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Toward deeper development of Biogeochemical-Argo floats

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1. Introduction

The Biogeochemical-Argo (BGC-Argo) Program aims at operating a network of profiling floats equipped with sensors of key biogeochemical variables for supporting research activities that address impacts of climate change on oceanic biogeochemical cycles and ecosystems (Claustre et al. 2010; IOCCG 2011; Johnson et al. 2009).

Following a series of publications reporting on successful long-term deployments of profiling floats with various biogeochemical sensors (e.g. Boss et al. 2008; Johnson, Riser, and Karl 2010; Körtzinger et al. 2004) and years of international coordination, the BGC-Argo program was officially launched in October 2016, as an extension of the Argo Program (Biogeochemical-Argo Planning Group 2016; Johnson and Claustre 2016). The objectives of the BGC-Argo Program are to establish and sustain an array with 1000 floats within five years. Similar to Argo, this is a coordinated, voluntary, distributed, and multinational network of profiling floats, but with a significant addition of sensors. At the moment, the global network is progressively maturing through a cluster of national projects, e.g. the French SOCLIM project (<http://soclim.com>), United States' SOCCOM project (<http://socom.princeton.edu>), South Africa's SOCCO BIO-ARGO project (<http://socco.org.za/research/#Bio-optics>), and Chinese ReMOCA project in the Southern Ocean; the European REMOCEAN project (<http://remocean.eu>) and Japanese INBOX project (<http://www.jamstec.go.jp/ARGO/inbox>) in the subtropical gyres; the United States' NAAMES project (<http://naames.larc.nasa.gov>) and UK-BIO-ARGO project in the subpolar gyres; as well as the French NAOS project (<http://en.naos-equipex.fr/>) in the Mediterranean Sea and Polar Area. As of November 2017, there are 282 such operational floats working in the global ocean, mainly covering the

Southern Ocean, Indian Ocean, eastern Pacific, Atlantic, and Mediterranean Sea (Figure 1). Six BGC-Argo core variables have been identified: dissolved oxygen, nitrate (NO₃), pH, Chl-*a*, suspended particles, and downwelling irradiance (Figure 1).

The price of a BGC-Argo float varies from around 25 000 USD to more than 120 000 USD, depending on the types and number of sensors. Although its cost is significantly higher than a simple Argo float (around 18 000 USD), which measures temperature, salinity and depth, these additional observations are critical to study the ocean's biogeochemistry.

On 10 and 11 October 2017, the Second Institute of Oceanography of the State Oceanic Administration of China hosted a workshop designed to summarize the latest achievements of the BGC Program, preview the short-term and long-term future perspectives, discuss data quality-control procedures and distribution, introduce some emerging technologies that could upgrade BGC floats in the future, as well as present and exchange new scientific and multidisciplinary applications of BGC-Argo observations. More than 15 participants were invited, which included members of the international BGC-Argo steering committee (from Australia, Europe, France, the UK, US, and China), national Argo project representatives from China, manufacturers of floats, sensors, and batteries, as well as other oceanographers and remote-sensing scientists who are interested in Biogeochemical-Argo float data.

2. Major achievements

Workshop participants exchanged views and ideas for future developments of BGC-Argo floats and a set of recommendations were adopted (see below).

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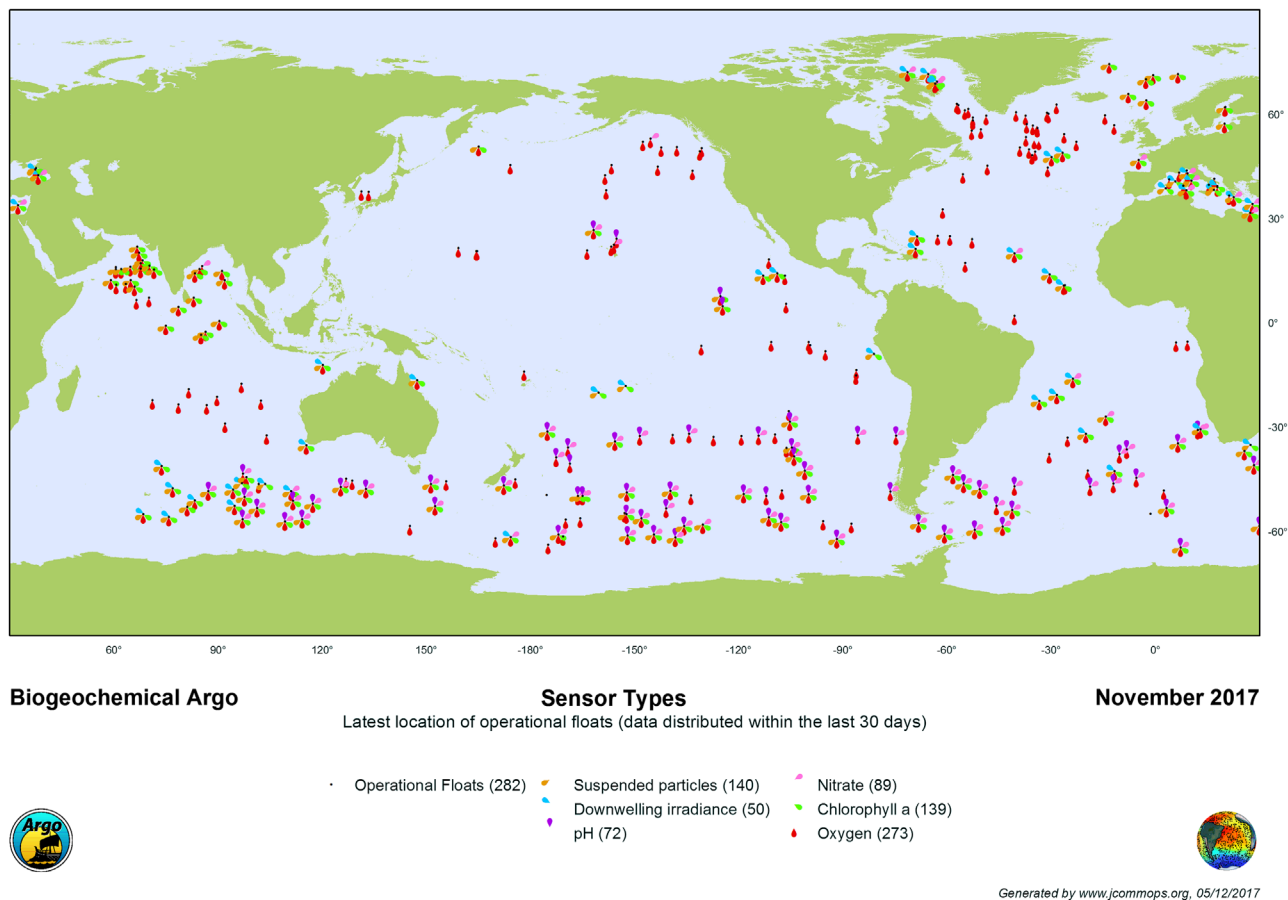


Figure 1. Map of operational Biogeochemical-Argo floats (November 2017). (Source: www.jcommops.org)

2.1. Overall challenges

The overall challenges of the International BGC-Argo Project were revisited, which include:

- (1) Progressive development of the network toward an ocean-wide operational fleet of 1000 floats measuring six primary variables, and especially the subsequent sustainability of this network in the long term. This objective requires the deployment of around 250 floats per year, which represents a yearly investment in the region of 25 million USD for the community (including data management and distribution).
- (2) Development of an efficient data management, quality control, and distribution system serving the end-user oceanography community.
- (3) Interest in further expanding the sensor suite, in particular toward the measurement of variables of key relevance for biogeochemical cycle and ecosystem studies (e.g. carbonate system, zooplankton), while respecting the international Argo framework.

2.2. Short-term perspectives

With respect to short-term progress, the following items were raised:

- Five key research topics were identified where BGC-Argo could contribute significantly: (1) ocean carbon uptake; (2) oxygen minimum zones and NO_3 cycling; (3) ocean acidification; (4) the biological carbon pump; and (5) phytoplankton communities. In addition, two topics of societal relevance were identified: living marine resources and carbon budget verification.
- Discussion took place on how to improve real-time quality-control procedures for chlorophyll fluorometry and delayed mode quality-control procedures of dissolved oxygen. This was important in light of the Argo Data Management Team (ADMT) meeting that followed a month later and where these issues were discussed at length.
- Derivation of new variables were discussed, such as euphotic depth, diffused attenuation coefficients, pCO_2 , size indices, and particle flux proxies.

- In consultation with the ADMT, organizing the B-ADMT (BGC-Argo Data Management Team) for more effective and efficient data quality-control and management.
- The need to establish three or four B-DACs (BGC-Argo Data Assembly Centers) around the world to improve data access to oceanographers to increase data utilization.
- The need for a fair data use statement of BGC-Argo data, with a generic statement of the Argo and Biogeochemical-Argo projects, and the DOI number(s) to specify the processing version of data used.
- The need for regular meetings among float and sensor manufacturers, engineers, and scientists to improve sensor technology and quality control, as well as for the development of new technology.
- Extending the community through special classes (e.g. summer schools) or training workshops, with emphasis on inviting participants from developing countries.
- Beginning to work on a 10-year BGC-Argo plan, which will be proposed in the OceanObs19' meeting.

2.3. Data quality control

With respect to core BGC-Argo variables and to their processing and quality control, various issues were discussed and recommendations were made to be discussed as part of the upcoming ADMT.

- The RTQC (Real-Time Quality Control) procedures on chlorophyll fluorometers were revised; the recommendation included applying the global factor between the WET Labs fluorescence chlorophyll product and chlorophyll-a concentration (Roesler et al. 2017);
- The calibration issues and the discrepancies between different types of backscattering sensors were discussed (Poteau, Boss, and Claustre 2017). Correction schemes were suggested to be agreed upon in the ADMT meeting that took place a month later.
- The use of oxygen measurements to assist in correcting drifts in NO_3 and pH sensors (Johnson et al. 2017; Williams et al. 2016);
- The use of the optical NO_3 sensor to retrieve additional parameters like chromophoric/colored dissolved organic matter (CDOM) absorption. CDOM fluorescence observations on the floats that have both measurements could be used for validation.

2.4. New technologies

Some cutting-edge technologies were presented:

- Temperature rechargeable battery technology provides a potential solution to reduce the cost per profile and increase the float lifetime (Chao 2016), especially in terms of the implementation floats with sensors with high power demand (e.g. active acoustic for zooplankton).
- Advanced anti-biofouling system approaches developed for BGC-Argo floats, including mechanical cleaning, coatings, hydraulics, and UV LED technology.
- Active control of float vertical positioning using circulation models to steer floats in space. Such control could, for example, improve horizontal coverage by floats and avoid shallow waters and coastlines, as well as maintain a uniform coverage.

2.5 Applications

To date, there are already approximately 120 peer-reviewed papers related to BGC-Argo technology, sensor calibration, data quality control, and scientific applications (<http://biogeochemical-argo.org/peer-review-articles.php>). In particular, in 2016 and 2017, 47 papers were published attesting to the great value of BGC-Argo floats in studying marine bio-optics, biogeochemistry, and physical-biological coupling.

Discussions at the workshop highlighted a variety of scientific applications, including studies of mesoscale and submesoscale phenomena, episodic events, seasonal variation, and the dynamics of biogeochemical variables.

For example, optical backscattering observed with BGC-Argo floats can detect the seasonal carbon export flux of small particles. In the Norwegian Sea, the estimated export was comparable to published export values, and contributed to long-term carbon sequestration. The results suggest the importance of small particles and of physical mixing in the biological carbon pump (Dall'Olmo and Mork 2014).

BGC-Argo float data are very often used to assess the phytoplankton response to eddies. Combining winter observations from ship and float, the study of Dufois et al. (2017) provided evidence for two mechanisms to enhance the surface chlorophyll-a concentration in anticyclonic eddies (ACEs) in the South Indian Ocean subtropical gyre: (1) ACEs can trap productive waters through horizontal advection, and/or (2) locally modify the chlorophyll distribution through enhanced convective mixing.

In addition, BGC-Argo float data could be utilized for validation of satellite-derived products. Based on a large number of BGC-Argo float data in the Southern Ocean, Haentjens, Boss, and Talley (2017) compared float-measured chlorophyll-a concentrations and particle organic carbon (POC) concentrations (derived from measured backscattering) with corresponding products derived from two ocean color satellite instruments: the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Aqua, and the Visible Infrared Imaging Radiometer Suite (VIIRS). They found the Ocean Color Index (OCI) global algorithm to agree well with the matchups (within 9% for VIIRS and 12% for MODIS), and POC estimates based on floats to agree well with NASA's POC algorithm. This study validated the effectiveness of the OCI chlorophyll-a algorithm in the Southern Ocean.

Disclosure statement

No potential conflict of interest was reported by the authors.

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