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Item **4.8** of the Revised Provisional Agenda

EVOLVING CAPABILITIES OF THE ARGO PROFILING FLOAT NETWORK

Summary

In Decision IOC-XXIX/6.1.1(III), the Assembly decided to consider the evolving capabilities of the Argo profiling float network as an agenda item at the 51st Session of the IOC Executive Council in 2018, with a view to deciding how to treat proposed new variables within IOC's cooperative framework

Purpose of the document: This document provides additional detailed technical information on the evolving capabilities of Argo profiling floats, including the variables they will measure, the societal and scientific benefits, and implementation plans.

The Executive Council is invited to approve the global implementation of Argo floats measuring six parameters: oxygen, pH, nitrate, chlorophyll, backscatter, and irradiance; and to agree to the continued use of IOC's "Guidelines for the Implementation of Resolution XX-6 of the IOC Assembly Regarding the Deployment of Profiling Floats in the High Seas within the Framework of the Argo Programme" (Resolution IOC/EC-XLI.4) for notification to coastal Member States of all Argo profiling floats likely to enter their EEZ, including those measuring these new variables.

The Executive Council is additionally invited to examine a framework for additional new parameters for Argo, which identifies experimental, pilot, and global implementation stages.

There are no financial and administrative implications.

The proposed decision is referenced EC-LI/Dec.4.8 in the Action Paper (document IOC/EC-LI/2 Prov.).

I. Introduction

1. The IOC Assembly at its 29th session (June 2017) took note of the evolving capabilities of the Argo profiling float network, and in Decision IOC-XXIX/6.1.1(III):

> Request[ed] the GOOS Steering Committee to provide additional detailed technical information on the evolving capabilities of Argo profiling floats (as described in IOC/INF-1344), including the variables they will measure, the societal and scientific benefits, and implementation plans, to the IOC secretariat for distribution to all Member States by circular letter by the end of October 2017;
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> Request[ed] that the IOC Officers, supported by the secretariat, consult Member States, requesting feedback by the end of December 2017; and
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> Decide[ed] to consider these evolving capabilities of the Argo profiling float network as an agenda item at the 51st Session of the IOC Executive Council in 2018, with a view to deciding how to treat these new variables within IOC's cooperative framework.

2. The IOC Officers, meeting in Paris 16–18 January 2018, reviewed the status of the information provided by Argo and GOOS, and adjusted the timeline for Member State feedback.

3. In Circular Letter 2714 (15 March 2018), Member States were asked to provide feedback on the contents of this working document and a draft of the decision found at its end. Comments received were incorporated into this final version of the document and the proposed decision.

II. Evolving Capabilities of the Argo Profiling Float Network to Monitor Large-Scale Ocean Biogeochemistry

4. Argo is a major contribution to the Global Ocean Observing System (GOOS), and its implementation over the past 15 years represented a revolution in the collection of climate information in the global ocean, and in the development of routine ocean services, as well as a revolution in the culture of free and open data sharing amongst nations. For the first time, six additional parameters for global Argo are proposed, focussing on the ocean's biogeochemistry aimed at tracking the largescale health of the offshore ocean, particularly acidification and deoxygenation, the ocean's role in the global carbon budget and the role of the deep offshore ocean in controlling the coastal environment. All of these issues are associated with significant societal Impacts for all countries and especially for coastal States.

Role of Argo as a contribution to GOOS

5. The oceans play a vital role in climate variability and change, with processes operating on a global scale. Understanding local and coastal ocean variability requires a large-scale context, as the offshore ocean will influence coastal conditions. However, the ocean is a challenging environment to observe, and historically ship-based ocean sampling has left large expanses unobserved for long periods of time. The Argo programme was established to address this challenge focussing on the ocean's temperature and salinity.

6. Argo profiling floats are freely-drifting robotic devices that adjust their depth in the ocean by changing their buoyancy. They are programmed to 'park' at 1,000 m depth, regularly dive to 2,000 m, and then rise to the surface measuring a profile of ocean variables with sensors on the float. At the surface the position of the float is obtained and the data are transmitted via satellites; the floats then descend back to their parking depth. At present, 3,900 Argo floats are roughly evenly spread across the ice-free oceans, and into the seasonally ice-covered regions. The floats profile on a roughly 10 day schedule.

7. A recent review[1] highlighted the major contribution of Argo to the Global Ocean Observing System (GOOS) over the past 15 years. For the first time the upper 2,000 m of the global ocean is routinely monitored uniformly in space and time. Within 24 hours of collection, the network provides freely available profile data from all floats. These data are used in a broad range of applications examining climate-relevant variability on seasonal to decadal timescales, multi-decadal climate change, improved initialization of coupled ocean—atmosphere climate forecasts, and constraining ocean analysis and forecasting systems. Thus Argo underpins key climate, weather, and ocean forecasting services. Argo data are routinely utilised across a breadth of applications from energy and agricultural planning through to marine search and rescue. In addition, more than 3,000 refereed science papers have been published using Argo data, as well as 250 Ph.D. theses. Argo has also supported several outreach programmes held in developing countries and hosted researchers in Argo partner institutions.

Institutional context

8. As a major contribution to the Global Ocean Observing System (GOOS), Argo remains a voluntary and independent network organized under the Argo Steering Team. GOOS is a creation of and governed by the Intergovernmental Oceanographic Commission of UNESCO, and co-sponsored by the World Meteorological Organization, United Nations Environment, and the International Council for Science. Argo's contributions to GOOS and WMO are coordinated through its membership of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) Observations Coordination Group, and the Argo Information Centre (AIC) is housed in the JCOMM Observing Programme Support Centre (JCOMMOPS).

IOC guidance, monitoring and the notification of Member States of Argo activities

9. At the intergovernmental level, the Argo programme was formally accepted and defined by IOC Resolution XX-6 (1999). The resolution also considered that Argo be "fully consistent with the UN Convention on the Law of the Sea." In 2005, the IOC Assembly instructed IOC's Advisory Body of Experts on the Law of the Sea (IOC/ABE-LOS) to address the deployment of floats on the high sea which may drift into EEZs. In response IOC Resolution EC-XLI.4 ("Guidelines for the Implementation of Resolution XX-6 of the IOC Assembly Regarding the Deployment of Profiling Floats in the High Seas within the Framework of the Argo Programme") was developed and adopted, and provides a practical set of guidelines for notification of coastal States that is used today with success, with the involvement of the Argo Information Centre (AIC) at JCOMMOPS. (see IOC Circular Letter 2271). An electronic notification procedure was implemented by the AIC to inform all Member States through their designated Argo National Focal Point (NFP), of all deployments of Argo profiling floats and the types of sensors that were carried. IOC Member States were recently requested to update their Argo NFP through IOC Circular Letter 2666 (1 June 2017).

10. Following up on Resolution EC-XLI.4, an additional notification system was set up to meet the requirements of Member States requesting a formal notification from the implementer when an Argo float approaches their Maritime Zone. The following coastal States have sent official requests for such notification to the IOC secretariat: Argentina, Brazil, Chile, China, Ecuador, Egypt, Greece, India, Peru, Russian Federation, Tunisia and Turkey.

11. Respecting the rights of coastal States and adhering to UNCLOS, Argo has operated for over 18 years under the above guidance of the IOC and the independent monitoring by the AIC, notifying Member States routinely of float locations, sensors carried, and status with respect to EEZs.

[1] Riser et al., 2016, *Fifteen years of ocean observations with the global Argo array*, Nature Climate Change, doi:10.1038/nclimate2872

The increasingly urgent need to track the ocean's biogeochemistry

12. The oceans play a crucial role in Earth's health, climate and food resources. The chemistry of the atmosphere is closely tied to that of the ocean: 50% of the oxygen produced each year is created by ocean plankton; atmospheric carbon dioxide levels are heavily buffered by exchanges with the ocean. Sparse historical data are suggesting that significant changes are already underway in the oceans that may have significant societal impacts.

13. Ocean carbon uptake is slowing down the rate of global warming, as oceans absorb around 25% of anthropogenic emissions of carbon dioxide. This uptake of carbon dioxide, which forms carbonic acid in solution, is acidifying the oceans by increasing proton concentration, $[H^+]$, and driving the pH (= $-\log_{10} [H^+]$) to lower values. Much of the heat absorbed by the ocean is sequestered in deep waters, away from Earth's surface where the impact of climate change on human populations is strongest. Warming and ocean circulation changes driven by the absorption of this excess heat are decreasing ocean oxygen concentrations.

14. Ocean ecosystems are sensitive to small changes in ocean chemistry. The [IPCC Assessment Report 5] assigns high confidence to a variety of ecosystem effects that will stem from the changes that are driven by ocean heating, ice loss, acidification from anthropogenic carbon dioxide, and the associated biogeochemical processes such as oxygen loss[2].

15. As a result of ocean acidification (decreasing the ocean pH), the calcium carbonate shells of marine organisms become susceptible to dissolution. Direct impacts of acidification on oyster production in hatcheries have been mitigated by improved coastal monitoring for low pH events. The Southern Ocean is projected to cross a similar ecosystem tipping point within a few decades[3]. This tipping point occurs when the entire water column becomes undersaturated with the mineral aragonite ($CaCO_3$) that constitutes the shells for a number of marine organisms. Monitoring for such events is rare in the open ocean.

16. Sparse observations also indicate that ocean oxygen concentrations are decreasing with unexpected results on continental shelves. Vast regions of low oxygen waters (oxygen minimum zones) may be increasing in size[4]. Small changes in open ocean conditions have created unexpected hypoxia on continental shelves[5].

Present rates of observing ocean biogeochemistry are inadequate

17. Despite its importance to both climate and ocean health, observations of the ocean biogeochemistry and the health of its ecosystems remain sparse. Presently, vast areas are sampled only once per decade at most, largely by ships, and with sampling occurring mainly in summer. As a result, for much of the global ocean, we cannot quantify the basic seasonal cycle of biogeochemical parameters, let alone have any ability to detect changes that may be underway due to the increasing atmospheric CO_2.

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[2] Pörtner, H.-O., et al., 2014, Ocean systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A. Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., et al., (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 411-484.

[3] McNeil, B. I., R. J. Matear, 2008, *Southern Ocean acidification: A tipping point at 450-ppm atmospheric* CO_2. Proceedings of the National Academy of Sciences, 105, 18860-18864, doi10.1073pnas.0806318105.

[4] Keeling, R. F. et. al., 2010, *Ocean deoxygenation in a warming world*, Annual Reviews of Marine Science,. 2, 199–229, doi:10.1146/annurev.marine.010908.163855

[5] Grantham, B. A. et al., 2004, *Upwelling-driven nearshore hypoxia signals ecosystem and oceanographic changes in the northeast Pacific.* Nature, 429, 749-754.

18. The Intergovernmental Panel for Climate Change's Assessment Report 5 lists the major drivers of ocean health as temperature and salinity, acidification (pH), oxygen, nutrients (nitrate), and light (Table 1). Each variable helps shed light on different applications as listed below.

Table 1. Biogeochemical sensors used on Argo profiling floats and their applications.

Parameter	**Method**	**Applications**
Oxygen	Fluorescence Quenching	Spread of anoxia and suboxia, detection of anoxic events, community production
pH	Ion Sensitive Transistor	Acidification, potential for shell dissolution events, carbon uptake from atmosphere, community production
Nitrate	UV Light Absorption	Nutrient availability, potential for Harmful Algal Blooms (with T sensor), community production
Chlorophyll	Chlorophyll Fluorescence	Phytoplankton biomass, bloom timing.
Backscatter	Optical backscatter	Particulate carbon production and export (biological pump).
Irradiance	Wavelength selective light sensor	Light availability for primary production, biomass.

19. Even as the ocean community becomes aware of changing ocean conditions, such as oxygen loss due to warming, our capability to observe these key parameters using conventional, ship-based approaches is deteriorating. For instance, we now collect on an annual basis only one tenth of the number of oxygen profiles from ships, relative to the number collected in the 1980s[6].

Table 2. Nations that have deployed Biogeochemical-Argo floats.
Australia, Bulgaria, Canada, Chile, China, Finland, France, Germany, Greece, India, Ireland, Italy, Japan, Korea (Rep. of), Norway, Poland, Portugal, Turkey, United Kingdom, United States

20. Since the current ship-based observing system will not meet future needs, a pilot is underway with over 600 Argo floats deployed by nearly 20 nations (Table 2) with one or more biogeochemical sensors, in addition to the conventional temperature and salinity (more than half are floats with only oxygen sensors).

Table 3. Average number of ship-based oceanographic profiles per year from 2000 to 2010 in the World Ocean Database 2013, which reach at least 900 m depth for the parameter indicated, and the number of profiles for the year 2016 collected by profiling floats and found in the Argo Global Data Assembly Center.

Parameter	**Ship Profiles per Year**	**Argo Pilot Profiles per Year**
Oxygen	1,730	11,332
Nitrate	1,231	3,835
pH (direct measurement)	460	1,862
Source	US National Center Environmental Information	Argo Global Data Assembly Center

6 Johnson, K. S. et al., 2015, *Air oxygen calibration of oxygen optodes on a profiling float array.* Journal of Atmospheric and Oceanic Technology. 32, 2160-2172.

21. Illustrating its effectiveness, the pilot activity has quickly become the dominant source of information for biogeochemical processes in the offshore oceans. Table 3 compares the mean number of ship-based profiles per year for oxygen, nitrate, and pH that were reported to international ocean databases from 2000 to 2010 with the number of vertical profiles from profiling floats. These pilot floats are providing from 3 to 6 times more data than come from ships and they are a key resource to understand changing conditions in the ocean.

A global expansion of a Biogeochemical-Argo array

22. Based on the success of the pilots, a major new global enhancement for Argo is now being considered: to monitor the largescale and slow evolution of the ocean's biogeochemistry and associated impacts on marine ecosystems. The emphasis would be on observing possible changes in ocean carbon dioxide uptake, ocean pH and ecosystem impacts, ocean oxygen concentrations, and nutrient supply to the productive upper ocean.

23. The goals of the Biogeochemical-Argo programme are to sustain an active array of 1,000 profiling floats which measure temperature and salinity, but are also equipped with sensors for the six key parameters: dissolved oxygen, nitrate, pH (proton concentration), chlorophyll fluorescence, light scattering by particles (particle abundance), and downwelling irradiance (solar light penetration). Each parameter is recognised by the GOOS community as either a primary or supporting Essential Ocean Variable[7]. The measurement method for each parameter is noted in Table 1. In addition to this desired array of 1,000 profiling floats, some Argo national programs will also deploy floats that are equipped with one or more of these sensors.

24. These Biogeochemical-Argo floats will be deployed with a relatively even spacing throughout the global ocean in waters deeper than 2,000 m. The proposed Biogeochemical-Argo program (www.biogeochemical-argo.org) would operate as an international consortium that reports to the Argo Steering Team under the same protocols used by core Argo, including free and open data availability in real time.

25. Observations of the key parameters of ocean health (temperature, salinity, oxygen, pH, nutrients, and light) by a broadly distributed Biogeochemical-Argo array are relevant to ocean management at 1,000 km or longer scales. They will provide a broad context for what might be observed at the coast and local regions, empowering a better understanding of how large-scale ocean changes offshore might be impacting local conditions. Without such information, teasing apart the impacts of local land-based changes from those due to large-scale ocean variability will be impossible, hampering the development of an evidence-based local management policy.

26. Argo operates under strong principles of transparency and openness, and under the guidance of the IOC resolutions and decisions noted in paragraphs 5–7. The first part of the proposed decision asks IOC Member States to approve the use of the "Guidelines for the Implementation of IOC Resolution XX-6 of the IOC Assembly Regarding the Deployment of Profiling Floats in the High Seas within the Framework of the Argo Programme" (IOC Resolution EC-XLI.4) for the global deployments of Argo floats including the six new parameters in Table 1.

III. A proposed framework for additional new parameters for Argo

27. Other future evolutions of Argo's suite of global ocean variables must be brought to the IOC Member States for consideration and approval, under the strong principles of transparency and openness underwhich Argo operates. It is impossible for Argo to be a global programme and deliver benefits to all nations without engagement and the support of coastal Member States.

[7] GOOS Essential Ocean Variables are listed at: http://www.goosocean.org/eov

28. Argo is implementing a ‘readiness-based’ framework to assess possible new parameters, following the Framework for Ocean Observations[8]. If a new parameter is being developed, it would pass through three stages: *experimental, global approved pilot* and *global implementation*.

29. Argo floats carrying sensors for *experimental* parameters developed under national research programmes must be operated in a manner consistent with UNCLOS. If a successful experimental phase is completed, the proponents would bring a proposal to the Argo Steering Team to seek approval for a global pilot.

30. In assessing whether a *global pilot* can be approved, the Argo Steering Team would ensure that several key requirements will be met: technological readiness (as evidenced from the experimental phase); a compelling global design and implementation plan; and delivery of major benefits to research and societal services. Approval of the global pilot will allow a limited number of new sensors to be tested across many ocean regimes and for the data to be distributed by the Argo data system for open and transparent assessment. Thus these pilot floats would operate under Argo’s current notification regime (Resolution IOC/EC-XLI.4). This is currently the status of the Argo-approved pilot BGC floats operating in Argo.

31. If the *global Argo-approved pilot* is deemed successful, the Argo Steering Team and the leadership of GOOS will share the results with the IOC Member States, and will then seek approval to formally include the new parameters under the Argo label for *global implementation*, and operation under Argo’s notification system.

32. The Argo Steering Team is seeking IOC Member State input and assistance in developing this framework for additional new parameters for Argo. The second part of the proposed decision provided for comment in IOC Circular Letter 2714 adopts this future framework for additional new parameters for Argo.

Proposed decision

33. In light of the foregoing, the IOC Executive Council may wish to consider draft EC-LI/Dec.4.8 proposed in the Action Paper (IOC/EC-LI/2 Prov.)

[8] A Framework for Ocean Observing. By the Task Team for an Integrated Framework for Sustained Ocean Observing, UNESCO 2012, IOC/INF-1284, doi: 10.5270/OceanObs09-FOO