EarthArxiv Preprint

The following unpublished, not yet peer-reviewed manuscript was submitted to the journal Open Quaternary on April 12, 2021.

A simplified palaeoceanography archiving system (PARIS) and GUI for storage and visualisation of marine sediment core proxy data vs age and depth.

Authors:

Bryan C. Lougheed\(^1\), Claire Waelbroeck\(^2\), Nicolas Smialkowski\(^2\), Natalia Vazquez Riveiros\(^4\), Stephen P. Obrochta\(^5\)

1. Department of Earth Sciences, Uppsala University, Uppsala, Sweden.
2. Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, Gif-sur-Yvette, France
3. LOCEAN/IPSL, Sorbonne Université-CNRS-IRD-MNHN, UMR7159, Paris, France.
4. IFREMER, Unité de Géosciences Marines, Plouzané, France
5. Graduate School of International Resource Science, Akita University, Akita, Japan.

Please address correspondence to: bryan.lougheed@geo.uu.se
A simplified palaeoceanography archiving system (PARIS) and GUI for storage and visualisation of marine sediment core proxy data vs age and depth.

Bryan C. Lougheed\textsuperscript{1,2}, Claire Waelbroeck\textsuperscript{3,2}, Nicolas Smialkowski\textsuperscript{2}, Natalia Vazquez Riveiros\textsuperscript{4,2}, Stephen P. Obrochta\textsuperscript{5}

1. Department of Earth Sciences, Uppsala University, Uppsala, Sweden.
2. Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, Gif-sur-Yvette, France
3. LOCEAN/IPSL, Sorbonne Université-CNRS-IRD-MNHN, UMR7159, Paris, France.
4. IFREMER, Unité de Géosciences Marines, Plouzané, France
5. Graduate School of International Resource Science, Akita University, Akita, Japan.

Corresponding author: B.C. Lougheed (bryan.lougheed@geo.uu.se)

Abstract

Scientific discovery can be aided when data is shared following the principles of findability, accessibility, interoperability, reusability (FAIR) data (Wilkinson et al., 2016). Recent discussions in the palaeoclimate literature have focussed on defining the ideal database format for storing data and associated metadata. Here, we highlight an often overlooked primary process in widespread adoption of FAIR data, namely the systematic creation of machine readable data at source (i.e. at the field and laboratory level). We detail a file naming and structuring method that was used at LSCE to store data in text file format in a way that is machine-readable, and also human-friendly to persons of all levels of computer proficiency, thus encouraging the adoption of a machine-readable ethos at the very start of a project. Thanks to the relative simplicity of downcore palaeoclimate data, we demonstrate the power of this simple but powerful file format to function as a basic database in itself: we provide a Matlab-based GUI tool that allows users to search and visualise data by sediment core location, proxy type and species type. The adoption of similarly accessible, machine-readable file formats at other laboratories will promote data sharing within projects, while also allowing for the automation of submission of data to online database repositories with particular formatting and/or metadata requirements, thus reducing post-hoc workload.

1.0 Introduction
A common desire for Earth Science laboratories in the computer age is the digital storage and archiving of datasets in searchable databases. Furthermore, a growing number of funding agencies and publication venues are mandating that datasets are deposited in an open repository, so that other researchers may have access to the data. The ‘big data’ benefits of such a system for palaeoceanography are clear; data from multiple locations and periods of the Earth’s history can be searched, sorted and presented according to, for example, proxy and/or species type. Such an approach would save significant person hours currently spent by researchers worldwide in searching for, downloading, understanding and digitising datasets, thus allowing for much more efficient analysis of data. The principles guiding this process are the principles of findability, accessibility, interoperability, reusability (FAIR) (Wilkinson et al., 2016).

Much of the discussion involving the establishment of standardised digitised data has revolved around defining an ideal database format and/or repository for the storage of data (Bolliet et al., 2016; Jonkers et al., 2020; Khider et al., 2019; McKay and Emile-Geay, 2016), which is indeed a key prerequisite for the ultimate end goal whereby all data is stored on a common, publicly searchable/queryable online database in line with the goals of FAIR data. However, an often overlooked primary step in the realisation of such an end goal is ensuring that palaeoclimatic data produced within a laboratory and/or research group is stored in some kind of machine readable format in the first place, i.e. during the creation step. Current practices at many laboratories involve multiple actors and researchers of various levels of computer proficiency saving their data using idiosyncratic and machine-unreadable file formats. These practices lead to increased workload both during the project and also at the end of the project when submitting data to online repositories (i.e. due to laborious post-hoc data formatting and manual metadata entry at the time of submission). If a given laboratory instead uses an internally consistent and machine readable format for saving data, post-hoc conversion to various database formats and/or uploading to a repository can essentially become an automated process. Therefore, we argue that the ideal database format should be a secondary consideration. A primary consideration should be to take concrete steps to promote and ensure early adoption and awareness of the machine readable ethos within a project and/or laboratory (i.e. upon the creation of the data), by creating a machine readable format that works for the laboratory in question.

Given the aforementioned issues, we determined that the ideal data file format for use within a research group should meet the following four criteria:
(1) it must be machine-readable across many operating system platforms, thus allowing for automated reading of data, as well as bulk conversion/uploading to common database formats;

(2) it must be human-friendly, thus allowing the human eye to quickly access and understand the data contained within the file if needed; not all project participants have sufficient proficiency with higher level storage formats such as SQL, NetCDF and/or JSON.

(3) the file creation process must be as accessible as possible and cause as little burden as possible for laboratory members of all levels of computer proficiency, thus encouraging the seamless and autonomous creation of machine-readable data formats from the very beginning of the project workflow (e.g., in the field or at the time of laboratory analysis.)

Here, we present a file naming and file structure format that is both human-friendly and machine-friendly. The Palaeoceanography ARchivIng System (PARIS) was developed as a spin-off from the ERC ACCLIMATE project at Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Gif-sur-Yvette. It is optimised for human-accessibility from the very beginning of a project (in this case, the stable isotope laboratory environment). Files stored in such a machine-readable file structure can subsequently easily be automatically batch-converted to the specific format requirements of a particular data repository, thus avoiding repeated manual metadata entry upon repository submission. We also demonstrate the machine-readable power of this simple file format as a basis for a simplified database structure to use within a laboratory: we have built a fully documented, GUI environment for interactive searching and plotting of data using our simple file format. This environment allows for the rapid searching and visual presentation of data by, latitude, longitude, water depth, age and, where applicable, species type. The entire setup was designed with modular expansion in mind, and both the file formatting conventions and GUI environment can be used and/or modified by other laboratories for their own particular needs. The structure of archiving system is shown in Figure 1 and described in the following sections.

2.0 File structure and organisation

2.1 File naming conventions
We use a file storage system based on universally readable, tab-delimited ASCII text files, which are more than sufficient for palaeoclimate datasets from sediment cores, seeing as such sediment cores contain discrete-depth measurements numbering only in the hundreds or thousands. Such files can easily be created directly from analytical software or by using basic spreadsheet software. A uniform file naming convention is used to create machine readable identifiers containing information about the data contained within the file: core name, data type (six character code) and measured material (e.g., foraminifera species). Select examples are shown in Table 1. The underscore character in the file name functions as a marker to distinguish various descriptive properties of the file, thus facilitating machine readability and automated searching of file names. As such, core names may not contain an underscore. The full species names associated with species abbreviations can be found in the file _abbreviations.txt.

2.2 Internal file structures

2.2.1 Raw data files

A common challenge preventing long-term data sharing in palaeoceanography is the publication of isotope data exclusively vs age, which prevents re-evaluation of the data by future researchers as understanding of geochronological methods improves and evolves. For these reasons, all isotope and other palaeoclimate proxy data in the PARIS scheme are stored against core depth as the primary format, allowing for the later application of new geochronologies, and/or comparison of proxy data vs multiple geochronologies. A further ambiguity commonplace in palaeoceanography is reporting only a single core depth value corresponding to a particular data point (for example, often only a single core depth value is given, even though subsamples represent a depth interval). To avoid such ambiguity, each data point stored using the PARIS scheme has two depth values (depth1 and depth2) which correspond to the top and bottom of a particular core interval ("depth slice"). Within the PARIS scheme, it is also possible to include NaN for depth2. In such a case, depth2 will simply be assumed to be 1 cm greater than depth1 (i.e. depth1 represents the depth value corresponding to the top of a depth interval with a thickness of 1 cm).

The tab-delimited ASCII text format is used to structure data in column/row format, whereby data such depth, measurement value and measurement uncertainty are stored in specified column numbers. When there is no data available for a particular sample (e.g. $\delta^{18}$O value but no accompanying $\delta^{13}$C value) a NaN is entered as a placeholder for the missing value, thus
ensuring structural integrity and machine-readability of the file. The formatting used for each
type of proxy is detailed in the user manual included with the GUI software. All raw data
files are stored within the "raw data" folder. Here, we supply a number of example files of
previously published Atlantic Ocean sediment core stable isotope data (Table 2) that were
collated by Waelbroeck et al. (2019).

2.2.2 Age-depth model files

Within the PARIS system, separate age-depth model files are used to assign age and age
uncertainty to the raw data that is stored against depth. Age-depth model files
(corename_admodel.txt) are contained in a folder called "master" within the "age models"
folder. The reason for this additional subdirectory level is to allow different age model
scenarios to be stored, which can subsequently be accessed from the GUI. For example, one
might wish to store and compare different age-depth models based on different methods (14C,
U/Th, etc) for the same set of sediment cores. Similarly, one may want to compare age-depth
models developed by different software packages (Blaauw and Christen, 2011; Bronk
Ramsey, 1995; Haslett and Parnell, 2008; Lougheed and Obrochta, 2019). In that case, an
additional folder can be made within the "age models" folder, and its contents will be
accessible from the GUI. Age-depth model files use the the "Undatable" (Lougheed and
Obrochta, 2019) output file format by default, but users can adjust to use the file format of a
different age-depth modelling software, or indeed any type of age-depth model file, by
editing the required admodelformat.m formatting file contained within the subdirectory
within the "age models" folder. Here, to demonstrate the PARIS system we supply a number
of age-depth model files produced for Atlantic Ocean sediment cores by Waelbroeck et al.
(2019).

2.2.3 Core information index file

All raw data files and age-depth model files contain a unique code detailing the sediment core
that they come from. An additional file (_core information.txt) is present within the main
folder of PARIS, which details some basic meta-data for each core, namely location (latitude
and longitude) and water depth (mbsl). This allows the PARIS system to subsequently search
for sediment core locations that match a specific search criteria (e.g. a certain water depth or
latitude/longitude bounding box) and search for all raw data and age-depth models associated
with sediment cores that correspond to the search criteria.
2.2.4 Reference records and bathymetry

Laboratories may also wish to store climate reference records for display within the GUI or for easy access. For this reason, we include some climate reference records that can be viewed within the GUI. These include the Greenland ice-sheet $\delta^{18}$O and Ca$^{2+}$ records (Andersen et al., 2006; Rasmussen et al., 2006; Seierstad et al., 2014), temperature derived from the Greenland isotop temperature record (Kindler et al., 2014), atmosphereic CO$_2$ derived from the Antarctic ice core record (Lüthi et al., 2008). We also include a downscaled version of the GEBCO bathymetry (General Bathymetric Chart of the Oceans, 2015), that is used within the PARIS GUI to provide a simple map showing core locations superimposed upon bathymetry.

3.0 GUI search interface

To demonstrate the power of the text file based archiving system, and in order to provide a system with which laboratory members at LSCE could browse and visualise sediment core data, a GUI system was developed in Matlab (Fig. 2). This system allows the user to search for sediment core locations according to certain criteria, and specify which types of data to plot, which are shown on to three vertically distributed separated panels (Fig. 3). Data from multiple sediment cores and/or species can be plotted on to one of the first two panels, in order to facilitate inter-core comparison. Data can be plotted against depth or against age (from one of the supplied age-depth models), and the user can choose to plot with our without error bars. The third panel is reserved for plotting reference data and or sediment accumulation rate (SAR) plots. The software automatically assigns a unique colour code to each sediment core, and unique symbol and line type to each type of data and/or species. Legends are also shown for ease of user interpretation. Finally, every time a plot is generated, a publication quality PDF of the plotted panels is generated within the main PARIS folder, saved under a name specified by the user.

4.0 Database inter-compatibility potential

Once all data from a given laboratory is stored using a common format, the process of submission to a given database or repository (i.e. changing the format to suit a particular repository) can be fully automated. One needs only to write a one-off batch script that can convert all files from the laboratory to the required format of the various repositories. Here, we provide an example of a similar such script (dataonage.m) that was used within the LSCE
laboratory to systematically read in all isotope data vs depth and output all isotope data vs age according to their respective age-depth models. Hence, systematically updating the age values for data submitted to repositories becomes a simple and rapid task.

5.0 Conclusion

The palaeoclimate literature has begun to embrace the principles of FAIR data and many good examples of useful database structures have been previously provided (Bolliet et al., 2016; Jonkers et al., 2020; Khider et al., 2019; McKay and Emile-Geay, 2016). We have provided an example of a concrete first step in the journey towards FAIR data, the creation of machine-readable data at the field and laboratory level. The involvement of multiple actors within a project requires that a machine readable format is fully accessible to persons with only basic computer proficiency. The simple PARIS file naming and structuring system, based on the ubiquitously accessible tabbed-text file format is one such example, and has been successfully deployed at LSCE. The simple structure is nonetheless powerful in that data can easily be indexed and searched, as demonstrated here. Such an approach can encourage a laboratory to adhere to the FAIR data principles from the very outset of a project, thus saving much time and resources that would often be spent on post-hoc data conversion.

Database and GUI availability

The database and GUI system can be downloaded from Zenodo:

https://doi.org/10.5281/zenodo.4680717

Acknowledgements

This is a contribution to the ACCLIMATE ERC project; the research leading to these results has received funding from the European Research Council under the European Union’s Seventh Framework Program (FP7/2007-2013 Grant agreement n° 339108). B.C. Lougheed acknowledges Swedish Reserch Council (Vetenskapsrådet) grants 637-2014-499 and 2018-04992.

References

Andersen, K.K., Svensson, A., Johnsen, S.J., Rasmussen, S.O., Bigler, M., Röthlisberger, R., Ruth, U., Siggaard-Andersen, M.-L., Peder Steffensen, J., Dahl-Jensen, D., Vinther, B.M., Clausen, H.B., 2006. The Greenland Ice Core Chronology 2005, 15–42ka. Part 1: constructing the time scale. Quaternary Science Reviews, Critical Quaternary Stratigraphy 25, 3246–3257. https://doi.org/10.1016/j.quascirev.2006.08.002
Arz, H.W., Pätzold, J., Wefer, G., 1999. The deglacial history of the western tropical Atlantic as inferred from high resolution stable isotope records off northeastern Brazil. Earth and Planetary Science Letters 167, 105–117. https://doi.org/10.1016/S0012-821X(99)00025-4

Bard, E., Arnold, M., Maurice, P., Duprat, J., Moyes, J., Duplessy, J.-C., 1987. Retreat velocity of the North Atlantic polar front during the last deglaciation determined by 14 C accelerator mass spectrometry. Nature 328, 791–794. https://doi.org/10.1038/328791a0

Blaauw, M., Christen, J.A., 2011. Flexible Paleoclimate Age-Depth Models Using an Autoregressive Gamma Process. Bayesian Analysis 6, 457–474. https://doi.org/10.1214/11-BA618

Bolliet, T., Brockmann, P., Masson-Delmotte, V., Bassinot, F., Daux, V., Genty, D., Landais, A., Lavrieux, M., Michel, E., Ortega, P., Risi, C., Roche, D.M., Vimeux, F., Waelbroeck, C., 2016. Water and carbon stable isotope records from natural archives: a new database and interactive online platform for data browsing, visualizing and downloading. Climate of the Past 12, 1693–1719. https://doi.org/10.5194/cp-12-1693-2016

Bronk Ramsey, C., 1995. Radiocarbon calibration and analysis of stratigraphy; the OxCal program. Radiocarbon 37, 425–430.

Came, R.E., Oppo, D.W., Curry, W.B., Lynch-Stieglitz, J., 2008. Deglacial variability in the surface return flow of the Atlantic meridional overturning circulation. Paleoceanography 23. https://doi.org/10.1029/2007PA001450

Curry, W.B., Oppo, D.W., 1997. Synchronous, high-frequency oscillations in tropical sea surface temperatures and North Atlantic Deep Water production during the Last Glacial Cycle. Paleoceanography 12, 1–14. https://doi.org/10.1029/96PA02413

Dickson, A.J., Beer, C.J., Dempsey, C., Maslin, M.A., Bendle, J.A., McClymont, E.L., Pancost, R.D., 2009. Oceanic forcing of the Marine Isotope Stage 11 interglacial. Nature Geoscience 2, 428–433. https://doi.org/10.1038/ngeo527

Dokken, T.M., Jansen, E., 1999. Rapid changes in the mechanism of ocean convection during the last glacial period. Nature 401, 458–461. https://doi.org/10.1038/46753

Dokken, T.M., Nisancioglu, K.H., Li, C., Battisti, D.S., Kissel, C., 2013. Dansgaard-Oeschger cycles: Interactions between ocean and sea ice intrinsic to the Nordic seas. Paleoceanography 28, 491–502. https://doi.org/10.1002/palo.20042

Dyez, K.A., Zahn, R., Hall, I.R., 2014. Multicentennial Agulhas leakage variability and links to North Atlantic climate during the past 80,000 years. Paleoceanography 29, 1238–1248. https://doi.org/10.1002/2014PA002698

Eynaud, F., Abreu, L. de, Voelker, A., Schönfeld, J., Salgueiro, E., Turon, J.-L., Penaud, A., Toucanne, S., Naughton, F., Goñi, M.F.S., Malaizé, B., Cacho, I., 2009. Position of the Polar Front along the western Iberian margin during key cold episodes of the last 45 ka. Geochemo, Geophysics, Geosystems 10. https://doi.org/10.1029/2009GC002398

Freudenthal, T., Meggers, H., Henderiks, J., Kuhlmann, H., Moreno, A., Wefer, G., 2002. Upwelling intensity and filament activity off Morocco during the last 250,000 years. Deep Sea Research Part II: Topical Studies in Oceanography, CANIGO I 49, 3655–3674. https://doi.org/10.1016/S0967-0645(02)00101-7

General Bathymetric Chart of the Oceans, 2015. GECBO_2014 Grid, version 20150318. www.gebco.net.

Haslett, J., Parnell, A., 2008. A simple monotone process with application to radiocarbon-dated depth chronologies. Journal of the Royal Statistical Society: Series C (Applied Statistics) 57, 399–418. https://doi.org/10.1111/j.1467-9876.2008.00623.x

Holzwarth, U., Meggers, H., Esper, O., Kuhlmann, H., Freudenthal, T., Hensen, C., Zonneveld, K.A.F., 2010. NW African climate variations during the last 47,000 years: Evidence from organic-walled dinoflagellate cysts. Palaeogeography, Palaeoclimatology, Palaeoecology 291, 443–455. https://doi.org/10.1016/j.palaeo.2010.03.013
Hoogakker, B.A.A., McCave, I.N., Vautravers, M.J., 2007. Antarctic link to deep flow speed variation during Marine Isotope Stage 3 in the western North Atlantic. Earth and Planetary Science Letters 257, 463–473. https://doi.org/10.1016/j.epsl.2007.03.003

Hüls, M., 1999. Stable isotope analysis on sediment core M35003-4. PANGAEA. https://doi.org/10.1594/PANGAEA.55754

Jonkers, L., Cartapanis, O., Langner, M., McKay, N., Mulitza, S., Strack, A., Kucera, M., 2020. Integrating palaeoclimate time series with rich metadata for uncertainty modelling: strategy and documentation of the PalMod 130k marine palaeoclimate data synthesis. Earth System Science Data 12, 1053–1081. https://doi.org/10.5194/essd-12-1053-2020

Jullien, E., Grousset, F., Malaizé, B., Duprat, J., Sanchez-Goni, M.F., Eynaud, F., Charlier, K., Schneider, R., Bory, A., Bout, V., Flores, J.A., 2007. Low-latitude “dusty events” vs. high-latitude “icy Heinrich events.” Quaternary Research 68, 379–386. https://doi.org/10.1016/j.yqres.2007.07.007

Jung, S.J., 1996. Wassermassenaustausch zwischen NE-Atlantik und Nordmeer während der letzten 300.000/80.000 Jahre im Abbild stabiler O- und C-Isotope (Ph.D. thesis). Christian-Albrechts-Universität Kiel.

Jung, S.J.A., 2004. Stable isotope analysis of foraminifera from sediment core SO82_5-2. PANGAEA. https://doi.org/10.1594/PANGAEA.201812

Keigwin, L.D., Jones, G.A., Lehman, S.J., Boyle, E.A., 1991. Deglacial meltwater discharge, North Atlantic Deep Circulation, and abrupt climate change. Journal of Geophysical Research: Oceans 96, 16811–16826. https://doi.org/10.1029/91JC01624

Keigwin, L.D., Swift, S.A., 2017. Carbon isotope evidence for a northern source of deep water in the glacial western North Atlantic. PNAS. https://doi.org/10.1073/pnas.1614693114

Khider, D., Emile-Geay, J., McKay, N.P., Gil, Y., Garjio, D., Ratanakar, V., Alonso-Garcia, M., Bertrand, S., Bothe, O., Brewer, P., Bunn, A., Chevalier, M., Comas-Bru, L., Csank, A., Dassié, E., DeLong, K., Felis, T., Francus, P., Frappier, A., Gray, W., Goring, S., Jonkers, L., Kahle, M., Kaufman, D., Kehrwald, N.M., Martrat, B., McGregor, H., Richey, J., Schmittner, A., Scroxton, N., Sutherland, E., Thirumalai, K., Allen, K., Arnaud, F., Axford, Y., Barrows, T., Bazin, L., Birch, S.E.P., Bradley, E., Bregy, J., Capron, E., Cartapanis, O., Chiang, H.-W., Cobb, K.M., Debret, M., Dommann, R., Du, J., Dyez, K., Emerick, S., Erb, M.P., Falster, G., Finsinger, W., Fortier, D., Gauthier, N., George, S., Grimm, E., Hertzberg, J., Hibbert, F., Hillman, A., Hobbs, W., Huber, M., Hughes, A.L.C., Jaccard, S., Ruan, J., Kienast, M., Konecky, B., Roux, G.L., Lyubchich, V., Novello, V.F., Olaka, L., Partin, J.W., Pearce, C., Phipps, S.J., Pignol, C., Piotrowska, N., Poli, M.-S., Prokopenko, A., Schwanck, F., Stepanek, C., Swann, G.E.A., Telford, R., Thomas, E., Thomas, Z., Truebe, S., Gunten, L. von, Waite, A., Weitzel, N., Wilhem, B., Williams, J., Williams, J.J., Winsstrup, M., Zhao, N., Zhou, Y., 2019. PaCTS 1.0: A Crowdsourced Reporting Standard for Paleoclimate Data. Paleoeceanography and Paleoclimatology 34, 1570–1596. https://doi.org/10.1029/2019PA003632

Kindler, P., Guillevic, M., Baumgartner, M., Schwander, J., Landais, A., Leuenberger, M., 2014. Temperature reconstruction from 10 to 120 kyr b2k from the NGRIP ice core. Clim. Past 10, 887–902. https://doi.org/10.5194/cp-10-887-2014

Labeyrie, L., Leclaire, H., Waelbroeck, C., Cortijo, E., Jean-Claude, D., Vidal, L., Elliot, M., Le Coat, B., Auffret, G., 1999. Temporal variability of the surface and deep waters of the North West Atlantic Ocean at orbital and millennial scales. GEOPHYSICAL MONOGRAPH-AMERICAN GEOPHYSICAL UNION 112, 77–98.

Lougheed, B.C., Obrochta, S.P., 2019. A rapid, deterministic age-depth modelling routine for geological sequences with inherent depth uncertainty. Paleoeceanography and Paleoclimatology 34, 122–133. https://doi.org/10.1029/2018PA003457

Lüthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola, J.-M., Siegenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura, K., Stocker, T.F., 2008. High-resolution carbon dioxide concentration...
record 650,000–800,000 years before present. Nature 453, 379–382. https://doi.org/10.1038/nature06949

Lynch-Stieglitz, J., Schmidt, M.W., Curry, W.B., 2011. Evidence from the Florida Straits for Younger Dryas ocean circulation changes. Paleoceanography 26. https://doi.org/10.1029/2010PA002032

McKay, N.P., Emile-Geay, J., 2016. Technical note: The Linked Paleo Data framework – a common tongue for paleoclimatology. Climate of the Past 12, 1093–1100. https://doi.org/10.5194/cp-12-1093-2016

Mulitza, S., Prange, M., Stuut, J.-B., Zabel, M., Dobeneck, T. von, Itambi, A.C., Nizou, J., Schulz, M., Wefer, G., 2008. Sahel megadroughts triggered by glacial slowdowns of Atlantic meridional overturning. Paleoceanography 23. https://doi.org/10.1029/2008PA001637

Ninnemann, U.S., Charles, C.D., Hodell, D.A., 1999. Origin of global millennial scale climate events: Constraints from the Southern Ocean deep sea sedimentary record. Geophysical Monograph-American Geophysical Union 112, 99–112.

Oppo, D.W., Horowitz, M., 2000. Glacial deep water geometry: South Atlantic benthic foraminiferal Cd/Ca and δ13C evidence. Paleoceanography 15, 147–160. https://doi.org/10.1029/1999PA000436

Oppo, D.W., Lehman, S.J., 1995. Suborbital timescale variability of North Atlantic Deep Water during the past 200,000 years. Paleoceanography 10, 901–910. https://doi.org/10.1029/95PA02089

Pastouret, L., Chamley, H., Delibrias, G., Duplessy, J.C., Thiede, J., 1978. Late Quaternary climatic changes in western tropical Africa deduced from deep-sea sedimentation off the Niger delta. Oceanologica Acta 1, 217–232.

Peck, V.L., Hall, I.R., Zahn, R., Scourse, J.D., 2007. Progressive reduction in NE Atlantic intermediate water ventilation prior to Heinrich events: Response to NW European ice sheet instabilities? Geochemistry, Geophysics, Geosystems 8. https://doi.org/10.1029/2006GC001321

Peterson, L.C., Haug, G.H., Murray, R.W., Yarincik, K.M., King, J.W., Bralower, T.J., Kameo, K., Rutherford, S.D., Pearce, R.B., 2000. Late Quaternary stratigraphy and sedimentation at site 1002, Cariaco Basin (Venezuela), in: Proc. Ocean Drill. Program Sci. Results. Ocean Drilling Program College Station, TX, pp. 85–99.

Portilho-Ramos, R.C., Cruz, A.P.S., Barbosa, C.F., Rathburn, A.E., Mulitza, S., Venancio, I.M., Schwenk, T., Rühlemann, C., Vidal, L., Chiessi, C.M., Silveira, C.S., 2018. Methane release from the southern Brazil margin during the last glacial. Scientific Reports 8, 5948. https://doi.org/10.1038/s41598-018-24420-0

Rasmussen, S.O., Andersen, K.K., Svensson, A.M., Steffensen, J.P., Vinther, B.M., Clausen, H.B., Siggaard-Andersen, M.-L., Johnsen, S.J., Larsen, L.B., Dahl-Jensen, D., Bigler, M., Röthlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M.E., Ruth, U., 2006. A new Greenland ice core chronology for the last glacial termination. Journal of Geophysical Research: Atmospheres 111. https://doi.org/10.1029/2005JD006079

Rasmussen, T.L., Thomsen, E., Weering, T.C.E.V., 1998. Cyclic sedimentation on the Faeroe Drift 53-10 ka BP related to climatic variations. Geological Society, London, Special Publications 129, 255–267. https://doi.org/10.1144/GSL.SP.1998.129.01.16

Rasmussen, T.L., Thomsen, E., Weering, T.C.E. van, Labeyrie, L., 1996. Rapid changes in surface and deep water conditions at the Faeroe Margin during the last 58,000 years. Paleoceanography 11, 757–771. https://doi.org/10.1029/96PA02618

Raymo, M.E., Oppo, D.W., Flower, B.P., Hodell, D.A., McManus, J.F., Venz, K.A., Kleiven, K.F., McIntyre, K., 2004. Stability of North Atlantic water masses in face of pronounced climate variability during the Pleistocene. Paleoceanography 19. https://doi.org/10.1029/2003PA000921
Röhrlemann, C., Mulitza, S., Lohmann, G., Paul, A., Prange, M., Wefer, G., 2004. Intermediate depth warming in the tropical Atlantic related to weakened thermohaline circulation: Combining paleoclimate data and modeling results for the last deglaciation. Paleoceanography 19. https://doi.org/10.1029/2003PA000948

Santos, T.P., Lessa, D.O., Venancio, I.M., Chiessi, C.M., Mulitza, S., Kuhnert, H., Govin, A., Machado, T., Costa, K.B., Toledo, F., Dias, B.B., Albuquerque, A.L.S., 2017. Prolonged warming of the Brazil Current precedes deglaciations. Earth and Planetary Science Letters 463, 1–12. https://doi.org/10.1016/j.epsl.2017.01.014

Sarnthein, M., Winn, K., Jung, S.J.A., Duplessy, J.-C., Labeyrie, L., Erlenkeuser, H., Ganssen, G., 1994. Changes in East Atlantic Deepwater Circulation over the last 30,000 years: Eight time slice reconstructions. Paleoceanography 9, 209–267. https://doi.org/10.1029/93PA03301

Shackleton, N.J., Hall, M.A., Vincent, E., 2000. Phase relationships between millennial-scale events 64,000–24,000 years ago. Paleoceanography 15, 565–569.

Skinner, L.C., Shackleton, N.J., 2004. Rapid transient changes in northeast Atlantic deep water ventilation age across Termination I. Paleoceanography 19. https://doi.org/10.1029/2003PA000983

Slowey, N.C., Curry, W.B., 1995. Glacial-interglacial differences in circulation and carbon cycling within the upper western North Atlantic. Paleoceanography 10, 715–732. https://doi.org/10.1029/95PA1166

Tjallingii, R., Claussen, M., Stuut, J.-B.W., Fohlenmeister, J., Jahn, A., Bickert, T., Lamy, F., Röhl, U., 2008. Coherent high- and low-latitude control of the northwest African hydrological balance. Nature Geoscience 1, 670–675. https://doi.org/10.1038/ngeo289

Vidal, L., Labeyrie, L., Cortijo, E., Arnold, M., Duplessy, J.C., Michel, E., Becquè, S., van Weering, T.C.E., 1997. Evidence for changes in the North Atlantic Deep Water linked to meltwater
surges during the Heinrich events. Earth and Planetary Science Letters 146, 13–27. https://doi.org/10.1016/S0012-821X(96)00192-6

Vidal, L., Schneider, R.R., Marchal, O., Bickert, T., Stocker, T.F., Wefer, G., 1999. Link between the North and South Atlantic during the Heinrich events of the last glacial period. Climate Dynamics 15, 909–919. https://doi.org/10.1007/s003820050321

Voelker, A.H.L., Abreu, L. de, 2011. A Review of Abrupt Climate Change Events in the Northeastern Atlantic Ocean (Iberian Margin): Latitudinal, Longitudinal, and Vertical Gradients, in: Abrupt Climate Change: Mechanisms, Patterns, and Impacts. American Geophysical Union (AGU), pp. 15–37. https://doi.org/10.1029/2010GM001021

Voigt, I., Cruz, A.P.S., Mulitza, S., Chiesi, C.M., Mackensen, A., Lippold, J., Antz, B., Zabel, M., Zhang, Y., Barbosa, C.F., Tisserand, A.A., 2017. Variability in mid-depth ventilation of the western Atlantic Ocean during the last deglaciation. Paleoceanography 32, 948–965. https://doi.org/10.1002/2017PA003095

Waelbroeck, C., Lougheed, B.C., Vazquez Riveiros, N., Missiaen, L., Pedro, J., Dokken, T., Hajdas, I., Wacker, L., Abbott, P., Dumoulin, J.-P., Thil, F., Eynaud, F., Rossignol, L., Fersi, W., Albuquerque, A.L., Arz, H., Austin, W.E.N., Came, R., Carlson, A.E., Collins, J.A., Dennielou, B., Desprat, S., Dickson, A., Elliot, M., Farmer, C., Giraudel, J., Gottschalk, J., Henderiks, J., Hughen, K., Jung, S., Knutz, P., Lebreiro, S., Lund, D.C., Lynch-Stieglitz, J., Malaizé, B., Marchitto, T., Martinez-Méndez, G., Mollenhauer, G., Naughton, F., Nave, S., Nürnberg, D., Oppo, D., Peck, V., Peeters, F.J.C., Penaud, A., Portilho-Ramos, R. da C., Repschläger, J., Roberts, J., Rühlemann, C., Salgueiro, E., Sanchez Goni, M.F., Schönfeld, J., Scussolini, P., Skinner, L.C., Skonieczny, C., Thoronlay, D., Toucanne, S., Roijj, D.V., Vidal, L., Voelker, A.H.L., Wary, M., Weldeab, S., Ziegler, M., 2019. Consistently dated Atlantic sediment cores over the last 40 thousand years. Scientific Data 6, 165. https://doi.org/10.1038/s41597-019-0173-8

Waelbroeck, C., Skinner, L.C., Labeyrie, L., Duplessy, J.-C., Michel, E., Riveiros, N.V., Gherardi, J.-M., Dewilde, F., 2011. The timing of deglacial circulation changes in the Atlantic. Paleoceanography 26. https://doi.org/10.1029/2010PA002007

Weldeab, S., Friedrich, T., Timmermann, A., Schneider, R.R., 2016. Strong middepth warming and weak radiocarbon imprints in the equatorial Atlantic during Heinrich 1 and Younger Dryas. Paleoceanography 31, 1070–1082. https://doi.org/10.1002/2016PA002957

Wilkinson, M.D., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L.B., Bourne, P.E., Bouwman, J., Brooks, A.J., Clark, T., Crosas, M., Dillo, I., Duman, O., Edmunds, S., Evelo, C.T., Finkers, R., Gonzalez-Beltran, A., Gray, A.J.G., Groth, P., Goble, C., Grethe, J.S., Heringa, J., ’t Hoen, P.A.C., Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S.J., Martone, M.E., Mons, A., Packer, A.L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M.A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., Mons, B., 2016. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3. https://doi.org/10.1038/sdata.2016.18

Zahn, R., Schönfeld, J., Kudrass, H.-R., Park, M.-H., Erlenkeuser, H., Groote, P., 1997. Thermohaline instability in the North Atlantic during meltwater events: Stable isotope and ice-rafted detritus records from Core SO75-26KL, Portuguese Margin. Paleoceanography 12, 696–710. https://doi.org/10.1029/97PA00581

Zahn, R., Winn, K., Sarnthein, M., 1986. Benthic foraminiferal δ13C and accumulation rates of organic carbon: Uvigerina Peregrina group and Cibicidoides Wuellerstorfi. Paleoceanography 1, 27–42. https://doi.org/10.1029/PA001i001p00027

Zarriess, M., Mackensen, A., 2011. Testing the impact of seasonal phytodetritus deposition on δ13C of epibenthic foraminifer Cibicidoides wuellerstorfi: A 31,000 year high-resolution record
Figure captions

Figure 1: A flowchart detailing the basic structure of the PARIS simplified database system.

Figure 2: An example of the PARIS GUI interface for visual browsing of the database system.

Figure 3: Example of an output figure from the PARIS GUI interface in the case of stable oxygen and carbon isotopes carried out on *C. wuellerstorfi* (CWU) for two sediment cores CH69-K09 (Labeyrie et al., 1999) & NA87-22 (Vidal et al., 1997). Also shown are Greenland ice core oxygen isotope data (Andersen et al., 2006; Rasmussen et al., 2006; Seierstad et al., 2014). Younger Dryas and Heinrich Stadial intervals are as defined by Waelbroeck et al. (2019).
Table 1. Example of the file naming conventions using in the PARIS system.

| Filename example          | Core   | Data type                                           | Species/material |
|--------------------------|--------|----------------------------------------------------|------------------|
| ODP1234_18O13C_CWU.txt   | ODP1234| Stable isotope raw data vs core depth              | C. wuellerstorfi |
| ODP1234_18O13C_GRU.txt   | ODP1234| Stable isotope raw data vs core depth              | G. ruber         |
| ODP1234_18O13C_MXB.txt   | ODP1234| Stable isotope raw data vs core depth              | Mixed benthics   |
| ODP1234_14CRAW.txt       | ODP1234| Radiocarbon raw ages vs core depth                 |                  |
| ODP1234_TIEPTS.txt       | ODP1234| Age-depth tie-points vs depth, or other non-14C age data vs core depth | Contained in file |
| ODP1234_MAGSUS.txt       | ODP1234| Magnetic susceptibility                             | n/a              |
| ODP1234_admodel.txt      | OPD1234| Age-depth model                                    | n/a              |

Table 2. Stable isotope data from the following sediment cores included in demonstration database.

| Core            | Study                                      |
|-----------------|--------------------------------------------|
| CH22-KW31       | (Pastouret et al., 1978)                   |
| CH69-K09        | (Labeyrie et al., 1999)                    |
| ENAM93-21       | (Rasmussen et al., 1998, 1996)             |
| EW9209-1JPC     | (Curry and Oppo, 1997)                     |
| GEOFAR-KF13     | (Richter, 2001)                            |
| GIK12392-1      | (Zahn et al., 1986)                        |
| GIK15669-1      | (Sarnthein et al., 1994)                   |
| Catalogue   | Reference                      |
|------------|--------------------------------|
| GIK23415-9 | Jung (1996)                    |
| GL1090     | Santos et al. (2017)           |
| GeoB1023-5 | Mulitza et al. (1999)          |
| GeoB1515-1 | Vidal et al. (1999)            |
| GeoB16202-2| Voigt et al. (2017)            |
| GeoB16206-1| Voigt et al. (2017)            |
| GeoB16224-1| Voigt et al. (2017)            |
| GeoB1711   | Vidal et al. (1999)            |
| GeoB1720-2 | Dickson et al. (2009)          |
| GeoB3202-1 | Arz et al. (1999)              |
| GeoB4240-2 | Freudenthal et al. (2002)      |
| GeoB5546-2 | Holzwarth et al. (2010)        |
| GeoB6201-5 | Portilho-Ramos et al. (2018)   |
| GeoB7920-2 | Tjallingii et al. (2008)       |
| GeoB9508-5 | Mulitza et al. (2008)          |
| GeoB9526-5 | Zarriess and Mackensen (2011)  |
| KNR159-5-36GGC | Oppo and Horowitz (2000)   |
| KNR166-2-26JPC | Schmidt and Lynch-Stieglitz (2011) |
| KNR166-2-29JPC | Lynch-Stieglitz et al. (2011) |
| KNR166-2-31JPC | Lynch-Stieglitz et al. (2011) |
| KNR166-2-73GGC | Lynch-Stieglitz et al. (2011) |
| KNR197-10-17GGC | Keigwin and Swift (2017)     |
| KNR31-GPC5 | Keigwin et al. (1991)          |
| Sample ID       | Reference                  |
|----------------|---------------------------|
| M35003-4       | Hüls (1999)               |
| M39008-3       | Eynaud et al. (2009)      |
| MD01-2461      | Peck et al. (2007)        |
| MD02-2575      | Ziegler et al. (2008)     |
| MD02-2588Q     | Ziegler et al. (2008)     |
| MD02-2594      | Dyez et al. (2014)        |
| MD03-2705      | Jullien et al. (2007)     |
| MD03-2707      | Weldeab et al. (2016)     |
| MD07-3076Q     | Waelbroeck et al. (2011)  |
| MD08-3180Q     | Repschläger et al. (2015a, 2015b) |
| MD95-2010      | Dokken and Jansen (1999)  |
| MD95-2039      | Zahn et al. (1997)        |
| MD95-2040      | Voelker and Abreu (2011)  |
| MD95-2041      | Voelker and Abreu (2011)  |
| MD95-2042      | Shackleton et al. (2000)  |
| MD99-2284      | Dokken et al., (2013)     |
| MD99-2334K     | Skinner and Shackleton (2004) |
| NA87-22        | Vidal et al. (1997)       |
| OCE205-2-100GGC| Came et al. (2008)        |
| OCE205-2-103GGC| Slowey and Curry (1995)   |
| ODP1002        | Peterson et al. (2000)    |
| ODP1060        | Hoogakker et al. (2007)   |
| ODP1078C       | Rühlemann et al. (2004)   |
| Sample Code | Reference               |
|------------|-------------------------|
| ODP983     | Raymo et al. (2004)     |
| PS2644-5   | Sarnthein et al., (2001)|
| RAPID-10-1P| Thornalley et al. (2010)|
| RAPID-17-5P| Thornalley et al. (2010)|
| SO82-5-2   | Jung (2004)             |
| SU81-18    | Bard et al. (1987)      |
| TNO57-21   | Ninnemann et al. (1999) |
| V29-202    | Oppo and Lehman (1995)  |
Figure 1.
Figure 2
