



**HAL**  
open science

## A global multiproxy database for temperature reconstructions of the Common Era

Julien Emile-Geay, Nicholas P. McKay, Darrell S. Kaufman, Lucien von Gunten, Jianghao Wang, Kevin J. Anchukaitis, Nerilie J. Abram, Jason A. Addison, Mark A. J. Curran, Michael N. Evans, et al.

► **To cite this version:**

Julien Emile-Geay, Nicholas P. McKay, Darrell S. Kaufman, Lucien von Gunten, Jianghao Wang, et al.. A global multiproxy database for temperature reconstructions of the Common Era. *Scientific Data*, 2017, 4, pp.170088. 10.1038/sdata.2017.88 . hal-01645001

**HAL Id: hal-01645001**

**<https://hal.science/hal-01645001v1>**

Submitted on 13 Apr 2018

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# SCIENTIFIC DATA

OPEN

## Data Descriptor: A global multiproxy database for temperature reconstructions of the Common Era

PAGES2k Consortium<sup>#</sup>

Received: 22 July 2016

Accepted: 3 May 2017

Published: 11 July 2017

Reproducible climate reconstructions of the Common Era (1 CE to present) are key to placing industrial-era warming into the context of natural climatic variability. Here we present a community-sourced database of temperature-sensitive proxy records from the PAGES2k initiative. The database gathers 692 records from 648 locations, including all continental regions and major ocean basins. The records are from trees, ice, sediment, corals, speleothems, documentary evidence, and other archives. They range in length from 50 to 2000 years, with a median of 547 years, while temporal resolution ranges from biweekly to centennial. Nearly half of the proxy time series are significantly correlated with HadCRUT4.2 surface temperature over the period 1850–2014. Global temperature composites show a remarkable degree of coherence between high- and low-resolution archives, with broadly similar patterns across archive types, terrestrial versus marine locations, and screening criteria. The database is suited to investigations of global and regional temperature variability over the Common Era, and is shared in the Linked Paleo Data (LiPD) format, including serializations in Matlab, R and Python.

<b>Design Type(s)</b>	observation design • data integration objective • time series design
<b>Measurement Type(s)</b>	archaeal metabolite • calcification • glacial ice • radiance • sediment • stable isotope analysis • temperature of environmental material • trace metal analysis • wood
<b>Technology Type(s)</b>	data acquisition system
<b>Factor Type(s)</b>	measurement method • environmental material • geographic location • temporal_interval
<b>Sample Characteristic(s)</b>	Democratic Republic of the Congo • lake sediment • Tanzania • South Africa • speleothem • Antarctica • glacial ice • borehole • United States of America • Russian Federation • Canada • Greenland • Finland • Norway • Iceland • Sweden • Bhutan • China • Indonesia • India • Japan • Kyrgyzstan • Kazakhstan • Mongolia • Nepal • Pakistan • Afghanistan • Thailand • Taiwan Province • Viet Nam • Australia • New Zealand • Slovakia • Romania • Austria • Switzerland • France • Spain • Germany • Estonia • Mexico • Atlantic Ocean • marine sediment • Pacific Ocean • Indian Ocean • Southern Ocean • Arctic Ocean • coral reef • marine sponge reef • Chile • Argentina • Peru

Correspondence and requests for materials should be addressed to J.E.-G. (email: julieneg@usc.edu).

<sup>#</sup>A full list of authors and their affiliations appears at the end of the paper.

## Background & Summary

Since the pioneering work of D'Arrigo and Jacoby<sup>1-3</sup>, as well as Mann *et al.*<sup>4,5</sup>, temperature reconstructions of the Common Era have become a key component of climate assessments<sup>6-9</sup>. Such reconstructions depend strongly on the composition of the underlying network of climate proxies<sup>10</sup>, and it is therefore critical for the climate community to have access to a community-vetted, quality-controlled database of temperature-sensitive records stored in a self-describing format. The Past Global Changes (PAGES) 2k consortium, a self-organized, international group of experts, recently assembled such a database, and used it to reconstruct surface temperature over continental-scale regions<sup>11</sup> (hereafter, 'PAGES2k-2013').

This data descriptor presents version 2.0.0 of the PAGES2k proxy temperature database (Data Citation 1). It augments the PAGES2k-2013 collection of terrestrial records with marine records assembled by the Ocean2k working group at centennial<sup>12</sup> and annual<sup>13</sup> time scales. In addition to these previously published data compilations, this version includes substantially more records, extensive new metadata, and validation. Furthermore, the selection criteria for records included in this version are applied more uniformly and transparently across regions, resulting in a more cohesive data product.

This data descriptor describes the contents of the database, the criteria for inclusion, and quantifies the relation of each record with instrumental temperature. In addition, the paleotemperature time series are summarized as composites to highlight the most salient decadal- to centennial-scale behaviour of the dataset and check mutual consistency between paleoclimate archives. We provide extensive Matlab code to probe the database-processing, filtering and aggregating it in various ways to investigate temperature variability over the Common Era. The unique approach to data stewardship and code-sharing employed here is designed to enable an unprecedented scale of investigation of the temperature history of the Common Era, by the scientific community and citizen-scientists alike.

## Methods

### Collaborative model

The database is the product of a community-wide effort, coordinated by PAGES through a network of nine working groups (<http://www.pastglobalchanges.org>). Calls for participation were disseminated broadly and regional leaders solicited input from scientists with relevant datasets and/or expertise. A provisional database was compiled into a uniform framework, then redistributed to regional groups for quality control and further additions. For this purpose, quality control plots, including basic metadata for each record, were prepared to enable coauthors of this data descriptor to efficiently recognize and correct errors. Examples of these plots are given in the Quality Control section, and the full collection is archived as pdf files in Data Citation 1.

### Data aggregation

The PAGES2k community aimed to identify records that are most relevant to understanding temperature evolution over the last 2000 years, while also assembling a uniform global database that can be culled to address a wide range of research questions. Specific criteria were developed to gather all published proxy records that meet five objective and reproducible criteria:

### Thermal sensitivity

Proxy records were gathered from archive types for which previous understanding of the proxy system indicated that the records are temperature-sensitive. Records were only included when the original study described the relation between the proxy value and one or more climate variables, including temperature, or when the correlation with nearby instrumental temperature data was high enough to reject the null hypothesis of zero correlation at the 5% level, taking into account both temporal autocorrelation and test multiplicity. Indeed, temporal autocorrelation is well known to reduce the number of degrees of freedom available to reject a null hypothesis<sup>14</sup>. The test multiplicity problem (aka the 'multiple comparisons problem' or 'look-elsewhere effect') is the propensity for false positives to arise when multiple hypothesis tests are conducted simultaneously; in this case, testing the null hypothesis at 1,000 grid points with a 5% level would be expected to yield fifty spurious 'discoveries'<sup>15</sup> even in the absence of any link to temperature. Our analysis controls for both effects (see 'Relationship to temperature').

In addition, regional and proxy experts who are authors on this data descriptor certified that the records reflect temperature variability and that they meet all other stated criteria (Supplementary Table 1). Note that temperature sensitivity does not preclude the potential for many proxy systems to be secondarily or additionally sensitive to other environmental variables, such as moisture availability.

### Record duration

A primary goal of the PAGES2k project is to understand climate dynamics over the entire Common Era. Records of this duration are most commonly accessible from sedimentary sequences that lack annual resolution; a minimum length of 500 years for these records serves as a coarse initial screen. For annually-banded terrestrial records (e.g., varves, glacier ice, tree rings), shorter-duration records that overlap with the instrumental period are important for calibration-validation exercises and for bridging between annually-resolved and lower-resolution records; as a result, annually resolved records from terrestrial archives over 300 years long were also included. Annually resolved records from marine

archives (corals, molluscs) are rarely this long, but provide critical information where instrumental data are often sparse or absent, and were included in the database if they exceeded 50 years in duration.

### Chronological accuracy

Most records in this database are layer-counted, with a dating uncertainty of a few percent or less, but generally extend back less than 500 years. Other proxy records may span many millennia but some have chronologies that are too uncertain for centennial and finer-scale paleotemperature reconstructions. Recognizing, however, that lake and marine sediments accumulate at approximately constant rates, and considering the goal of building a comprehensive database from which records can be culled as necessary, depending on the scientific question, the initial screen for chronological control was relatively coarse. Once suitable records have been identified, their age-model uncertainty can be quantified using existing statistical procedures<sup>16–20</sup>, providing a useful basis for including or weighting individual records in paleotemperature reconstructions. Namely, when annual layers cannot be counted, the timelines for records selected for this database were constrained by at least one chronological control point near the most recent end of the record and another near the oldest part of the record, or 1 CE, whichever is younger. Records that are longer than 1,000 years must include at least one additional age approximately midway between the other two. What constitutes ‘approximately’ was open to reasonable interpretation but was typically within two centuries of the mid-point.

### Record resolution

PAGES2k scientific questions focus on centennial and finer time scales. Terrestrial and lacustrine records were included with average sample resolution of 50 years or finer. However, such records are rare from marine sediments, and thus a minimum average sample resolution of 200 years was accepted for this database. We also included 4 borehole records, although quantifying median resolution is less straightforward in boreholes than in other archives. The borehole records in the database are appropriate for examining decadal to multi-centennial scale variability, depending on the timeframe of interest<sup>21</sup>.

### Public availability

Proxy records used in the PAGES2k synthesis products are publicly available through previous publications or online data archives, or because their owners made them available for inclusion in this open-access data product. The original data for 49 records are made available for the first time in this data product (specified in Supplementary Table 1). Open access is a critical component of this endeavor, and led us to reject some records that would have been suitable under the other criteria. The focus on annual- to centennial-scale temperature of the past 2000 years led to the exclusion of those paleoclimate records that did not meet the resolution or geochronological control criteria required for meaningful inferences of the temperature history of Common Era.

### Relation to previous release

The selection criteria for this dataset are specific to the type of proxy archive; for some proxy types, the standards in this version were broadened compared to the criteria used previously by PAGES2k regional groups. In most regions, records have been added that have become available since the publication of PAGES2k-2013, or that were not used in the continental-scale reconstructions because they are not annually resolved and therefore did not conform to the reconstruction method used by a particular regional group. In Antarctica, for example, PAGES2k-2013 included only the longest annually resolved ice cores, whereas the present version includes shorter and decadal-scale-resolution records.

For other proxy types, more stringent criteria resulted in the exclusion of some records. The excluded records are tracked in Supplementary Table 2. In most regions, some records were excluded because they did not meet the stricter standards for the minimum length or temporal resolution (criteria detailed above), or because of ambiguities related to the temperature sensitivity of the proxy, or because they have been superseded by higher-quality records from the same site. Of the 641 records that together comprise the previously published PAGES2k datasets, 177 are now excluded, of which 124 are tree-ring-width series that are inversely related to temperature. To be included in the current database, tree-ring data were required to correlate positively ( $P < 0.05$ ) with local or regional temperature (averaged over the entire year or over the growing season). Trees whose growth increases with temperature (e.g., direct effect of temperature on physiological processes and photosynthetic rates) are more likely to produce a reliable expression of past temperature variability compared to trees that respond inversely to temperature, for which the proximal control on growth is moisture stress (e.g., evapotranspiration demand)<sup>22</sup>. Because many trees are more strongly influenced by moisture availability than by growing season temperatures<sup>23</sup>, including only the positive responders reduces the overall number of tree-ring records to a more selective subset (see Supplementary Information, section 1).

### Metadata

The current database includes a large number of metadata fields to facilitate the intelligent reuse of the data. Table 1 (available online only) lists a subset of information in a single-page format. Supplementary Table 1 includes additional metadata fields with critical information to convey the appropriate use of each dataset, namely: the PAGES2k identifier assigned for this data product, the identifier used in previous PAGES2k

products by the Ocean2k working group<sup>12,13</sup>, or by PAGES2k-2013, whether the record is superseded by another in this version, the archive type, the primary publication citation, its associated digital object identifier (DOI; if one exists), the secondary publication citation and DOI, the URL link to where the data were archived by the original author, the associated data citation, the geographic coordinates (latitude, longitude, elevation), the name of the site, the ISO 3166-1 standard name of the country/ocean basin where it is located, the earliest and latest years covered by the record, the resolution of the time series (median spacing between consecutive observations), the type of proxy observation, the name of the variable used as the temperature-sensitive time series and its units, the physical feature whose temperature is sensed by the proxy (e.g., surface air temperature, sea-surface temperature), the part of the seasonal cycle recorded by the proxy, the direction of the relationship between the proxy and temperature (positive or negative), quality control (QC) comments, initials of PAGES2k Consortium author who performed QC certification, and a permalink to the dataset's page at the NCEI-Paleo/World Data Service for Paleoclimatology.

### Annualization

Annualization is necessary to compare proxies of varying sampling resolution with instrumental observations or with each other. Records with a superannual resolution were interpolated to annual resolution via nearest-neighbor interpolation. Interpolating records may alter their spectral content<sup>24</sup>, but permits comparison of information on a common time grid and for shared spectral resolutions.

Seasonally-resolved proxies (e.g., most corals) were averaged to produce annual (ANN: Jan-Dec), DJF (December January February) and JJA (June July August) anomalies. Some records from glacier ice have a sampling resolution finer than 1 year. However, firn diffusion smooths subannual signals, such that the shortest recoverable periodicity is generally no shorter than 1 year<sup>25,26</sup>. Such records were therefore annualized to a Jan-Dec window.

The vast majority of records in the database are annually-resolved, and are not affected by this processing. We note, however, that many such records subsample part of the annual cycle (e.g., for tree rings, the growing season). For this purpose it is instructive to compare such records to annual (Jan-Dec), DJF and JJA averages of the HadCRUT4.2 temperature field (Technical Validation). The annualized data are archived alongside the original data, so either may be used in subsequent analyses.

### Code availability

The Matlab code (<https://www.mathworks.com/products/matlab.html>) necessary to reproduce the figures of this descriptor is available at [https://github.com/CommonClimate/PAGES2k\\_phase2](https://github.com/CommonClimate/PAGES2k_phase2) under a free BSD license.

## Data Records

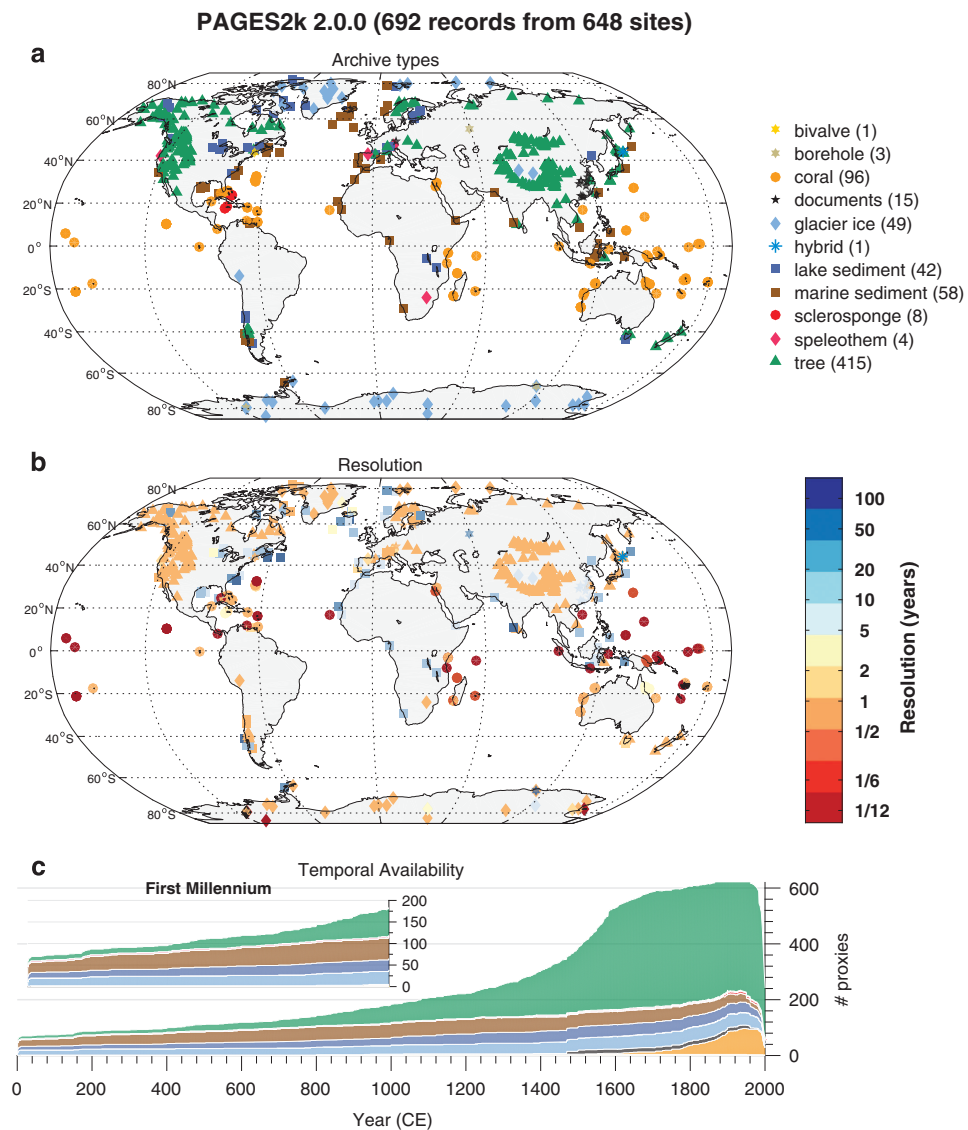
### Proxy dataset

The PAGES2k temperature database (Fig. 1, Supplementary Fig. 1) includes 692 records (Data Citation 2 to Data Citation 477) from 49 countries and 11 distinct types of archives: 415 from trees (ring width and density), 96 from corals (e.g., isotopes, elemental composition, calcification rate), 58 from marine sediments (e.g. geochemistry, floral and faunal assemblages), 49 from glacier ice, 42 from lake sediments (e.g., floral and faunal assemblages, sediment accumulation, geochemistry), 15 from documentary sources, 8 from sclerosponges, 4 from speleothems, 3 from boreholes, 1 from bivalves, and 1 hybrid (tree/borehole) record. Each of these archives bears the imprint of a proxy system responding to temperature changes, with the signal recorded in one or more of the archive's chemical, physical, or biological properties<sup>27</sup>. The details behind the collection, analysis and interpretation of each of the records in the database are beyond the scope of this data descriptor, and we refer readers to the original publications for that information.

The records cover a wide range of time spans, from a minimum of 52 years to a maximum of 2000 years. The average length is 760 years, the median 547 years, not counting the duration of any record beyond 2000 years; temporal resolution ranges from biweekly to centennial, with a majority of annual records. As seen in Fig. 1, many proxy records spanning the last 2000 years are not annually resolved, and in some regions, most of the available records of any length lack annual resolution. The mean resolution of non-tree archives is 11 years, the median 1 year. For sedimentary archives the mean and median resolutions are 25 and 18 years, respectively. A list of sites comprising the database, along with basic metadata, is presented in Table 1 (available online only), an expanded version of which is in Supplementary Table 1. Note that some sites include more than one proxy temperature record.

The majority (59%) of the records are based on tree rings because they are annually resolved, precisely dated, and geographically widespread, especially in the mid-latitudes of the Northern Hemisphere (Supplementary Information, section 1). The PAGES2k collection is unique among previous efforts in the amount of paleoclimate evidence from sources other than tree rings, such as lake and marine sediments, corals, glacier ice and speleothems, thus expanding the geographic and temporal coverage of the database, as well as mitigating potential issues regarding the use of tree rings for temperature reconstructions<sup>28</sup>.

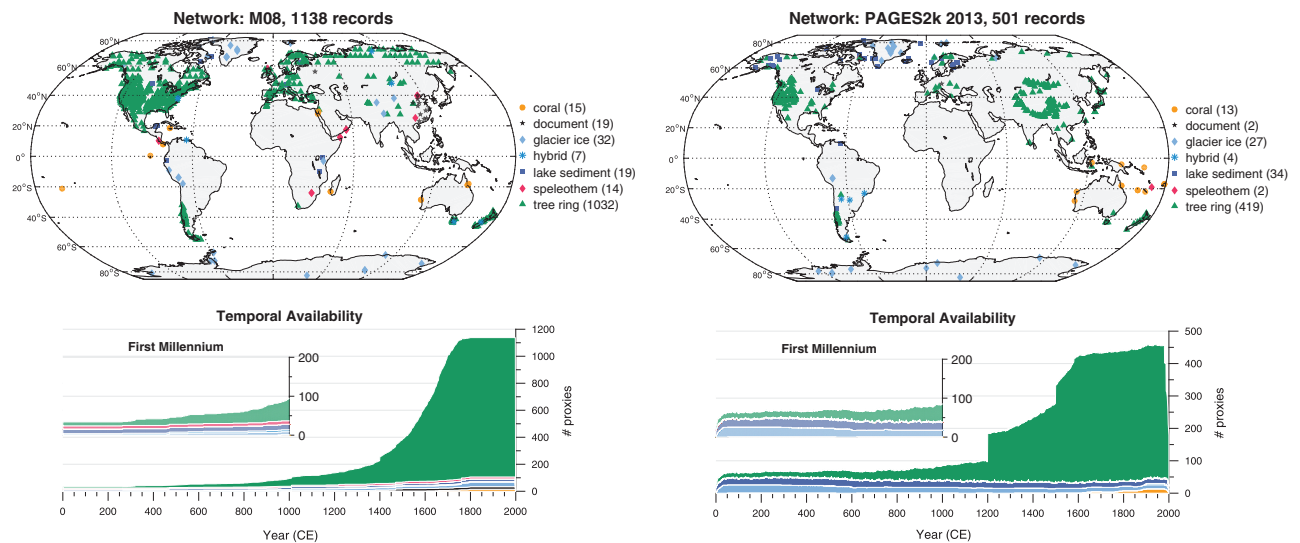
While the vast majority of the records gathered herein were layer-counted, there are 87 sediment (marine or lake) datasets whose chronologies are derived from radiometric methods. For 41 of those datasets (47%), Data Citation 1 includes the primary geochronological information needed for a formal treatment of time uncertainty using various age-modelling techniques<sup>19,29,30</sup>. Additionally, 30 records



**Figure 1. Spatiotemporal data availability in the PAGES2k database.** (a) Geographical distribution, by archive type, coded by color and shape. (b) Temporal resolution in the PAGES2k database, defined here as the median of the spacing between consecutive observations. Shapes as in (a), colors encode the resolution in years (see colorbar). (c) Temporal availability, coded by color as in (a).

(overlapping, but not exclusively, with the 41 above) include chronology ensembles from the Arc2k 1.1.1 dataset<sup>31</sup>. These include both sedimentary records with age ensembles derived via BACON<sup>19</sup>, and ice and varved records with age ensembles derived via BAM<sup>32</sup>.

For comparison, Fig. 2 displays the spatiotemporal distribution of proxy archives in the databases of Mann *et al.*<sup>33,34</sup> (hereafter M08) and PAGES2k-2013 (ref. 11). While the M08 database contains 75% more records than this collection, these records are overwhelmingly land-based, from the Northern Hemisphere, and relatively short. Indeed, the M08 database is disproportionately composed of tree rings from North America, many of which start after 1000 CE, so that fewer than 100 records reach beyond this date. In contrast, the present collection contains 176 records out to 1000 CE, most of which are not tree-based. While the PAGES2k-2013 effort had succeeded in diversifying the network prior to 1,000 CE, it focused on terrestrial sites, and was dominated by tree-based records after 1200 CE. The proportion of records from the Southern Hemisphere is comparable between all three databases (15% in M08, 12% in PAGES2k-2013, 16% in this study), but the number of records from Antarctica has steadily improved between databases (8 in M08, 9 in PAGES2k-2013, 26 here). The present dataset therefore constitutes a major leap in terms of the diversity and duration of records, as well as oceanic and polar coverage. The present compilation also marks an unprecedented effort at rigorously assessing their quality as temperature indicators (Technical Validation). While the overall quantity of records has declined with respect to M08, this is largely the result of more selective inclusion criteria (Methods).



**Figure 2.** Data availability in the M08 (refs 33,34) and PAGES2k-2013 (ref. 11) databases. Graphical conventions as in Fig. 1. Note that the *y*-axis scale varies between plots on account of the large differences in number of records, but the first millennium inset uses the same scale between all comparable panels in Fig. 1 and this one, to highlight progress made in bolstering coverage of this time period.

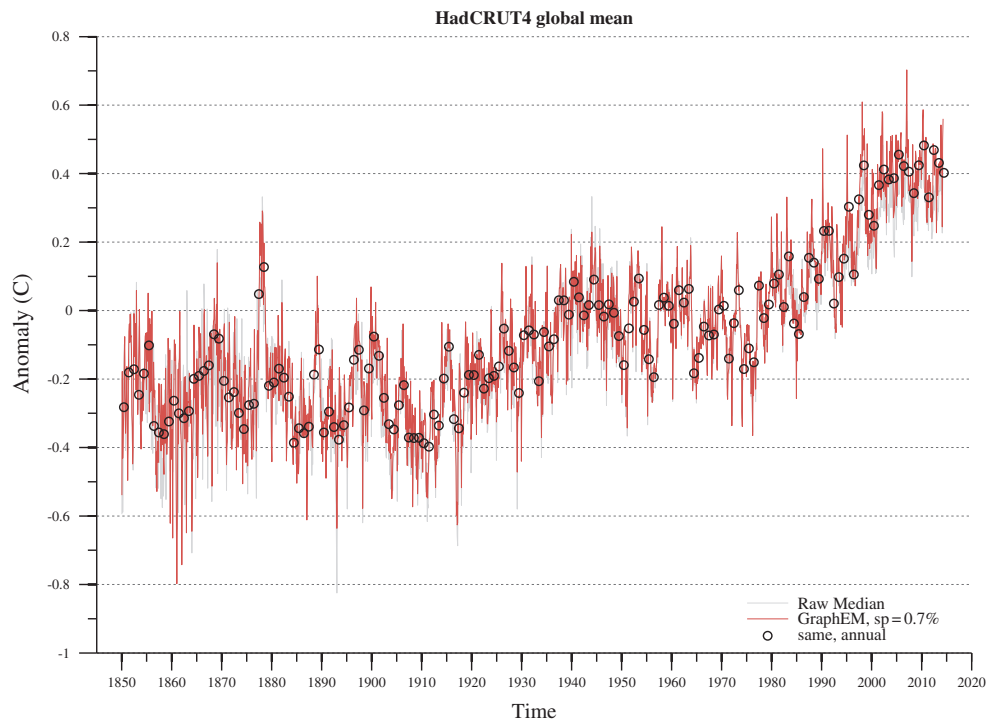
Indeed, a unique aspect of the PAGES2k effort is the richness of the metadata annotating each record. In Supplementary Table 1, all proxy records are accompanied by information about their paleotemperature interpretation, including where the proxy senses temperature (e.g., surface-air temperature, sea-surface temperature), the sign of this relationship (positive or negative), and the part of the annual cycle that is preferentially recorded (e.g., May June July). Some of the records from marine sediments were processed for additional quality control as described by ref. 12. The ‘QC Notes’ column of Supplementary Table 1 specifies data processing that was done, and explains modifications relative to the original data citation. In addition to the metadata in Supplementary Table 1, which are complete for every record, Data Citation 1 includes additional metadata for some records. The type of additional information depends on the proxy record and some of the information is missing for some records. For example, when available, the basis for the temperature interpretation is stated (e.g., calibration or first principles). Some records that were calibrated to temperature (e.g., ref. 35) include the native data from which the temperature series was derived, as well as a description of the calibration (equation, reference, uncertainty, units). This metadata structure follows the Linked Paleo Data (LiPD) structure, and the interested reader is referred to the associated publication<sup>36</sup> for a full exposition of the format.

Accordingly, the database is primarily encoded as LiPD<sup>36</sup> files: a structured, machine-readable format for paleoclimate data based on Javascript Object Notation (JSON) that accommodates the wide diversity of information comprising this database (PAGES2k\_v2.0.0\_LiPD.zip, Data Citation 1). Serializations are also available in the Python (PAGES2k\_v2.0.0-ts.pklz, Data Citation 1), Matlab (PAGES2k\_v2.0.0.mat, Data Citation 1) and R (PAGES2k\_v2.0.0.Rdata, Data Citation 1) languages. Utilities for interacting with LiPD files in Matlab and Python are available at <http://github.com/nickmckay/LiPD-utilities>. Utilities in R are forthcoming.

### Instrumental temperature dataset

The ability of the proxy network to capture temperature information is assessed with respect to the instrumental HadCRUT4.2 dataset<sup>37</sup>, covering CE 1850–2014. The dataset merges surface air temperature over land (CRUTEM4) and sea-surface temperature over ocean regions (HadSST3). We use the Cowtan & Way version<sup>38</sup> of the dataset, which corrects for missing values and incomplete post-1979 Arctic coverage via the use of satellite observations. Even with the correction, the HadCRUT4.2 dataset is incomplete, with about 60% of the monthly values missing, so the remaining missing values were infilled via the GraphEM<sup>39</sup> algorithm. The graph was chosen via the graphical lasso<sup>40</sup> using a sparsity parameter of 0.7%, which was chosen by cross-validation as the minimizer of the expected prediction error (HADCRUT4\_median\_GraphEM.mat, Data Citation 1).

The global (area-weighted) mean from this dataset is charted in Fig. 3. We note that this dataset may result in temperature variations whose amplitude is biased downwards in regions of poor observational coverage, hence potentially distorting proxy-temperature correlations. Regionally-specific temperature datasets (e.g., ref. 41 for Antarctica) would therefore be more appropriate in regional applications.



**Figure 3.** Global mean temperature from the HadCRUT4.2 dataset before (gray) and after (red) imputing missing monthly values via GraphEM. Black circles mark the yearly averages (mean annual temperature, or MAT) of GraphEM-imputed temperature values (red line).

### Technical Validation

A unique challenge for technical validation of paleoclimatological datasets is that the target, here, site-local temperature over the Common Era, is unknown. Addressing this issue is an important objective of the current study. Our approach to validation includes comparison with the instrumental data for annually-resolved records, subsampling the dataset to assess reproducibility among proxy types and other subsets based on different screening criteria, and coarse-graining the time series to different extents to address issues related to combining records of different resolution and age certainty. Evidence that the records in the database reflect past temperature variability can be found in the original publications associated with each record. In addition, each series incorporated in the dataset was examined by one or more regional experts, who certified that each proxy record included in the database was accurate and related to temperature (Supplementary Table 1). This level of expert elicitation is unique among existing paleoclimate syntheses covering the last two millennia, and is a key value proposition of the PAGES2k crowd-curation process.

### Quality control

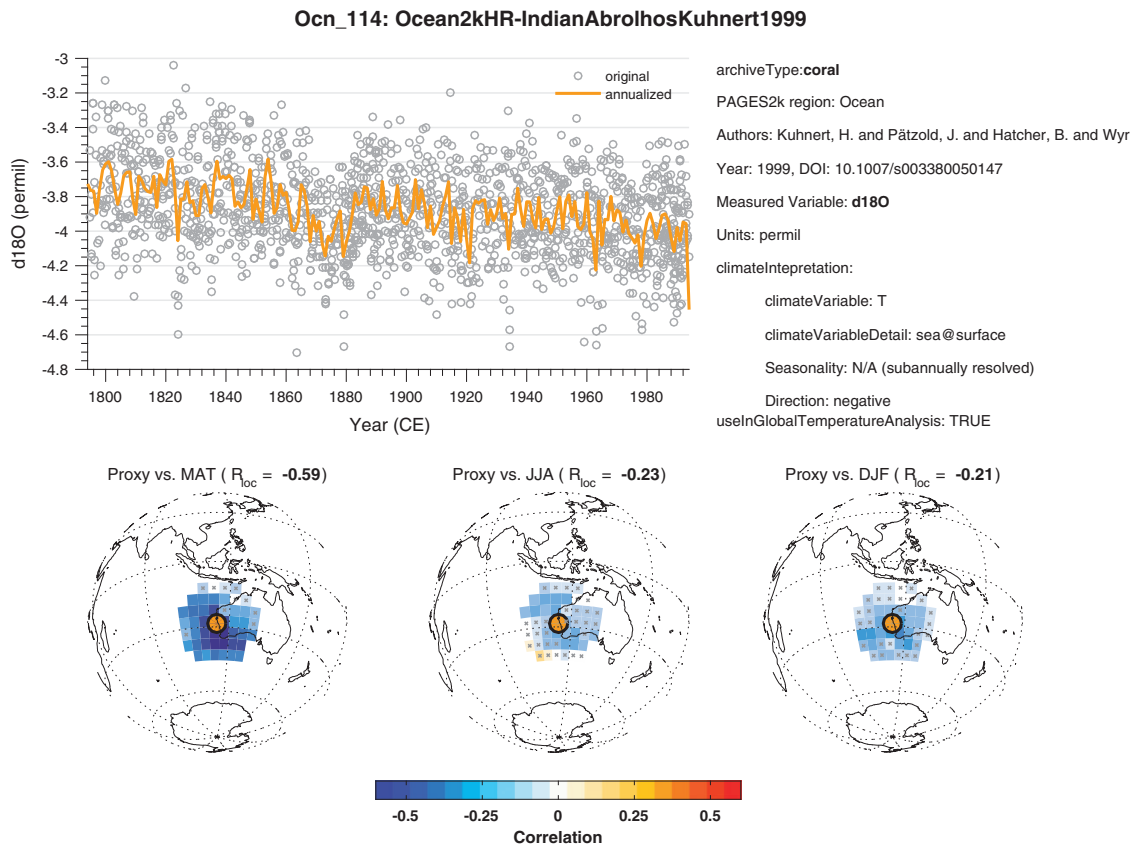
To facilitate quality control of individual records within the database, dashboards displaying raw data, their annualized version and the extent to which they may be informative of annual, JJA or DJF temperature were created. These figures are grouped by region or globally and included on the FigShare repository associated with this publication ([Global\\_QCfig\\_bundle.pdf](#), Data Citation 1).

Fundamentally there are two ways to infer past temperatures from paleoclimate records. They can be calibrated using either:

1. direct (in-time) calibration; or
2. indirect (space for time) calibration.

In the first approach, the record must overlap with the instrumental period (here: 1850–2014), and this period of overlap must contain enough points for a statistical calibration to an instrumental temperature product such as HadCRUT4 to be meaningful. In the second approach, one often uses transfer functions or laboratory-based culture experiments. Accordingly, summary plots for all records are divided into two categories, described below. The instrumental overlap threshold requirement is set at  $n = 20$  based on sensitivity tests (not shown). This parameter may be changed in the code associated with this dataset (see Code Availability).





**Figure 4.** Quality-control plot for record Ocn\_114 (Ocean\_QCfig\_bundle.pdf, Data Citation 1). See text for details as an example of record that can be calibrated in time.

### Records that can be calibrated in time

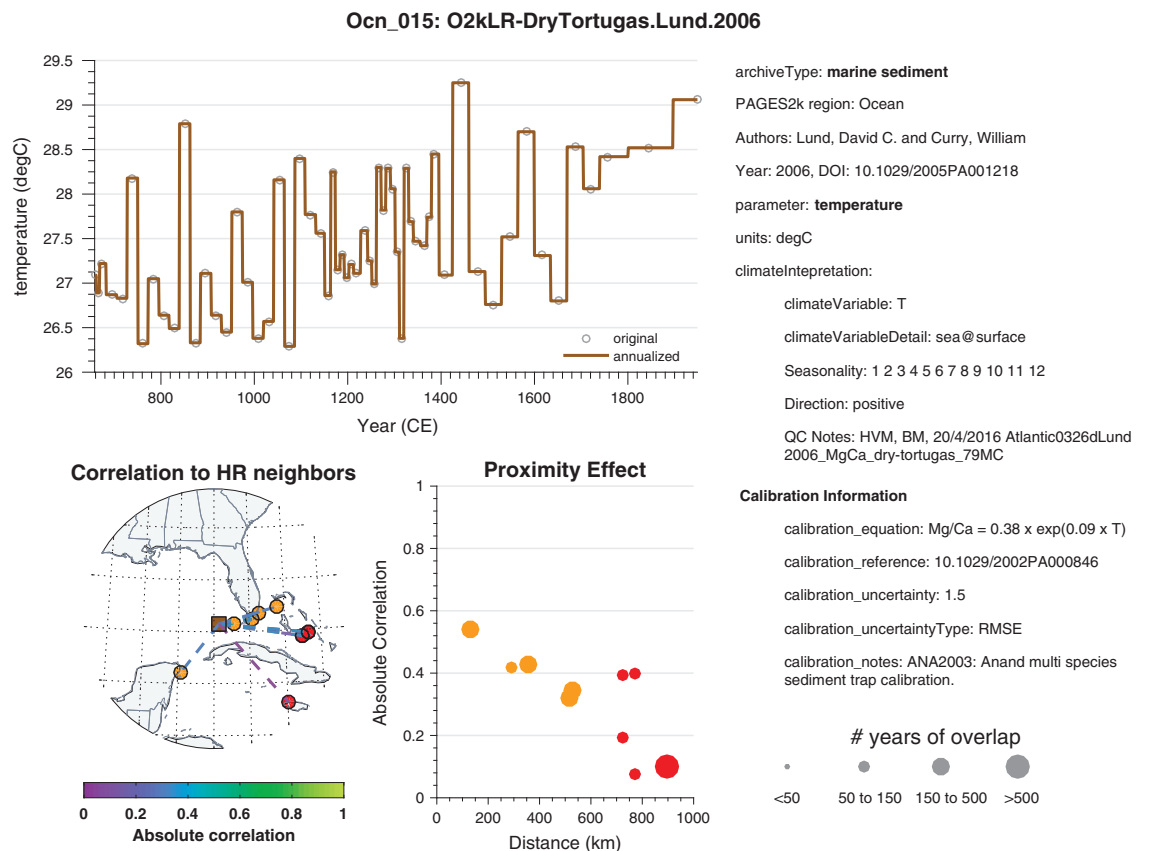
Record Ocn\_114 (ref. 42) (Fig. 4) is one such example. The top panel shows the (monthly) raw data as gray circles and an annualized curve whose color code matches that of Fig. 1a. The three bottom plots depict correlations with temperature grid points taken within a 2,000 km radius. The bottom left plot shows correlations with mean annual temperature (MAT), with insignificant correlations (as per an isospectral test<sup>43</sup>, 1,000 surrogates, 5% level) denoted by hatching. The local correlation is  $-0.59$  and its bold font weight indicates statistical significance, also at the 5% level. Similar plots are shown for boreal summer (JJA, center) and boreal winter (DJF, right). Essential textual metadata are displayed on the right hand side. Similar plots follow identical conventions.

### Records that cannot be calibrated in time

If a record has too coarse a resolution, or ends too early, to contain 20 points over the 1850–2000 interval, it belongs to this category. One such record is Ocn\_015, a foraminifera Mg/Ca record from the Caribbean<sup>35</sup> (Fig. 5). This record was independently calibrated to temperature, as reflected in the ordinate of the time series plot (top left). As before, the right side of the page displays metadata, including the calibration method and its reported uncertainties. Since a comparison to an instrumental temperature series is neither possible nor meaningful for such a record, the bottom left panel displays its correlation to the 10 nearest high-resolution records (bottom left), coded by lines whose color represents the absolute correlation. Thick, solid lines represent significant correlations (again, as per ref. 43 at the 5% level), and thinner dashed lines represent correlations that did not pass the test. The bottom central panel stratifies these correlations by distance; the color corresponds to the proxy code (i.e., corals in orange, sclerosponges in red, c.f. Fig. 1a), with significant correlations circled in black. The size of the symbol scales with the number of years of overlap, as shown at the bottom right.

### Relationship to temperature

Here we examine the extent to which the database as a whole captures the observed temperature variability at local and regional scales. We do so via correlation analysis, which makes the common assumption that the relation between the proxy value and temperature over the twentieth century is representative of the entire record (stationarity). Unstable or multivariate associations between proxies and local temperature would represent a significant challenge to this assumption; however, this problem



**Figure 5.** Quality-control plot for record Ocn\_015 (Ocean\_QCfig\_bundle.pdf, Data Citation 1). See text for details as an example of record that cannot be calibrated in time.

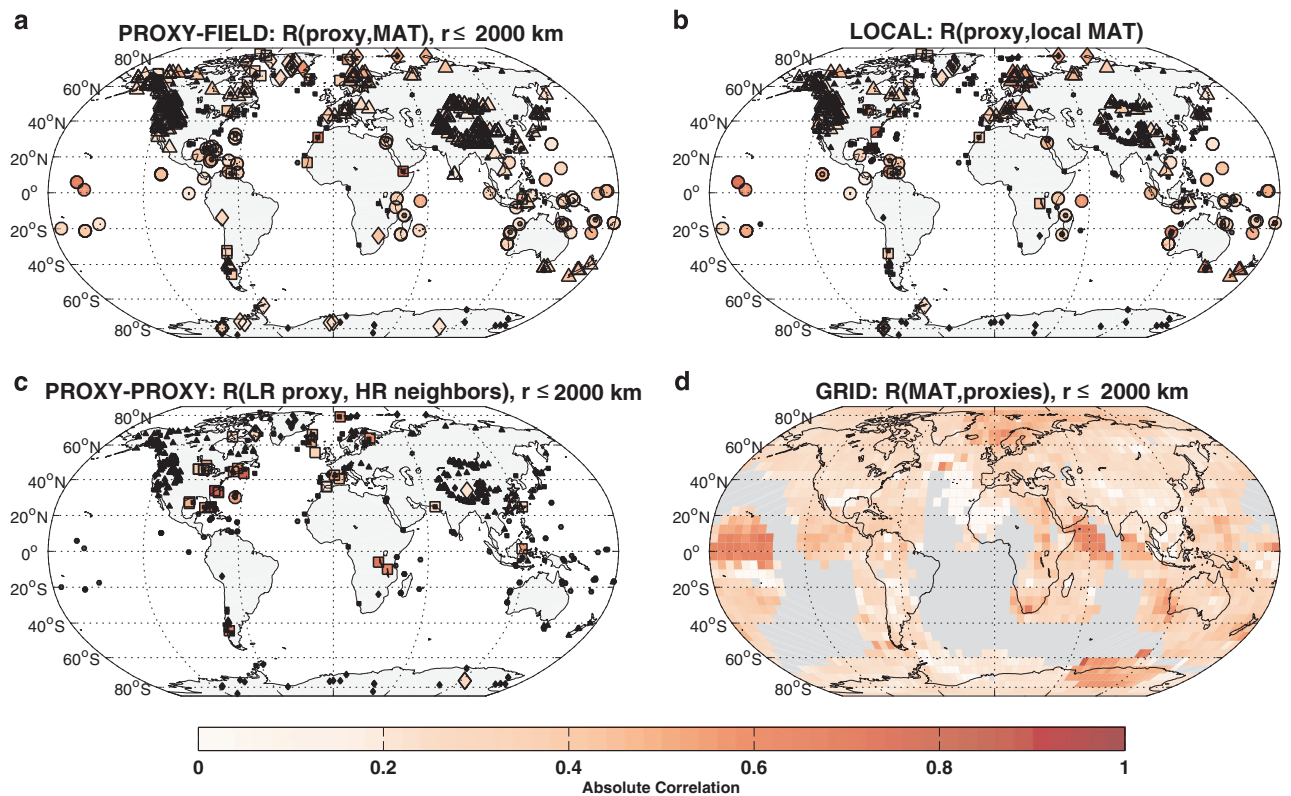
is not unique to paleoclimatology within the Earth sciences. The approach also assumes that the observational temperature time series itself is accurate and unbiased for each proxy site, which may not be true in areas of sparse coverage or complex topography.

The relationship between the current proxy database and the global temperature field is quantified via Pearson's linear correlation coefficient ( $R$ ) between proxy values and temperature averages (ANN, JJA, DJF). Statistical significance is established via a non-parametric, isospectral test<sup>43</sup>, which accounts for the loss of degrees of freedom due to large serial correlations common to proxy time series. Again, we restricted correlation analyses to records comprising a minimum of 20 samples over the instrumental era (CE 1850–2014), which limits the pool of proxies that may be evaluated in this way ( $n = 597$ ).

**Regional screening.** First, we search for significant correlations ( $P < 0.05$ ) within a search radius  $r_s$ , ensuring that correlations are local to regional. Compared to a global search, this limits the extent to which spurious correlations may arise, for instance, due to strong trends. Since spatial correlations are non-uniform and highly anisotropic, using a distance-based criterion that is uniform over the globe represents an oversimplification. No single distance is likely to be globally optimal, so its choice reflects a compromise between various factors: autocorrelation in land versus ocean temperatures, annual versus longer resolution, or seasonal biases. With  $r_s = 2,000 \text{ km}$ <sup>44</sup>, 411 records show significant correlations with annual temperature—their absolute values are shown in Fig. 6a and their locations are shown in Supplementary Fig. S3. Results change modestly depending on the value used for  $r_s$ .

**Regional screening adjusted for the false discovery rate.** Searching for potentially hundreds of suitable correlations within such a search radius runs the risk of false discoveries<sup>45</sup>. The problem of multiple hypothesis tests has long been known to statisticians and several solutions exist<sup>46</sup>. We use a method based on the false-discovery rate (FDR)<sup>47</sup>, adapted to the climate context<sup>48,49</sup>. In all, 277 records passed this test with annual data (Supplementary Fig. 4).

**Local screening.** The search may be further restricted to the nearest HadCRUT4.2 grid point. The results of this evaluation are mapped in Fig. 6b. In some cases this may be problematic because sites may sit at the boundary between grid cells. For sites located in the vicinity of frontal zones with large spatial temperature gradients, choosing the most appropriate neighbor can be particularly difficult. Gridded temperature data may represent observations from a range of elevations or



**Figure 6. Relationships with temperature and other records.** Median absolute correlations (a) of each record with mean annual temperature within a 2,000 km radius; (b) of each record with mean annual temperature at the nearest grid point; (c) of each low-resolution record with its 10 closest high-resolution proxy neighbors; (d) of temperature at each grid point and its proxy neighbors within a 2,000 km radius. Proxy-centric correlations (a–c) are reported in color if significant; as small black symbols if insignificant or not applicable. Grid-centric correlations (d) are reported in color if significant; in grey if insignificant or not computable (i.e., no proxy neighbor within 2,000 km).

environments, and therefore may not be representative of the archive’s actual location. Furthermore, the nearest grid point can in some instances be located thousands of kilometers from a site, because of the incomplete coverage of HadCRUT4. This limitation is particularly acute for Antarctic records, because of poor instrumental coverage over the Southern Ocean and Antarctic continent. A total of 181 records passed this test with annual data, including 5 from Antarctica, versus 9 in the regional+FDR case (Supplementary Fig. 5).

### Seasonal effects

The extent to which proxies are informative of annual temperature depends, sometimes very strongly, on the portion of the annual cycle which they preferentially sample<sup>7</sup>. Thus, before using seasonally-dependent proxies to reconstruct mean-annual temperature, one must ascertain the relationship between seasonal averages and the annual mean.

Supplementary Fig. S6 explores how much of the mean annual temperature (MAT) signal can be explained by boreal summer (JJA, top) versus winter (DJF, bottom) averages in the HadCRUT4.2 dataset. Correlations are generally very high ( $>0.8$ ) in the tropics, where the MAT range is small, and low in the extra-tropics, particularly over northern hemisphere continental interiors for JJA, where the MAT range is large and dominated by winter synoptic variability. This means that proxies that preferentially record summer conditions may be adequate predictors of the annual mean if they are located in the tropics, but (all other things being equal) less so if they are located on Northern Hemisphere continents. Extratropical winter variability is known to dominate the annual average<sup>44</sup>, so correlations to the MAT primarily reflect winter conditions in those regions.

Table 2 summarizes the result of the aforementioned correlation-based screening for the three approaches (regional, regional with FDR control, and local), as well as the part of the year that goes into the annual average: ANN (calendar year), DJF, JJA, or April–March (AMA). The results make it clear that some proxy records are sensitive to JJA temperature, but not to DJF or annual temperature. The vast majority are tree-ring records from the Northern Hemisphere.

method	ANN	DJF	JJA	AMA
reg	411	396	488	398
fdr	277	230	318	260
loc	181	114	228	168

**Table 2. Number of records retained in the correlation-based screening depending on the method used and the part of the annual cycle selected.** ANN: Mean Annual Temperature. DJF: December-January-February. JJA: June July August. AMA: April-March ('tropical year') reg: regional screening. fdr: regional screening, controlling for a 5% false discovery rate. loc: local screening. See text for details.

### Relationship to other proxies

A total of 95 proxies could not be directly correlated to MAT, either because they ended prior to 1850 or because they featured too few samples after this date. As an alternate validation method, we searched for significant correlations among the 10 closest neighbors from within the proxy dataset that can be correlated with HadCRUT4 (colored dots on Fig. 6a), and reported these significant correlations, along with their magnitude, in Fig. 6c. To minimize issues related to correlating time series with very different resolutions, the time series of proxy neighbors were smoothed to match the resolution of the target proxy. In regions where proxy-record density is high, this is a reasonable approach to assess the mutual consistency between various series; in sparsely sampled regions, this approach implies that proxy series that cannot be directly correlated to instrumental temperature must look like those that can, even if they belong to different climate settings. Moreover, despite the precautions taken with the isospectral test, correlations between a low-resolution record and its high-resolution neighbors are often driven by trends, even if no geophysical connection is present. Correlations between high- and low-resolution records must therefore be interpreted with caution. With these caveats in mind, 54 of the 95 proxies showed a significant correlation to neighboring high-resolution proxies.

### Grid-based spatial correlations

An alternate way to evaluate the extent to which variability in the global temperature field is captured by a heterogeneous network of paleoclimate proxies is to quantify the correlation between each grid cell's instrumental temperature time series and that of all the proxy series within the radius  $r_s^{50}$ . Viewed in this manner, the statistical relationship between the regular grid and the irregular proxy network provides information about the extent to which different regions of the global temperature target field are represented by the paleoclimate data, and the strength of that relationship. The results of this evaluation are shown in Fig. 6d. It shows that surface temperature over 73% of the planet is significantly correlated to a proxy time series within a 2,000 km radius—about twice as great an area as covered by the previous PAGES2k compilation<sup>11</sup>.

### Global trends

Having quantified the degree to which proxy records from this dataset respond to temperature, we now synthesize the largest-scale thermal signal embedded therein. We do so by use of composite time series, which efficiently summarize the global trends captured in this large and diverse collection. Composites allow us to readily compare signals contained in various subsets of the database; these comparisons, in turn, are an essential check on the mutual consistency of the temperature proxies across regions, geographic settings, and proxy archives.

Our focus here is purposefully general, centered on multidecadal to centennial time scales and ignoring the spatial features. This simple approach is intended as a preliminary estimate of global mean temperature fluctuations over the past 2000 years, and sets the stage for future community endeavors. Indeed, several PAGES2k working groups are currently working to generate spatially resolved reconstructions of annual or seasonal temperature fluctuations at regional to global scales, as well as cross-validated estimates of global mean surface temperature using a variety of statistical approaches. The composites allow this database to be placed in the context of past reconstruction efforts, and to serve as a benchmark for future ones.

Following recent compilations<sup>11–13</sup>, we average all records (scaled to unit variance) into a composite. We do so at a coarse resolution by applying a simple binning procedure. Compositing makes two implicit assumptions:

- (i) all proxy records are linearly related to global, mean-annual temperature.
- (ii) all proxy records are equally representative of global mean-annual temperature at any given time, and are thus given equal weight.

Given suitable transformations, (i) may be satisfied for a broad class of proxy records, even very nonlinear ones<sup>51</sup>. Assumption (ii) is more problematic, for three reasons. First, as Fig. 1a shows, the network is dominated by tree rings from the northern midlatitudes, whose temperature sensitivity is

primarily linked to the growing season (boreal summer), representing only a fraction of the annual variance. Second, the mix of proxies is also non-stationary (Fig. 1c). Coral records are relatively abundant over the instrumental era but practically absent prior to 1,600 CE. Tree rings dominate the network after around 1,400 CE but less so prior to that. Finally, the majority of records have annual (or better) resolution, but some records have median resolution on the order of 100 years (Fig. 1b). The information density per unit time of such records is thus quite different. Furthermore, dating uncertainties in low-resolution (non layer-counted) proxies are not quantified, but are mitigated to some extent by multidecadal binning.

Despite assumptions (i) and (ii) above, and their potential violation, we suggest that a simple treatment of the data constitutes an informative appraisal of the largest-scale thermal signal embedded in the dataset. We emphasize, however, that the above concerns are all legitimate, and that more rigorous treatment of these assumptions should and will be applied in formal temperature reconstructions. Compositing involved the following processing steps:

**Sign adjustment.** Records were multiplied by  $-1$  if their values decrease with increasing temperature (i.e., if their *interpDirection* parameter is negative); by  $+1$  otherwise. This step ensures that all proxy values point upward (downward) in response to warming (cooling).

**Normalization.** Records were mapped to a standard normal distribution via inverse transform sampling<sup>51</sup>, resulting in zero mean and unit variance.

**Binning.** Since the main focus of this composite is on low-frequency (decadal and longer) variability, all records were averaged in bins of 25, 50, and 100 years. Binning also mitigates the effect of age uncertainties, as it is known that even small age offsets between annual records could otherwise cause large spurious trends in composites made from them<sup>32</sup>.

**Scaling.** Standardized composites were scaled to temperature over identical bins.

**Screening.** For high-resolution records (HR: median resolution finer than 5 years), we applied either no screening (*none*), regional temperature screening (*regional*), or regional screening adjusted for the false discovery rate (*regionalFDR*). For low-resolution records (LR: median resolution coarser than or equal to 5 years), *basicFilter* denotes records that comprise at least 20 values over the Common Era (Supplementary Fig. 2), while *hrNeighbors* denotes records with at least one significantly correlated HR neighbor (see above for the caveats of this approach).

**Bootstrap.** Uncertainties in the composite are quantified via a bootstrap approach<sup>52</sup>. This assumes exchangeability, and primarily measures sampling uncertainty. We plot 95% confidence intervals derived from an ensemble of 1,000 bootstrap samples; in general, such intervals widen with proxy attrition, as expected.

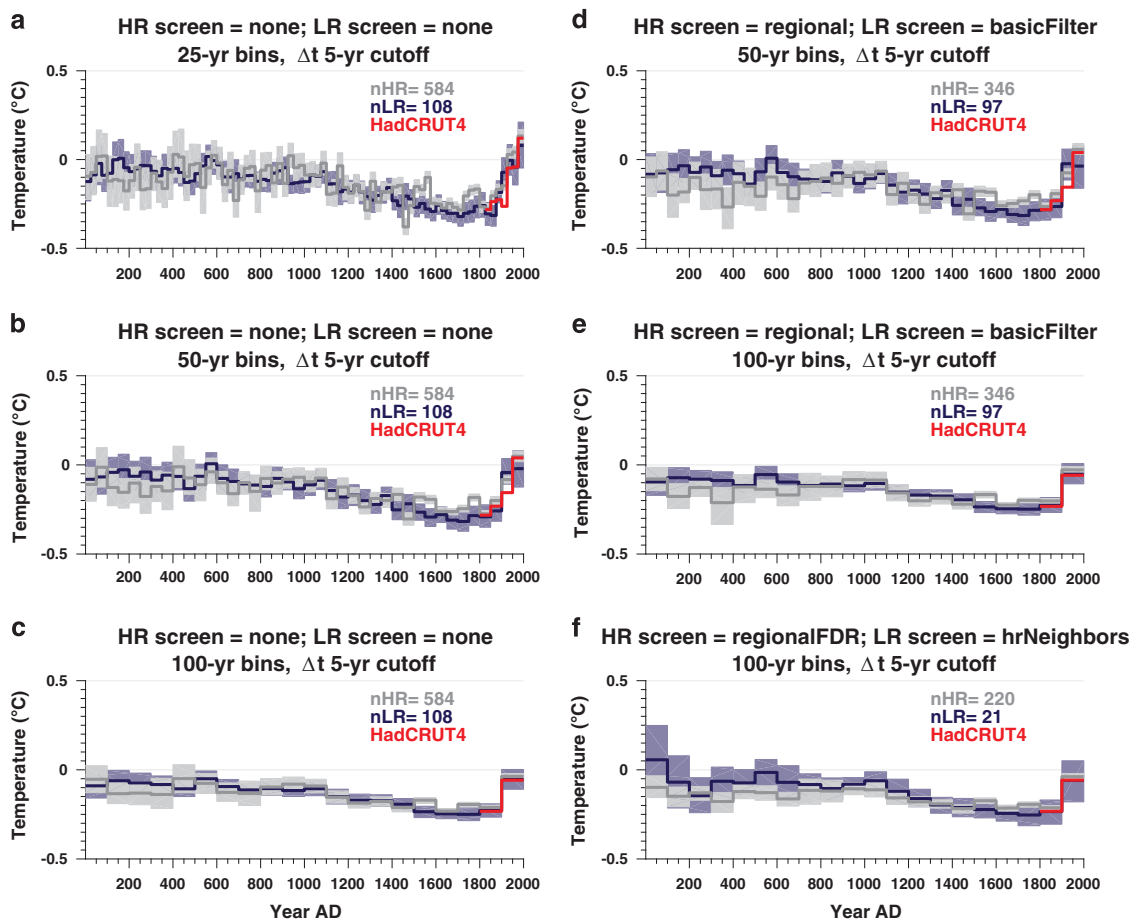
### Sensitivity analysis

Figure 7 presents the composites (HR in gray, LR in blue) and the HadCRUT4.2 target (red) scaled to temperature. Cases presented in the left column applied no screening, while the right column explores combinations of screening and binning interval. A striking feature is that in all cases, both HR and LR composites display a long-term cooling trend until the 19th century, after which an abrupt warming takes place, consistent with a very large body of literature<sup>5,8,11,12</sup>. We also note that temperature variability decreases with increasing bin size, as would be expected for data with random and independent errors.

We find the main results robust to screening choices, with the exception of the case in Fig. 7f (*regionalFDR*, *hrNeighbors*). The latter shows the most discrepancy between HR and LR, mainly because the number of LR proxies is very low ( $n = 22$ ) and they have little overlap with the instrumental era, making their temperature calibration unstable. In all cases the HR composites display slightly shallower variations than LR composites. There are two non-exclusive explanations for this. Firstly, it is known that some HR records, particularly the tree-ring chronologies that form the majority of this subset, can be limited in their ability to capture low-frequency variability beyond the mean segment length<sup>53</sup>. Second, LR records are known to redden climate signals, often exaggerating low-frequency variability at the expense of high frequencies<sup>54</sup>. Our analysis cannot distinguish between these two possibilities.

It is important to consider whether any of the primary features of the composite series are strongly controlled by a particular subset of proxies, or if they are shared among archive types. There are many potential ways to analyze this dataset. We give but one example in Fig. 8, gathering composites from individual archive types that include 5 or more records among the proxy collection: corals, documentary archives, glacier ice, lake and marine sediments, as well as trees. For this case we apply regional HR screening and basic LR filtering, then average records from coral, documentary, glacier ice, lake sedimentary, marine sedimentary, and tree-ring archives.

Most composites show a strong twentieth century warming trend that emerges above the variability of comparable centennial trends over the last two millennia. This is clearest in the tree- and coral-based

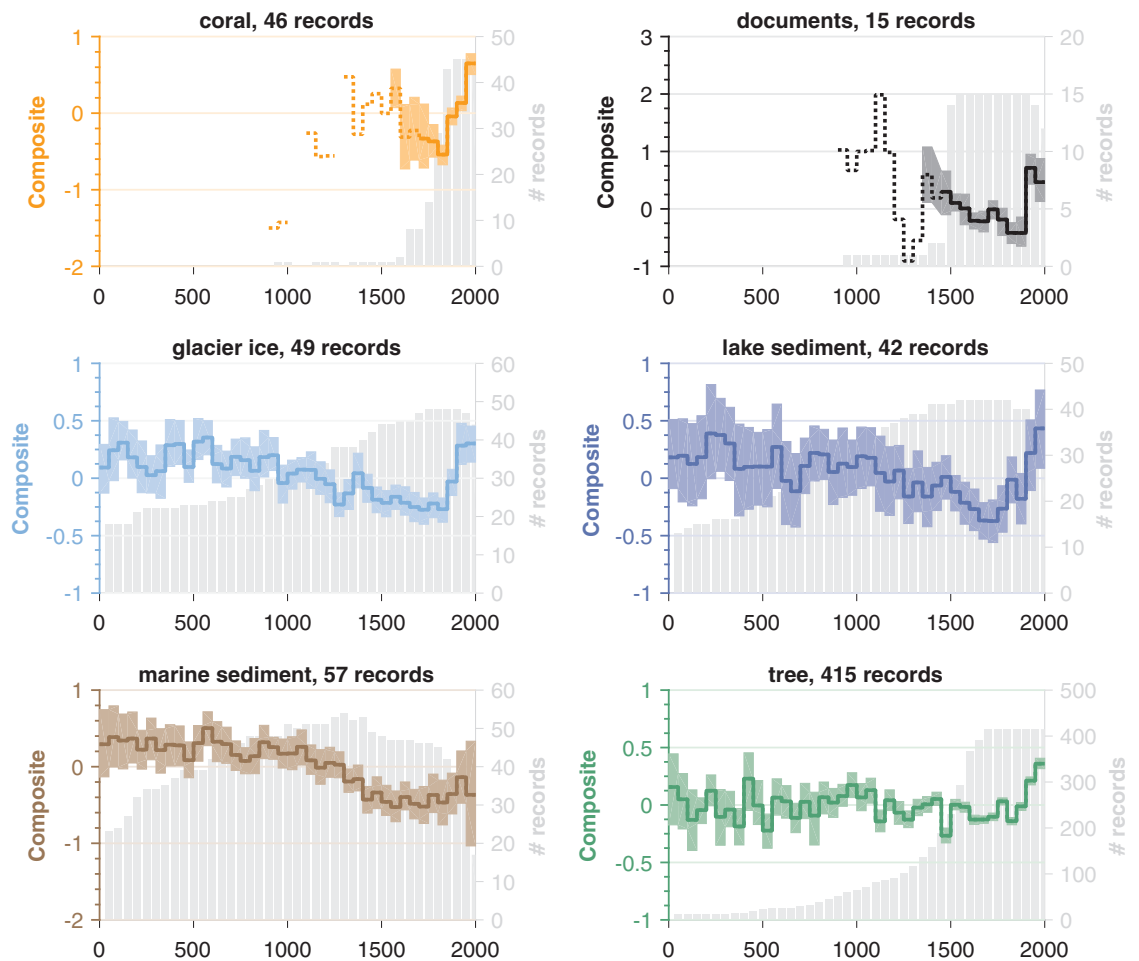


**Figure 7.** Global composites for various binning intervals and screening criteria, as indicated in subplot titles. The composites are scaled to temperature for comparison, and the shading denotes 95% bootstrap confidence intervals with 500 replicates, to constrain uncertainties. The cutoff between high-resolution (HR) and low-resolution (LR) records is defined as a median resolution of 5 years. Screening options comprise: no screening (*none*), regional temperature screening (*regional*), or regional screening adjusted for the false discovery rate (*regionalFDR*). For low-resolution records, *basicFilter* denotes records that comprise at least 20 values over the Common Era (Supplementary Fig. 2), while *hrNeighbors* denotes records with at least one significantly correlated HR neighbor.

composites, despite very large uncertainties in the latter during the seventeenth century, due to the paucity of records (Figs 1 and 8). An exception to this pattern is in the marine sediment composite (Fig. 8), which shows a cooling trend through most the Common Era. This may be explained by the low resolution of marine sediment records noted earlier, and the process of bioturbation of the sediment archive. These factors diffuse and damp changes occurring over years and decades (e.g., ref. 12), including the most recent warming. Local oceanographic factors may also play a role<sup>12,55</sup>.

Uncertainties in these composites include changes in sample size and available data network over time, the potential for non-climatic or non-temperature influences to bias these smaller subsets of the dataset, and the high spatial heterogeneity of subsample networks (Fig. 8). In general, uncertainty bands widen back in time (cf tree composite), with the notable exception of the marine sediment and documentary composites, which show widening bootstrap intervals in the last 2 bins, coincident with a drop in observational coverage in these archives. Note that multidecadal trends present in coral  $\delta^{18}\text{O}$  records from the eastern tropical Pacific may not be driven by temperature<sup>13,56,57</sup> possibly biasing the trend of this coral composite. The network of lake records is regionally constrained (Fig. 1), and that composite may contain multiple environmental influences beyond temperature. As a result, from the lake subset only, we cannot exclude the possibility of above-modern levels of warmth in the third century CE, though uncertainty bands for early centuries are wide, and the recent rate of warming is clearly unprecedented over the Common Era.

The global composites derived from this dataset, despite their simplicity, supersede the composite-of-opportunity published in the last synthesis<sup>11</sup>, which was an average of regional indices obtained by very different means (hence not statistically homogeneous) and did not include the majority of the marine



**Figure 8.** 50-year binned composites stratified by archive type, for all types comprising 5 or more series.

Composites with fewer than 10 available series are shown by a dotted curve, while solid lines indicate more than 10 series. Shading indicates 95% bootstrap confidence intervals with 500 replicates. Gray bars indicate the number of records per bin. The composites are expressed in standard deviation units, not scaled to temperature.

records gathered here. Nevertheless, the present composites share many similarities and some of the same caveats; namely, that a composite tends to give more weight to numerically abundant records (e.g., tree rings), and regions with more abundant observations (e.g., the Northern Hemisphere continents). An in-depth analysis of these composites, along with their climatic interpretation, will be the subject of a companion paper.

### Usage Notes

Data Citation 1 gathers data records in multiple digital formats, as well as quality control dashboards for all PAGES 2k regions (Table 3). This collection is the cornerstone of current and future efforts by the PAGES 2k Consortium to better reconstruct surface temperature, attribute its variability to climate forcings, understand its relationship to other components of the climate system, and constrain model simulations. It is appropriate for many purposes, ranging from developing reconstructions of climate indices (e.g., global mean surface temperature, NINO3.4) and fields, to proxy-proxy and proxy-model comparisons, and it was designed to be functional and relatively inclusive so that appropriate records could be selected, depending on the intended purpose, of which some are presently unforeseen.

The 692 temperature-sensitive records described and validated in this manuscript were selected based on the criteria listed above. In addition to these records, Data Citation 1 contains 2,240 ancillary time-series data from the same sites. Most (87%) are associated with tree-ring records from North America, including raw measurements, sample density and expressed population statistics; some are the native observations used to derive the temperature reconstructions included in the restricted group of 692 (e.g., Mg/Ca of foraminifera for sea-surface temperature); others are not directly related to climate but represent environmental changes at the site that might be useful in interpreting the climatic significance of the record (e.g., sedimentary magnetic susceptibility); some are proxy climate records that are sensitive

Filename	Contents
LoadData.md	Markdown-style text file explaining how to load the data
PAGES2k_v2.0.0_LiPD.zip	Original records in LiPD format
PAGES2k_v2.0.0.mat	Matlab-readable data structure
PAGES2k_v2.0.0-ts.pklz	Python-readable data structure
PAGES2k_v2.0.0.Rdata	R-readable data structure
HADCRUT4_median_GraphEM.mat	Mat file containing the GraphEM-infilled version of HadCRUT4.2
Africa2k_QCfig_bundle.pdf	Quality-control plots for Africa
Ant2k_QCfig_bundle.pdf	Quality-control plots for Antarctica
Arc_QCfig_bundle.pdf	Quality-control plots for the Arctic
Asia_QCfig_bundle.pdf	Quality-control plots for Asia
Aus_QCfig_bundle.pdf	Quality-control plots for Australasia
Eur_QCfig_bundle.pdf	Quality-control plots for Europe
NAm_QCfig_bundle.pdf	Quality-control plots for North America
SAm_QCfig_bundle.pdf	Quality-control plots for South America
Ocean_QCfig_bundle.pdf	Quality-control plots for ocean regions
Global_QCfig_bundle.pdf	Quality-control plots for all regions

**Table 3. Contents of the FigShare repository associated with this descriptor.**

to climate variables other than temperature. These 2,240 records are all timeseries, in that the datasets are year/data pairs. These ancillary time series are provided ‘as is’; the authors make no claims or guarantee as to their scientific usage.

Within Data Citation 1, the 692 temperature-sensitive records that comprise v2.0.0 are each assigned a unique PAGES2k identifier, as listed in Table 1 (available online only) and Supplementary Table 1. The 2,240 ancillary records are not assigned PAGES2k identifiers. In addition, the 692 records are easily discoverable in Data Citation 1 (PAGES2k\_v2.0.0\_LiPD.zip, PAGES2k\_v2.0.0.mat, PAGES2k\_v2.0.0.Rdata, PAGES2k\_v2.0.0-ts.pklz) by querying the metadata property ‘paleoData\_useInGlobalTemperatureAnalysis’, which is set to ‘TRUE’ only for the 692 temperature-sensitive records described here.

Several factors stand in the way of the PAGES2k compilation being fully comprehensive: records are continuously being generated and published, while some existing records are not publicly archived. This synthesis represents a major community effort to compile data records and captures a substantial majority of relevant records; it is to be continuously expanded and curated by the PAGES2k community. In addition to Data Citation 1, the entire database will be made available as part of a more comprehensive, web-based data management platform (<http://linked.earth>). This cyberinfrastructure facilitates crowd curation, transparent discussions of proxy interpretations, tracking and versioning of paleo data, and is supported by the first paleoclimate ontology (<http://linked.earth/projects/ontology>). In the near future, the current PAGES2k temperature dataset will be integrated with other paleoclimate datasets in this platform—for example, one dedicated to water isotopes (Iso2k<sup>58</sup>)—to enable the data-intensive studies of the last 2,000 years envisaged by the PAGES2k community<sup>59</sup>. The LinkedEarth cyberinfrastructure will enable crowdsourced additions and edits to the database, allowing it to be a living entity, with careful versioning to ensure workflow reproducibility.

Our versioning scheme is as follows: the version number for a data compilation is of the form  $C_1.C_2.C_3$ , where  $C_1$  is a counter associated with a publication of the dataset (e.g., ref. 1),  $C_2$  is a counter updated every time a record is added or removed, and  $C_3$  is a counter updated every time a modification is made to the data or metadata in an individual record. The dataset published here is thus v2.0.0 of the PAGES2k proxy temperature dataset. Future versions of the dataset, along with a change log that specifies the modifications associated with each new version, will be posted at <http://wiki.linked.earth/PAGES2k>. This versioning applies only to the temperature-sensitive records in Data Citation 1; changes to ancillary time series are not tracked.

In addition, an archival version of the dataset is available on the website of NCEI-Paleo/World Data Service for Paleoclimatology (<https://www.ncdc.noaa.gov/paleo/study/21171>), in both the LiPD format and the WDS ASCII template format developed in conjunction with the PAGES2k consortium, which will be updated and versioned as the dataset continues to evolve.

## References

- Jacoby, G. C. Jr & D’Arrigo, R. Reconstructed Northern Hemisphere annual temperature since 1671 based on high-latitude tree-ring data from North America. *Climatic Change* **14**, 39–59 (1989).



2. D'Arrigo, R. D. & Jacoby, G. C. Secular trends in high northern latitude temperature reconstructions based on tree rings. *Climatic Change* **25**, 163–177 (1993).
3. D'Arrigo, R., Jacoby, G., Free, M. & Robock, A. Northern Hemisphere temperature variability for the past three centuries: tree-ring and model estimates. *Climatic Change* **42**, 663–675 (1999).
4. Mann, M. E., Bradley, R. S. & Hughes, M. K. Global-scale temperature patterns and climate forcing over the past six centuries. *Nature* **392**, 779–787 (1998).
5. Mann, M. E., Bradley, R. S. & Hughes, M. K. Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *Geophysical Research Letters* **26**, 759–762 (1999).
6. Jones, P. & Mann, M. Climate over past millennia. *Reviews of Geophysics* **42** (2004).
7. Jones, P. *et al.* High-resolution palaeoclimatology of the last millennium: a review of current status and future prospects. *The Holocene* **19**, 3–49 (2009).
8. Masson-Delmotte, V. *et al.* Information from Paleoclimate Archives In, Stocker T. F. *et al.* (eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* 383–464 (Cambridge University Press 2013).
9. Smerdon, J. E. & Pollack, H. N. Reconstructing Earth's surface temperature over the past 2000 years: the science behind the headlines. *Wiley Interdisciplinary Reviews: Climate Change* **7**, 746–771 (2016).
10. Wang, J., Emile-Geay, J., Guillot, D., McKay, N. P. & Rajaratnam, B. Fragility of reconstructed temperature patterns over the common era: Implications for model evaluation. *Geophysical Research Letters* **42**, 7162–7170 (2015).
11. PAGES2k Consortium. Continental-scale temperature variability during the past two millennia. *Nature Geoscience* **6**, 339–346 (2013).
12. McGregor, H. V. *et al.* Robust global ocean cooling trend for the pre-industrial Common Era. *Nature Geoscience* **8**, 671–677 (2015).
13. Tierney, J. E. *et al.* Tropical sea surface temperatures for the past four centuries reconstructed from coral archives. *Paleoceanography* **30**, 492–495 (2015).
14. Yule, G. U. Why do we sometimes get nonsense-correlations between time-series—a study in sampling and the nature of time-series. *Journal of the Royal Statistical Society* **89**, 1–63 (1926).
15. Holm, S. A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* **6**, 65–70 (1979).
16. Bronk Ramsey, C. Radiocarbon calibration and analysis of stratigraphy: The oxcal program. *Radiocarbon* **37**, 425–430 (1995).
17. Haslett, J. & Parnell, A. A simple monotone process with application to radiocarbon-dated depth chronologies. *Journal of the Royal Statistical Society: Series C (Applied Statistics)* **57**, 399–418 (2008).
18. Blaauw, M. Methods and code for 'classical' age-modelling of radiocarbon sequences. *Quaternary Geochronology* **5**, 512–518 (2010).
19. Blaauw, M. & Christen, J. A. Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis* **6**, 457–474 (2011).
20. Anchukaitis, K. & Tierney, J. Identifying coherent spatiotemporal modes in time-uncertain proxy paleoclimate records. *Climate Dynamics* **41**, 1291–1306 (2013).
21. Orsi, A. J., Cornuelle, B. D. & Severinghaus, J. P. Little Ice Age cold interval in West Antarctica: Evidence from borehole temperature at the West Antarctic Ice Sheet (WAIS) Divide. *Geophysical Research Letters* **39**, L09710 (2012).
22. Cook, E. R. *et al.* Tree-ring reconstructed summer temperature anomalies for temperate East Asia since 800 C.E. *Climate Dynamics* **41**, 2957–2972 (2012).
23. St George, S. An overview of tree-ring width records across the Northern Hemisphere. *Quaternary Science Reviews* **95**, 132–150 (2014).
24. Rehfeld, K., Marwan, N., Heitzig, J. & Kurths, J. Comparison of correlation analysis techniques for irregularly sampled time series. *Nonlinear Processes in Geophysics* **18**, 389–404 (2011).
25. Cuffey, K. M. & Steig, E. J. Isotopic diffusion in polar firn: implications for interpretation of seasonal climate parameters in ice-core records, with emphasis on central Greenland. *Journal of Glaciology* **44**, 273–284 (1998).
26. Küttel, M., Steig, E. J., Ding, Q., Monaghan, A. J. & Battisti, D. S. Seasonal climate information preserved in west antarctic ice core water isotopes: relationships to temperature, large-scale circulation, and sea ice. *Climate Dynamics* **39**, 1841–1857 (2012).
27. Evans, M. N., Tolwinski-Ward, S. E., Thompson, D. M. & Anchukaitis, K. J. Applications of proxy system modeling in high resolution paleoclimatology. *Quaternary Science Reviews* **76**, 16–28 (2013).
28. National Research Council. *Surface Temperature Reconstructions for the Last 2,000 Years*. The National Academies Press, (2006).
29. Ramsey, C. B. Deposition models for chronological records. *Quaternary Science Reviews* **27**, 42–60 (2008).
30. Parnell, A. C., Buck, C. E. & Doan, T. K. A review of statistical chronology models for high-resolution, proxy-based holocene palaeoenvironmental reconstruction. *Quaternary Science Reviews* **30**, 2948–2960 (2011).
31. McKay, N. P. & Kaufman, D. S. An extended arctic proxy temperature database for the past 2,000 years. *Scientific Data* **1** (2014).
32. Comboul, M. *et al.* A probabilistic model of chronological errors in layer-counted climate proxies: applications to annually banded coral archives. *Climate of the Past* **10**, 825–841 (2014).
33. Mann, M. E. *et al.* Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences* **105**, 13252–13257 (2008).
34. Mann, M. E. *et al.* Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. *Science* **326**, 1256–1260 (2009).
35. Lund, D. C. & Curry, W. Florida Current surface temperature and salinity variability during the last millennium. *Paleoceanography* **21**, PA2009 (2006).
36. McKay, N. P. & Emile-Geay, J. Technical note: The Linked Paleo Data framework—a common tongue for paleoclimatology. *Climate of the Past* **12**, 1093–1100 (2016).
37. Morice, C. P., Kennedy, J. J., Rayner, N. A. & Jones, P. D. Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 data set. *Journal of Geophysical Research: Atmospheres* **117**, D08101 (2012).
38. Cowtan, K. & Way, R. G. Coverage bias in the hadcrut4 temperature series and its impact on recent temperature trends. *Quarterly Journal of the Royal Meteorological Society* **140**, 1935–1944 (2014).
39. Guillot, D., Rajaratnam, B. & Emile-Geay, J. Statistical paleoclimate reconstructions via Markov random fields. *Annals of Applied Statistics* **324–352** (2015).
40. Friedman, J., Hastie, T. & Tibshirani, R. Sparse inverse covariance estimation with the graphical lasso. *Biostatistics* **9**, 432–441 (2008).
41. Nicolas, J. P. & Bromwich, D. H. New reconstruction of antarctic near-surface temperatures: Multidecadal trends and reliability of global reanalyses. *Journal of Climate* **27**, 8070–8093 (2014).
42. Kuhnert, H. *et al.* A 200-year coral stable oxygen isotope record from a high-latitude reef off Western Australia. *Coral Reefs* **18**, 1–12 (1999).

43. Ebisuzaki, W. A method to estimate the statistical significance of a correlation when the data are serially correlated. *Journal of Climate* **10**, 2147–2153 (1997).
44. Briffa, K. & Jones, P. Global surface air temperature variations during the twentieth century: Part 2, implications for large-scale high-frequency palaeoclimatic studies. *The Holocene* **3**, 77–88 (1993).
45. Miller, R. *Simultaneous statistical inference* (Springer-Verlag, 1981).
46. Benjamini, Y. Simultaneous and selective inference: Current successes and future challenges. *Biometrical Journal* **52**, 708–721 (2010).
47. Benjamini, Y. & Hochberg, Y. Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B (Methodological)* **57**, 289–300 (1995).
48. Ventura, V., Paciorek, C. J. & Risbey, J. S. Controlling the proportion of falsely rejected hypotheses when conducting multiple tests with climatological data. *Journal of Climate* **17**, 4343–4356 (2004).
49. Hu, J., Emile-Geay, J. & Partin, J. Correlation-based interpretations of paleoclimate data—where statistics meet past climates. *Earth and Planetary Science Letters* **459**, 362–371 (2017).
50. Schneider, L. *et al.* Revising midlatitude summer temperatures back to a.d. 600 based on a wood density network. *Geophysical Research Letters* **42**, 4556–4562 (2015).
51. Emile-Geay, J. & Tingley, M. Inferring climate variability from nonlinear proxies: application to palaeo-ens0 studies. *Climate of the Past* **12**, 31–50 (2016).
52. Efron, B. & Tibshirani, R. J. *An Introduction to the Bootstrap* (Chapman & Hall, 1993).
53. Cook, E. R., Briffa, K. R., Meko, D. M., Graybill, D. A. & Funkhouser, G. The segment length curse in long tree-ring chronology development for paleoclimatic studies. *Holocene* **5**, 229–237 (1995).
54. Kennett, J. P. *Marine Geology* (Prentice-Hall, 1982).
55. Abram, N. J. *et al.* Early onset of industrial-era warming across the oceans and continents. *Nature* **536**, 411–418 (2016).
56. Lough, J. A strategy to improve the contribution of coral data to high-resolution paleoclimatology. *Palaeogeography, Palaeoclimatology, Palaeoecology* **204**, 115–143 (2004).
57. Nurhati, I. S., Cobb, K. M. & Di Lorenzo, E. Decadal-scale SST and salinity variations in the central tropical Pacific: Signatures of natural and anthropogenic climate change. *Journal of Climate* **24**, 3294–3308 (2011).
58. Partin, J. & Konecky, B. Iso2k consortium: A community-driven effort to develop a global database of paleo-water isotopes covering the past two millennia. In *American Geophysical Union*, vol. Fall Meeting American Geophysical Union, (2015).
59. Kaufman, D. S. PAGES 2k Consortium. A community-driven framework for climate reconstructions. *Eos, Transactions American Geophysical Union* **95**, 361–368 (2014).
60. Tierney, J. E. *et al.* Late-twentieth-century warming in Lake Tanganyika unprecedented since AD 500. *Nature Geoscience* **3**, 422–425 (2010).
61. Powers, L. A. *et al.* Organic geochemical records of environmental variability in Lake Malawi during the last 700 years, Part I: The TEX86 temperature record. *Palaeogeography, Palaeoclimatology, Palaeoecology* **303**, 133–139 (2011).
62. Sundqvist, H. S. *et al.* Evidence of a large cooling between 1690 and 1740 AD in southern Africa. *Scientific Reports* **3** (2013).
63. Stenni, B. *et al.* Eight centuries of volcanic signal and climate change at Talos Dome (East Antarctica). *Journal of Geophysical Research: Atmospheres* **107**, ACL3/1-3/13 (2002).
64. Plummer, C. T. *et al.* An independently dated 2000-yr volcanic record from Law Dome, East Antarctica, including a new perspective on the dating of the 1450s CE eruption of Kuwae, Vanuatu. *Climate of the Past* **8**, 1929–1940 (2012).
65. Thamban, M., Naik, S. S., Laluraj, C. M., Chaturvedi, A. & Ravindra, R. Antarctic climate variability during the past few centuries based on ice core records from coastal Dronning Maud Land and its implications on the recent warming. *Society of Earth Scientists Series* **6**, 51–66 (2012).
66. Graf, W. *et al.* Stable-isotope records from Dronning Maud Land, Antarctica. *Annals of Glaciology* **35**, 195–201 (2002).
67. Steig, E. J. *et al.* Recent climate and ice-sheet changes in West Antarctica compared with the past 2,000 years. *Nature Geoscience* **6**, 372–375 (2013).
68. Abram, N. J. *et al.* Acceleration of snow melt in an Antarctic Peninsula ice core during the twentieth century. *Nature Geoscience* **6**, 404–411 (2013).
69. Mosley-Thompson, E., Thompson, L., Grootes, P. M. & Gundestrup, N. Little Ice Age (Neoglacal) paleoenvironmental conditions at Siple Station, Antarctica. *Annals of Glaciology* **14**, 199–204 (1990).
70. Mulvaney, R. *et al.* 1000 year ice-core records from Berkner Island, Antarctica. *Annals of Glaciology* **35**, 146–154 (2002).
71. Jouzel, J. *et al.* A new 27 ky high resolution East Antarctic climate record. *Geophysical Research Letters* **28**, 3199–3202 (2001).
72. Stenni, B. *et al.* An oceanic cold reversal during the last deglaciation. *Science* **293**, 2074–2077 (2001).
73. Horiuchi, K. *et al.* Ice core record of <sup>10</sup>Be over the past millennium from Dome Fuji, Antarctica: A new proxy record of past solar activity and a powerful tool for stratigraphic dating. *Quaternary Geochronology* **3**, 253–261 (2008).
74. Motizuki, Y. *et al.* Dating of a Dome Fuji (Antarctica) shallow ice core by volcanic signal synchronization with B32 and EDML1 chronologies. *The Cryosphere Discussions* **8**, 769–804 (2014).
75. Thomas, E. R., Bracegirdle, T. J., Turner, J. & Wolff, E. W. A 308 year record of climate variability in West Antarctica. *Geophysical Research Letters* **40**, 5492–5496 (2013).
76. Dahl-Jensen, D., Morgan, V. & Elcheikh, A. Monte Carlo inverse modelling of the Law Dome (Antarctica) temperature profile. *Annals of Glaciology* **29**, 145–150 (1999).
77. Rhodes, R. H. *et al.* Little Ice Age climate and oceanic conditions of the Ross Sea, Antarctica from a coastal ice core record. *Climate of the Past* **8**, 1223–1238 (2012).
78. Stenni, B. *et al.* Expression of the bipolar see-saw in Antarctic climate records during the last deglaciation. *Nature Geoscience* **4**, 46–49 (2010).
79. Steig, E. J. *et al.* Wisconsinan and Holocene climate history from an ice core at Taylor Dome, western Ross Embayment, Antarctica. *Geografiska Annaler, Series A: Physical Geography* **82**, 213–235 (2000).
80. Bertler, N., Mayewski, P. & Carter, L. Cold conditions in Antarctica during the Little Ice Age? Implications for abrupt climate change mechanisms. *Earth and Planetary Science Letters* **308**, 41–51 (2011).
81. Ekaykin, A., Kozachek, A., Lipenkov, V. Y. & Shibaev, Y. A. Multiple climate shifts in the Southern Hemisphere over the past three centuries based on central Antarctic snow pits and core studies. *Annals of Glaciology* **55**, 259–266 (2014).
82. Bird, B. W., Abbott, M. B., Finney, B. P. & Kutchno, B. A 2000-year varve-based climate record from the central Brooks Range, Alaska. *Journal of Paleolimnology* **41**, 25–41 (2008).
83. Briffa, K. R. *et al.* Trends in recent temperature and radial tree growth spanning 2000 years across northwest Eurasia. *Philosophical Transactions of the Royal Society B: Biological Sciences* **363**, 2269–2282 (2008).
84. Cook, T. L., Bradley, R. S., Stoner, J. S. & Francus, P. Five thousand years of sediment transfer in a High Arctic watershed recorded in annually laminated sediments from Lower Murray Lake, Ellesmere Island, Nunavut, Canada. *Journal of Paleolimnology* **41**, 77–94 (2008).
85. Dansgaard, W., Johnsen, S. J., Moller, J. & Langway, C. C. One thousand centuries of climatic record from Camp Century on the Greenland Ice Sheet. *Science* **166**, 377–380 (1969).

86. Wiles, G. C. *et al.* Surface air temperature variability reconstructed with tree rings for the Gulf of Alaska over the past 1200 years. *The Holocene* **24**, 198–208 (2014).
87. D'Arrigo, R., Wilson, R. & Jacoby, G. On the long-term context for late twentieth century warming. *Journal of Geophysical Research* **111**, D03103 (2006).
88. Groote, P. M. & Stuiver, M. Oxygen 18/16 variability in Greenland snow and ice with 10<sup>3</sup> to 10<sup>5</sup> year time resolution. *Journal of Geophysical Research* **102**, 26455–26470 (1997).
89. Haltiahoivi, E., Saarinen, T. & Kukkonen, M. A 2000-year record of solar forcing on varved lake sediment in eastern Finland. *Quaternary Science Reviews* **26**, 678–689 (2007).
90. Hughes, M., Touchan, R., Funkhouser, G., Vaganov, E. & Shiyatov, S. Twentieth-century summer warmth in northern Yakutia in a 600-year context. *The Holocene* **9**, 629–634 (1999).
91. Isaksson, E. *et al.* Climate oscillations as recorded in Svalbard ice core d18O records between AD 1200 and 1997. *Geografiska Annaler, Series A: Physical Geography* **87**, 203–214 (2005).
92. Lamoureux, S. F. & Bradley, R. S. A late Holocene varved sediment record of environmental change from northern Ellesmere Island, Canada. *Journal of Paleolimnology* **16**, 239–255 (1996).
93. Larsen, D. J., Miller, G. H., Geirsdóttir, A. & Thordarson, T. A 3000-year varved record of glacier activity and climate change from the proglacial lake Hvtárvatn, Iceland. *Quaternary Science Reviews* **30**, 2715–2731 (2011).
94. MacDonald, G. M., Case, R. A. & Szeicz, J. M. A 538-year record of climate and treeline dynamics from the lower Lena River region of northern Siberia, Russia. *Arctic and Alpine Research* **30**, 334–339 (1998).
95. Moore, J., Hughes, K., Miller, G. & Overpeck, J. Little Ice Age recorded in summer temperature reconstruction from varved sediments of Donard Lake, Baffin Island, Canada. *Journal of Paleolimnology* **25**, 503–517 (2001).
96. Ojala, A. E. & Alenius, T. 10000 years of interannual sedimentation recorded in the Lake Nautajärvi (Finland) clastic--organic varves. *Palaeogeography, Palaeoclimatology, Palaeoecology* **219**, 285–302 (2005).
97. Fischer, H. *et al.* Little Ice Age clearly recorded in northern Greenland ice cores. *Geophysical Research Letters* **25**, 1749–1752 (1998).
98. Thomas, E. K. & Briner, J. P. Climate of the past millennium inferred from varved proglacial lake sediments on northeast Baffin Island, Arctic Canada. *Journal of Paleolimnology* **41**, 209–224 (2009).
99. Vinther, B. M. *et al.* A synchronized dating of three Greenland ice cores throughout the Holocene. *Journal of Geophysical Research* **111**, D13102 (2006).
100. Vinther, B. M. *et al.* Synchronizing ice cores from the Renland and Agassiz ice caps to the Greenland ice core chronology. *Journal of Geophysical Research* **113**, D08115 (2008).
101. Vinther, B. *et al.* Climatic signals in multiple highly resolved stable isotope records from Greenland. *Quaternary Science Reviews* **29**, 522–538 (2010).
102. Bergthorsson, P. An estimate of drift ice and temperature in Iceland in 1000 years. *Jokull* **19**, 94–101 (1969).
103. Clegg, B. F. *et al.* Six millennia of summer temperature variation based on midge analysis of lake sediments from Alaska. *Quaternary Science Reviews* **29**, 3308–3316 (2010).
104. Clegg, B., Kelly, R., Clarke, G., Walker, I. & Hu, F. S. Nonlinear response of summer temperature to Holocene insolation forcing in Alaska. *Proceedings of the National Academy of Sciences* **108**, 19299–19304 (2011).
105. D'Andrea, W. J., Huang, Y., Fritz, S. C. & Anderson, N. J. Abrupt Holocene climate change as an important factor for human migration in West Greenland. *Proceedings of the National Academy of Sciences* **108**, 9765–9769 (2011).
106. Fisher, D. A. *et al.* Effect of wind scouring on climatic records from ice-core oxygen-isotope profiles. *Nature* **301**, 205–209 (1983).
107. Fisher, D. A. Penny Ice Cap cores, Baffin Island, Canada, and the Wisconsinan Foxe Dome connection: Two states of Hudson Bay ice cover. *Science* **279**, 692–695 (1998).
108. Luoto, T. P., Sarmaja-Korjonen, K., Nevalainen, L. & Kauppi, T. A 700 year record of temperature and nutrient changes in a small eutrophied lake in southern Finland. *The Holocene* **19**, 1063–1072 (2009).
109. Luoto, T. P. & Helama, S. Palaeoclimatological and palaeolimnological records from fossil midges and tree-rings: the role of the North Atlantic Oscillation in eastern Finland through the Medieval Climate Anomaly and Little Ice Age. *Quaternary Science Reviews* **29**, 2411–2423 (2010).
110. Okuyama, J., Narita, H., Hondoh, T. & Koerner, R. M. Physical properties of the P96 ice core from Penny Ice Cap, Baffin Island, Canada, and derived climatic records. *Journal of Geophysical Research* **108**, 2090 (2003).
111. Rolland, N., Larocque, I., Francus, P., Pienitz, R. & Laperrière, L. D. G. Frey and E.S. Deevey Review 1: Numerical tools in palaeolimnology—Progress, potentialities, and problems. *Journal of Paleolimnology* **20**, 307–332 (2009).
112. Schneider, L. *et al.* Revising midlatitude summer temperatures back to A.D. 600 based on a wood density network. *Geophysical Research Letters* **42**, 4556–4562 (2015).
113. Melvin, T. M., Grudd, H. & Briffa, K. R. Potential bias in 'updating' tree-ring chronologies using regional curve standardisation: Re-processing 1500 years of Tornetrask density and ring-width data. *The Holocene* **23**, 364–373 (2012).
114. Zhang, P., Linderholm, H. W., Gunnarson, B. E., Björklund, J. & Chen, D. 1200 years of warm-season temperature variability in central Scandinavia inferred from tree-ring density. *Climate of the Past* **12**, 1297–1312 (2016).
115. Opel, T., Fritzsche, D. & Meyer, H. Eurasian Arctic climate over the past millennium as recorded in the Akademii Nauk ice core (Severnaya Zemlya). *Climate of the Past* **9**, 2379–2389 (2013).
116. Björklund, J. A., Gunnarson, B. E., Seftigen, K., Esper, J. & Linderholm, H. W. Blue intensity and density from northern Fennoscandian tree rings, exploring the potential to improve summer temperature reconstructions with earlywood information. *Climate of the Past* **10**, 877–885 (2014).
117. Björklund, J. A. *et al.* Advances towards improved low-frequency tree-ring reconstructions, using an updated *Pinus sylvestris* L. MXD network from the Scandinavian Mountains. *Theoretical and Applied Climatology* **113**, 697–710 (2012).
118. McKay, N. P., Kaufman, D. S. & Michelutti, N. Biogenic silica concentration as a high-resolution, quantitative temperature proxy at Hallet Lake, south-central Alaska. *Geophysical Research Letters* **35**, L05709 (2008).
119. D'Andrea, W. J. *et al.* Mild Little Ice Age and unprecedented recent warmth in an 1800 year lake sediment record from Svalbard. *Geology* **40**, 1007–1010 (2012).
120. D'Andrea, W. J., Huang, Y., Fritz, S. C. & Anderson, N. J. Abrupt Holocene climate change as an important factor for human migration in West Greenland. *Proceedings of the National Academy of Sciences* **108**, 9765–9769 (2011).
121. McCarroll, D. *et al.* A 1200-year multiproxy record of tree growth and summer temperature at the northern pine forest limit of Europe. *The Holocene* **23**, 471–484 (2013).
122. Divine, D. *et al.* Thousand years of winter surface air temperature variations in Svalbard and northern Norway reconstructed from ice-core data. *Polar Research* **30**, 73–79 (2011).
123. Porter, T. J., Pisarcik, M. F., Kokelj, S. V. & deMontigny, P. A ring-width-based reconstruction of June–July minimum temperatures since AD1245 from white spruce stands in the Mackenzie Delta region, northwestern Canada. *Quaternary Research* **80**, 167–179 (2013).
124. Kinnard, C. *et al.* Reconstructed changes in Arctic sea ice over the past 1,450 years. *Nature* **479**, 509–512 (2011).

125. Huguen, K., Overpeck, J. & Anderson, R. Recent warming in a 500-year palaeotemperature record from varved sediments, Upper Soper Lake, Baffin Island, Canada. *The Holocene* **10**, 9–19 (2000).
126. Briffa, K. R. *et al.* Reassessing the evidence for tree-growth and inferred temperature change during the Common Era in Yamalia, northwest Siberia. *Quaternary Science Reviews* **72**, 83–107 (2013).
127. Panyushkina, I. P., Ovtchinnikov, D. V. & Adamenko, M. F. Mixed response of decadal variability in larch tree-ring chronologies from upper tree-lines of the Russian Altai. *Tree-Ring Research* **61**, 33–42 (2005).
128. Magda, V. N., Block, J., Oidupaa, O. C. & Vaganov, E. A. Extraction of the climatic signal for moisture from tree-ring chronologies of Altai-Sayan mountain forest-steppes. *Contemporary Problems of Ecology* **4**, 716–724 (2011).
129. Ovtchinnikov, D., Adamenko, M. & Panyushkina, I. An 1105-year tree-ring chronology in Altai Region and its application for reconstruction of summer temperatures. *GeoLines* **11**, 121–122 (2000).
130. Briffa, K. R. *et al.* Tree-ring width and density data around the Northern Hemisphere: Part 1, local and regional climate signals. *The Holocene* **12**, 737–757 (2002).
131. Cook, E. R. *et al.* Asian monsoon failure and megadrought during the last millennium. *Science* **328**, 486–489 (2010).
132. Cook, E. R. *et al.* Tree-ring reconstructed summer temperature anomalies for temperate East Asia since 800 C.E. *Climate Dynamics* **41**, 2957–2972 (2013).
133. Qin, N. *et al.* Climate change over southern Qinghai Plateau in the past 500 years recorded in *Sabina tibetica* tree rings. *Chinese Science Bulletin* **48**, 2484–2488 (2003).
134. Yasue, K., Funada, R., Fukazawa, K. & Ohtani, J. Tree-ring width and maximum density of *Picea glehnii* as indicators of climatic changes in northern Hokkaido, Japan. *Canadian Journal of Forest Research* **27**, 1962–1970 (1997).
135. Esper, J., Frank, D. C., Wilson, R. J. S., Büntgen, U. & Treyde, K. Uniform growth trends among central Asian low- and high-elevation juniper tree sites. *Trees* **21**, 141–150 (2007).
136. Sano, M., Furuta, F. & Sweda, T. Tree-ring-width chronology of *Larix gmelinii* as an indicator of changes in early summer temperature in east-central Kamchatka. *Journal of Forest Research* **14**, 147–154 (2009).
137. Panyushkina, I., Chang, C., Clemens, A. & Bykov, N. First tree-ring chronology from Andronovo archaeological timbers of Bronze Age in Central Asia. *Dendrochronologia* **28**, 13–21 (2010).
138. Davi, N. K., Jacoby, G. C., Curtis, A. E. & Baatarbileg, N. Extension of drought records for central Asia using tree rings: west-central Mongolia. *Journal of Climate* **19**, 288–299 (2006).
139. Ahmed, M. *et al.* The dendroclimatic potential of conifers from northern Pakistan. *Dendrochronologia* **29**, 77–88 (2011).
140. Sano, M., Buckley, B. M. & Sweda, T. Tree-ring based hydroclimate reconstruction over northern Vietnam from *Fokienia hodginsii*: eighteenth century mega-drought and tropical Pacific influence. *Climate Dynamics* **33**, 331–340 (2008).
141. Buckley, B. M. *et al.* Climate as a contributing factor in the demise of Angkor, Cambodia. *Proceedings of the National Academy of Sciences* **107**, 6748–6752 (2010).
142. Wang, S., Ye, J. & Gong, D. Climate in China during the Little Ice Age. *Quaternary Sciences* **1**, 54–64 (1998).
143. Chu, G. *et al.* Seasonal temperature variability during the past 1600 years recorded in historical documents and varved lake sediment profiles from northeastern China. *The Holocene* **22**, 785–792 (2011).
144. Thompson, L. G. A high-resolution millennial record of the south Asian monsoon from Himalayan ice cores. *Science* **289**, 1916–1919 (2000).
145. Wang, S. & Wang, R. Reconstruction of winter temperature in east China during the last 500 years using historical documents. *Acta Meteorologica Sinica* **48**, 108–189 (1990).
146. Zheng, S.-Z. Climate in the Little Ice Age and its effects in Guangdong, China. *Chinese Science Bulletin* **27**, 302–304 (1982).
147. Zhang, D. Winter temperature changes during the last 500 years in south China. *Chinese Science Bulletin* **6**, 497–500 (1980).
148. Thompson, L. G. Tropical climate instability: The last glacial cycle from a Qinghai-Tibetan ice core. *Science* **276**, 1821–1825 (1997).
149. Demezko, D. Y. & Solomina, O. N. Ground surface temperature variations on Kunashir Island in the last 400 years inferred from borehole temperature data and tree-ring records. *Doklady Earth Sciences* **426**, 628–631 (2009).
150. Thompson, L. G. *et al.* Holocene climate variability archived in the Puruogangri ice cap on the central Tibetan Plateau. *Annals of Glaciology* **43**, 61–69 (2006).
151. Demezko, D. Y. & Golovanova, I. V. Climatic changes in the Urals over the past millennium; an analysis of geothermal and meteorological data. *Climate of the Past* **3**, 237–242 (2007).
152. Cook, E. R. *et al.* Millennia-long tree-ring records from Tasmania and New Zealand: a basis for modelling climate variability and forcing, past, present and future. *Journal of Quaternary Science* **21**, 689–699 (2006).
153. Cook, E. R., Palmer, J. G., Cook, B. I., Hogg, A. & D'Arrigo, R. D. A multi-millennial palaeoclimatic resource from *Lagarostrobos colensoi* tree-rings at Oroko Swamp, New Zealand. *Global and Planetary Change* **33**, 209–220 (2002).
154. Allen, K. J., Cook, E. R., Francey, R. J. & Michael, K. The climatic response of *Phyllocladus aspleniifolius* (Labill.) Hook. f in Tasmania. *Journal of Biogeography* **28**, 305–316 (2001).
155. Duncan, R. P., Fenwick, P., Palmer, J. G., McGlone, M. S. & Turney, C. S. M. Non-uniform interhemispheric temperature trends over the past 550 years. *Climate Dynamics* **35**, 1429–1438 (2010).
156. Buckley, B. M., Cook, E. R., Peterson, M. J. & Barbetti, M. A changing temperature response with elevation for *Lagarostrobos franklinii* in Tasmania, Australia. *Climatic Change* **36**, 477–498 (1997).
157. Saunders, K., Grosjean, M. & Hodgson, D. A 950 yr temperature reconstruction from Duckhole Lake, southern Tasmania, Australia. *The Holocene* **23**, 771–783 (2013).
158. D'Arrigo, R. D., Buckley, B. M., Cook, E. R. & Wagner, W. S. Temperature-sensitive tree-ring width chronologies of pink pine (*Halocarpus biformis*) from Stewart Island, New Zealand. *Palaeogeography, Palaeoclimatology, Palaeoecology* **119**, 293–300 (1996).
159. Xiong, L. & Palmer, J. G. Reconstruction of New Zealand temperatures back to AD 1720 using *Libocedrus bidwillii* tree rings. *Climatic Change* **45**, 339–359 (2000).
160. Esper, J. *et al.* Orbital forcing of tree-ring data. *Nature Climate Change* **2**, 862–866 (2012).
161. Büntgen, U. *et al.* Filling the eastern European gap in millennium-long temperature reconstructions. *Proceedings of the National Academy of Sciences* **110**, 1773–1778 (2013).
162. Popa, I. & Kern, Z. Long-term summer temperature reconstruction inferred from tree-ring records from the Eastern Carpathians. *Climate Dynamics* **32**, 1107–1117 (2008).
163. Büntgen, U. *et al.* 2500 years of European climate variability and human susceptibility. *Science* **331**, 578–582 (2011).
164. Büntgen, U., Frank, D. C., Nievergelt, D. & Esper, J. Summer temperature variations in the European Alps, A.D. 755–2004. *Journal of Climate* **19**, 5606–5623 (2006).
165. Büntgen, U., Frank, D., Neuenchwander, T. & Esper, J. Fading temperature sensitivity of Alpine tree growth at its Mediterranean margin and associated effects on large-scale climate reconstructions. *Climatic Change* **114**, 651–666 (2012).
166. Dorado Liñán, I. *et al.* Estimating 750 years of temperature variations and uncertainties in the Pyrenees by tree-ring reconstructions and climate simulations. *Climate of the Past* **8**, 919–933 (2012).

167. Dobrovolný, P. *et al.* Monthly, seasonal and annual temperature reconstructions for Central Europe derived from documentary evidence and instrumental records since AD 1500. *Climatic Change* **101**, 69–107 (2009).
168. Pla, S. & Catalan, J. Chrysophyte cysts from lake sediments reveal the submillennial winter/spring climate variability in the northwestern Mediterranean region throughout the Holocene. *Climate Dynamics* **24**, 263–278 (2004).
169. Helama, S. *et al.* A palaeotemperature record for the Finnish Lakeland based on microdensitometric variations in tree rings. *Geochronometria* **41**, 265–277 (2014).
170. Larocque-Tobler, I., Grosjean, M., Heiri, O., Trachsel, M. & Kamenik, C. Thousand years of climate change reconstructed from chironomid subfossils preserved in varved lake Silvaplana, Engadine, Switzerland. *Quaternary Science Reviews* **29**, 1940–1949 (2010).
171. Trachsel, M., Grosjean, M., Schnyder, D., Kamenik, C. & Rein, B. Scanning reflectance spectroscopy (380–730 nm): a novel method for quantitative high-resolution climate reconstructions from minerogenic lake sediments. *Journal of Paleolimnology* **44**, 979–994 (2010).
172. Larocque-Tobler, I. *et al.* A last millennium temperature reconstruction using chironomids preserved in sediments of anoxic Seebensee (Switzerland): consensus at local, regional and Central European scales. *Quaternary Science Reviews* **41**, 49–56 (2012).
173. Martín-Chivelet, J., Muñoz Garca, M. B., Edwards, R. L., Turrero, M. J. & Ortega, A. I. Land surface temperature changes in northern Iberia since 4000 yr BP, based on  $\delta^{13}\text{C}$  of speleothems. *Global and Planetary Change* **77**, 1–12 (2011).
174. Mangini, A., Spötl, C. & Verdes, P. Reconstruction of temperature in the Central Alps during the past 2000 yr from a  $\delta^{18}\text{O}$  stalagmite record. *Earth and Planetary Science Letters* **235**, 741–751 (2005).
175. Leijonhufvud, L. *et al.* Five centuries of Stockholm winter/spring temperatures reconstructed from documentary evidence and instrumental observations. *Climatic Change* **101**, 109–141 (2009).
176. Tarand, A. & Nordli, P. The Tallinn temperature series reconstructed back half a millennium by use of proxy data. *Climatic Change* **48**, 189–199 (2001).
177. Salzer, M. & Kipfmüller, K. Reconstructed temperature and precipitation on a millennial timescale from tree rings in the southern Colorado Plateau. *USA Climatic Change* **70**, 465–487 (2005).
178. Barclay, D. J., Wiles, G. C. & Calkin, P. E. A 1119-year tree-ring-width chronology from western Prince William Sound, southern Alaska. *The Holocene* **9** (1999).
179. Bunn, A. G., Graumlich, L. J. & Urban, D. L. Trends in twentieth-century tree growth at high elevations in the Sierra Nevada and White Mountains, USA. *The Holocene* **15**, 481–488 (2005).
180. Schweingruber, F. H. & Briffa, K. R. *Tree-ring density networks for climate reconstruction, vol. 41 of NATO ASI Series (Series I: Global Environmental Change)* 43–66 (Springer Berlin Heidelberg, 1996).
181. Youngblut, D. K. & Luckman, B. H. Evaluating the temperature sensitivity of radial growth patterns from whitebark pine in the western Canadian Cordillera. *Dendrochronologia* **31**, 16–28 (2013).
182. Colenutt, M. & Luckman, B. The dendrochronological characteristics of alpine Larch. *Canadian Journal of Forest Research* **25**, 777–789 (1995).
183. Clague, J. J. *et al.* Rapid changes in the level of Kluane Lake in Yukon Territory over the last millennium. *Quaternary Research* **66**, 342–355 (2006).
184. Pederson, G. T. *et al.* The unusual nature of recent snowpack declines in the North American Cordillera. *Science* **333**, 332–335 (2011).
185. Gajewski, K. Late Holocene climate changes in eastern North America estimated from pollen data. *Quaternary Research* **29**, 255–262 (1988).
186. Kipfmüller, K. F. Reconstructed summer temperature in the northern Rocky Mountains wilderness, USA. *Quaternary Research* **70**, 173–187 (2008).
187. Salzer, M. W., Bunn, A. G., Graham, N. E. & Hughes, M. K. Five millennia of paleotemperature from tree-rings in the Great Basin, USA. *Climate Dynamics* **42**, 1517–1526 (2013).
188. Schiefer, E., Menounos, B. & Slaymaker, O. Extreme sediment delivery events recorded in the contemporary sediment record of a montane lake, southern Coast Mountains, British Columbia. *Canadian Journal of Earth Sciences* **43**, 1777–1790 (2006).
189. Paquette, N. & Gajewski, K. Climatic change causes abrupt changes in forest composition, inferred from a high-resolution pollen record, southwestern Quebec, Canada. *Quaternary Science Reviews* **75**, 169–180 (2013).
190. St. Jacques, J.-M., Cumming, B. F. & Smol, J. P. A 900-year pollen-inferred temperature and effective moisture record from varved Lake Mina, west-central Minnesota, USA. *Quaternary Science Reviews* **27**, 781–796 (2008).
191. Ersek, V., Clark, P. U., Mix, A. C., Cheng, H. & Lawrence Edwards, R. Holocene winter climate variability in mid-latitude western North America. *Nature Communications* **3**, 1219 (2012).
192. Kipfmüller, K. F. & Salzer, M. W. Linear trend and climate response of five-needle pines in the western United States related to treeline proximity. *Canadian Journal of Forest Research* **40**, 134–142 (2010).
193. Gennaretti, F., Arseneault, D., Nicault, A., Perreault, L. & Bégin, Y. Volcano-induced regime shifts in millennial tree-ring chronologies from northeastern North America. *Proceedings of the National Academy of Sciences* **111**, 10077–10082 (2014).
194. D'Arrigo, R., Mashig, E., Frank, D., Wilson, R. & Jacoby, G. Temperature variability over the past millennium inferred from Northwestern Alaska tree rings. *Climate Dynamics* **24** (2005).
195. Davi, N. K., Jacoby, G. C. & Wiles, G. C. Boreal temperature variability inferred from maximum latewood density and tree-ring width data, Wrangell Mountain region, Alaska. *Quaternary Research* **60** (2003).
196. Jarvis, S. K., Wiles, G. C., Appleton, S. N., D'Arrigo, R. D. & Lawson, D. E. A Warming-Induced Biome Shift Detected in Tree Growth of Mountain Hemlock [*Tsuga mertensiana* (Bong.) Carrière] Along the Gulf of Alaska. *Arctic, Antarctic, and Alpine Research* **45** (2013).
197. Anchukaitis, K. J. *et al.* Tree-ring-reconstructed summer temperatures from northwestern North America during the last nine centuries. *Journal of Climate* **26**, 3001–3012 (2013).
198. Cropper, J. P. & Fritts, H. C. Tree-ring width chronologies from the North American Arctic. *Arctic and Alpine Research* **13**, 245–260 (1981).
199. D'Arrigo, R., Buckley, B., Kaplan, S. & Woollett, J. Interannual to multidecadal modes of Labrador climate variability inferred from tree rings. *Climate Dynamics* **20**, 219–228 (2003).
200. Luckman, B. H. & Wilson, R. J. S. Summer temperatures in the Canadian Rockies during the last millennium: a revised record. *Climate Dynamics* **24**, 131–144 (2005).
201. St George, S. & Luckman, B. H. Extracting a paleotemperature record from *Picea engelmannii* tree-line sites in the central Canadian Rockies. *Canadian Journal of Forest Research* **31**, 457–470 (2001).
202. Luckman, B. & Kavanagh, T. Impact of climate fluctuations on mountain environments in the Canadian Rockies. *AMBIO: A Journal of the Human Environment* **29**, 371–380 (2000).
203. Bigler, C., Gavin, D. G., Gunning, C. & Veblen, T. T. Drought induces lagged tree mortality in a subalpine forest in the Rocky Mountains. *Oikos* **116**, 1983–1994 (2007).

204. Jiang, H., Eiríksson, J., Schulz, M., Knudsen, K.-L. & Seidenkrantz, M.-S. Evidence for solar forcing of sea-surface temperature on the North Icelandic Shelf during the late Holocene. *Geology* **33**, 3–13 (2005).
205. Sejrup, H., Hafliðason, H. & Andrews, J. A Holocene North Atlantic SST record and regional climate variability. *Quaternary Science Reviews* **30**, 3181–3195 (2011).
206. Berner, K. S., Koç, N., Godtliëbsen, F. & Divine, D. Holocene climate variability of the Norwegian Atlantic Current during high and low solar insolation forcing. *Paleoceanography* **26**, PA2220 (2011).
207. Newton, A., Thunell, R. & Stott, L. Changes in the Indonesian Throughflow during the past 2000 yr. *Geology* **39**, 63–66 (2010).
208. Nieto-Moreno, V. *et al.* Climate conditions in the westernmost Mediterranean over the last two millennia: An integrated biomarker approach. *Organic Geochemistry* **55**, 1–10 (2013).
209. Doose-Rolinski, H., Rogalla, U., Scheeder, G., Lückge, A. & von Rad, U. High-resolution temperature and evaporation changes during the Late Holocene in the northeastern Arabian Sea. *Paleoceanography* **16**, 358–367 (2001).
210. Saenger, C., Came, R. E., Oppo, D. W., Keigwin, L. D. & Cohen, A. L. Regional climate variability in the western subtropical North Atlantic during the past two millennia. *Paleoceanography* **26**, PA2206 (2011).
211. Kim, J.-H. *et al.* Impacts of the North Atlantic gyre circulation on Holocene climate off northwest Africa. *Geology* **35**, 387–390 (2007).
212. McGregor, H. V., Dima, M., Fischer, H. W. & Mulitza, S. Rapid 20th-century increase in coastal upwelling off northwest Africa. *Science* **315**, 637–639 (2007).
213. Black, D. E. *et al.* An 8-century tropical Atlantic SST record from the Cariaco Basin: Baseline variability, twentieth-century warming, and Atlantic hurricane frequency. *Paleoceanography* **22**, PA4204 (2007).
214. Lea, D. W. Synchronicity of tropical and high-latitude Atlantic temperatures over the last glacial termination. *Science* **301**, 1361–1364 (2003).
215. Lamy, F., Rühlemann, C., Hebbeln, D. & Wefer, G. High- and low-latitude climate control on the position of the southern Peru-Chile Current during the Holocene. *Paleoceanography* **17**, PA000727 (2002).
216. Kuhnert, H. & Mulitza, S. Multidecadal variability and late medieval cooling of near-coastal sea surface temperatures in the eastern tropical North Atlantic. *Paleoceanography* **26**, PA4224 (2011).
217. Keigwin, L. D., Sachs, J. P. & Rosenthal, Y. A 1600-year history of the Labrador Current off Nova Scotia. *Climate Dynamics* **21**, 53–62 (2003).
218. Sachs, J. P. Cooling of Northwest Atlantic slope waters during the Holocene. *Geophysical Research Letters* **34**, L03609 (2007).
219. Richter, T., Peeters, F. & van Weering, T. Late Holocene (0–2.4 ka BP) surface water temperature and salinity variability, Feni Drift, NE Atlantic Ocean. *Quaternary Science Reviews* **28**, 1941–1955 (2009).
220. Richey, J. N., Poore, R. Z., Flower, B. P., Quinn, T. M. & Hollander, D. J. Regionally coherent Little Ice Age cooling in the Atlantic Warm Pool. *Geophysical Research Letters* **36**, L21703 (2009).
221. Weldeab, S., Lea, D. W., Schneider, R. R. & Andersen, N. 155,000 years of west African monsoon and ocean thermal evolution. *Science* **316**, 1303–1307 (2007).
222. Sepúlveda, J. *et al.* Late Holocene sea-surface temperature and precipitation variability in northern Patagonia, Chile (Jacaf Fjord, 44°S). *Quaternary Research* **72**, 400–409 (2009).
223. Isono, D. *et al.* The 1500-year climate oscillation in the midlatitude North Pacific during the Holocene. *Geology* **37**, 591–594 (2009).
224. Keigwin, L. D., Sachs, J. P., Rosenthal, Y. & Boyle, E. A. The 8200 year B.P. event in the slope water system, western subpolar North Atlantic. *Paleoceanography* **20**, PA2003 (2005).
225. Calvo, E., Grimalt, J. & Jansen, E. High resolution  $U_{37}^K$  sea surface temperature reconstruction in the Norwegian Sea during the Holocene. *Quaternary Science Reviews* **21**, 1385–1394 (2002).
226. Linsley, B. K., Rosenthal, Y. & Oppo, D. W. Holocene evolution of the Indonesian throughflow and the western Pacific warm pool. *Nature Geoscience* **3**, 578–583 (2010).
227. Oppo, D. W., Rosenthal, Y. & Linsley, B. K. 2,000-year-long temperature and hydrology reconstructions from the Indo-Pacific warm pool. *Nature* **460**, 1113–1116 (2009).
228. Moreno, A. *et al.* The Medieval Climate Anomaly in the Iberian Peninsula reconstructed from marine and lake records. *Quaternary Science Reviews* **43**, 16–32 (2012).
229. Harada, N., Ahagon, N., Uchida, M. & Murayama, M. Northward and southward migrations of frontal zones during the past 40 kyr in the Kuroshio-Oyashio transition area. *Geochemistry, Geophysics, Geosystems* **5**, Q09004 (2004).
230. Sicre, M.-A. *et al.* Sea surface temperature variability in the subpolar Atlantic over the last two millennia. *Paleoceanography* **26**, PA4218 (2011).
231. Came, R. E., Oppo, D. W. & McManus, J. F. Amplitude and timing of temperature and salinity variability in the subpolar North Atlantic over the past 10 k.y. *Geology* **35**, 315 (2007).
232. Wu, W., Tan, W., Zhou, L., Yang, H. & Xu, Y. Sea surface temperature variability in southern Okinawa Trough during last 2700 years. *Geophysical Research Letters* **39**, L14705 (2012).
233. Thornalley, D. J. R., Elderfield, H. & McCave, I. N. Holocene oscillations in temperature and salinity of the surface subpolar North Atlantic. *Nature* **457**, 711–714 (2009).
234. Saraswat, R., Lea, D. W., Nigam, R., Mackensen, A. & Naik, D. K. Deglaciation in the tropical Indian Ocean driven by interplay between the regional monsoon and global teleconnections. *Earth and Planetary Science Letters* **375**, 166–175 (2013).
235. Zhao, M., Eglinton, G., Read, G. & Schimmelmann, A. An alkenone ( $U_{37}^K$ ) quasi-annual sea surface temperature record (A.D. 1440 to 1940) using varved sediments from the Santa Barbara Basin. *Organic Geochemistry* **31**, 903–917 (2000).
236. Leduc, G., Herbert, C. T., Blanz, T., Martinez, P. & Schneider, R. Contrasting evolution of sea surface temperature in the Benguela upwelling system under natural and anthropogenic climate forcings. *Geophysical Research Letters* **37**, L20705 (2010).
237. Zhao, M., Huang, C.-Y., Wang, C.-C. & Wei, G. A millennial-scale  $U_{37}^K$  sea-surface temperature record from the South China Sea (8°N) over the last 150 kyr: Monsoon and sea-level influence. *Palaeogeography, Palaeoclimatology, Palaeoecology* **236**, 39–55 (2006).
238. Mohtadi, M., Romero, O. E., Kaiser, J. & Hebbeln, D. Cooling of the southern high latitudes during the Medieval Period and its effect on ENSO. *Quaternary Science Reviews* **26**, 1055–1066 (2007).
239. deMenocal, P. Coherent high- and low-latitude climate variability during the Holocene warm period. *Science* **288**, 2198–2202 (2000).
240. Abrantes, F. *et al.* Shallow-marine sediment cores record climate variability and earthquake activity off Lisbon (Portugal) for the last 2000 years. *Quaternary Science Reviews* **24**, 2477–2494 (2005).
241. Stott, L., Timmermann, A. & Thunell, R. Southern Hemisphere and deep-sea warming led deglacial atmospheric CO<sub>2</sub> rise and tropical warming. *Science* **318**, 435–438 (2007).
242. Bonnet, S., de Vernal, A., Hillaire-Marcel, C., Radi, T. & Husum, K. Variability of sea-surface temperature and sea-ice cover in the Fram Strait over the last two millennia. *Marine Micropaleontology* **74**, 59–74 (2010).
243. Shevenell, A. E., Ingalls, A. E., Domack, E. W. & Kelly, C. Holocene Southern Ocean surface temperature variability west of the Antarctic Peninsula. *Nature* **470**, 250–254 (2011).

244. Spielhagen, R. F. *et al.* Enhanced modern heat transfer to the Arctic by warm Atlantic water. *Science* **331**, 450–453 (2011).
245. Swart, K., Dodge, R. & Judson, H. A 240-year stable oxygen and carbon isotopic record in a coral from south Florida: Implications for the prediction of precipitation in southern Florida. *PALAIOS* **11**, 362–375 (1996).
246. Zinke, J. *et al.* Mayotte coral reveals hydrological changes in the western Indian Ocean between 1881 and 1994. *Geophysical Research Letters* **35**, L23707 (2008).
247. Cléroux, C. *et al.* Mg/Ca and Sr/Ca ratios in planktonic foraminifera: Proxies for upper water column temperature reconstruction. *Paleoceanography* **23**, PA3214 (2008).
248. Saenger, C., Cohen, A. L., Oppo, D. W., Halley, R. B. & Carilli, J. E. Surface-temperature trends and variability in the low-latitude North Atlantic since 1552. *Nature Geoscience* **2**, 492–495 (2009).
249. Goodkin, N. F., Hughen, K. A., Doney, S. C. & Curry, W. B. Increased multidecadal variability of the North Atlantic Oscillation since 1781. *Nature Geoscience* **1**, 844–848 (2008).
250. Kuhnert, H., Crüger, T. & Pätzold, J. NAO signature in a Bermuda coral Sr/Ca record. *Geochemistry, Geophysics, Geosystems* **6**, Q04004 (2005).
251. DeLong, K. L. *et al.* A reconstruction of sea surface temperature variability in the southeastern Gulf of Mexico from 1734 to 2008 C.E. using cross-dated Sr/Ca records from the coral *Siderastrea siderea*. *Paleoceanography* **29**, 403–422 (2014).
252. Hetzinger, S., Pfeiffer, M., Dullo, W.-C., Garbe-Schönberg, D. & Halfar, J. Tropical sea surface temperatures for the past four centuries reconstructed from coral archives. *Paleoceanography* **30**, 226–252 (2010).
253. Vázquez-Bedoya, L., Cohen, A., Oppo, D. & Blanchon, P. Tropical sea surface temperatures for the past four centuries reconstructed from coral archives. *Paleoceanography* **30**, 226–252 (2012).
254. Charles, C. D., Cobb, K., Moore, M. D. & Fairbanks, R. G. Monsoon-tropical ocean interaction in a network of coral records spanning the 20th century. *Marine Geology* **201**, 207–222 (2003).
255. Zinke, J., Dullo, W.-C., Heiss, G. & Eisenhauer, A. ENSO and Indian Ocean subtropical dipole variability is recorded in a coral record off southwest Madagascar for the period 1659 to 1995. *Earth and Planetary Science Letters* **228**, 177–194 (2004).
256. Nakamura, N. *et al.* Mode shift in the Indian Ocean climate under global warming stress. *Geophysical Research Letters* **36**, 226–252 (2009).
257. Damassa, T. D., Cole, J. E., Barnett, H. R., Ault, T. R. & McClanahan, T. R. Enhanced multidecadal climate variability in the seventeenth century from coral isotope records in the western Indian Ocean. *Paleoceanography* **21**, PA2016 (2006).
258. Cole, J. E. Tropical Pacific forcing of decadal SST variability in the western Indian Ocean over the past two centuries. *Science* **287**, 617–619 (2000).
259. Abram, N. J., Gagan, M. K., Cole, J. E., Hantoro, W. S. & Mudelsee, M. Recent intensification of tropical climate variability in the Indian Ocean. *Nature Geoscience* **1**, 849–853 (2008).
260. Felis, T. *et al.* A coral oxygen isotope record from the northern Red Sea documenting NAO, ENSO, and North Pacific teleconnections on Middle East climate variability since the year 1750. *Paleoceanography* **15**, 679–694 (2000).
261. Pfeiffer, M., Timm, O., Dullo, W.-C. & Podlech, S. Oceanic forcing of interannual and multidecadal climate variability in the southwestern Indian Ocean: Evidence from a 160 year coral isotopic record (La Réunion, 55°E, 21°S). *Paleoceanography* **19**, PA4006 (2004).
262. Moustafa, Y. A., Pätzold, J., Loya, Y. & Wefer, G. Mid-Holocene stable isotope record of corals from the northern Red Sea. *Journal of Earth Sciences* **88**, 742–751 (2000).
263. Charles, C. D. Interaction between the ENSO and the Asian monsoon in a coral record of tropical climate. *Science* **277**, 925–928 (1997).
264. Alibert, C. & Kinsley, L. A 170-year Sr/Ca and Ba/Ca coral record from the western Pacific warm pool: 2. A window into variability of the New Ireland Coastal Undercurrent. *Journal of Geophysical Research* **113**, 226–252 (2008).
265. Dunbar, R. B., Wellington, G. M., Colgan, M. W. & Glynn, P. W. Eastern Pacific sea surface temperature since 1600 A.D.: The  $\delta^{18}\text{O}$  record of climate variability in Galápagos Corals. *Paleoceanography* **9**, 291–315 (1994).
266. Asami, R. Interannual and decadal variability of the western Pacific sea surface condition for the years 1787–2000: Reconstruction based on stable isotope record from a Guam coral. *Journal of Geophysical Research* **110**, 226–252 (2005).
267. Tudhope, A. *et al.* Variability in the El Niño-Southern Oscillation through a glacial-interglacial cycle. *Science* **291**, 1511–1517 (2001).
268. Linsley, B. K. *et al.* Tracking the extent of the South Pacific Convergence Zone since the early 1600s. *Geochemistry, Geophysics, Geosystems* **7**, Q05003 (2006).
269. Cole, J. E., Urban, F. E. & Overpeck, J. T. Influence of mean climate change on climate variability from a 155-year tropical Pacific coral record. *Nature* **407**, 989–993 (2000).
270. Boiseau, M. *et al.* Atmospheric and oceanic evidences of El Niño-Southern Oscillation events in the south central Pacific Ocean from coral stable isotopic records over the last 137 years. *Paleoceanography* **13**, 671–685 (1998).
271. DeLong, K. L., Quinn, T. M., Taylor, F. W., Lin, K. & Shen, C.-C. Sea surface temperature variability in the southwest tropical Pacific since AD 1649. *Nature Climate Change* **2**, 799–804 (2012).
272. Cobb, K. M., Charles, C. D., Cheng, H. & Edwards, R. L. El Niño/Southern Oscillation and tropical Pacific climate during the last millennium. *Nature* **424**, 271–276 (2003).
273. Linsley, B. K., Dunbar, R. B., Wellington, G. M. & Mucciarone, D. A. A coral-based reconstruction of Intertropical Convergence Zone variability over Central America since 1707. *Journal of Geophysical Research* **99**, 9977–9994 (1994).
274. Bagnato, S., Linsley, B. K., Howe, S. S., Wellington, G. M. & Salinger, J. Coral oxygen isotope records of interdecadal climate variations in the South Pacific Convergence Zone region. *Geochemistry, Geophysics, Geosystems* **6**, 226–252 (2005).
275. Cole, J. E. & Fairbanks, R. G. The Southern Oscillation recorded in the  $\delta^{18}\text{O}$  of corals from Tarawa Atoll. *Paleoceanography* **5**, 669–683 (1990).
276. Quinn, T. M., Crowley, T. J. & Taylor, F. W. New stable isotope results from a 173-year coral from Espiritu Santo, Vanuatu. *Geophysical Research Letters* **23**, 3413–3416 (1996).
277. Wu, H. C., Linsley, B. K., Dassí, E. P., Schiraldi, B. & deMenocal, P. B. Oceanographic variability in the South Pacific Convergence Zone region over the last 210 years from multi-site coral Sr/Ca records. *Geochemistry, Geophysics, Geosystems* **14**, 1435–1453 (2013).
278. Swart, P. K. *et al.* The stable oxygen and carbon isotopic record from a coral growing in Florida Bay: a 160 year record of climatic and anthropogenic influence. *Paleogeography, Palaeoclimatology, Palaeoecology* **123**, 219–237 (1996).
279. Kilbourne, K. H. *et al.* Paleoclimate proxy perspective on Caribbean climate since the year 1751: Evidence of cooler temperatures and multidecadal variability. *Paleoceanography* **23**, PA3220 (2008).
280. Heiss, G., Dullo, W., Joachimski, M., Reijmer, J. & Schuhmacher, H. Increased seasonality in the Gulf of Aqaba, Red Sea, recorded in the oxygen isotope record of a *Porites lutea* coral. *Senckenbergiana Maritima* **30**, 17–26 (1999).

281. Kuhnert, H., Pätzold, J., Wyrwoll, K. & Wefer, G. Monitoring climate variability over the past 116 years in coral oxygen isotopes from Ningaloo Reef, Western Australia. *International Journal of Earth Sciences* **88**, 725–732 (2000).
282. Linsley, B. K., Ren, L., Dunbar, R. B. & Howe, S. S. El Niño Southern Oscillation (ENSO) and decadal-scale climate variability at 10°N in the eastern Pacific from 1893 to 1994: A coral-based reconstruction from Clipperton Atoll. *Paleoceanography* **15**, 322–335 (2000).
283. Felis, T. *et al.* Subtropical coral reveals abrupt early-twentieth-century freshening in the western North Pacific Ocean. *Geology* **37**, 527–530 (2009).
284. Druffel, E. R. M. & Griffin, S. Variability of surface ocean radiocarbon and stable isotopes in the southwestern Pacific. *Journal of Geophysical Research* **104**, 23607–23613 (1999).
285. Gorman, M. K. *et al.* A coral-based reconstruction of sea surface salinity at Sabine Bank, Vanuatu from 1842 to 2007 CE. *Paleoceanography* **27**, PA3226 (2012).
286. Guilderson, T. P. & Schrag, D. P. Reliability of coral isotope records from the Western Pacific Warm Pool: A comparison using age-optimized records. *Paleoceanography* **14**, 457–464 (1999).
287. Quinn, T. M., Taylor, F. W. & Crowley, T. J. Coral-based climate variability in the Western Pacific Warm Pool since 1867. *Journal of Geophysical Research* **111**, C11006 (2006).
288. Munz, P. M. *et al.* Decadal-resolution record of winter monsoon intensity over the last two millennia from planktic foraminiferal assemblages in the northeastern Arabian Sea. *The Holocene* **25**, 1756–1771 (2015).
289. Abrantes, F. *et al.* Climate of the last millennium at the southern pole of the North Atlantic Oscillation: an inner-shelf sediment record of flooding and upwelling. *Climate Research* **48**, 261–280 (2011).
290. Moffa-Sánchez, P., Born, A., Hall, I. R., Thornalley, D. J. R. & Barker, S. Solar forcing of North Atlantic surface temperature and salinity over the past millennium. *Nature Geoscience* **7**, 275–278 (2014).
291. Tierney, J. E., Ummenhofer, C. C. & deMenocal, P. B. Past and future rainfall in the Horn of Africa. *Science Advances* **1**, e1500682 (2015).
292. Kuhnert, H., Pätzold, J., Schnetger, B. & Wefer, G. Sea-surface temperature variability in the 16th century at Bermuda inferred from coral records. *Palaeogeography, Palaeoclimatology, Palaeoecology* **179**, 159–171 (2002).
293. Rosenheim, B. E. Salinity change in the subtropical Atlantic: Secular increase and teleconnections to the North Atlantic Oscillation. *Geophysical Research Letters* **32**, L02603 (2005).
294. Draschba, S., Pätzold, J. & Wefer, G. North Atlantic climate variability since AD 1350 recorded in  $\delta^{18}\text{O}$  and skeletal density of Bermuda corals. *International Journal of Earth Sciences* **88**, 733–741 (2000).
295. Moses, C. S., Swart, P. K. & Rosenheim, B. E. Evidence of multidecadal salinity variability in the eastern tropical North Atlantic. *Paleoceanography* **21**, PA3010 (2006).
296. Hetzinger, S. *et al.* Caribbean coral tracks Atlantic Multidecadal Oscillation and past hurricane activity. *Geology* **36**, 11–14 (2008).
297. Wanamaker, A. D. *et al.* Coupled North Atlantic slope water forcing on Gulf of Maine temperatures over the past millennium. *Climate Dynamics* **31**, 183–194 (2007).
298. Haase-Schramm, A. *et al.* Sr/Ca ratios and oxygen isotopes from sclerosponges: Temperature history of the Caribbean mixed layer and thermocline during the Little Ice Age. *Paleoceanography* **18**, PA1073 (2003).
299. Zinke, J. *et al.* Corals record long-term Leeuwin current variability including Ningaloo Niño/Niña since 1795. *Nature Communications* **5**, 4607 (2014).
300. Zinke, J., Loveday, B. R., Reason, C. J. C., Dullo, W.-C. & Kroon, D. Madagascar corals track sea surface temperature variability in the Agulhas Current core region over the past 334 years. *Scientific Reports* **4**, 4393 (2014).
301. Cooper, T. F., O’Leary, R. A. & Lough, J. M. Growth of Western Australian Corals in the Anthropocene. *Science* **335**, 593–596 (2012).
302. Wu, H. C., Moreau, M., Linsley, B. K., Schrag, D. P. & Corrège, T. Investigation of sea surface temperature changes from replicated coral Sr/Ca variations in the eastern equatorial Pacific (Clipperton Atoll) since 1874. *Palaeogeography, Palaeoclimatology, Palaeoecology* **412**, 208–222 (2014).
303. Calvo, E. *et al.* Interdecadal climate variability in the Coral Sea since 1708 A.D. *Palaeogeography, Palaeoclimatology, Palaeoecology* **248**, 190–201 (2007).
304. Tudhope, A. *et al.* Recent changes in climate in the far western equatorial Pacific and their relationship to the Southern Oscillation; oxygen isotope records from massive corals, Papua New Guinea. *Earth and Planetary Science Letters* **136**, 575–590 (1995).
305. Sun, Y. *et al.* Strontium contents of a *Porites* coral from Xisha Island, South China Sea: A proxy for sea-surface temperature of the 20th century. *Paleoceanography* **19**, PA2004 (2004).
306. Moses, C. & Swart, P. Stable isotope and growth records in corals from the island of Tobago: Not simply a record of the Orinoco. *Proceedings of the 10th International Coral Reef Symposium (Okinawa)* 580–587 (2006).
307. Wei, G., McCulloch, M. T., Mortimer, G., Deng, W. & Xie, L. Evidence for ocean acidification in the Great Barrier Reef of Australia. *Geochimica et Cosmochimica Acta* **73**, 2332–2346 (2009).
308. Evans, M. N., Fairbanks, R. G. & Rubenstone, J. L. A proxy index of ENSO teleconnections. *Nature* **394**, 732–733 (1998).
309. Osborne, M. C., Dunbar, R. B., Mucciarone, D. A., Druffel, E. & Sanchez-Cabeza, J.-A. A 215-yr coral  $\delta^{18}\text{O}$  time series from Palau records dynamics of the West Pacific Warm Pool following the end of the Little Ice Age. *Coral Reefs* **33**, 719–731 (2014).
310. Kilbourne, K. H., Quinn, T. M., Taylor, F. W., Delcroix, T. & Gouriou, Y. El Niño-Southern Oscillation-related salinity variations recorded in the skeletal geochemistry of a *Porites* coral from Espiritu Santo, Vanuatu. *Paleoceanography* **19**, PA4002 (2004).
311. Hendy, E. J. Abrupt decrease in tropical Pacific sea surface salinity at end of Little Ice Age. *Science* **295**, 1511–1514 (2002).
312. von Gunten, L., Grosjean, M., Rein, B., Urrutia, R. & Appleby, P. A quantitative high-resolution summer temperature reconstruction based on sedimentary pigments from Laguna Aculeo, central Chile, back to AD 850. *The Holocene* **19**, 873–881 (2009).
313. Neukom, R. *et al.* Multiproxy summer and winter surface air temperature field reconstructions for southern South America covering the past centuries. *Climate Dynamics* **37**, 35–51 (2011).
314. Neukom, R. *et al.* Inter-hemispheric temperature variability over the past millennium. *Nature Climate Change* **4**, 362–367 (2014).
315. Thompson, L. G. *et al.* Annually resolved ice core records of tropical climate variability over the past 1800 years. *Science* **340**, 945–950 (2013).
316. de Jong, R., von Gunten, L., Maldonado, A. & Grosjean, M. Late Holocene summer temperatures in the central Andes reconstructed from the sediments of high-elevation Laguna Chepical, Chile (32° S). *Climate of the Past* **9**, 1921–1932 (2013).
317. Elbert, J. *et al.* Late Holocene air temperature variability reconstructed from the sediments of Laguna Escondida, Patagonia, Chile (45°30’S). *Palaeogeography, Palaeoclimatology, Palaeoecology* **369**, 482–492 (2013).



## Data Citations

1. PAGES 2k Consortium. *figshare* <https://doi.org/10.6084/m9.figshare.c.3285353> (2017).
2. Tierney, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10428> (2010).
3. Powers, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13216> (2012).
4. Sundqvist, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14349> (2013).
5. Stenni, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2465> (2002).
6. Moy, A. *Australian Antarctic Data Centre* <https://data.aad.gov.au/metadata/records/LD2012-d18O-Native-age> (2016).
7. Graf, W. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.104881> (2002).
8. Steig, E. *National Snow and Ice Data Center* <http://dx.doi.org/10.7265/N5QJ7F8B> (2013).
9. Mulvaney, R. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.728157> (2002).
10. Jouzel, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6080> (2007).
11. Stenni, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2492> (2006).
12. Rhodes, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13175> (2012).
13. Graf, W. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.104882> (2002).
14. Graf, W. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.104888> (2002).
15. Steig, E. *PANGAEA* <http://doi.org/10.17911/S9H59X> (2016).
16. Bertler, N. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.866368> (2016).
17. Bird, B. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/6192> (2009).
18. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14188> (2013).
19. Cook, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6195> (2008).
20. Fisher, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2429> (1977).
21. Wilson, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/19743> (2016).
22. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13758> (2012).
23. Grootes, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/17796> (1997).
24. Haltia-Hovi, E. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/8661> (2011).
25. Hughes, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14188> (2013).
26. Isaksson, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/11173> (2011).
27. Lamoureaux, S. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8662> (2009).
28. Larsen, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14730> (2013).
29. McDonald, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3902> (2009).
30. Moore, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6234> (2003).
31. Ojala, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8660> (2009).
32. Schwager, M. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.218274> (2004).
33. Schwager, M. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.57158> (2000).
34. Schwager, M. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.57291> (2000).
35. Thomas, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6203> (2008).
36. Vinther, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2494> (2006).
37. Vinther, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/11131> (2008).
38. Vinther, B. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.786356> (2010).
39. Vinther, B. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.786302> (2010).
40. Vinther, B. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.786354> (2010).
41. Bergthorsson, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14188> (2012).
42. Clegg, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/9953> (2010).
43. Clegg, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12443> (2012).
44. D'Andrea, W. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/11176> (2011).
45. Fisher, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2437> (1997).
46. Fisher, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2474> (2003).
47. Luoto, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14188> (2013).
48. Okuyama, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14188> (2013).
49. Rolland, N. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14188> (2013).
50. Melvin, T. *Climatic Research Unit* <https://crudata.uea.ac.uk/cru/papers/melvin2012holocene/> (2013).
51. Opel, T. *PANGAEA* <https://doi.pangaea.de/10.1594/PANGAEA.824732> (2013).
52. McKay, N. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6199> (2008).
53. D'Andrea, W. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13458> (2012).
54. Porter, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/19851> (2016).
55. Hughen, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5465> (2003).
56. Briffa, K. *Climatic Research Unit* <https://crudata.uea.ac.uk/cru/papers/briffa2013qsr/> (2013).
57. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15342> (2013).
58. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15343> (2013).
59. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15344> (2013).
60. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15345> (2013).
61. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15346> (2013).
62. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15347> (2013).
63. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15348> (2013).
64. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15349> (2013).
65. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15350> (2013).
66. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15351> (2013).
67. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4710> (2001).
68. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4707> (2001).
69. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12484> (2011).
70. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12485> (2011).
71. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12486> (2011).
72. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12487> (2011).
73. PAGES2k Consortium. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14188> (2013).
74. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12489> (2011).
75. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12547> (2011).
76. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12548> (2011).
77. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12549> (2011).
78. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12557> (2011).



158. Krusic, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3793> (2002).
159. Krusic, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3776> (2002).
160. Krusic, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3784> (2002).
161. Krusic, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3796> (2002).
162. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15312> (2013).
163. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15313> (2013).
164. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10714> (2010).
165. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10715> (2010).
166. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10716> (2010).
167. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10717> (2010).
168. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15315> (2013).
169. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15316> (2013).
170. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15317> (2013).
171. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15318> (2013).
172. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15319> (2013).
173. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12767> (2010).
174. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12768> (2010).
175. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15320> (2013).
176. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15322> (2013).
177. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15323> (2013).
178. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15324> (2013).
179. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15325> (2013).
180. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12782> (2010).
181. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12783> (2010).
182. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12784> (2010).
183. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12785> (2010).
184. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15327> (2013).
185. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15330> (2013).
186. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15332> (2013).
187. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15333> (2013).
188. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12787> (2010).
189. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12788> (2010).
190. Esper, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12789> (2010).
191. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15337> (2013).
192. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15338> (2013).
193. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14928> (2013).
194. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15129> (2013).
195. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15131> (2013).
196. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14929> (2013).
197. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15128> (2013).
198. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14948> (2013).
199. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15048> (2013).
200. Brauning, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15130> (2013).
201. Buckley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12644> (2011).
202. Wright, W. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12634> (2011).
203. Buckley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10453> (2010).
204. Thompson, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/11180> (2000).
205. Thompson, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12426> (1997).
206. Thompson, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/11929> (2006).
207. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6240> (2002).
208. Cook, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003986> (2013).
209. Allen, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003970> (2013).
210. Duncan, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003988> (2013).
211. Buckley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003968> (2013).
212. Allen, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003971> (2013).
213. Saunders, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/20452> (2016).
214. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003992> (2013).
215. Xiong, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5375> (1997).
216. Esper, J. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/1003406> (2012).
217. Büntgen, U. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/1003402> (2013).
218. Popa, I. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/1003409> (2008).
219. Büntgen, U.. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/1003403> (2012).
220. Büntgen, U. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/1003401> (2006).
221. Büntgen, U. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/1003400> (2012).
222. Dorado-Linan, I. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/1003405> (2012).
223. Dobrovolný, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/9970> (2010).
224. Helama, S. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/16790> (2014).
225. Larocque-Tobler, I. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/10427> (2010).
226. Trachsel, M. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/13016> (2010).
227. Larocque-Tobler, I. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/12899> (2012).
228. Martn-Chivelet, J. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/12194> (2011).
229. Mangini, A. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/5433> (2005).
230. Leijonhufvud, L. *World Data Center for Paleoclimatology* <http://www.ncdc.noaa.gov/paleo/study/10429> (2010).
231. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3404> (1995).
232. King, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3706> (2003).
233. Barclay, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14274> (2013).
234. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3355> (1995).
235. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3413> (1995).
236. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3348> (1995).

237. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3407> (1995).
238. King, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3726> (2000).
239. Graumlich, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3301> (2006).
240. Graumlich, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3335> (2006).
241. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4320> (2000).
242. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13782> (2012).
243. Colenutt, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13783> (2013).
244. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13785> (2013).
245. Brown, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2871> (2005).
246. King, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3739> (2002).
247. Hughes, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3566> (2005).
248. Littell, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12696> (2011).
249. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3395> (1994).
250. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3384> (1994).
251. Graumlich, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3313> (2003).
252. Graumlich, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3330> (2003).
253. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2858> (1996).
254. Gajewski, K. *World Data Center for Paleoclimatology* <ftp://ftp.ncdc.noaa.gov/pub/data/paleo/pollen/recons/> (1993).
255. Paquette, N. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/18735> (2015).
256. St. Jacques, J.-M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16761> (2014).
257. Ersek, V. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13543> (2012).
258. Gennaretti, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16558> (2014).
259. Fritts, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3264> (1995).
260. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4397> (2000).
261. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4409> (2000).
262. T., H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3480> (1998).
263. Wiles, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5244> (2000).
264. Lloyd, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3879> (2002).
265. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3043> (2000).
266. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3044> (2000).
267. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3047> (2000).
268. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3059> (2000).
269. Jacoby, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3605> (2000).
270. Jacoby, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3587> (2000).
271. Wiles, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12445> (2011).
272. Wiles, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12449> (2011).
273. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13707> (2011).
274. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13708> (2011).
275. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13709> (2011).
276. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13710> (2011).
277. Anchukaitis, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14790> (2013).
278. Kaiser, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3669> (1996).
279. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2854> (1996).
280. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2838> (1996).
281. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2862> (1996).
282. King, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3690> (2000).
283. Biondi, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2754> (2001).
284. Fritts, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3263> (1995).
285. Church, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2939> (1995).
286. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4583> (2000).
287. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4499> (2000).
288. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4400> (2000).
289. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4658> (2000).
290. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4344> (2000).
291. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4670> (2000).
292. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4584> (2000).
293. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2860> (1996).
294. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2808> (1996).
295. Parish, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4090> (2000).
296. Jacoby, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3592> (2000).
297. Jacoby, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3598> (2000).
298. Jacoby, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3615> (2000).
299. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4349> (2000).
300. Schweingruber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4319> (2000).
301. Buckley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2923> (1997).
302. Wilson, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5520> (2007).
303. Wilson, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5529> (2007).
304. Wilson, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5524> (2007).
305. Wilson, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5511> (2007).
306. Wilson, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5512> (2007).
307. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12568> (2011).
308. Jacoby, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12577> (2011).
309. D'Arrigo, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13756> (2011).
310. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15368> (2013).
311. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15369> (2013).
312. Kenigsberg, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15520> (2013).
313. Kenigsberg, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15525> (2013).
314. Kenigsberg, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15527> (2013).
315. Colenutt, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16577> (2013).

316. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16587> (2014).
317. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16590> (2014).
318. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16592> (2014).
319. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16593> (2014).
320. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16595> (2014).
321. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16596> (2014).
322. Kavanagh, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16597> (2014).
323. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16602> (2014).
324. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16605> (2014).
325. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16608> (2014).
326. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16609> (2014).
327. Luckman, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16612> (2014).
328. Kienast, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3680> (1996).
329. Graybill, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3381> (1994).
330. T., H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2842> (1996).
331. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2813> (1996).
332. Bigler, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5502> (2007).
333. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2819> (1996).
334. Hughes, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3576> (2005).
335. Conkey, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2949> (1994).
336. Biondi, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2755> (2001).
337. Fule, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8509> (2009).
338. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2822> (1996).
339. Hughes, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/3563> (2005).
340. Littell, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12697> (2011).
341. Colenutt, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12703> (2011).
342. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2814> (1996).
343. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2810> (1996).
344. Sauchyn, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/20653> (2016).
345. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2812> (1996).
346. Sauchyn, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/20654> (2016).
347. Peterson, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4126> (1994).
348. Peterson, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4127> (1994).
349. Peterson, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4129> (1994).
350. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2839> (1996).
351. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2850> (1996).
352. Peterson, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4139> (1994).
353. Peterson, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4154> (1994).
354. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2844> (1996).
355. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2833> (1996).
356. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2820> (1996).
357. Briffa, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2859> (1996).
358. Brown, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2875> (2005).
359. Jiang, H. *Geological Society of America* <ftp://rock.geosociety.org/pub/reposit/2005/2005010.pdf> (2005).
360. Berner, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/17475> (2014).
361. Newton, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/4154> (1994).
362. Nieto-Moreno, V. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.802259> (2012).
363. Doose-Rolinski, H. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.735717> (2001).
364. Saenger, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/11816> (2011).
365. Doose-Rolinski, H. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.737217> (2001).
366. McGregor, H. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.603183> (2007).
367. Black, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6397> (2007).
368. Lea, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2585> (2003).
369. Lamy, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6242> (2002).
370. Lund, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5968> (2007).
371. Kuhnert, H. PANGAEA <http://doi.pangaea.de/10.1594/1PANGAEA.773754> (2011).
372. Keigwin, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10891> (2011).
373. Keigwin, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5966> (2007).
374. Richter, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8725> (2009).
375. Richey, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10492> (2010).
376. Weldeab, S. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5596> (2007).
377. Sepúlveda, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12898> (2012).
378. Isono, D. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.841034> (2009).
379. Grimalt, J. PANGAEA <https://doi.pangaea.de/10.1594/PANGAEA.438810> (2006).
380. Linsley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10420> (2010).
381. Oppo, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8699> (2009).
382. Moreno, A. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.780423> (2012).
383. Harada, N. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8458> (2004).
384. Sicre, M.-A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12359> (2011).
385. Came, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5593> (2007).
386. Wu, W. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.803648> (2012).
387. Richey, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5584> (2007).
388. Thornalley, D. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8623> (2009).
389. Saraswat, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/17575> (2014).
390. Zhao, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/17755> (2015).
391. Leduc, G. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.776883> (2010).
392. Zhao, M. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.758916> (2011).
393. Mohtadi, M. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.676709> (2007).
394. deMenocal, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/2561> (2000).

395. Abrantes, F. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.761849> (2005).
396. Stott, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/5917> (2007).
397. Bonnet, S. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.780179> (2012).
398. Shenell, A. PANGAEA <https://doi.pangaea.de/10.1594/PANGAEA.769699> (2011).
399. Spielhagen, R. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.755092> (2011).
400. Swart, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1885> (2004).
401. Zinke, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8606> (2009).
402. Cleroux, C. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.776444> (2012).
403. Stott, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6400> (2007).
404. Saenger, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16440> (2009).
405. Goodkin, N. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6115> (2009).
406. Kuhnert, H. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.738188> (2005).
407. DeLong, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16217> (2014).
408. Steinhilber, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12894> (2012).
409. Vásquez-Bedoya, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13284> (2012).
410. Charles, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1903> (2004).
411. Zinke, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16438> (2014).
412. Nakamura, N. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12994> (2012).
413. Damassa, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10808> (2011).
414. Cole, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1855> (2000).
415. Abram, N. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8607> (2008).
416. Felis, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1861> (2000).
417. Pfeiffer, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1890> (2004).
418. Moustafa, Y. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.388665> (2006).
419. Charles, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1857> (1997).
420. Alibert, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8604> (2010).
421. Dunbar, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1850> (1994).
422. Asami, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1915> (2005).
423. Tudhope, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1866> (2001).
424. Linsley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16216> (2014).
425. Linsley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6089> (2008).
426. Kuhnert, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1866> (2001).
427. Urban, F. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1859> (2000).
428. Boiseau, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1876> (2003).
429. DeLong, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13035> (2012).
430. Cobb, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1875> (2003).
431. Linsley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1853> (1994).
432. Bagnato, S. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1916> (2005).
433. Cole, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1845> (1993).
434. Quinn, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1839> (1994).
435. Wu, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/15238> (2013).
436. Swart, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1886> (2004).
437. Kilbourne, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6117> (2009).
438. Kuhnert, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1856> (1999).
439. Heiss, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1854> (1994).
440. Kuhnert, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1867> (2001).
441. Linsley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1846> (2000).
442. Felis, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8608> (2009).
443. Druffel, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1911> (2004).
444. Gorman, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13439> (2012).
445. Guilderson, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1842> (1999).
446. Nurhati, I. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/8609> (2010).
447. Quinn, T. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6116> (2008).
448. Munz, P. PANGAEA <https://doi.pangaea.de/10.1594/PANGAEA.853971> (2015).
449. Abrantes, F. PANGAEA <https://doi.pangaea.de/10.1594/PANGAEA.784992> (2011).
450. Moffa-Sanchez, P. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/19804> (2016).
451. Tierney, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/19200> (2015).
452. Kuhnert, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1872> (2009).
453. Rosenheim, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1920> (2005).
454. Draschba, S. PANGAEA <http://doi.pangaea.de/10.1594/PANGAEA.711835> (2000).
455. Moses, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6184> (2009).
456. Hetzinger, S. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/12891> (2012).
457. Wanamaker, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6405> (2008).
458. Haase-Schramm, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1878> (2003).
459. Zinke, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16316> (2014).
460. Wu, H. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/17380> (2014).
461. Calvo, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6087> (2007).
462. Tudhope, A. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1844> (1995).
463. Sun, Y. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1894> (2004).
464. Moses, C. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1924> (2006).
465. Wei, G. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/10425> (2010).
466. Evans, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1847> (1998).
467. Linsley, B. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/6089> (2000).
468. Osborne, M. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16339> (2014).
469. Kilbourne, K. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1925> (2007).
470. Hendy, E. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1869> (2002).
471. von Gunten, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003957> (2013).
472. Villalba, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003952> (2013).
473. Mundo, I. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/1003953> (2013).

474. Thompson, L. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/14174> (2013).  
 475. Neukom, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/16196> (2014).  
 476. de Jong, R. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/20366> (2016).  
 477. Elbert, J. *World Data Center for Paleoclimatology* <https://www.ncdc.noaa.gov/paleo/study/13567> (2012).

## Acknowledgements

PAGES, a core project of Future Earth, is supported by the U.S. and Swiss National Science Foundations. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. Some of this work was conducted as part of the North America 2k Working Group supported by the John Wesley Powell Center for Analysis and Synthesis, funded by the U.S. Geological Survey. B. Bauer, W. Gross, and E. Gille (NOAA National Centers for Environmental Information) are gratefully acknowledged for helping assemble the data citations and creating the NCEI versions of the PAGES 2k data records. We thank all the investigators whose commitment to data sharing enables the open science ethos embodied by this project.

## Author Contributions

Julien Emile-Geay and Nicholas P. McKay created the database structure. Nicholas P. McKay wrote code to collate and standardize input from data contributors. Darrell S. Kaufman located missing essential metadata, cross-referenced the database with previous products, and was responsible for the Author Contributions section. Jianghao Wang, Julien Emile-Geay, and Kevin J. Anchukaitis wrote code to analyze and visualize the database contents, with input from Kaustubh Thirumalai and Michael N. Evans. Darrell S. Kaufman, Lucien von Gunten and Nicholas P. McKay coordinated the development of the data product, with input from other PAGES2k coordinators (Nerilie J. Abram, Michael N. Evans, Hugues Goosse, Raphael Neukom, Chris Turney). Julien Emile-Geay made all of the figures and wrote the initial data descriptor, with substantial input from Nerilie J. Abram, Kathryn J. Allen, Kevin J. Anchukaitis, Dmitry V. Divine, Daniel A. Dixon, Michael N. Evans, Helena L. Filipsson, Konrad Gajewski, Hugues Goosse, Darrell S. Kaufman, Belen Martrat, Helen V. McGregor, Nicholas P. McKay, David J. Nash, Raphael Neukom, Thomas Opel, Steven J. Phipps, Cody C. Routson, Marit-Solveig Seidenkrantz, Marie-Alexandrine Sicre, Jeannine-Marie St. Jacques, Jessica E. Tierney, Chris Turney, Jonathan J. Tyler, Andre E. Viau, Lucien von Gunten and Johannes P. Werner. All authors reviewed the manuscript and take responsibility for the integrity of the data. The list of author names is divided into four groups:

**Tier 1:** The first six co-authors are the principal data analyzers, manuscript writers and project coordinators. They include: Julien Emile-Geay, Nicholas P. McKay, Darrell S. Kaufman, Lucien von Gunten, Jianghao Wang, Kevin J. Anchukaitis.

**Tier 2:** The next group of 14 co-authors are the primary regional data managers who spent at least three weeks compiling and formatting a large number of proxy records for this data product. They include: Nerilie J. Abram, Jason A. Addison, Mark A.J. Curran, Michael N. Evans, Benjamin J. Henley, Zhixin Hao, Belen Martrat, Helen V. McGregor, Raphael Neukom, Gregory T. Pederson, Barbara Stenni, Kaustubh Thirumalai, Johannes P. Werner, Chenxi Xu.

**Tier 3:** The next 10 are the secondary regional data managers. They include: Dmitry V. Divine, Bronwyn C. Dixon, Joelle Gergis, Ignacio A. Mundo, Takeshi Nakatsuka, Steven J. Phipps, Cody C. Routson, Eric J. Steig, Jessica E. Tierney, Jonathan J. Tyler.

**Tier 4:** The next 68 contributed in various ways, generally amounting to less than one week working on the database. They include: Kathryn J. Allen, Nancy A.N. Bertler, Jesper Björklund, Brian M. Chase, Min-Te Chen, Ed Cook, Rixt de Jong, Kristine L. DeLong, Daniel A. Dixon, Alexey A. Ekaykin, Vasile Ersek, Helena L. Filipsson, Pierre Francus, Mandy B. Freund, Massimo Frezzotti, Narayan P. Gaire, Konrad Gajewski, Quansheng Ge, Hugues Goosse, Anastasia Gornostaeva, Martin Grosjean, Kazuho Horiuchi, Anne Hormes, Katrine Husum, Elisabeth Isaksson, Selvaraj Kandasamy, Kenji Kawamura, K. Halimeda Kilbourne, Nalan Koc, Guillaume Leduc, Hans W. Linderholm, Andrew M. Lorrey, Vladimir Mikhalenko, Graham P. Mortyn, Hideaki Motoyama, Andrew D. Moy, Robert Mulvaney, Philipp M. Munz, David J. Nash, Hans Oerter, Thomas Opel, Anais J. Orsi, Dmitriy V. Ovchinnikov, Trevor J. Porter, Heidi A. Roop, Casey Saenger, Masaki Sano, David Sauchyn, Krystyna M. Saunders, Marit-Solveig Seidenkrantz, Mirko Severi, Xuemei Shao, Marie-Alexandrine Sicre, Michael Sigl, Kate Sinclair, Scott St. George, Jeannine-Marie St. Jacques, Meloth Thamban, Udaya Kuwar Thapa, Elizabeth R. Thomas, Chris Turney, Ryu Uemura, Andre E. Viau, Diana O. Vladimirova, Eugene R. Wahl, James W.C. White, Zicheng Yu, Jens Zinke.

The time devoted, as specified above, includes only the activities related to the generation of this data product, not the time to generate the original data or anything that was included in a prior publication. Author names are ordered alphabetically for each group, except the first. Most (69) authors contributed data: they either generated the proxy data or they obtained them from existing archives or publications, or they formatted and entered the data into the database. In addition, most (61) authors certified the data: they verified that the records met the criteria as described in the data descriptor, including the temperature sensitivity of the proxy record, and in some cases, they provided comments to facilitate the informed reuse of individual records. The data certifier for each record is identified in Supplementary Table 1.

## Additional Information

Table 1 is only available in the online version of this paper.

Supplementary Information accompanies this paper at <http://www.nature.com/sdata>

**Competing interests:** The authors declare no competing financial interests.

**How to cite this article:** PAGES2k Consortium. A global multiproxy database for temperature reconstructions of the Common Era. *Sci. Data* 4:170088 doi: 10.1038/sdata.2017.88 (2017).

**Publisher's note:** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>

The Creative Commons Public Domain Dedication waiver <http://creativecommons.org/publicdomain/zero/1.0/> applies to the metadata files made available in this article.

© The Author(s) 2017

## PAGES2k Consortium

Julien Emile-Geay<sup>1</sup>, Nicholas P. McKay<sup>2</sup>, Darrell S. Kaufman<sup>2</sup>, Lucien von Gunten<sup>3</sup>, Jianghao Wang<sup>4</sup>, Kevin J. Anchukaitis<sup>5</sup>, Nerilie J. Abram<sup>6</sup>, Jason A. Addison<sup>7</sup>, Mark A.J. Curran<sup>8,9</sup>, Michael N. Evans<sup>10</sup>, Benjamin J. Henley<sup>11</sup>, Zhixin Hao<sup>12</sup>, Belen Martrat<sup>13,14</sup>, Helen V. McGregor<sup>15</sup>, Raphael Neukom<sup>16</sup>, Gregory T. Pederson<sup>17</sup>, Barbara Stenni<sup>18</sup>, Kaustubh Thirumalai<sup>19</sup>, Johannes P. Werner<sup>20</sup>, Chenxi Xu<sup>21</sup>, Dmitry V. Divine<sup>22,23</sup>, Bronwyn C. Dixon<sup>24</sup>, Joelle Gergis<sup>25</sup>, Ignacio A. Mundo<sup>26</sup>, Takeshi Nakatsuka<sup>27</sup>, Steven J. Phipps<sup>28</sup>, Cody C. Routson<sup>2</sup>, Eric J. Steig<sup>29</sup>, Jessica E. Tierney<sup>30</sup>, Jonathan J. Tyler<sup>31</sup>, Kathryn J. Allen<sup>32</sup>, Nancy A.N. Bertler<sup>33</sup>, Jesper Björklund<sup>34</sup>, Brian M. Chase<sup>35</sup>, Min-Te Chen<sup>36</sup>, Ed Cook<sup>37</sup>, Rixt de Jong<sup>16</sup>, Kristine L. DeLong<sup>38</sup>, Daniel A. Dixon<sup>39</sup>, Alexey A. Ekaykin<sup>40,41</sup>, Vasile Ersek<sup>42</sup>, Helena L. Filipsson<sup>43</sup>, Pierre Francus<sup>44</sup>, Mandy B. Freund<sup>25</sup>, Massimo Frezzotti<sup>45</sup>, Narayan P. Gaire<sup>46,47</sup>, Konrad Gajewski<sup>48</sup>, Quansheng Ge<sup>12</sup>, Hugues Goosse<sup>49</sup>, Anastasia Gornostaeva<sup>50</sup>, Martin Grosjean<sup>16</sup>, Kazuho Horiuchi<sup>51</sup>, Anne Hormes<sup>52</sup>, Katrine Husum<sup>22</sup>, Elisabeth Isaksson<sup>22</sup>, Selvaraj Kandasamy<sup>53</sup>, Kenji Kawamura<sup>54,55</sup>, K. Halimeda Kilbourne<sup>56</sup>, Nalan Koç<sup>22</sup>, Guillaume Leduc<sup>57</sup>, Hans W. Linderholm<sup>58</sup>, Andrew M. Lorrey<sup>59</sup>, Vladimir Mikhalenko<sup>60</sup>, P. Graham Mortyn<sup>61</sup>, Hideaki Motoyama<sup>62</sup>, Andrew D. Moy<sup>8,9</sup>, Robert Mulvaney<sup>63</sup>, Philipp M. Munz<sup>64</sup>, David J. Nash<sup>65,66</sup>, Hans Oerter<sup>67</sup>, Thomas Opel<sup>68</sup>, Anais J. Orsi<sup>69</sup>, Dmitriy V. Ovchinnikov<sup>70</sup>, Trevor J. Porter<sup>71</sup>, Heidi A. Roop<sup>72</sup>, Casey Saenger<sup>73</sup>, Masaki Sano<sup>27</sup>, David Sauchyn<sup>49</sup>, Krystyna M. Saunders<sup>74,75</sup>, Marit-Solveig Seidenkrantz<sup>76</sup>, Mirko Severi<sup>77</sup>, Xuemei Shao<sup>12</sup>, Marie-Alexandrine Sicre<sup>78</sup>, Michael Sigl<sup>79</sup>, Kate Sinclair<sup>80</sup>, Scott St. George<sup>81</sup>, Jeannine-Marie St. Jacques<sup>82,83</sup>, Meloth Thamban<sup>84</sup>, Udyia Kuwar Thapa<sup>81</sup>, Elizabeth R. Thomas<sup>63</sup>, Chris Turney<sup>85</sup>, Ryu Uemura<sup>86</sup>, Andre E. Viau<sup>48</sup>, Diana O. Vladimirova<sup>40,41</sup>, Eugene R. Wahl<sup>87</sup>, James W.C. White<sup>88</sup>, Zicheng Yu<sup>89</sup> & Jens Zinke<sup>90,91,92</sup>

<sup>1</sup>Department of Earth Sciences and Center for Applied Mathematical Sciences, University of Southern California, Los Angeles, CA 90089, USA. <sup>2</sup>School of Earth Sciences and Environmental Sustainability, Northern Arizona University, Flagstaff, AZ 86001, USA. <sup>3</sup>PAGES International Project Office, Bern 3012, Switzerland. <sup>4</sup>The Mathworks Inc., Natick, MA 01760, USA. <sup>5</sup>School of Geography and Development and Laboratory of Tree Ring Research, University of Arizona, Tucson, AZ 85721, USA. <sup>6</sup>Research School of Earth Sciences and the ARC Centre of Excellence for Climate System Science, The Australian National University, Canberra, ACT 2601, Australia. <sup>7</sup>U.S. Geological Survey, Menlo Park, CA 94025, USA. <sup>8</sup>Australian Antarctic Division, Kingston, TAS 7050, Australia.



<sup>9</sup>Antarctic Climate and Ecosystems CRC, University of Tasmania, Hobart, TAS 7050, Australia. <sup>10</sup>Department of Geology and Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD 20742, USA. <sup>11</sup>School of Earth Sciences, University of Melbourne, Melbourne, VIC 3010, Australia. <sup>12</sup>The Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China. <sup>13</sup>Department of Environmental Chemistry, Institute of Environmental Assessment and Water Research, Spanish Council for Scientific Research, Barcelona 08034, Spain. <sup>14</sup>Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, UK. <sup>15</sup>School of Earth and Environmental Sciences, University of Wollongong, Wollongong, NSW 2522, Australia. <sup>16</sup>Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern, Bern 3012, Switzerland. <sup>17</sup>U.S. Geological Survey, Northern Rocky Mountain Science Center, Bozeman, MT 59715, USA. <sup>18</sup>Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, Venice 30170, Italy. <sup>19</sup>Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, Austin, Texas 78758, USA. <sup>20</sup>Department for Earth Science and Bjerknes Centre for Climate Research, University of Bergen, Bergen 5020, Norway. <sup>21</sup>Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China. <sup>22</sup>Norwegian Polar Institute, Fram Centre, Tromsø 9296, Norway. <sup>23</sup>Department of Mathematics and Statistics, Faculty of Science and Technology, University of Tromsø—The Arctic University of Norway, Tromsø 9037, Norway. <sup>24</sup>School of Geography, The University of Melbourne, Melbourne, VIC 3010, Australia. <sup>25</sup>School of Earth Sciences and Australian Research Council Centre of Excellence for Climate System Science, University of Melbourne, Melbourne, VIC 3010, Australia. <sup>26</sup>IANIGLA-CONICET and Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Cuyo, Mendoza M5502IRA, Argentina. <sup>27</sup>Research Institute for Humanity and Nature, Kyoto 603-8047, Japan. <sup>28</sup>Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, TAS 7001, Australia. <sup>29</sup>Quaternary Research Center and Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, USA. <sup>30</sup>Department of Geosciences, University of Arizona, Tucson, AZ 85721, USA. <sup>31</sup>Department of Earth Sciences and Sprigg Geobiology Centre, The University of Adelaide, Adelaide, SA 5005, Australia. <sup>32</sup>School of Ecosystem and Forest Sciences, University of Melbourne, Melbourne, VIC 3121, Australia. <sup>33</sup>Joint Antarctic Research Institute, Victoria University of Wellington and GNS Science, Wellington 6012, New Zealand. <sup>34</sup>Swiss Federal Research Institute WSL, Birmensdorf 8903, Switzerland. <sup>35</sup>Centre National de Recherche Scientifique, UMR 5554, Institut des Sciences de l'Evolution-Montpellier, Université Montpellier, Montpellier, cedex 5 34095, France. <sup>36</sup>Institute of Applied Geosciences, National Taiwan Ocean University, Keelung 20224, Taiwan. <sup>37</sup>Lamont-Doherty Earth Observatory, Palisades, NY 10964, USA. <sup>38</sup>Department of Geography and Anthropology, Louisiana State University, Baton Rouge, LA 70803, USA. <sup>39</sup>Climate Change Institute, University of Maine, Orono, ME 04469, USA. <sup>40</sup>Arctic and Antarctic Research Institute, St Petersburg 199397, Russia. <sup>41</sup>Institute of Earth Sciences, St Petersburg State University, St Petersburg 199178, Russia. <sup>42</sup>Department of Geography, Northumbria University, Newcastle upon Tyne NE1 8ST, UK. <sup>43</sup>Department of Geology, Lund University, Lund SE-223 62, Sweden. <sup>44</sup>Institut National de la Recherche Scientifique, Centre Eau Terre Environnement, Québec, QC G1K 9A9, Canada. <sup>45</sup>ENEA, CR Casaccia, Rome 00123, Italy. <sup>46</sup>Faculty of Science, Nepal Academy of Science and Technology, Lalitpur, Nepal. <sup>47</sup>Central Department of Environmental Science, Tribhuvan University, Kathmandu, Nepal. <sup>48</sup>Department of Geography, Environment and Geomatics, University of Ottawa, Ottawa, ON K1N 6N5, Canada. <sup>49</sup>Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve 1348, Belgium. <sup>50</sup>Institute of Geophysics of the Urals Branch of RAS, Yekaterinburg, Russian Federation. <sup>51</sup>Graduate School of Science and Technology, Hirosaki University, Aomori 036-8561, Japan. <sup>52</sup>Department of Earth Sciences, The Faculty of Science, University of Gothenburg, Göteborg SE-405 30, Sweden. <sup>53</sup>State Key Laboratory of Marine Environmental Science and Department of Geological Oceanography, Xiamen University, Xiamen 361102, China. <sup>54</sup>National Institute of Polar Research and Department of Polar Science, Tachikawa, Tokyo 190-8518, Japan. <sup>55</sup>Institute of Biogeosciences, Japan Agency for Marine-Earth Science and Technology, Yokosuka 237-0061, Japan. <sup>56</sup>University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, Maryland 20688, USA. <sup>57</sup>Aix Marseille Université, CNRS, IRD, CEREGE UM34, Aix-en-Provence, Cedex 4 13545, France. <sup>58</sup>Department of Earth Sciences, University of Gothenburg, Göteborg SE-405 30, Sweden. <sup>59</sup>National Institute of Water and Atmospheric Research, Auckland Central 1010, New Zealand. <sup>60</sup>Institute of Geography, Russian Academy of Sciences, Moscow 119017, Russia. <sup>61</sup>Institute of Environmental Science and Technology, and Department of Geography, Universitat Autònoma de Barcelona, Bellaterra 08193, Spain. <sup>62</sup>National Institute of Polar Research, Research Organization of Information and Systems, Midoricho 10-3, Tachikawa, Tokyo, Japan. <sup>63</sup>British Antarctic Survey, Cambridge CB3 0ET, UK. <sup>64</sup>Eberhard Karls Universität Tübingen, Tübingen 72074, Germany. <sup>65</sup>School of Environment and Technology, University of Brighton, Brighton BN2 4GJ, UK. <sup>66</sup>School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Wits 2050, South Africa. <sup>67</sup>Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven 27515, Germany. <sup>68</sup>Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Potsdam 14473, Germany. <sup>69</sup>Laboratoire des Sciences du Climat et de l'Environnement, Gif-sur-Yvette 91191, France. <sup>70</sup>Sukachev Institute of Forest of the Siberian Branch of the Russian Academy of the Sciences, Krasnoyarsk 660036, Russia. <sup>71</sup>Department of Geography, University of Toronto, Mississauga, ON L5L 1C6, Canada. <sup>72</sup>Department of Geology, University of Buffalo, NY 14260, USA. <sup>73</sup>Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, WA 98105, USA. <sup>74</sup>Australian Nuclear Science and

Technology Organisation, Lucas Heights, NSW 2234, Australia. <sup>75</sup>Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern, Bern 3012, Switzerland. <sup>76</sup>Centre for Past Climate Studies, and Arctic Research Centre, Department of Geoscience, Aarhus University, Aarhus C DK-8000, Denmark. <sup>77</sup>Chemistry Department, University of Florence, Sesto Fiorentino, Italy. <sup>78</sup>LOCEAN, Sorbonne Universités, Case 100, Paris F-75005, France. <sup>79</sup>Laboratory of Environmental Chemistry, Paul Scherrer Institut, Villigen, PSI Ost 5232, Switzerland. <sup>80</sup>Applied Aquatic Research Ltd., Calgary, AB T3C 0K3, Canada. <sup>81</sup>Department of Geography, Environment and Society, University of Minnesota, Minneapolis, MN 55455, USA. <sup>82</sup>Prairie Adaptation Research Collaborative, University of Regina, Regina, SK S4S 0A2, Canada. <sup>83</sup>Geography, Planning and Environment, Concordia University, Montreal, QC H3G 1M8, Canada. <sup>84</sup>National Centre for Antarctic and Ocean Research, Goa 403804, India. <sup>85</sup>Climate Change Research Centre, School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia. <sup>86</sup>Department of Chemistry, Biology, and Marine Science, Faculty of Science, University of the Ryukyus, Nishihara, Okinawa 903-0213, Japan. <sup>87</sup>NOAA's National Centers for Environmental Information, World Data Service for Paleoclimatology, Boulder, CO 80305, USA. <sup>88</sup>Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado 80309, USA. <sup>89</sup>Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA 18015, USA. <sup>90</sup>Department of Environment and Agriculture, Bentley, WA 6845, Australia. <sup>91</sup>Australian Institute of Marine Science, Townsville, QLD 4810, Australia. <sup>92</sup>Institute of Geological Sciences, Paleontology, Freie Universität Berlin, Berlin 12249, Germany.