
# Overview of BGC Argo : Accomplishments & Capabilities

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SOCCOM | Unlocking the mysteries of the Southern Ocean

GO-BGC Global Ocean Biogeochemistry Array

NSF NOPP NOAA NASA

REFINE
ROBOTS EXPLORE PLANKTON-DRIVEN FLUXES IN THE MARINE TWILIGHT ZONE

cnrs SORBONNE UNIVERSITÉ erc cnes

# Before Argo (1999): A Century of Undersampling



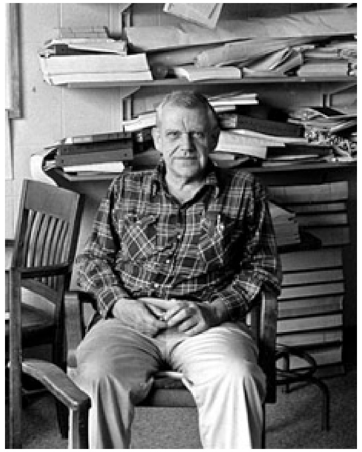
*"If I were to choose a single phrase to characterize the first century of modern Oceanography it would be a century of undersampling"*

*"Establish the World Ocean Observing System [WOOS], a facility capable of monitoring the global ocean….",*

*"…Using a fleet of small neutrally-buoyant floats called Slocum…"*

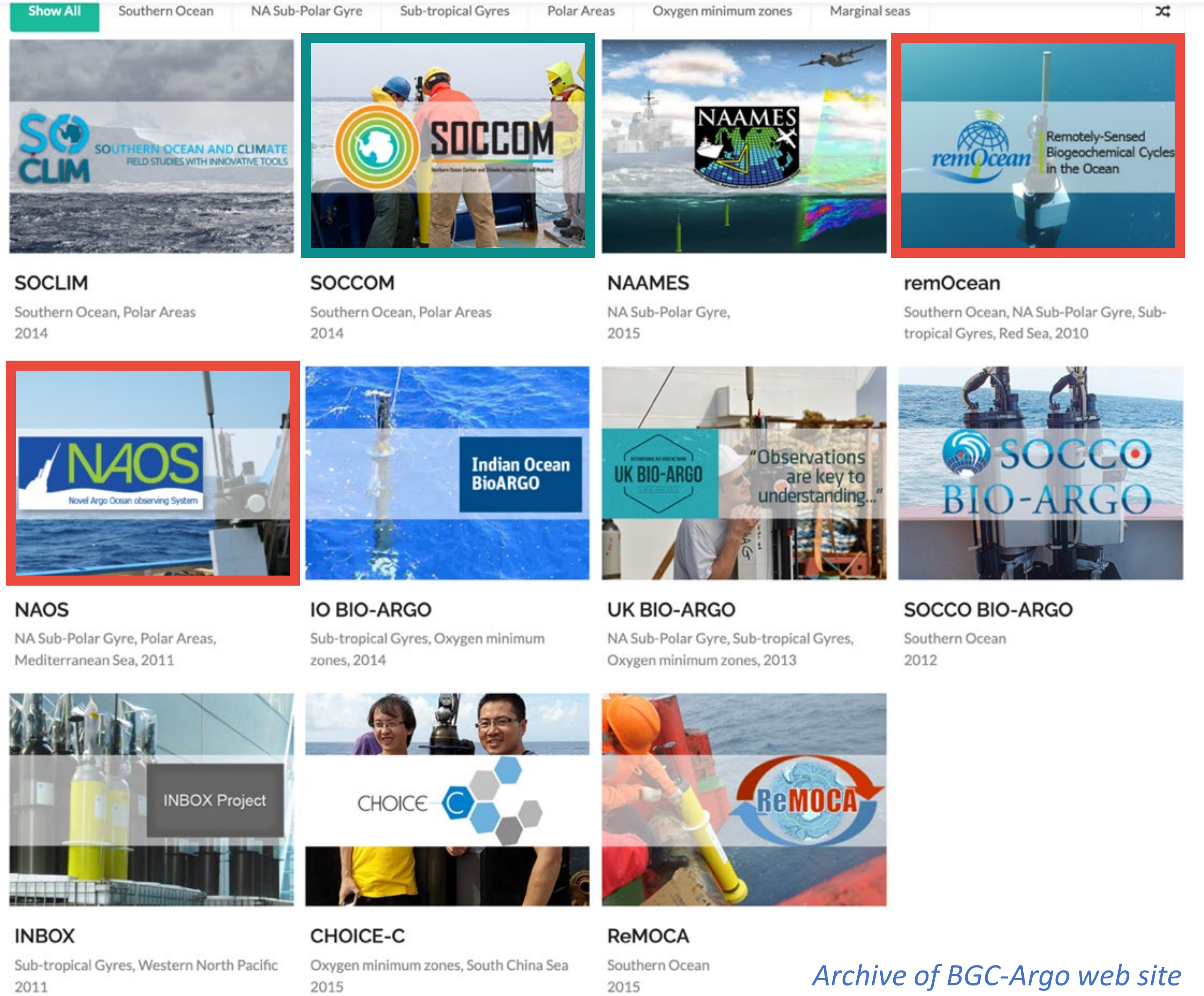
*Each day we get about 3000 CTD profiles from our Sentinel fleet"….*

MUNK, 2000: Oceanography before, and after, the advent of satellite



STOMMEL 1989: The slocum mission. Oceanography

# From Argo to BGC-Argo : Expanding the Vision



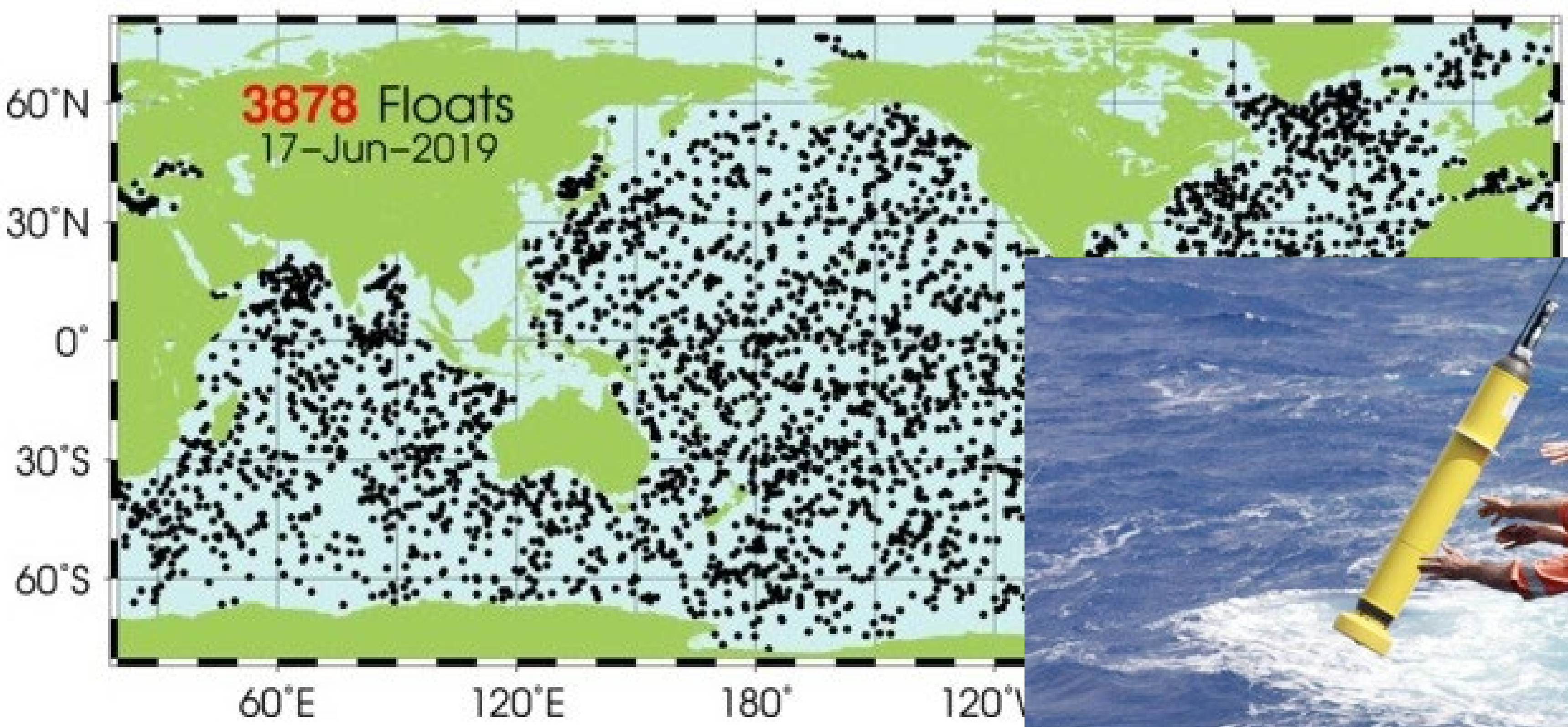

*Archive of BGC-Argo web site*

**Pilot projects in "key" zones :** remOcean (EU), 2010-2016, 62 floats; NAOS (Fr), 2011-2017 45 floats
**Med, NASPG, STG, SO, Arctic**

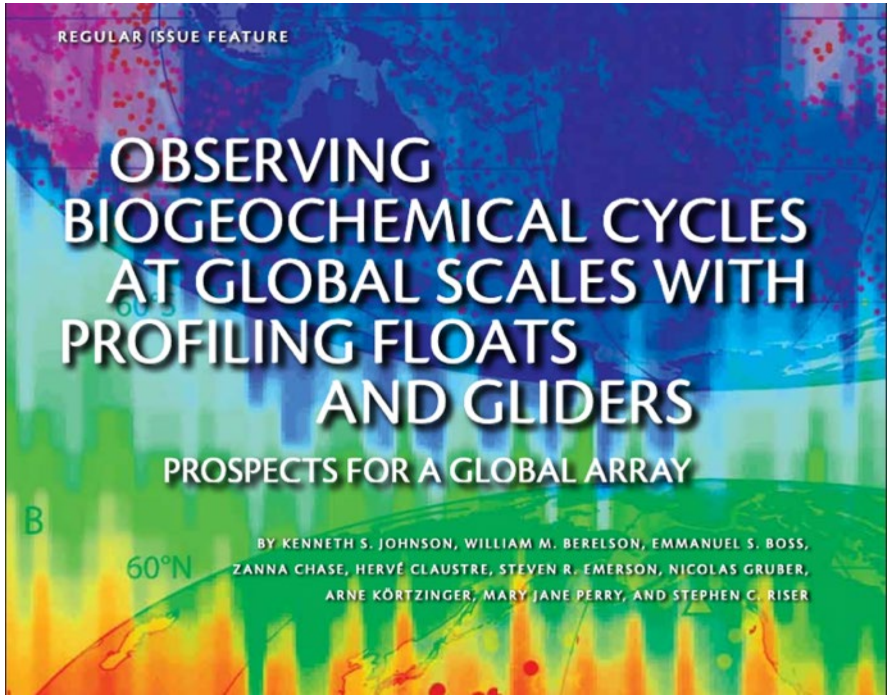
**Basin-Scale implementation in the Southern Ocean :** SOCCOM (US) : 2014- 2026 328 floats

***From pilots to sustained system: Array design is carefully tested before any scaling !***

# From Argo to BGC-Argo : Expanding the Vision




# 2008-2015: BGC-Argo structuring : Working groups & white papers



***Designed by the community (science and users), for the community***

# 2016 : Biogeochemical-Argo Science And Implementation Plan


Biogeochemical-Argo Network - Group photo

http://biogeochemical-argo.org

## *Research topics*

- Biological carbon pump
- Phytoplankton communities
- OMZs and nitrate cycling
- Carbon uptake
- Acidification

## *Six core variables*

- Chl*a*
- Suspended particles ($b_{bp}$)
- Downwelling irradiance
- $O_2$
- $NO_3$
- pH

## *Management topics*

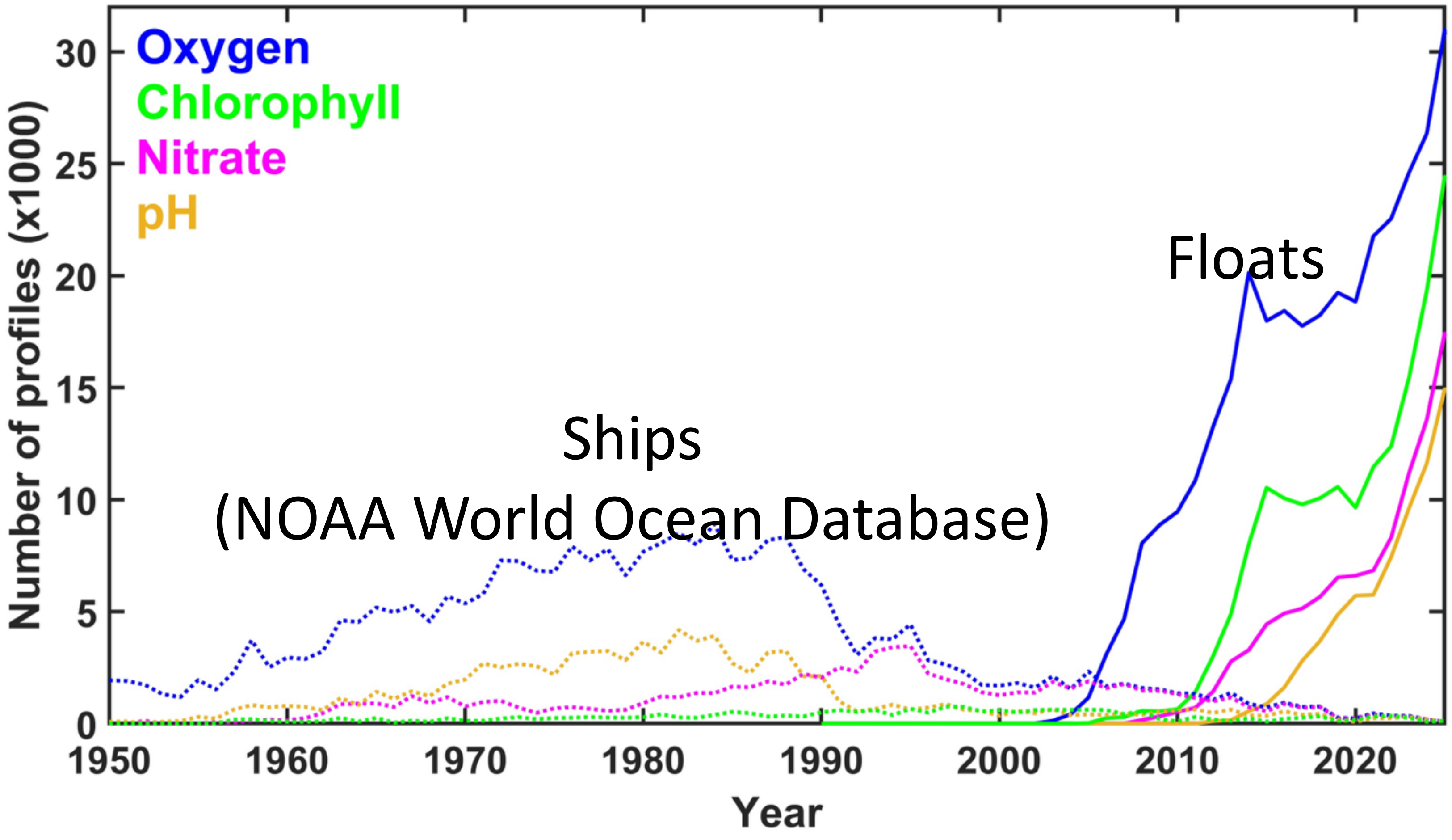
- Living marine resources
- Carbon budget verification

## *One fleet objective*

- 1000 operational floats

***Extensive international coordination shaped the system***

# Floats are the dominant source of ocean interior BGC data!



INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
(of UNESCO)

**Fifty-first Session of the Executive Council**
UNESCO, Paris, 3–6 July 2018

**EVOLVING CAPABILITIES OF THE ARGO PROFILING FLOAT NETWORK**

- **Approves the global implementation of Argo floats measuring six parameters** – oxygen, pH , nitrate, chlorophyll, backscatter and irradiance
- Recognizing the value of Argo for responding to global challenges on climate variability and change and its role in underpinning ocean and marine services, encourages all IOC Member States to further support and participate in the implementation of the Argo programme and to **facilitate the deployment of Argo floats within their area of jurisdiction**
- **Agrees that Argo Steering Team can designate Argo approved pilot parameters** based on requirement of technological readiness; a compelling design and implementation plan; and the potential to deliver major benefits to research and societal services.

⇒ ***OneArgo participation enables sustained observations across the global ocean, including EEZs***
⇒ ***In the same time this participation requires transparency and best practices***

# Following Science and Implementation Plan, Two Key Milestones For BGC-Argo



OCEAN OBS'19

frontiers in Marine Science
REVIEW
published: 02 August 2019
doi: 10.3389/fmars.2019.00439

**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†], Brian King[4†], James Moum[5†], Peter Oke[6†], W. Brechner Owens[7†], Sylvie Pouliquen[8†],*

UN OCEAN CONFERENCE NICE 2025 FRANCE

ONE OCEAN SCIENCE CONGRESS

frontiers in Marine Science
TYPE Review
PUBLISHED 02 June 2025
DOI 10.3389/fmars.2025.1593904

**Advancing ocean monitoring and knowledge for societal benefit: the urgency to expand Argo to OneArgo by 2030**

Virginie Thierry[1*], Hervé Claustre[2], Orens Pasqueron de Fommervault[3], Nathalie Zilberman[4], Kenneth S. Johnson[5], Brian A. King[6], Susan E. Wijffels[7],

**2019** - BGC-Argo mission becomes fully integrated into the « One Argo » vision : Core, Deep, BGC, (polar)

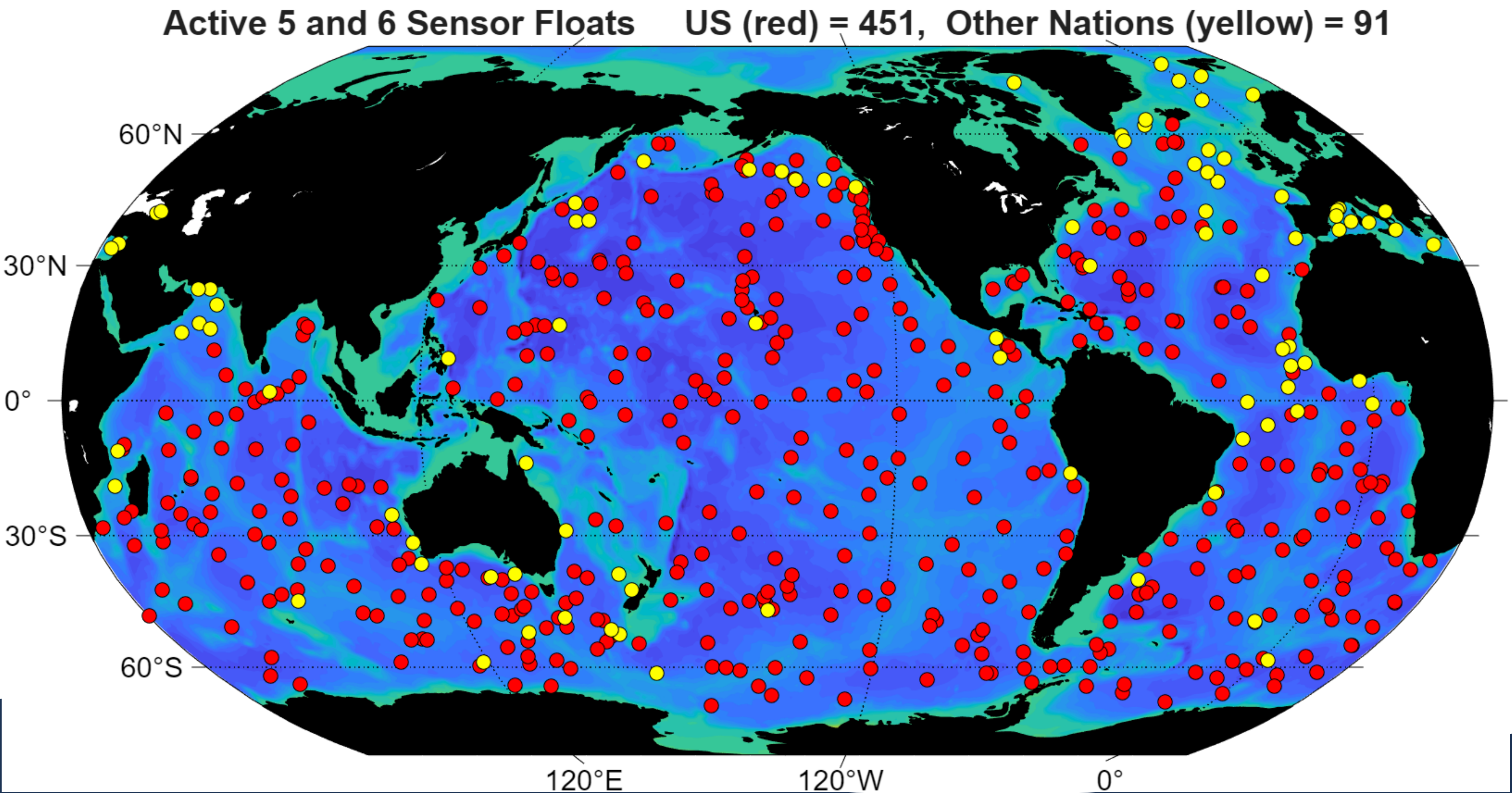
**2025** - One Argo as a cornerstone global observation program to inform society and decision. Synergies with end-users New emerging topics for BGC-Argo

- MPAs for the high Sea
- MCDR (MRV)
- Deep Sea mining

***Considerable community input, increasing roles of endusers***

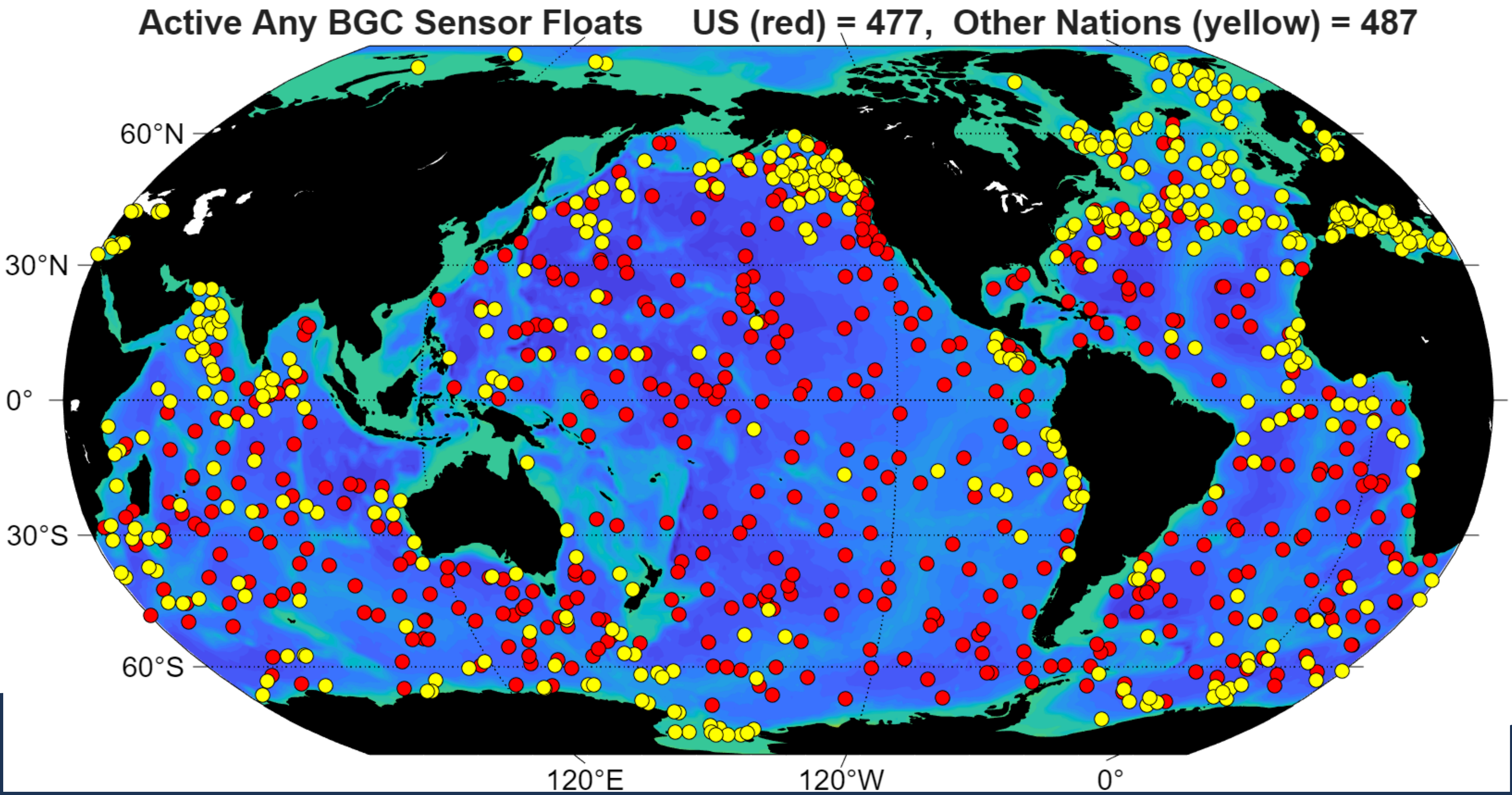
# Array status: 5 and 6 sensor floats

US floats are the majority of the BGC-Argo array with $O_2$, $NO_3^-$, pH, bio-optics



# Array status: any BGC sensor

## Strong international contribution of floats with oxygen or oxygen and bio-optics.




Ocean-ops.org

Floats reporting in last 30 days
3/30/26

# Coordinating Data Quality and Technological Innovation to Sustain and Advance the Global BGC-Argo System

## BGC-ADMT (2018-)

The **BGC-ADMT task team** has been established under the mandate to drive and enhance the development of BGC data management procedures following the scientific guidance of the BGC-Argo Steering Team, stimulate communication, engagement and operational consistency among regional **BGC Data Assembly Centers (DACs)**, and support the general advancement of the Argo program.

TERMS OF REFERENCE


Tanya Maurer
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AUSTRALIA


Udaya Bhaskar
INDIA


Chihiro Kawamura
JAPAN


Anh Tran
CANADA


Kanako Sato
JAPAN


Zenghong Liu
CHINA

## BGC-TTT (2023-)

The **BGC-Argo Technological Task Team** has been established to provide technical expertise for BGC-Argo sensors. Its goals include assessing the performance of approved sensors, fostering sensor diversification and innovation, and facilitating community discussions on **BGC-Argo sensor technologies**. The BGC-Argo Technological Task Team follows the scientific guidance of the BGC-Argo Steering Team and supports the overall advancement of the Argo program.

TERMS OF REFERENCE


Edouard Leymarie
Co-chair - FRANCE


Yuichiro Takeshita
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David Nicholson
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Griet Neukermans
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Henry Bittig
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Margaret Estapa
USA


Mariana Bernardi Bif
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Nathan Briggs
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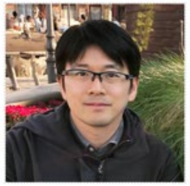
Tetsuichi Fujiki
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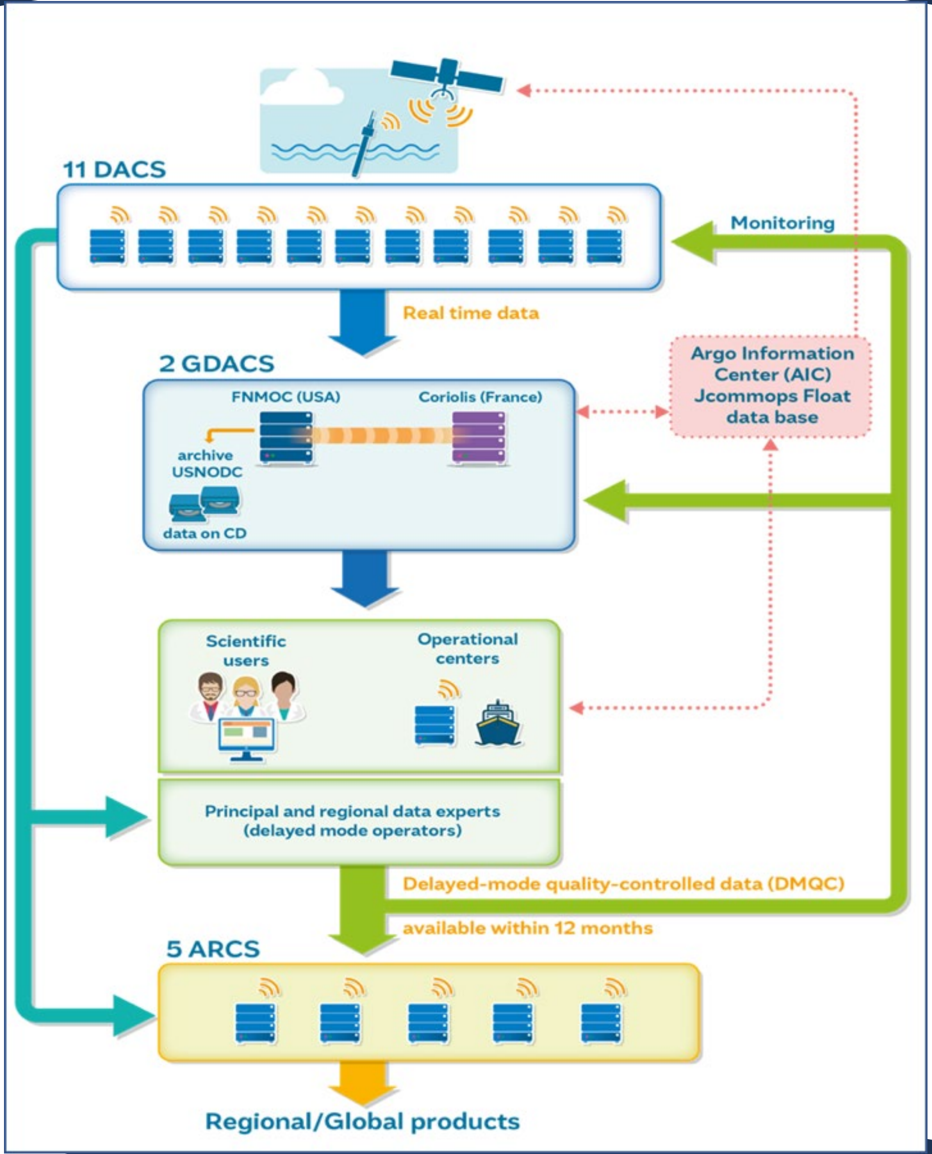
# Real-time data system




**Argo Data Management Goals Align with FAIR**

Data Findability, Accessibility, Interoperability, and Reusability

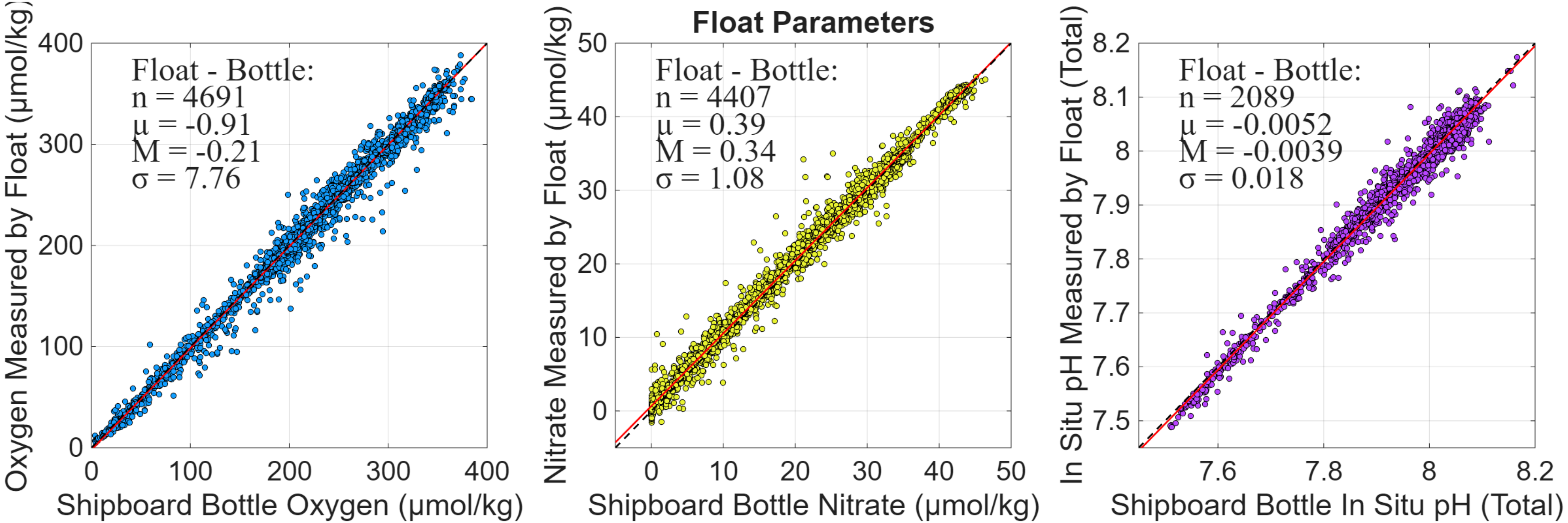
Argo Data Management Documentation:

www.argodatamgt.org/Documentation

Some Data Access Sources:

https://www.go-bgc.org/data/access-and-visualization

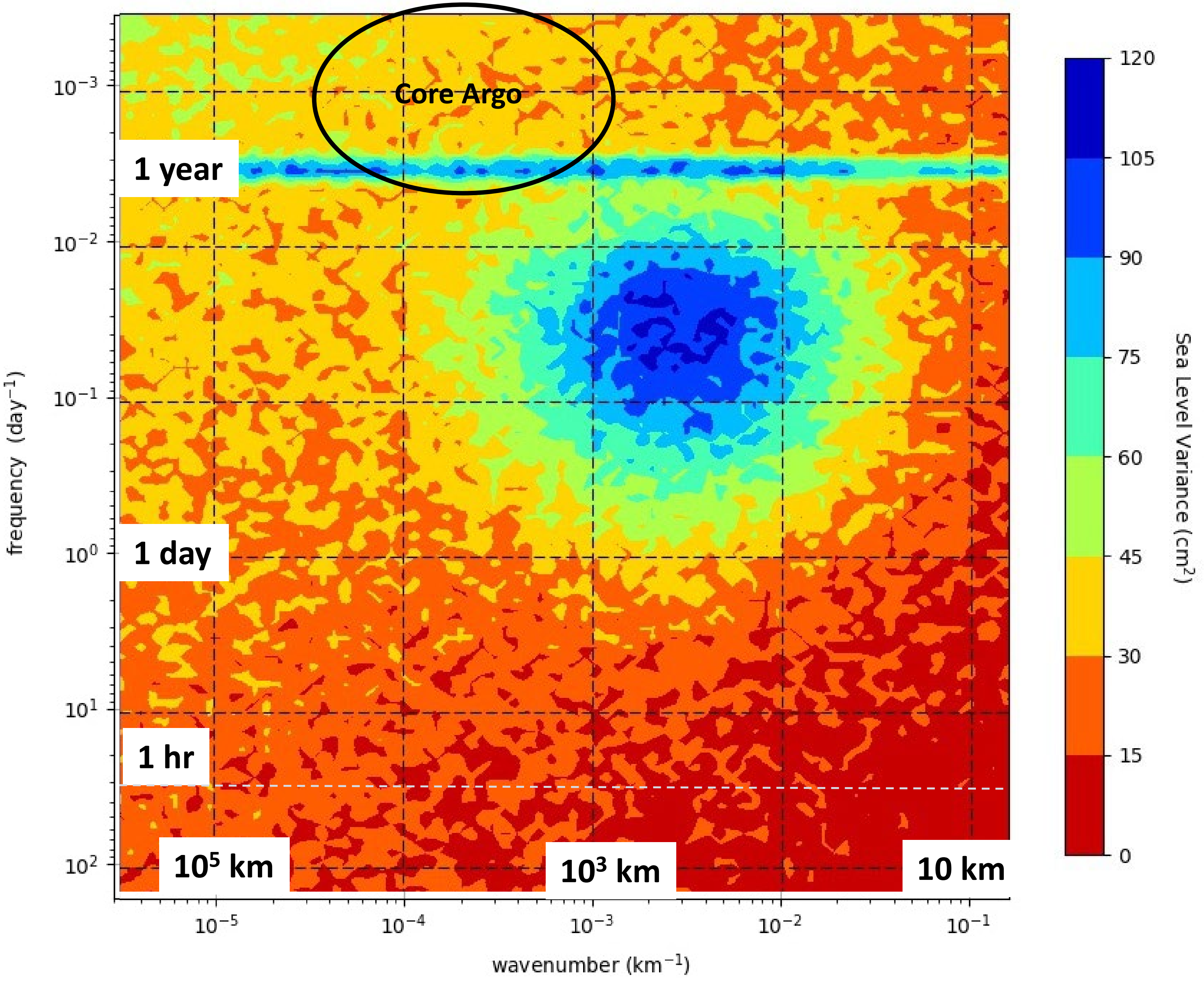
# High quality data




GO-BGC Global Ocean Biogeochemistry Array

# What can you do with a global, consistent data set?

Steve Riser, Argo Science Workshop 2018



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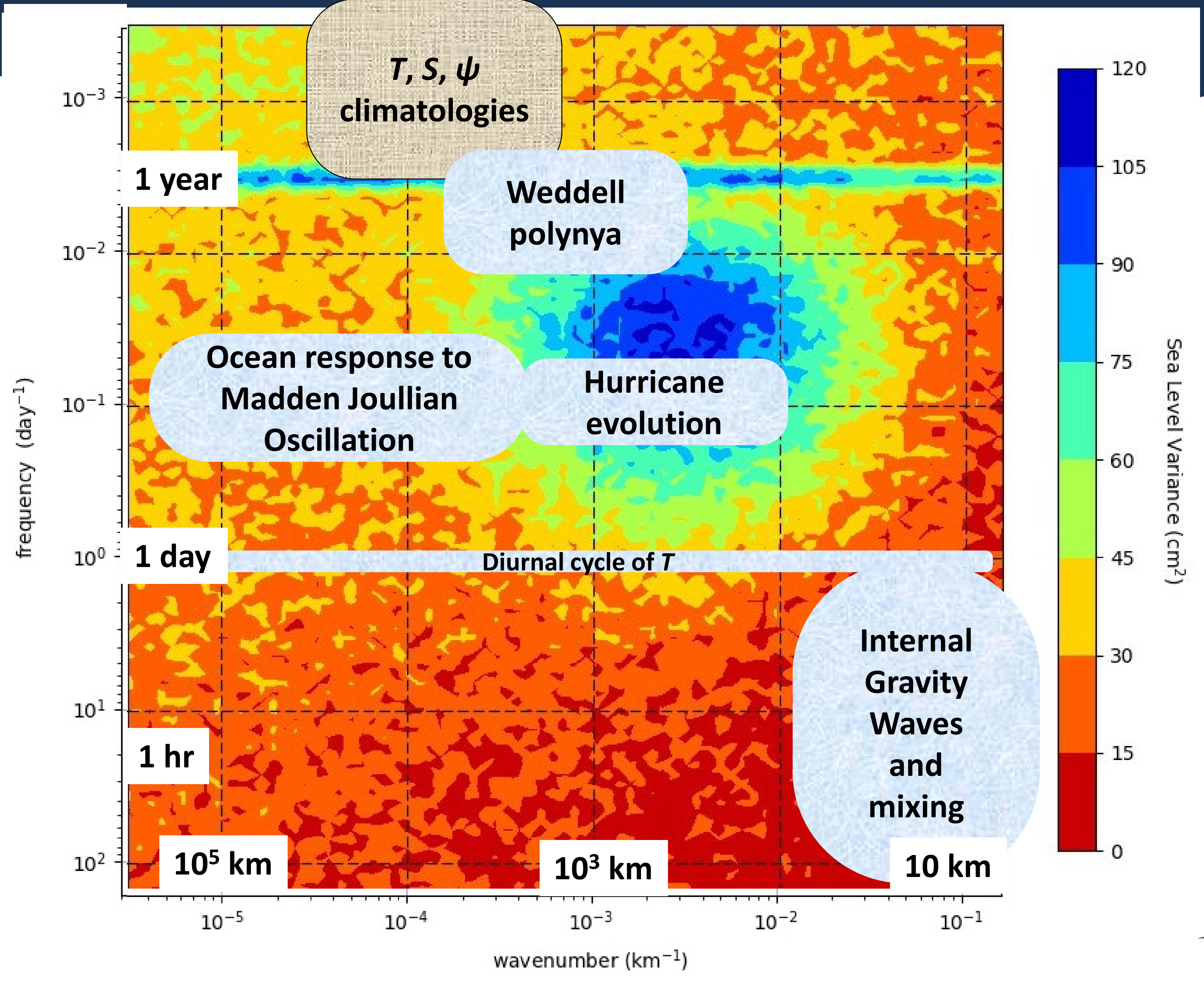
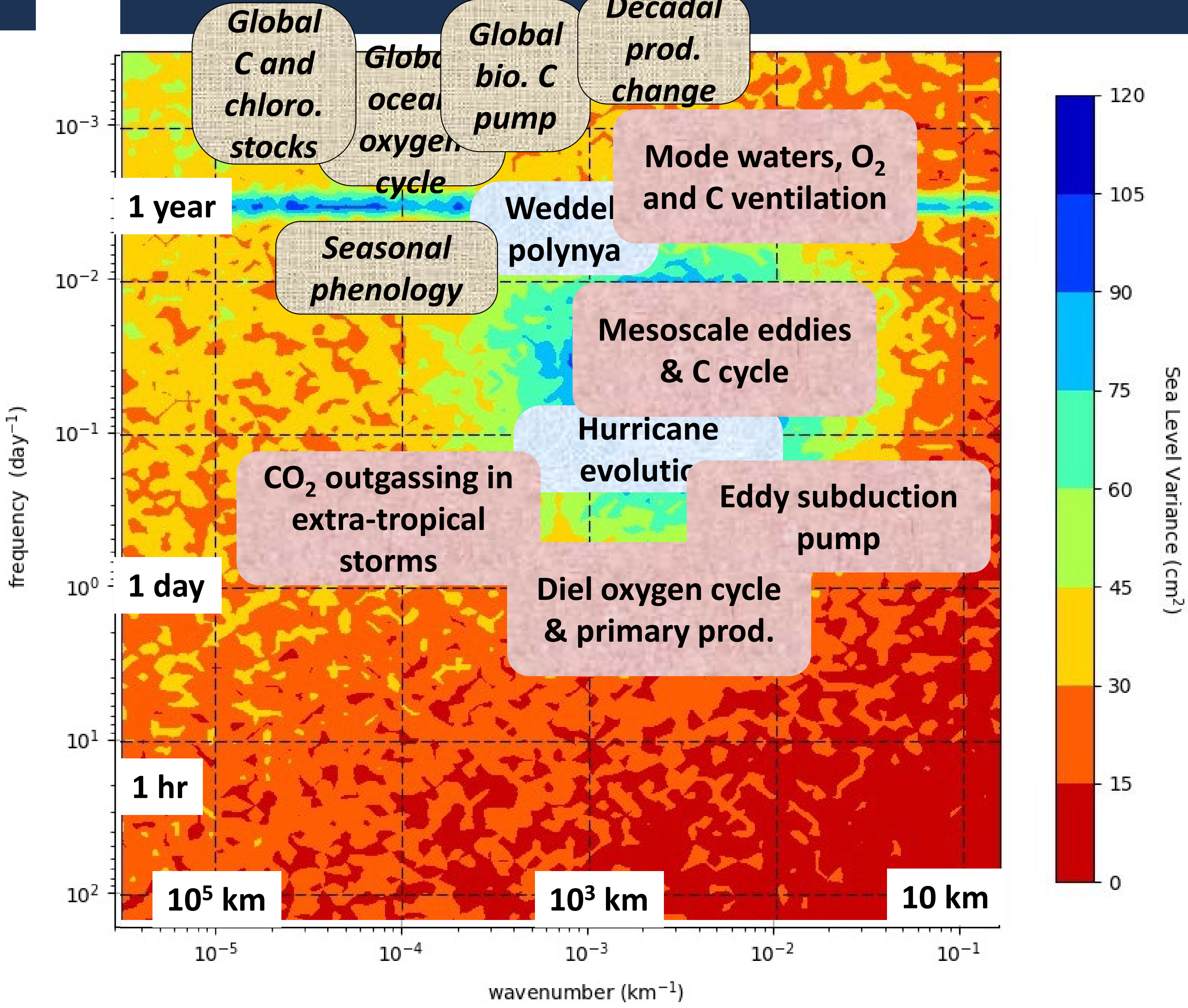


What can you do with a global, consistent data set?

The consistent BGC-Argo dataset enables access to a broad range of signals.



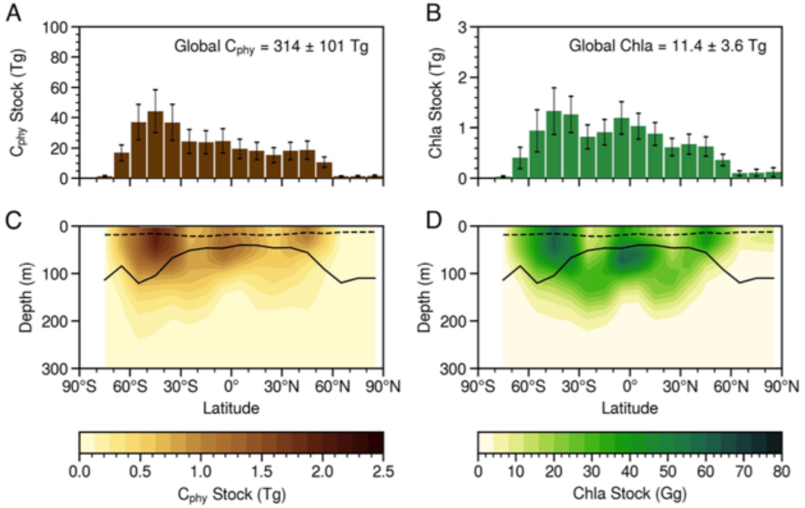
# Rethinking Global Phytoplankton Biomass and Phenology

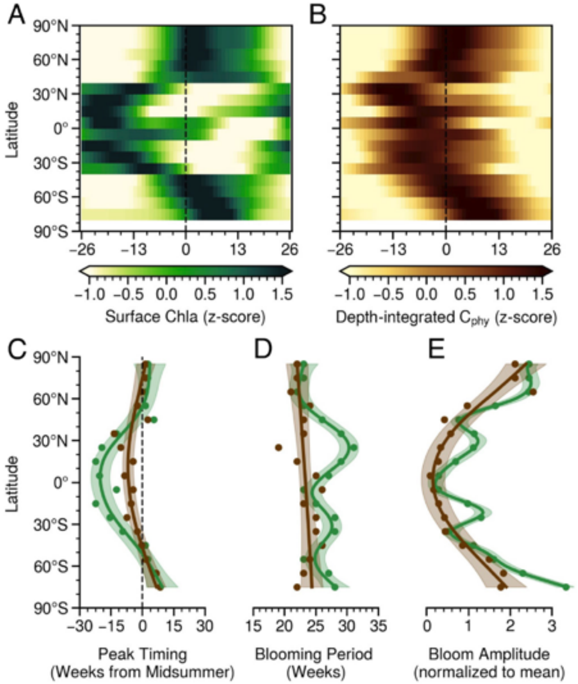


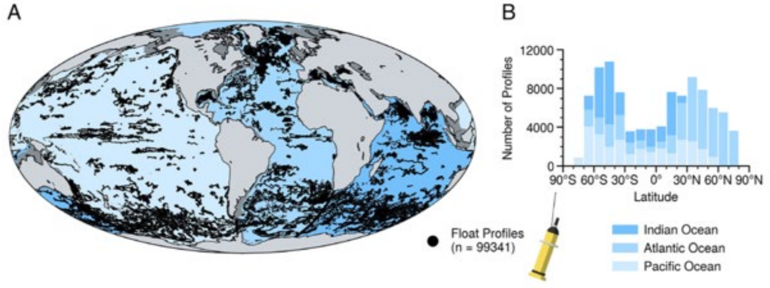
PNAS RESEARCH ARTICLE | ECOLOGY

## Carbon-centric dynamics of Earth's marine phytoplankton

Adam C. Stoer[a,1] and Katja Fennel[a]



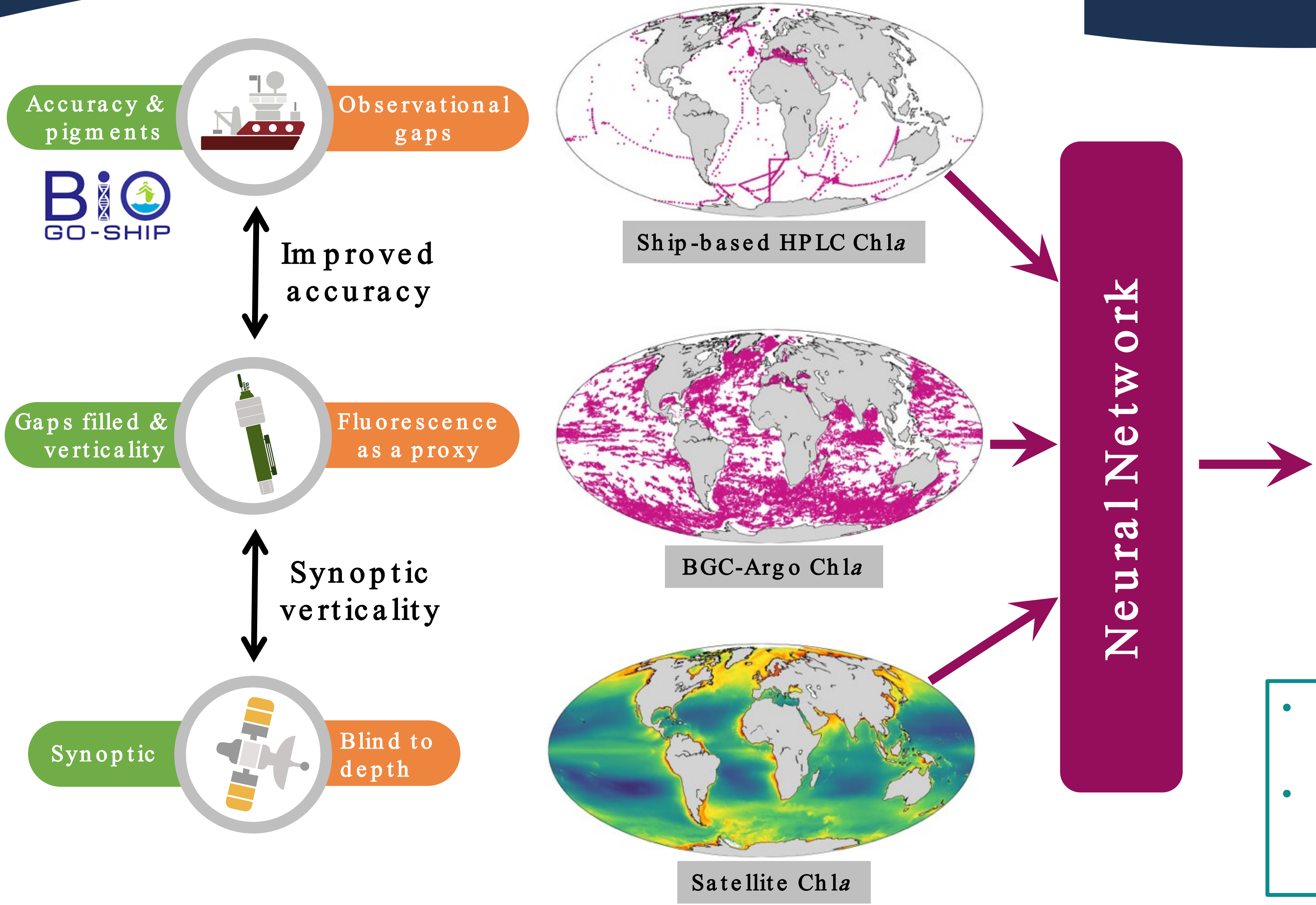



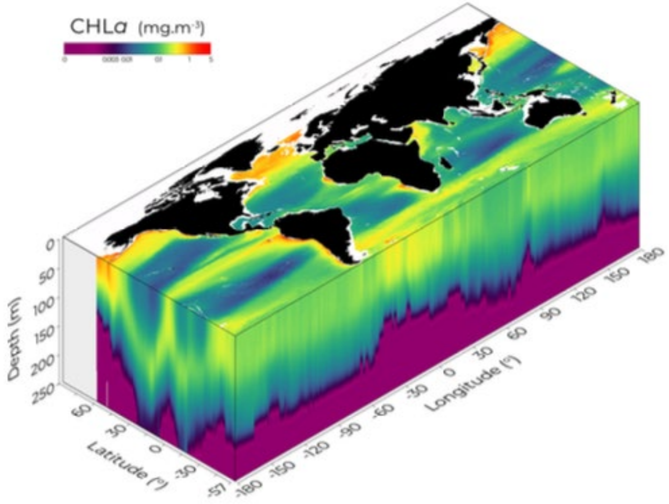

- Half of ocean phytoplankton biomass is invisible to satellites.
- Surface chlorophyll is an imperfect proxy for biomass.
- We have been misreading the ocean's biological clock.
- Phytoplankton blooms are weaker, shorter, and later than we thought.

*=> Floats enhance and refine satellite capability*

# Designed Complementarity Across Observing Systems




4D BGC operational products distributed by Copernicus Marine Service (CMS)




- No single observing system can resolve ocean complexity alone
- Cross-system consistency strengthens the overall observing system

# From Observations to Carbon Flux : a 4D Ocean View



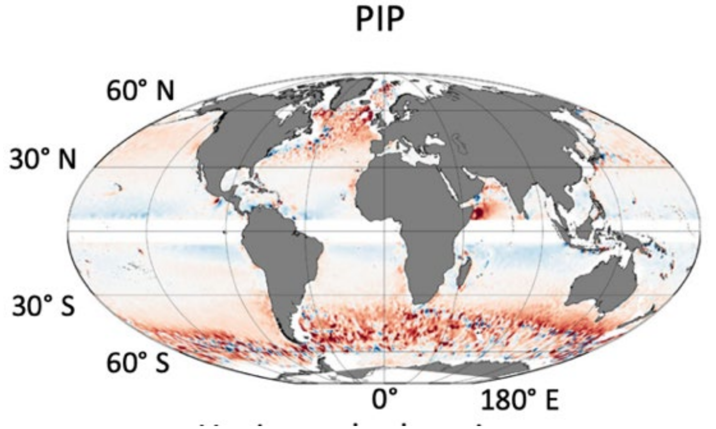
nature communications

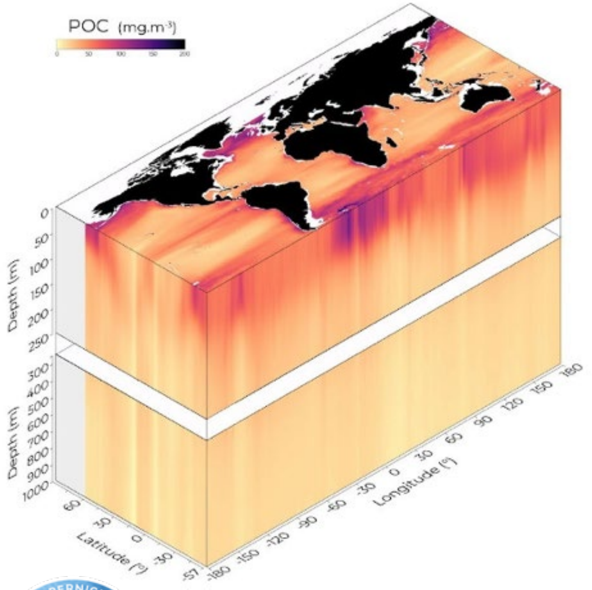
Article

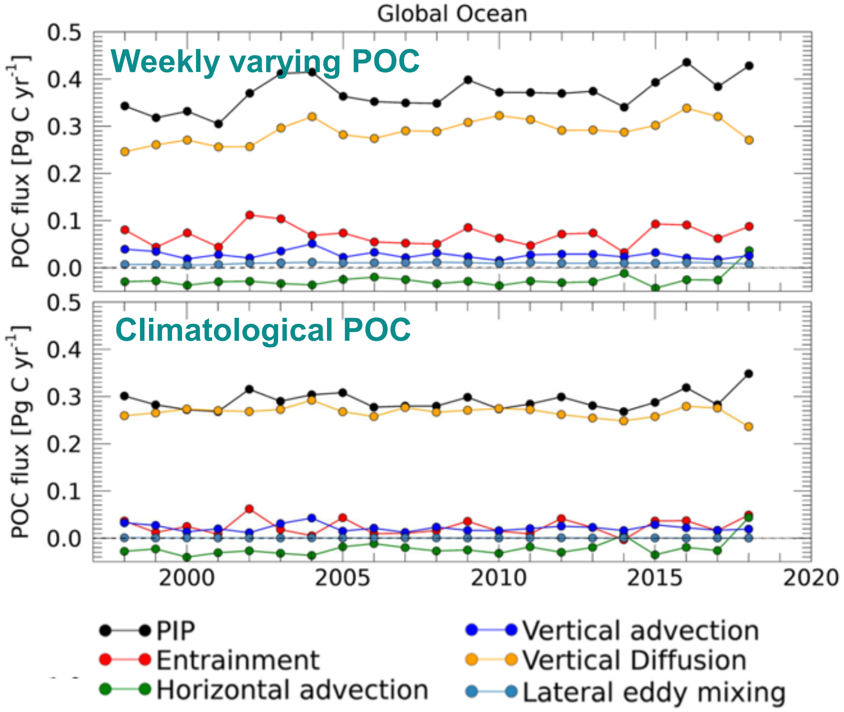
https://doi.org/10.1038/s41467-025-62363-z

**The oceanic physical injection pump of organic carbon**

Marco Bellacicco[1], Salvatore Marullo[1], Giorgio Dall'Olmo[2], Daniele Iudicone[3] & Bruno Buongiorno Nardelli[4]




- 3D biogeochemical fields provide the gradients that physics turn into carbon fluxes
- Physics injects carbon, but only when biology provides it.
- Only time-resolved observations capture the true dynamics of export.
- Estimated at ~0.4 GT C $y^{-1}$
- Highly sensitive on the parametrization of diffusion

*=> The BGC-Argo design enables the 4D gradients needed to quantify carbon fluxes*

# From Particle Spikes to Carbon flux attenuation…..

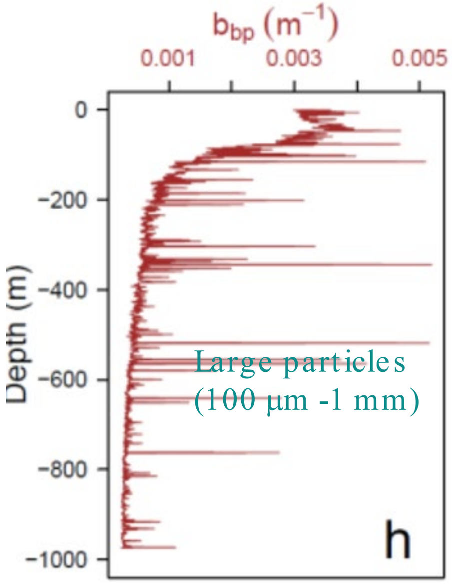


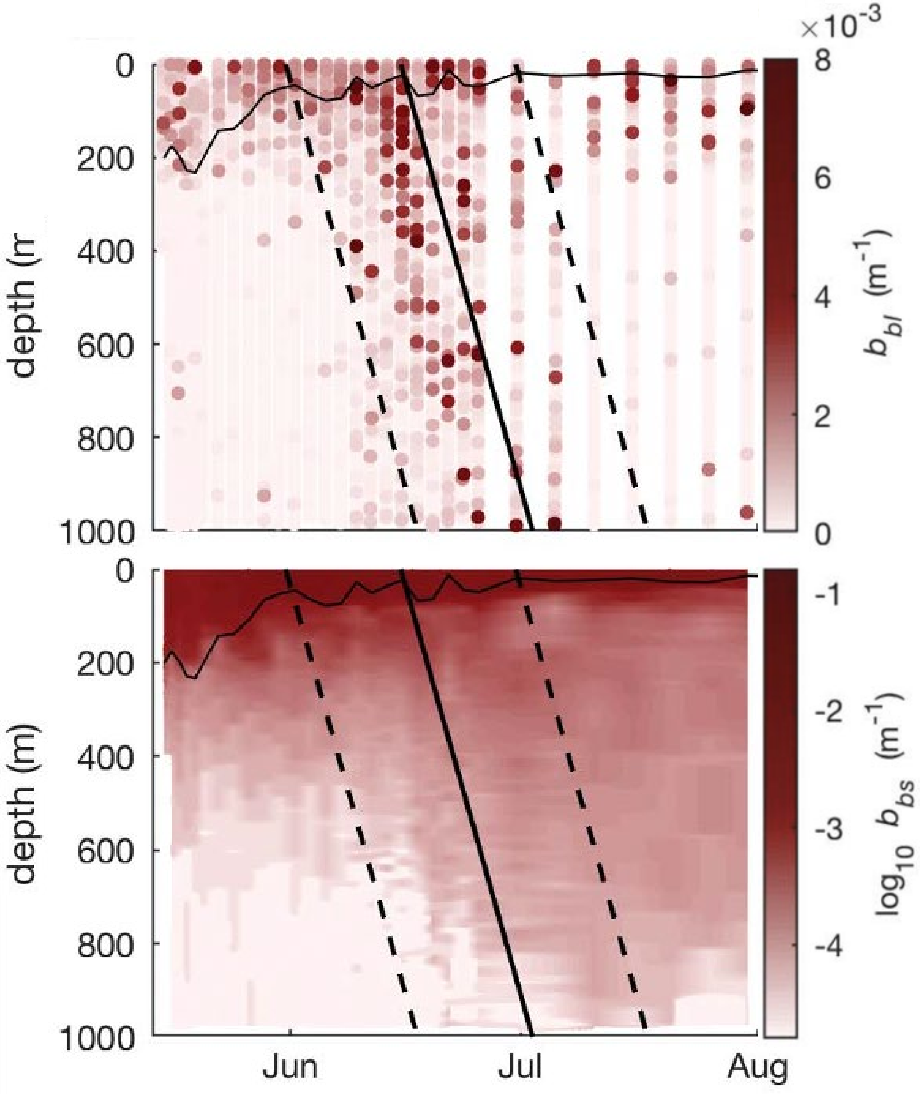
REPORT

CARBON CYCLE

**Major role of particle fragmentation in regulating biological sequestration of $CO_2$ by the oceans**

Nathan Briggs[1,2]*, Giorgio Dall'Olmo[3,4], Hervé Claustre[2]



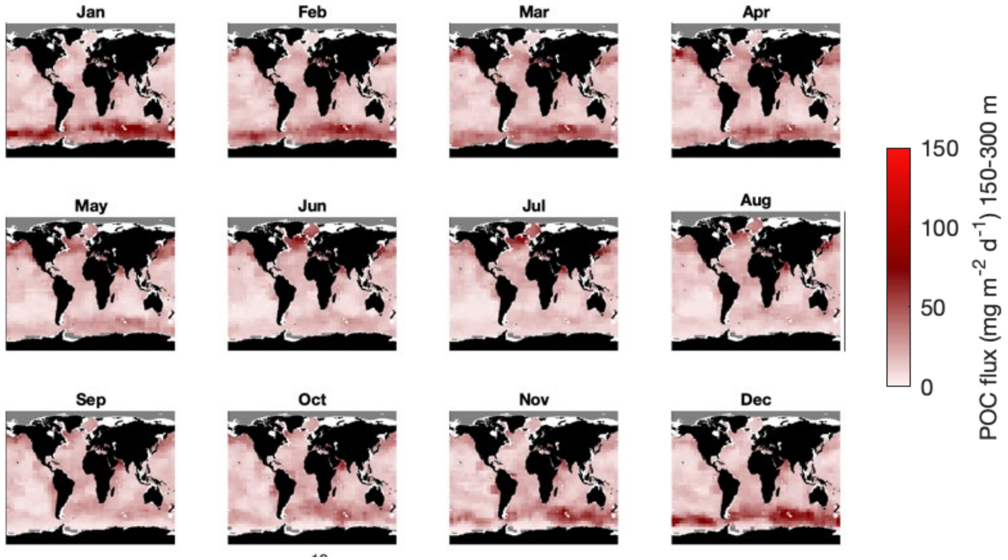

- High-frequency bbp spikes reveal episodic particle export
- Sinking particles are progressively fragmented into smaller, slower particles
- Fragmentation explains ~50% of flux attenuation
- Carbon export is highly dynamic, not steady

⇒ *Repeated vertical profiles resolve transformation processes during sinking*

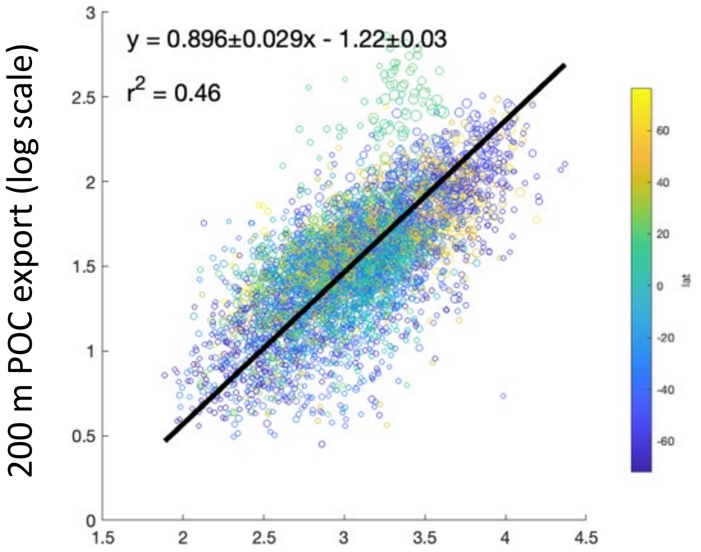
⇒ *Higher temporal resolution helps capturing these episodic export events*

# Towards Global Carbon Export Products






GLOBESINK monthly global POC flux at 200 m, courtesy of Nathan Briggs




*Can be derived from satellite* => Surface POC*mean diameter (log scale)

- Global POC flux estimates now emerging from BGC-Argo (e.g., GLOBESINK)
- Export at 200 m linked to surface POC and particle size
- Scalable using satellite ocean color products
- ~150,000 profiles enable global coverage

⇒ *Global, standardized repeated observations enable consistent upscaling*

⇒ *Large-scale coverage is essential to constrain regional variability*

⇒ *System design enables transition from observations to operational products*

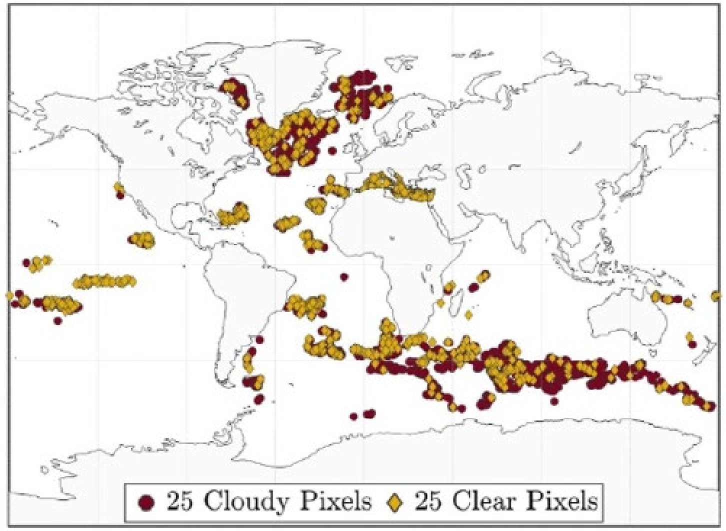
# Ocean Productivity: a Blind Spot Hidden by Clouds

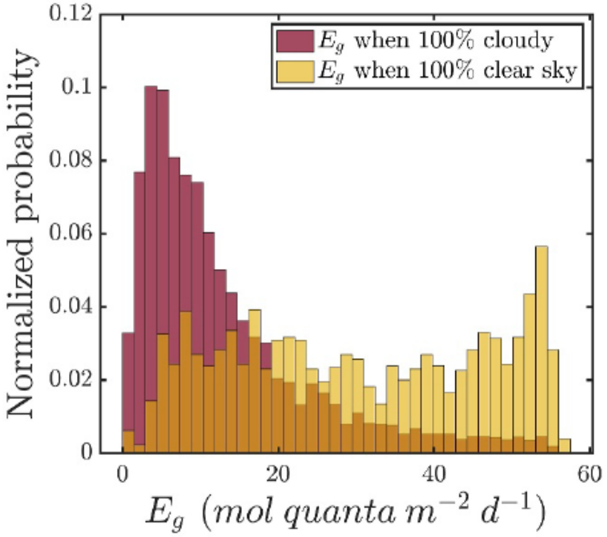


Geophysical Research Letters

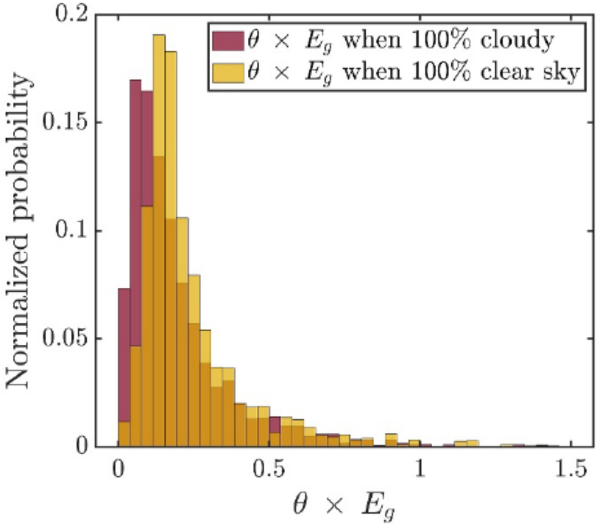
RESEARCH LETTER Phytoplanktonic Photoacclimation Under Clouds

Begouen et al., 2025




Irradiance within Mixed layer




Phyto growth proxy

Clear sky

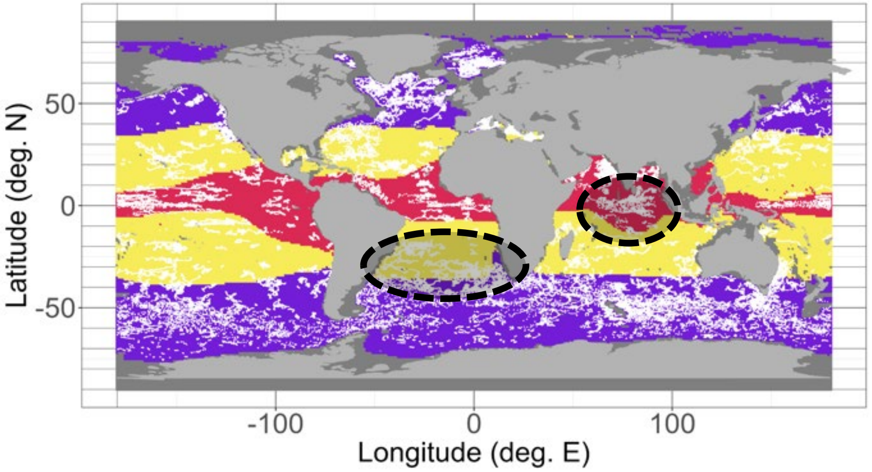
Cloudy

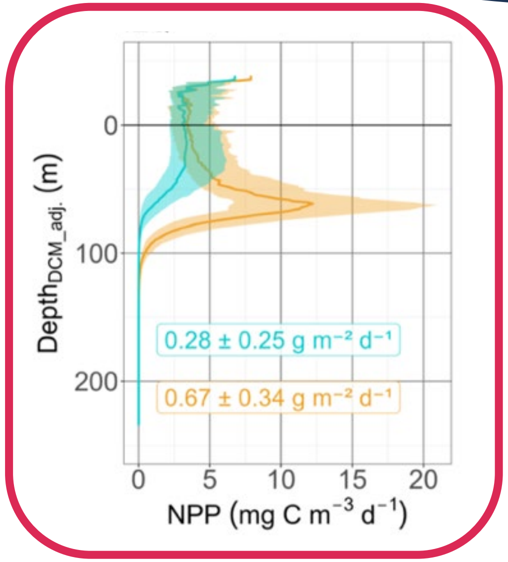
- Clouds reduce available light by up to ~70%
- Satellite models assume no biological adaptation
- Phytoplankton adjusts via photoacclimation
- → Growth remains nearly unchanged despite light reduction
- **Satellite-based estimates underestimate productivity**

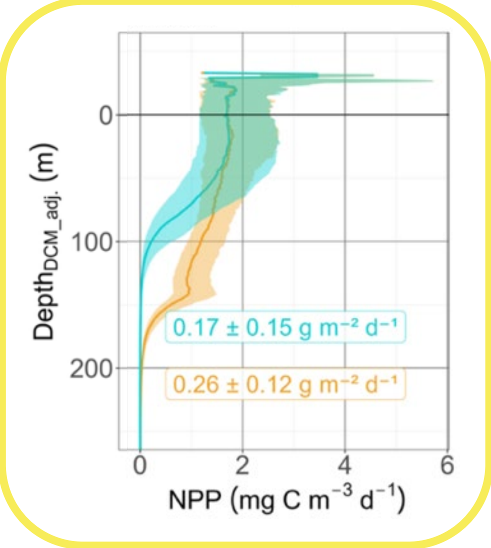
*=> Global float distribution ensures observations under cloudy regions*

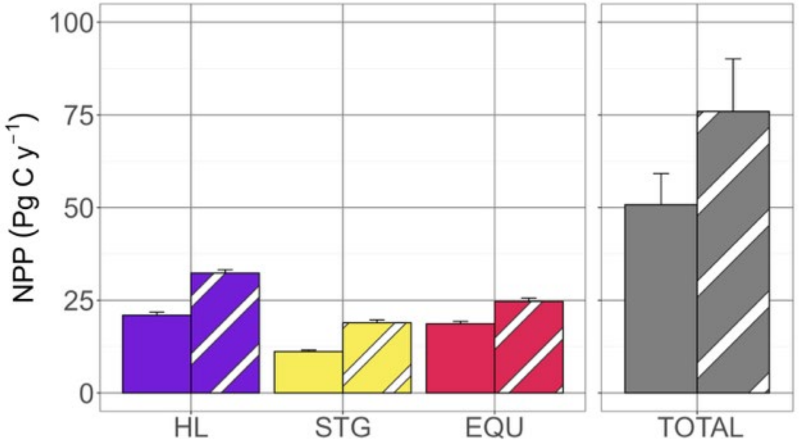
*=> Autonomous profiling captures conditions satellites systematically miss*

# Ocean Productivity: a Blind Spot Hidden by Clouds




Courtesy of Marin Cornec

- Same NPP model applied to both satellite and BGC-Argo
- Satellite-based inputs rely on inferred vertical distributions
- BGC-Argo provides direct, depth-resolved measurements (Chl-a, bbp, PAR)
- Substantial subsurface production missed by satellite-driven estimates
- Up to 2× higher regional NPP and +50% globally

=> Vertical profiling is essential to resolve subsurface productivity

=> Multi-sensor floats enable simultaneous biological and optical measurements

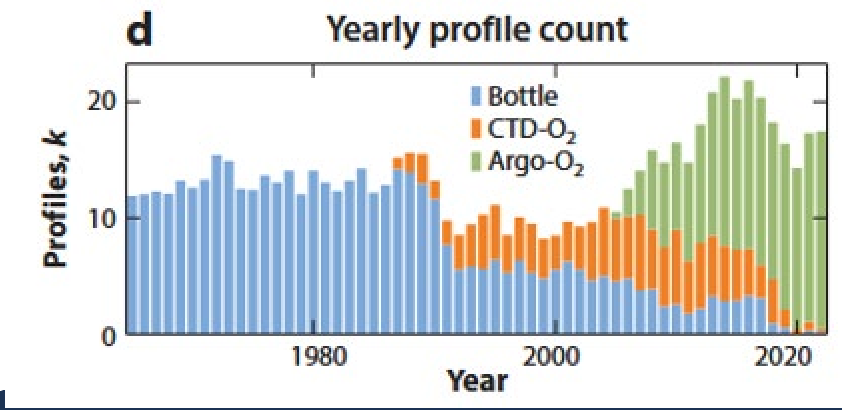
# A consistent data set enables global scale analysis

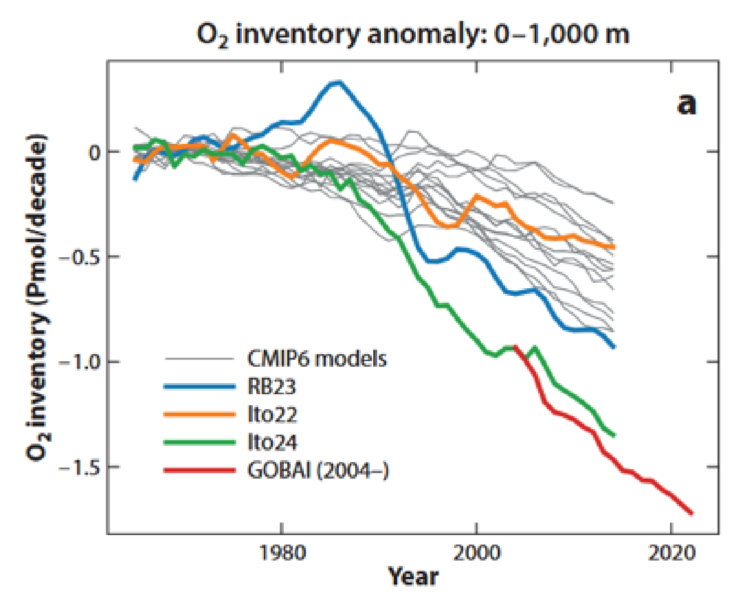
## Ocean deoxygenation

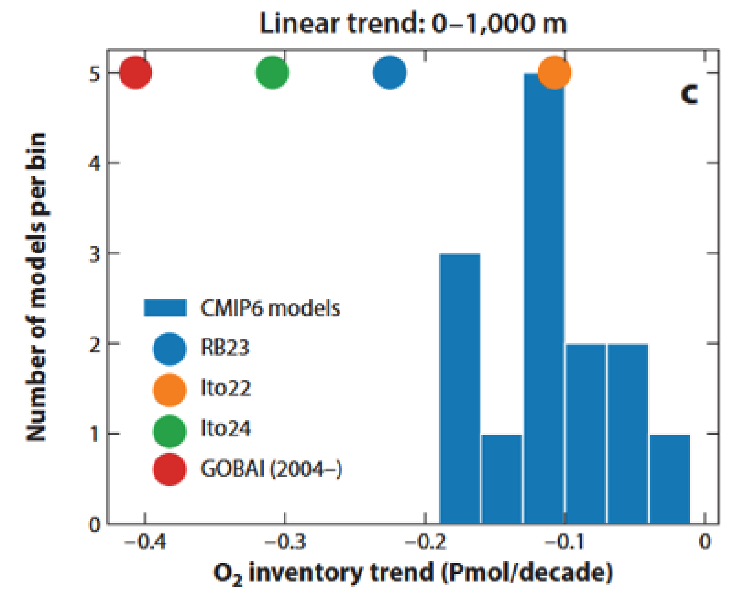
*Annual Review of Earth and Planetary Sciences*

Are Simulated Ocean Deoxygenation Rates Consistent with the Observational Reconstructions?

Takamitsu Ito,[1] Yohei Takano,[2] Yassir A. Eddebbar,[3] Jerry F. Tiputra,[4] Zhankun Wang,[5] Shoshiro Minobe,[6] Lijing Cheng,[7] Juan Du,[8] and Yumi Abe[1]



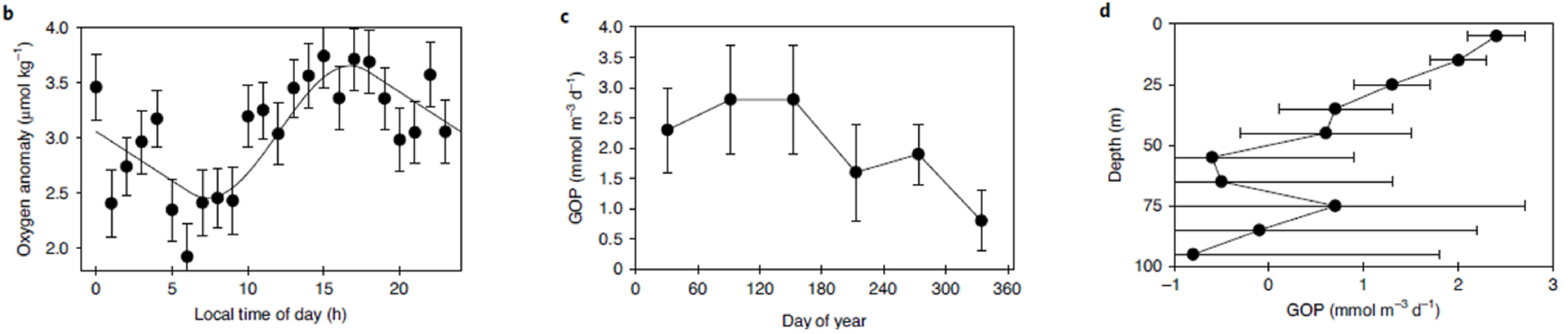




*Total $O_2$ inventory in the ocean is ~310 Pmol.

# A consistent data set enables high frequency signals to be extracted by signal processing.

## The diel O2 signal of primary productivity can be quantified with enough floats.

### Northern Hemisphere Gross Oxygen Production from BGC Argo floats




"Enough" is about 1000 floats (Izett et al., 2024)

GO-BGC Global Ocean Biogeochemistry Array

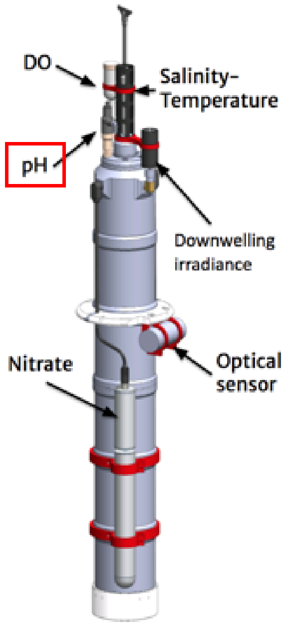
Johnson and Bif (Nat. Geosci. 2021)

# Emerging science opportunity

## Observing ocean Dissolved Inorganic Carbon uptake directly

**Background and Motivation**

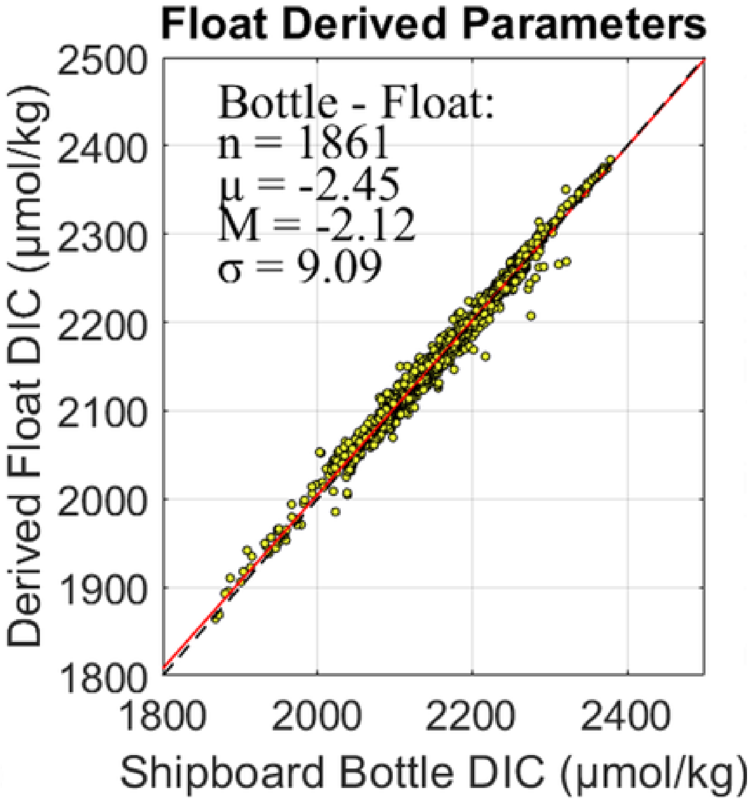
DIC computed accurately from pH and $A_T$




Float pH + Estimated Alkalinity

↓

Dissolved Inorganic Carbon




Predicted value agree very well with measured ones

GO-BGC Global Ocean Biogeochemistry Array

# Emerging science opportunity

## Create a gridded, monthly DIC product

**Ship + Float data**

- Year / DOY
- Latitude
- Longitude
- Pressure
- Temp
- Salinity
- DO

**Machine Learning (NN)**

**Get an output !**

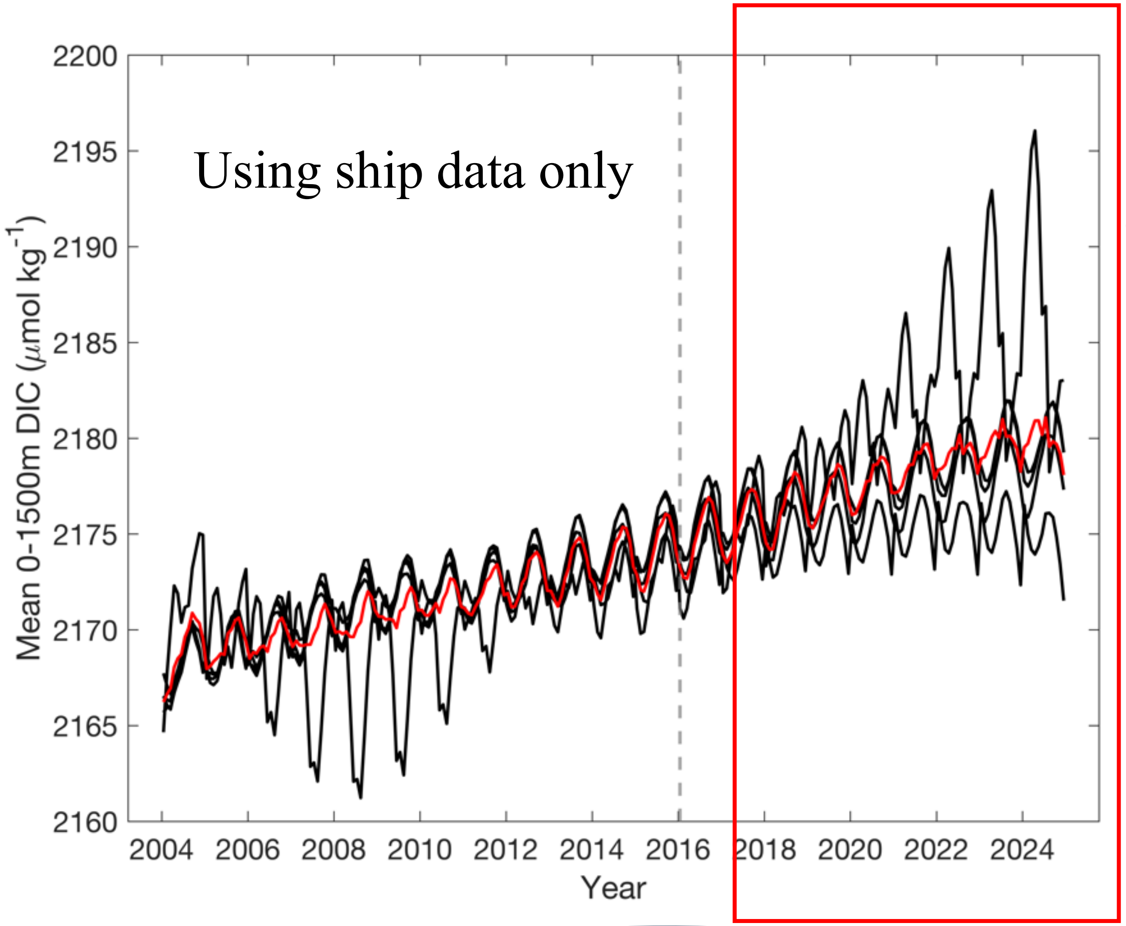
G. Liniger, MBARI

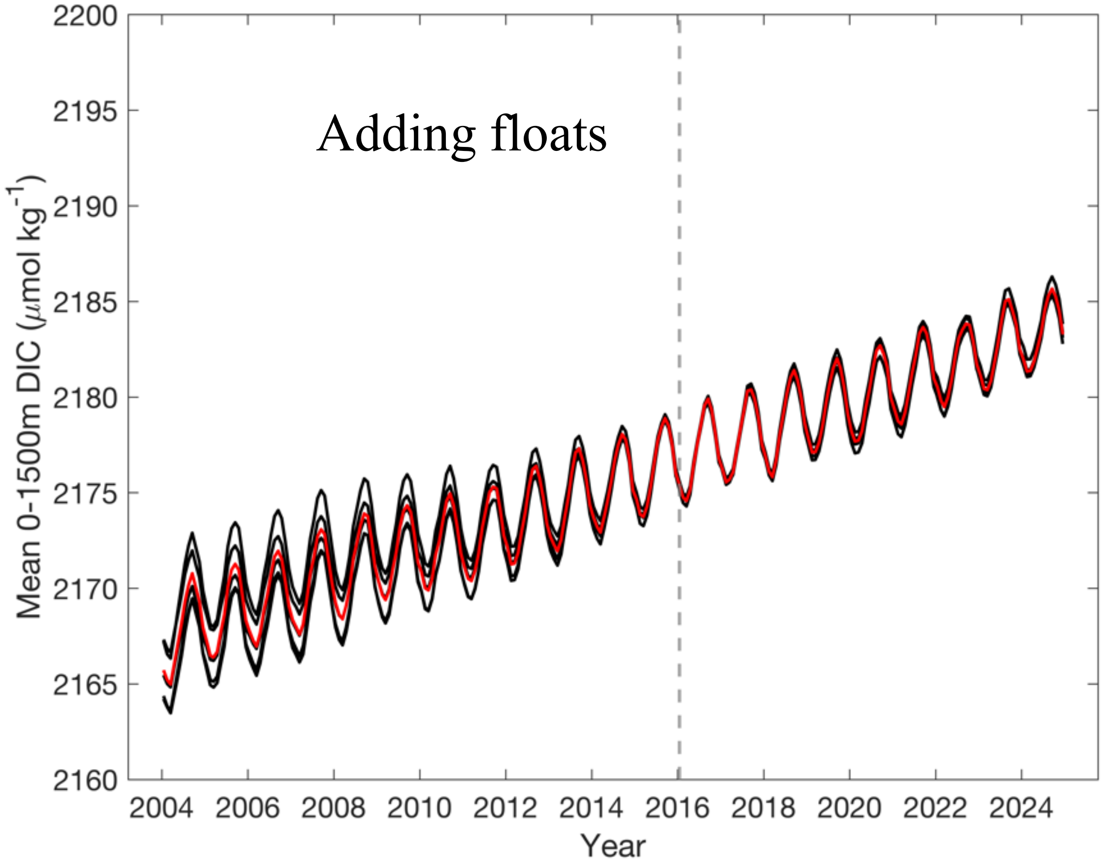
SOCCOM

*Unlocking the mysteries of the Southern Ocean*

# Emerging science opportunity

We have ship DIC data, what do floats add?
5 Neural Networks trained on available data.




G. Liniger, MBARI

# Emerging science opportunity

## Southern Ocean DIC increase in time

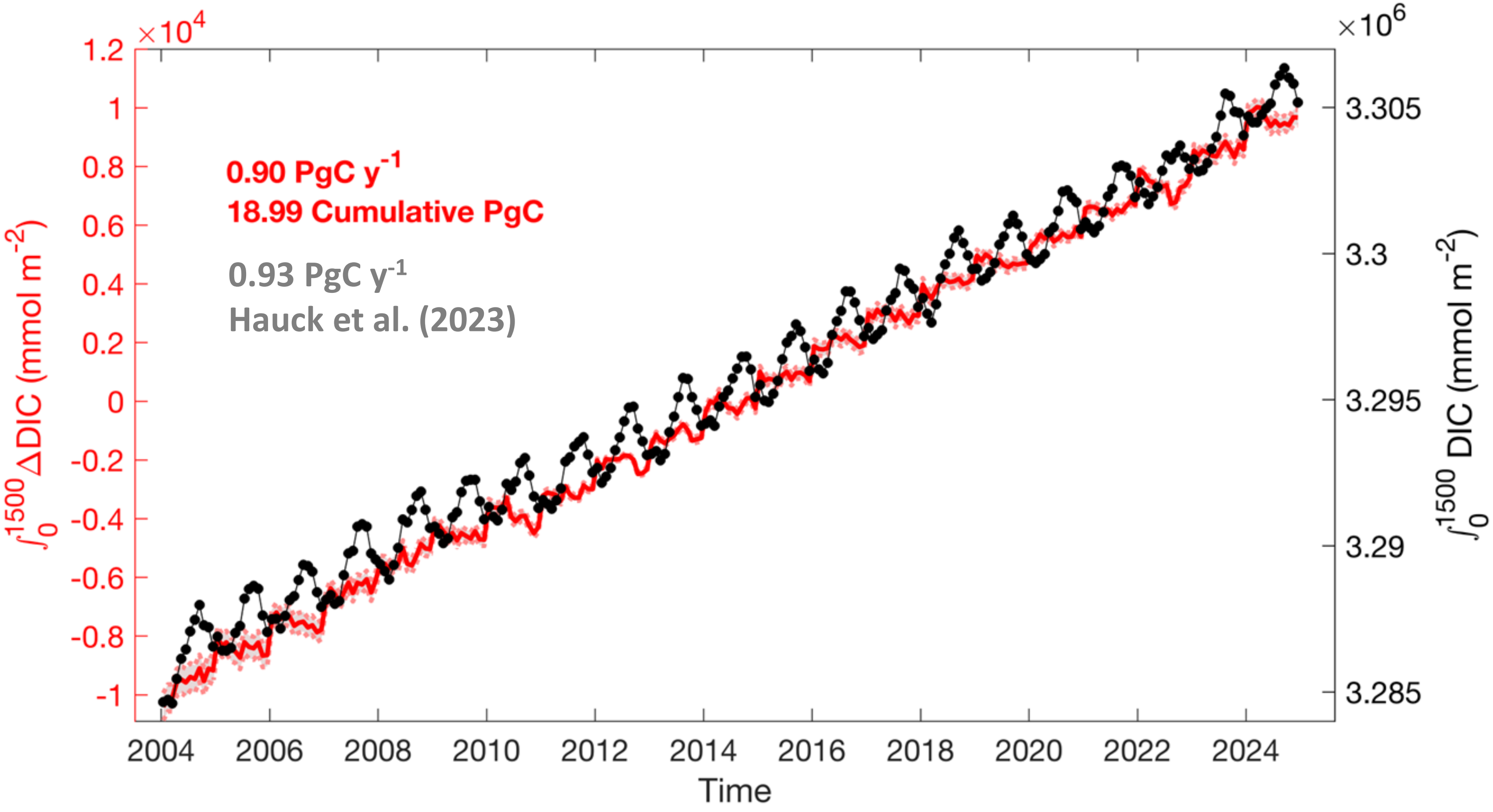
The synergism of multiple observing systems and sustained observations.

**WMO Global Greenhouse Gas Watch (G3W) has a goal of building a real-time $CO_2$ observing system.**

**It will need real-time ocean $CO_2$ uptake.**

G. Liniger, MBARI

SOCCOM | *Unlocking the mysteries of the Southern Ocean*



# Real-time data

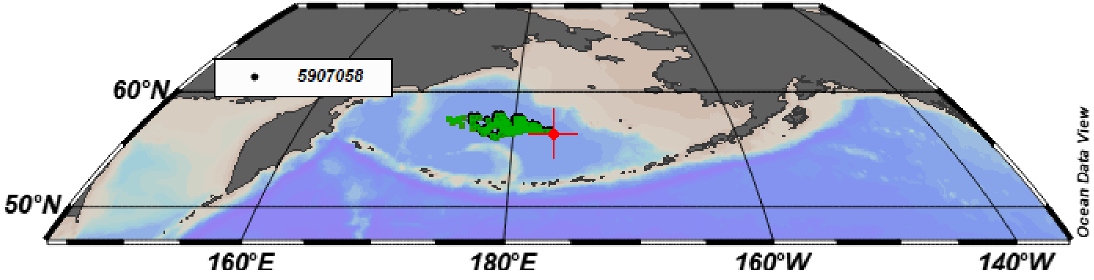
## Allows emerging signals to be detected (if you look)

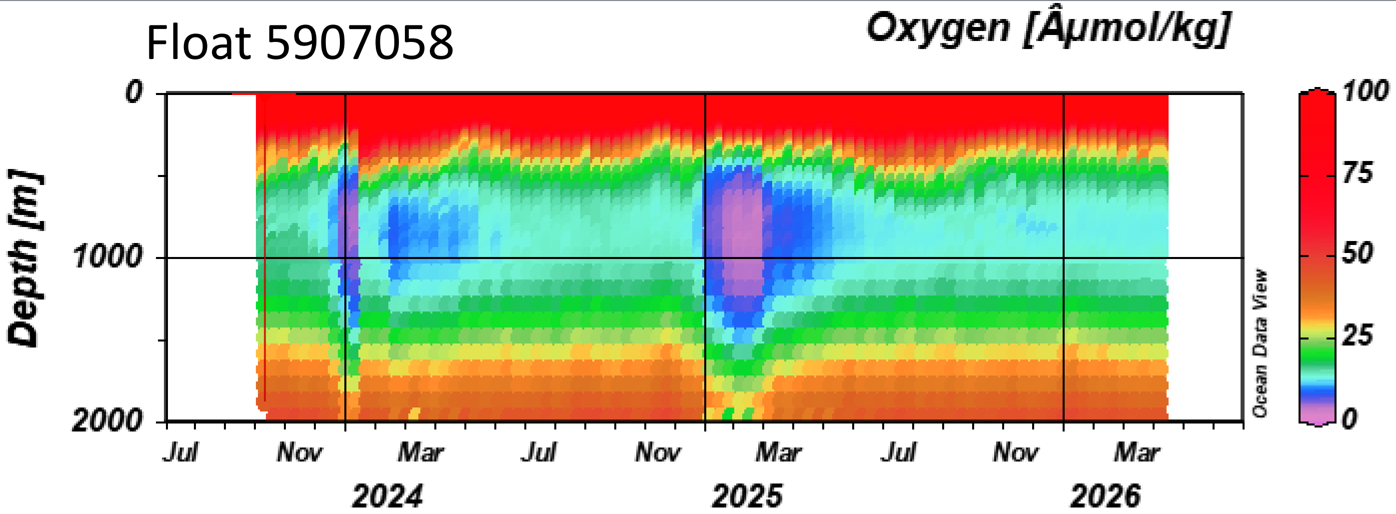
NOAA FISHERIES

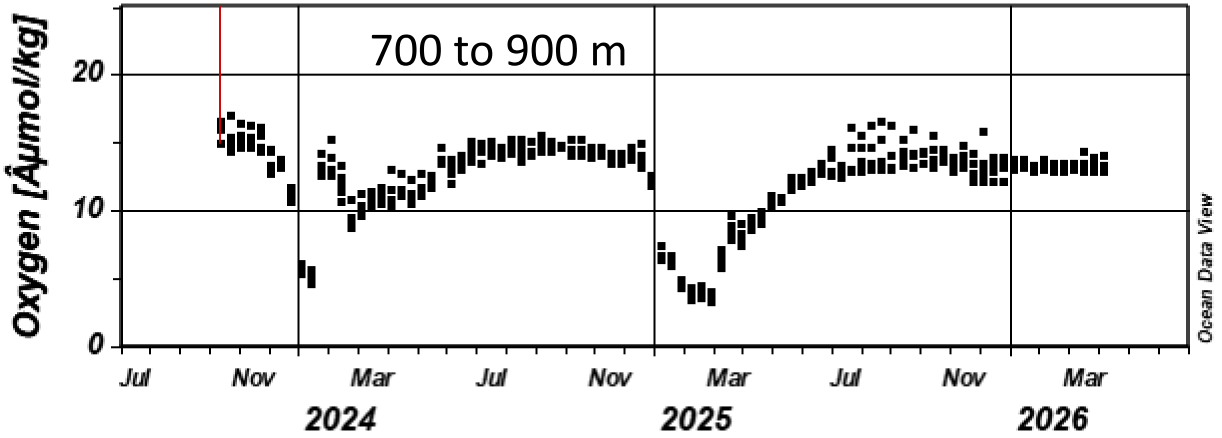
≡ Menu

NEWS

**Snow Crab Collapse Due to Ecological Shift in the Bering Sea**



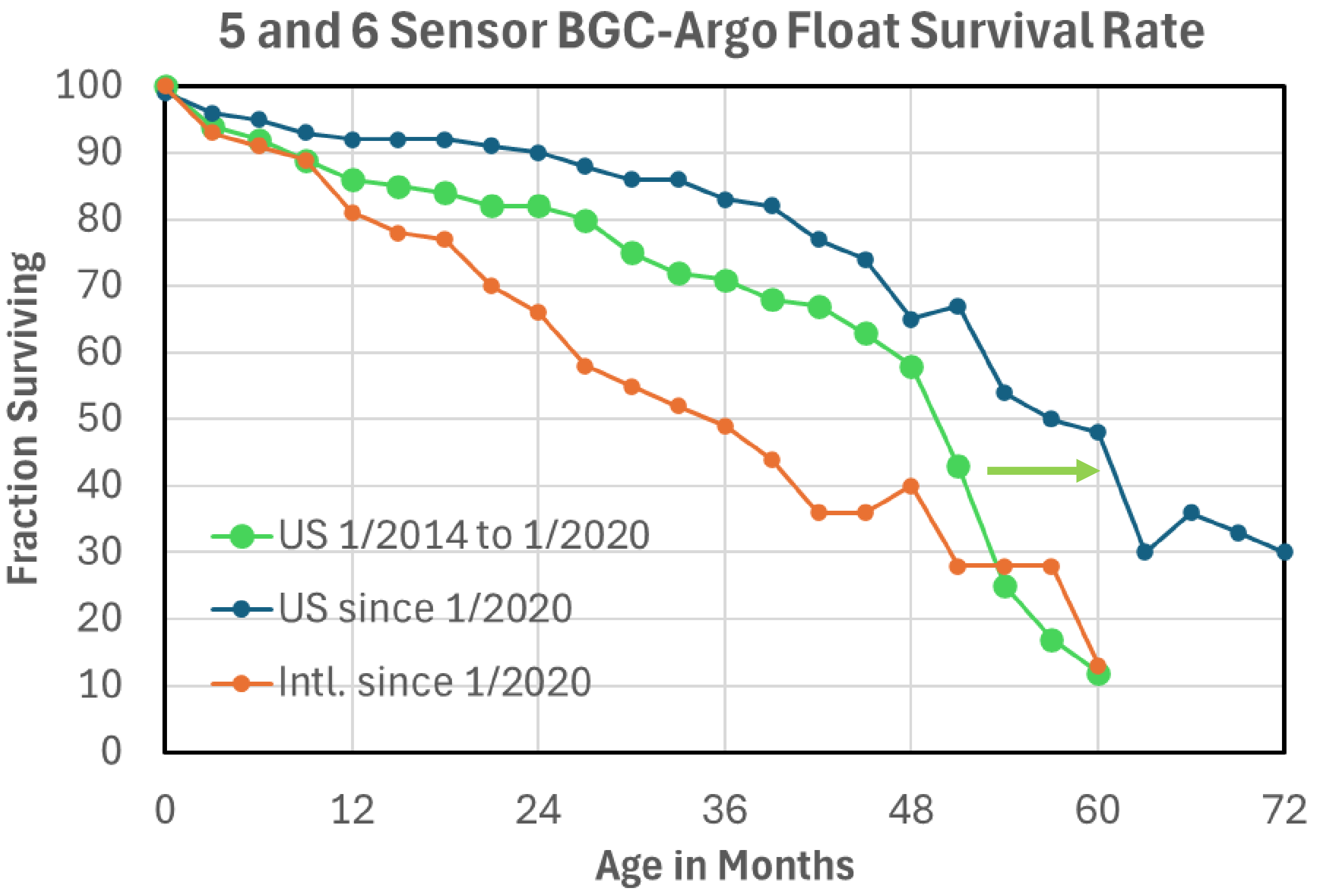
# Float lifetimes

## Floats with $O_2$, $NO_3^-$, pH, bio-optics sensors

50% of US floats survive 5 years:

- Increased from 4 years in SOCCOM-1.

- Shorter international float lifetimes is a reflection of the science funding goals.




Ocean-ops survival rate 3

# Float cycle times

## Floats with $O_2$, $NO_3^-$, pH, bio-optics sensors

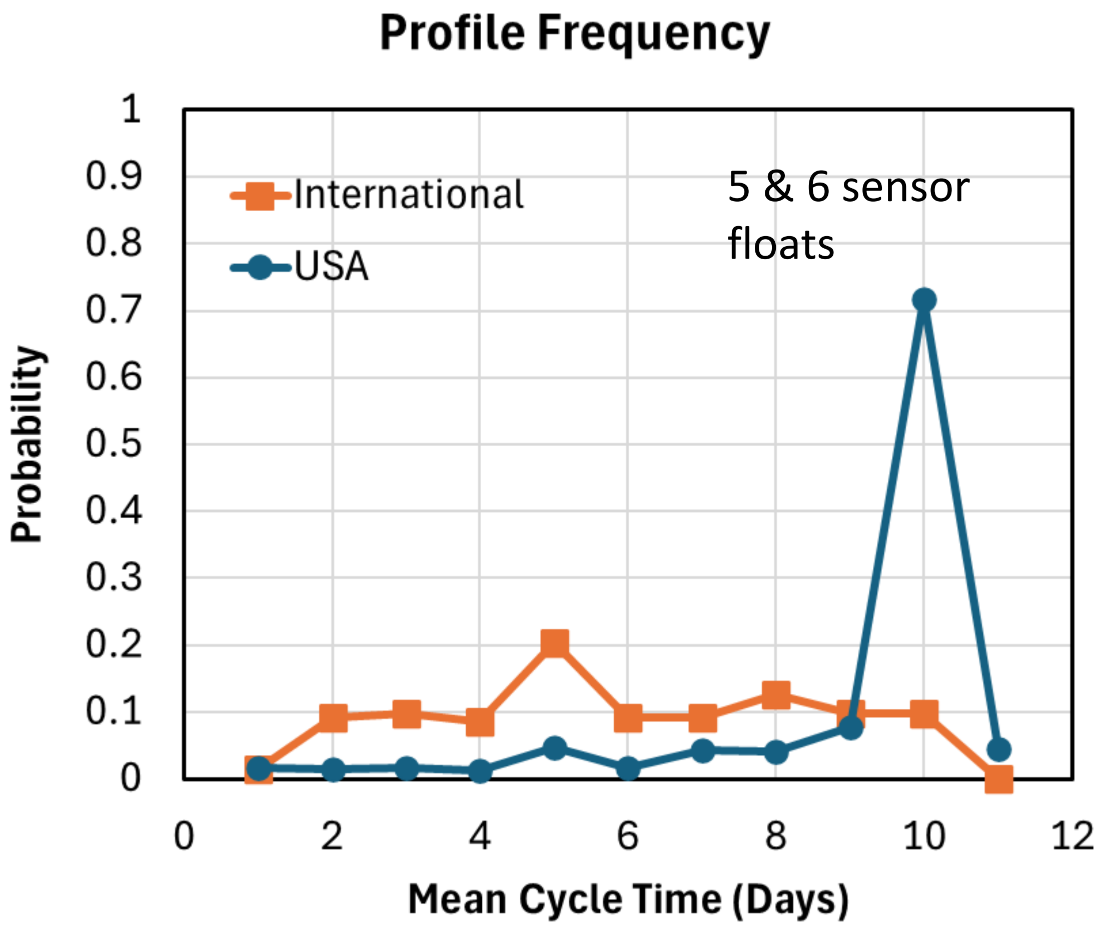
The standard Argo mission is designed to sustain the observing system:

- 10 day cycles
- 1000 m park depth
- 2000 m profile

SOCCOM and GO-BGC goals are operated as a sustained system, primarily 10 day cycles.

International groups are mostly funded for process oriented science projects that require faster cycle times.

That drives a 'non-Argo' mission which reduces float lifetime. It's expensive!




Data from Ocean-ops

# Challenges

## Is a 1000 float array a good target?

**Assimilating synthetic Biogeochemical-Argo and ocean colour observations into a global ocean model to inform observing system design**

**David Ford**

Biogeosciences, 18, 509–534, 2021

“assimilation of BGC-Argo profiles of Chl a, $NO_3$, $O_2$, and pH brought clear improvements to all assimilated variables …. The impact was increased with a larger BGC-Argo array, suggesting that benefits may be seen up to and beyond the target array size of 1000 floats.

# Challenges

## Is a 1000 float array a good target?

NN learns to predict DIC from T/S/$O_2$/position/time

Predict DIC with gridded T/S/$O_2$ using NN

Results change with increasing number of floats.

Is 244 floats enough?

Southern Ocean (S of 30°S) target in a 1000 float array is ~320.

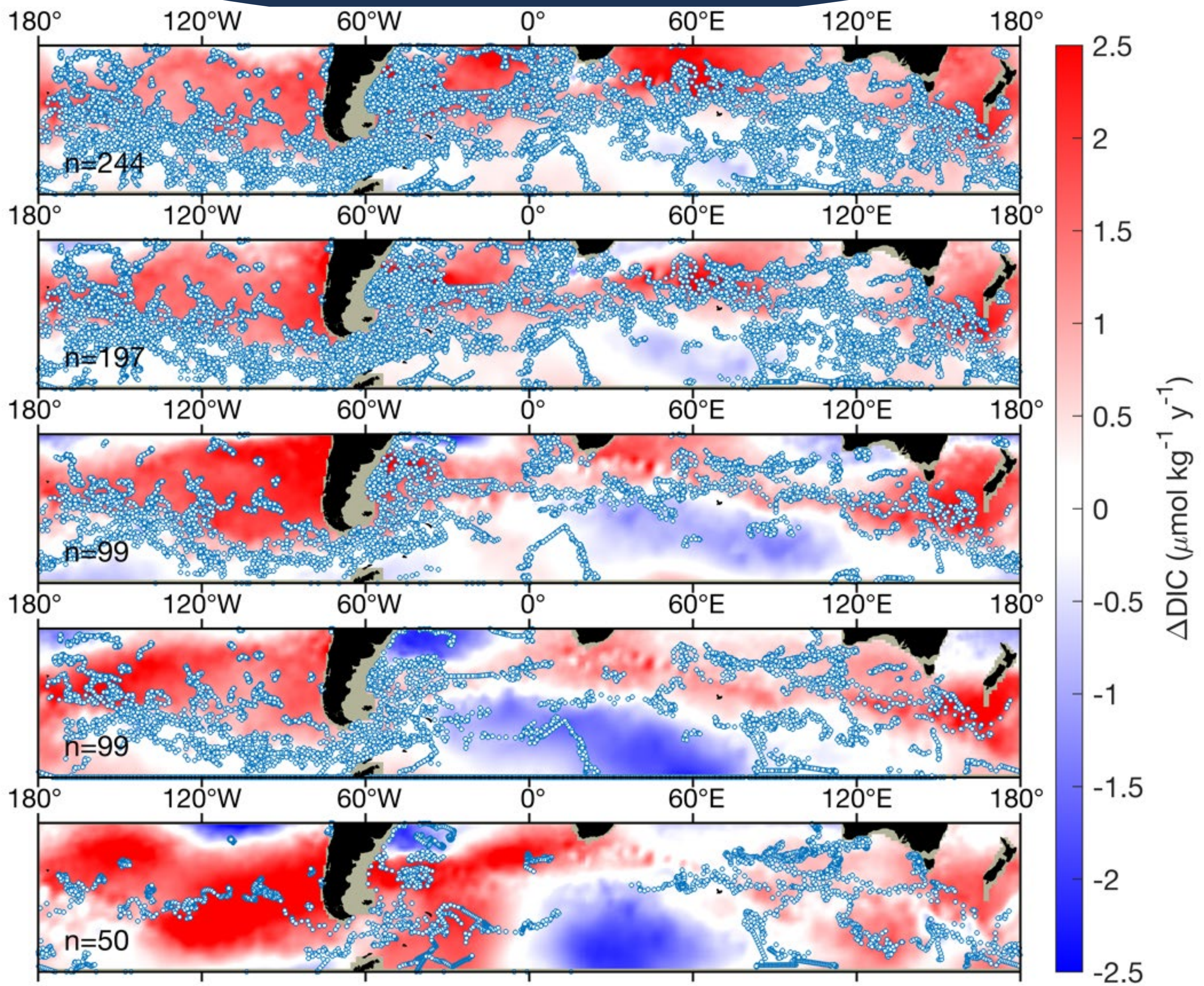
n=1,985,405
244 floats

n=1,670,667
197 floats

n=692,718
99 floats

n=719,356
99 floats

n=392,744
50 floats

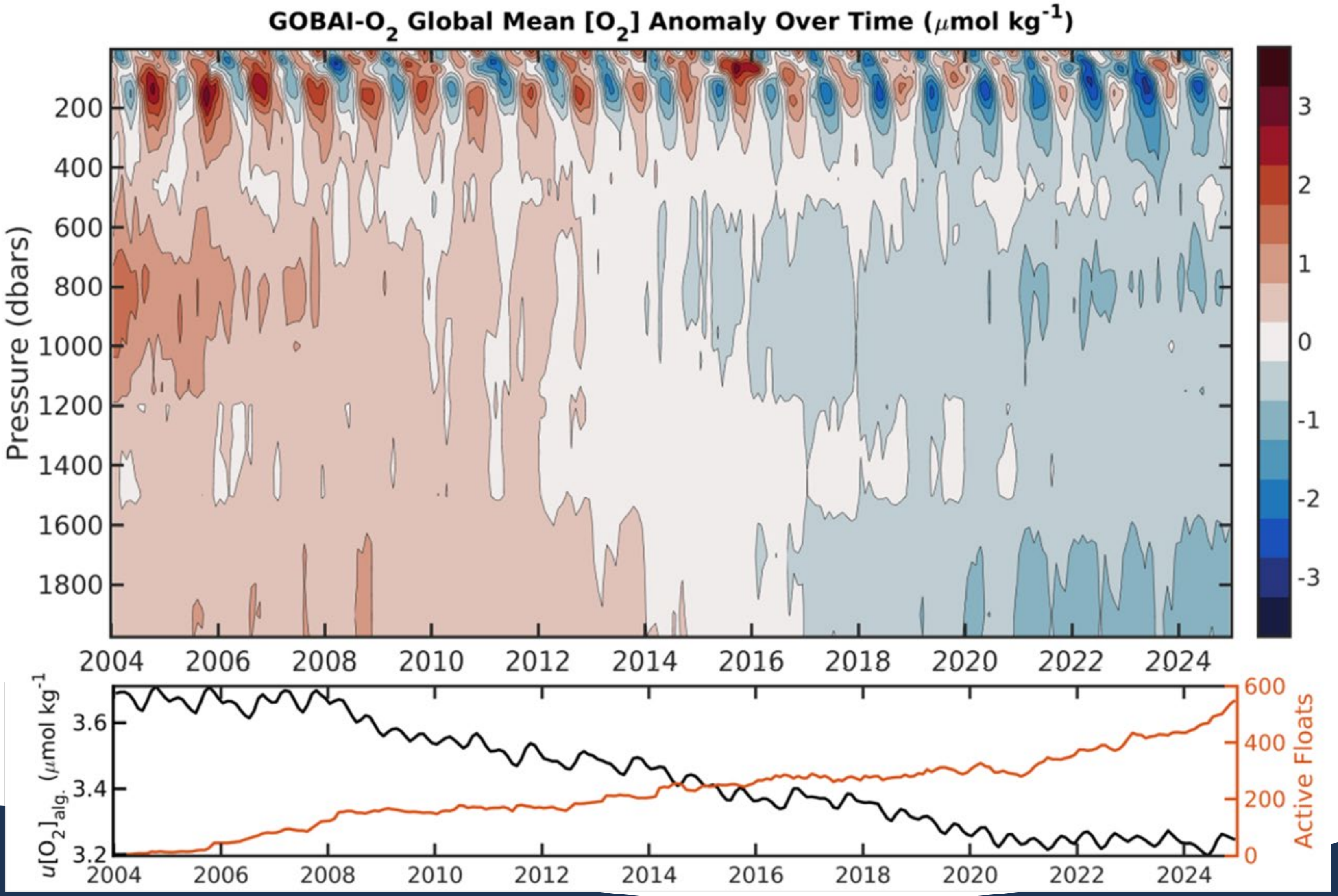


# Challenges

## Is a 1000 float array a good target?

Uncertainty in GOBAI-O2 assessed by sampling CMIP models with artificial floats and comparing Machine Learning $O_2$ with model 'truth'.

Error decreases as number of model floats approaches 1000 float target.




Jon Sharp et al.

# Challenges

## Cost

| Program | Float Lifetime Cost | Inflation Correction to 2026 | Float Mean Life (Yrs) & Profiles | Per Profile Cost (2026) | % Decrease Per Profile Cost |
|---|---|---|---|---|---|
| BGC-Argo Implementation Plan 2016 | $107,600 | $147,400 | 4/150 | $982 | |
| GO-BGC Renewal 2025 | $151,000 | $151,000 | 5/180 | $833* | 15% |

*A **15-fold savings** vs. a ship cost of ~$13,000/profile for ship time alone (~$40,000/ship day / 3 profiles/day). Analytical and data processing costs may double that and create a 30-fold savings.

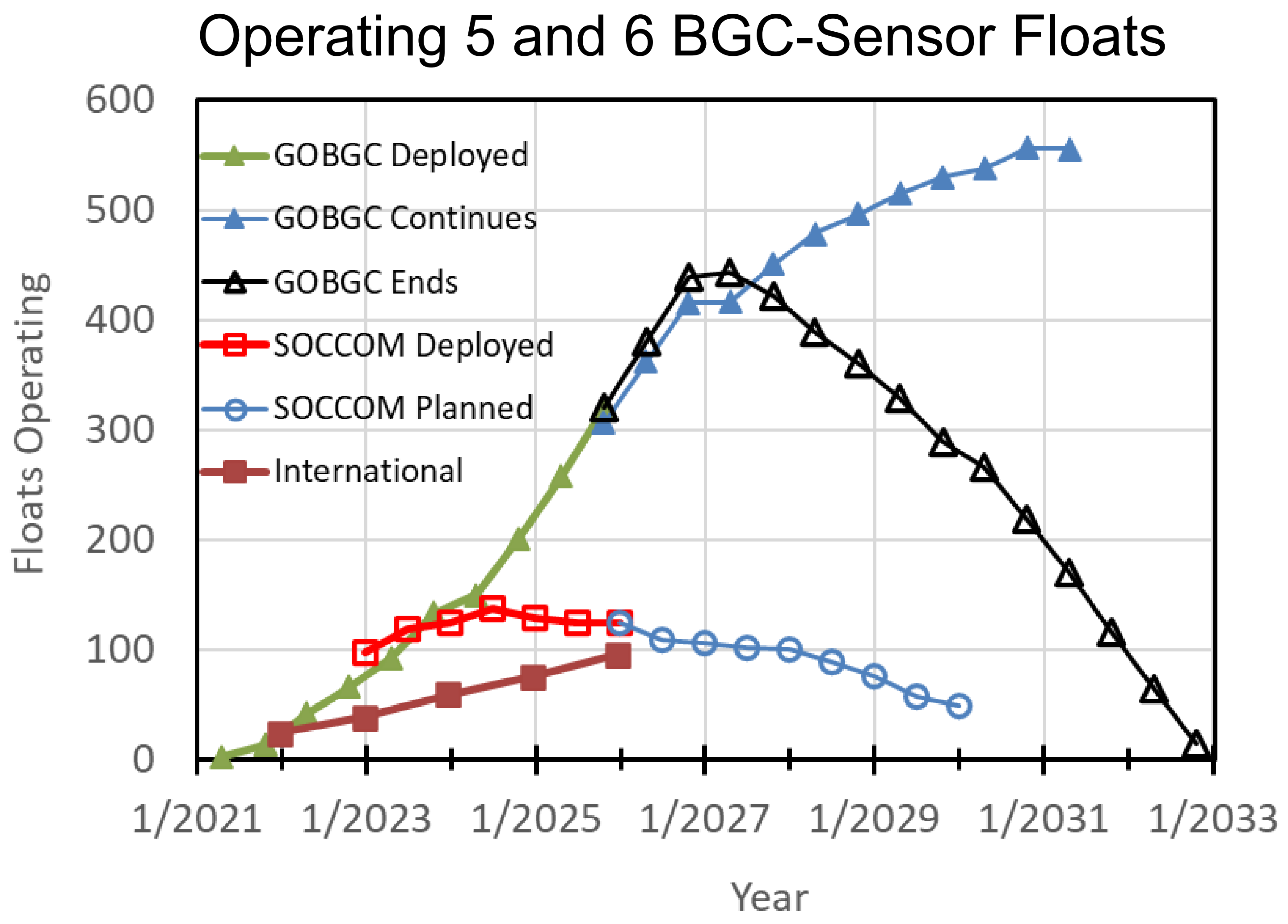
A lesson: we don’t usually think about the ship time costs in science proposals. They are a facility and that cost is generally covered. BGC-Argo needs to operate in the same model.

BGC-Argo faces 3 main challenges

1. Increase the international array of 5+ sensor floats
   - Fewer than 100 now operating.

2. Sustain the US array of 500, 5+ sensor floats.
   - GO-BGC funding ends Oct. 31, 2026.

3. Develop a stronger operational user base.
   - Real-time products must be available to create 'customer demand'.



# Why This Array Design?



**Global distribution**

- *Even global coverage minimizes sampling bias*
- *Ensures observations across all regimes (including cloudy and remote regions)*

**Multi-sensor floats**

- *Capture coupled physical and biogeochemical processes*
- *Enable better mechanistic understanding, not just correlations*

**Standardization**

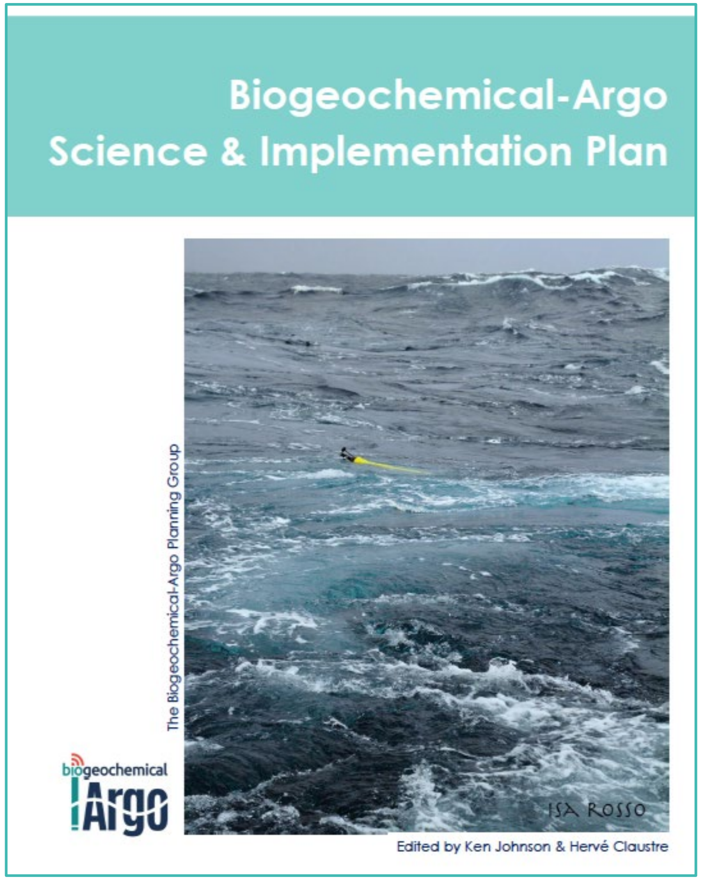
- *Ensures data comparability and long-term consistency*
- *Critical for climate applications and trend detection*

**Autonomous profiling**

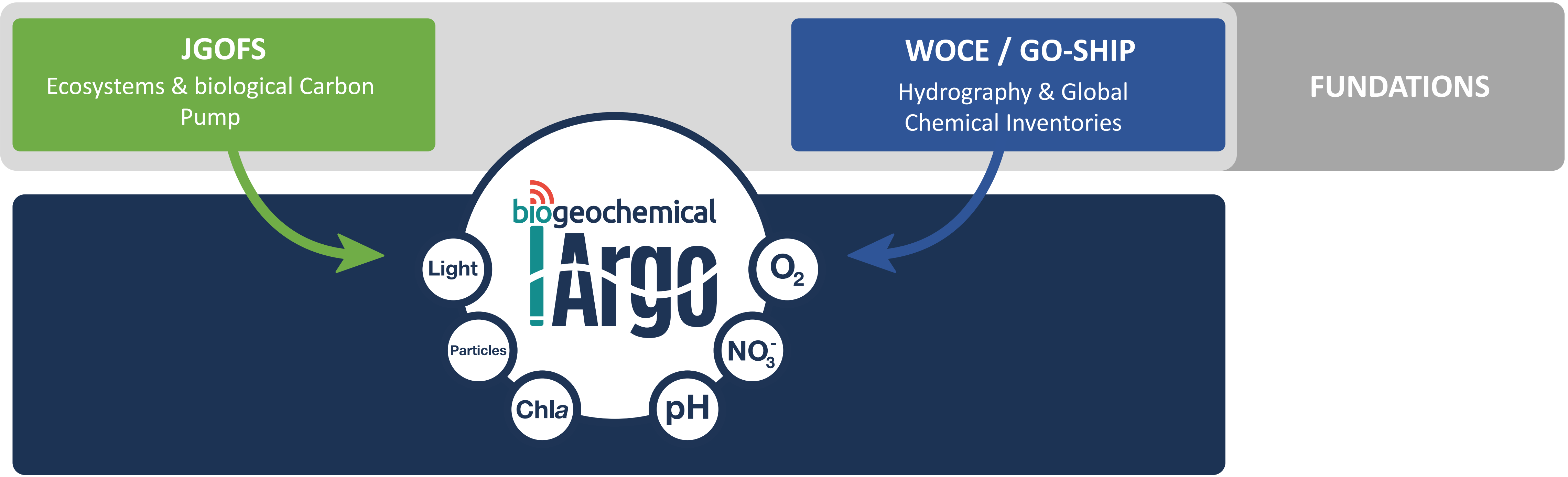
- *Provides vertical and temporal resolution (4D ocean view)*
- *Resolves subsurface and transient processes*

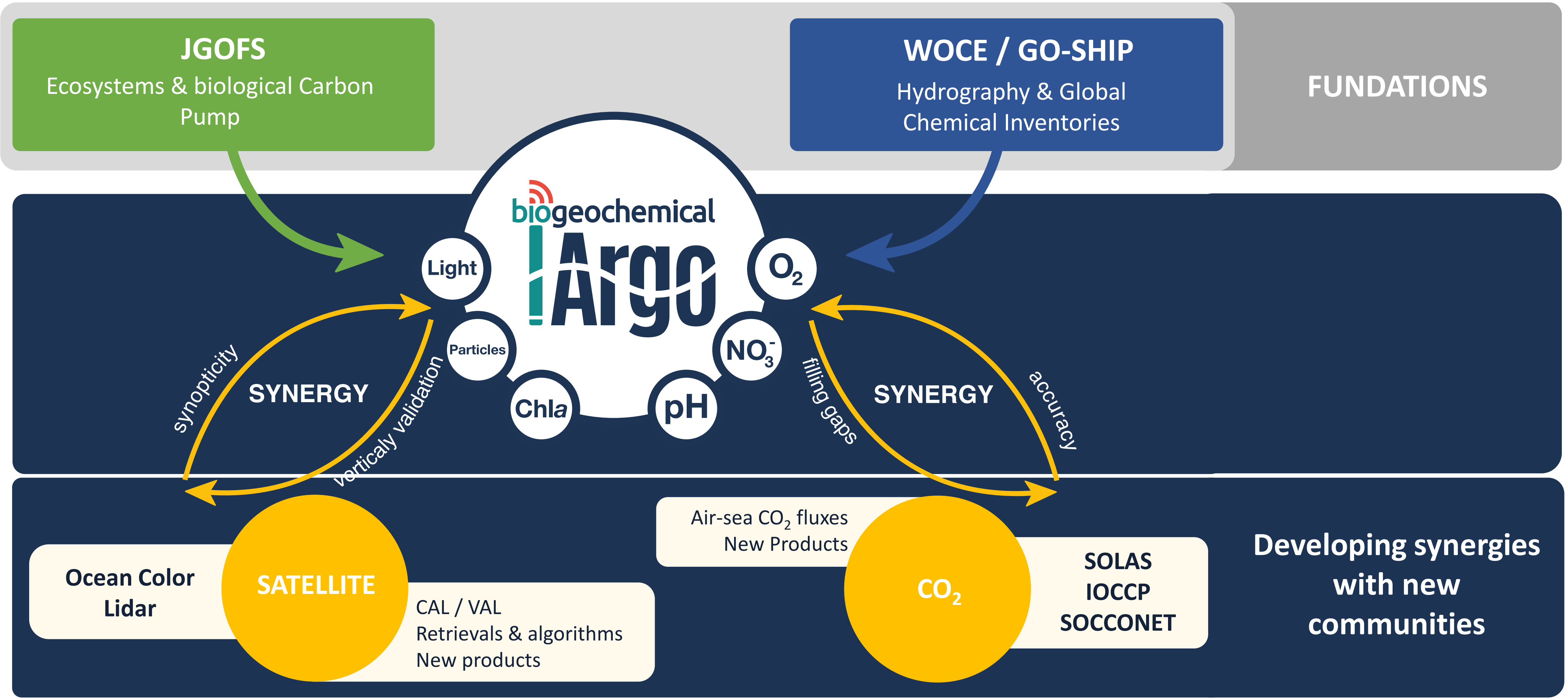
**1000-float target**

- *Required to resolve seasonal to basin-scale variability*
- *Balances coverage, resolution, and sustainability*




***BGC-Argo is not just a set of observations : it is a system designed to resolve key ocean processes and to allow discoveries***


JGOFS
Ecosystems & biological Carbon Pump
WOCE / GO-SHIP
Hydrography & Global Chemical Inventories
FUNDATIONS
biogeochemical Argo
Light
Particles
Chla
pH
NO3-
O2



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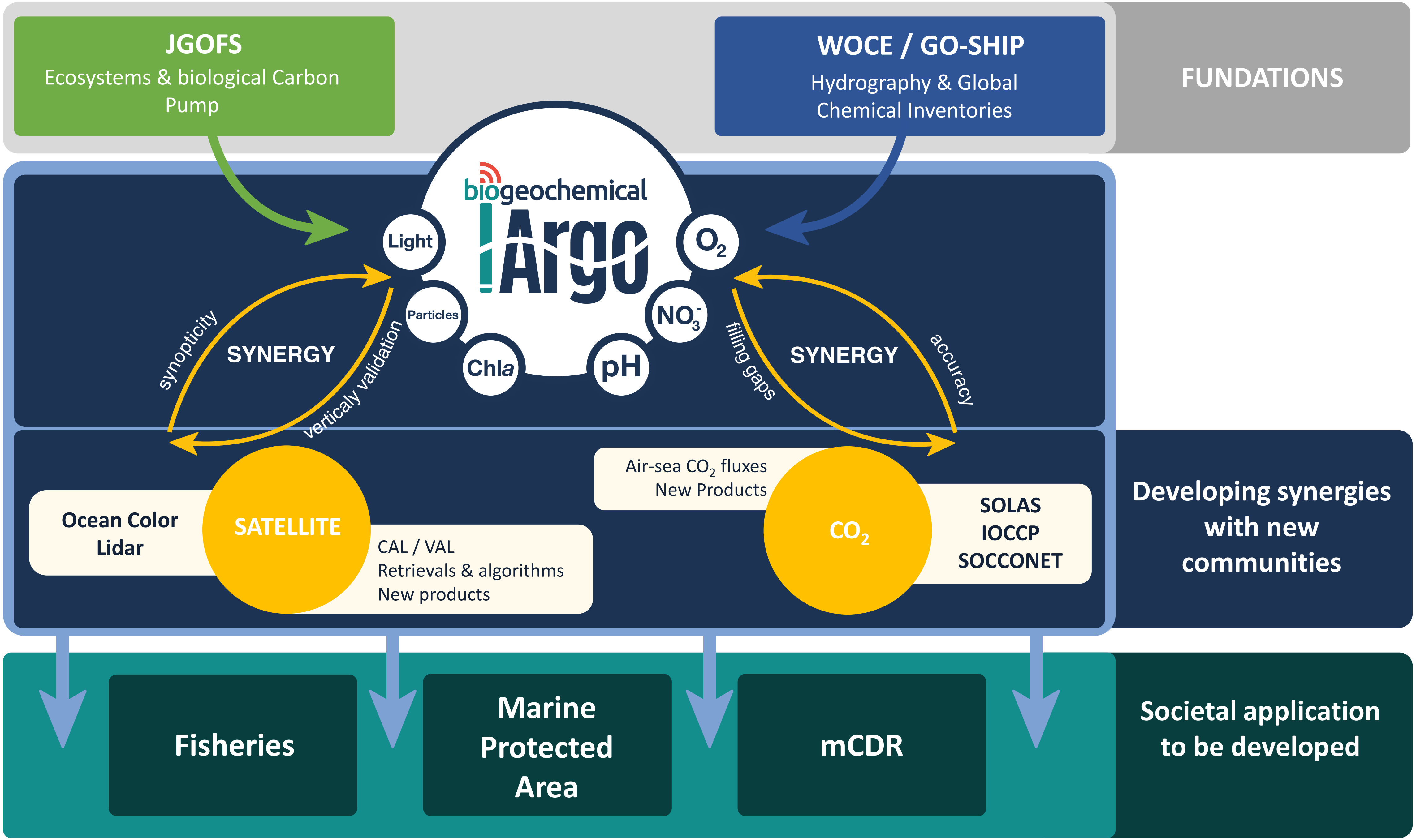
Developing synergies with new communities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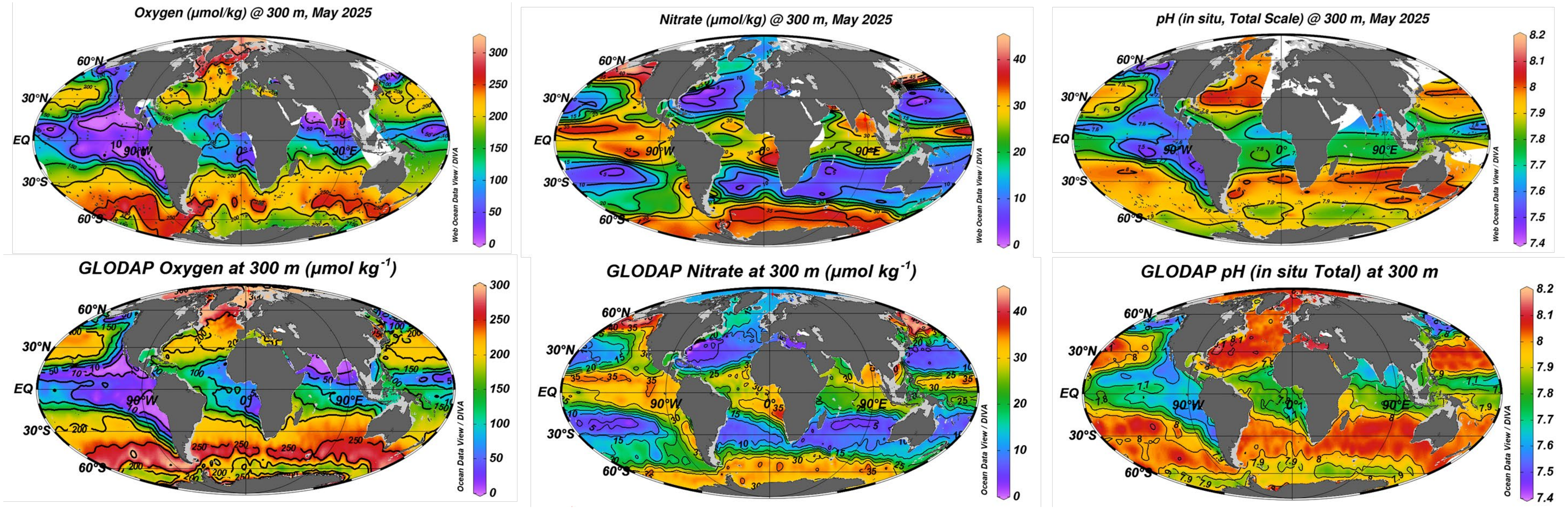
Developing synergies with new communities
Fisheries
Marine Protected Area
mCDR
Societal application to be developed

Property distributions at 300 m:
BGC-Argo in May, 2025
GLODAPv2:2023, 1973-2024




webODV EGI-ACE > Ocean > Biogeochemistry > Argo > BGC-Argo_Global_Profiles

# BGC-sensor reliability, US floats

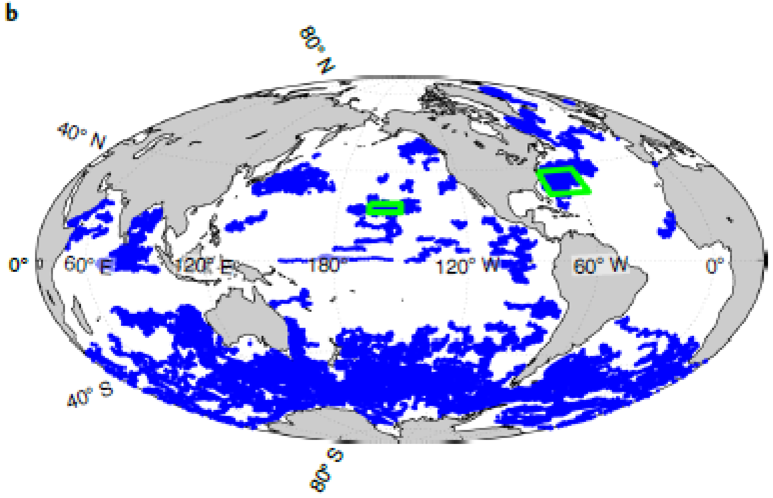
## Since Oct, 2020:

| PROGRAM | CTD | O2<br>Aand | O2<br>SBS | NO3<br>ISUS | NO3<br>SUNA | pH<br>MBARI DSD | pH<br>MBARI GDF | pH<br>SBS DSD | Bio-opt | OCR |
|---|---|---|---|---|---|---|---|---|---|---|
| GO-BGC | 5/385 | 2/135 | 2/250 | 7/155 | 10/230 | 14/61 | 1/40 | 58/284 | 15/385 | 0/75 |
| SOCCOM | 1/138 | 2/122 | 1/16 | 10/125 | 6/13 | 8/51 | 3/27 | 18/60 | 7/135 | 0/18 |
| OTHER | 1/37 | 1/11 | 1/24 | 2/5 | 4/22 | 1/2 | 0/1 | 8/24 | 2/27 | 0/9 |
| TOTAL | 7/560 | 5/268 | 4/290 | 19/285 | 20/265 | 23/114 | 4/68 | 84/368 | 24/547 | 0/102 |
| % FAILED | 1.2 | 1.9 | 1.4 | 6.7 | 7.5 | 20.2 | 5.9 | 22.8 | 4.4 | 0.0 |
| **Survival per year** | **99.6%** | **99.4%** | **99.5%** | **97.7%** | **97.4%** | **92.8%** | **98.0%** | **91.7%** | **98.5%** | **100%** |
| Last year | | | | | | **100%** | **100%** | **98.1%** | | |

GO-BGC Global Ocean Biogeochemistry Array

With enough floats, GOP can be determined regionally & annually.

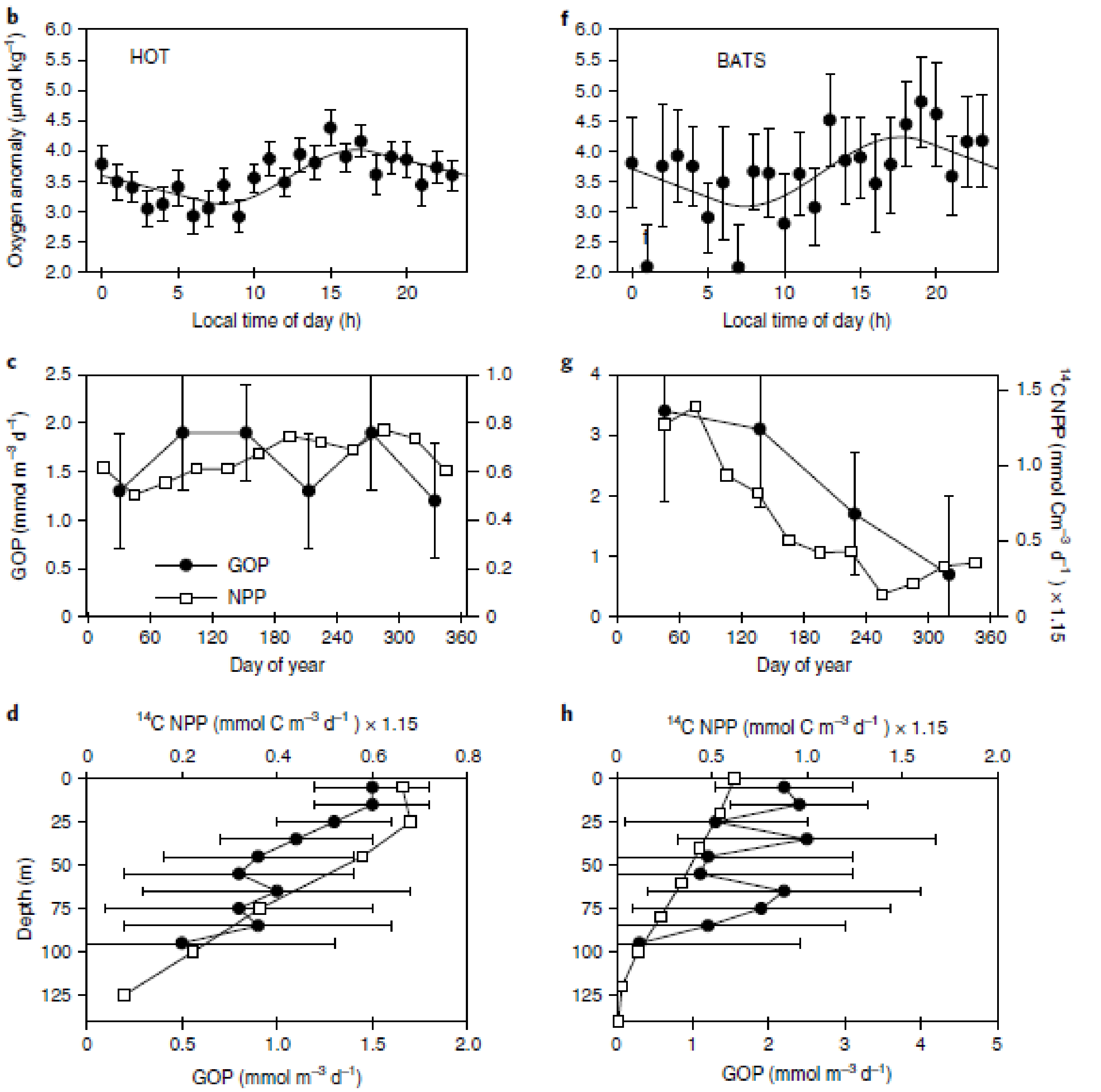
Enough is about 1000 floats (Izett et al., 2024)




GO-BGC Global Ocean Biogeochemistry Array

Hawaii Ocean Time-series

Bermuda Atlantic Time-Series




Johnson and Bif (Nat. Geosci. 2021)

# Cost
# Why are BGC sensors expensive?

It's not the cost of the sensor, it's the cost of running a business!

Imagine a business selling 700 sensors/ year with $1,000 in parts for each sensor.

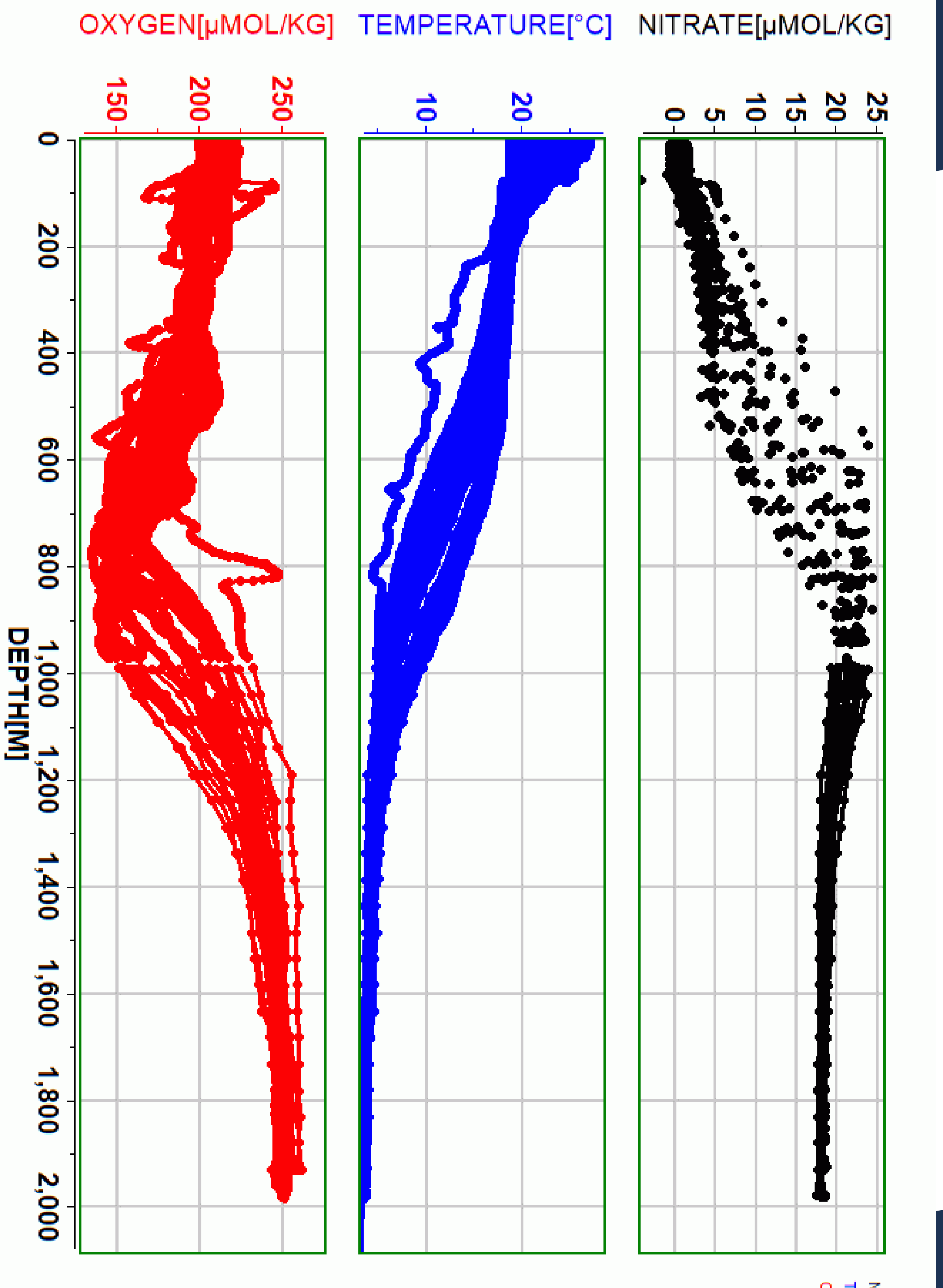
| Staff Cost | | Business Cost | |
|---|---|---|---|
| $200,000 | President | $1,020,000 | Salary total |
| $200,000 | Engineer | $510,000 | Benefits |
| $300,000 | 3 assemblers and support | $765,000 | Overhead (rent, utilities, insurance, taxes, travel, ….) |
| $100,000 | Calibration/metrologist | $200,000 | Research |
| $70,000 | Admin | $700,000 | materials (700 units/yr at $1000/unit) |
| $150,000 | Sales | $165,000 | 5% warranty & return hedge |
| | | | |
| $1,020,000 | total | $3,360,000 | total |
| | | $168,000 | 5% profit |
| | | **$5,040** | **per unit cost of 700 sensors (about the cost of $O_2$)** |

# Profile depth
# Why go to 2000 m?

As for Argo salinity, BGC sensors may require correction for sensor drift and calibration offsets.

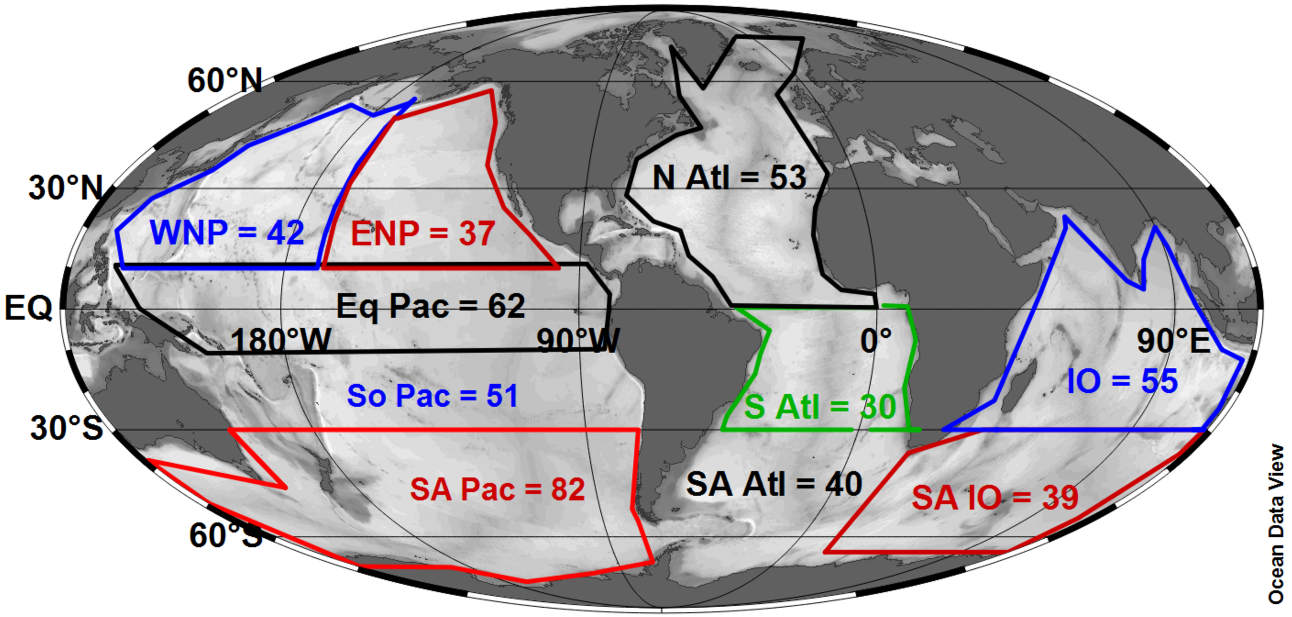
This is done by comparing sensor data to the climatology of ship-based measurements.

Deeper comparisons (below 1000 m) have much less variability and produce more robust comparisons and better quality control of data.



4/7/2026

# Number of floats needed for half of an evenly distributed, 1000 float array




August 3, 2025

Combined GO-BGC, SOCCOM, Other

| Region | Want | Actual | Diff. | % | N/yr# |
|---|---|---|---|---|---|
| No Pacific | 79 | 110 | 31 | **139** | **16** |
| No Atl. | 53 | 53 | 0 | **100** | **11** |
| Eq. Pacific | 62 | 57 | -5 | **92** | **12** |
| So. Pacific | 51 | 26 | -25 | **51** | **10** |
| So. Atl. | 30 | 34 | 4 | **113** | **6** |
| Indian Oc. | 55 | 56 | 1 | **102** | **11** |
| So. Ocean | 161 | 239* | 78 | **148** | **32** |
| Arctic | 7 | 0 | -7 | **0** | **1** |
| Total | 498 | 575** | 77 | **115** | **100** |

*Includes 143 SOCCOM floats

**143 SOCCOM & 49 "others" (NOAA, TPOS, NASA…)

# Replacement rate/yr assuming 5 year mean life

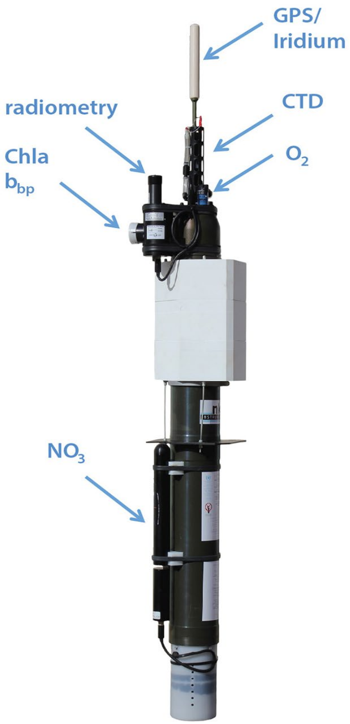
Actual numbers based on deployment location, not most recent position

# Primary BGC-Argo float types

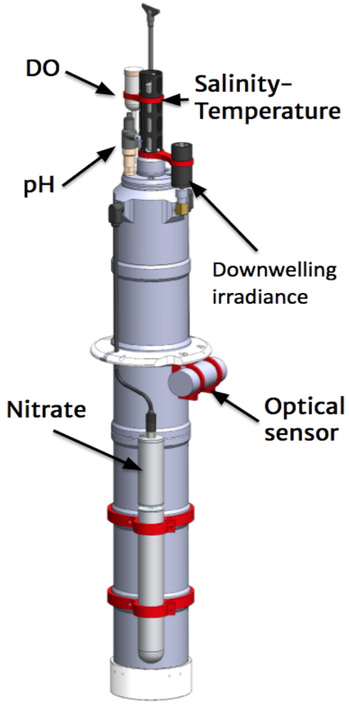
Apex


Navis


Provor




BGC-SOLO




- **Oxygen, nitrate, pH, fluorescence, backscatter, (downwelling irradiance) + T/S/p**
- Enough batteries for ~250 cycles from ~2000 m to surface
- ~6 year life at 1 cycle/10 days