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« Argo Data Requirements of Copernicus Entrusted Entities »

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List of abbreviations

Abbreviation	Name	Reference
ARCs	Argo Regional Centres	
AST	Argo Steering Team	
BGC	Biogeochemical	
BBP	Particulate backscattering coefficient	
C3S	Copernicus Climate Change Service	https://climate.copernicus.eu/
Cal/Val	Calibration and Validation	
CDOM	Coloured dissolved organic matter	
ChlA	Chlorophyll-A	
CIMR	Copernicus Imaging Microwave Radiometer	https://www.esa.int/ESA_Multimedia/Images/2020/11/CIMR
CMEMS	Copernicus Marine Services	https://marine.copernicus.eu/
COINS	Copernicus Observations In Situ	https://insitu.copernicus.eu/
CRISTAL	Copernicus Polar Ice and Snow Topography Altimeter	https://www.esa.int/ESA_Multimedia/Images/2020/09/CRISTAL
DIC	Dissolved Inorganic Carbon	
DMQC	Delayed-mode quality control	
ECMWF	European Centre for Medium Range Weather Forecasts	https://www.ecmwf.int
EEA	European Environment Agency	www.eea.europa.eu
ENVRI	Community of Environmental Research Infrastructures	https://envri2.eu/
ERIC(s)	European Research Infrastructure(s)	
ESA	European Space Agency	https://www.esa.int/
EUMETNET	European Meteorological Network (A network of 31 European National Meteorological & Hydrological Services)	https://www.eumetnet.eu/
EUMETSAT	The European Organisation for the Exploitation of Meteorological Satellites	https://www.eumetsat.int/
FRM	Fiducial Reference Measurements	
GDAC	Global Data Assembly Centre	
GEORGE	Horizon Europe GEORGE project	https://george-project.eu/
GTS	Global Telecommunication System	
HPLC	High-performance liquid Chromatography (HPLC)	

IBI	Iberia-Biscay-Irish Monitoring and Forecasting Centre	https://marine.copernicus.eu/about/producers/ibi-mfc
IOCCG	International Ocean Colour Coordinating Group	https://ioccg.org/
IMU	Inertial measurement unit	
IN SITU TAC	Copernicus Marine IN Situ Thematic Assembly Centre	
JERICO	JERICO Research Infrastructure: the European gateway for coastal observation	https://www.jerico-ri.eu/
LOV	Laboratory of Oceanography of Villefranche, France	
MFCs	Monitoring and Forecasting Centres	
MFF	Multiannual Financial Framework	
MOB-TAC	Multi-Observations Thematic Assembly Centre	https://marine.copernicus.eu/about/producers/mob-tac
MOBY	Marine Optical BuoY	https://mlml.sjsu.edu/moby/
POC	Particulate Organic Carbon	
OGS	Italian National Institute of Oceanography and Applied Geophysics	https://www.ogs.it/en
OSEs	Observation System Experiments	
OSSEs	Observation System Simulation Experiments	
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem	https://science.nasa.gov/mission/pace/
PAR	Photosynthetically active radiation	
POC	Particulate organic carbon	
QC	Quality Control	
RI(s)	European Research Infrastructure(s)	
RT	Real Time	
SSH	Sea Surface Height	
SSS	Sea Surface Salinity	
SST	Sea Surface Temperature	
T&S	Temperature and salinity	
TAC	Thematic Assembly Centres of the Copernicus Marine Service	
UVP	Underwater Vision Profiler	
WMO	World Meteorological Organization	

1. Introduction

The Euro-Argo ERIC – Copernicus In Situ Workshop: "Argo Data Requirements of Copernicus Entrusted Entities" was organised as part of the COINS Specific Contract 3, on two half-days. It was hosted by Mercator Ocean International in Toulouse, France. The aim was to initiate a discussion with Copernicus Entrusted entities to (1) assess their requirements in terms of Argo data, (2) see how Euro-Argo ERIC could better respond to these requirements in the context of the OneArgo design and (3) develop a common strategy to advocate for EU complementary funding. It gathered 27 participants, about half of them remotely. ECMWF, EUMETSAT and ESA as well as almost all Monitoring and Forecasting Centres (MFCs) and Thematic Assembly Centres (TACs) of the Copernicus Marine Service (CMEMS) were represented (although in some cases by implementers of the physics part only). The list of participants is provided in Annex 1, as well as the Background Document for this meeting in Annex 6.

A general introduction of both the Copernicus In Situ Component and the COINS Specific Contract 3 was made by Jose Miguel Rubio Iglesias from the European Environment Agency (EEA). An overview of the Argo programme, the new OneArgo design, its implementation in Europe and the associated challenges, and the objectives of the workshop, was provided by Yann Hervé De Roeck, Director General of the Euro-Argo ERIC. Participants were then asked to answer a set of questions for each of the 8 essential ocean variables measured by Argo – temperature, salinity and the six biogeochemical (BGC) variables – and discussions occurred informally between all participants along these questions. The second half-day, dedicated to bio-optical parameters measured by BGC-Argo, was introduced by Hervé Claustre (Senior Scientist at the Laboratory of Oceanography of Villefranche (LOV), France, member of Euro-Argo ERIC Scientific and Technical Advisory Group and co-chair of the international BGC-Argo mission team). Argo-BGC products and new additional BGC-Argo variables (e.g. measured by hyperspectral radiometers and Underwater Vision Profilers) were also discussed. The three introductory presentations are provided in Annex 2-3-4.

This report summarises the discussions and requirements, variable by variable, expressed by the Copernicus Services implementers represented at the workshop. The variables were discussed by order of maturity in the Argo network. The specific requirements of each MFC or entrusted entity are provided in Annex 5. The last section of this report highlights the main conclusions and recommendations that came out of this first workshop.

2. Requirements

2.1 Temperature

Temperature is absolutely needed for validation activities of Sentinel-3 and others satellites and is assimilated in all ocean and coupled forecast systems represented.

High latitudes temperature and salinity (T&S) measurements are needed for satellite data validation. In the context of the future CIMR (Copernicus Imaging Microwave Radiometer) & CRISTAL (Copernicus polaR Ice and Snow Topography Altimeter) missions, high latitudes are seen as a priority for Copernicus

(Polar Copernicus missions 2027-2028). Subsurface T&S measurements are valuable for indirect validation of ice thickness (through the computation of buoyancy).

The importance of **surface** measurements was highlighted. WMO is currently not considering Argo as providing Sea Surface Temperature (SST) but this could change if good arguments are pushed forward. The TRUSTED project was mentioned, as a pilot aiming at answering the question of the interpretation of the surface bin in terms of temperature. Drifting buoys for SST measurements with FRM standard have been funded in that purpose through the Copernicus TRUSTED project. It was also reminded that the next version of the European manufactured core floats should be able to sample up to 0.1 dB.

SST is a priority for Numerical Weather Predictions, for boundary conditions, and also very important for all ocean systems. ECMWF assimilates both SST from satellites and near surface temperature from Argo and they are sometimes different, which can cause issues. The need for Real-Time data (RT, i.e. a few hours after the measurement) was stated. Models without assimilation do not display the right amplitude of the temperature signal at depth, hence assimilation of **deep measurements** (below 2000m) is beneficial. RT deep data are also of interest.

A discussion was held on **Fiducial Reference Measurements (FRM).** This concept of FRM is described in the recent publication of Goryl et al. (2023), including the concept of maturity matrix. ESA is currently defining the requirements for the CRISTAL mission on Sea Surface Height (SSH), with one of the main features being the traceability. It could be interesting to see how Argo data could be stamped FRM for satellite Cal/Val applications. About SSH, the issue of the imbalance of sea level rise in recent years needs to be resolved: there is a growing mismatch between altimetric observations by satellites and the addition of ocean mass increase (observed by GRACE) and steric effect (temperature and salinity observed by Argo).

The need for coastal temperature measurements was recalled and the Horizon Europe GEORGE project mentioned. Euro-Argo and several of its partners are involved in GEORGE, in particular for the redefinition of a coastal Argo float, presumably through classical Argo floats tuned for coastal applications (same sensors). Collaboration with the emerging Research Infrastructure JERICO is obviously to be considered for coastal measurements.

Regarding **Quality Control** and **delivery time** of temperature data, no specific enhancement was requested.

2.2 Salinity

The impact of Argo data assimilation (% of improvement) is around the same on the Heat and Freshwater content but the quality of the models without assimilation is worse in representing the salinity variability compared to temperature. Moreover, **Argo is almost the only source of in situ salinity data.**

EUMETSAT is developing a Sea Surface Salinity (SSS) product from the future CMIR mission. It was noted that Argo is the main source of validation for such missions (Boutin et al. 2024). Argo salinity is also used to produce the debiased SMOS SSS L3 maps. RBR sensors equipping some of the Argo floats, which do not need any pumping and then measure salinity up to the surface, are a plus.

In the framework of the SynObs project (UN Decade), discussions are occurring between many international groups assimilating Argo data in their ocean prediction systems. From these discussions, it seems that the **impact of doubling the number of Argo profiles in Western Boundary Currents is not obvious**. No clear conclusion was possible from the Observation System Simulation Experiments (OSSEs) performed by Mercator in their ¼° system, although it may differ in higher resolution systems. However, the **doubling of Argo profiles in the equatorial band has a positive impact** both on temperature and salinity.

Although Argo measures temperature and salinity with the same resolution (same sensor), the requirements from both the satellite and modeler users are not the same for both parameters. It was noted that forecast error maps are different for temperature and salinity, namely in high precipitation regions.

Salinity measurements below 2000m are required in addition to temperature to properly represent the deep ocean dynamics, driven by the density, in ocean models. To complement satellite altimetry data, both vertical profiles of temperature and salinity are also needed. The lack of salinity data in **high latitude regions** was highlighted. Despite the increasing role of the ocean observations by marine mammals for temperature and salinity in in situ data provision, **Argo is still a crucial data provider in these regions**, and should develop its capacity to measure under ice, in both hemispheres (with a priority in the Arctic). Argo salinity measurements **close to the coast** are also important because of the poor quality of satellite measurements in these areas.

The issue of "Abrupt Salinity Drift" of some sensors encountered by Argo and its impact on the Argo salinity dataset quality was pointed out. The impact on model results was significant. More generally, modelers raised the **need to decrease the delay for delayed-mode quality control (DMQC)**, although they are aware of constrains (time series have to be long enough to properly assess the data quality). E.g., in the RT modelling systems, reanalyses are performed in less than one month, so one year for DMQC is too long. A discussion occurred on the Argo quality control processes, in which the historical role of Argo Regional Centres (ARCs) was described. The ARCs are supposed to perform consistency checks at regional level for temperature and salinity, but they are currently underfunded, apart from the Atlantic and the Mediterranean ones. Participants were surprised to learn that Argo data are never reprocessed after the float's end of life, whereas this is a common practice with satellite data. Everyone agreed to state that **regular 'state of the art' reprocessing of the historical Argo dataset would be very beneficial**. This activity could be envisaged at the Argo Global Data Assembly Centre (GDAC) level. The **ESA *Climate Change initiative*** was mentioned as a **possible way to support this action**.

A discussion on the source of Argo temperature and salinity data used by the various entities revealed that some entities take Argo data from the IN SITU TAC, while others use the EN4 product from the

Met Office for reanalyses and data from the Global Telecommunication System (GTS) for Real-Time predictions.

2.3 Oxygen

Oxygen is one of the most important BGC variables.

It is important for validation and is already assimilated (Mediterranean Sea MFC) or will be in the years to come (2-3y, e.g. global MFC) by some MFCs, together with Dissolved Inorganic Carbon (DIC) and Alkalinity. **Uncertainties are needed** as Oxygen also allows to infer other BGC variables: carbonate and nutrients.

Regarding the source of data, Mercator (global system) uses the products distributed by the MOB-TAC (profiles). These products are made using oxygen data from the IN SITU TAC and machine learning techniques. The MOB-TAC aims at releasing monthly updates of these carbonate system products. (NB: Oxygen is distributed both by IN SITU & MOB TACs). The Mediterranean MFC (OGS) uses Oxygen data directly from the GDAC, for historical reasons. They previously used the RT-adjusted Oxygen data, but had to stop since the density of data decreased in the recent years. OGS performs local quality control (QC) of the Oxygen data because the **QC performed by Argo is not done early enough**. The need to organise a discussion between OGS teams in charge of this local QC and the Argo data management team was raised.

The IBI and Baltic MFCs mentioned the lack of density in Oxygen data availability for data assimilation.

The discussion about Oxygen data led to the suggestion to equip all Argo floats with an Oxygen sensor as a target for Euro-Argo, given the importance of this variable in inferring other parameters. The **need to perform consistency checks at regional level**, which become increasingly important with new sensor types entering the market, was also noted. With this need comes the need to fund such activities.

To be used to infer other key parameters assimilated in BGC ocean models, oxygen data need to be very accurate, and the **uncertainty needs to be known**. It was thus reiterated that the **DMQC for Oxygen and associated uncertainties are not performed soon enough by the Argo community**. For the Black Sea and Baltic Sea MFCs, the quality control remains an issue as the standard procedures cannot be applied directly.

No MFC uses Deep (below 2000m) Oxygen data.

2.4 pH

Euro-Argo recalled that at present, Europe has stopped buying pH sensors, since there is an issue with the Seabird IFSET sensor (currently the only sensor on the Argo market)[1]. The **carbon community is reluctant about using pH to estimate carbon**, but pCO2 sensors are not yet mature enough to be deployed on Argo floats.

The pressing issue of air-sea fluxes for carbon estimation was stated. It was noted that the goal of the World Meteorological Organisation (WMO) is to get estimates with an accuracy of 2-5µATM, whereas the best we can currently get with Argo is 15 µATM. In a research proposal (TRICUSO) submitted in March 2024 and in which Euro-Argo is involved, Observation System Experiments (OSEs) are proposed for carbon fluxes estimates using Oxygen, pH and wind data from Argo.

Mercator is only starting to assimilate pH, using **gridded maps because of the lack of global coverage**, which is not ideal. In general, **pH is very useful for BGC models validation** - even if not assimilated.

2.5 Nitrate

Nitrate sensors on Argo floats are **5 times more expensive than, e.g., Oxygen sensors**, and Argo is facing a monopolistic situation (only one manufacturer currently on the market). However, tests are currently undertaken by Argo teams with a new Nitrate sensor manufactured by TRIOS (Germany), showing promising results. It was noted that the MOB-TAC products of Nitrate, estimated from Neural Networks techniques (see below, “3D-products” section), have an associated uncertainty of the same order of the Argo Nitrate sensor accuracy (~0.7 µmol/kg).

Nitrate measurements from Argo are used for validation of model outputs. It is presently not assimilated by any group. For the global system, the timeline is the same as for Oxygen, i.e. Nitrates should be assimilated in the 2-3 years to come. The **Mediterranean system used to assimilate Nitrates** data from Argo but **had to stop because of the lack of data**. There was a gap of 2 years without any Nitrate data in the Mediterranean Sea, due to the end of deployments in the region by the scientific teams, and although deployments have started again (through new projects) the data coverage is recovering but still not dense enough for assimilation. The **value of Nitrate for validation** purposes was highlighted, e.g. for **checking the depth vertical profile shape** provided by the models.

The Baltic Sea MFC encounters the same issue for Nitrates as for Oxygen, i.e. a coverage too poor for data assimilation. Given the high cost of the Nitrate sensor, it was not deemed a priority to equip Argo floats with Nitrate sensors, but rather to deploy more floats with other parameters. Moreover, this parameter is **not particularly useful in anoxic areas, which are characteristic of the Baltic Sea**.

Under-ice Nitrate measurements are very valuable, for the same reasons as for Oxygen (strong variability), and the importance of having Nitrate data on the shelf was raised for the IBI MFC.

[1] It seems from presentations made at the 25th AST meeting the week after this COINS workshop that the SBE pH sensor issue has now been solved.

Regarding QC timeliness, the requirements are the same as for Oxygen and Temperature/Salinity (7 days window).

No MFC uses Deep Nitrate data (below 2000m).

The future strategy for Nitrates was inquired. As we can retrieve Nitrates values through Neural Networks techniques, the idea **in Europe is to put fewer Nitrate sensors on floats**, while continuing the efforts for sensor diversification (with TRIOS) and possibly an associated cost decrease. As an asset, it was also noted that Argo is one of the best platforms to avoid biofouling (as the floats stay in the dark during 10 days).

2.6 Chlorophyll-A, particulate backscatter coefficient (BBP), downwelling irradiance & associated products and their potential for satellite validation

Chlorophyll-A (ChlA), BBP & downwelling irradiance are key parameters for Ocean Colour Radiometry.

ChlA:

ChlA data are measured by fluorescence (FchlA). It was recalled that the ratio FclhA/ChlA (slope) is not constant; it varies with phytoplankton type, light history, and nutrients limitation and is therefore regionally dependent on the biogeochemical state. Recent studies have highlighted several ways to estimate this slope (Roesler et al. 2017), which provides a potential framework for reprocessing the whole Argo database, for consistency. It was noted that the seasonal variability is not yet taken into account in the present method developed for slope estimation.

A discussion on the slope factor occurred, where it **was suggested to compare the maps of slope factor obtained from the global MFC and the one from the LOV team**. This comparison should benefit both communities. It was noted that, in the Mediterranean Sea, globally-tuned satellite algorithms do not work well because of the specific bio-optical properties of the basin, so Argo measurements are really needed. The average slope factor of 2 currently used in the global Argo dataset is appropriate for the Mediterranean Sea (compared to variability). The methodology developed by the LOV team for the slope factor FchlA/ChlA estimation is ready, and the documentation is being finalized. This method was later endorsed by the Argo Steering Team (AST) at the AST25 meeting, the week following the workshop. It will then start to be implemented by the Argo Data Management Team on the global Argo dataset. The Argo dataset adjusted using this method cannot be straightforwardly used by EUMETSAT for satellite Ocean Colour validation, because of non-independence of the datasets, but could be used for Quality Control as well as to identify potential regional differences.

EEA could recommend focusing on this topic within the next research framework programme of the EU (FP10) and also recommend the full reprocessing of the existing dataset. The ENVRI cluster could be targeted in this recommendation.

The Global MFC currently uses ChlA for model evaluation and parametrisation and plans to assimilate ChlA in the future, while the Mediterranean Sea MFC is already assimilating this parameter.

Suspended Particles (BBP)

BBP is much more reliable than ChlA for satellite validation purposes. It is a proxy for Particulate Organic Carbon (POC) concentration and for phytoplankton carbon biomass.
No interest in deep (below 1000m) measurements was raised. However, **measurements during the float drift were deemed interesting**. It was mentioned that BBP, ChlA (although poor) and reflectance surface products are provided by the Ocean Colour TAC.

Downwelling Irradiance

There are currently 3 downwelling irradiance sensors available on the Argo market, with various sensitivities.

Some studies have shown the potential of in situ irradiance measurements from Argo for the validation of satellite algorithms for diffuse attenuation of downward irradiance. The float measurements give access to **profile values of Kd** (diffuse attenuation coefficient) and have the advantage of being more representative of various regimes (with respect to historical ship-based database skewed towards less clear waters). A Neural Network based model has been developed (**SOCA-light**) to **infer vertical distribution of light thanks to physical data from Argo and satellites Ocean Colour data** (Renosh *et al.*, 2023). The **retrieved values are less noisy than the direct measurements** (sometimes contaminated by clouds and/or wave-focusing) and could thus be of interest for modellers. This light gridded product should be implemented in the MOB-TAC in the future.

The irradiance sensors make measurements along 4 bandwidths and all Argo floats are not configured to measure the same bandwidths. In 2021, an Argo Working Group issued recommendations for a common set of bandwidths that should be measured by Argo, which enable photosynthetically active radiation (PAR) computation, but these recommendations are not yet implemented by all teams deploying Argo floats.

Overall, under ice and coastal ChlA, BBP and irradiance measurements were mentioned as very important.

3D-PRODUCTS:

The MULTIOBS_GLO_BIO_BGC_3D_REP product provides global **3D-gridded so-called SOCA** (Satellite Ocean-Color merged with Argo data to infer bio-optical properties to depth) **products of ChlA, POC, radiometric variables (PAR)**, etc. from Copernicus satellite data (Ocean Colour and altimetry) and Copernicus INS-TAC temperature and salinity data (ARMOR-3D). The November 2024 release of this product will use the new slope factor developed by the LOV team (see above), using the SOCA-light method, i.e. with no radiometry as input. In this product, the POC data is provided using two different algorithms for computation from BBP, so that the user can choose its preferred one.

It was noted that there is a factor of 2 between surface (satellite) and depth (Argo) ChlA. This is currently a problem that is being addressed, in particular using historical High-performance liquid Chromatography (HPLC) measurements that can now be related to a modelled (using neural Network techniques) Argo ChlA profile, providing the HPLC measurements were performed during the ocean color era (i.e. after the launch of Seawifs).

The question whether **it would be useful for MFCs to get the data at the float location instead of gridded** was asked and the answer was positive, as such inputs would be easier for performing OSSEs and are **more appropriate for assimilation** (no correlation in assimilated datasets). The question of where and how Argo should deliver these "along track" products was raised but needs to be further discussed, including within the Argo community.

It was reminded that these products cannot be used for satellite validation because they are not independent.

FROM VAL TO CAL ACTIVITY (radiometry)

The purpose of the BOUSSOLE project was to establish a time series of optical properties in open ocean waters, in support of bio-optics research, for the calibration of ocean colour satellite observations, and validation of the products derived from these observations. This project has now ended and another European waters site will be chosen to continue the acquisition of in situ optical data for satellite calibration activities. Several **examples in favour of using a dedicated fleet of BGC-Argo for calibration, in complement to this new in situ calibration site**, were presented: the Argo platform is appropriate to avoid seasonal bias (Bisson et al. 2021). Floats can be used to validate Reflectance measurements thanks to availability of both downwelling irradiance and upwelling radiance (Gerbi et al. 2016) and are able to provide correction for temperature dependency of the radiometry measurements and to catch the diversity that is not seen by few moorings as MOBY (Hawaii) is presently the only a dedicated one.

As of March 2024, 12 floats equipped with hyperspectral downwelling and upwelling radiance sensors are at sea (EU ERC REFINE project) and there are more to come. NASA is presently supporting four pairs of additional hyperspectral sensors for equipping new French BGC-Argo floats. Since the launch of NASA PACE hyperspectral ocean colour sensor, the float cycles of the 12 floats currently at sea have been set to 5 days instead of 10 days to increase the possibilities of matchups during satellite commission phase. CNR will deploy 6 floats in the Mediterranean Sea through the ITINERIS project equipped with hyperspectral downwelling and upwelling radiance sensors. A few hyperspectral floats are equipped with an additional ChlA channel (instead of CDOM). These JUMBO floats equipped with additional sensors are also bigger and contain more batteries, in order to be able to comply with the classical Argo mission (10-day cycle, for 5 years), leaving sufficient energy to accommodate fit-to-purpose sampling strategies when required as it is here the case for validation purposes.

The **importance of recovering the floats for re-calibration in order to be able to be FRM-stamped was mentioned**. The Ocean Colour community, to get the FRM stamp on radiometry for CAL/VAL, has established specific steps/protocols through EUMETSAT and the FRM4SOC initiative.

Radiometric measurements need to occur at the zenith or at the time of the satellite overpass. An inertial measurement unit (IMU) controls the inclination of the float. The proper calibration of the sensor also requires some profiles in the darkest time of the night to assess the temperature dependence of the sensor: a specific piloting of this kind of float is therefore needed.

The need to **push for incorporating the financing of such CAL/VAL/QC activities in the next Multiannual Financial Framework (MFF)** of the European Commission was highlighted. In the next MFF, there should also be opportunities for buying additional equipment (similar to the TRUSTED project), e.g., through CNES. This **idea will be brought at the International Ocean Colour Coordinating Group (IOCCG) level** by Hervé Claustre.

2.7 New Argo variables and their potential

Zooplankton

There are currently **32 floats equipped with an Underwater Vision Profiler (UVP)** sensor at the GDAC. This sensor contributes to the **study of the carbon pump**. The sinking speed of particles in the water can be computed for each particle size range. This sensor can show evidence of diurnal migration (work of Leo Lacour) which could be used for model parametrisation. It was mentioned that it **would be useful to get the information in units of carbon**. This is work in progress. When it will be available (units of carbon), the global MFC will be very interested.

Documentation for UVP data processing is ready and published, but the parameter is not yet endorsed as an official OneArgo variable. The data are available on the GDAC “aux” directory. The idea for the future, if UVP data becomes a OneArgo variable, is to provide UVP data the same way as BBP.

MFCs mentioned that a **global coverage of such data would be interesting**.

PCO2 and other carbonate system and nutrients variables (provided as products)

Although tests are currently carried out with Argo floats equipped with a pCO2 sensor (in the HE GEORGE and German C-SCOPE projects), further sensor developments are required for a large-scale deployment.

The MULTIOBS_GLO_BGC_NUTRIENTS_CARBON_PROFILES_MYNRT product, delivered by MOB-TAC, provides Nutrients (since 2019) and Carbonate system (including pCO2, since 2022) synthetic profiles obtained from the CANYON-B method, using the GlodapV2 product for training and Argo Temperature, Salinity and Oxygen data as inputs. Uncertainties of all the recomputed variables are provided in Annex 4. pCO2 is provided with an accuracy of 15 µATM. This product will be released monthly, using

Oxygen data adjusted in RT, increasing the uncertainties when it is only available in RT. The issue of data quality information at the MOB-TAC level yet has to be defined.

pCO2 can be used for model validation, but for assimilation it is useful only if pH is also available, because the parameters assimilated are DIC & Alkalinity (inferred from pH and pCO2). Depth data are not important as the interesting part is surface fluxes.

No representative of the Copernicus Climate Change Service (C3S) team in charge of the carbon issue participated in the workshop. In a former discussion between Paul Poli (ECMWF) and YH De Roeck, the interest of C3S for all contributing observations for assessing carbon fluxes was expressed.

It was agreed to **bring to the EC the need to fund the development of pCO2 sensors for BGC floats**, which could have huge perspectives for the monitoring of the carbon uptake by the ocean.

<u>**Acoustic winds**</u>

Wind measurements via acoustics is another prospective field for Argo. First tests were done on USA floats in the 2000's (Riser et al. 2008, data available on the aux directory) and tests of wind sensors are currently carried out in the GEORGE project. The **aim of such measurements is to estimate CO2 fluxes** (FCO2=pCO2 x fct(wind intensity)).

The complementarity of such direct measurements versus satellite observation by scatterometers still needs to be quantified. The new NASA mission ODYSEA dedicated to winds and surface measurements was mentioned. Satellites measure wind stress, whereas with hyperspectral sensors we also get Sea State data.

Such **wind measurements can also be useful for scatterometers validation, but it depends on uncertainties**, since other in situ measurements are available. It was noted that **rain data would be interesting**. In fact, this passive acoustic measurement records the sea state, which is then converted to wind stress. An IMU would also be a plus to interpret these data, but it only exists so far on floats that carry hyperspectral sensors. Developments at Ifremer/LOV for active acoustic targeting small animals were also mentioned.

It was **suggested to Euro-Argo to contact the responsible of the WIND-TAC (KNMI)**.

3. Conclusions, Recommendations and Next Steps

3.1 Summary

The workshop gathered a group of scientists in charge of the implementation of the Copernicus Climate and Marine Services and Euro-Argo representatives. Discussions were very productive and both data users and providers learnt from each other. The willingness to continue these exchanges was expressed by all participants.

In situ ocean observations are crucial for the entrusted Copernicus entities represented at the workshop. All participants valued the importance of achieving a OneArgo implementation by 2030. The table below summarises the use of all variables currently measured by Argo by the various entrusted entities.

Table 1 - Current and future use of Argo data by Copernicus entrusted entities represented at the workshop - more details are provided in Annex 5

	Temperature	Salinity	Oxygen	Nitrate	pH	Chlorophyll a	Suspended particles	Downwelling irradiance (Ed)	Upwelling radiance (Lu)	pCO_2	Surface wind	Zooplankton
ECMWF-PHY	used in operational ocean DA system	used in operational ocean DA system	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ARC-MFC	NRT for forecast and DM for reanalysis with DA system	NRT for forecast and DM for reanalysis with DA system	For validation of BGC forecast and reanalysis	DM for DA and validation of nitrate concentration	DM for validation of carbon chemistry (not implemented yeat)	NRT and DM for DA and validation of phytoplankton biomass	Validation for POC			DM for validation of carbon chemistry (not implemented yet)		DM for validation of zooplankton biomass (not implemented yet)
MED-MFC	DA, Validation + NN for reconstructed profiles	DA, Validation + NN for reconstructed profiles	Data Assimilation + NN for reconstructed profiles	DA, Validation	Validation	DA, Validation	Validation for PhytoC and PPOC	At the moment validation just for PAR				
GLO-MFC	validation and data assimilation in RT and in DM (mostly) for reanalysis	validation and data assimilation in RT and in DM (mostly) for reanalysis	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026		RT Data Assimilation planned in 2026
BLACK-BGC-MFC								cal/val of spectral radiation model, more than 3 wavelengths would be even better				calibration/validation of BGC model
IBI-MFC	validation and data assimilation in RT and in DM (mostly) for reanalysis	validation and data assimilation in RT and in DM (mostly) for reanalysis	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026	RT Data Assimilation planned in 2026		RT Data Assimilation planned in 2026
BAL-MFC	CAL/VAL	CAL/VAL	CAL/VAL	CAL/VAL		CAL/VAL						
OC-TAC						Product validation/ intercomparison	Product validation/ intercomparison (depending on wavelength)	CAL/VAL Product Validation	CAL/VAL			
EUMETSAT	Validation	Validation				Validation, if direct measurement and more accurate (better than 30% uncertainty)					For validation of scatterometer winds	

The workshop allowed to produce a non-exhaustive list of recommendations that should help Euro-Argo to (i) update its strategy for the implementation of the OneArgo array and (ii) find some complementary fundings needed to achieve the OneArgo design and better serve Copernicus services. These recommendations are detailed hereafter.

3.2 Recommendations

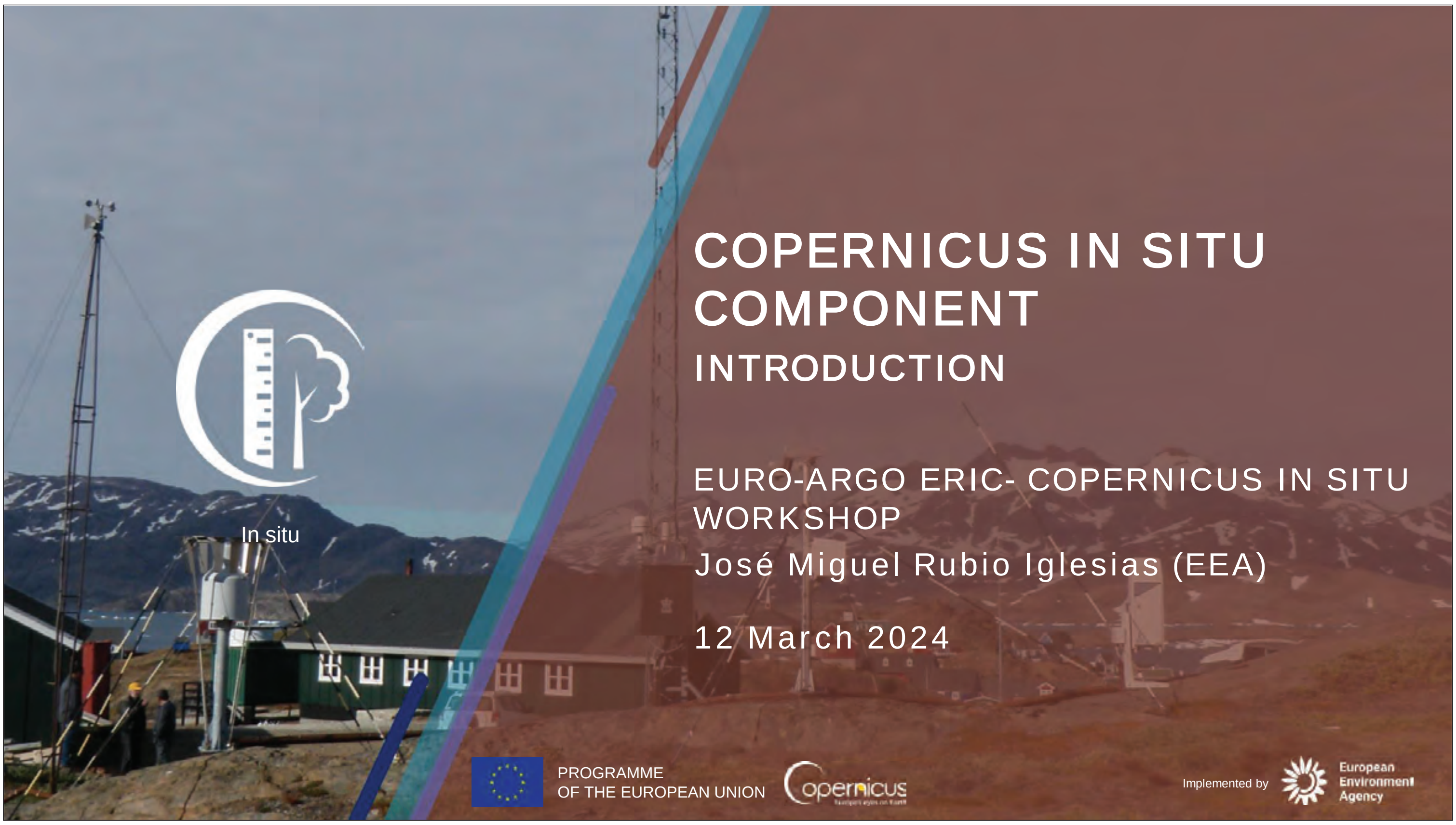
- It is indispensable for CMEMS and EUMETSAT that Argo ensures, in the future, the same level of service as currently (the implementation of OneArgo should not degrade the current core array).
- Euro-Argo is encouraged to demonstrate the value of Argo in providing Sea Surface Temperature (SST) measurements. Although other data sources exist, it could be beneficial that WMO considers Argo as an SST data provider, which is not the case today.
- Recurrent reprocessing of the whole Argo dataset should be performed. This could be envisaged at the GDAC level, and Euro-Argo should investigate how the Climate Change initiative of the ESA could support such an action.
- It is recommended that Euro-Argo investigate the possibility to get Argo data, at least for some parameters, stamped as Fiducial Reference Measurements (Goryl et al., 2023). This would imply recurrent reprocessing of the historical Argo dataset related to these parameters.
- The use of synthetic BGC data products inferred from Argo measurements and Machine Learning techniques is widespread in the different MFCs. For certain applications (data assimilation, e.g. Nitrate), these datasets are even better suited than real observations. Although it is obvious that real observations are always required, a balance could be considered, taking into account the relative cost of the different BGC sensors, when defining the strategy for an efficient OneArgo implementation.
- Argo Oxygen measurements play an important role in the production of BGC synthetic products, in particular to infer carbonate system variables. For this reason, it is recommended that Euro-Argo maintains a sufficient array of floats equipped with Oxygen sensors and investigate the possibility to go up to equipping all core-Argo floats with an Oxygen sensor.
- A prerequisite for an efficient use of Argo Oxygen data by the MFCs is the provision of precise uncertainties associated with the data. These uncertainties have a crucial impact on the inferred parameter values which are then assimilated by the MFCs, and efforts should be pursued by Euro-Argo to improve the uncertainties provided with Oxygen data.
- Polar data (under ice), and coastal data are seen as priorities for Copernicus, for most of the parameters, and it is recommended that Euro-Argo continues to develop its activities in this regard.
- Copernicus would benefit from an improved timeliness of DMQC data provision for all parameters.

- There is an interest from Copernicus in the measurements of new variables by Argo, in addition to the 8 official OneArgo variables, and Euro-Argo is encouraged to continue the ongoing developments for a future integration of Zooplankton, Hyperspectral irradiance, and wind data as part of Argo. The further development of a pCO2 sensor compatible with Argo is also encouraged.
- As part of the SEAMLESS HE project, developments and experiments of joint satellite and in situ ensemble biogeochemical data assimilation were performed by several MFCs, which led to recommendations on the use of BGC Argo data in the Marine Copernicus MFC 3D domains. Euro-Argo is encouraged to read the associated Deliverable of Cossarini et al. 2023 and the related publication of Ford (2021).
- Euro-Argo should submit proposals to continue activities aiming at demonstrating the usefulness of Argo for Ocean Colour satellite calibration. EEA could recommend focusing on this topic within the next research framework programme of the EU (FP10) and also recommend the full reprocessing of the existing dataset. The ENVRI cluster could be targeted in this recommendation.
- Euro-Argo ERIC and Copernicus Entrusted Entities should prepare a joint lobbying/advocacy paper on the need to include, in FP10, calls for specific Argo technological or other developments related to/answering the needs of operational users.

Annex 1: Participants list

(*=remote attendance)

- Estelle Obligis – EUMETSAT: interest in validation of SST, Ocean Colour, altimetry
- Pierre-Yves Le Traon, Antonio Reppucci, Elisabeth Rémy, Alexandre Mignot, Julien Lamouroux, Elodie Gutnecht, Stefano Ciavatta – Mercator Ocean International: CMEMS global and IBI MFC
- Emanuele Organelli – CNR: CMEMS, OC-TAC
- Hervé Claustre – CNRS/LOV: Euro-Argo member, Argo BGC Vice-Chair
- Antoine Mangin – ACRI: CMEMS, OC-TAC
- Jérome Bouffard* – ESA: ocean remote sensing
- Laura Tuomi* – FMI: CMEMS, Baltic sea MFC
- Laura Feudale* – OGS: CMEMS, Med MFC
- Tsuyoshi Wakamatsu* – NERSC: CMEMS/ MFC Nordic seas
- Diana Azevedo* – OGS: CMEMS, Black Sea MFC
- Hao Zuo* – ECMWF: CMEMS global modelling
- Gianpiero Cossarini* – OGS: CMEMS Med MFC
- Eric Jansen* – CMCC: CMEMS Black Sea MFC
- Helen Morrison* – BSH: CMEMS Baltic MFC
- Jenny Pistoia* – CMCC: CMEMS Med MFC
- Alessandro Grandi* – CMCC: CMEMS Med MFC
- Jose Miguel Rubio Iglesias* – European Environmental Agency, principal for the COINS project
- Kirsty McBeath* – EUMETSAT (UK Met Office): COINS project manager
- Yann-Hervé De Roeck, Claire Gourcuff, Luc van Dyck, Romain Cancouet* – Euro-Argo ERIC



2

Why in situ data in Copernicus?

In situ

In Situ data is used both for **production** and **validation** in Copernicus Services, as well as being provided to users as observations.

Satellite sensors need to be **calibrated**, and their data products **validated**, using independent in situ data sources.

In Situ data comes from a **myriad of data providers** and networks at national, regional and global level, including **Research Infrastructures**.

Without in situ data, Copernicus simply cannot deliver its data, products and services.

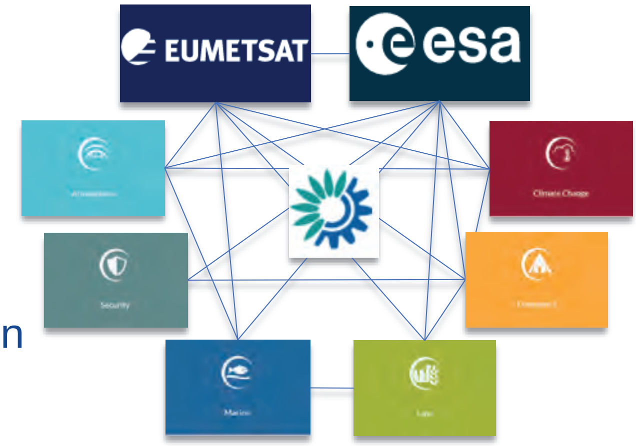
European Environment Agency | European Commission | Copernicus

The role of EEA in Copernicus In Situ

In situ

Entrusted Entities access and manage in situ data directly according to their operational needs on a day-to-day basis.

The EEA intervenes when a coordinated approach to accessing in situ data is required at a programmatic level.



PROGRAMME OF THE EUROPEAN UNION Copernicus Europe's eyes on Earth

Implemented by European Environment Agency

In Situ expert support to EEA

In situ

PROGRAMME OF THE EUROPEAN UNION Copernicus Europe's eyes on Earth

Implemented by European Environment Agency

In situ

Cross-cutting coordination activities (2021-2028)

STATE OF PLAY
- **State of Play report**
- CIS2
- Factsheets

DATA ACCESS
- CORDA
- Access to specific in situ data

ENGAGING WITH DATA PROVIDERS
- Licensing agreements
- Use cases
- **Research Infrastructures**

SUPPORT AND ADVICE
- In Situ Working groups
- Reports, inventories
- GEO, R&D

PROGRAMME OF THE EUROPEAN UNION Copernicus Europe's eyes on Earth

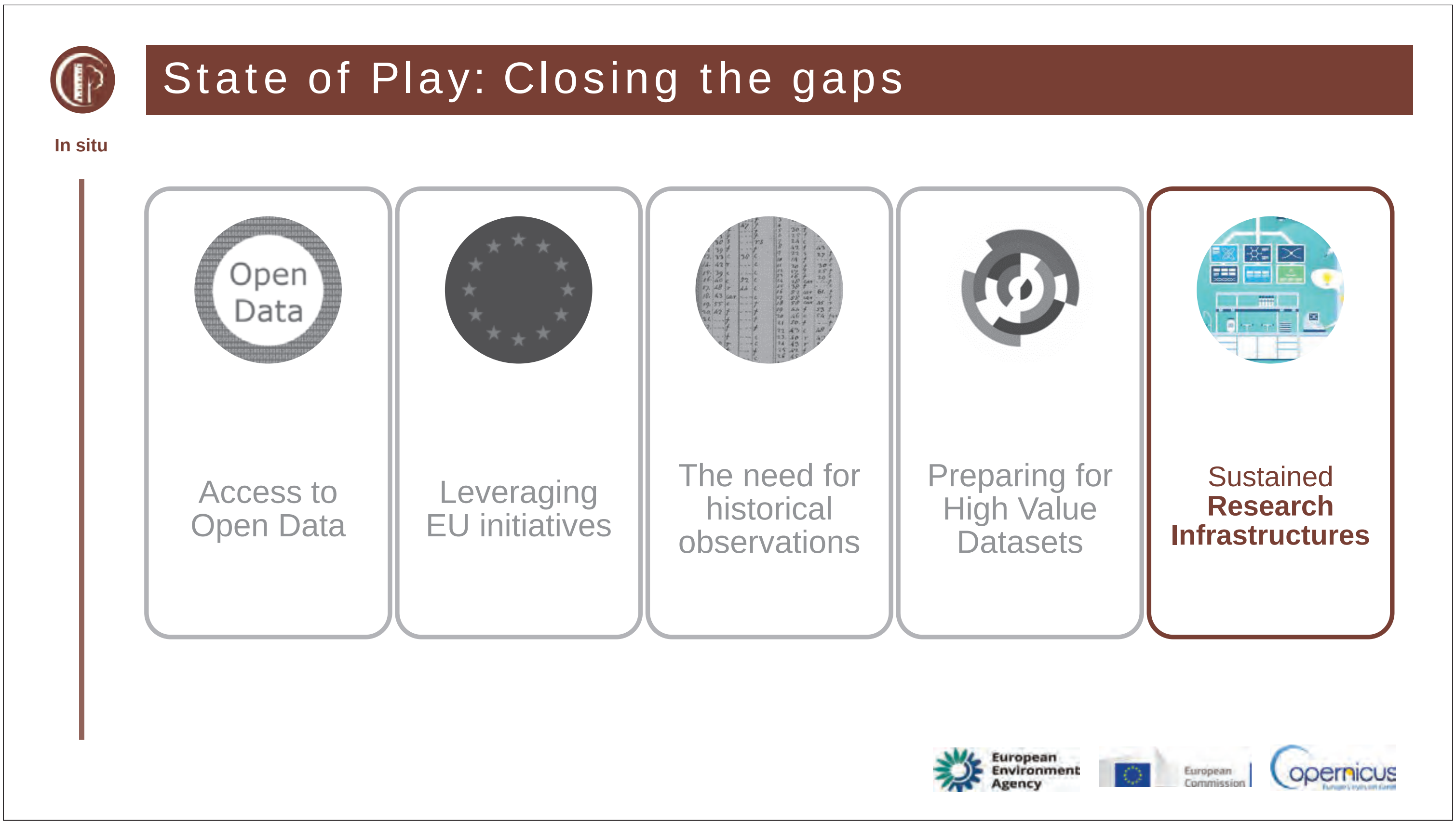
Implemented by European Environment Agency

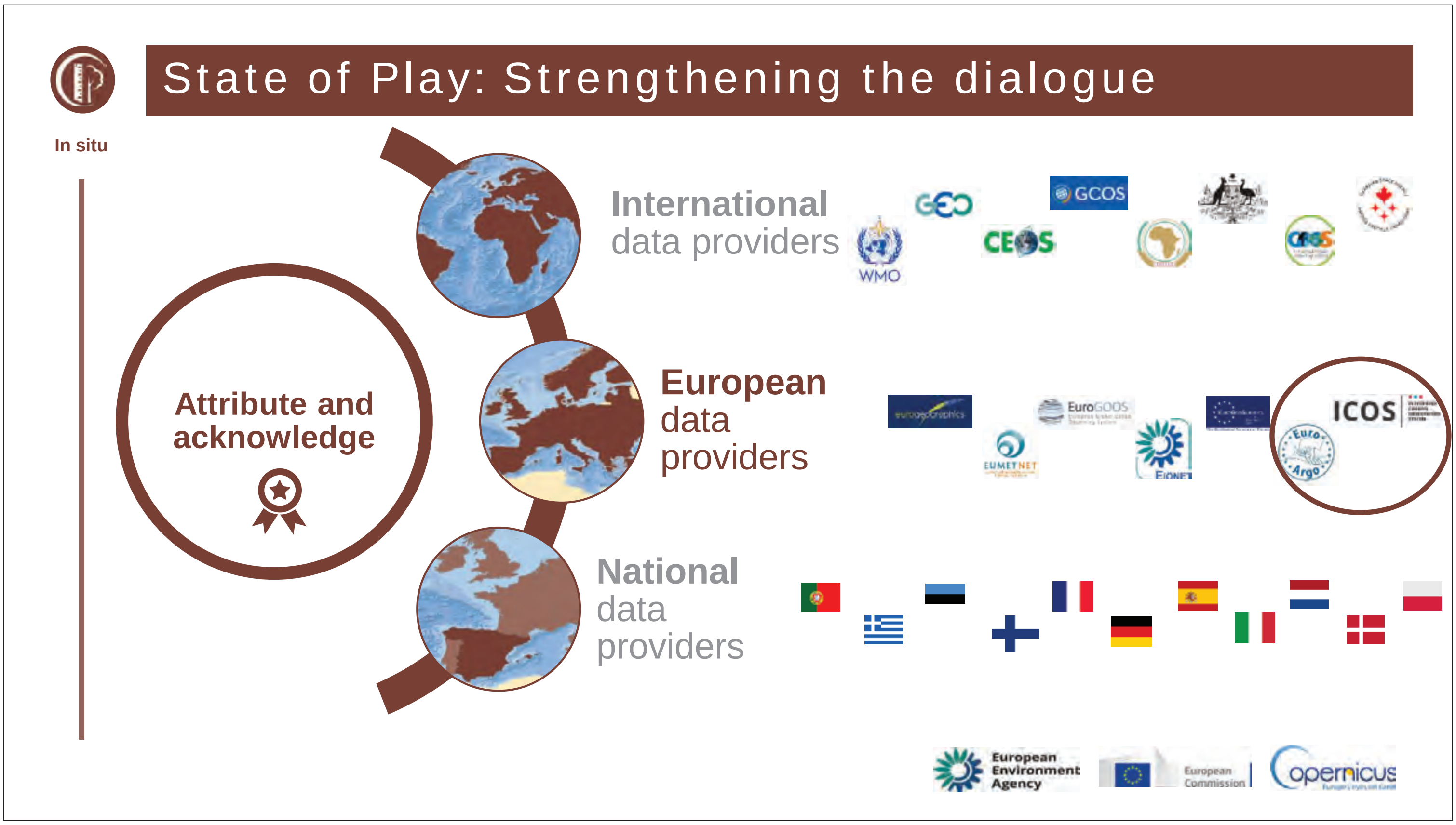
In situ

State of Play 2024: key issues encountered

- Access conditions and use restrictions
- Insufficient spatial coverage
- Uncertain sustainability of critical networks
- Fragmentation and heterogeneity
- Lack of alignment with data providers
- Insufficient acknowledgement
- Not long enough historical high time series
- More data needed on specific areas
- Increasing demands in frequency and resolution
- Rapid accessibility

European Environment Agency European Commission Copernicus Europe's eyes on Earth


State of Play: Closing the gaps
In situ
Open Data
Access to Open Data
Leveraging EU initiatives
The need for historical observations
Preparing for High Value Datasets
Sustained Research Infrastructures
European Environment Agency
European Commission
Copernicus


State of Play: Strengthening the dialogue
In situ
Attribute and acknowledge
International data providers
GEO
GCOS
WMO
CEOS
European data providers
EuroGOOS
EUMETNET
EIONET
ICOS
Euro Argo
National data providers
European Environment Agency
European Commission
Copernicus

Copernicus and Research Infrastructures

In situ

Several **Entrusted Entities** depend on data collected, managed and delivered by **European Research Infrastructures**

The already existing collaboration between Copernicus and RI may benefit from **additional dialogue** and **information exchange**

There is a need to address the gap between Copernicus requirements and availability of resources for RI

Environment Agency | European Commission | Copernicus

Engaging with Research Infrastructures

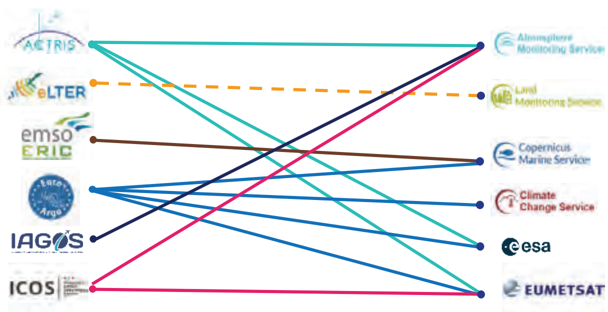
In situ

Create an **overview** of main links and dependencies with Copernicus

Bring Copernicus requirements to RIs at the **ERIC fora** and relevant meetings

Highlight the relevance of RI to **Copernicus Governance Bodies** and **Commission**

Organise workshops to discuss specific requirements and solutions to address them



This workshop serves as a blueprint for future similar workshops between Entrusted Entities and RIs


In situ
insitu.copernicus.eu

EUROARGO
EUROPEAN RESEARCH INFRASTRUCTURE CONSORTIUM
FOR OBSERVING THE OCEAN

Euro-Argo ERIC – Copernicus In-Situ Workshop
Argo Data Requirements of Copernicus Entrusted Entities
12 March 2024

Copernicus Observations In Situ Networking and Sustainability COINS project

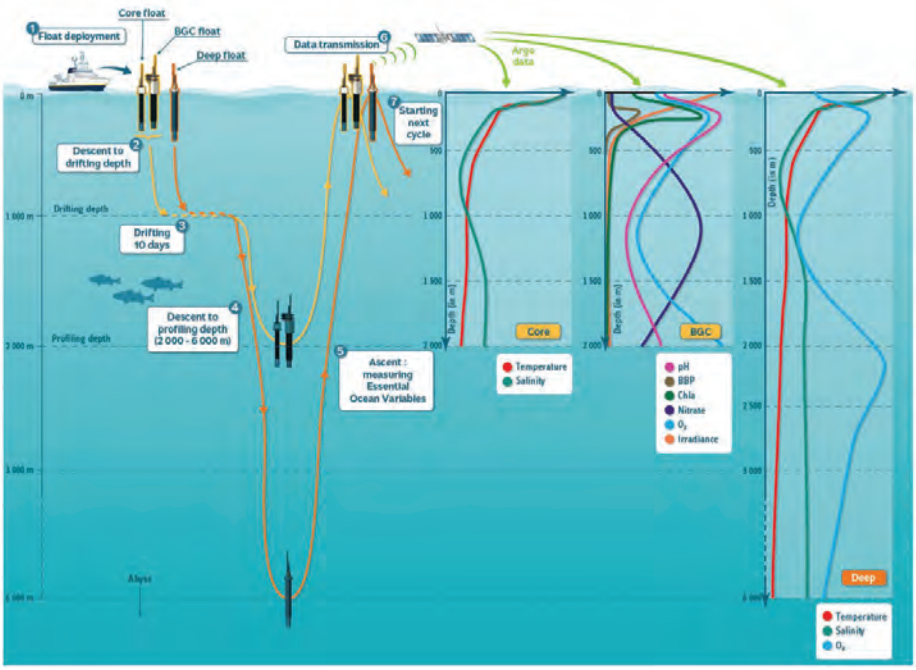
GEORGE

What is Euro-Argo ERIC

- Euro-Argo ERIC is the Research Infrastructure coordinating and strengthening the European contribution to the International Argo Programme

- Argo is a global real-time *in situ* ocean observing network, of about 4,000 autonomous floats worldwide, performing recurring vertical profiles of the water column while drifting in the oceans

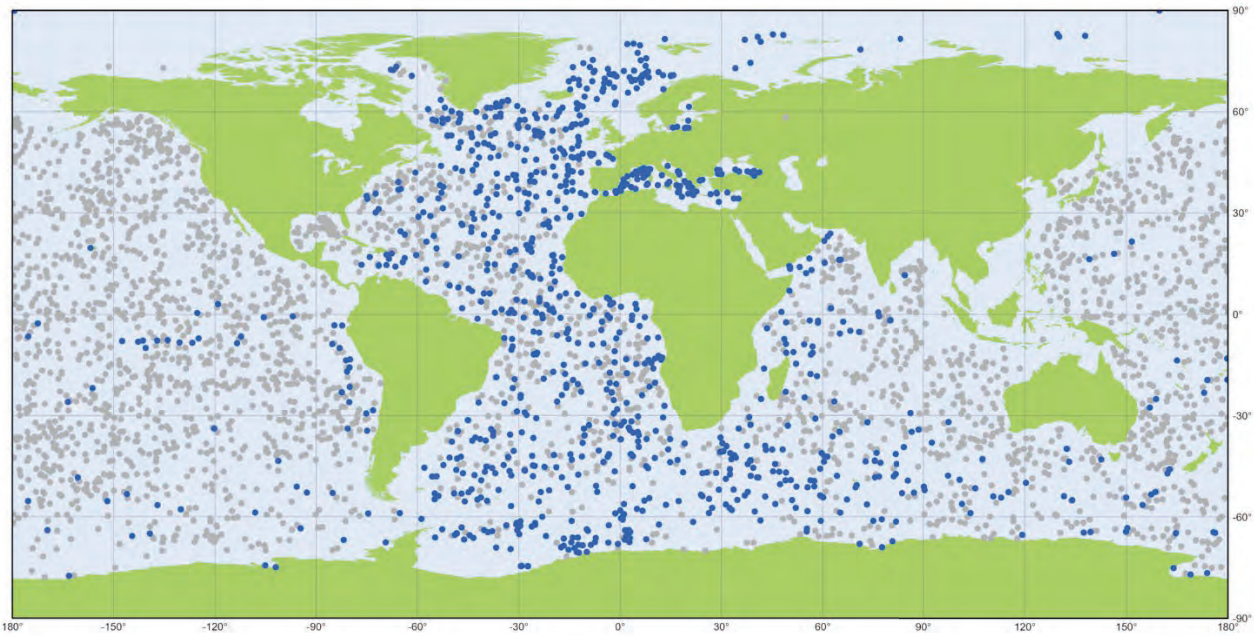
- Euro-Argo ERIC aims at procuring, deploying and operating 25% of the Argo floats network that provide an unprecedented free and open quality-controlled dataset



Ten day cycle of an Argo float
Along the initial floats **(Core floats)** measuring T & S, new generations of Argo floats are also able to measure up to six biogeochemical parameters (**BGC floats**) and to dive till -6 000 m (**Deep floats**)

Argo global array today

1 float / $(3°)^2$



Argo EuroArgo January 2024

European contribution to the Argo program via EuroArgo Research Infrastructure
Latest locations of operational profiling floats (data distributed within the last 30 days)

• Argo EU (972) • Argo non EU (2907)

Generated by ocean-ops.org, 2024-02-01
Projection: Plate Carree

Argo evolution since 2001

Progressive deployment of the floats
Floats drift during 4 to 6 years
2008: Argo Core mission covered

10% recovery

Since 2019, new design of the global programme: OneArgo

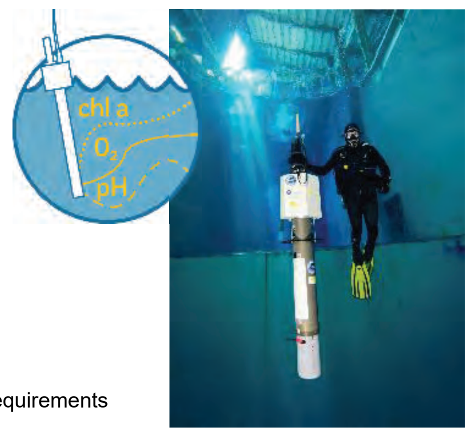
Geographical extent:

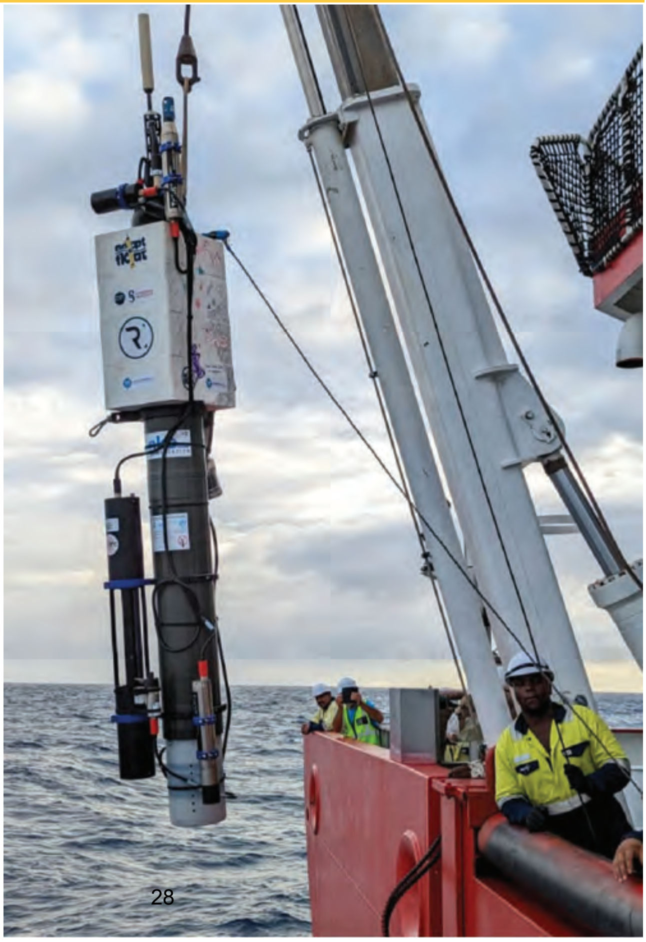
- ✓ beyond 60 N et 60 S
- ✓ Marginal seas (even closed ones)
- ✓ Doubled density in:
  - ➢ equatorial zones
  - ➢ western boundary currents

Since 2019, new design of the global programme: OneArgo

Biogeochemical variables:

- ✓ Oxygen
- ✓ Chlorophyl-A
- ✓ pH
- ✓ Nitrate
- ✓ Particules (back scattering)
- ✓ Light (irradiance)

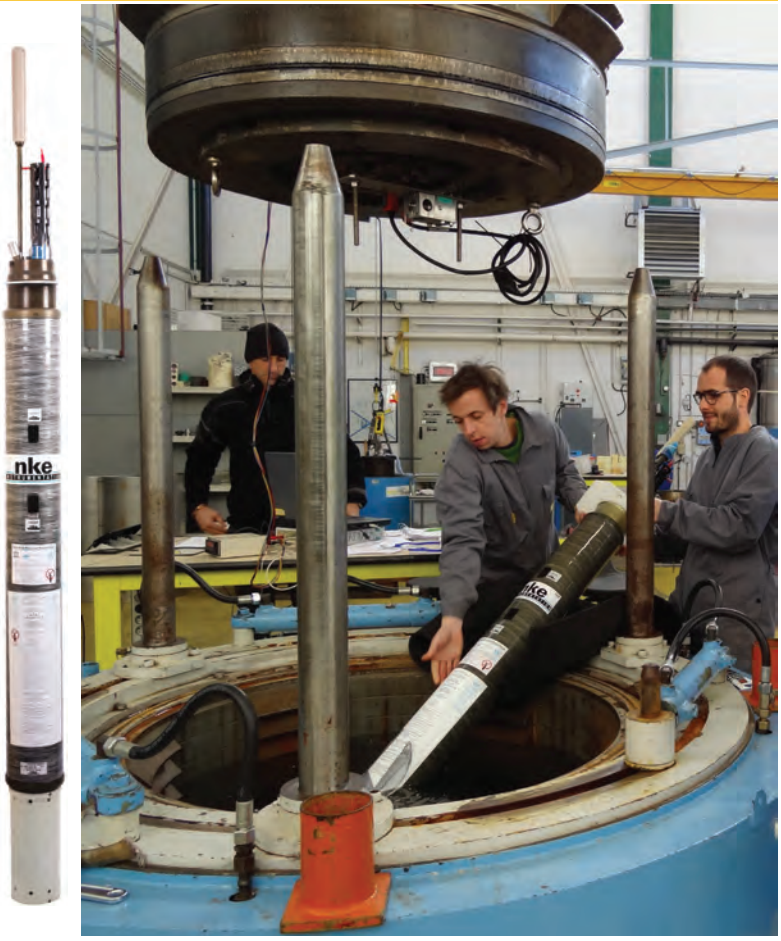




Since 2019, new design of the global programme: OneArgo

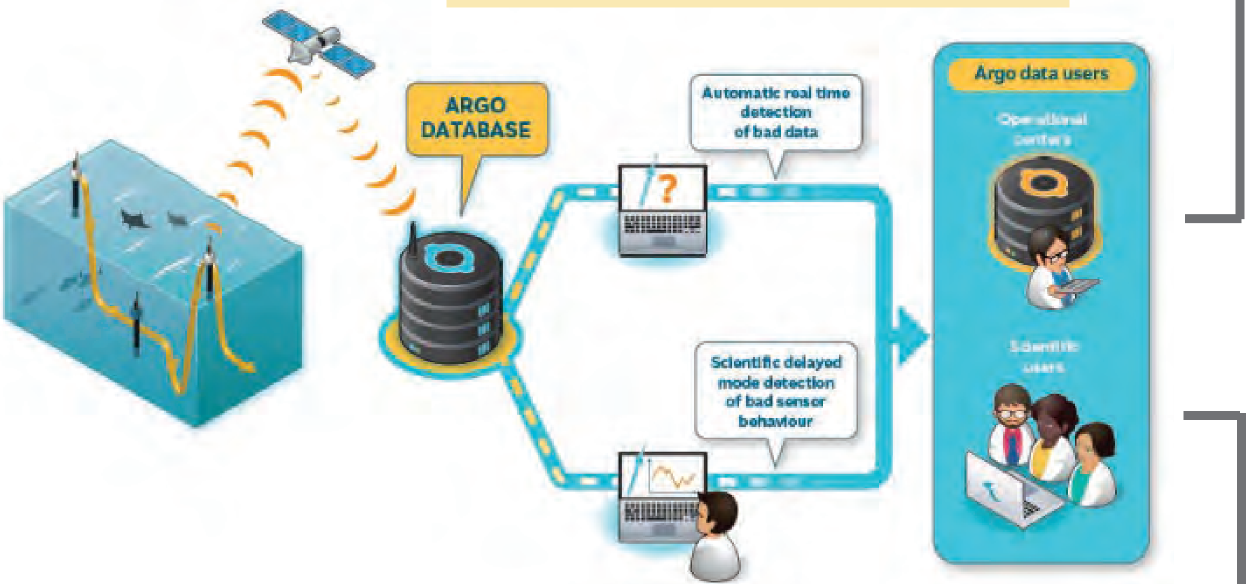
Deep ocean and abysses:

- ✓ 4000 m (90% of the ocean)
- ✓ 6000 m



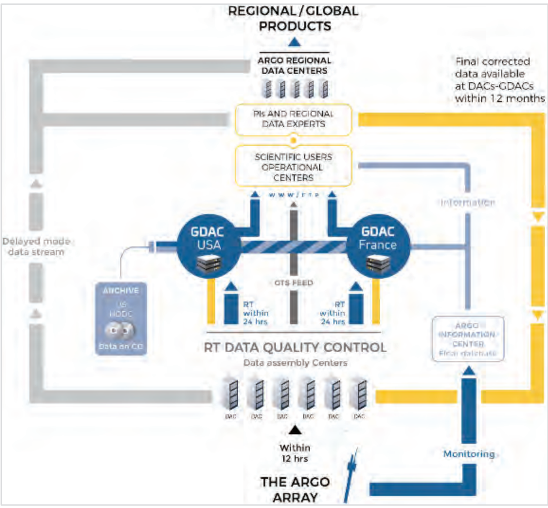
User access and data policy

Weather forecast, seasonal forecast
Operational oceanography, also for the navies
Satellite validation
Environmental monitoring (MSFD, CC)



Ocean circulation, Air-sea interaction
Climate and carbon budgets
Ecosystem evolution
Satellite calibration

DATA MANAGEMENT SYSTEM



Data are managed **at international level**:

- Floats send their measurements to DACs*, where raw data are processed and sent to the 2 GDACs*:
  - ✓1 GDAC in Europe (Coriolis/Ifremer)
  - ✓2 DACs in Europe (Coriolis/Ifremer, France and BODC, UK)
- 3 ARCs* are coordinated by European partners:
  - ✓Atlantic ARC (Ifremer, France)
  - ✓Southern Ocean ARC (BODC, UK)
  - ✓Med & Black Seas ARC (OGS, Italy)
- Argo Information Centre (AIC) at OceanOPS:
  - ✓Registration of floats
  - ✓Information on data (“metadata”)

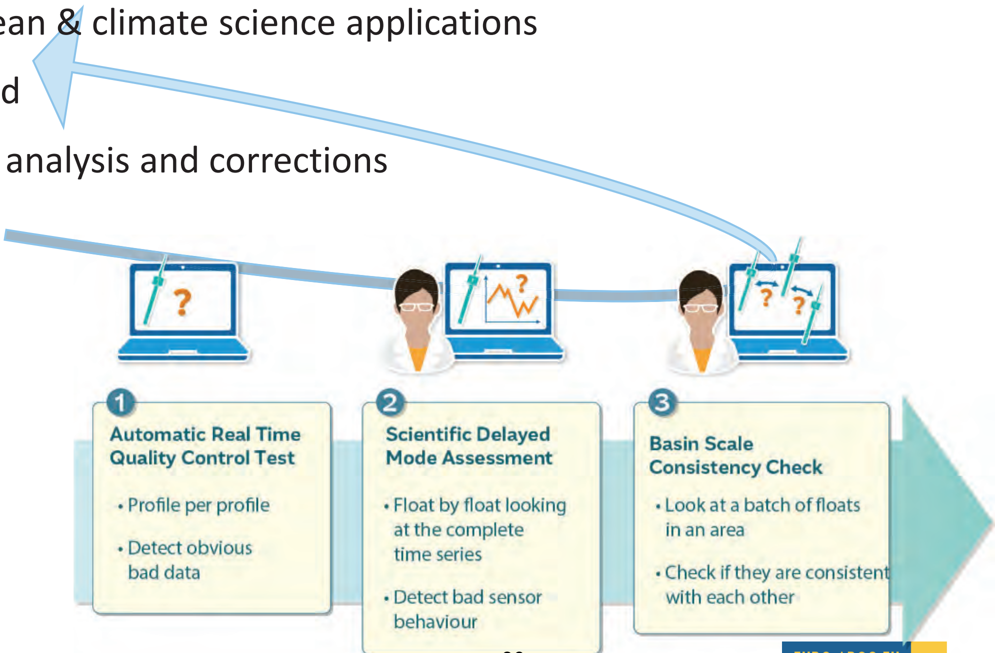
Data system existed before the Euro-Argo ERIC set-up
=> with support from EU projects , helped to enhance the existing elements and develop new ones needed for the extensions

ARGO DATA SYSTEM RELIES ON 2 DATA FLOWS

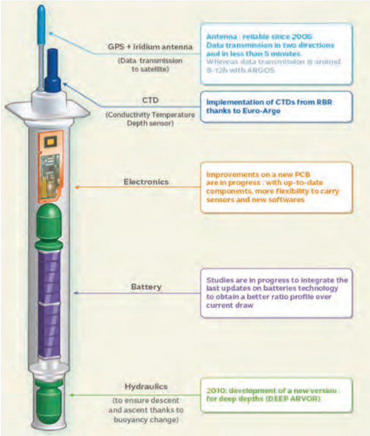
GEORGE

- Real Time ⇨ Operational applications
  - ✓4 hours max
  - ✓Automatic Quality Control tests
- Delayed Mode ⇨ Ocean & climate science applications
  - ✓12 months targetted
  - ✓Detailed time serie analysis and corrections
- Consistency check
  - ✓Additional analysis
  - ✓at bassin scales

(Argo Regional Centres)



Recovery of Argo floats



- Float recovery: a valuable operation for several reasons
  - Environmental: decommissioning process vs operation footprint
  - Economical: refitting and reuse vs operation cost
  - Quality control: recalibration of sensors
  - Scientific: exhaustive use of original observations (ex. UVP) stored as raw data in internal memory (too expensive to transmit by satellite)
  - Technical: analysis of default factors

- Euro-Argo has a recovery rate of 10% in recent years
  - mostly in European Marginal Seas
  - some in North Atlantic

- Ongoing progress, aim to develop this strategy and build a recovery pilot program

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Argo key achievements

The infrastructure	The data	The science
18 652 floats deployed	2.9 millions of T&S profiles	6269 research papers
+3 800 monthly active floats	Open, free & live data stream	1 paper/day since 2014
Global coverage, 350 ships mobilised	100% RT QCed 80% DM QCed	Essential to any ocean state reports
32 float models, 20 sensor manufacturers	11 coordinated Data Centers	Essential to ocean model evaluation and development
	2 GDACs	

The general Argo DOI
Argo (2000). Argo float data and metadata from Global Data Assembly Centre (Argo GDAC). SEANOE. https://doi.org/10.17882/42182

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Euro-Argo consortium

Euro-Argo ERIC is a distributed European Research Infrastructure Consortium, composed of: 12 members (countries), 28 entities and an office hosted by France

EURO-ARGO.EU

Challenges: operational funding & sustainability

Euro-Argo ERIC is a Research Infrastructure:

- Its primary mission is NOT to answer the needs of operational users but to support science
- Its funding is mostly research based with little mid-term visibility
- **Activities are set according to national priorities and research objectives (geographic deployments and types of floats/variables measured)**
- Inflation: 2021-2023: floats and sensors have increased by up to 30%; trend on-going
- OneArgo 3 times more expensive than Core Argo (by far not matched by foreseen national funding)

- **There is little room for manoeuvre to fill in current gaps identified by the Copernicus entities, let alone future developments**
- **Given the retail price inflation, the drastic funding gap and as a result of national priorities, the level and spatial distribution of data currently available to Copernicus thematic entities is jeopardized at the horizon 2030**

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Euro-Argo European and global partnership

EURO-ARGO.EU

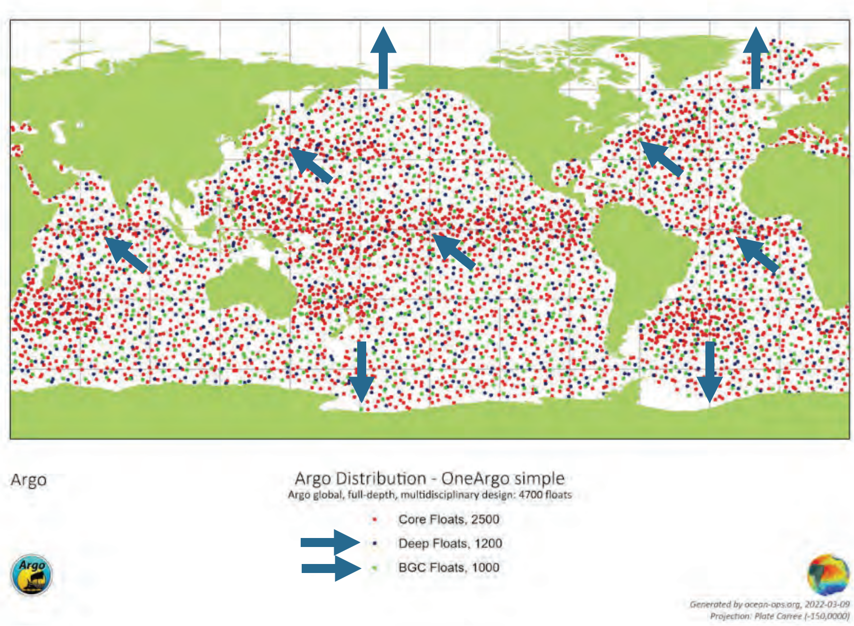
One Argo design articulated at OceanObs'19 approved by GCOS/GOOS

... 100 M€/year

Comprises 4700 floats including:

- 1200 deep floats
- 1000 biogeochemical floats
- Expansion into seasonal ice zones
- Enhanced sampling in the equatorial and western boundary regions

OneArgo upgrade is an action of the Ocean Decade



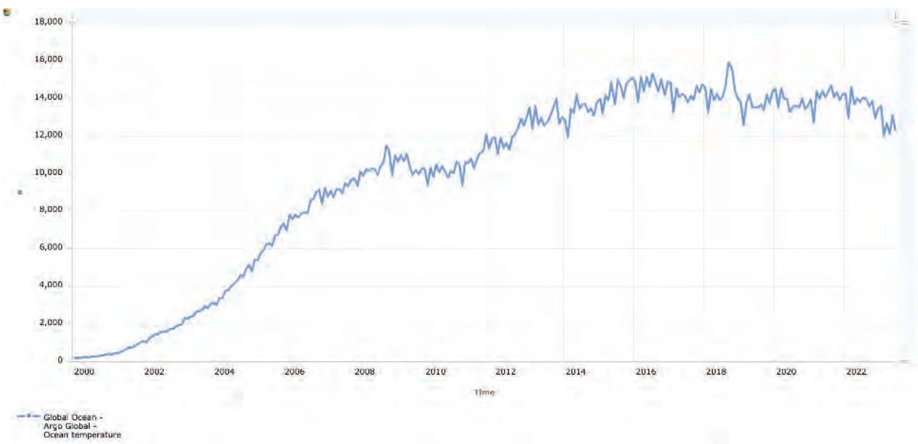
Costs of the progressive transition from Core Argo to OneArgo

2023 cost assessment

Type of deployed floats	2023 float retail price	International Core Argo Design < 2019	EU share to be deployed per year (25%)	EURO-ARGO mean annual float depl. 2019-2022	Mean annual cost EURO-ARGO	International OneArgo Design 2030	EU share to be deployed per year (25%)
Core	20.000 €	4000	200	139	2.780.000 €	2500	125
Deep -4000m	40.000 €			20,25	810.000 €		
Deep -6000m	80.000 €					1200	75
BGC 1-5 variables	80.000 €			40,5	3.240.000 €		
BGC 6 variables	120.000 €			7,75	930.000 €	1000	62,5
Total		4000	200	207,5	7.760.000 €	4700	262,5
Annual cost EURO-ARGO			**6.960.000 €**		**15.260.000 €**		**26.883.750 €**

Funding gap: more than 11 M€ per year for the implementation of the full OneArgo design by 2030 (at current prices)

Presently the global Argo system is in net decline



- Total = 3849/4700 (83%)
- Deep = 190/1250 (14%)
- Biogeochemical (>=5 params) = 355/1000 (28%)

Number of active floats of the global Argo programme

Flat budgets coming mostly from research fundings…
… while developing new capabilities and facing inflation

Challenges: operational funding & sustainability

GEORGE

- ➢ No sustainable solution without significant & recurrent EU funding
- ➢ Merit of the claim recognized by DG Grow in 2018… without follow-up
- ➢ Advocacy needed before approval of the adoption of the next EU MFF (2027)
- ➢ Support from Copernicus thematic services indispensable!

EUROPEAN COMMISSION
Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

Aerospace, Maritime and Defence Industries
Director

Brussels, 110418
GROW/I2/RG/
grow.ddg3.i.2(2018)1390146

EURO-ARGO European Research
Infrastructure Consortium
Head of office
Technopôle Brest Iroise
1625 Route de Sainte Anne
29280 Plouzané
FRANCE

The Copernicus programme is already investing in the space component and operating the marine and climate services and, given the importance of ARGO to the development of these services and the aforementioned policy objectives, we will investigate to what extent the future Copernicus programme could support such activities, especially in view of the global dimension of the ARGO network, meaning that it falls outside the usual funding scope of the member states. Given that many of the aforementioned actions are managed by other DGs, DG GROW therefore will contact the relevant DGs and verify to what extent a critical mass of interest could be gathered to justify a possible EU investment applied consistently and complementarily across DGs to best develop and sustain these essential in-situ networks. You will however understand that we are not able to make any financial commitment at this early stage before the approval of the next multi-annual financial framework.

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Conclusions

- Argo and observations from space are **a powerful observing system combination**
- **Major gaps remain** in the deep and polar oceans, and for biogeochemical sampling
- **OneArgo** is a new design that targets these gaps
- It requires ~ **$100M/year funding globally,**
  similar in cost to a single sensor Earth Observing Satellite…
- At the EU level, ~11.5 M€/year is missing to reach 25% of the OneArgo design
- National Argo programs and our industrial partners have
  successfully developed the capacity to operate the OneArgo array
- Without strong support to **implement OneArgo** (and maintain core Argo),
  past successes will be under **threat** and **future gains not realized**
- We need **strong support** to drive the required investment
  in the **OneArgo** new observing revolution
- **Combining Research and Operational requirements** like in Argo,
  means to agree at the global level on a **shared financial support**

Objectives of the workshop

- For operational usage of OneArgo,
  reach a shared **understanding** of the **potential and requirements**
- Present, at the European level, the **specific priorities** for OneArgo deployment
- Elaborate a common **strategy** and find **advocacy** arguments to ensure
  the **sustainability of Europe's share of OneArgo**,
  finding the most efficient pathway to **secure funding**
- Investigate **specific developments** and the possibility to fund them
- Consider this action as a **pilot approach**
  to other **relevant MRIs** that provide operational data:
  connexion to GEORGE project HE INFRA-2022-TECH-01-01 grant n°101094716
  WP7.2: "build a roadmap for the European RI landscape to adopt the new
  technologies and products in their operations in the future"

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Temperature: sensors

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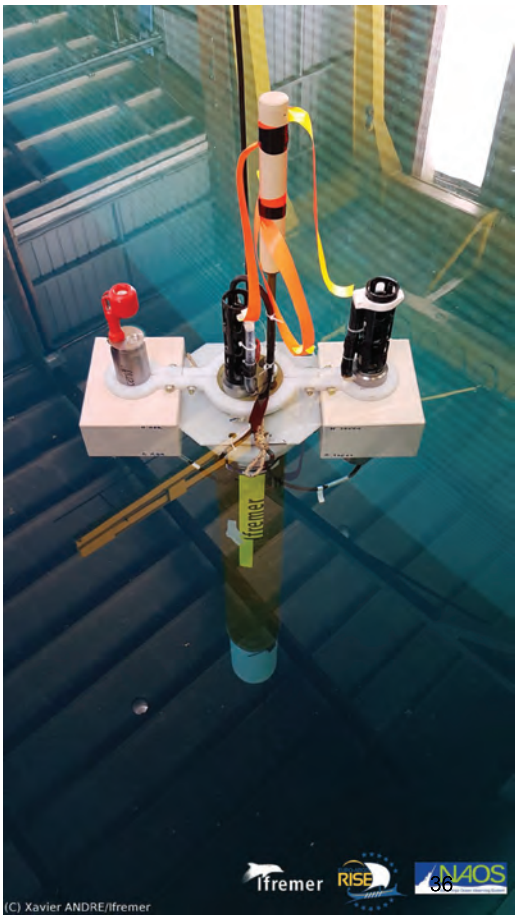
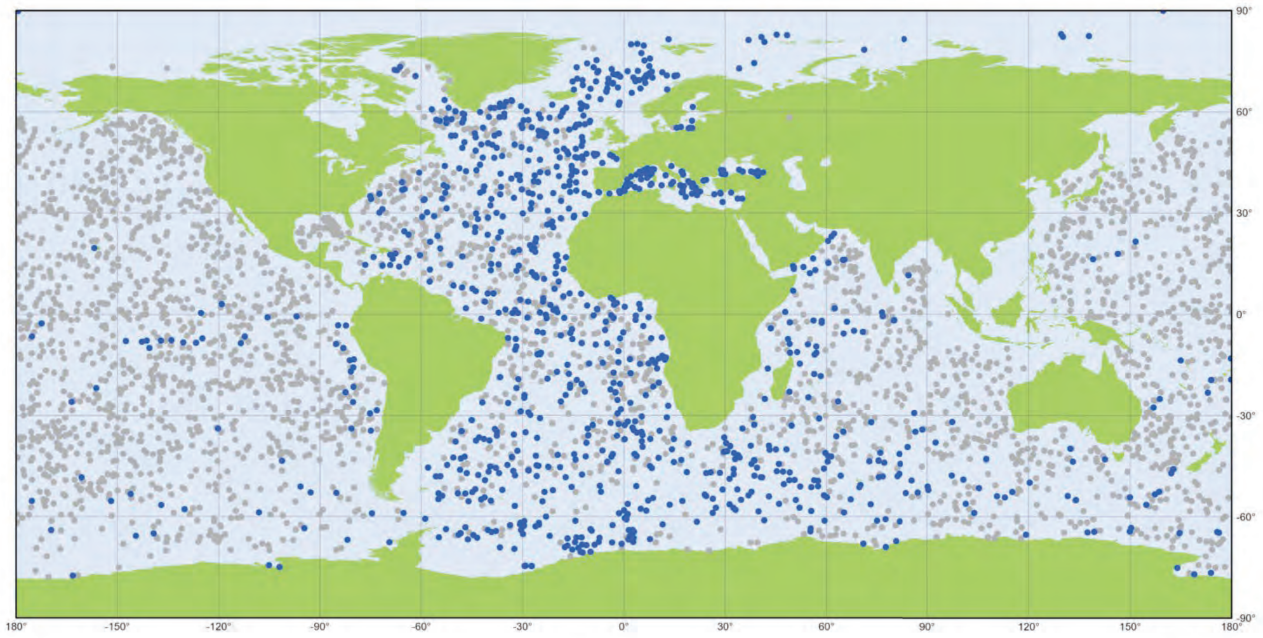
3-head comparison



Temperature: geographical coverage



Temperature: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Pressure				2,4 dbar / 0,1 dbar		2907
Temperature	Ocean circulation, heat fluxes, Air-Sea exchanges, Water cycle	Core Deep BGC	Thermistor	0,002 °C / 0,001 °C	1 dbar / 1dbar	2907

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?

2. What is the geographic coverage and density needed?

3. Would deep measurements be relevant for this variable?

4. Would under-ice measurements be relevant for this variable?

5. Should this variable be included if coastal Argo is developed?

6. What are your quality control requirements (e.g., in terms of timing)?

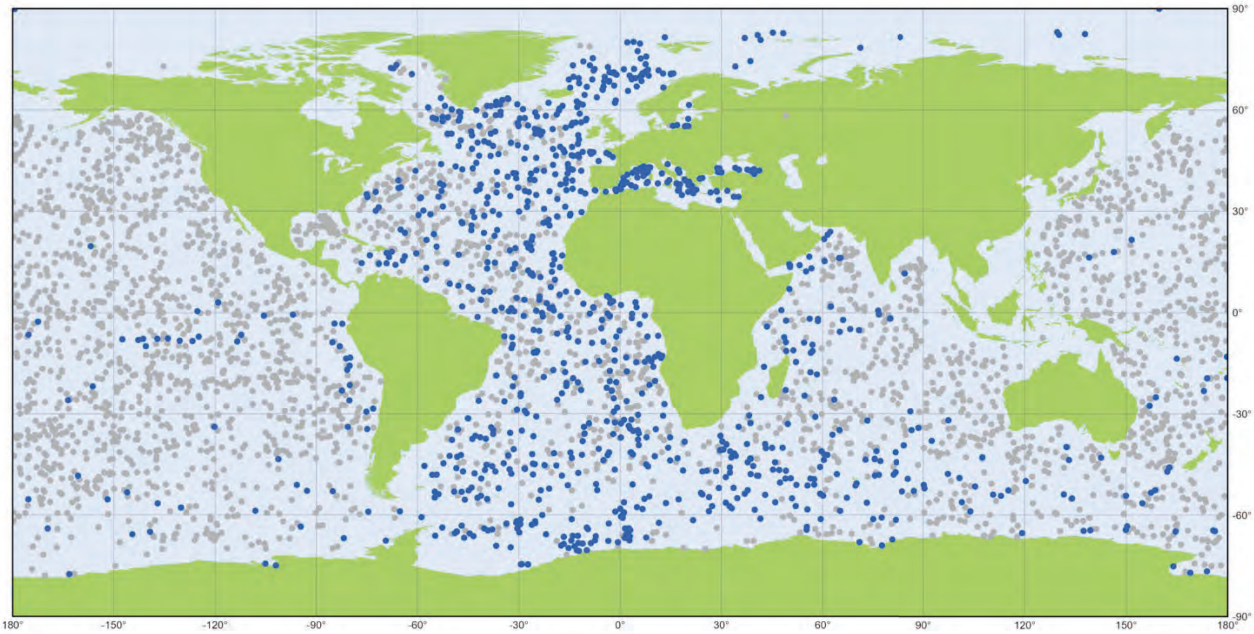
7. What is the appropriate implementation timing to respond to your Service's needs?

Salinity: sensors

Lab test

EURO-ARGO.EU

Salinity: geographical coverage



Argo EuroArgo January 2024

European contribution to the Argo program via EuroArgo Research Infrastructure
Latest locations of operational profiling floats (data distributed within the last 30 days)

• Argo EU (972) • Argo non EU (2907)

Generated by ocean-ops.org, 2024-02-01
Projection: Plate Carree

Salinity: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Salinity	Ocean circulation, freshwater fluxes, Water cycle	Core Deep BGC	Conductivity	0,01 psu in delayed mode; 0,1 psu in real time	2 dbar / 1 dbar	2907
			Inductivity	0,01 psu in delayed mode; 0,1 psu in real time	1 dbar / 1 dbar	

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?

2. What is the geographic coverage and density needed?

3. Would deep measurements be relevant for this variable?

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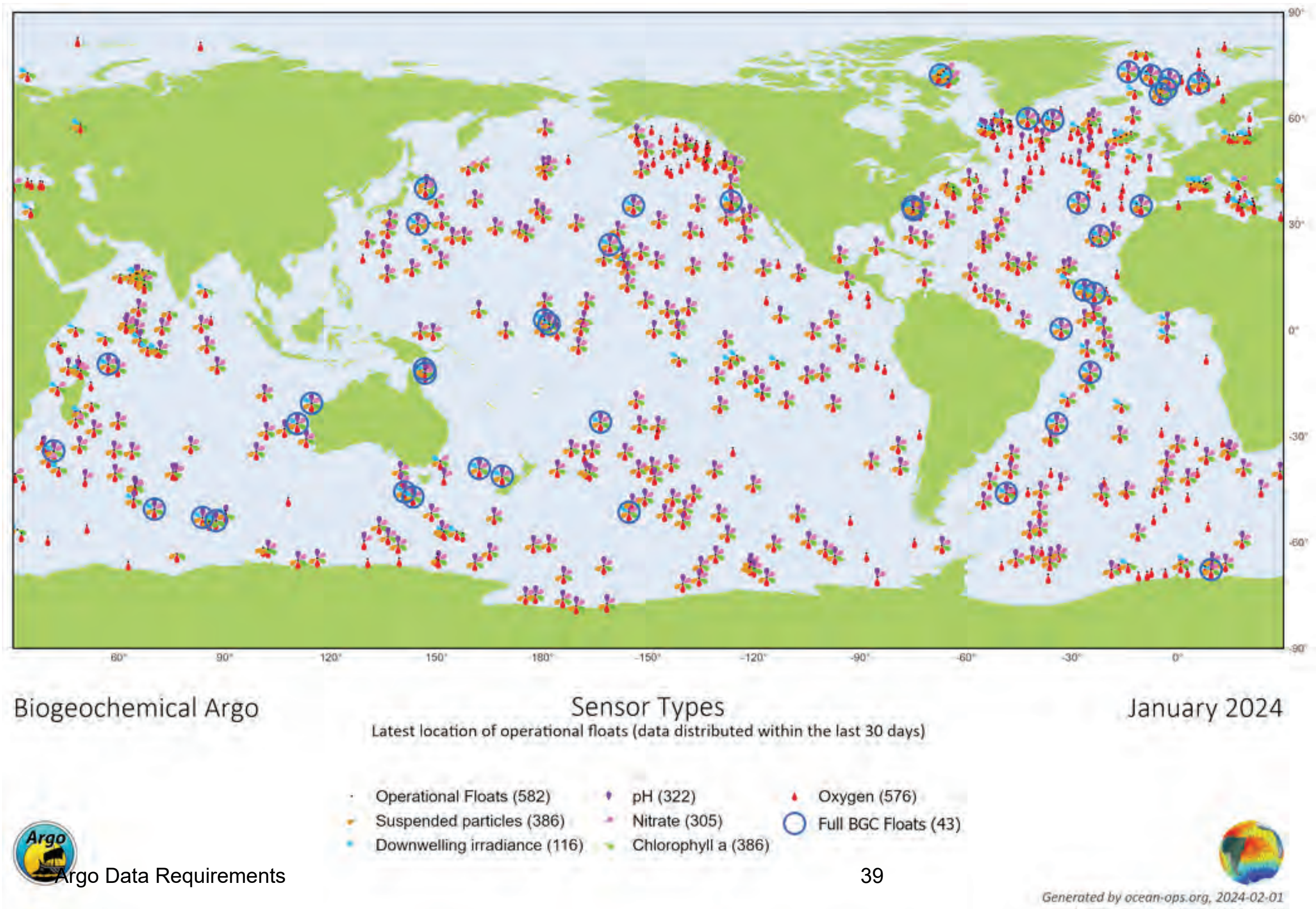
7. What is the appropriate implementation timing to respond to your Service's needs?

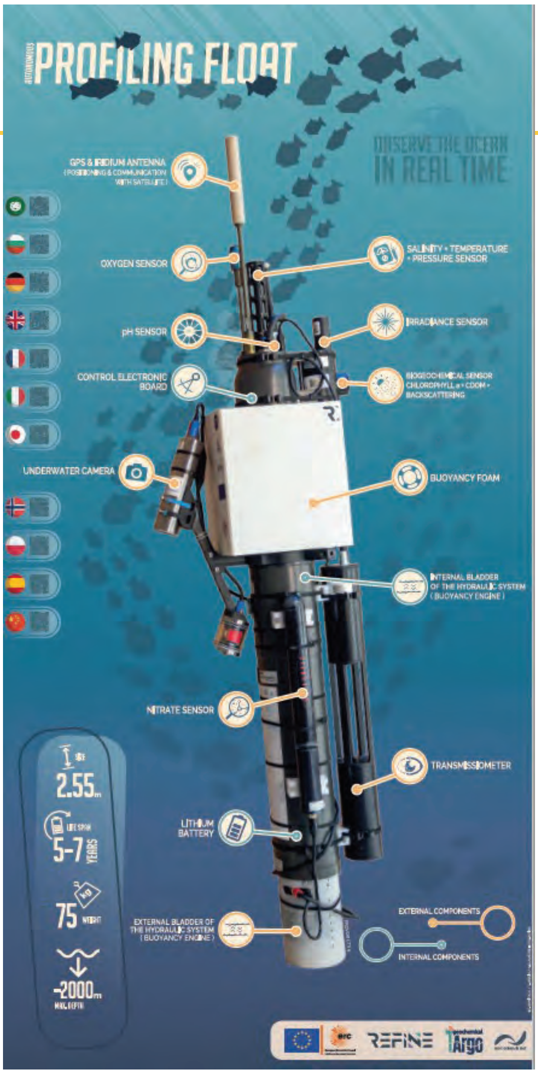
EURO-ARGO.EU

BGC Argo floats: geographical coverage

GEORGE



BGC Argo floats: sensors

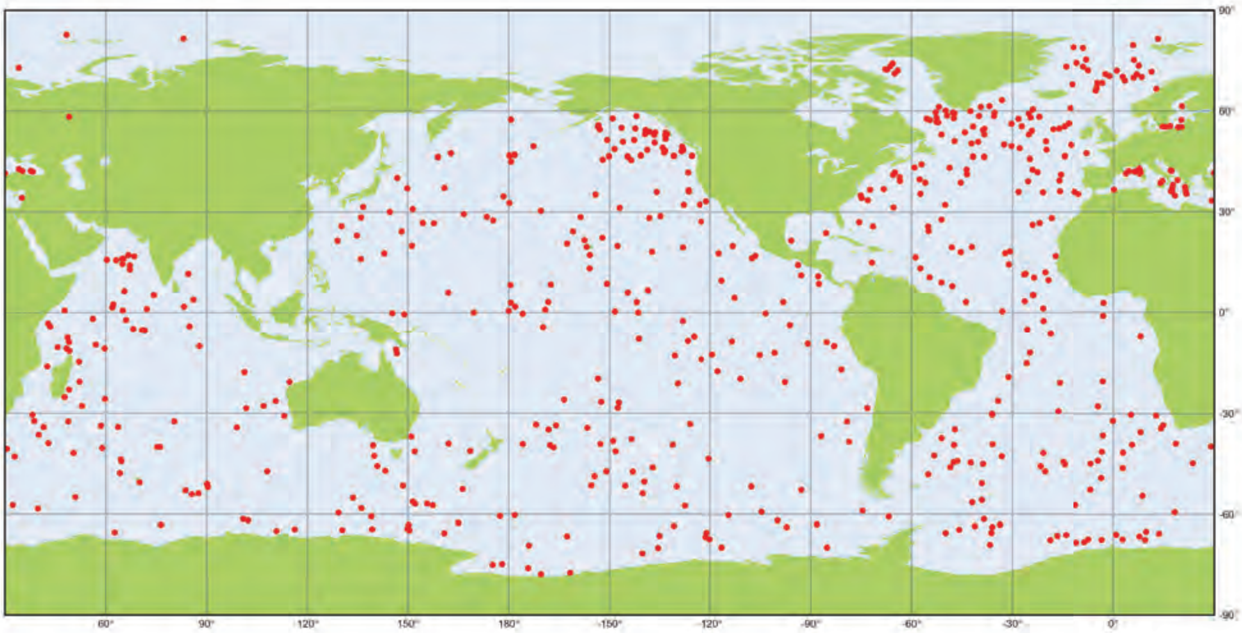


GEORGE

EURO-ARGO.EU

Oxygen: geographical coverage

GEORGE



Argo

BioGeoChemical Argo - Oxygen

January 2024

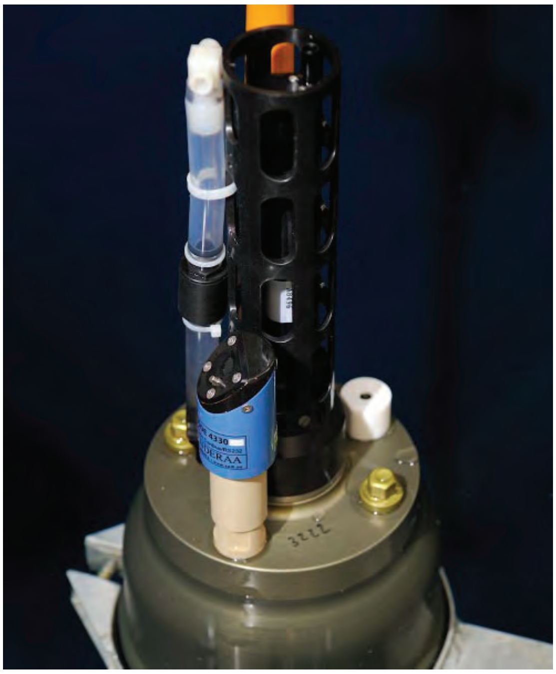
Latest location of operational floats (data distributed within the last 30 days)

- IDO_DOXY (0)
- OPTODE_DOXY (576)

Generated by ocean-ops.org, 2024-02-01
Projection: Plate Carree (-150,0000)

Oxygen: sensor

Optode



EURO-ARGO.EU

Oxygen: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Oxygen	Decrease of oxygenation and oxygen minimum zones, carbon cycle	Core (some) Deep (some) BGC	Optode	1% of surface O2 / 0.2 µmol kg^{-1}	-0,2 dbar / 0,1 dbar	576

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?

2. What is the geographic coverage and density needed?

3. Would deep measurements be relevant for this variable?

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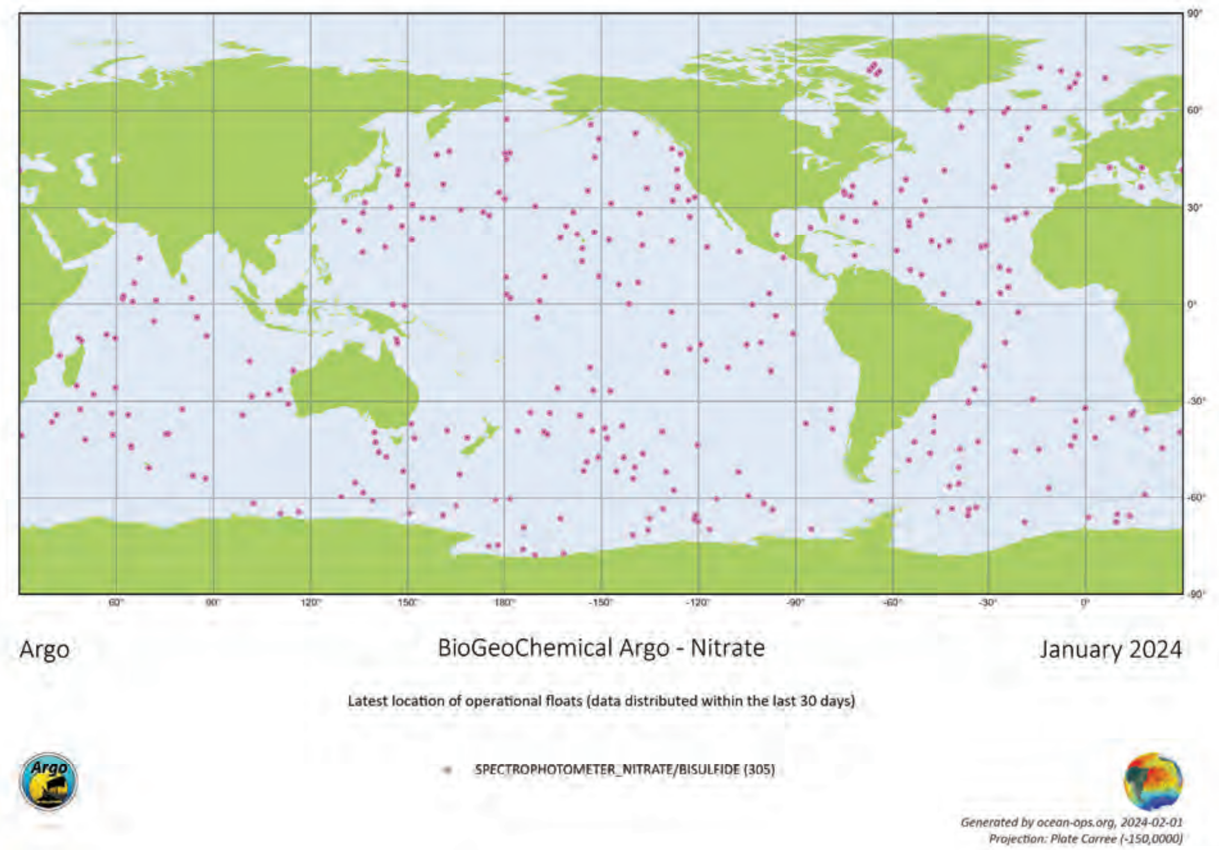
Nitrate: geographical coverage



EURO-ARGO.EU

Nitrate: sensor

Optical SUNA

Nitrate: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Nitrate	Eutrophication, toxic algal blooms, biological productivity	BGC	Ultraviolet absorbance	1 µmol kg^{-1} / 0.1 µmol kg^{-1}		305

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?

2. What is the geographic coverage and density needed?

3. Would deep measurements be relevant for this variable?

4. Would under-ice measurements be relevant for this variable?

5. Should this variable be included if coastal Argo is developed?

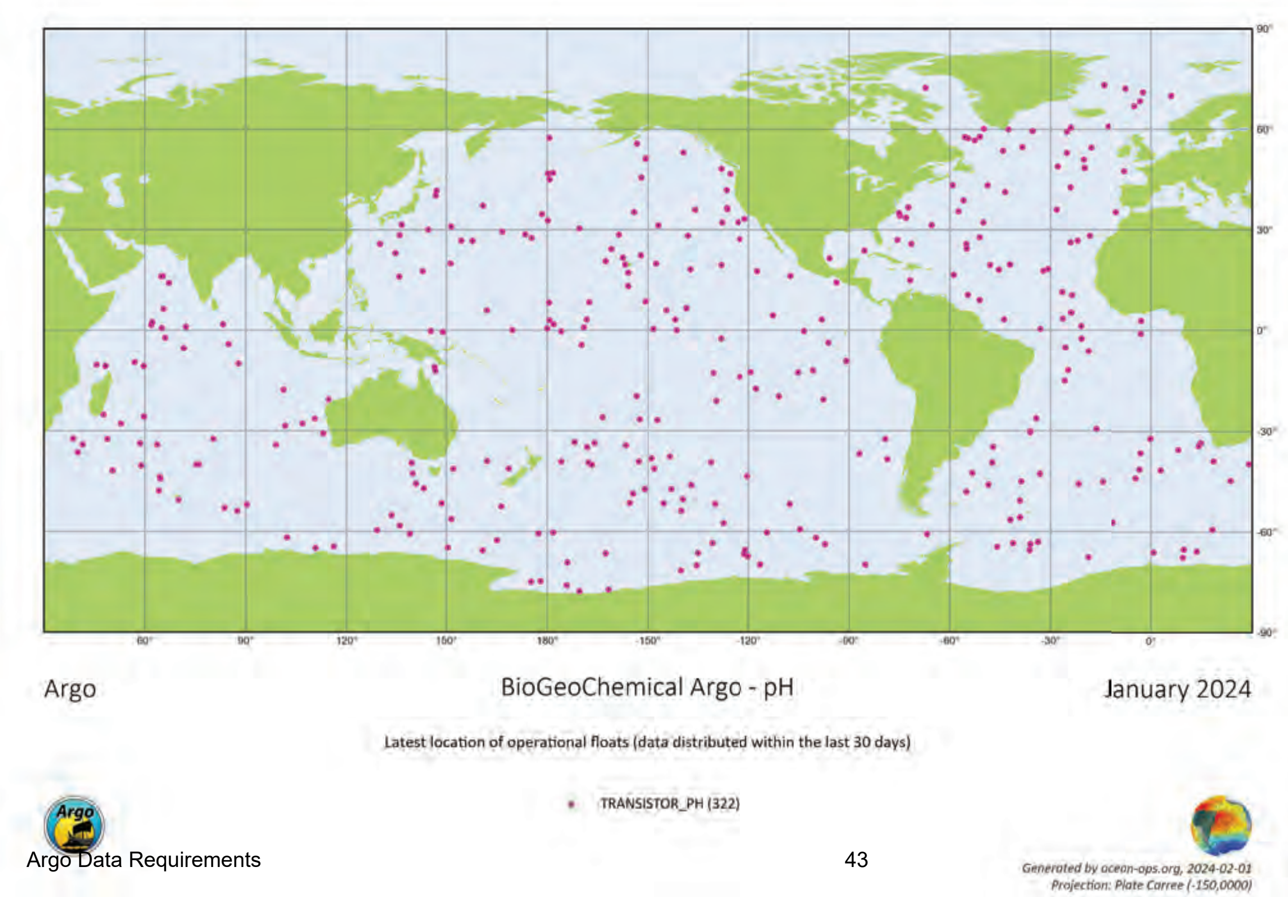
6. What are your quality control requirements (e.g., in terms of timing)?

7. What is the appropriate implementation timing to respond to your Service’s needs?

EURO-ARGO.EU

pH: geographical coverage

GEORGE



pH: sensor

IFSET
ion sensitive field effect transistor

pH: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
pH	Ocean acidification, CO_2-Uptake	BGC	Ion Sensitive Field Effect Transistor	0.01 pH / 0.0005 pH		322

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?

2. What is the geographic coverage and density needed?

3. Would deep measurements be relevant for this variable?

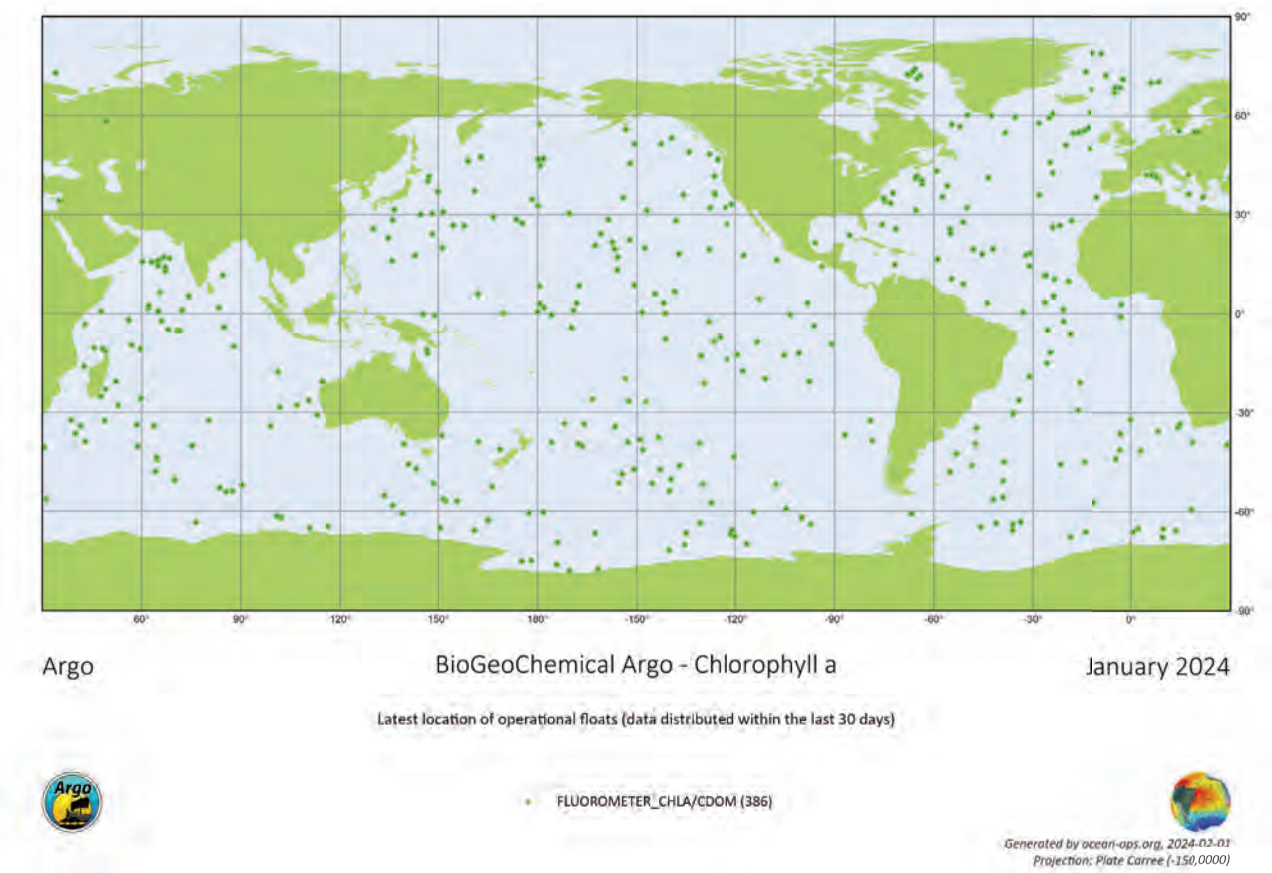
4. Would under-ice measurements be relevant for this variable?

5. Should this variable be included if coastal Argo is developed?

6. What are your quality control requirements (e.g., in terms of timing)?

7. What is the appropriate implementation timing to respond to your Service's needs?

Chlorophyll A: geographical coverage



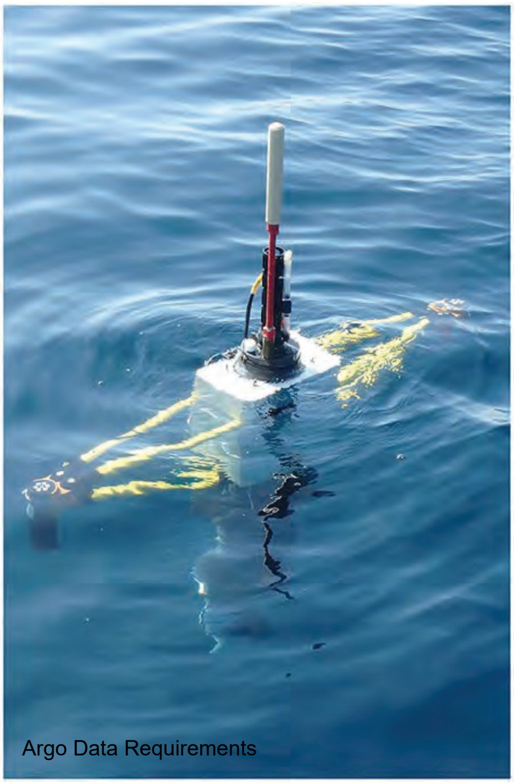
GEORGE

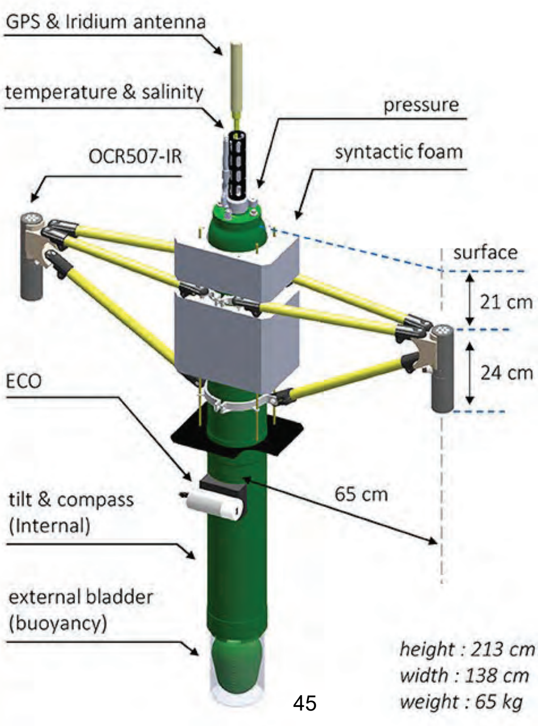
Chlorophyll-A: sensor

GEORGE

Radiometer

Fluorometer?





EURO-ARGO.EU

Chlorophyll-A: sensor

GEORGE

Fluorometer

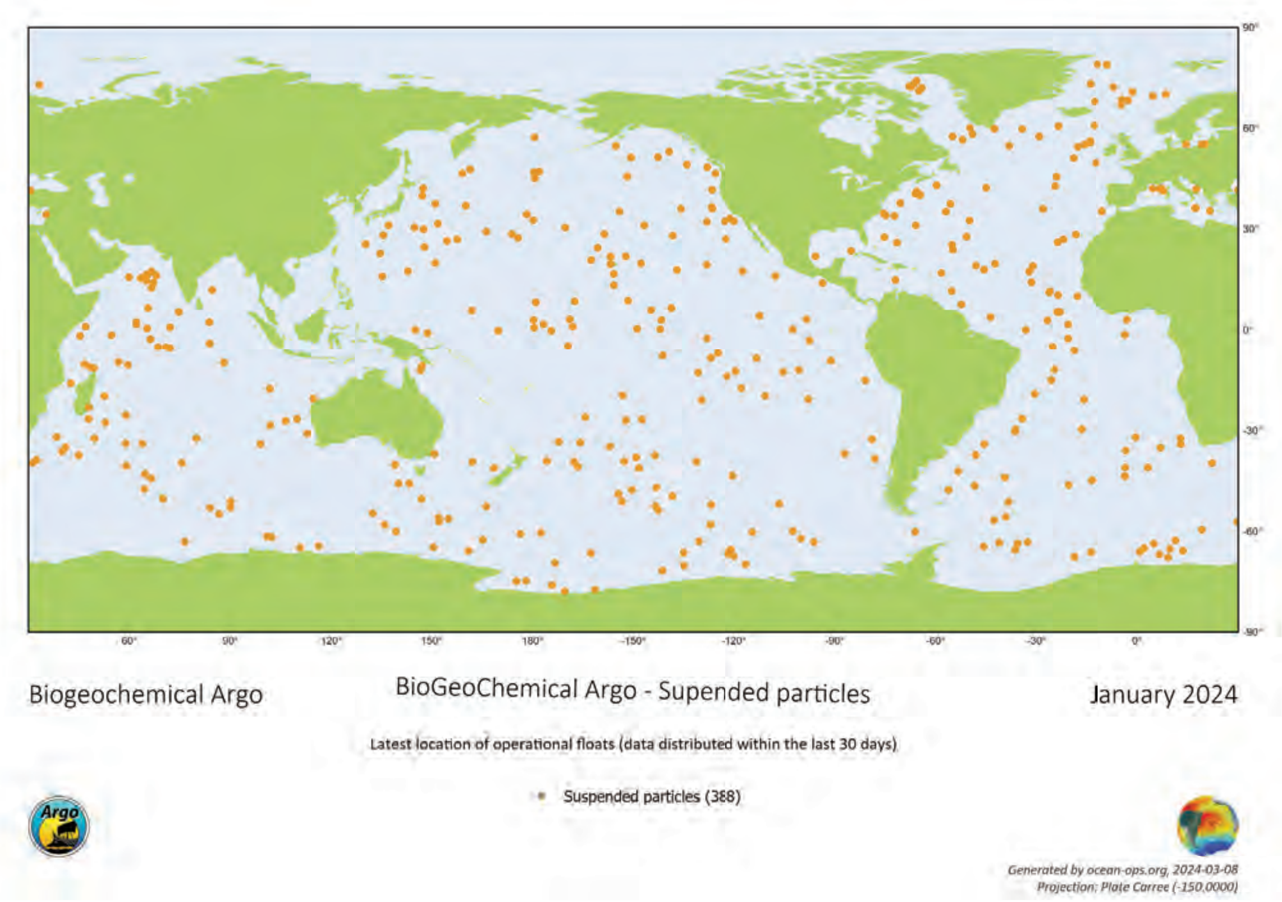
EURO-ARGO.EU

Chlorophyll a: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Chlorophyll a	Biological productivity, carbon cycle	BGC	Fluorescence	Max (30%,0.03 mg Chia m-3) / 0.025 mg Chla m-3		386
			Radiometer	Max (24%,0.03 mg Chia m-3) / 0.025 mg Chla m-3		

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?
2. What is the geographic coverage and density needed?
3. Would deep measurements be relevant for this variable?
4. Would under-ice measurements be relevant for this variable?
5. Should this variable be included if coastal Argo is developed?
6. What are your quality control requirements (e.g., in terms of timing)?
7. What is the appropriate implementation timing to respond to your Service’s needs?

Suspended particles: geographical coverage



Suspended particles: sensor

Optical backscatter (+fluorometer)

Suspended particles: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Suspended particles	Biological productivity, carbon cycle	BGC	Optical backscatter	Suspended particles: Max (50%, 1.5 µg kg^{-1}) / 1 µg kg^{-1} Backscattering coefficient: Max (10 %, 10^{-5} m^{-1}) / 4 $x10^{-6}$ m^{-1} POC : Max (30%, 20 mg m^{-3}) / 10 mg m^{-3} PC: Max (30%, 6 mg m^{-3}) / 3 mg m^{-3}	0,1 dbar / 0,1 dbar for upper 300m	386

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?

2. What is the geographic coverage and density needed?

3. Would deep measurements be relevant for this variable?

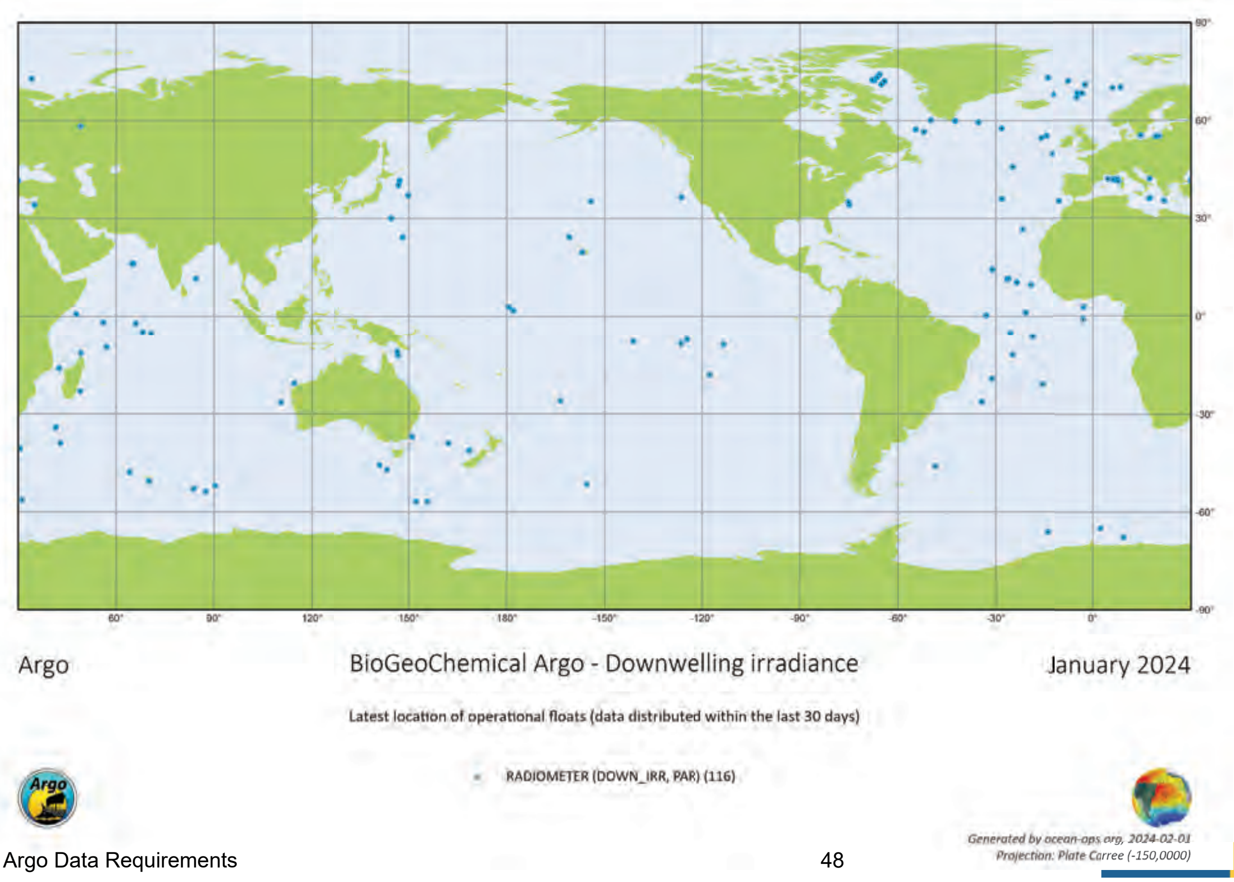
4. Would under-ice measurements be relevant for this variable?

5. Should this variable be included if coastal Argo is developed?

6. What are your quality control requirements (e.g., in terms of timing)?

7. What is the appropriate implementation timing to respond to your Service's needs?

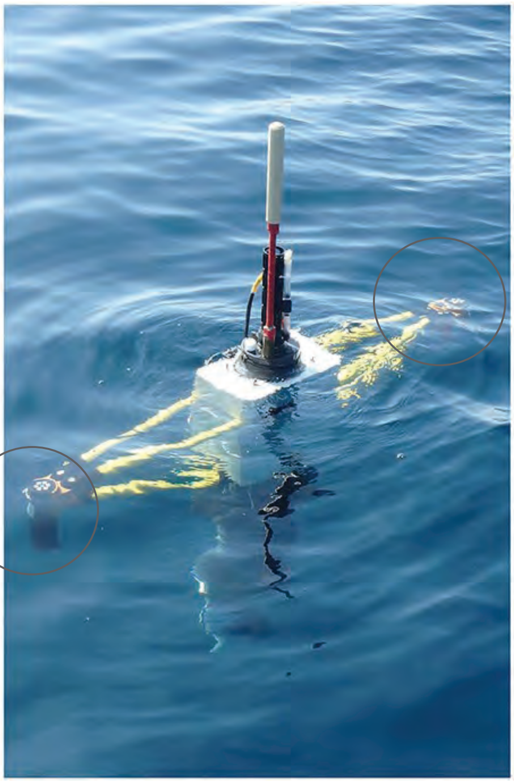
Downwelling irradiance: geographical coverage

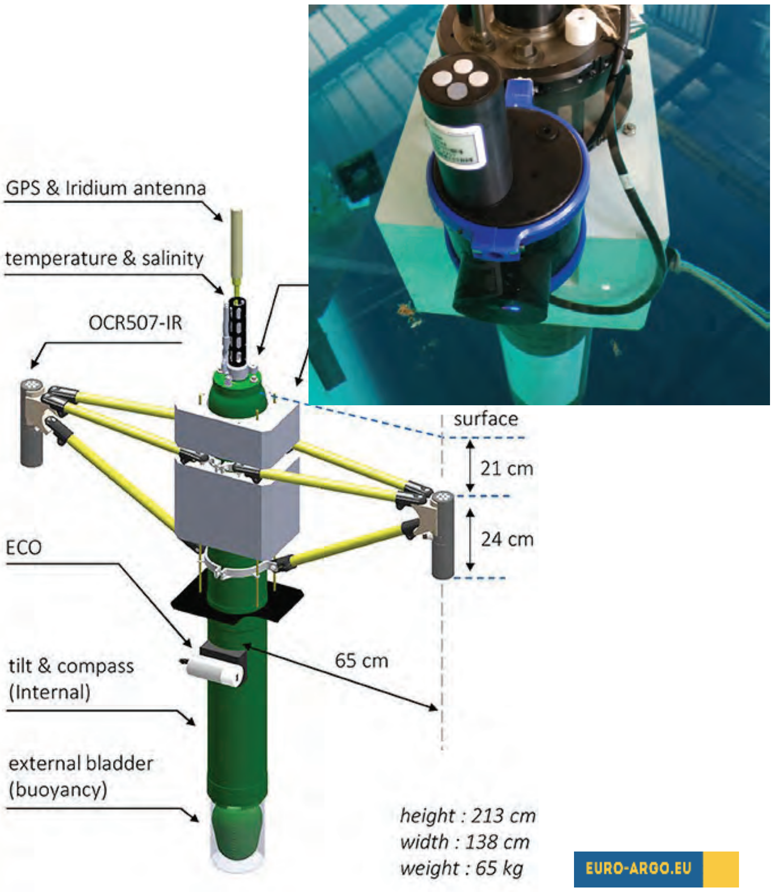


Downwelling irradiance: sensor

GEORGE

Radiometer





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Downwelling irradiance: requirements

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Downwelling irradiance (Ed)	Underwater light field, biological productivity, carbon cycle	BGC	Radiometer	PAR: Max (3%, 5 µmol photons m^{-2} s^{-1}) / 1 µmol photons m^{-2} s^{-1} Spectral: Max (3%, 5 x10^{-3} µW cm^{-2} nm^{-1}) / 2.5 X 10^{-3} µW cm^{-2} nm^{-1}	0,1 dbar / 0,1 dbar for upper 300m	116
		BGC/Provor CTS5	Hyperspectral radiometer	< 6-10% (depends on wavelength range&calibration quality)	Acquisition from 300db to surface at 0.3 db resolution near surface	14

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?

2. What is the geographic coverage and density needed?

3. Would deep measurements be relevant for this variable?

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5. Should this variable be included if coastal Argo is developed?

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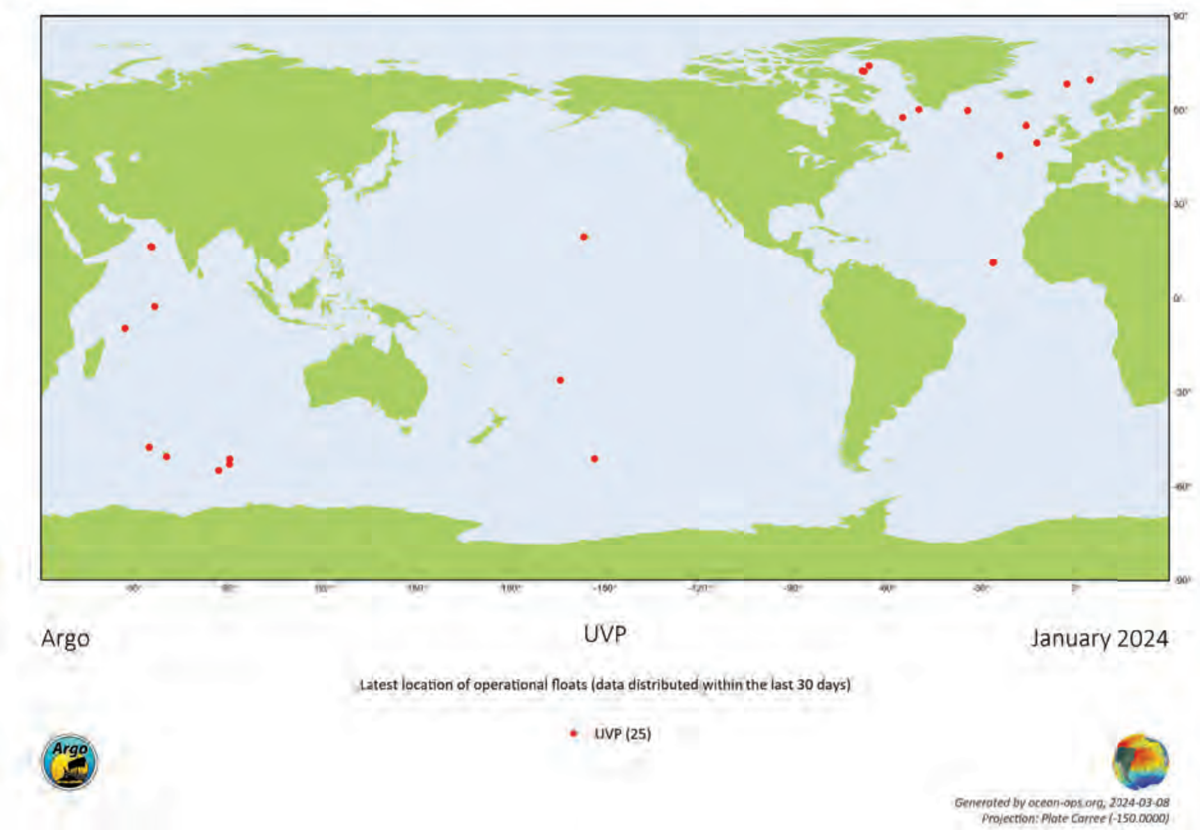
7. What is the appropriate implementation timing to respond to your Service's needs?

Additional variable: underwater vision profiler (UVP)



EURO-ARGO.EU

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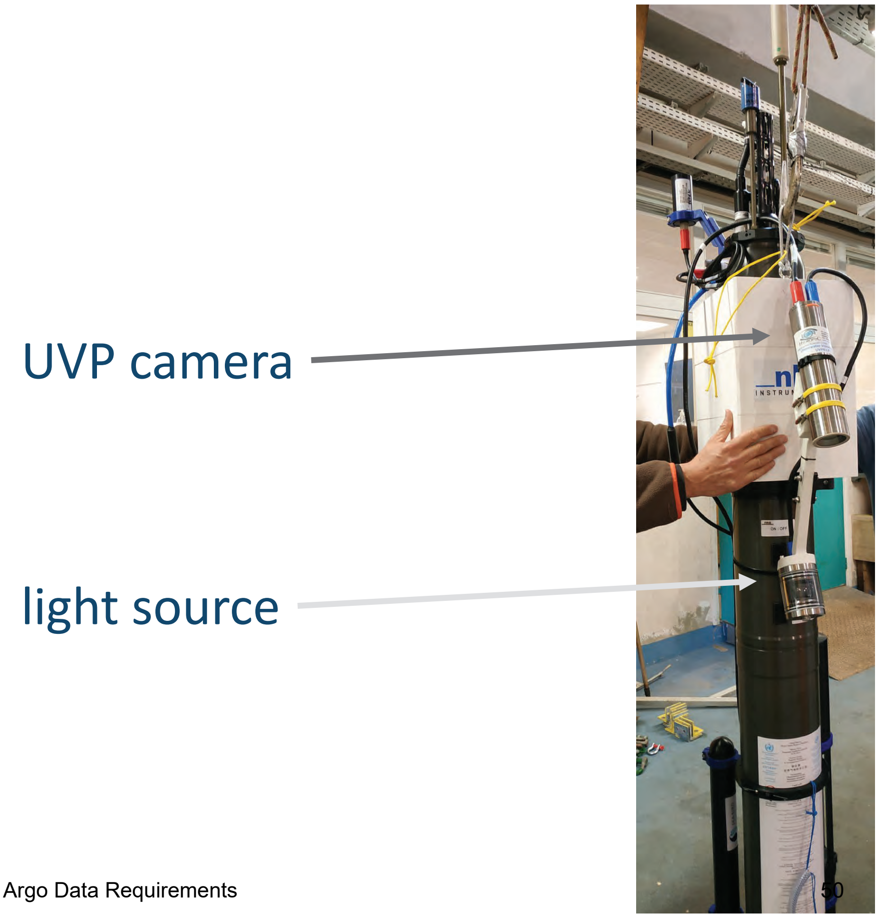

EURO-ARGO.EU

Additional variable: underwater vision profiler (UVP)

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Zooplankton	Ecosystems, biodiversity	Prospective (REFINE)	Optic			33

1. **Is this variable used/needed for products, CAL/VAL and/or assimilation?**
2. **What is the geographic coverage and density needed?**
3. **Would deep measurements be relevant for this variable?**
4. **Would under-ice measurements be relevant for this variable?**
5. **Should this variable be included if coastal Argo is developed?**
6. **What are your quality control requirements (e.g., in terms of timing)?**
7. **What is the appropriate implementation timing to respond to your Service's needs?**

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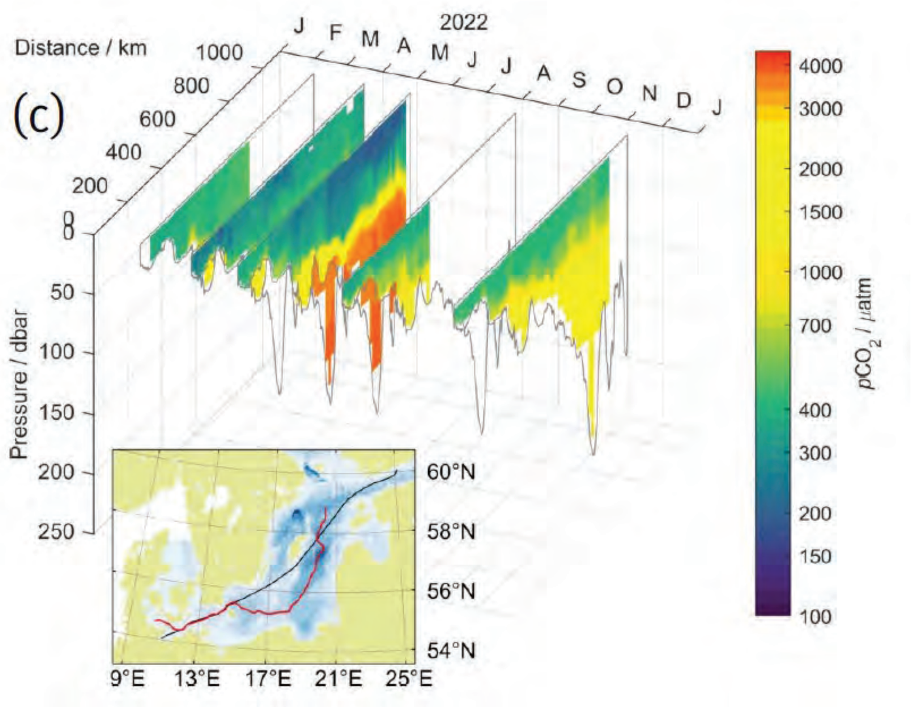
Additional variable: pCO2

GEORGE



First experiments in the Baltic Sea (H. Bittig, IOW)

Additional variable: pCO2

GEORGE

EURO-ARGO.EU

Additional variable: pCO2

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
pCO_2	Carbon uptake	Prospective (C-SCOPE, GEORGE)	Membrane equilibrator/IR absorbance		1 dbar / 1dbar	2

1. Is this variable used/needed for products, CAL/VAL and/or assimilation?
2. What is the geographic coverage and density needed?
3. Would deep measurements be relevant for this variable?
4. Would under-ice measurements be relevant for this variable?
5. Should this variable be included if coastal Argo is developed?
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7. What is the appropriate implementation timing to respond to your Service’s needs?

Additional variable: surface wind

GEORGE

Developped in the GEORGE project

EURO-ARGO.EU

Additional variable: surface wind

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Surface wind	Air-Sea exchanges	Prospective (GEORGE)	Passive acoustic			-

1. **Is this variable used/needed for products, CAL/VAL and/or assimilation?**
2. **What is the geographic coverage and density needed?**
3. **Would deep measurements be relevant for this variable?**
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Euro-Argo ERIC - Copernicus in situ Workshop
Mercator Ocean, Toulouse March 12 &13

Bio-optical BGC-Argo variables
New BGC-variables and products coming into game

Hervé Claustre
Laboratoire d'Océanographie de Villefranche

Variables considered today

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Pressure				2,4 dbar / 0,1 dbar		2907
Temperature	Ocean circulation, heat fluxes, Air-Sea exchanges, Water cycle	Core Deep BGC	Thermistor	0,002 °C / 0,001 °C	1 dbar / 1dbar	2907
Salinity	Ocean circulation, freshwater fluxes, Water cycle	Core Deep	Conductivity Inductivity	0,01 psu in delayed mode; 0,1 psu in real time 0,01 psu in delayed mode; 0,1 psu in real time	2 dbar / 1 dbar 1 dbar / 1 dbar	2907
Oxygen	Decrease of oxygenation and oxygen minimum zones, carbon cycle	Core (some) Deep (some) BGC	Optode	1% of surface O2 / 0.2 µmol kg^{-1}	-0,2 dbar / 0,1 dbar	576
Nitrate	Eutrophication, toxic algal blooms, biological productivity	BGC	Ultraviolet absorbance	1 µmol kg^{-1} / 0.1 µmol kg^{-1}		305
pH	Ocean acidification, CO_2-Uptake	BGC	Ion Sensitive Field Effect Transistor	0.01 pH / 0.0005 pH		322
Chlorophyll a	Biological productivity, carbon cycle	BGC	Fluorescence Radiometer	Max (30%,0.03 mg Chla m^{-3}) / 0.025 mg Chla m^{-3} Max (24%,0.03 mg Chla m^{-3}) / 0.025 mg Chla m^{-3}		386
Suspended particles	Biological productivity, carbon cycle	BGC	Optical backscatter	Suspended particles: Max (50%, 1.5 µg kg^{-1}) / 1 µg kg^{-1} Backscattering coefficient: Max (10 %, 10^{-5} m^{-1}) / 4 $x10^{-6}$ m^{-1} POC : Max (30%, 20 mg m^{-3}) / 10 mg m^{-3} PC: Max (30%, 6 mg m^{-3}) / 3 mg m^{-3}	0,1 dbar / 0,1 dbar for upper 300m	386
Downwelling irradiance (Ed)	Underwater light field, biological productivity, carbon cycle	BGC	Radiometer	PAR: Max (3%, 5 µmol photons m^{-2} s^{-1}) / 1 µmol photons m^{-2} s^{-1} Spectral: Max (3%, 5 $x10^{-3}$ µW cm^{-2} nm^{-1}) / 2.5 X 10^{-3} µW cm^{-2} nm^{-1}	0,1 dbar / 0,1 dbar for upper 300m	116
		BGC/Provor CTS5	Hyperspectral radiometer	< 6-10% (depends on wavelength range&calibration quality)	Acquisition from 300db to surface at 0.3 db resolution near surface	14
Upwelling radiance (Lu)	Underwater light field, biological productivity, carbon cycle	BGC/Provor CTS5 Prospective (REFINE, ITINERIS)	Hyperspectral radiometer	< 6% (depends on wavelength range&calibration quality)	Acquisition from 300db to 1.78db at 0.3 db resolution near surface	12
pCO_2	Carbon uptake	Prospective (C-SCOPE, GEORGE)	Membrane equilibrator/IR absorbance		1 dbar / 1dbar	2
Surface wind	Air-Sea exchanges	Prospective (GEORGE)	Passive acoustic			-
Zooplankton	Ecosystems, biodiversity	Prospective (REFINE)	Optic			33

Biogeochemical-Argo : Science plan and implementation targets

Research topics

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

Management topics

- Living marine resources
- Carbon budget verification

http://biogeochemical-argo.org

Six core variables

- Chla*
- Suspended particles (b_{bp})*
- Downwelling irradiance*
- O_2
- NO_3
- pH

One fleet objective

1000 operational floats

* Key Variables Product of Ocean Color Radiometry (OCR)

Science p ... n targets

Research topics

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http

Six core variables

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Variables considered today

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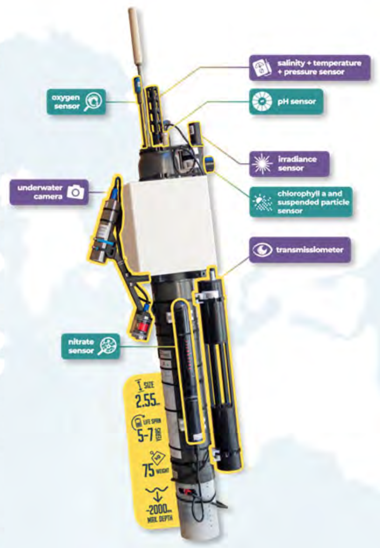
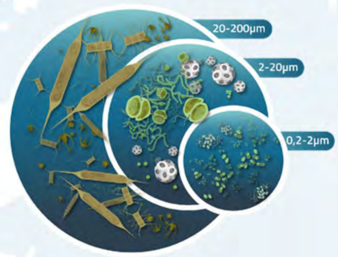
Suspended particles	Biological productivity, carbon cycle	BGC	Optical backscatter	Suspended particles: Max (50%, 1.5 µg kg^{-1}) / 1 µg kg^{-1}	0,1 dbar / 0,1 dbar for upper 300m	386
				Backscattering coefficient: Max (10 %, 10^{-5} m^{-1}) / 4 x10^{-6} m^{-1}		
				POC : Max (30%, 20 mg m^{-3}) / 10 mg m^{-3}		
				PC: Max (30%, 6 mg m^{-3}) / 3 mg m^{-3}		
Downwelling irradiance (Ed)	Underwater light field, biological productivity, carbon cycle	BGC	Radiometer	PAR: Max (3%, 5 µmol photons m^{-2} s^{-1}) / 1 µmol photons m^{-2} s^{-1}	0,1 dbar / 0,1 dbar for upper 300m	116
				Spectral: Max (3%, 5 x10^{-3} µW cm^{-2} nm^{-1}) / 2.5 X 10^{-3} µW cm^{-2} nm^{-1}		
		BGC/Provor CTS5	Hyperspectral radiometer	< 6-10% (depends on wavelength range&calibration quality)	Acquisition from 300db to surface at 0.3 db resolution near surface	14
Upwelling radiance (Lu)	Underwater light field, biological productivity, carbon cycle	BGC/Provor CTS5 Prospective (REFINE, ITINERIS)	Hyperspectral radiometer	< 6% (depends on wavelength range&calibration quality)	Acquisition from 300db to 1.78db at 0.3 db resolution near surface	12
pCO_2	Carbon uptake	Prospective (C-SCOPE, GEORGE)	Membrane equilibrator/IR absorbance		1 dbar / 1dbar	2
Surface wind	Air-Sea exchanges	Prospective (GEORGE)	Passive acoustic			-
Zooplankton	Ecosystems, biodiversity	Prospective (REFINE)	Optic			33

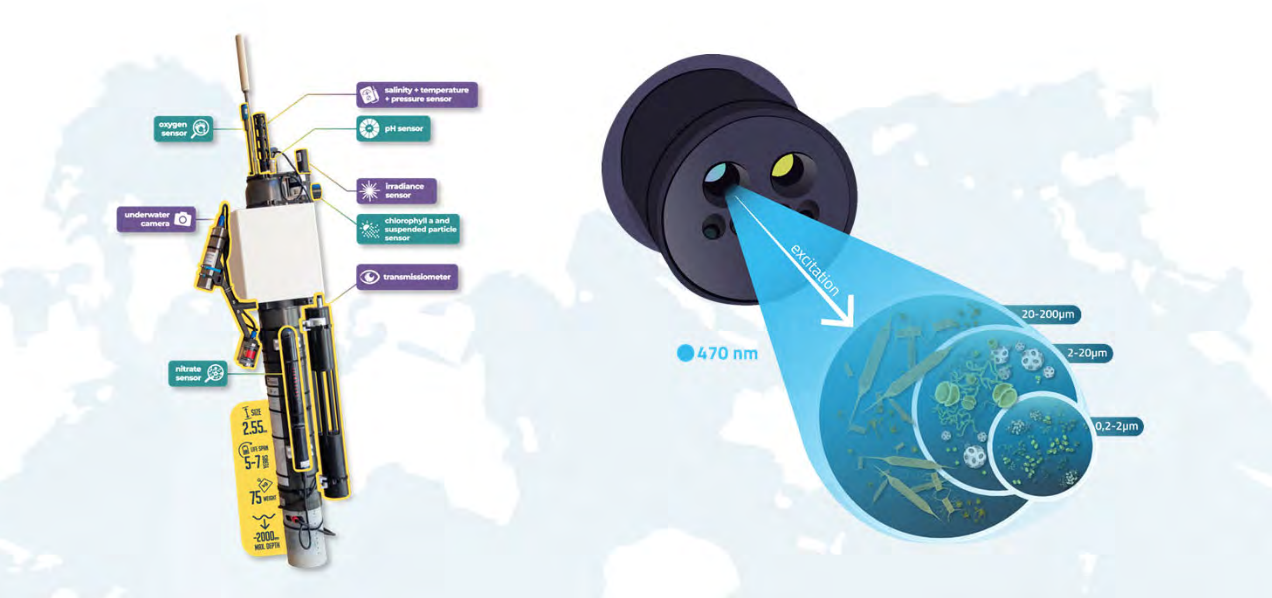
Phytoplankton biomass is measured…

…with a fluorometer



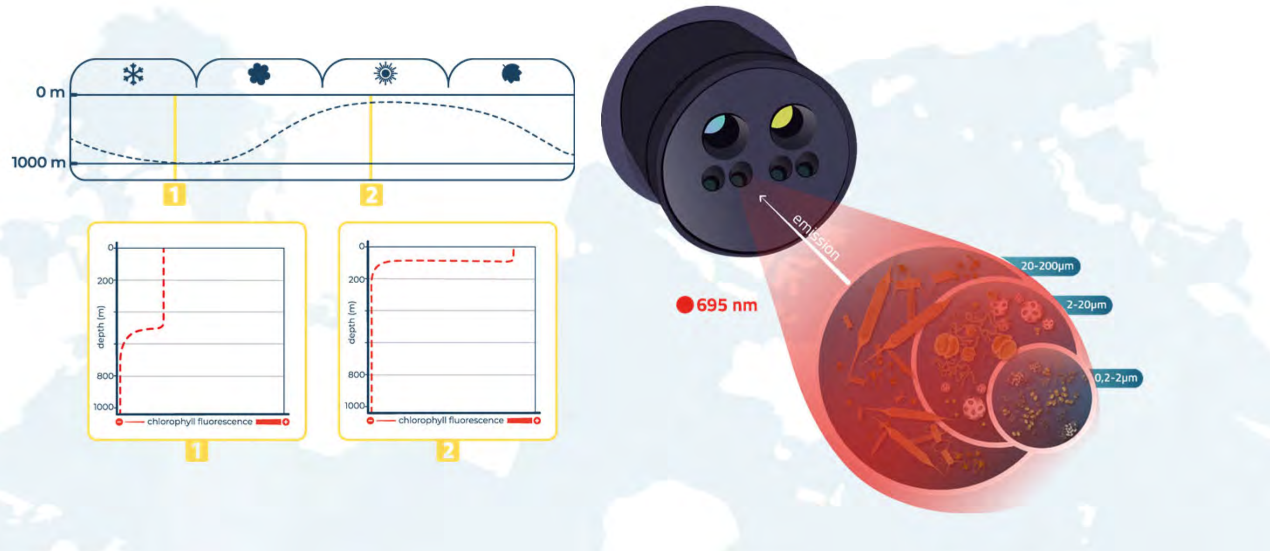


Phytoplankton biomass is measured…
…with a fluorometer

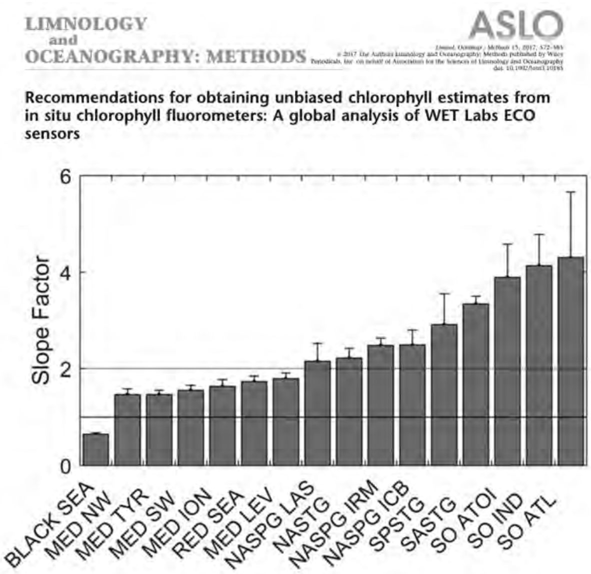


Phytoplankton biomass is measured…
…with a fluorometer

Phytoplankton biomass is measured…
…with a fluorometer



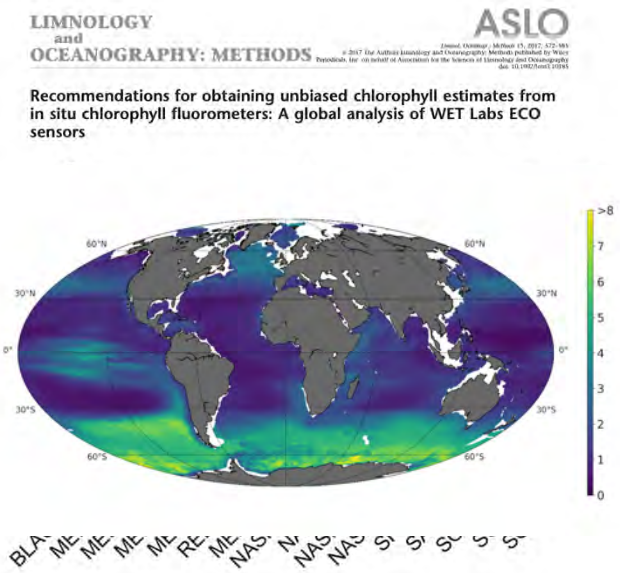
The ratio Fchla/[Chla] (slope Factor) is not constant



The slope varies with:

- phytoplankton type
- light history
- nutrient limitation

The ratio Fchla/[Chla] (slope Factor) is not constant

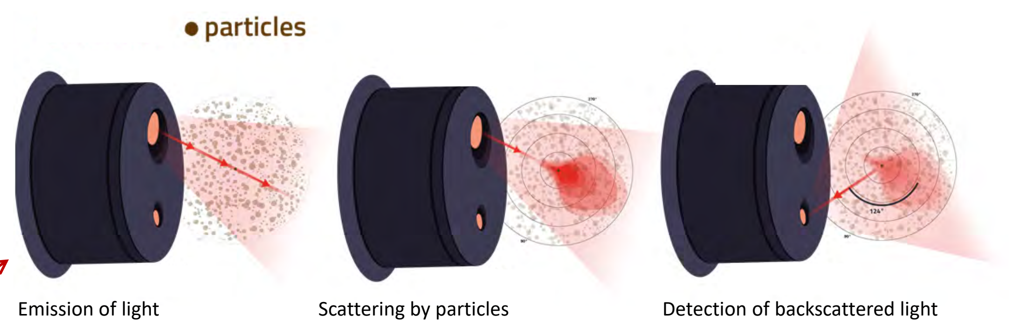


The slope varies with:

- phytoplankton type
- light history
- nutrient limitation

Particulate backscattering (b_{bp})

13



Proxy for :
POC concentration [POC]

Application :
Particle biomass
Characteristics of particles
(size, composition)

Radiometer on Float

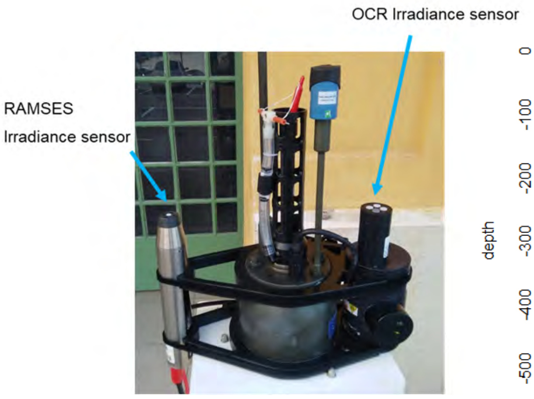
OCR-504 (SeaBird)

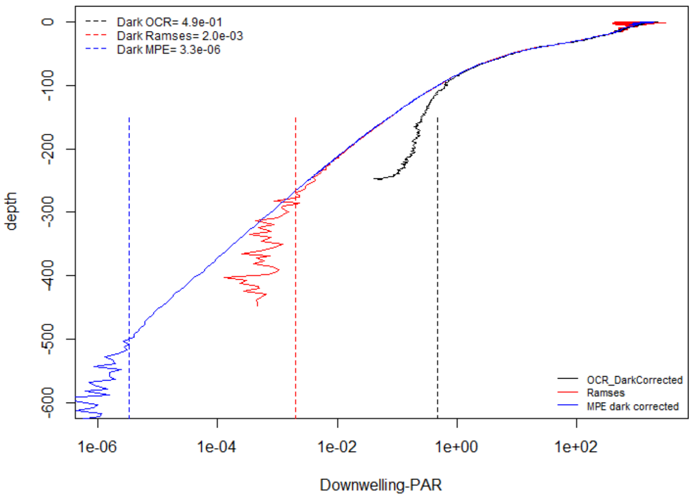
MPE-PAR (BSI)

Ramses (Trios)

Sensor	Float type	Spectral domain	frequency
OCR504	All	4 channels (Vis + PAR)	0.5 Hz (on Provor)
MPE-PAR	Provor	1 channel (VIS + PAR), high sensitivity	1 Hz (on Provor)
RAMSES	Provor + Apex	200 (320-950 or 280-720)	Variable Max 0.25 Hz

Sensors sensibility comparison (PAR)

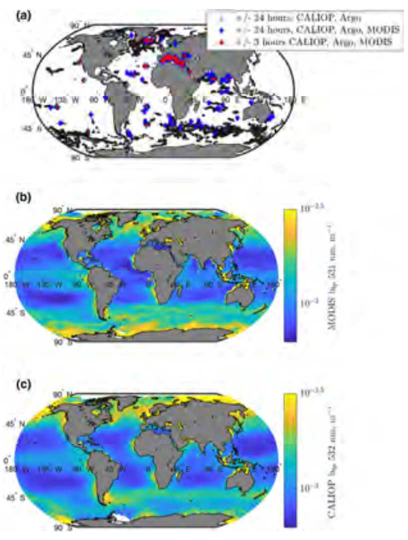




Synergies between BGC-Argo and satellite Ocean Color Radiometry (OCR) & Lidar : three possible domains
Chla, b_{bp}, radiometry

- **Validation of Ocean Color Radiometry satellite products**
- Development of 3D products
- From validation to calibration?

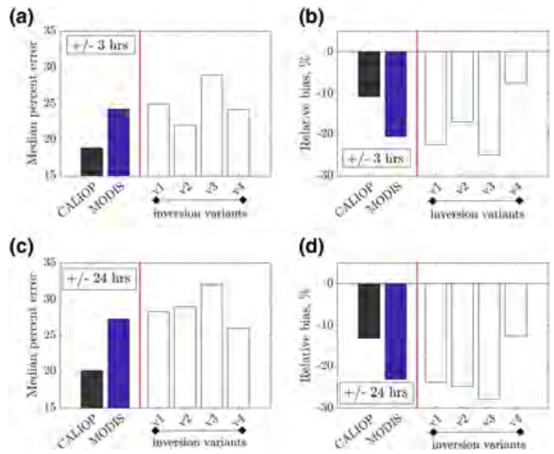
Validation of products. b_{bp} : floats vs CALIOP & MODIS



Geophysical Research Letters

RESEARCH LETTER
10.1029/2020GL090909

Particulate Backscattering in the Global Ocean: A Comparison of Independent Assessments
Bisson et al., 2021

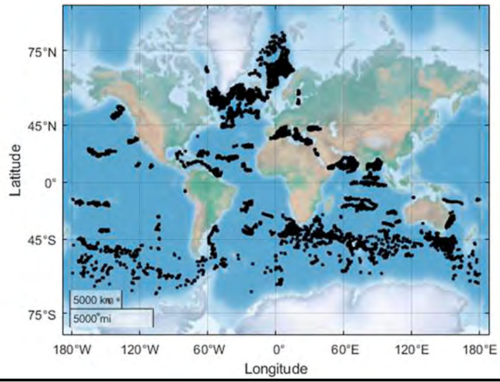


Validation of products. b_{bp} : floats vs CALIOP

frontiers | Frontiers in Remote Sensing

Validation protocol for the evaluation of space-borne lidar particulate back-scattering coefficient b_{bp}

Vadakke-Chanat and Jamet 2023



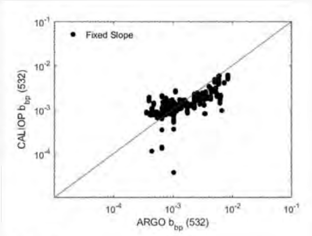


FIGURE 5
Scatter plot showing the matchup of BGC-Argo and CALIOP for 24 h–9-km window.

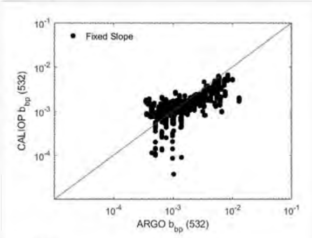


FIGURE 6
Scatter plot showing the matchup of BGC-Argo and CALIOP for 24 h–15-km window.

Validation of products. Chla : floats vs MODIS & VRIIS

AGU PUBLICATIONS

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2017JC012844

Special Section:

Revisiting Ocean Color algorithms for chlorophyll *a* and particulate organic carbon in the Southern Ocean using biogeochemical floats

Haentjens et al., 2017

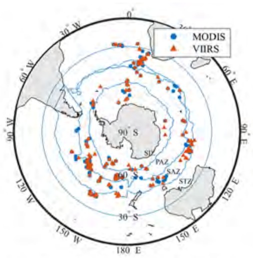
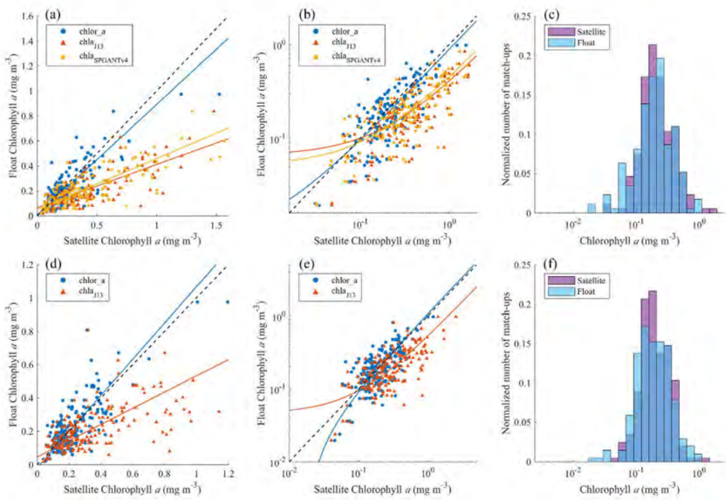


Figure 1. SOCCOM and pre-SOCCOM float and Ocean Color (OC) matchup locations (MODIS in blue circles and VIIRS in red triangles). The acronyms of each region of the Southern Ocean stands for sea ice zone (SIZ), Polar Antarctic Zone (PAZ), Subantarctic Zone (SAZ), and the Sub-tropical Zone (STZ).



Validation of products. Kd: floats vs various satellites

remote sensing MDPI

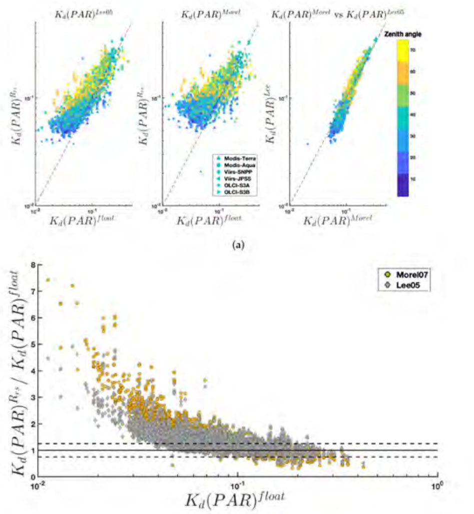
Article

Validation of Remote-Sensing Algorithms for Diffuse Attenuation of Downward Irradiance Using BGC-Argo Floats

Begouen Demeaux and Boss, 2022

Abstract: Estimates of the diffuse attenuation coefficient (K_d) at two different wavelengths and band-integrated (PAR) were obtained using different published algorithms developed for open ocean waters spanning in type from explicit-empirical, semi-analytical and implicit-empirical and applied to data from spectral radiometers on board six different satellites (MODIS-Aqua, MODIS-Terra, VIIRS-SNPP, VIIRS-JPSS, OLCI-Sentinel 3A and OLCI-Sentinel 3B). The resultant K_ds were compared to those inferred from measurements of radiometry from sensors on board autonomous profiling floats (BGC-Argo). Advantages of BGC-Argo measurements compared to ship-based ones include: 1. uniform sampling in time throughout the year, 2. large spatial coverage, and 3. lack of shading by platform. Over 5000 quality-controlled matchups between K_ds derived from float and from satellite sensors were found with values ranging from 0.01 to 0.67 m^{-1}. Our results show that although all three algorithm types provided similarly ranging values of K_d to those of the floats, for most sensors, a given algorithm produced statistically different K_d distributions from the two others. Algorithm results diverged the most for low K_d (clearest waters). Algorithm biases were traced to the limitations of the datasets the algorithms were developed and trained with, as well as the neglect of sun angle in some algorithms. This study highlights: 1. the importance of using comprehensive field-based datasets (such as BGC-Argo) for algorithm development, 2. the limitation of using radiative-transfer model simulations only for algorithm development, and 3. the potential for improvement if sun angle is taken into account explicitly to improve empirical K_d algorithms. Recent augmentation of profiling floats with hyper-spectral radiometers should be encouraged as they will provide additional constraints to develop algorithms for upcoming missions such as NASA's PACE and SBG and ESA's CHIME, all of which will include a hyper-spectral radiometer.

Keywords: radiometry; diffuse attenuation coefficient; algorithm validation; ocean optics; BGC-Argo



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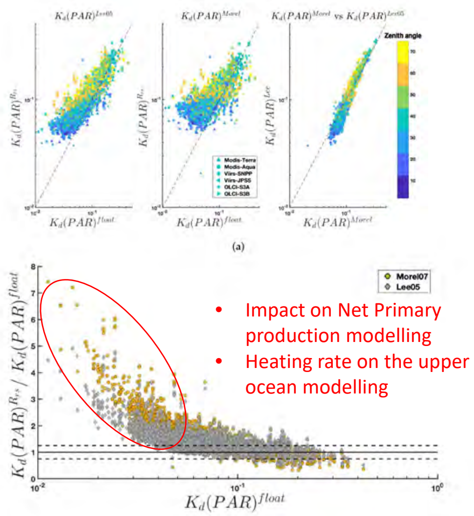

- Impact on Net Primary production modelling
- Heating rate on the upper ocean modelling

Validation of products. Kd: floats vs various satellites

remote sensing MDPI

Article

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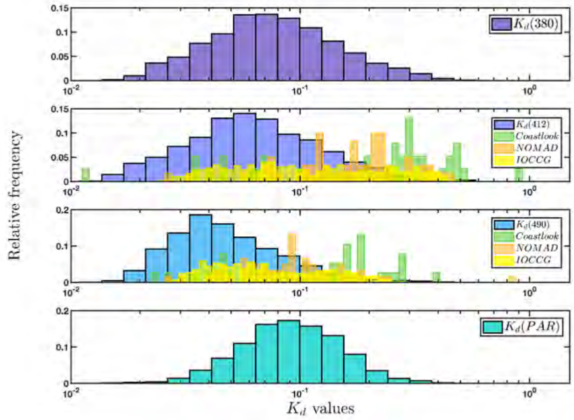
Keywords: radiometry; diffuse attenuation coefficient; algorithm validation; ocean optics; BGC-Argo

The discrepancies between observed and modeled Kd derive form the representativeness of BGC-Argo data with respect to historical ship-based database skewed towards less clear waters (typical of winter conditions or remote sub-topical gyres).

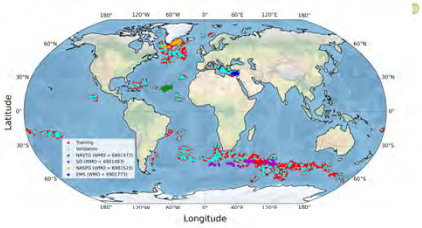


remote sensing MDPI

Article

Vertically Resolved Global Ocean Light Models Using Machine Learning

Pannimpullath



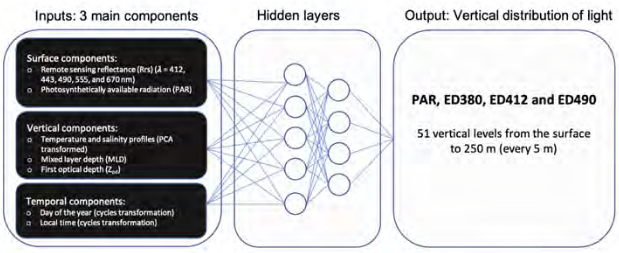
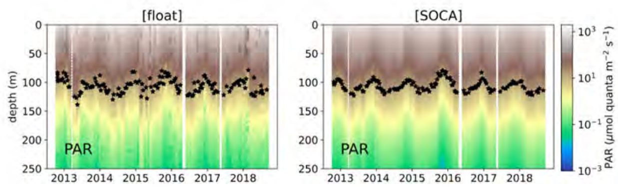
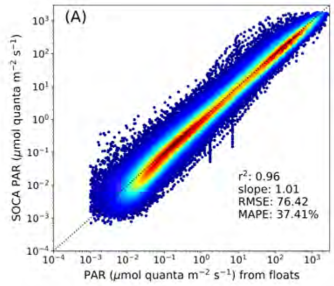


Figure 4. Schematic representation of the SOCA-light multilayer perceptron.

Neural networks can be trained from BGC-Argo data bases to model "synthetic" radiometric profiles from the "sole" knowledges of (1) the satellite Ocean Color Radiometry surface and (2) the vertical distribution of the physical properties beneath.

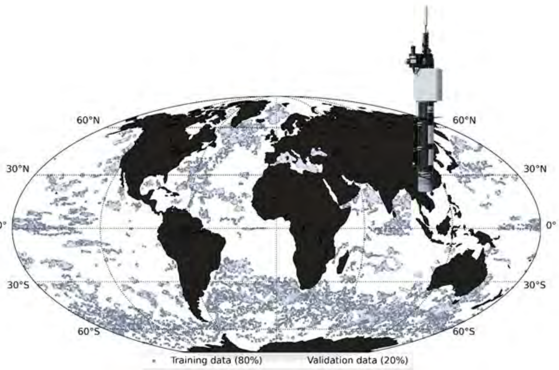




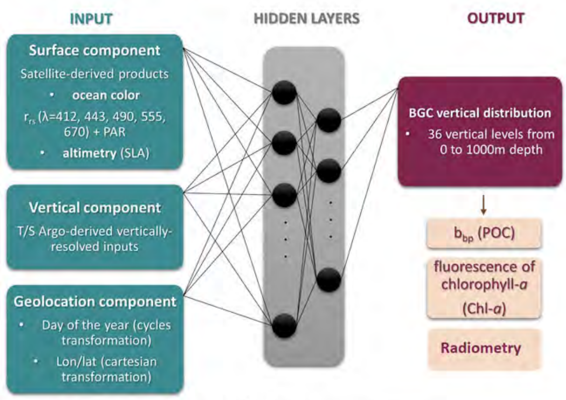
Synergies between BGC-Argo and satellite OCR (& Lidar) : three possible domains
Chla, b_{bp}, radiometry

- Validation of Ocean Color Radiometry satellite products
- **Development of 3D products**
- From validation to calibration?

3D SOCA products : Satellite Ocean-Color merged with BGC-Argo (Chla, b_{bp}, radiometry) data



The proposed approach takes advantage of the synoptic coverage of satellite observations (OC & SLA) coupled with vertically resolved BGC-Argo bio-optical measurements, to develop SOCA algorithms, based on artificial neural networks (ANN), which infer the vertical distribution of various products: Chla, POC (b_{bp}), radiometric variables (PAR), etc.



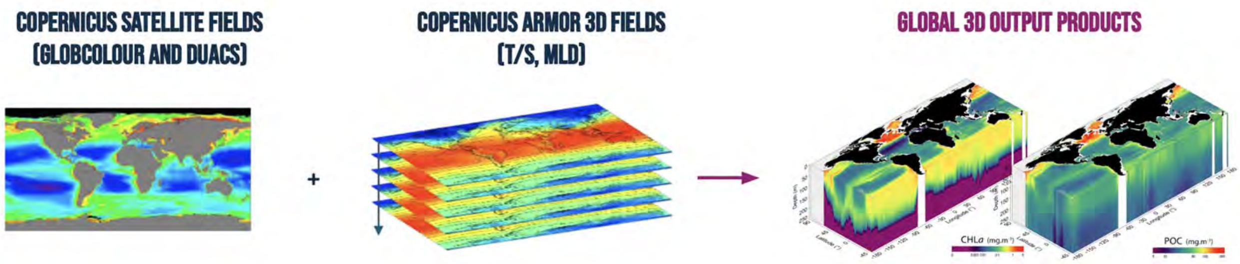
Journal of Geophysical Research: Oceans

RESEARCH ARTICLE 10.1002/2015JC011408

A neural network-based method for merging ocean color and Argo data to extend surface bio-optical properties to depth: Retrieval of the particulate backscattering coefficient

Sauzède et al., 2016

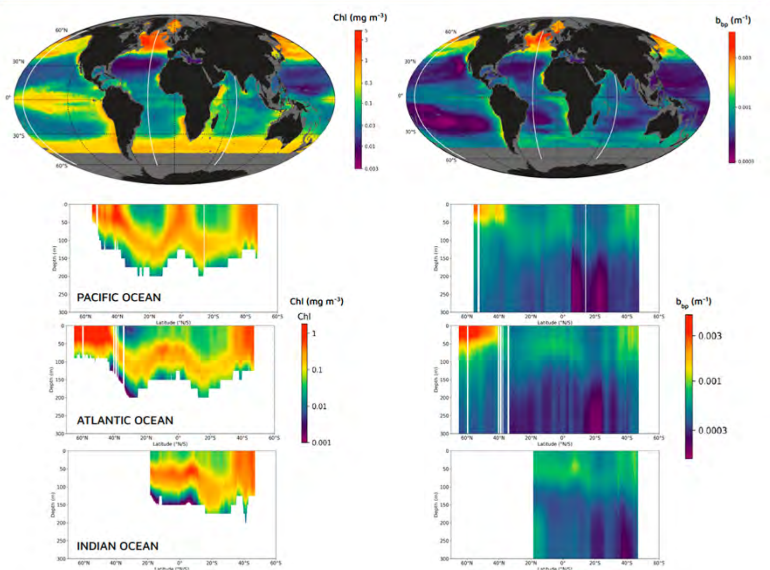
3D SOCA products : Satellite Ocean-Color merged with BGC-Argo (Chla, b_{bp}, radiometry) data



Operational products distributed by Copernicus Marine Service (CMEMS)

- MULTIOBS_GLO_BIO_BGC_3D_REP_015_010 product from MULTIOBS TAC
- 0.25°x 0.25° (horizontal resolution)
- 36 vertical levels from surface to 1000 m depth (vertical resolution)
- Weekly fields from 1998 to 2021 (temporal resolution)
- Monthly climatological fields (temporal resolution).

3D SOCA products : Satellite Ocean-Color merged with BGC-Argo (Chla, b_{bp}, radiometry) data



Synergies between BGC-Argo and satellite OCR (& Lidar) : three possible domains

~~Chla, b_{bp},~~ radiometry (Rrs)

- Validation of Ocean Color Radiometry satellite products
- Development of 3D products
- **From validation to calibration?**

From Validation to Calibration activity?

- Any OCR satellite needs reference measurements at the ocean surface to evaluate the possible evolution of its gain.
- This requires a complete characterization of the uncertainties related to the in situ reference measurements
- Fiducial Reference Measurements FRM (few points but precise) = > vicarious calibration.
- Validation against in-situ measurements (more points less precise)
- Few reference FRM mooring are available for this (e.g. NASA MOBY site Hawaii is presently the only one).
  - Such sites are expensive and not necessarily easy to maintain (e.g. sensor biofouling ….)
- Could a (dedicated) fleet of BGC-Argo Argo contribute to CAL in complement to reference moorings ?

From validation to calibration? : Rrs

6978 Vol. 60, No. 23 / 10 August 2021 / Applied Optics Research Article

applied optics

Seasonal bias in global ocean color observations

Bisson et al., 2021

In this study, we identify a seasonal bias in the ocean color satellite-derived remote sensing reflectances ($R_{rs}(\lambda)$; sr^{-1}) at the ocean color validation site, Marine Optical BuoY. The seasonal bias in $R_{rs}(\lambda)$ is present to varying degrees in all ocean color satellites examined, including the Visible Infrared Imaging Radiometer Suite, Sea-Viewing Wide Field-of-View Sensor, and Moderate Resolution Imaging Spectrometer. The relative bias in R_{rs} has spectral dependence. Products derived from $R_{rs}(\lambda)$ are affected by the bias to varying degrees, with particulate backscattering varying up to 50% over a year, chlorophyll varying up to 25% over a year, and absorption from phytoplankton or dissolved material varying by up to 15%. The propagation of $R_{rs}(\lambda)$ bias into derived products is broadly confirmed on regional and global scales using Argo floats and data from the cloud-aerosol lidar with orthogonal polarization instrument aboard the cloud-aerosol lidar and infrared pathfinder satellite. The artifactual seasonality in ocean color is prominent in areas of low biomass (i.e., subtropical gyres) and is not easily discerned in areas of high biomass. While we have eliminated several candidates that could cause the biases in $R_{rs}(\lambda)$, there are still outstanding questions regarding potential contributions from atmospheric corrections. Specifically, we provide evidence that the aquatic bidirectional reflectance distribution function may in part cause the observed seasonal bias, but this does not preclude an additional effect of the aerosol estimation. Our investigation highlights the contributions that atmospheric correction schemes can make in introducing biases in $R_{rs}(\lambda)$, and we recommend more simulations to discern these influence $R_{rs}(\lambda)$ biases. Community efforts are needed to find the root cause of the seasonal bias because all past, present, and future data are, or will be, affected until a solution is implemented.

https://doi.org/10.1364/AO.426137

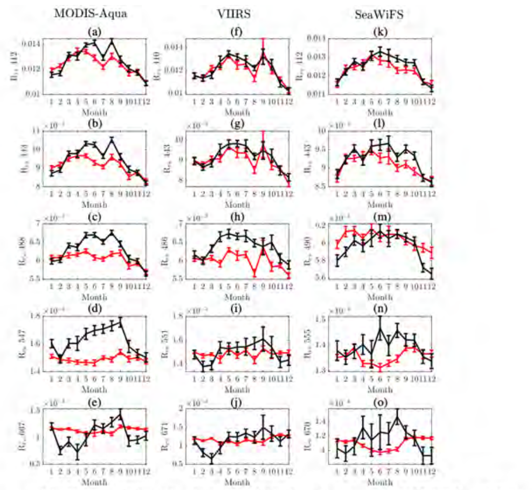


Fig. 1. Monthly averaged $R_{rs}(\lambda)$ with standard error bars for paired validation observations between (a)–(e) MODIS-Aqua, black line; (f)–(j) VIIRS, black line; (k)–(o) SeaWiFS, black line, and MOBY (red line), for each month. Note that wavelengths displayed in a row are not always similar.

From validation to calibration? : Rrs

Journal of Atmospheric and Oceanic Technology

Validation of Ocean Color Remote Sensing Reflectance Using Autonomous Floats

Gerbi et al. 2016

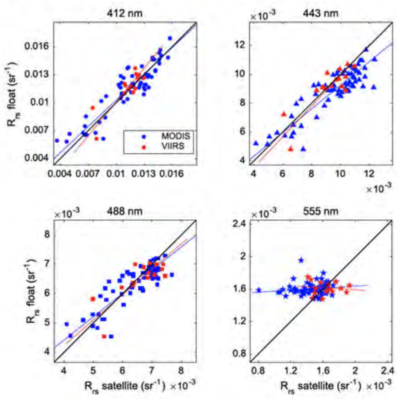


FIG. 9. Scatterplots of R_{rs}. Vertical axes are float estimates. Horizontal axes are satellite estimates. Blue is MODIS *Aqua*. Red is VIIRS. Black lines are 1:1, and thin colored lines show the least squares major axis fits to the observations.

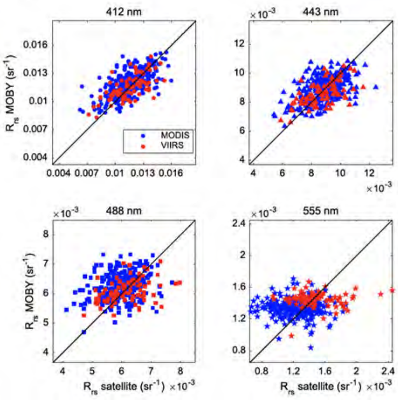


FIG. 15. Scatterplots of R_{rs}. Vertical axes are MOBY estimates. Horizontal axes are satellite estimates. Blue is MODIS *Aqua*. Red is VIIRS. Shapes correspond to wavelength as in previous figures. Black lines are 1:1.

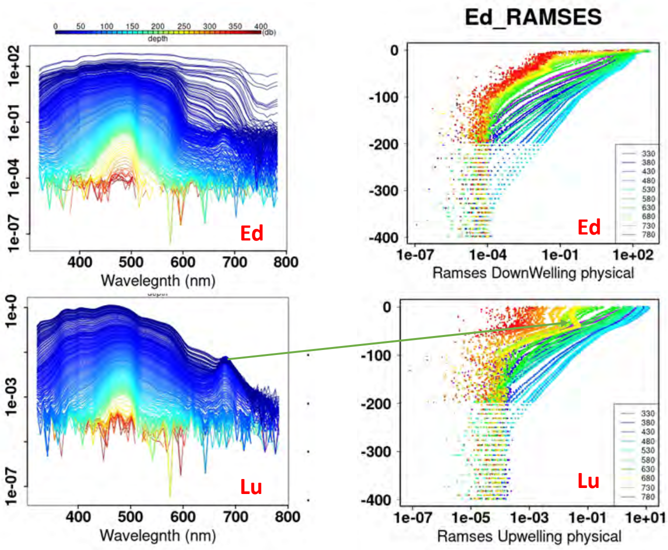
From validation to calibration? : Rrs
Development of a new float

CTS5 NKE float JUMBO (60% more batteries)
- Extended time series : ~ 5 years, vertical profiles every 10 days
- 3 depths over the ~ 9 days drift period: *e.g.* 150m, 500m, 1000m

Standard BGC-Argo Variables
- T, S
- O_2
- NO_3
- pH
- **b_{bp}(700)**
- **Chla fluorescence**
- **PAR, Ed(380), Ed(412), Ed(490)**

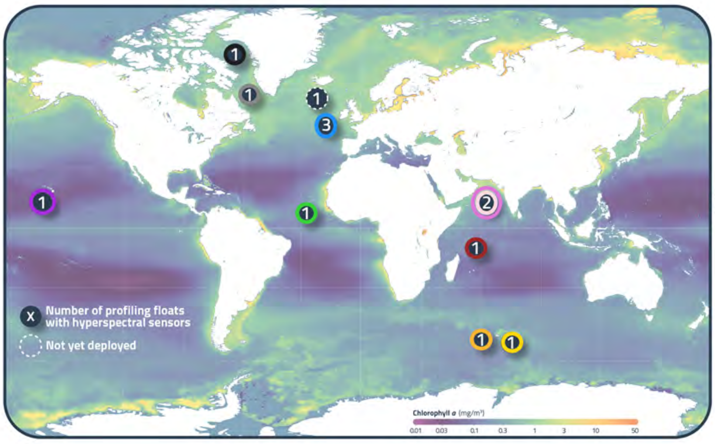
Additional REFINE measurements
- **Lu / Ed (Rrs) hyperspectral** : optically significant substance, link with remote sensing
- **Underwater Vision Profiler (UVP)**: particle size and flux, zooplankton

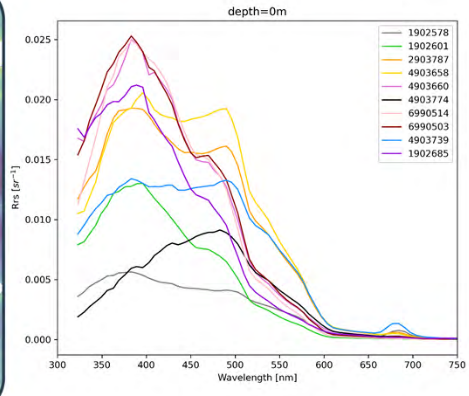
From validation to calibration? : Rrs
Development of a new float



From validation to calibration? : Rrs

12 REFINE floats deployed so far in various areas
more to come (support from CNES and NASA)

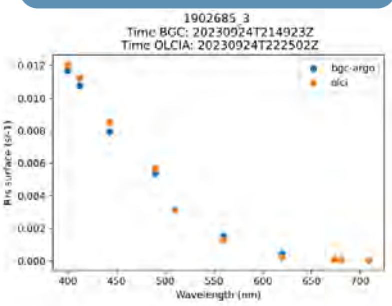


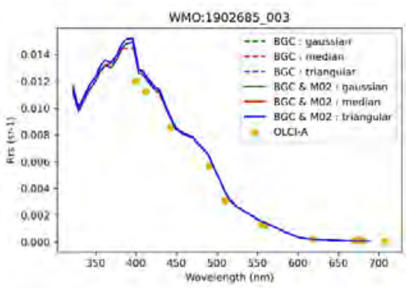


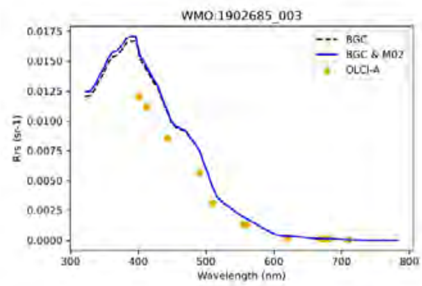
As part of the PACE mission commission phase, the REFINE fleet is being (March 25) accommodated to increase its sampling frequency (from one profile / 10 days to 5 days) and acquisition of more Ed measurements when the float is @ surface

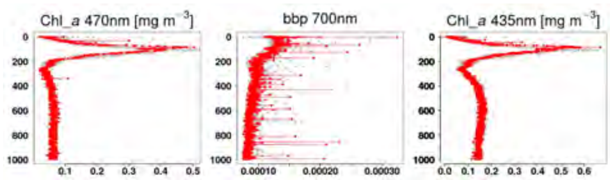
Exemple of comparison with OLCI : Hawaii (near MOBY)

Extrapolation en exponentielle au-dessus de 25m	Méthode Begouen-Demeaux + BRDF *Morel et al. 2002*	Méthode *Gerbi et al. 2016* + BRDF *Morel et al. 2002*







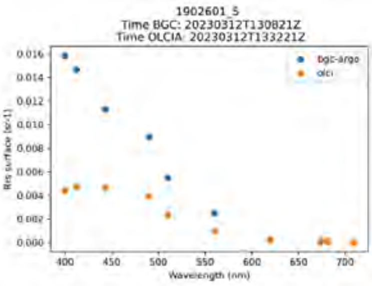


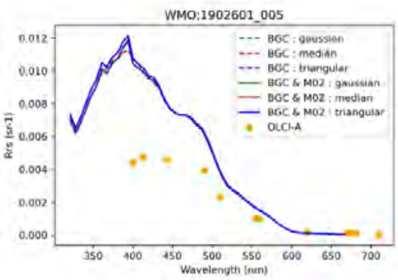
Exemple of comparison with OLCI : Subequatorial Atlantic

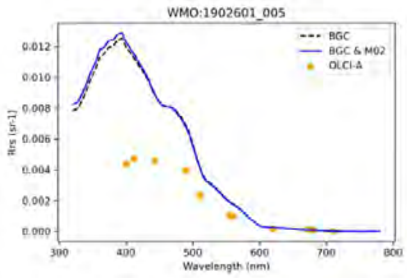
Extrapolation en exponentielle au-dessus de 25m

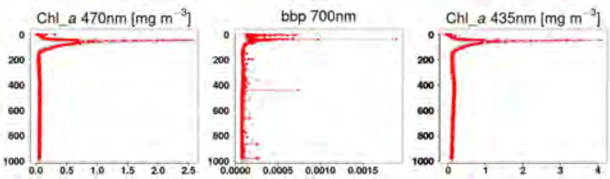
Méthode Begouen-Demeaux + BRDF *Morel et al. 2002*

Méthode *Gerbi et al. 2016* + BRDF *Morel et al. 2002*

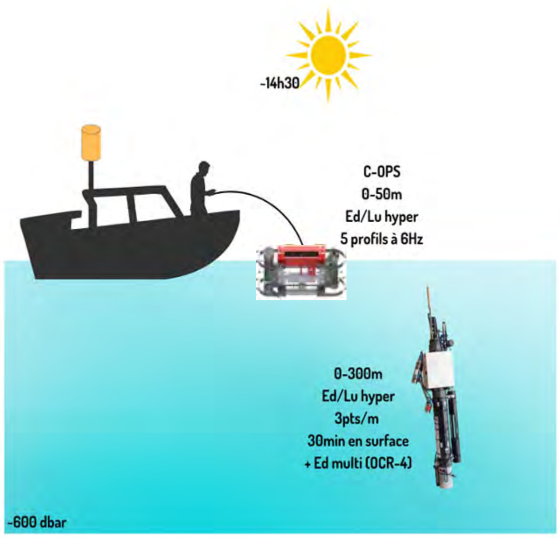




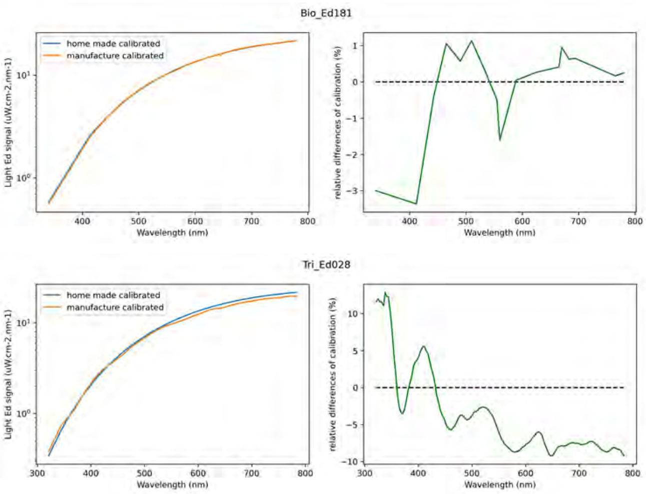


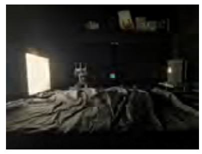


On going activities: in situ comparison between Lu/Ed float and C-Ops (reference profiler) near former Boussole site



On going activities: absolute calibration of sensors in black rooms





Radiomètre	Calibration Difference with respect to lamp
Seabird OCR (Ed)	~20%
Trios RAMSES (Ed)	<10%
Trios RAMSES (Lu)	<25%
Biospherical C-OPS (Ed)	<3%
Biospherical C-OPS (Ed)	<3%
Biospherical C-OPS (Lu)	<5%

From Validation to Calibration activity?

- Could a (dedicated) fleet of BGC-Argo Argo contribute to CAL in complement to reference moorings ?
  - Effort to fully characterize the uncertainty and their evolution with time
  - Not necessarily recovered and recalibrated (but could be envisaged in specific places)
  - Profiling float + sensor : highly resilient to bio-fouling
  - Changing paradigm: considering the uncertainty on a fleet rather on a single platform
  - ....

Conclusions on "synergies" between BGC-Argo and satellite OCR (& Lidar) activities

- Validation : The BGC-Argo data base (Chla, b_{bp}, Kd) is the densest ever acquired and is largely representative of the diversity of open ocean conditions. It is increasingly used in validation exercises. Help highlighting (regional) discrepancies and could become reference database to tune inversion algorithms
- 3D product : They are increasingly used for various purposes (Biological carbon pump; modeling primary production; quality control of BGC-Argo databases; fisheries models)
- Towards calibration?:
  - paradigm change : to possible move from only one / few calibration platforms (MOBY presently the only one) to a mixed system with a complementary fleet of BGC-Argo "RRS" floats capturing the open diversity (and associated variability).
  - BGC-Argo can accommodate several requirement and has sampling flexibilities
  - Discussion with TRIOS attending the Argo Steering Meeting Next week.

Variables considered today

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Pressure				2,4 dbar / 0,1 dbar		2907
Temperature	Ocean circulation, heat fluxes, Air-Sea exchanges, Water cycle	Core Deep BGC	Thermistor	0,002 °C / 0,001 °C	1 dbar / 1dbar	2907
Salinity	Ocean circulation, freshwater fluxes, Water cycle	Core Deep	Conductivity	0,01 psu in delayed mode; 0,1 psu in real time	2 dbar / 1 dbar	2907
			Inductivity	0,01 psu in delayed mode; 0,1 psu in real time	1 dbar / 1 dbar	
Oxygen	Decrease of oxygenation and oxygen minimum zones, carbon cycle	Core (some) Deep (some) BGC	Optode	1% of surface O2 / 0.2 µmol kg^{-1}	-0,2 dbar / 0,1 dbar	576
Nitrate	Eutrophication, toxic algal blooms, biological productivity	BGC	Ultraviolet absorbance	1 µmol kg^{-1} / 0.1 µmol kg^{-1}		305
pH	Ocean acidification, CO_2-Uptake	BGC	Ion Sensitive Field Effect Transistor	0.01 pH / 0.0005 pH		322
Chlorophyll a	Biological productivity, carbon cycle	BGC	Fluorescence	Max (30%,0.03 mg Chla m^{-3}) / 0.025 mg Chla m^{-3}		386
			Radiometer	Max (24%,0.03 mg Chla m^{-3}) / 0.025 mg Chla m^{-3}		
Suspended particles	Biological productivity, carbon cycle	BGC	Optical backscatter	Suspended particles: Max (50%, 1.5 µg kg^{-1}) / 1 µg kg^{-1} Backscattering coefficient: Max (10 %, 10^{-5} m^{-1}) / 4 x$10^{-6}$$m^{-1}$ POC : Max (30%, 20 mg m^{-3}) / 10 mg m^{-3} PC: Max (30%, 6 mg m^{-3}) / 3 mg m^{-3}	0,1 dbar / 0,1 dbar for upper 300m	386
Downwelling irradiance (Ed)	Underwater light field, biological productivity, carbon cycle	BGC	Radiometer	PAR: Max (3%, 5 µmol photons m^{-2} s^{-1}) / 1 µmol photons m^{-2} s^{-1} Spectral: Max (3%, 5 x10^{-3} µW cm^{-2} nm^{-1}) / 2.5 X 10^{-3} µW cm^{-2} nm^{-1}	0,1 dbar / 0,1 dbar for upper 300m	116
		BGC/Provor CTS5	Hyperspectral radiometer	< 6-10% (depends on wavelength range&calibration quality)	Acquisition from 300db to surface at 0.3 db resolution near surface	14
Upwelling radiance (Lu)	Underwater light field, biological productivity, carbon cycle	BGC/Provor CTS5 Prospective (REFINE, ITINERIS)	Hyperspectral radiometer	< 6% (depends on wavelength range&calibration quality)	Acquisition from 300db to 1.78db at 0.3 db resolution near surface	12
pCO_2	Carbon uptake	Prospective (C-SCOPE, GEORGE)	Membrane equilibrator/IR absorbance		1 dbar / 1dbar	2
Surface wind	Air-Sea exchanges	Prospective (GEORGE)	Passive acoustic			-
Zooplankton	Ecosystems, biodiversity	Prospective (REFINE)	Optic			33

Zooplankton and particle size
Development of a new float

CTS5 NKE float JUMBO (60% more batteries)
- Extended time series : ~ 5 years, vertical profiles every 10 days
- 3 depths over the ~ 9 days drift period: *e.g.* 150m, 500m, 1000m

Standard BGC-Argo Variables
- T, S
- O_2
- NO_3
- pH
- **b_{bp}(700)**
- **Chla fluorescence**
- **PAR, Ed(380), Ed(412), Ed(490)**

Additional REFINE measurements
- **Underwater Vision Profiler (UVP)**: particle size and flux, zooplankton
- **Transmissometer** : Carbon flux and phytoplankton community composition.

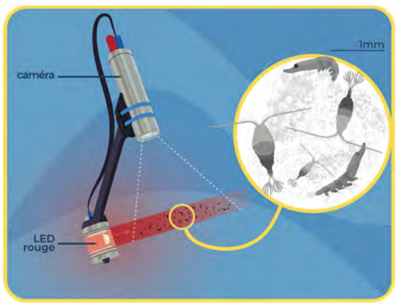
The Underwater Vision Profiler (UVP6) : particles and zooplancton

LIMNOLOGY and OCEANOGRAPHY: METHODS

ASLO

The Underwater Vision Profiler 6: an imaging sensor of particle size spectra and plankton, for autonomous and cabled platforms

Picheral et al., 2021

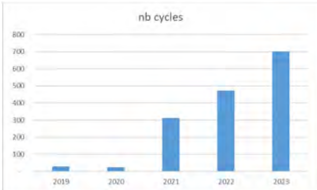


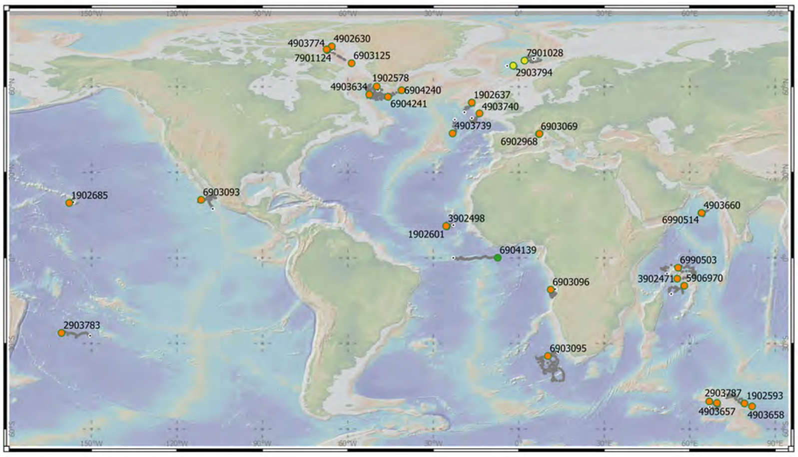
- Low power, image based, sampling volume: 0.7 L
- **particle size counter** 100 µm - 2.5mm
- **Embedded (AI) zooplankton identification** (20 classes)
  - ✓ Count per class vs depth
  - ✓ Volume per class vs depth
  - ✓ Mean grey per class vs depth

The Underwater Vision Profiler (UVP6) : particles and zooplancton

32 floats at the GDAC

Année	nb cycles
2019	30
2020	24
2021	312
2022	473
2023	703
Total	1 542





Argo floats equipped with UVP sensor
19 October 2023

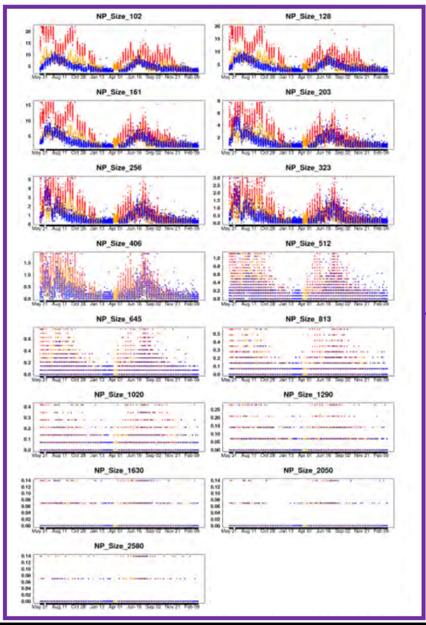
Last positions of floats with UVP
- FRANCE
- GERMANY
- NORWAY

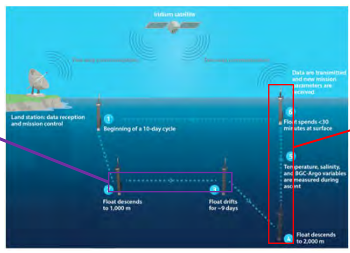
- Deployment positions
- Profiles

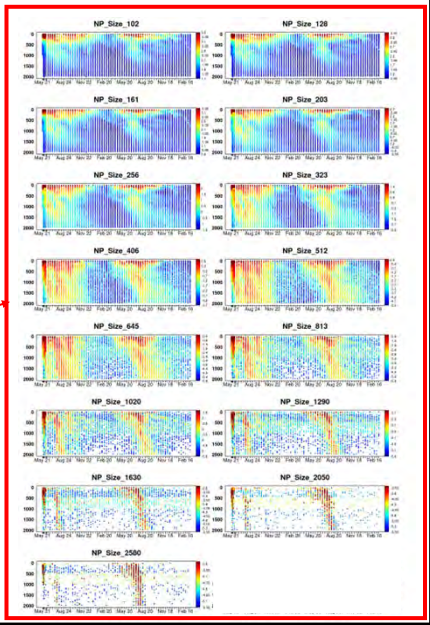
The Underwater Vision Profiler (UVP6) : ongoing ~ two-year time-serie of particle size distribution (µm) in the Labrador Sea

Time serie of drift @ 200m 500m 1000m

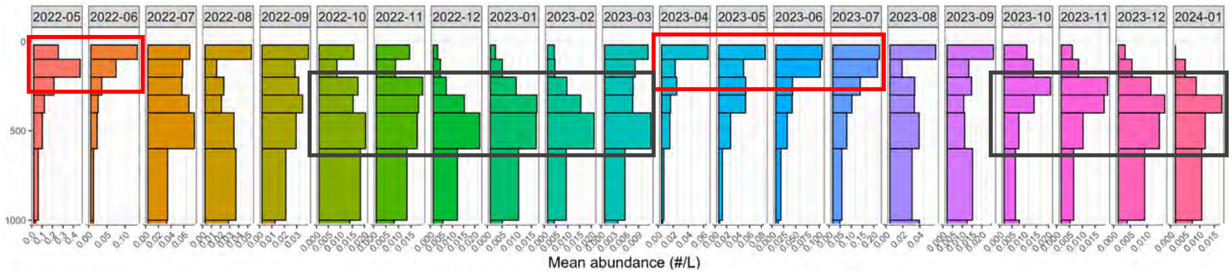
Time serie of 0-2000 m profiles



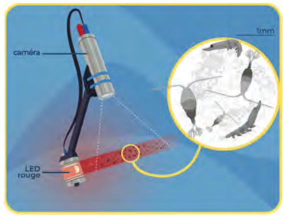




The Underwater Vision Profiler (UVP6) : ongoing two years time serie of copepods (crustaceans ~1 mm size) in the Labrador Sea



Possible evidence of seasonal migration which impact the sequestration of carbon



Variables considered today

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision (subject to rapid updates)	Upper bin shallowest / size	# active floats
Pressure				2,4 dbar / 0,1 dbar		2907
Temperature	Ocean circulation, heat fluxes, Air-Sea exchanges, Water cycle	Core Deep BGC	Thermistor	0,002 °C / 0,001 °C	1 dbar / 1dbar	2907
Salinity	Ocean circulation, freshwater fluxes, Water cycle	Core Deep	Conductivity Inductivity	0,01 psu in delayed mode; 0,1 psu in real time 0,01 psu in delayed mode; 0,1 psu in real time	2 dbar / 1 dbar 1 dbar / 1 dbar	2907
Oxygen	Decrease of oxygenation and oxygen minimum zones, carbon cycle	Core (some) Deep (some) BGC	Optode	1% of surface O2 / 0.2 μmol kg^{-1}	-0,2 dbar / 0,1 dbar	576
Nitrate	Eutrophication, toxic algal blooms, biological productivity	BGC	Ultraviolet absorbance	1 μmol kg^{-1} / 0.1 μmol kg^{-1}		305
pH	Ocean acidification, CO_2-Uptake	BGC	Ion Sensitive Field Effect Transistor	0.01 pH / 0.0005 pH		322
Chlorophyll a	Biological productivity, carbon cycle	BGC	Fluorescence Radiometer	Max (30%,0.03 mg Chla m^{-3}) / 0.025 mg Chla m^{-3} Max (24%,0.03 mg Chla m^{-3}) / 0.025 mg Chla m^{-3}		386
Suspended particles	Biological productivity, carbon cycle	BGC	Optical backscatter	Suspended particles: Max (50%, 1.5 μg kg^{-1}) / 1 μg kg^{-1} Backscattering coefficient: Max (10 %, 10^{-5} m^{-1}) / 4 x10^{-6}m^{-1} POC : Max (30%, 20 mg m^{-3}) / 10 mg m^{-3} PC: Max (30%, 6 mg m^{-3}) / 3 mg m^{-3}	0,1 dbar / 0,1 dbar for upper 300m	386
Downwelling irradiance (Ed)	Underwater light field, biological productivity, carbon cycle	BGC	Radiometer	PAR: Max (3%, 5 μmol photons m^{-2} s^{-1}) / 1 μmol photons m^{-2} s^{-1} Spectral: Max (3%, 5 x10^{-3} μW cm^{-2} nm^{-1}) / 2.5 X 10^{-3} μW cm^{-2} nm^{-1}	0,1 dbar / 0,1 dbar for upper 300m	116
		BGC/Provor CTS5	Hyperspectral radiometer	< 6-10% (depends on wavelength range&calibration quality)	Acquisition from 300db to surface at 0.3 db resolution near surface	14
Upwelling radiance (Lu)	Underwater light field, biological productivity, carbon cycle	BGC/Provor CTS5 Prospective (REFINE, ITINERIS)	Hyperspectral radiometer	< 6% (depends on wavelength range&calibration quality)	Acquisition from 300db to 1.78db at 0.3 db resolution near surface	12
pCO_2	Carbon uptake	Prospective (C-SCOPE, GEORGE)	Membrane equilibrator/IR absorbance		1 dbar / 1dbar	2
Surface wind	Air-Sea exchanges	Prospective (GEORGE)	Passive acoustic			-
Zooplankton	Ecosystems, biodiversity	Prospective (REFINE)	Optic			33

From BGC-Argo measurements to inference of "chemical" products example of CO_2 and carbonate system and nutrients

CTS5 NKE float JUMBO (60% more batteries)

- Extended time series : ~ 5 years, vertical profiles every 10 days
- 3 depths over the ~ 9 days drift period: *e.g.* 150m, 500m, 1000m

Standard BGC-Argo Variables

- T, S
- O_2
- pH
- NO_3

→ pCO2, DIC, nutrients…

- **b_{bp}(700)**
- **Chla fluorescence**
- **PAR, Ed(380), Ed(412), Ed(490)**

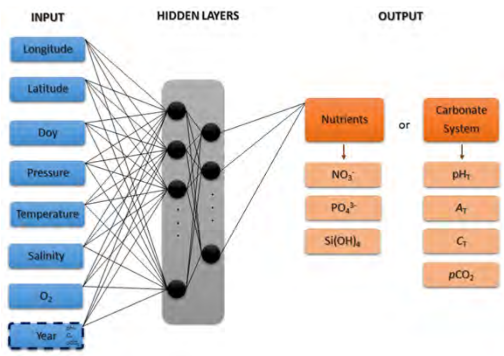
Additional REFINE measurements

- **Lu / Ed (Rrs) hyperspectral** : optically significant substance, link with remote sensing
- **Underwater Vision Profiler (UVP)**: particle size and flux, zooplankton

CANYON : Carbonate system and Nutrients concentrations from hYdrological properties and Oxygen using a Neural network

Concept : Nutrient and Carbonate system variables vertical profiles inferred from BGC-Argo O_2 profiles qualified in delayed mode Sauzède et al. 2017.

- Based on a **neural-network method** trained on high quality nutrient data collected over the last 30 years (**GLODAPv2** database, **Olsen et al., 2016**)
- **CANYON-B** (Bittig et al., 2018)
- Regional version for the Mediterranean Sea: **CANYON-MED** (Fourier et al. 2020)



Outputs

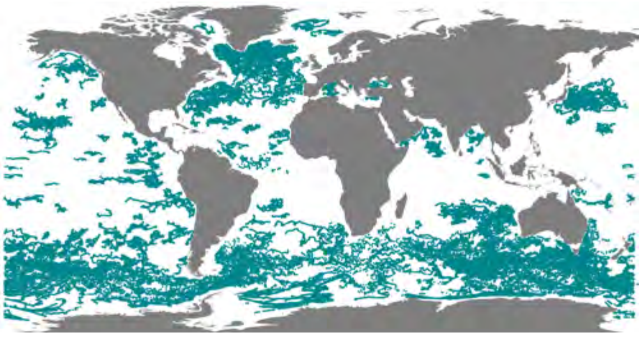
- Profiles of concentration of nitrates (**NO_3^-**), phosphates (**PO_4^{3-}**) and silicates (**$Si(OH)_4$**)
- Profiles of Carbonate system variables (**pH**, total alkalinity (**A_T**), dissolved inorganic carbon (**C_T**), and partial pressure of CO_2 (**pCO_2**))

Global CANYON accuracies

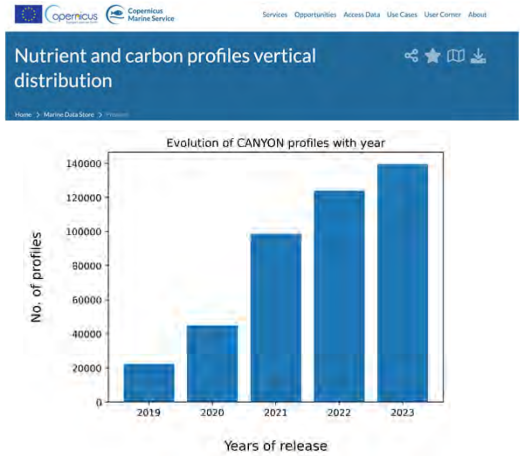
NO_3^- : 0.68 µmol kg^{-1}	pH_T : 0.015
PO_4^{3-} : 0.05 µmol kg^{-1}	A_T : 7.1 µmol kg^{-1}
$Si(OH)_4$: 2.3 µmol kg^{-1}	C_T : 6.9 µmol kg^{-1}
	pCO_2 : 15 µatm

CANYON products are delivered by CMEMS

CMEMS product of **profiles of nutrients concentrations** (1st release in 2019) and **carbonate system variables** (1st release in 2022) derived from BGC-Argo O_2 profiles qualified in delayed mode and release yearly



NRT delivery targeted for the end of 2024



https://data.marine.copernicus.eu/product/MULTIOBS_GLO_BGC_NUTRIENTS_CARBON_PROFILES_MYNRT_015_009/description

Acoustic winds on float

- $FCO_2 = pCO_2$ x fct (wind intensity)
- Wind sensor is being implemented / tested on floats as part of the GEORGE project
- EU projects submitted to combine Wind measurements and Machine Learning approaches (e.g. CANYON) to infer pCO_2 and FCO_2 from floats to fill observational gaps in critical areas (e.g. Southern Ocean, especially in winter)
- Wind speed (and rain) potentially interesting validation products…

- **Acquisition during the drift phase (9 days over 10)**
- **Transmission of Sound Pressure Level (SPL) for 9 spectral band between 63 Hz and 21 kHz**
- **Derivation / test of various algorthims**

- Riser, S. C., J. Nystuen, and A. Rogers (2008), Monsoon effects in the Bay of Bengal inferred from profiling float-based measurements of wind speed and rainfall, *Limnology and Oceanography*, *53*(5), 2080-2093, doi:10.4319/lo.2008.53.5_part_2.2080.

Final message

- BGC-Argo is quickly filling many observational gaps for key biogeochemical and bio-optical variable
- The community is working to improve the evaluation of the uncertainties of the measurements
- While the uncertainties of some key measurements (Rrs, pCO2) might remain larger that of moorings (Rrs) or ship-base (e.g. pCO2), the density of the dataset acquired by BGC-Argo might help reconsidering the fleet as a whole (rather than on a platform by platform basis) to reduce the uncertainty in those key measurements.
- While more and more and new product are derived from Argo, it is not the mandate of Argo (DAC and GDAC) to deliver and maintain them. The help of Copernicus is essential in this respect (MOBTAC and in situ TAC)

ANNEX 5 - Argo_Description

Variable	Scientific use	Float types	Sensor Type	Accuracy/Precision	Upper bin	# active	1st
Pressure				2,4 dbar / 0,1 dbar		2907	1996
Temperature	Ocean circulation, heat fluxes,	Core	Thermistor	0,002 °C / 0,001 °C	1 dbar / 1dbar	2907	1996
Salinity	Ocean circulation, freshwater fluxes, Water cycle	Core	Conductivity	0,01 psu in delayed mode; 0,1 psu in real time	2 dbar / 1 dbar	2907	1996
		Deep	Inductivity	0,01 psu in delayed mode; 0,1 psu in real time	1 dbar / 1 dbar		
Oxygen	Decrease of oxygenation and	Core (some)	Optode	1% of surface O2 / 0,2 µmol kg^{-1}	-0,2 dbar / 0,1 dbar	576	2002
Nitrate	Eutrophication, toxic algal blooms, biological productivity	BGC	Ultraviolet absorbance	1 µmol kg^{-1} / 0.1 µmol kg^{-1}		305	2007
pH	Ocean acidification, CO_2-Uptake	BGC	Ion Sensitive Field Effect Transistor	0.01 pH / 0.0005 pH		322	2012
Chlorophyll a	Biological productivity, carbon cycle	BGC	Fluorescence	Max (30%,0.03 mg Chla m^{-3}) / 0.025 mg Chla m^{-3}		386	2004
			Radiometer	Max (24%,0.03 mg			
Suspended particles	Biological productivity, carbon cycle	BGC	Optical backscatter	Suspended particles: Max (50%, 1.5 µg kg^{-1}) / 1 µg kg^{-1}	0,1 dbar / 0,1 dbar for upper 300m	386	2005
				Backscattering coefficient: Max (10 %, 10^{-5} m^{-1}) / 4 x10^{-6} m^{-1}			
				POC : Max (30%, 20 mg m^{-3}) / 10 mg m^{-3}			
				PC: Max (30%, 6 mg m^{-3}) / 3 mg m^{-3}			
Downwelling irradiance (Ed)	Underwater light field, biological productivity, carbon cycle	BGC	Radiometer	PAR: Max (3%, 5 µmol photons m^{-2} s^{-1}) / 1 µmol photons m^{-2} s^{-1}	0,1 dbar / 0,1 dbar for upper 300m	116	2012
				Spectral: Max (3%, 5 x10^{-3} µW cm^{-2} nm^{-1}) / 2.5 X 10^{-3} µW cm^{-2} nm^{-1}			
		BGC/Provor CTS5	Hyperspectral radiometer	< 6-10% (depends on wavelength range&calibration quality)	Acquisition from 300db to surface at 0.3 db resolution near surface	14	
Upwelling radiance (Lu)	Underwater light field, biological productivity, carbon cycle	BGC/Provor CTS5 Prospective (REFINE, ITINERIS)	Hyperspectral radiometer	< 6% (depends on wavelength range&calibration quality)	Acquisition from 300db to 1.78db at 0.3 db resolution near surface	12	2014
pCO_2	Carbon uptake	Prospective (C-SCOPE, GEORGE)	Membrane equilibrator/IR absorbance		1 dbar / 1dbar	2	2022
Surface wind	Air-Sea exchanges	Prospective (GEORGE)	Passive acoustic			-	2025?
Zooplankton	Ecosystems, biodiversity	Prospective (REFINE)	Optic			33	2020

ANNEX 5 - ECMWF-PHY_Requirements

Variable	**Specific usage:** variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	**Delay** (timeliness)	**Upper bin / Lower bin** (size)	**Geographic coverage and density needed** (density)	Deep relevant	Under-Ice relevant
Pressure	used in obs oper to match model levels			12h		Global coverage; enhanced density needed for ITCZ region and WBCs	y	y
Temperature	used in operational ocean DA system		current accuracy is sufficient	12h		Global coverage; enhanced density needed for ITCZ region and WBCs	y	y
Salinity	used in operational ocean DA system		accuracy is sufficient; drfiting is a issue	12h		Global coverage; enhanced density needed for ITCZ region and WBCs	y	y
Oxygen	Data Assimilation (DA), NN for reconstructed profiles							
Nitrate	DA, Validation							
pH	Validation							
Chlorophyll a	DA, Validation							
Suspended particles	Validation for PhytoC and PPOC							
Downwelling irradiance (Ed)	At the moment validation just for PAR							
Upwelling radiance (Lu)								
pCO_2								
Surface wind								
Zooplankton								

ANNEX 5 - ARC-MFC_Requirements

Variable	Specific usage: variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	Delay (timeliness)	Upper bin / Lower bin (size)	Geographic coverage and density needed (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure	For matching Temperature and Salinity profiles to model levels with DA system			1 day for NRT (daily forecast)		Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle	yes	yes	yes	now
Temperature	NRT for forecast and DM for reanalysis with DA system			1 day for NRT (daily forecast)	1 dbar/1 bar for upper 2000m	Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle	yes	yes	yes	now
Salinity	NRT for forecast and DM for reanalysis with DA system			1 day for NRT (daily forecast)	1 dbar/1 bar for upper 2000m	Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle	yes	yes	yes	now
Oxygen	For validation of BGC forecast and reanalysis			1 to 2 years	1 dbar for upper 500m	Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle for winter, 5 days cycle for bloom period	yes	yes	yes	now
Nitrate	DM for DA and validation of nitrate concentration			1 year for DM (annual reanalysis update)	1 dbar for upper 500m	Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle for winter, 5 days cycle for bloom period	yes	yes	yes	now
pH	DM for validation of carbon chemistry (not implemented yeat)			1 to 2 years	1 dbar/1 bar for upper 2000m	Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle	yes	yes	yes	2026
Chlorophyll a	NRT and DM for DA and validation of phytoplankton biomass			1 year for DM (annual reanalysis update)	1 dbar for upper 500m	Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle for winter, 5 days cycle for bloom period	no	yes	yes	now
Suspended particles	Validation for POC			1 to 2 years	1 dbar for upper 500m	Arctic Mediteranean Seas, 3 degree by 3 degree,10 days cycle for winter, 5 days cycle for bloom period	no	yes	yes	2026
Downwelling irradiance (Ed)						Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle	no	yes	yes	
Upwelling radiance (Lu)						Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle	no	yes	yes	
pCO_2	DM for validation of carbon chemistry (not implemented yet)			1 to 2 years	1 dbar/1 bar for upper 2000m	Arctic Mediteranean Seas, 3 degree by 3 degree, 10 days cycle	yes	yes	yes	2026
Surface wind							no	no	no	
Zooplankton	DM for validation of zooplankton biomass (not implemented yet)			1 to 2 years		Arctic Mediteranean Seas, 3 degree by 3 degree, 5 days cycle	no	yes	yes	2026

ANNEX 5 - Med-MFC-PHY_Requirements

Variable	**Specific usage:** variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	**Delay** (timeliness)	**Upper bin / Lower bin** (size)	**Geographic coverage and density needed** (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure	Neural Network (NN) for reconstructed profiles			24h			y	N/A	y	
Temperature	DA, Validation	Thermistor		24h	1 dbar /1dbar	Additional floats are desiderable in Aegean, Levantine, Gulf of Sidra and in the Atlantic near theStrait of Gibraltar.	y	N/A	y	
Salinity	DA, Validation	Conductivity Inductivity		24h	2 dbar /1dbar 1 dbar /1dbar	Additional floats are desiderable in Aegean, Levantine, Gulf of Sidra and in the Atlantic near the Strait of Gibraltar.	y	N/A	y	
Oxygen										
Nitrate										
pH										
Chlorophyll a										
Suspended particles										
Downwelling irradiance (Ed)										
Upwelling radiance (Lu)										
pCO_2										
Surface wind										
Zooplankton										

Variable	**Specific usage:** variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	Delay (timeliness)	Upper bin / Lower bin (size)	Geographic coverage and density needed (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure	Neural Network (NN) for reconstructed profiles									
Temperature	NN for reconstructed profiles		0.05 K	24h	As close of the surface as possible	Global including high latitudes	no		yes	continuity of the current service is mandatory. Extension to high latitudes by 2028
Salinity	NN for reconstructed profiles		0.1 PSU ?	24h	the surface	Global including high latitudes	no		yes	By 2028
Oxygen	Data Assimilation (DA), NN for reconstructed profiles									
Nitrate	DA, Validation									
pH	Validation									
Chlorophyll a	DA, Validation								yes	Yes if direct measurement
Suspended particles	Validation for PhytoC and PPOC									
Downwelling irradiance (Ed)	At the moment validation just for PAR									
Upwelling radiance (Lu)										
pCO2										
Surface wind			0.1 m/s	24h		global			yes	For validation of our scatterometer winds
Zooplankton										

Variable	**Specific usage:** variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	Delay (timeliness)	Upper bin / Lower bin (size)	Geographic coverage and density needed (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure	Neural Network (NN) for reconstructed profiles			48h						
Temperature	NN for reconstructed profiles	Thermistor		48h	1 dbar /1dbar					
Salinity	NN for reconstructed profiles	Conductivity Inductivity		48h	2 dbar / 1 dbar					
Oxygen	Data Assimilation (DA), NN for reconstructed profiles	Optode		48h (in DM it would be feasable 1month to align with Satellite Products and Interim production)	-0,2 dbar / 0,1 dbar	Now, 25 active floats in the MED. Additional floats are desiderable in Tyrrhenian, Southern Ionan, Aegean and Southern Levantine.	no, for the Med	N/A in the Med		Adjusted NR mode in 48h (for operational DA); Delay mode in 1 year or earlier as possible (for validation and reanalysis)
Nitrate	DA, Validation	Ultraviolet absorbance		48h		Now, 3 active floats in the MED. It is desideble to have at least 7 (one in each macro-region: NorthWestern Med, SouthWestern Med, Tyrrhenian, Ionian, Southern Adriatic, Levantine, Aegean)	no, for the Med			Adjusted NR mode in 48h (for operational DA); Delay mode in 1 year, or earlier as possible (for validation and reanalysis)
pH	Validation	Ion Sensitive Field Effect Transistor		48h		no float active in the Med	no, for the Med			
Chlorophyll a	DA, Validation	Fiuorescence Radiometer		48h		Now, 9 active floats in the MED. It is desideble to have at least 14 (two floats in each macro-region: NorthWestern Med, SouthWestern Med, Tyrrhenian, Ionian, Southern Adriatic, Levantine, Aegean)	no, for the Med			Adjusted NR mode in 48h (for operational DA); Delay mode in 1 year or earlier as possible (for validation and reanalysis)
Suspended particles	Validation for PhytoC and PPOC	Optical backscatter			0,1 dbar / 0,1 dbar for upper 300m	It is desideble to have at least 14 floats (two floats in each macro-region: NorthWestern Med, SouthWestern Med, Tyrrhenian, Ionian, Southern Adriatic, Levantine, Aegean)	no, for the Med			
Downwelling irradiance (Ed)	At the moment validation just for PAR	Radiometer		48n	0,1 dbar / 0,1 dbar for upper 300m	It is desideble to have at least 7 (one floats in each macro-region: NorthWestern Med, SouthWestern Med, Tyrrhenian, Ionian, Southern Adriatic, Levantine, Aegean)	no, for the Med			
Upwelling radiance (Lu)		Hyperspectral radiometer				highly desiderable, at least one to test these new data for bio-optics model validation				
pCO_2		Membrane equilibrator/IR absorbance				not present in the Med, but highly desiderable. A minimun requirement is as for the other bgc-variables(one in each macro-region)				
Surface wind		Passive acoustic								
Zooplankton		Optic				highly desiderable, at least one to test these new data for model validation				

ANNEX 5 - GLO-MFC-BGC_Requirements

Variable	Specific usage: variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	Delay (timeliness)	Upper bin / Lower bin (size)	Geographic coverage and density needed (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation
Pressure	use when comparing the model equivalent to T,S and BGC observations when the depth variable not available.		20 cm/surf to 20 m at 6000 m depth	1 day for assimilation in real time (assimilation window of 7-days)						
Temperature	validation and data assimilation in RT and in DM (mostly) for reanalysis	Thermistor	current accuracy ok	1 day for assimilation in real time (assimilation window of 7-days)	as close as possible to the surface (10 cm bin is fine), to the bottom where the bins can be larger	global coverage, at least with the present density ((3°x3° - 10 days); with "coastal" and under ice floats	yes	yes	yes	now
Salinity	validation and data assimilation in RT and in DM (mostly) for reanalysis	Conductivity Inductivity (same requirements)	current accuracy ok	1 day for assimilation in real time (assimilation window of 7-days)	as close as possible to the surface (10 cm bin is fine), to the bottom where the bins can be larger	global coverage, at least with the present density ((3°x3° - 10 days); with "coastal" and under ice floats	yes	yes	yes	now
Oxygen		Optode	1 µmol kg-1 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	Global coverage, at least (3° x3°)	No	Yes	Yes	2026
Nitrate		Ultraviolet absorbance	1 µmol kg-1 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	Global coverage, at least (3° x3°)	No	Yes	Yes	2026
pH		Ion Sensitive Field Effect Transistor	0.01 pH / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	Global coverage, at least (3° x3°)	No	Yes	Yes	2026
Chlorophyll a		Fluorescence Radiometer	0.01 mg/m3 /10-20 % . There is a significant discrepancy between chlorophyll-a (Chl-a) estimates derived from BGC Argo floats and those derived from satellite data. This discrepancy may hinder efforts to use both data sources for assessment and data assimilation. To achieve a more robust analysis, the Chl-a measurements from BGC Argo floats and satellite observations need to be reconciled.	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	Global coverage, at least (3° x3°)	No	Yes	Yes	2026
Suspended particles		Optical backscatter	POC: 10 mg m-3 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	Global coverage, at least (3° x3°)	No	Yes	Yes	2026
Downwelling irradiance (Ed)		Radiometer		1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	Global coverage, at least (3° x3°)	No	Yes	Yes	2026
Upwelling radiance (Lu)		Hyperspectral radiometer		1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	Global coverage, at least (3° x3°)	No	Yes	Yes	2026
pCO_2		Membrane equilibrator/IR absorbance	5-10 uatm / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)		Global coverage, at least (3° x3°)	No	Yes	Yes	2026
Surface wind		Passive acoustic								
Zooplankton		Optic	10-20 mg m-3 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)		Global coverage, at least (3° x3°)	No	Yes	Yes	2026

ANNEX 5 - Black-Sea-BGC_Requirements

Variable	Specific usage: variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	Delay (timeliness)	Upper bin / Lower bin (size)	Geographic coverage and density needed (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure										
Temperature		Thermistor								
Salinity		Conductivity Inductivity								
Oxygen		Optode								
Nitrate		Ultraviolet absorbance								
pH		Ion Sensitive Field Effect Transistor								
Chlorophyll a		Fiuorescence Radiometer								
Suspended particles		Optical backscatter								
Downwelling irradiance (Ed)	calibration/validation of spectral radiation model, more than 3 wavelengths would be even better	Radiometer	Max 5 % error	not important	0.1 db	black sea				
Upwelling radiance (Lu)		Hyperspectral radiometer								
pCO2		Membrane equilibrator/IR absorbance								
Surface wind		Passive acoustic								
Zooplankton	calibration/validation of BGC model	Optic		not important		black sea				

ANNEX 5 - IBI-MFC-BGC_Requirements

Variable	Specific usage: variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	Delay (timeliness)	Upper bin / Lower bin (size)	Geographic coverage and density needed (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure	use when comparing the model equivalent to T,S and BGC observations when the depth variable not available.		20 cm/surf to 20 m at 6000 m depth	1 day for assimilation in real time (assimilation window of 7-days)						
Temperature	validation and data assimilation in RT and in DM (mostly) for reanalysis	Thermistor	current accuracy ok	1 day for assimilation in real time (assimilation window of 7-days)	as close as possible to the surface (10 cm bin is fine), to the bottom where the bins can be larger		N/A	N/A	yes	now
Salinity	validation and data assimilation in RT and in DM (mostly) for reanalysis	Conductivity	current accuracy ok	1 day for assimilation in real time (assimilation window of 7-days)	as close as possible to the surface (10 cm bin is fine), to the bottom where the bins can be larger		N/A	N/A	yes	now
Oxygen		Optode	1 µmol kg-1 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
Nitrate		Ultraviolet absorbance	1 µmol kg-1 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
pH		Ion Sensitive Field Effect Transistor	0.01 pH / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
Chlorophyll a		Fluorescence Radiometer	0.01 mg/m3 /10-20 % . There is a significant discrepancy between chlorophyll-a (Chl-a) estimates derived from BGC Argo floats and those derived from satellite data. This discrepancy may hinder efforts to use both data sources for assessment and data assimilation. To achieve a more robust analysis, the Chl-a measurements from BGC Argo floats and satellite observations need to be reconciled	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
Suspended particles		Optical backscatter	POC: 10 mg m·3 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
Downwelling irradiance (Ed)		Radiometer		1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
Upwelling radiance (Lu)		Hyperspectral radiometer		1 day for assimilation in real time (assimilation window of 7-days)	1 dbar from surface to 2000 m	at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
pCO_2		Membrane equilibrator/IR absorbance	5-10 uatm / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)		at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026
Surface wind		Passive acoustic				at least 1 float by 1° in the IBI region		N/A in IBI		
Zooplankton		Optic	10-20 mg m·3 / 10-20 %	1 day for assimilation in real time (assimilation window of 7-days)		at least 1 float by 1° in the IBI region	No	N/A in IBI	Yes	2026

ANNEX 5 - BAL-MFC_Requirements

Variable	Specific usage: variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	Delay (timeliness)	Upper bin / Lower bin (size)	Geographic coverage and density needed (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure	Cal/Val			24h		Baltic Sea - North Sea		Y but coordinates are needed	Y	
Temperature	Cal/Val	Thermistor		24h		Baltic Sea - North Sea		Y but coordinates are needed	Y	
Salinity	Cal/Val	Conductivity Inductivity		24h		Baltic Sea - North Sea		Y but coordinates are needed	Y	
Oxygen	Cal/Val	Optode		24h		Baltic Sea - North Sea		Y but coordinates are needed	Y	
Nitrate	Cal/Val	Ultraviolet absorbance		24h		Baltic Sea - North Sea		Y but coordinates are needed	Y	
pH		Ion Sensitive Field Effect Transistor								
Chlorophyll a	Cal/Val	Fiuorescence Radiometer		24h		Baltic Sea - North Sea		Y but coordinates are needed	Y	
Suspended particles		Optical backscatter								
Downwelling irradiance (Ed)		Radiometer								
Upwelling radiance (Lu)		Hyperspectral radiometer								
pCO_2		Membrane equilibrator/IR absorbance								
Surface wind		Passive acoustic								
Zooplankton		Optic								

ANNEX 5 - OC-TAC_Requirements

Variable	**Specific usage:** variable used/needed for products, CAL/VAL and/or assimilation?	Sensor Type	Expected Accuracy/Precision	**Delay** (timeliness)	**Upper bin / Lower bin** (size)	**Geographic coverage and density needed** (density)	Deep relevant	Under-Ice relevant	Coastal Argo relevant	appropriate implementation timing
Pressure										
Temperature	N/A									
Salinity	N/A									
Oxygen	N/A									
Nitrate	N/A									
pH	N/A									
Chlorophyll a	Product validation/intercomparison	Fluorescence Radiometry		12-18h	0,5 dbar for upper 50 m	Global, Med Sea, Black Sea, Baltic Sea, Arctic Ocean	No	No	Yes	2025
Suspended particles	Product validation/intercomparison (depending on	Optical Backscatter		12-18h	0,5 dbar for upper 50 m	Global, Med Sea, Black Sea, Baltic Sea, Arctic Ocean	No	No	Yes	2025
Downwelling irradiance (Ed)	CAL/VAL Product Validation	Radiometer Hyperspectral radiometer		12-18h	0,1 dbar for upper 50 m	Global, Med Sea, Black Sea, Baltic Sea, Arctic Ocean	No	No	Yes	2025
Upwelling radiance (Lu)	CAL/VAL	Hyperspectral Radiometer		12-18h	0,1 dbar for upper 50 m	Global, Med Sea, Black Sea, Baltic Sea, Arctic Ocean	No	No	Yes	2025
pCO_2	N/A									
Surface wind	N/A									
Zooplankton	N/A									

Annex 6

Implemented by European Environment Agency

Euro-Argo ERIC – COINS S3 Workshop

Argo Data Requirements of Copernicus Entrusted Entities

Venue: Mercator Ocean International
2 Av. de l'Aérodrome de Montaudran
31400 Toulouse, France

Dates: From 12 March 2024 at 2 PM to 13 March 2024 at 1 PM

Background, Agenda and Provisional List of Participants

Table of Content

Introduction

COINS S3 is an EEA-funded project whose purpose is to assist the EEA in accomplishing the delegated activities pertaining to the cross-cutting coordination of the Copernicus in-situ component. Copernicus Services rely on many environmental measurements collected by data providers external to Copernicus, from ground-based, sea-borne or air-borne monitoring systems, as well as geospatial reference or ancillary data, collectively referred to as “in situ” data. The Copernicus In-Situ Component maps the landscape of in situ data availability, identifies data access gaps or bottlenecks, supports the provision of cross-cutting data and manages partnerships with data providers to improve access and use conditions.

Euro-Argo ERIC is third-party to the project. The research infrastructure coordinates the European component of Argo, which is a key in-situ oceanographic network for operational applications. As such, it is a major data provider and natural partner of the Copernicus Services. The objectives of the workshop are to (1) discuss the Argo data needs and gaps identified by the Copernicus Services, (2) develop various scenarios allowing to respond to the needs of the services, and (3) provide a rationale as well as data to advocate for EU complementary funding. The workshop is also meant to be a pilot exercise that could be repeated with other relevant European research infrastructures.

1.1 The International Argo Programme

Argo is a scientists-driven international programme that collects information from inside the ocean using free drifting profiling floats (Fig. 1). The programme was initiated in 1999 as a pilot project endorsed by the Climate Research Program of the World Meteorological Organization, the Global Ocean Observing System (GOOS), and the Intergovernmental Oceanographic Commission of UNESCO. The Argo network is now a global array of about 4000 autonomous instruments, deployed over the world ocean, reporting subsurface ocean properties in near real-time. The data are provided to a wide range of users via satellite transmission links to data centres. The network provides 100,000 temperature/salinity profiles and reference velocity measurements per year.

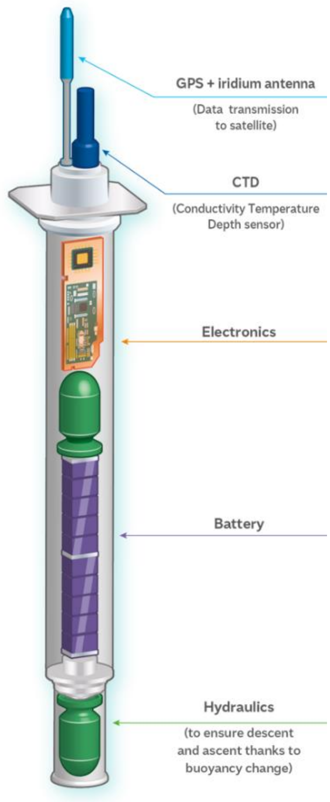


Fig. 1 Argo float

The objectives of Argo are to:

1. Provide a quantitative description of the evolving state of the upper ocean by collecting temperature and salinity profiles from the surface to 2,000 meters depth at a resolution of 1 float/$(3°)^2$.

2. Improve weather and climate forecasts through the assimilation of Argo data in ocean and coupled (ocean and atmosphere) forecast models.

Argo data are used for initialization and validation of ocean models. They provide an essential complement to satellite observations by delivering information on the ocean interior. Argo data are also useful for the calibration and validation of satellite measurements (e.g. ocean colour).

1.2 From Core Argo to OneArgo

The initial Mission of the International Argo Programme, Core Argo, aimed to measure temperature and salinity in the upper 2,000 meters of the global ocean from 60°N to 60°S. Successful pilot studies carried out in the 2010's have shown the potential and the technology readiness of Argo to extend its mission towards greater depths and biogeochemistry. Since 2020, Argo is progressively transitioning to OneArgo, an enhancement of the programme which adds a higher regional resolution in key areas like the Western Boundary currents and equatorial regions, geographical extensions (polar zones, marginal seas) as well as a BioGeoChemical (BGC) Mission (measuring O2, pH, and 4 other parameters) and a Deep Mission (down to 6000m) (Roemmich *et al*., 2019). The life cycles of Core, BGC and Deep floats is depicted in Fig. 2.

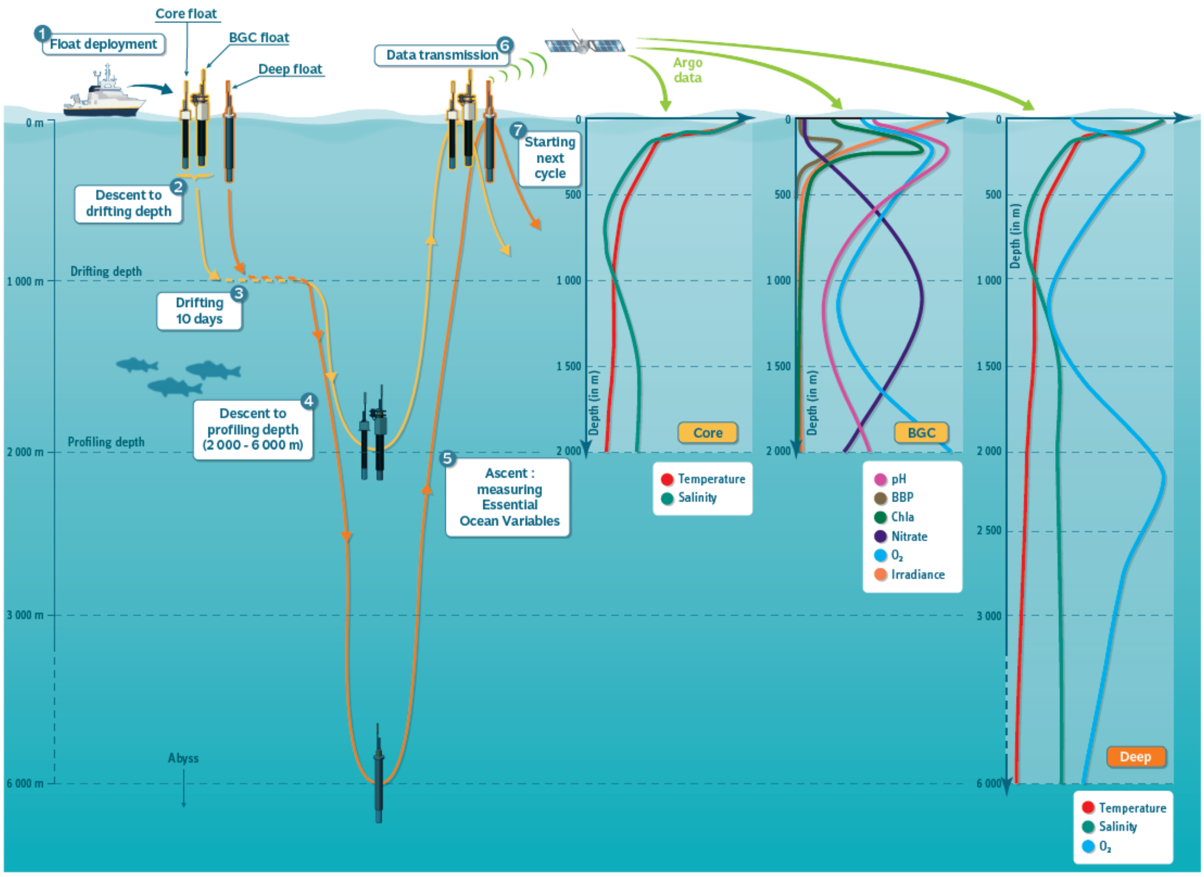


Fig. 2 Life cycles of Argo floats. *The autonomous platforms drift in all oceans at a depth of 1000m (which, by means of geo-localization, provides information on currents), dive further down and, on their way to the surface, measure essential ocean variables. Quality controlled data are then transmitted by satellite in near real-time before a new measurement cycle begins. Data are also reprocessed in delayed mode.*

Eight essential environment variables are measured by Core, BGC and Deep floats. Their scientific use and the type of floats on which appropriate sensors are installed are presented in Fig. 3. Argo floats have an average lifespan of 3- to 5 years depending on the type of float, and have to be replaced to maintain the global coverage.

Parameter	Scientific use	Float types
Salinity	Ocean circulation, heat and freshwater fluxes, Air-Sea exchanges, Water cycle	**Core** **Deep** **BGC**
Temperature	Ocean circulation, heat and freshwater fluxes, Air-Sea exchanges, Water cycle	**Core** **Deep** **BGC**
Oxygen	Decrease of oxygenation and oxygen minimum zones, carbon cycle	**Core (some)** **Deep (some)** **BGC**
pH	Ocean acidification, CO_2-Uptake	**BGC**
Nitrate	Eutrophication, toxic algal blooms, biological productivity	**BGC**
Chlorophyll	Biological productivity, carbon cycle	**BGC**
Suspended particles	Biological productivity, carbon cycle	**BGC**
Downwelling irradiance	Underwater light field, biological productivity, carbon cycle	**BGC**

Fig. 3 Essential ocean variables measured by Argo and their scientific uses.

The OneArgo design includes four elements:

- Driving towards spatial completeness to include Polar sea-ice zones and marginal seas
- Increasing regional resolution in key areas like the Western Boundary currents and equatorial regions
- The BioGeoChemical (BGC) mission
- The Deep Argo mission

Achieving the full implementation of the design will require an increase of the total number of active floats (4,700 floats for OneArgo compared to 4,000 floats for the initial Core Argo) (Fig. 4).

The tentative objective of the Argo community is to reach the implementation of the OneArgo design by 2030. This, however, represents a major challenge in technical, operational and financial terms.

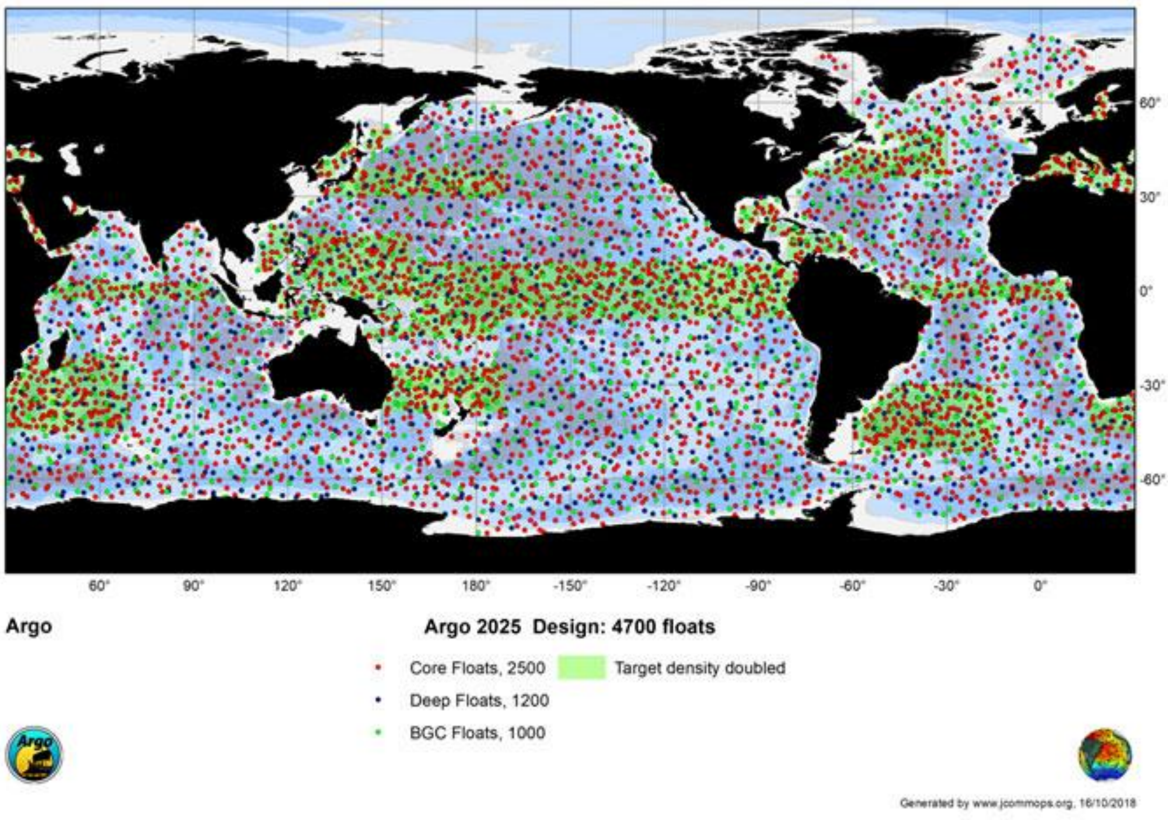


Fig. 4 Global OneArgo design as foreseen at the horizon 2030.

1.3 The Euro-Argo European Research Infrastructure Consortium (Euro-Argo ERIC)

Euro-Argo is the European contribution to the International Argo Programme. Since 2014, it is coordinated by the Euro-Argo European Research Infrastructure Consortium (Euro-Argo ERIC). The ERIC comprises 12 Member States and one candidate (see Fig. 5). Their national Argo programmes constitute most of the European Argo contribution – a very limited number of floats have been purchased over time via EU-research project funding.

Fig. 5 Membership of Euro-Argo ERIC

The Euro-Argo objectives, set at the creation of Euro-Argo ERIC in the context of Core Argo, are to:

1. Provide, deploy and operate an array of around 800 floats contributing to the global array (a European contribution of ¼ of the global array).
2. Provide enhanced coverage in the European regional seas.
3. Provide quality controlled data and access to the data sets and data products to the research (climate and oceanography) and operational oceanography communities.

1.4 Current status of the OneArgo array implementation

The European objective to cover ¼ of the global array has, so far, been achieved by Euro-Argo (Fig. 6). With the implementation of the new phase of Argo, OneArgo, it will be necessary to increase the number of annual deployments to reach the full OneArgo design.

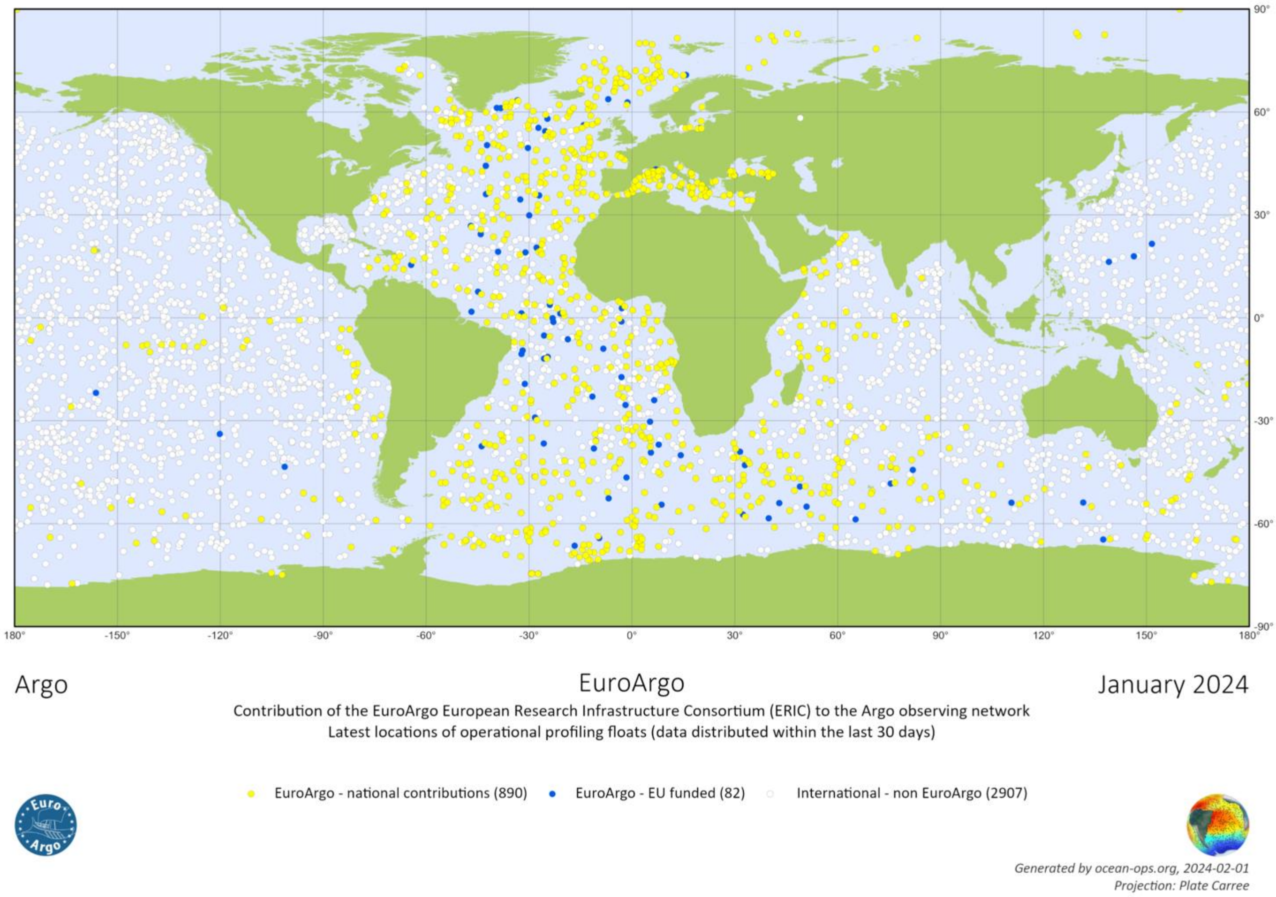
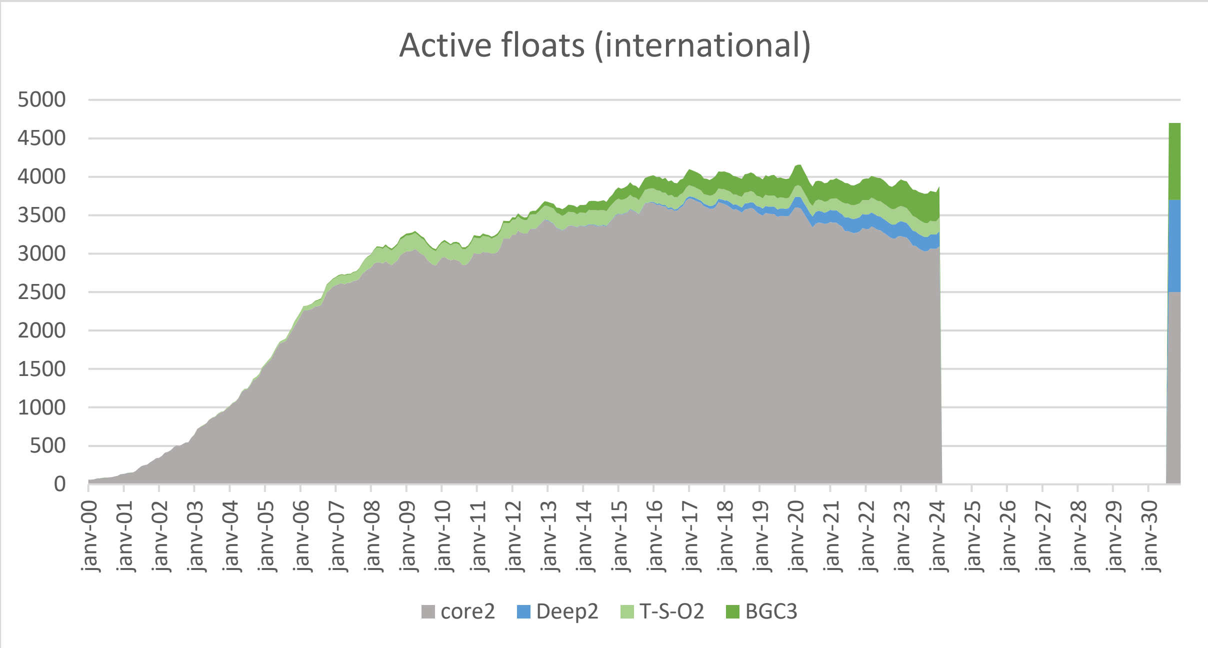


Fig 6. Euro-Argo contribution to the global Argo array as of January 2024: 972 active floats out of 3979 (25%)

The initial Core Argo design was achieved in 2008, with a total of 3000 active floats (Fig 7). The deployment of Deep and BGC floats has started in the 2010's through pilot research projects and the number of active Deep and BGC Argo floats has grown since then, the total number of floats reaching a plateau in 2017-2018. Although much efforts have already been put by Euro-Argo members to start implementing the new OneArgo design (Fig 8), mainly through short-term research projects, the gap towards the OneArgo ambitious targets remains very significant.



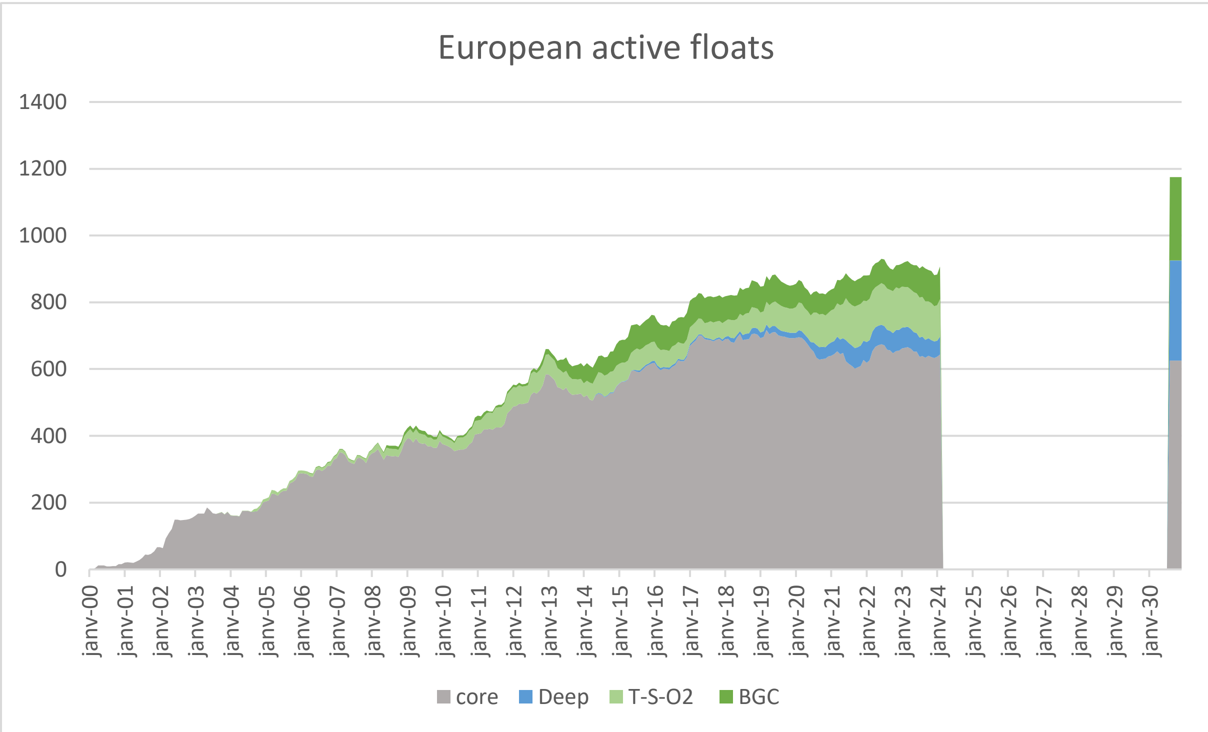


Fig 7. OneArgo implementation as a function of time. Top: international effort. Bottom: European effort. The numbers for the period 2000 to 2024 represent the active floats while, for 2030, they represent the targets to achieve.

1.5 Challenges: Euro-Argo operational funding & sustainability

Beside the technical and operational aspects, the major challenge for the implementation of the OneArgo design is undoubtedly of financial nature. It should be recalled time and again that Euro-Argo ERIC is a research infrastructure. Funding is almost exclusively provided by the ERIC Member States via their national Argo programmes. As their primary mission is to support science and not to answer evolving needs of operational users, funding is primarily research based, which offers little mid- and long-term visibility on the resources that will be available. Consequently also, activities are set according to national priorities and research objectives (in terms of geographic deployments, types of floats and/or variables measured).
The implementation of the OneArgo design has been decided by the scientists-driven International Programme and endorsed by Euro-Argo ERIC. It is supported by the UN Decade of Ocean Science for Sustainable Development (2021-2030) ('the Ocean Decade') coordinated by UNESCO's Intergovernmental Oceanographic Commission (IOC). OneArgo is progressively being implemented since 2020. The objective is to reach the implementation of the full design by 2030 or shortly after. However, whether this objective can be met is highly doubtful. Since 2021, the prices of floats and sensors have increased by more than 30% and the inflation trend is on-going. This inflation has not been compensated by the funders. Most importantly, OneArgo is 3 times more expensive than Core Argo (see Fig. 5). These costs are, by far, not matched by the foreseen national funding.

Type of deployed floats	2023 float retail price	International Core Argo Design < 2019	EU share to be deployed per year (25%)	EURO-ARGO mean annual float depl. 2019-2022	Mean annual cost EURO-ARGO	International OneArgo Design 2030	EU share to be deployed per year (25%)
Core	20.000 €	4000	200	139	2.780.000 €	2500	125
Deep -4000m	40.000 €			20,25	810.000 €		
Deep -6000m	80.000 €					1200	75
BGC 1-5 variables	80.000 €			40,5	3.240.000 €		
BGC 6 variables	120.000 €			7,75	930.000 €	1000	62,5
Total		4000	200	207,5	7.760.000 €	4700	262,5
Annual cost EURO-ARGO			**6.960.000 €**		**15.260.000 €**		**26.883.750 €**

Fig. 5 Costs of the progressive transition from Core Argo to OneArgo. *At current prices and given the commitments of the Euro-Argo ERIC Member States, a funding gap of more than 11 M€ per year can be estimated for the implementation of the full OneArgo design by 2030.*

Given the retail price inflation, the drastic funding gap and as a result of national priorities, the level and spatial distribution of Argo data currently available to Copernicus Services is jeopardized at the horizon 2030. Responding to the Copernicus Services' needs through the implementation of the OneArgo design will require large-scale, complementary EU funding. The support of the Copernicus Entrusted Entities will be required for advocating for complementary EU funding. The objective of the workshop for Euro-Argo ERIC is therefore to assess more precisely the needs of Copernicus Entrusted Entities and identify priorities in terms of Argo data (geographical coverage, types of measurements, data quality and vertical resolution, etc.). On the long run, ways to better associate the operational users to the OneArgo array design should be sought.

1. Agenda of the workshop

Tuesday 12 March 2024	
14:00	Welcome Address & Tour de Table *Pierre-Yves Le Traon & Yann-Hervé De Roeck*
14:15	COINS SC3 *Jose Miguel Rubio Iglesias*
14:25	Argo Challenges & Objectives of the Workshop *Yann-Hervé De Roeck*
Eight thematic sessions will address the Copernicus Services' needs regarding the essential ocean variables measured in OneArgo. The sessions should provide, for each Service, answers to the following questions (where appropriate): 1. Is this variable used/needed for products, CAL/VAL and/or assimilation? 2. What is the geographic coverage and density needed? 3. Would deep measurements be relevant for this variable? 4. Would under-ice measurements be relevant for this variable? 5. Should this variable be included if coastal Argo is developed? 6. What are your quality control requirements (e.g., in terms of timing)? 7. What is the appropriate implementation timing to respond to your Service's needs?	
14:45	Session 1: Temperature
15:25	Session 2: Salinity
16:00	Coffee Break
16:30	Session 3: Oxygen
17:10	Session 4: pH
17:50	Session 5: Nitrate
18:30	End of day 1
Wednesday 13 March 2024	
9:00	Session 6: Chlorophyll
9:40	Session 7: Suspended Particles
10:20	Session 8: Downwelling Irradiance
11:00	Coffee Break
11:30	Additional Copernicus Services' needs • Additional variables not measured currently (e.g., hyperspectral radiometry) • Operational refinements (e.g., measurements at or near the ocean surface) • Coastal Argo? Others? *Moderation: Hervé Claustre*
12:30	Variables priority ranking for the Copernicus Services Wrap-up & Concluding Remarks *Yann-Hervé De Roeck & Henrik Steen Andersen*
13:00	End of the workshop

2. Provisional List of Participants

Mercator Ocean International:

- Pierre-Yves Le Traon (pletraon@mercator-ocean.fr)
- Antonio Repucci (areppucci@mercator-ocean.fr)
- Representatives of Marine Forecasting Centres
- Representative of in-situ and Mobs TACs

EUMETSAT:

- Thierry Marbach (Thierry.Marbach@eumetsat.int)

ECMWF:

- Hao Zuo (hao.zuo@ecmwf.int)
- Richard Engelen (richard.engelen@ecmwf.int) – invited

ESA:

- Jerome Bouffard (jerome.bouffard@esa.int)

Euro-Argo ERIC:

- Yann-Hervé De Roeck (Yann.Herve.De.Roeck@euro-argo.eu)
- Claire Gourcuff' (claire.gourcuff@euro-argo.eu)
- Luc van Dyck (luc.van.dyck@euro-argo.eu)
- Hervé Claustre (herve.claustre@imev-mer.fr)

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- Jose Miguel Rubio Iglesias (jose.rubio@eea.europa.eu)