Southern Ocean Argo: characterisation of Argo float profiles associated with ACC fronts and zones

Project report

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Project aims

The main objectives of this Argo characterisation project are to deliver the following:

1. A deployable code to characterise Southern Ocean Argo float profile data into the major Antarctic Circumpolar Current fronts and zones
    a. Code usage guidance
    b. A brief explanation of all functions and script usage/input/output
2. Report
    a. Background to the ACC
    b. Argo data format
    c. Code deployment and rationale
    d. Code limitations

1. Introduction

The Argo programme was launched in 2000, with currently about 4000 floats in use around the globe. The US has deployed the majority of these floats, with 2194 floats worldwide. Other countries/organisations considerably involved in the Argo programme include Australia, France, the UK, Japan and Germany (and Europe). The core mission of the Argo array is to record a common set of seawater measurements to a depth of 2000 m: pressure (P), temperature (T) and salinity (S). In recent years, the core mission of Argo floats has been built upon, with: 345 floats now also measuring biogeochemical variables (BGC floats); 77 Deep Argo floats recording deep-ocean water properties (>2000 m); as well as marginal seas floats; floats operating in seasonal sea-ice; and near surface Argo floats.

A typical Argo float profile is recorded over a 10-day cycle (T_{tot}). The float will sit at the surface for up to12 hours transmitting data, before descending to 1000 db (~1000 m) at 10 cm s^{-1}. Here it will drift for 9 days, before descending again to 2000 db (~2000 m), then measure profiles of P, T and S during the ascent to the surface to transmit the data to satellites alongside a range of technical and trajectory information. This data is transmitted from the receiving satellite to Data Assembly Centres (DACs).

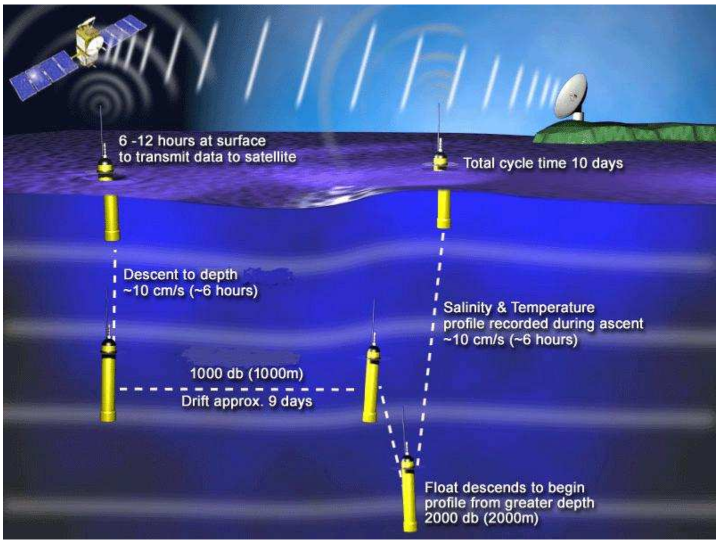

Figure 1: Typical core Argo float cycle to collect one profile. Source www.argo.ucsd.edu

The ACC

The Antarctic Circumpolar Current (ACC) flows easterly around the globe unbroken, driven by strong westerly winds between 45-55'S (Trenberth et al., 1990). The ACC consists of several meridional gradients in surface properties known as oceanic fronts, that separates the Southern Ocean from northern waters of higher temperature and salinity (Orsi, Whitworth, & Nowlin, 1995). The fronts are characterised by strong gradient changes in water mass properties such as density, temperature and salinity with movement south. Isotherms and isohalines rise with distance polewards in bands of large gradients and are associated with strong surface currents.

Between the subtropical and subpolar circulation, the northern and southern boundaries of the ACC are defined as the Sub-Tropical Front (STF) and the Southern Boundary (SBdy), respectively (Kim & Orsi, 2014). The STF lies at around -30 to -40 °S, although studies find discrepancy in the temporal and spatial positioning of the front (Belkin & Gordon, 1996; Orsi et al., 1995; Sokolov & Rintoul, 2009a). The SBdy varies greatly in latitudinal position, with the Antarctic Peninsula and Weddell Gyre steering the southern fronts northwards around the tip of the Peninsula and north of the South Scotia Ridge (Fig. 2). The three major deep-reaching jets are the Sub-Antarctic Front (SAF), the Polar Front (PF) and the Southern ACC Front (SACCF). The ACC SAF lies approximately between at 47°S (Trenberth et al., 1990). South of the SAF is the Polar Front (PF) at approximately 50°S, and the Southern ACC Front (SACCF) at between 52 and 54 °S. Orsi et al., (1995) show that these deep currents are continuous features in the Southern Ocean and converge but do not merge across the Drake Passage, a region of approximately 1000 km wide. The Drake Passage has been a common region for study due to the highly dynamic nature of the seaway, with a change in dynamic height from 0.90 to 0.35 dyn m across its width from north to south (Orsi et al., 1995).

Defining the frontal zones

The ACC frontal zones have been characterised using various combinations of satellite altimetry measurements of sea surface height (SSH); P, T and S measurements using measurements using measurements from ships and Argo floats; and even elephant seals (Boehme et al., 2008; Orsi et al., 1995; Sokolov & Rintoul, 2009b, 2009a). Table A1 summarises the main characterisation criteria from four studies upon the ACC fronts/zones. It is noted that each characterisation uses different criteria with varying complexity and uncertainty.

The physical properties of fronts and zones are highly influenced by the surrounding topography, and winds. Satellite altimetry and Argo data reveal the intensification and convergence of the three major jets, the SAF, the PF and the SACCF, through the Drake Passage, as a well-documented example of the influence of topography over front positioning (Sokolov & Rintoul, 2009b). Wind direction and intensity exerts influence over ocean currents, but model simulations of climate-driven wind changes appear to be a lesser driver for ACC front properties than topography (Graham et al., 2012). Considering the importance of the ACC to whole-ocean processes of heat and nutrient transport, understanding the sensitivity of the ACC to external properties helps elucidate this influence over all ocean basins. For example, the Subtropical Front dictates the volume of warm/saline water reaching Agulhas current into the Atlantic, driving North Atlantic Deep water formation. It is theorised that a wind-induced polar shift of the STF would strengthen the Atlantic Meridional Overturning Circulation by increasing the salt flux to the Atlantic via the Agulhas current (Bard & Rickaby, 2009; Graham & De Boer, 2013).

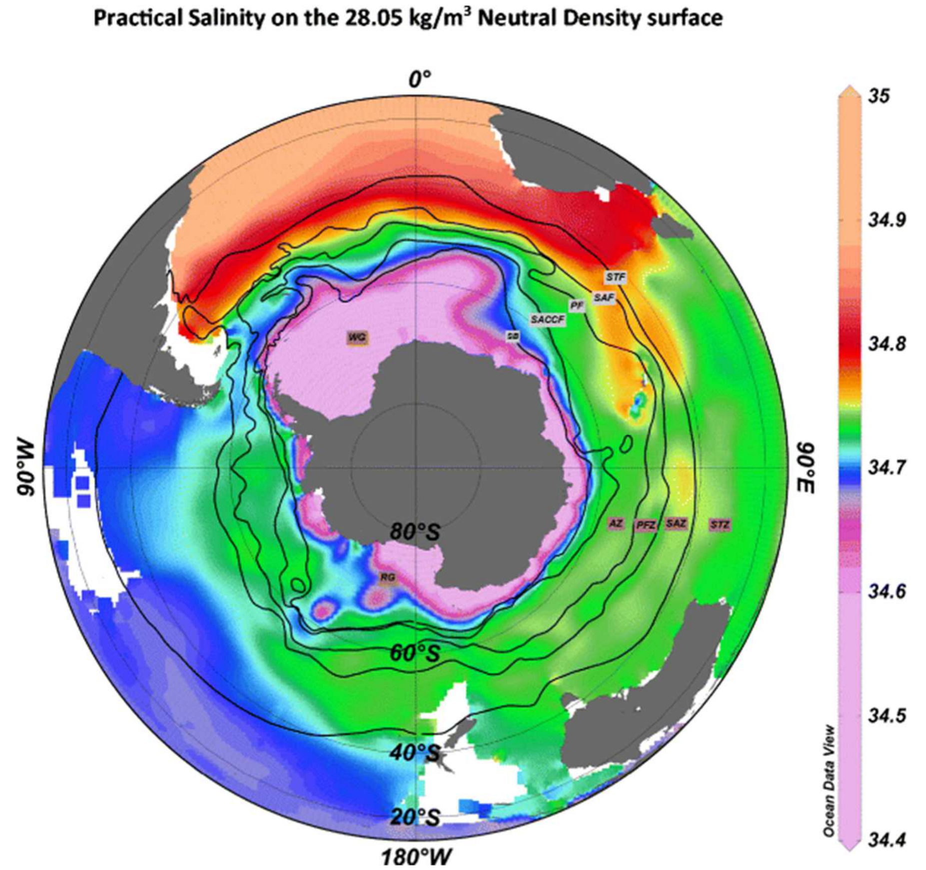

Figure 2: Salinity on the 28.05 kg m^{-3} neutral density surface map from Donnelly et al., (2017) using World Ocean Atlas 2009 density data. The major fronts (black lines and grey highlighted labels) and zones (brown highlighted labels) as follows: the Sub-Tropcial Front (STF), Sub-Antarctic Front (SAF), Polar Front (PF), Southern ACC Front (SACCF), Southern Boundary (SB), Sub-tropical Zone (STZ), Sub-Antarctic Zone (SAZ), Polar Front Zone (PFZ), Antarctic Zone (AZ), Weddell Gyre (WG) and Ross Gyre (RG).

In this study, the front and zone characterisation are adapted from the current literature (Table 1). As can be seen from the variability between studies in characterisation criteria, a definitive criterion for all fronts and zones creates limitations in the interpretation of the result. This study provides a baseline classification that allows for efficient evaluation of front/zone temporal and spatial variability, and the model is designed for simple adaptation to meet user hypotheses.

2. Argo data infrastructure

Data Assembly Centres

Argo Data Assembly Centres (DACs) retrieve and secure data from the satellite telecommunication providers and perform real-time quality control tests on Argo data. DACs provide the real-time quality control tested data to the global telecommunication system (GTS) in under 24 hours from data generation. The Global Data Assembly Centres (GDACs) and Argo float principal investigators (PIs) will receive quality-controlled data from the DACs too.

Available data via the GDACs is indexed by which DAC is responsible for the data, so all profiles are traceable back to the DAC that provided them.

Delayed-Mode Quality Control operators

All Argo floats are assigned a clearly defined delayed-mode quality control (DMQC) operator. These DMQC operators will qualify the data for use in **climate-grade** research within a year of receipt. This involves flagging systematic and instrumental errors of all Argo data for use. Within this project the data used for profiling is the unadjusted **real-time** data only, as the classification work is partly aimed at providing DMQC operators with information to inform the DMQC process

GDACs

The two Argo GDACs at Ifremer in Europe and USGODAE in the USA provide access to both the real-time and the DMQC-controlled data. These can be accessed by: www.Argo.net.

Data retrieval

Both the US GODAE and IFREMER (US and France) provide FTP (File Transfer Protocol) and HTTP (Hypertext Transfer Protocol servers:

- IFREMER FTP: ftp://ifremer.fr/ifremer/Argo
- US FTP: ftp://usgodae.org/pub/outgoing/Argo

These sites are updated each day with new profiles. The profile list of all profiles on ftp.ifremer.fr is named ar_index_global_prof.txt.

FTP servers are suitable for a **data retrieval by a script/program.** This data is organised:

- geo: geographically (by ocean basin) and then temporally (by year/month/day) in each basin (Atlantic, Indian and Pacific)
- dac: by data provider and platform (DAC and Argo float number)
- latest_data: latest processed data organised by processing day

Useful resources

SOARC

Responsible for information pertaining specifically to Southern Ocean Argo, the Southern Ocean Argo Regional Centre (SOARC) provides information on Argo data, data retrieval, and a current location status map of Southern Ocean floats (http://www.soarc.aq/status).

JCOMMOPS

The WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology in-situ Observing Programmes Support Centre (JCOMMOPS) (http://www.jcommops.org/board) provides a desktop-style interface with live status Argo float data available (both ascii and netCDF). The interface provides several useful tools. All floats currently deployed, whether active or inactive, are mapped. Information on each float including metadata, profile and trajectory is available. Various filtering techniques are employable; all floats above -30 °S can be filtered out. Also, each active float has scatter plots for T, S and P of data from time of deployment to most recent profile.

DACs

There are 11 relevant DACs that provide data to the GDACs:

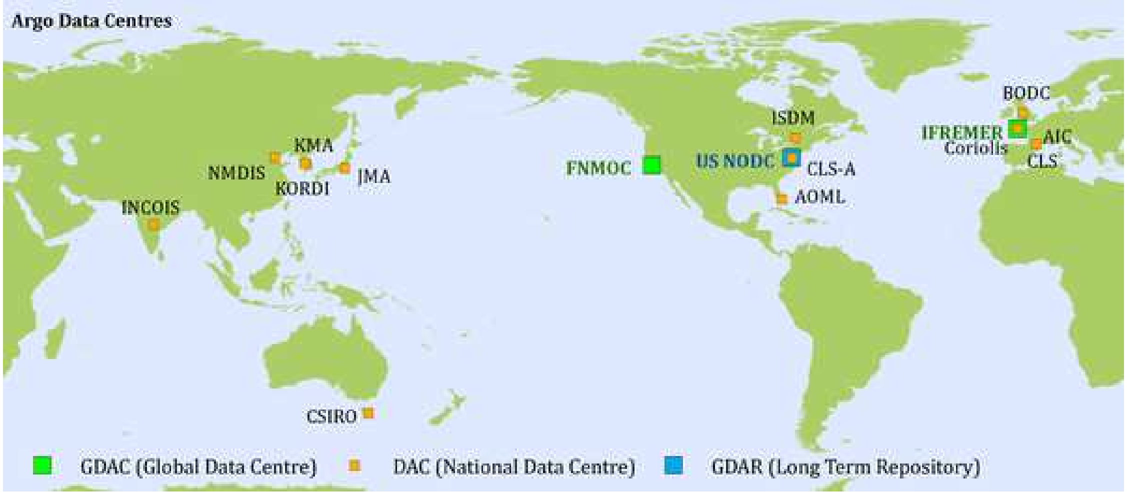

Figure 3: Global map of the 11 Argo data assembly centres, from http://www.argodatamgt.org/Data-Mgt-Team/Argo-Data-System-components

3. Code deployment

Argo data format

Argo profiles are provided in netCDF (Network Common Data Form), with file extension '.nc'. NetCDF files provide an interface to a library of data access functions, oriented for the storing and retrieving of data in the form of arrays. Each NetCDF object is self-describing and accessed through MATLAB or other various software/applications with ease. The nature of netCDF files provides a standardised-format, and in the case of Argo float profiles, each netCDF contains identical attributes allowing straightforward iteration over a series of netCDF files to obtain large arrays of data. NetCDF is commonly used for large data arrays in oceanographic studies. See https://www.unidata.ucar.edu/software/netcdf/docs/netcdf_introduction.html for an overview of netCDF formats and information.

Software requirements

To deploy the code the user needs MATLAB 2016a or newer.

NetCDF files are self-describing and easily standardised. All Argo profiles possess an identical variable list that within it describes all aspects of the float profile metadata along with core profile pressure/temperature/salinity measurements. Software that allows straightforward visualisation of NetCDF arrays and determination of array names and properties include:

- ncbrowse https://www.pmel.noaa.gov/epic/java/ncBrowse/
- Panoply https://www.giss.nasa.gov/tools/panoply/ (good for 3D data visualisation)

Recent MATLAB versions have a built-in netCDF api, allowing straightforward access to NetCDF data. This project uses the built-in function to manipulate NetCDF data.

Data retrieval

The total Argo float library contains a huge amount of data beyond the storage capabilities of a normal PC. Windows PC are often not compatible with terminals connecting to FTP servers remotely and so manually downloading the data using a secure shell client such as WinSCP is probably the most efficient option.

Two main options to retrieve the data:

1. Windows: Use WinSCP to manually download all real-time profiles to the users working directory (see Appendix 1 for detailed breakdown)

2. Mac OS X: Use the Unix command terminal and the supplied shell script to download the relevant profiles (see Appendix 1 for detailed breakdown)

Either options will likely require an external hard drive or alternative data repository.

Default float categorisation

The MATLAB code categorises all loaded profiles into one of the ACC zones based on criteria for P, S and T adapted from the literature (see; Barboni, 2018; Boehme et al., 2008; Orsi et al., 1995; Sokolov & Rintoul, 2009a). The following fronts and zones are characterised. Fronts: Subtropical Front, Subantarctic Front, Polar Front, Southern ACC Front, Southern Boundary; zones: Subtropical Zone, Subantarctic Zone, Polar Zone, Antarctic Zone, Southern Zone and Sub-polar region.

The zonal classification is performed using the upper and lower limits of the equatorward/poleward front criterion, due to an absence of direct zonal classification in the literature. Default values are provided in Table 2. Only zones are characterised and plotted, allowing for the determination of front location through the upper and lower limits of zone positioning. The function values for float categorisation are editable. There is the option to classify and plot fronts, but it has been found this creates a plot that is perceptually difficult to analyse.

Those profiles that satisfy more than one criterion are categorised as unclassified, or ‘unclass’. If there are floats that satisfy no criterion, they are categorised as non-classified, or ‘noclass’.

Table 1: The default zone characterisation used in this study for each implemented zone. Characterisation is adapted from the given references.

Zone	**Characterisation**			**Reference**
	T (°C)	*S (PSU)*	*P (dbar)*	
Subtropical Zone	> 11.5	> 35.05	< 105	*Orsi et al., 1995*
Subantarctic		< 34.6	< 105	*Orsi et al., 1995*
Zone	>6.85		< 400	*Sokolov and Rintoul, 2009a*
Polar zone	>2		200	*Boehme et al., 2008*
	<2.63		400	*Sokolov and Rintoul 2009a*
Antarctic Zone	>1.8		~ 500	*Boehme et al., 2008*
	<2		~ 200	*Boehme et al., 2008*
Southern Zone	T > -0.66		~ 500	*Sokolov and Rintoul, 2009a*
	T < 1.75		~ 500	*Boehme et al., 2008*
Sub-polar region	$T_{max} \leq -1.24$			*Sokolov and Rintoul, 2009a*

Required functions

Soarc_plotfronts.m uses m_map, a freely available mapping toolbox for oceanographic data, found at https://www.eoas.ubc.ca/~rich/map.html. See the usage guidance for an overview of plotting requirements. Downlaod m_map and save it to your working directory. The bathymetry data used in soarc_plotfronts.m is the ETOPO1v1 ; https://www.ngdc.noaa.gov/mgg/global/relief/ETOPO1/data/ice_surface/grid_registered/binary/

Known issues and limitations

Data retrieval

The GDAC websites are updated daily with real-time and delayed-mode data and so the user should be aware that to include all profiles the profile repository should be updated daily. At ftp.ifremer.fr/ifremer/argo/latest_data the user can download profiles updated most recently.

Float filtering

The current code uses a driver file in which longitude and month can be defined. The nature of the code uses a minimum and maximum limit for both, meaning that to filter from e.g. 330 – 030 longitude or 10/2012 - 02/2013 is not yet enabled. This is something that could be enabled with some code adaptation.

Zone characterisation

The zone characterisation outlined in version 1.0 of the supplied code is based on the upper and lower limits of the frontal characterisation of the equatorward and poleward fronts, respectively. Float measurements of P, T and S are taken in discrete increments and so float positioning is not a definite locator of a front/zone boundary. Furthermore, the discrete nature of Argo float data collection requires a P, T and S range for each zone characterisation, rather than a precise boundary in order to capture profiles on the boundary (such as a pressure range from 195 – 205 dbar for T < 1.75 °C, rather than 200 dbar, see Antarctic Zone, Table 1). The characterisation process also assumes that the literature definition for each front is correct and that the definition of each ACC front allows the definition of an ACC zone by exclusion.

Zone characterisation definition is taken from a range of studies. Each study applies differing techniques for data collection such as sea surface height using satellite altimetry, or ship-based / Argo measurements for T, S and P (Orsi et al., 1995). This cross-reference approach increases the uncertainty upon boundaries.

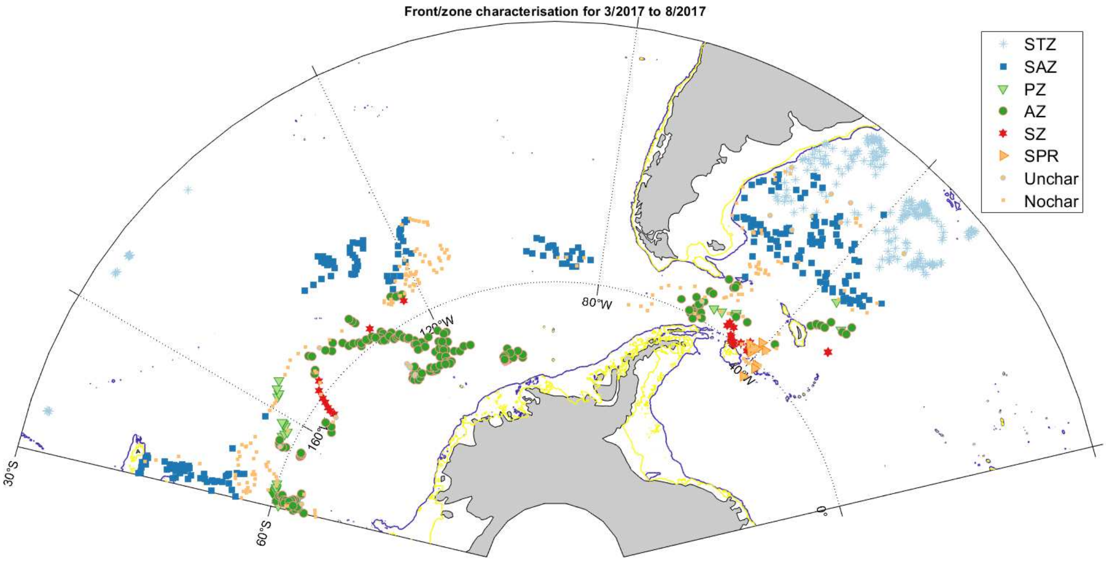

Figure 4: Example surface plot of characterised zones for the period 03/2017 – 08/2017 of R- files. This plot does not include D- files. Zones characterised are the STZ, SAZ, PZ, AZ, SZ and SPR.

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Appendix

Data retrieval methods for Windows v.s Mac

Windows

WinSCP is a client for SFTP, FTP, SCP for Microsoft Windows, designed mainly for secure file transfer between your local directory and a remote server.

To sign in to the FTP:

1. Choose FTP from the login screen drop down menu 'File protocol'
2. Type ifremer.fr into the host name box
3. Select 'anonymous login' and log in
4. Navigate to ifremer/argo
5. Drag and drop the ar_index_global_prof.txt file into your preferred MATLAB directory
6. This file contains all the current float profile indexes and needs to be in your preferred MATLAB directory for the code execution.

To specify file mask for download:

7. In the top tab go to transfer settings → configure
8. In Transfer → add a transfer setting preset
9. In the 'Add transfer settings preset' in 'file mask' type the following:
    a. */R*; */D*
    b. The '*' character is a 'wildcard', and will instruct WinSCP to find any directory or file with any length of characters, i.e. every subdirectory within the dac directory will be searched and downloaded
    c. Save this setting and select it for transfer settings
10. Drag the 'dac' folder into your working directory

Mac

Secure shell clients exist for Macs too, and if the user would prefer a manual download process, clients such as FileZilla work much in the same way as WinSCP.

Unix command line (Mac terminal)

To remotely connect to an FTP server:

Type ‘ftp’ (ftp>) → open <ip address> (in this case ftp.ifremer.fr)

Username: anonymous

Password: user email address

ls : list all files and folders in the directory

cd : change directory

For ftp.ifremer.fr navigate to the Argo directory:

> cd ifremer/Argo

> ls

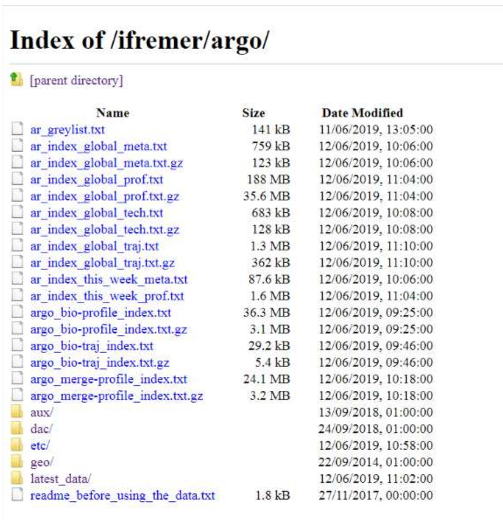
will display a series of files and folders listed including ar_index_global_prof.txt

> mget ar_index_global_prof.txt.gz

Will download a (compressed) index file to the current working directory unless otherwise specified

This file contains all the current float profile indexes and needs to be in the users preferred MATLAB directory for the code execution.

The deployed code will save an updated index file with Southern Ocean only profiles (> 30 ° S).



Index of /ifremer/argo/

[parent directory]

Name	Size	Date Modified
ar_greylist.txt	141 kB	11/06/2019, 13:05:00
ar_index_global_meta.txt	759 kB	12/06/2019, 10:06:00
ar_index_global_meta.txt.gz	123 kB	12/06/2019, 10:06:00
ar_index_global_prof.txt	188 MB	12/06/2019, 11:04:00
ar_index_global_prof.txt.gz	35.6 MB	12/06/2019, 11:04:00
ar_index_global_tech.txt	683 kB	12/06/2019, 10:08:00
ar_index_global_tech.txt.gz	128 kB	12/06/2019, 10:08:00
ar_index_global_traj.txt	1.3 MB	12/06/2019, 11:10:00
ar_index_global_traj.txt.gz	362 kB	12/06/2019, 11:10:00
ar_index_this_week_meta.txt	87.6 kB	12/06/2019, 10:06:00
ar_index_this_week_prof.txt	1.6 MB	12/06/2019, 11:04:00
argo_bio-profile_index.txt	36.3 MB	12/06/2019, 09:25:00
argo_bio-profile_index.txt.gz	3.1 MB	12/06/2019, 09:25:00
argo_bio-traj_index.txt	29.2 kB	12/06/2019, 09:46:00
argo_bio-traj_index.txt.gz	5.4 kB	12/06/2019, 09:46:00
argo_merge-profile_index.txt	24.1 MB	12/06/2019, 10:18:00
argo_merge-profile_index.txt.gz	3.2 MB	12/06/2019, 10:18:00
aux/		13/09/2018, 01:00:00
dac/		24/09/2018, 01:00:00
etc/		12/06/2019, 10:58:00
geo/		22/09/2014, 01:00:00
latest_data/		12/06/2019, 11:02:00
readme_before_using_the_data.txt	1.8 kB	27/11/2017, 00:00:00

Figure A1: Layout of the /ifremer/argo ftp directory containing the index file ar_index_global_prof.txt

To retrieve profiles using Unix:

a. Install homebrew and the wget command https://www.maketecheasier.com/install-wget-mac/

From your local directory

1. To download the full index file, ar_index_global_prof.txt

```
$ wget -c -x -P./"destinationfolder" -r -N ftp://ftp.ifremer.fr/ifremer/argo/ar_index_global_prof.txt
```

2. To download several files (e.g. all real-time profiles from the Coriolis folder):

```
$ wget -c -x -P./"destinationfolder" -r -N
```

ftp://ftp.ifremer.fr/ifremer/argo/dac/coriolis/7900521/profiles/R*.nc

Table A1: Summary of frontal characterisation

Front	Study				
	Orsi 1995	**Barboni 2018**	**Sokolov Rintoul 2009a**	**Boehme et al., 2008**	**Belkin and gordon 1996**
STF	10-12 °C 34.6-35.0 psu At 100 m				35.0 psu at surface
SAF	S < 34.2 psu at Z < 300m T > 4-5 °C at 400 m	T >4.5 °C S < 34.20 psu	T 2.8 – 6.1 °C at 400 dbar 2.78 ± 0.15 °C, SAF-S 4.06 ± 0.35 °C, SAF-M 6.06 ± 0.79 °C, SAF-N	T = 4°C at 300 dbar	
PF	T < 2 °C or T_{min} at Z < 200m (N) T > 2.2 °C along T_{max} at Z > 800m (S)	T < 2 °C at Tmin (N) T_l> 2.2 °C at Tmax (S)	T= 2 °C (N) T= 1.2 – 2.3 (M) T = 1 – 2.1 (S)	T_{min} = 2°C T=2 °C at 200 dbar	
SACCF	T_{min} > 1.8 °C at Z > 500m T_{min} < 0 °C at Z < 150 m S > 34.3 psu S_{max} at Z > 800m	T_{max} > 1.8 °C T_{min} < 0 °C S_{max} > 34.73 psu		T = 1.8 °C at P = 500 dbar	
SBdy			T at Tmin = -0.95 ± 0.29 °C		