

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY: Argo float

- Riccardo Martellucci

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-
Mission 4 “Education and Research” - Component 2: “From research to business” - Investment
3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”



Argo network

Argo is the first real-time global in situ observation network in the history of oceanography.



~4000 Argo profilers in the world ocean



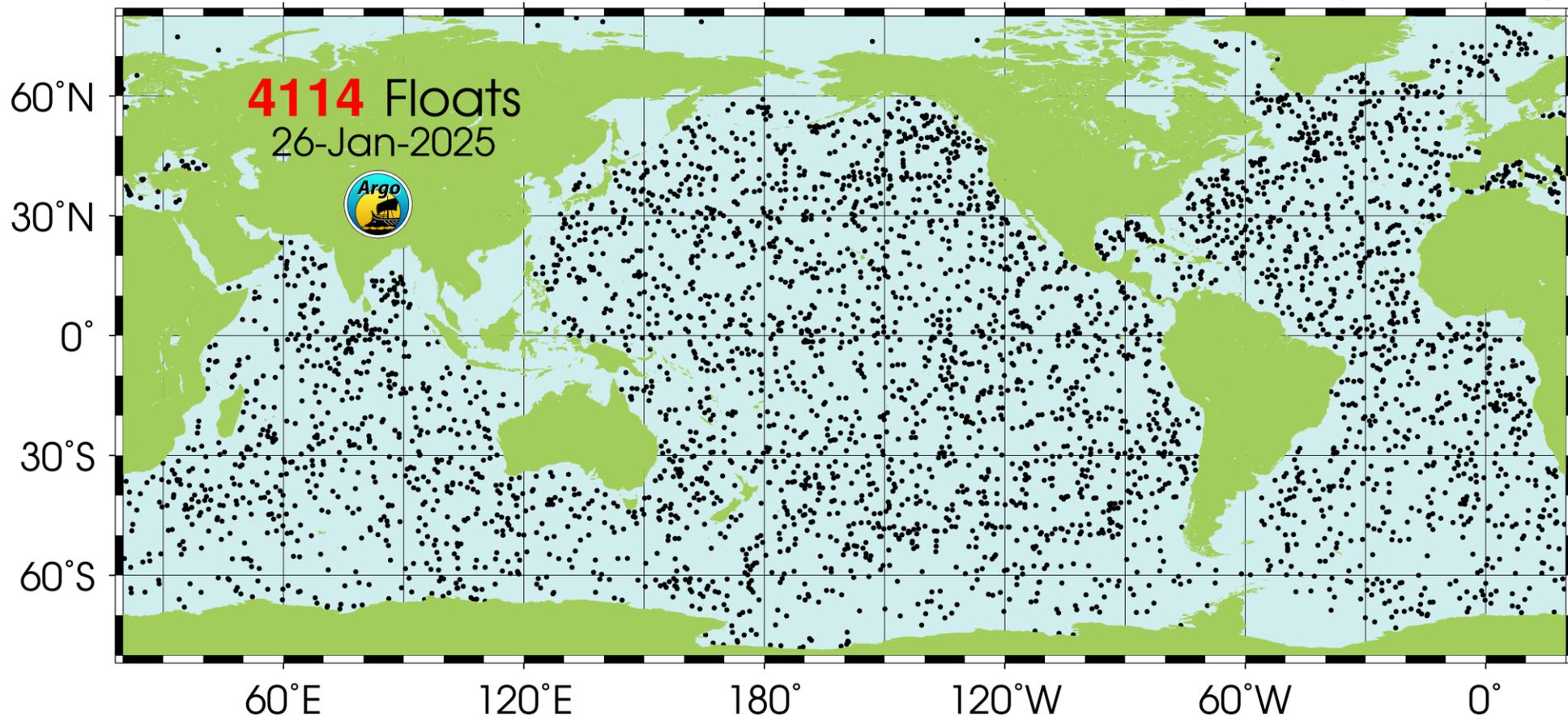
Measurement of physical chemical and biological properties of the oceans



Up to 6000 m depth



> 20 years operativeness

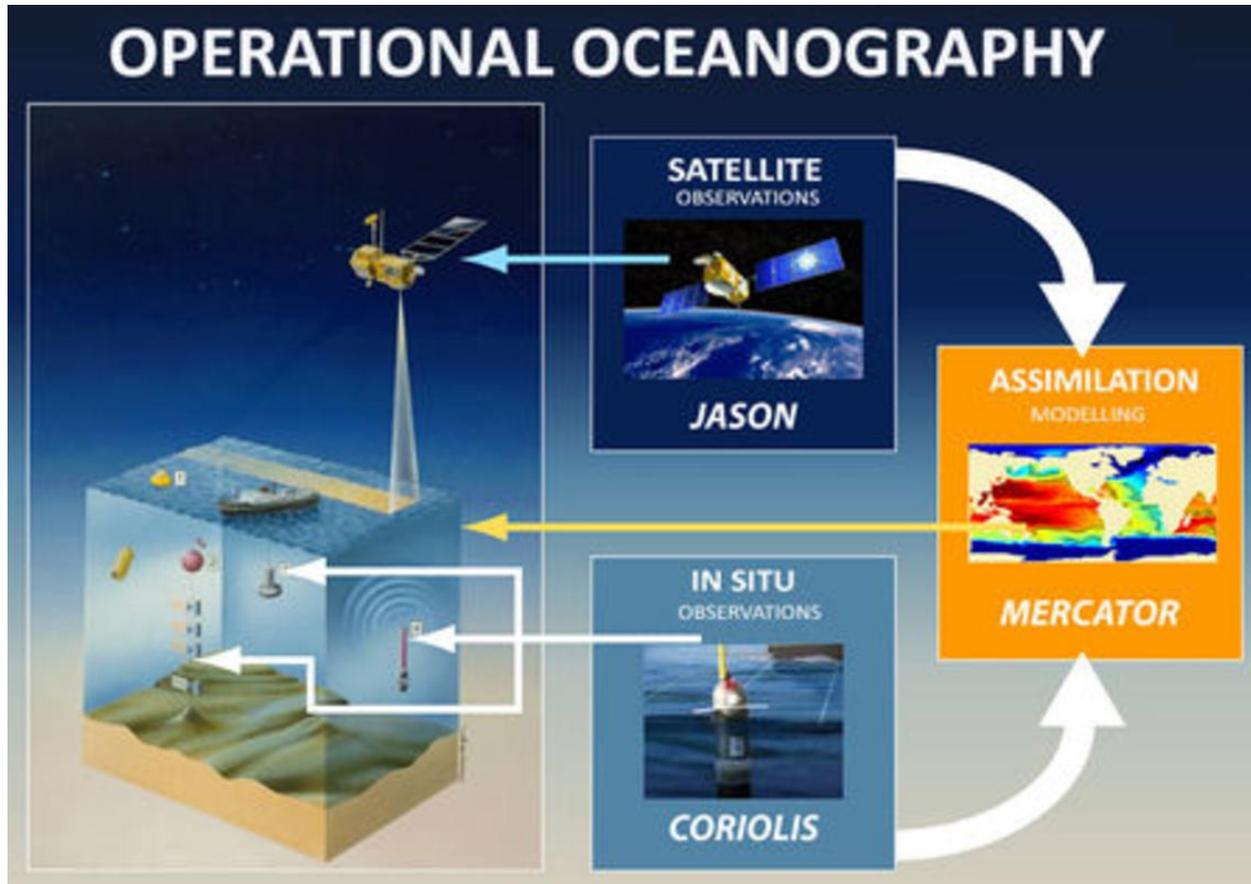


What oceanic processes are scientists trying to explain?

- The **operational oceanography** also uses Argo floats data.
- Operational Oceanography usually proceeds by the rapid transmission of observational data to data assimilation centres. There, powerful computers using numerical forecasting models process the data. The outputs from the models include for instance warnings (of coastal floods, ice and storm damage, harmful **algal blooms*** and contaminants, etc.), electronic charts, optimum routes for ships, prediction of seasonal or annual **primary productivity***, ocean currents, ocean climate variability, etc.



Argo benefits



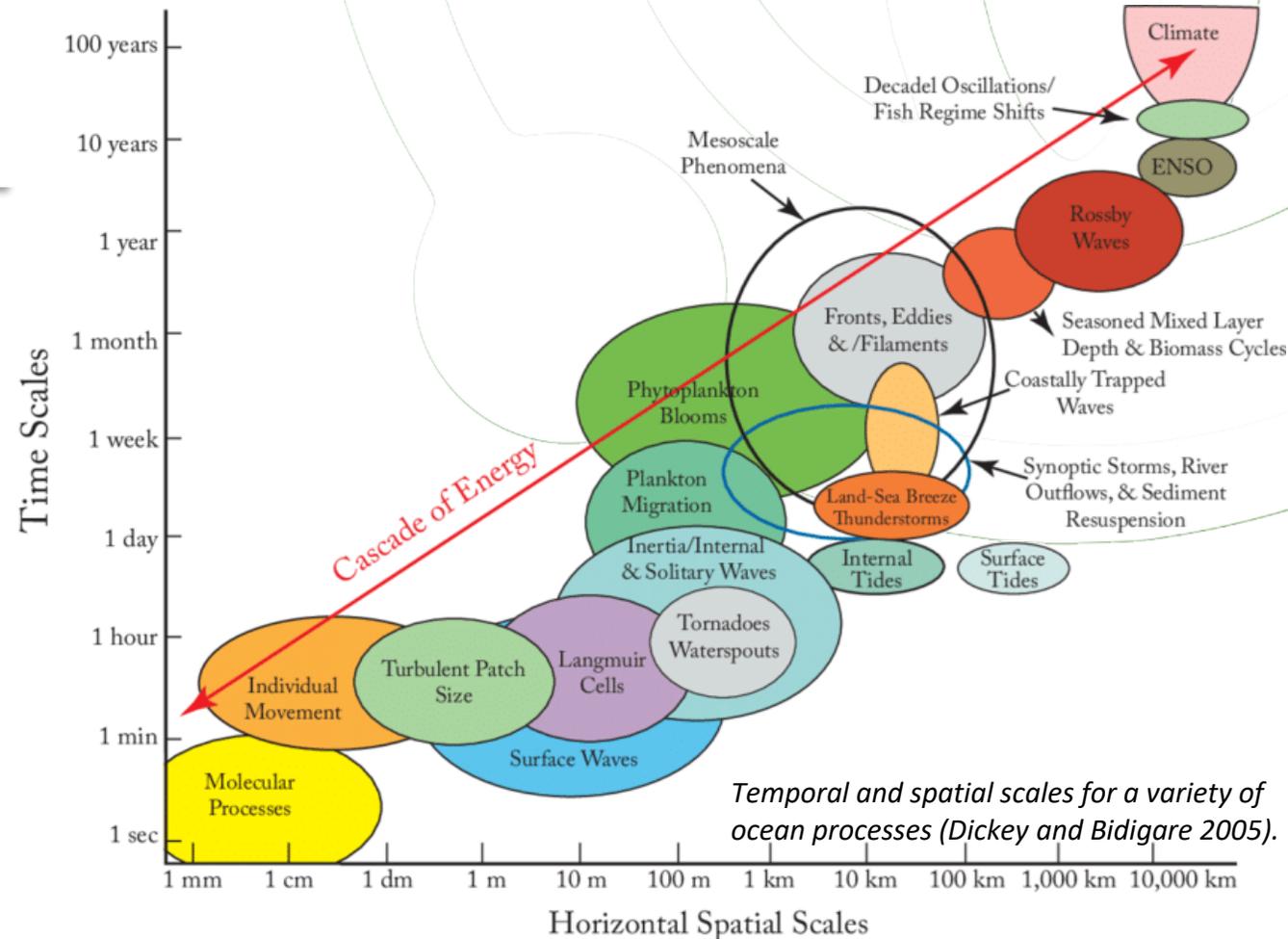
- ✓ **Argo data** will provide a quantitative **description** of the evolving **state of the upper ocean** and the patterns of ocean **climate variability**, including **heat** and freshwater **storage** and **transport**.
- ✓ The data will **enhance** the value of the **Jason altimeter** through measurement of subsurface **vertical structure** ($T(z)$, $S(z)$) and reference **velocity**, with sufficient coverage and **resolution** for interpretation of altimetric **sea surface height variability**.
- ✓ **Argo data** will be used for **initialization** of ocean and **coupled forecast models**, **data assimilation** and dynamical model testing.

Temporal and spatial scales of ocean processes

Environmental phenomena vary in space and time. Spatial and temporal variability may be attributed to a combination of environmental factors that modulates marine ecosystems.

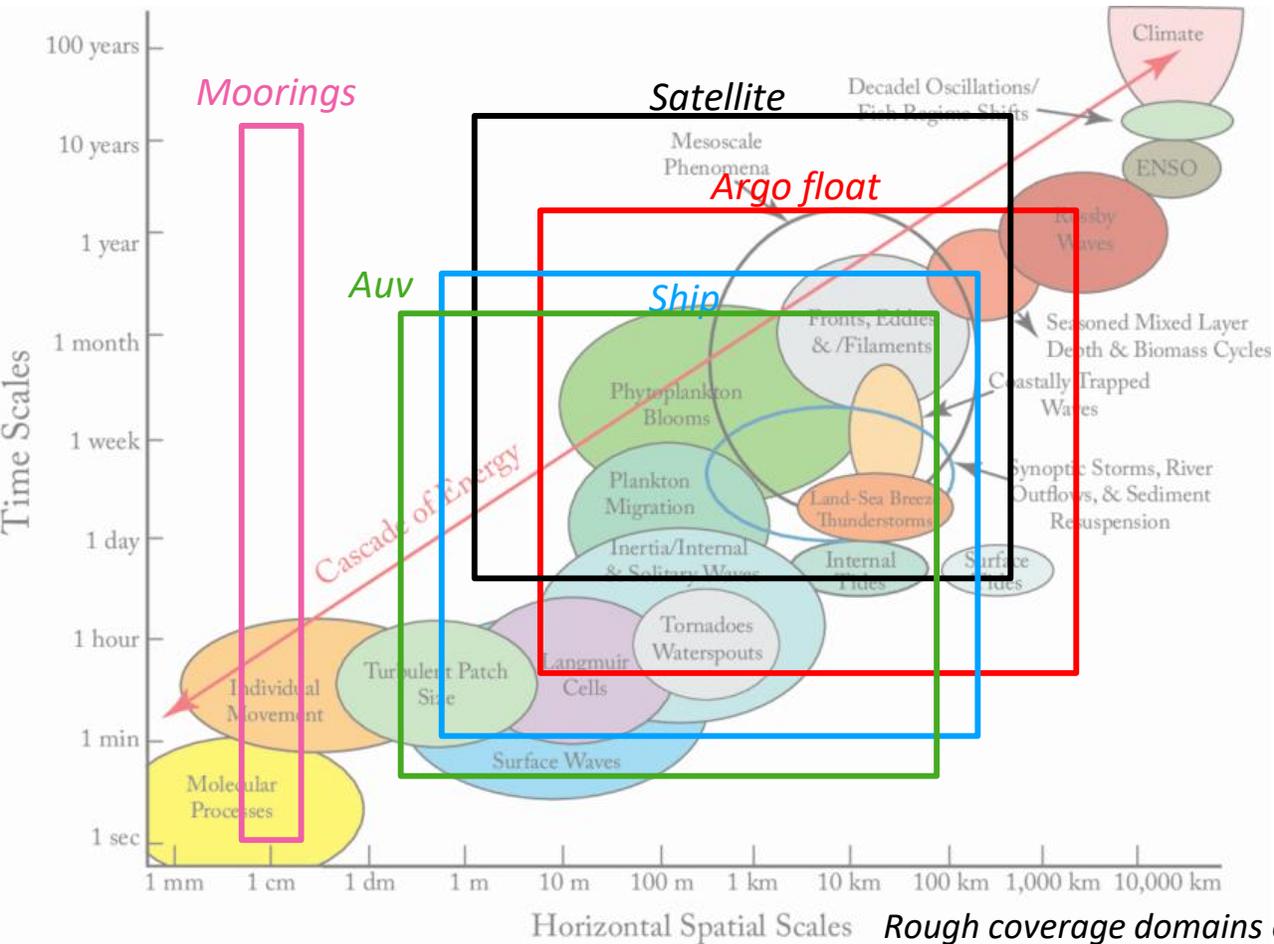
In general, spatial variability ranges from millimetres to meters to kilometres to thousands of kilometres while temporal variability ranges from seconds to minutes to hours to days to weeks to seasons to years to decades and onto millennia.

The challenge is to collect correctly data to recognize the key elements to describe appropriately phenomena in its spatial and temporal scale.



Temporal and spatial scales: oceanographic platform

In marine processes studies the knowledge of a phenomenon depends observations, which are usually extremely complex because of the intrinsic difficulty of the type of measurements that have to be made.



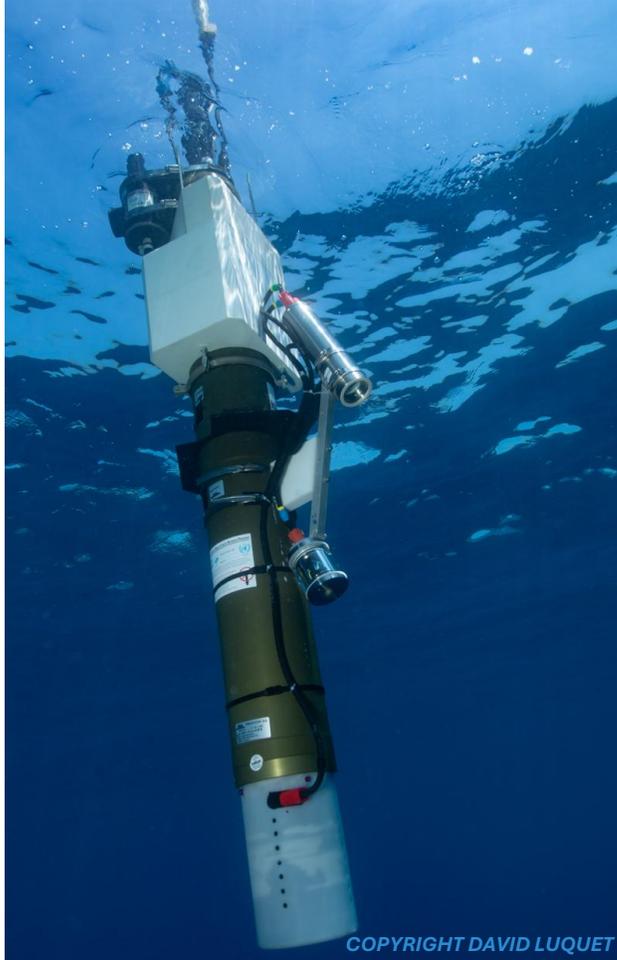
Rough coverage domains of various oceanographic platform (Dickey and Bidigare 2005).

- ✓ To correctly assess a phenomenon, it is necessary to use measurement platforms that can correctly measure the spatial and temporal scale relative to the phenomenon itself .
- ✓ Information on phenomena is often described from a combination of historical information, satellite imageries, in situ data, and numerical model output.
- ✓ These issues are specifically urgent and strategic for coastal areas, that present an extremely high spatial-temporal variability.

What does Argo mean?

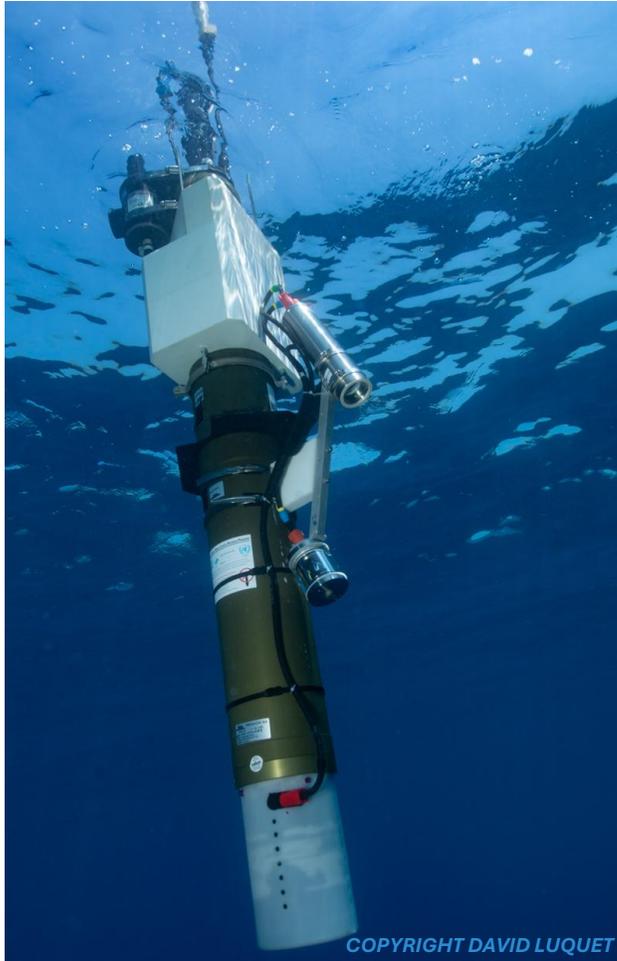
Array for Real-time Geostrophic Oceanography

Roemmich Dean, SIO



- Began in **1999**, initiated by the "**Argo Science Team**" to create a **global array** of autonomous floats for measuring **temperature** and **salinity** in the upper **2,000 meters** of the ocean.
- Recognized as a **pilot program (*Indian ocean*)** under the Global Ocean Observing System (**GOOS**).
- Scaled up to global deployments by 2004
- Deploy **3,000 floats** in a 3° x 3° array between **60°N and 60°S** in **2007**
- Initially supported by countries like U.S., Australia, Canada, France, Japan and the U.K., with over 700 floats deployed annually by 2002.
- Today, **34 countries** are involved.

New way to monitor the ocean



Argo network is a descendent of the **WOCE** (World Ocean Circulation Experiment, 1990-1997) hydrographic float program, **TOGA** (Tropical Oceans and Global Atmosphere, 1985-95), and **XBT** (Expendable Bathythermograph) sampling networks (which started in the 1970s - during the 1990's about 40,000 XBT profiles have been collected to 450 m or 750 m depth per year). Large-scale float deployments were integral to the WOCE sampling strategy. The **Argo network extends** the spatial and temporal **coverage**, depth range and **accuracy of its predecessors, enhancing** them through the **addition of salinity** measurements.

*A major breakthrough of the float family occurred in WOCE, when floats were developed that could repeatedly cycle to the ocean surface from their mid-depth drift pressure. This surfacing feature enabled global satellite tracking and communication, and by the late 1990s, **CTD** (Conductivity Temperature Depth) sensors were added to the instruments to collect vertical profiles of temperature and salinity.*

History



The **idea** of using neutrally buoyant **floats** to measure **sub-surface ocean currents** was first developed in the mid-1950s by **Henry Stommel** John Swallow.

The **first floats** were built and tested by Dr. **Swallow** and consisted of pressure cases made of aluminium scaffold tube and that were tracked by obtaining bearings from an attendant ship on the floats' free-running 10 kHz sound source.

Henry Stommel's theoretical model for deep circulation, suggested that the water carried equatorward in the deep western boundary currents must be brought back to the poles by slowly bleeding into the interior and then drifting sluggishly poleward and upward through the main thermocline.

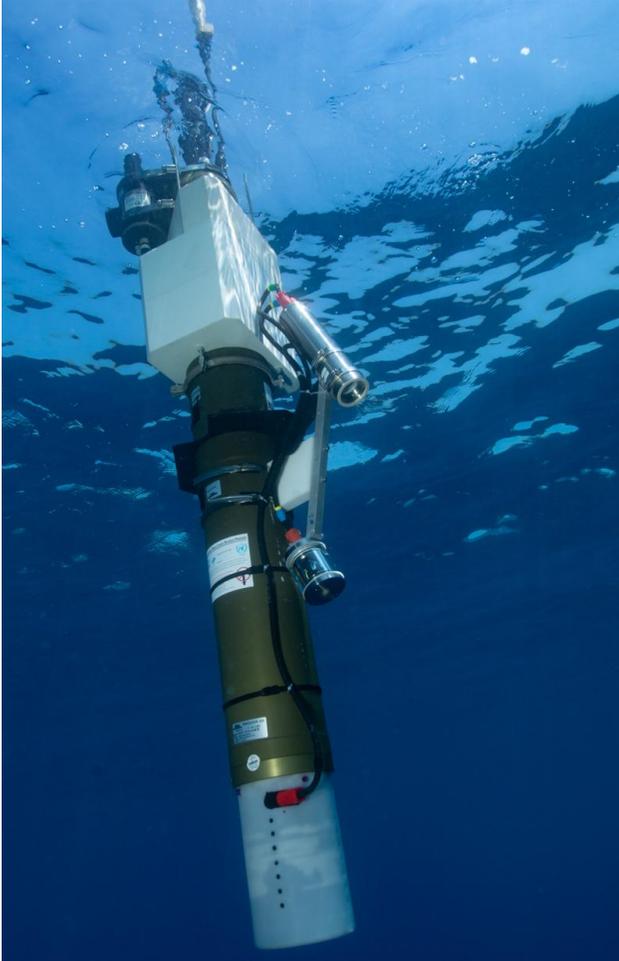
The **“Swallow Float”** **uncovered** important elements of the **ocean's general circulation**, confirming this slow, poleward drift in the ocean interior, the **Deep Western Boundary Current** a crucial part of the ocean's thermal engine.

J.C. Swallow. (1953). A neutral-buoyancy float for measuring deep currents. , 3(1), 74–81. doi:10.1016/0146-6313(55)90037-x

Argo objectives

- Collect global temperature/salinity data set.
- Make data available in real-time (24h)
- Achieve delay-mode data quality approaching that of R/V observations
- Document ocean heat and freshwater storage and large-scale transport (CLIVAR).
- Use with other in situ and satellite data for ocean state estimation and ocean forecasting.
- Maintain a global array of autonomous profiling floats integrated with other elements of the climate observing system

Argo is a major contributor to the [World Climate Research Programme's \(WCRP\) Climate Variability and Predictability Experiment \(CLIVAR\)](#) project and to the Global Ocean Data Assimilation Experiment (GODAE). The Argo array is part of the Global Climate Observing System/Global Ocean Observing System OceanView GCOS /GOOS).



AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Curiosity!!

In September 2018, a float drifting in the Ionian Sea, a familiar place for an Argonaut, collected its two millionth profile.



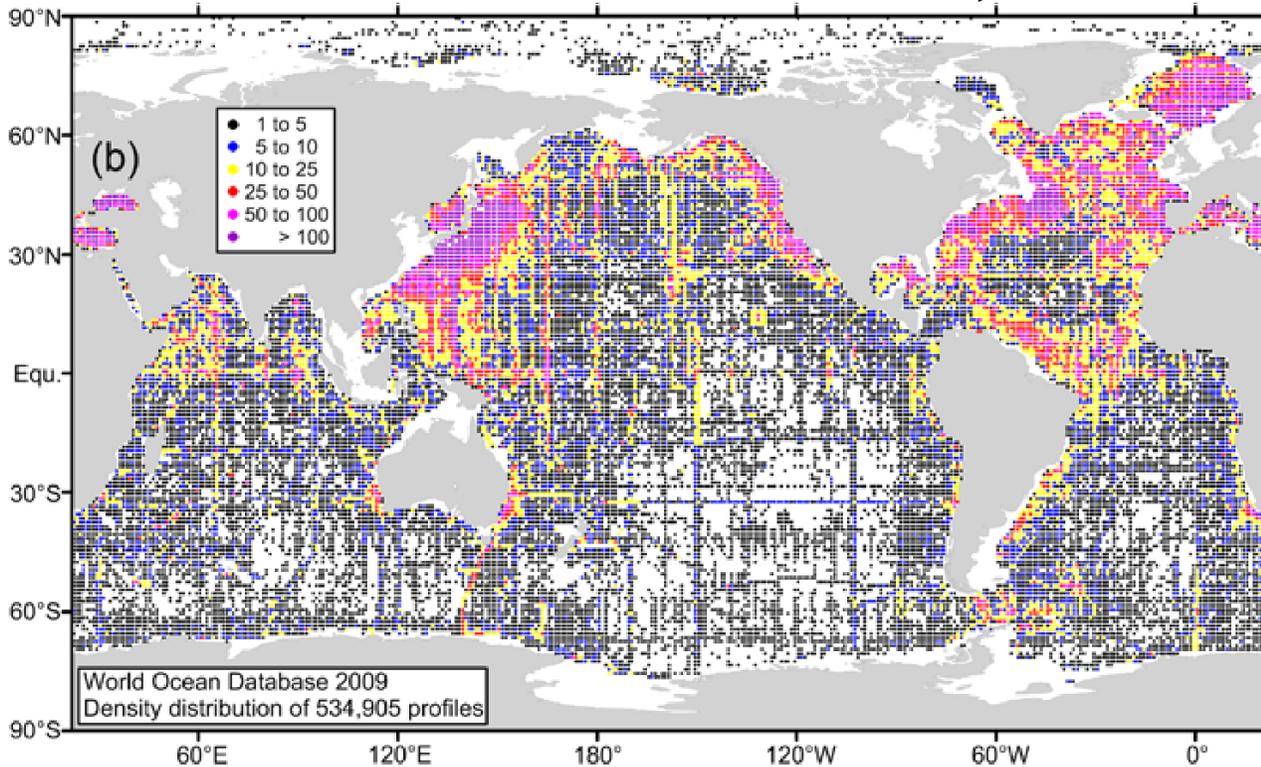
In the Greek epic Argonautica, Jason and his crew sail their ship, the Argo, on the Mediterranean Sea and the Black Sea, voyaging from Greece to what is now the modern-day Republic of Georgia. The name Argo was chosen because of the program's partnership with the Jason earth observing satellites that measure the shape of the ocean surface.



In Greek mythology, Jason sailed on his ship the Argo. In oceanography, Jason and Argo together would provide regular global sea surface height and subsurface temperature and salinity measurements.

Argo advantages

G.C. Johnson et al., 2021 - ARMS



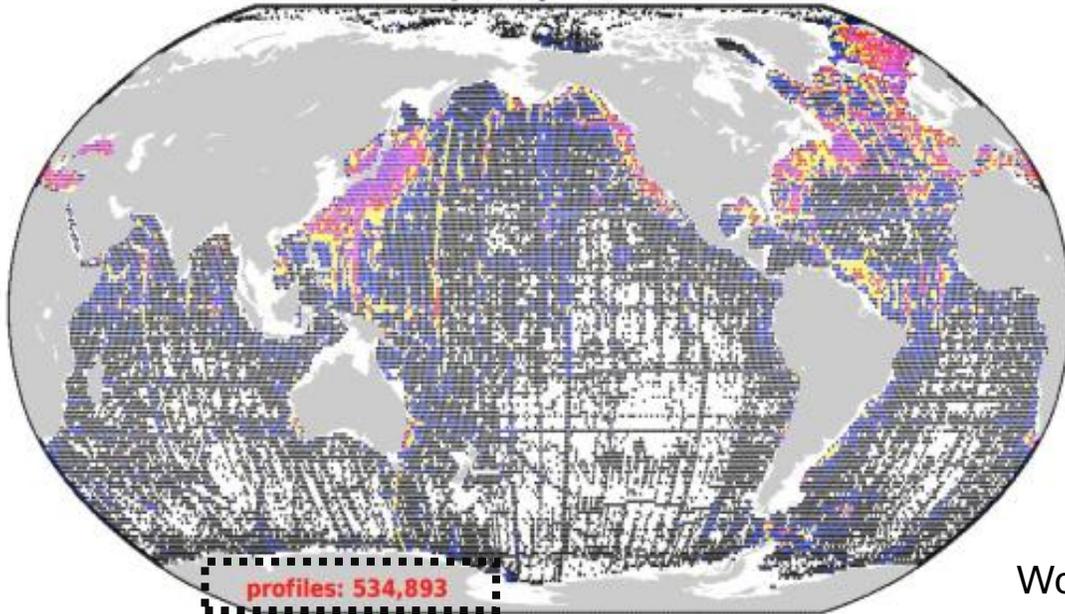
- The array of Argo floats, serves as a pilot program of the **Global Ocean Observing System** and be used to fill in the large data gaps in ocean observations.
- **Throughout history**, scientists and explorers have **observed** the **ocean** using **ships, buoys**, and other tools.
- **The seas** are often **inhospitable** for people and scientific instruments alike, with **raging storms** and **ice cover** at the surface, and **crushing pressures at depth**.

Comprehensive **data** on the physical state of the **ocean** have been **difficult to collect**, serious limitations to further advances included **poor spatial and temporal** coverage over much of the globe, **insufficient depth range** and **accuracy of XBT data**, and a lack of **systematically repeating salinity measurements**.

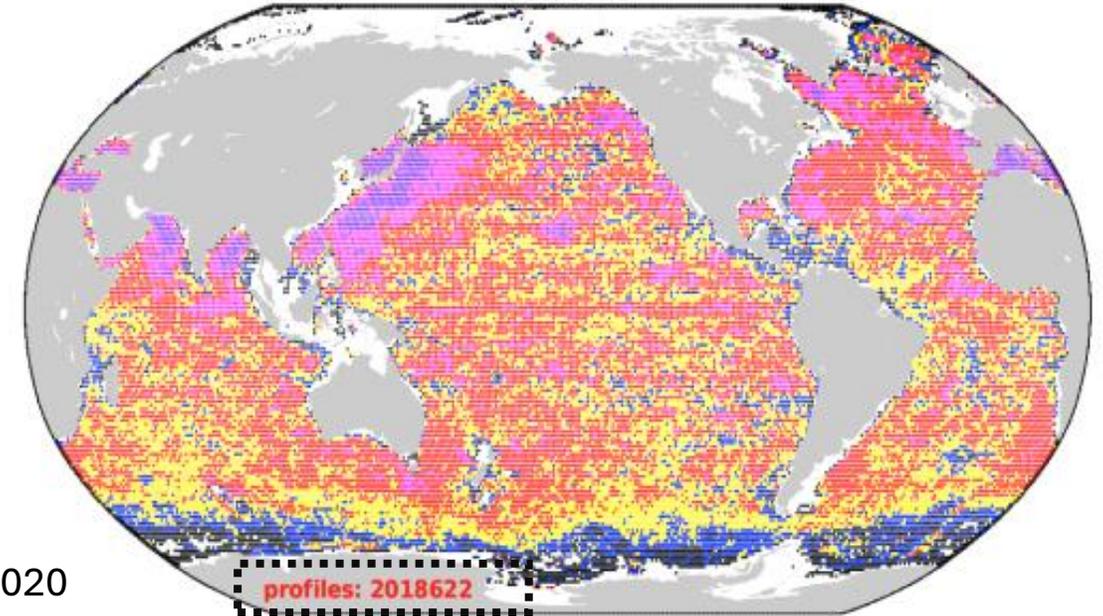
AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

- **Beginning** with the first major **oceanographic cruise**, the British **Challenger** expedition in the **1870's**, about **535000** temperature and salinity **profiles** (to at least 1000 meters) have been **collected** by **ship-based** instruments.
- In **two decades**, **Argo** has nearly **quadrupled** the **number** of deep-ocean profiles.
- **Argo observations** also **provide** a more **complete picture** of the ocean because they are **not limited** to a few **shipping tracks**, and sample through all **seasons** regardless of **weather conditions**.

World Ocean Database observation density
in profiles per 1 degree box
January 2018



Argo observation density
in profiles per 1 degree box
10/31/2018



Wong et al. 2020

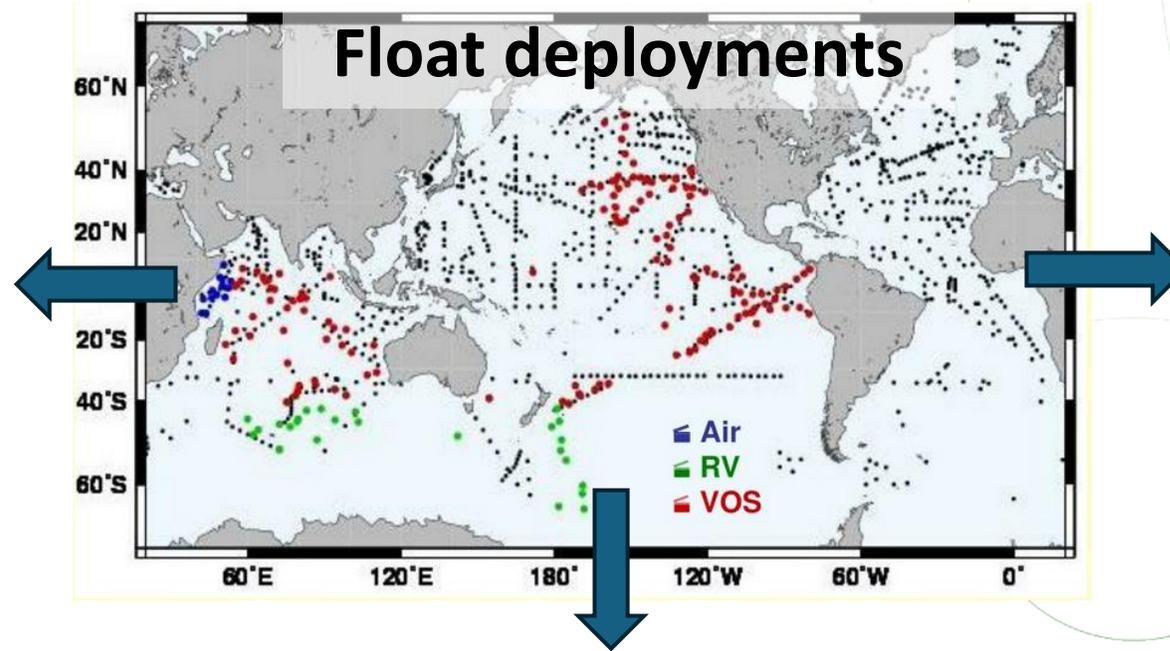


AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Research vessel



Rarely visited area
Technical support available
Ancillary data collection
Few R/V



Commercial vessel



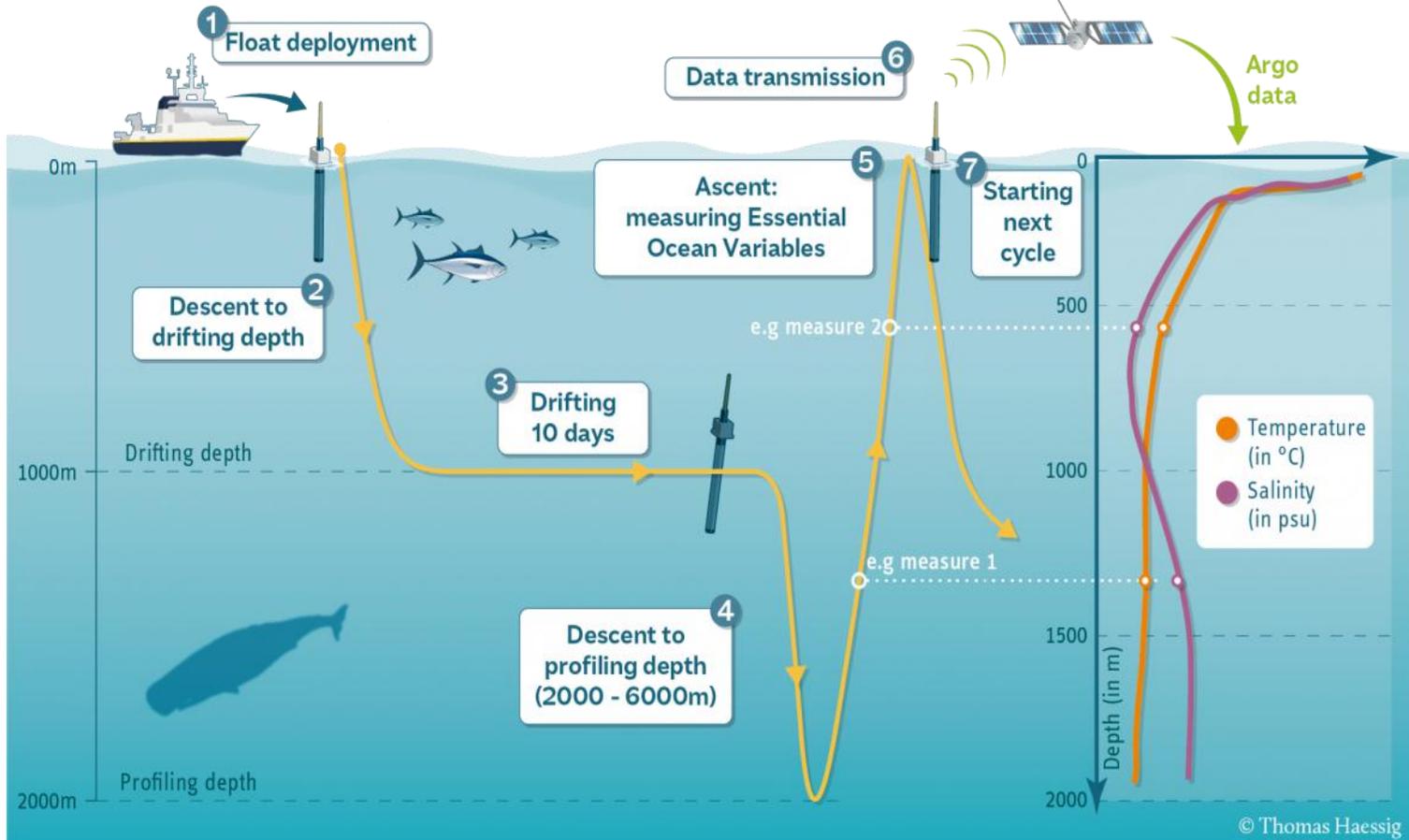
Long tracks
Mostly North hemisphere
Need to provide tech support
Vessel won't stop



Aircraft

Dedicate mission
Remote area coverage
Logistics
Higher failure rate

Standard Argo profiling and data flow



- The float descends to a **target depth of 1000m** to “park” (350m Med-sea) and drift with the ocean currents.
- Every **10 days** (5 Med-sea) the float descends to **2000m** and then collects a **vertical profile of temperature and salinity** during ascent to the surface.
- When a float **surfaces**, the data are **transmitted** and the float’s position is determined either by **Argos** or by **GPS**.
- The **float** then **returns** to the target **park** pressure and the **cycle** is repeated.

4 Years
Expectation of
operation

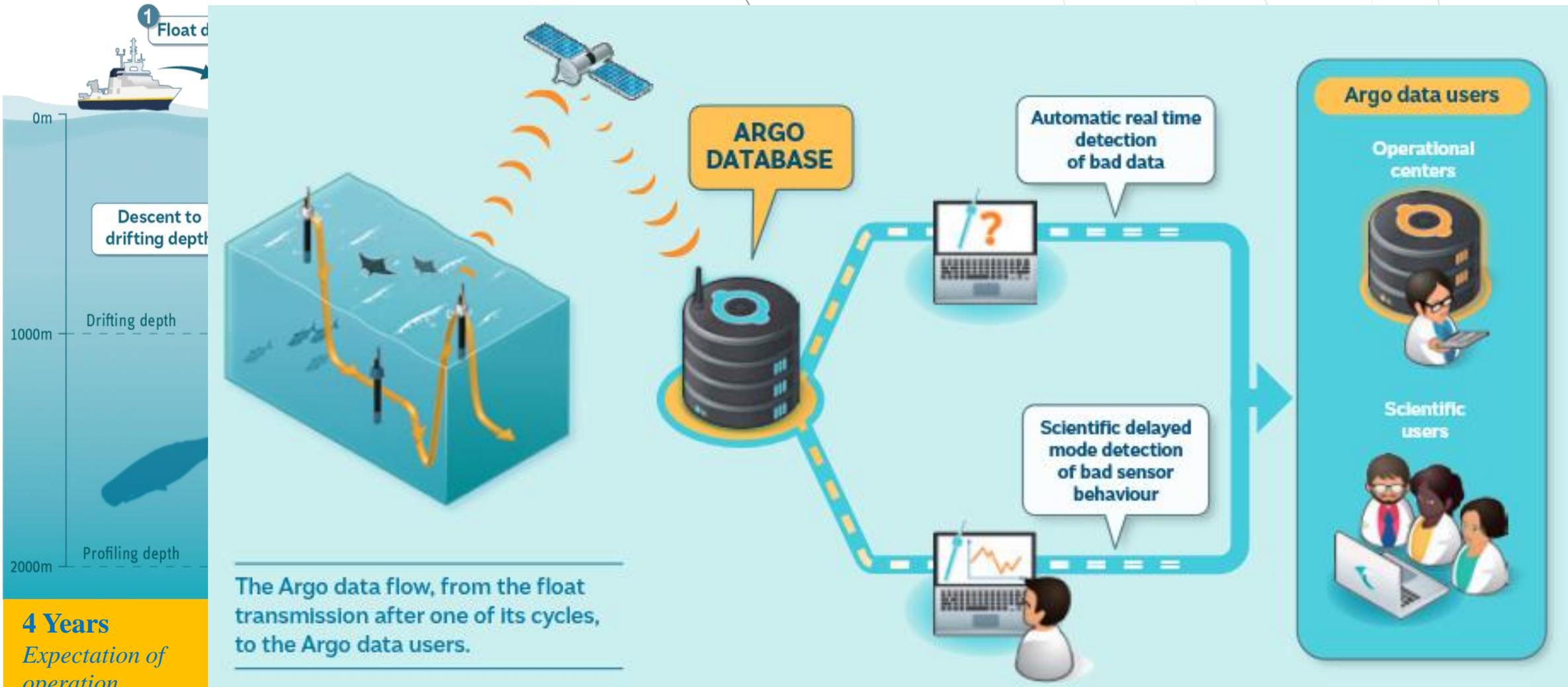
~ 10 days
Realization of a full
cycle

~ 12 hours
Real-time data
transmission

Morris, Tamaryn, et al. "Best practices for Core Argo floats-part 1: getting started and data considerations." *Frontiers in Marine Science* 11 (2024): 1358042.

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Standard Argo profiling and data flow



4 Years
Expectation of
operation

cycle

IT (2024). 133042.

of
drift

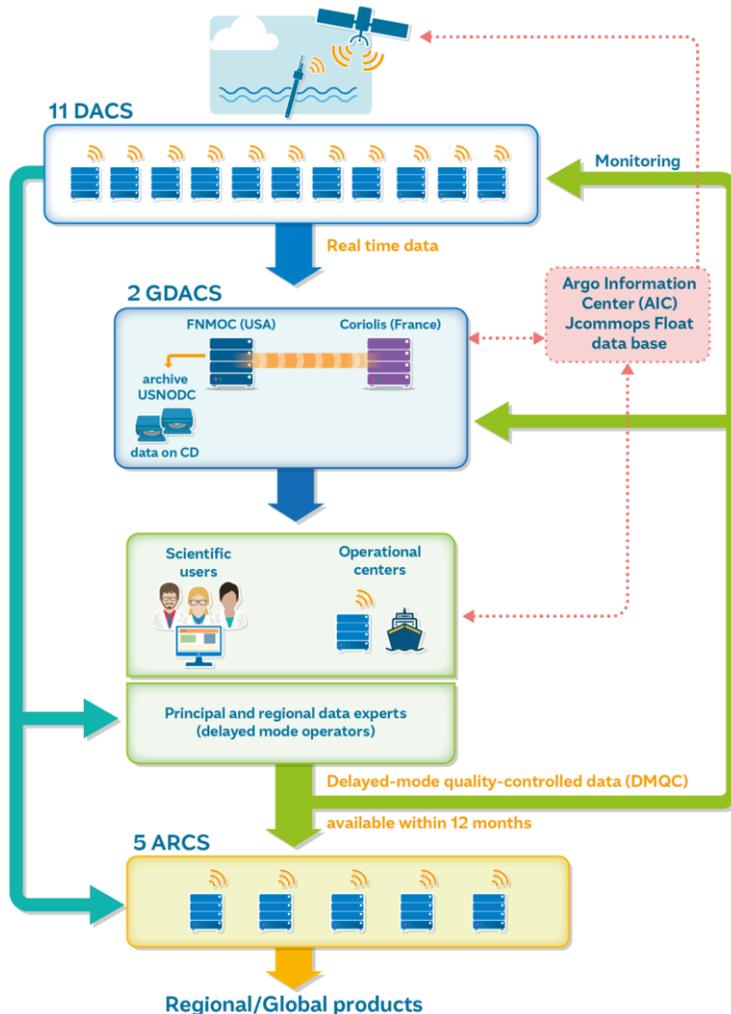
sa

S

.

ark

Argo Data System



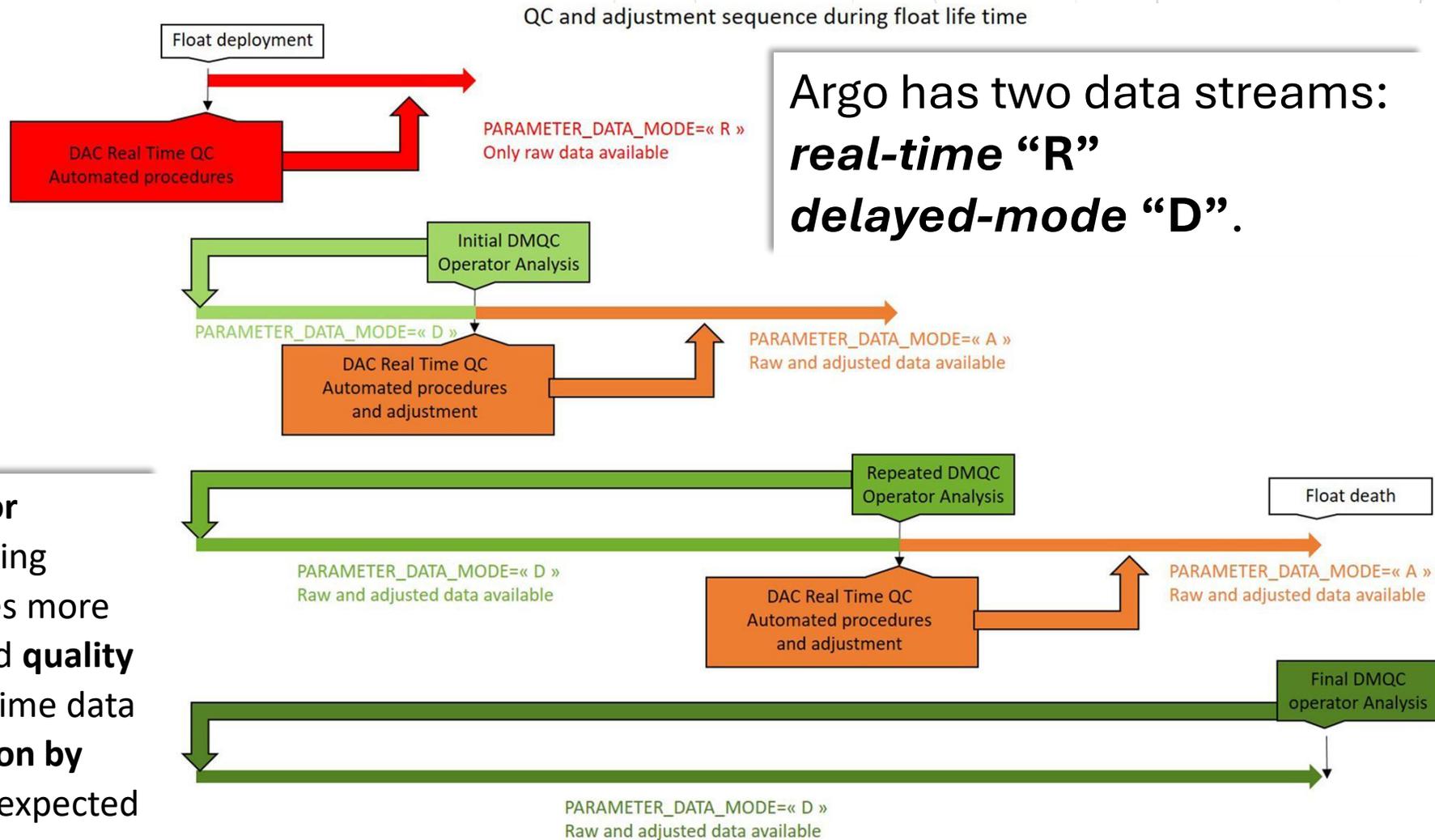
Argo data are relayed and made **freely available within hours** after collection. **International Argo Data System** is based on two Global Data Assembly Centres:

- ❖ **GDACs** (Global Data Centres), located at Coriolis/France and FNMOC/USA, supervise collecting the processed Argo data from the 11 DACs and to provide users with access to the best version of an Argo profile.
- ❖ **DACs** (Data Assembly Centres), receive the data, **decode and quality control** the data according to a set of **19 real time automatic tests** agreed by the international Argo programme. **Erroneous data are flagged, corrected** where possible and then passed to the two GDACs .
- ❖ **ARCs** (Argo Regional Centres) **provide wide expertise on specific geographical ocean regions** in order to provide the most comprehensive data sets (including non-Argo data) of the **highest quality**. ARCs provide three main services: act as the **delayed mode operator** for "orphan" floats (i.e. float deployed by an institute that does not have a capability to perform delayed mode QC); **gather the recent complementary in situ ship-based data** needed for **delayed mode validation**; check the **overall consistency of the Argo dataset** in an area.

Argo Data System

R: latency requirement of **24 h**. Data in **R** is subject to **real-time quality control checks**; only automated quality control and data checks can be applied. R data are aimed to **serve operational users** (models).

D: provide the **best quality data for science** at the present date, including **realistic error estimates**. It includes more **sophisticated data adjustment and quality control procedures** than the real-time data stream, including **manual inspection by expert**. **DMQC** process is typically expected to occur on an **annual basis**.



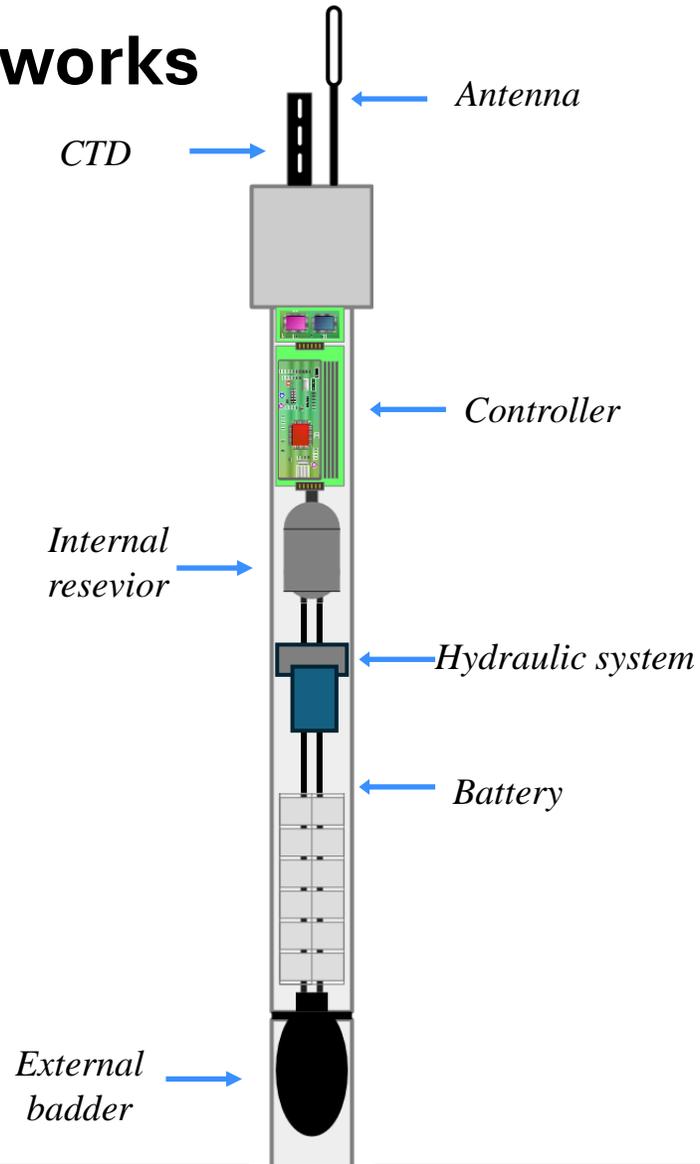
Argo has two data streams:
real-time “R”
delayed-mode “D”.

Bittig et al., 2019

Argo Data System

QC flag	Meaning	Real time comment	Delayed mode comment
0	No QC performed	No QC performed	No QC performed
1	Good data	All real time QC tests passed	The adjusted value is statistically consistent and a statistical error estimate is supplied.
2	Probably good data		Probably good
3	Bad data that are potentially correctable	Test 15 or Test 16 or Test 17 failed and all other real-time QC tests passed. These data are not to be used without scientific correction. A flag '3' may be assigned by an operator during additional visual QC for bad data that may be corrected in delayed mode.	An adjustment has been applied, but the value may still be bad.
4	Bad data	Data have failed one or more of the real-time QC tests, excluding Test 16. A flag '4' may be assigned by an operator during additional visual QC for bad data that are not correctable.	Bad data. Not adjustable.
5	Value changed	Value changed	Value changed
6	Not currently used	Not currently used	Not currently used
7	Not currently used	Not currently used	Not currently used
8	Estimated	Estimated value (interpolated, extrapolated or other estimation).	Estimated value (interpolated, extrapolated or other estimation).
9	Missing value	Missing value	Missing value

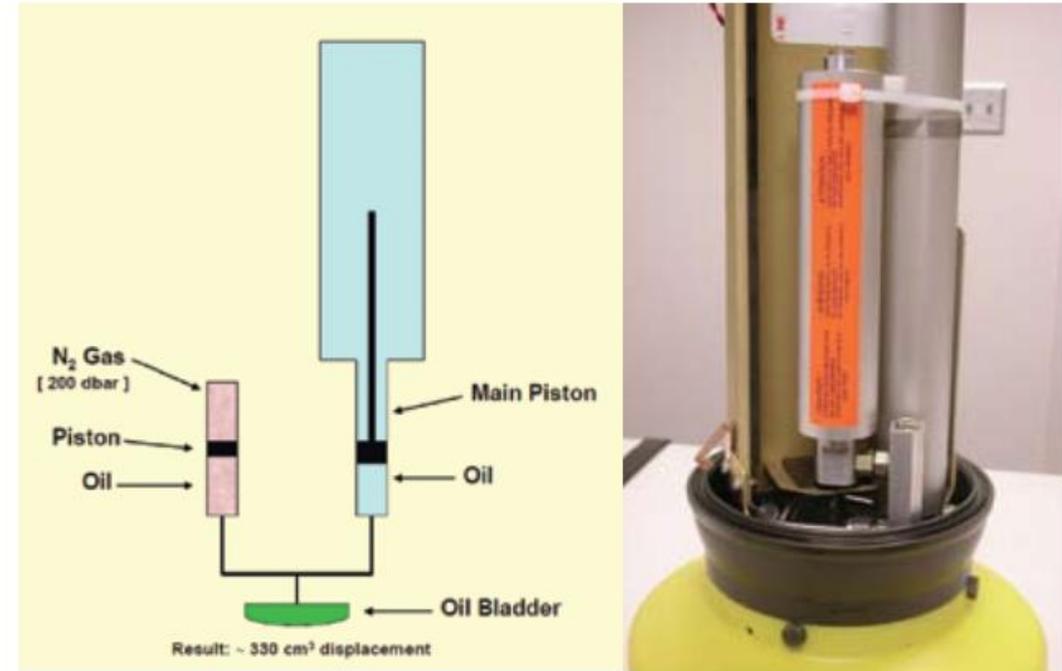
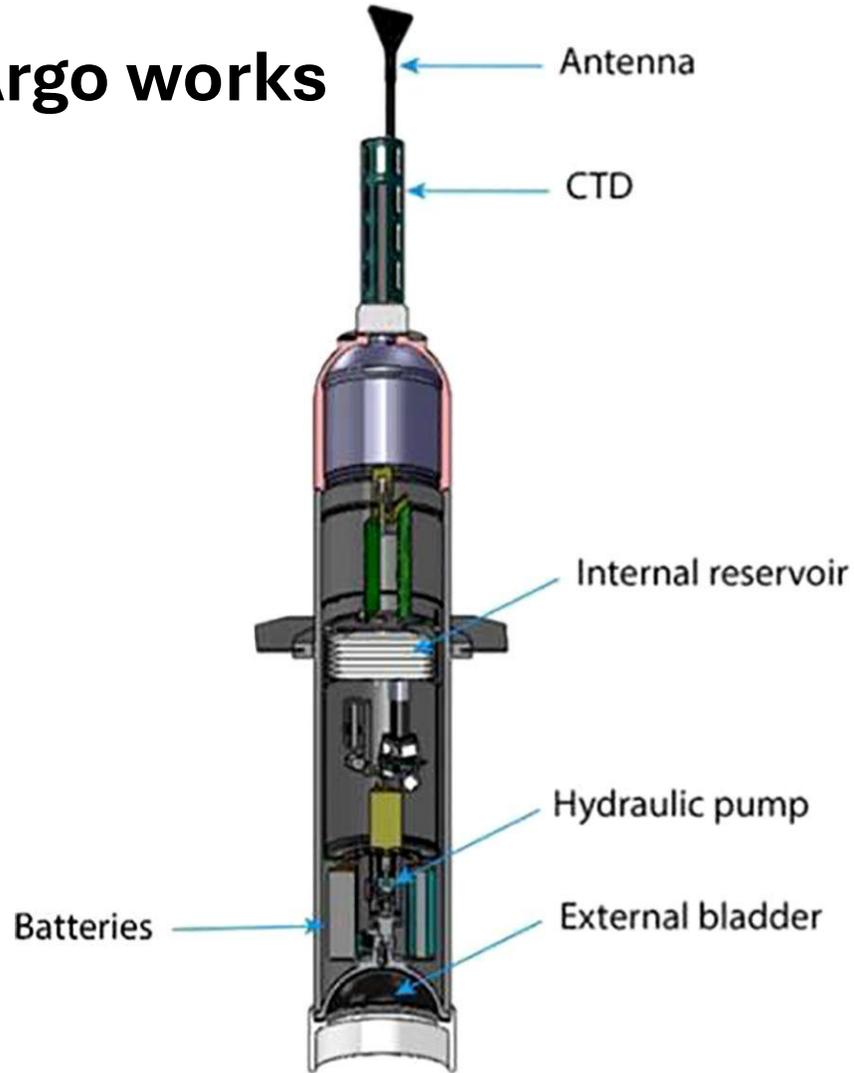
How Argo works



- The **antenna**, used to communicate with passing satellites, sits proud at the top of the Argo float, allowing clear access for communications above the water line.
- The **CTD** is positioned at the top to acquire data relatively free of water turbulence (ascends).
- The **internal reservoir** stores the hydraulic oil when it is not being used to inflate the external bladder.
- The **hydraulic system** is used to pump the hydraulic oil between the internal reservoir and the external bladder.
- The **batteries** supplies the power. Battery are the primary limiting factor for longevity.
- The **external bladder** control the buoyancy. When the oil is pumped into the external bladder it increases the volume of the Argo float, decreasing the density and allows the Argo float to rise and viceversa.
- All workings of the Argo float is controlled by **specialist firmware** on a main **electronic circuit board**. This **controller** determines exactly how much hydraulic oil needs to be shifted to allow the Argo float to drift at a particular depth.

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

How Argo works



Schematic diagram of the main piston and nitrogen gas canister arrangement on a Webb N2 Apex profiling float. For N₂ floats, the additional oil and piston connected to the gas canister provide a means to store energy as the gas is compressed during the float descent, recover this energy, and use it to increase the float's buoyancy during the ascent phase.

Morris, Tamaryn, et al. "Best practices for Core Argo floats-part 1: getting started and data considerations." *Frontiers in Marine Science* 11 (2024)

Roemmich et al., *The Argo Program: Observing the global ocean with profiling floats. Oceanography* (2009)

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Argo floats

A variety of float types have been used:

1. **PROVOR** and the **ARVOR**, designed by Ifremer and built by *NKE Instrumentation*.
2. **APEX**, built by Teledyne Webb Research.
3. **SOLO-I** and the **SOLO-II**, built by *Scripps Institution of Oceanography*.
4. **S2A**, a commercial version of SOLO-II, built by *MRV Systems*.
5. **NAVIS**, built by *Sea-Bird Scientific*.
6. **NOVA**, built by *MetOcean*.



AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Argo missions

The **Argo** floats are **equipped** with a suite of **sensors** that gather information about the ocean. All Argo measure temperature and salinity. **Based** on the **sensors** installed and **depth range** the Argo float can be divided in **three category**:



Core

Variables:

Temperature

Salinity

Oxygen

Turbulence

Depth range:

0-2000m



BGC

Variables:

Oxygen

Nutrients

pH

Chlorophyll a

Backscatter (POC)

Downwelling irradiance

Light (radiometry)

Light (PAR)

Particles (UVP6)

Depth range:

0-2000m



Deep

Variables:

Temperature

Salinity

Oxygen

Depth range:

0-2000m

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Argo missions

The **Argo** floats are **equipped** with a suite of **sensors** that gather information about the ocean. All Argo measure temperature and salinity. Based on the **sensors** installed and **depth range** the Argo float can be divided in **three category**:

Core

Variables:

Temperature
Salinity
Oxygen
Turbulence

Depth range:
0-2000m

BGC

Variables:

Oxygen
Nutrient
pH
Chlorophyll
Backscatter (POC)
Downwelling irradiance
Fluorescence (rad) (OC2)
Light (PAR)
Particles (UVP6)

Depth range:
0-2000m

Deep

Variables:

Temperature
Salinity
Oxygen

Depth range:
0-2000m

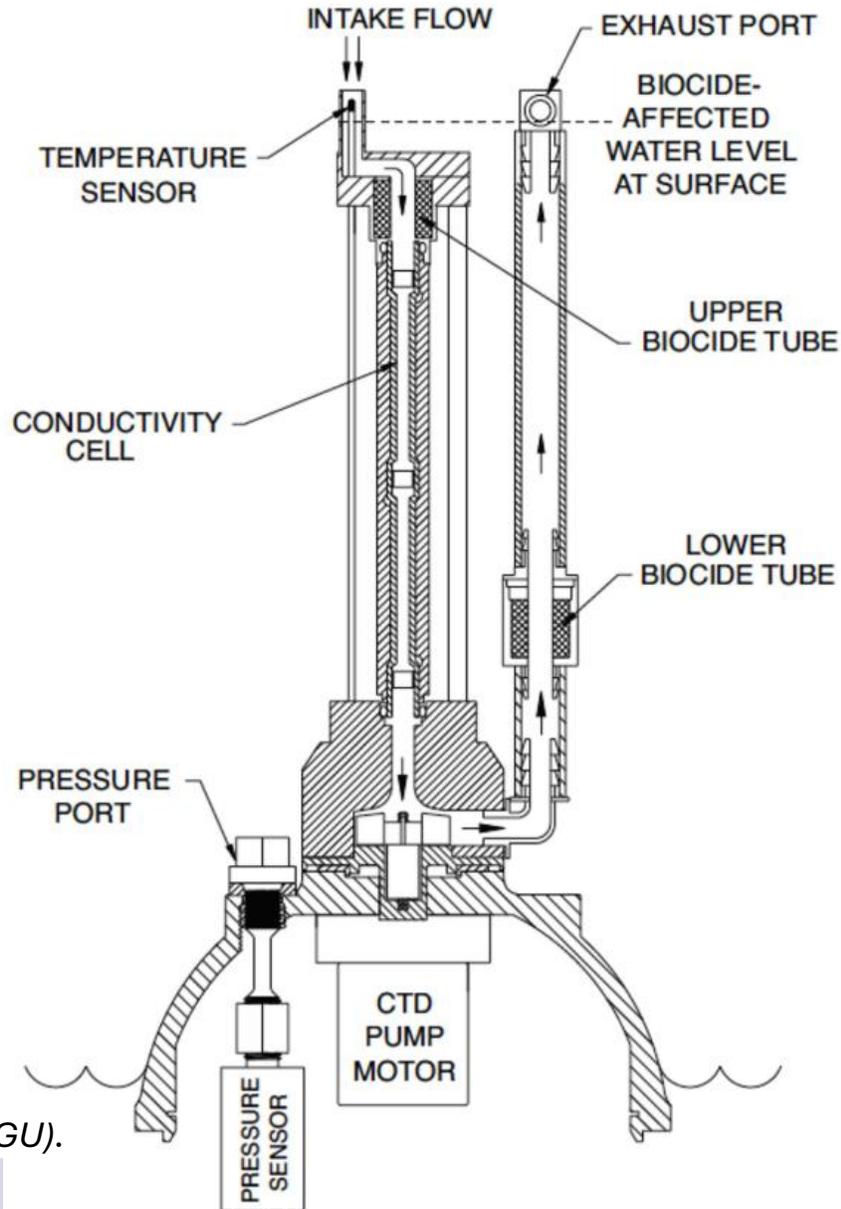
ONE ARGO

2021-2030

Core

The **CTD** pump draws the **seawater** through the inlet and lets it pass over the **temperature** sensor before it is fed into the **conductivity cell**. The water from the cell exits through an exhaust port positioned perpendicular to the inlet, **minimizing** the risk of **contaminating** the incoming water. The **pressure** sensor is located on the **end cap** of the float, close to the CTD unit. The temperature and electrical conductivity of the seawater in the cell are **measured directly**.

*Sea-Bird Scientific CTD unit. (Riser et al., 2018).
Copyright 2018 American Geophysical Union (AGU).*



Core Argo is the temperature / salinity/ pressure operational mission that was the **original** goal the **Argo Program**. The basic **mission** of Argo is to track where **heat** and **salinity** are changing across the **global ocean**, down to a depth of **2000 meters**.

CTD sensors package measure **temperature** within an **accuracy** of **0.001 °C**, **pressure** (closely related to depth) within **0.1 dbar**, and calculate **salinity** using conductivity, temperature, and pressure within **0.01**.

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Salinity

Salinity is obtained from conductivity, pressure and temperature.

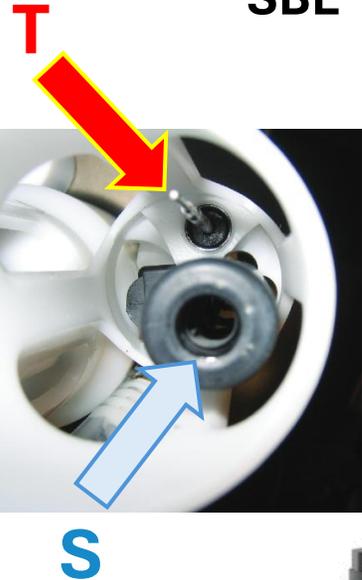
The primary objective of the Argo Project is to document the current and changing state of the upper ocean, focusing on heat and freshwater storage and transport.

Electrode-Conductivity Cell

SBE

Inductive-Conductivity Cell

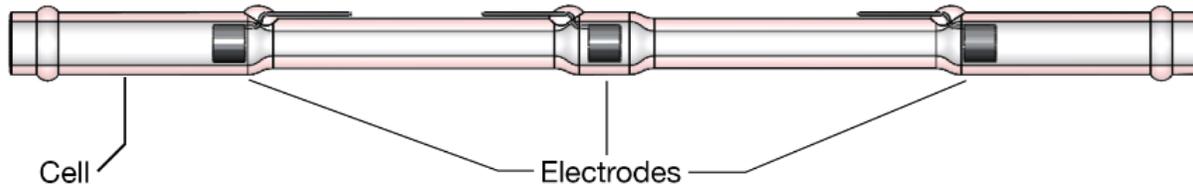
RBR



- Argo aims for **accuracies** of **5 dB** for pressure, **0.005 °C** for temperature, and **0.01** for salinity.
- While **temperature** and **pressure** measurements generally **meet accuracy** requirements, **salinity is more problematic** due to sensor sensitivity and conductivity cell geometry.
- The **oceanic environment** is generally harsh for **electronic sensors** used for mapping, thus making it inevitable to have some **spurious measurements**.
- **Standardized delayed mode** procedures have been **developed** and are regularly updated to address **salinity data drift or offset**.

Salinity sensors

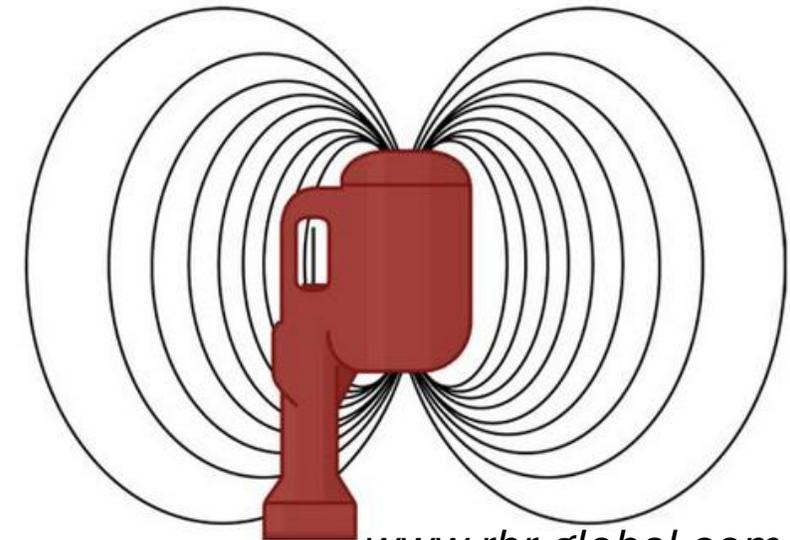
Electrode -Conductivity Cell SBE



- **SBE** conductivity sensors measure **conductance** (voltage in response to a known current) and calculate conductivity using the conductance and the **length-to-cross-sectional area** ratio of the sampled water.
- The conductivity **cells** encapsulate **three electrodes** in platinized **borosilicate glass**, forming a two-terminal cell where the **electrode resistances** are in **series** with the **cell resistance**.
- The low electrode resistances and high cell resistance minimize errors due to changes in electrode resistances, ensuring precise measurements.

- RBR conductivity cells operate based on **Faraday's law of induction**, using two toroidal coils: a generating coil and a receiving coil.
- An AC signal in the generating coil creates a magnetic flux and an **electric field**, inducing a current in the seawater at the center of the cell.
- This seawater current induces a **secondary current** in the receiving coil, proportional to water resistance and inversely proportional to conductivity.
- The electric field generates **closed rings of current**, densest inside the cell, which spread outward as they extend into the water.

Inductive-Cell
RBR



www.rbr-global.com

DMQC- OWC

- Verify real-time QC flags
- Visually inspect profiles (P,T); (P,S); (P/Rho); (Theta/S)
- Plots of temperature, salinity and density plotted against the nearby historical CTD profiles

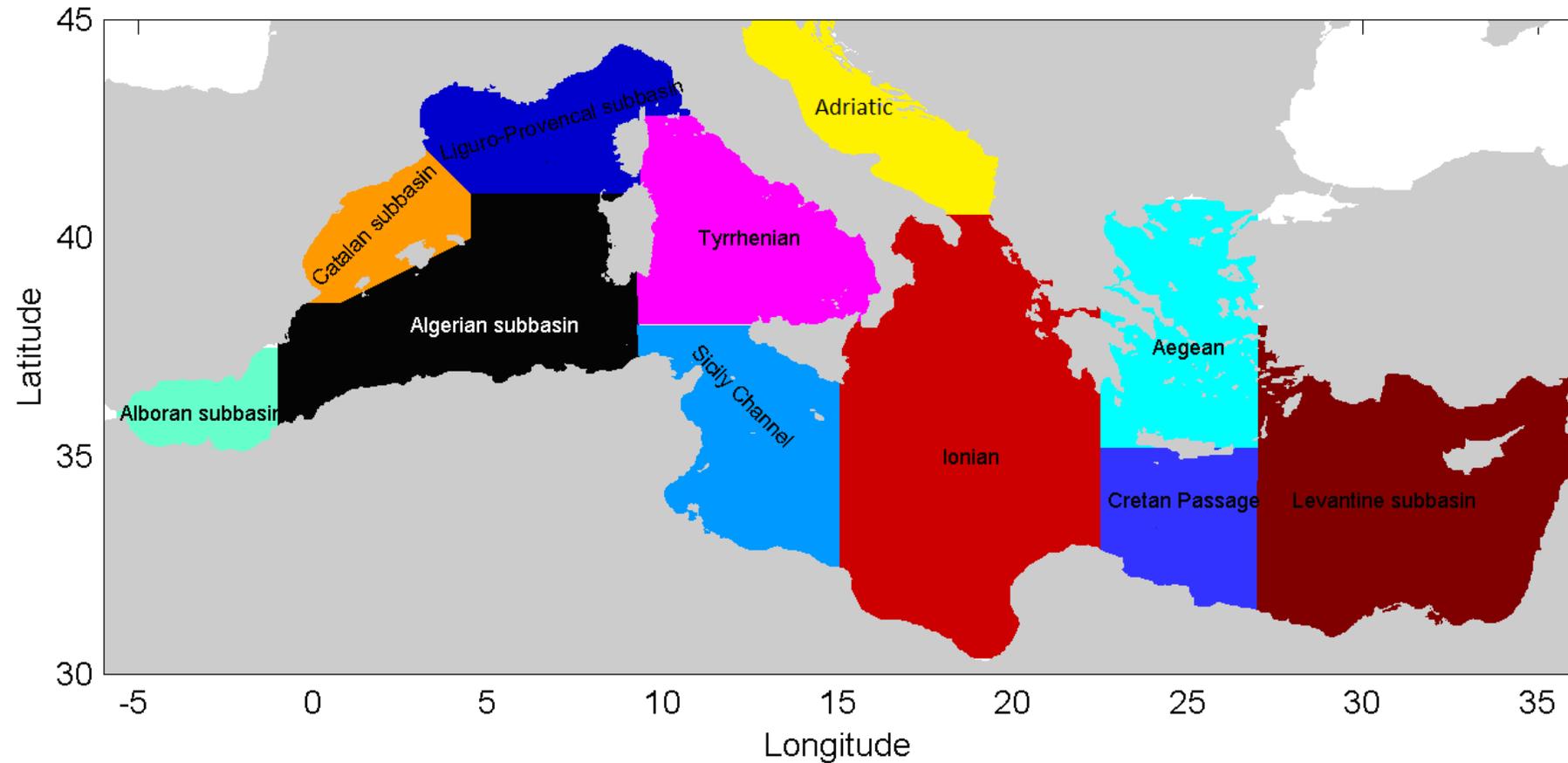
OWC method (Owens and Wong 2009; Cabanes et al 2016)

- For each profile of a given float, selection of the reference profiles that are closest in space and most contemporaneous in time and interpolation of salinity reference data onto the potential temperatures measured by the float (float profile θ levels)
- Salinity of the reference profiles is then objectively mapped at the float profile location using a two-stage optimal interpolation (OI) method
- The ten most stable θ levels that have the minimum salinity variance are used to compare floats and reference salinity data
- A time-varying potential conductivity correction is estimated using a time-varying multiplicative factor ($C_{\theta}^s/C_{\theta}^f$)
- The additive adjustment in salinity (ΔS_{fit}) is then obtained from the multiplicative factor used to adjust the float potential conductivity

DMQC- OWC – example in Mediterranean sea

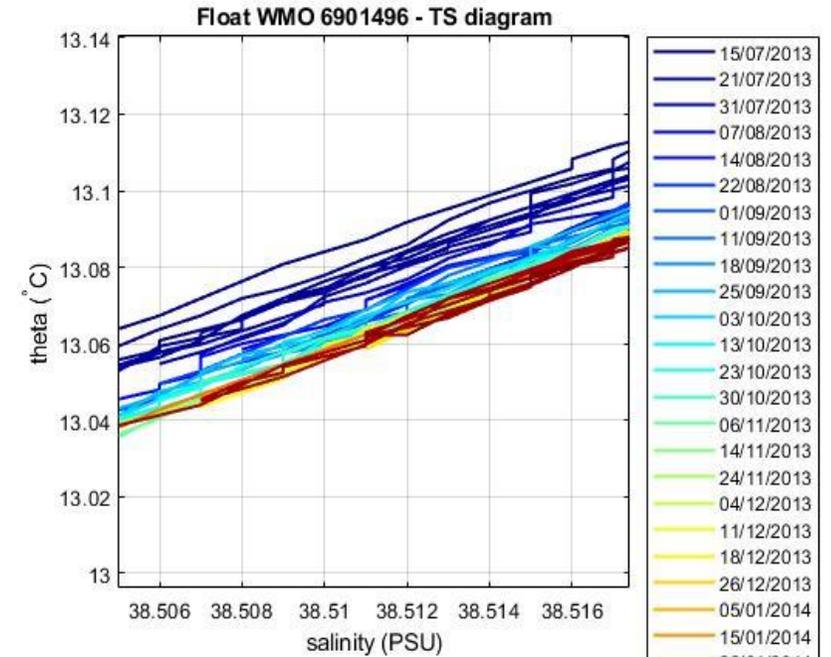
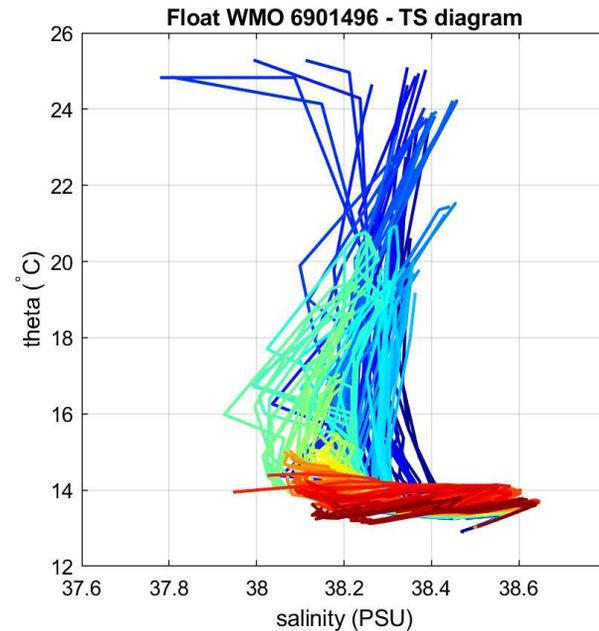
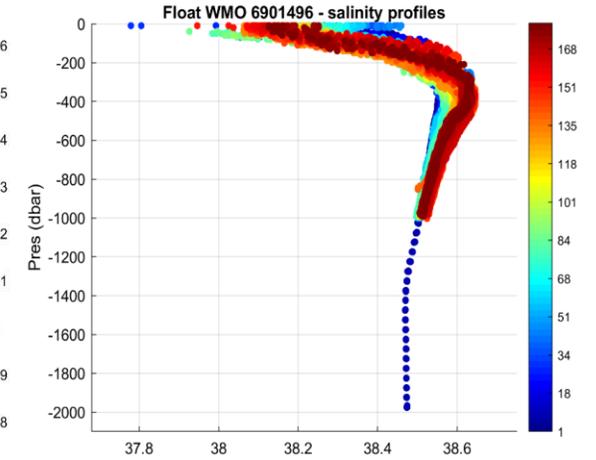
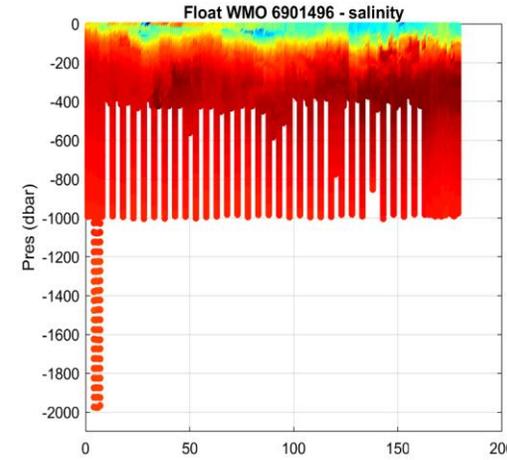
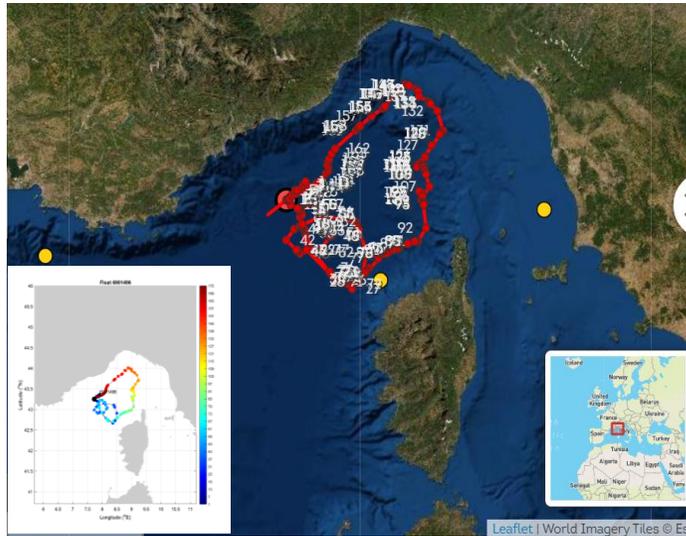
Reference dataset selection

To apply DMQC method, the Mediterranean is divided in the various sub-basins separately due to the different nature of the existing water masses, in order to avoid selecting historical data for calibration coming from completely different oceanographic regions.

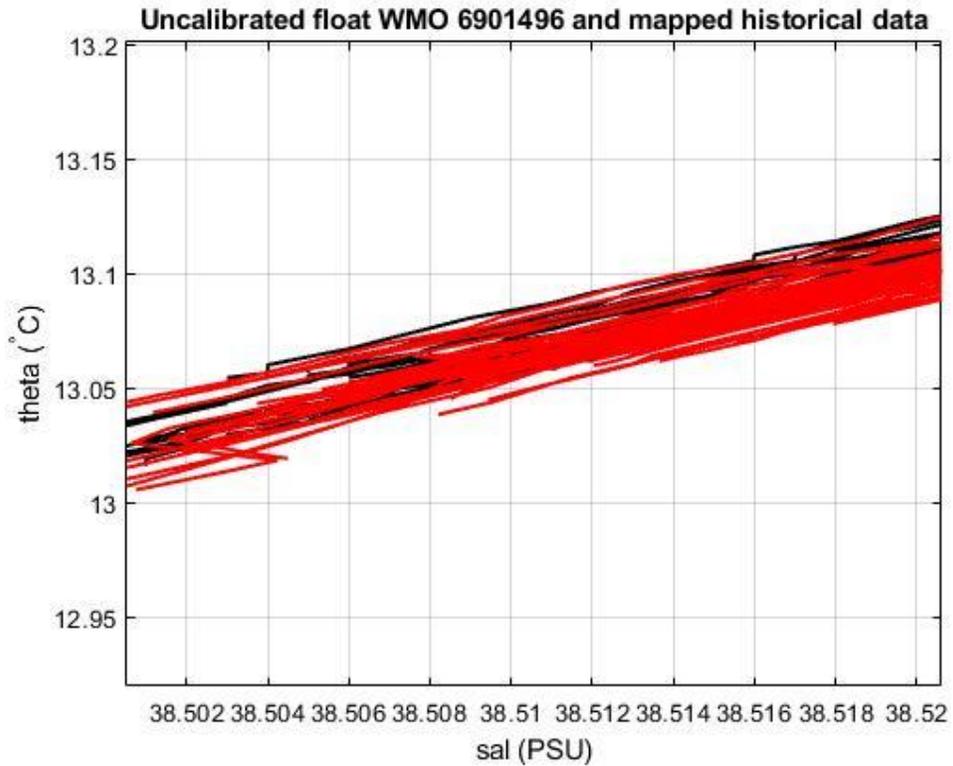


AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

DMQC- OWC example in Mediterranean sea

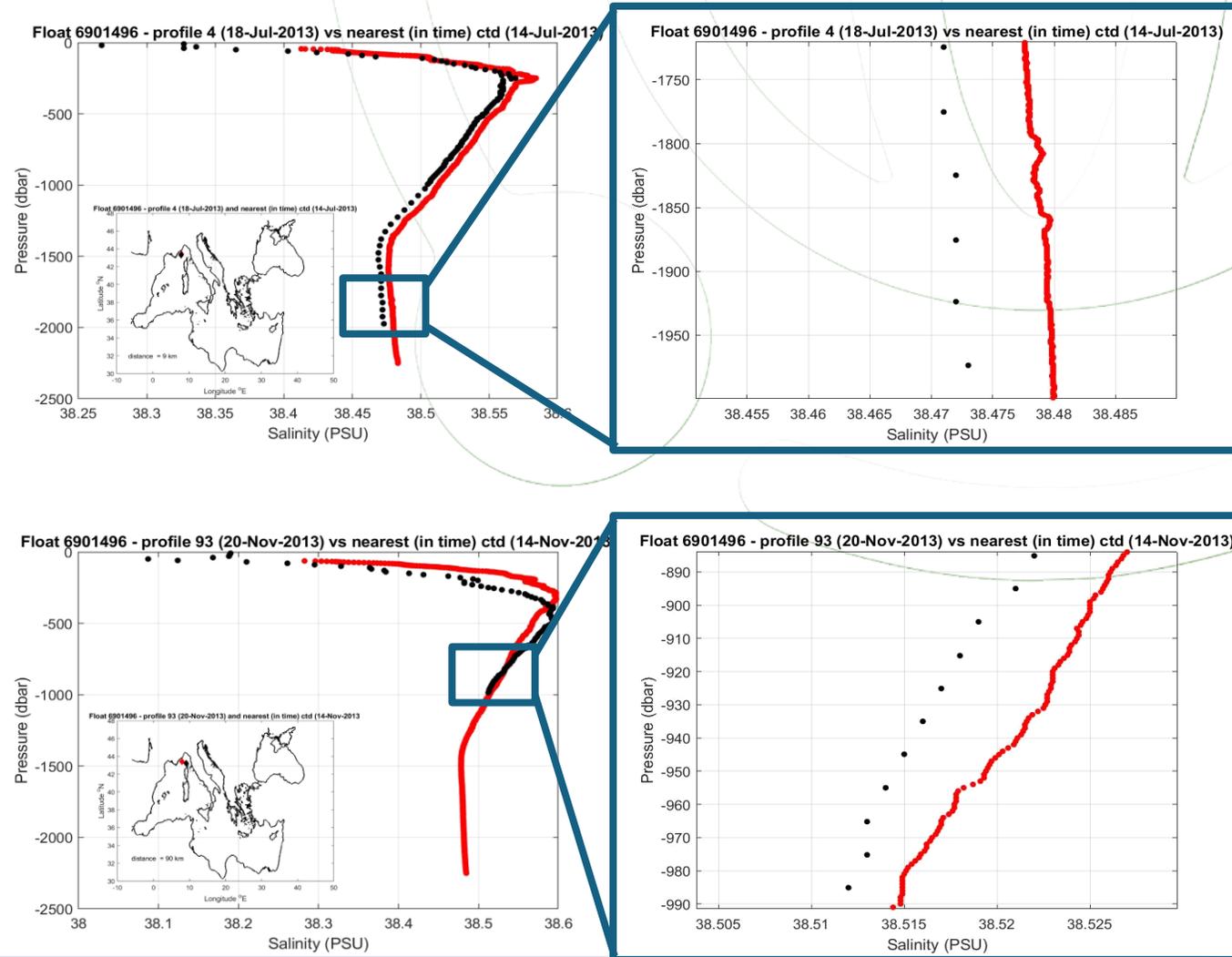


DMQC- OWC example in Mediterranean sea



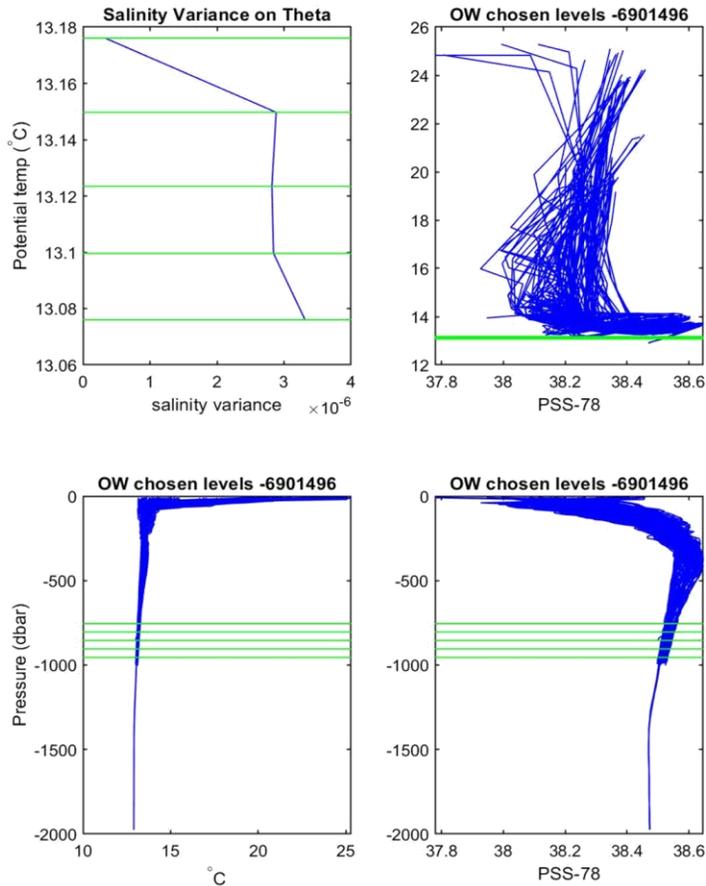
Comparison of uncalibrated float salinity profile (black lines) and mapped historical data (red lines) in the most uniform part of the θ -S curve.

Comparison with the historical data

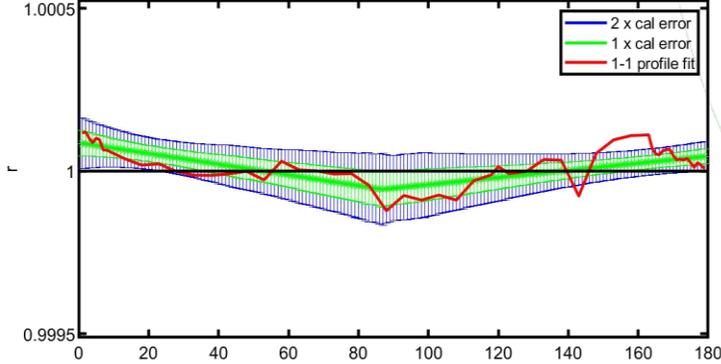


DMQC- OWC example in Mediterranean sea

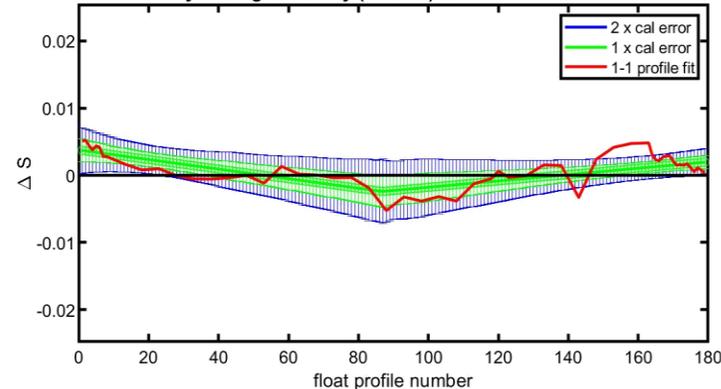
The θ levels chosen for calibration



6901496 potential conductivity (mmho/cm) multiplicative correction r with errors

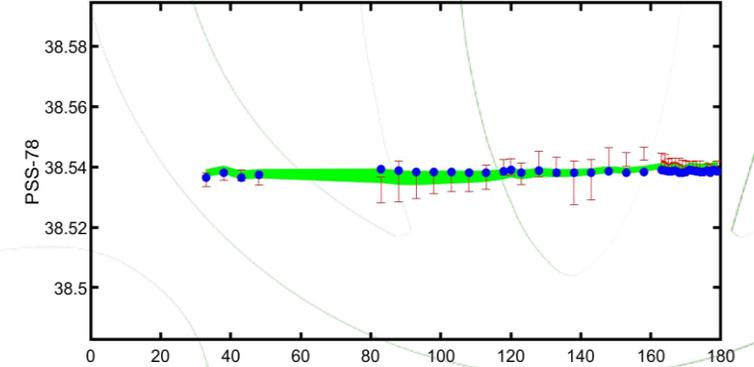


6901496 vertically-averaged salinity (PSS-78) additive correction ΔS with errors

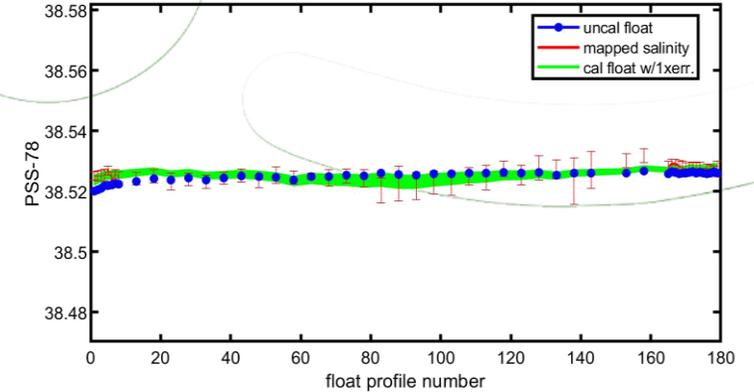


Evolution of the suggested adjustment with time. The red line denotes weighted mean one-to-one C_θ^s/C_θ^f profile fit. Little variability, low fit error!

6901496 salinities with error on $\theta=13.1761^\circ\text{C}$



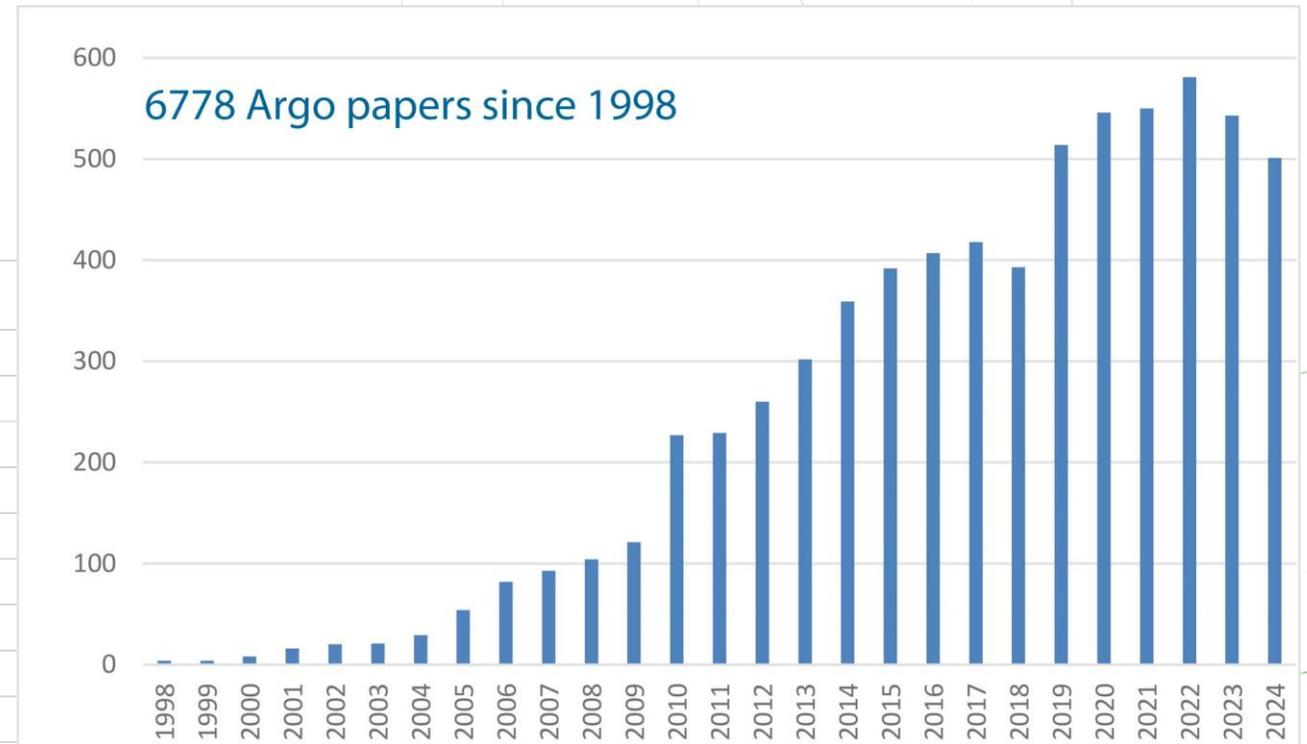
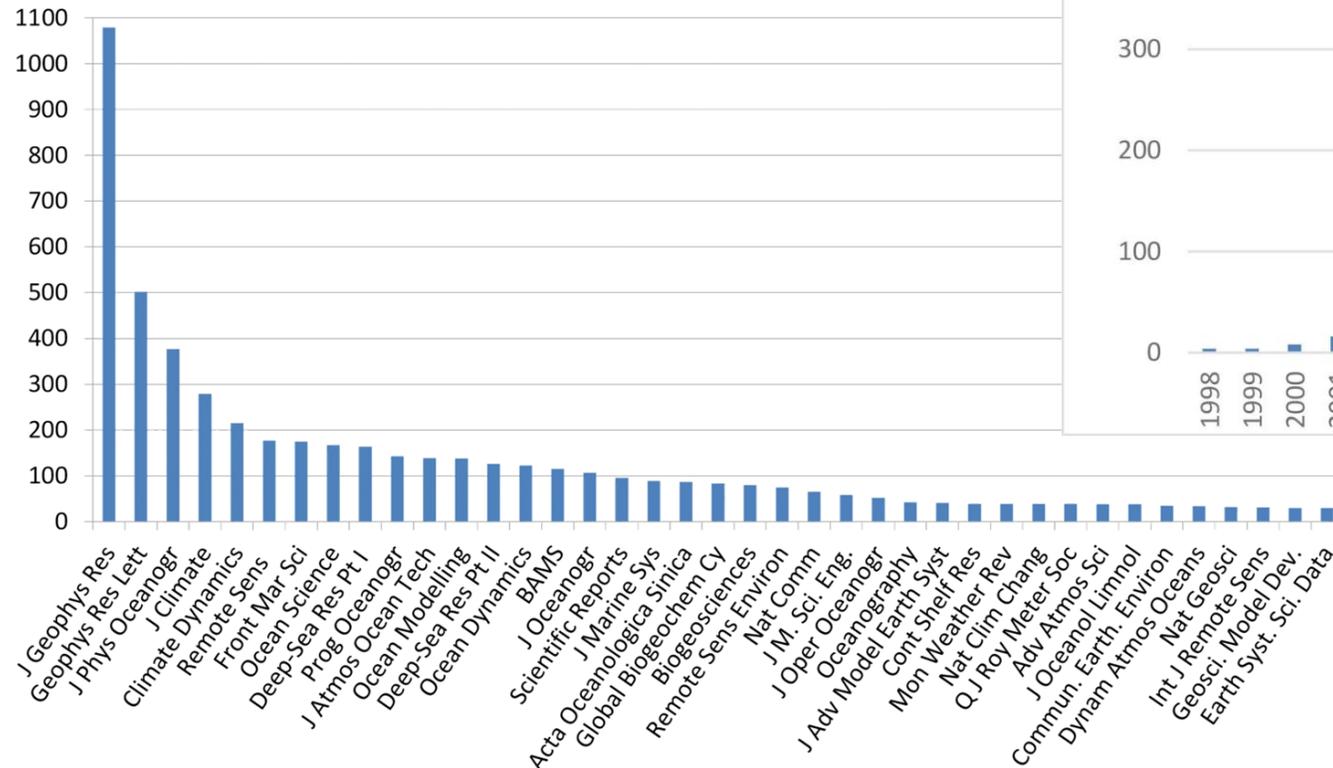
6901496 salinities with error on $\theta=13.1235^\circ\text{C}$



Evolution of salinity with time along with selected θ levels with minimum salinity variance.

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Science numero di paper



argo.ucsd.edu

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

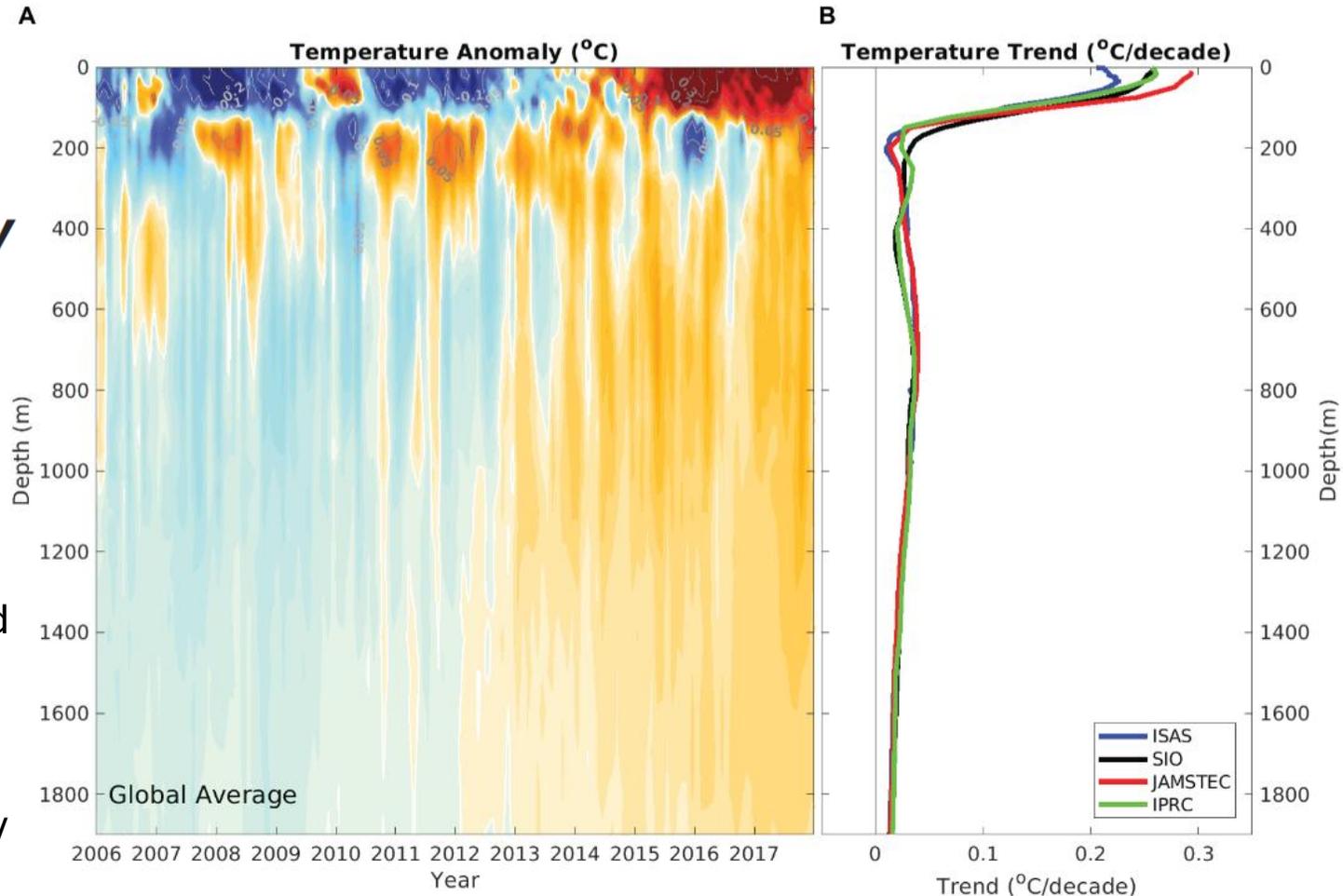
Core T/S science – global ocean



On the Future of Argo: A Global, Full-Depth, Multi-Disciplinary Array

Dean Roemmich^{1*}, Matthew H. Alford^{1†}, Hervé Claustre^{2†}, Kenneth Johnson^{3†}.

(A) Global averaged temperature anomaly (C – from SIO) and (B) trend (C/decade, 2006–2018) versus depth, based on gridded Argo data. Gridded product sources are: ISAS (Gaillard et al., 2016), SIO (Roemmich and Gilson, 2009); IPRC- from the Asia-Pacific Data Research Center (http://apdrc.soest.hawaii.edu/projects/Argo/data/gridded/On_standard_levels/index-1.html); JAMSTEC (Hosoda et al., 2008).



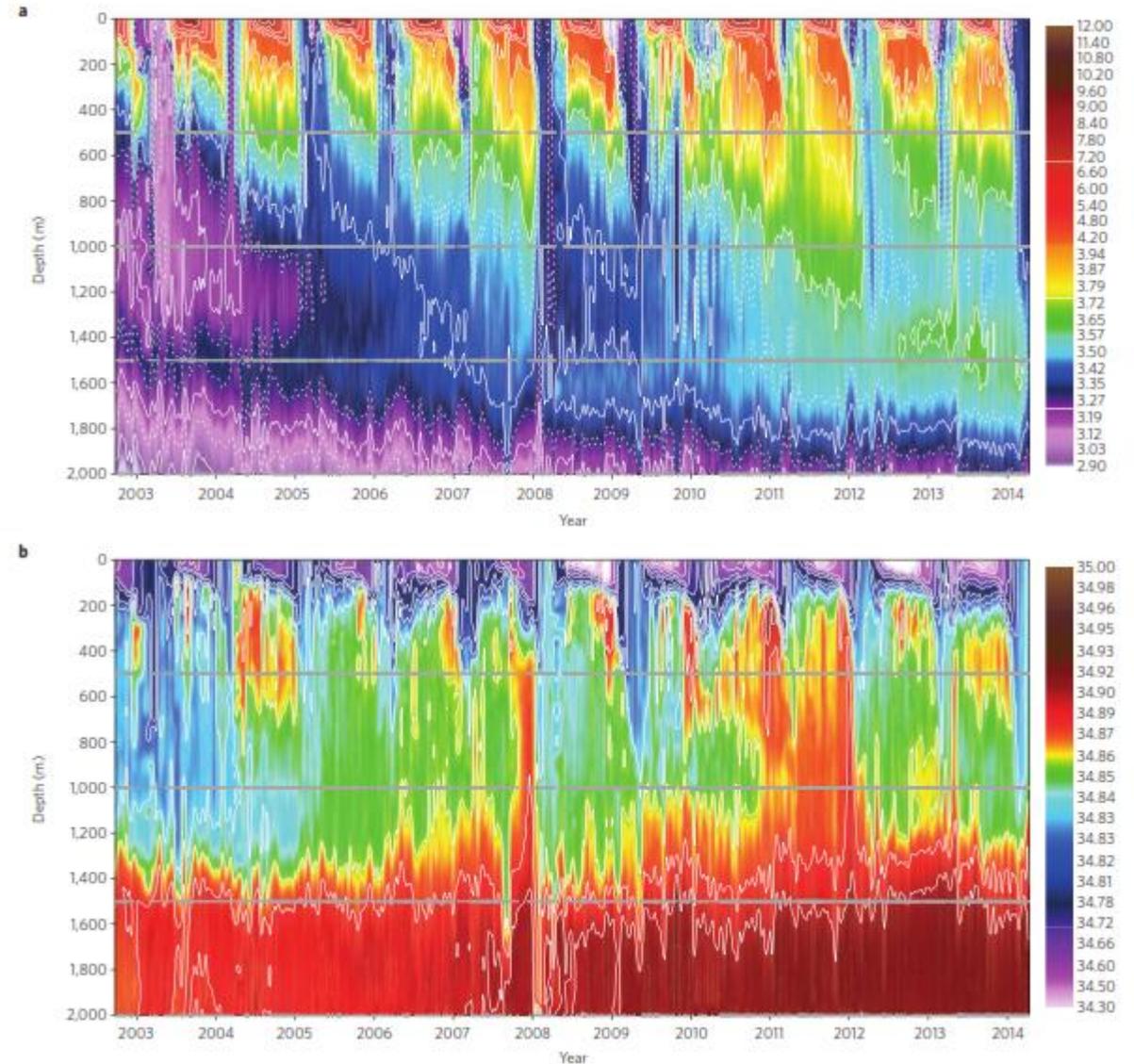
Core T/S science – global ocean



Fifteen years of ocean observations with the global Argo array

Stephen C. Riser¹, Howard J. Freeland^{2*}, Dean Roemmich³, Susan Wijffels⁴, Ariel Troisi⁵,

Convection in the Labrador Sea. a,b, The bi-weekly to interannual evolution of potential temperature (a) and salinity (b) in the upper 2,000 m of the Labrador Sea during the period 2002–2014; data compiled from quality-controlled Argo float and vessel profiles. Figure courtesy of Igor Yashayaev (Bedford Institute of Oceanography, Canada), updating data from refs 32,33.



Core T/S science – global ocean

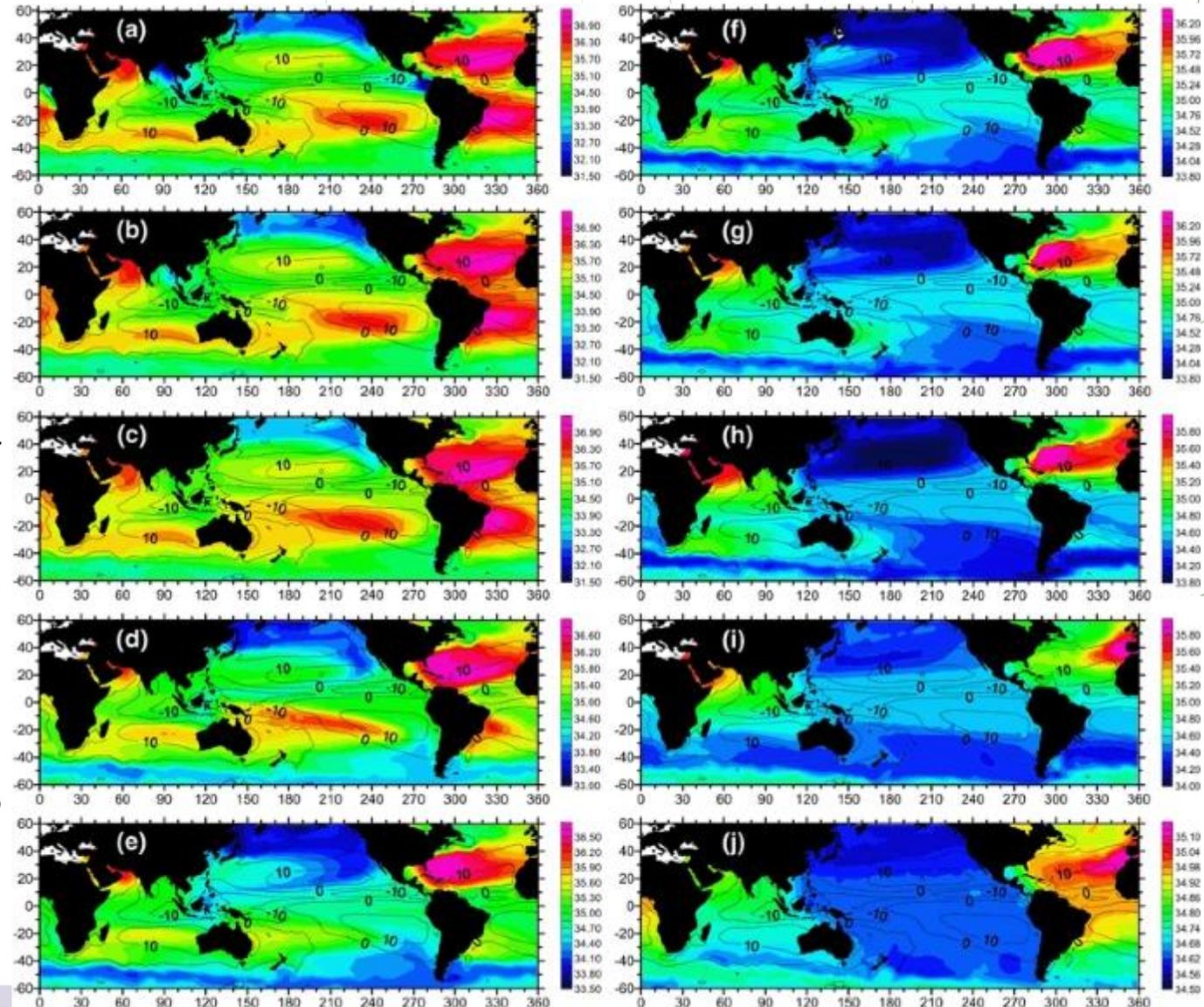
Clim Dyn (2018) 50:2169–2182
DOI 10.1007/s00382-017-3742-6

Climatology and seasonality of upper ocean salinity: a three-dimensional view from argo floats

Ge Chen^{1,2} · Lin Peng¹ · Chunyong Ma^{1,2}

Along with temperature and pressure, salinity is one of the three key variables for determining the seawater density.

Global climatologies of ocean salinity for 2004–2014 derived from Argo data at selected depths: a 5 m, b 50 m, c 100 m, d 200 m, e 300 m, f 400 m, g 500 m, h 600 m, i 1000 m, and j 1950 m. Note that the color scale (in psu) changes with depth. The E–P contours replotted from e of Yu (2011) are also overlaid on each panel for comparison



AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Core T/S science – polar ocean

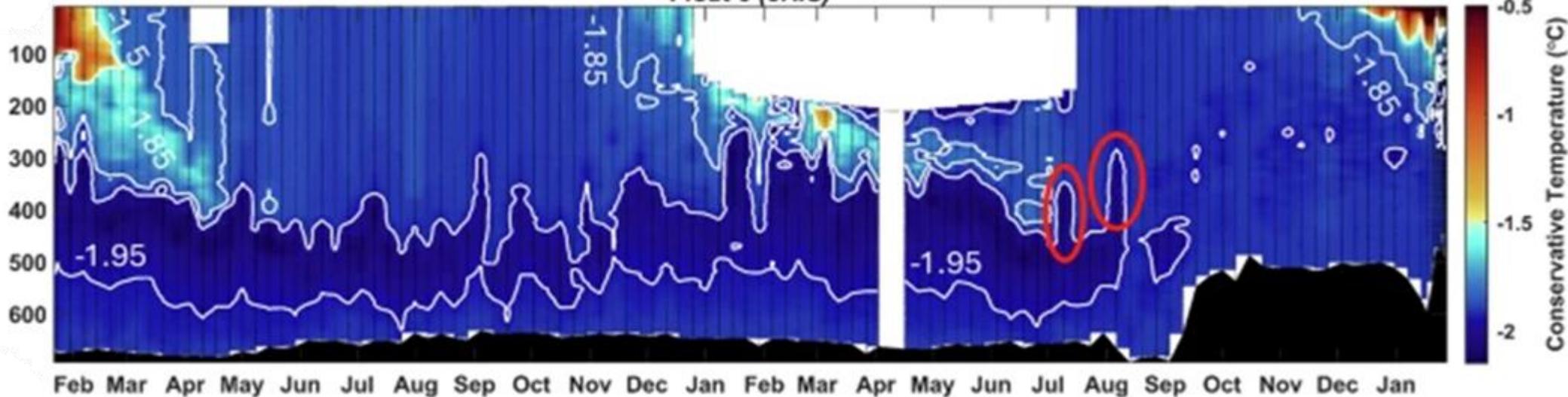
nature communications

Winter thermohaline evolution along and below the Ross Ice Shelf

[Pierpaolo Falco](#), [Naomi Krauzig](#), [Pasquale Castagno](#), [Angela Garzia](#), [Riccardo Martellucci](#), [Yuri Cotroneo](#)



Float 6 (cRIS)



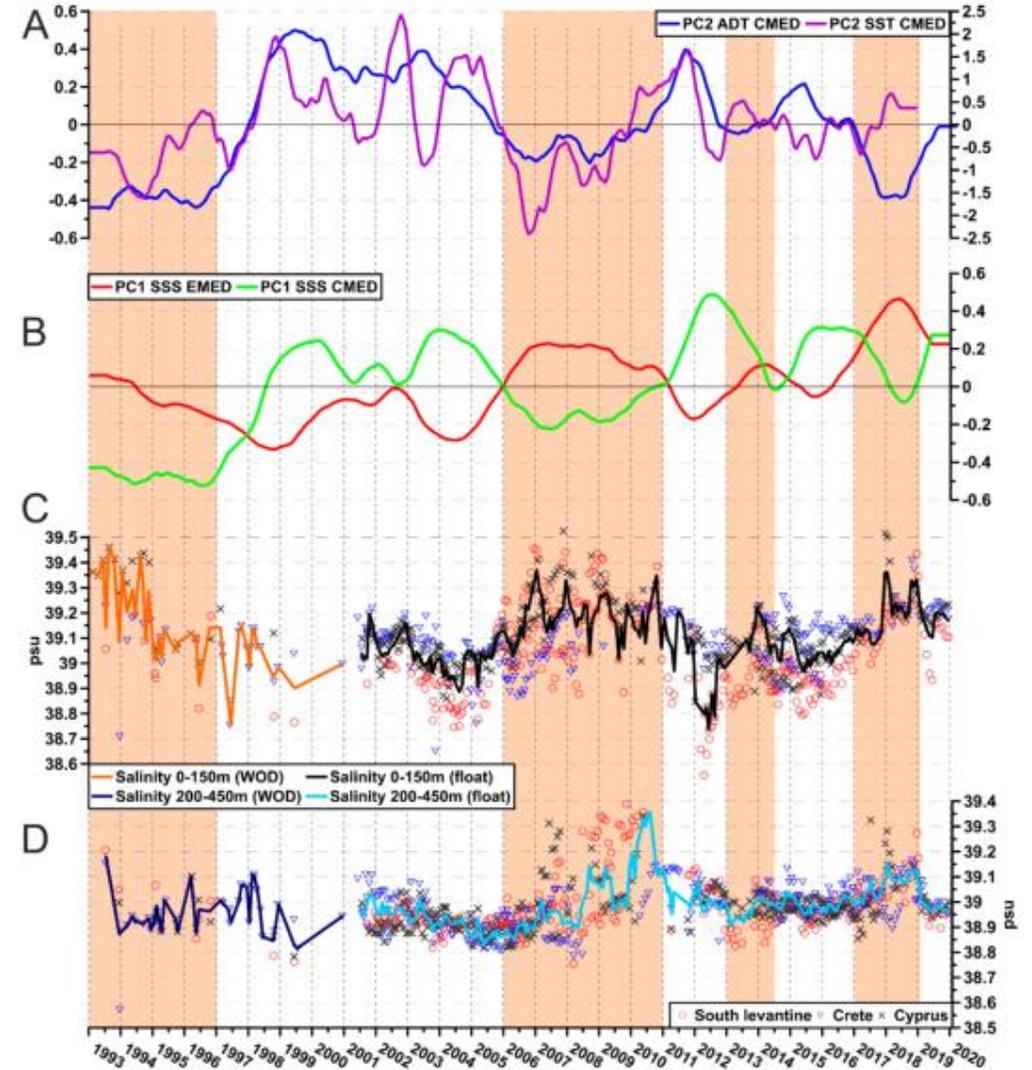
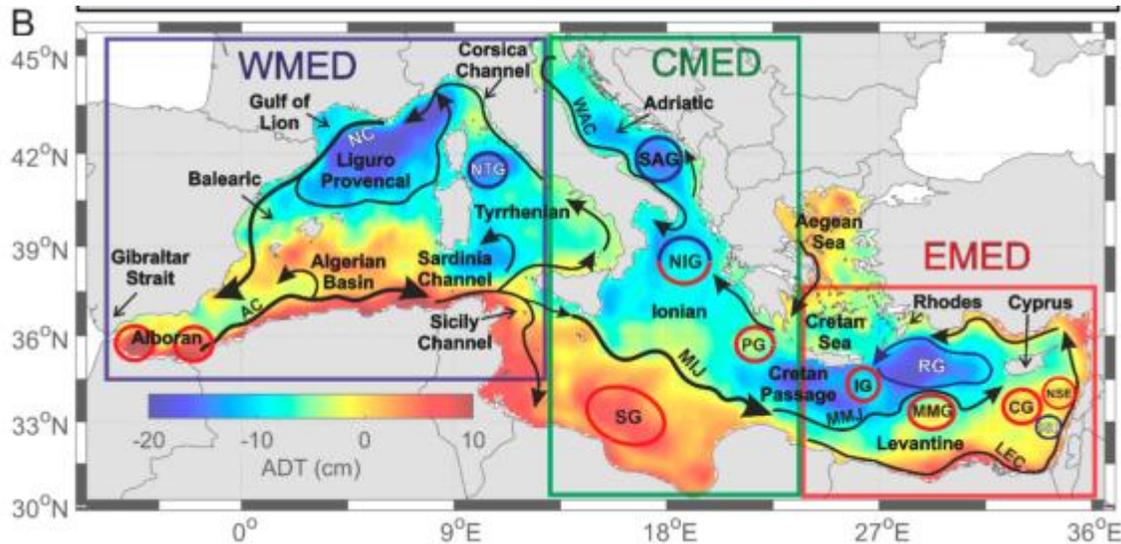
Core T/S science – marginal seas



Article

Climatic, Decadal, and Interannual Variability in the Upper Layer of the Mediterranean Sea Using Remotely Sensed and In-Situ Data

Milena Menna ^{1,*}, Miroslav Gačić ¹, Riccardo Martellucci ¹, Giulio Notarstefano ¹, Giusy Fedele ², Elena Mauri ¹, Riccardo Gerin ¹ and Pierre-Marie Poulain ¹



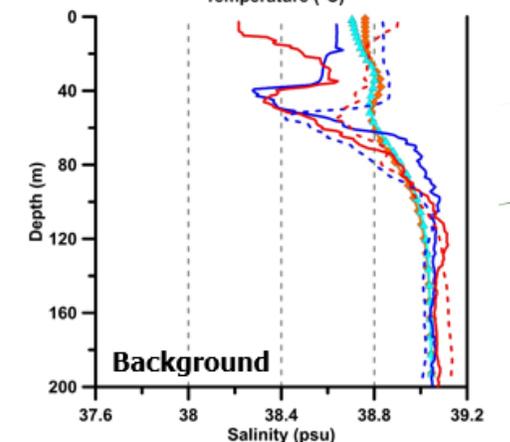
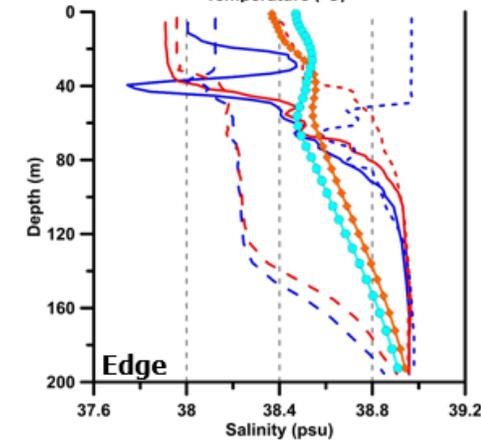
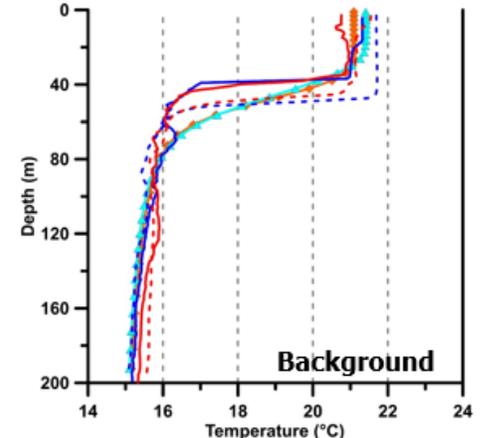
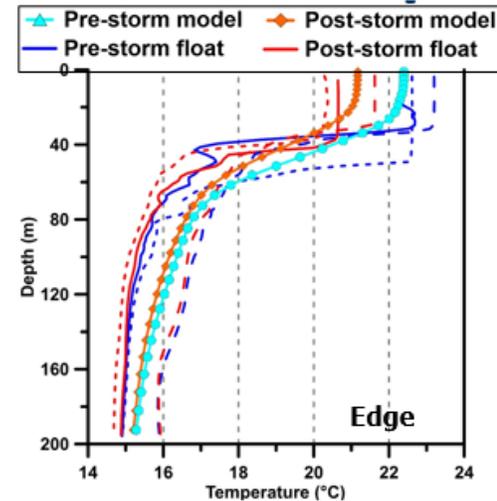
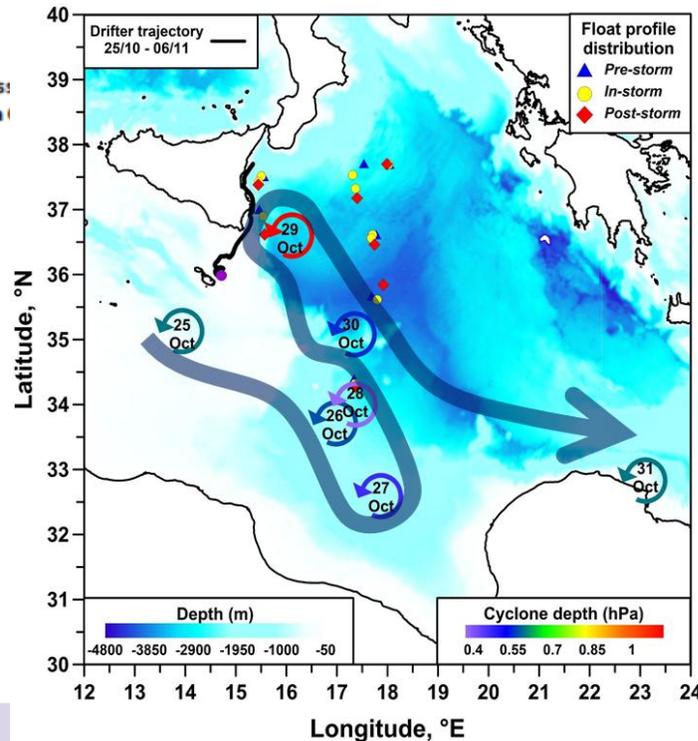
AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Core T/S science - extremes

scientific reports

A case study of impacts
of an extreme weather system
on the Mediterranean Sea
circulation features: Mediane
Apollo (2021)

Milena Menna, Riccardo Martellucci, Marco Reale, Gianpiero Cosi,
Giulio Notarstefano, Elena Mauri, Pierre-Marie Poulain, Antonella

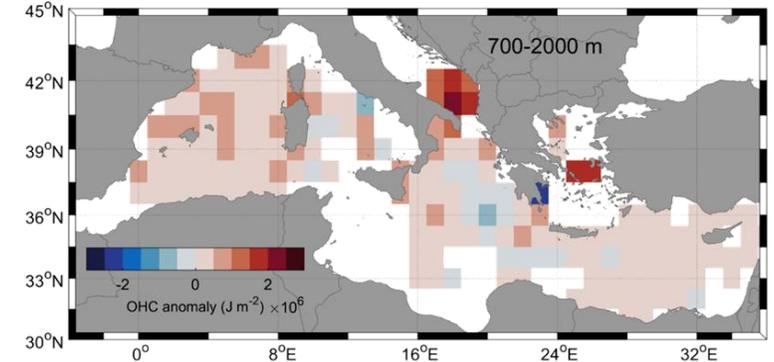
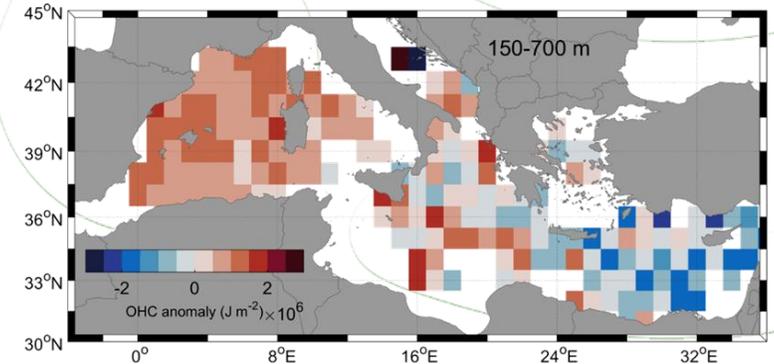
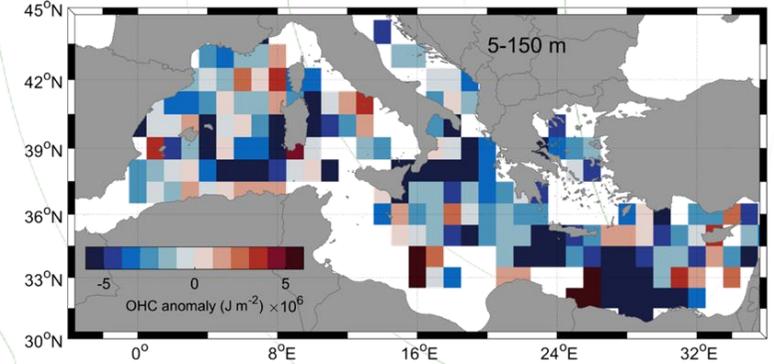
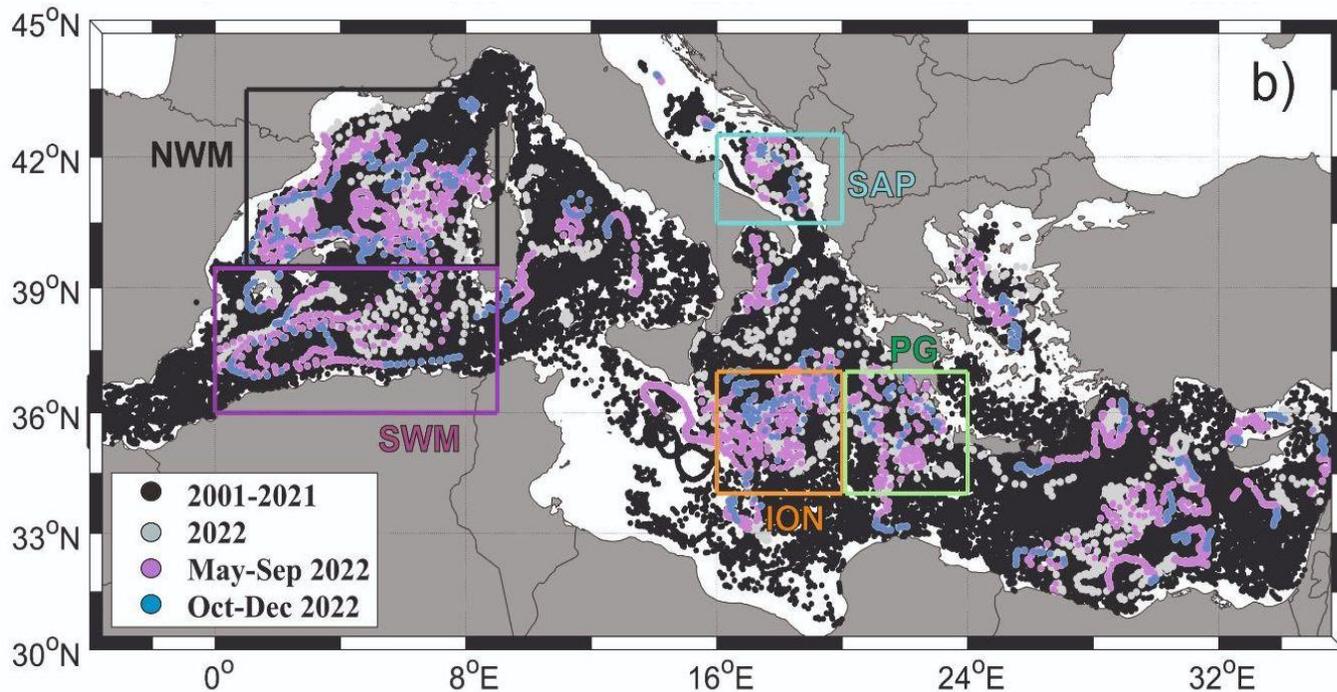


Core T/S science – extremes



Subsurface warming derived from Argo floats during the 2022 Mediterranean marine heat wave

Annunziata Pirro¹, Riccardo Martellucci¹, Antonella Gallo¹, Elisabeth Kubin¹, Elena Mauri¹,
Mélanie Juza², Giulio Notarstefano¹, Massimo Pacciaroni¹, Antonio Bussani¹, and Milena Menna¹



BGC

BGC-Argo aims at developing a **global** network of **biogeochemical** sensors on **Argo** profiling floats. The **BGC-Argo** network represents the most promising **strategy** for collecting **temporally** and **spatially** resolved **observations** of biogeochemical properties throughout the **upper 2000 m** of the ocean.

- The **BGC-Argo** program began between **2000 and 2003** through the **inclusion** of **oxygen** sensors on **Argo** platforms and the launch the same year of a working group of the International **Ocean- Color Coordinating Group**, “Bio-optical sensors on Argo floats” (IOCCG, 2011).
- **2016** was the starting point of the BGC-Argo program, suggesting that a **1000-float array** would significantly constrain the processes that control **global oxygen** and **carbon distributions**, including air-sea fluxes and **exports** from the surface.
- Each of the floats would carry sensors for **six core ocean variables** measured with targeted accuracies: *chlorophyll fluorescence, Suspended particles, oxygen, nitrate, pH, and irradiance*.
- Future deployment of new sensors

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

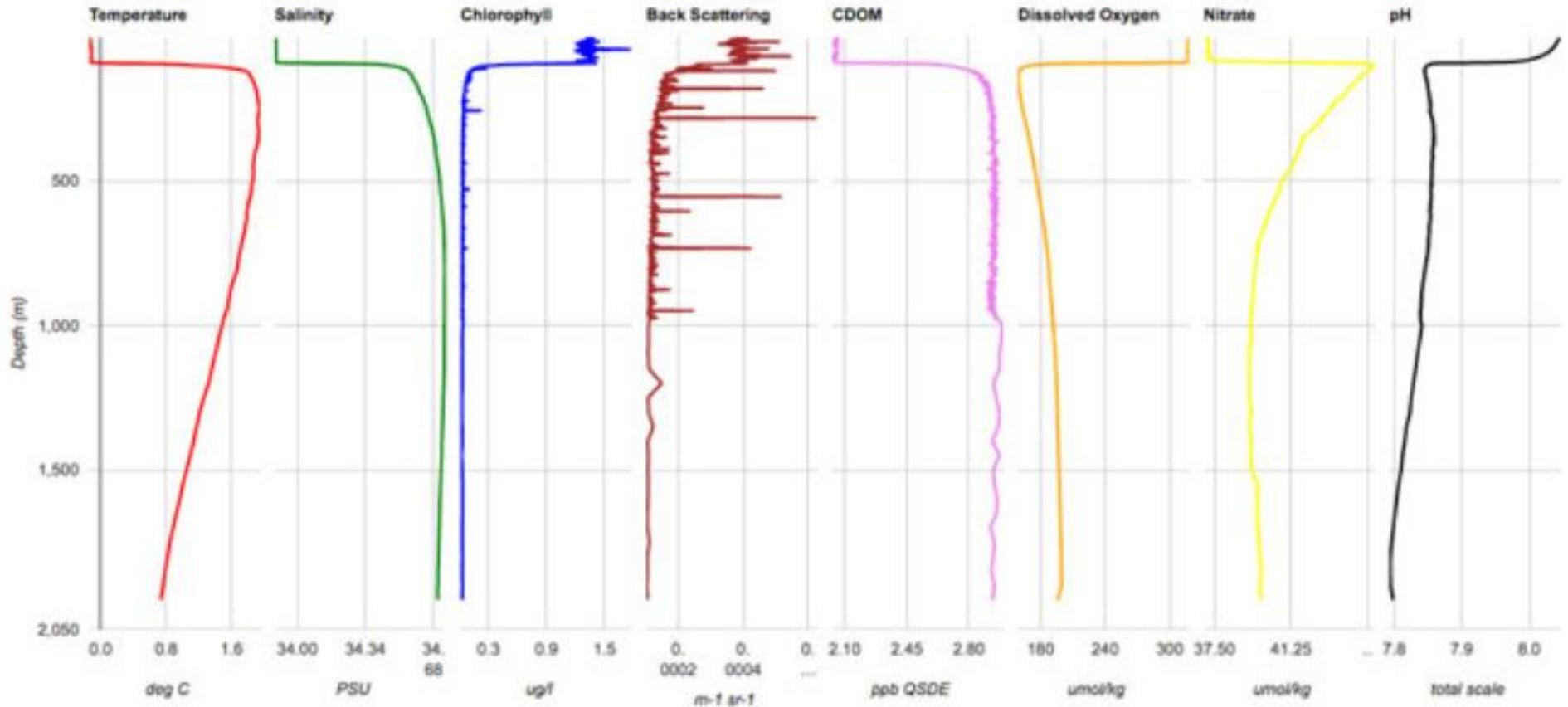
BGC

BGC-Argo aims at developing a **global** network of **biogeochemical** sensors on **Argo** profiling floats. The **BGC-Argo** network represents the most promising **strategy** for collect through



Navis BGC 32, Profile 171, 2014-04-15 16:28:22, 44.5691, -48.6167

[Download](#)



- Future deployment of new sensors

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

BGC

Three main BGC-Argo platforms **Navis**, **APEX**, **MRV**, **PROVOR** floats

The **scientific objectives** of the BGC-Argo program focus on quantifying: ***air-sea carbon fluxes, ocean deoxygenation, ocean acidification, the biological carbon pump, and phytoplankton community dynamics***. This observing system aims to enhance the management of marine resources and improve carbon budget verification, addressing critical societal needs.

(Roemmich et al. 2019)

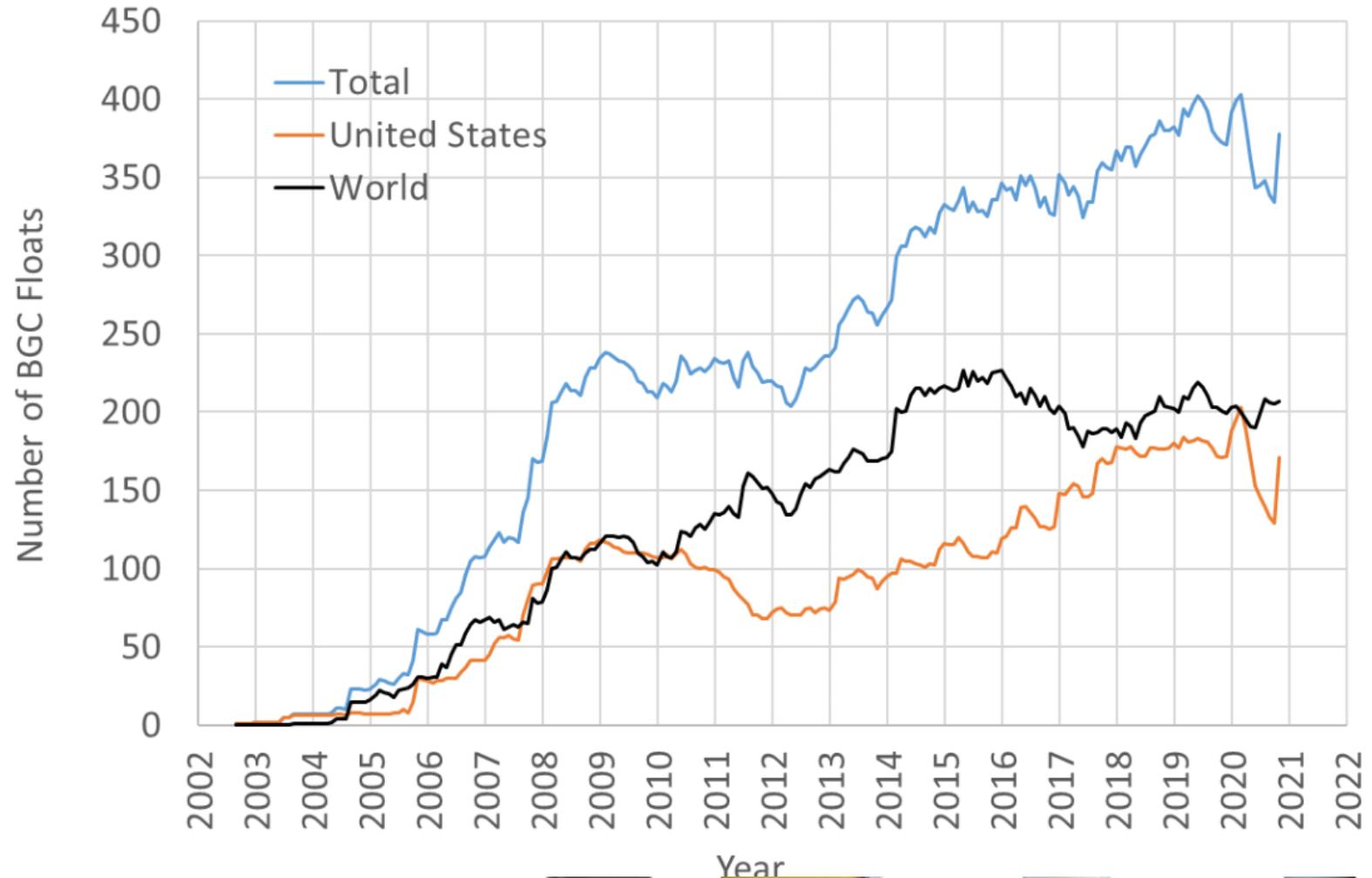


AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

BGC

The **scientific objective** program focus on quantifying **carbon fluxes, ocean acidification, carbon pump, and community dynamics**. The system aims to enhance understanding of marine resources, budget verification, and societal needs.

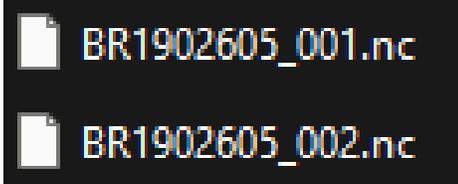
Three main BGC-Argo platforms **Navis, APEX, MRV, PROVOR** floats



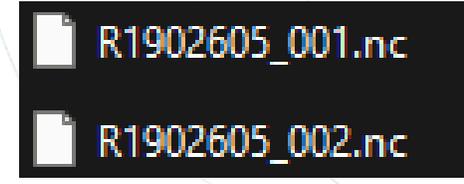
BGC- data quality and solutions

Profile data received from each BGC-Argo float cycle is formatted into **two types of files**: a core file (T/S) and a b-file (BGC). These two files are combined into a **synthetic-profile file**, which **aligns** or **interpolates** each measurement along a **synthetic pressure axis** and associated quality control information.

This **process accounts** for any **misalignment** of the **CTD** and **BGC** measurements during **onboard processing**.



BR1902605_001.nc
BR1902605_002.nc



R1902605_001.nc
R1902605_002.nc

Biofouling on sensors, sensor **drift** over time, and the **timing of profile acquisition** pose significant challenges for BGC-Argo floats. Some variables are best measured at night, such as chlorophyll fluorescence, while others, like light penetration, require daytime sampling, making it difficult to optimize profiling schedules. Additionally, **the limited number and uneven distribution** of BGC-Argo floats reduce the spatial coverage needed for **comprehensive monitoring** of global **biogeochemical processes**.

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Dissolved oxygen sensor



Provor

Optic

**Anderaa
4380/4330**



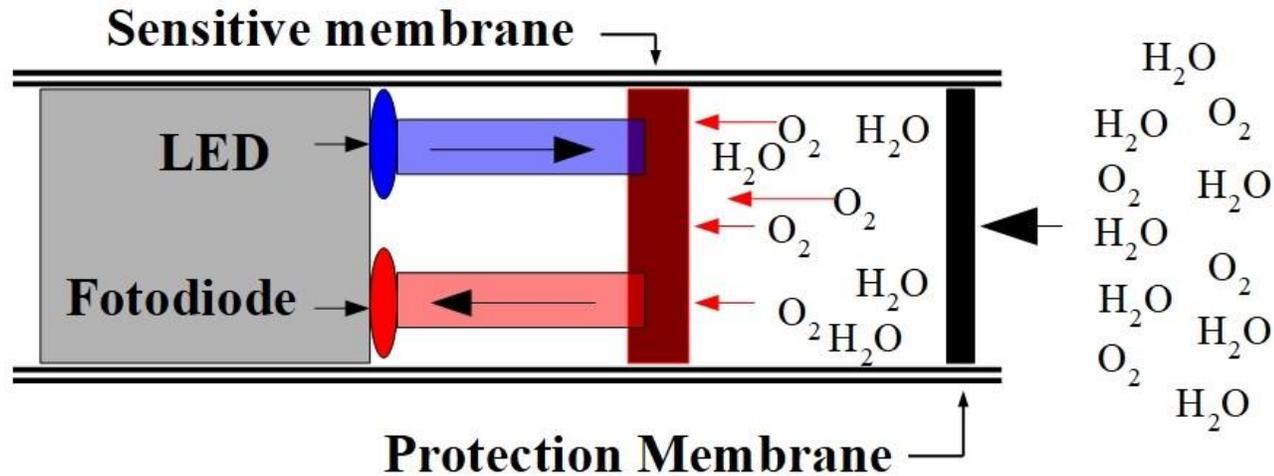
Navis

Optic

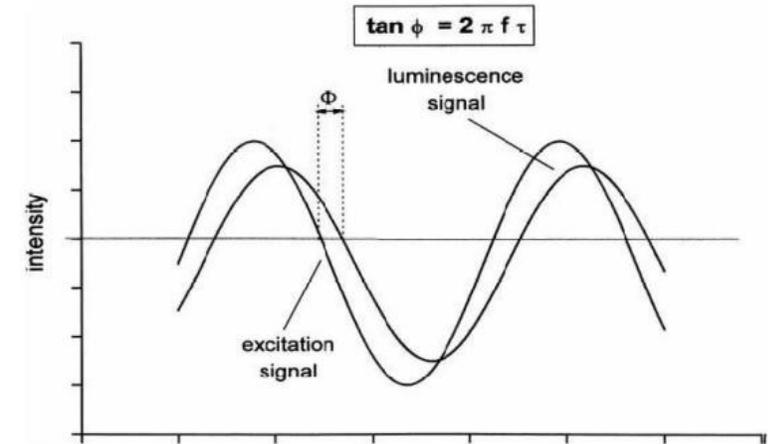
**SBE 63 ODO
sensor**

Dissolved oxygen sensor

The **Optode** sensor operates based on **fluorescence quenching**. Some materials **emit light** when **excited** by a light. A **blue LED excites** fluorescent **platinum-porphyrin molecules** immobilized on the sensor's **optical surface**.



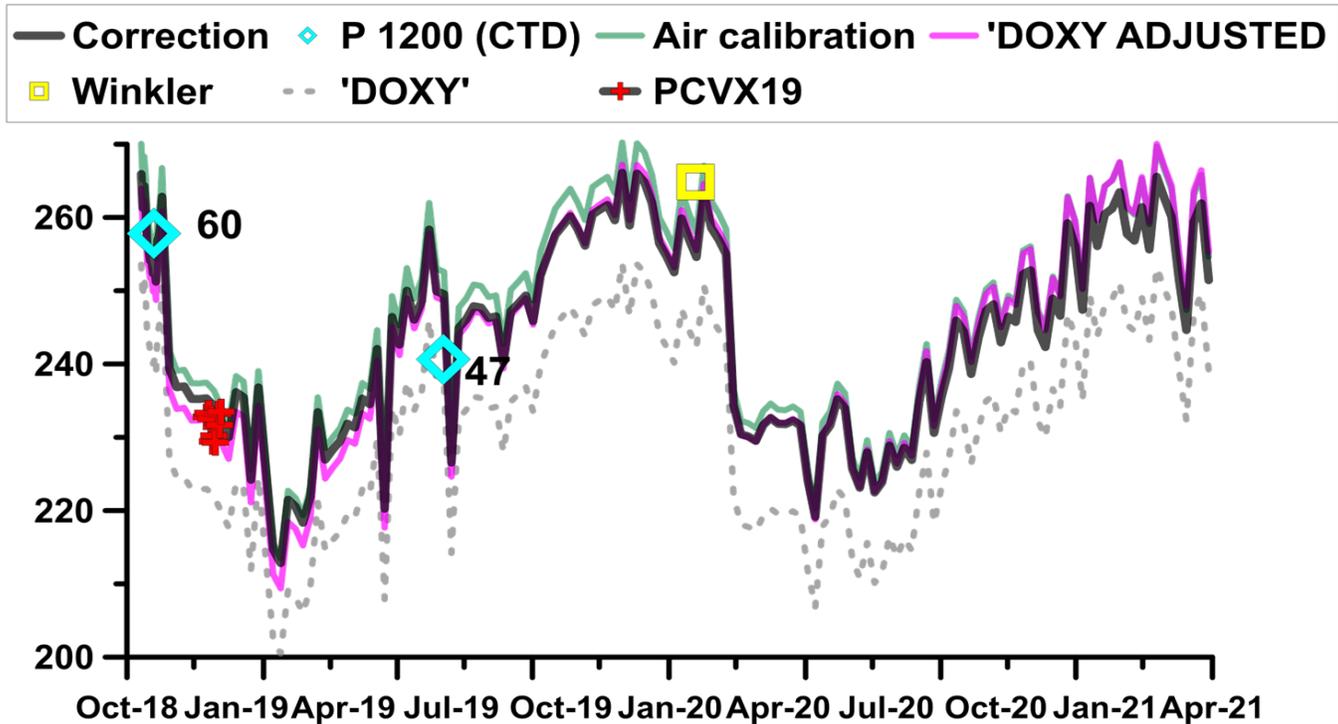
These **molecules emit photons** at a longer wavelength, but when oxygen diffuses into the film, it can **collide with excited molecules, transferring energy** to O_2 instead of emitting fluorescence. This reduces the **fluorescence lifetime**, which the sensor detects.



Measuring **fluorescence lifetime** rather than intensity **enhances sensor stability**, as it remains **unaffected** by dye loss due to **photobleaching** or **diffusion**.

Dissolved oxygen problem

WMO 6903250

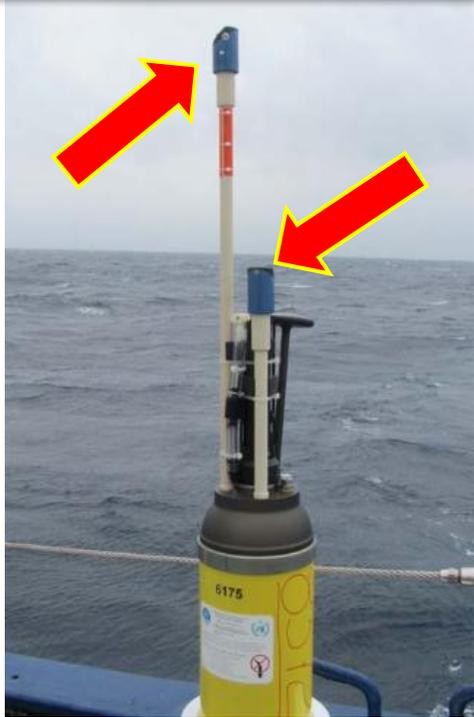


Gerin et al., 2024, Correction and harmonization of dissolved oxygen data from autonomous platforms in the South Adriatic Pit (Mediterranean Sea)

- Optodes have known **calibration problems** (Bittig et al., 2018). Sensors often show **significant deviations** from factory calibration.
- An analysis of 130 optodes found a **mean error of ~10 mmol kg⁻¹** in surface waters, typically reading too low (Takeshita et al. 2013).
- Once **in the ocean**, sensors show **no substantial drift** (Tengberg et al. 2006; Takeshita et al. 2013; Bittig and Körtzinger 2015).
- The **drift** is believed to occur primarily **before deployment**.
- Optode **errors reduce** the reliability of profiling float data for **detecting** long-term **oxygen** changes.

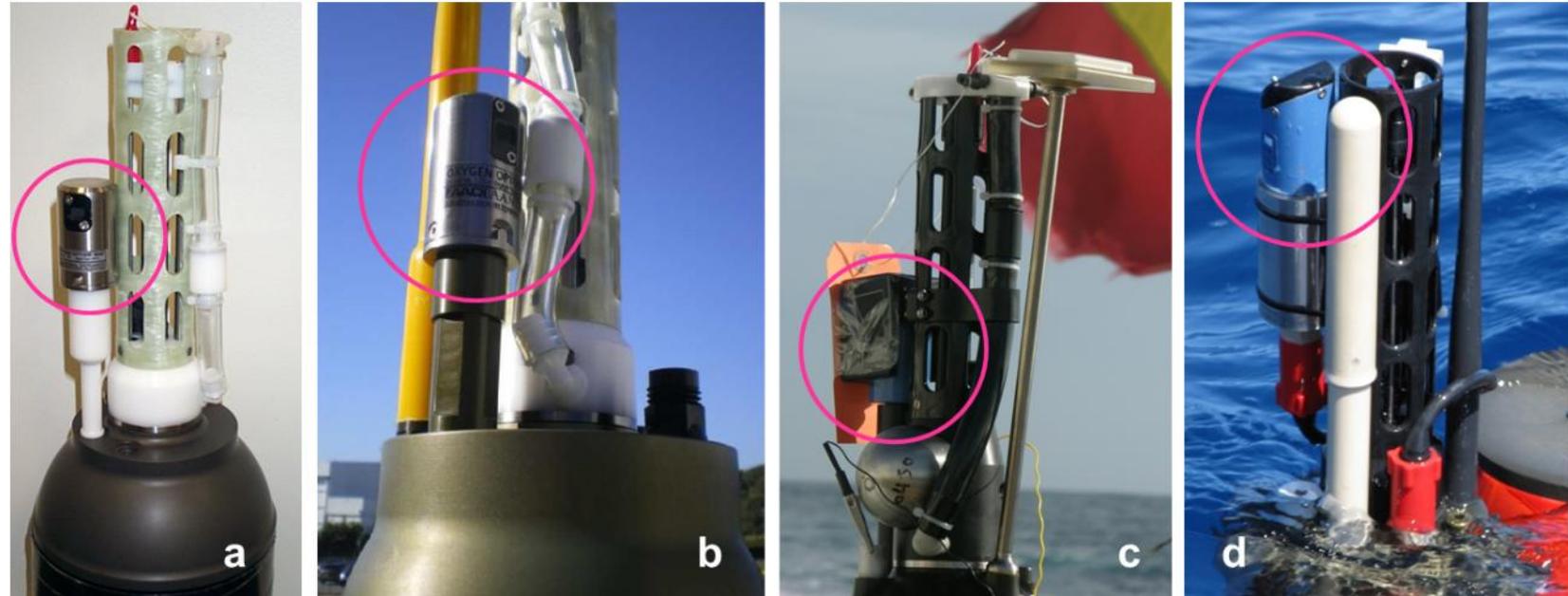
Dissolved oxygen solution

Many experiments have been made to achieve the best possible result



Bushinsky et al., 2016

Addressing the **long-term drift issue**, Körtzinger et al. (2005) proposed to **mount the optode on the float's top cap**



Oxygen optodes mounted on the top caps of floats: (a) APEX with Aanderaa 3830, (b) PROVOR CTS3 DO with Aanderaa 3830, (c) NAVIS float with pole-mounted Aanderaa optode 4330, and NEMO float with cable-mounted Aanderaa optode 4330.

Recalibrating optodes by measuring the partial pressure of oxygen in air (Körtzinger et al. 2005, Emerson and Bushinsky 2014, Jhonson et al., 2016).

Dissolved oxygen correction

- **In-air measurement:** The optode sensor measures oxygen partial pressure when the float surfaces.
- **Calibration process:** The measured partial pressure is compared to the expected atmospheric value to calculate a correction factor, compensating for **storage drift**.
- **Limitations:** Accuracy depends on full sensor exposure to air; rough seas, biofouling, or moisture can affect measurements.

Air Oxygen Calibration of Oxygen Optodes on a Profiling Float Array

KENNETH S. JOHNSON AND JOSHUA N. PLANT

The air oxygen values were used to correct the reported (raw) oxygen values $(O_2)_{\text{raw}}$ by applying only a gain correction (G):

$$(O_2)_{\text{corr}} = G \times (O_2)_{\text{raw}}, \quad (3)$$

where $(O_2)_{\text{corr}}$ is the corrected oxygen concentration. The gain factor g on each profile i was determined from the ratio of the expected partial pressure of oxygen in air (pO_2) to the partial pressure of oxygen in air measured by the optode ($pO_{2,\text{optode}}$):

$$g_i = pO_2 / pO_{2,\text{optode}}, \quad (4)$$

where pO_2 was calculated from the NCEP estimate of atmospheric pressure (P_{NCEP}) at the location and time of each float surfacing, the contribution of water vapor (assuming 100% humidity at the observed temperature), and the mole fraction of oxygen in dry air as

$$pO_2 = (P_{\text{NCEP}} - p_{\text{H}_2\text{O}}) \times 0.20946. \quad (5)$$

The vapor pressure of water was calculated using the empirical equation found in the Aanderaa model 4330 operating manual,

$$p_{\text{H}_2\text{O}} = e^{[52.57 - [6690.9/(t+273.15)] - 4.681 \times \ln(t+273.15)]}, \quad (6)$$

where t is the temperature ($^{\circ}\text{C}$). The gain factors g_i were then averaged to obtain a single value of G that was applied to all of the data for each float.

$$g_i = [(O_2)_{\text{soly}} \times (P_{\text{NCEP}} - p_{\text{H}_2\text{O}})] / [(1013.25 - p_{\text{H}_2\text{O}}) / (O_2)_{\text{raw,air}}], \quad (9)$$

where $(O_2)_{\text{soly}}$ is the oxygen solubility ($\mu\text{mol L}^{-1}$) in pure water at an atmospheric pressure of 1013.25-mbar pressure (Garcia and Gordon 1992).

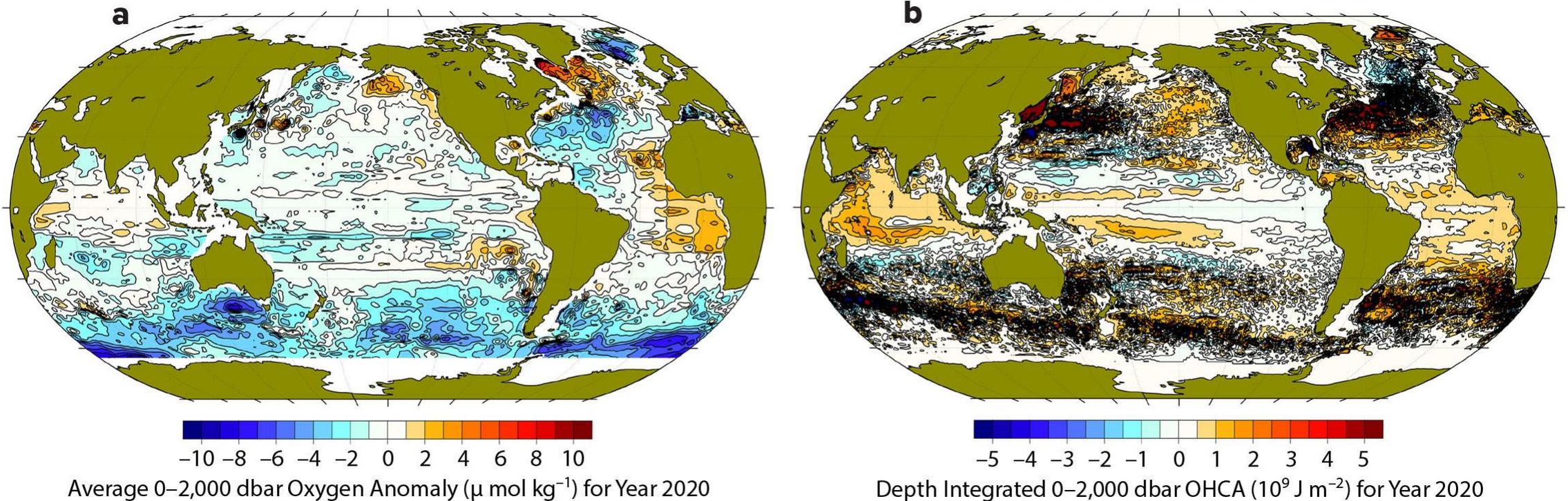
Dissolved oxygen science

Oceanography THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY

After Two Decades, Argo at PMEL, Looks to the Future

By [Gregory C. Johnson](#) and [Andrea J. Fassbender](#)

Map of 0 to 2,000 m depth-averaged oxygen anomaly (color contours in $\mu\text{mol kg}^{-1}$) in 2020 relative to a 2004–2021 mean (Sharp et al., 2023).
(b) Map of 0–2,000 m ocean heat content anomaly (OHCA, color contours in 10^9 J m^{-2}) in 2020 relative to a 1993–2021 mean (Lyman and Johnson, 2023).

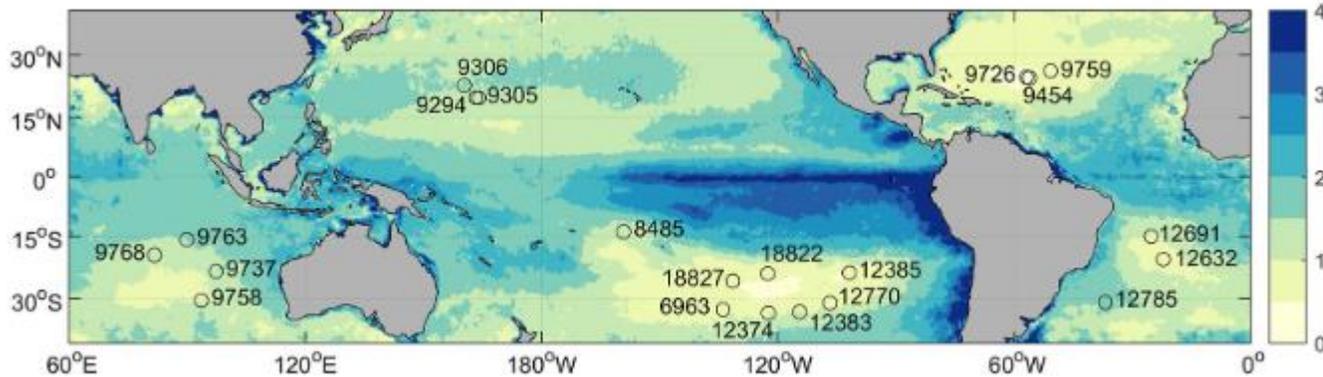


Dissolved oxygen science

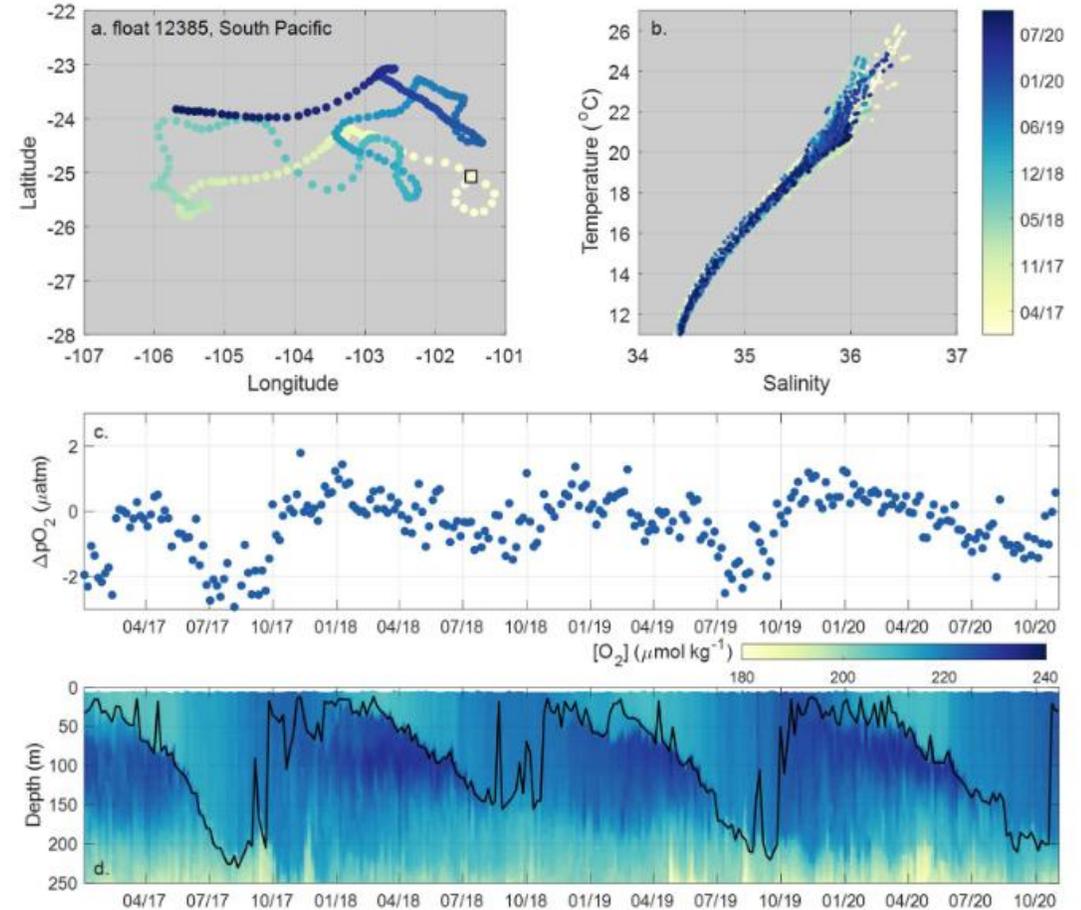
Geophysical Research Letters

The Ocean's Biological Pump: In Situ Oxygen Measurements in the Subtropical Oceans

Steven Emerson Bo Yang



The magnitude and distribution of the ocean's biological pump (the downward flux of organic carbon (OC) from the ocean surface) influences the $p\text{CO}_2$ of the atmosphere and the O_2 content of the deep sea, but has not been well quantified. We determine this flux in the ocean's five subtropical gyres using upper-ocean oxygen mass balance and measurements of T , S , and $p\text{O}_2$ by autonomous profiling floats.



Dissolved oxygen science

Journal of Marine Systems 245 (2024) 103988

Contents lists available at ScienceDirect

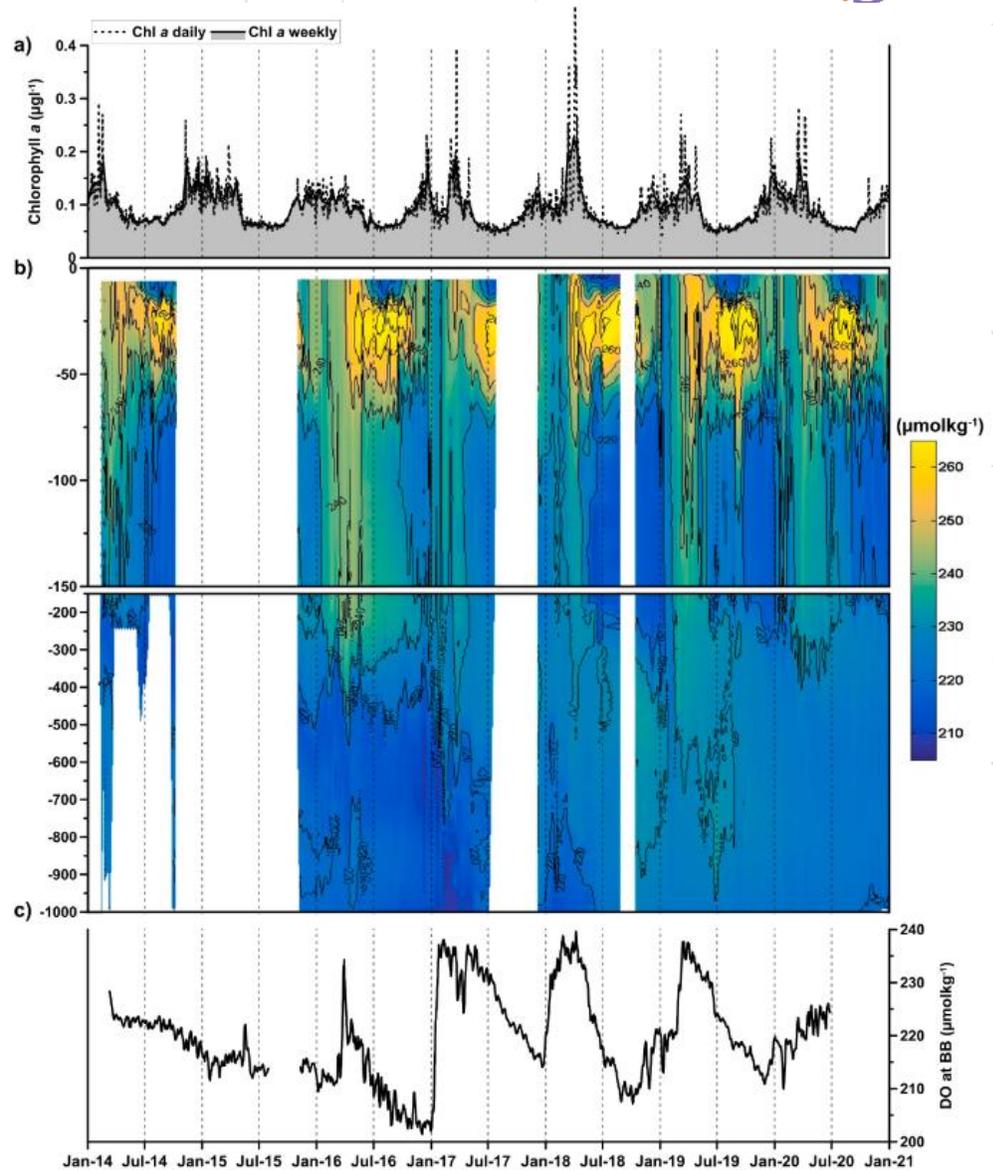
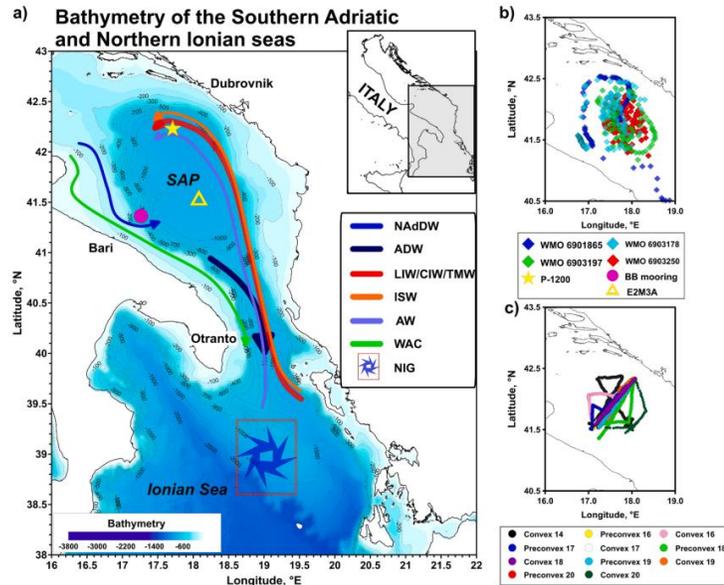
Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys



Recent changes of the dissolved oxygen distribution in the deep convection cell of the southern Adriatic Sea

R. Martellucci^{a,*}, M. Menna^a, E. Mauri^a, A. Pirro^a, R. Gerin^a, F. Paladini de Mendoza^b, R. Garić^c, M. Batistić^c, V. di Biagio^a, P. Giordano^d, L. Langone^d, S. Miserocchi^d, A. Gallo^a, G. Notarstefano^a, G. Savonitto^a, A. Bussani^a, M. Pacciaroni^a, P. Zuppelli^a, P.-M. Poulain^e



Optical sensors APEX



PROVOR



Navis



RBR tridente



SBE ECO FLNTU and more



The **optical sensors** allow to **measure** different **physical quantities**. The physical principle on which an optical measurement is based is that **the detectors converts** the parameter to be measured (light spectrum) **into** some form of **electrical signal**, in general the optical sensor converts light into an electrical current.

BGC ARGO use optical sensor to measure **fluorescence of chlorophyll a, suspended particles, CDOM, downwelling irradiance** as photosynthetically available radiation (PAR) and irradiance. Using filters or other means to separate different colors specific colors (wavelength band-width) are sensed

Chlorophyll a



Phytoplankton, are similar to terrestrial plants in that they contain **chlorophyll** and require **sunlight** in order to live and **grow**.

Marine phytoplankton are the basis of **aquatic ecosystems** and generate **half of global primary production**.

- ✓ Oceanic **Chlorophyll a** concentration, (Chl a) is considered as the **universal proxy** for **phytoplankton biomass**.
- ✓ Because of the **key role** of phytoplankton in the global **cycle of elements**, mapping and understanding the **spatio-temporal distribution** and variability in **Chl a** thus appear of **primary importance**.
- ✓ **Remote sensing** of Ocean Color Radiometry offers a unique way to map **quasi-synoptically Chl a at the ocean surface**. The implementation of miniature Chl a fluorometers on **BGC-Argo floats** allows the systematic collection of **vertical profiles of Chl a**.

Chlorophyll a sensor

Fluorescence is the **emission** of light by a substance that has **absorbed** light.

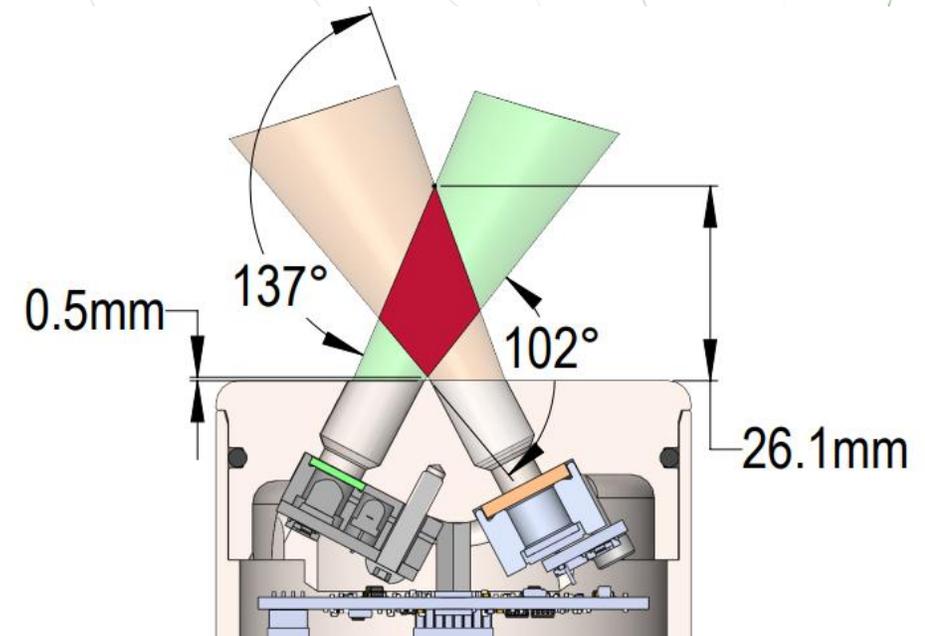
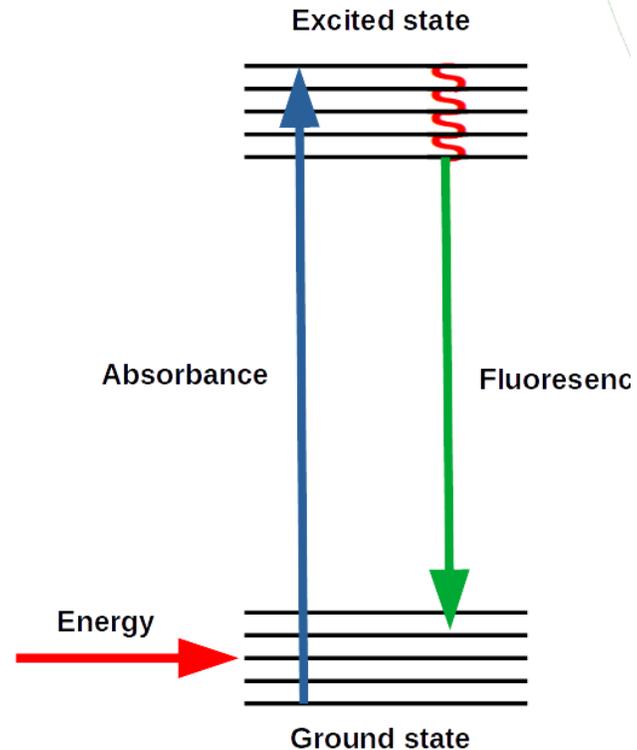
When **light** is **absorbed**, the light energy promotes an **electron to a higher** (excited) energy level.

The **additional energy** can be **released** several **different ways**. The molecule could lose some of the energy through enhanced vibrations (red squiggly line).

Fluorescence occurs when the molecule releases that remainder of the energy by emitting light.

Because of the energy loss due to molecular vibration in between the absorbency and emission processes, the fluorescence is usually lower energy (higher wavelength) than the absorbency.

Chlorophyll a is obtained through fluorescence measurements. Phytoplankton absorbed (440nm) the blue light reemitting the red (675nm)



RBRtridente

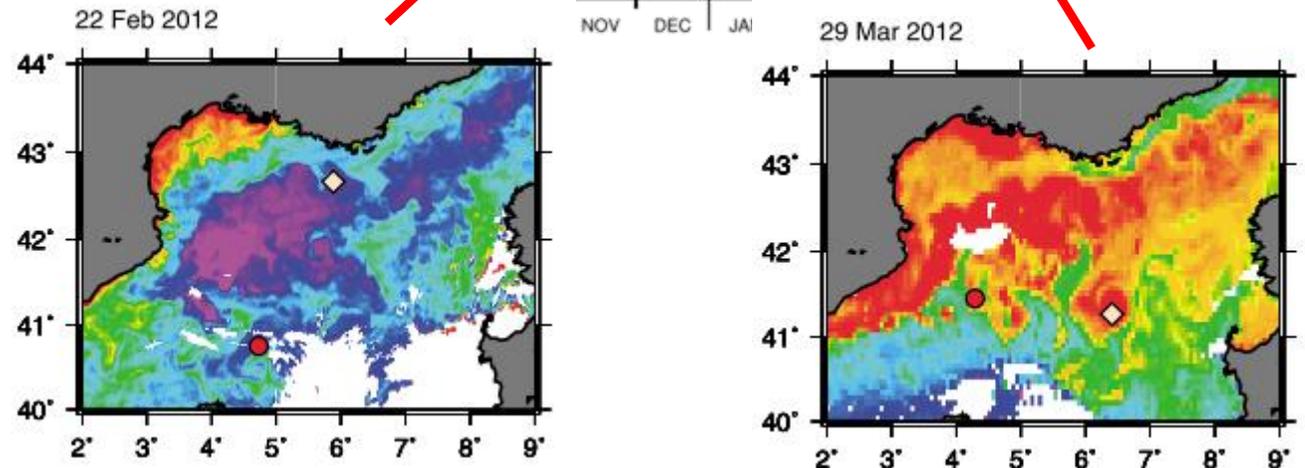
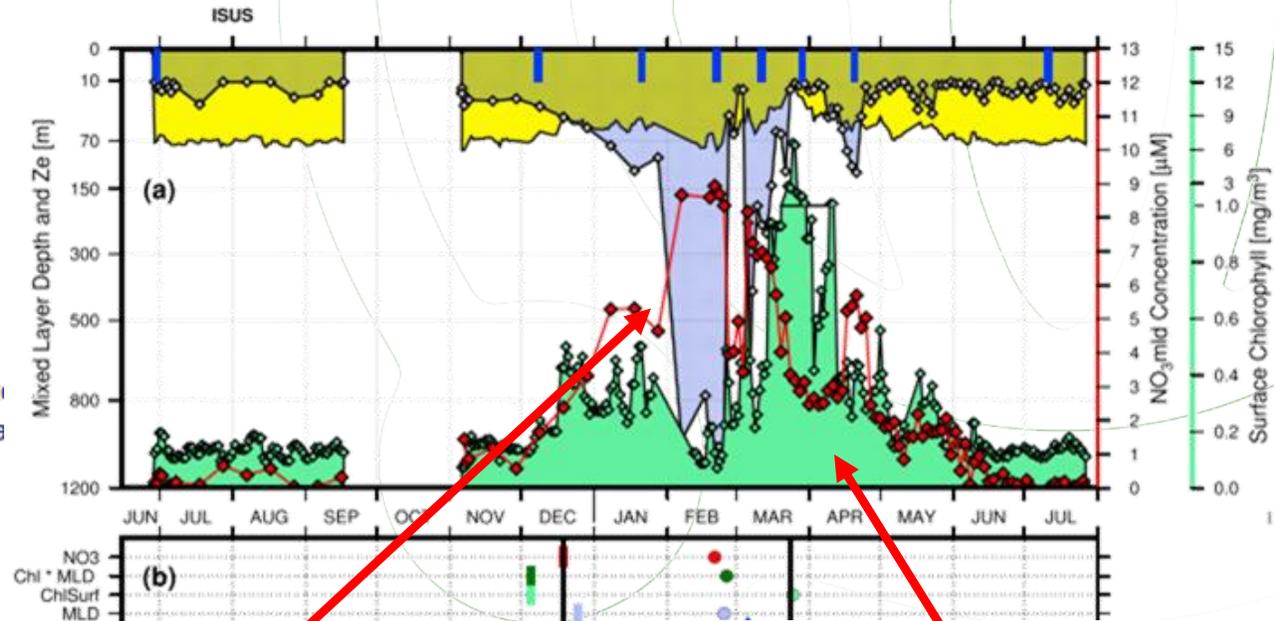
Chlorophyll a science

Geophysical Research Letters*

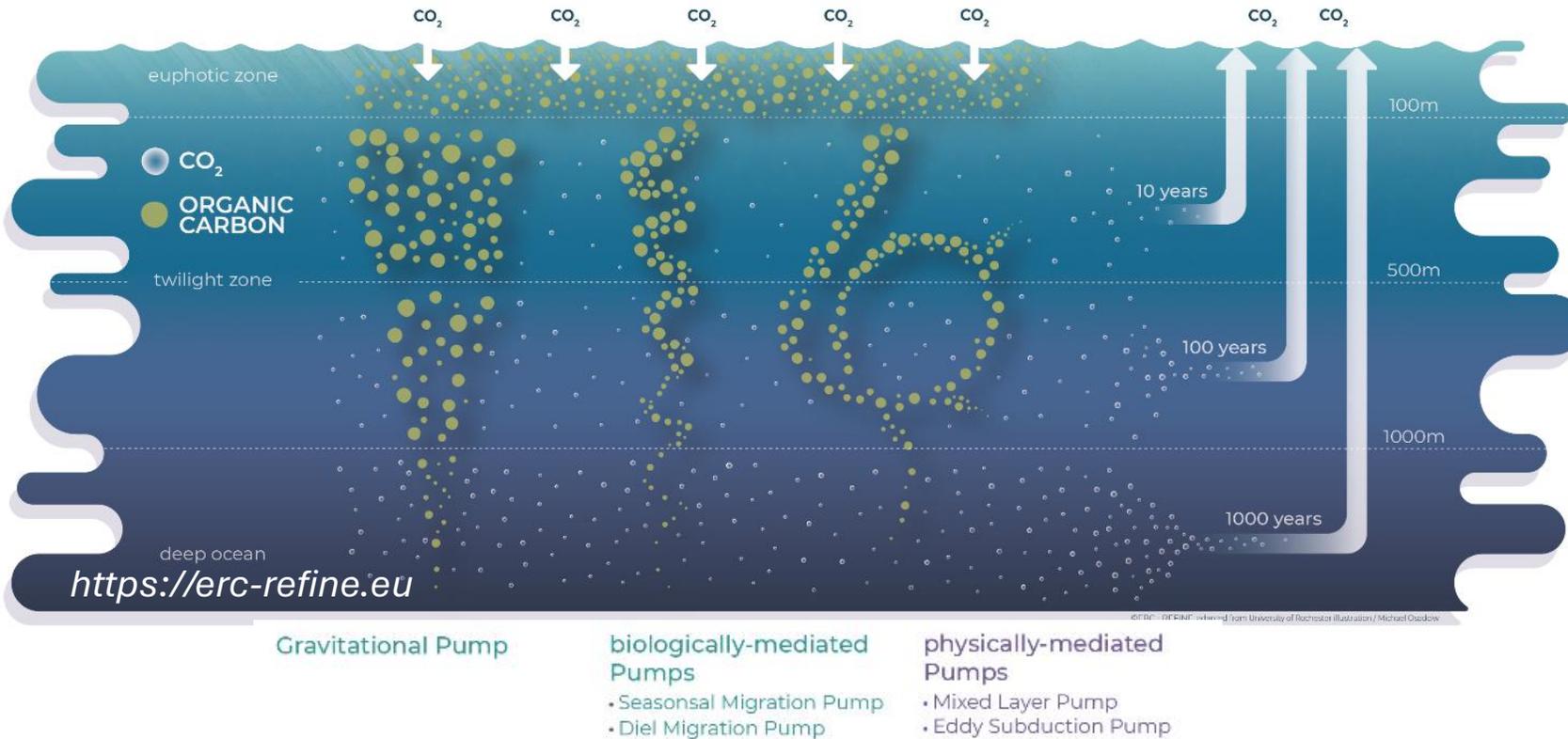
Observing mixed layer depth, nitrate and chlorophyll concentrations in the northwestern Mediterranean: A combined satellite and NO₃ profiling floats experiment

Fabrizio D'Ortenzio ✉, H  lo  se Lavigne, Florent Besson, Herv   Claustre, Laurent Coppola, Nicola Agathe La  s-Huon, Serge Le Reste, Damien Malard  , Christophe Migon, Pascal Morin ... See a

Two profiling floats, equipped with nitrate concentration sensors were deployed in the northwestern Mediterranean from summer 2012 to summer 2013. Satellite ocean color data were extracted to evaluate surface chlorophyll concentration at float locations. Time series of mixed layer depths and nitrate and chlorophyll concentrations were analyzed to characterize the interplay between the physical-chemical and biological dynamics in the area.



Suspended particles



Suspended particles include phytoplankton bacteria and their microscopic predators and bacteria. **The concentration of suspended particles** is estimated from **backscattering** or attenuation measurements on **profiling floats**, providing a **good proxy** for particulate organic carbon (**POC**) and phytoplankton carbon (**PC**).

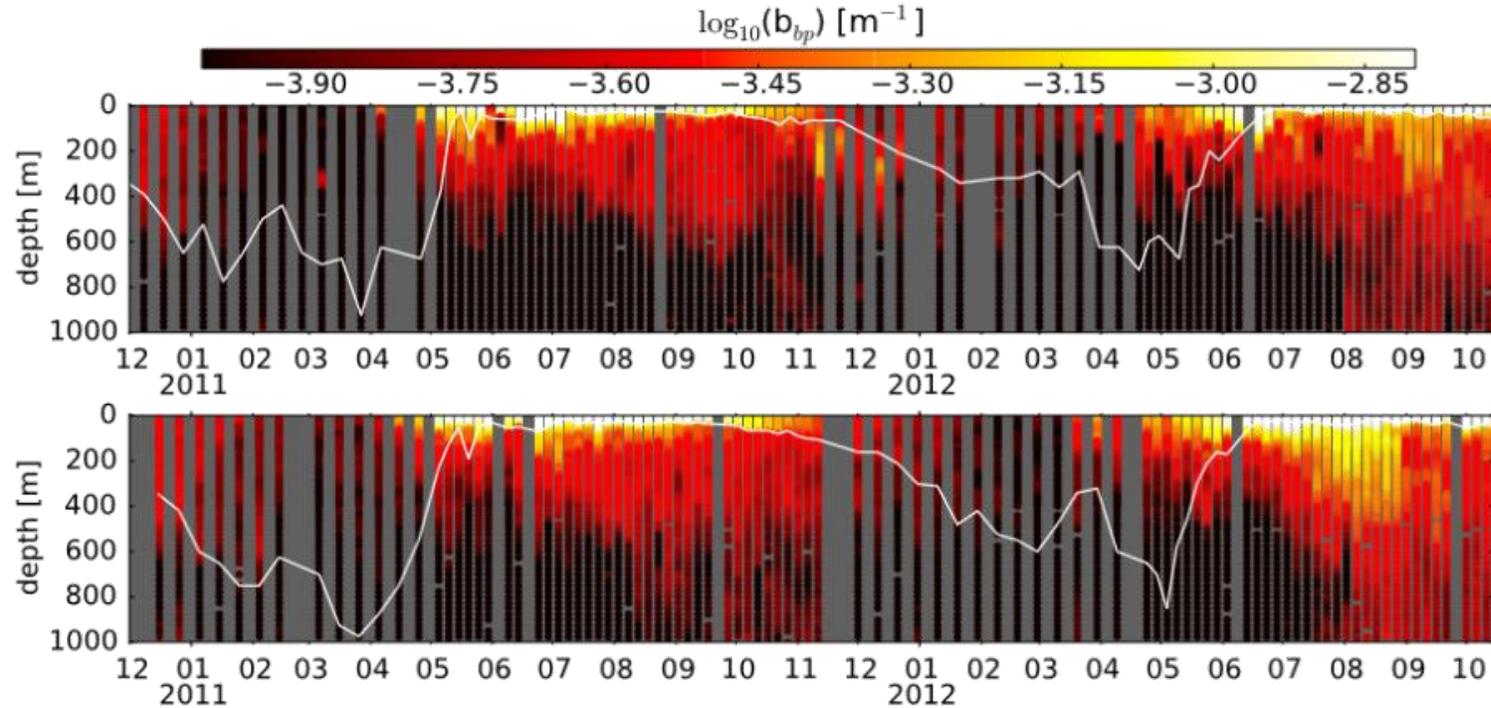
Photosynthetic organisms at surface allows the production of **organic carbon** from its **inorganic** from **CO₂**. All **five pumps transport** organic material at various depth of the **twilight zone** and **deep ocean**, progressively returning into **mineral phase CO₂** due to bacterial remineralization. This represent the **major process** that works significantly to **reduce CO₂** from the atmosphere.

Suspended particles - science

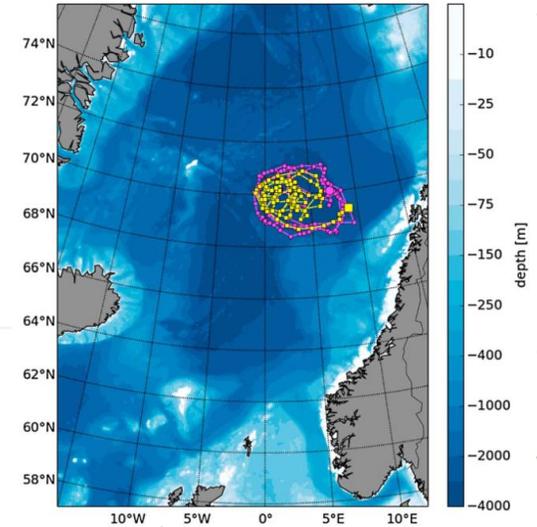
Geophysical Research Letters*

Carbon export by small particles in the Norwegian Sea

Giorgio Dall'Olmo ✉ Kjell Arne Mork

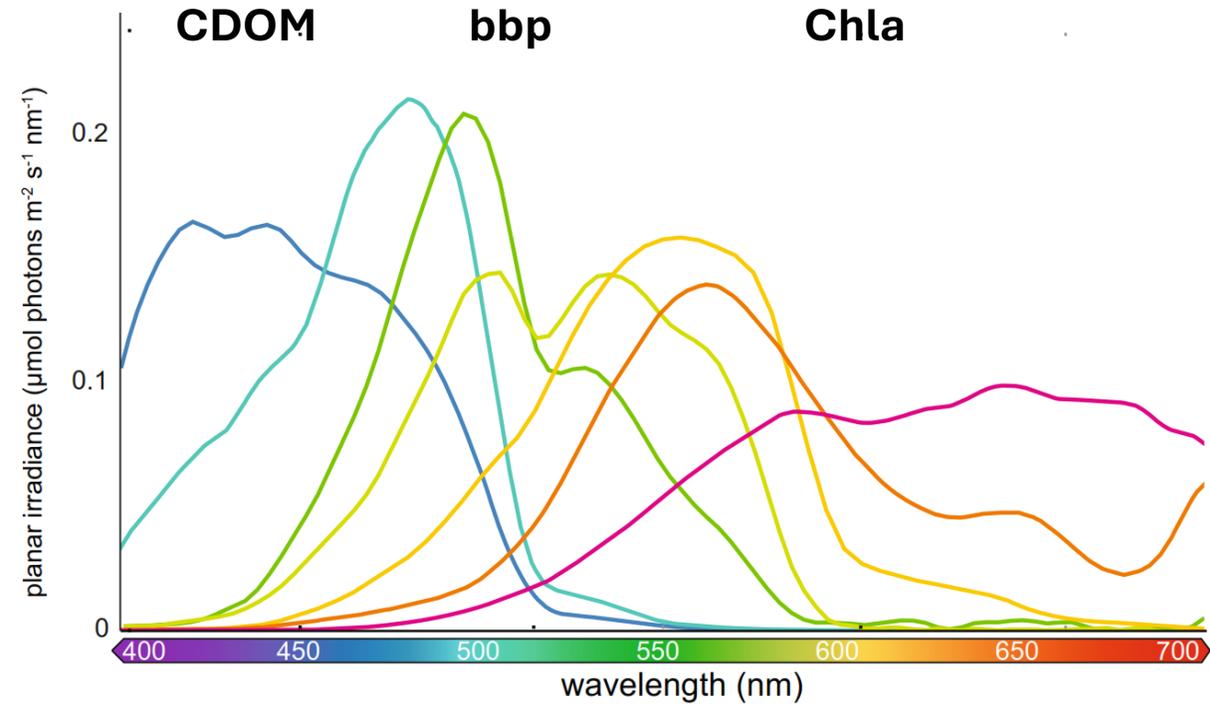


The white continuous line represents an estimate of the mixed layer depth



Optical backscattering measured by Bio-Argo floats can detect a seasonal carbon export flux in the Norwegian Sea. This export was most likely due to small particles (i.e., 0.2–20 μm) ... Our findings highlight the importance of small particles and of physical mixing in the biological carbon pump and support the use of autonomous platforms as tools to improve our mechanistic understanding of the ocean carbon cycle.

Downwelling irradiance



- South Pacific gyre
hyper-oligotrophic
- North Pacific gyre
oligotrophic
- subtropical North Atlantic
oligotrophic
- temperate North Atlantic
mesotrophic
- Baltic Sea
eutrophied coastal water
- lake IJsselmeer
eutrophic lake
- lake 't Joppe
hyper-eutrophic turbid lake

Holtrop et al., 2021, *Nature Ecology & Evolution*

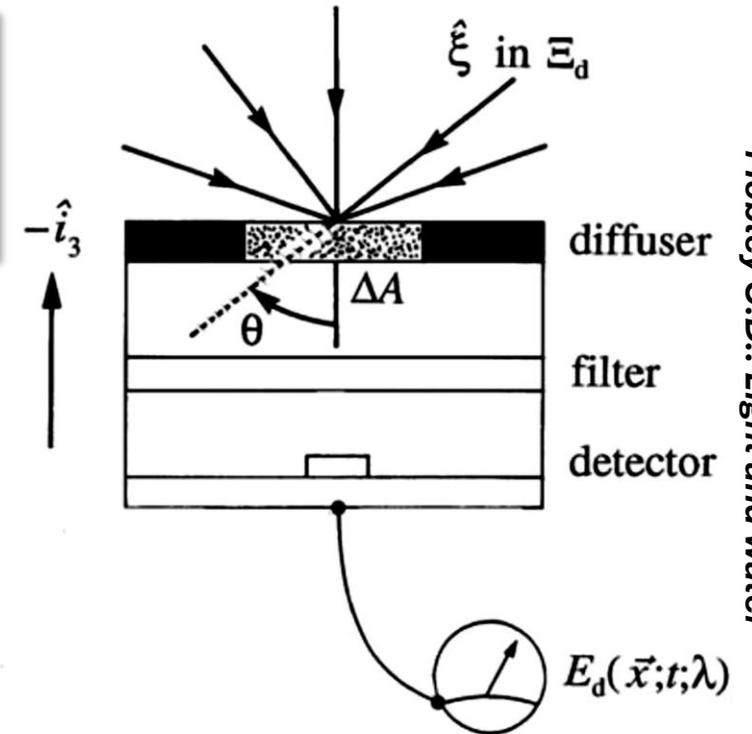
The **radiation** emanating from the **sun** and impinging on the **ocean** is the major **source of energy** driving **life** in the ocean and is also involved in processes such as heating and photo-oxidation. Light is **attenuated** in the water column due to its **absorption** by in-water **constituents** and hence spectral light **attenuation** is used to **infer** the **concentrations of materials in the ocean**. **Radiometers** deployed on **floats** typically measure the **down-welling radiation** intensity at several channels, a few narrow spectral channels from which the concentration of chlorophyll and dissolved organic materials are inferred and a broad-band PAR channel, **providing an estimate** of the light available for **primary production** in the ocean. A few floats, designed for validation of remote sensing radiance field, are equipped with **upwelling radiometers**.

biogeochemical-argo.org

Downwelling irradiance

Radiometers typically contain electric elements, photo-detectors.

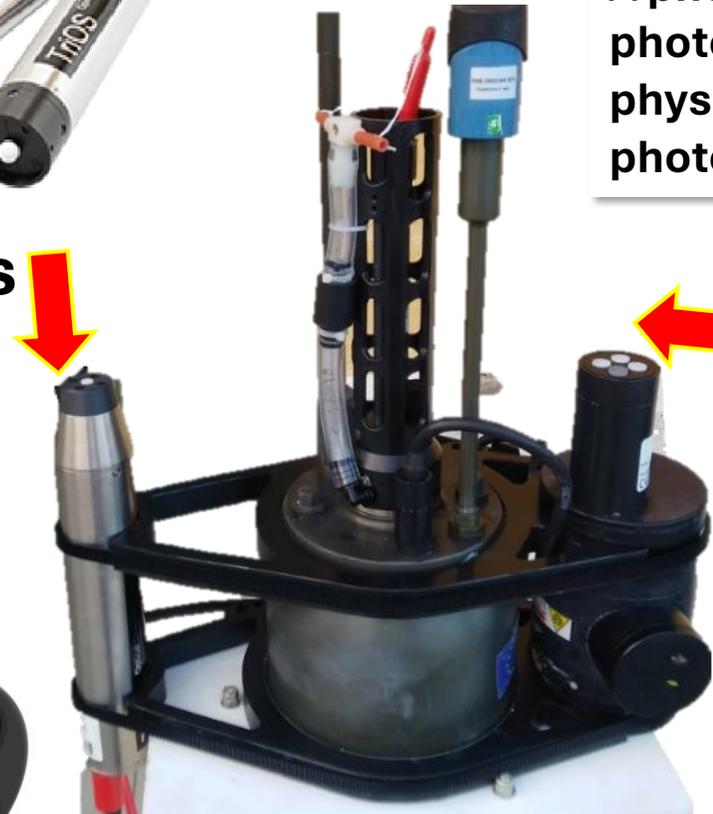
A **photodiode** is a particular type of **photo-detector** diode based on the **physical** principle of the **photoelectric effect**..



Mobley C.D.: Light and water



OCR-Trios



OCR-SBE

The **energy** of the incident **photon** causes an **external electron** shift that **generates** a potential difference within the photodiode, which generates an **electric current**.



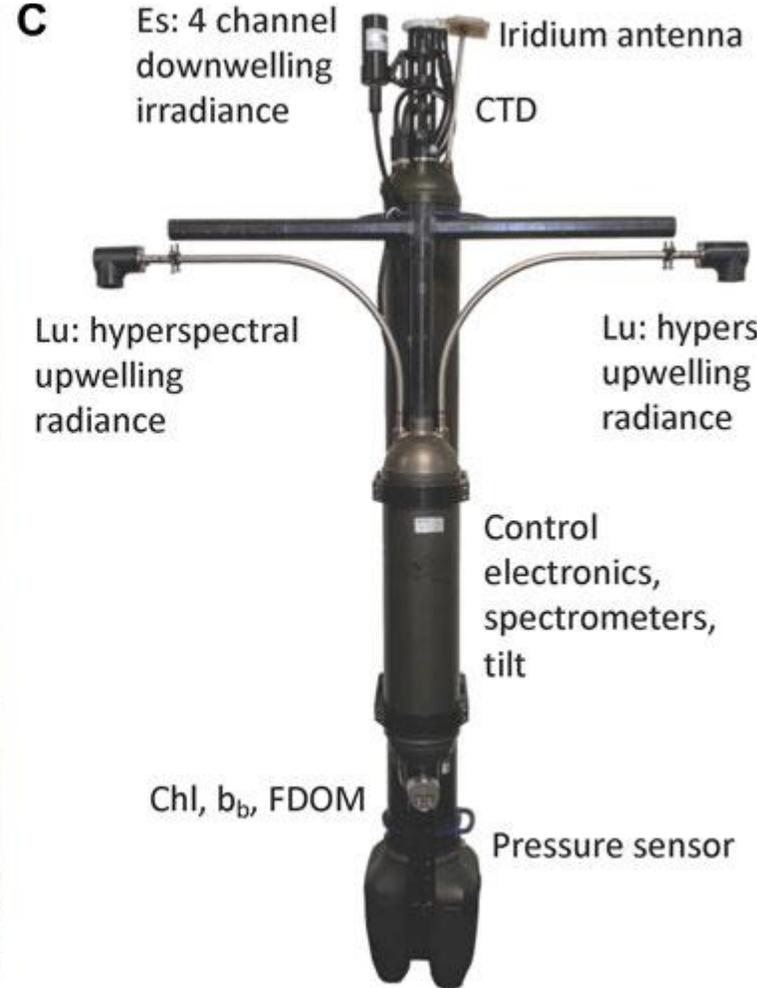
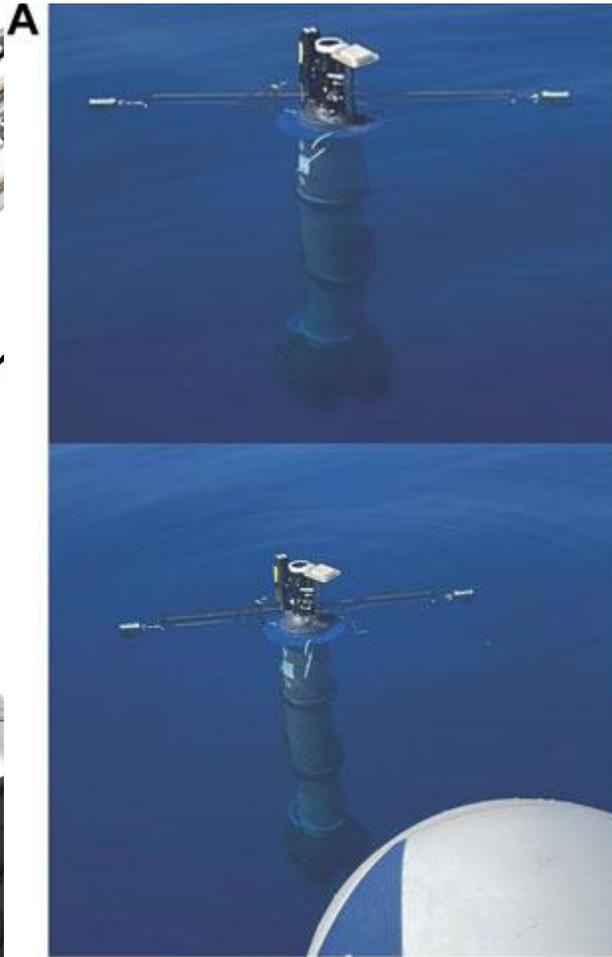
RBR quadrante

AUTOC

Down

IRIS

The HyperNav float-based system. (A) Photos of the system from a test deployment North of Crete. (B) Photo of the system taken onshore before deployment during system testing. The Navis float is shown in the forefront. (C) Photo of HyperNav showing the locations of the sensors. Barnard et al., 2024 A float-based Ocean color vicarious calibration program.



Mobley C.D.: Light and water

$\vec{x};t;\lambda)$

electron diode,

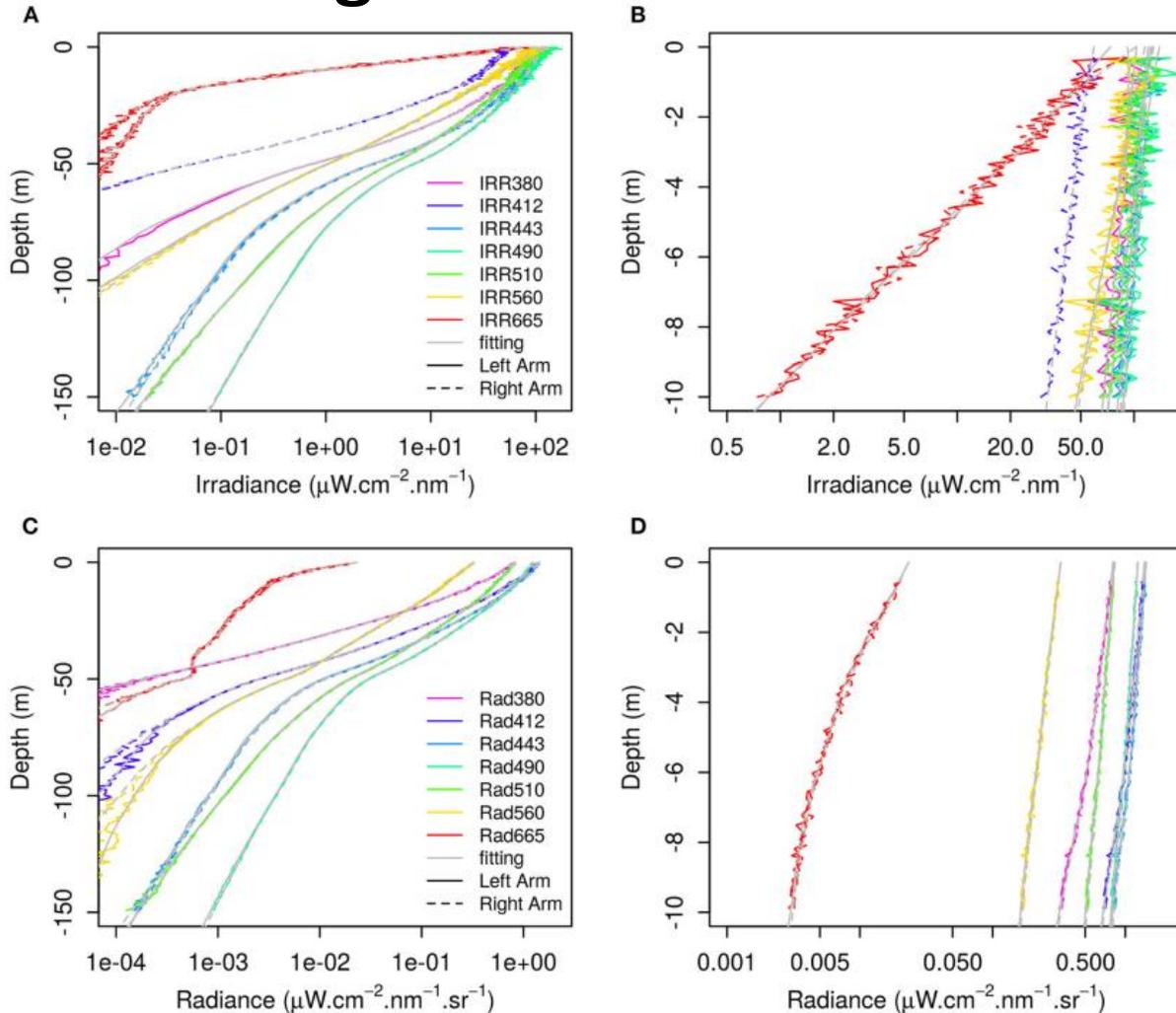


OCR-Tr



RBR quadrants

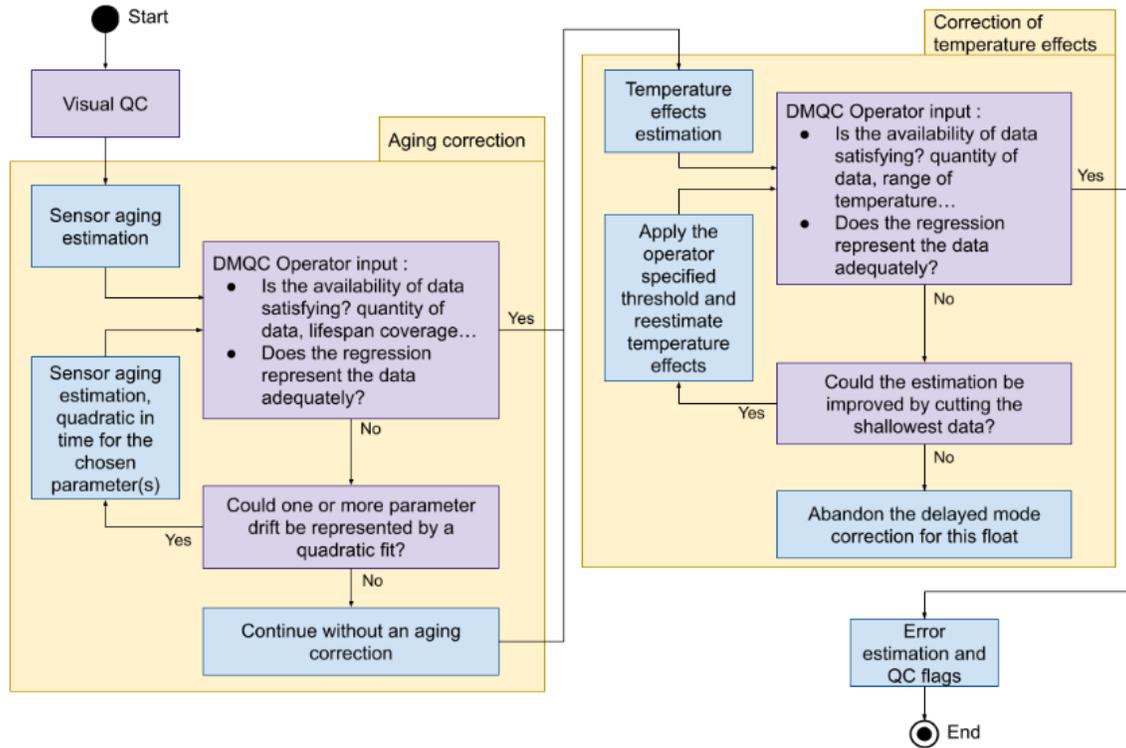
Downwelling irradiance



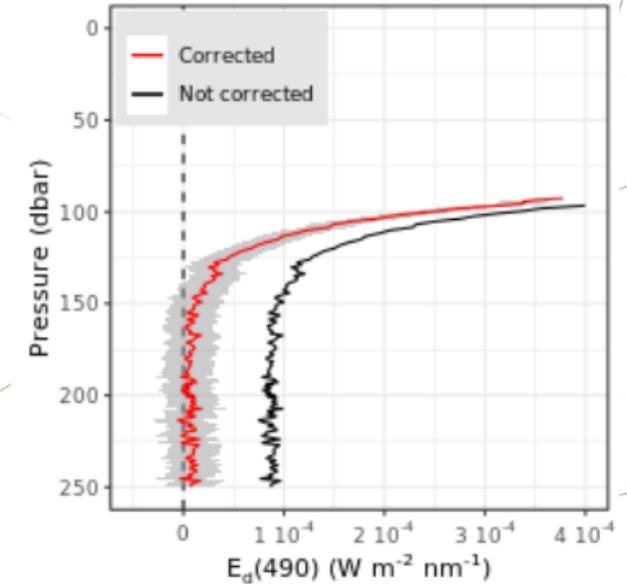
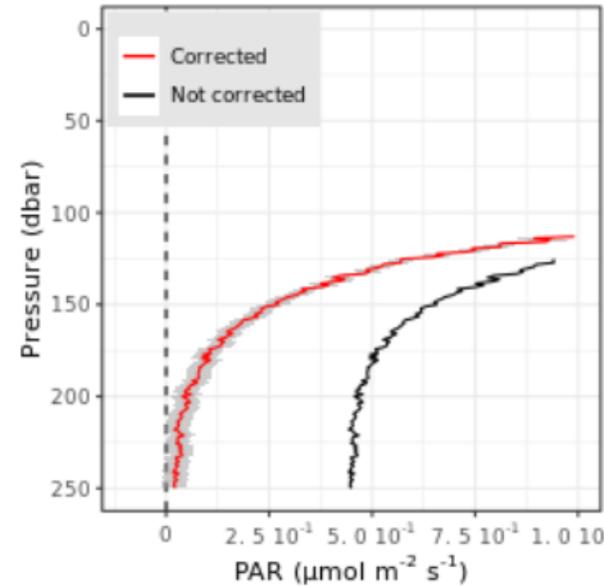
Using **filters** or other means to **separate different colors** specific colors (wavelength band-width) are sensed. **PAR** sensors are designed to have a **response** proportional to the number of **visible wavelength** photons impinging on them to mimic **phytoplankton**.

Example of data, float lovapm006f (profile 57, 2017–08–02). Data (color) and fitting functions (gray), for irradiance (A,B), and radiance (C,D) data, for the whole profile (A,C) and close to the surface (B,D). *Leymarie et al., 2018 ProVal: A New Autonomous Profiling Float for High Quality Radiometric Measurements.*

Downwelling irradiance DMQC



Correction for drift and temperature dependence



The overall quality-control procedure includes five consecutive steps, which will be described in the following sections, and are the same both for $E_d(\lambda)$ and PAR: (i) Visual quality control; (ii) Correction of the sensor aging; (iii) Correction of the sensor temperature-dependence; (iv) Error estimation; and (v) Assignment of quality flags.

Jutard et al., 2021, Sensor

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Nutrients



PROVOR

SBE SUNA

Trios OPUS



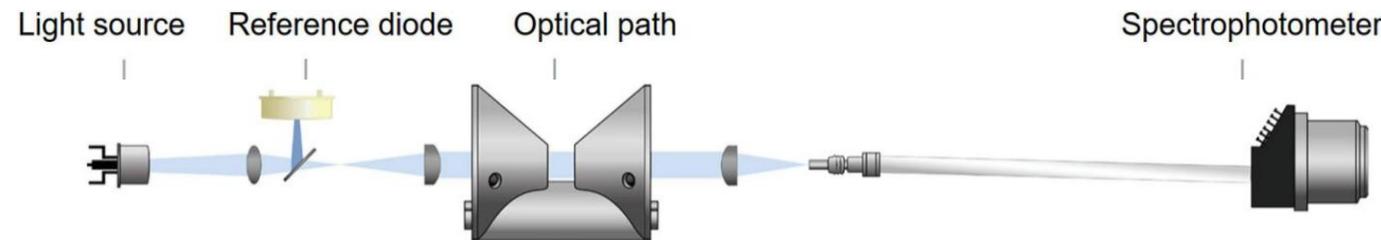
MBARI-ISUS



APEX

Nitrate is an **essential** macronutrient **for growth**. Phytoplankton need nitrogen to build aminoacids and proteins. Recent advances have led to the **development** of low power **In Situ Ultraviolet Spectrophotometers (ISUS)**, which are capable of making **optical measurements of nitrate** in seawater as deep as 4000 m.

Nitrate, amongst other compounds, can be **identified** based on its **UV** absorption spectrum. **Spectral deconvolution techniques** allow **determination of nitrate** in seawater with **no interferences** or chemical manipulations. This method **allows high temporal resolution** sampling (up to one measurement per second) to concentrations near $0.1 \mu\text{M}$ (Johnson and Coletti, 2002).



Nheir et al. 2021

Nutrients problems and solution

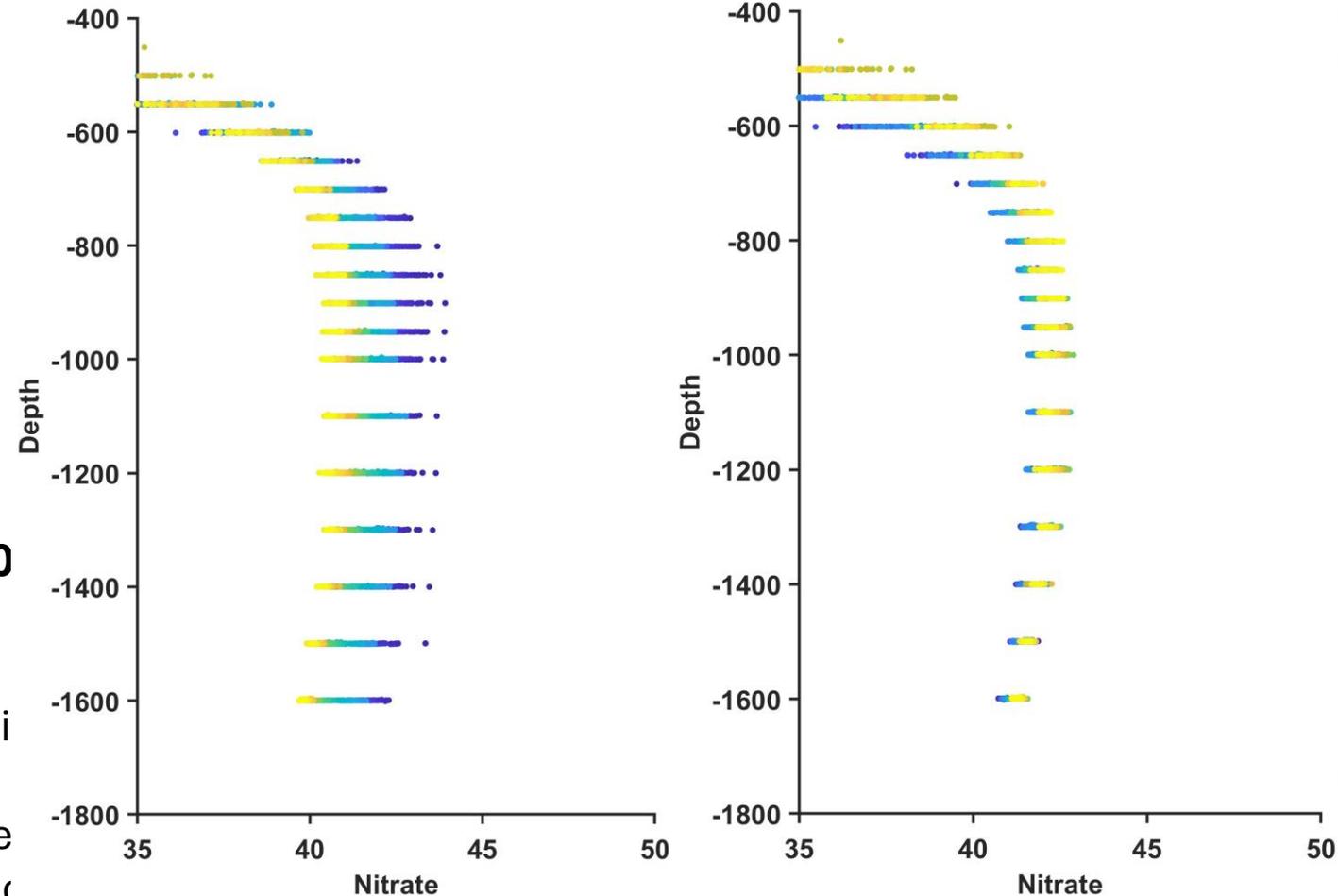
As noted by Johnson et al. (2017) and Maurer et al. (2021), **most BGC-Argo nitrate data require real-time adjustments** to meet Argo's goal of providing research-quality observations. The main problems are **inaccurate initial calibrations due to sensor instability during storage and transport** before deployment, and subsequent **drift or offsets post-deployment**.

Nitrate – correct using mapped nitrate at 1500

- $\text{NO}_3 \text{ correct} = \text{NO}_3 \text{ raw} + 1500 \text{ m error}$

Nitrate correction relies on an accurate model for nitrate variability is minimal over decadal scales.

The approach involves calculating the correction between 1000 and 2000 m, then applying these correction values. Correction values are estimated through spatial and temporal interpolation of the WOA dataset at 1000–2000 m depth.



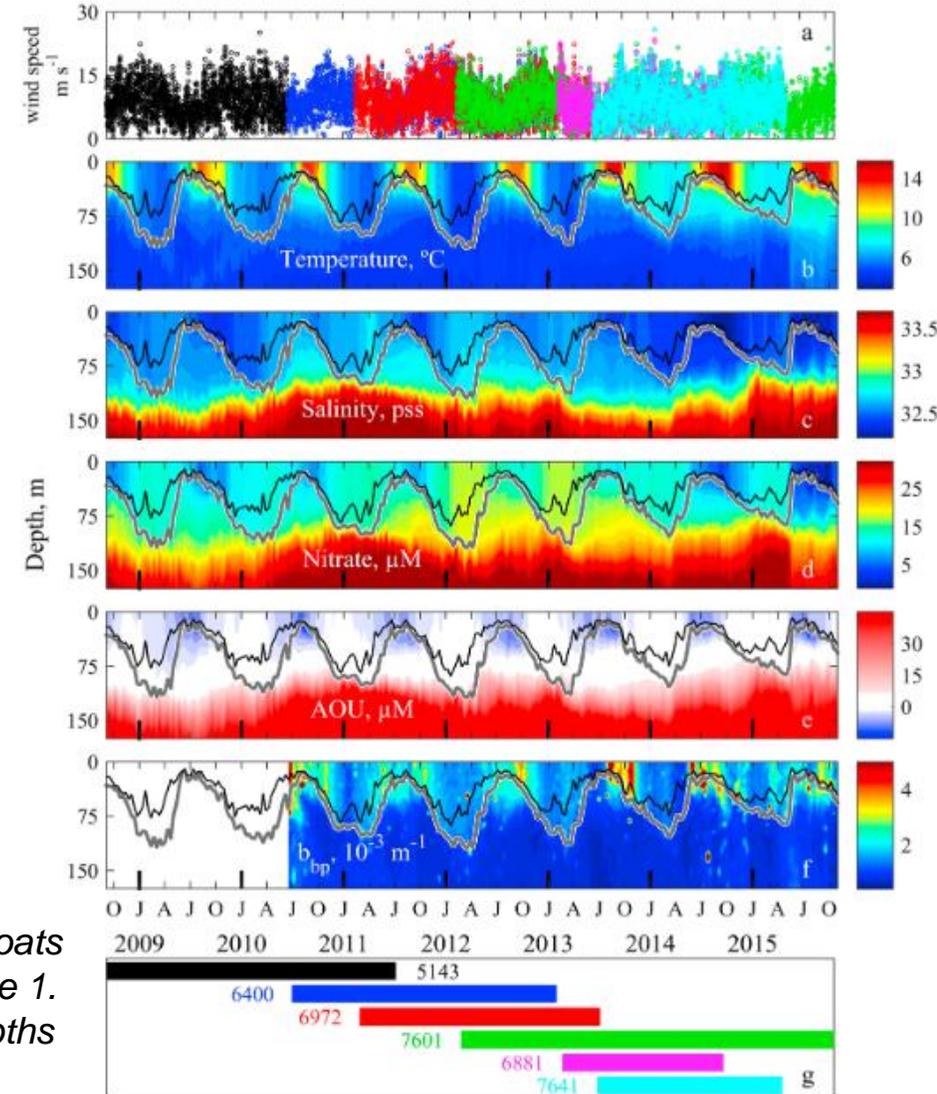
Nutrients science

Global Biogeochemical Cycles*

Net community production at Ocean Station Papa observed with nitrate and oxygen sensors on profiling floats

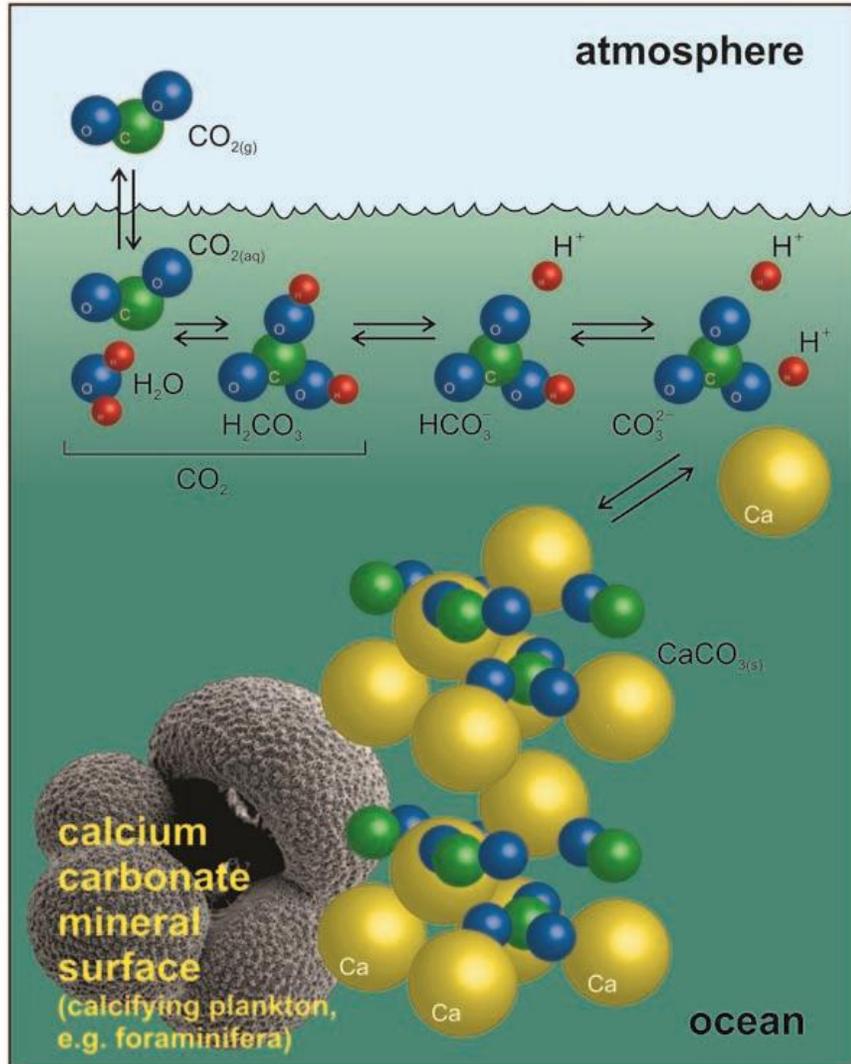
Joshua N. Plant ✉, Kenneth S. Johnson, Carole M. Sakamoto, Hans W. Jannasch, Luke J. Coletti, Stephen C. Riser, Dana D. Swift

Six profiling floats equipped with nitrate and oxygen sensors were deployed at Ocean Station P in the Gulf of Alaska. The resulting six calendar years and 10 float years of nitrate and oxygen data were used to determine an average annual cycle for net community production (NCP) in the top 35 m of the water column.



(a) NCEP wind speeds along the float tracks, (b–f) water properties observed by the profiling floats above the halocline, and (g) float deployment durations within the bounding box shown in Figure 1. Thick grey lines represent the mixed layer depth Thin black lines define the average mixing depths determined by the model.

pH



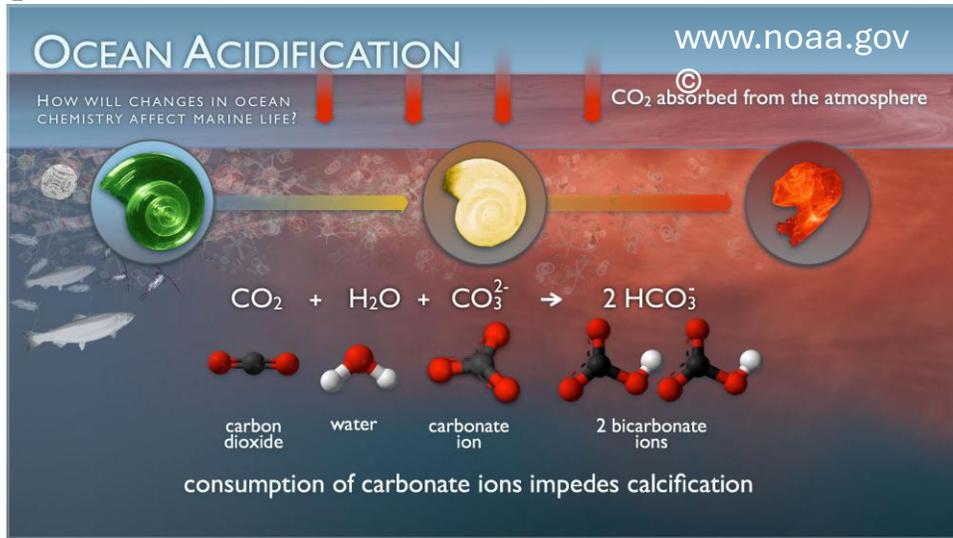
When **CO₂** dissolves in seawater to produce aqueous CO₂ (CO_{2(aq)}) it also forms **carbonic acid** (H₂CO₃) (1). Carbonic acid rapidly dissociates (splits apart) to **produce bicarbonate ions** (HCO₃⁻, 2). In turn, bicarbonate ions can also dissociate into **carbonate ions** (CO₃²⁻, 3). Both of **these** reactions also **produce protons** (H⁺) and therefore **lower the pH** of the solution (i.e., the water is now more acidic than it was — **recall that pH is the negative logarithm of the proton concentration or activity, -log₁₀[H⁺].**



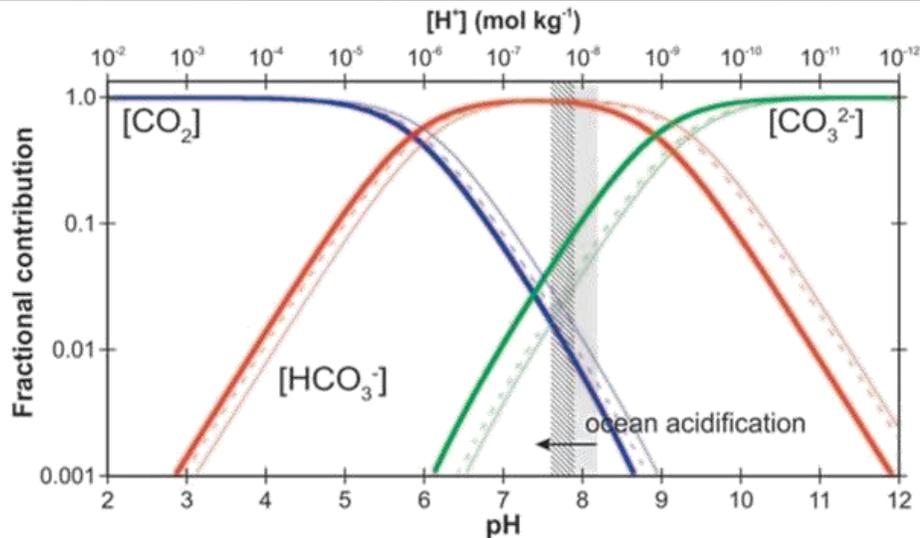
Barker, S. & Ridgwell, A. (2012) Ocean Acidification. Nature Education Knowledge 3(10):21

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

pH

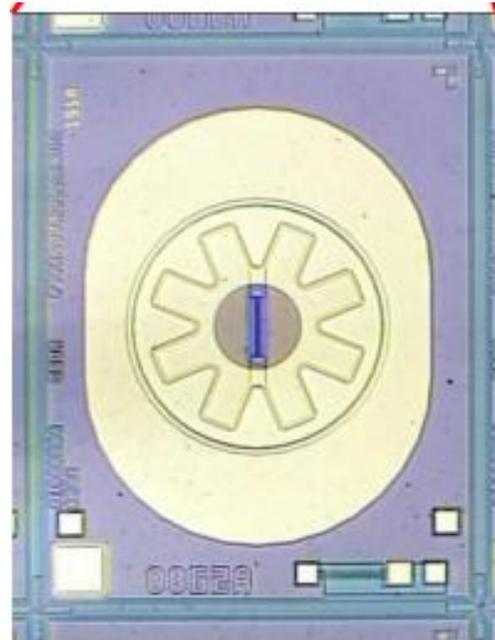


- **Ocean pH** is a dynamic variable that **changes** on **daily, seasonal, interannual, and decadal** to **centennial** time scales.
- **Variability** at daily to annual time scales is **produced** by a variety of processes including **photosynthesis, respiration, heating, and ocean physics**.
- The **short-term** changes are **superimposed** on a **century-scale** decrease in surface ocean pH at a rate near $-0.002 \text{ pH year}^{-1}$, which is driven by the long-term increase in atmospheric carbon dioxide created by combustion of fossil fuels.
- This **long-term pH decrease**, termed **ocean acidification**, may have profound **effects** on some **organisms**.
- **Observations** of the annual to weekly scale **pH** changes **provide** important constraints on **net photosynthesis** and **respiration** in the ocean
- The **Honeywell Durafet** is an **Ion Sensitive Field Effect Transistor pH** sensor mounted in the **BGC ARGO**.

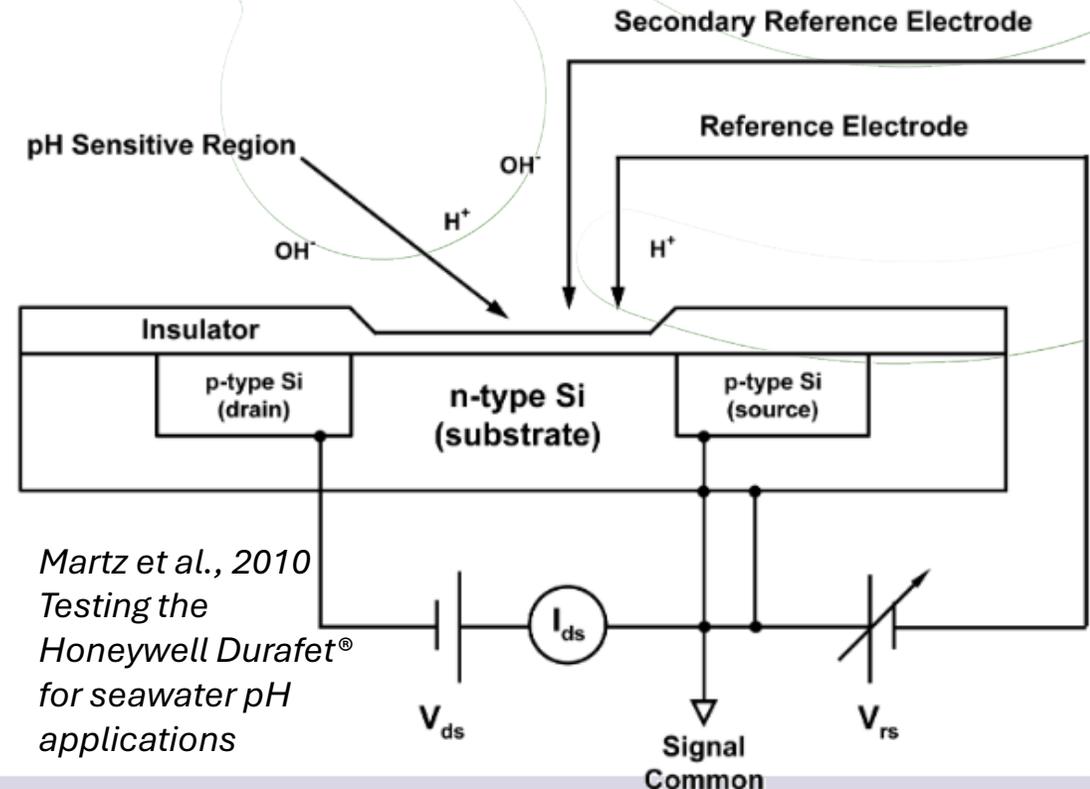


pH -Durafet

The Honeywell has been shown to have exceptional stability and accuracy. The conduction channel of the transistor is covered with an insulator that has a surface coating of an amphoteric oxide. The surface charge of this coating is dependent on the pH of the solution. Changes in solution pH then alter the potential on the conduction channel and the performance of the transistor which allows ocean pH to be measured..



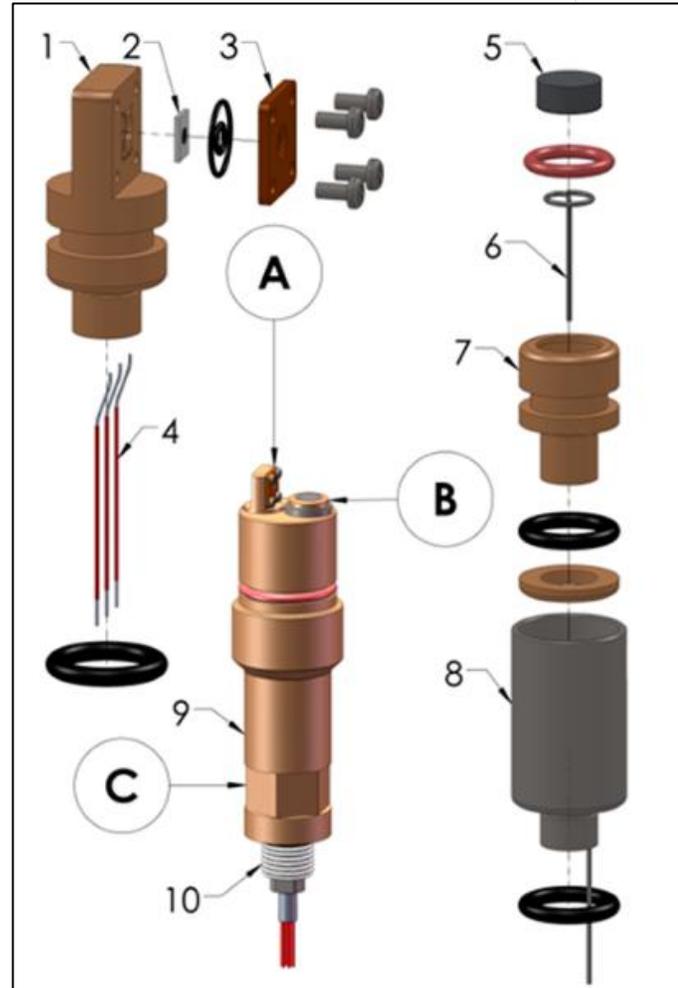
p-channel enhancement mode **ISFET**, operated at a **constant** drain-source **voltage** and **current**, obtained by adjusting an **external reference** electrode to **source voltage** (V_{rs}) to maintain **constant I_{ds}** . V_{rs} obeys a **Nernstian** response to protons in solution. The secondary reference **EMF** is also **measured** versus signal common.



AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

pH The **Honeywell Durafet** is **not pressure tolerant**, so a modified version is used. This modification, the **Deep-Sea DuraFET** is pressure tolerant to **2 km depth**.

ISFET housing (1) holds the silicon die (2) which is sealed with two O-rings and a cover (3). Three silver wires (4) make contact with gold pads on the back of the die. The AgCl reference pellet (5) and connecting wire (6) are bonded into housing (7) with silver conductive epoxy and then screwed into the Ti counter electrode (8). The assembled ISFET sensor (A) and reference and counter electrodes (B) are then mounted in a PEEK stem (9) which mounts on a pressure housing with a stainless steel connector (10).



*Johnson et al. 2016 **Deep-Sea DuraFET: A Pressure Tolerant pH Sensor Designed for Global Sensor Networks***

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

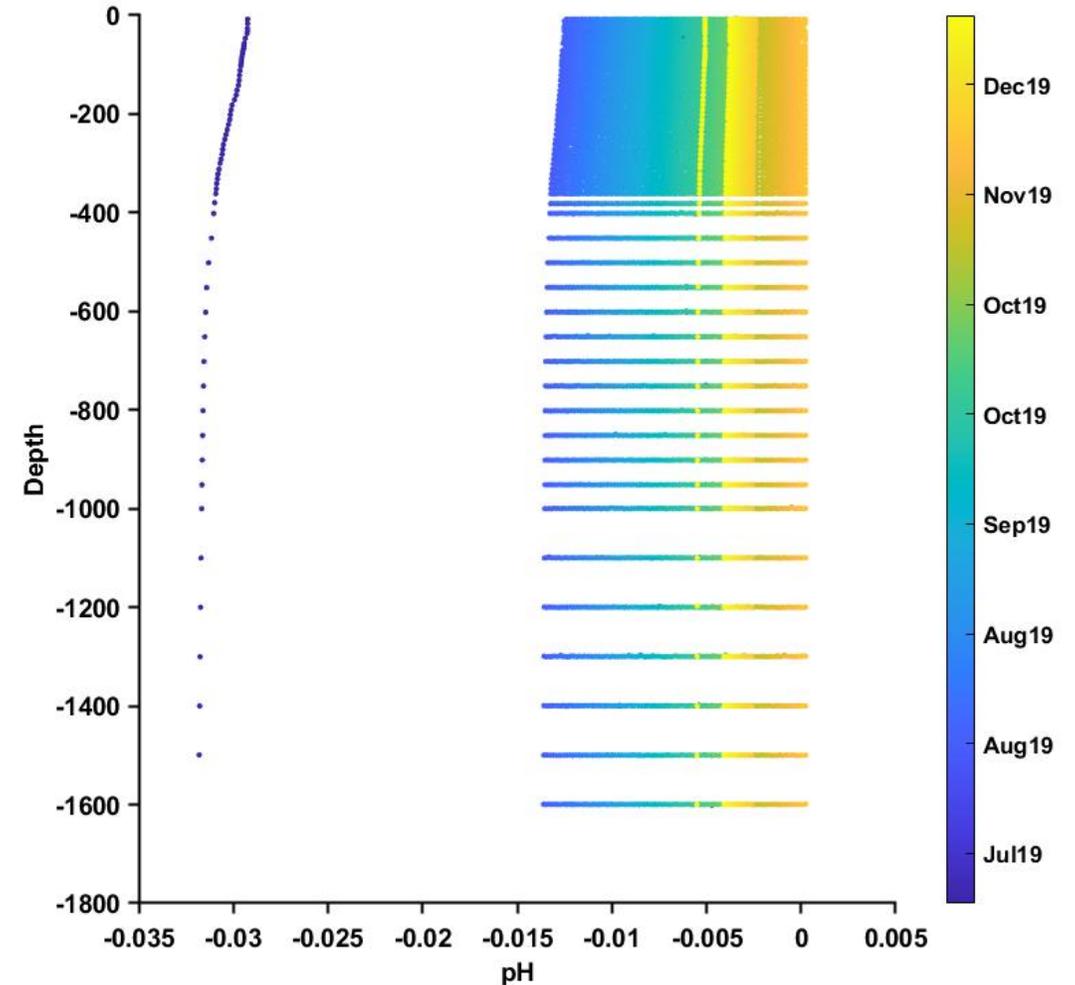
pH

Real-time unadjusted PH_IN_SITU_TOTAL data should receive a quality flag of '3'.

The majority of **pH sensors** deployed on **BGC Argo** profiling floats suffer from **shifts in calibration** (of varying magnitude) that often occur during the time between initial laboratory calibration and float deployment.

Because this is a **known bias** that affects the majority of **pH sensors** within the array, and because it is something that **can be corrected**.

(Argo Data Management BGC-Argo Quality Control Manual for pH Version 1.0 2.2.2.1.)



Difference between pH_IN_SITU_TOTAL data and pH_IN_SITU_TOTAL_ADJUSTED, WMO 5906039

pH - science

Global Biogeochemical Cycles*

Calculating surface ocean pCO₂ from biogeochemical Argo floats equipped with pH: An uncertainty analysis

N. L. Williams ✉ L. W. Juranek, R. A. Feely, K. S. Johnson, J. L. Sarmiento, L. D. Talley, A. A. R. Gray, R. Wanninkhof, J. L. Russell, S. C. Riser, Y. Takeshita

More than 74 biogeochemical profiling floats that measure water column pH, oxygen, nitrate, fluorescence, and backscattering at 10 day intervals have been deployed throughout the Southern Ocean.

Our results based on four representative floats suggest that despite their uncertainty relative to direct measurements, the float data can be used to improve estimates for air-sea carbon flux, as well as to increase knowledge of spatial, seasonal, and interannual variability in this flux.

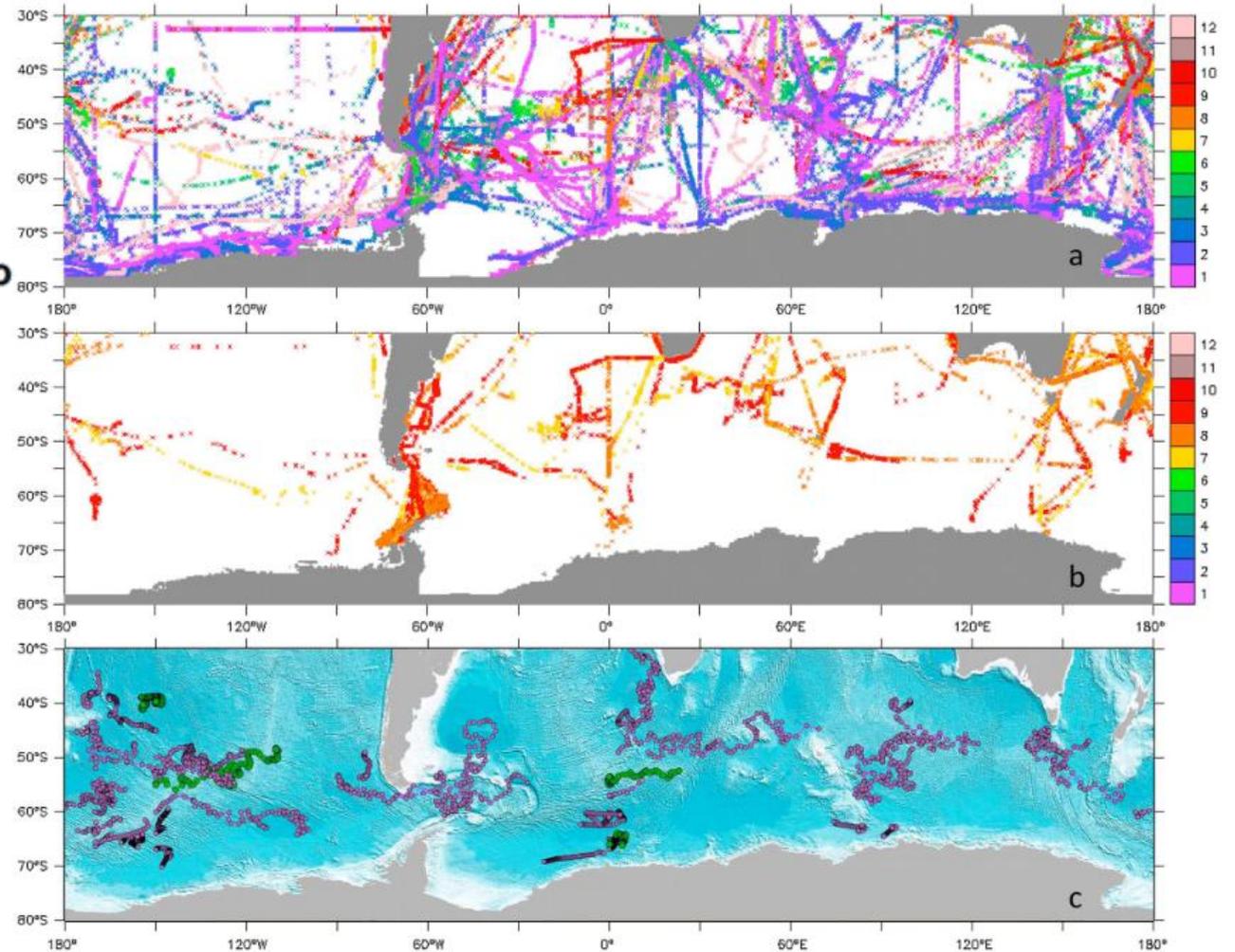
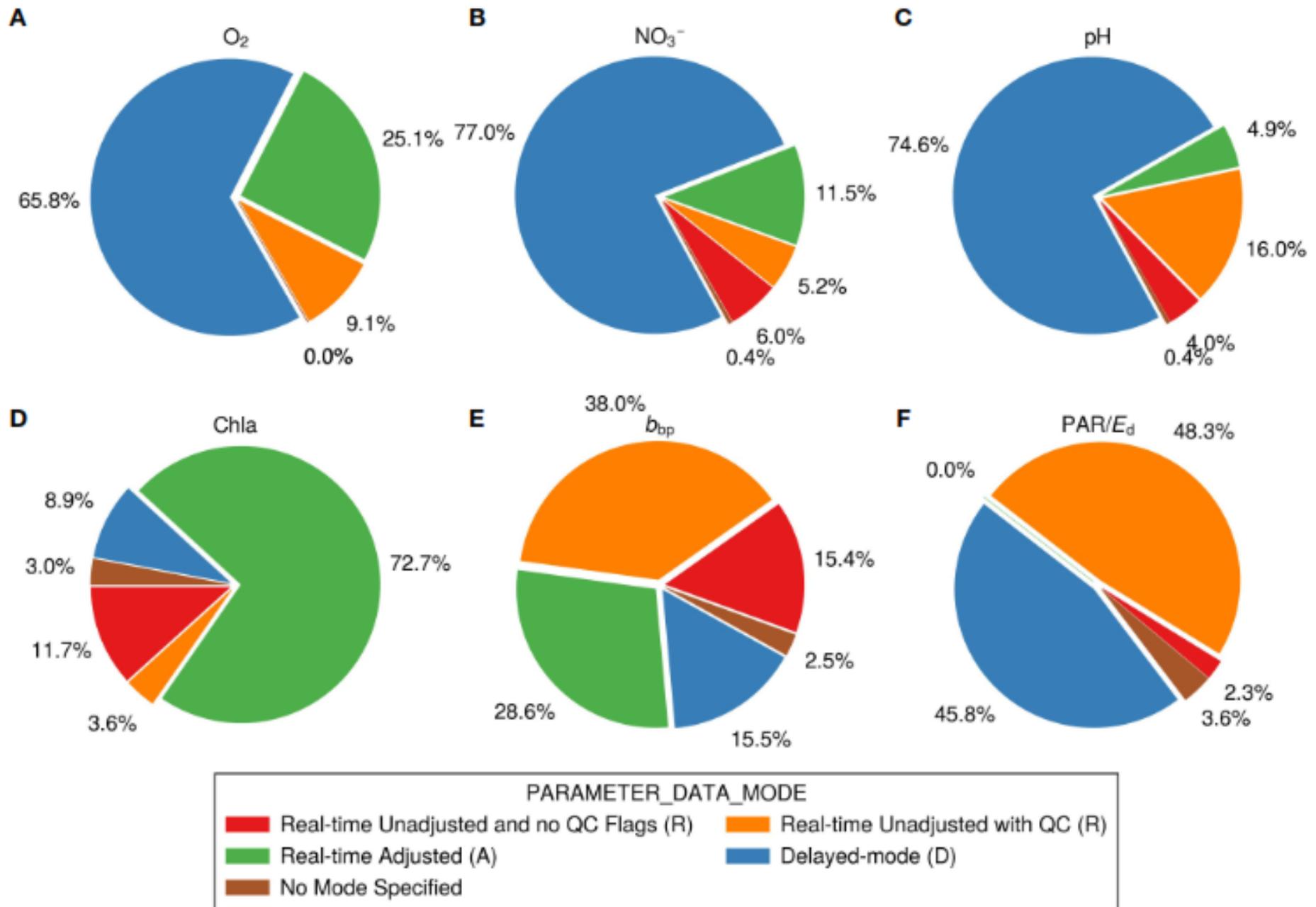
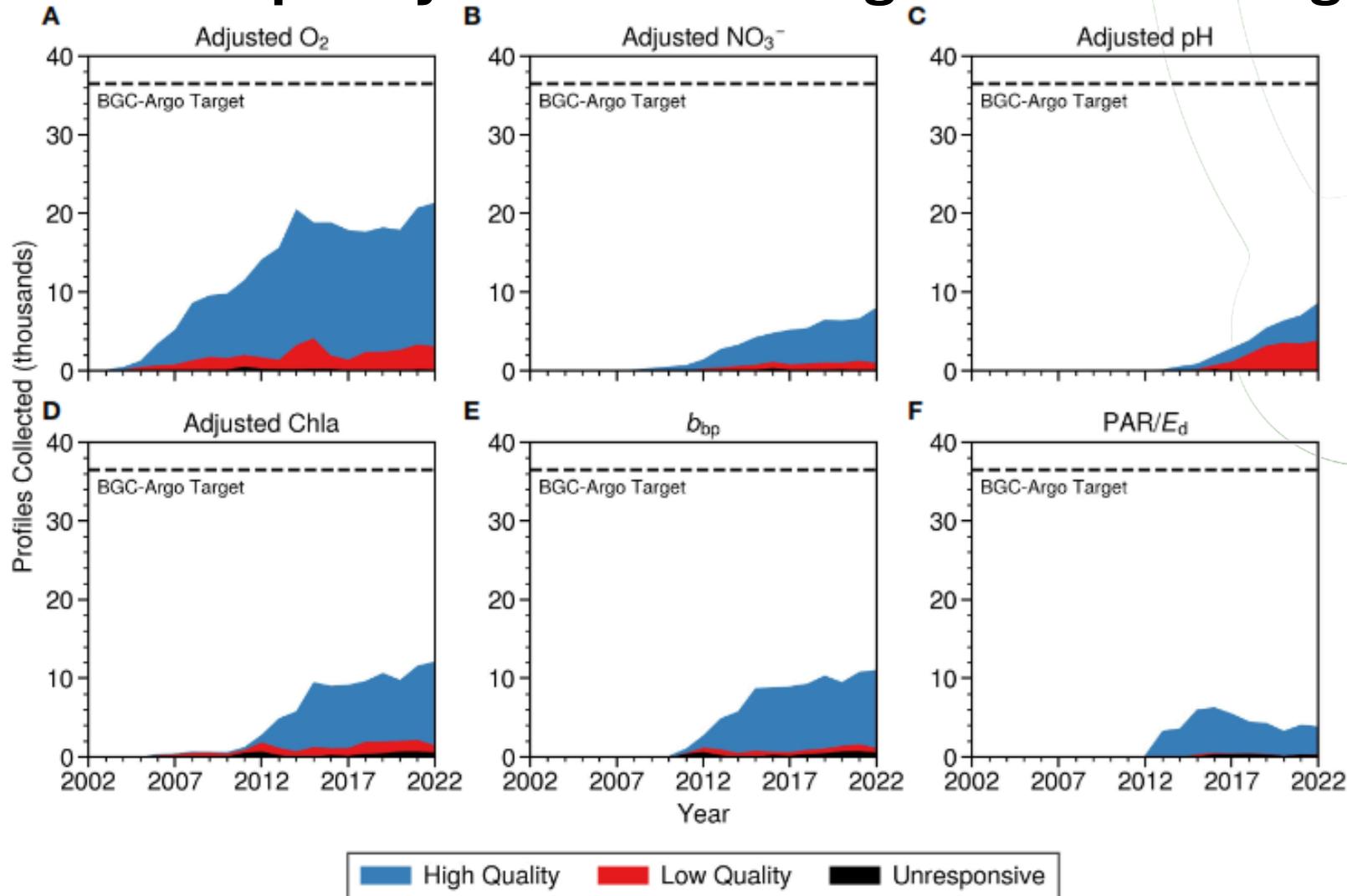


Figure 1. SOCATv4 pCO_{2sw} data [Bakker et al., 2016] south of 30°S colored by month for years 1957–2015 (a) for all months and (b) for only austral winter months (July–September). (c) A map of trajectories of all SOCCOM floats from 26 March 2014 to 4 January 2017 with the floats used in this study colored in green.

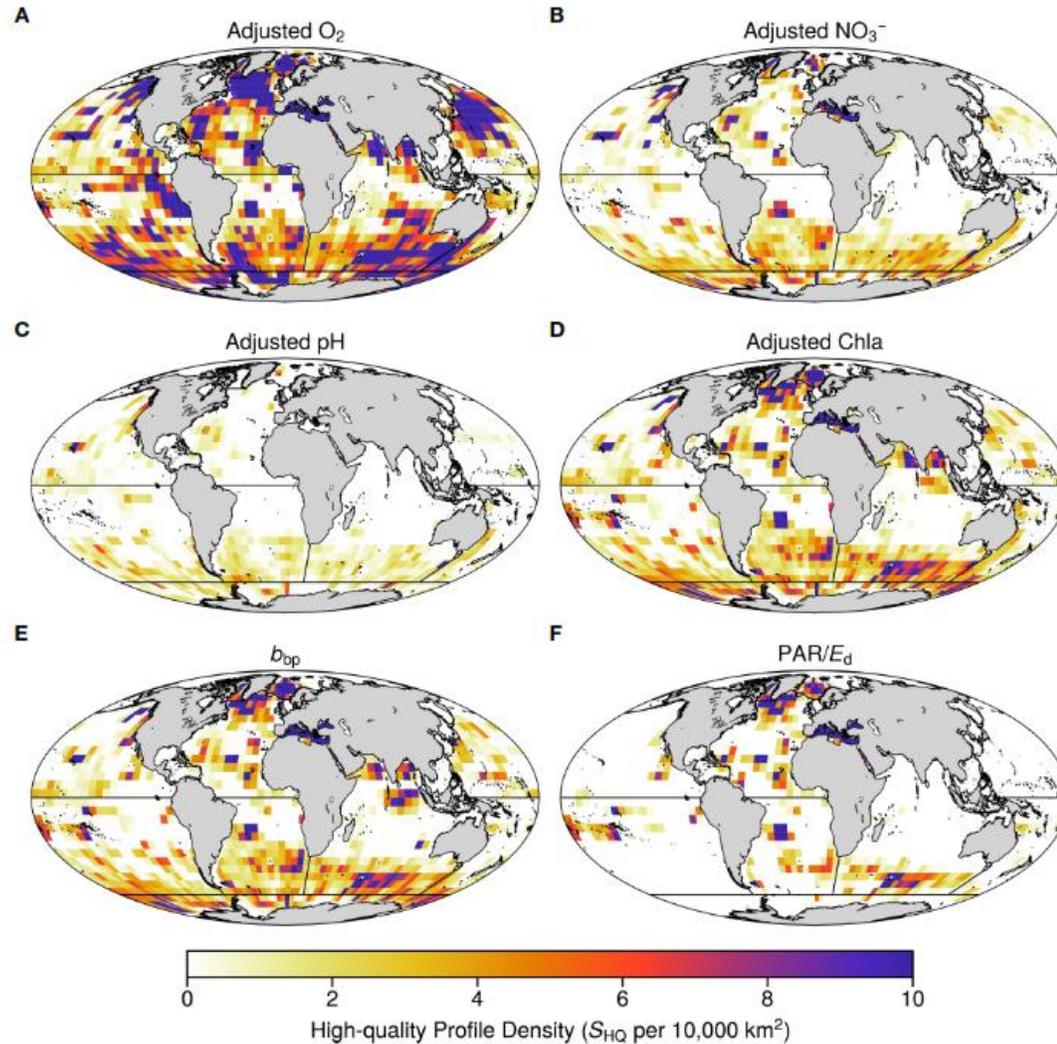


A census of quality-controlled Biogeochemical-Argo float measurements



Stoer et al., 2023,
DOI 10.3389/fmars.2023.1233289

A census of quality-controlled Biogeochemical-Argo float measurements



Stoer et al., 2023,
DOI 10.3389/fmars.2023.1233289

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Argo BGC science

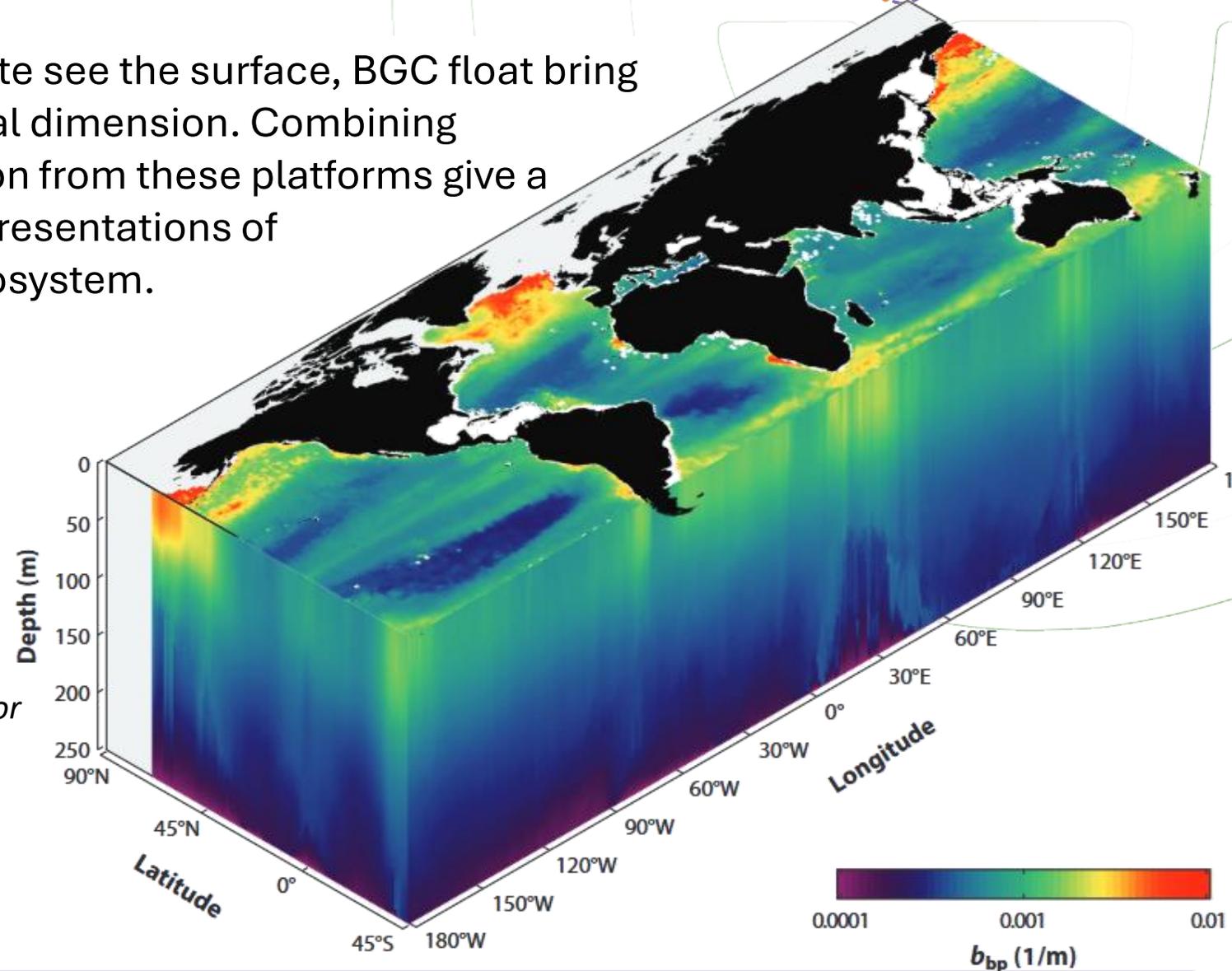
OC satellite see the surface, BGC float bring the vertical dimension. Combining information from these platforms give a better representations of ocean ecosystem.

Annual Review of Marine Science

Observing the Global Ocean with Biogeochemical-Argo

Hervé Claustre,¹ Kenneth S. Johnson,² and Yuichiro Takeshita²

A three-dimensional view of particle backscattering (bbp) for the month of June. This representation is an outcome of the neural network developed by Sauzède et al. (2016), which allowed the merging of remote-sensing ocean-color data (chlorophyll a and bbp) with Argo-based density profiles to retrieve 0–1,000-m vertical profiles of bbp .

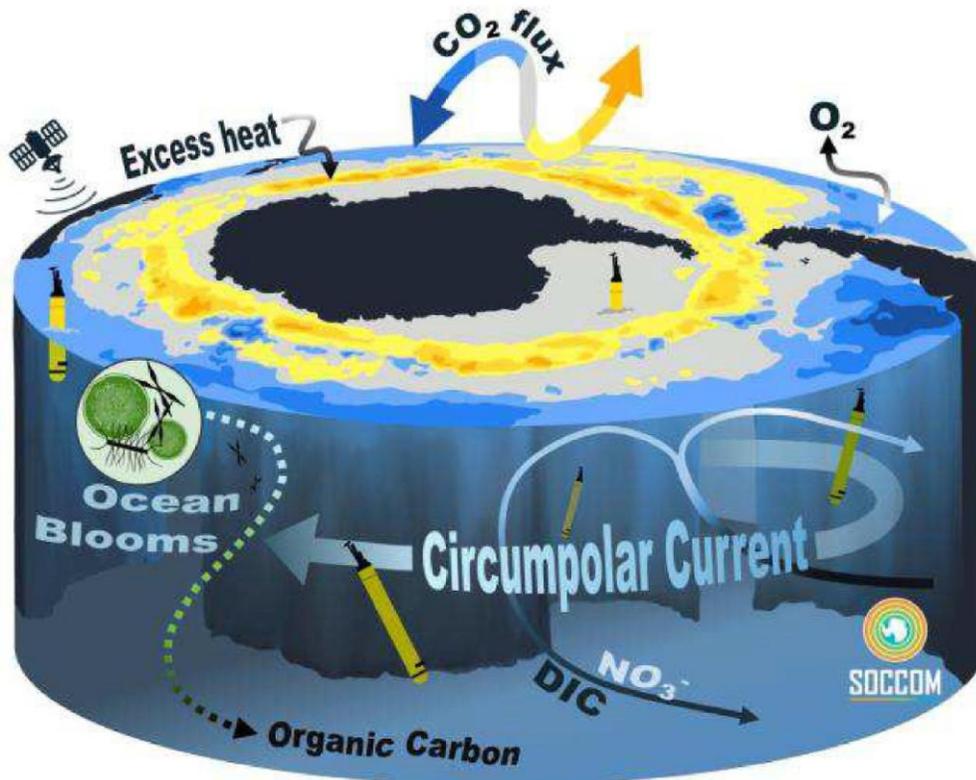


Argo BGC science

JGR Oceans

Southern Ocean Acidification Revealed by Biogeochemical-Argo Floats

Matthew R. Mazloff ✉ Ariane Verdy, Sarah T. Gille, Kenneth S. Johnson, Bruce D. Cornuelle, Jorge Sarmiento



Argo floats equipped with biogeochemical (BGC) sensors have been continuously measuring Southern Ocean pH since 2014. These BGC-Argo floats were deployed as part of the Southern Ocean Carbon and Climate Observations and Modeling project. Here we present a **SOCCOM-era Objectively Mapped pH (SOM-pH) 2014–2019...**

Comparison with previous ship-based measurements reveals decreases in pH of up to 0.02 per decade, with a structure decaying with depth. An assessment of the trend structure reveals a pattern indicative of the meridional overturning circulation...

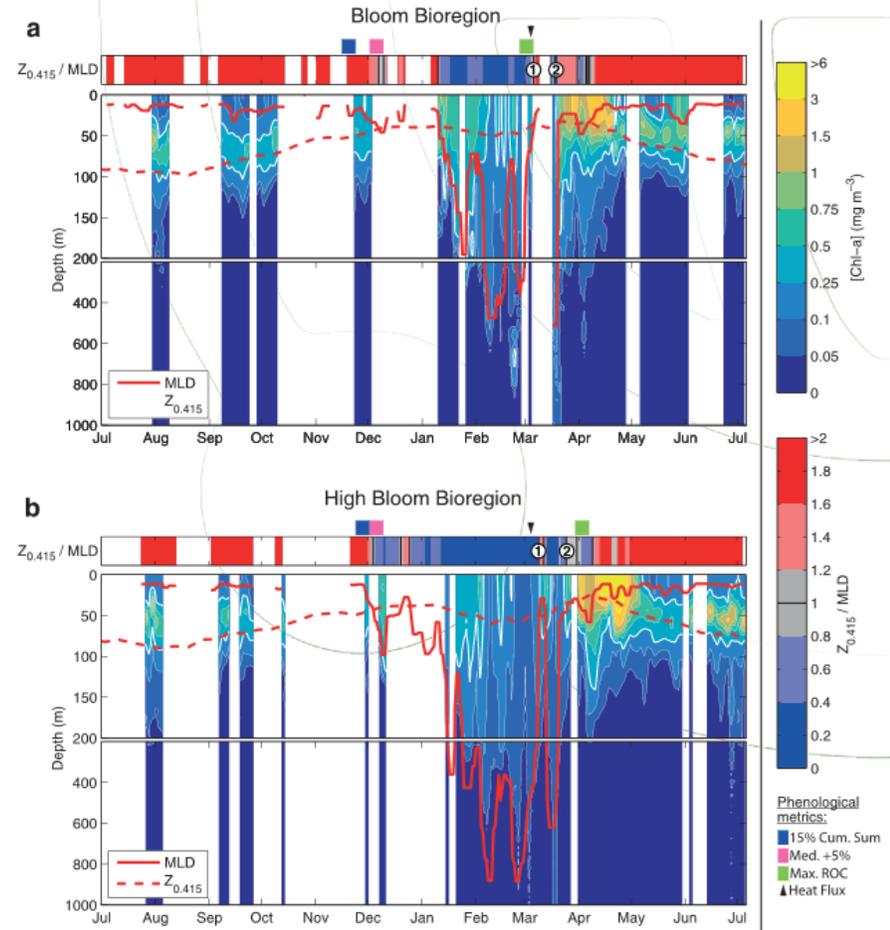
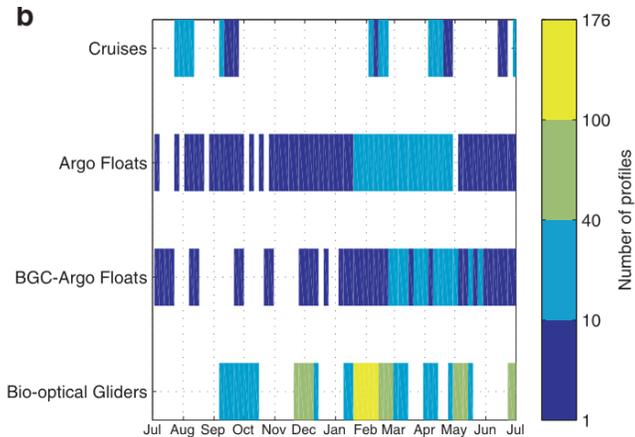
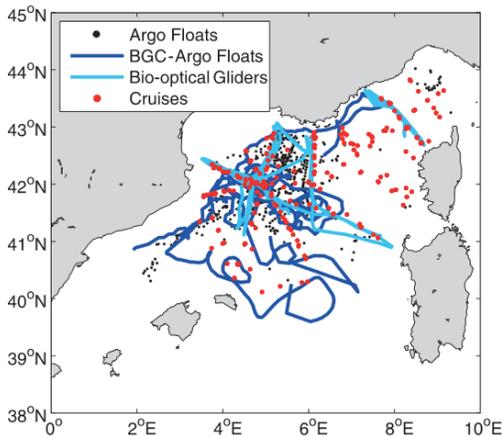
Thus comparison of this new BGC-Argo mapped pH estimate to historic observations allows quantifying the structure of Southern Ocean acidification.

Argo BGC science

JGR Oceans

Physical and Biogeochemical Controls of the Phytoplankton Blooms in North Western Mediterranean Sea: A Multiplatform Approach Over a Complete Annual Cycle (2012–2013 DEWEX Experiment)

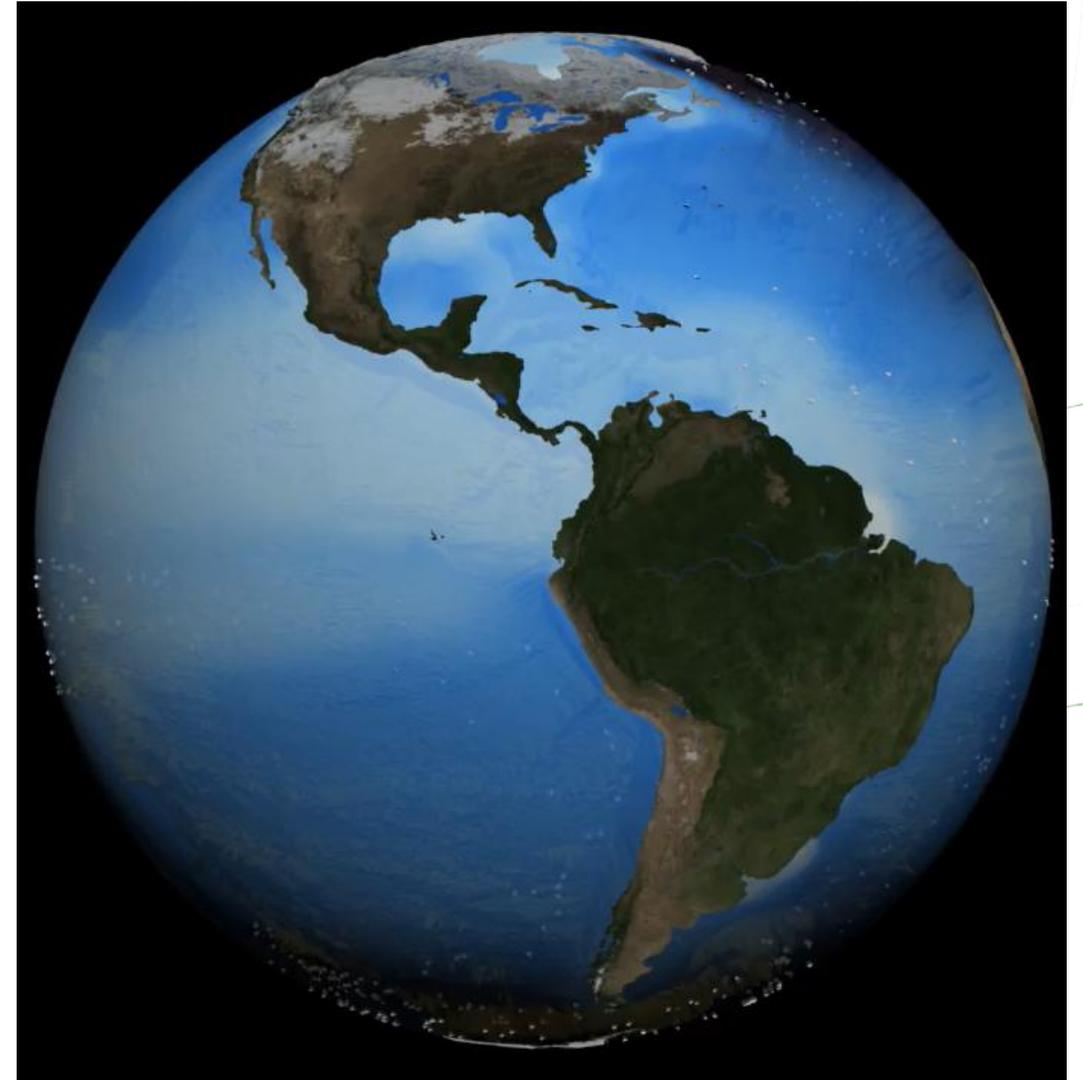
Nicolas Mayot ✉ Fabrizio D'Ortenzio ✉ Vincent Taillandier, Louis Prieur, Orens Pasqueron de Fommervault, Hervé Claustre, Anthony Bosse, Pierre Testor, Pascal Conan



To determine the potential control of physical and biogeochemical factors on these phytoplankton blooms data from a multiplatform approach were analyzed in association with satellite observations in 2012–2013.

Deep ocean require extensive observation networks

- Atarctic Bottom Water is warming and freshening, contributing to sea level rise.
- Heat accumulation in the deep ocean accounts for 10 % of the heat increase in the upper ocean.
- Current estimates of OHC of deep sea are uncertain
- Abyssal trends and diffusivities are not well constrained in current ocean state estimates.
- The North Atlantic Deep Water is changing,
- Current observations are limited and costly, relying on moored arrays and repeated hydrographic transects.
- Deep Argo would provide complementary and continuous data.
- Deep Argo would support decadal climate predictions and improve the assimilation of ocean data from depth.



NASA/Goddard Space Flight Center Scientific Visualization Studio
The Blue Marble Next Generation data is courtesy of Reto Stockli
(NASA/GSFC) and NASA's Earth Observatory.

Deep ocean require extensive observation networks

JOURNAL OF CLIMATE

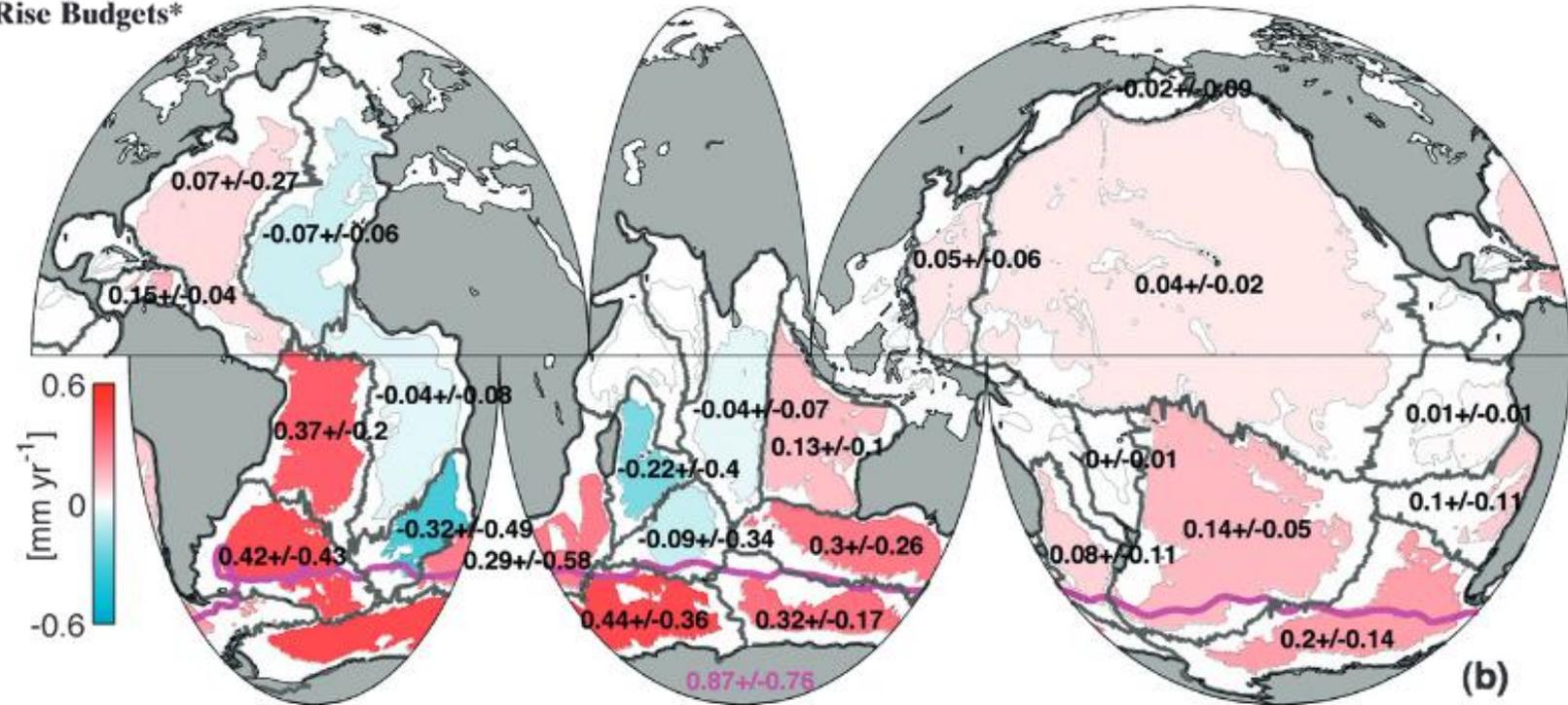
VOLUME 23

Basin means of sea level rise from the 1990s to the 2000s due to abyssal thermal expansion

Warming of Global Abyssal and Deep Southern Ocean Waters between the 1990s and 2000s: Contributions to Global Heat and Sea Level Rise Budgets*

SARAH G. PURKEY GREGORY C. JOHNSON

Abyssal global and deep Southern Ocean temperature trends are quantified between the 1990s and 2000s to assess the role of recent warming of these regions in global heat and sea level budgets.



The abyssal warming produces a 0.053 (60.017) mm yr^{-1} increase in global average sea level and the deep warming south of the Subantarctic Front adds another 0.093 (60.081) mm yr^{-1} . Thus, warming in these regions, ventilated primarily by Antarctic Bottom Water, accounts for a statistically significant fraction of the present global energy and sea level budgets.

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Deep

Deep Argo aims to sample T/S up to 6,000 meters.

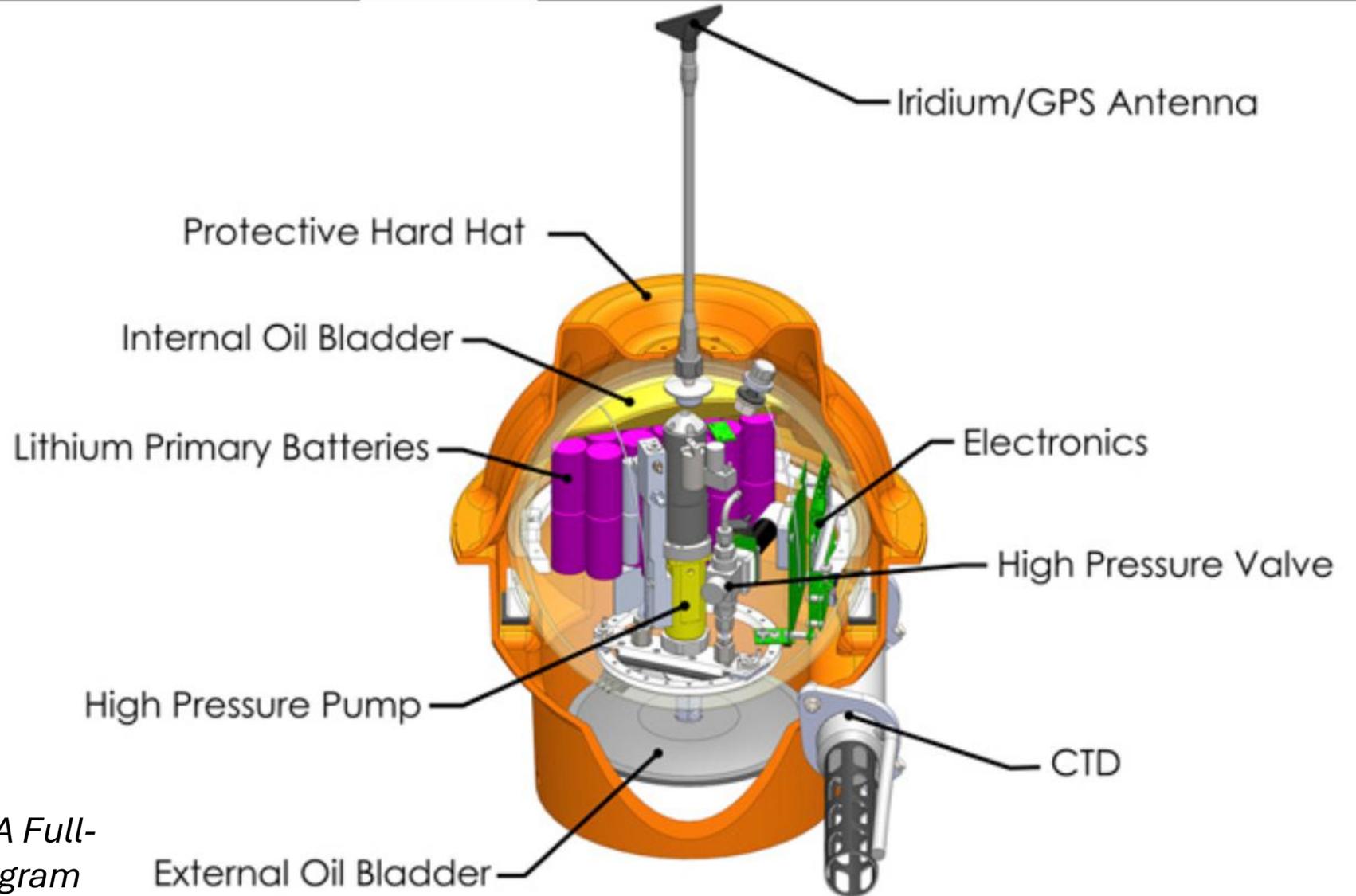
1. **The Deep Arvor (<4000m)**
NKE
2. **Deep NINJA (<4000m),**
tsurumi-seik
3. **Deep SOLO (<6000m)**
MRV Systems
4. **Deep APEX (<6000m)** *Teledyne*

Two CTD models developed by Sea-Bird, the SBE-61 CTD, SBE-41 CTD and RBRargo. Dissolved oxygen (DO) sensors have been mounted on most 4000 dbar floats.



Deep SOLO

A Deep SOLO float: the spherical glass pressure housing is protected by a plastic shell. The Iridium/GPS antenna, SBE-61 CTD, and passive “bottom finder” wire can all be seen. The float’s pancake bladder is inside the cowling, behind the CTD.



Roemmich et al., 2019 Deep SOLO: A Full-Depth Profiling Float for the Argo Program

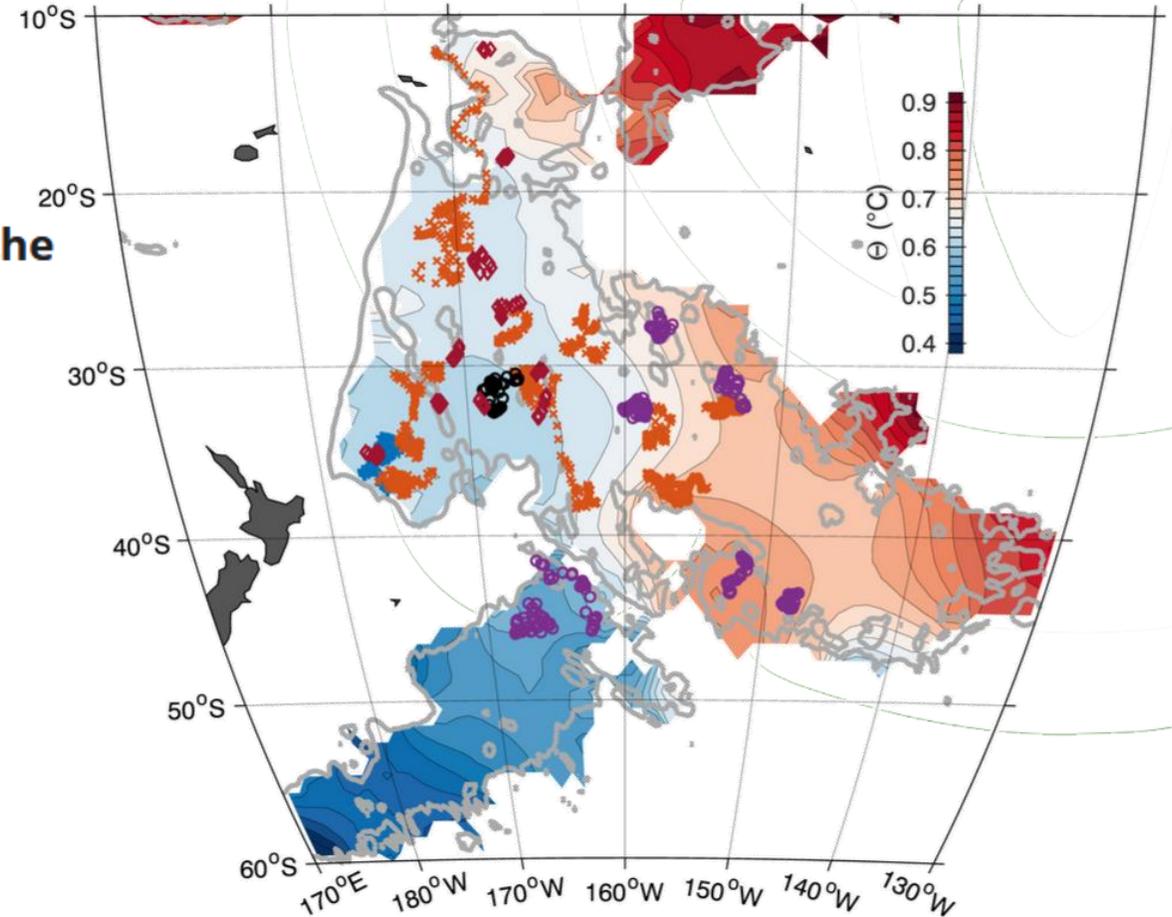
Deep science

Geophysical Research Letters*

Deep Argo Quantifies Bottom Water Warming Rates in the Southwest Pacific Basin

Gregory C. Johnson ✉ Sarah G. Purkey, Nathalie V. Zilberman, Dean Roemmich

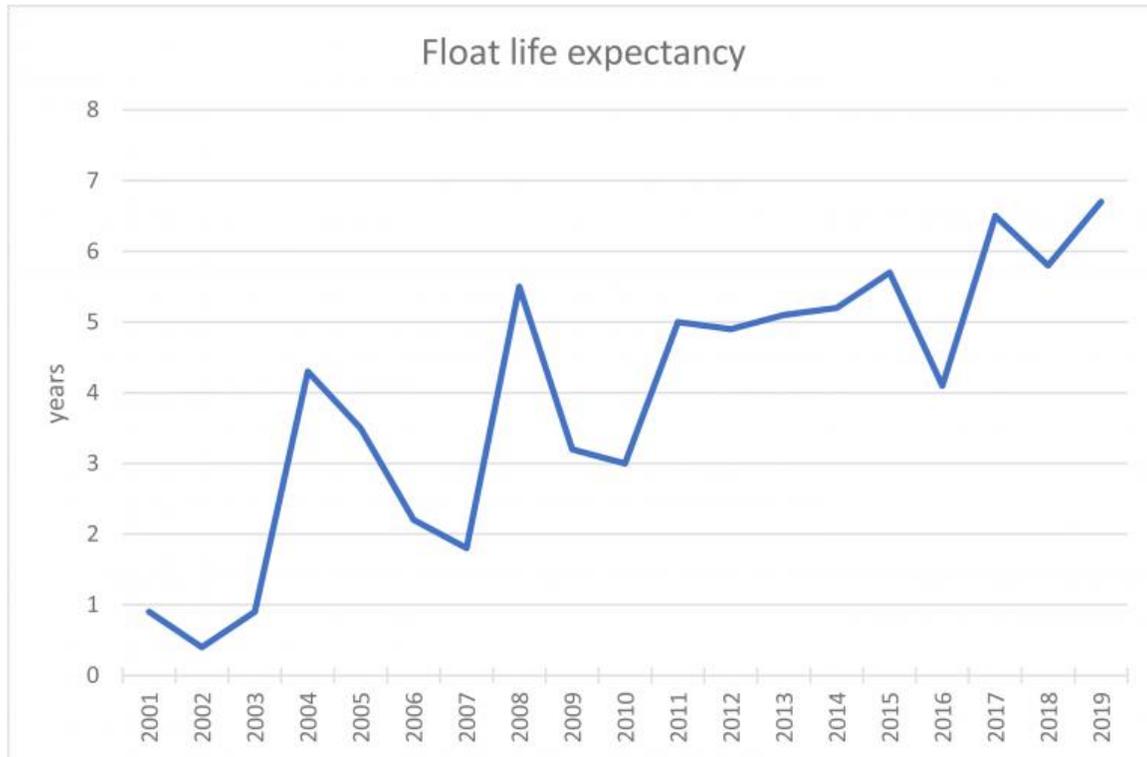
These results suggest acceleration of previously reported long-term warming trends in the abyssal waters in this region. They also demonstrate the ability of Deep Argo to quantify changes in the deep ocean in near real-time over short periods with high accuracy.



Locations of Deep Argo float profiles in the Southwest Pacific Basin as of 20 November 2018 deployed in 2014 (blue plus symbols), 2016 (orange cross symbols), 2017 (purple circles, except black circles around 32°S, 168°W for float WMO 5902528), and 2018 (red diamonds) with climatological conservative temperature Θ values from World Ocean Atlas 2018 (<https://www.nodc.noaa.gov/OC5/woa18/>) contoured at 0.02 °C intervals (see color bar) at 5,000 m

New tech float & sensors

Improving float lifetimes & communications



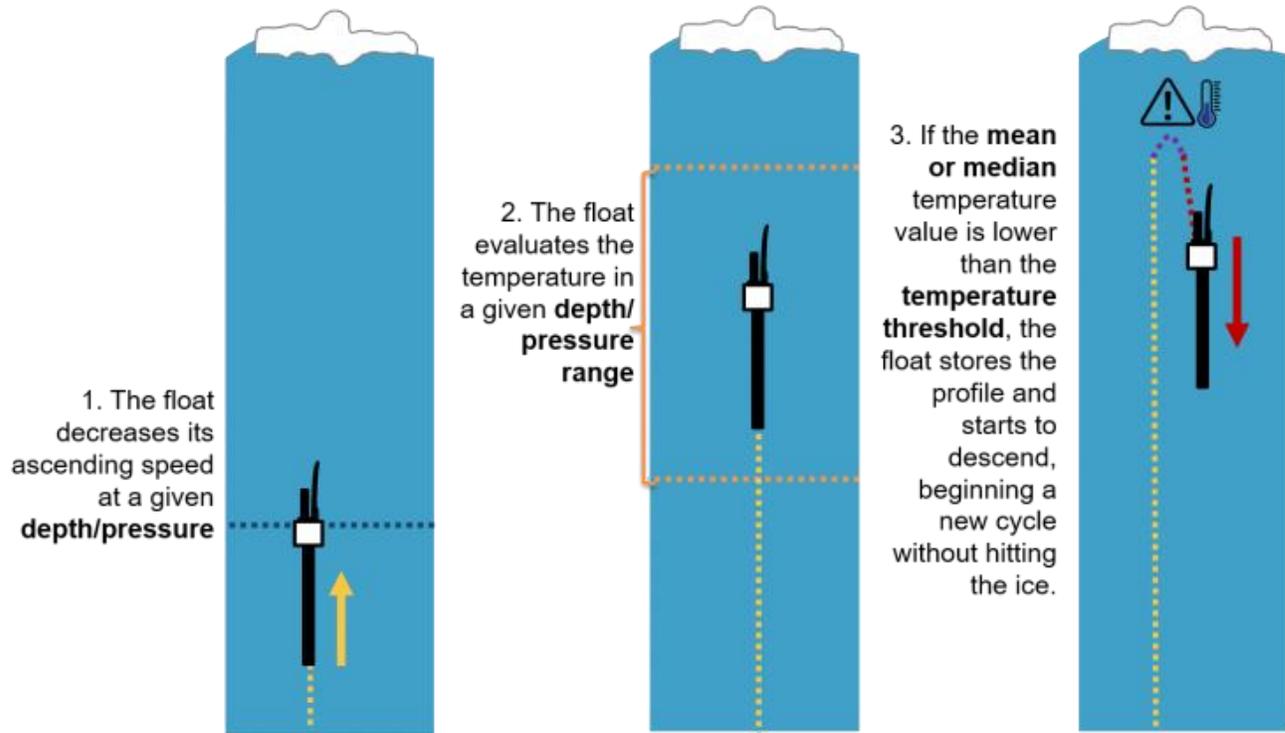
- Extending **float lifetimes** reduces the need for use, controls **costs** and **minimizes** environmental **impact**. **Originally**, the Argo floats used **alkaline batteries** that lasted about 3 to 5 years, but data showed that the energy was depleted **after 3 years**. To improve performance, **lithium and hybrid batteries** were introduced, which have better cold resistance and higher energy requirements. BGC floats that require more energy are now equipped with **additional battery packs**. These advances have **significantly extended the life** of the floats since the introduction of Argo.
- Early Argo floats used **Système Argos**, requiring long surface times and risking drift or grounding. **Iridium** transmitters now reduce surface time to 15–30 minutes, enabling more data transmission and real-time mission updates. **GPS** improves positioning, enhancing ocean current measurements.

New tech float & sensors UVP6

Ice detection

Main steps of the Ice Sensing Algorithm

The most important parameters to be set according to the local under-ice hydrography are written in bold letters.

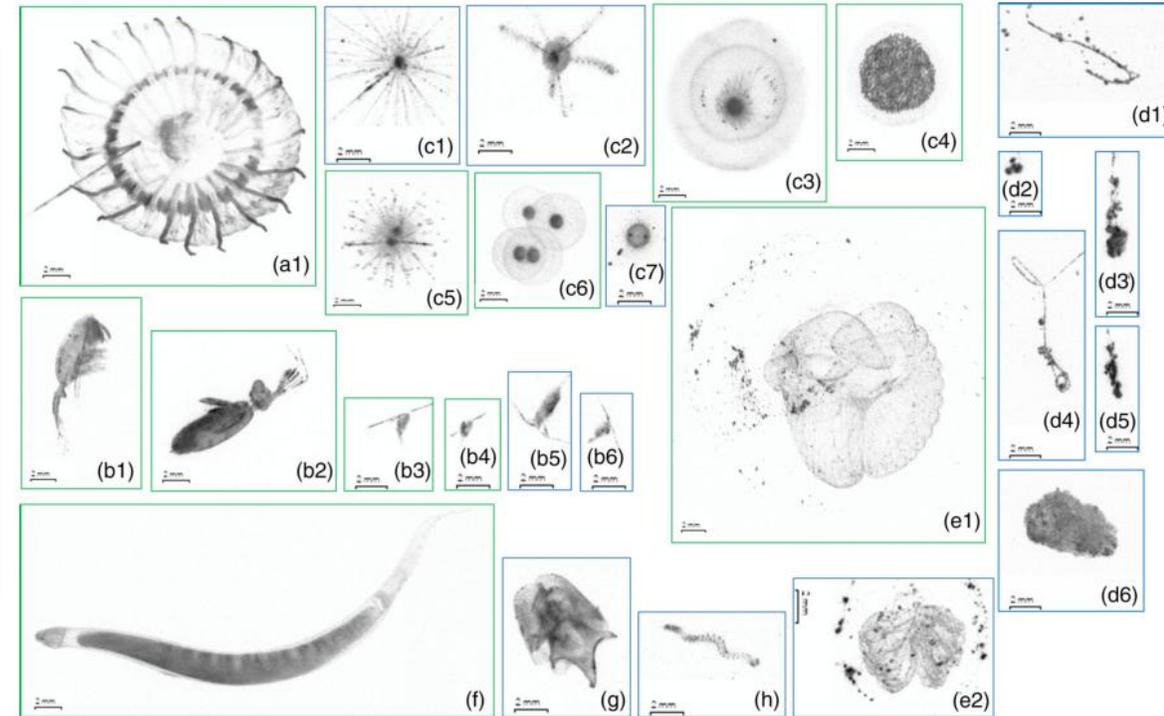
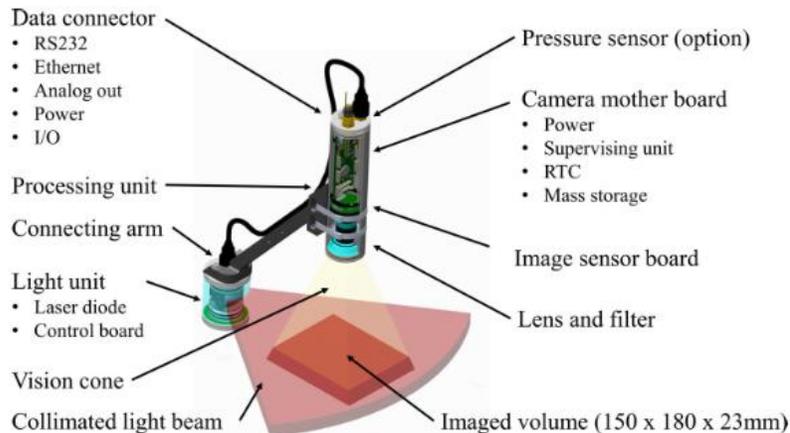


© I.M. Angel-Benavides/BSH

Sea ice covers vast areas of the Southern and Arctic Oceans, making underwater observations challenging. Argo floats can operate autonomously in ice-covered regions, but collisions with ice pose risks to sensors, antennas, and hull integrity. To mitigate this, Klatt et al. (2007) developed an **Ice Sensing Algorithm (ISA)** for the Weddell Sea, which detects near-freezing temperatures and prevents floats from surfacing under ice. Instead, the float delays ascent, storing profiles until conditions allow safe surfacing. This approach, successfully used in the Southern Ocean, has been adapted for the Arctic, where greater hydrographic variability requires regional tuning of the algorithm's parameters.

New tech float & sensors UVP6

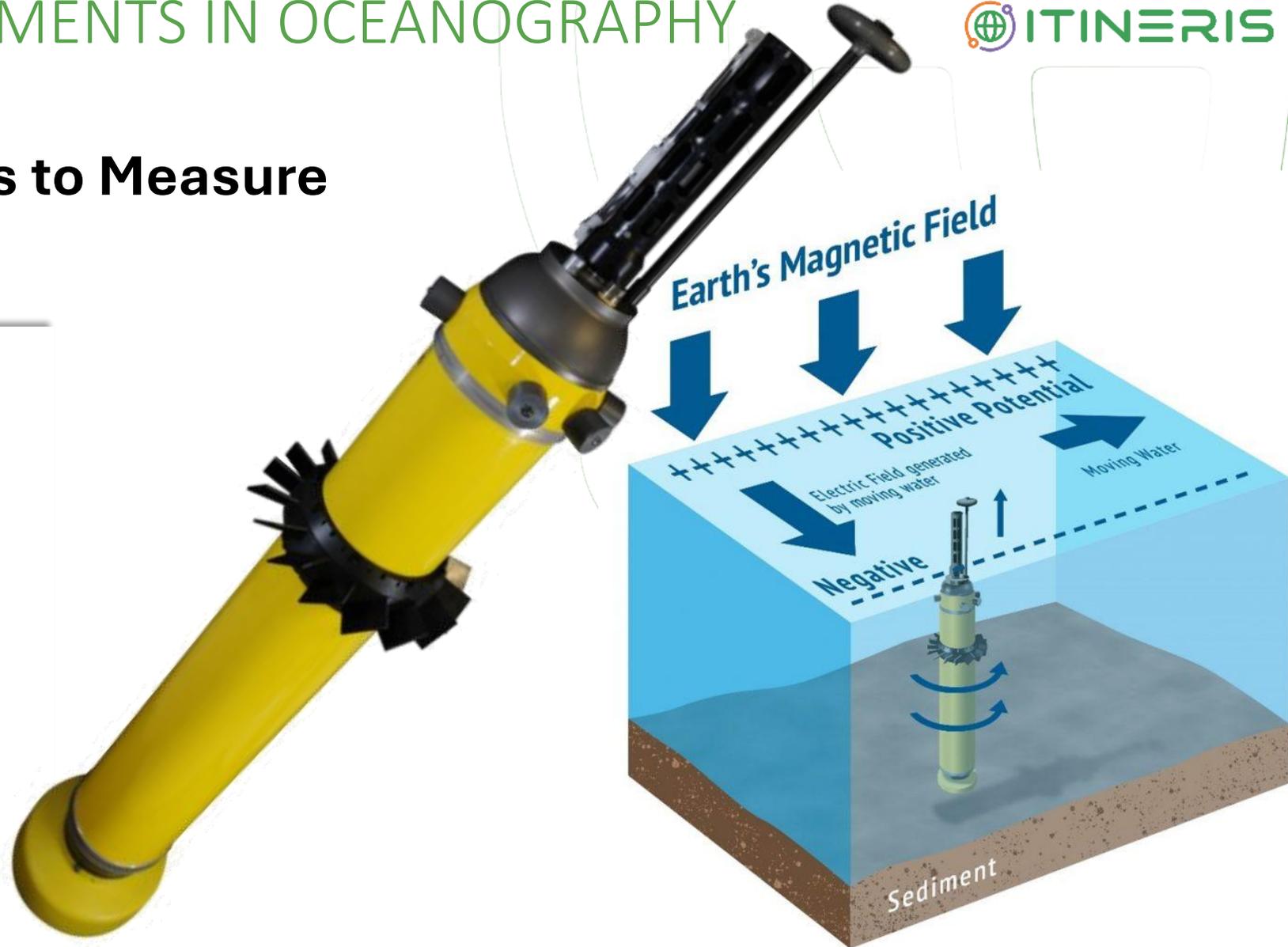
The **Underwater Vision Profiler 6 (UVP6)** is an advanced imaging sensor designed for ARGO floats. It captures high-resolution images of suspended particles and plankton, enabling the study of marine biogeochemical processes and carbon flux. With its low power consumption and deep-sea capability, UVP6 is ideal for long-term autonomous deployments. I



Examples of plankton and detritus images acquired by UVP6-LP (blue frames) off the coast of Nice in March 2021, and UVP6-HF (green frames) south of Tasmania during the Solace cruise in December 2020. The different organisms displayed are: (a1) a narcomedusa, (b1–b6) copepods, (c1–c7) rhizarian protozoa, (d1–d6) marine snow particles, (e1,e2) appendicularian houses, (f) a chaetognath, (g) a thecosome pteropod, and (h) a planktonic polychaete.

New tech float & sensors Induced Electric Currents to Measure Ocean Speeds

The float measures **water motion** by detecting induced **electric currents**. **Ocean electric fields** arise because **saltwater** is conductive and moves through **Earth's magnetic field**, generating an electric current. This current completes a circuit through slower bottom water and weakly conductive sediments. By measuring these currents, **the float can precisely determine seawater velocity**.



<https://magneticsmag.com/teledyne-float-uses-induced-electric-currents-to-measure-ocean-speeds/>

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

New tech float & sensors turbulence

The Argo community has identified ocean mixing measurements as an achievable scientific goal of the Argo mission (Roemmich et al., 2019). This new branch, named Argo-mix, would provide the scientific community repeated micro-structure measurements at a global scale. These measurements would offer insights into the impact of ocean mixing on water mass transformations, air-sea interactions, and a plethora of other processes (Garabato and Meredith, 2022).

microalto



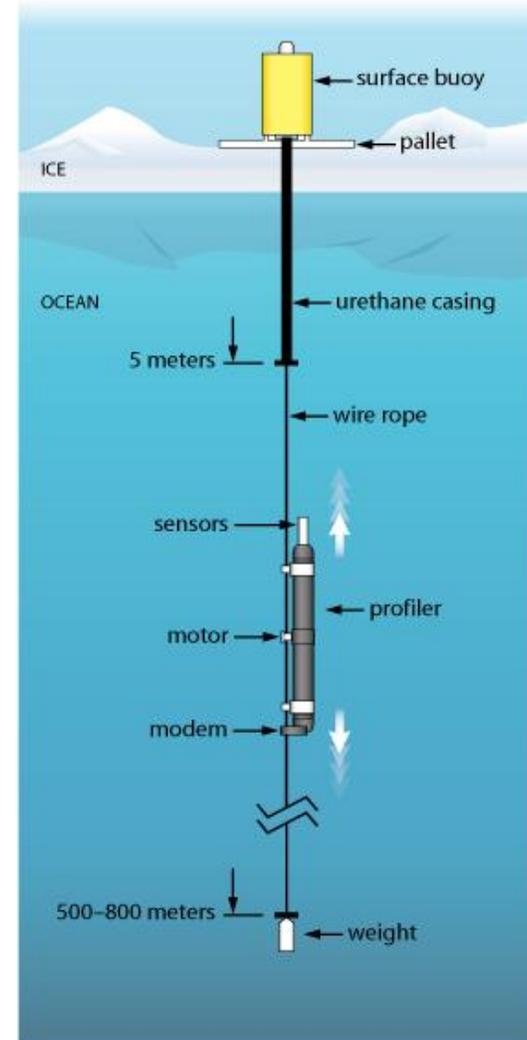
APEX-epsi



AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

New tech float & sensors

Ice tethered profilers



The ITP system consists of a small surface capsule that sits atop an ice flow and supports a plastic-jacketed wire rope tether that extends through the ice and down into the ocean, ending with a weight (intended to keep the wire vertical). A cylindrical underwater instrument (in shape and size much like an Argo float) mounts on this tether and cycles vertically along it, carrying oceanographic sensors through the water column. Water property data are telemetered from the ITP to shore in near-real time.

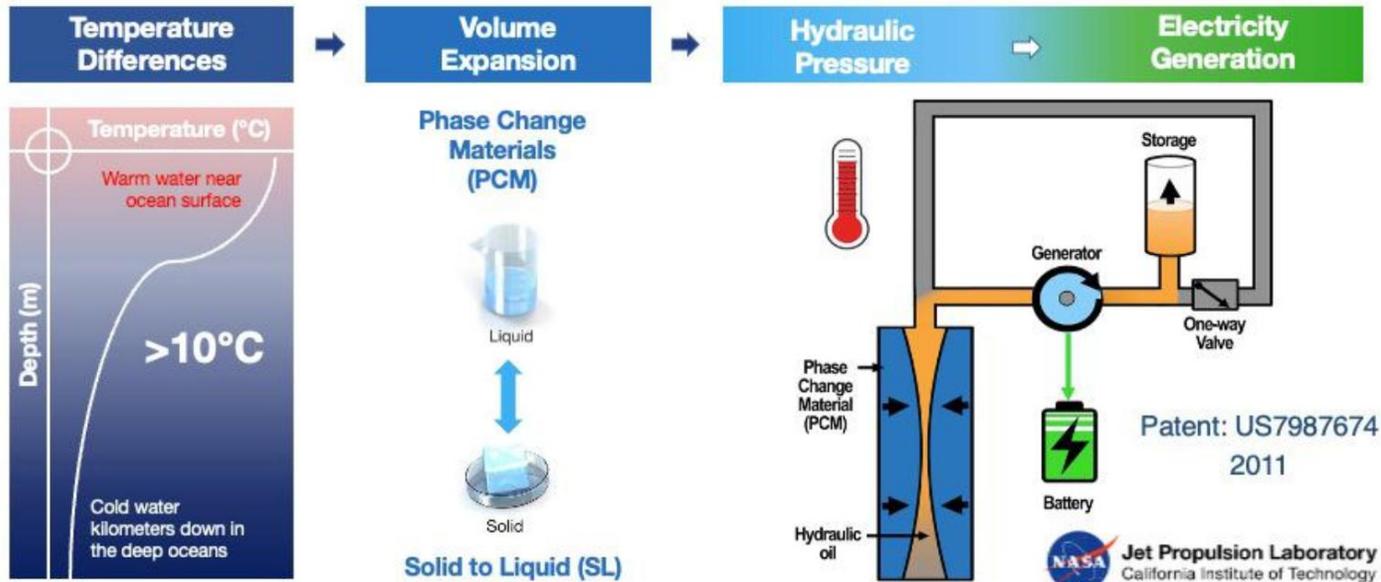
<https://www2.whoi.edu/site/itp>

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

New tech float & sensors

infiniTE™ Float SEATREC

This float moves up and down through layers of water, a paraffin-filled chamber expands and contracts. That brings around 3,000psi to drive the pumping action of a pressurised fluid, turning a motor at around 1,000rpm. Around 3Wh of energy is generated on every rise and fall



AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Argo system

The backbone of the Argo revolution



A Deep Argo float tested at the hyperbaric chamber of Ifremer facility, to reproduce the extremely high pressures of the abyssal zone.



- Euro-Argo Office **federates and optimizes this European effort** through various **centralised activities**: floats procurement and deployment, floats testing, at-sea monitoring, integrated data processing & access and joint outreach & trainings.

ENVIRONMENTAL IMPACTS OF ARGO FLOATS

WHEN ARGO FLOATS ARE OBSERVING THE OCEAN

Carbon footprint because of fossil fuels consumption

Energy consumption
Disappearance of non-renewable resources

Transportation of float

Deployment of float

Energy consumption for data transmission and processing

Manufacturing of float

Transport of several units together to reduce their individual impacts

Float cycles

The float spends more than 90% of its life under 1,000 meters and data transmission is only around 20 minutes, so the float's interaction with most marine life is limited

~12,000 floats are now lying on the sea bed and would cover less than a football pitch

Death of float

Float reaching the seabed

Negative environmental impacts

Actions to face these environmental impacts

Two ways are currently being studied to increase float life expectancy in order to reduce the number of float deployments:

- Decreasing the floats' energy consumption (with improved transmission or hydraulics systems) and increasing the battery efficiency.
- Increasing the floats' reliability, thanks to better at-sea monitoring and improvement of early issue detection for instance.

WHEN ARGO FLOATS REACH THE END OF THEIR LIFE

When their batteries are exhausted, Argo floats can't reach the surface anymore and they drift in the ocean. At this point, sea water fills the hull and starts its corrosive action. The float eventually sinks to the seafloor, mostly over deep abyssal regions. Decomposition processes will take place over the course of a number of years. Some elements from the battery will then spill to the surrounding sea water.

GPS/Satellite

Sensor

TBTO: this biocide is used in some floats to prevent the fouling of the floats' sensors by algae and bacteria and will likely end up in marine sediments, where it will break down into inert, harmless components within a week

8 % Plastic: will likely degrade only very slowly

Electronics

70 % Aluminum: will slowly corrode into mainly harmless oxides

22 % Battery components: the speed at which these potentially toxic metals corrode and the level of concentration present around a dead float are not known and will likely vary with local conditions on the seafloor

Hydraulics

1.5 m high, 20-30 kg

Argo float's battery composition

Lead	70 %
Zinc	4 %
Copper	9 %
Lithium	17 %

Recent developments to reduce the environmental impact

- New electronics with less rare metals
- Better choice of some electronics/mechanical components
- Less and less polluting material
- Evolution towards no TBTO for every float
- Optimisation of the profiler energy consumption, via the mechanical, electronic and software design
- Very high-capacity battery technology, which allows maximum energy storage in minimum volume
- The impact of dead floats can also be limited by using or designing recovery systems

SMALL AMOUNTS OF CHEMICAL COMPONENTS DILUTED IN THE OCEAN

Given the generally slow corrosion rates in the deep ocean, the speed of abyssal currents, the strength of nearbottom turbulence, and the large distances between floats (~300 km), a significant, local, short-term concentration of dissolved metal salts originating from a float seems unlikely.

The chemical species injected into the abyssal waters generally represent negligible amounts in comparison to the natural and anthropogenic fluxes of these substances. It would take over 176,000 years of Argo operations to inject the same amount of aluminum into the ocean that is employed annually to produce soda drink cans and a single year of the human contribution of plastic to the ocean is equivalent to 4.4 million years of the input from Argo.

By weight, the amount of chemical components released into the ocean by Argo floats is equivalent to:

- COPPER: 90 kg ~80
- ALUMINIUM: 17,000 kg ~70,000
- LITHIUM: 180 kg ~65

POSITIVE IMPACTS ON THE ENVIRONMENT

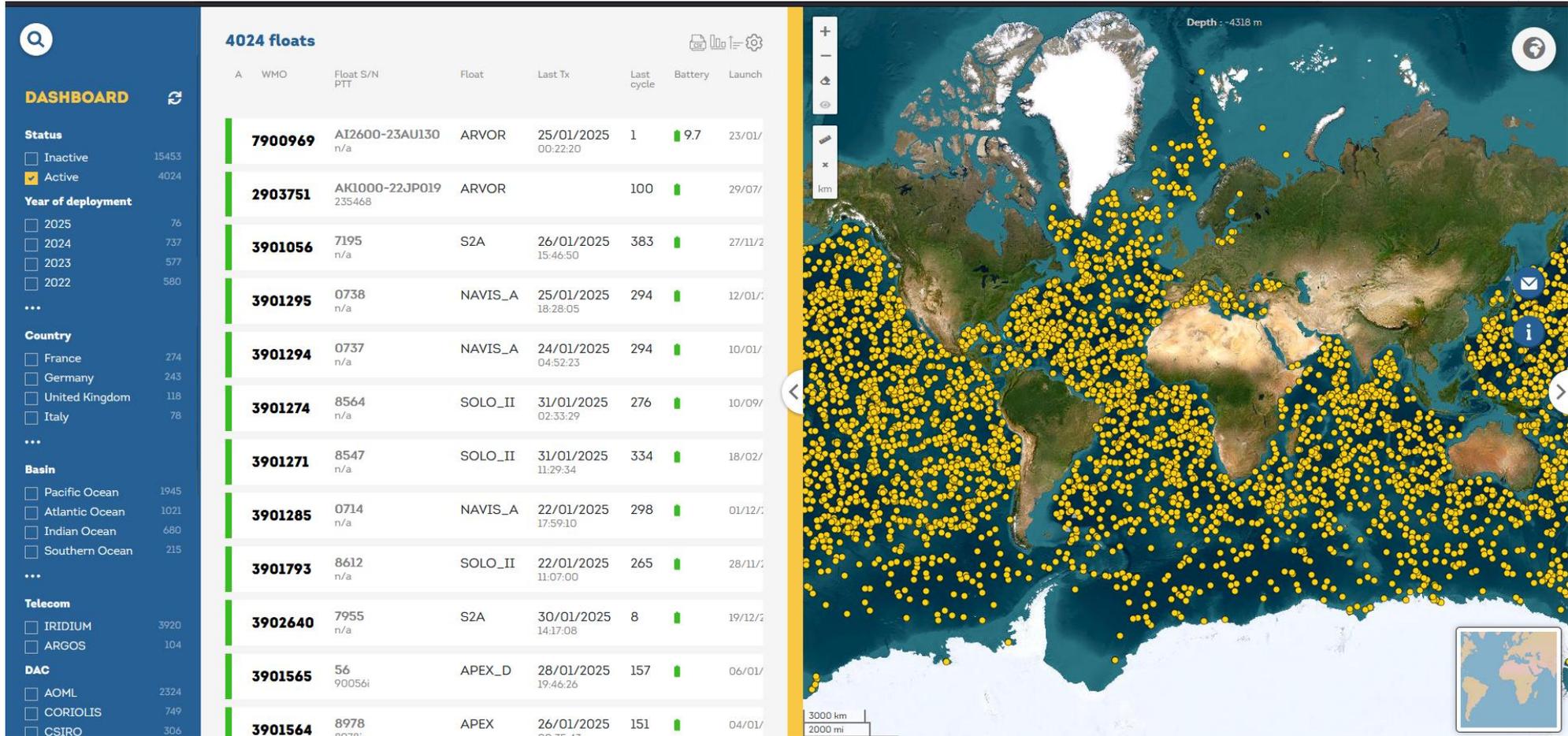
Argo is a game changer in terms of ocean observations. Argo floats collect about 120,000 surface-to-2,000 meters profiles of temperature, pressure and salinity per year. Presently there is no method of observing the global subsurface ocean that is more cost effective and less environmentally damaging than Argo.

© Thomas Halesig / Tealogs

Designed by EURO-ARGO ERIC; Bibliography: "Environmental Issues and the Argo Array", Stephen C. Riser, University of Washington; Susan Wijffels, Woods Hole Oceanographic Institution and the Argo Steering Team; Graphic Design: Marie-Christine Bailly-Maitre, Infographics: Thomas Halesig

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Argo data portal



The screenshot displays the Argo data portal dashboard. On the left is a navigation sidebar with filters for Status, Year of deployment, Country, Basin, and Telecom. The main content area is titled "4024 floats" and contains a table of active floats. On the right is a world map showing the global distribution of these floats as yellow dots.

A	WMO	Float S/N PTT	Float	Last Tx	Last cycle	Battery	Launch
	7900969	AI2600-23AU130 n/a	ARVOR	25/01/2025 00:22:20	1	9.7	23/01/
	2903751	AK1000-22JP019 235468	ARVOR		100		29/07/
	3901056	7195 n/a	S2A	26/01/2025 15:46:50	383		27/11/2
	3901295	0738 n/a	NAVIS_A	25/01/2025 18:28:05	294		12/01/:
	3901294	0737 n/a	NAVIS_A	24/01/2025 04:52:23	294		10/01/
	3901274	8564 n/a	SOLO_II	31/01/2025 02:33:29	276		10/09/
	3901271	8547 n/a	SOLO_II	31/01/2025 11:29:34	334		18/02/
	3901285	0714 n/a	NAVIS_A	22/01/2025 17:59:10	298		01/12/:
	3901793	8612 n/a	SOLO_II	22/01/2025 11:07:00	265		28/11/:
	3902640	7955 n/a	S2A	30/01/2025 14:17:08	8		19/12/:
	3901565	56 90056i	APEX_D	28/01/2025 19:46:26	157		06/01/
	3901564	8978 9078:	APEX	26/01/2025 00:25:47	151		04/01/

<https://fleetmonitoring.euro-argo.eu/dashboard?Status=Active>

AUTONOMOUS INSTRUMENTS IN OCEANOGRAPHY

Argo data portal



<https://dataselection.euro-argo.eu/>

Argo NetCDF format - training

Argo data in **NetCDF** format follow a standardized structure to ensure consistency and ease of use. The data are organized into different file types, each serving a specific purpose:

1. Profile Files (*_prof.nc)

- Contain vertical profile data (e.g., temperature, salinity, pressure).
- Structured per mission cycle of the float.
- Key variables:
 - PRES (pressure in dbar)
 - TEMP (temperature in °C)
 - PSAL (practical salinity)
 - JULD (time in Julian days)
 - LATITUDE / LONGITUDE (geographical position)

2. Trajectory Files (*_traj.nc)

- Contain the float's position and state over time.
- Key variables:
 - JULD (timestamp of measurement)
 - LATITUDE / LONGITUDE
 - PRES (pressure at different float phases)

3. Delayed Mode Data Files (*_D.nc)

- More accurate versions of the data, with applied calibrations and corrections.

4. Biogeochemical (BGC) Argo Files (*_Bprof.nc, *_Btraj.nc)

- Contain biogeochemical data such as dissolved oxygen, pH, chlorophyll, nitrates, etc.

5. Metadata Files (*_meta.nc)

- Store information about the float, sensors, and operational configurations.

6. Technical Files (*_tech.nc)

- Record float status data (e.g., battery level, pressure, sensor performance).

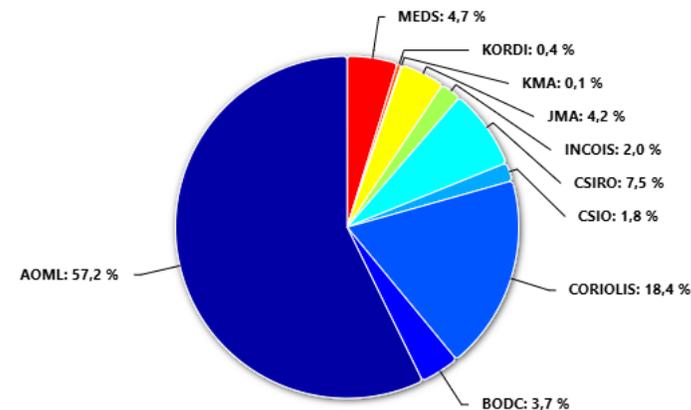


THANKS!

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
 (D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-
 Mission 4 “Education and Research” - Component 2: “From research to business” - Investment
 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

4034 active floats on Argo GDAC

(C) Coriolis data center - 28/01/2025



Histogram of profiles on Argo GDAC

(C) Coriolis data center - 28/01/2025

