Provor BGC floats and sensors

Hervé Claustre & LOV TEAM & NKE

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Biogeochemical-Argo topics

Research topics

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

Management topics

- Living marine resources
- Carbon budget verification

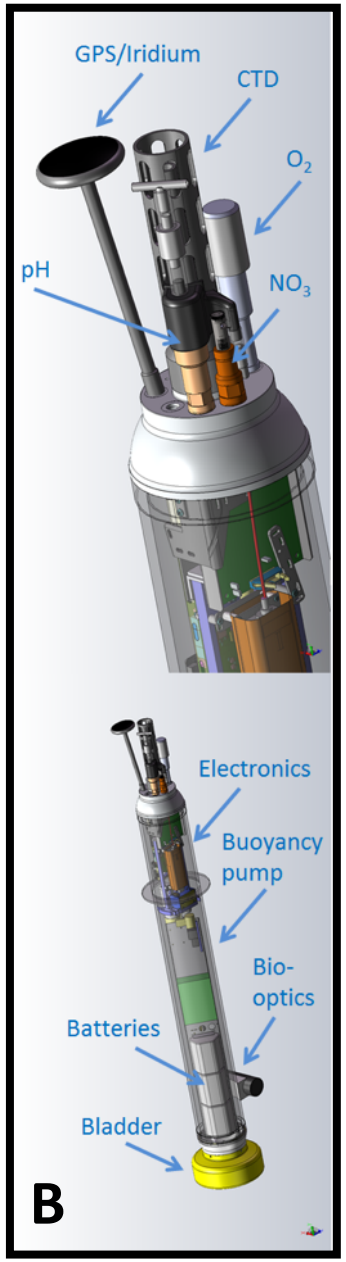
http://biogeochemical-argo.org

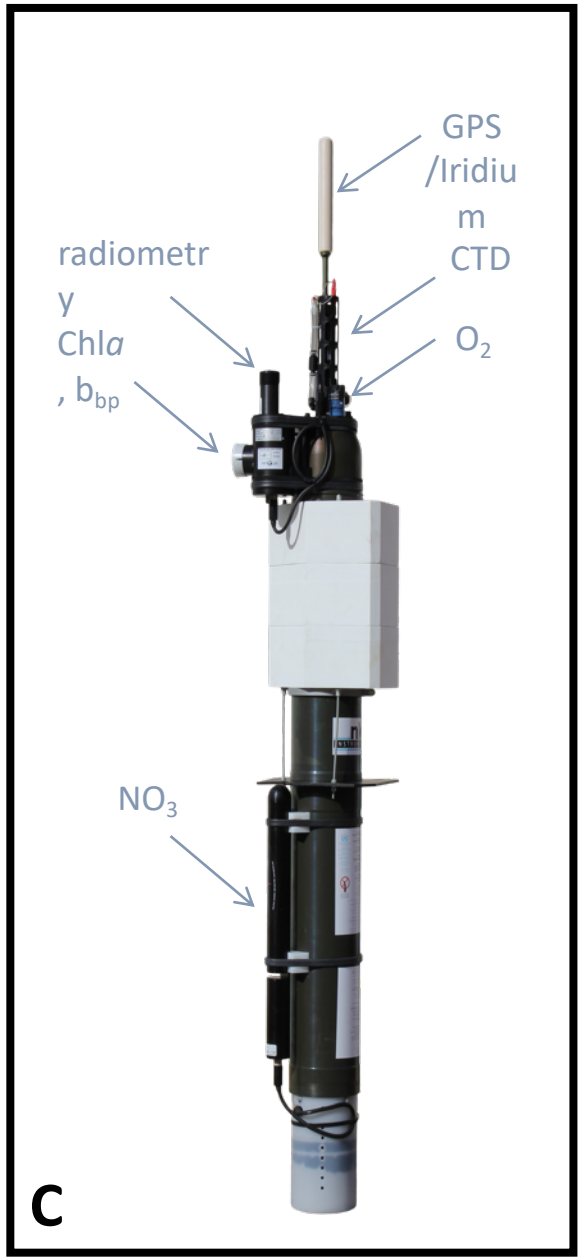
Biogeochemical-Argo core variables

- O_2
- NO_3
- pH
- Chl*a*
- Suspended particles
- Downwelling irradiance

http://biogeochemical-argo.org

Three main BGC-Argo platforms





Roemmich et al., 2019

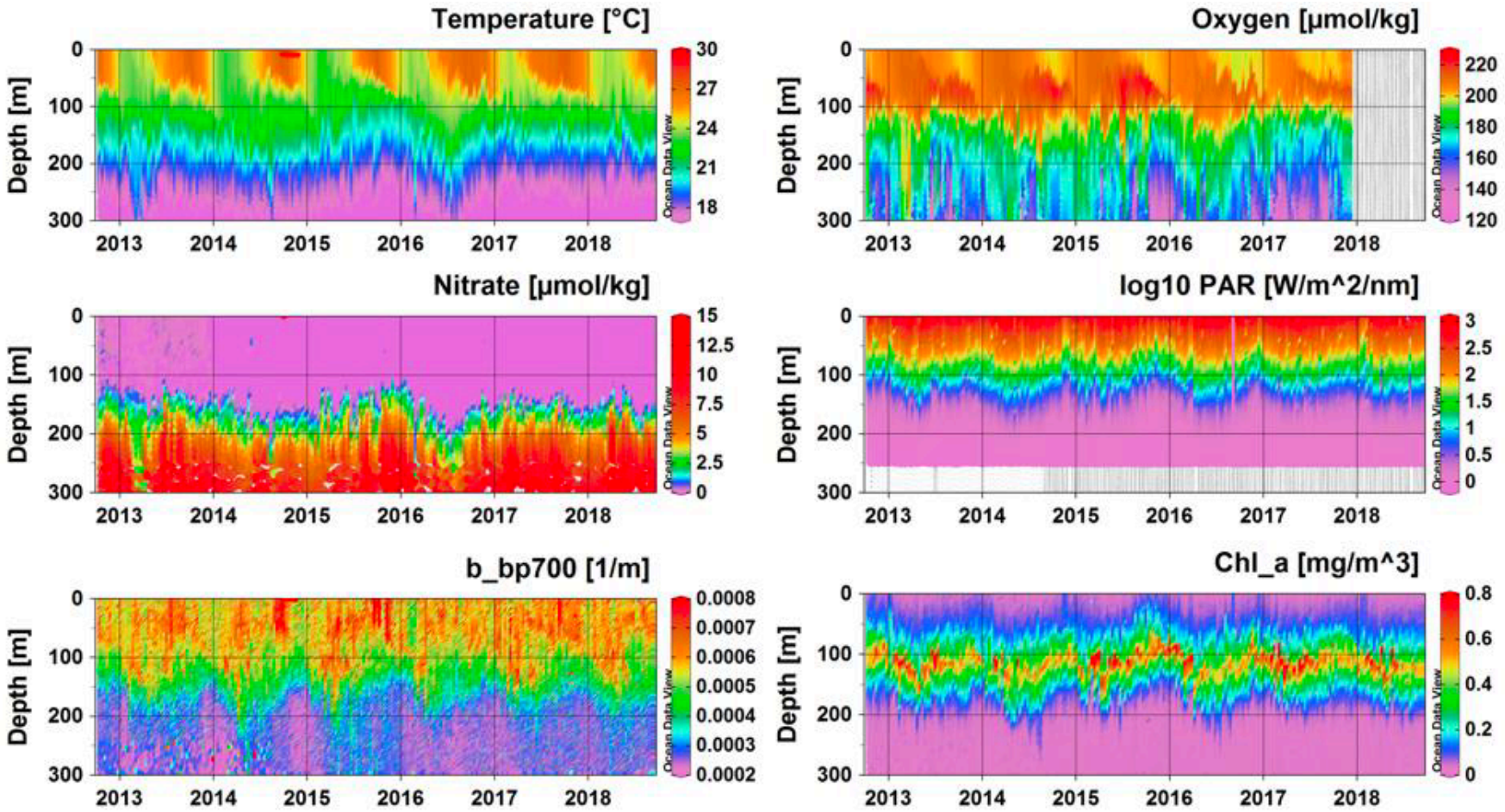
The BGC-Argo float we « upgraded » with NKE

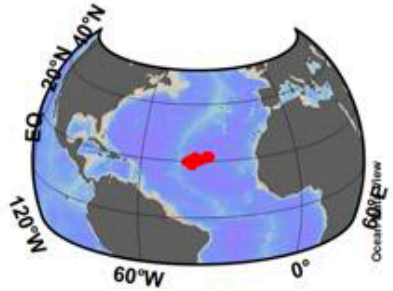
- **Measurements**
  - PAR, Ed(380), Ed(412), Ed(490)
  - $b_{bp}(700)$
  - Chla fluorescence
  - O2
  - NO3
  - pH
  - c_p (660)
  - CDOM fluorescence

- **Missions**
  - Temporal resolution configurable: from diel cycle to Argo 10 day cycling mode: adaptative sampling strategy
  - Vertical configuration configurable: up to 0.1m resolution

European Research Council

~six-year time-serie





OUTLINE

- **Past** : some results with respect to the “specificities” of PROVOR …
  ….and the way of using it (Biological Carbon Pump and Phytoplankton communities)
  - Transmissiometry
  - Measurements during drift
  - Radiometry
  - High vertical resolution
  - High temporal resolution

- **Future** : balancing Argo monitoring rules with the need for developing BGC-Argo process studies at specific scales and implement new sensors (Living marine ressources)

Tranmissiometry: why c_p measurements are interesting ?

- Tranmissiometry allows to measure c_p, the particle attenuation coefficient.
- As first order (and as for b_{bp}), c_p is a proxy for suspended particles and POC (extensive literature)
- But c_p, when combined to b_{bp}, can allow deriving the so-called backscattering ratio which gives access to the nature of particles (refractive index, e.g. high for calcite)
- Specific applications on float includes:
  - Proxy for carbon flux
  - Combined with other measurements: retrieval of phytoplankton communities

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE
10.1002/2017JC013067

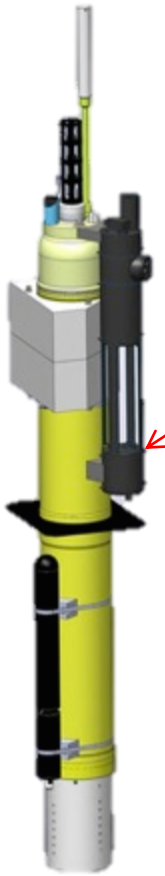
Plankton Assemblage Estimated with BGC-Argo Floats in the Southern Ocean: Implications for Seasonal Successions and Particle Export

Key Points:
- Calibration of physical and optical data from the SOCLIM cruise in terms of plankton assemblage in the Southern Ocean (SO)

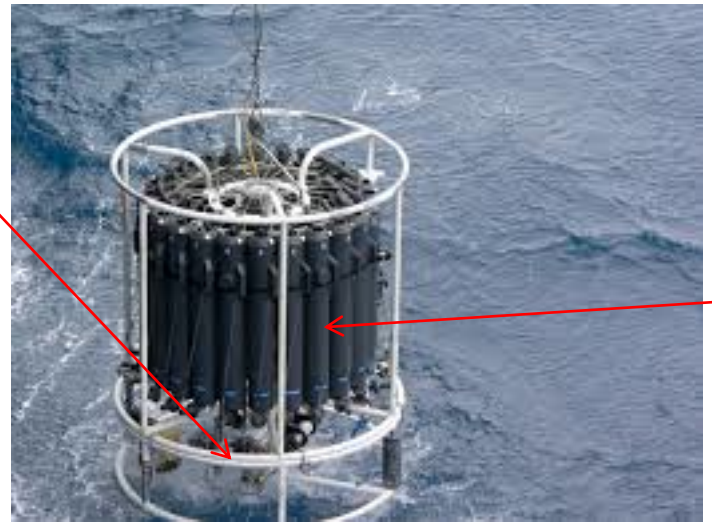
Mathieu Rembauville[1], Nathan Briggs[1], Mathieu Ardyna[1], Julia Uitz[1], Philippe Catala[2], Cristophe Penkerc'h[1], Antoine Poteau[1], Hervé Claustre[1], and Stéphane Blain[2]

- Same optical sensors on float and on CTD rosette
- Discrete water sample for cytometry, microscopy (+ sizing), POC

=> Data base of optical proxies and plankton fraction contribution to POC



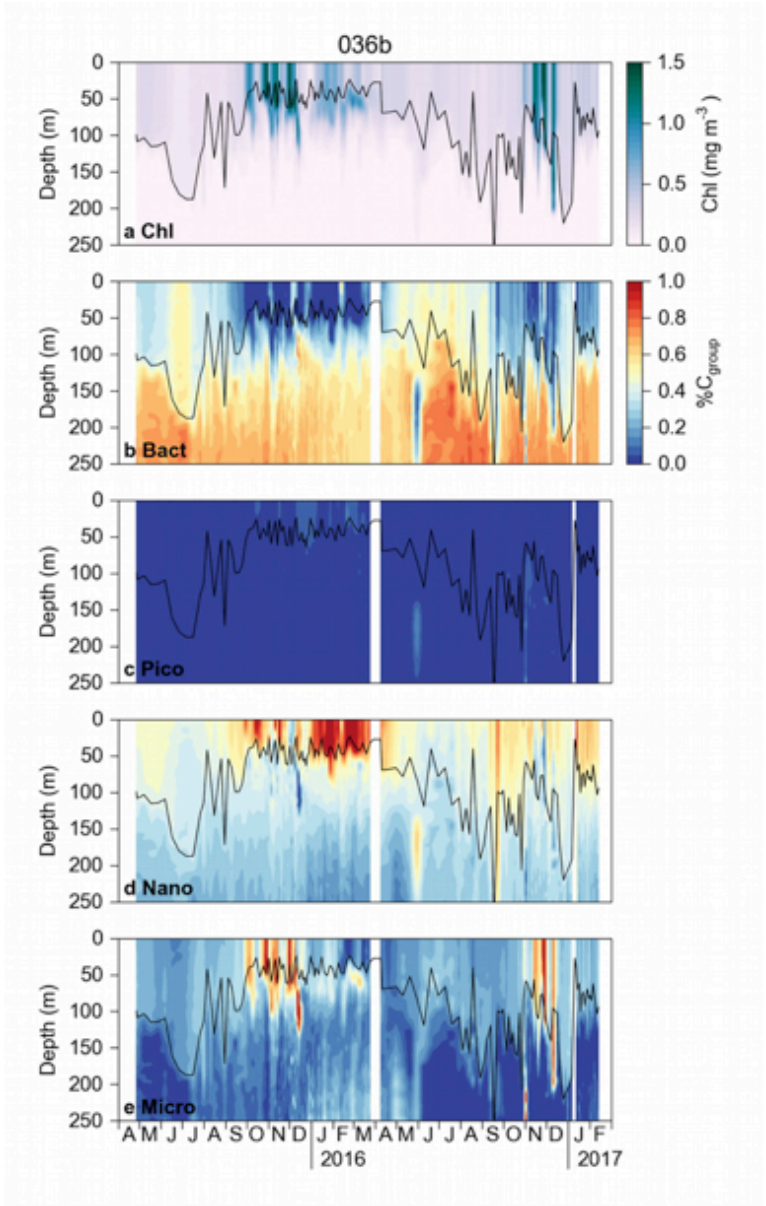
Chl
b_{bp}
c_p

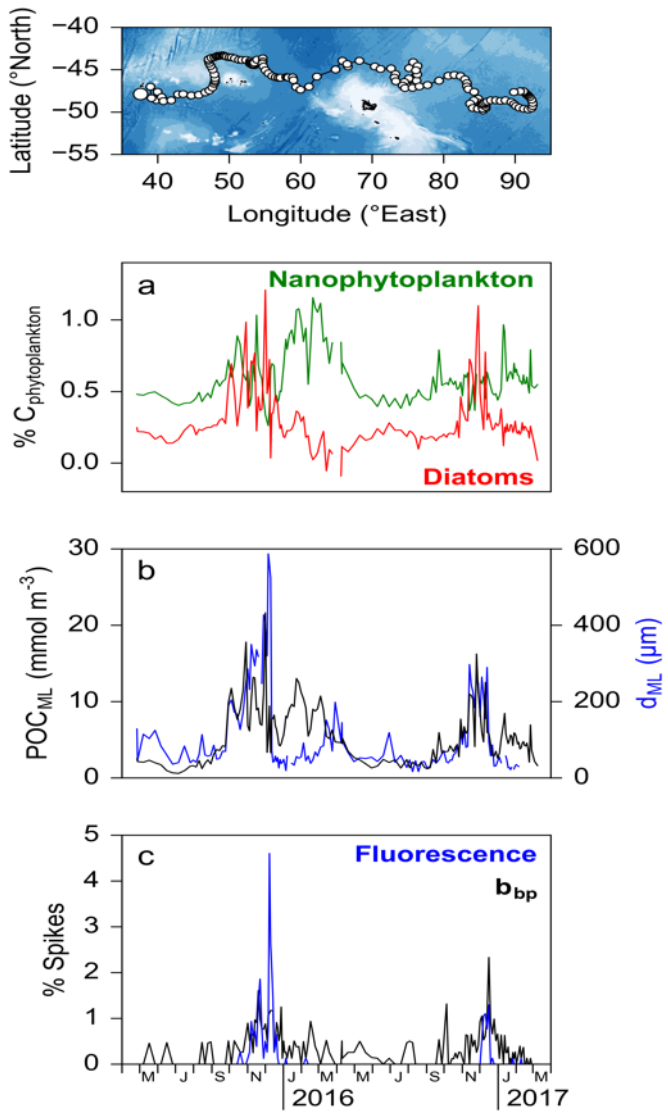


- POC
- Plankton counting, identification and sizing (microscopy and flow cytometry)

NIPALS (nonlinear iterative partial leastsquares)

Tranmissiometry: Phytoplankton community composition



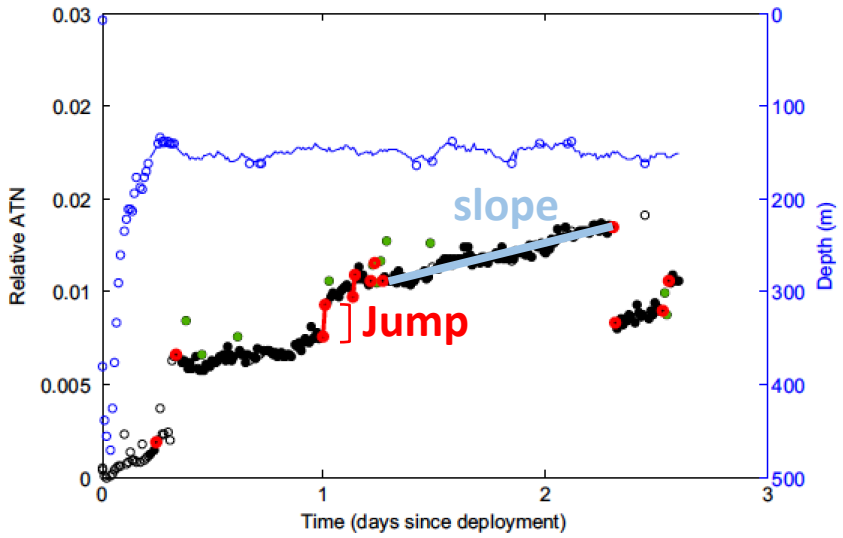


Tranmissiometry and sinking particles (gravitational pump): The optical sediment trap techniques

Carbon flux from bio-optical profiling floats: Calibrating transmissometers for use as optical sediment traps

Meg Estapa[a,*], Colleen Durkin[b,1], Ken Buesseler[b], Rod Johnson[c], Melanie Feen[a]

Deep-Sea Research Part I 120 (2017) 100–111



Slope (steady flux) and cumulative jumps (episodic flux) over a given period have units of m^{-1} d^{-1} which can be converted into carbon fluxes

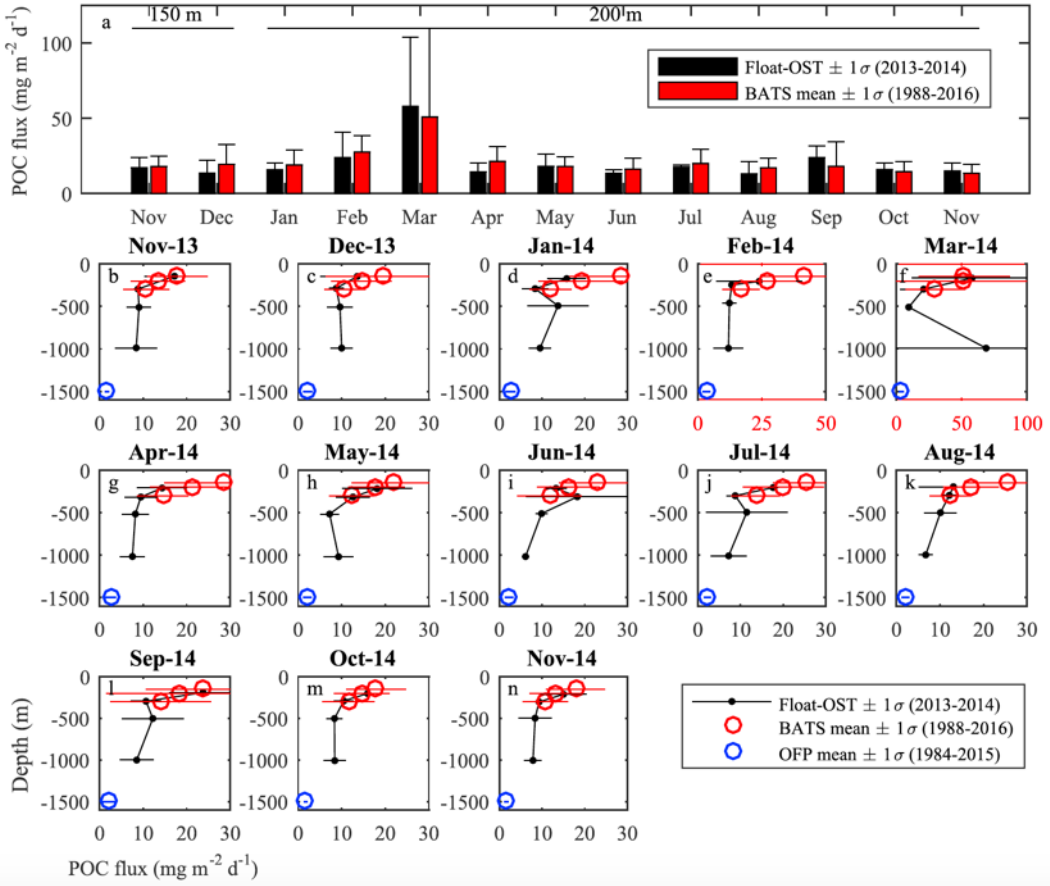
Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1029/2018GB006098

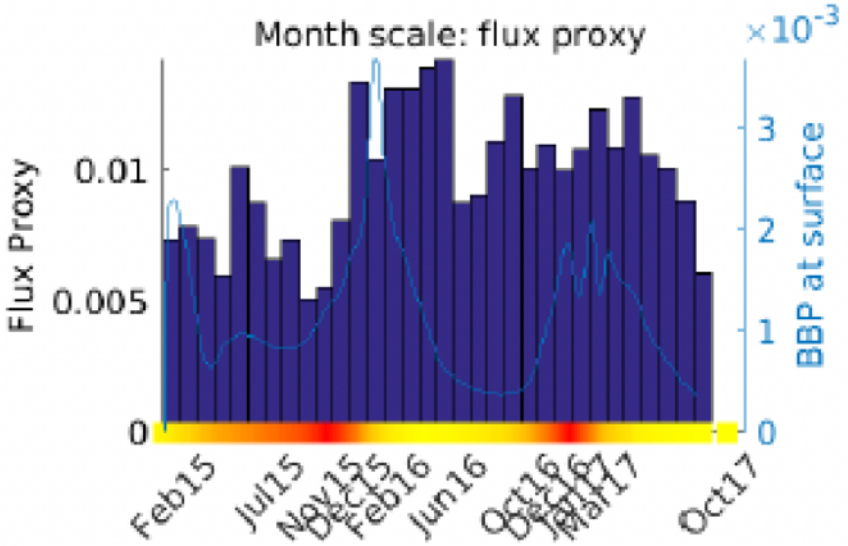
Direct Observations of Biological Carbon Export From Profiling Floats in the Subtropical North Atlantic

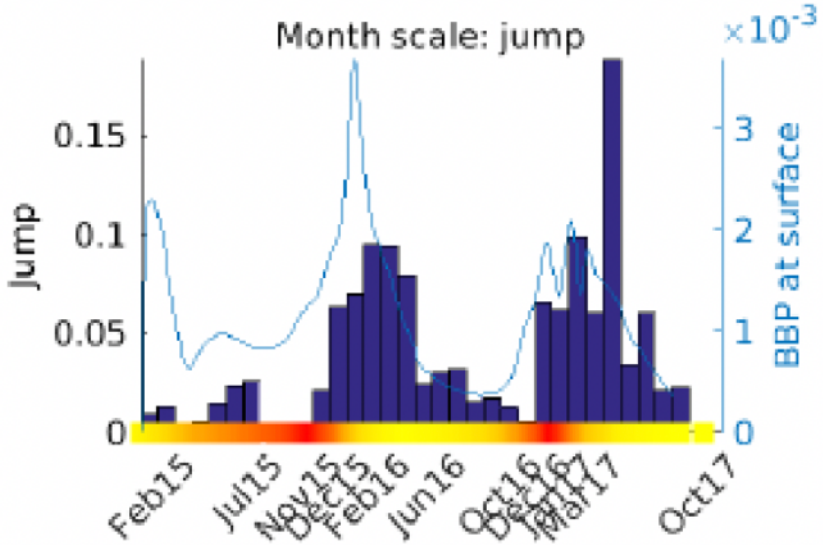
M. L. Estapa[1], M. L. Feen[1,2], and E. Breves[1]

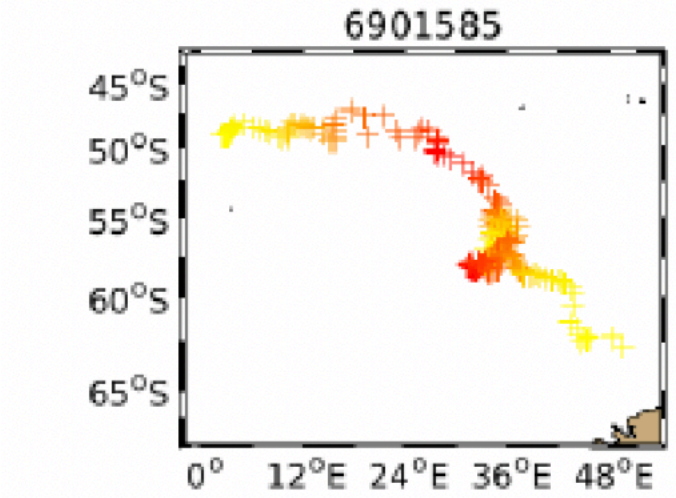
Key Points:
- Profiling floats captured strong

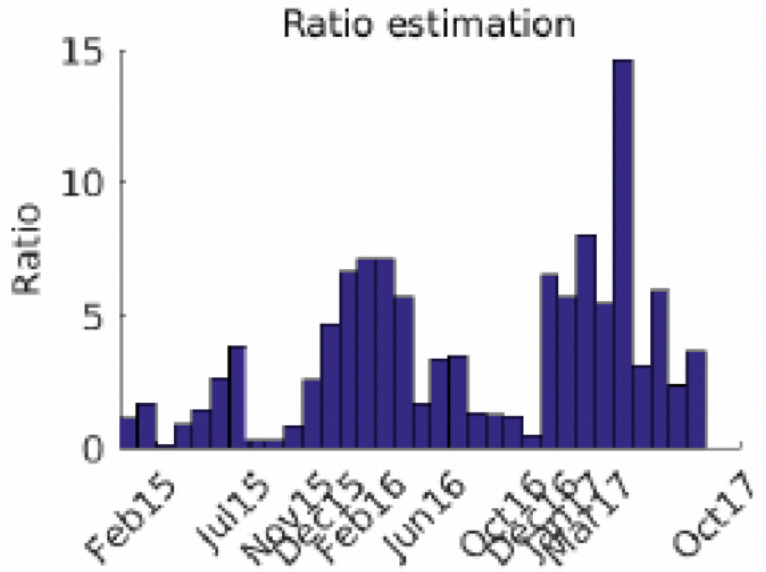


Transmissiometry : Optical Sediment Traps time-serie in the Southern Ocean

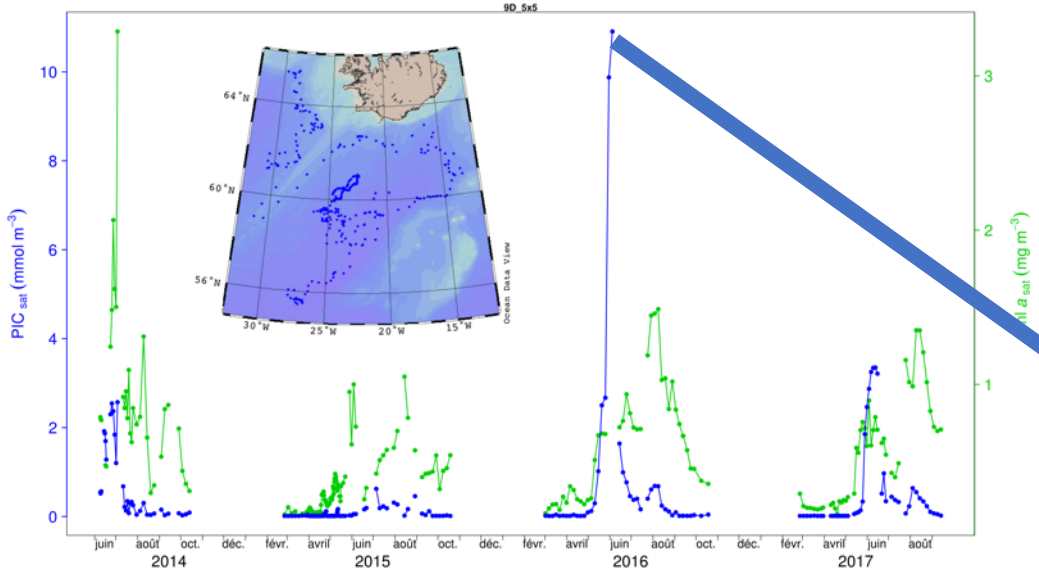


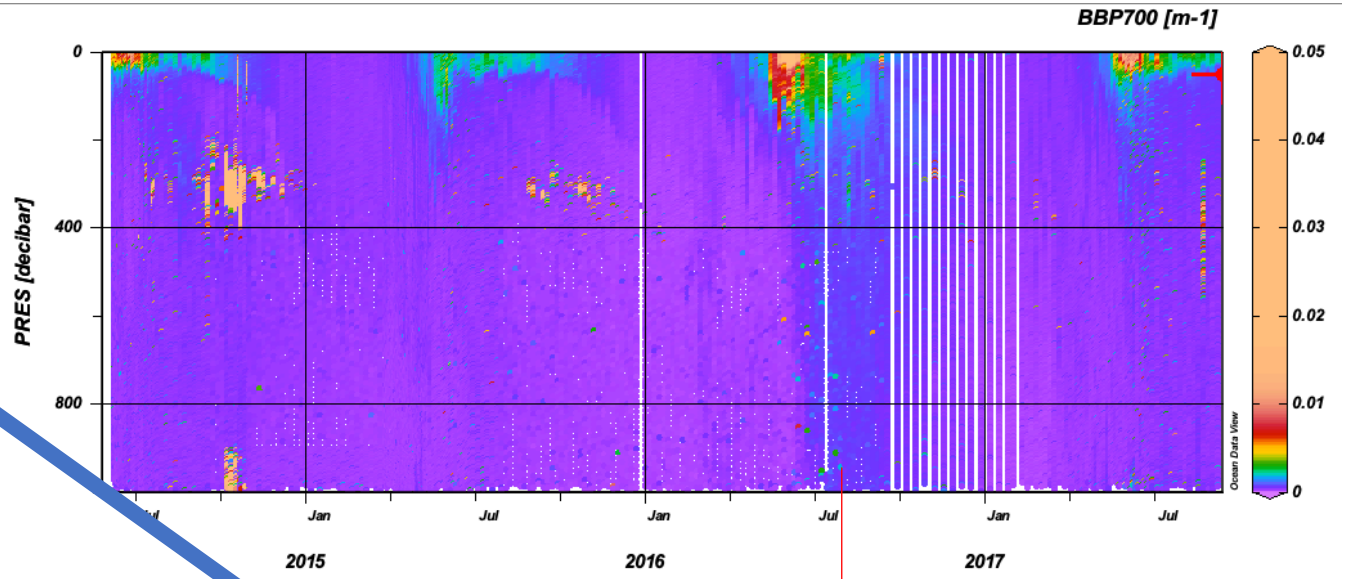


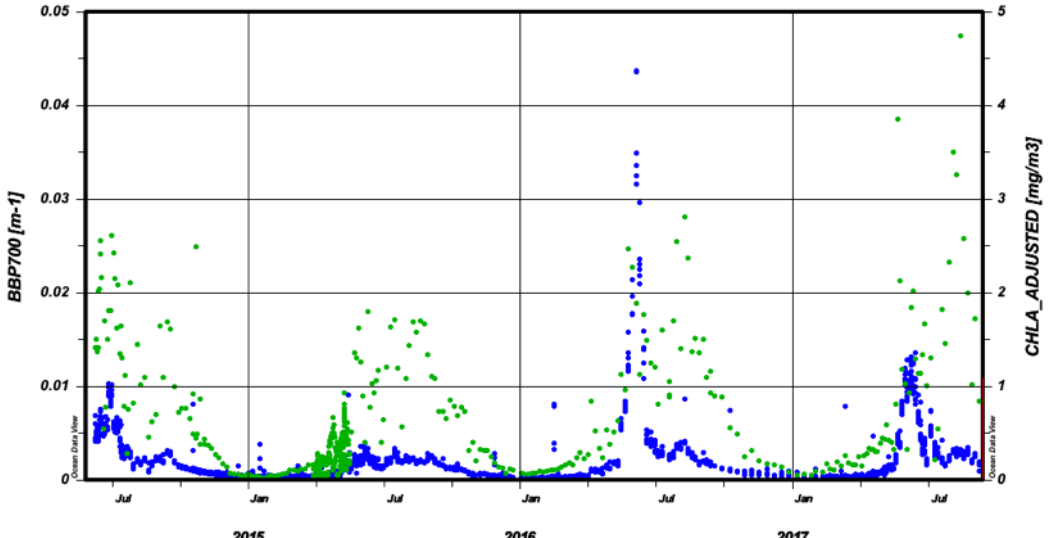


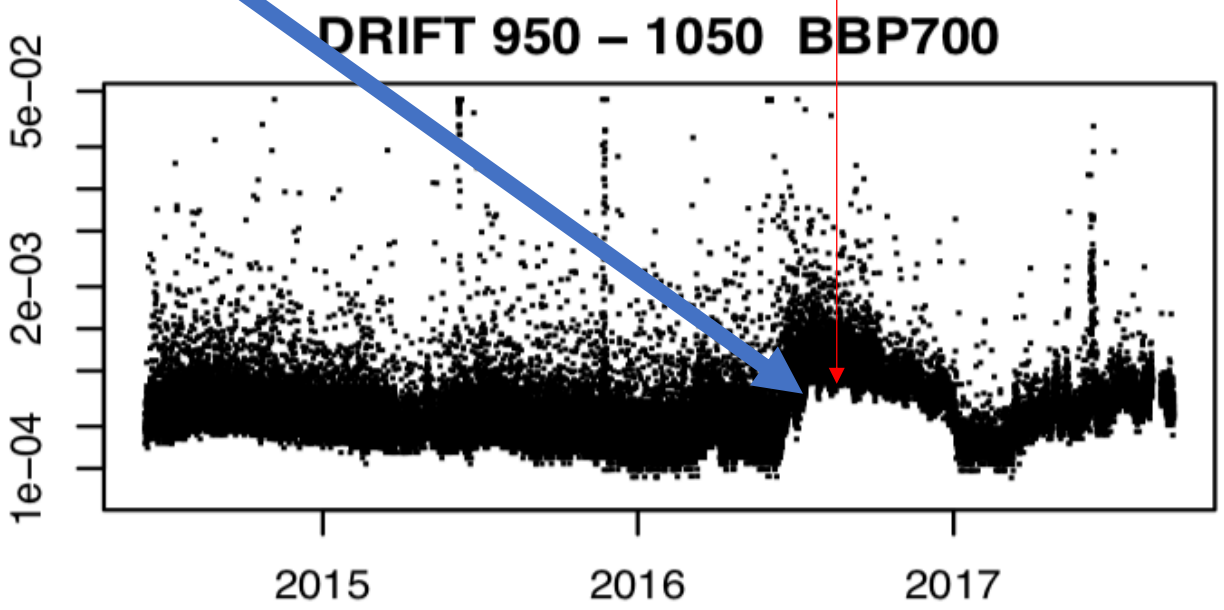


Monitoring during the drift: propagating satellite information to export at 1000m









rep

Radiometry

- Relation to ocean color = > Validation of bio-optical algorithms linking products (e.g. [Chl]) to optical properties (e.g. diffuse attenuation coefficient)
- Large datasets allowing to track regional “nuances” in these datasets (e.g. CDOM vs Chla)
- Allow for better constraining the calibration slope (Fchla vs [Chla]) of fluorometers

A Novel Near-Real-Time Quality-Control Procedure for Radiometric Profiles Measured by Bio-Argo Floats: Protocols and Performances

EMANUELE ORGANELLI,* HERVÉ CLAUSTRE,* ANNICK BRICAUD,* CATHERINE SCHMECHTIG,+ ANTOINE POTEAU,* XIAOGANG XING,#,@ LOUIS PRIEUR,* FABRIZIO D'ORTENZIO,* GIORGIO DALL'OLMO,&,** AND VINCENZO VELLUCCI*

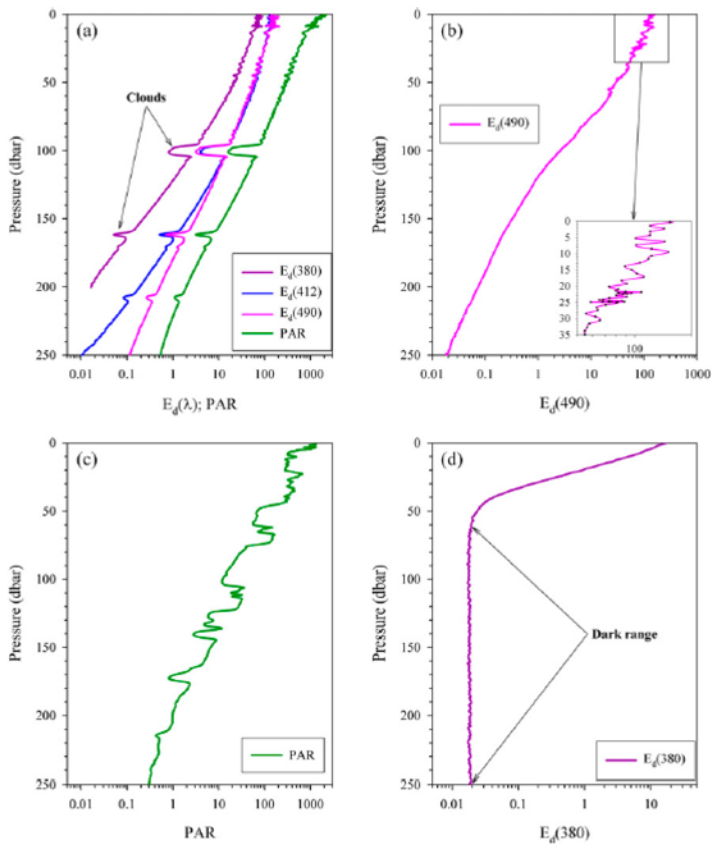


FIG. 3. Examples of (a) atmospheric cloud occurrence along profiles acquired by Bio-Argo floats (float WMO 6901439), (b) wave focusing in the surface layer (float WMO 6901655), (c) profile acquired in very unstable sky and sea conditions (float WMO 6901439), and (d) dark occurrence along the profile (float WMO 6901486). Values of $E_d(\lambda)$ at 380, 412, and 490 nm are expressed as μW cm^{-2} nm^{-1}. PAR values are expressed as μmol quanta m^{-2} s^{-1}. Depth is expressed in units of pressure.

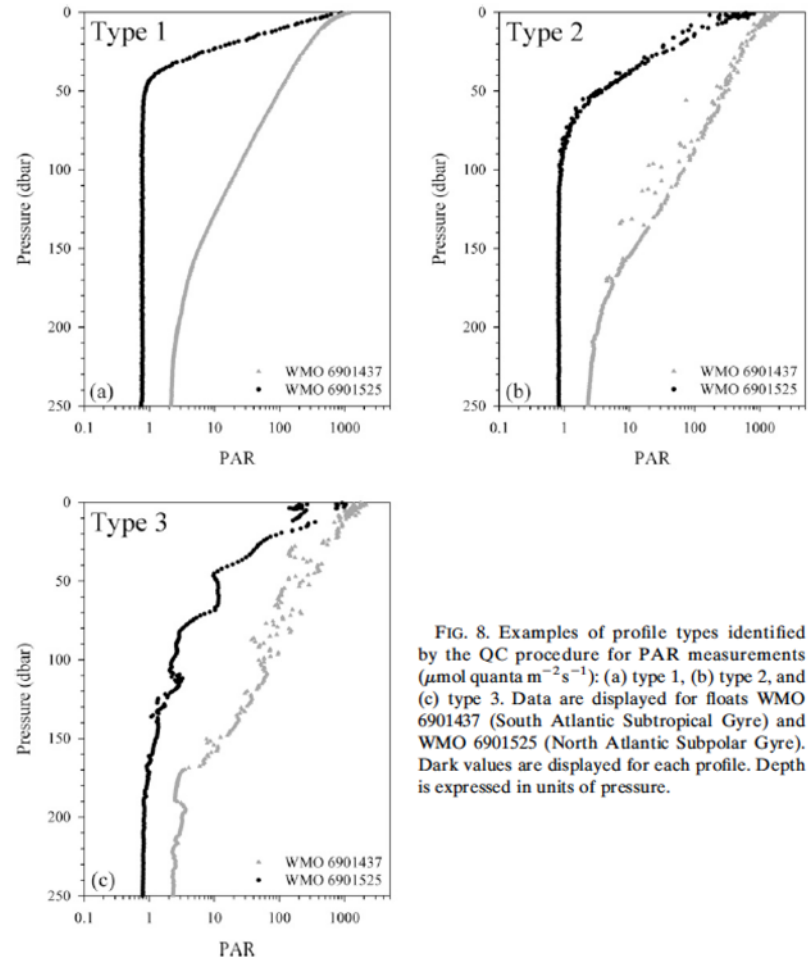


FIG. 8. Examples of profile types identified by the QC procedure for PAR measurements (μmol quanta m^{-2} s^{-1}): (a) type 1, (b) type 2, and (c) type 3. Data are displayed for floats WMO 6901437 (South Atlantic Subtropical Gyre) and WMO 6901525 (North Atlantic Subpolar Gyre). Dark values are displayed for each profile. Depth is expressed in units of pressure.

Journal of Geophysical Research: Oceans

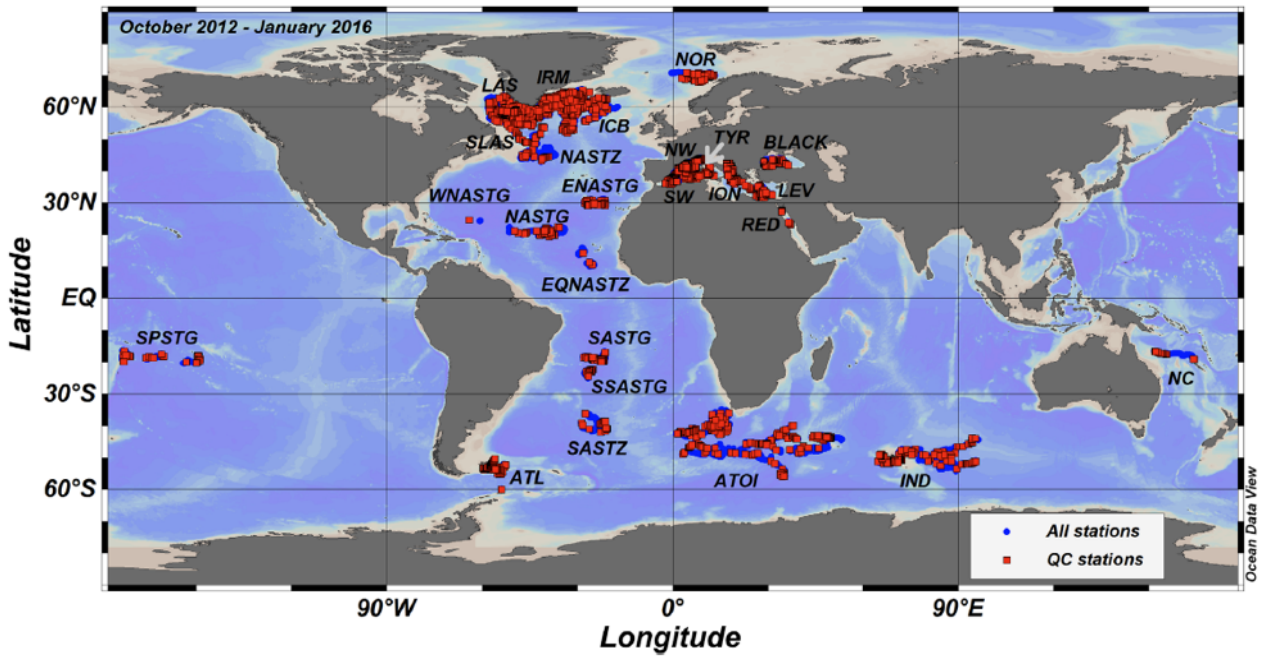
RESEARCH ARTICLE
10.1002/2016JC012629

Bio-optical anomalies in the world's oceans: An investigation on the diffuse attenuation coefficients for downward irradiance derived from Biogeochemical Argo float measurements

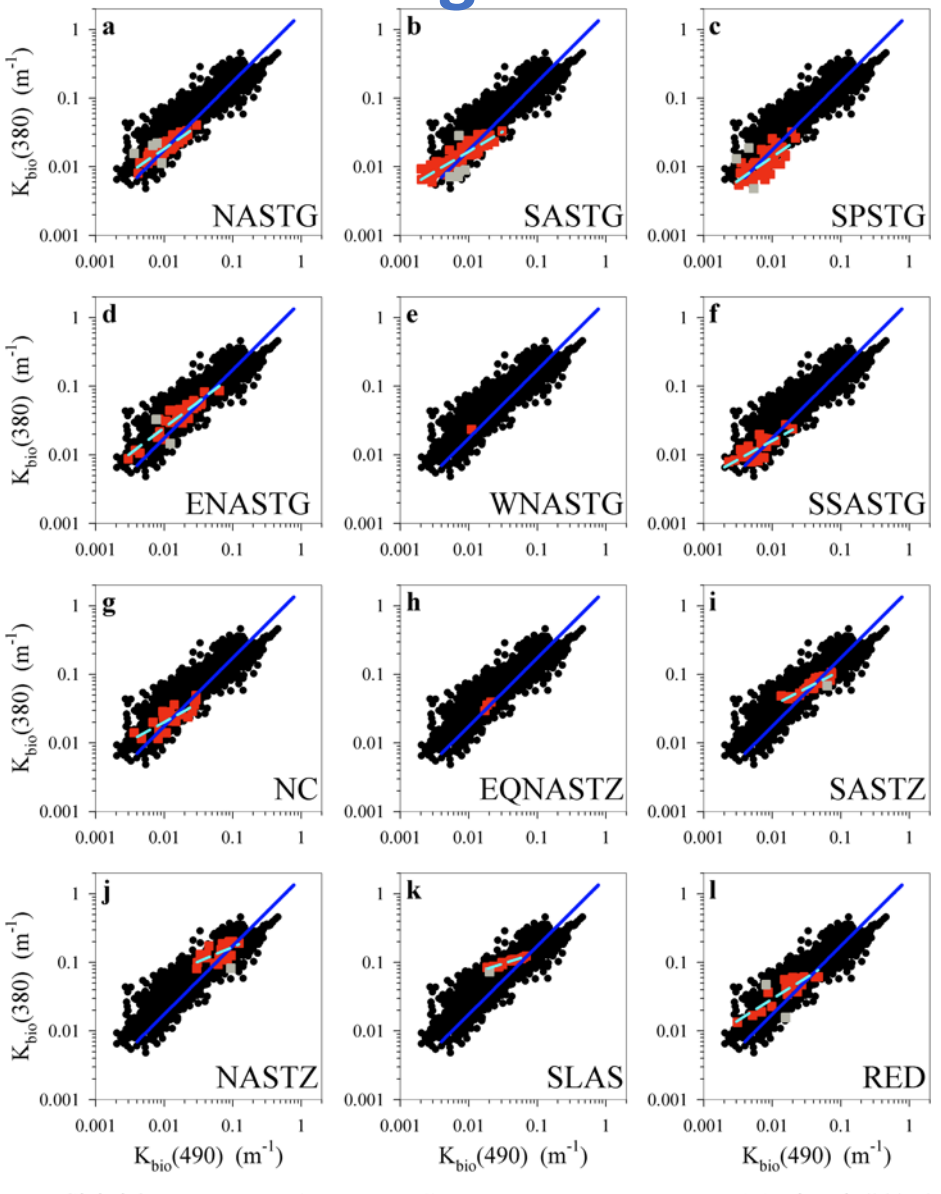
Emanuele Organelli[1,2], Hervé Claustre[1], Annick Bricaud[1], Marie Barbieux[1], Julia Uitz[1], Fabrizio D'Ortenzio[1], and Giorgio Dall'Olmo[2,3]

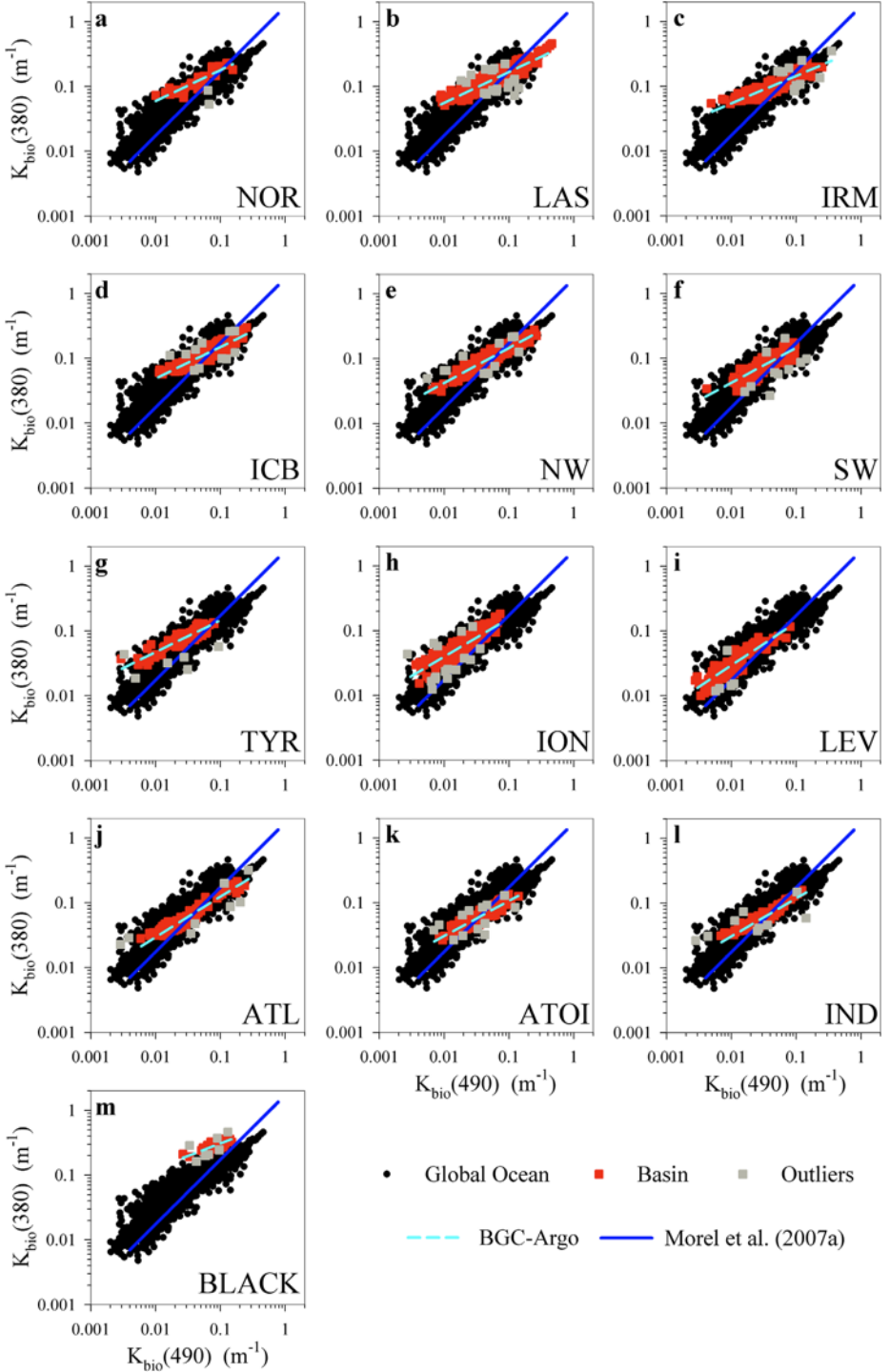
[1]Sorbonne Universités, UPMC Univ Paris 06, CNRS, UMR 7093, Laboratoire d'Océanographie de Villefranche (LOV), Villefranche-sur-mer, France, [2]Plymouth Marine Laboratory, Plymouth, UK, [3]National Centre for Earth Observation, Plymouth Marine Laboratory, Plymouth, UK

Key Points:
- Different optical behaviors among oceanic regions as observed from diffuse attenuation coefficients within the first optical depth
- High content of colored dissolved organic matter causes the deviation of most open ocean waters from existing bio-optical models
- Bio-optical anomalies as proxies for

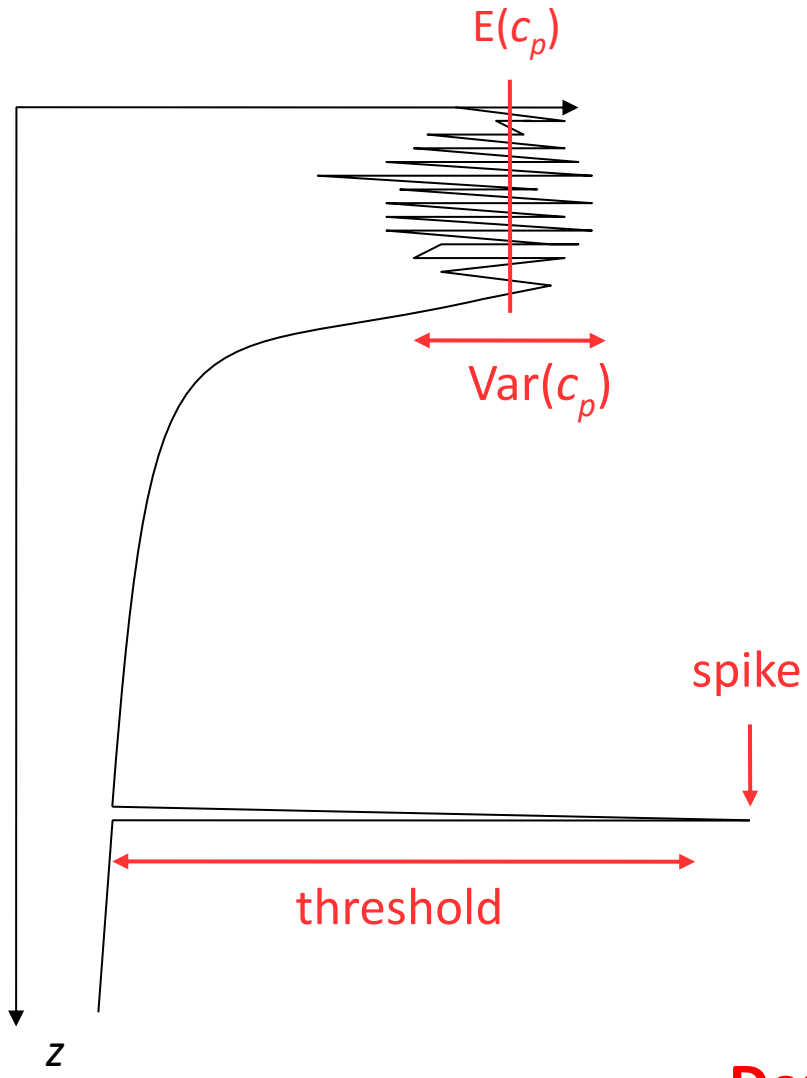


Radiometry: Nonanomalous and anomalous regions as compared to the global ocean





High vertical resolution : from noise and spikes to proxies



Particle diameter in the mixed layer

$d_{ML} \sim Var(c_p) / E(c_p)$

(Briggs et al. 2013)

Particle export in the mesopelagic

Spike when

signal - baseline > threshold

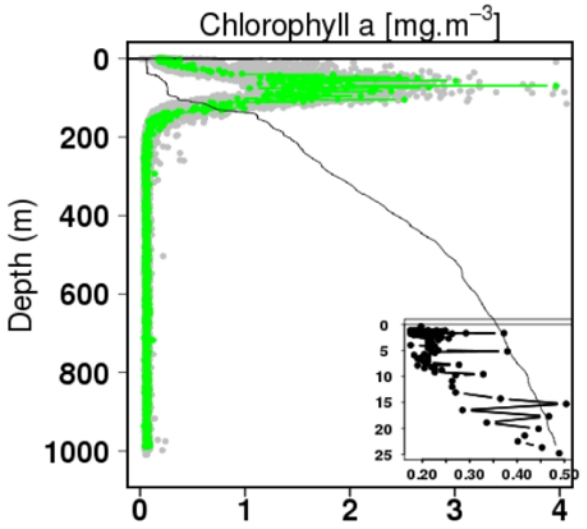
(Briggs et al. 2011)

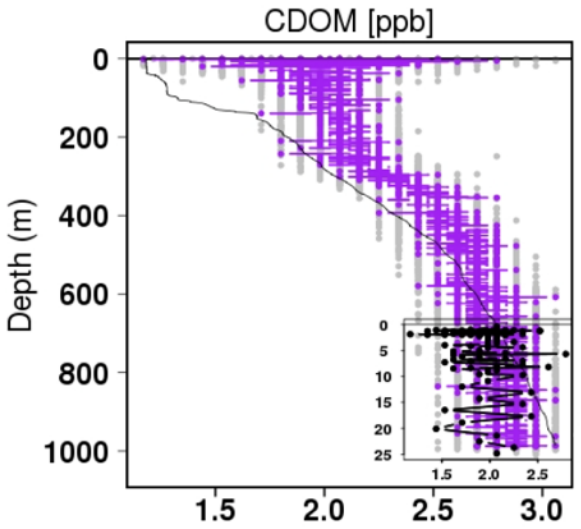
Importance of adaptive sampling :

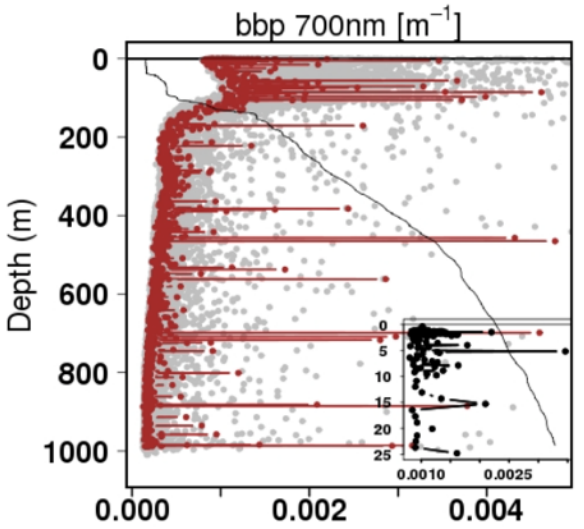
Depth resolution, tuneable thanks to iridium

High vertical resolution (spikes) : sinking of large particles / agregates: Differences on each side of Kerguelen plateau

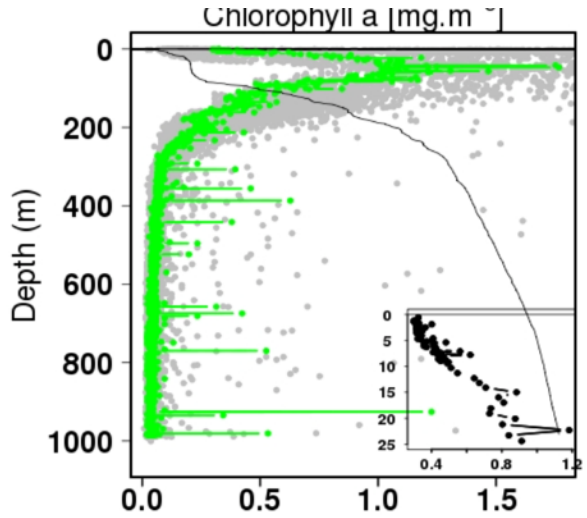
West Iron-limited

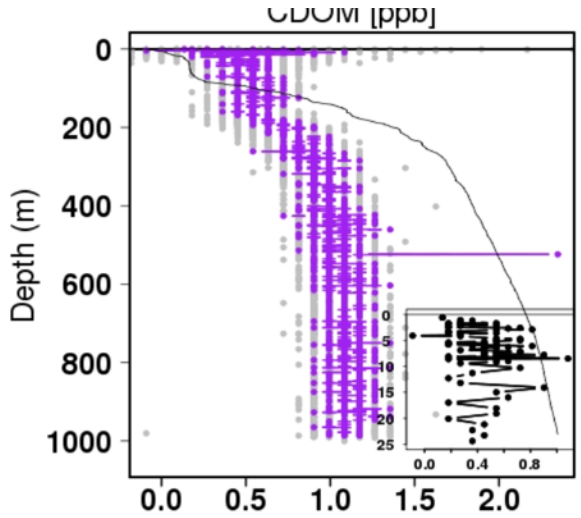


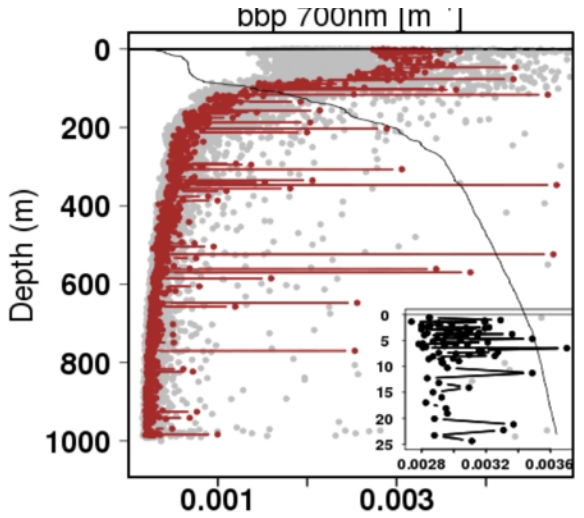




East: Non-limited

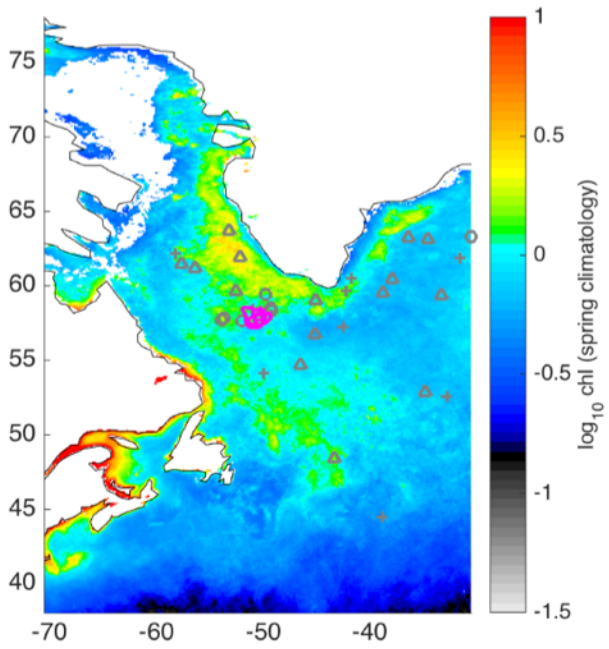


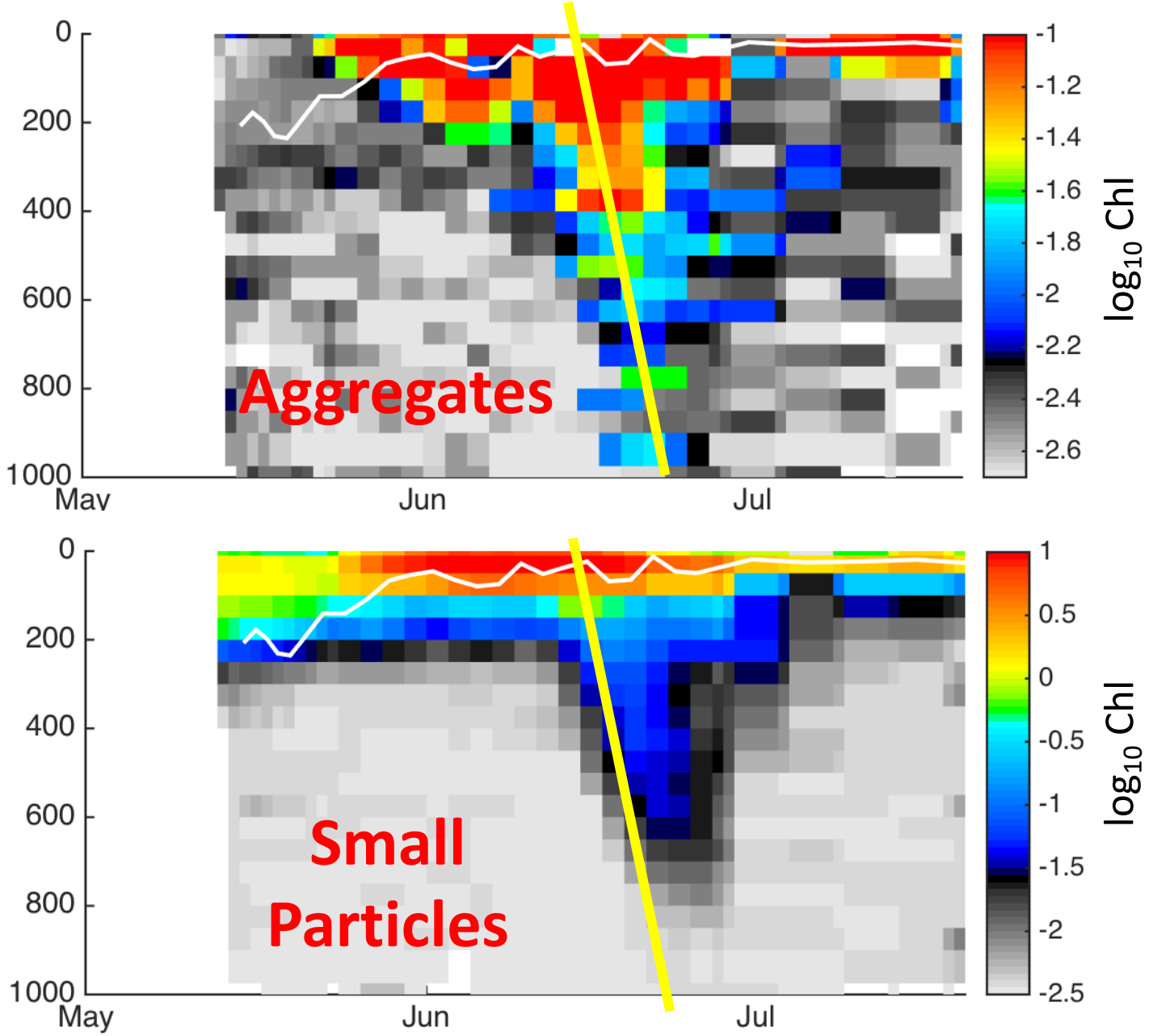




High vertical resolution (spikes)

50% of aggregates are « lost » in the mesopelagic by fragmentation



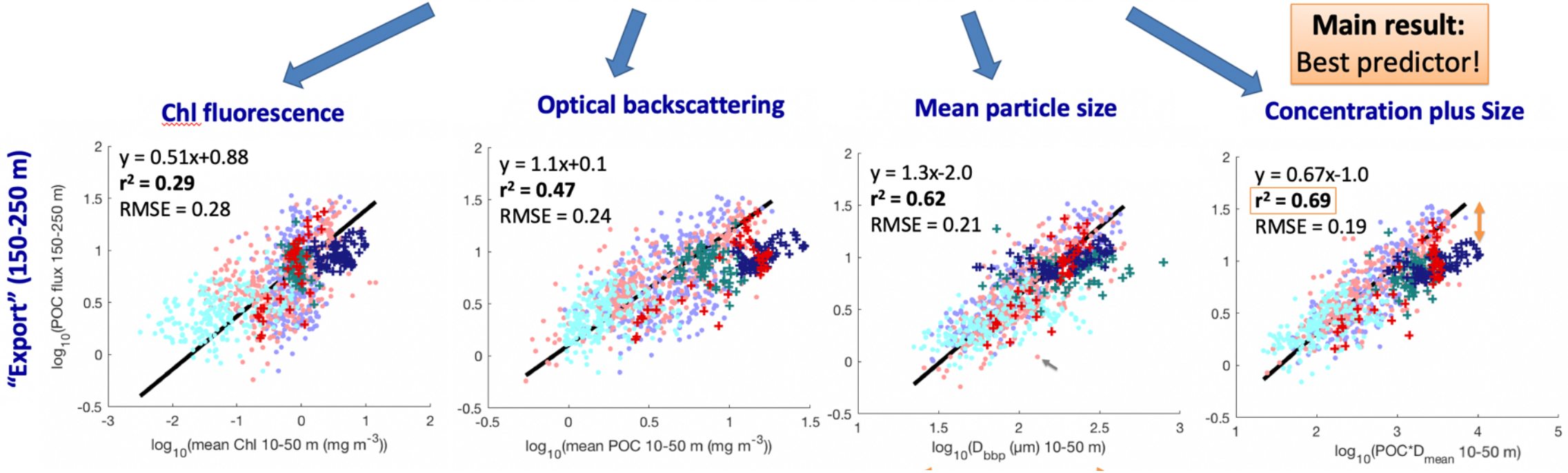


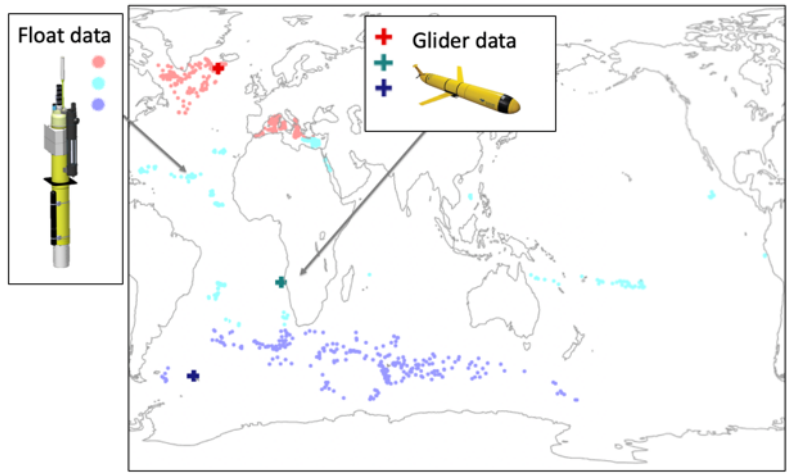
Briggs, Dall'Olmo & Claustre (2020): Major role of particle fragmentation in regulating biological sequestration of CO2 by the oceans. *Science*, in press

High vertical resolution (noise): size at surface impacts on export at depth

Near-surface predictors of deep sinking particle concentrations

Main result:
Best predictor!





The mechanisms of export from surface to the mesopelagic domain (Biological Carbon Pump) are potentially multiple : we need to reconsider the classical paradigm of the “gravitational pump”

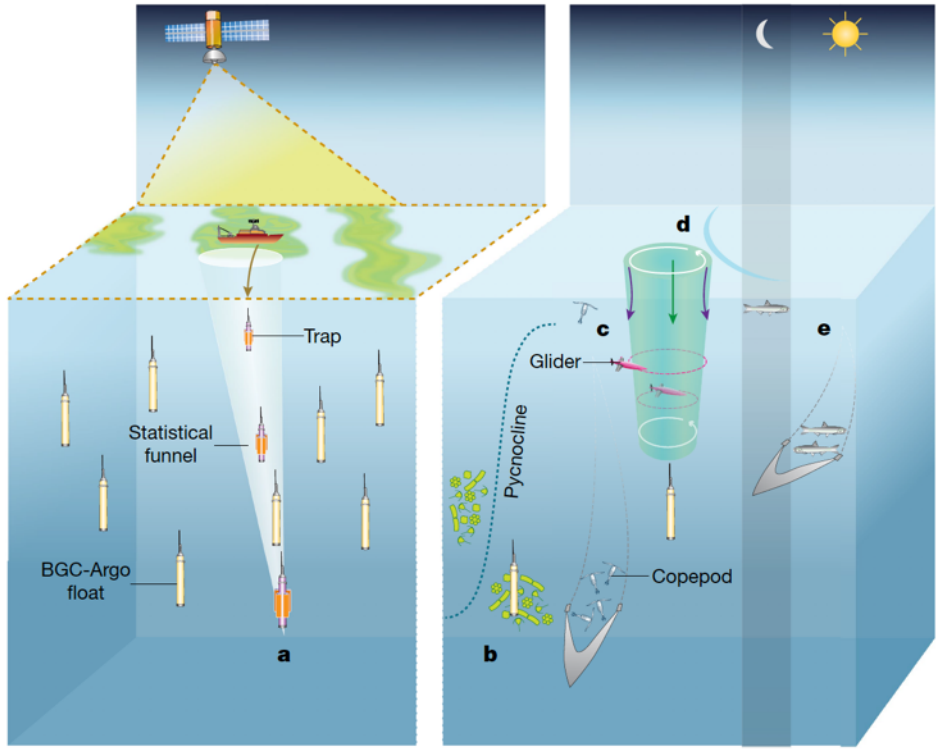
- Particle Injection Pumps (PIPs) also contribute delivering POC and DOC at depth:
  - Physically mediated pumps
    - Subduction (at various scale)
    - Mixed layer (seasonal, event)
  - Biologically mediated pumps
    - Diel migration
    - Seasonal migration
- **BGC-Argo could become an essential network for understanding and quantifying these mechanisms.**

REVIEW

https://doi.org/10.1038/s41586-019-1098-2

Multi–faceted particle pumps drive carbon sequestration in the ocean

Philip W. Boyd[1]*, Hervé Claustre[2,6], Marina Levy[3,6], David A. Siegel[4,6] & Thomas Weber[5,6]



Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1029/2018GB005997

Key Points:
- The density of BGC-Argo float network enables identification of episodic mixed layer pump events

The Intraseasonal Dynamics of the Mixed Layer Pump in the Subpolar North Atlantic Ocean: A Biogeochemical-Argo Float Approach

L. Lacour[1,2], N. Briggs[3], H. Claustre[1], M. Ardyna[1,4], and G. Dall'Olmo[5,6]

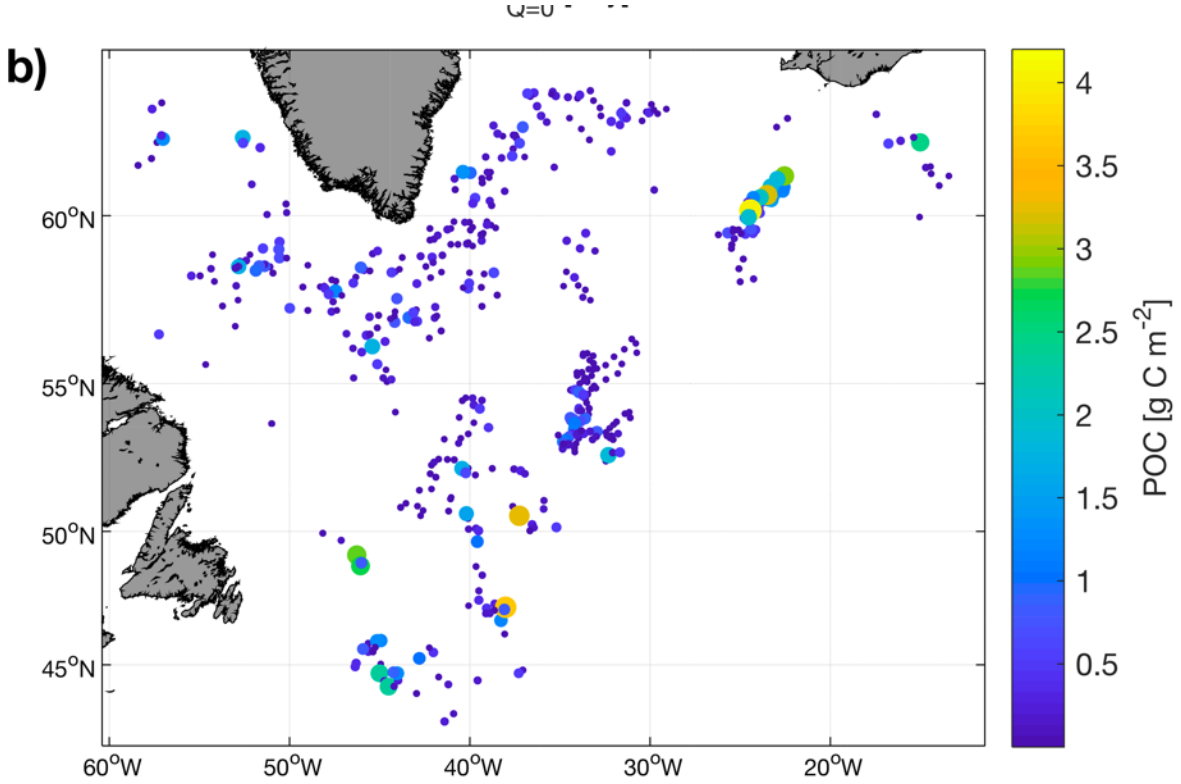
JGR
Journal of Geophysical Research: Oceans

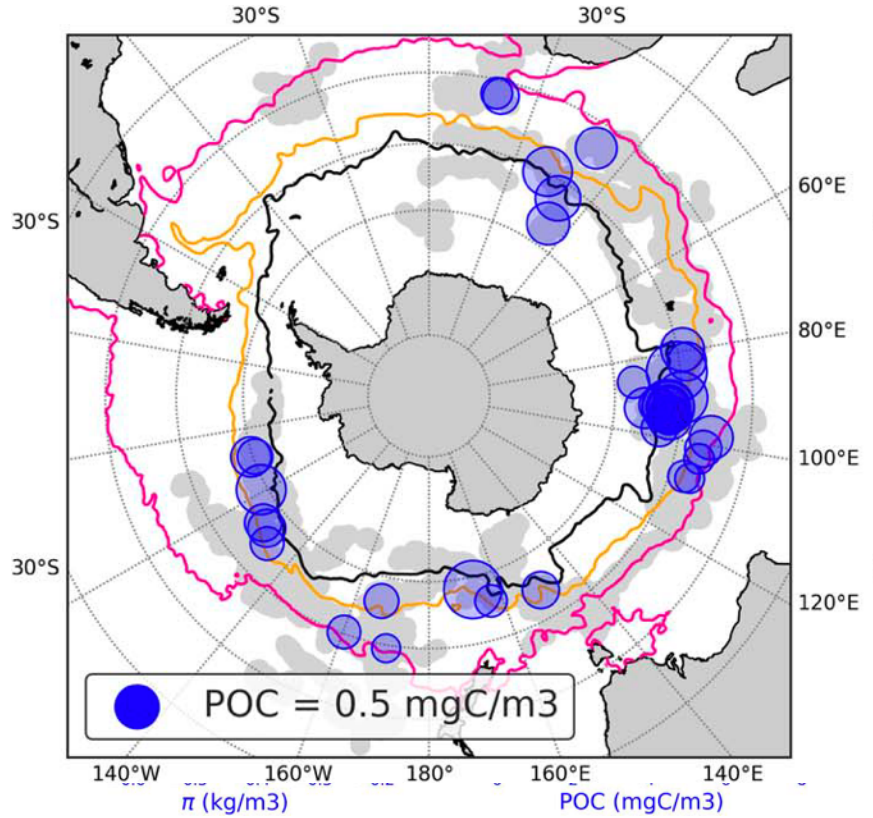
RESEARCH ARTICLE
10.1002/2017JC012861

Special Section:
The Southern Ocean Carbon and Climate Observations and

Evaluating Southern Ocean Carbon Eddy-Pump From Biogeochemical-Argo Floats

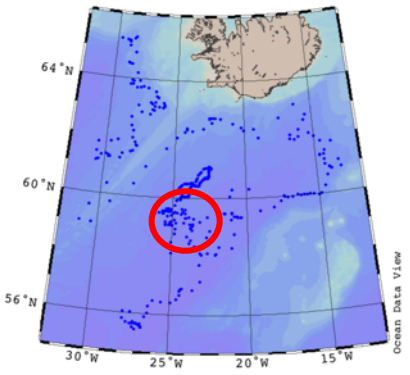
Joan Llort[1,2,3], C. Langlais[3], R. Matear[2,3], S. Moreau[1,4], A. Lenton[3,5], and Peter G. Strutton[1,2,3]



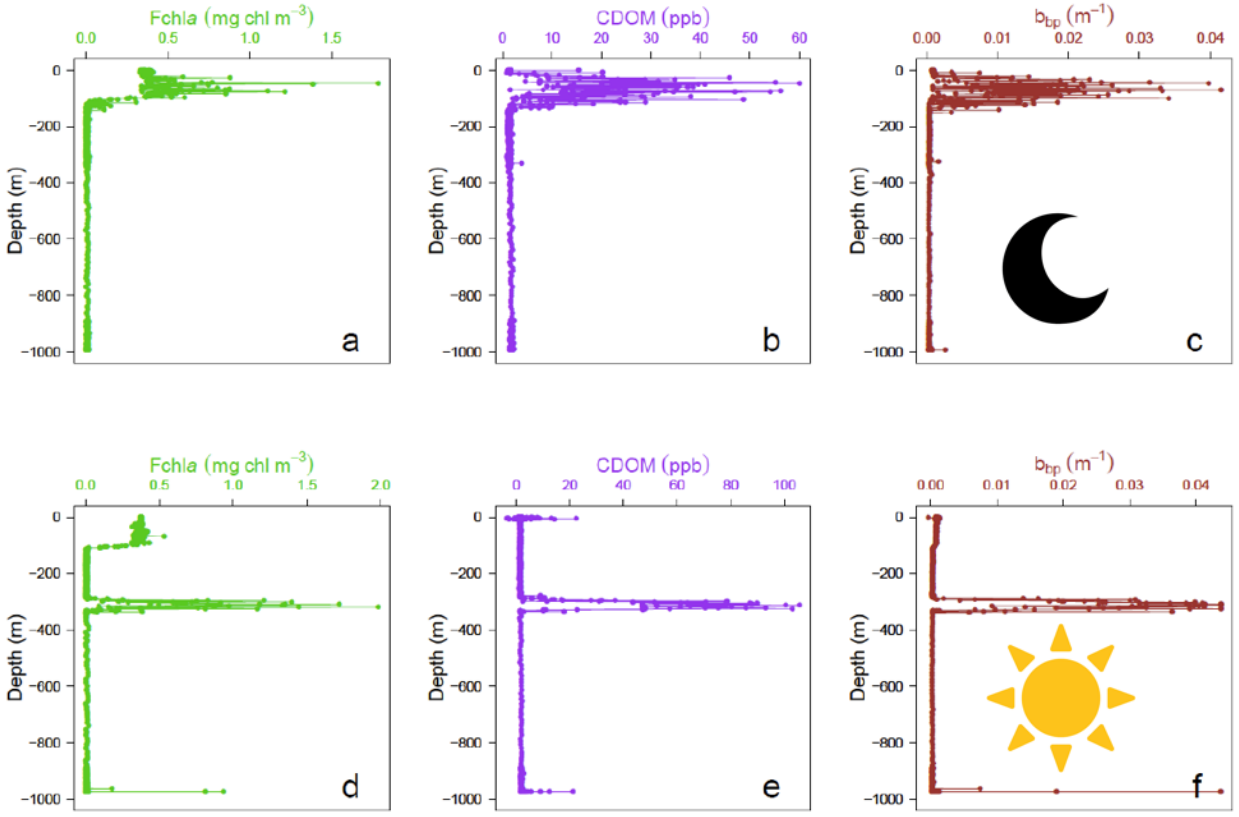


Converting the TZ signature of PIPs into fluxes requires additional assumption / constraints (MLP: time elapsed since the last mixing event, ESP : advective velocities) = > uncertainties

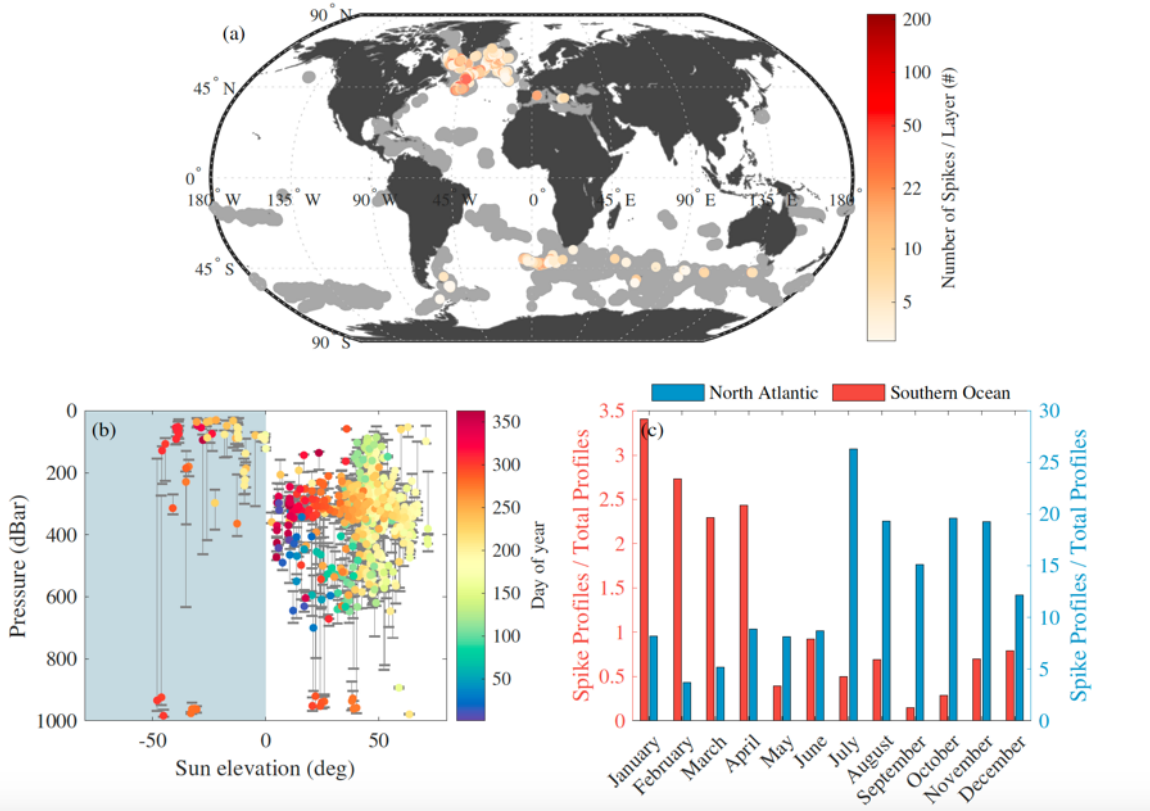
Float-based evidences of mesopelagic organisms migration



Icelandic Basin, end of October

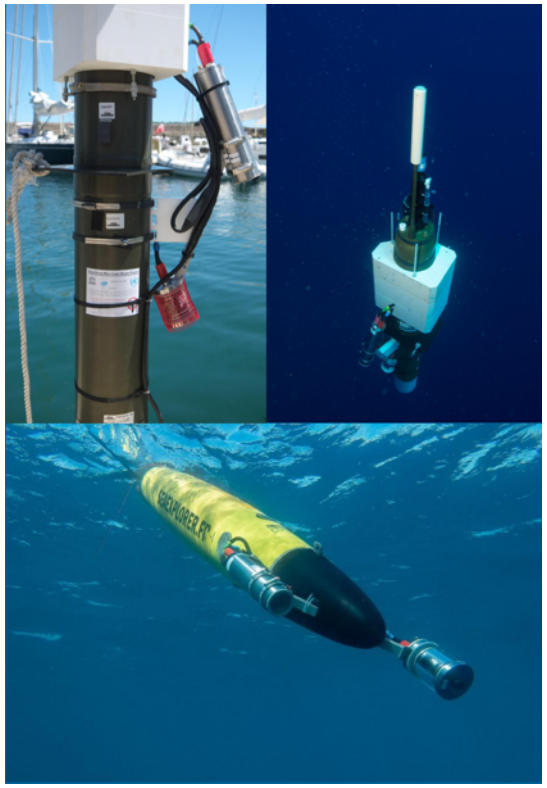


From Boyd et al. (supplementary), 2019

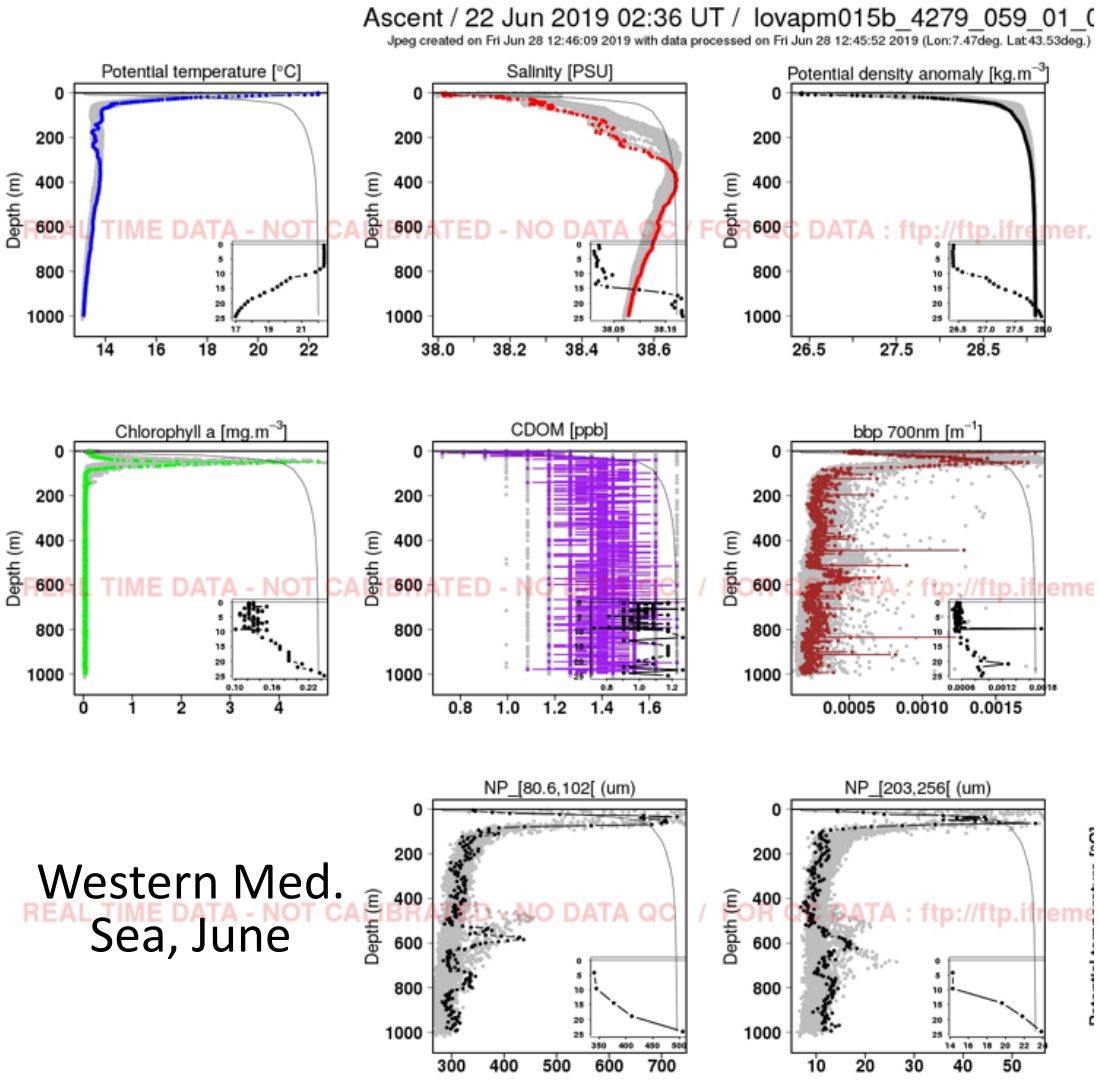


Haentjen et al., in review

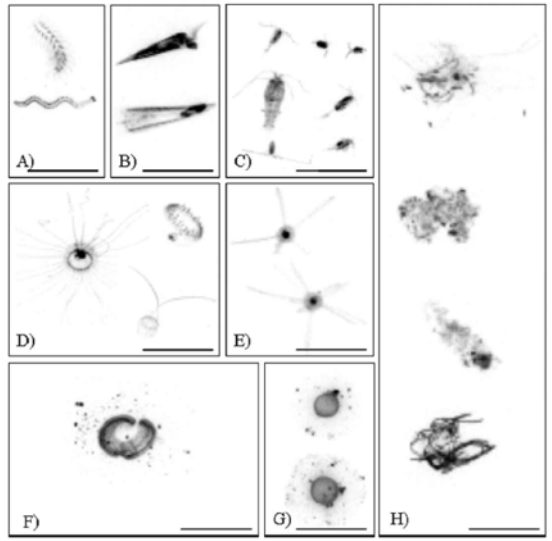
The under-water vision profiler
particle sizing & « onboard » image analysis



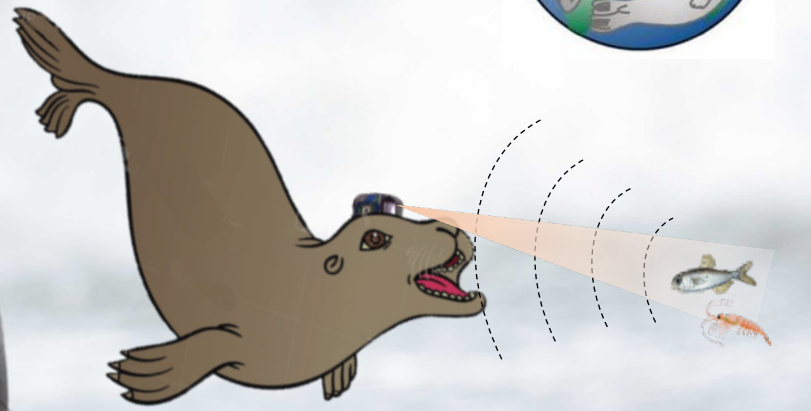
- 2.6 kg in air, 1.6 kg in water
- Depth rating: 6000m
- Collimated illumination in the red
- Intelligent camera
- Size : 100 um to 1 cm
- Volume sampled: 0.6 L
- 1 W at 1.5 Hz max



Western Med. Sea, June



Active µ-sonar: collaboration with M. Johnson & P. Goulet, Sea Mammal Research Unit):



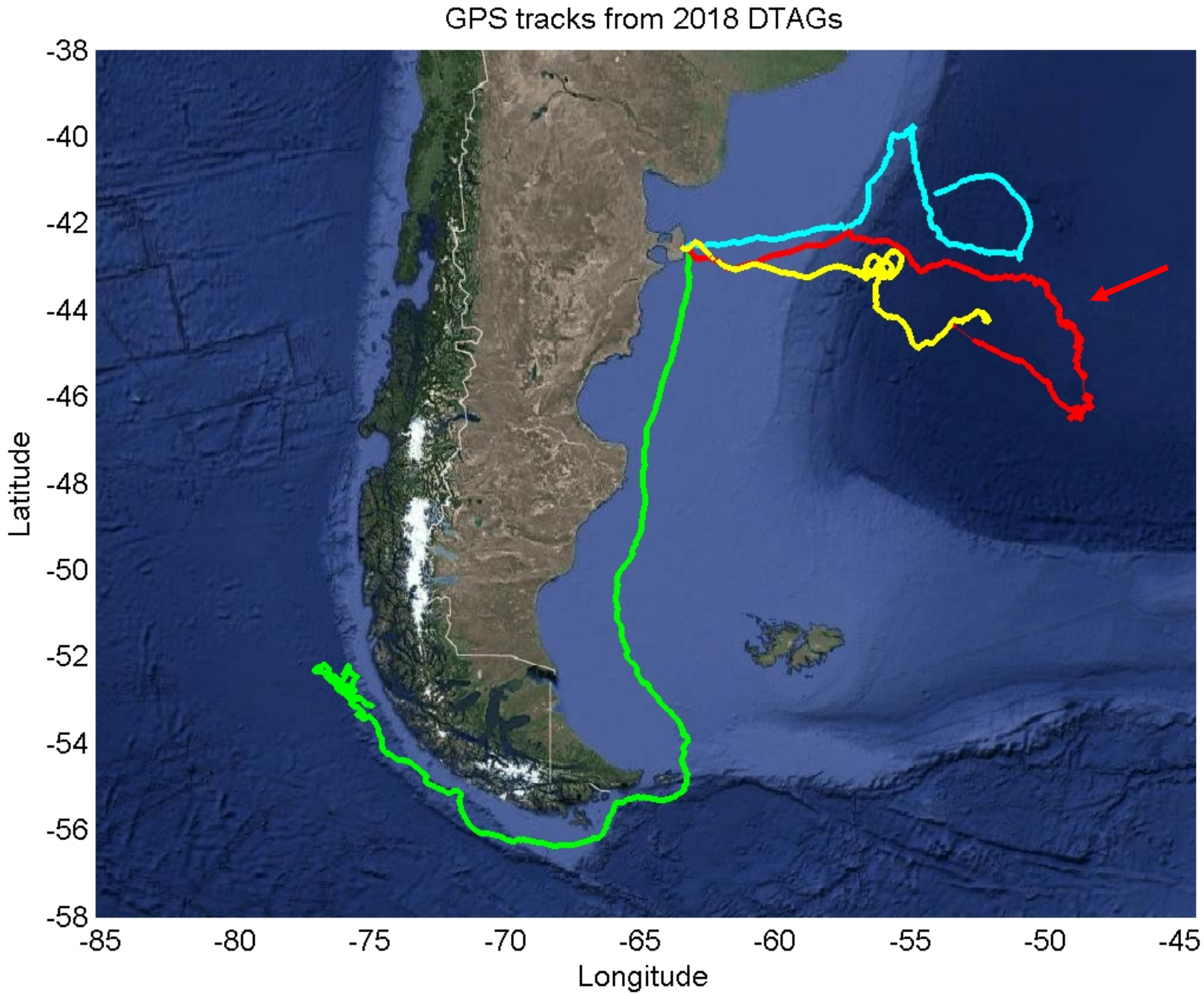
SenSe SENTINELS OF THE SEA ICE

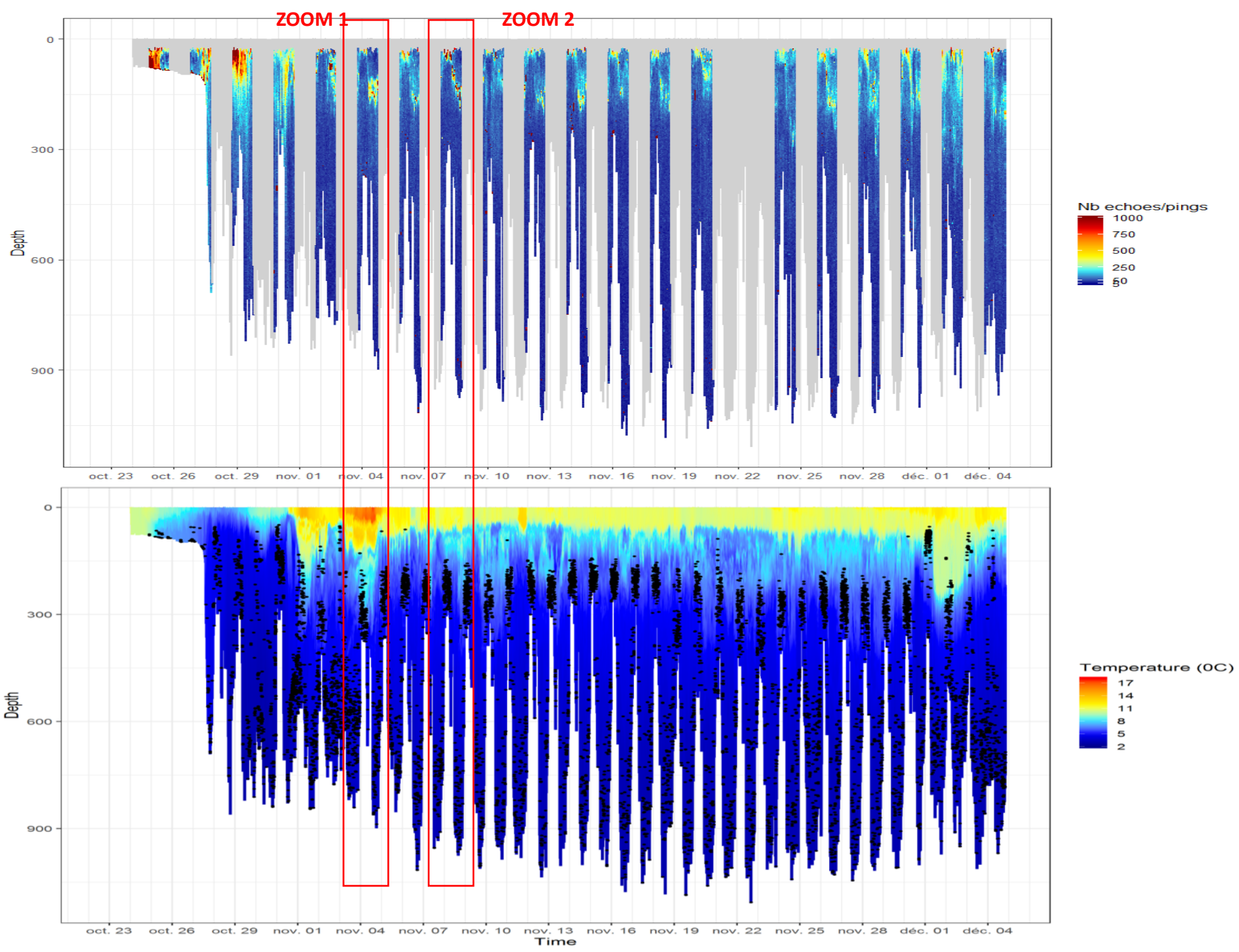
FONDATION BNP PARIBAS

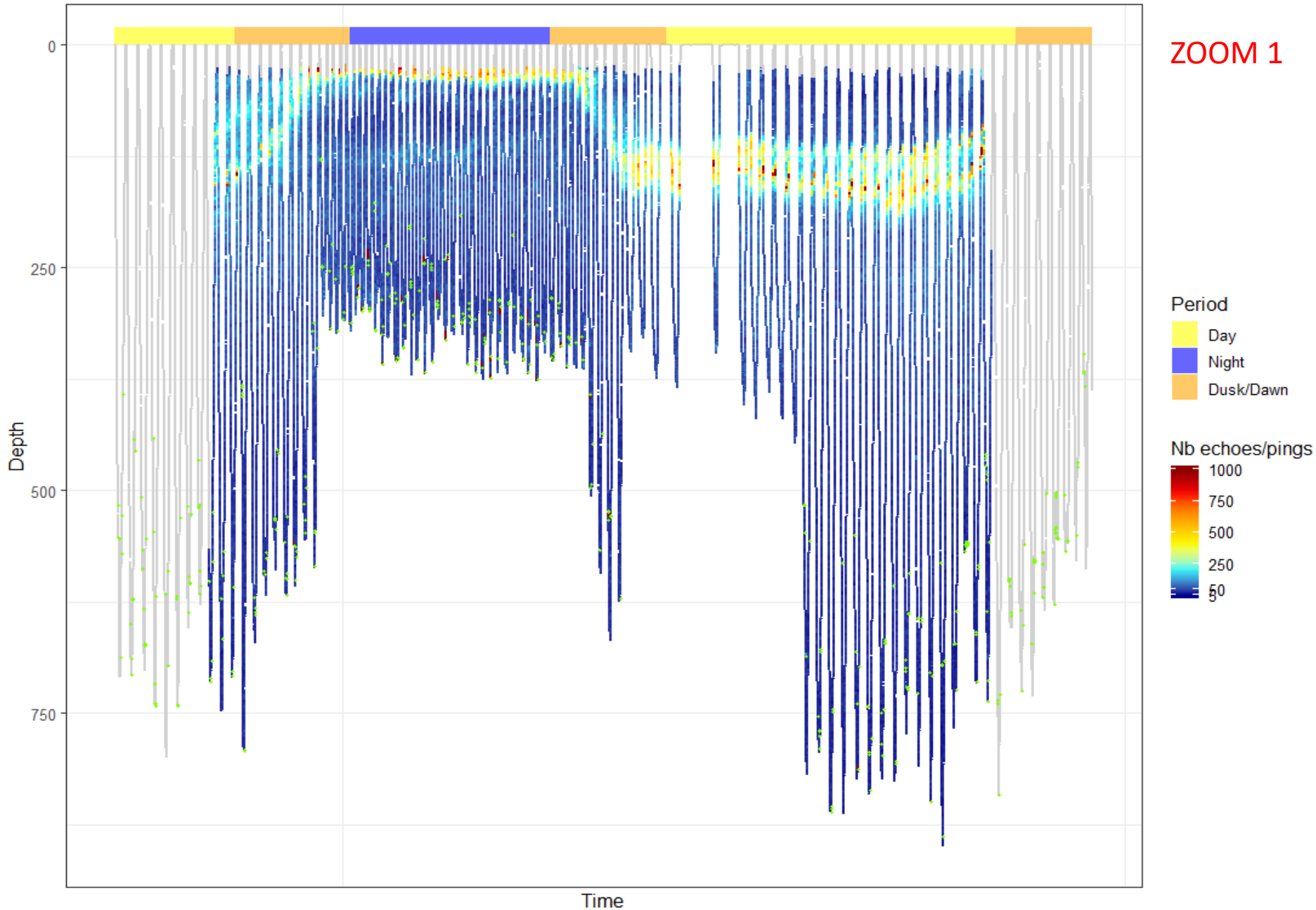
Sous l'égide de la Fondation de France

cnes

CENTRE NATIONAL D'ÉTUDES SPATIALES

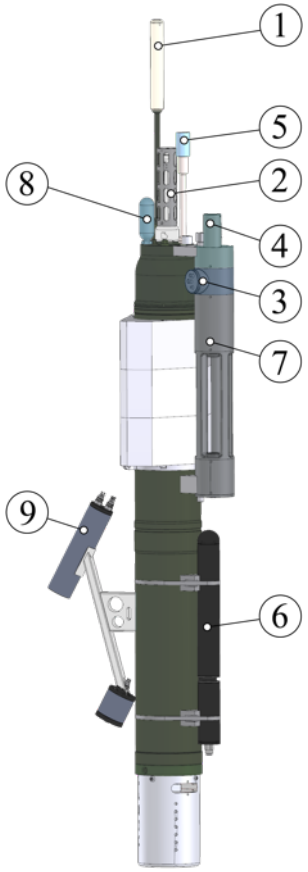

GPS tracks from 2018 DTAGs
-38
-40
-42
-44
-46
-48
-50
-52
-54
-56
-58
Latitude
-85
-80
-75
-70
-65
-60
-55
-50
-45
Longitude


ZOOM 1
ZOOM 2
Depth
0
300
600
900
oct. 23
oct. 26
oct. 29
nov. 01
nov. 04
nov. 07
nov. 10
nov. 13
nov. 16
nov. 19
nov. 22
nov. 25
nov. 28
déc. 01
déc. 04
Nb echoes/pings
1000
750
500
250
50
5
Temperature (0C)
17
14
11
8
5
2
Time

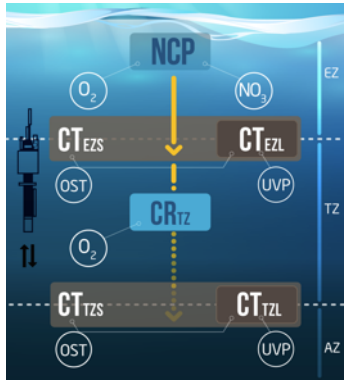

ZOOM 1
Depth
0
250
500
750
Time
Period
Day
Night
Dusk/Dawn
Nb echoes/pings
1000
750
500
250
50
5

REFINE: Robotic Exploration of plankton-driven Flux in the marIne twilight zoNE) 2020-2025

European Research Council



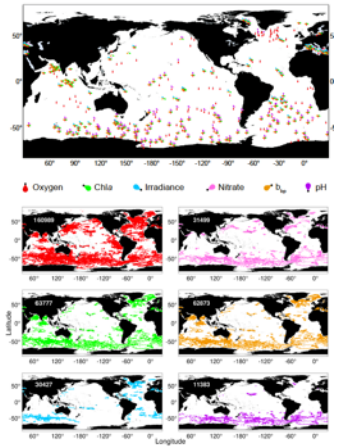
New floats



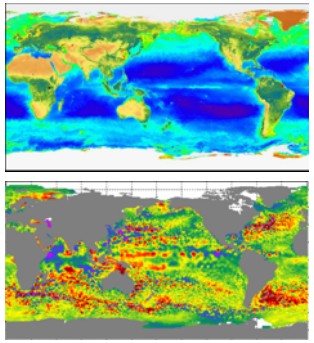
Budget of carbon export in...

....five key locations

Process studies

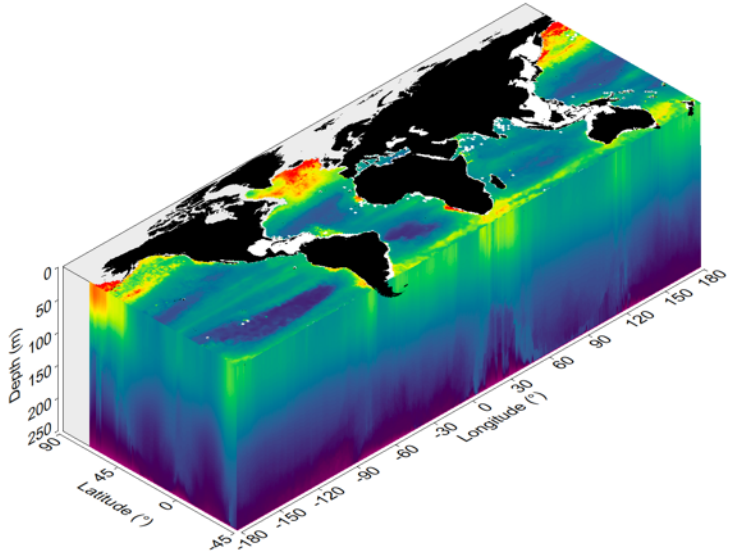


Argo, BGC-Argo



Satellite, reanalysis

Evaluate predictors of carbon export



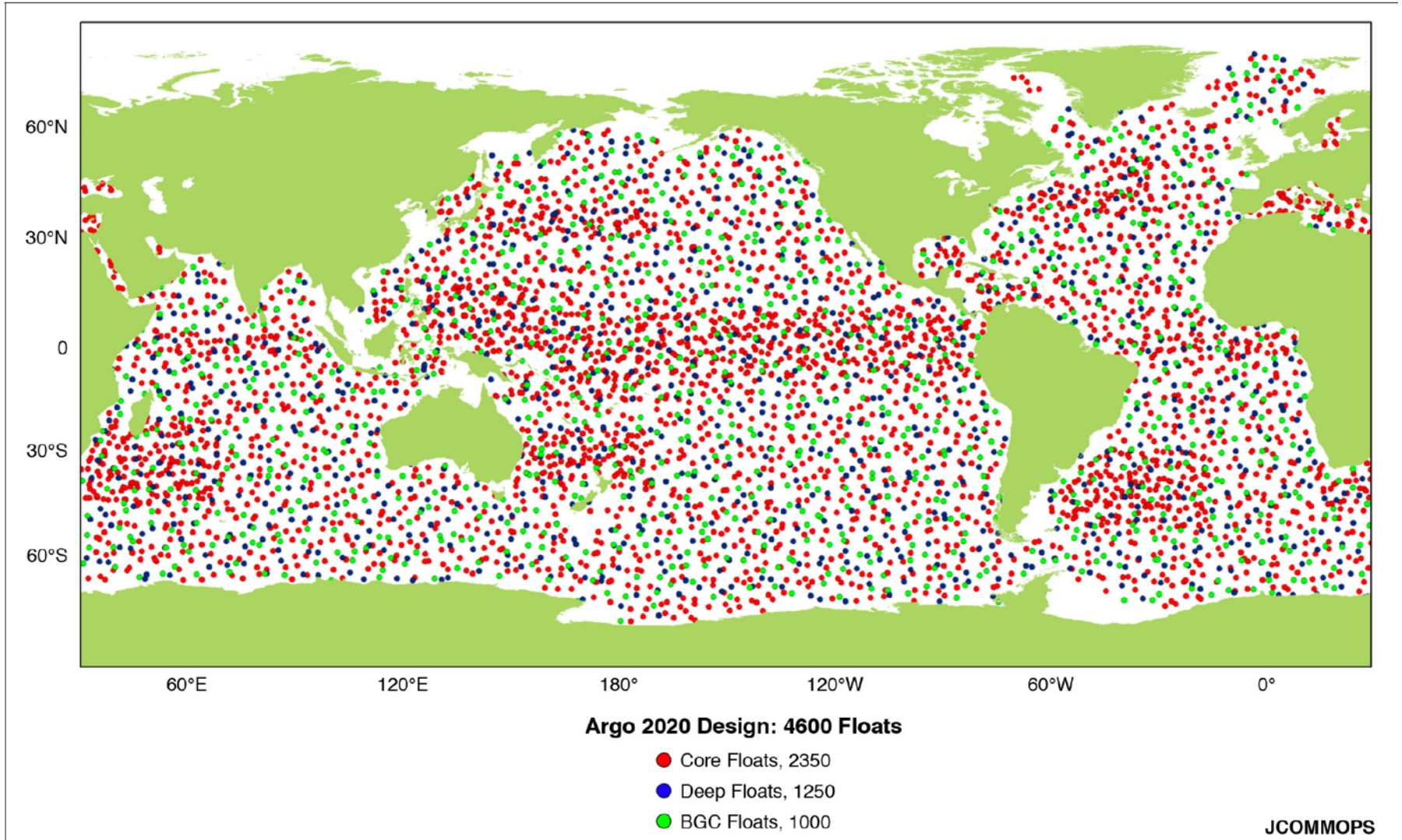
Upscaling carbon export

Technology

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*



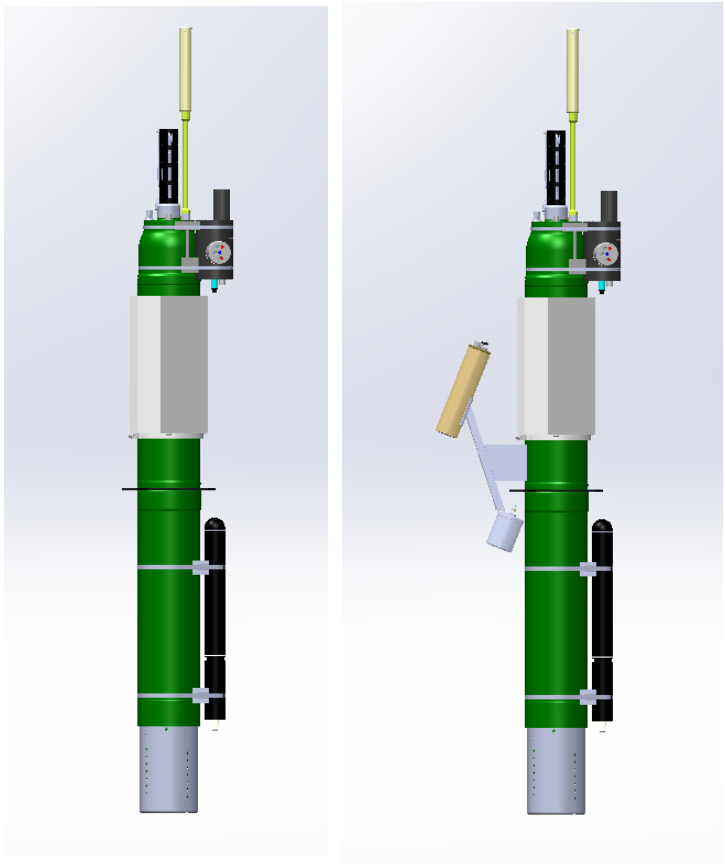
How to accommodate BGC process studies while complying with Argo rules

- Some essential biogeochemical processes can sometimes not be tackled with sufficient detail by Argo standard sampling rule
  - Dynamic of the blooms
  - Export and processes in the mesopelagic
- Their study and quantification require
  - to adapt vertical and/or temporal resolution
  - To implement new sensors
- In the mean time, we need to comply with the Argo standard mission. Basically a float should live at least 5 years (4 years was in the implementation plan) with 6 variables
- We need to have float with extend life-time

Need to develop a better knowledge of the power consumption of the various float's actions

- **Standard BGC-Argo PROVOR 6 core variables : 181 profiles, 5 y**
- b_{bp} and Chla at metric resolution:
  207 profiles, 4.7 y
- + UVP (no transmissiometer):
  180 profiles, 4.2 y

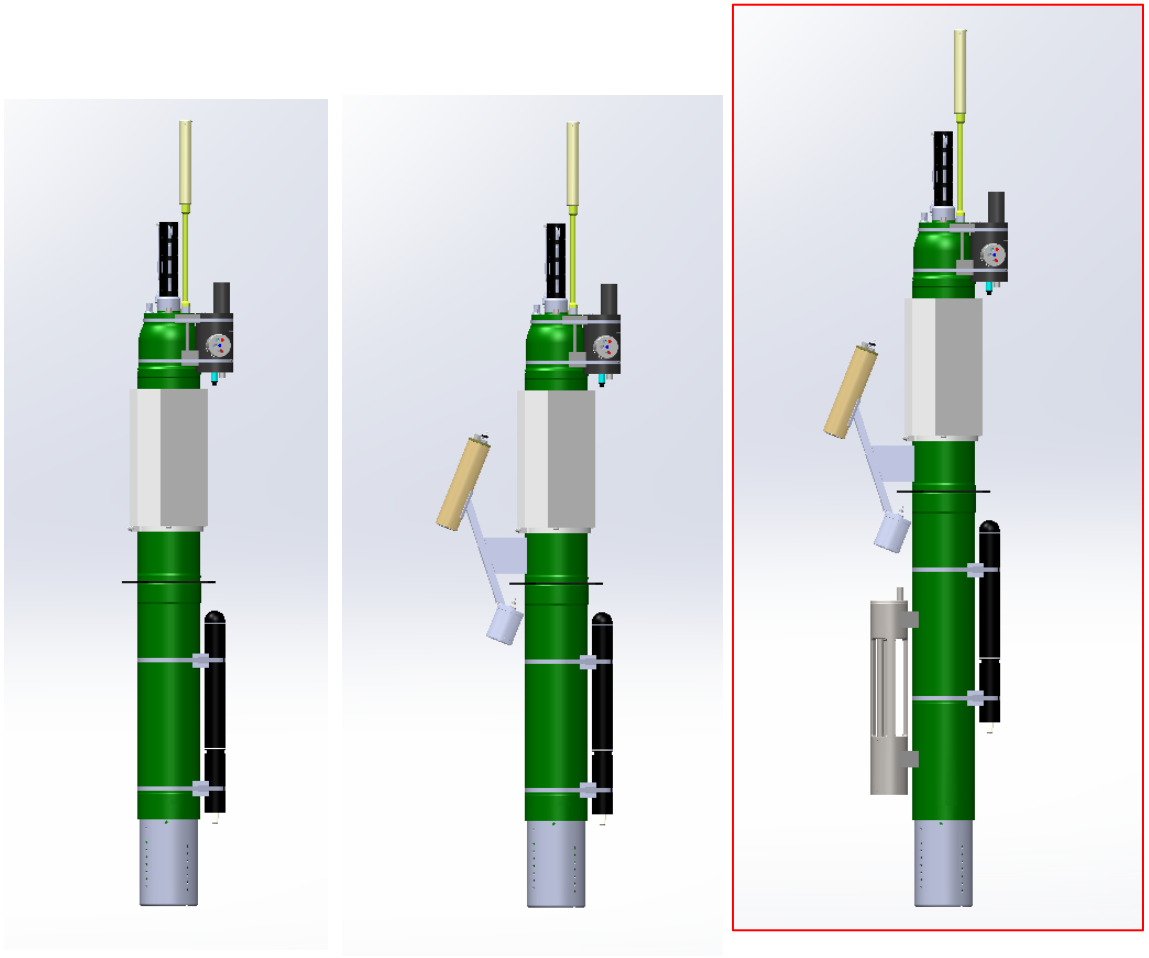
- **Standard but one cycle to 2000 m every 3 (other @ 1000) : 213 profiles, 5.8 y**
- + UVP (no transmissiometer)
  180 profiles, 4.9 y
- b_{bp} and Chla at metric resolution
  207 profiles, 5.7 y



Need to develop a better knowledge of the power consumption of the various float's actions: some

- **Standard BGC-Argo PROVOR 6 core variables : 181 profiles, 5 y** / 271 profiles, 7.5 y
- b_{bp} and Chla at metric resolution: 171 profiles, 4.7 y / 256 profiles, 7 y
- + UVP (no transmissiometer): 152 profiles, 4.2 y/ 228 profiles, 6.3 y

- **Standard but one cycle to 2000 m every 3 (other @ 1000) : 213 profiles, 5.8 y** / 320 profiles, 8.7 y
- b_{bp} and Chla at metric resolution 207 profiles, 5.7 y / 310 profiles, 8.5 y
- + UVP (no transmissiometer) 180 profiles, 4.9 y / 270 profiles, 7.3 y



Hull + 20 cm & 60% more batteries

Some final messages

- The technology is ready for developing comprehensive time series of processes driving Biological Carbon pumps and for addressing the biomass mesopelagic animals (resources).
- We are ready to implement, in complement to “background” BGC-Argo (6 variables, 10-day resolution), robotic process studies with enhanced BGC-Argo payload (imaging, acoustic, OST…) and adaptative sampling.
- Many the properties inferred from such robotic observation are done trough the use of (optical) proxies. => Calibration cruises are essential.

Thanks for your attention !

Balancing between Argo monitoring rules and the need for BGC-Argo process studies at specific scales

- If we want to attract new players into BGC-Argo who will become our advocates we need to find ways to satisfy them
- Increased temporal resolution.
  - Catching biological event (blooms, export, diurnal migration) with specific time scales
  - Cyclone : coordination of fltas on one place
- Increased temporal resolution
  - Thin layers, Deep Chlorophyll maxima, raze event of particle linked to export
- New sensors
  - Imaging and size particle for zooplankton / export
  - Active acoustic for zooplankton
- Several options for this
  - The scientist contribute to the additional consumption linked to it's a
  - In the mean time we improve technology for delivering more energy

- Last AST, Dean pushed the community to target float with ~7 years life-time on Argo mode (i.e. 250 profiles)…
- This is even more challenging for BGC-Argo.
  - Additional standard sensors => additional consummations
  - Possible new applications / variables in the future
    - According to