

CrocoLakeTools: A Python package to convert ocean observations to the parquet format

Enrico Milanese¹, David Nicholson¹, Gaël Forget², and Susan Wijffels¹

¹ Woods Hole Oceanographic Institution, United States of America ² Massachusetts Institute of Technology, United States of America

DOI: [10.xxxxxx/draft](https://doi.org/10.xxxxxx/draft)

Software

- [Review](#)
- [Repository](#)
- [Archive](#)

Editor: [Open Journals](#)

Reviewers:

- [@openjournals](#)

Submitted: 01 January 1970

Published: unpublished

License

Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#))

Summary

Investigations of the ocean state are possible thanks to the ever growing number of measurements performed with multiple instruments by different research missions. The vast and heterogeneous efforts have brought the community to define data storage conventions (e.g. CF-netCDF) and to assemble collections of datasets (e.g. the World Ocean Database). Yet, accessing these datasets often requires the usage of specialized tools, is generally inefficient over the cloud, and remains a major obstacle to new users in terms of pre-required knowledge and time. CrocoLakeTools is a Python package that addresses those challenges by providing workflows to convert various oceanographic datasets from their original format to a uniform parquet dataset with a shared schema.

Statement of need

CrocoLakeTools is a Python package to build workflows that convert ocean observations from their original formats (e.g. netCDF, CSV) to parquet. CrocoLakeTools takes advantage of Python's well-established and growing ecosystem of open tools: it uses dask's parallel computing capabilities to convert multiple files at once and to handle larger-than-memory data. dask is already well-integrated with xarray and pandas, two widely used Python libraries for the treatment of array and tabular data, respectively, and with pyarrow, the API to the Apache Arrow library which is used to generate the parquet dataset.

Parquet is a data storage format for big tidy data which presents several advantages: it is language agnostic (it can be accessed with Python, Matlab, Julia and web development technologies); it offers faster reading performances than other tabular formats such as CSV; it is optimized for cloud systems storage and operations; it is widespread in the data science community, leading to a multitude of freely accessible tools and educational material.

CrocoLakeTools was developed with the goal of building and serving CrocoLake, a regularly refreshed database of sparse oceanographic observations that are pre-filtered to contain only quality-controlled measurements. CrocoLakeTools was designed to be used by researchers, engineers and data scientists in oceanography and to be accessed by the wider oceanographic community.

State of the field

In-situ measurements of ocean characteristics are collected by a wide range of projects at different scales: from small research groups to international consortia, from time-limited regional explorations to continuous global observation arrays. This has led to a highly heterogeneous landscape of products that often differ for schema (variable names, data types), data format,

39 and access services. As a result, ingesting and analyzing data from different sources, e.g. for
40 research purposes, presents technical and logistical challenges. The need for homogenized
41 ocean data products has then prompted several efforts, in particular when it comes to point-wise
42 observations, which are characterized by discrete measurements that can be generally irregular
43 and sparse in time and space.

44 One of the most comprehensive projects to date is the World Ocean Database (WOD) ([Mishonov
45 et al., 2024](#)), which contains more than 40 variables gathered from several sources (buoys,
46 gliders, floats, bathythermographs, etc.). The earliest record dates back to 1772, the data
47 is quality-controlled, and the database is regularly updated with the latest measurements
48 available. The data is public and freely available through different interfaces ([WODselect](#),
49 THREDDS, HTTPS, FTP) in ASCII, Comma Separated Value (CSV) and netCDF formats.
50 WOD is maintained by the National Centers for Environmental Information (NCEI) of the
51 United States' National Oceanic and Atmospheric Administration (NOAA).

52 Copernicus Marine Service is an initiative of the European Union that provides a wide range
53 of ocean data products: physical, biogeochemical and sea ice data at regional and global
54 scales, obtained from numerical models, in-situ observations and satellite observations. Among
55 Copernicus' products, CORA([Szekely et al., 2019](#)) (Coriolis Ocean database for ReAnalysis)
56 provides quality-controlled in-situ temperature and salinity measurements gathered from several
57 global and regional networks.

58 The International Quality-controlled Ocean Database (IQuOD) ([Team, 2018](#)) is an effort by
59 the oceanographic community “with the goal of producing the highest quality and complete
60 single ocean profile repository along with (intelligent) metadata and assigned uncertainties”. It
61 includes subsurface ocean profiles of several variables, paying particular attention to temperature
62 measurements. The database is prepared by NCEI, and it is freely available in netCDF format
63 through multiple channels (THREDDS, HTTPS, FTP).

64 `argopy` ([Maze & Balem, 2020](#)) is a Python library that facilitates access and manipulation
65 of data from the real-time observing system Argo ([Wong et al., 2020](#)). The user provides
66 some filters (e.g. coordinate and time ranges, measurement name, etc) and `argopy` retrieve the
67 relevant data from the Argo Global Data Assembly Center (GDAC). `ArgoData.jl`([Gael Forget,](#)
68 [2025](#)) and `OceanRobots.jl`([Gaël Forget & Gebbie, 2025](#)) are Julia packages that provide similar
69 functionalities to `argopy`.

70 `Argovis` ([Tucker et al., 2020](#)) is a REST API and web application hosted at the University of
71 Colorado, Boulder (United States) and serving profile data in JSON format from the Argo
72 program, and from ship and drifters missions.

73 `oce`([Kelley et al., 2022](#)) is a package written in R providing multiple functions to access
74 oceanographic observations stored in a variety of formats. It focuses on datasets for physical
75 oceanography with the goal of providing more tools in the future. `argoFloats`([Kelley et al.,](#)
76 [2021](#)) is a derived package that focuses on fetching and manipulating Argo data.

77 The Ocean Data Platform ([Ocean, n.d.](#)) by the non-profit HUB Ocean is among the youngest
78 projects in the community, and it allows to find and access datasets from a catalog. The user
79 can interact with the platform through different interfaces (SDK, REST API, OQS, JupyterHub
80 workspaces), loading the datasets in tabular format.

81 The above efforts often serve data in ASCII, CSV, JSON, or netCDF formats. For context,
82 netCDF is a binary format that offers the advantage to be compact and efficient when dealing
83 with multidimensional data, while the others have the advantage of being human-readable
84 (but can be very inefficient for large datasets). None of these formats is optimized for cloud
85 object storage, although there are ongoing efforts for netCDF (see Zarr and Icechunk). For this
86 reason, Parquet has been drawing more and more attention from the earth sciences community
87 recently.

88 Parquet is a cloud-optimized binary format for tidy and large data (i.e. large tables) that is

language-agnostic. It is widely used in the data science and corporate worlds, and the software ecosystem around it is sound, mature, and growing. An overview of the characteristics of each format is in Table 1. We chose Parquet as the target format for CrocoLake because (1) it is optimized for cloud storage and cloud computing, (2) its mature software ecosystem includes packages in multiple coding languages to access it (Python, Julia, MATLAB, web technologies, etc.), and (3) novel users are generally more familiar with tabular data than to specialized oceanographic data formats.

As we aim to make CrocoLake easily accessible from a technical standpoint, the main drawbacks of Parquet at present are that (1) many workflows in ocean modeling are based on multidimensional data structures (not tabular ones) and (2) attaching attributes to the data is not as straightforward as it could be. However, we see CrocoLake as a major building bloc in workflows that require fast access to sparse in-situ ocean observations, responding to necessities of data storage with fast access both on disk and the cloud, rather than as an end-all solution for ocean observations. For example, workflows that rely mostly on regular and gridded observations (such as satellite recordings), might benefit from storing those observations in some array-based format.

Table 1. Comparison between different common file formats for oceanographic datasets.

Feature Name	CSV	netCDF	Parquet	ASCII	JSON	Zarr + Icechunk
Cloud-Optimized Structure	No Tabular	No Array-based	Yes Tabular	No Tabular	No Hierarchical	Yes Array-based
Available tools in:						
Python	Yes	Yes	Yes	Yes	Yes	Yes
Julia	Yes	Yes	Yes	Yes	Yes	Zarr only
MATLAB	Yes	Yes	Yes	Yes	Yes	Zarr only
Attributes descriptors	Dedicated columns, header	Dictionary, accessed with data	Dictionary, separate access from data	Dedicated column	Dedicated field in object	Dictionary, accessed with data

Another key feature of CrocoLakeTools is that, unlike most aforementioned projects, it is fully open-source. Anyone can thus use CrocoLakeTools to build their own flavor of CrocoLake. We also welcome new contributors to CrocoLakeTools, for example by adding converters to support new datasets.

Code architecture

Converters

The core task of CrocoLakeTools is to take one or more files from a dataset and convert them to parquet, ensuring that CrocoLake's schema is followed. This is achieved through the methods contained in the Converter class and its subclasses. While the conversion of all datasets requires some general functionality (e.g. renaming the original variables to the final schema), each conversion requires specialized tools that differ between datasets (e.g. the map used to rename variables). CrocoLakeTools then contains the Converter class, which contains the methods shared across datasets, and from which converter subclasses inherit and implement the specific needs of each dataset.

Workflow

Local mirrors

The first step in our workflow is to retrieve original files from each data provider (Figure 1). The original source data follow the format, schema, nomenclature, and conventions defined by their side (project, mission, scientist, etc.) independently of CrocoLake's workflow. Modules to download the original data are optional. They are expected to inherit from the Downloader class and be called `downloader<DatasetName>` (e.g. `downloaderArgoGDAC`). At the time of writing CrocoLakeTools is released with a downloader to build a local mirror of the Argo Global Data Assembly Center (GDAC), and we hope to support more data providers in the future. Whether a downloader module exists or the user downloads the data themselves, the original data is stored on disk and this is the starting point for the converter.

Parquet datasets

The second step is to convert the data to parquet, and finally merge the datasets into CrocoLake (Figure 2). The core of CrocoLakeTools are the modules in the Converter class and its subclasses. Each original dataset has its own subclass called `converter<DatasetName>`, e.g. `converterGLODAP`; further specifiers can be added as necessary (e.g. at this time there are a few different converters for Argo data to prepare different datasets). The need for a dedicated converter for each project despite the usage of common data formats (e.g. netCDF, CSV) is due to differences in schema (e.g. variable names or units). Depending on the dataset, multiple converters can be applied. For example, to create CrocoLake, Argo data goes through two converters: 1. `converterArgoGDAC`, which converts the original Argo GDAC preserving most of its original conventions; 2. `converterArgoQC`, which takes the output of the previous step and applies some filtering based on Argo's QC flags and makes the data conforming to CrocoLake's schema.

CrocoLake

CrocoLake is one parquet dataset that contains all converted datasets merged together. This can be achieved with the script `merge_crocoLake.py`. The script first creates a directory containing symbolic links to each converted dataset. It then uses the submodule CrocoLakeLoader to seamlessly load all the converted datasets into memory as one dask dataframe with a uniform schema, merges them into CrocoLake, and stores it back to disk.

CrocoLake can be accessed with several programming languages with just a few lines of codes: the submodules CrocoLake-Python, CrocoLake-Matlab, and CrocoLake-Julia contain tools and examples in some languages.

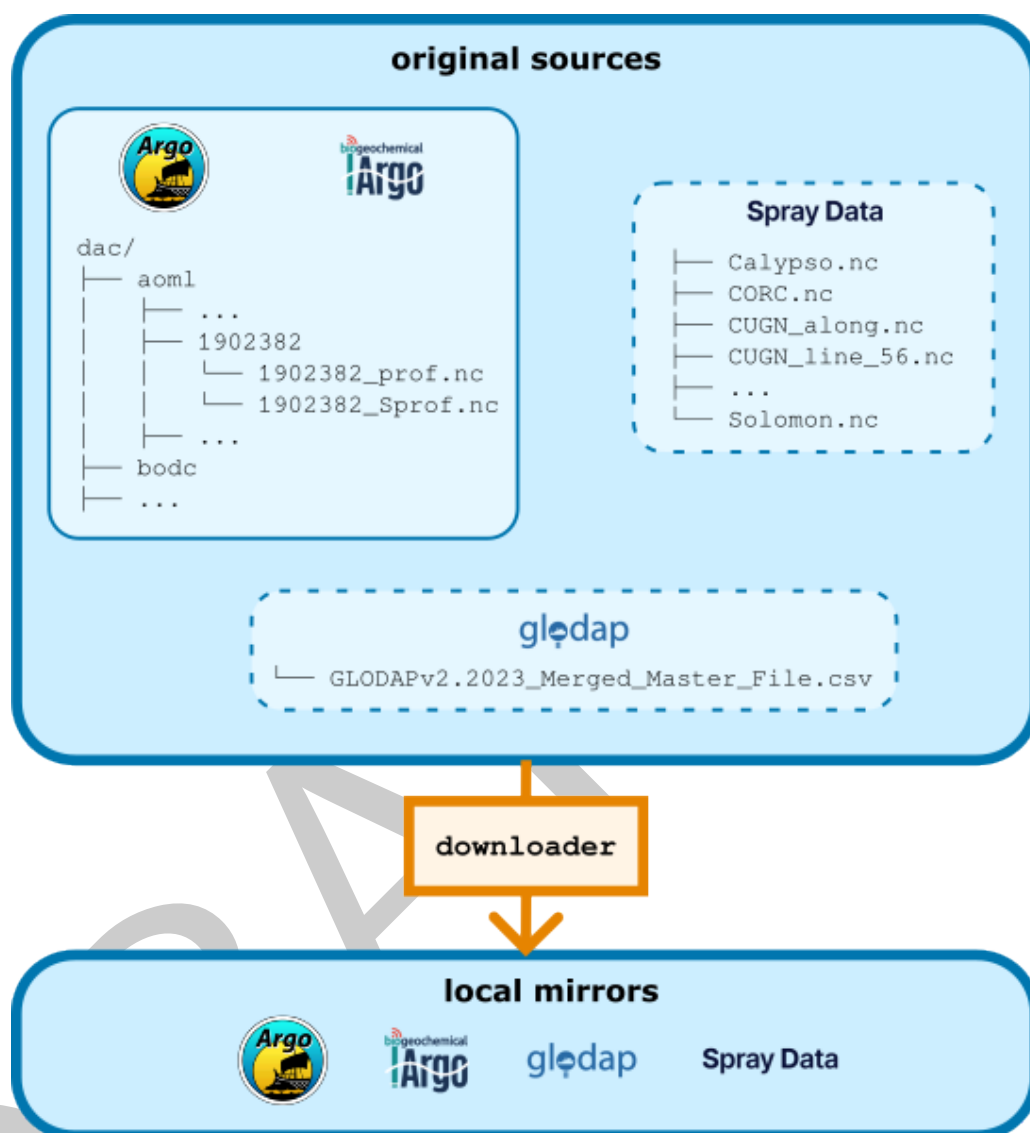


Figure 1: CrocoLake's workflow: 'downloader's. 'CrocoLakeTools' is set up to host modules that are dedicated to download the desired datasets from the web. It currently supports the download only of Argo data (solid line subset), and other datasets require the user to download them manually (dashed border subsets). Argo, Spray Data and GLODAP (Global Ocean Data Analysis Project) are different data providers.

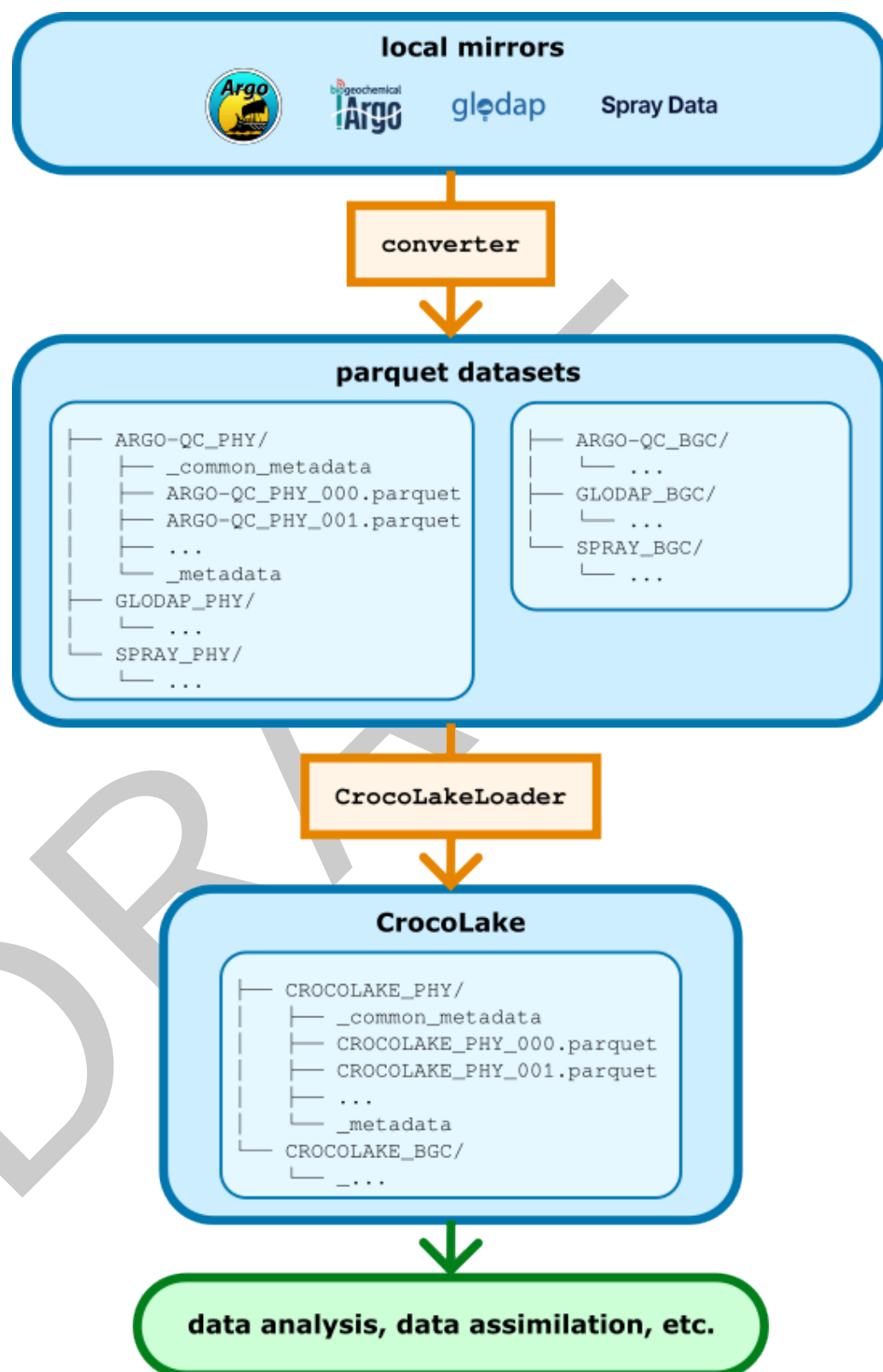


Figure 2: CrocoLake's workflow. 'converter's read the data in their original format, transform it following CrocoLake's conventions, converts it to parquet, and stores it back to disk. Each dataset is converted to its own parquet version. Thanks to the submodule 'CrocoLakeLoader', multiple parquet datasets are merged into a uniform dataframe which is saved to disk as CrocoLake. For each dataset, a version containing only physical variables ('PHY') or also biogeochemical variables ('BGC') can be generated.

153 Schema

154 The nomenclature, units and data types are generally based on Argo's (<https://vocab.nerc.ac.uk/collection/R03/current/>). For CrocoLake's variables that are not present in the
155 Argo program, we provide new names maintaining consistency with Argo's style.

157 Profile numbering

158 Ocean data is often accessed by profiles and we provide this functionality for CrocoLake too:
159 the user can retrieve the profiles through the `CYCLE_NUMBER` variable, which is unique and
160 progressive for each `PLATFORM_NUMBER` of each subdataset (`DB_NAME`). As each original product
161 uses its own conventions, the `CYCLE_NUMBER` of some datasets is generated ad hoc during their
162 conversion if no obvious match with `CYCLE_NUMBER` exists. The procedure for each dataset is
163 detailed in the online documentation.

164 Quality control

165 CrocoLake contains only quality-controlled (QC) measurements. We rely exclusively on QCs
166 performed by the data providers and at the time we do not perform any additional QC ourselves
167 (although this might change in the future). Each parameter `<PARAM>` has a corresponding
168 `<PARAM>_QC` flag that is generally set to 1 to indicate that the data is reliable. For Argo
169 measurements, the original QC value is preserved, and only measurements with QC values of
170 1, 2, 5, and 8 considered.

171 Measurement errors

172 Each parameter `<PARAM>` has a corresponding `<PARAM>_ERROR` that indicates a measurement's
173 error as provided in the original dataset. When no error is provided, `<PARAM>_ERROR` is set to
174 null.

175 Documentation and updates

176 Documentation is available at (<https://crocolakedocs.readthedocs.io/en/latest/index.html>).
177 It describes the specifics of each dataset (e.g. what quality-control filter we apply to each
178 dataset, the procedure to generate the profile numbers, etc.), and get updated every time a
179 new feature is made available.

180 Citation

181 If you use CrocoLakeTools and/or CrocoLake, please do not limit yourself to citing this
182 manuscript but also remember to cite the datasets that you have used as indicated in the
183 documentation. For example, if your work relies on Argo measurements, acknowledge Argo
184 ([Wong et al., 2020](#)). This is important both for the maintainers of each product to track their
185 impact and to acknowledge their efforts that made your work possible.

186 Acknowledgements

187 We acknowledge funding from [NSF CSSI CROCODILE details] and [NASA ECCO NSC...].

188 References

- 189 Forget, Gael. (2025). *Euroargodev/ArgoData.jl* [Data set]. Zenodo. <https://doi.org/https://doi.org/10.5281/zenodo.3633717>
190
191 Forget, Gaël, & Gebbie, G. J. (2025). *JuliaOcean/OceanRobots.jl* [Data set]. Zenodo.
192 <https://doi.org/https://doi.org/10.5281/zenodo.4718472>

- 193 Kelley, D. E., Harbin, J., & Richards, C. (2021). argoFloats: An r package for analyzing argo
194 data. *Frontiers in Marine Science*, 8, 635922.
- 195 Kelley, D. E., Richards, C., & Layton, C. (2022). Oce: An r package for oceanographic analysis.
196 *Journal of Open Source Software*, 7(71), 3594.
- 197 Maze, G., & Balem, K. (2020). Argopy: A python library for argo ocean data analysis. *Journal*
198 *of Open Source Software*, 5.
- 199 Mishonov, A. V., Boyer, T. P., Baranova, O. K., Bouchard, C. N., Cross, S. L., Garcia, H. E.,
200 Locarnini, R. A., Paver, C. R., Reagan, J. R., Wang, Z., & others. (2024). *World ocean*
201 *database 2023*.
- 202 Ocean, H. (n.d.). *The ocean data platform*. <https://www.huboccean.earth/platform>.
- 203 Szekely, T., Gourrion, J., Pouliquen, S., Reverdin, G., & Merceur, F. (2019). *CORA, coriolis*
204 *ocean dataset for reanalysis*.
- 205 Team, T. I. (2018). *International quality controlled ocean database (IQuOD) version 0.1*
206 *- aggregated and community quality controlled ocean profile data 1772-2018 (NCEI ac-*
207 *cession 0170893) [Data set]*. NOAA National Centers for Environmental Information.
208 <https://doi.org/https://doi.org/10.7289/v51r6nsf>
- 209 Tucker, T., Giglio, D., Scanderbeg, M., & Shen, S. S. (2020). Argovis: A web application for
210 fast delivery, visualization, and analysis of argo data. *Journal of Atmospheric and Oceanic*
211 *Technology*, 37(3), 401–416.
- 212 Wong, A. P., Wijffels, S. E., Riser, S. C., Pouliquen, S., Hosoda, S., Roemmich, D., Gilson,
213 J., Johnson, G. C., Martini, K., Murphy, D. J., & others. (2020). Argo data 1999–2019:
214 Two million temperature-salinity profiles and subsurface velocity observations from a global
215 array of profiling floats. *Frontiers in Marine Science*, 7, 700.