BGC-Argo European Workshop

27 September – 1 October 2021 (13:00 to 16:00 UTC)

Virtual meeting

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Workshop Report

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1. Introduction & workshop objectives

The objectives of the workshop were to:

- review progress done in implementing best practices in the area of BGC Argo floats preparation, float deployment and data management (session 1),
- exchange with user community (e.g. biogeochemical modellers, ocean colour) to listen to their needs and develop synergies (session 4),
- to foster interaction with other components of the ocean observing system, including deep Argo (session 3 described below).

2. BGC-Argo: Best practices

As an introduction of this session, Henry Bittig rapidly presented the BGC-Argo mission, currently expanding, which will induce the involvement of new players. The BGC-Argo community published a Best Practices paper in Frontiers in Marine Science in (Bittig et al. 2019), covering all aspects of the BGC-Argo mission, from operation planning up to data handling and usage. The purpose of this session was to review Best Practices and discuss the following points: are these Best Practices used, are they known? Are there gaps? Any need to update? The course of the workshop followed the publication's outline.

2.1 Float technology and new sensors

◆ SOLO II BGC - *S. Purkey*

A new model of BGC-Argo float based on the SOLO-II core Argo float is in the final development and testing phase. The BGC SOLO will carry the full suite of 6 BGC sensors including pH, dissolved oxygen, nitrate, downwelling irradiance, particle backscattering and chlorophyll fluorescence. The new float will be equipped with both RUDICS and SBD two-way iridium communication and has an estimated 9 years of battery life when run on a standard Argo 10 day mission. The float is 21.6kg and stands approximately 1.5m high with a buoyancy system that will allow it to profile to 2000m anywhere in the global ocean including highly stratified regions such as the Equatorial Pacific and Arctic. The float design is currently being transferred to MRV systems for commercial sale in 2022.

◆ NKE BGC CTS4, CTS5-USEA Jumbo float - E. Leymarie

Edouard presented the full line of PROVOR BGC-Argo floats.There are two generations of PROVOR floats: CTS4 and CTS5. CTS4 is a mature float, self ballasted, it can support all sensors together to achieve the 6 BGC-Argo parameters. CTS5 is a new PROVOR with the same mechanical design and suitable for high payload. A full simulation chain allows to better validate the product and get a better understanding of the float. It can carry new sensors (OCR507, OCR507 IR, C-Rover, Trios OPUS & RAMSES, etc.). New capabilities are available for the mission flexibility: metadata file is generated by the float itself; it comes with a graphical interface where the mission can be tested in advance to check the validity of the choices, and get an energy budget estimation. Acquisition can be made at 1 Hz and all data points are time stamped. The CTS5 also has a dedicated phase for oxygen optodes in-air measurements.

The Jumbo option of the PROVOR allows +60% of energy, and the Jumbo-e option allows it to carry 2 extra sensors in addition. Jumbo option is dedicated to additional scientific needs (sensors, improve resolution) while still permitting to ensure the standard BGC-Argo mission.

◆ Sensors: OPUS (NO3), RAMSES (radiometry), UVP (particle size + zooplankton)
E. Leymarie + H. Bittig

Radiometry (RAMSES): LOV is testing the hyperspectral radiometer RAMSES (Trios) within the context of the Euro-Argo RISE H2020 project. This sensor consumes more energy but it's a well known sensor. It has two acquisition geometries (down or upwelling irradiance). Two Provor and three Apex were tested in the Mediterranean and Baltic seas. The sensor has an interesting acquisition rate: 30 acquisitions in the shallow part of the profile (last 10m) and a submetric acquisition rate close to the surface. The sensor has a better sensitivity than the classical radiometers OCR-504 from Seabird. The amount of data produced is quite important. The energy consumed is also significant but there are areas of improvement to use the sensor in a cost-effective way.

Imaging system (UVP6). The Underwater Vision Profiler (UVP6) is a particle size counter (100 um to 2 mm). Presently there are 7 floats at sea, 400 profiles were made up to now. The data stream is already implemented with Coriolis DAC. The sensor will be ready in 2022 to implement image recognition, based on artificial intelligence to class zooplancton.

Nitrate (OPUS): The aim is to diversify nitrate sensor options for BGC-Argo. Tests have been undertaken in the Baltic Sea in the context of the DArgo 2025 German project. Preliminary analysis shows that the general structure of the data is comparable to the SUNA data.

◆ Discussion

There were discussions on the price of RAMSES data transmission, which depends on the depth and resolution chosen, and on the flexibility of the new SOLO-II BGC float, which can support additional sensors and allows switching off sensors. The weight of the OPUS Nitrate sensor was raised. The UVP6 algorithm will be trained using as many images as possible, using recovered floats, gliders and UVP6 on a rosette.

2.2 Sensors and float and preparation

◆ Preparation and programmation - *A. Poteau*

- **Fleet analysis of sampling resolution in the current BGC array - Is there a "standard"?** Antoine Poteau described the detailed sampling schemes used on PROVOR floats for all 6 BGC variables (see slides), on 4 different depth layers (0-10m, 10-300m, 300-1000m, 1000-2000m), and compared these settings with the global BGC-Argo fleet for year 2020. There seems to be no real standard. Antoine also noted a high increase in float sampling resolution between old deployments (2005) and recent deployments (2020) for CHLA and DOXY.
- **Procedures for testing sensors**
  Antoine also described the pre-deployment tests made at sea off Villefranche by the LOV for all sensors. Since 2012, the system used has been SIBO (System of Intercalibration of Bio-Optic sensors), upgraded in 2020 (CIDRE system - Commun Interface - Data Retriever Enhanced) to allow it to go down to 2000m depth

(instead of 200m with SIBO). These tests allow to detect sensors malfunctioning but also factory calibration issues or pressure effect errors.

- **Provor CTS5 GUI**
  A new Graphical User Interface (mentioned by E. Leymarie in the PROVOR talk) for float operators was also presented, that allows to change settings and parameters easily (e.g. sampling, predefined patterns, etc.). The tool also provides information on expected battery usage (i.e. lifetime expectation) depending on the chosen settings.

◆ Pre-deployment procedure - *N. Poffa*

Noe Poffa detailed the tests made at Ifremer facilities (common procedures shared by Euro-Argo & Argo-France). The facility consists of a 20m depth pool of seawater, with the possibility to test up to 20 floats at the same time. The procedures are comparable to what is recommended in Bittig et al. (2019) based on University of Washington procedures, except that they do not open the floats (this is done by the manufacturer).

◆ Discussion

Noe thinks the tests made at Ifremer are very useful because they allow to detect issues each time (no statistics available because not enough BGC floats tested yet but for instance in January 2021, on a batch of 7 floats tested, 3 were sent back to the manufacturer).

A working group was set up to make a common choice on sampling rate for radiometry, anyone interested to join should contact Emanuele Organelli.

A suggestion was made on the usefulness of sampling during parking for some parameters (e.g. Irradiance) and the cause of faulty sensors detected through pre-deployment tests was questioned (during shipping, integration by manufacturer, etc.).

At European scale we could decide that all European floats are centrally tested.

2.3 Float at Sea

◆ Float monitoring:

- Euro-Argo fleetmonitoring and data selection web interfaces - R. Cancouët

  These tools are two easy-to-use, powerful and complementary web interfaces available at Euro-Argo for Argo fleet operators, PIs & scientists or Public at large: https://fleetmonitoring.euro-argo.eu/ that provides “Visualization of Argo profiling float metadata, ocean measurements, trajectories and technical parameters” and https://dataselection.euro-argo.eu/ that allows “Selection, visualisation and download of Argo scientific data”. The main interface features were presented. All metadata and data are also accessible through APIs (for external use), details can be found on https://www.euro-argo.eu/Argo-Data-access. Ongoing and future work was briefly described, with targeted activities on User Documentation (pdf, webinars/videos), a link with the Argo Online School (Euro-Argo RISE project) and improvements of the big data infrastructure and refresh rate. All users are very welcomed to send their feedback or questions on the interface, to contact@euro-argo.eu.

- Shipboard operations: ancillary data to provide metrological verification of sensors

- A. Poteau.

- Antoine briefly presented tests made by Edouard Leymarie at deployment. The tests consist in deploying the float attached to the rosette (concomitant so-called “bicorn” profile). This can be done with 2 floats attached to the rosette. With CTS5, this can be done without changing the mission parameters and results are obtained quickly. The comparison with winckler (Oxygen), colorimetric (Nitrate) and HPLC (Chl-A) measurements is much better with this technique than with the usual nearby CTD, thanks to a close matchup in space and time.

◆ Recovery activities - *N. Poffa*

Recovery is done for some floats for various reasons: environmental impact, data QC, cost (BGC sensors). A European Working Group has been set up to share experience and protocols (planning operations, etc.). Documents are available on euroargodev github, including a checklist of what has to be done for recovery. An example of successful recovery was presented: three different BGC-Argo floats were recovered during MOOSE 2021 cruise. eExisting new tools to support float recovery (e.g. fleetmonitoring.euro-argo.eu, ocean-ops.org, floatrecovery.euro-argo.eu) were also presented.

◆ Ice strategy - *I. Angel Benavides*

Argo floats are able to sample the water column even under the sea ice. As sea ice is a hazard for the physical integrity of the floats, ice avoidance strategies are a must for the operation of argo floats in polar regions. The key component for ice avoidance strategies are Ice Sensing Algorithms (ISA, Klatt et al., 2007). ISA uses the temperature measured during ascend to predict the presence of ice before collision and therefore should be tuned locally, specially in the Arctic. The parameters of ISA are defined based on the historical analysis of temperature profiles and sea ice concentration in the region of operation. Other components of the ice avoidance strategy are auxiliary tests (for example satellite communication tests) and special float features. Questions were raised regarding the possibility of using salinity to improve the ISA algorithm - it was tested but not successful - and light: it is difficult because in winter there is not much light in this region.

2.4 Data management

◆ BGC-Argo data visualization interface - *H. Claustre / A. Poteau*

Antoine presented the https://maps.biogeochemical-argo.com visualisation tool. Users can choose floats by various means (e.g. DACs, variables, WMO). The main difference with the euro-argo data selection tool is that the data come from the GDAC sfiles and only provide jpeg files of profiles less than 20 days old. It also gives access to data quality information and comparison with other profiles from the same float, which can be useful for quality assessment. The link for the netcdef file is provided for each float.

◆ Metadata and NVS - *V. Paba*

In 2018, BODC received Horizon 2020 ENVRI-FAIR program funding to transfer all of Argo’s metadata holdings onto the NERC Vocabulary Server (NVS). The NVS provides list of controlled vocabularies that can be used as Linked Data, meaning that Argo NVS vocabularies will be machine-readable, thus enhancing the program’s FAIRness (Findable, Accessible, Interoperable, Reusable). To this end, we set up the 'Argo Vocabulary Task Team', aka AVTT, which is an Argo metadata focus group with members from the Argo community. Communications within the AVTT and beyond are facilitated through the use of a dedicated area part of the wider NVS GitHub space, accessible here. Information on NVS vocabularies can be found in this page of the Argo data management website. Our progress so far has seen 25 of the Argo reference tables listed in the Argo User Manual transferred onto the NVS as 'R' collections (filtered here). We have designed the mapping framework between related collections, some of which have already been built (e.g. R26 to R27). We have investigated the yet 'unconstrained' Argo metadata fields, summarised in a comprehensive report from which stemmed specific GitHub discussions. We are currently focusing on creating vocabularies for the trajectory tables as well as for the yet unconstrained PI_NAME, CONTROLLER_BOARD_TYPE and DEPLOYMENT_PLATFORM NetCDF fields, in close collaboration with Ifremer and with input from the AVTT and the wider Argo community.

◆ RT and DMQC - C. Schmechtig / G. Dall'Olmo

Catherine Schmechtig presented the BGC-Argo web site and where to find information on:

- All presentations and reports from previous meetings (https://biogeochemical-argo.org/past-meetings.php)
- All available tools and audits (https://biogeochemical-argo.org/data-tools.php)
  - with an emphasis on the status of the QC performed on the parameters (https://biogeochemical-argo.org/cloud/document/implementation-status/BGC_summary.pdf)
- All operational documentations (processing and QC) and their status (https://biogeochemical-argo.org/data-management.php)

Giorgio Dall'Olmo presented the new RT QC tests for BBP data. New tests have been developed and are now waiting for community feedback before endorsement at the follwing ADMT meeting in December 2021. Ongoing work also focuses on error estimates for BBP, which is important for assimilation activities in the context of biogeochemical modeling

◆ GDAC overview - *T. Carval*

In september 2021, ~250000 BGC-Argo profiles from ~1600 floats are available. The index files are available on ftp and more recently on https (see slides for links). Data are also available using ERDDAP server, or through the Argo data selection portal previously presented by Romain. A tool also allows to get graphs, and jupyter notebooks can also be run with a direct access to the GDAC. Another solution is to query Euro-Argo APIs.

◆ Discussion

Hervé opened the discussion on a possible new forum for the community to discuss technical issues. The existence of a FAQ was asked and the Argo Online School was mentioned as one tool to help in educating people on Argo.

3. Interactions: BGC/Deep Argo and cross networks

3.1 Implementing O2 sensor on Deep-Argo

◆ **Scientific motivation and users need (sampling, accuracy) (biological community, water mass identification) -** ***Laurent Coppola***

There is a need to extend oxygen observation to the deep ocean to: 1) observe the expansion of OMZs and its impact on biodiversity (habitats, species adaptation, and vertical migration), 2) improve IPPC models, 3) estimate the impact of ventilation on deep waters and 4) study the impact of hydrothermal vents on the O2 solubility. The methods to correct the deep Argo-O2 data are not yet defined but the cross-networks approach would be interesting, especially with fixed moorings able to measure O2 in deep waters (e.g. the MedSea NW). The WOA plans to integrate O2 Argo data and lacks deep water data for the deep ocean variability. One of the objectives will be to combine both data from in situ measurements (Winkler) and CTDO2 profiles close to the Argo profiles. Finally, the GO2DAT initiative (Global Ocean Oxygen Database and ATlas) aims to assess and predict deoxygenation and ocean health in the open and coastal ocean (Grégoire et al., 2021). This is an international effort to combine all O2 data following the FAIR principles with open access. It also highlights the need for the community to cover deep ocean variability to better understand global O2 dynamics.

◆ **Scientific results**

ISOW spreading and mixing as revealed by deep-Argo floats with O2 sensor launched in the Charlie Gibbs Fracture Zone - *Virginie Racape*

While knowledge in deep circulation is required to understand long term changes in acidification or ventilation of the deep ocean, large uncertainties remain on deep circulation pathways. To improve our understanding of deep circulation, five Deep-Argo floats equipped with oxygen sensors were deployed in the Charlie-Gibbs Fracture Zone (CGFZ), a gap in the Mid-Atlantic Ridge that constrains the pathway of deep water masses. Those autonomous platforms freely drifted at 2,750 dbar in the core of the Iceland-Scotland Overflow Water (ISOW), a young water mass, rich in O2, originating from the Nordic Seas. Oxygen data acquired by the floats coupled to surface velocity analysis revealed that the interaction between the North Atlantic Current and the deep flow in the CGFZ favors the mixing of ISOW with the North East Atlantic Deep Water, an old water mass characterized by low O2. These results advocate for equipping Deep-Argo floats with oxygen sensors to improve understanding of deep circulation and water mass mixing.

- Multiplatform investigations of oxygen in the subpolar North Atlantic - *David Nicholson*

  The North Atlantic is a critical region driving the Atlantic meridional overturning circulation (AMOC), including the uptake/ventilation of carbon dioxide and oxygen. The region 'recharges' oxygen that is subsequently respired in the interior of the rest of the Atlantic basin. To quantify these processes of the oxygen cycle, a multidisciplinary collection of observing systems are now characterizing target regions on the Labrador and Irminger Sea. This includes ~70 moored oxygen optodes deployed in 2020 on infrastructure from the OSNAP AMOC mooring array. A range of processes within the Labrador, including deep convection, exchange between the gyre and boundary currents and seasonal photosynthesis and respiration result in a highly seasonal and dynamic oxygen cycle.

By combining oxygen measurements from BGC and Deep Argo with moored and ship-board measurements we aim to fully characterize the annual cycle of ventilation and transport for the Labrador Sea.

◆ Sensors readiness (performance versus needed accuracy from the users) and QC

- Aanderaa and SBE63 - *Henry Bittig*
  Sensor accuracy is a mixed bag – historically! Prospects aren't as grim. Floats that go into the water have both multi-point calibrated optodes and in air observation capabilities -> Primed to give accurate results if QCed according to BGC-Argo specs.
  Unaddressed issue: Operational Implementation of time response correction is an unaddressed issue: 1) Errors increased in gradient regions. 2) Ascent as default profile -> systematic effect!
  Deep Argo: 1) Optode pressure dependence is only roughly characterized with ca. 0.3% / 1000 dbar uncertainty. 2) Calibration against deep, "stable" water mass ?? -> Creates hen-egg problem if looking for deep O2 trends!

- **SBE83** Steve Riser and Seabird

  SeaBird-83 is more precise than Aanderaa for air gains.

  - After air-calibration, SeaBird-83 and Aanderaa 4330 agree to better ~1 µmol/kg (~0.5% at surface).
  - It appears to be better to use Aanderaa temperature for Aanderaa air calibration. The difference in temperature (SB-83 vs Aanderaa) likely reflects real microenvironments.
  - The daytime bias is likely caused by biofouling or light interference. This idea needs more study.
  - SeaBird-83 appears to work equally well on Apex and Navis floats.

- **AROD-FT(RINKO) -** Hiroshi Uchida / Kanako Sato and Hua LI (JFE)

  Optode-based oxygen sensors (RINKO series) have been developed by JFE Advantech Co., Ltd., for over 15 years. RINKO has the originally developed sensing foil and optimally designed electronics and is calibrated with a high accuracy multi-points calibration method. RINKO is used in a variety of observations: the GO-SHIP hydrography in Japan, continuous surface water measurement along these cruise tracks, and an OceanSITES mooring observation (station K2). RINKO for float (ARO-FT/AROD-FT) has also been installed into BGC- and Deep-Argo floats since 2014 (MRV-S3A, BGC-Apex, Deep-Ninja and Deep-Apex). RINKO has the advantage especially in the fast-profiling shipboard CTD measurement due to its fast response. Although RINKO with a brand-new sensing foil usually shows time drift (~10 µmol/kg) due to degradation of the sensing foil, RINKO with a well-used sensing foil is satisfactorily stable in time. The electronics of ARO-FT/AROD-FT is updated to suppress degradation of the sensing foil. RINKO shows time-dependent pressure-induced hysteresis (about −4 µmol/kg) like the electrode oxygen sensor (SBE 43). A practical method to correct the hysteresis might be required, especially for the Deep-Argo measurement.

◆ **Discussion (Discussion Lead: Brian King)**

The diurnal cycle was discussed, as optical measurements are optimum at noon (?) and optode measurements are better during the night. The issue of oxygen measurements accuracy and more especially sensor responses were also discussed.

3.2 Cross networks interactions

In order to help identify how Deep & BGC Argo could better collaborate with other observing neworks, representatives of the main ocean observing networks were invited to present their programme with an emphasis on what they can do for and expect from (i) Deep Argo and (ii) BGC Argo.

◆ **EOV shared by various platforms: T, S, O2 (Deep) and Chla, bbp, pH, O2, UVP (BGC) (including data management) Hervé Claustre, Virginie Thierry**

As an introduction to this cross network session, the common EOV were presented, as well as the importance of collaboration between networks for an optimized ocean observing system. Several opportunities for enhanced collaboration were listed, for instance in technological development, observing system design, data management, or communication and outreach.

◆ **DOOS presentation Lisa Levin**

DOOS, the Deep Ocean Observations Strategy, is a network of observing, modeling and policy-user platforms aimed at maximizing the potential of available observations and models to gain insight into deep-ocean physics, biogeochemistry and ecology, and to translate this into science-informed policy making. DOOS will work to develop best practices to observe the deep ocean, including advancing the measurement of essential ocean variables (EOVs). This will involve both site-specific observations needed for ecosystem exploration or for managing particular human activities (e.g. deep-ocean mining or fishing) as well as the global-scale network of observations needed to have an in-depth knowledge of the present and future state of the deep ocean circulation and biogeochemistry. The interactions between DOOS and the BGC/Deep Argo programs are several: (i) The DO

OS focus is strongly interdisciplinary and it connects BGC/Deep Argo observations with a broader scientific community. (ii) DOOS brings together multiple stakeholders (scientists, policy and society) and can be the vessel to translate BGC/Deep Argo data and knowledge to science-based decision-making, regulation and governance. (iii) The Argo programs provide an extremely successful example of scaling up an observational platform to global scale. DOOS will take advantage of the key characteristics of such success (e.g. EOVs observed, cost-efficient, etc.) in the design of a sustainable, long-term, integrated observing system for the deep ocean. (iv) Existing and new floats will be used in DOOS demonstration projects. (v) DOOS will promote BGC/Deep Argo data access (e.g,. for Deep Ocean Early-career Researchers, DOERs).

◆ **OceanGlider presentation Pierre Testor**

OceanGliders is a developing but still emerging GOOS observing network. It develops its own scientific objectives with Boundary currents, Storms, Water Transformation, Ocean Health but there are scientific and technological commonalities with Argo, Deep Argo and BGC Argo that must be taken into account to optimize the global efforts. OceanGliders Data Management has progressed well. Ok for real time but still work in progress for delayed mode. There is a lack of personnel resources to develop that more rapidly. OceanGliders Best Practices are developing well. Relatively few glider endurance lines are really sustained but the number is growing with many 'candidates'. None yet with a 6000 m depth objective, but it will come soon.

What can Ocean Gliders do for Argo, Deep Argo and BGC-Argo ?

Core-Argo: Develop services (climate, ocean health, operational) for the public and the

industrial sectors. Avoid the launch of numbers of floats in "divergence" areas, and reduce the models' forecasting errors by sampling required areas, thanks to glider maneuverability (Observing System co-design exercises). Provide our two-way communication expertise for handling sampling. Co-develop/assess scientific payloads. Provide high quality data for inter-comparison purposes and delayed mode data management (applies to OceanSites and GO-SHIP as well). Corrections could be propagated → better data consistency.

Deep-Argo: Provide estimates of the drift of the float during dive/ascent to 6000 m depth, with glider depth-average currents. Provide reference profile data for inter-comparison (with pre/post-calibrated sensors)+ smaller scale variability estimates at regional scale and uncertainties quantification

BGC-Argo: Provide reference profile data for inter-comparison (with pre/post-calibrated sensors) + smaller scale variability estimates at regional scale and uncertainties quantification

What can Argo, Deep Argo and BGC-Argo do for Ocean Gliders ?

Core argo: Gliders are very similar to profiling floats. We expect to benefit from Argo examples/resources in order to improve our scientific payloads with a GOOS perspective, improve our real time and delayed mode data management (adding gliders data in existing systems is really about almost nothing?), procure with new gliders? and develop a shared vision/design for a more integrated GOOS, that would be more focused on the various oceanic (phys/bgc/bio) phenomena that we need to observe, and better public outreach

Deep-Argo: Work together on 6000 m sensors. Better ocean state estimates helping glider mission planning and implementation

BGC-Argo: Work together on new BGC sensor integration and complement with different BGC variables collection. Develop data management and best practices for the collection of BGC variables. Provide large scale and high quality BGC data to provide a context

◆ GO-SHIP presentation Yvonne Firing

The Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP) coordinates and facilitates ship-based climate-quality hydrographic sections to achieve a decadal-resolution, full-depth, global survey of heat, freshwater, oxygen, carbon, nutrients and transient tracers as part of the global ocean and climate observing systems, with the objective of tracking and predicting the interrelated changes in ocean circulation, nutrient budgets and acidity, heat and carbon storage, and the water cycle. GO-SHIP also contributes to high-quality measurements by the community as a whole through development and maintenance of expertise and best practices for sampling, measurement, calibration, and data availability. GO-SHIP and Argo have overlapping goals and complementary approaches. GO-SHIP cruises provide opportunities to deploy Argo floats in infrequently-visited regions. GO-SHIP makes an outsize contribution to the calibration of Deep and BGC Argo data because of its coverage of different watermasses and regions over the full depth, and the high standard of measurements of both physical and biogeochemical parameters. Deployment cast data from GO-SHIP cruises have proved valuable for validating assumptions about pressure-dependence of the calibration function for BGC parameters, and GO-SHIP data will contribute to evaluating pressure and salinity biases and drifts as well as checking calibration of newer BGC variables and sensors in different regions. GO-SHIP's best practices and training also contribute indirectly to the set of data available for Argo calibration and validation. Argo's higher temporal resolution and spatial coverage, meanwhile, has added value to GO-SHIP's global decadal survey by allowing investigators to contextualise and understand the uncertainties in section-based estimates of ocean property inventories. As this is extended to the deep ocean we will be able to better quantify changes in deep water mass distributions and full-depth heat content; and as it is extended to BGC variables we will be able to investigate more questions about the potentially changing roles of circulation and biogeochemical processes in the carbon cycle.

◆ OceanSITES presentation Raquel Somavilla

OceanSITES is the global network with the mission to coordinate the collection, delivery and promotion of high-quality data from long-term, high-frequency multidisciplinary observations at **fixed locations** in the open ocean. The time series observations cover the whole water column – from the seafloor to the atmosphere and address air/sea exchange processes such as heat and freshwater fluxes, and ocean carbon and oxygen update; ocean transport, but also other more biogeochemical and biological integrated in global ocean watch and finally deep ocean processes. OceanSITES presentation during the Deep and BGC Argo cross-network interaction session highlighted the idea that combining the truly Eulerian nature of moored observations affected only by temporal variability with the mixed Eulerian/Lagrangian float observations will not only improve our understanding of ocean variability and dynamics but of sensors characteristic helping to identify sources of drift ant behaviour of instruments in different platforms. Intercomparisons between moored and Argo sensors could also facilitate 2^{ndary} QC, since OceanSITES high quality data is ensured by cross calibration with standardized instruments but also through water samples taking during ship visits to specific SITES. There is potential for this interaction between networks in all the places where OceanSITES have BGC instruments and/or deeper than 2000 or 5000 meters and several examples were presented to illustrate such potential interaction.

◆ Discussion on the way forward (Discussion Lead: George Petihakis)

It was stated that we need a multiplatform approach, but implementing the concept is not straightforward. Networks are in different stages of maturity which does not facilitate collaboration. One way to progress would be to interact more between networks, for example by having representatives of other networks in one network committee. There are various levels of collaborations possible, and the opportunities to collaborate on sensors, for instance, were noted and discussions were already held on this subject by the workshop participants in the chat. Common working groups on specific issues shared between networks could also be set up, such as the SCOR WG on BGC parameters on floats and gliders in the past. OCG could be a good forum for such cross network activities.

4. BGC-Argo: interaction with users - modeling and ocean color communities

Introduction of the session

Hervé Claustre reminded the objective of this session which was to foster interactions with BGC-Argo end users. The session was divided in two parts: one dedicated to the satellite (ocean color) community and the other one to modelers.

4.1 Ocean Color

◆ **From multi- to hyper-spectral radiometry on BGC-Argo floats** E. Organelli

Radiometry is a core variable of the BGC-Argo array and helps study and understand several components of the ocean carbon cycle. Radiometry also makes a bridge with satellite observations of the Ocean Colour (OC). The presentation shows how radiometry data acquired at four bands in the ultraviolet and visible light by several BGC-Argo floats distributed across the globe have the potential to improve the quality of OC derived biogeochemical products. First, BGC-Argo radiometric measurements drastically increase the number of available match-ups with satellites to validate biogeochemical products that are operationally delivered by space agencies and services, such as the diffuse attenuation coefficient at 490 nm (Kd(490)) and the depth of the euphotic zone (Zeu) with more than 4000 and 2000 potential match-ups respectively (Xing et al., 2020). Second, the large amount of radiometric data acquired by floats help to check the consistency of well-established bio-optical relationships that are widely used to derive biogeochemical products from space. Thanks to the high spatial and temporal coverage of float measurements, the consistency of previous bio-optical relationships is now established as never done before, and allows identifying those regions with a bio-optical behaviour that deviates from the average one (Organelli et al., 2017). Finally, in the presentation, it is shown the first deployments of five floats equipped with hyperspectral radiometers in two European seas in 2021: the Baltic Sea and the Mediterranean Sea. Examples of vertically-resolved measurements of downwelling irradiances in the region 320-780 nm (every 3.3 nm) acquired during bloom conditions are given to highlight the potential of integrating such measurements on the global array. Such an advance will boost the monitoring of the diversity of phytoplankton communities, harmful algal blooms and other components of the ocean carbon cycle, along the water column and in synergy with current and upcoming hyperspectral satellite missions of the Ocean Colour.

◆ **How BGC-Argo contributes to to cal/val of present and future satellites** E. Boss

BGC-Argo data is unique: it provides relatively unbiased sampling in space and time, and measures properties of direct relevance to ocean color. Relevant parameters include radiometry, backscattering and fluorescence. There are overlaps in these properties which make them useful for QA/QC of satellites products. Standard BGC-Argo floats cannot contribute to ocean color calibration, because the post calibration of float sensors is generally impossible unless the float is retrieved. Emanuel presented some examples of case studies in validation of ocean color products related to all these parameters, as well as for assessment of calibration using Argo measurements. Bisson et al. 2021 shows for instance that backscattering from both Argo & lidar (CALIOP) show more seasonal signal at low latitude compared to MODIS/VIIRS/SeaWIFS. Some Argo floats are also dedicated for calibration, e.g. the PROVAL float & the HyperNAV system. More comprehensive sensing such as hyper-spectral radiometry will open new possibilities.

◆ BGC-Argo floats for satellite sensors and product validation A. Mangin

Comparison between Chlorophyll derived from fluorescence of floats and from satellite's Ocean Colour is difficult; each of these measurement systems being entitled to specific errors. As part of the EA RISE project, a study was conducted on how to use Ocean Colour (satellites) to help to make the Delayed Mode Data Quality Control of BGC-Argo floats. Uncertainties of each data source are derived thanks to the triple collocation method (here using the NEMO-PISCES model, BGC-Argo and GlobColor). The matchup strategy used is classical, using either OC5 or GSM algorithms (although OC5 is recommended because of better coverage). Results of Argo deviation from CHL-GSM and CHL-OC5 are both good, with most profiles between +/- 3RMS. In some cases there is a problem due to satellite data (e.g. clouds). These results will be used to define flagging rules for Delayed Mode Argo products. BGC-Argo data are used operationally (daily) for qualification of Ocean Color data in the Copernicus Marine Service.

◆ Synergies between OC and BGC-Argo for a 3D ocean R. Sauzède

The SOCA (for Satellite Ocean Color merged with Argo data to infer bio-optical properties to depth) machine learning-based methods have been developed with the aim to take advantage of the growing amount of bGC-Argo profiling floats data (> 90,000 profiles of Chl and bbp, the particulate backscattering coefficient) with the final objective to finally provide useful and easy usable 3D gridded end-users products. The SOCA method has first been published by Sauzede et al. (2016) and then has been upgraded as part of CMEMS. It now retrieves bbp and Chl with ~10% and ~30% of errors, respectively. A dedicated POC vs bbp relationship has been developed using a global POC in situ database merged with bbp SOCA-based estimations in order to derive POC estimations from SOCA. The SOCA-Chl method has been compared to the Ultz et al. (2006) parameterization to estimate the vertical distribution of Chl from ocean color and improves it significantly by decreasing the bias of Chl estimated vs. HPLC Chl of reference. Applying these SOCA-bbp/POC and -Chl methods on CMEMS satellite and hydrological fields fields, global 3D gridded POC (+bbp) and Chl are released from CMEMS website (0.25° horizontal resolution, 36 vertical depth levels, weekly fields from 1998 to 2019 and monthly climatological fields). This represents a mostly valuable source of data useful for the QC of BGC-Argo float observations and for initialization/validation of biogeochemical models.

◆ Discussion

Here are a few points that were discussed:

- There is currently a group working on defining the best wavelengths to be used for irradiance measurements, (if we don't move to hyperspectral radiometry) and 490nm will be kept for sure because of the usefulness for the cal/val community.
- There should be some recommendations to make efforts to recover some floats in order to be able to make post-calibration.
- The possibility to get atmospheric data with floats making irradiance measurements outside the water was discussed. It is possible, with a sensor looking straight at the sun.
- Temperature dependence in radiometry measurements: there is a recommendation of having punctual night profiles and at measurements during the parking depth. A temperature sensor inside the radiometer would be helpful as well.

- BGC-Argo is very helpful for the Ocean Color community, but there are perspectives of improvement, such as better estimates of the uncertainties. However it is better to have a lot of measurements with large uncertainties than a few high quality measurements.

4.2 BGC-modelers/assimilators

Julien Lamouroux introduced the sub-session which aimed at discussing interactions between BGC-Ago and the modeling and data assimilation communities, in the framework of the Copernicus Marine Service, focusing on 2 specific Working Groups: the Biogeochemical Data Assimilation WG and Product Quality WG.

◆ **Bridging the gaps between particulate backscattering measurements and modeled particulate organic carbon in the ocean** M. Gali

There is a need to assess whether, and how, measurements of particulate backscattering (bbp) can be compared to particulate organic carbon (POC) simulated by ocean bgc models. Uncertainty in the comparison arises mainly from (1) bbp-to-POC conversion factors; (2) imperfect match between real POC and model tracers; and (3) bias in model physics. However, these uncertainties can be constrained through careful data analysis, selection of good case studies, and dedicated model simulation frameworks. Analysis of both climatological fields (3D approach) and profile time series (1D approach) indicates that the PISCES-v2 model shows, to first-order, good agreement with small and big POC concentrations derived from BGC-Argo data. Moreover, characteristic patterns of model-data misfits are found in subpolar vs. subtropical biomes. In summary, this assessment opens the door to using POC estimates based on BGC-Argo data for evaluating and eventually improving model parameterizations, and could also facilitate POC data assimilation. Work is underway to optimize PISCES-v2 parameters for different regions based on their comparison to BGC-Argo observations over the annual cycle.

◆ **BGC-Argo: Overview of present use, needs and future outlook for BGC data assimilation** Julien Lamouroux and Annette Samuelsen

We asked the 7 Monitoring and Forecasting Centres (MFCs) within CMEMS about their present use of BGC Argo, further ambitions for the use of this dataset, and challenges with using the dataset. The results from this survey were presented, and some key outcomes were: All MFCs use BGC-Argo for model validation in delayed mode, they find the dataset very useful and have ambition to use it more in the future. Challenges are related to where it is best to download the data, uncertainty about calibration routines and quality control and concerns about inconsistencies with other observations, for example satellites. For assimilating BGC-Argo, status differ because the dataset is quite heterogeneous from one region to another, for example the Black Sea and the Baltic Sea have very few floats available, but also because the MFCs are in very different stages of developing the BGC data assimilation systems. There were also concerns about the quality of the NRT observations.

◆ **Discuss the usefulness of new BGCArgo-based products**

- Nutrients CANYON based products R. Sauzède

  As part of CMEMS a product of profiles of nutrients (nitrate, phosphate and silicates) concentrations is released online. These profiles are derived from BGC-Argo oxygen profiles qualified in delayed mode. This represents ~100,000 profiles at the global scale currently and the product is updated with new available profiles every year. The profiles are estimated using the CANYON-B method (for CArbonate system and Nutrients concentration from hYdrological properties and Oxygen using a Neural-network) for the global ocean and its regional dedicated CANYON-MED method for the Mediterranean Sea. This product can be used as any in situ BGC-Argo profiles, for example for data assimilation in biogeochemical models (note that associated errors are available together with each data in the product).

- Discussion

  Following R. Sauzède talk on the nutrient CANYON based products, we had a discussion on the general usefulness of these kinds of products for modelers. Some key points:

  - Because the MOB products are presently available in delayed mode, they can be used for validating hind-casts and/or for assimilation in reanalysis. The real-time product will take more time to develop.
  - The product is an output from a statistical model, provided with its own uncertainty (of the order of the measurement uncertainty when it comes to NO3); in that way, the product can be used the same way as direct observations. Nevertheless, it has been stressed out that direct observation shall be preferred for assimilation purposes, or evaluation of model accuracy, while derived/gridded products shall be very useful for intercomparisons. These notions are still in debate.
  - The uncertainty estimates are provided as an output from the NN-CANYON-B method, only at global scale for now (cf. Bittig et al, 2018; Sauzède et al, 2017). More detailed error estimates, for example taking into account instrument errors, are not yet being computed.
  - POC would be useful to constrain the carbon cycle in the model. POC estimates can be as useful as those for chlorophyll and do not necessarily have larger errors.

◆ **Status on bio-optical modules integration in BGC models (invited speaker: J.Skakala)**

Ecosystem indicators, such as chlorophyll concentrations, phytoplankton community structure, or nutrient concentrations are sensitive to spectrally and directionally resolved radiances, as well as to the attenuation of light by the biogeochemical tracers. However, since the radiative transfer models are computationally expensive, the physical-biogeochemical models tend to represent light quite poorly: typically via broadband PAR, or 2-3 waveband schemes, lacking directional resolution and attenuating light only by the clear sea water and phytoplankton. Recently there have been several important developments to go beyond the state-of-the-art modelling, including simplified radiative models, such as OASIM, and explicitly modelling attenuation by POM and CDOM. These approaches opened up new opportunities to improve the realism of biogeochemical modelling, to explicitly simulate the spectrally resolved water leaving radiances, as well as the underwater light field. The improved optical modelling also enables us to directly assimilate reflectances into the model, which can be superior to the established OC chlorophyll assimilation in the coastal waters, where OC algorithms can have large uncertainties and biases. Furthermore, the more realistic optics and light attenuation can provide us with feedback from the biogeochemical model to physics and further improve the realism of our physical-biogeochemical marine models.

◆ General discussion on the items above as well as ideas on how to improve interaction between modellers/assimilators/OC/ BGC-Argo communities

Following the last presentation, we had a more general discussion in the topics raise in the session, and here are some key points that were discussed:

Regarding usefulness of BGC-Argo for physics: Spectral sensors are also important for physical modelling and the heating by the sun. The physical oceanography community is still using short and long wave radiation measurements and parametrization for heating purposes.

The QUID for the BGC-Argo distributed by CMEMS states the accuracy of the instrument, which is very useful. Additionally, it will be useful for the modellers if the “adjusted error” field is filled when the parameter is adjusted in real time. More quality control can be done in delayed mode. Calibration can be challenging as it can vary between regions. The MED MFC is already doing its own regional quality control of the BGC-Argo, and this information can be useful to share with the BGC-Argo community.

It was discussed what variable and format of data is most useful for modellers. Both gridded and profile data are useful for assessment and intercomparison with other sources of data (models, other networks), but assimilation of gridded product is still in debate. For assimilation, profiles can be used directly and for estimating model accuracy. Different variables have different value for the model in an assimilation framework: oxygen is mature and cost-effective, but may not correct phytoplankton biomass; Chla can correct phytoplankton biomass, but the effect can be short-lived since plankton grow and die very fast; nutrient can correct the model more in the long term, but there are few measurements and the latter are costly; the MOB product can be thus very useful here. How the different BGC-Argo observations correct other BGC model variables when assimilated is an important research topic. Products connected to the carbon cycle can be useful to assimilate when modelling the air-sea CO2-flux.

We ran out of time at the end, so the issue of better interaction between modellers/assimilators/OC/ BGC-Argo communities was not discussed.