effects of salinity and pH, temperature estimates were recalculated. For seawater  
167 temperatures based on the alkenone unsaturation index we used the BAYSPLINE calibration  
168 (Tierney and Tingley, 2018) and applied the suggested prior for the standard deviation of sea  
169 surface temperature of 5 °C. The resulting estimates represent in general annual mean sea  
170 surface temperature. However, for specific regions the temperatures are seasonal averages  
171 (Tierney and Tingley, 2018). This seasonality of the estimate is indicated in the metadata.  
172 Whenever available, or whenever values could be calculated from inferred seawater  
173 temperatures, planktonic foraminifera Mg/Ca ratios were converted to calcification temperature  
174 using MgCaRB (Gray and Evans, 2019). In this way we account for the effects of salinity and pH  
175 on the Mg/Ca ratios based on sensitivities determined from culture studies. However, as the  
176 past salinity and pH variability is unknown for most time series in the synthesis, we, like (Gray  
177 and Evans, 2019; Tierney et al., 2019), approximate the temporal evolution of salinity using a  
178 scaling to sea level and of pH based on atmospheric  $p\text{CO}_2$  from ice cores and the constant  
179 disequilibrium from atmospheric  $\text{CO}_2$  ( $Dp\text{CO}_2$ ) and alkalinity fixed at pre-industrial and modern  
180 levels respectively. For each site, we obtained modern sea surface salinity and temperature  
181 (needed for the calculation of  $Dp\text{CO}_2$ ) from the World Ocean Atlas 2023 (Reagan et al., 2023)  
182 from within a circle with a radius of 100 km. Carbonate system parameters (total dissolved  
183 inorganic carbon (DIC), its anthropogenic contribution (DIC\_anthro) and total alkalinity were  
184 derived from the GLODAPv2 gridded data product (Lauvset et al., 2016) in the same way. Since  
185 GLODAPv2 does not cover the Gulf of Mexico and the Caribbean Sea, we used the median  
186 surface DIC and alkalinity from the GLODAPv2.2023 (Olsen et al., 2016) adjusted cruise data

187 from the area between 10° and 30° N west of 80° W (Barbero et al., 2016a, b, 2019; Jiang et al.,  
188 2020; Salisbury, 2017; Salisbury and Shellito, 2019; Wanninkhof et al., 2007, 2014) for the  
189 affected time series. For simplicity we assumed global mean DIC\_anthro for those sites. Local  
190 ocean  $p\text{CO}_2$  was subsequently calculated using pre-industrial DIC (DIC-DIC\_anthro), alkalinity,  
191 salinity and temperature using SeaCarb (Gattuso et al., 2024). Finally,  $Dp\text{CO}_2$  was calculated as  
192 the difference between the calculated oceanic  $p\text{CO}_2$  and pre-industrial atmospheric  $p\text{CO}_2$  (280  
193 ppm). For the species *Globigerinoides ruber*, *Trilobatus sacculifer*, *Globigerina bulloides* we  
194 used the sensitivity of Mg/Ca to temperature, salinity and pH as provided in Gray and Evans  
195 (Gray and Evans, 2019). For *Neogloboquadrina pachyderma* and *N. incompta* we used the  
196 temperature and salinity sensitivity as used in Boscolo-Galazzo et al. (2025) and ignored the  
197 effect of pH as this is poorly constrained for these species. We used the generic calibration for  
198 all other species. To account for Mg loss in foraminifera tests that were treated by reductive and  
199 oxidative cleaning, we multiplied the respective Mg/Ca ratios by 1.1 to make them comparable  
200 with ratios measured on samples that only underwent oxidative cleaning (Barker et al., 2003).  
201 For seawater temperatures derived from both proxies, estimates are presented as the median  
202 and 95% confidence intervals. The recalculated values are indicated using the strings  
203 “recalc\_UKSST” or “recalc\_mgcaSST” and accompanied by a note containing the text  
204 “Recalculated for PALMOD.”. For further analysis, 1,000 ensemble time series of seawater  
205 temperature are provided separately.  
206 Unlike for the two proxy types mentioned above, seawater temperature estimates based on  
207 microfossil assemblages were not harmonised. This is because in too many cases the  
208 calibration that was used to generate the reported temperature estimates and/or the fossil  
209 abundance data on which the estimates are based are not publicly available.

## 210 4 Structure, terms and format

211 The structure of the synthesis has slightly changed since version 1. The main change is the  
212 inclusion of the revised age information directly with the proxy data. These were kept separate  
213 in version 1 to highlight the fact that observations on the (core) depth scale are static, whereas  
214 the age-depth model can be updated or revised as per user demand. However, this separation  
215 into raw and derived data rendered use of the data more complex and we have hence decided  
216 to include the revised age data directly with the proxy data. The second change in the structure  
217 is the addition of ensembles of seawater temperature time series.

218

219 The synthesis is organised by site, which usually is the sediment core from which the data were  
220 extracted, but it may also refer to a spliced record comprising multiple sediment cores.  
221 Depending on the availability of alkenone or Mg/Ca-derived seawater temperature estimates,  
222 each site is associated with information on seven or eight themes. Names in square brackets  
223 below are those used in the data files.

- 224 • **Geographic data** [site] includes the position of the site in decimal degrees and its water  
225 depth in m and, new in this version, the ocean basin in which the site is located. The  
226 basin assignment is based on the Global Oceans and Seas dataset, version 1 (Flanders  
227 Marine Institute (VLIZ), Belgium, 2021). This theme also contains additional notes that  
228 apply to the entire site.
- 229 • **Metadata** [meta] contains the original and standardised variable name, units where  
230 applicable, information about the origin of the data and where applicable information  
231 about the proxy sensor and the seasonal or vertical attribution (as specified by the data  
232 generators in the [original publications](#)) and the calibration. A complete list of metadata  
233 terms is provided in Table 1. Metadata are only included if they were available in the  
234 dataset or could be obtained from the accompanying publication. Not all fields are  
235 relevant for all parameters (e.g. species is not defined for parameters that are not based  
236 on measurements on organisms) and fields that are completely empty for a site are  
237 excluded. The metadata now also includes a unique identifier for each time series to  
238 facilitate cross-referencing.
- 239 • **Chronological data** [chron] includes the information to revise the age-depth model of  
240 the site. It contains raw radiocarbon ages, ages based on tephra layers and  
241 palaeomagnetism, as provided by the data generators and the ages of the tie points  
242 identified for this study. The calendar ages of all tie points are based on the approach  
243 outlined above (section Age-depth modelling). Information about the source and the  
244 citation of the chronological information is provided. A full list of chronological data terms  
245 is provided in Table 2.
- 246 • **Proxy data** [data] are presented on a common depth scale. Original ages and original  
247 seawater temperature estimates are included, updated seawater temperature estimates  
248 are flagged in the notes field using the string "Recalculated for PALMOD". The  
249 standardised parameter names are provided in Table 3.
- 250 • **Age-depth model ensembles** [AgeEnsemblesBACON]: 1,000 posterior age-depth  
251 models inferred from sediment accumulation rates as modelled using BACON.

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253 • **Seawater temperature ensembles** [SurfaceTempEnsembles]: 1,000 sea water  
 254 temperature time series for each UK37' or Mg/Ca time series. The ensembles are  
 255 accompanied by metadata describing the algorithm settings and [information about the](#)  
 256 [confidence of the resulting temperature estimates \(expressed as convergence, see](#)  
 257 [Tierney and Tingley \(2018\) for further explanation](#)) and details on the species in the case  
 258 of Mg/Ca.

259  
 260 Each site also contains information about the version, import date and date at which the age-  
 261 depth model was last updated. These fields are largely for internal use.

262  
 263 The data are available in serialised R format (\*RDS) and structured as a list where the elements  
 264 contain the information about the themes indicated above. RDS files can be easily read using  
 265 the open source software R. To ensure interoperability the data product is also available as  
 266 (simple) JSON formatted data following the LiPD structure and vocabulary. [Resources for](#)  
 267 [reading and querying the data are provided in the section 7 Usage notes.](#)

268  
 269 Table 1: metadata fields

270 \* Original parameter names are preserved even when they contain errors. These errors have  
 271 been corrected in the standardised parameter name and additional metadata.

| Name                     | Description  |
|--------------------------|--|
| ParameterOriginal        | Parameter name as provided in the original data file*                                |
| Parameter                | Standardised parameter name  |
| ParameterType            | Indication of whether the parameter was measured or inferred                         |
| ParameterUnit            | Unit of the parameter  |
| ParameterAnalyticalError | Parameter uncertainty based on repeat measurements of a standards (not standardised) |
| ParameterReproducibility | Parameter uncertainty based on repeat measurements of samples (not standardised)     |
| Instrument               | Instrument used for the measurements   |
| Laboratory               | Laboratory where the measurements were   |

|                             |   |
|-----------------------------|---|
|                             | done  |
| SampleThickness_cm          | Thickness of the analysed samples in cm   |
| Material                    | Material on which the measurements were performed or on which the inferred variable is based  |
| Species                     | Species of foraminifera analysed or on which the inferred parameter is based  |
| SizeFraction_microm         | Size range of the foraminifera shells used for the analysis (in $\mu\text{m}$ )   |
| Nshells                     | Number of foraminifera shells used for analysis   |
| RecordingSeason             | Recording season of the proxy as specified by the data generators   |
| RecordingDepth              | Recording depth of the proxy as specified by the data generators  |
| CalibrationEquation         | Equation used to calculate inferred parameter from measured parameter (usually seawater temperature)  |
| CalibrationUncertainty      | Uncertainty of the calibration equation <u>as specified in the original publication (not standardised). Note that the revised calibrations of Mg/Ca and UK37-based nSST supersede this field.</u> |
| CalibrationDOI              | DOI of the calibration equation   |
| TransferFunctionTrainingSet | Training set used for the development of the transfer function model  |
| TransferFunctionUncertainty | Uncertainty of the transfer function model (RMSE)   |
| TransferFunctionDOI         | DOI of the transfer function model  |
| Notes                       | Notes about the parameter (e.g. the cleaning procedure for Mg/Ca)   |
| PublicationDOI              | DOI of the publication describing the data  |
| PublicationLink             | Link to the publication describing the data (when no DOI available)   |
| Publication                 | Publication describing the data (when no DOI  |

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|                 |                                       |
|-----------------|---------------------------------------|
|                 | or link available)                    |
| DataDOI         | DOI of the dataset                    |
| DataLink        | Link where the data were obtained     |
| RetrievalNumber | Retrieval number (for internal use)   |
| TSuID           | Unique identifier for the time series |

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Table 2: chronology data fields

| Name                     | Description  |
|--------------------------|--|
| ChronType                | Type of chronology tie point ( <sup>14</sup> C, tephra, etc)                       |
| ChronDepthMid_cm         | Mid depth of the tie point in cm   |
| ChronDepthTop_cm         | Top depth of the tie point in cm   |
| ChronDepthBottom_cm      | Bottom depth of the tie point in cm  |
| ChronSampleThickness_cm  | The thickness of the tie point sample in cm  |
| ChronDatedMaterial       | The material dated (usually for <sup>14</sup> C)                                   |
| ChronCalendarAge_kaBP    | The median calendar age in ka BP   |
| ChronCalendarAgeMin_kaBP | The 2.5th percentile of the calendar age in ka BP                                  |
| ChronCalendarAgeMax_kaBP | The 97.5th percentile of the calendar age in ka BP                                 |
| ChronDatedSpecies        | The species (usually foraminifera) dated   |
| ChronNshellsDated        | The number of shells (of foraminifera) used for the dating                         |
| Chron14CLabcode          | The laboratory code for the <sup>14</sup> C age                                    |
| ChronAge14C_kaBP         | The <sup>14</sup> C age of the sample in ka BP                                     |
| ChronAge14CError_ka      | The uncertainty of the <sup>14</sup> C age in ka (1 $\sigma$ )                     |
| ChronAge14CErrorUp_ka    | The uncertainty of the <sup>14</sup> C age towards younger age in ka (1 $\sigma$ ) |
| ChronAge14CErrorDown_ka  | The uncertainty of the <sup>14</sup> C age towards older age in ka (1 $\sigma$ )   |
| ChronNotes               | Notes pertaining to the individual tie point                                       |

|                  |   |
|------------------|---|
| ChronAgeRejected | An indication of whether the tie point was included in the original age-depth model (boolean)         |
| ChronSource      | The source of the chronology information (denoted PALMOD if based on tuned tie point from this study) |
| ChronDOI         | The publication in which the chronology information was presented                                     |

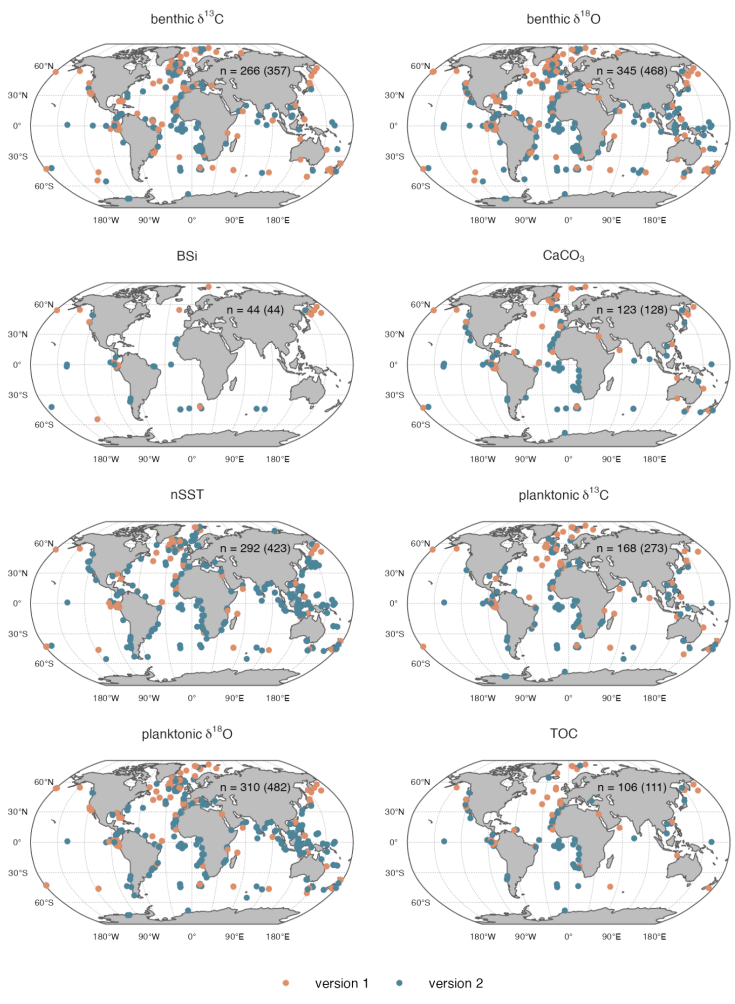
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## 279 5 Description/contents

### 280 5.1 Spatial data coverage

281 Version 2 of the PALMOD marine palaeoclimate data synthesis contains 2,286 time series with  
 282 one of the eight ~~synthesised~~ climate-relevant variables each, originating from 475 unique sites  
 283 (Fig. 1, Table 4). The majority of the newly added time series in this version stem from the  
 284 tropics. Most time series are of planktonic foraminifera  $\delta^{18}\text{O}$  ( $n = 482$ ), with often multiple time  
 285 series from different species (each with potentially different vertical and seasonal recording  
 286 preferences) per site. The number of time series with benthic foraminifera  $\delta^{18}\text{O}$  and with near  
 287 sea surface temperature closely follow the number of time series with benthic  $\delta^{18}\text{O}$  ( $n = 468$  and  
 288  $n = 423$ , respectively). Time series of the other variables are considerably fewer in number. For  
 289 all variables but biogenic silica content, the highest density of sites is in the Atlantic Ocean.  
 290 Coverage in the Pacific and the southern hemisphere remains relatively poor, reflecting both  
 291 historical research focus and the (logistical) challenges of obtaining sediment cores far offshore.  
 292 In general, sites tend to be located close to the continents, where higher sedimentation rates  
 293 facilitate the recovery of records with higher temporal resolution.

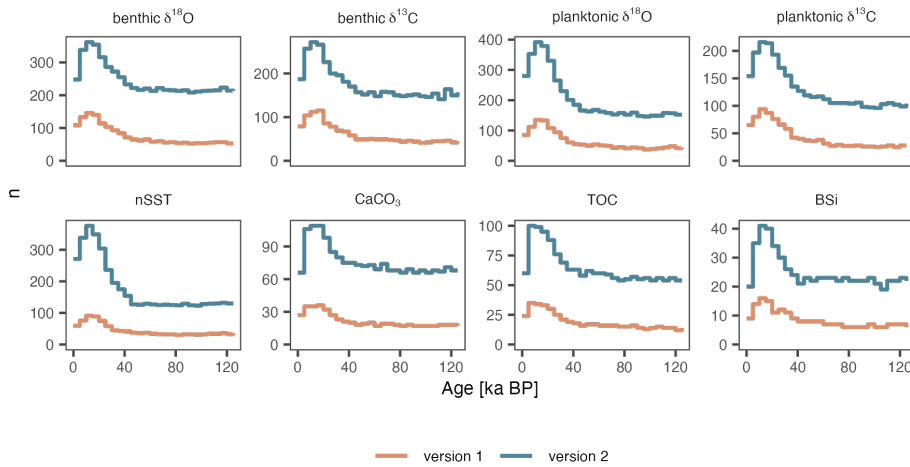
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295  
 296 *Figure 1: spatial distribution of sites with time series of the eight parameters. Locations are*  
 297 *coloured by the version in which they were first included (version 2 also includes all data of*  
 298 *version 1). The total number of sites and time series are indicated in brackets.*  
 299

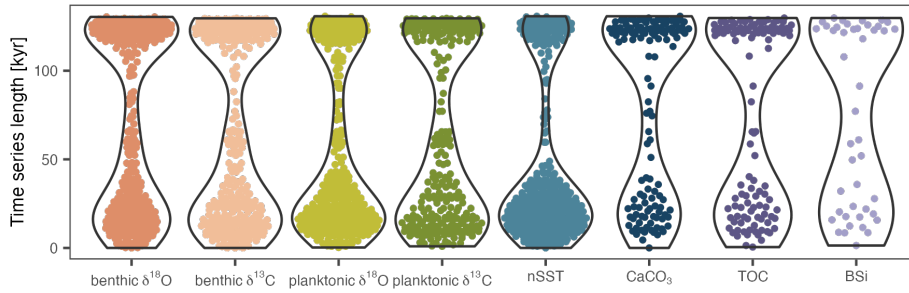
300 **5.2 Temporal data coverage**

301 Compared to version 1, the temporal coverage has approximately doubled over the 130 kyr time  
302 frame and for all variables (Fig. 2). The temporal distribution of data reflects research focus on  
303 the last deglaciation, with the highest data density between 10–25 ka BP. Importantly, the  
304 coverage does not markedly drop off beyond approximately 40 ka BP, facilitating continuous  
305 analysis across the entire last glacial cycle. This coverage pattern is consistent across all  
306 variables and has not substantially changed in version 2.



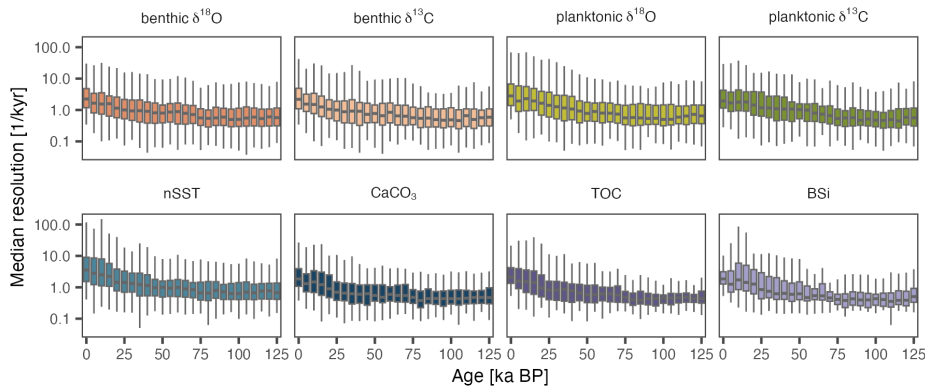
307  
308 *Figure 2: temporal distribution of temporal coverage of each parameter. Lines show the number*  
309 *of time series per 5 kyr bin, colour show the total number of time series for each version. Like in*  
310 *the previous version, version 2 shows highest coverage during the last deglaciation. Note the*  
311 *different scaling on the y axes.*

312  
313 The length of the time series shows a clear bimodal distribution across all variables (Fig. 3).  
314 Most time series are shorter than 40 kyr or longer than 110 kyr, reflecting the research focus on  
315 investigating either the transition from the last glacial to the Holocene, or glacial-interglacial  
316 cycles on long(er) time scales.



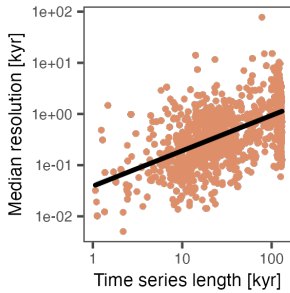
317  
 318 *Figure 3: distribution of time series length split by parameter. Time series between 40 and 110*  
 319 *kyr long are uncommon across all parameters.*

320  
 321 The temporal resolution of the time series varies considerably, but the median temporal  
 322 resolution of the time series tends to be below 3 kyr (Fig. 4). In general, the highest temporal  
 323 resolution of the time series is in the youngest part of the 130 kyr time frame (Fig. 4). Even  
 324 though the resolution decreases with age, this decrease generally stops or reduces around 75  
 325 ka BP. The resolution of the time series is, to a first order, related to their length (Fig. 5),  
 326 reflecting both the challenge of obtaining long sediment cores in high accumulation settings and  
 327 the amount of work involved in generating the data.



328  
 329 *Figure 4: temporal resolution (observations per kyr) of the time series split by parameter. The*  
 330 *general trend shows decreasing resolution until approximately 75 ka BP, after which resolution*  
 331 *remains more or less constant. Even though there is considerable spread, the median resolution*  
 332 *is below 3 kyr across all parameters. Box-whisker plots show distribution of median resolution*

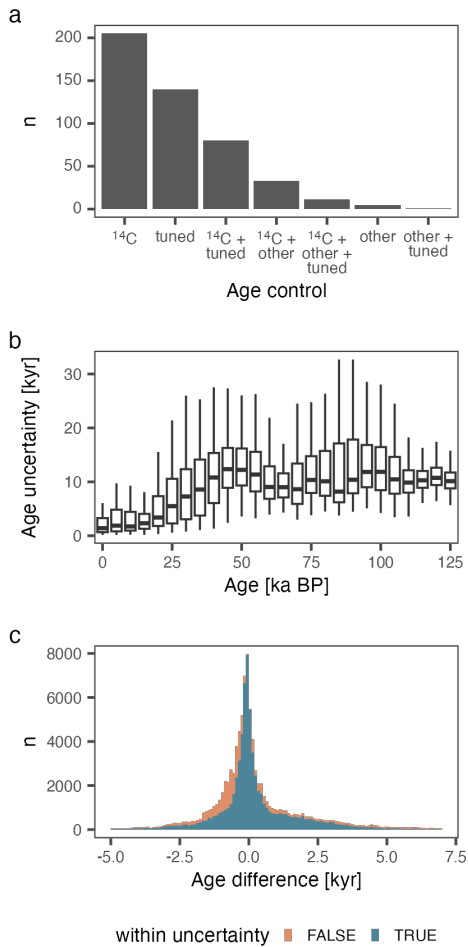
333 per 5 kyr bin; thick lines indicate median values, boxes show interquartile range and whiskers  
334 extend to 1.5 times this range.  
335



336  
337 *Figure 5: longer time series tend to have lower resolution. Cross plot of median resolution (time*  
338 *between consecutive observations) and time series length. The linear fit (black line) is shown to*  
339 *highlight the general trend; 14 time series shorter than 1 kyr are not shown.*

### 340 5.3 Chronology

341 Nearly 90 % of the time series have an age-depth model based on exclusively radiocarbon  
342 dating and tuning of benthic foraminifera  $\delta^{18}\text{O}$  (Fig. 6a). Only five time series have age-depth  
343 models entirely based on other - e.g. tephra, biostratigraphy or palaeomagnetism - age controls.  
344 The age uncertainty shows to some degree the nature of the dating methods, it tends to be low  
345 up to approximately 20 ka BP, reflecting the prevalence of radiocarbon dating within this interval  
346 (Fig. 6b). Beyond ca. 20 ka BP, the age uncertainty shows the structure of the benthic  
347 foraminifera  $\delta^{18}\text{O}$  tuning targets with reduced uncertainties near the marine isotope stage  
348 boundaries.



349  
 350 *Figure 6: type of age control tie points across all sites (a), age uncertainty across the time series*  
 351 *in the dataproduct (b) and differences between the original and updated age-depth models (c).*  
 352 *The category “other” in panel a includes tephra, palaeomagnetism and biostratigraphy. Low age*  
 353 *uncertainties (b) up to approximately 25 ka BP reflect the prevalence of radiocarbon ages within*  
 354 *this interval. The age uncertainty in the older parts of the time series tends to be lower near the*  
 355 *boundaries of the marine isotope stages that were used in the construction of the age depth*  
 356 *models. Box-whisker plots show the distribution of median age uncertainty (95 % confidence*

357 interval) across the sites per 5 kyr bin. Further explanation of the plots is provided in Figure 4.  
358 Colours in c show whether or not the difference between the age estimates is within the 95 % CI  
359 of the revised age-depth model. In 2 % of the data points the difference is outside the range  
360 shown here.

361  
362 The revised age-depth models differ in many cases from the original age-depth models (Fig 6c).  
363 However, these differences are small, the median difference (revised - original) is -0.07 kyr (-  
364 3.28 – 5.24, 95 % CI) and for 74 % of all data points the difference is within the uncertainty of  
365 the revised age-depth model. These differences are to some degree due to the different  
366 approaches used to model the age-depth relationship and/or to differences in the radiocarbon  
367 calibration curve, the applied reservoir age, the tuning parameters and the tuning targets.

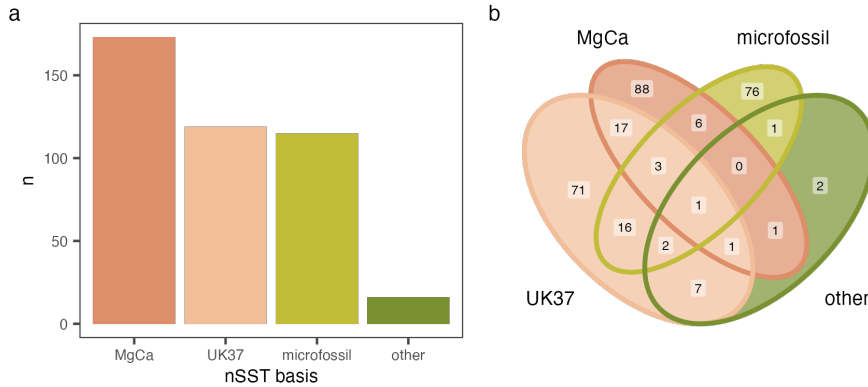
## 368 5.4 Near sea surface temperature

369 The majority of the near sea surface temperature time series (n = 173) is based on planktonic  
370 foraminifera Mg/Ca (Fig. 7a). Near sea surface temperature estimates based on alkenone  
371 unsaturation indices and microfossil assemblages (predominantly planktonic foraminifera) make  
372 up approximately equal proportions (n = 119 and 115, respectively). Only 16 time series are  
373 based on other proxies, including TEX<sub>86</sub> (Schouten et al. 2002) and the long chain diol index  
374 (Rampen et al. 2012). Twenty-nine sites have near sea surface temperature estimates based on  
375 the Mg/Ca of more than one species of planktonic foraminifera and 55 sites have near sea  
376 surface temperature time series based on more than one proxy (Fig. 7a), thus potentially  
377 allowing for comparison and/or the reconstruction of seasonal or vertical temperature gradients.  
378 The uncertainty of the revised near sea surface temperature estimates (1 SD) remains  
379 approximately constant through time and its median value across all samples is 0.93 °C (0.64–

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381 2.44 °C, 95%).



382  
383 *Figure 7: Number of the near sea surface temperature time series sorted by proxy (a) and a*  
384 *Venn diagram showing the overlap among records based on different proxies across the sites*  
385 *(b; numbers indicated). In total 55 sites have near sea surface temperature data based on more*  
386 *than one proxy.*

## 387 6 Data availability

388 [The PALMOD 130k marine palaeoclimate data synthesis version 2](https://doi.pangaea.de/10.1594/PANGAEA.984602) is freely available at  
389 <https://doi.pangaea.de/10.1594/PANGAEA.984602> (Jonkers et al., 2025b). The data can also  
390 be visualised and downloaded in LiPD format from [https://lipdverse.org/PalMod/current\\_version/](https://lipdverse.org/PalMod/current_version/)  
391 (last access: September 30, 2025). [Python and Matlab serialisations of the data as well as csv](#)  
392 [files of the palaeoclimate and chronological data can also be downloaded from the lipdverse](#)  
393 [website](#). We explicitly encourage users to also cite the original data when using this data  
394 product [to provide credit to the data generators](#). For instance, when using a selection of the time  
395 series from this data product, we recommend including a statement like *"We selected time*  
396 *series from the PALMOD 130k marine palaeoclimate synthesis version 2 (Jonkers et al., 2026).*  
397 *The time series that meet our selection criteria, including their original publications, are detailed*

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399 [in the table below.](#). See [Weitzel et al. \(2024\)](#) for an additional example and [Smith et al. \(2023\)](#)  
400 [for a general discussion on the issue of crediting data generators.](#)

## 401 7 Usage notes

402 General comments on data usage and potential applications can be found in Jonkers et al.  
403 (2020). The PALMOD synthesis contains data about sediment composition (calcium carbonate,  
404 organic carbon and biogenic silica content) that is relatively straightforward to interpret. The  
405 data product also contains information derived from measurements on biological material  
406 (foraminifera stable carbon and oxygen isotope ratios) and estimates of seawater derived  
407 indirectly from the chemical or species composition of microfossils or from biomarkers. The  
408 biological origin of the data renders its interpretation less straightforward as environmental  
409 preferences of the organisms may affect the recorded climate signal. A detailed description of  
410 the proxy sensors and the intricacies of the proxies is provided in the data descriptor of version  
411 1 (Jonkers et al., 2020). We encourage users to read the relevant section. A general proxy  
412 system modelling framework for marine sediment time series can e.g. be found in Dolman and  
413 Laepple (2018). In this section we focus on the main advance compared to version 1 that is  
414 relevant to usage: the harmonisation of seawater temperature estimates.

415  
416 Estimates of near sea surface temperature based on planktonic foraminifera Mg/Ca and UK37'  
417 have been updated and harmonised whenever possible. For UK37', these updated estimates  
418 required relatively little user input, but the use of different priors may affect the results. Since  
419 planktonic foraminifera Mg/Ca is not only affected by seawater temperature, the inference of  
420 Mg/Ca-based temperatures is more complex. Estimates of salinity and pH are indirect and, by  
421 necessity, rather crude as they ignore existing, but unknown, spatiotemporal variation.  
422 Importantly, the estimates of salinity and pH depend on the age and updates to the age-depth  
423 model therefore require recalculation of the inferred temperatures. The influence of these  
424 nuisance factors can in principle also be corrected using measured estimates of ocean pH  
425 based on boron isotope ratios (Gray and Evans, 2019) or indirectly by using oxygen isotopes  
426 (Morley et al., 2024), but this requires additional data that is not available for all time series. We  
427 have hence chosen a correction approach that is consistent across all time series. Whilst for the  
428 species *Globigerinoides ruber*, *Trilobatus sacculifer*, *Globigerina bulloides*, *Neogloboquadrina*  
429 *pachyderma* and *N. incompta* the sensitivity of Mg/Ca to temperature, salinity and pH is well  
430 constrained, this is not the case for other, generally deeper dwelling species. For these other

431 species we have used the generic calibration. Care thus needs to be taken with the temperature  
432 estimates based on this calibration and we encourage the use of anomalies, rather than reliance  
433 on absolute values. To allow users to compare the harmonised seawater temperature estimates  
434 with the values provided by the data generators, the original temperature values are included in  
435 the data product. It is important to note that the range of possible nSST trajectories may be  
436 overestimated as temporal autocorrelation in the temperature and its uncertainty are ignored in  
437 the calibration. Whether such autocorrelation would be preserved in sedimentary time series  
438 and how large the effect would be, remains to be investigated. For this, and other reasons,  
439 users may also want to use different calibration schemes. For this purpose, the synthesis also  
440 contains the raw UK37' and Mg/Ca values.

441  
442 Seawater temperatures based on microfossil assemblage composition are included in the  
443 synthesis only in the form reported by the authors. Because of the fragmentary nature of the  
444 required metadata, the originally reported estimates could not be updated to a common  
445 standard and are associated with uncertainty estimates only where the data generators  
446 provided them. From the accompanying publications it is not always clear how the uncertainty  
447 has been derived and the methods certainly vary among the different studies because of  
448 personal preferences and methodological progress on how to deal with issues like spatial  
449 autocorrelation. In light of new insights regarding the uncertainty of seawater temperature  
450 estimates based on microfossil assemblages (Telford et al., 2013; Trachsel and Telford, 2016),  
451 the reported uncertainties are likely too optimistic. Interested users can refer to Jonkers et al.  
452 (2023) for an example of comprehensive estimates of calibration uncertainty associated with  
453 planktonic foraminifera assemblage derived seawater temperatures.

454  
455 Whenever publicly available, the original age-depth models are included in the data product, but  
456 they almost universally lack uncertainty estimates. Still, these original age estimates can be  
457 used for a comparison of the revised and original age models. Future updates to the  
458 radiocarbon calibration curve, to the reservoir age estimates, or the stacks may require updating  
459 the age-depth models. The raw chronology data provided in the data product enables this  
460 updating in an automated fashion. Please note that the Mg/Ca-based temperature estimates  
461 depend on the age of the samples for a correction of the effects of salinity and pH. The  
462 temperature estimates thus need to be updated if the age-depth model is revised. Uncertainty  
463 estimates on the chronology are to some degree method dependent, but the Bayesian approach  
464 we utilised appears to provide reasonable results (Trachsel and Telford, 2017). However, our

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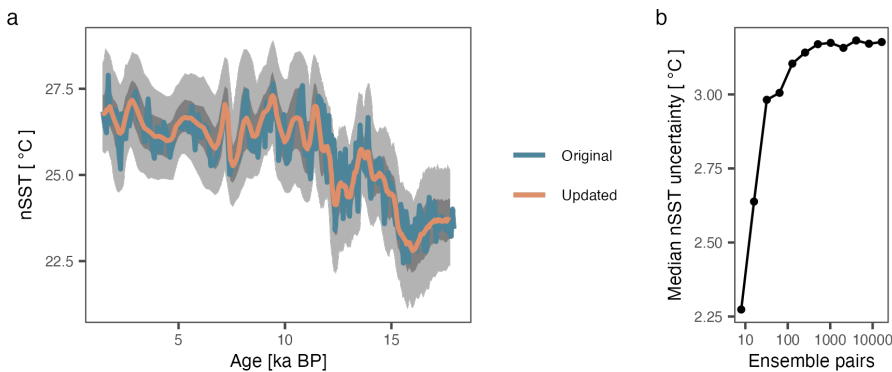
470 approach ignores additional uncertainty caused by bioturbation and uncertainty related to  
471 alignment of the benthic foraminifera  $\delta^{18}\text{O}$  records. Recent work suggests ways to incorporate  
472 these sources of uncertainty (Lee et al., 2023). Other approaches may thus provide different  
473 results and the user may wish to compare age-depth models using different age-depth  
474 modelling strategies like for instance done by Comas-Bru et al., (2020).

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

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490 Figure 8: An example of joint estimation of chronological and calibration uncertainty of nSST  
491 timeseries. Panel a shows the original nSST time series of site A7 in the North Pacific that is  
492 based on the Mg/Ca ratio of Globigerinoides ruber albus (Sun et al. 2005), as well as the  
493 updated nSST time series.

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497 *updated time series with uncertainty estimated as described in the main text. The solid line*  
498 *shows the median nSST and the light and dark grey are 90 % and 50 % central percentiles,*  
499 *respectively. Panel b shows the median uncertainty of all nSST (90 %) values of the entire time*  
500 *series as a function of the number of ensemble pairs (age and nSST). This example shows that*  
501 *out of 1,000,000 possible pairs about 500 – 1,000 are sufficient to characterise the uncertainty*  
502 *of this time series. The number of ensemble pairs required for other time series, or other*  
503 *purposes, needs to be evaluated on a case-by-case basis.*

504  
505 Some example scripts for filtering the data product by location, length, resolution and age  
506 control are available from the lead author's GitHub repository  
507 (<https://github.com/lukasonkers/PALMODutils>, last access [January 22, 2026](#)). *Example code to*  
508 *estimate the uncertainty of the nSST time series based on the age and temperature ensembles*  
509 *is available at the same location.* An extensive documentation of the LiPD format is available at  
510 <https://lipdverse.org> (last access: 23 May 2025) and utilities to interact with LiPD files in R *are*  
511 *available at* <https://github.com/nickmckay/lipdR> (last access 20 January 2026) and a user guide  
512 *to the lipdR package is available at* <https://nickmckay.org/lipdR/> (last access 20 January 2026.  
513 *Python users can use the PyLiPD package* (<https://pylipd.readthedocs.io/en/latest/>; last access  
514 [20 January 2026](#)), which is documented at <https://linked.earth/pylipdTutorials/intro.html> (last  
515 [access 20 January 2026](#)). *Resources for Matlab users* are available at  
516 <https://github.com/nickmckay/LiPD-utilities> (last access: 23 May 2025).

517  
518 Whilst we have done our best to address errors and omissions and aimed for standardisation  
519 across the entire data product, it comes with the guarantee of remaining errors and  
520 inconsistencies. Users are encouraged to report those to the lead author *by email* so they can  
521 be corrected. *Updates to the data synthesis will be published on PANGAEA and linked to the*  
522 *current version. Minor updates with corrections only will not be associated with a new data*  
523 *descriptor. The updating and versioning strategy is described in detail in Jonkers et al. (2020).*

## 524 8 Recommendations for palaeoclimate data 525 stewardship

526 This synthesis would not have been possible without good data stewardship of the marine  
527 palaeoclimate science community. For many decades researchers have been sharing their

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533 research data through (dedicated) publicly accessible data repositories. Even so, this synthesis  
534 makes a lot of invaluable metadata and chronological information publicly available for the first  
535 time. This is because such metadata and chronology data are often not directly associated with  
536 the primary proxy data, but reported in accompanying publications instead. When these  
537 publications are publicly accessible, this important information to interpret and reuse the data  
538 can be retrieved with considerable additional effort. However, more often than not, the  
539 publications are not publicly available and the information remains hidden behind the paywalls  
540 of publishers, rendering the data difficult to reuse.

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541  
542 Community guidelines on how to report general palaeoclimate data are available (Khider et al.,  
543 2019), as are more specific guidelines for microfossil assemblage data (Jonkers et al., 2025a).  
544 However, legacy datasets invariably do not adhere to such guidelines, thus necessitating  
545 (community) effort to increase the reusability of these data. For new datasets, we recommend  
546 data sharing not only from the point of view of reproducing single studies, but explicitly consider  
547 reuse when sharing data and ensure that that research data files are scientific works that are  
548 comprehensible in themselves. In this way, reuse and reinterpretation of scientific data and  
549 knowledge is greatly facilitated, allowing our field to address new questions that cannot be  
550 answered using a single palaeoclimate time series.

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551  
552 With the National Climate Data Center (NCDC) at NOAA and PANGAEA the palaeoclimate  
553 community has access to at least two dedicated data repositories that enforce standardisation  
554 and perform data curation. This is a tremendously advantageous position to facilitate the  
555 reusability of palaeoclimate data and we explicitly encourage data generators to continue  
556 sharing their data through these recognised and specific data repositories. Nevertheless and  
557 despite the existence of the LinkedEarth ontology (<https://linked.earth/ontology/>, last access 20  
558 January 2026) and the PaST thesaurus (Morrill et al., 2021), the lack of a adaptation of a single  
559 standardised vocabulary and consistent ontology across the repositories, remains a hurdle to  
560 reusability. The PaST thesaurus is used at NCDC, but standardisation is only performed under  
561 the hood at PANGAEA (Felden et al., 2023), where structured and standardised data can be  
562 accessed in xml format. Synthesis efforts benefit from such standardisation, but increased  
563 harmonisation across the repositories, or tools to do so, would further facilitate synthesis efforts  
564 and the reusability of data.

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Deleted: Progress is made in this regard at the two largest repositories for palaeo(climate) data, at

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but it requires that data generators share their data through these recognised and specific community repositories.

585 The value of this data product arguably not only lies in the standardisation of the format and  
586 vocabulary, but also in the updating and standardisation of the age-depth models and of the  
587 seawater temperature estimates. Such updating and standardisation is only possible when raw  
588 chronology and proxy data are available on a depth scale. Radiocarbon data is often publicly  
589 available or can, with additional effort, be scraped from publications. However, information on  
590 aligned chronologies, including ages and uncertainty on tuning tie points is seldom reported,  
591 rendering reevaluation of such chronologies difficult. Regarding proxy data, measured Mg/Ca  
592 and UK37' can, provided the calibration equation is known, be calculated from reported  
593 seawater temperatures, but ambiguities are likely to remain and the chance of deriving  
594 erroneous values is non-negligible (especially when the calibration equation is not explicitly  
595 included in the data file, or provided in secondary publication). For seawater temperatures  
596 based on microfossil assemblage the situation is different. Raw assemblage data are not as  
597 often shared as geochemical proxy data and due to the multi-dimensional character of the data,  
598 raw assemblage data cannot be inferred from the temperature estimates. This not only prevents  
599 revising temperature estimates reported without the underlying raw count data, but also  
600 prevents reuse of such assemblage data in other contexts, such as for estimates of past  
601 biodiversity change (e.g. Strack et al., 2024). This is unfortunate given the tremendous effort  
602 that went into generating such species assemblage data. In our opinion, the amount of work and  
603 the relevance of such data is so large that it would justify a coordinated international action to  
604 rescue the unpublished microfossil counts underlying seawater temperature reconstructions.

## 605 Acknowledgements

606 We are grateful to all researchers who generously shared their data and responded to requests  
607 for information. We thank Nick McKay for help with converting the data product to LiPD format  
608 and Anjuly Janßen for help with sorting out the bibliography.

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615 Author contributions

616 LJ Conceptualization, Data Curation, Funding Acquisition, Visualization, Writing – Original Draft.

617 MH Data Curation, Writing – Review & Editing. MS Data Curation, Writing – Review & Editing.

618 MK Conceptualization, Funding Acquisition, Writing – Review & Editing.

619 Table 3: standardised parameter names.

| Parameter         | Description  |
|-------------------|--|
| benthic.d18O      | benthic foraminifera stable oxygen isotope ratio   |
| benthic.d13C      | benthic foraminifera stable carbon isotope ratio   |
| planktonic.d18O   | planktonic foraminifera stable oxygen isotope ratio  |
| planktonic.d13C   | planktonic foraminifera stable carbon isotope ratio  |
| surface.temp      | (near) sea surface temperature   |
| deep.temp         | bottom water temperature   |
| CaCO3             | CaCO <sub>3</sub> content  |
| TOC               | Total organic carbon content   |
| BSi               | Biogenic silica content  |
| DBD               | Dry bulk density   |
| IRD               | Ice-rafted detritus  |
| planktonic.MgCa   | planktonic foraminifera Mg/Ca ratio  |
| benthic.MgCa      | benthic foraminifera Mg/Ca ratio   |
| UK37              | alkenone unsaturation index (rare cases where this ratio is not expressed as UK37' are indicated in the Notes) |
| C37.concentration | alkenone concentration   |

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623 Table 4: sites included in the PALMOD 130k marine palaeoclimate data synthesis version 2.

| site      | doi   | reference   |
|-----------|---|---|
| 108_658   | 10.2312/reports-gpi.1991.46 &<br>10.2973/odp.proc.sr.108.169.1989   | Tiedemann (1991)<br>Tiedemann et al. (1989)   |
| 108_658C  | 10.1594/PANGAEA.227736 &<br>10.1016/S0277-3791(99)00081-5 &<br>10.1029/94PA03354 &<br>10.1126/science.288.5474.2198   | Knaack and Sarnthein (2005)<br>deMenocal et al. (2000a)<br>Zhao et al. (1995)<br>deMenocal et al. (2000b)   |
| 108_659   | 10.2312/reports-gpi.1991.46   | Tiedemann (1991)  |
| 108_664B  | 10.1029/97PA01019 &<br>10.2973/odp.proc.sr.108.165.1989   | Raymo et al. (1997)<br>Ruddiman and Janecek (1989)  |
| 117_723A  | 10.1029/95GL02558 &<br>10.1038/nature01340 &<br>10.1016/j.marmicro.2010.09.006 &<br>10.1016/S0031-0182(03)00629-1   | Naidu and Malmgren (1995)<br>Gupta et al. (2003)<br>Godad et al. (2011)<br>Naidu and Niitsuma (2003)  |
| 121_758   | 10.1029/94PA02290 &<br>10.2973/odp.proc.sr.121.124.1991   | Chen et al. (1995)<br>Farrell and Janecek (1991)  |
| 130_806B  | 10.2973/odp.proc.sr.130.023.1993 &<br>10.1007/BF02369003 &<br>10.2973/odp.proc.sr.130.025.1993 &<br>10.2973/odp.proc.sr.130.024.1993 &<br>10.1126/science.1115933 &<br>10.2973/odp.proc.ir.130.1991 &<br>10.2973/odp.proc.sr.130.002.1993 | Berger et al. (1993)<br>(Berger et al., 1993) (1996)<br>Bickert et al. (1993)<br>Schmidt et al. (1993)<br>Medina-Elizalde and Lea (2005)<br>Kroenke et al. (1991)<br>Janecek (1993) |
| 133_819A  | 10.2973/odp.proc.sr.133.224.1993  | Wanninkhof et al. (2014)  |
| 154_925C  | 10.2973/odp.proc.sr.154.110.1997 &<br>10.5194/cp-13-779-2017  | Bickert et al. (1997)<br>Wilkens et al. (2017)  |
| 154_927   | 10.2973/odp.proc.sr.154.110.1997 &<br>10.5194/cp-13-779-2017  | Bickert et al. (1997)<br>Wilkens et al. (2017)  |
| 154_929   | 10.2973/odp.proc.sr.154.110.1997 &<br>10.5194/cp-13-779-2017  | Bickert et al. (1997)<br>Wilkens et al. (2017)  |
| 160_963A  | 10.1016/j.palaeo.2011.04.030  | Incarbona et al. (2011)   |
| 161_976   | 10.1130/0091-<br>7613(2002)030<0863:EAAAHP>2.0.CO;<br>2 & 10.1016/j.quascirev.2014.06.016 &<br>10.1002/2014PA002710   | Comboureu Nebout et al. (2002)<br>Martrat et al. (2014)<br>Jiménez-Amat and Zahn (2015)   |
| 162_983   | 10.1029/1998PA900021 &<br>10.1038/nature14330 & 10.1016/S0012-<br>821X(97)00164-7 &<br>10.1029/2003PA000921   | Ortiz et al. (1999)<br>Barker et al. (2015)<br>Channell et al. (1997)<br>Raymo et al. (2004)  |
| 167_1011C | 10.2973/odp.proc.sr.167.225.2000 &  | Andreasen et al. (2000)   |

|           |  |   |
|-----------|--|---|
|           | 10.2973/odp.proc.sr.167.214.2000   | Lyle et al. (2000)  |
| 167_1014  | 10.2973/odp.proc.sr.167.205.2000 &<br>10.1029/2004GL020138   | Hendy and Kennett (2000)<br>Yamamoto et al. (2004)  |
| 167_1017E | 10.2973/odp.proc.sr.167.242.2000 &<br>10.2973/odp.proc.sr.167.210.2000 &<br>10.2973/odp.proc.sr.167.222.2000                             | Kennett et al. (2000)<br>Ishiwatari et al. (2000)<br>Tada et al. (2000)                             |
| 167_1018C | 10.2973/odp.proc.sr.167.225.2000 &<br>10.2973/odp.proc.sr.167.214.2000   | Andreasen et al. (2000)<br>Lyle et al. (2000)   |
| 167_1019C | 10.1029/GM112p0127 &<br>10.1029/2002PA000768   | Mix et al. (1999)<br>Barron et al. (2003)   |
| 172_1058C | 10.1016/j.gloplacha.2013.08.013  | Bahr et al. (2013)  |
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