Framework for adding new sensors and new mission parameters in OneArgo

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# 1. Introduction

In 2018, the 51st Session of the Executive Council of the Intergovernmental Oceanographic Commission (IOC) of UNESCO approved six biogeochemical (BGC) mission parameters for Argo floats ([Decision EC-LI/4.8](https://unesdoc.unesco.org/in/documentViewer.xhtml?file=/in/rest/annotationSVC/DownloadWatermarkedAttachment/attach_import_5d92d5b5-ff70-4078-8dc5-d596ab5375a2%3F_%3D372521eng.pdf) in IOC/EC-LI/3: <https://unesdoc.unesco.org/ark:/48223/pf0000372521>), as well as a framework for future additional new mission parameters for Argo (IOC/EC-LI/2 Annex 9 Section III: <https://unesdoc.unesco.org/ark:/48223/pf0000265129>). In the ensuing years, new BGC sensors and new CTDs were evaluated for their readiness and cost-effectiveness in delivering approved-parameter data on behalf of the global OneArgo program. Following the terminologies used by IOC-UNESCO for adopting new mission parameters, 3 phases of development were established to track the progress of new sensor advancement within the OneArgo program: experimental, pilot, and global implementation.

As OneArgo continues to expand, the need for more explicit definitions of the 3 phases and the transition between them has become apparent. There is also the need to institute a framework that supports experimentation, and at the same time acts as a filter to not allow all experimentation to overwhelm and jeopardize OneArgo. The goal of this document is to describe this framework and the pathway to admit new sensors and new mission parameters into OneArgo, through the 3 phases: experimental, pilot and global implementation. The pathway outlined follows the IOC-UNESCO guidelines for new mission parameters, but we expanded them to include new sensors, and added considerations for the Argo data system in order to prevent it from becoming overburdened unnecessarily. In this framework, some experimentation will progress to the pilot phase or global implementation, but some will remain in the experimental phase indefinitely. This document should therefore provide transparency to users on the procedure required, as well as practical guidance on what needs to be done at each phase.

# 2. Definitions

The terminologies used in this document are defined below.

*Mission parameter*

A mission parameter is a general ocean state parameter approved by the IOC-UNESCO. A mission parameter can spawn several ocean state parameters. For example, under the mission parameter of “downwelling irradiance”, there can be several ocean state parameters with specific wavelengths, such as “downwelling irradiance at 412 nanometers”, or “downwelling irradiance at 443 nanometers”, etc.

*Ocean state parameter and intermediate parameter*

An ocean state parameter is an Argo label for the final computed parameter serving an approved mission parameter. An intermediate parameter is the raw sensor ingredient that goes into the computation. For example, DOXY is an ocean state parameter. TPHASE\_DOXY, TEMP\_DOXY, etc, are the intermediate parameters that contribute to the computation of DOXY.

*Argo parameter label*

An Argo parameter label is a char string <PARAM> that is used to name the variables in the Argo netCDF files. These variables are used to store data from an ocean state parameter and its associated intermediate parameters. All Argo parameter labels are listed in R03. Ocean state parameters are listed as ‘c’- or ‘b’- parameter labels. Their associated intermediate parameters as ‘ic’- or ‘ib’- parameter labels.

*New mission parameter*

A new mission parameter is a new general ocean state parameter that has not yet been approved by Argo and the IOC-UNESCO.

*New sensor*

A sensor is considered to be a ‘new sensor’ if it employs a new sensing principle (e.g. RBR inductive CTD versus SBS electrode-based CTD), or if it comes from a different original manufacturer (e.g. Aanderaa versus SBS Optode). Minor modification of an existing sensor (e.g. SBS63 versus SBS83, which vary only in the packaging of the same hardware components and same data stream) does not qualify as a ‘new sensor’. This means that with the related metadata, processing and QC updated accordingly and adopted by the Argo Data Management Team (ADMT), it may start off as a pilot sensor. Major modification of an existing sensor (e.g. Aanderaa 3830 versus Aanderaa 4330 optode, which differ in their temperature sensing), however, requires an assessment as a ‘new sensor’. (Depending on the extent of the modification, the assessment may be expedited.)

Table 1: List of IOC-UNESCO approved mission parameters for BGC-Argo (at the time of writing), and their corresponding terminologies in other usages. See <https://unesdoc.unesco.org/ark:/48223/pf0000265129>

| **IOC-UNESCO mission parameters (IOC/EC-LI/2 Annex 9: Table 1. and Item 23.)** | **BGC-Argo Science and Implementation Plan mission parameters** | **Argo reference table R03 parameter labels <PARAM> of ocean state parameters** |
| --- | --- | --- |
| Dissolved oxygen | Dissolved oxygen | DOXY |
| pH | pH | PH\_IN\_SITU\_TOTAL |
| Nitrate | Nitrate | NITRATE |
| Chlorophyll / chlorophyll fluorescence | Chlorophyll fluorescence | CHLA, CHLA\_FLUORESCENCE |
| Backscatter / light scattering by particles (particle abundance) | Suspended particles | BBP<nnn>, CP<nnn>, TURBIDITY |
| Irradiance / downwelling irradiance (solar light penetration) | Downwelling irradiance | DOWN\_IRRADIANCE<nnn>, DOWNWELLING\_PAR |
|  |  | CDOM |
|  |  | UP\_RADIANCE<nnn> |
|  |  | BISULFIDE |

(The Argo b-<PARAM>: CDOM, UP\_RADIANCE<nnn> and BISULFIDE, have a status of *pilot* in the Argo system. They do not have a correspondence to an approved mission parameter in the IOC/Science Plan parameter list. They are legacy parameters that pre-date this document.)

# 3. Implementation guidelines and requirements

This section describes the process to advance a new mission parameter or a new sensor through the 3 phases: experimental, pilot and global implementation. They largely follow the same sequence and requirements, but a new mission parameter will have additional requirements: mainly, for a new mission parameter to be approved as a new Argo ocean state parameter for global implementation, it will need to go through IOC-UNESCO approval.

## 3.1. Going from experimental to pilot

### i. New sensors for an existing mission parameter

Sensors are considered *experimental* if their viability has not been fully demonstrated on profiling floats. Data from experimental sensors should be distributed on the GDACs in the auxiliary (‘aux’) directory, along with a readme file that describes the format and content of the data file submissions or with a self-explanatory format. Initially, there is no defined vocabulary for the profile or meta data for experimental sensors. During the experimental phase, the PI(s) should work to improve sensor technology, and collaborate with at least one DAC to develop proper data management protocols and vocabulary, if the sensor technology shows promise to progress to the *pilot* phase.

**Introducing new sensors into the Argo data system is a burden on the already overworked DACs. Therefore, while in the *experimental* phase, most of the data management work should be done by the PI(s) who deploy the experimental sensors on the floats. Alternatively, sufficient resources should be provided to the DACs to take on this additional responsibility. If the latter, the PI(s) should engage the DACs during the proposal process to scope out appropriate resources.**

In order to advance from *experimental* to *pilot*, the viability of the sensor technology and data management must be demonstrated. It is the responsibility of the PI(s) to demonstrate the viability for each of the following two categories (a)-(b), and each category will be assessed by the appropriate Argo teams.

* *(a). Sensor technology viability*: The ability for the new sensor to deliver reliable data for multiple years on profiling floats must be demonstrated. Sensor performance should meet the expected performance, after drift corrections are applied. For new sensors, the performance should be comparable to approved sensors (as listed in Argo reference R27 table) that measure the same mission parameter. This will be assessed in terms of sensor longevity, mission-effectiveness (e.g., power consumption), processed mission parameter accuracy and precision, their comparability with existing data, as well as their capacity to deliver on the science and management goals outlined for the given mission parameter. Peer-reviewed articles or technical reports must be published that assess the sensor performance on profiling floats. Exceptions to reduce some criteria may be made if other compelling benefits exist on a case-by-case basis. The presence of systematic biases should be carefully scrutinized. For BGC sensors, technology viability should be reviewed by the BGC Technological Task Team (BGC-TTT). For non-BGC sensors, technology viability should be reviewed by other task teams (experts to be appointed as needed).
* *(b). Data management viability*: The ability for DACs to process the raw sensor data to the target ocean state parameter value must be demonstrated. For this, a draft of the real-time processing document should be completed and reviewed by the ADMT. Additionally, the vocabulary for the BR- or R-files and the metadata files should be fully developed. This means that new ‘b’ ‘c’ ‘ib’ ‘ic’ labels will need to be proposed in line with Argo data management practices. Efforts to standardize sensor output across platforms and to standardize sensor mission configuration across platforms should be made to reduce the burden on the DACs. At least one DAC has to show that it is capable of processing the raw data to the target mission parameter, and upload the proposed data files to the ‘aux’ directory at the GDACs. These results should be presented and reviewed at the annual ADMT meeting.

The outcome of (a) and (b) are to be presented to the Argo Steering Team (AST) for approval to progress to the *pilot* phase.

Only approved *pilot* sensors will have corresponding Argo parameter labels in R03 and SENSOR labels in R27, and will have their data distributed to the public via the regular ‘dac’ directories at the Argo GDACs.

### ii. New mission parameters

Every new mission parameter to Argo needs to go through an *experimental* phase where:

1. technological readiness;
2. a compelling global design and implementation plan; and
3. delivery of major benefits to research and societal services

are demonstrated.

A.-C. are requirements from IOC-UNESCO. Here, we extend these requirements for new mission parameters to include (a)-(b), as described above for new sensors, plus (c):

* *(c). Scientific viability*: For new mission parameters, potential scientific utility of the data should be presented to the AST, and approved.

The outcomes of A.-C. and (a)-(c) are to be presented to the AST for approval to progress to the *pilot* phase.

While in the *experimental* phase, all data from experimental mission parameters are to be distributed to the public via the ‘aux’ directory at the Argo GDACs. Only approved *pilot* mission parameters will have corresponding Argo b-<PARAM> and SENSOR labels, and will have their data distributed to the public via the regular ‘dac’ directories at the Argo GDACs (see IOC/EC-LI/2 Annex 9, §30).

## 3.2. Going from pilot to global implementation

New sensors and new mission parameters are considered to be in the *pilot* phase when the criteria in Section 3.1 are met. Other interested parties beyond the initial PI are welcome to contribute resources to participate in the *pilot* phase. In the *pilot* phase, raw data should be disseminated in the main ‘dac’ directory at the Argo GDACs in near-real time, with approved <PARAM> labels in R03 and SENSOR labels in R27. Initially, it is acceptable for only raw, un-QC’d data to be distributed while in this phase, with QF of ‘0’, until QC procedures get developed.

During the *pilot* phase, sensing technology should continue to get refined, and scalability for both manufacturing and calibration should be demonstrated. If not done so already, a commercial partner should be identified for widespread availability. Additionally, RTQC and DMQC protocols should be developed and validated during this time. Close collaboration with DAC members is encouraged to ensure that the developed protocols are able to be implemented by all DACs. Sufficient resources should be provided to the DACs to take on these additional responsibilities.

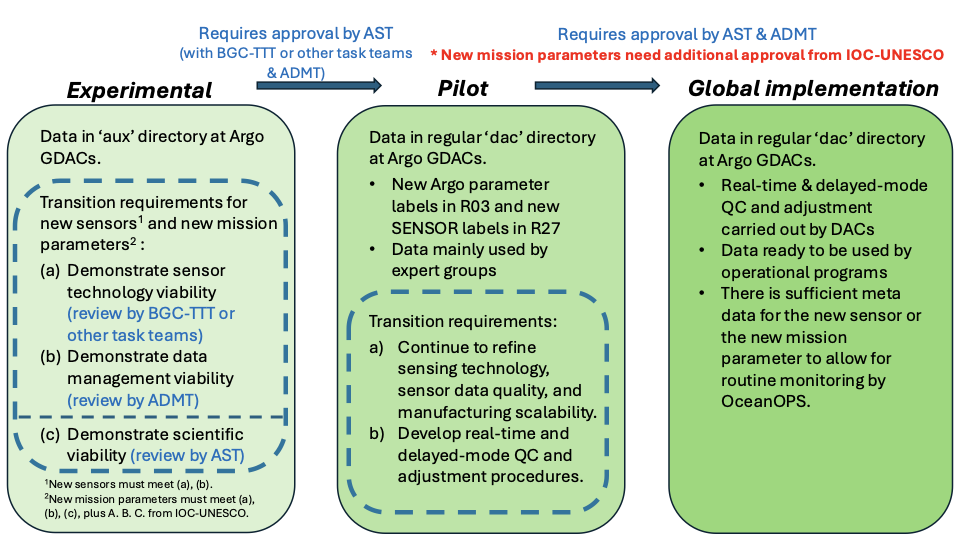
In order to advance from *pilot* to *global*, the sensor technology and data management must be ready for global implementation within Argo. Thus, the technology must be mature enough to be integrated on multiple float types, and the data successfully managed across multiple DACs in the form of having sufficient knowledge to carry out real-time and delayed-mode QC procedures and adjustments.

* *Sensor technology*: Commercially available, and the vendor has demonstrated an ability to manufacture high quality sensors at the scale required for the global array. Well characterized sensor calibration and drift correction protocols exist. Data quality should meet expected accuracy criteria, as defined within Argo documentation. Data from a new sensor for an existing mission parameter should be interoperable by end users. In other words, users should not be able to notice differences in data quality between this new sensor and existing sensors, unless a pre-identified exception has been discussed and documented within Argo documentation and metadata fields. The readiness of technology should be reviewed by the BGC-TTT or other dedicated expert task teams.
* *Data management*: Argo documents for real-time and delayed-mode QC and adjustment protocols must be published and reviewed by multiple DACs to assess implementation capabilities. Demonstrated track record of real-time adjustment, and timely delayed-mode QC and adjustment of data, ideally across multiple DACs (if applicable). The readiness of data management should be reviewed by the ADMT.

The outcome of the above is to be presented to the AST and the ADMT for approval to advance to the *global implementation* phase. **In addition, for a new mission parameter to advance from *pilot* to the *global implementation* phase, approval from the IOC-UNESCO is required. This is a lengthy process that involves the creation of a white paper and presentation at the IOC-UNESCO Assembly, and so is not to be taken lightly.**

A new sensor or a new mission parameter is considered to be in the *global implementation* phase when the data are ready to be used by operational programs, not just by expert groups. It should be noted that once a new sensor or a new mission parameter is within the global implementation phase, the tracking of its performance and associated data quality should be incorporated within OceanOPS routine fleetwide monitoring procedures.

# 4. Summary scheme



# 5. Examples

The examples below are taken from the history of Argo, when the formal process outlined above or the IOC-UNESCO process for new mission parameters and new sensors have not yet been established. These examples are described here in retrospect in how they fit into the process and requirements.

## 5.1. New sensor for DOXY: Aanderaa optode 4330

In 2008, Aanderaa introduced a new oxygen optode model, the 4330 model, to measure dissolved oxygen. Their previous model, the 3830 model, was an approved DOXY sensor that has been in use on Argo floats since the beginning of Argo-O2 in 2003 and has been implemented on multiple float platforms with established processing and QC procedures.

Both the 3830 and 4330 models sense oxygen by the same luminescence quenching principle, using the same optical components, phase shift technique, and sensing foils (PreSens PSt3 type). The 4330 model added a reference reading to the phase shift technique. The major difference of the 4330 model is an advanced temperature sting that improves ambient temperature readings compared to the 3830 model by decoupling it from the large thermal mass of the sensor.

* *(a). Sensor technology viability*: The 4330 model uses the same sensing principle, parts and evaluation routine for the oxygen sensitive parts as the established 3830 model. They differ in the mechanical packaging. In addition, the temperature measurement part is different between the models. Given laboratory experiments it could be shown that if anything, the 4330’s temperature measurements were superior to the 3830’s temperature output, i.e., providing improved performance in the field.  
  As the Aanderaa 4330 model’s oxygen sensing part is identical to the proven Aanderaa 3830 model, and with improved performance in the measurement of temperature (i.e., the ‘secondary’ part of DOXY sensing), the Aanderaa 4330 model’s sensor technology viability could be proven in different studies (Bittig et al., 2012; Johnson et al., 2015).
* *(b). Data management viability*: The 4330 model uses slightly different terms for the sensor parameters than the 3830 model (e.g., for phase shift), a new red LED reference phase shift, and a different number of calibration coefficients. However, the calibration principle (batch foil calibration at that time) as well as the calculation principle are the same, i.e., apart from an update in terminology and minor modifications of equations (e.g., number of polynomial terms), it followed the established 3830 model’s procedure.

This qualifies the Aanderaa 4330 model for *pilot* implementation.

* *Sensor technology*: In the ensuing years, Aanderaa optode 4330 models were deployed by several programs and groups. Their experience confirmed the reliability of the sensor as well as the accuracy of the acquired data, being consistent with previous observations. The Aanderaa optode 4330 model was consistently produced in excellent quality, being the BGC-Argo sensor with the smallest failure rate.
* *Data management*: Several DACs are able to process the Aanderaa optode 4330 model’s according to the common processing document. Sensor characterization including sensor adjustment got small refinements with a larger number of sensors being deployed (Bittig et al., 2018).

This qualified the Aanderaa 4330 model for *global* implementation.

References

Bittig, H. C., and Coauthors, 2012: A novel electrochemical calibration setup for oxygen sensors and its use for the stability assessment of Aanderaa optodes. Limnol. Oceanogr.: Methods, 10, 921–933, <https://doi.org/10.4319/lom.2012.10.921>.

Bittig, H. C., and Coauthors, 2018: Oxygen Optode Sensors: Principle, Characterization, Calibration, and Application in the Ocean. Front. Mar. Sci., 4, 429, [https://doi.org/10.3389/fmars.2017.00429](https://doi.org/10.4319/lom.2012.10.921).

Johnson, K. S., and Coauthors, 2015: Air Oxygen Calibration of Oxygen Optodes on a Profiling Float Array. J. Atmos. Oceanic Technol., 32 (11), 2160–2172,<https://doi.org/10.1175/JTECH-D-15-0101.1>.

## 5.2. New sensor for PRES, TEMP and PSAL: RBR CTD

Beginning in 2015, a small number of floats equipped with the RBR CTD were being deployed to test the viability of this new CTD. RBR’s inductive conductivity cell employs a different sensing principle than the electrode-based SBS CTD. Also, the low aspect ratio of the RBR CTD allows water to freely flush through the cell without requiring a pump, as does the pump-based SBS CTD. Hence the RBR CTD was considered a new sensor which entered the *experimental* phase in Argo in 2015.

In the ensuing few years, much work was done to demonstrate the viability of the sensor technology and data management of the RBR CTD. At the 23rd AST meeting in Monaco in 2022 and the 24th AST meeting in Halifax in 2023, the status of the RBR CTD in Argo progressed from *experimental* to *pilot* to the *global implementation* phase based on the following:

* *(a). Sensor technology viability*: This aspect was demonstrated via two peer-reviewed papers (Nezlin et al., 2020; Dever et al., 2022). Long-term stability of the salinity measurements from the RBR CTD is demonstrated in both papers. In addition, Dever et al (2022) shows that the static accuracy of the RBR salinity measurements is improved significantly by using a time lag for temperature, a quadratic pressure dependence, and a unit-based calibration at the manufacturer level. These improvements make the accuracy of the salinity measurements from the RBR CTD comparable to that from the SBS CTD.
* *(b). Data management viability*: This aspect was demonstrated by the creation of new chapters in the Argo QC manual on real-time and delayed-mode QC and adjustments for RBR CTD measurements. The adjustment procedures for RBR salinity include compressibility correction for cells without the manufacturer unit-based calibration (pre-April 2021), and thermal inertia correction from Dever et al (2022). The ADMT also agreed that RBR salinity with manufacturer unit-based calibration (post-April 2021) should receive PSAL\_QC = ‘1’ in real-time, thus recognizing that RBR salinity was comparable to other existing salinity data in Argo. To facilitate integrating metadata into the Argo data files, RBR was the first sensor manufacturer to make available its metadata in direct correspondence to Argo metadata file variable names in its OEM lookup system.

References

Nezlin, N. P., and Coauthors, 2020: Accuracy and long-term stability assessment of inductive conductivity cell measurements on Argo floats. J. Atmos. Oceanic Technol., 37, 2209–2223,<https://doi.org/10.1175/JTECH-D-20-0058.1>.

Dever, M., and Coauthors, 2022: Static and dynamic performance of the RBR argo3 CTD. J. Atmos. Oceanic Technol., 39 (10), 1525-1539,<https://doi.org/10.1175/JTECH-D-21-0186.1>.

## 5.3. New mission parameter: BISULFIDE

For the decomposition of organic matter, oxic respiration (i.e., oxidation of the organic matter and reduction of oxygen, O2) is the energetically most favorable process in oxic environments. It consumes oxygen in the process. If all oxygen is consumed but organic matter still available for decomposition, O2 as an electron acceptor that is reduced in the process is replaced by other electron acceptors according to the microbial redox-chain, ordered by the amount of energy they provide: (i) Nitrate (to yield N2 by denitrification), (ii) oxidized forms of manganese and iron (to yield reduced forms of manganese and iron, respectively), and (iii) sulfate (to yield hydrogen sulfide, H2S). The presence of hydrogen sulfide thus indicates strong respiratory pressure by which all oxygen (and nitrate) has been consumed. The total amount of sulfide gives an indication of the ‘oxygen deficit’ present, i.e., the amount of oxygen needed to bring water back to the edge of anoxia.

Hydrogen sulfide is a weak acid, which dissociates into bisulfide (HS-) and protons. With an acid base constant around 7, the majority of all sulfide is present as bisulfide in seawater. Bisulfide (HS-) shows a very intense and characteristic absorbance peak in the UV around 235 nm.

* *A. Technological readiness*: It uses the same UV absorbance based sensing principle and sensor as NITRATE, an approved Argo mission parameter in the global implementation stage. The sensor (ISUS or SUNA) has been implemented on different float platforms, shown to be long-term stable over multiple years, and methods to account for sensor drift of the UV absorbance data have been established.
* *B. A compelling global design and implementation plan*: Sulfide presence is only expected in (seasonally or permanently) anoxic waters, i.e., only certain ocean areas (oxygen minimum zones, OMZs) and potentially only episodically whenever ventilation is limited. However, the parameter’s measurements can piggy-back on nitrate sensing and its global coverage from using the same sensor.
* *C. Delivery of major benefits to research and societal services*: Quantification of bisulfide or total sulfide links directly with the BGC-Argo Science and Implementation Plan topic of “Oxygen Minimum Zones and Nitrate cycling” with questions “How does the volume of Oxygen Minimum Zones change in time?” and “How does this affect the cycling of nitrate?” with insight into the oxygen deficit in anoxic areas. It extends BGC-Argo’s observation capabilities of the IOC-approved mission parameter OXYGEN with applications of “spread of anoxia and suboxia, detection of anoxic events” into anoxic zones.
* *(a). Sensor technology viability*: See A. The Argo nitrate sensors have been demonstrated to show viable sensor technology.
* *(b). Data management viability*: The raw data are identical to raw data acquired for NITRATE, except that the wavelength range of the spectrum should be extended from ~217-240 nm to ~217-285 nm. Processing runs analogous to NITRATE with an additional degree of freedom for the bisulfide reference spectrum.
* *(c). Scientific viability*: First deployments of Argo floats in the Black Sea demonstrated that useful and accurate BISULFIDE data can be obtained.

This qualifies the BISULFIDE mission parameter for *pilot* implementation.

# 6. Appendix: IOC-UNESCO documents

### EC-LI/Dec.4.8: Evolving Capabilities of the Argo Global Array of Profiling Floats

Section “I. Global implementation of six new biogeochemical parameters for Argo floats” adopts the present 6 BGC-Argo mission parameters to be part of Argo, while section “II. The approval framework for additional new parameters for Argo” adopts the below framework. Specifically (bold highlighting not in original but only here):

Notes that **experimental new parameters** on Argo floats will **be tested through individual national research programmes**, in a manner consistent with the United Nations Convention on the Law of the Sea (UNCLOS);

Agrees that the **Argo Steering Team can designate Argo-approved pilot parameters based on** requirements of **technological readiness**, **a compelling global design and implementation plan**, and **the potential to deliver major benefits to research and societal services**, for deployment under Argo's notification regime (IOC resolution EC-XLI.4) and under its free and open data policy, for a limited period allowing for the scientific evaluation of the results; and

Requests the Argo Steering Team and the GOOS Steering Committee **to bring the results of Argo-approved pilots to an IOC governing body for approval before moving to a stage of global implementation**.

### IOC/EC-LI/2 Annex 9, Item 4.8: EVOLVING CAPABILITIES OF THE ARGO PROFILING FLOAT NETWORK

Section “III. A proposed framework for additional new parameters for Argo” deals with further expansions of Argo beyond the current BGC-mission (bold highlighting not in original but only here):

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 under which 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.

28. Argo is implementing a ‘readiness-based’ framework to assess possible new parameters, following the Framework for Ocean Observations. 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.