Deep Argo

A composite introduction

Brian King
NOC, UK

with slides from V. Thierry,
D. Desbruyeres, N Zilberman,
D. Roemmich and
others who contributed to those talks

4 Types of Deep Argo float models

Deep SOLO
Argo float lab at SIO
Commercial version: MRV
0-6000 m
25 kg
13″ glass sphere

Deep Arvor
NKE, CNRS, IFREMER
0-4000 m
26 kg
4′-high cylinder

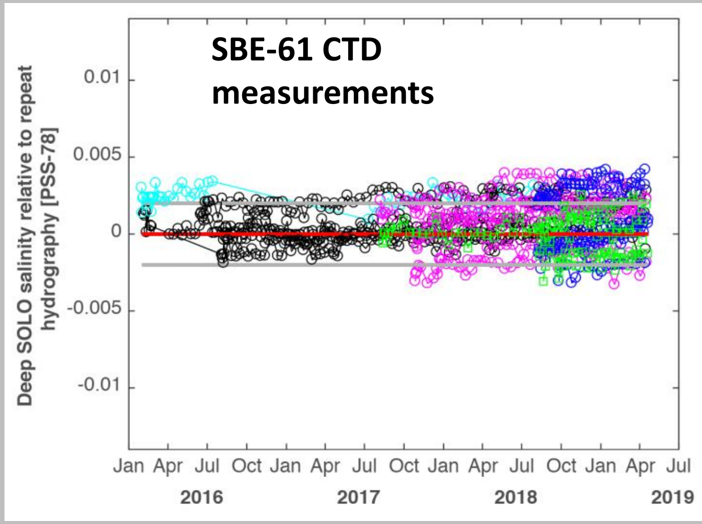
Deep APEX
TWR
0-6000 m
50 kg
17″ glass sphere

Deep NINJA
TSK Co LTD, JAMSTEC
0-4000 m
50 kg
6′-high cylinder

Technology Evolution (1)

- **Float and sensor lifetime** target > 4 years
- **Cost effectiveness** target < $500 / profile
- **Deep Argo conductivity-temperature-depth (CTD) sensors** high-accuracy, low power

1. 6000-m SBE-61 CTD from Sea-Bird Scientific
10 out of 30 (~33%) 6000-m SBE-61 CTDs deployed in the Southwest Pacific Basin, show accuracy within ± 0.002 PSS-78, in comparison with shipboard data.

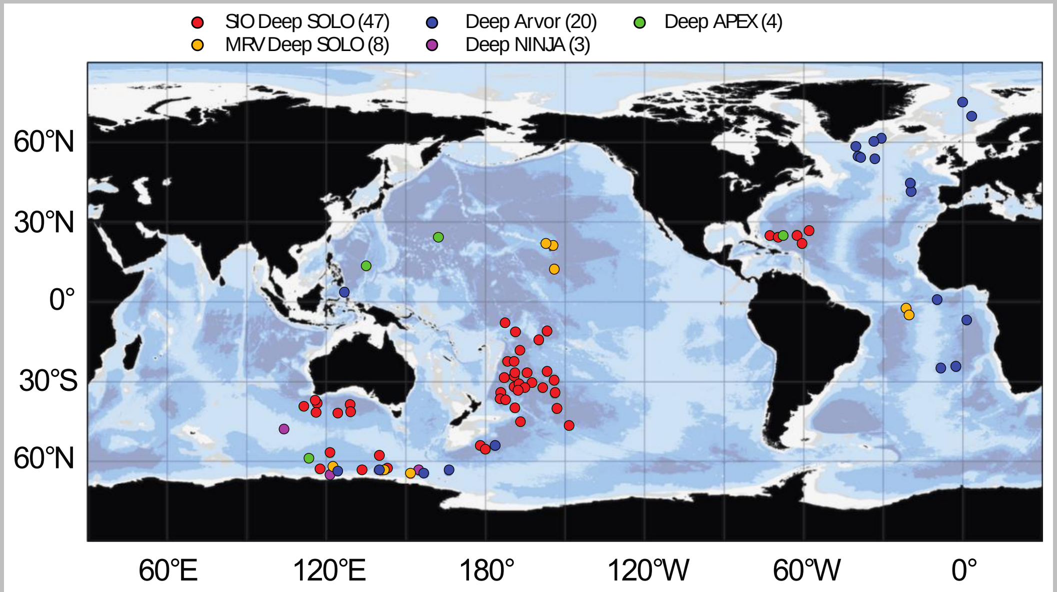


2. Extended-depth SBE-41 CTD from Sea-Bird Scientific
Performance is improving

3. 6000-m CTD from RBR
Under development

- **Oxygen measurements** from some Deep Argo floats

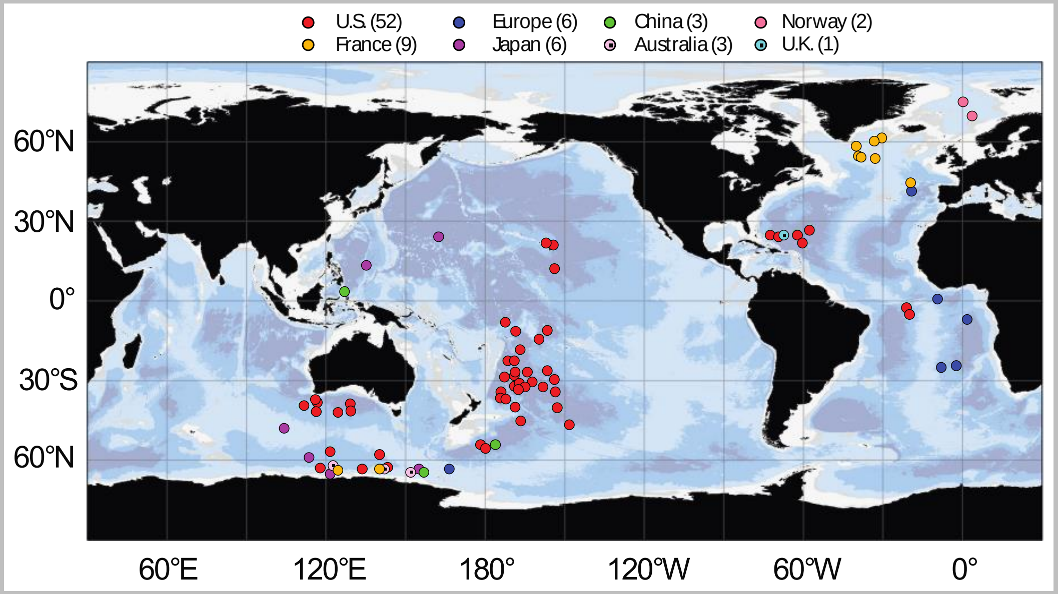
82 Deep Argo floats currently active



- Regional Deep Argo pilot arrays have been implemented in deep regions, in the vicinity of dense water formation, and where high accuracy repeat hydrography data is available

- Objectives of the pilot phase are to test the performance of the Deep Argo floats, to define the accuracy and stability of the Deep Argo sensors, and to demonstrate the scientific value of the Deep Argo data

International Program

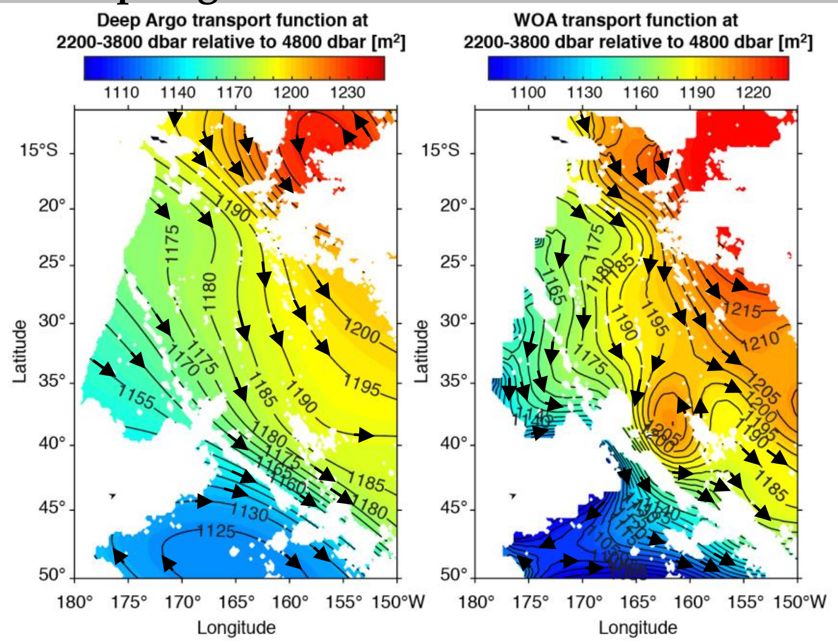


- Coordination between international Deep Argo partners is needed to support the implementation of a sustained and truly-global Deep Argo array

Deep Argo improves knowledge of mean deep-ocean circulation

Deep Argo relative **Historical Data relative**

Deep transport function 2200-3800 dbar



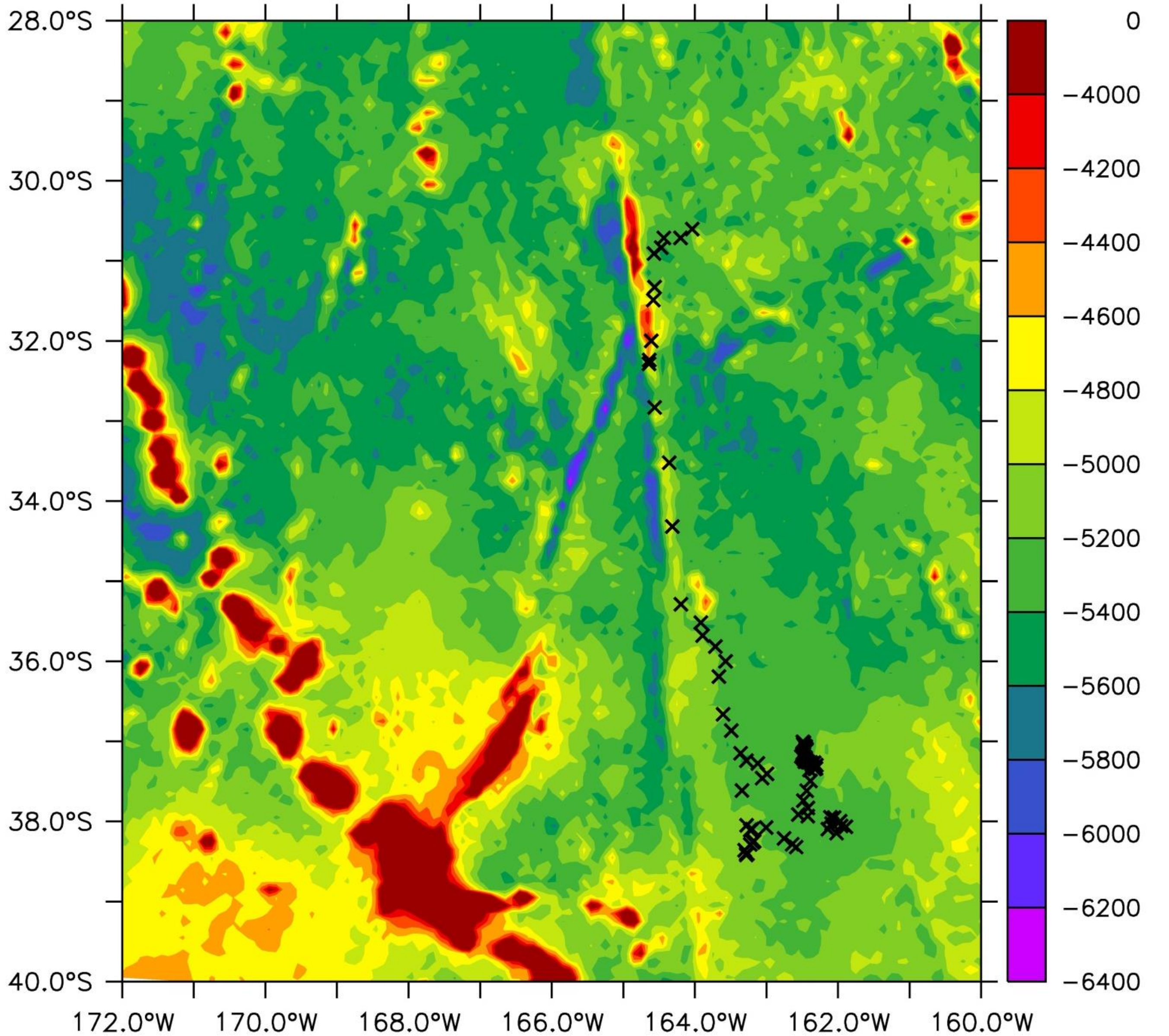
(Zilberman et al., submitted)

- The number of deep profiles collected from Deep Argo floats between 2016-2018, is similar to historical measurements between 1950-2018.
- Deep Argo based transport function **referenced to 4800 dbar**, indicates <u>dominant southeastward deep flow</u> out of DWBC and across the abyssal plain
- Transport function calculation for 2200-3800 dbar layer **referenced to 4800 dbar** using historical data between 2005-2017, shows broad agreement with Deep Argo estimates

Float 6004 – Discovering new circulation features

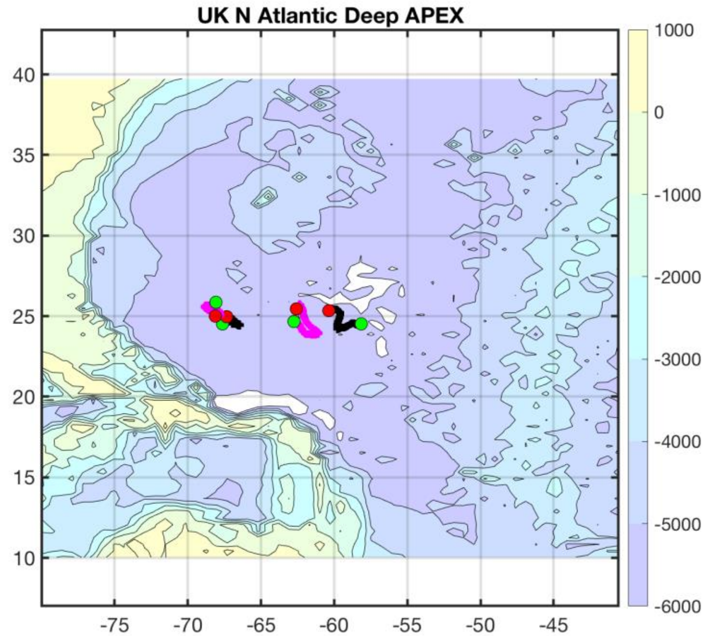
Drifting a few hundred meters above the bottom, float 6004 is entrained in a swift, narrow flow along a minor topographic ridge.

Many new and unknown features of the abyssal ocean circulation are waiting for discovery by Deep Argo floats.



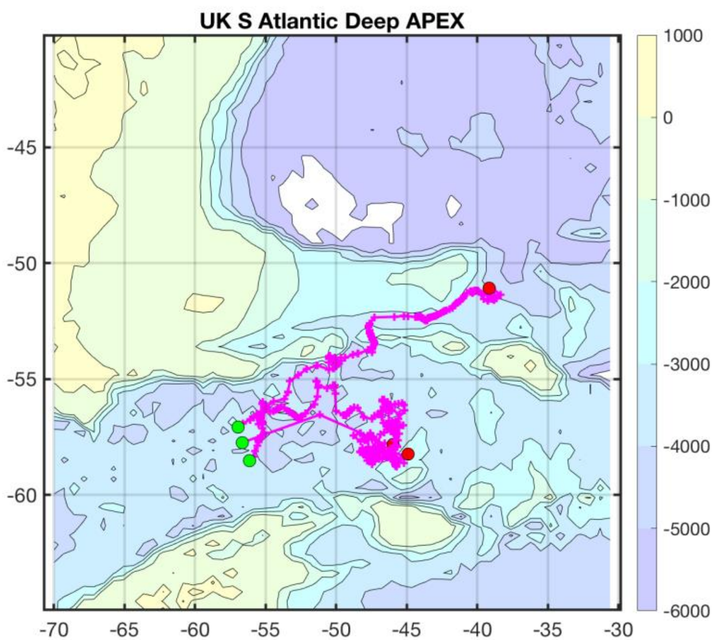
An example from UK Deep APEX floats (Drake Passage and Atlantic 24N)

Illustrating some things that can go wrong with salinity



N Atlantic:
s/n 07, 08
Active Dec 2015 to Jun 2016
s/n 7 recovered Feb 2017

s/n 22, 23
Active Nov 2018 to present; 3-day cycles



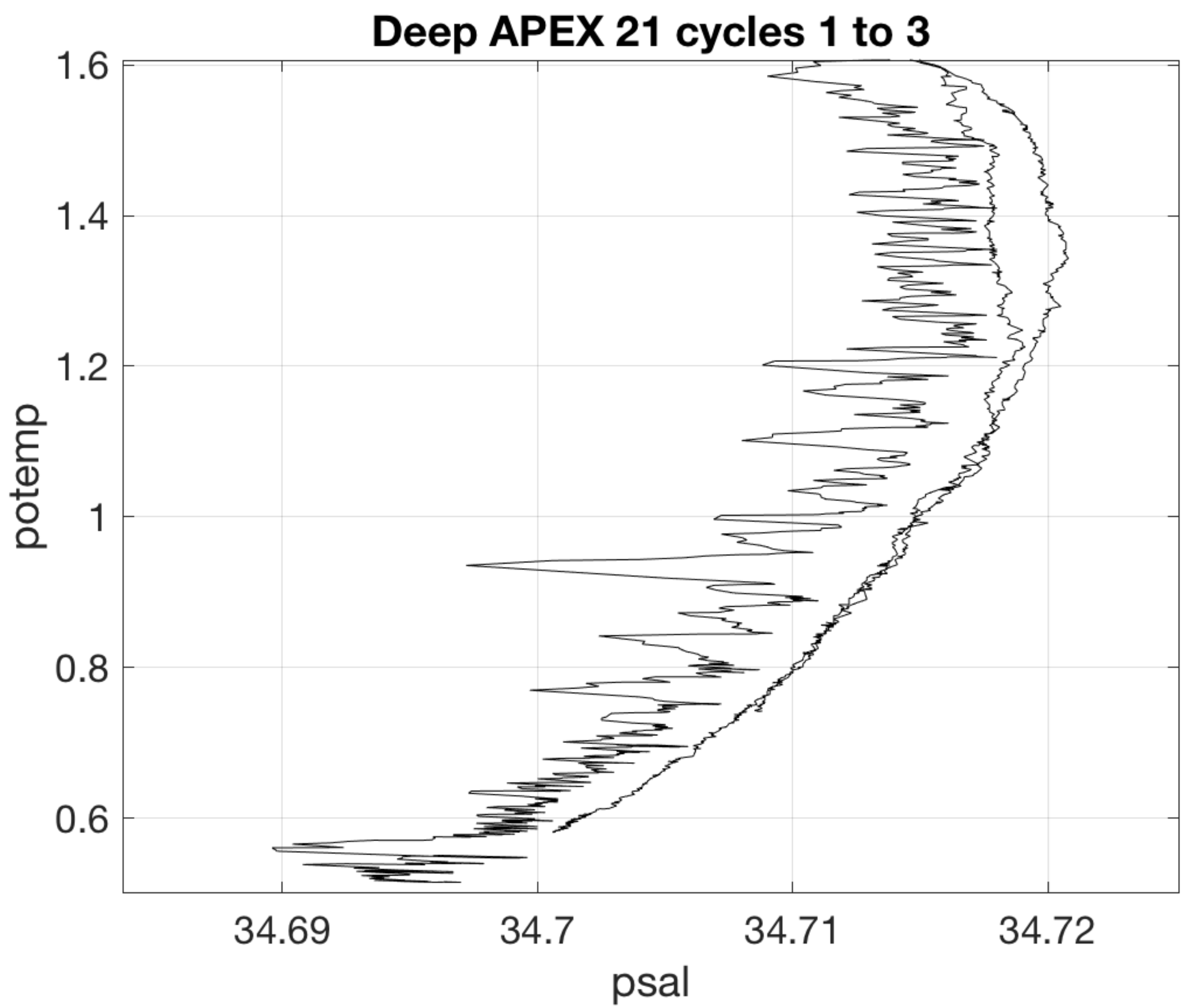
S Atlantic:

s/n 18, 20, 21
Active Dec 2017 to present; 3-day cycles
s/n 21 at 51S, 39W is 30 days overdue

s/n 21 Drake Passage

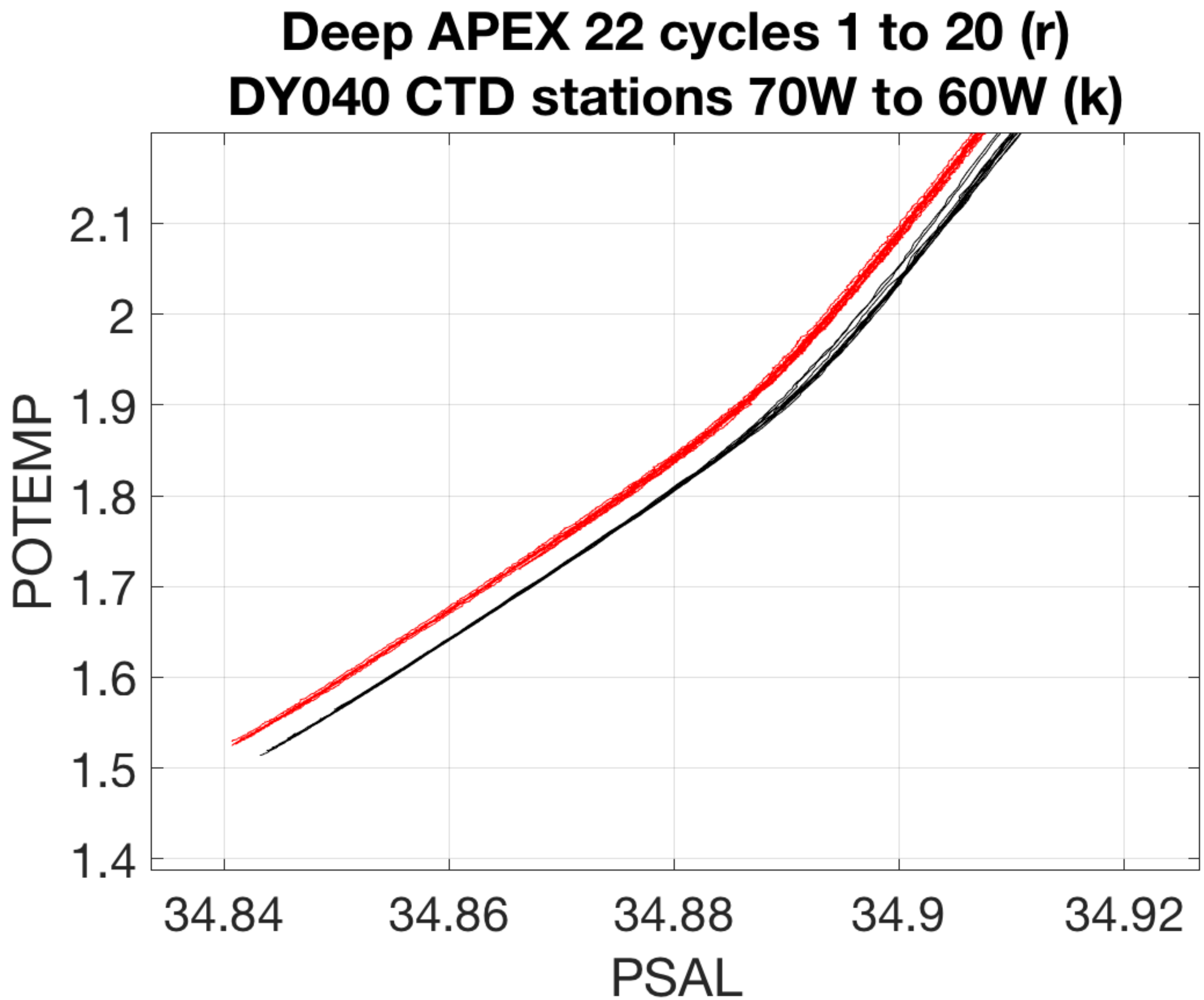
Salinity goes noisy on cycle 3 and stays that way

T and C(S,T,P) are individually smooth, suggesting the problem is a time constant problem calculating S (C,T,P).



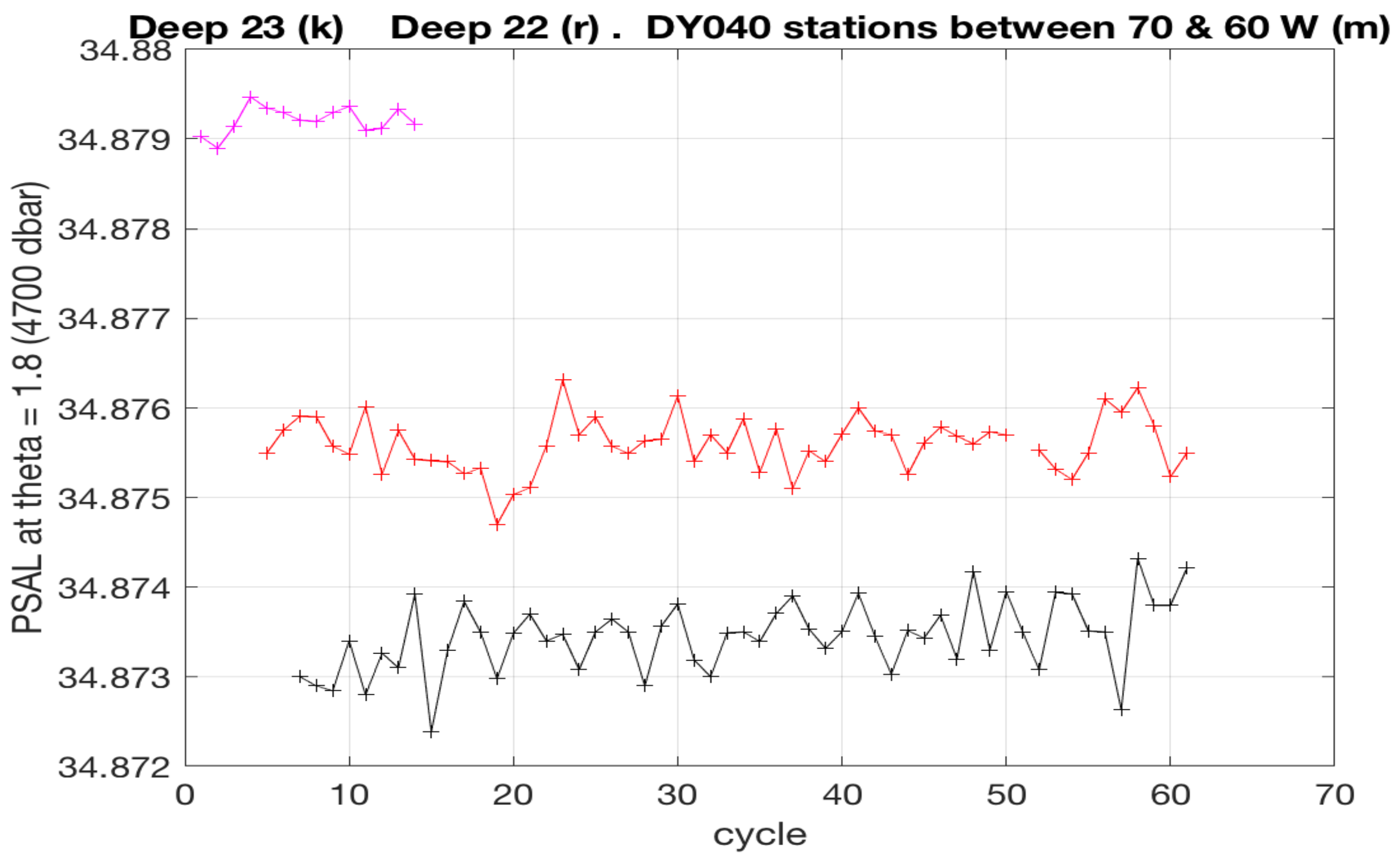
s/n 22 and 23 Atlantic 24N – Nov 2018 to present

Salinity is very stable over 60 cycles, but offset compared with 2016 GO-SHIP data



s/n 22 and 23 Atlantic 24N – Nov 2018 to present
PSAL on PTMP = 1.8 for floats (black, red)
and GO-SHIP cruise 14 stations between 70W and 60W

Offset presumed to be CpCor, but offset is equivalent to 12 dbar PRES error at 4700 dbar



An example from Deep Arvor floats in the N Atlantic

Oxygen was a critical addition for this science application

Slides from Virginie Thierry, and collaborators at IFREMER

JGR Oceans

RESEARCH ARTICLE
10.1029/2019JC015040

Racape et al. 2019

Key Points:
- A direct route is suggested for ISOW from the Charlie-Gibbs Fracture Zone to the Deep Western Boundary Current at Flemish Cap
- At the Charlie-Gibbs Fracture Zone, oxygen measurements are key to quantifying ISOW mixing with North East Atlantic Deep Water
- Mixing between ISOW, North East Atlantic Deep Water, Labrador Sea

ISOW Spreading and Mixing as Revealed by Deep-Argo Floats Launched in the Charlie-Gibbs Fracture Zone

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Abstract To improve our understanding of deep circulation, we deployed five Deep-Argo floats (0–4,000 m) in the Charlie-Gibbs Fracture Zone (CGFZ), which channels the flow of Iceland-Scotland

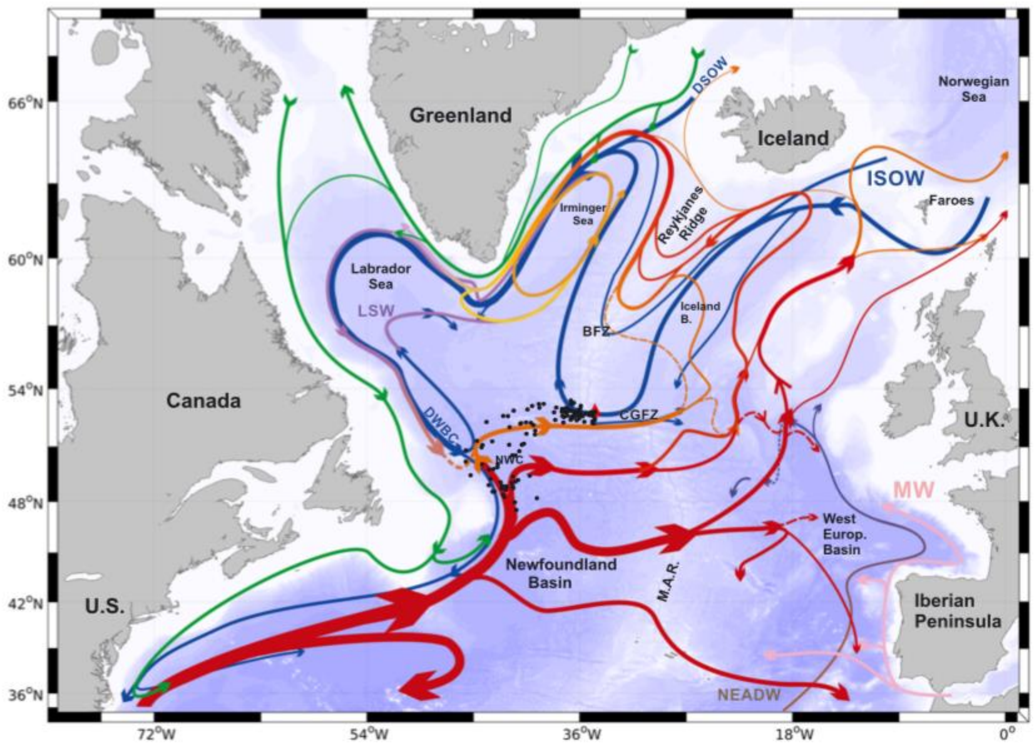


Figure 1. Schematic of the large-scale circulation of the North Atlantic Subpolar gyre from Daniault et al. (2016). Bathymetry is plotted in color, with isobaths at 100 m, 1,000 m, and every 1,000 m below 1,000 m. Deep circulation delimited by the isopycnal $\sigma_0 = 27.80$ is shown in blue. The North Atlantic Current is shown in red. Abbreviations indicate the Deep Western Boundary Current (DWBC), Labrador Sea Water (LSW), Iceland-Scotland Overflow Water (ISOW), Denmark Strait Overflow Water (DSOW), Mediterranean Water (MW), North East Atlantic Deep Water (NEADW), Meridional Atlantic Ridge (MAR), Charlie-Gibbs Fracture Zone (CGFZ), Bight Fracture Zone (BFZ), and North-West Corner (NWC). The orange triangle indicates the deployment position in the CGFZ of the five Deep-Argo floats. The black dots represent the position of the float profiles.

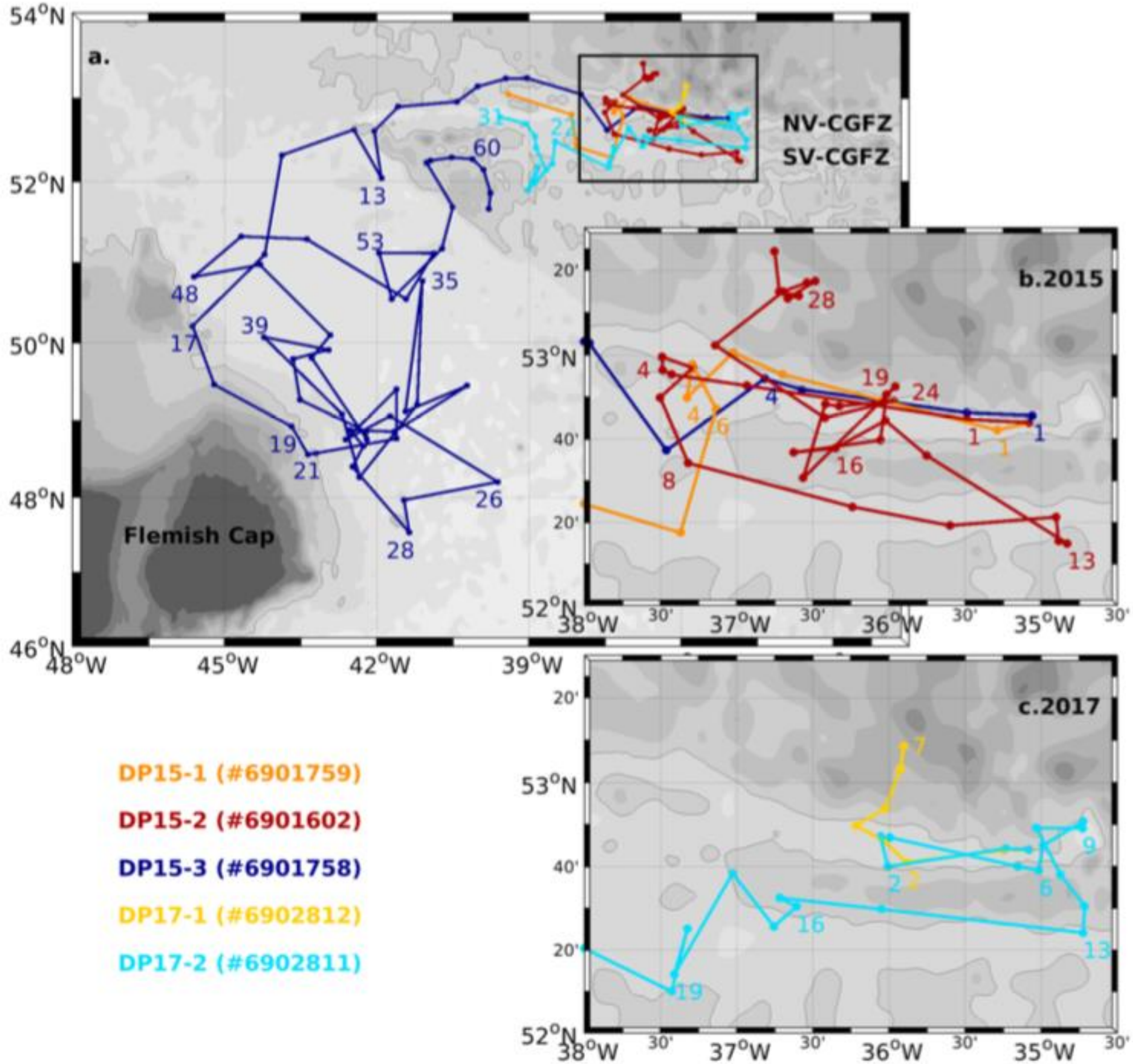
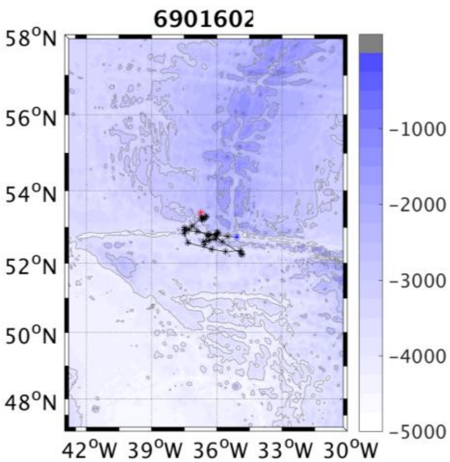


Figure 2. (a) Trajectories of the five Deep-Argo floats deployed in the Charlie-Gibbs Fracture Zone (CGFZ) in summers 2015 and 2017: DP15-1 (WMO#6901759) in orange; DP15-2 (#6901602) in red; DP15-3 (#6901758) in blue; DP17-1 (#6902812) in yellow; DP17-2 (#6902811) in cyan. (b, c) Zoom over the northern and the southern valleys (NV and SV) of the CGFZ for 2015 (b) and 2017 (c). Some cycle numbers where P, T, S, and O_2 profiles were collected are indicated. Bathymetry (m) is colored in gray (the darkest shade indicates the shallowest areas). The gray line shows the 3,500-m isobath.

Deep-Argo data set : **Oxygen correction**

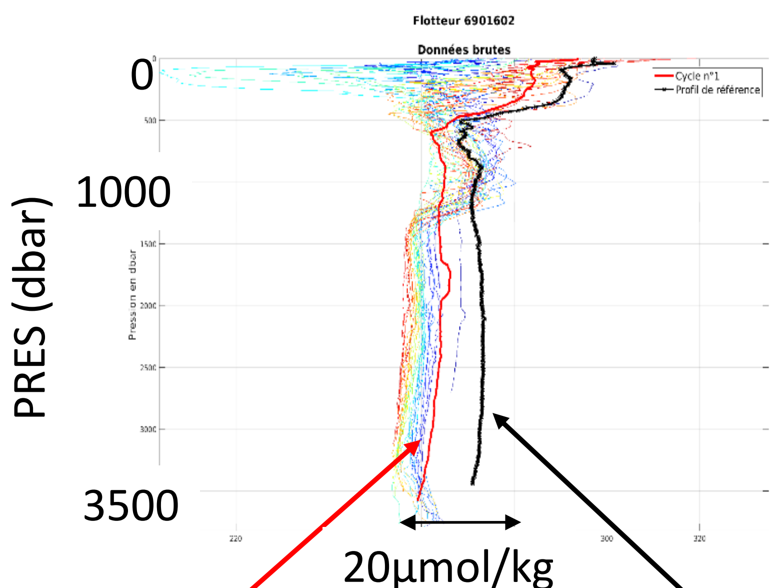


Exemple for float 6901602

After correction following Takeshita et al. 2013:

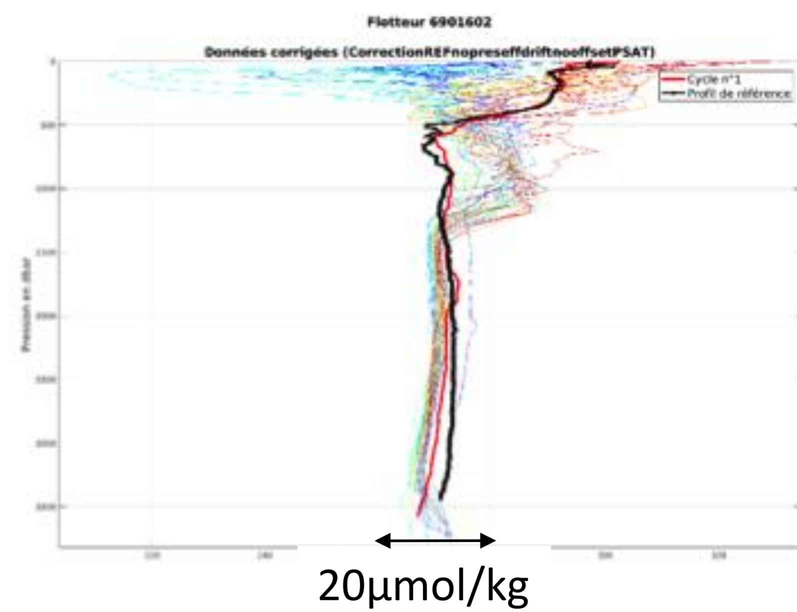
- Time drift
- PSAT_adjusted=a*PSAT

Before correction



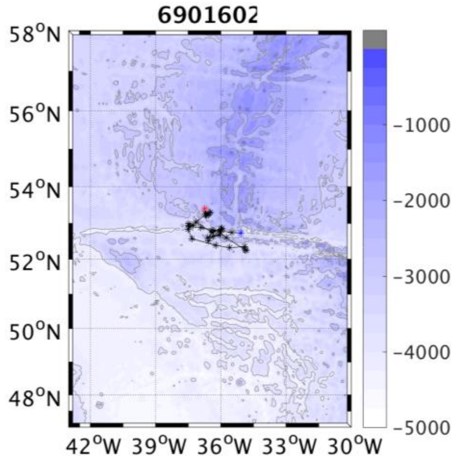
Argo profile to be compared to the reference profile

Reference profile



After correction

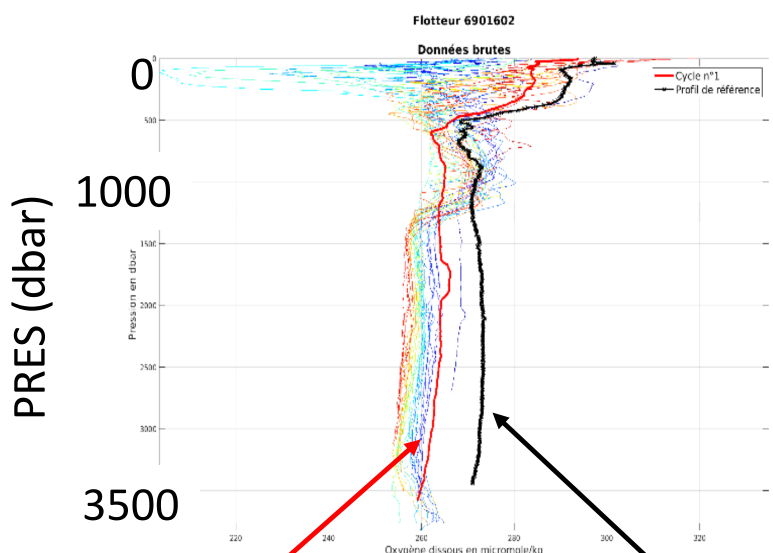
Deep-Argo data set : **Oxygen correction**

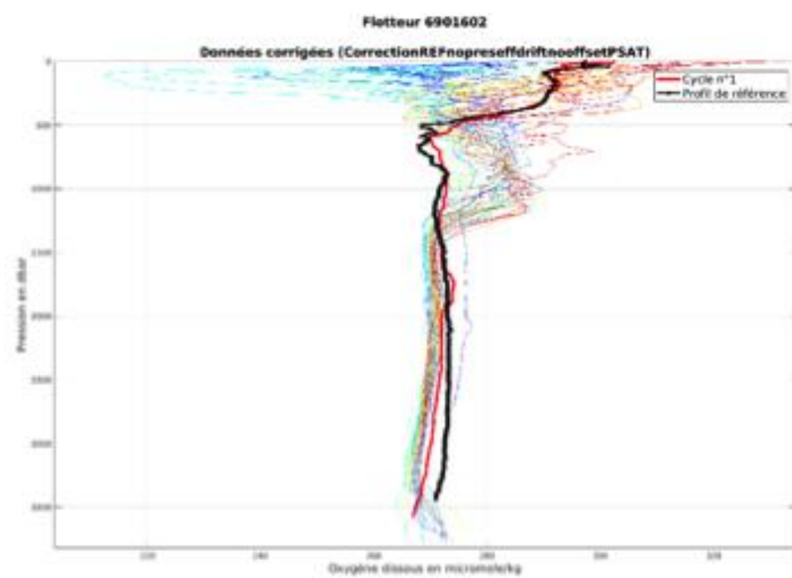


Exemple for float 6901602

After correction following Takeshita et al. 2013:
- A pressure effect remains
- Although pressure correction proposed by Bittig et al, 2015 taken into account

Before correction



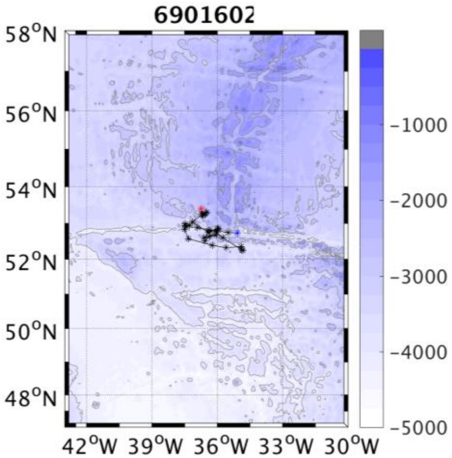


Argo profile to be compared to the refrence profile

Reference profile

After correction

Deep-Argo data set : **Oxygen correction**



Exemple for float 6901602

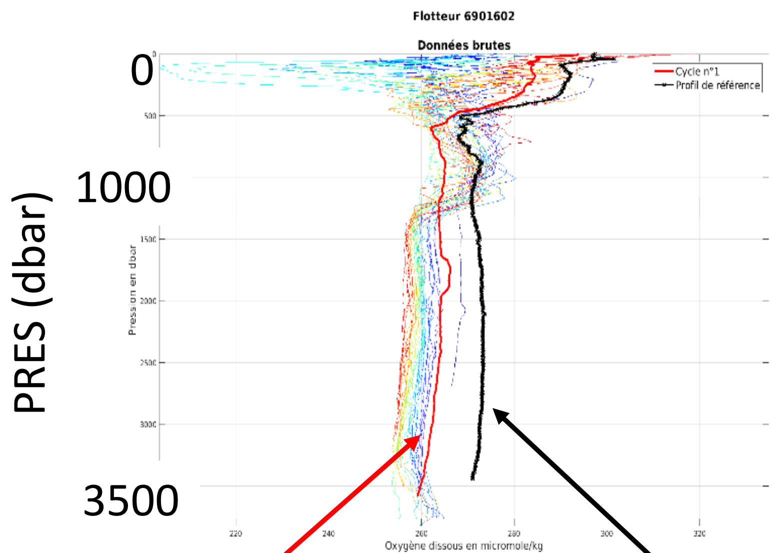
We applied an additional pressure correction on the raw data

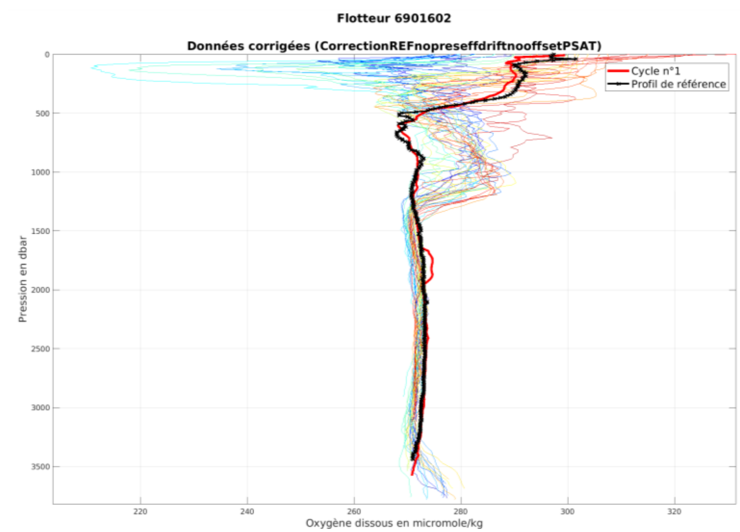
DOXY_corr=DOXY*(1+0.007*PRES/1000)

Time drift

PSAT_adjusted=a*PSAT

Before correction





Argo profile to be compared to the refrence profile

Reference profile

After correction

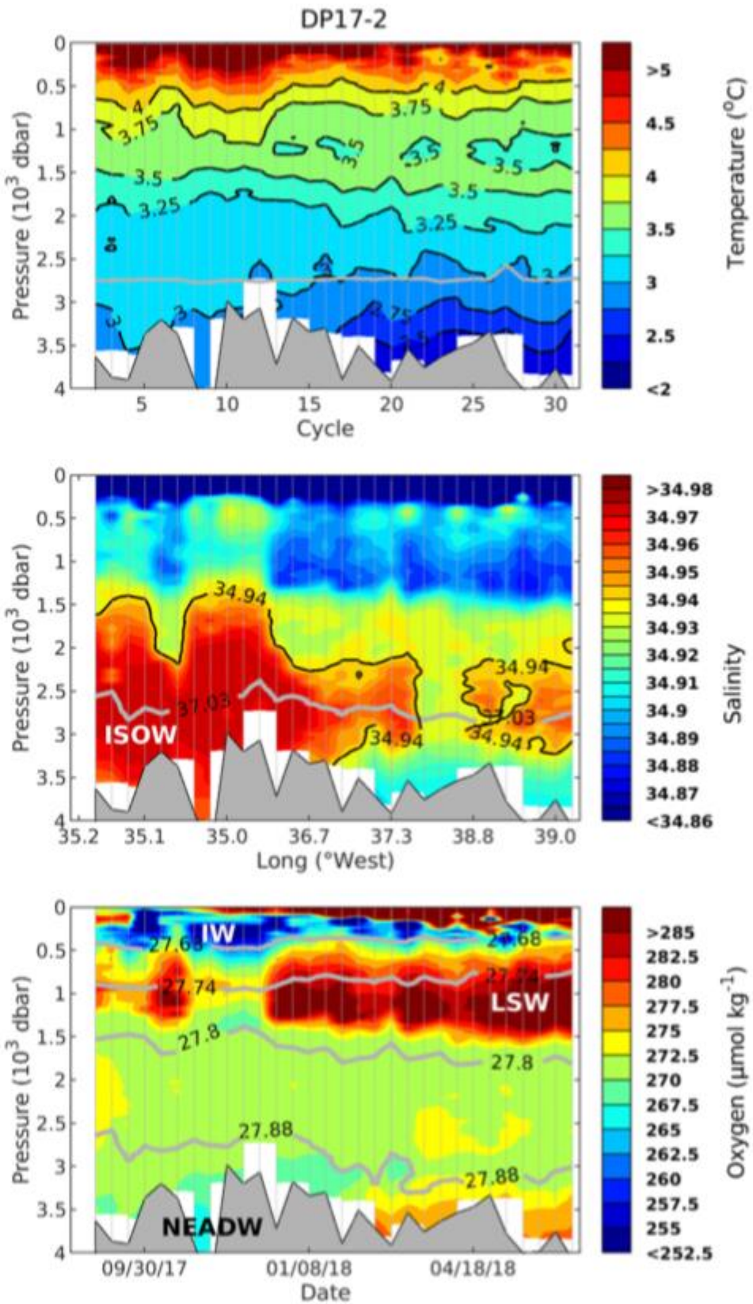


Figure 4. Same as Figure 3, but for DP17-2. The following local water types used in the Optimum Multiparameter analysis are indicated: Iceland-Scotland Overflow Water (ISOW), Intermediate Water (IW), Labrador Sea Water (LSW), and North East Atlantic Deep Water (NEADW).

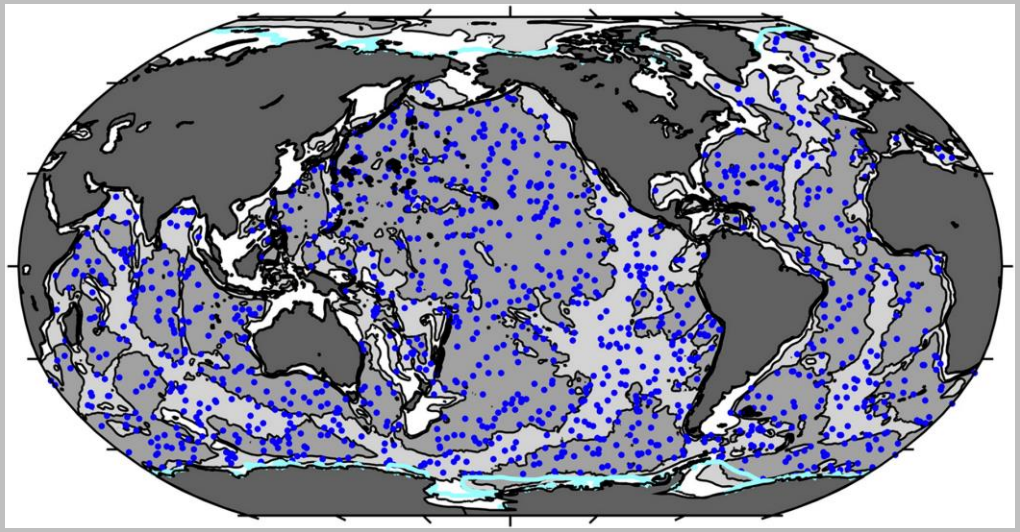
Oxygen measurements from Deep-Argo floats are essential for a better understanding and characterization of the mixing and spreading of deep water masses.

Conclusions

- The five Deep-Argo floats drifted in the ISOW layer and generally moved westward in the CGFZ.
- Northward pathway and recirculation were observed due to NAC interactions with westward deep flow in the ISOW layer
- Deep-Argo floats revealed a direct route for ISOW from the Charlie Gibbs Fracture Zone to the Deep Western Boundary Current
- ISOW is more diluted by NEADW in the southern valley of CGFZ than in the northern valley and when the NAC moves north
- Mixing between ISOW, NEADW, LSW and DSOW is observed in the western basin
- **Biogeochemical sensors are essential** to better identify water masses and understand mechanisms involved.

Future of Deep Argo

Global Deep Argo array



2000-4000 m bottom depth
Bottom depth > 4000 m

(Johnson et al., 2015)

- Deep Argo array of 1200 floats at 5° x 5° x 10-day sampling, will increase accuracy of long-term variations of ocean heat content and sea level (Johnson et al., 2015) and provide the first systematic estimates of deep and abyssal ocean circulation
- Technical readiness and commercial capacity of Deep Argo floats and CTD will be achieved in 2 years
- Deployment strategy for 4000-m and 6000-m floats, will be implemented to resolve the deep-ocean signals of importance
- Implementation of global Deep Argo array would take 4 years based on > 4-year lifetime and 300 float deployments/year

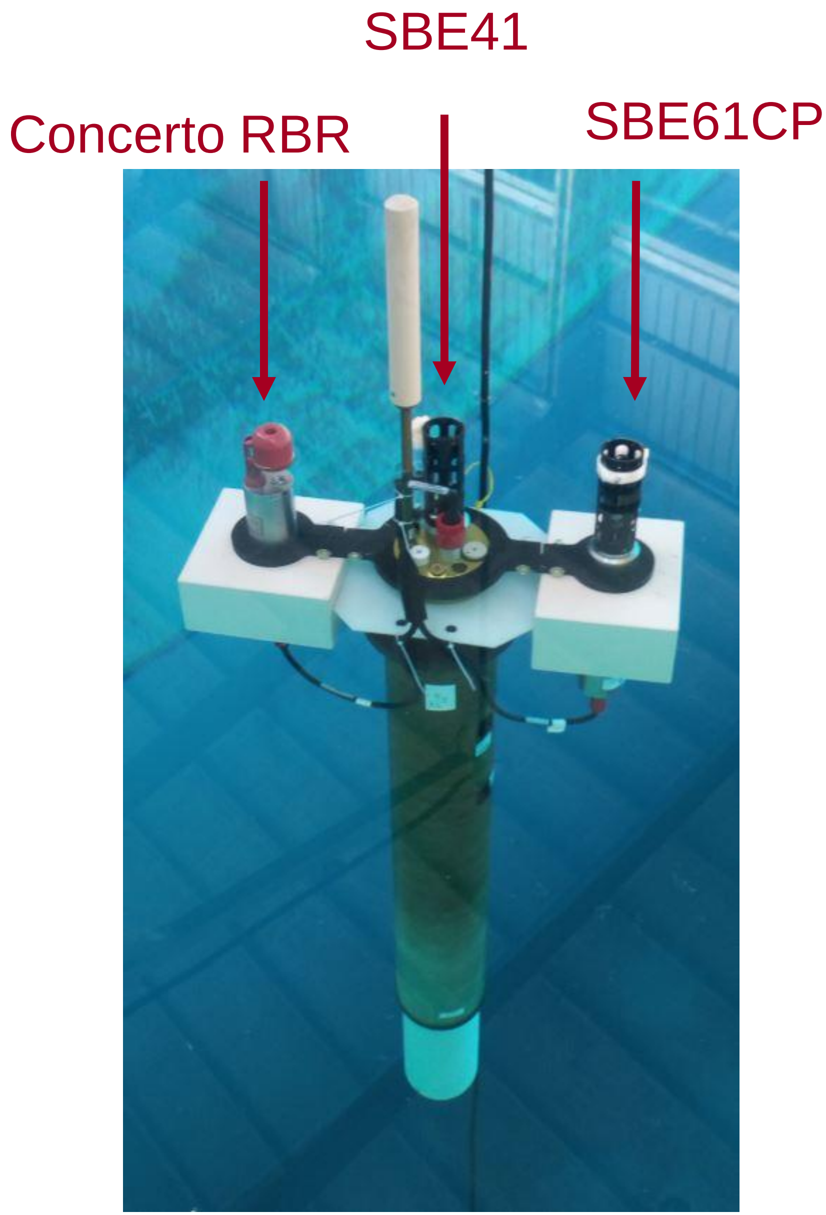
National plans

France

- Floats to be deployed in 2019/2020
  - 6 (NAOS project) + 12 (CPER2017) +15 (CPER2018)
  - Continue regional pilot array in the North-Atlantic
  - Continue deployment in the Equatorial Atlantic and in the Southern Ocean

- Current funding
  - 15 Deep-Arvor floats/year until 2021 (3x15 floats) as part of CPER project

- No sustained funding beyond 2021 yet; two possible funding source will be followed (national and regional level)
  - 30 Core Argo
  - 20 Argo-O2
  - 15 Deep-Argo-O2
  - 15 BGC-Argo

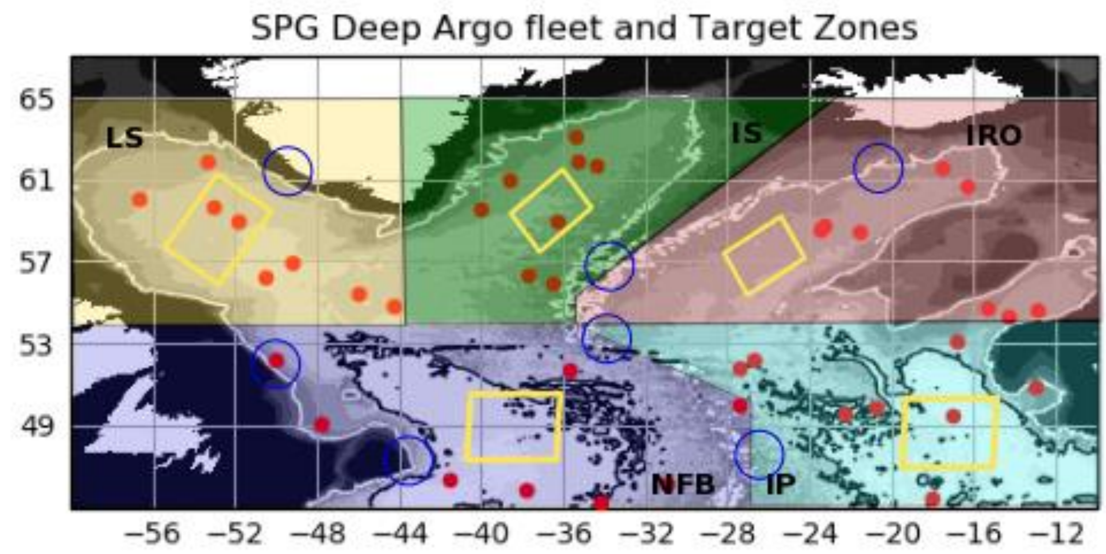


Proposed test for technology development

Compare the two main types of CTD in use at present (SBE41, SBE61) and a newer design (RBR)

Other European contributions (mainly ARVOR)

- Italy
  - 2 deep floats to be deployed in the Western Med in 2019
  - Future plan: 2 floats every 2 years with the goal to monitor the deepest areas of the Western Med continuously
- Spain
  - 2 two-head Deep-Arvor floats (EA-RISE project)
- Norway
  - Funding from the Norwegian Research Council (2018-2023) for purchase of BGC, Deep, core Argo floats.
- Germany
  - Contribution to the sub-polar gyre array



Other international activity

Japan persevering with Deep APEX, as well as Deep Ninja

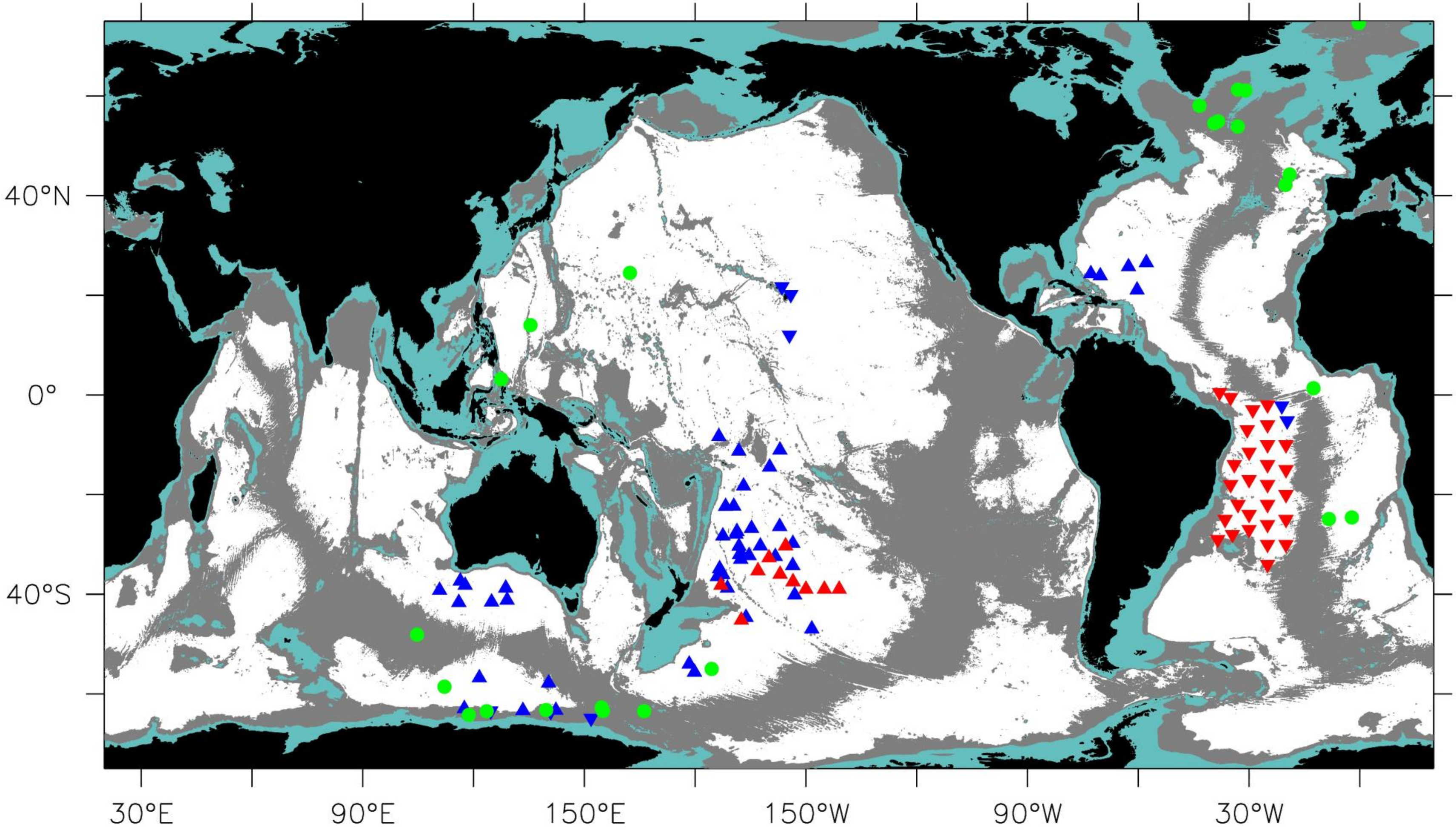
Australia have some Deep SOLOs

China and India have indicated an intention to procure Deep floats

USA will deploy a significant number of Deep SOLOs in the next 12 months

Plus other proposals under consideration

38 Deep SOLOs will be deployed in the next 6 months



- 47 SIO Deep SOLO
- 8 MRV Deep SOLO
- 26 Other Deep Argo
- 10 Planned SIO Deep SOLO
- 28 Planned MRV Deep SOLO (PMEL/PGAFF)

Other international activity

Following the Second Deep Argo Workshop in Hobart in May 2019, the Argo Steering Team has established a Deep Argo Mission Team, co-chairs N Zilberman, B King,
to coordinate international Deep Argo activity and work on experiment design issues.

Issues to address or consider for the design

Sensor performance:

SBE61 and SBE41 have issues with Cp_Cor

RBR being tested

Establish and extend float and sensor survival lifetime for all float types;

need to aim for an average 4-year lifetime; 150 cycles.

Evolve design to blend 4000m and 6000m floats

Consider other aspects of design:

10-day sampling to contribute to core mission

park depth

near-surface sampling for quick delivery by SOLO floats (which normally measure on the descending profile);

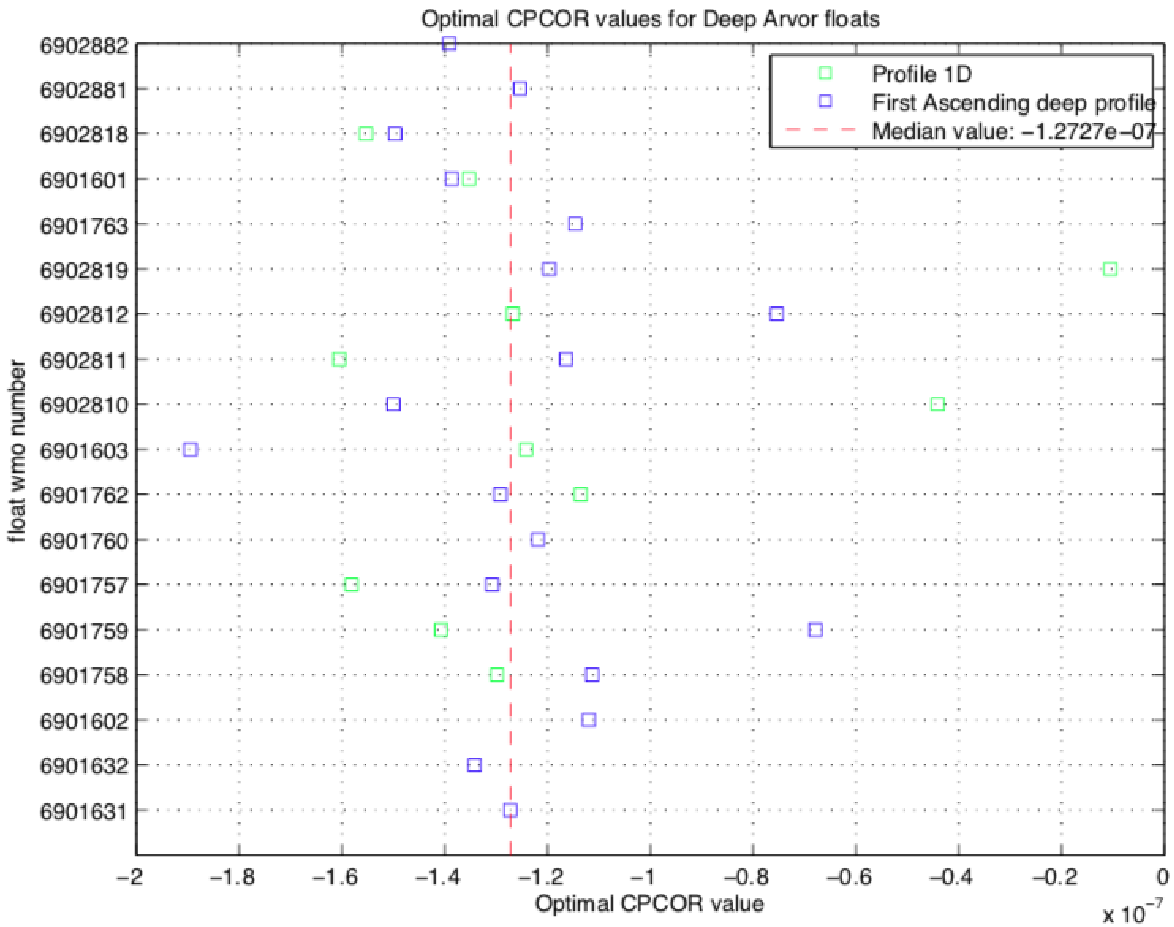
enhanced near-bottom sampling

Issues to address or consider for the design

DMQC will require a selected high-quality reference database, more demanding than for core DMQC – GO-SHIP are helping with this

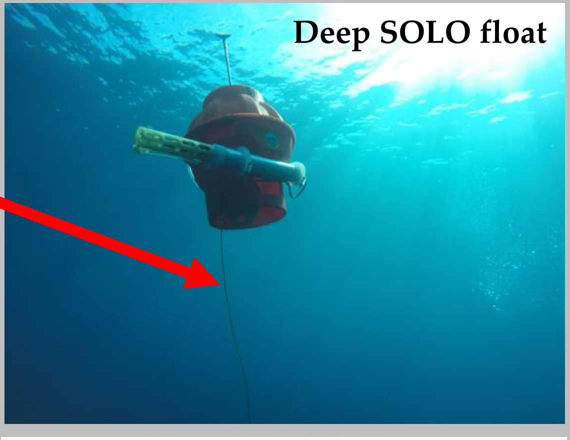
Optimal CPCOR values for Deep Arvor floats

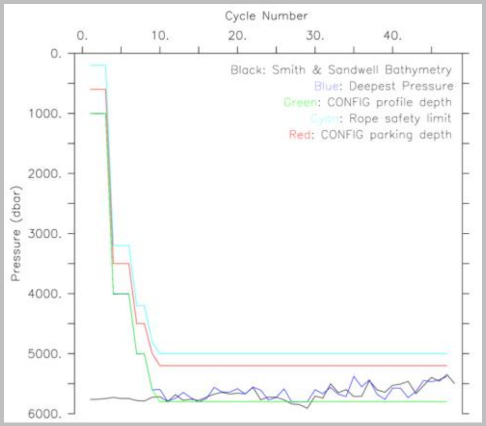
Value used for calculation inside SBE CTD is 9.57 e-8
This issue is holding back the release of Deep Argo data, because it is a bias in deep salinity of 0.006 at 5000 dbar



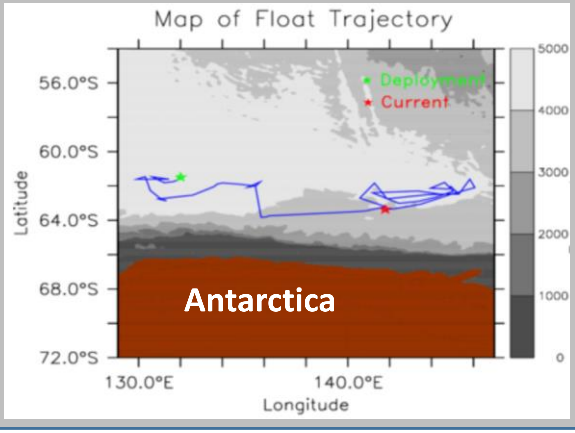
Technology Evolution (2)

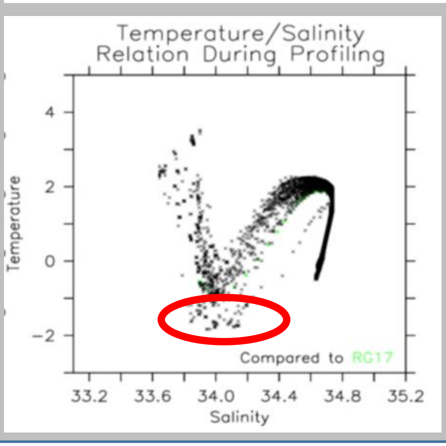
- **Sampling near the sea floor**
  - 3-m wire mechanical bottom detection device on Deep SOLO floats
  - Grounding software on Deep Arvor and Deep NINJA floats



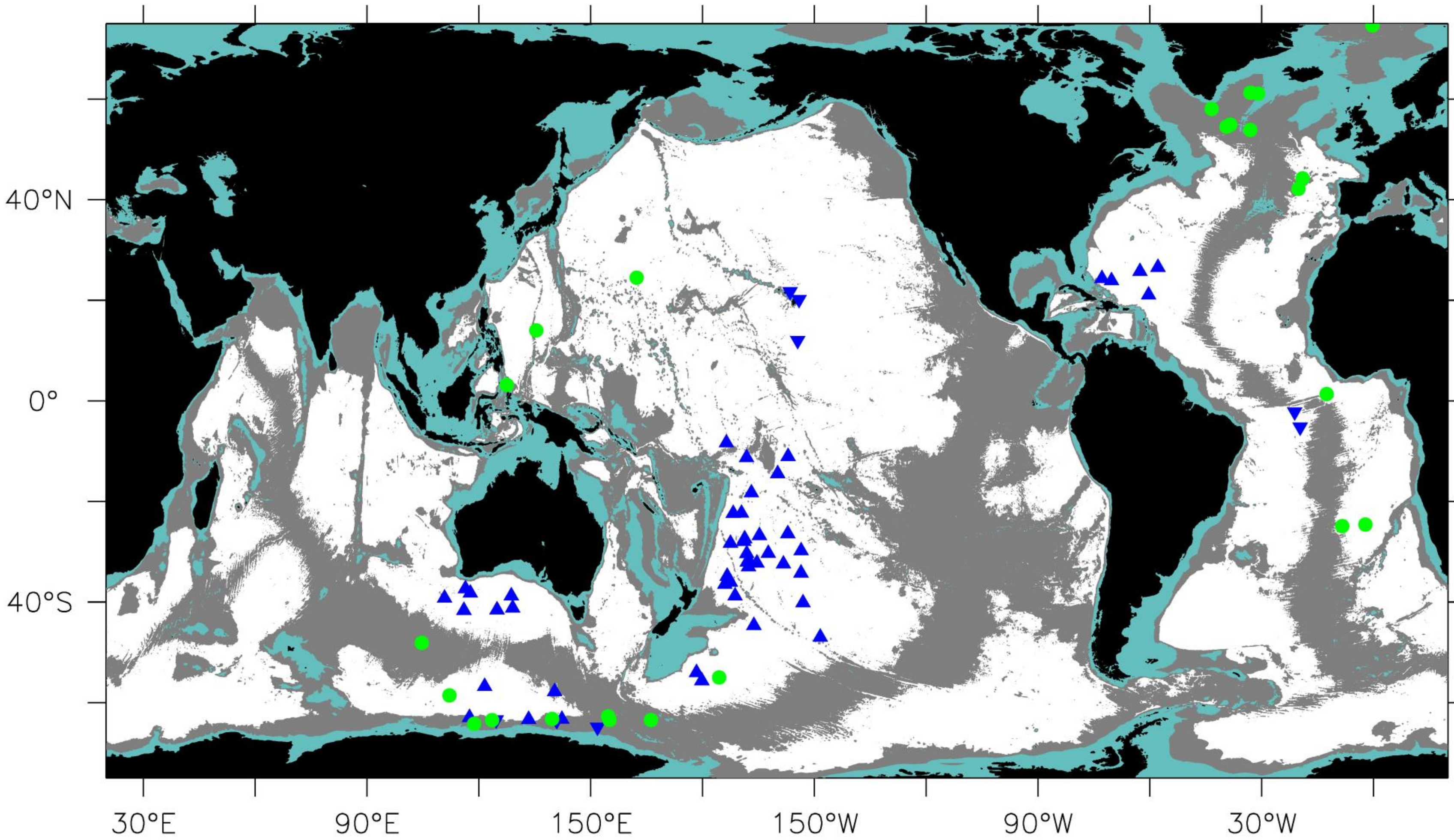


- **Sea-ice avoidance software**
  - Similar to Core Argo floats
  - Implemented on Deep Argo floats deployed at high latitude (i.e. Deep SOLO in Australian Antarctic Basin)





55 Deep SOLOs make up 2/3 of the 81 operational Deep Argo floats. It is important for Argo to have several Deep float models available.

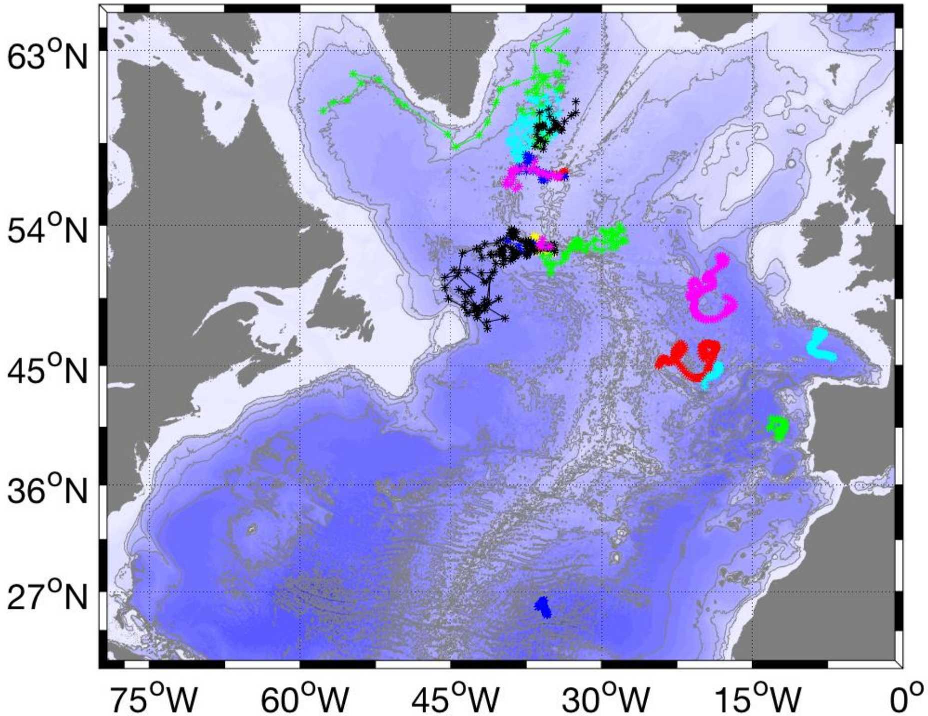


▲ 47 SIO Deep SOLO

▼ 8 MRV Deep SOLO (5 PMEL/PGAFF, 3 CSIRO)

● 26 Other Deep Argo

Maintain and continue the regional pilot experiment in the North-atlantic Ocean



- 20 floats deployed since 2012
- 7 are still active (including the 5 deployed in 2018 + 2 floats deployed in 2017)
- Continue float deployment in the area. Research opportunity cruise for 2020
  - OSNAP
  - AR7W

Sampling strategy

- 10-day cycling period as for core Argo
- parking depth of the float in the core of the ISOW
  - 2750 m in the CGFZ
  - 2100 m in the Irminger Basin
- Oxygen measurements