ACTIVITY REPORT
2014-2018

EURO**ARGO**

EUROPEAN RESEARCH
INFRASTRUCTURE CONSORTIUM
FOR OBSERVING THE OCEAN

Foreword

Our climate regulation relies on it. The global ocean currently stores 26% of the anthropogenic carbon released to the atmosphere, and more than 90% of heat excess, due to the greenhouse effect. But at the same time, it's also one of the main victims of climate change. According to the last Intergovernmental panel on climate change report (IPCC), the global ocean becomes warmer, more acidic and less oxygen rich, which affects its regulation role. Neglected for too long, this vicious circle is a real call to action for ocean observation.

Twenty years ago, scientists from all around the world gathered their strengths to create the first global, real-time, *in situ* ocean observing network: the Argo international programme. It allows measuring the evolution of the state of the ocean, thanks to an army of four thousands floats, diving in the depths of the global ocean. Since the beginning, Europe took part in this true revolution in global ocean observation. Ten years ago, European partners decided to strengthen their contribution, preparing a successful Design Study, that led to the set-up of a European Research Infrastructure Consortium (ERIC), in 2014. The Euro-Argo ERIC was born.

For its first 5 years, the Euro-Argo ERIC Members joined their effort to get a better grasp of climate change, but also to serve marine ecosystem health and to support operational oceanography. Five years already! Five years that allowed to set up the main components of an efficient Research Infrastructure: a coordination team that expended over time, a governance structure with clear involvement of its 12 Member States and a funding structure, based on both national and EU funds, successfully building a great Euro-Argo community.

I guess that it has been this unique cocktail of scientific and technological excellence and international collaboration that has convinced the European Strategic Forum on Research Infrastructure (ESFRI), the European Commission – through EMODNet and H2020 projects – and many national ministries to support Euro-Argo during its first steps, from its set-up in 2014 to its positive evaluation, in June 2019.

The Euro-Argo ERIC is now at a corner stone of its history: the ERIC Office and its Members set up a reliable infrastructure, that both manages to strengthen the European contribution to Argo and to start implementing the new missions. This "Activity Report 2014-2018" summarizes the Euro-Argo ERIC achievements and the new ERIC services that allow to share work load among the Office and the Members, for the benefit of all.

I'm proud to have been acting as a Programme Manager of Euro-Argo for the past five years and proud of all the progress achieved so far. The next five years will also be exciting, with new challenges to address and new scientific frontiers to reach. Today, I can say with total certainty that the Euro-Argo ERIC is ready to face them.

Sylvie Pouliquen, Euro-Argo Programme Manager

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Executive summary

The Euro-Argo European Research Infrastructure Consortium (ERIC) provides in situ ocean observations to a range of user communities, with an interest in the ocean's state and its evolution. Euro-Argo ERIC aims at maintaining one quarter of the international Argo network, one of the most important components of the Global Ocean Observing System (GOOS).

The Euro-Argo ERIC is composed of a central infrastructure (the ERIC Office, hosted in Brest, France, for the first 5 years) and distributed national facilities. It was formed in 2014 with 9 founding countries: 7 Members (Finland, France, Germany, Greece, Italy, Netherlands and UK) and 2 Observers (Norway and Poland). Since then, Euro-Argo ERIC membership has strengthened with the addition of new countries: Ireland became a full member in 2016, followed by Spain in 2017, as well as Norway and Bulgaria in 2018.

> The Euro-Argo ERIC has proven its capability to acquire and deploy approximately 250 floats per annum and to monitor these floats appropriately.

To fulfil its overarching objective of contributing to meeting societal challenges, as well as addressing the United Nations Sustainable Development Goals (SDG14 - Ocean Health and SDG13 - Climate Action), the Euro-Argo ERIC has fostered developments in several domains, thanks to a strong collaboration between the ERIC Office and the National Members.

In particular, the Euro-Argo ERIC has defined and started to implement a float-deployment strategy and is coordinating the European contribution to the Argo network accordingly, while minimizing oversampling in certain areas and maintaining the array at global scale. The original Euro-Argo strategic plan was defined in 2016 to identify scientific gaps and needs. This plan was developed from the input of National Members, who are responsible for bringing the Argo community together in their respective countries and coordinating national scientific needs. European deployments have been set out to meet both the needs of the international Argo programme (geographical distribution) and those of the European scientific and operational oceanographic community. These needs (Argo and national strategies) have led increased sampling in areas of specific European interest (e.g. Atlantic Ocean, Marginal Seas such as the Baltic Sea, the Mediterranean and the Black Seas) and at high latitudes, (i.e. regions seasonally covered with sea ice, such as the Nordic Seas, the Arctic and Southern Oceans). Euro-Argo also put substantial effort into the development of Deep and Biogeochemical components of the Argo programme, with a strategy that anticipated the new Argo mission recently endorsed by Argo International: a vision for a "global, full-depth and multidisciplinary Argo".

The Euro-Argo ERIC has proven its capability to acquire and deploy approximately 250 floats per annum and to monitor these floats appropriately. European deployment is undertaken via the efficient coordination of activities between members: the acquisition of floats is supported either by National Members or by the ERIC Office through floats funded via European projects (MOCCA, AtlantOS). Since 2014, the overall European contribution to the global Argo network has increased from 16% of the total number of operational floats to 22% in 2018. The enhanced contribution of Euro-Argo to the global array is clearly demonstrated within the Deep component, with an increase from 2 floats deployed in 2014 to 20 in 2018 and aiming for 50 floats per annum by 2030. Similar advances have been made for the Biogeochemical component, with 30 floats measuring at least two biogeochemical parameters deployed in 2018, aiming for 50 floats per year by 2030. A diverse deployment strategy has ensured a significant contribution in the open ocean as well as Marginal Seas (including at northern latitudes i.e. Nordic and Barents Seas).

The Euro-Argo ERIC has established centralised float procurement, providing substantial value for Members especially countries procuring relatively small numbers of floats per annum. The ERIC Office's technical team conducts pre-deployment tests on the floats in Ifremer installations in Brest, France, including a 20m deep tank and a hyperbaric chamber, a particularly beneficial service for Euro-Argo ERIC members lacking access to such facilities. Once floats are deployed, it is essential that critical technical parameters (e.g. energy budget, transmission power, battery voltage and data transmission) be monitored. The ERIC Office has developed a web-based at-sea monitoring system, enabling instant monitoring of the fleet, as well as individual float status. This service allows the performance of instruments to be evaluated and malfunctions to be detected at an early stage. Euro-Argo ERIC at-sea activities are performed in collaboration with both the Argo Information Centre (AIC) and the Coriolis Data Centre.

> The ERIC Office has developed a web-based at-sea monitoring system enabling instant monitoring of the fleet, as well as individual float status.

The ERIC's efforts have contributed to the improvement of float technology and performance. France, Spain, Germany and the UK have worked on the new generation of Biogeochemical (BGC) and Deep Argo floats, while other member countries (Bulgaria, Finland, Greece, Ireland, Italy, Norway, Poland) have collaborated by testing floats in their own specific areas of interest (Marginal Seas, shallow waters and high latitudes). National Members are instrumental in sensor innovation as they develop accurate and stable sensors whose performance is then evaluated by other Members. Float improvement is also increased by the ERIC's close collaboration with the NKE Instrumentation (float manufacturer).

The Euro-Argo ERIC has the ability to process all European float data and to distribute this data to users through the implementation of a powerful European Argo data system, capable of evolving to match the new generation of floats. The ERIC Office, as coordinator of the European contribution to Argo data management, has improved Europe's ability to meet its data-processing commitments under the Global Argo Programme. It offers quality-controlled services to new Members and provides training on data processing and use.

The ERIC reinforces European integration into the global ocean-observing network and provides necessary support for activities.

The visibility of the Euro-Argo ERIC is undertaken by the ERIC Office (by providing access to outreach materials) and by National Members (who participate in awareness-raising activities and educational programmes, both nationally and at European level). The Euro-Argo ERIC has organised scientific workshops and training courses on quality-controlled data for end-users. Euro-Argo's visibility is also promoted via the ERIC's participation in European research projects, some of which being coordinated by the Euro-Argo ERIC itself. The ERIC reinforces European integration into the global ocean-observing network and provides necessary support for activities, including deployment, innovation, communication and links with end-users, such as Copernicus and climate communities. Scientific dissemination is demonstrated by the large number of publications based on Argo data, with an average of more than one publication per day at international level, one out of three involving European partners as first authors.

The Euro-Argo ERIC is also a driving force in engagement with the European scientific community and the ERIC's coordination capacity puts it in a strong position with regard to the submission of successful European funding proposals (e.g. E-AIMS, SIDERI, MOCCA and Euro-Argo RISE). The Euro-Argo ERIC also plays a key role in stimulating national implementation (such as Argo-Italy and NorArgo in Norway) and in promoting coordination at the regional level with neighbouring countries (Mediterranean Sea, Black Sea and Baltic Sea).

Based on a strong European Argo expertise developed over the past 20 years by the institutes forming its consortium, the Euro-Argo ERIC has managed to set up a Research Infrastructure (RI). The Euro-Argo ERIC was designed during the Euro-Argo preparatory phase to sustain ¼ of the Argo array and to prepare the transition toward the 2030 vision of a "global, full-depth and multidisciplinary Argo" network. Over the past 5 years, the foundation of the ERIC has been successfully built. Challenges for the next decade with the implementation of the new Argo design are multiple (technological, financial, operational and scientific), requiring strong support and additional resources from both member countries and the European Commission (EC).

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WHAT IS EURO-ARGO?

Long-term and high-quality global ocean observations are crucial to get a better understanding of climate change. To achieve this, it is essential to improve our knowledge and prediction of the ocean's role in climate, and to support political decisions on how to mitigate and adapt to a changing climate.

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WHY STUDY THE OCEAN?

The ocean plays a major role in the global climate system: through its continuous exchange of energy and fresh water with the atmosphere, it is the primary regulator of global climate. Most of the excess energy generated by the greenhouse effect – enhanced by human activity – is stored in the ocean. This comes at a price: the temperature of the ocean is rising, triggering changes in ocean dynamics and impacts on marine ecosystems.

The ocean plays a major role in the global climate system: through its continuous exchange of energy and fresh water with the atmosphere, it is the primary regulator of global climate.

The effects of climate change are global in scope, ranging from shifting weather patterns to rising sea levels, and from warming of the high latitudes to the shrinking Arctic sea-ice cover. To cope with these evolutions, policy-makers need information regarding ongoing and future changes in climate and its variability. This includes reliable measurements for all components of the climate system, including the ocean.

Such observations are crucial in order to quantify climate change more accurately, providing scientists with data, to further understand and predict the role of seas and oceans in the climate system, and to help policy-makers to make informed decisions about mitigating and adapting to climate change.

The Global Ocean Observing System (GOOS) has two major observation-delivery components. Firstly, remote sensing from satellites, enabling the monitoring of sea-surface height, sea-surface temperature, salinity, ocean colour and sea-ice extent (year-round and global measurements). However, satellite measurements have a limitation: they can't reach underneath the sea-surface, so they need to be matched with observations from within the water column. Data is obtained by *in situ* measurements, which have traditionally been taken via ships. Ship surveys are extremely costly, time-consuming and their global coverage is limited. With the arrival of Argo float technology, *in situ* observation capabilities, as a complement to ship-based measurements, have dramatically improved.

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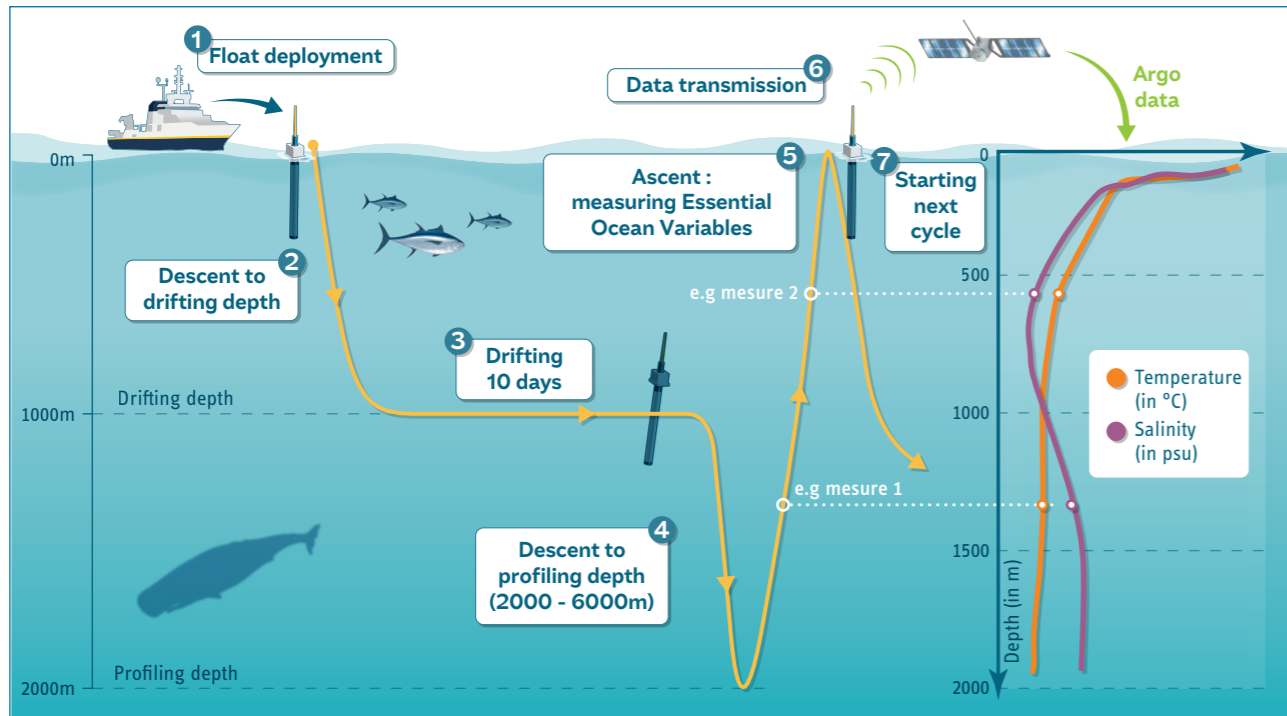
Figure 1: An Argo float's 10 days complete cycle in the ocean with an example of a standard measured T&S profile.

IEO Campaign, October 2018.

© Alberto González Santana/IEO

Argo is the first global, real time, *in situ* ocean observing network and marks a true revolution in global ocean observation.

ARGO IN A NUTSHELL

The initial aim of Argo was to provide sustainable global measurements of two key oceanic variables: temperature and salinity. Launched by oceanographers in 2000 and endorsed by international organisations (World Meteorological Organisation (WMO), Global Ocean Observing System (GOOS), Intergovernmental Oceanographic Commission (IOC)), it is the first global *in situ* ocean-observing network in the history of oceanography.

An Argo float is an autonomous underwater instrument, approximately 1.5m high, that performs measurements, while actively going up and down the water column → Figure 1.

It's a platform carrying instruments for monitoring temperature and salinity as well as other environmental parameters (e.g. chlorophyll a, oxygen, nutrients and pH). Floats are deployed in the open ocean from oceanographic research vessels or ships of opportunity. They are programmed to dive to a depth of 1000m, and then drift for approxima-

tely nine days, before descending to perform measurements at greater depths, from 2000m to 6000m. Profiles on temperature, salinity, pressure and other parameters are recorded during the ascending phase (six to sixteen hours). Once at surface, the float transmits data via satellite, to a wide range of users, in near real time. The rapid transmission of observational data to data centres enhances the usefulness of Argo floats for numerical ocean forecasts.
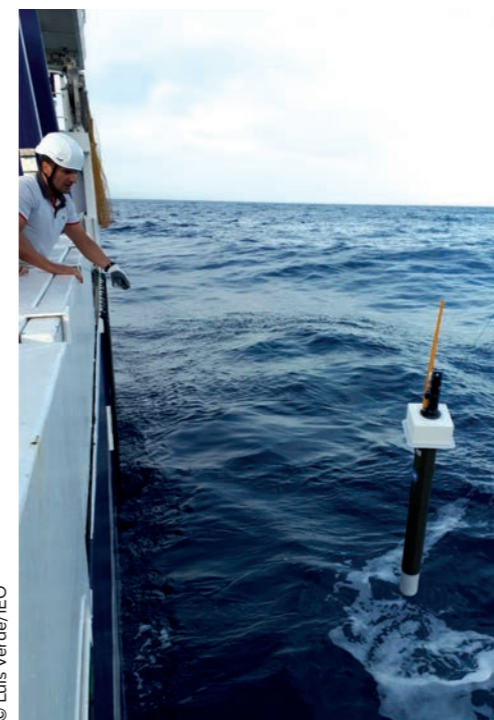
Originally designed as a research experiment with just a few deployments, Argo now launches at the rate of about 800 floats per year. The global array is today composed of nearly 4000 autonomous profiling floats that record pressure, temperature and salinity in real time across the global ocean, from the sea surface down to depths reaching 2000m. Freely available, Argo data is combined with satellite data and modelling activities to produce state-of-the-art analyses, daily forecasts of ocean variables and assessments of their evolution over time. These data are essential to operational

oceanography, which focuses on the state of the ocean. The data is also vital for scientific research: Argo sheds light on large-scale oceanic and climatic features and processes that once remained hidden to scientists, due to a lack of data. In particular, Argo promotes new insights about ocean dynamics that are helping researchers to understand and forecast global change.

Argo floats are now the key source of hydrographic measurements within the water column. It is fundamental to climate change research that the Argo global ocean-observing network be sustained, and that it be given the means to evolve allowing Argo respond to new scientific and operational needs.

Deployment of an Argo float out of the Gulf of Cādiz.

© Luis Verde/IEO

There are 7 Euro-Argo major float types deployed by Euro-Argo → Figure 2. These 7 models represent approximately 95% of the global operational platforms. They are manufactured by:

– Teledyne Webb Research (TWR) Apex float (USA), designed at the outset of Argo to provide a 2000m rated instrument with Conductivity/Temperature/Depth (CTD) sensors. They have been extended to Biogeochemical Argo (BGC);

– NKE Instrumentations (NKE) Arvor float (France), providing 2000m rated CTD option from ~2006 onwards, third provider for global Argo and primary provider for Europe;

– SeaBird Navis (USA), providing a 2000m rated float with CTD and BGC options from ~2011 onwards;

– Optimare Gmbh NEMO (Germany), providing a 2000m float with CTD, a small part of the array;

– NKE PROVBIO (France), providing a 2000m rated float optimised for carrying the full suite of BGC Argo sensors;

– NKE Deep Arvor (France), providing a 4000m rated float with CTD + oxygen;

– TWR Deep Apex (USA), providing a 6000m rated float with CTD + oxygen.
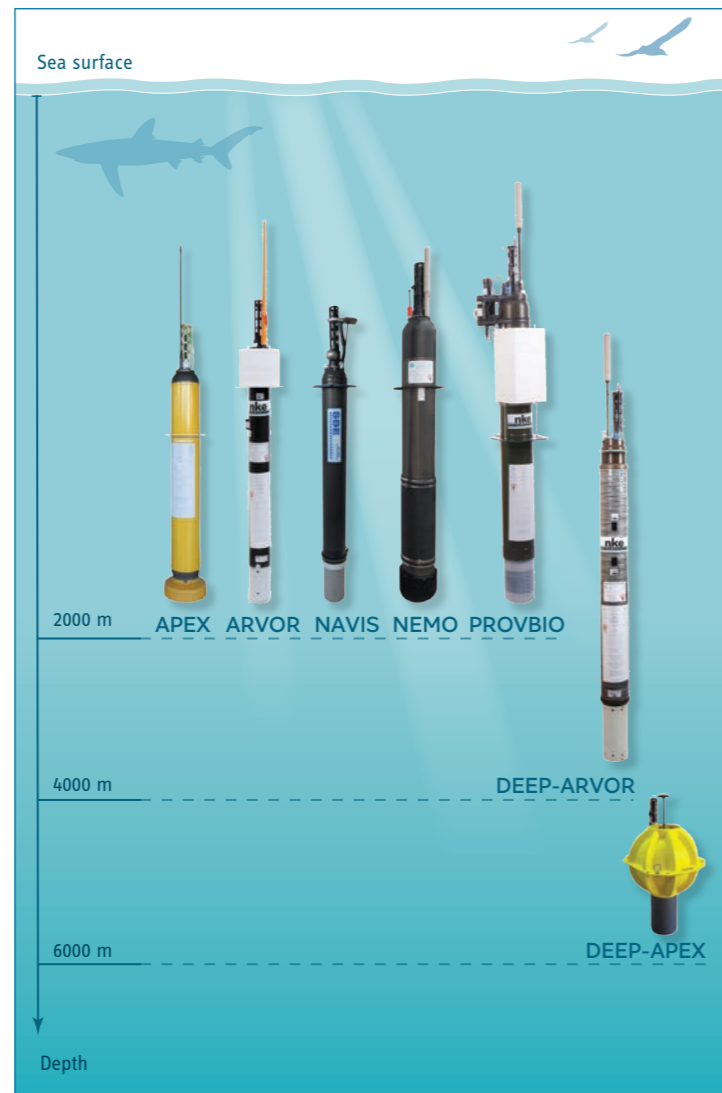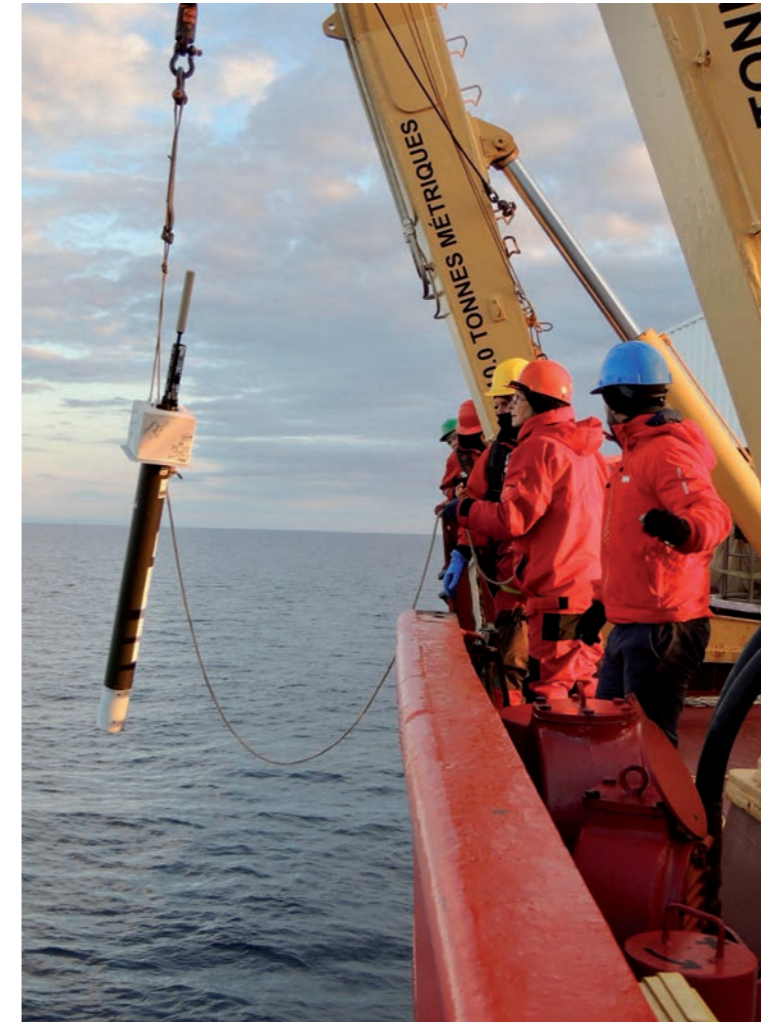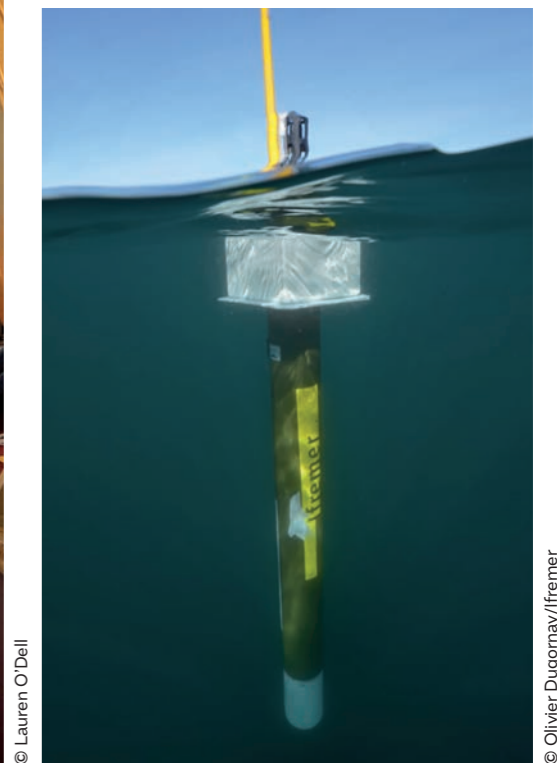

Figure 2: The 7 major float types deployed in the Euro-Argo network.

Two distinct floats: an ARVOR (left) and a PROVOR (right).

Deployment, Amundsen 2019-leg2A, Baffin Bay, 2019.

Argo-Spain programme deployment.

~250 FLOATS
DEPLOYED PER YEAR
BY EUROPE

~1,000 FLOATS
IN OPERATION AT ANY TIME

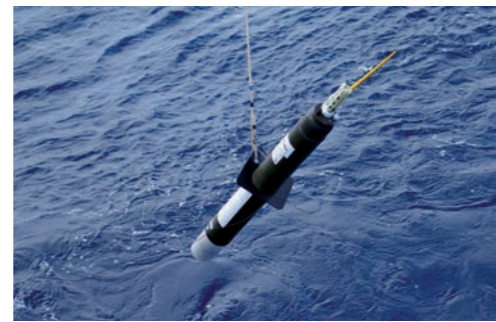The European contribution represents ¼ of the global array.

Figure 3: Worldwide distribution of Euro-Argo (yellow dots) and Argo fleet (blue dots).

EURO-ARGO, A MAJOR CONTRIBUTOR TO ARGO

Through a sustained and optimised European contribution to the international Argo network, Euro-Argo provides quality-controlled data on seas of European interests including the global ocean, in real time.

In December 2018, 30% of the global operational Biogeochemical Argo floats were European.

Argo's success is mainly due to the high degree of international cooperation behind the initiative and European partners have played a crucial role in setting up and developing the Argo network.

Euro-Argo's implementation follows the same lines as that of other European infrastructures dedicated to observing the ocean. Such infrastructures aim to respond to environmental issues arising not only in European waters, but also at global scale. They are embedded in the European roadmap for research infrastructures, supported by European Strategy Forum on Research Infrastructures (ESFRI), with the latter stimulating their implementation and updating the roadmap as needed for the next 10-20 years.

Euro-Argo ERIC represents a major contribution to Argo, providing, deploying and operating an array of around ¼ of the global array → Figure 3.

Established in 2014, the Euro-Argo European Research Infrastructure Consortium (ERIC) has matured to the stage

that it is now able to initiate network upgrades in response to specific European research interests, especially the "Deep" and "BGC" extensions. Initially, the parameters measured by the Argo programme were temperature and salinity. Since 2008, they extended to oxygen concentration, nitrate concentration, pH, chlorophyll a concentration, suspended particles and downwelling irradiance, thanks to significant input from the Euro-Argo ERIC.

The Euro-Argo ERIC is currently composed of 12 countries → Figure 4, and its coordination is managed by the Euro-Argo ERIC Office, hosted by Ifremer (in Brest, France).

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Deployment test in the Rade de Villefranche, France.

Euro-Argo ERIC partners
- Member
- Candidate
- Observer

Euro-Argo ERIC (Brest, France)

Finland
Norway
Ireland
United Kingdom
Netherlands
Poland
Germany
France
Portugal
Spain
Italy
Bulgaria
Greece

© Thomas Haessig
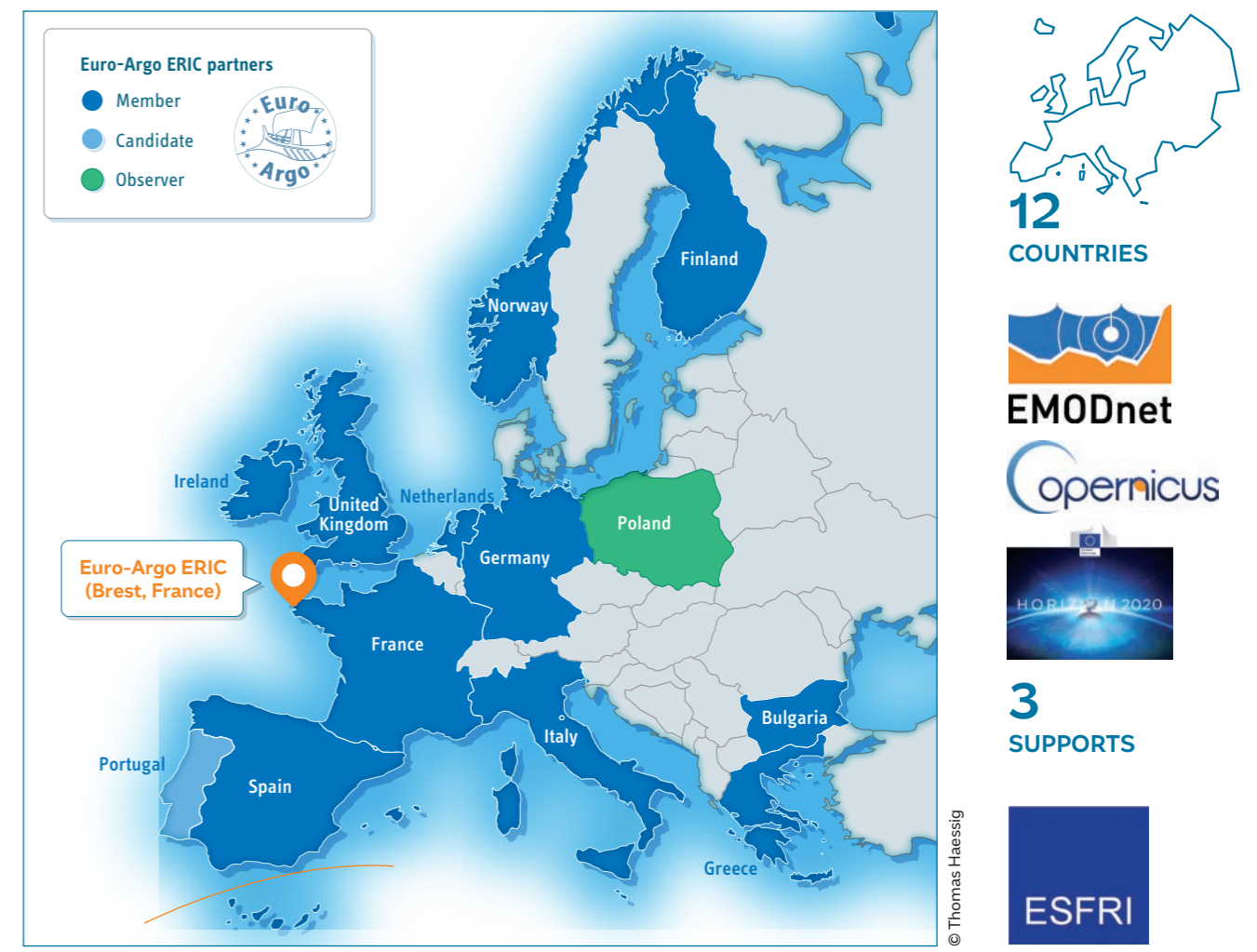
Figure 4: The Euro-Argo ERIC National Members.

12 COUNTRIES

EMODnet

Copernicus

HORIZON 2020

3 SUPPORTS

ESFRI

1 LABEL

30 INSTITUTES

100 SHIPS

150 SCIENTISTS

Deployment test
by HCMR Institute,
Greece.

© HCMR

© Olivier Dugornay/Ifremer

Biogeochemical (BGC) floats
test in the Ifremer tank, 2015.

EURO-ARGO RESEARCH INFRASTRUCTURE: OBJECTIVES FOR 2014-2018

The main goal of the Euro-Argo ERIC is to meet the challenge of observing the global ocean, on a sustained basis, across an increasing range of essential ocean variables, and to play a prominent role in the international Argo programme.

For its first 5 year phase, the specific objectives of the Research Infrastructure were to:
– provide, deploy and operate an array of around 800 floats contributing to the global array (a European contribution of ¼ of the global array);
– provide additional coverage in the European Marginal Seas;
– develop further the infrastructure, e.g. improving float technology and adding new sensors, improving the data processing and distribution system;
– provide quality-controlled data and products to the research (in climate and oceanography fields) and operational (e.g. Copernicus Marine Environment Monitoring Service, CMEMS) communities.

To achieve these objectives, the Euro-Argo ERIC has established a high level of cooperation between National Members and the ERIC Office, including:
– array monitoring and evolution;
– at-sea operations (deployment);
– technological and scientific developments;
– improvement of data access for research and operational oceanography;
– links with the international management of the Argo programme;
– promoting Argo, enlarging its community of data users and responding to their needs.

The Euro-Argo ERIC contributes to regular and systematic reference information on the physical state, variability and dynamics of the ocean and marine biogeochemical cycles and ecosystems, for both the global ocean and European regional seas. National Euro-Argo programmes, implemented by the various partners, coordinate Euro-Argo communities and activities at national levels. They also provide a unique voice for integration into national strategies and roadmaps.

EURO-ARGO HISTORY: FROM A NETWORK OF SCIENTISTS TO A RESEARCH INFRASTRUCTURE

Since its implementation in 2014, the Euro-Argo ERIC has launched a range of activities to upgrade its capabilities for providing accurate, timely and easily accessible data. This effort is the fruit of active contributions by the Euro-Argo ERIC components: the ERIC Office and the National Members, supported by national funding streams and various European research projects.

The ERIC's initial activities focused on coordinating and developing the European contribution to Argo. Its core aims are to maintain one quarter of the Argo network and to enhance the European offer of high value data on all variables to its users' community. The Euro-Argo's implementation history and major milestones in the past years fall into three main activity categories (concept and strategic development, data management and operational development), detailed thereafter.

A STRATEGIC DEVELOPMENT AND A STRONG PARTNERSHIP

The Euro-Argo story begins in 2008 → Figure 5, driven by a primary goal that Europe would be sustaining a long-term contribution to Argo. For this to happen, an infrastructure was needed to underpin Argo European activities, with demonstrated feasibility and readiness for operational monitoring. The initial strategy relied on synergy between 12 countries (Bulgaria, Finland, France, Germany, Greece, Ireland, Italy, Norway, Poland, Netherlands, Spain and the UK). In 2014, ministries from Finland, France, Germany, Greece, Italy, Netherlands, Norway, Poland and UK agreed to form a new European legal entity. The Euro-Argo ERIC was set up by the European Commission Implementing Decision (2014/261/EU) on 5 May 2014. Since then, its membership has strengthened with the addition of new countries: Ireland was granted full membership in 2016, followed by Spain in 2017, as well as Norway and Bulgaria in 2018. Since 2018, Portugal has entered discussions with its national Ministry in view of joining the ERIC.

© Ifremer

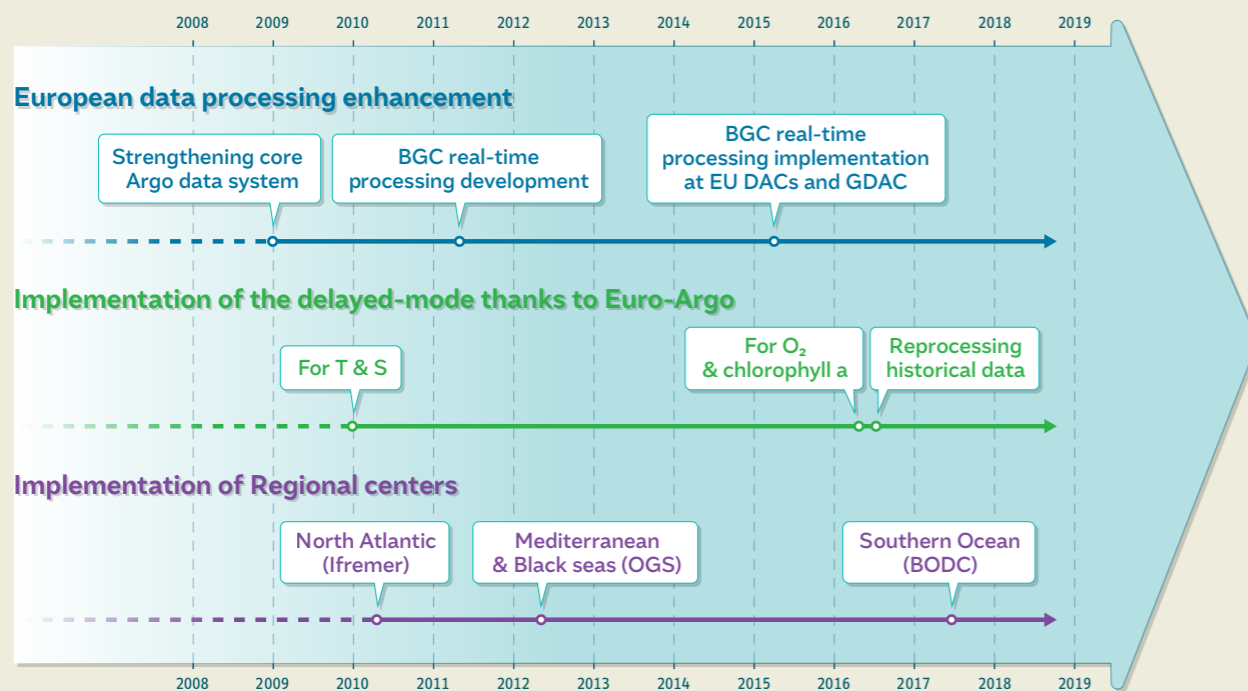Figure 5: Evolution of Euro-Argo strategy and partnership.

Figure 6: Evolution of data management infrastructure.

Figure 7: Evolution of operational management.

ENHANCING THE DATA MANAGEMENT

The first objectives of the Euro-Argo ERIC as a RI and legal entity were to enhance and sustain the existing European components of the Argo data system, as well as to extend them to new missions, in order to deliver regular, timely and accurate real-time and delayed-mode data (see Box 1, p. 32). A solid data system is essential for establishing the credibility necessary to successfully approach various user communities. In the past five years, the Biogeochemical-Argo (BGC-Argo) processing chain has gradually been implemented, with National Members making significant contributions to processing-chain specifications, as well as implementation and definition of the real-time quality-controlled procedures → Figure 6.

Argo's real-time data processing for temperature and salinity, developed since the early 2000's, was extended to six biogeochemical parameters (oxygen, chlorophyll, suspended particles, downwelling irradiance, nitrate and pH) in 2015. The development of the processing chain at the French and UK Data Assembly Centres (DACs) was supported by national and European projects, such as NAOS (French project, see Box 5, p. 52) and AtlantOS (EU H2020 project, see Box 9, p. 73).

Delayed-mode data management, launched in the early 2000's for temperature and salinity was supplemented by operational delayed-mode quality-controlled of oxygen and chlorophyll data from 2016 onwards. In parallel, Argo Regional Centres (ARCs),
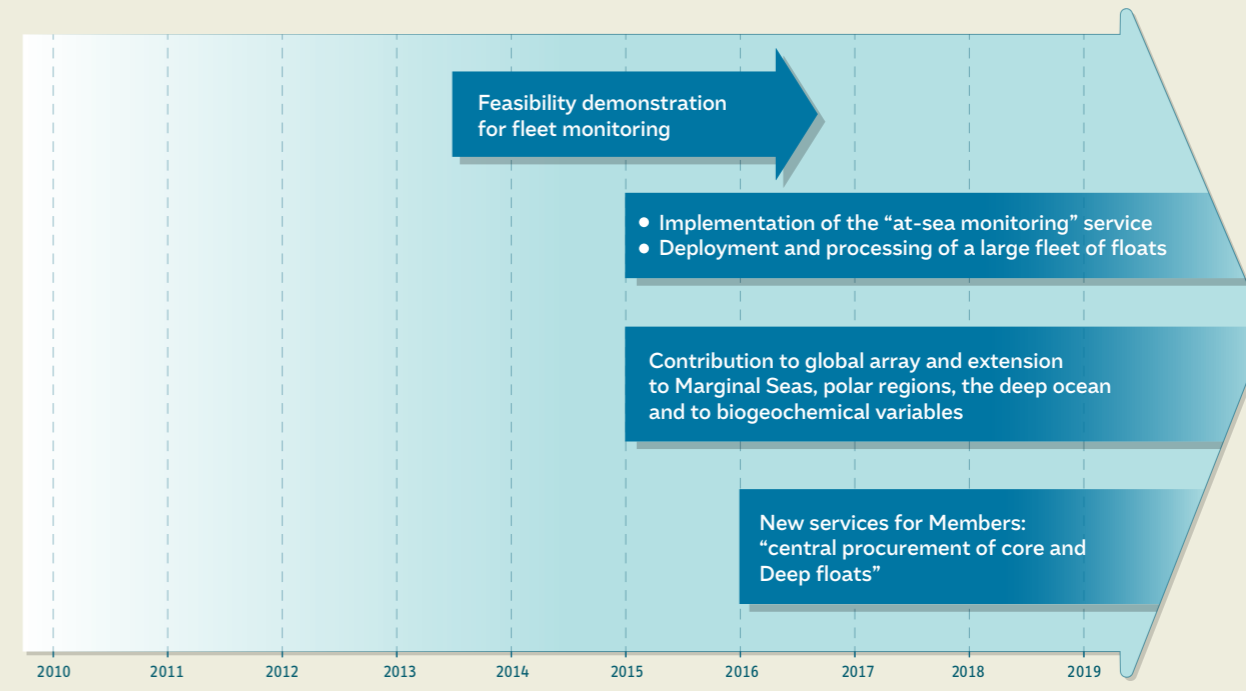
focusing on specific regional areas, have gradually developed. They aim at ensuring consistently high-quality data and products at a regional scale, as well as additional services: the North Atlantic ARC in 2010, followed by the Med-ARC in 2012, then finally the reinvigoration of the Southern Ocean-ARC in 2017 (see Chapter 4, p. 32). Since 2017, large-scale reformatting of historical data has been undertaken in both UK and France.

AN EFFICIENT OPERATIONAL DEVELOPMENT

Before Euro-Argo could be implemented, its feasibility and readiness to operationally procure and deploy floats had to be demonstrated → Figure 7. This hurdle was crossed in 2013 thanks to the European FP7 E-AIMS project, showing Euro-Argo's capability to conduct

research activities driven by European needs, including those of Copernicus, the EU Programme for Earth Observation and Monitoring. Today, Euro-Argo is an essential component of Copernicus Marine Environment Monitoring Service (CMEMS), designed for Maritime Safety (marine operations, ship routing, incident response, etc.), Marine Resources (for sustainable management of living resources, including fisheries and aquaculture), and Weather, Seasonal Forecasting and Climate Activities (daily and long-term time series of reprocessed data and reanalyses) (see Chapter 9, p. 70).
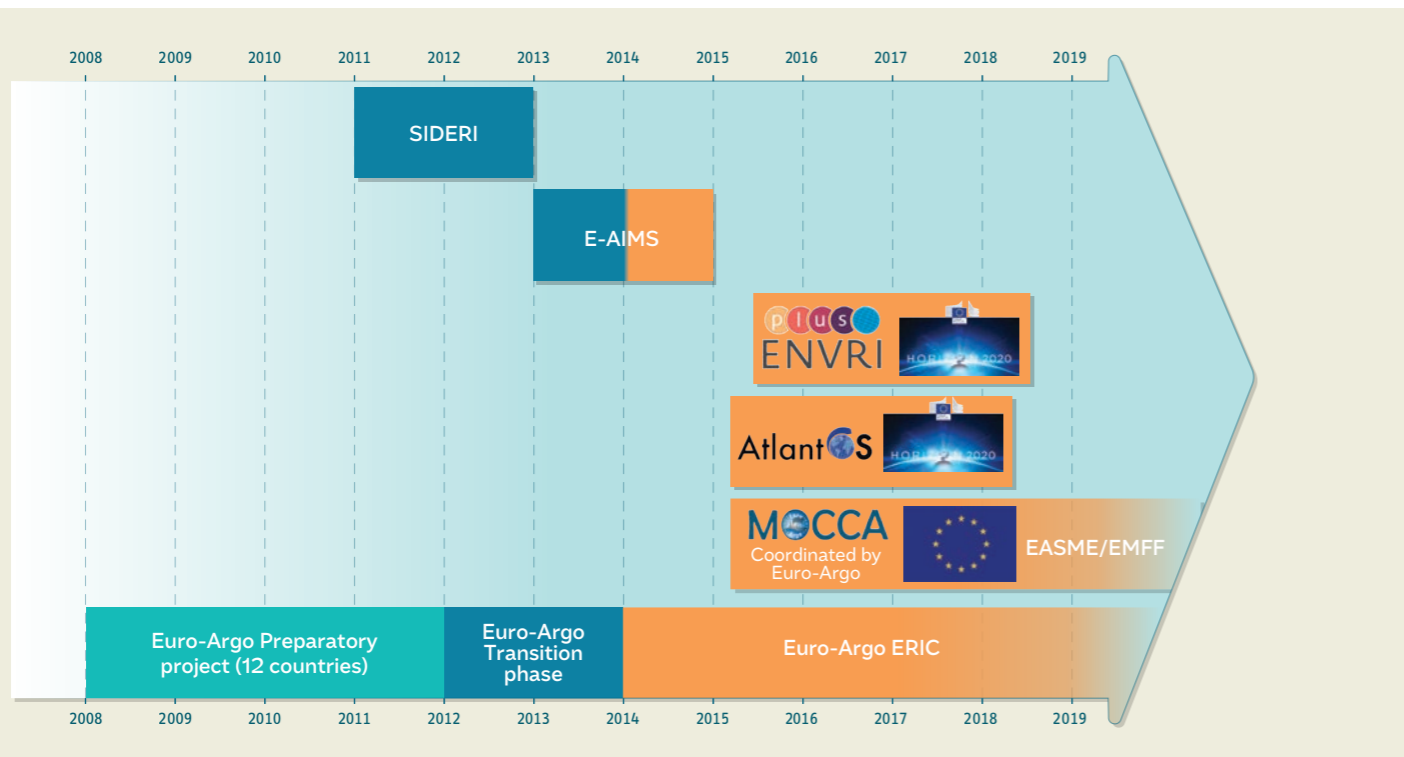
Figure 8: Implementation history and major milestones of key projects supporting the Euro-Argo ERIC development.

EU SUPPORT THROUGH KEY PROJECTS

In 2015, the Euro-Argo ERIC made significant progress in operational monitoring of the Argo fleet thanks, to its participation in European research projects → Figure 8. The ERIC gained the capacity to deploy and organise the processing of a large fleet (150 floats), with extensions to Marginal Seas and high-latitude regions thanks to the DG MARE MOCCA project (see Box 4, p. 48). The H2020 AtlantOS project (see Box 9, p. 73) offered an excellent framework for testing biogeochemical sensors and deep-ocean measurements in the Atlantic Ocean. In addition, the H2020 ENVRIplus project facilitated Euro-Argo's integration into a European cluster of environmental RIs, in terms of data standardisation and improvements of float technology.

In parallel, the past five years have seen strong involvement of the National Members in the:
– set-up or consolidation of infrastructures at national levels, in terms of reliability, efficiency and visibility, together with improvements to the human resources allocated to the infrastructures;
– improvement of float performances via evaluation tests;
– design and testing of innovative sensors on Argo floats to answer European scientific needs;
– creation of coordinated regional programmes, such as the Baltic Sea Argo programme with long-term deployments in the Baltic.
Activities implemented at the Euro-Argo ERIC are coordinated and shared by the ERIC Office and the National Members → Table 1.

ERIC Office's tasks	Euro-Argo ERIC activities	National Members' tasks
Ensure coherence with Argo international strategy	• Implement a strong Euro-Argo programme • Define Euro-Argo roadmap	Ensure coherence with national roadmaps
Organise centralised float procurement and international collaboration for deployments	• Enhance and optimize European contribution to Argo • Support ¼ of the global network	Organise float procurement & deployments
• Coordinate European contributions to Argo data management • Organise training	Enhance the Argo system and data quality	Run (Global) Data Assembly Centres and Argo Regional Centres
• Develop and implement tools for "At-sea monitoring" • Test float performance (Ifremer facilities)	Monitor and improve float behaviour and lifetime	• Test float performance *in situ* • Enhance float technology
• Watch on new possibilities and new users needs • Organise joint R&D activities	Develop the Euro-Argo strategic plans, including test and integration of new sensors measuring new parameters	• Develop innovative sensors • Coordinate national R&D activities
Maintain centralised communication tools and activities	Enhance Euro-Argo visibility and awareness	Organise outreach activities and maintain Argo national websites

Table 1. The different Euro-Argo ERIC activities and the tasks shared between Euro-Argo ERIC Office and National Members.

EURO-ARGO GOVERNANCE, COORDINATION & FINANCE

In the past five years, the Euro-Argo ERIC has started to develop Argo extensions, which represent nearly 50% of the budget dedicated to floats purchase and between 20-30% of the number of acquired floats. They are implemented as an upgrade of core floats which guaranty sustained contribution to the present network. The funding dedicated to core Argo float – measuring temperature and salinity – is sustainable, whereas the budget dedicated to extensions floats – measuring other parameters – relies on European projects.

STRONG COORDINATION FOR EFFECTIVE GOVERNANCE

The Euro-Argo ERIC comprises more than 20 organisations (see Annex I, p. 101) from 12 countries. Guided by a main objective of maintaining and consolidating the global Argo array and regional coverage for European Seas, the ERIC aims to sustain about ¼ of the entire Argo network. It corresponds approximately to a European contribution of 250 floats per year and prepare its extensions to deeper depths and biogeochemical parameters. To meet this goal, the Euro-Argo ERIC requires strong coordination embedded in an effective governance structure → Figure 9, p. 26. The ERIC's aims are described in the Euro-Argo Strategy, which takes into account international, European and national requirements.

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EURO**ARGO** ERIC

The Council	The Management Board	The ERIC Office	The Scientific and Technical Advisory Group (STAG)
Defines the broad strategic direction of the ERIC and its evolution. It is composed of one delegate per member.	Supervises the operation of the Euro-Argo ERIC, ensures that it operates and evolves in accordance with the strategic direction set by the Council.	Responsible for the implementation of decisions & programmes adopted by the Management Board.	Advises on any scientific and technical matters.

Figure 9: Governance of Euro-Argo
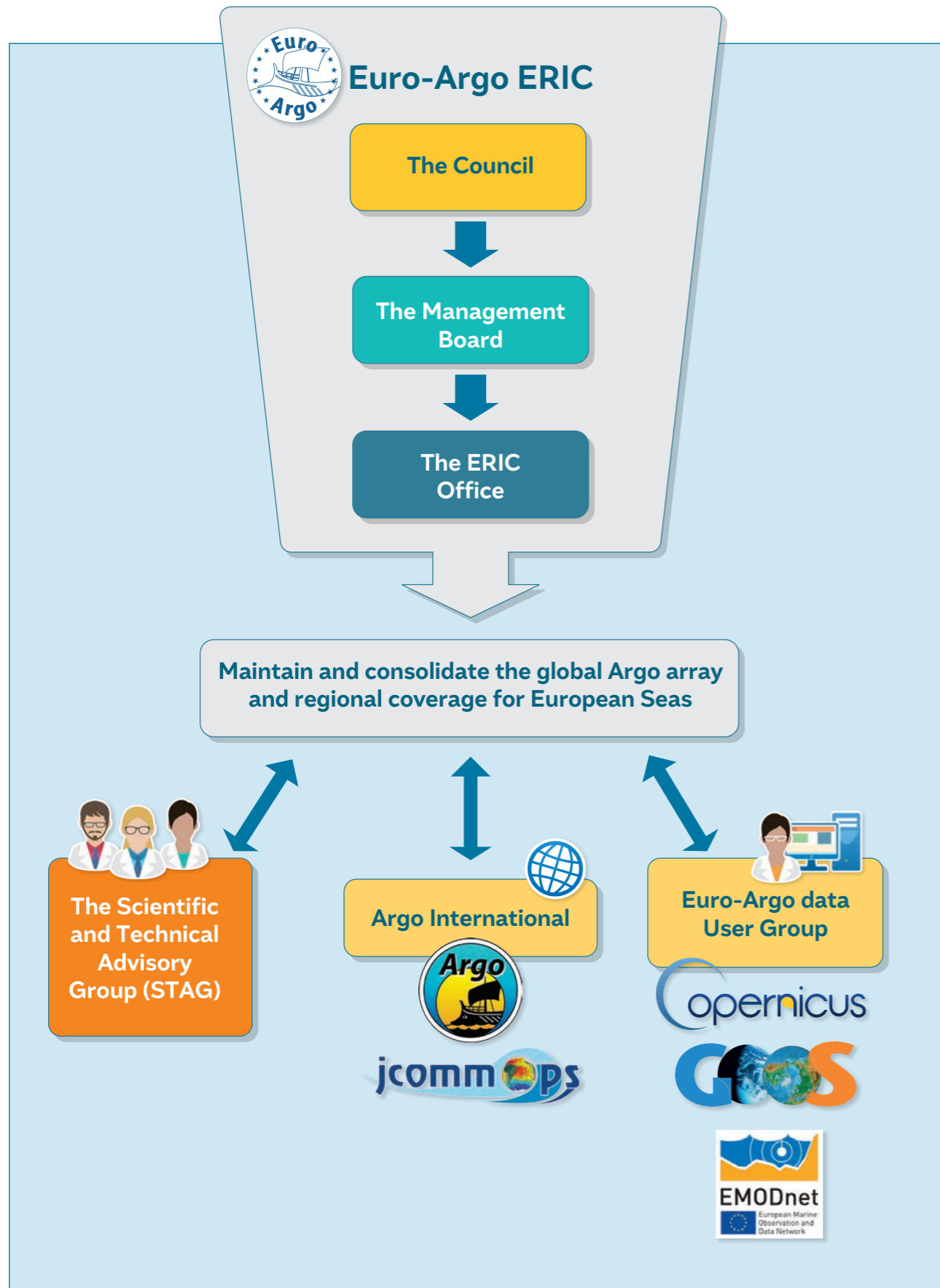
© Thomas Haessig

The ERIC Office team, from left to right: Grigor Obolensky (engagement officer), Claire Gourcuff (scientific officer), Francine Loubrieu (administrative assistant), Sylvie Pouliquen (manager of the ERIC Office), Andrea Garcia-Juan (MOCCA research engineer) and Romain Cancouët (operational engineer).

© Euro-Argo ERIC

Euro-Argo Council

The Council is the body with ultimate decision-making authority. It is composed of one delegate per Member, from the ministries.

Euro-Argo Management board

The Management Board supervises the operation of the infrastructure and ensures that it evolves in accordance with the strategic directions set by the Council, and with the requirements put forward by research and operational communities. It is composed of one scientific delegate per Member, from the institutes.

Euro-Argo Office

The Euro-Argo Office is led by the Programme Manager, appointed by the Council as the Euro-Argo ERIC's executive officer and legal representative. The ERIC Office handles the ERIC's management and communication, the coordination of Euro-Argo float deployments and float-monitoring activities in cooperation with the Joint technical Commission for Oceanography and Marine Meteorology *in situ* Observing Platform

Support (JCOMMOPS) jointly established by the World Meteorological Organisation and UNESCO's Intergovernmental Oceanographic Commission (see Box 2, p. 38) and Argo International. Euro-Argo's strategy and implementation plan – including Argo extensions to Biogeochemical (BGC)-Argo, Deep Argo and Marginal Seas – are monitored by the Euro-Argo ERIC Office. The ERIC Office also plays a major role in driving the infrastructure towards European funding and seeking additional long-term support from the European Commission. In 2018, the ERIC Office team was composed of six persons.

Euro-Argo Scientific and Technical Advisory Group (STAG)

The Scientific and Technical Advisory Group (STAG) is formed from independent experts who advise the Council on any scientific or technical matters (including data management and instrumentation) relevant to the operation, development, and evolution of the Euro-Argo ERIC. One of the co-chairs of Argo International is an appointed member of the STAG, so guaranteeing coherency with Argo International.

EURO-ARGO NETWORK:
THREE LEVELS OF COORDINATION

The ERIC Office, together with the Management Board, coordinates the contribution of the Euro-Argo ERIC (funded both by National Members and by the European Union) to the Argo ocean observing network.

National

The Euro-Argo ERIC relies on national Argo programmes set up in the Member countries → Figure 4, p. 15. These programmes are important for ensuring national coordination, fostering sustainability, and developing more visibility for Euro-Argo. Most of the national programmes (or Euro-Argo ERIC) are integrated into national "road maps" → Table 2.

Regional

Activities can also be coordinated between two or more National Members, at a regional level. This is the case of the Baltic Sea Argo programme, where Poland and Finland work together. National Members have developed technological improvements. The ERIC Office offers assistance via monitored tuning of floats configuration for shallow water deployment.

The Black Sea offers another example of regional cooperation, with Bulgaria, Italy and Poland, jointly deploying Argo floats. Euro-Argo floats have offered the primary observation network capable of sampling sub-surface temperature and salinity variation in the Black Sea's shallow waters, over the last decade.

In the Mediterranean Sea, countries such as Algeria, Bulgaria, France, Spain, Greece, Germany, Turkey, Malta, Romania, Israel and Lebanon, were consulted on the planning and coordination of float deployment.
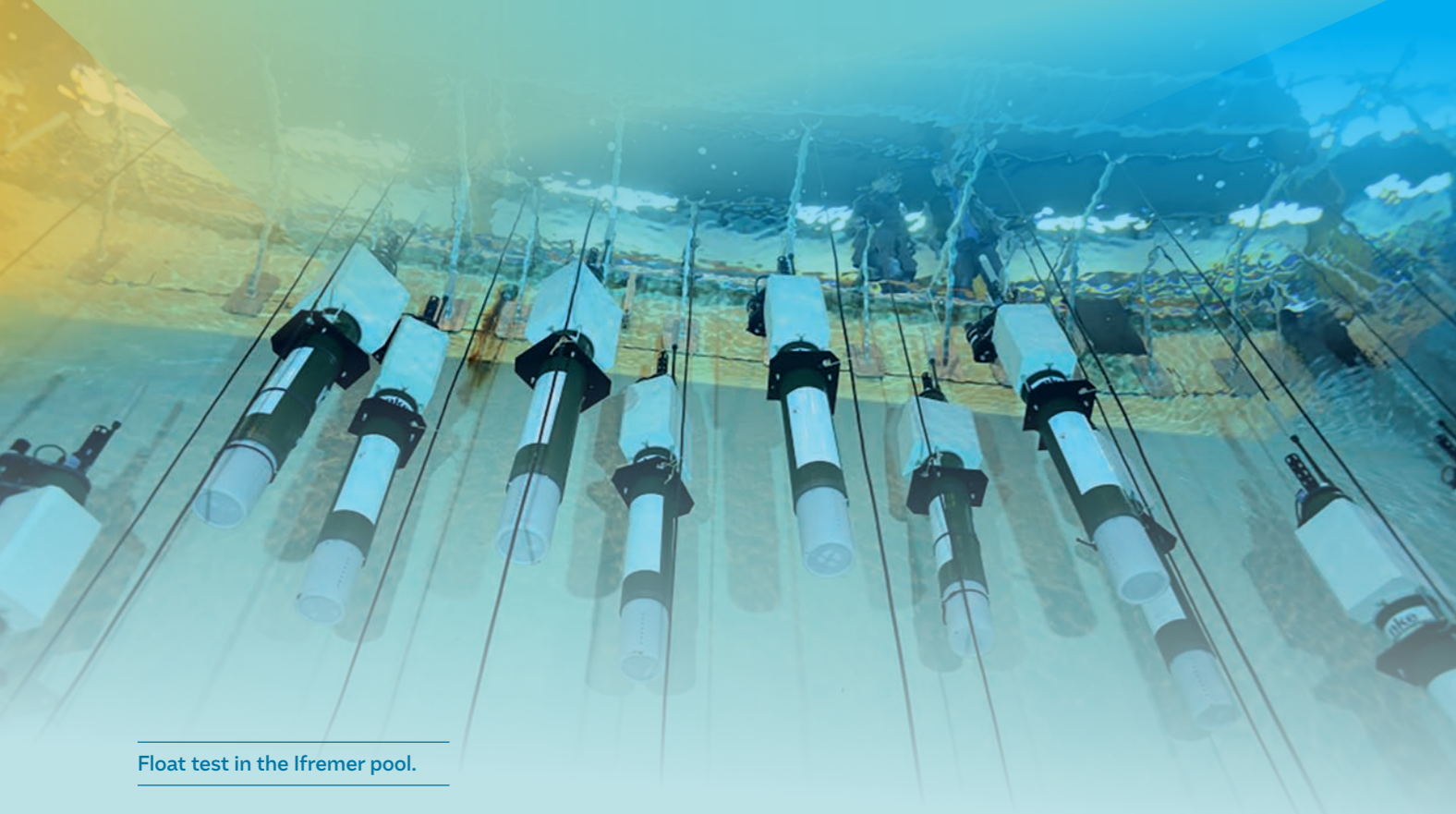
International

Europe is represented at the annual Argo Steering Team (AST) and Data Management Team (ADMT) meetings (which gather the international Argo community) by a combination of the ERIC office and representatives of national programmes. The participation of Euro-Argo representatives is also valued in a number of dedicated scientific sessions at international events, such as the Ocean Carbon Biogeochemistry (OCB), Biogeochemical Profiling Float Workshop in Seattle, AtlantOS BluePrint workshop in Brussels (2018) and the Global Earth Observation (GEO) Blue Planet Symposium in Toulouse (2018). Euro-Argo's presence at these meetings and workshops is now recognised as essential, which, in-turn, provides an opportunity to promote Argo data internationally.

ARGO NATIONAL PROGRAMMES	NATIONAL ROADMAPS IDENTIFYING ARGO
BulArgo	National road map for scientific Infrastructure of Republic of Bulgaria: MASRI – Infrastructure for sustainable development of marine research (2017-2023) of Ministry of Education and Research.
Greek-Argo	Greek Strategy for the European Research Area (ERA), National Roadmap (2015-2020) under the auspices of the General Secretariat of Research and Technology (GSRT).
Argo-France	Ministry of Research national roadmap 2016 and 2018 on large research infrastructures (TGIR).
NorArgo	Norwegian road map for Research Infrastructure 2018-2025. National Financing Initiative for Research Infrastructures (INFRASTRUKTUR).
Argo-Finland	Finland's strategy and road map for research infrastructures 2014-2020 Interim review report 2018 and Finnish national marine research infrastructure (FINMARI).
Irish-Argo	Coordinated by the Marine Institute on behalf of the Department of Agriculture, Food and the Marine (DAFM).
Argo-Poland	Polish road map for Research Infrastructures developed by the Ministry of Science and Higher Education.
UK Argo	Joint programme led by the Met Office, with the National Oceanography Centre (NOC), and Plymouth Marine Laboratory (PML). The programme is funded by the Department for Business, Energy and Industrial Strategy (BEIS) and the Natural Environment Research Council (NERC).
Argo-Italy	National Programme for Research Infrastructures 2014–2020 (PNIR) among the European Research Infrastructures of Italian interest.
Argo-Germany	Coordinated by the Federal Maritime and Hydrographic Agency on behalf of the Federal Ministry of Transport and Digital Infrastructure (BMVI) as part of its operational activities.
Argo-Netherlands	Coordinated and funded by KNMI as part of their climate monitoring effort.
Argo-Spain	Included as priority in the Spanish strategy to participate in international infrastructures. The Spanish contribution is carried out and funded by the IEO and SOCIB.

Table 2: National road maps identifying Argo.
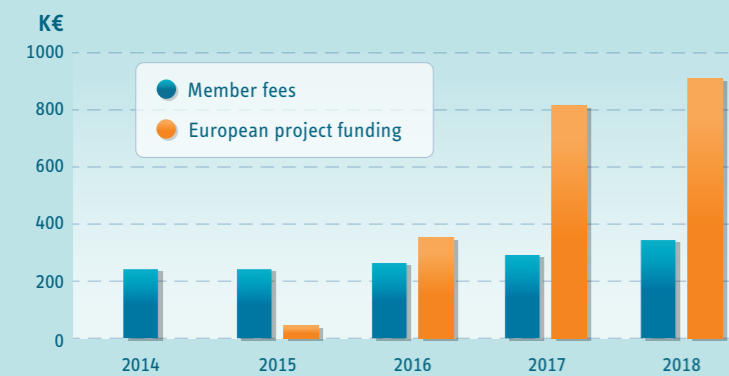
Float test in the Ifremer pool.

© Olivier Dugornay/Ifremer

EURO-ARGO BUDGET

Over the past 5 years, the Euro-Argo ERIC's overall budget has ranged between €6 and €8 million, depending on funding levels from EU funded projects. Approximately 90% of the budget comes from the National Members and covers the costs of float procurement, deployment and data transmission (including data processing). It does not encompass research and development (R&D) activities.
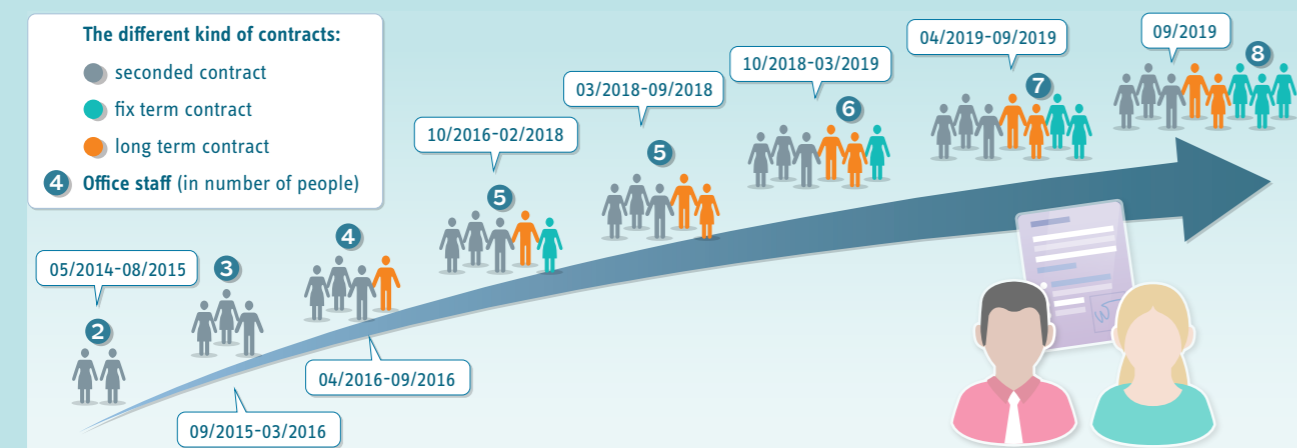

Figure 10: Evolution of the Euro-Argo ERIC budget.

Figure 11: Evolution of the Office staff.

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Euro-Argo ERIC Office's budget

The ERIC Office's 2018 budget, managed at the ERIC Office, is €1.2 million → Figure 10 with 30% coming from Member fees and 70% from European project funding (covering purchases of additional floats). Since 2014, the Euro-Argo ERIC office staff has raised → Figure 11.

Budget dedicated to float purchase

The budget allocated to float purchases, including transmission costs to data centres, accounts for nearly 80% of the ERIC's budget and 20% of the budget covers data management activities (real-time and delayed-mode processing). In the past five years, the Euro-Argo ERIC has started to develop Argo extensions, which represent nearly 50% of the purchased floats budget and between 20-30% of the number of floats → Figure 12. The drop in 2016 → Figure 13 is linked to a delay following a new call for tenders.

> The Euro-Argo ERIC has started to develop Argo extensions, which represent nearly 50% of the purchased floats.

The prices of the different types of floats → Figure 14 show that Deep and BGC floats double the total cost for the same number of floats.

In accordance with general ESFRI policy, the Euro-Argo ERIC receives stable and sustained funding from its Member countries to support infrastructure operations. Research and development activities are carried out through projects funded at either national or European level (H2020 and EMODnet projects). The decision to engage in EU proposal is first discussed at the Euro-Argo Management Board level and then approved by the Council.
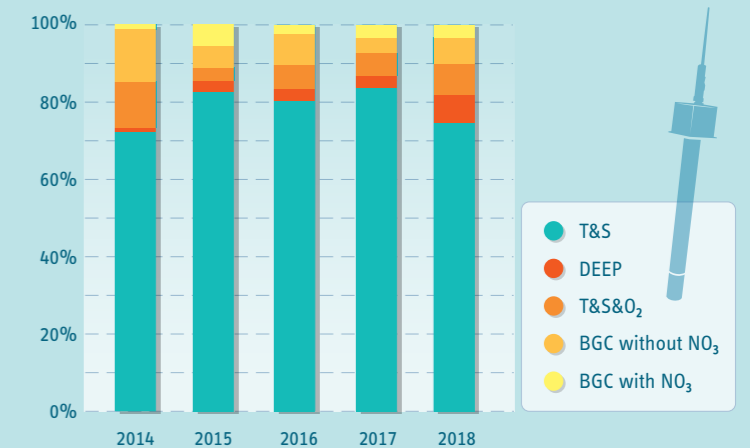

Figure 12: Evolution of the type of floats deployed per year by Euro-Argo. (T&S: Temperature and Salinity; O_2: Dissolved Oxygen; NO_3: Nitrate).
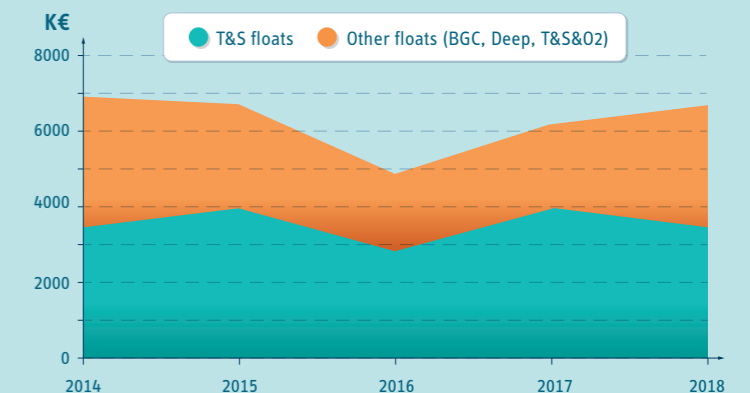

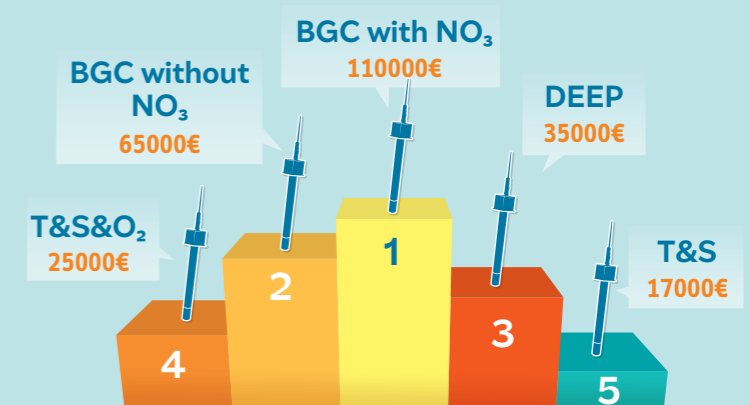Figure 13: Euro-Argo ERIC float budget evolution.

Figure 14: Average price of the various float types deployed by Euro-Argo (TS: Temperature and Salinity; O_2: Oxygen; NO_3: Nitrate).

© Thomas Haessig

A STRONG DATA MANAGEMENT SYSTEM

Data that reflect the state of the ocean in real time can only be dispatched by a powerful data-management system supported by dependable quality-control processes.

A FREE AND OPEN DATA POLICY

The Argo data-management system is world-renowned for its supply of data within 24 hours of acquisition (around six hours for European Data Assembly Centres (DACs)), under a free and open data policy. For this near real-time data to be reliable, the system depends on efficient data transmission to shore and on a solid and homogeneous quality control to ensure errors in position, temperature, salinity and pressure are eliminated – a key task covered by the DACs ➔ Figure 15.

Over longer periods, delayed-mode data profiles are validated by oceanographic experts, through comparisons with reference data, established by climatologists, from high-quality ship-based CTD casts and existing delayed-mode Argo data **(see Box 1)**. To optimise the accuracy, the delayed-mode quality control (DMQC) is performed after a minimum of one year of deployment, and then carried out every year thereafter, with the entire time series reassessed upon each review ➔ Figure 15.

BOX 1 Two versions of Argo data

Argo data are available in two versions:
► real-time data, the first form of Argo data, available to the public, automatically checked to detect obvious bad data (sensor issues, incorrect measurements or corrupted transmission to shore);
► delayed-mode data, subject to detailed scrutiny by oceanographic experts and corrected by comparison with high-quality ship-based CTD data on at least yearlong data time-series.
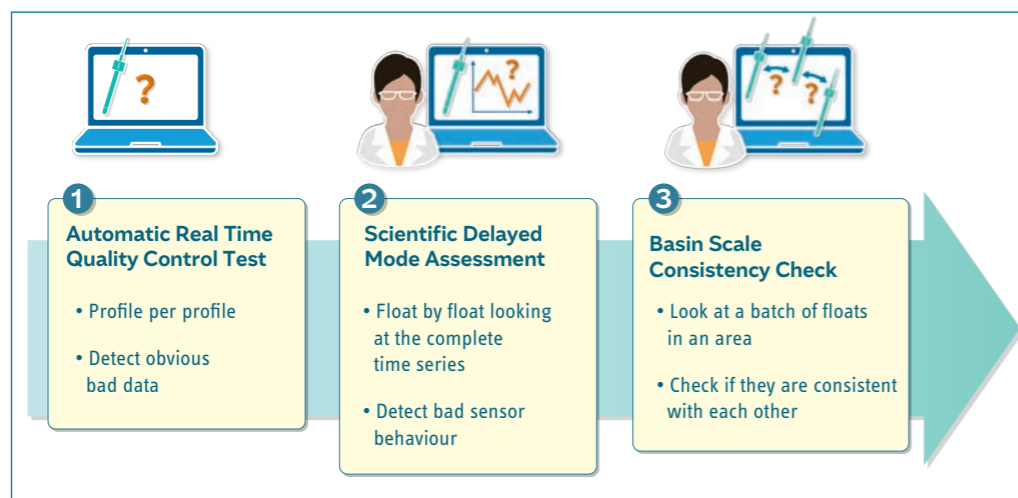
Figure 15: The different quality-control processing steps on Argo float data.

1 Automatic Real Time Quality Control Test
• Profile per profile
• Detect obvious bad data

2 Scientific Delayed Mode Assessment
• Float by float looking at the complete time series
• Detect bad sensor behaviour

3 Basin Scale Consistency Check
• Look at a batch of floats in an area
• Check if they are consistent with each other

© Thomas Haessig

Float test in the Ifremer pool.

© Olivier Dugornay/Ifremer
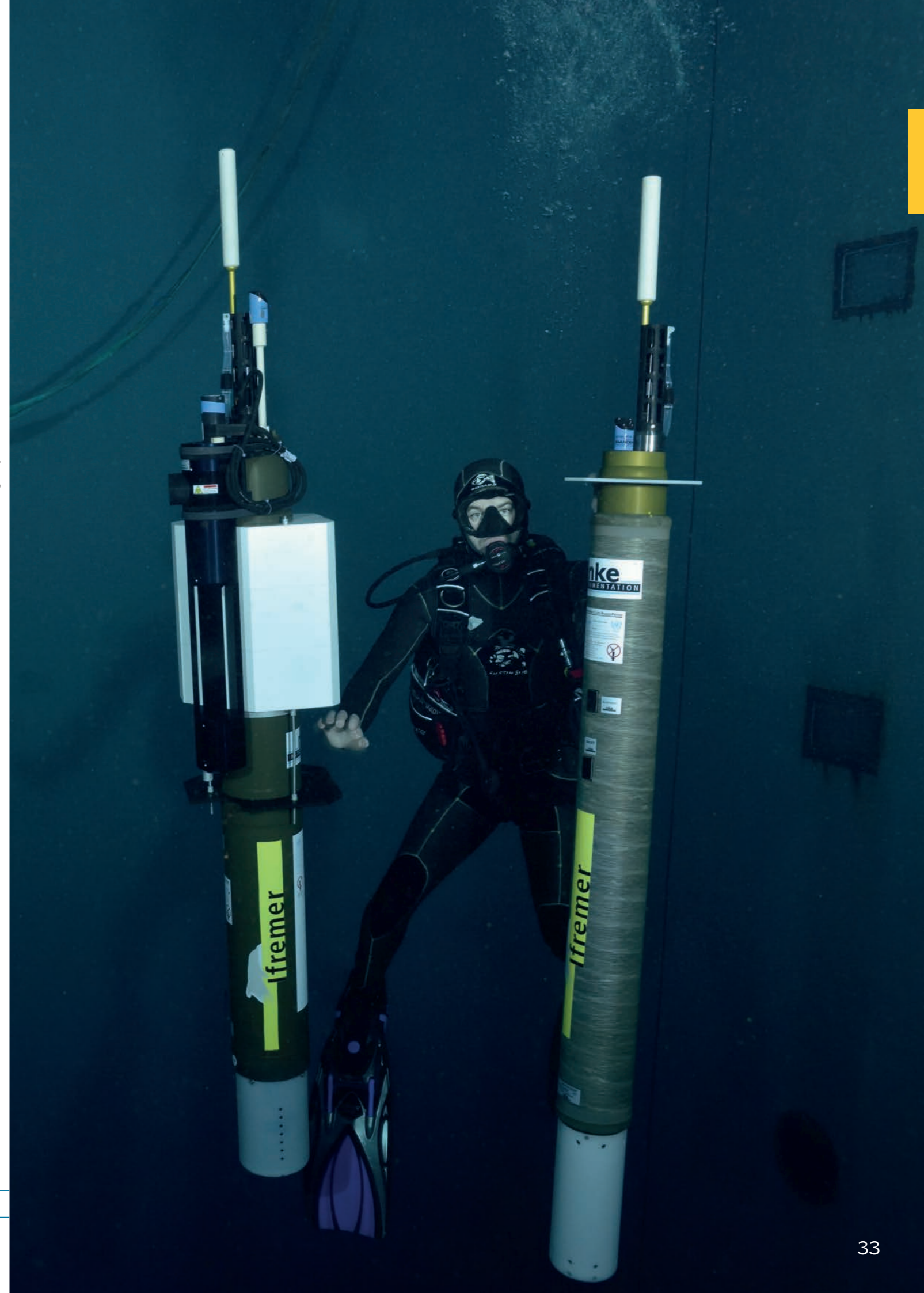
THE DIFFERENT DATA CENTRES

The Euro-Argo ERIC plays an active role in the international Argo Data System, which is based on two GDACs, eleven national DACs and six ARCs, located across the world and managed by the Argo Data Management Team → Figure 16.

GDACS

There are two GDACs: one is operated by Coriolis, in France and the other one is operated by FNMOC in the US. They synchronise their database on a daily basis and provide a unique portal to serve operational users or research communities. The data is also archived in the Global Argo Data repository operated by the National Centre for Environmental Information (NCEI) in the US.

Delayed-mode operator groups

For the delayed-mode streams, the Euro-Argo ERIC contributes with four delayed-mode operator groups working from four national institutions : BSH in Germany, Coriolis in France, OGS in Italy and BODC in the UK, all of which process European float data. One example of data is presented → Figure 17.

DACS

Two national DACs are based in Europe:
– the French DAC, operated by Coriolis to process floats deployed by Bulgaria, Finland, France, Germany, Greece, Italy, Netherlands, Norway, Poland, Spain and EU floats;
– the UK DAC, operated by the British Oceanographic Data Centre (BODC), to process all UK and Irish data, as well as from Mauritius, Saudi Arabia, Portugal and some floats from Italy, Netherlands and the EU as part of the MOCCA project.

After receiving data from the satellite operators, the DACs carry out decoding and quality-control processes, according to a set of real-time automatic tests agreed on by the international Argo programme (Argo Quality Control Manual). The data is then sent on to the two GDACs, which distribute it to the community. These data flows enable near real-time exchange of information, which is critical for forecasting and warnings on hydro/meteorological hazards, in accordance with approved procedures.

ARCS

Three ARCs, that offer regional analysis of regional Argo data to assess its internal consistency with recent shipboard data, are coordinated by the Euro-Argo ERIC. The North Atlantic ARC (NA-ARC, managed by Ifremer), the Mediterranean and Black Seas ARC (Med-ARC or MedArgo, managed by OGS) and the Southern Ocean ARC (SOARC, managed by an international collaboration of partner institutions: BSH, CSIRO, SOCCOM/MBARI and BODC). An additional regional centre for the Nordic Seas, currently under development, will be managed by BSH.

Figure 17: Temperature vs. Salinity diagram of 5 years of profiles from float #6901564, in the North Atlantic Ocean.

© Coriolis data Center

© Thomas Haessig
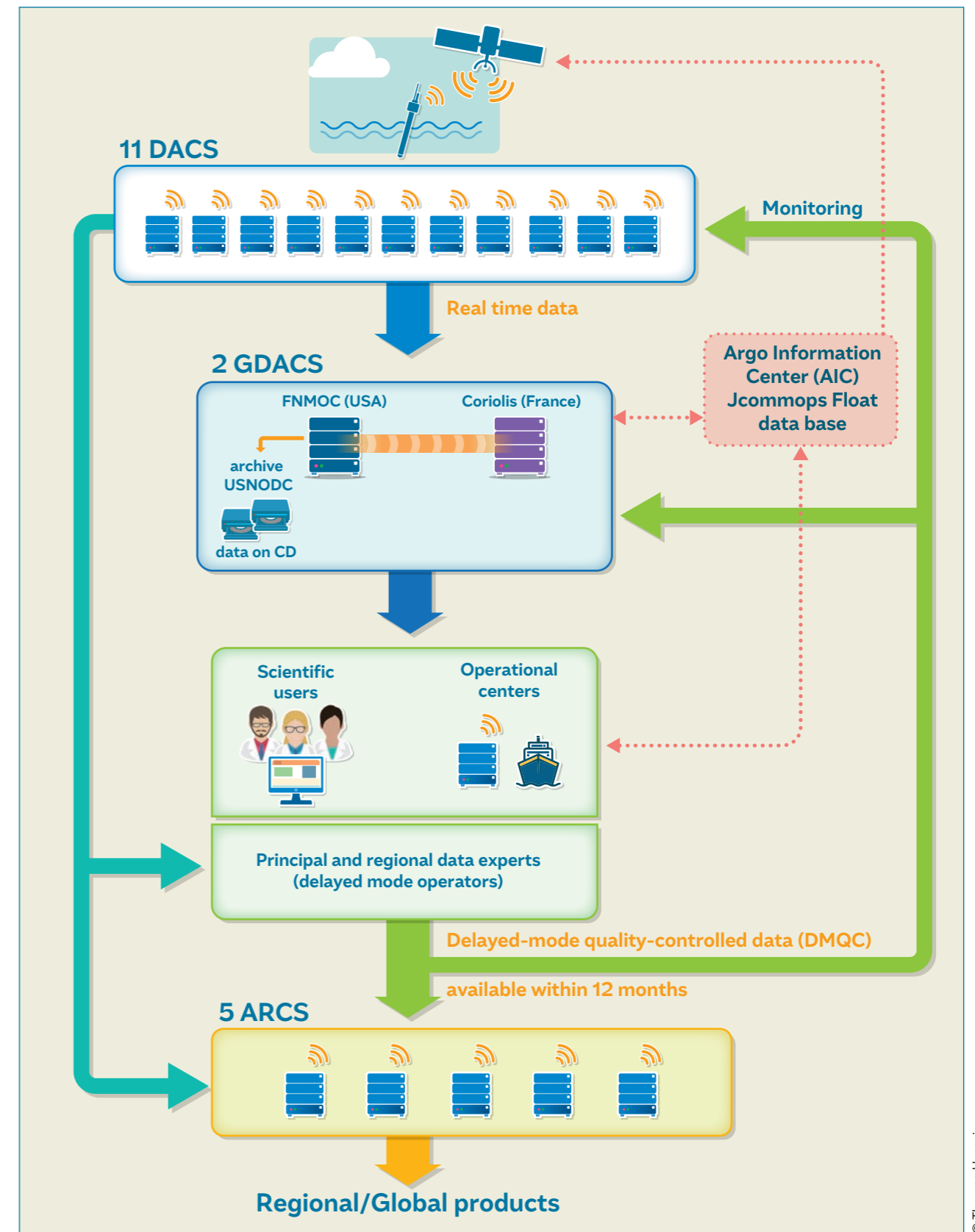
Figure 16: International Argo Data Management System. US NODC: US National Oceanographic Data Centre (now called NCEI: National Centre for Environmental Information); JCOMMOPS: Argo Information Centre (see Box 2 p. 38); PIs: Principal Investigators; RT: Real Time; (G)DAC: (Global) Data Assembly Centre.

EURO-ARGO SERVICES FOR MEMBERS

To be successful, float deployments require adequate logistical support and easy access to information regarding deployment opportunities. The Euro-Argo ERIC, via collaboration between the ERIC Office, JCOMMOPS and national facilities, facilitates logistics-backed monitoring at-sea, and has developed related services for Members.

ACCURATE FLOAT PROCUREMENT, TESTING AND DEPLOYMENT PLANNING

The procurement of Argo floats represents one of the major costs of the infrastructure. Float procurement is supported by national programmes and by EU-funded projects. The ERIC Office has implemented a centralised procurement service through which Members can purchase floats for their national programmes at significant discounts and reduced overhead costs. Since 2017, Euro-Argo's centralised procurement service has supported the purchase of 97 floats (valued at more than €1.5M).

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Acceptance tests are performed by the Euro-Argo Office technical team, using Ifremer facilities. By helping to identify technical problems before deployment, these tests contribute to reducing early at-sea failures. The ERIC Office organises shipment/transportation of the floats, and offers technical training of crews' on-board vessels for the correct deployment procedures of Argo floats. The JCOMMOPS/AIC portal **(see Box 2, p. 38)** allows the infrastructure to register floats prior to deployment and to collect standardised metadata. Through collaboration with the ERIC Office, the portal is routinely updated and is operant in providing mandatory information (float declaration, metadata, and a standardised deployment sheet needed to initiate the decoding chain at the DACs).

Acceptance test in the Ifremer facilities.

© Stéphane Lesbats/Ifremer

Collaborative acceptance test with German team.
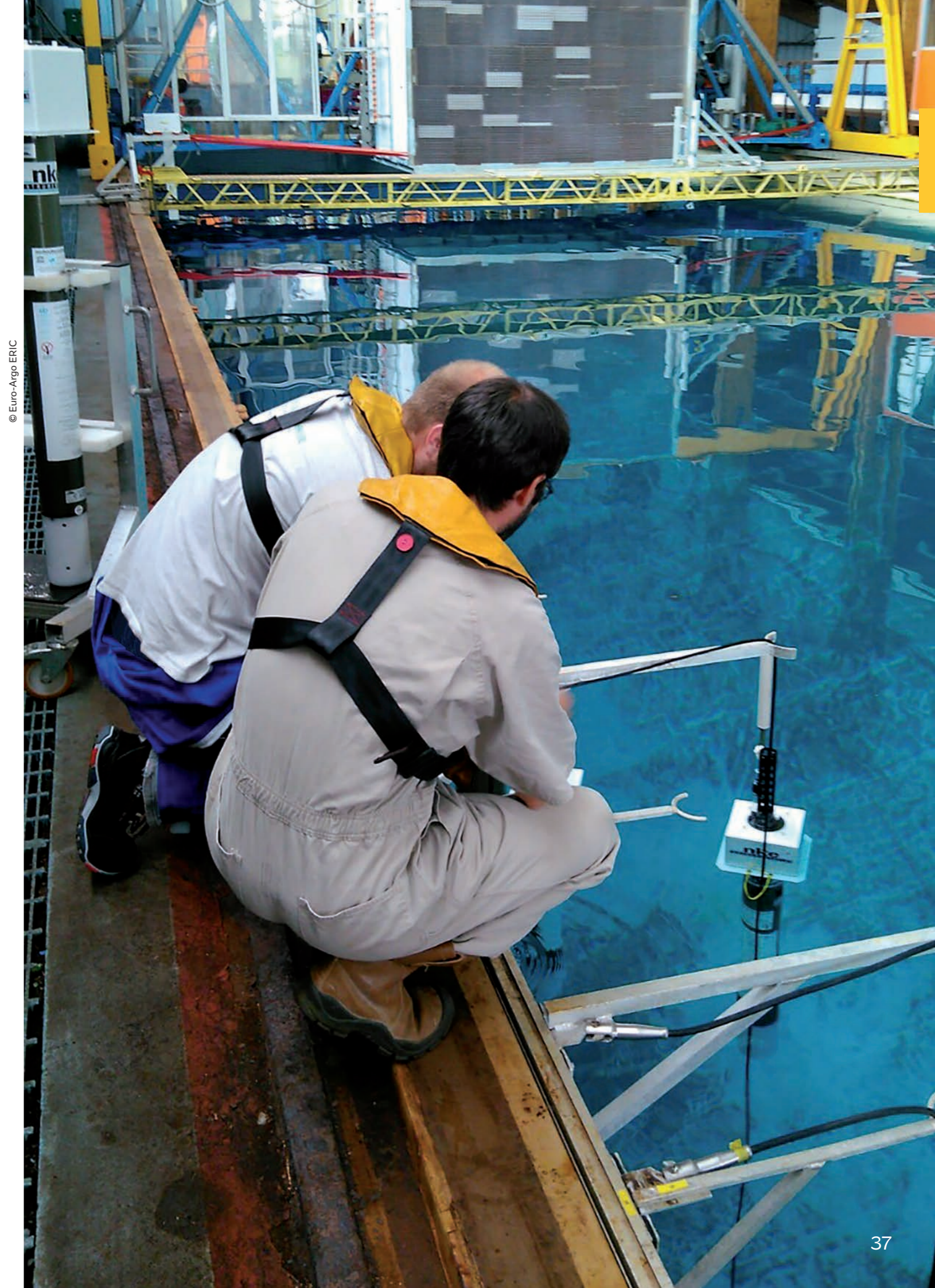
© Euro-Argo ERIC

Float test by Euro-Argo ERIC, 2019

BOX 2 JCOMMOPS and AIC

JCOMMOPS is the *in situ* Observations Programme Support Centre to the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology. It was established in 2011 to build synergies between the existing programmes: Data Buoy Cooperation Panel (DBCP), Ship Of Opportunity (SOOP) and Argo (see Chapter 9 p. 70). It provides a technical support on a day-to-day basis, and integration of the various *in situ* marine observing systems: nowadays, the observing systems includes GO-SHIP, gliders, fixed moorings, etc. → Figure 24, p.75.

The Argo Information Centre (AIC) was established specifically to monitor the development of the Argo float array and the implementation of the IOC XX-6 resolution (drift in coastal waters warning). The Centre and its coordinator, as part of JCOMMOPS, fulfil a wide monitoring and information-gathering function for Argo.

The ERIC Office also coordinates deployment planning between Members and the international community, with the aim of bringing deployed floats in line with the Argo array design for ocean coverage.

The Euro-Argo ERIC backs strong collaboration with international and national programmes for the sharing of ship-time. More than 80% of the European floats have been deployed from Research Vessels.

A PERMANENT "AT-SEA MONITORING"

Complementary to JCOMMOPS system, the "at-sea monitoring" system allows surveying of individual floats and the evolution of their technical parameters (e.g. battery voltage, grounding and data transmission by satellite)

Monitoring activities maximize float life expectancy, so increase the cost-effectiveness of the Argo programme.

after deployment. Developed under the MOCCA project (see Box 3), it consists of a web page for each float, displaying all available information such as metadata, float trajectory and collected scientific data.

Several alerts and warnings regarding technical parameters have been implemented to detect malfunctions arising from float or sensor failures, inadequate float programming, or unforeseen hazards at sea. Early detection of malfunctions for a batch of floats will pause/stop further deployments, thus allowing the floats to be returned to the manufacturer to be repaired. Periodic follow-up of fleet behaviour provides improved testing procedures, feedback on anomalies/suggestions for float manufacturers, and may drive technical specifications for future procurement. In addition, in-depth analyses of float behaviour in specific areas (e.g. shallow waters, under-ice regions) are regularly performed offline by the ERIC Office technical team.


Deployment test by HCMR Institute, Greece, 2016.
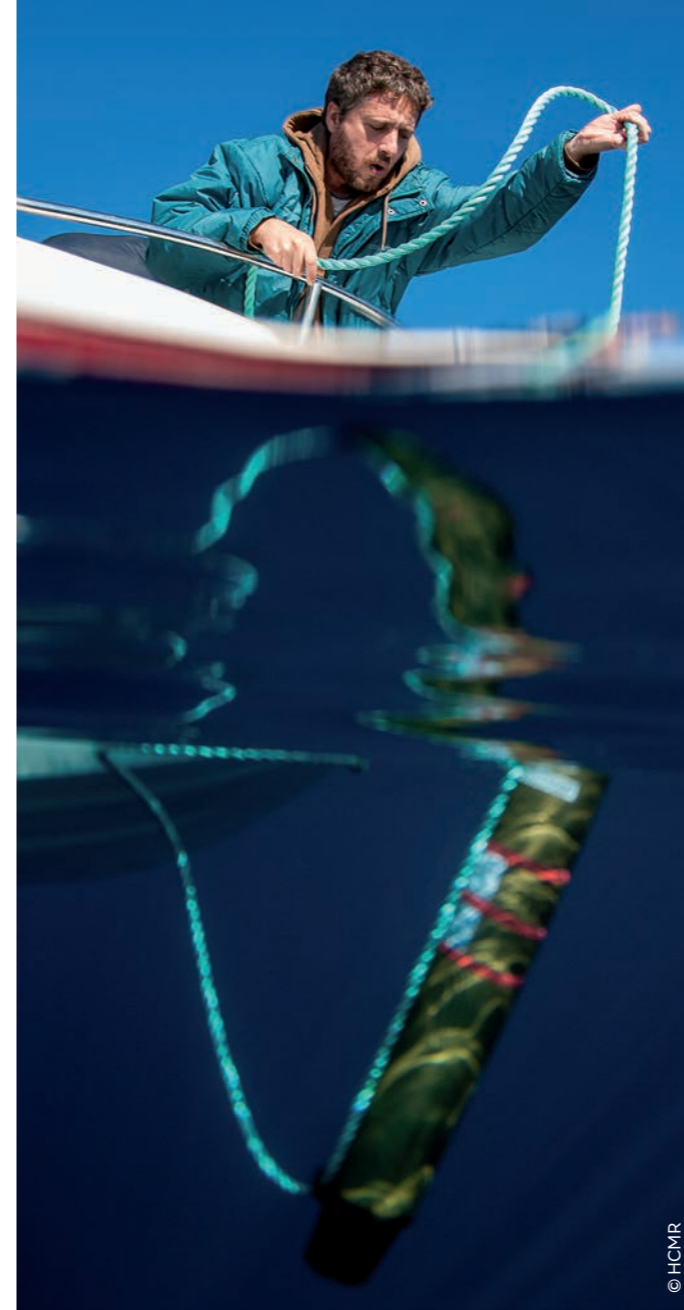
BOX 3 MOCCA

The European project MOCCA (Monitoring the Oceans and Climate Change with Argo, 2015-2020) was co-financed by the European Marine and Fisheries Fund (EMFF) and the EC DG MARE, to help Euro-Argo progress towards its "Monitoring the Oceans" objectives and contributes to the international Argo programme. MOCCA has made it possible to procure a large fleet (150 Argo T/S floats) and organise their deployment (2016-2018), to develop the at-sea monitoring system and to process the data collected in real time and in delayed mode (2016-2019). MOCCA represents a major step in the development of the Euro-Argo ERIC by:

▶ demonstrating the operational capabilities of the ERIC to manage a large fleet, from procurement to deployment, at-sea monitoring and data processing;

▶ setting up of a reliable and reusable baseline for Euro-Argo float operations (e.g. technical specifications for float procurement, acceptance tests procedures, monitoring tools, etc.);

▶ showcasing that centralizing a large fleet is beneficial for decreasing the overall costs (e.g. discount rate for float procurement, reduced data management efforts to handle floats equipped with the same firmware version, etc.) and providing a better vision for monitoring activities (homogenous fleet);

▶ means to implement the Euro-Argo strategy, with abundant float deployments in the targeted areas, including Argo global array and additional coverage in European Marginal Seas;

▶ demonstrating that Europe can significantly contribute in a coordinated way to the international Argo programme (commitments on the number of floats to be deployed per year, processing and doing a quality-control of float data, monitoring of data dissemination).
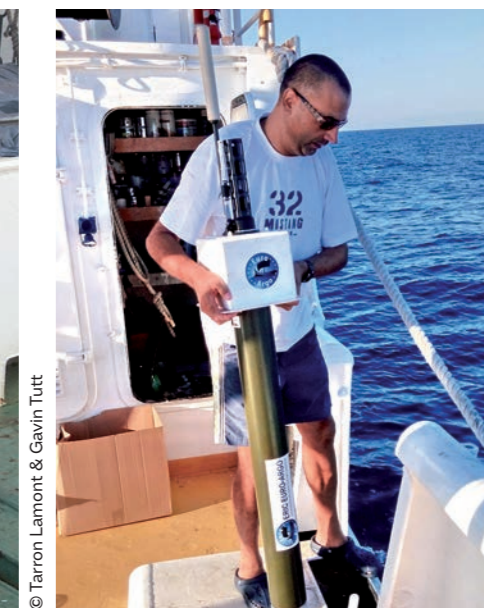
Deployments of MOCCA floats in the Agulhas Current (left) and in Adriatic Sea (right).

© BSH

Test of an APEX float's communication during MSM7 cruise in the North Atlantic, 2018.

© Lauren O'Dell

SOME TRAININGS FOR CAPACITY BUILDING

Training for data quality-control

As Euro-Argo extends to new countries, Members have identified a need to build capacity for Argo data processing, in particular for the DMQC of temperature and salinity. Euro-Argo organised the 1st European Argo DMQC workshop in 2018, as part of the MOCCA project, to help new European teams develop common understanding of the Argo system and the temperature and salinity DMQC process. The longer term aim is to boost the DMQC capabilities of European partners. With an increasing European fleet and significant national programmes deploying floats in poorly

> **Members have identified a need to build capacity for Argo data processing, in particular for the DMQC of temperature and salinity.**

sampled areas, it is important to involve new teams and to develop new expertise within DMQC activities, at a European level. This will be critical in enabling successive planning and knowledge transfer to the next generation of experts.

Training activities have also been initiated by Euro-Argo Members at the national level (e.g. Italy and the UK).

Training for float handling before deployment

At national level, some training activities have been provided for scientists and technicians in float and sensor handling, before and during deployments (e.g. France in 2016 and the UK in 2018).

In the framework of the International Seakeepers Society, four Argo-Italy floats were deployed in the Tyrrhenian and Ionian Seas. The non-expert operators were trained by OGS personnel on deployment procedures (maxi-yachts Exuma, in 2017, and ROE, in 2018).

Non-expert operators were also trained by OGS personnel for deployment and recovery operations of Argo-Italy floats, in the south Adriatic in 2017 (University of Dubrovnik, Croatia) and in the Sicily Channel in 2018 (University of Malta).

In France, deployment procedures have been taught to non-scientific personnel in charge of Argo float deployments, based on ships of opportunity. Such deployments include regular collaboration with private yachts from the NGO such as "Voiles Sans Frontières" (since 2012), tall ships or round-the-world sai-

> **Euro-Argo organised the 1st European Argo DMQC workshop in 2018, as part of the MOCCA project.**

ling races (e.g. Barcelona World Race, in 2016 or "La Longue Route", in 2018). This type of training often raises opportunities to conduct wider public-outreach events. Opportunistic deployments and associated team trainings in France have also been carried out in the framework of collaboration between Euro-Argo and Orange Marine (2017-2018), and between Argo-France and the French Navy.

6 EURO-ARGO EXPANSION

As defined in its Strategic Roadmap, the Euro-Argo operational network, supported by European projects and National Members, extends its geographic coverage for two areas of European/National scientific interest and regions identified as being under sampled.

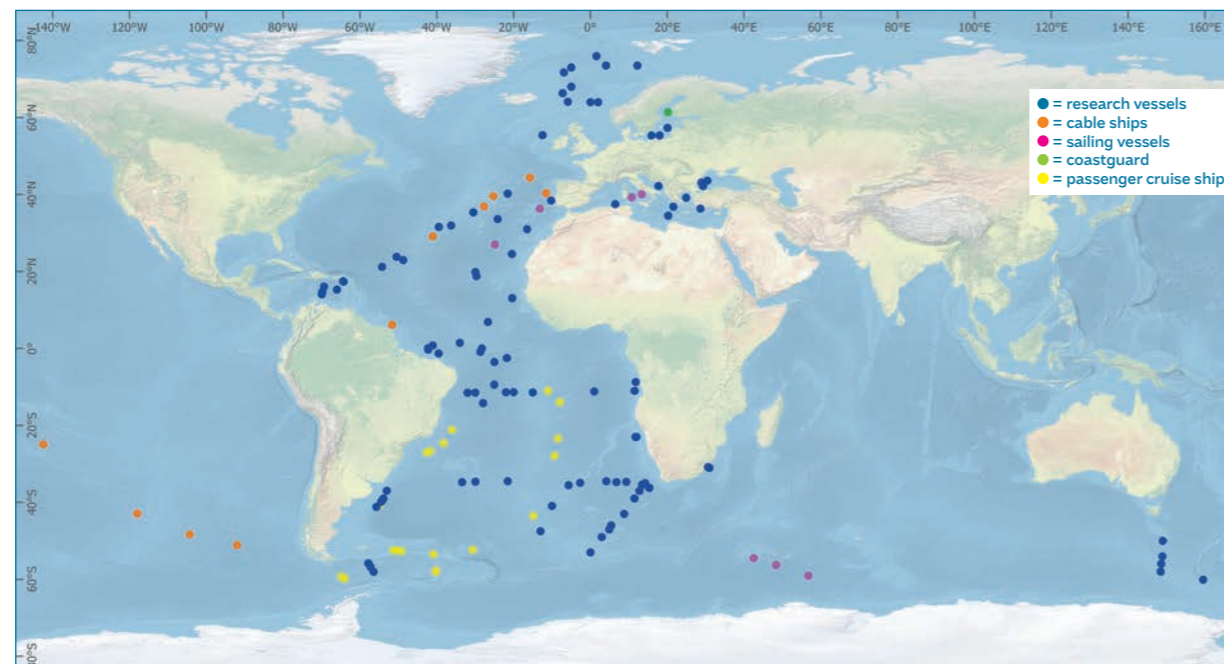## EXTENDING OUR CONTRIBUTION TO THE GLOBAL NETWORK

The DG MARE-funded MOCCA project → Figure 18 demonstrated the capacity of the Euro-Argo ERIC in extending its deployments in new areas thanks to 150 floats (see Box 3, p. 39). Those floats are deployed by varius types of ships. This effort also benefited from collaboration with international programmes: they assisted in the deployment of floats in under sampled areas thanks to surveys and campaigns.

National strategies in combination with the DG-MARE MOCCA project, have allowed the Euro-Argo ERIC to focus on four target deployment areas the South Atlantic and Southern Ocean (ice-free), the Polar ocean, the Marginal Seas and the contribution to the global network.

The number of European floats deployed has doubled – from 150 to 300 – over the past number of years. The Atlantic Ocean is a region of significant interest for the European research community, which has deployed floats with the aim of establishing appropriate sampling in equatorial and boundary regions. MOCCA floats have also been deployed in the Equatorial Pacific, a region identified as being under sampled by Argo.

Figure 18:
MOCCA Argo floats deployment positions vs. ship's type.

Test of BGC floats at Ifremer facilities.

5% North Atlantic Ocean

15% South Atlantic Ocean

17% Nordic Seas

60% Baltic Sea

30% Black Sea

7% Mediterranean Sea

Data collected from:
- EURO-ARGO
- MOCCA
- ARGO INTERNATIONAL
- % MOCCA floats

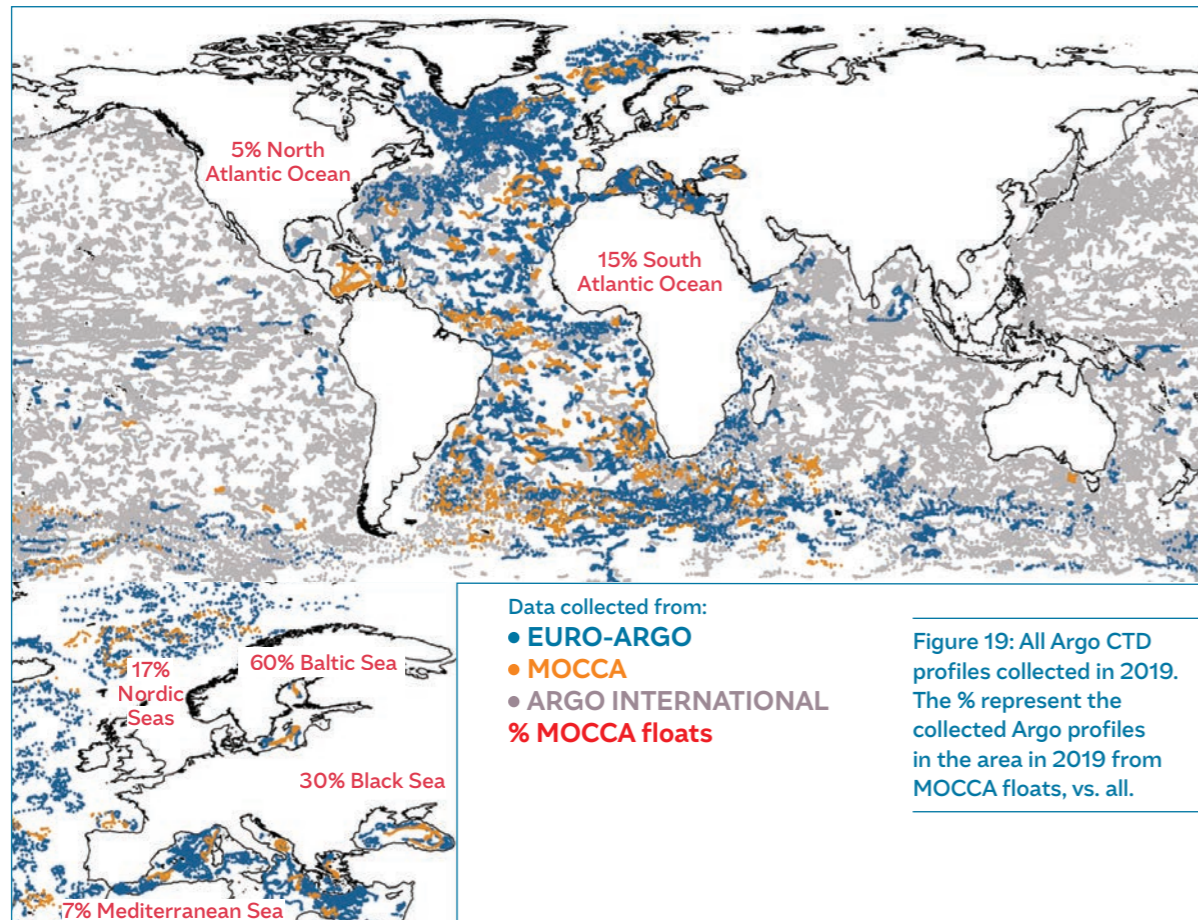Figure 19: All Argo CTD profiles collected in 2019. The % represent the collected Argo profiles in the area in 2019 from MOCCA floats, vs. all.

© Thomas Haessig

Amundsen cruise in Baffin Bay, summer 2019.

© Claudie Marec

IMPROVING DENSITY WITH SPECIFIC EXTENSIONS

The South Atlantic and Southern Ocean (ice-free)

To improve the low density of the Argo network at present, Argo floats have been deployed in the South Atlantic (south of 60°) and the Eastern Boundary Upwelling region off Angola and Namibia, the Agulhas Current (South of Cape Town), Drake Passage (south of Argentina) and the Weddell Gyre.

The Polar Ocean, with a focus on Nordic Seas and the Arctic Ocean

The collection of observations in the Arctic Ocean is a major challenge in the strategy for Argo's evolution in Europe, as this region requires floats to operate in partially ice-covered seas. Over the past number of years, approxima-

tely 15 Euro-Argo floats, equipped with the Ice Avoidance Algorithm software, have been deployed as part of the EU MOCCA and the French NAOS projects, close to the Fram Strait and the West Spitsbergen Current. These are among the northernmost deployments of autonomous Argo floats, collecting some of the northernmost data out of the few Argo observations in this region north of the 80°N parallel.

Marginal Seas

At present, there are 60 active floats in the Mediterranean Sea. This density – representing twice the standard Argo density – needs to be maintained to resolve spatial and temporal scales, smaller than in the open ocean. A significant number of BGC floats have been deployed in the Aegean, Ionian and Levantine Seas, in the framework of the

MedArgo programme. The number of valid profiles has increased tenfold in the Eastern Mediterranean basin over the past 5 years. In the Mediterranean Sea, international coordination and collaboration has been set up by the ERIC between Algeria, Bulgaria, France, Spain, Greece, Germany, Turkey, Malta, Romania, Israel and Lebanon, for planning and coordinating the deployment of floats. These collaborations will be strengthened by the EA RISE project (see Box 12, p. 77).

The Black Sea is a region of particular interest as almost one third of continental Europe fresh waters drains into it. This deep sea, with a maximum depth of 2200m, is also the world's largest anoxic basin. Bulgarian activities have focused on the Black Sea through the deployment of a number of floats, including some with oxygen sensors. Italy has also deployed floats in the Black Sea to measure concentrations of nitrate and sulphide.

The number of valid profiles has increased tenfold in the Eastern Mediterranean basin over the past 5 years.

The Baltic Sea is a shallow region with low surface salinity, strong density gradients and partial seasonal ice coverage with some of the deeper areas depleted of oxygen. The relatively small area allows to recover the floats for reuse. All these features make it both a challenging and interesting site for Argo float operation. As a matter of fact, the Black Sea is an optimal laboratory for testing new sensors measuring biogeochemical parameters and developing new information. Experience from the Baltic Sea is valuable for designing of the monitoring activities in the Arctic shelf regions and other ice-covered seas. Based on national initiatives some of these developments are already underway. In addition, Poland and Finland have deployed floats equipped with oxygen and fluorometric sensors in the Baltic Sea.
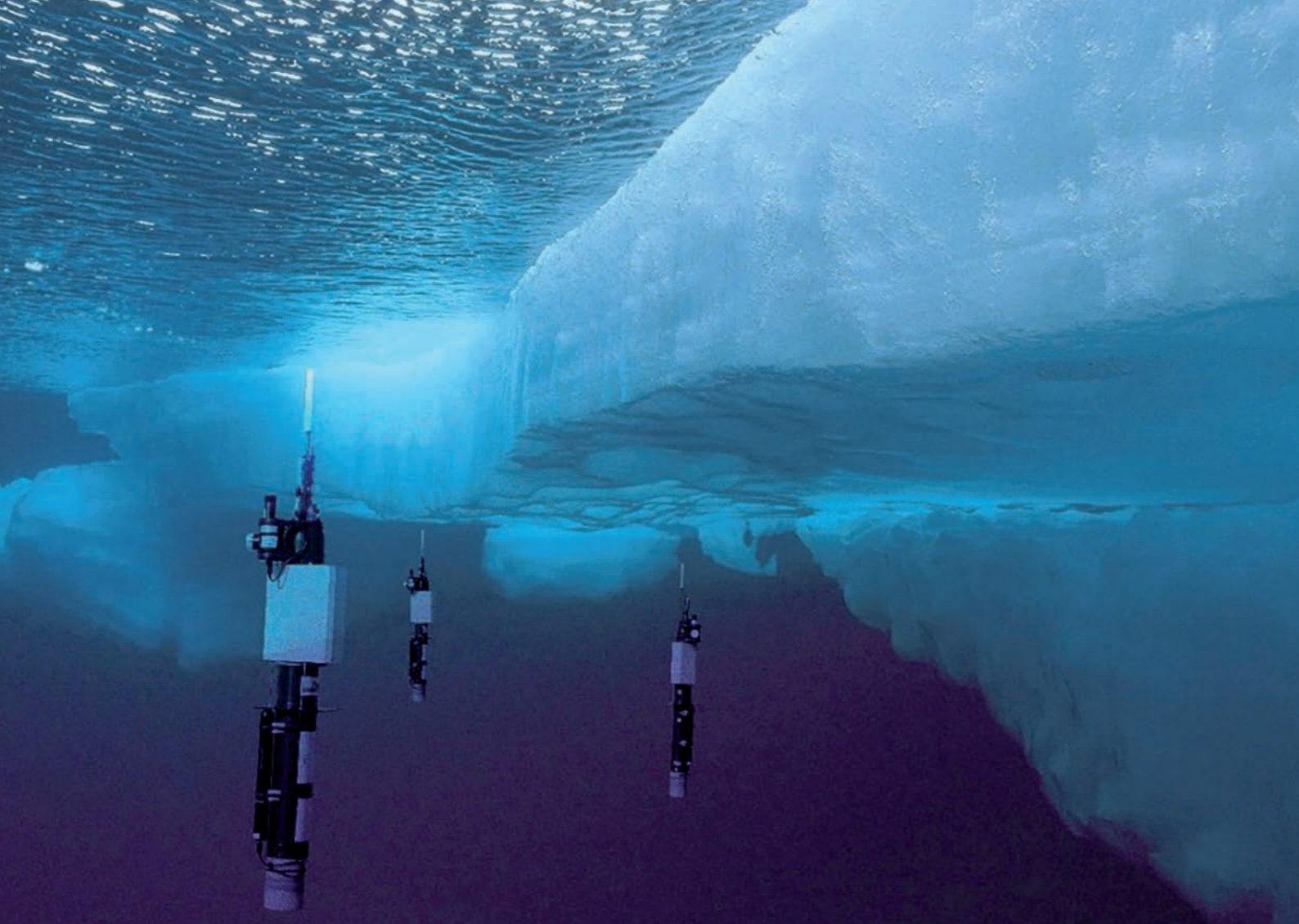
© Thomas Jessin/LOV

Artistic view of BGC
Argo floats under ice.

© Francesco Nencioli

BGC Argo float –
AMT27 Cruise.

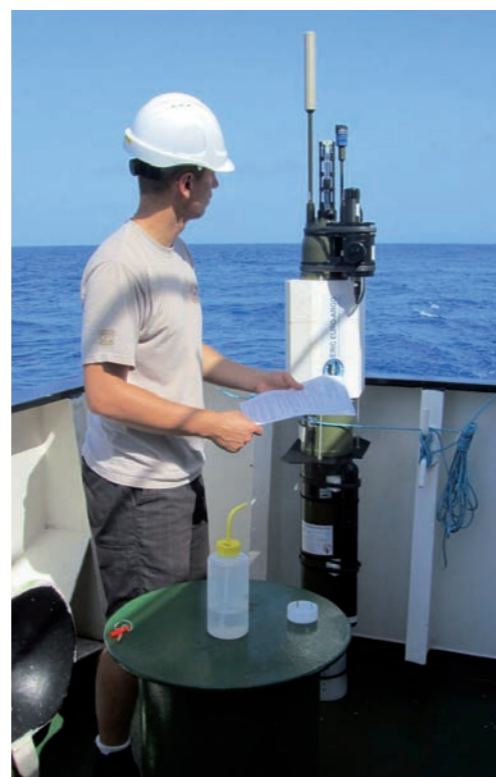## BGC parameters endorsed by the IOC

Oxygen concentration

Nitrate concentration

pH

Chlorophyll a concentration

Suspended particles

Downwelling irradiance

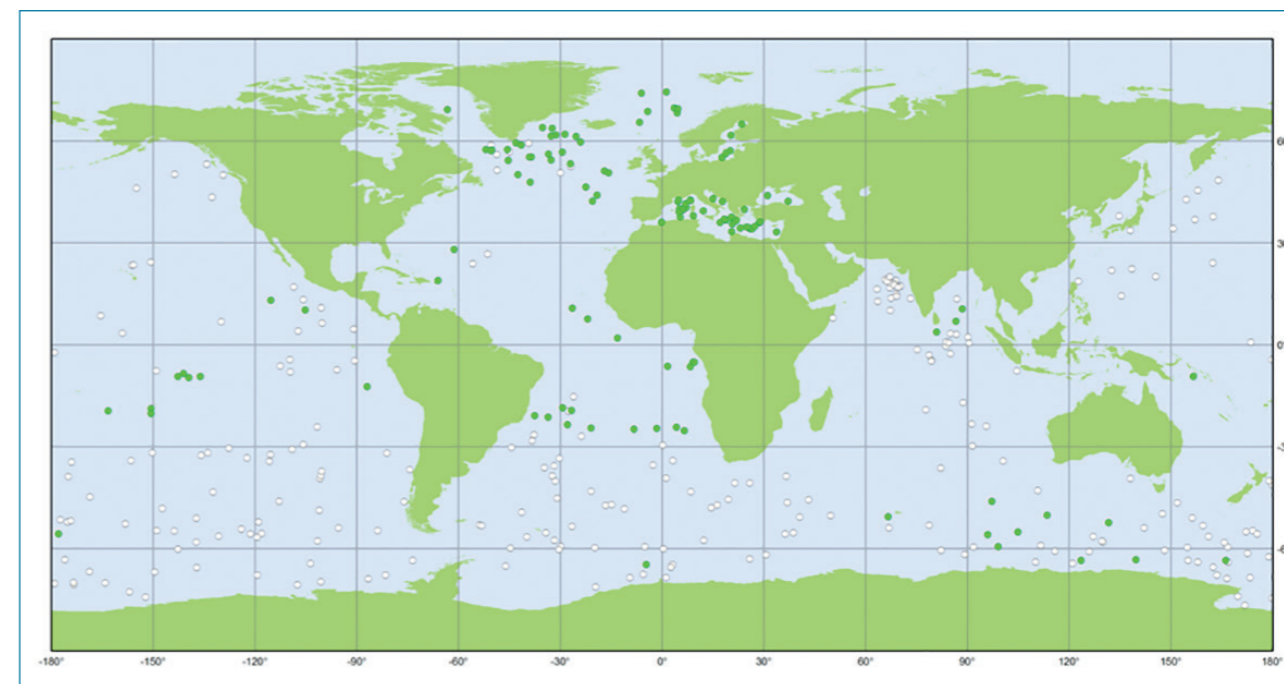Table 3. List of the six BGC parameters endorsed by the IOC.

Figure 20: The Biogeochemical floats deployed in September 2019 (green dots: by Euro-Argo, white dots: by others).

THEMATIC EXTENSION TO BGC & DEEP ARGO

Extension of the Global Argo Pro-gramme to the deep-ocean (DEEP) and biogeochemical parameters (BCG) is being actively developed by the Euro-Argo ERIC. The contribution of Natio-nal Members has been essential to:
– develop/integrate new sensors and technologies (France and Germany);
– test the reliability of new floats (France, Italy and UK);
– deploy floats in areas of special interest (Poland, Greece, Finland and Norway).

Euro-Argo is operating more than one quarter of the global Biogeochemical Argo fleet.

A major contribution to BGC

Biogeochemistry sensing initially began with the deployment of sensors for dis-solved oxygen on Argo floats, before widening to new bio-optical sensors, such as for chlorophyll a fluorescence (Chl a), backscattering or radiometry, as well as other chemical sensors, such as nitrate or pH. Euro-Argo focused on improving BGC-Argo float capabilities → Figure 20, specifically via implementing in-air calibration procedures, adapting new biogeochemical sensors, integra-ting pH sensors and prototyping a float with the capacity to carry a pCO2 (par-tial pressure of carbon dioxide) optode. These new sensors have now been fully integrated into the floats, with pH having been assessed both technically and scien-tifically and pCO2 still at a prototype phase and requiring further research. Euro-Argo has been instrumental to the adoption of the revised IOC resolution IOCXX-6, prepared by Argo, Argo BGC leadership and the GOOS Project office. This proposal was presented at the 2018 IOC General Assembly and extended the previous resolution scope to the six BGC Argo parameters → Table 3. Euro-Argo national representatives provided strong support to the adoption of this proposal.

BOX 4 FRENCH CONTRIBUTION, NAOS AND RemOcean PROJECTS

The objective of NAOS (Novel Argo Ocean observing System) project is to consolidate and improve the French contribution to Argo and to prepare the next scientific challenges for Argo. NAOS is designed as a complement to Argo France and Euro-Argo ERIC (funded through the French Ministry for research and Education: Equipex).

RemOcean was a project CNRS/SU, LOV funded in 2010 by the European Research Council, which aimed at addressing the causes of variability in the biological oceanic pump with a strong focus on the role of phytoplankton production. RemOcean was a highly regarded programme that contributed to the emergence of international Biogeochemical-Argo programme.

A boost for deep sensing

The ocean deeper than 2000m is currently under sampled, even though it represents more than 50% of the total ocean volume. Given the role of the deep ocean in the Earth's climate, a global long-term monitoring system for depths greater than 2000m is essential. Technology to perform valuable measurements down to 4000m was developed under the French NAOS project: two prototypes, developed by Ifremer, were tested at-sea in 2012, followed by two other floats, produced by NKE Instrumentation, and deployed in the northern North Atlantic in 2014.
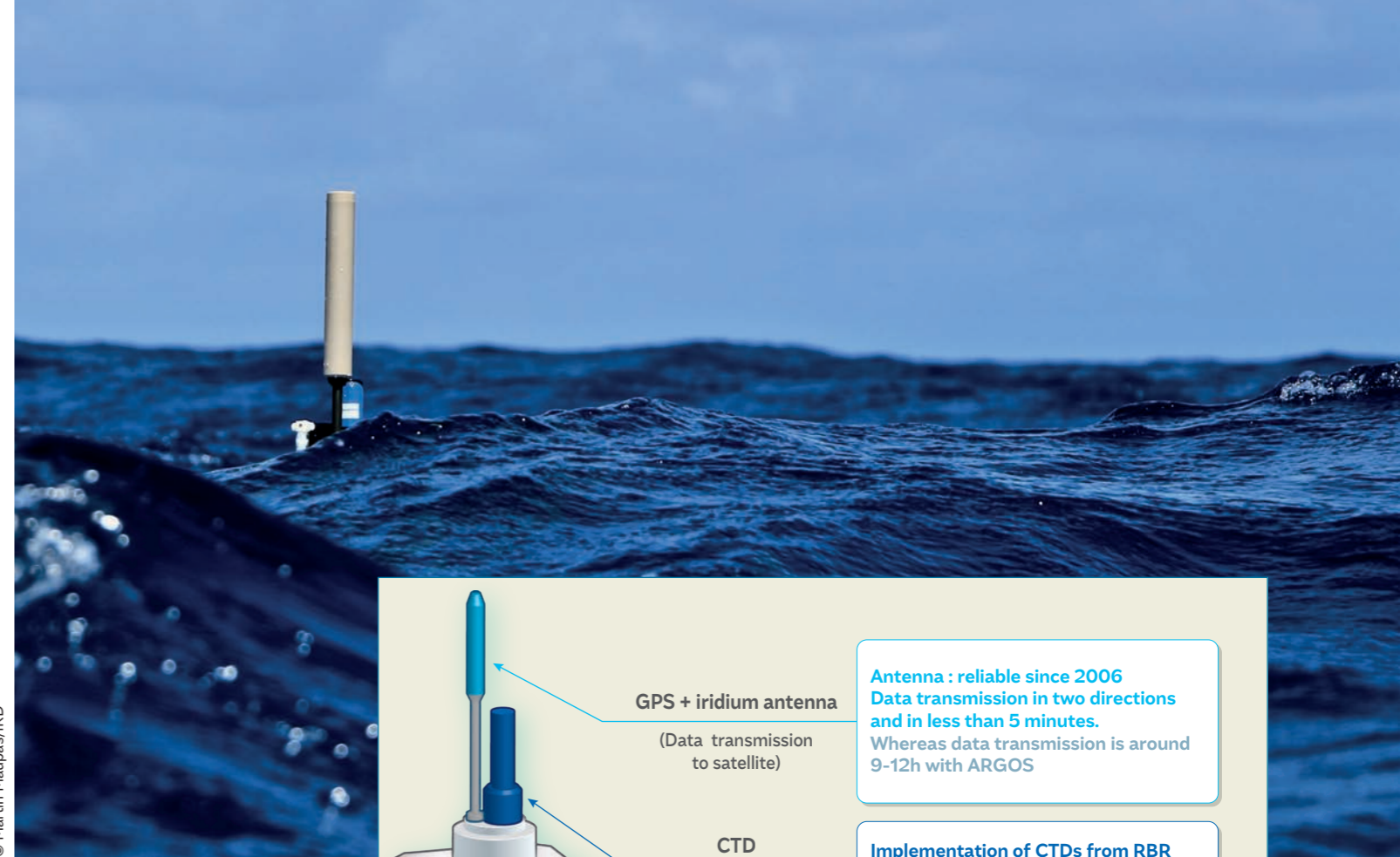
> The ocean deeper than 2000m is currently under sampled, even though it represents more than 50% of the total ocean volume.

Following on from a public procurement process conducted by Ifremer, NKE Instrumentation was awarded a license to manufacture and commercialize a new float model (Deep-Arvor). The deep floats were further tested under the European projects E-AIMS (2013-2015)

and AtlantOS (2015-2019). These tests allowed to highlight satisfactory initial performance of the Deep-Arvor floats, despite some issues remaining, regarding the quality of CTD (Conductivity Temperature Depth sensor) measurements. Thus, there were some salinity bias that can be corrected after calibration. Deployment of Deep-Apex floats with the ability to sample to 6000m have also been conducted in parallel (UK), resulting in a total contribution of Europe of almost one third of the total deployment of Deep Argo floats since 2012.

Various technologies have been developed over the past five years to meet users' needs → Figure 21, thanks to collaboration with the private sector in the framework of the H2020 AtlantOS and ENVRIplus projects. National contributions and specifically French participation played a pivotal role in supporting these technological improvements, thanks to funding from ERC RemOcean, CPER and ANR Equipex NAOS, CNES (see Box 4).

© Martin Maupas/IRD

Deployed Deep float with Dissolved Oxygen sensor.

GPS + iridium antenna
(Data transmission to satellite)

Antenna : reliable since 2006 Data transmission in two directions and in less than 5 minutes. Whereas data transmission is around 9-12h with ARGOS

CTD
(Conductivity Temperature Depth sensor)

Implementation of CTDs from RBR thanks to Euro-Argo

Electronics

Improvements on a new PCB are in progress : with up-to-date components, more flexibility to carry sensors and new softwares

Battery

Studies are in progress to integrate the last updates on batteries technology to obtain a better ratio profile over current draw

Hydraulics
(to ensure descent and ascent thanks to buoyancy change)

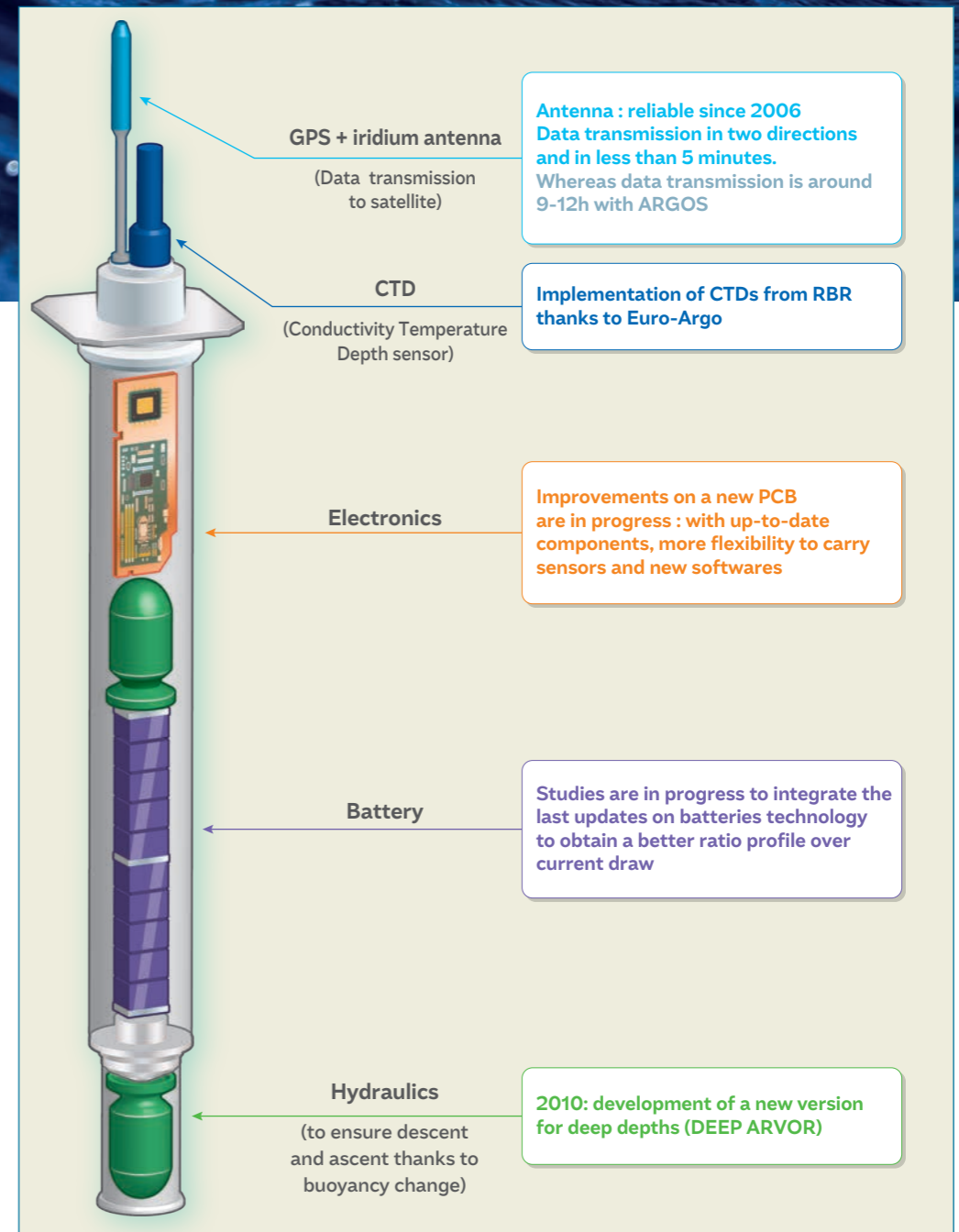2010: development of a new version for deep depths (DEEP ARVOR)

Figure 21: technological innovations on Argo floats in the past five years.

© Thomas Haessig

A VISIBLE AND ACCESSIBLE INFRASTRUCTURE

Euro-Argo's visibility is of paramount importance in boosting the accessibility and value of Argo data. The interactive Euro-Argo website provides access to Argo data and highlights the activities involving the Euro-Argo community.
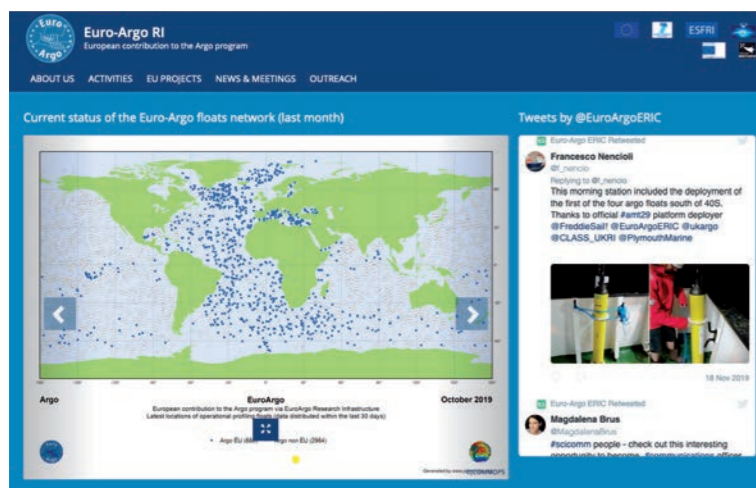
WEBSITES AND TOOLS FOR AN INTERACTIVE INFRASTRUCTURE

Euro-Argo's visibility and access to information regarding its infrastructure are promoted at different levels including:
– Euro-Argo Office, via the official Euro-Argo website (www.euro-argo.eu), providing a dynamic news section based on updates by Members, as well as providing direct access to data and individual float webpages. The main Euro-Argo ERIC website centralises all information on the ERIC and contains links to the National contributors, scientific partners and stakeholders, as well as information on the projects to which the Euro-Argo Office contributes;
– National Members have developed webpages dedicated to their relevant national Argo programmes;

– "At-sea Monitoring" website, hosted by Ifremer for the European fleet;
– Argo Regional Centres provide direct and simplified access to data and maps showing the state of the ocean in the relevant regions. Reference datasets are updated regularly (see Chapter 4 p. 32). These ARC websites are directly managed by the Argo Regional Centres.

To develop synergies with the Argo scientific community, a newsletter is released every 4 months. It highlights the Euro-Argo ERIC activities developed by the ERIC Office and National Members and includes: meetings, conferences, training, science & technology highlights and float deployments. The newsletter, distributed to more than 400 people, also presents new scientific publications based on Euro-Argo data.
Social media is also part of the communication strategy: an ERIC Twitter account (@EuroArgoERIC, has undergone significant expansion from 90 followers in 2016, to approximately 800 in 2019) retweets news, events, interesting articles and images from various linked accounts including national Argo programmes such as Argo-Italy (@OGS_MAOS), Argo Spain (@Argo-Spain1) or Argo UK (@ukargo).

Quai des Sciences, Brest 2016, (right).

Euro-Argo website front page (www.euro-argo.eu).

© Olivier Dugornay/Ifremer

Brest 2016.

A STRONG PRESENCE IN RELEVANT EVENTS

The Euro-Argo Office directs communication towards the scientific community and the public at large, in various forms. All communication activities are reinforced by active national contributions. To stimulate the scientific community's interest in using Argo data, many actions have been undertaken at national level. Participation via a booth and dedicated presentation at the GAIC Workshop 2015, "Sustained Ocean Observing for the Next Decade", in Ireland, provided effective exchanges with the Global Ocean

Ship-based Hydrographic Investigation Programme (GO-SHIP) and International Ocean Carbon Coordination Project (IOCCP) communities. Lectures on the Argo programme are delivered as part of the UNESCO/ICTP Diploma Course in Earth System Science (2011 onward), and the International Summer School on Sustainable Blue Growth (2014 onward), in Italy. Euro-Argo's participation in the international conference on communication in the marine sciences (commOCEAN 2016) provided an opportunity to exchange tips on communication tools and strategies with other scientific communities. Some touristic boats also allow a real synergy between science and the public at large **(see Box 5)**.

BOX 5 SYNERGY OF SCIENCE AND TOURISM

Since 2012, KNMI (Koninklijk Nederlands Meteorologisch Instituut – Royal Netherlands Meteorological Institute) and Oceanwide Expeditions (a cruise operator) have cooperated in deploying Argo floats, in southern latitudes. Oceanwide's Antarctica cruises offer a unique opportunity to reach these remote areas. More than 30 floats have been deployed on these voyages to date. Float deployment is done "in public" (i.e. with passengers in attendance and who are provided with background information on Argo).

EOOS Conference (left) and Brest, 2016 (right).

Galway Sea Fest, 2017 (left) and Fête de la Science, Paris 2017 (right).

Argo revolves around a technology relatively unknown to the public. To present this new innovative technology and its related challenges, several communication tools, designed by the Euro-Argo Office, are available to support National Members in their outreach activities. It includes: a demonstration float with a mobile booth, brochures, posters as well as templates, allowing members to create targeted, specific thematic leaflets. A public outreach brochure, translated into various Members' languages, has also been developed. Argo outreach events are popular with the public and generate a significant amount of interest. Public events are largely undertaken nationally by Members, with the most prominent events being:

– Argo exhibition at SeaFest (Ireland's national maritime festival) in 2016-2018, included Argo specific video, brochures, JCOMMOPS deployment map, an Argo demonstration float, all done on-board public tour of the Irish Research Vessel (RV Celtic Explorer);

– the International Maritime Festival in Brest in 2016, with deployment of ocean-observation techniques via different instruments (profiling floats, drifters, opportunity vessels, tide gauges and satellite);

– an exhibition at the Cité des Sciences et de l'Industrie, in Paris. Visitors were offered explanations on climatic phenomena such as the El Niño-Southern

> Several communication tools, designed by the Euro-Argo Office, are available to support National Members in their outreach activities.

Oscillation, oceanic circulation, and biogeochemical mechanisms. An estimated 21000 visitors attended the six-day event;

– Trieste Next (a large annual scientific-research festival in Italy), at which an Argo-Italy exhibit corner is permanently set up, with posters and demonstration equipment;

– the European Researchers' Night, Open Days for national research institutions (Italy, Germany and Ireland).

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Scholar visits.

A STRONG IMPLICATION IN EDUCATIONAL PROGRAMS

Marine-science knowledge transfer is essential in raising awareness in order to keep the ocean healthy for the wellbeing of future generations. The Euro-Argo Office and Members actively participate in educational programmes, involving both pupils and teachers (e.g. France "Adopt a Float", "Sea and Education", the online educational platform " Connected Oceans", school visits in Greece, and the Argo Ambassador's programme in Finland – **see Box 6**).

Euro-Argo with JCOMMOPS, co-initiated the first international "Ocean Observers" workshop in 2017. The workshop brought together marine scientists, representatives of educational institutions, teachers, maritime-communication experts and representatives from the sailing world. These stakeholders shared resources and experience from marine-science education and explored opportunities for international collaboration in this domain.

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EURO-ARGO AND THE PRESS

Several radio broadcasts in Italy (on RAI station) have been dedicated to Argo, Euro-Argo and Argo-Italy. Press releases have been published in Spain and Ireland, while popular-science articles have been published in newspapers, on the Norwegian Argo infrastructure. The UK provides material to Public Understanding of Science, a fully peer-reviewed international journal covering all aspects of the inter-relationships between science and the public.

HIGH QUALITY USER TRAININGS & WORKSHOPS

To facilitate the processing of Argo data and to stimulate use of Argo data in European research, the Euro-Argo ERIC has organised several "users workshops" on a bi-annual (every 2 years) basis. The objective of the user workshops is to enhance access to the Argo programme, especially among young scientists. The workshops also aim to go beyond essential uses in physical oceanography and climate research and investigate topics

> The goal of users workshops is to enhance access to the Argo programme, especially among young scientists.

such as ocean deoxygenation, ocean acidification and areas of interest (e.g. Marginal Seas, boundary currents and high latitudes). National Members are heavily involved in the organisation of these meetings and in thematic scientific workshops (e.g. the Argo session on oxygen measurement, during the French workshop in 2017).

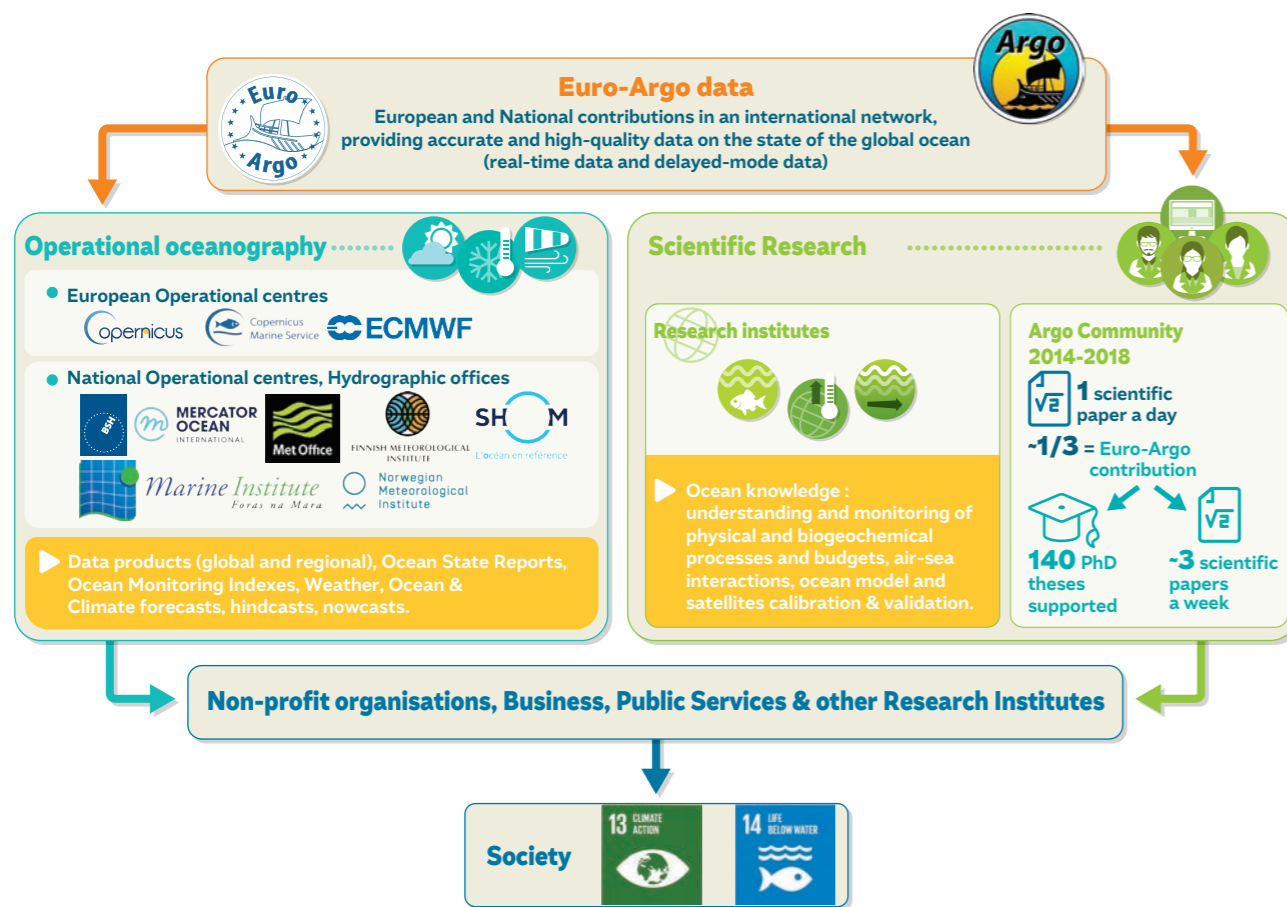Participants to the 5th Euro-Argo Users Meeting in Brest, March 2015.

© Ifremer

EURO-ARGO DATA USE

Argo is a global in situ observation network of crucial scientific importance, generating unprecedented datasets used in operational centres to produce standardised products. The scientific community relies on Argo data to understand the ocean's physical processes, as well as the marine ecosystem, and to make forecasts for the ocean. Euro-Argo contributes approximately one quarter of this data.

The free and open-access policy of Argo makes the data easily accessible to a wide range of users. Argo data are distributed through various data portals and converted into numerous products used by both public agencies and private companies. It remains the main *in situ* data provider with such a large, sustained and uniform coverage of the global ocean.
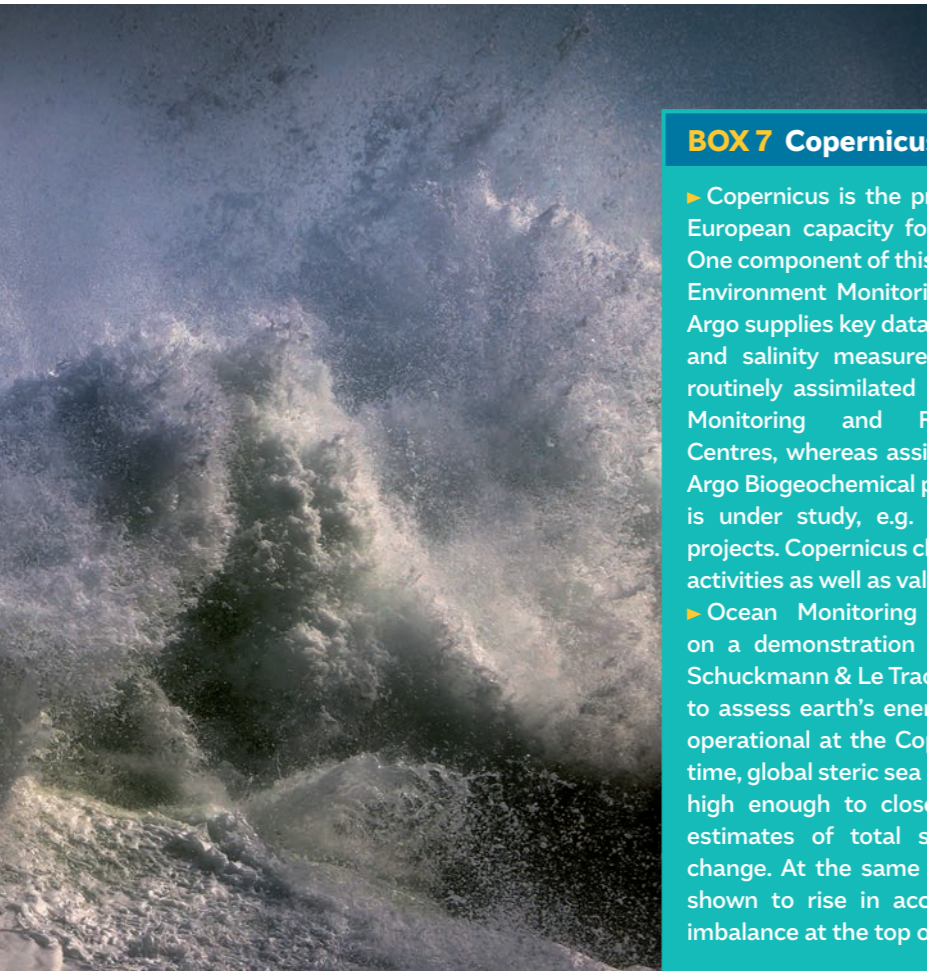
© Pixabay

Euro-Argo data
European and National contributions in an international network, providing accurate and high-quality data on the state of the global ocean (real-time data and delayed-mode data)

Operational oceanography
- European Operational centres
  Copernicus • Copernicus Marine Service • ECMWF
- National Operational centres, Hydrographic offices
  BSH • MERCATOR OCEAN INTERNATIONAL • Met Office • FINNISH METEOROLOGICAL INSTITUTE • SHOM L'océan en référence • Marine Institute Foras na Mara • Norwegian Meteorological Institute

  ▶ Data products (global and regional), Ocean State Reports, Ocean Monitoring Indexes, Weather, Ocean & Climate forecasts, hindcasts, nowcasts.

Scientific Research

Research institutes

▶ Ocean knowledge : understanding and monitoring of physical and biogeochemical processes and budgets, air-sea interactions, ocean model and satellites calibration & validation.

Argo Community 2014-2018
1 scientific paper a day
~1/3 = Euro-Argo contribution
140 PhD theses supported
~3 scientific papers a week

Non-profit organisations, Business, Public Services & other Research Institutes

Society
13 CLIMATE ACTION
14 LIFE BELOW WATER

Figure 21: Argo data-user communities.

© Ray Bilcliff/Pexels

BOX 7 Copernicus and OMI

▶ Copernicus is the programme for the establishment of a European capacity for Earth Observation and Monitoring. One component of this programme is the Copernicus Marine Environment Monitoring Service (CMEMS), to which Euro-Argo supplies key data in near real time. Today, temperature and salinity measurements are routinely assimilated in CMEMS Monitoring and Forecasting Centres, whereas assimilation of Argo Biogeochemical parameters is under study, e.g. through CMEMS "service evolution" projects. Copernicus checks both monitoring and forecasting activities as well as validating satellite observations.

▶ Ocean Monitoring Indicators (OMIs) were calculated on a demonstration basis in 2014 from Argo data (von Schuckmann & Le Traon, 2011) to gauge global warming and to assess earth's energy and sea-level budget. This is now operational at the Copernicus Marine Service. For the first time, global steric sea level can be estimated with a precision high enough to close the gap between satellite-derived estimates of total sea-level change and mass-induced change. At the same time, global ocean heat content was shown to rise in accordance with the estimated energy imbalance at the top of the atmosphere.

FOR OPERATION SERVICES

Operational centres integrate *in situ* and satellite-observation data in real time (operational oceanography), using numerical models. The output from the models is used to generate data products including:

The Argo time-series over the past two decades have enabled the CMEMS to produce a number of Ocean Monitoring Indicators (OMIs).

– nowcasts, which provide accurate descriptions of the present state of the sea, including living resources;
– forecasts, which predict the sea's future condition as far ahead as possible;
– hindcasts, which describe past states;
– time-series, which show trends and changes over time.

Copernicus: Europe's eyes on Earth

Sustained Euro-Argo data contribute to the monitoring and the ongoing assessment of oceanic phenomena at both regional and global scales. CMEMS publishes an Ocean State Report annually, targeting scientists and policy-makers. It describes the current state of the global ocean and the European regional seas, as well as any recent changes. The Argo time-series over the past two decades have enabled the CMEMS to produce a number of Ocean Monitoring Indicators (OMIs) to monitor any changes in the ocean and trends over the past 25 years **(see Box 7)**.

Forecasting centres

At national level, the use of Argo data for ocean monitoring and forecasts is important and supports interaction

**Katrina hurricane.
(on right)**

with national operational centres. Euro-Argo assists with the enhancement of monitoring and observing systems at regional scales, which is already used for model-validation purposes, such as for the Greek Poseidon system, or the Western Mediterranean Operational forecasting system (SOCIB-WMOP) model. Argo data have been assimilated into the Arctic Modelling and Forecasting Centre (NERSC/METno) in the Nordic Seas and Fram Strait. It is planned that Argo data will be assimilated into other regional forecasting models in the future (e.g. Baltic Sea, Bay of Biscay) and to use Euro-Argo (specifically BGC-Argo) data for Marine Strategy Framework Directive (MSFD), monitoring in conjunction with other observing systems.

European Centre for Medium Range Weather Forecasting (ECMWF) integrates Argo data into models in conjunction with other data, to come up with global forecasts, climate reanalyses and

specific datasets designed to meet different user requirements. The Centre produces a set of predictions on how weather is most likely to evolve, as well as the likelihood of a range of future weather scenarios.

Meteo France uses Argo data to define quality ocean-model products that are then used for various applications, such as weather forecasts.

In Ireland, Argo floats are deployed on an annual climate change survey: a collaborative survey between the Ocean Science and Information Services (OSIS) and the Marine Environment and Food Safety (MEFS) teams of the Marine Institute.

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A German Navy frigate.

MOCCA float deployment in the Agulhas Current, August 2017.

BOX 8 Met Office

At the Met Office, Argo data are used operationally. The data are routinely assimilated into its Forecasting Ocean Assimilation Model (FOAM) suite, which is run daily, produces two analysis per day and a seven-day forecast. Fields from global FOAM are also used in the ocean component of coupled monthly-to-seasonal forecasts and for decadal predictions. A coupled ocean/atmosphere prediction system has been developed for weather forecasting timescales which delivers information to CMEMS.

The Met Office in the UK interacts closely with the atmospheric community who uses Argo data to validate output from the Met Office's OSTIA (Operational Sea Surface Temperature and Sea Ice Analysis) (see Box 8).

National maritime hydrographic services

National maritime hydrographic services exploit Argo data to improve knowledge regarding ocean circulation, an essential aspect of national operations. For example:
– FMI maritime service in Finland uses Argo data for situation-awareness analysis to support national authorities and the public;
– SHOM in France uses Argo data to enhance ocean-circulation forecasts for navy vessels, and contributes to Argo's floats purchases and deployments;
– the Polish Navy relies on Baltic-Argo data;
– the German Navy uses Argo data extensively in its operations, and in turn provides deployment opportunities in data-poor regions or those with safety concerns.

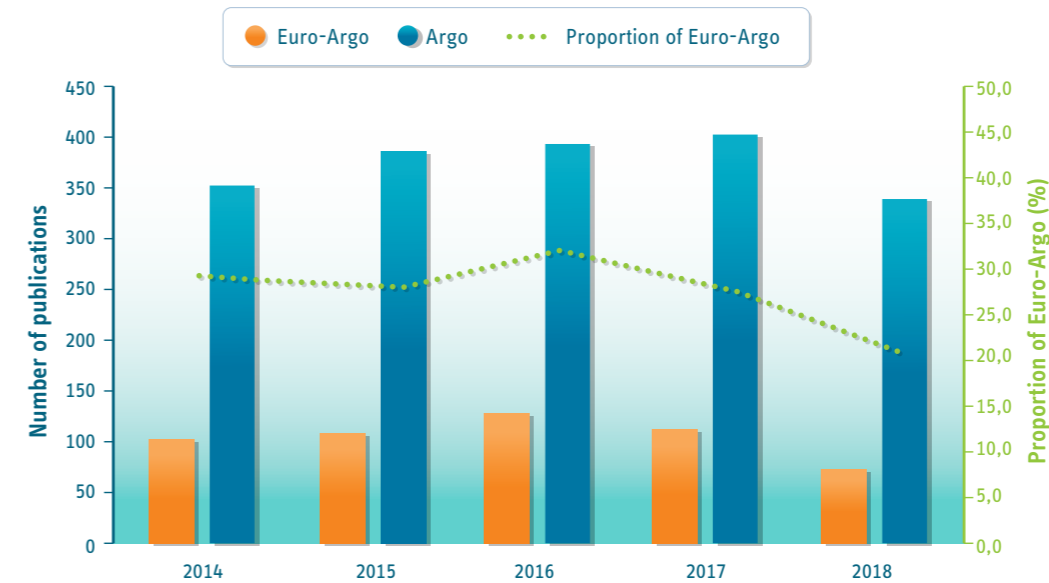**140** PHD THESIS/2014-2018

~3 PEER REVIEWED PAPERS PER WEEK

Figure 22: Evolution of Euro-Argo vs. Argo publications (2014-2018).

FOR THE SCIENTIFIC RESEARCH

At international level, more than 3300 scientific papers have been published since 1990 by the Argo community, with a publication rate exceeding one paper per day over the last five years. Taking Euro-Argo papers as publications with the first author affiliated in a European country, Euro-Argo contributed, on average, to more than 27% of these papers (→ Figure 22). Since the beginning of the Euro-Argo programme approximately 140 PhD theses have been supported, and nearly 1000 scientific papers have been published by the Euro-Argo community.

Physical oceanography

To better understand global sea-level rise and to study various ocean processes

Many recent scientific achievements have been attained in Europe due to the availability of Argo data. Argo data have been used to better understand global
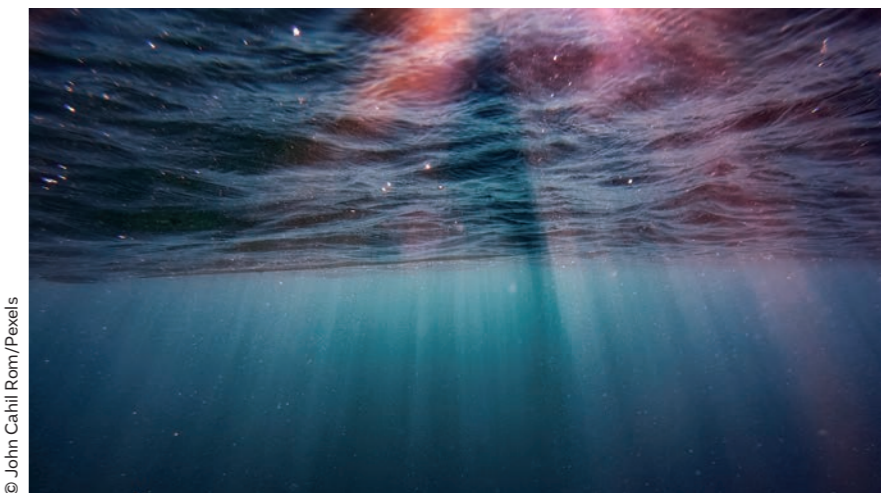
sea-level rise (e.g. Dieng et al., 2017) and ocean heat content (Roberts et al., 2017; Maze et al., 2017). Argo dataset enables analyse of large-scale ocean circulation (Ollitrault & De Verdière, 2014) and ocean circulation in specific regions. In Europe, we can list for instance the recent studies of de Jong et al. (2018) in the Iceland Sea, Pingree & Garcia-Soto (2014) in the Bay of Biscay, Mackay et

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Sea were only possible thanks to Argo data. In the Mediterranean Sea, Testor et al. (2018) have also used Argo data combined with other *in situ* measurements such as gliders and moorings to record deep convection during winter (2012-2013) and its multiscale aspect.

> The profiles acquired by Argo floats in high latitudes during winter provide crucial data for the study of dense water mass formation, a major process in ocean physics.

To investigate Atlantic Water inflow into the Arctic Ocean

Investigations of the Atlantic Water inflow into the Arctic Ocean and climatic aspect of this process for over 20 years is now possible. An annual summer survey is organised to the Nordic Seas and Arctic Ocean, using the IOPAN research vessel Oceania. Data from the Argo floats deployed in this region support the study of the advection of warm Atlantic Water through the Nordic Seas and changes in Atlantic water properties. Argo results are compared with data from standard *in situ* measurements which are then used to calculate propagation velocities to infer current pathways. The Argo measurements fill in gaps during winter.

al. (2018) in the Arctic and the Subpolar North Atlantic, Somavilla et al. (2016) in the North Atlantic, Rousselet et al. (2016) in the Coral Sea, Czeschel et al. (2015) in the South Pacific Ocean, Hummels et al. (2015) in the South Atlantic, Kovačević et al. (2015) in the Ionian Sea, Meredith et al. (2015) in the Southern Ocean and Velaoras et al. (2014) in the Cretan Sea.

Argo data are also used to study various ocean processes. Raj et al. (2016) and Keppler et al. (2018) have respectively described the main surface characteristics of mesoscale eddies in the Norwegian Sea and the Southwest Tropical Pacific Ocean thanks to satellite altimetry data and their vertical structure reconstructed by Argo floats. In the Tropical South Indian Ocean, Aguiar-González et al. (2016) have suggested that a thermohaline front created by the encounter of Indian Equatorial Water and relatively warmer and fresher

Indonesian through-flow water plays an important role as remote forcing to the tropical gyre.

To study ocean circulation and water mass properties

Argo data have also been combined with other measurements such as moorings and altimetry to estimate the Atlantic meridional overturning circulation which plays a key role in the global climate system, through its redistribution of heat (McCarthy et al., 2015) and its variability (Mercier et al., 2015).
Recent studies have been published highlighting hydrographic property changes assessed thanks to Argo measurements in the Subpolar Atlantic (Tesdal et al., 2018) and in the Nordic Seas (Lauvset et al., 2018; Mork et al., 2019).
Argo provides information on water mass properties useful to understand ocean processes such as water mass formation. The profiles acquired by Argo

floats in high latitudes during winter when ship-based measurements are unreliable (due to challenging weather conditions) are particularly important as they provide crucial data for the study of dense water mass formation, a major process in ocean physics. Many studies such as the work of Våge et al. (2009) and more recently Piron et al. (2017) on deep convection events in the Labrador

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© Linus Nylund/Unsplash

To better understand the exchange of energy between the atmosphere and the ocean

Argo has also significantly increased the amount of near-surface temperature and salinity measurements at global scale, enabling better description of the exchange of energy between the atmosphere and the ocean (Castro et al., 2014; Moore et al., 2014), a key process in regulating both the mean state and the variability of the climate system.

> Long-term observation of the deep ocean demonstrates how much and how fast the ocean will warm due to increasing greenhouse-gas concentrations.

To study heat storage and heat transport

The ocean's abyssal layers play a crucial role in the long-term evolution of the Earth's surface temperature through their ability to store and transport heat. Intermediate, deep and abyssal ocean layers make critical contributions to global energy and sea-level balances. Monitoring these layers is now possible thanks to Deep-Argo (Le Reste et al., 2016). In the Nordic Seas, Argo-type measurements collected since 2001 have allowed investigation into the role of each of the seas' deep basins in the water-mass transformation process. Latarius & Quadfase (2016) established the seasonal cycle in the upper 1300-2000m of the water column in these basins, through observations of their water-mass transformations. Meanwhile in the Atlantic, Argo data helped to reveal that the Canary Islands archipelago disrupts the deep poleward undercurrent, even at depths where the flow is not blocked by the bathymetry (Vélez-Belchí et al., 2017).

To investigate the deep circulation

The North Atlantic Subpolar gyre is an important region for the formation of deep-water masses. To help understand deep circulation and its driving mechanisms the Laboratoire d'Océanographie Physique et Spatiale (LOPS, France) deployed five Deep Arvor floats (capable of sampling temperature, salinity and dissolved oxygen down to 4000m) in this region, between 2015 and 2016. None of these floats circulated northward to the Irminger basin as expected, from recent work on general deep-circulation structures (e.g. Daniault et al., 2016). One deployed Deep Arvor revealed a new pathway, directly westward towards Newfoundland, as far as the western boundary current (Racapé et al., 2019). Taking all float trajectories combined with satellite observations and analysis of deep-water mass characteristics, the LOPS study shows that surface circulation strongly influences float displacements while the deep circulation is influenced by the North Atlantic Current.

To better understand the Marginal Seas

Semi-enclosed marginal seas such as the Mediterranean and Black Seas, characterised by much smaller scales of variability than the global ocean, are strongly affected by climate change. The Mediterranean region is one of the climate change "hotspots", with an increasing demographic growth and overexploitation exerting exceptional pressure on its environment, ecosystems, services and resources. As a result, the deployment of Argo floats in these marginal seas is a way to feed data into models and obtain indicators regarding anthropogenic impacts. Increased monitoring in the Black Sea has led to a better understanding of its circulation, thermohaline stratification and the factors that control its biogeochemical cycles. The spatio-temporal distribution of coexisting water masses in the Aegean Sea, examined using an unprecedented number of profiles acquired from Argo floats, has shed light on hydrodynamic features and changes throughout the basin (Kassis et al., 2016). Thanks to a multiplatform approach, including gliders and Argo profiling floats, a unique dataset was collected over a one-year period in the Gulf of Lion, leading to an improved description of the underlying hydrodynamic processes at work (before, during, and after deep-ocean convection events), and their link with the area's considerable phytoplankton spring bloom (Kessouri et al., 2018).

> The Mediterranean region is one of the climate change "hotspots", with an increasing demographic growth and overexploitation exerting exceptional pressure on its environment, ecosystems, services and resources.

Argo floats operating in the Baltic Sea also make valuable contributions, by allowing accurate monitoring of the seasonal changes of water masses (Haavisto et al., 2018). Float trajectories have also been studied as a method for estimating currents in the deeper layers of the Baltic Sea (Roiha et al., 2018). In the Bothnian Sea (linked to the Baltic Sea), a new dataset, produced by autonomous shallow-water Argo floats, was used to validate a NEMO-based model of large-scale seasonal variations in temperature (Westerlund & Tuomi, 2016).

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To better know the Polar Regions

Polar Regions (specifically continental icecaps) are more vulnerable to global warming than other regions. Melting icecaps not only affect ocean and atmospheric systems, but also sea-levels, global transport processes, energy and thermal balances. Observation of the Arctic Ocean is a major target within Argo's strategy for Europe, as a supplement to

> Recent changes in the Arctic Ocean's ice cover and hydrography call for enhanced monitoring of ocean properties.

other observing systems, such as moorings, ice-tethered profilers and gliders. Recent changes in the Arctic Ocean's ice cover (Serreze & Stroeve, 2015; Meier et al., 2007) and hydrography (Polyakov et al., 2008) call for enhanced monitoring of ocean properties, in terms of both temporal and spa-

tial resolution. Harsh Arctic conditions require the Argo community to take a considerably different approach in this region compared to oceans in general. Over the past number of years, approximately 15 Euro-Argo floats with ice-avoidance capabilities have been deployed close to the Fram Strait and the West Spitsbergen. Argo floats usually recirculate to the Greenland Sea or move to the Arctic Ocean. Euro-Argo aims to deploy floats in marginal ice zones, while other systems such as ice-tethered profilers, moorings and icebreakers already monitor multi-year ice zones.

Discussion with the Arctic community is underway regarding the possibility of integrating Argo into the Arctic observing system. In the Southern Ocean, Argo floats also contribute to the provision of valuable data, which complement other sources of data such as measurements from sea mammals as shown by Pellichero et al. (2017).

To validate models

In addition to their importance for constraining operational models, Argo measurements provide datasets widely used for model validation. Over the past number of years, salinity and temperature measurements have been used to assess the performance of different models:

– Regional scale (Clementi et al., 2017; Kassis et al., 2017) in the Mediterranean Sea, and Westerlund & Tuomi (2016) in the Baltic Sea;

– Global model studies (e.g. study by Mogensen et al. (2017) in the ECMWF coupled ocean-atmosphere model).

Biogeochemical properties and ecosystem variables

The ocean's chemical composition influences phytoplankton production and affects other plankton communities. It triggers a cascade effect on the food chain in its entirety, as well as the marine ecosystem. Argo allows investigation of the ocean's biogeochemical properties (key indicators of ocean health), thanks to the BGC-Argo dataset.

To better understand biological production

Argo data give indications of the nutrient levels in monitored regions, and their potential productivity. Nitrate measurements offer insights into important mechanisms of nutrient supply to the ocean surface that supports biological production (D'Ortenzio et al., 2014; Pasqueron De Fommervault et al., 2015).

### To identify components of the biological carbon pump

Components of the biological carbon pump – the ocean's potential to sequester carbon through biogeochemical processes – can also be researched via BGC-Argo floats (for review see Claustre

et al., 2020). pH measurements are used to estimate dissolved inorganic carbon (DIC) concentrations (Williams et al., 2018), mainly derived from the uptake of atmospheric carbon when combined with estimates of total alkalinity (Bittig et al., 2018; Carter et al., 2018). BGC-Argo measurements using bio-optical sensors help to identify new carbon-export pathways and mechanisms (Dall'Olmo et al., 2016; Lacour et al., 2019; Boyd et al., 2019).

To study the role of eddies in biological processes

Argo floats can be trapped in mesoscale eddies, potentially providing information on the remineralization process (the reconversion of organic matter into CO2) (Karstensen et al., 2015) and carbon export (Fiedler et al., 2016) below the surface. BGC-Argo data has also revealed the role of eddies and allowed measurement of deep and surface chlorophyll (Dufois et al., 2017; Pasqueron De Fommervault et al., 2015). They can also be useful in characterizing different types and origins of particulate organic matter (Ohde et al., 2015).
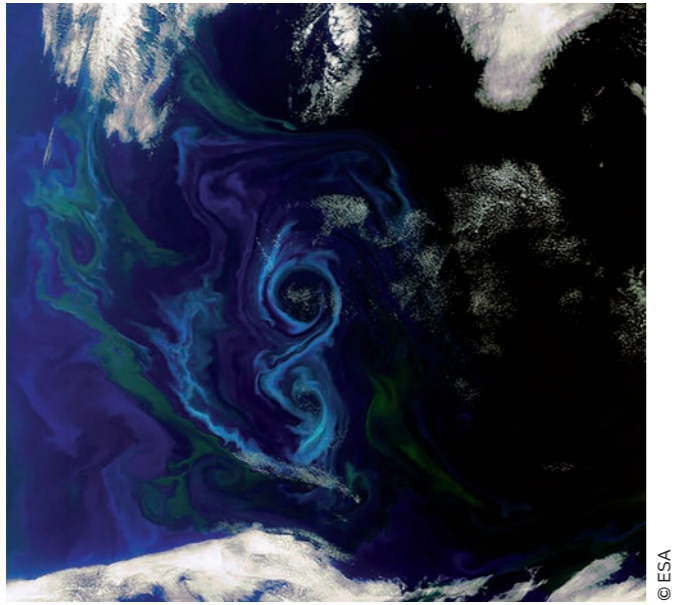
A phytoplankton bloom that swirls a figure-of-8 in the South Atlantic Ocean about 600 km east of the Falkland Islands.

© ESA

To better understand phytoplankton dynamics

Argo floats have provided data on seasonal phytoplankton dynamics in the euphotic layer and their dependence on the light regime (Mignot et al., 2014). Argo floats have also supported studies on the timing, duration and magnitude of phytoplankton blooms, in different regions, as well as comparisons between different areas such as the Pacific, Atlantic and Indian sectors of the Southern Ocean (Claustre et al., 2020).

To improve model estimates and climatologies

The combination of biogeochemical data with ocean-colour data improves model estimates of oxygen, nutrients and carbon throughout the water column (Fennel et al., 2019), and mitigates models on seasonal and vertical dynamics of Chlorophyll a in the Mediterranean (Cossarini et al., 2019).

Argo variables (temperature and salinity) and ocean-colour have also been merged thanks to a neural network-based method to extend surface bio-optical properties to depth, fostering the development of global climatologies encompassing 4 dimensions (latitude, longitude, depth and time) (Sauzède et al., 2016).

To explore the under-sampled meso-pelagic zone and oxygen minimum zones

BGC-Argo data allows exploration of the under-sampled mesopelagic zone (~100-1000m) (Dall'Olmo & Mork, 2014; Estapa et al., 2017; Rembauville et al., 2017). Although too deep for photosynthesis, this zone is a major part of the ocean's carbon cycle (Costello & Breyer, 2017) as it collects and partly remineralizes the by-products of photosynthesis occurring in the euphotic layer (~0-100m).

Czeschel et al. (2018) have demonstrated that Argo floats with oxygen and nitrate sensors deployed in oxygen minimum zones (OMZs) allow observation – unattainable by other approaches – of long-term trends in the ocean's carbon cycle. In anoxic waters such as the Black Sea, nitrate measurements help revealing the structure of the anoxic interface (Stanev et al., 2018).

To infer biogeochemical properties from physical parameters using machine-learning techniques

In addition, recent studies based on machine-learning techniques open new avenues in ocean monitoring. Machine-learning can be used on BGC-Argo vertical profiles to predict nutrients and carbonate systems from temperature, salinity and O2 (Sauzède et al., 2018; Bittig et al., 2018).

According to:		The scientists can make conclusion on:
The BGC parameters measured thanks to Argo float	Nitrates	Biological production
	pH	DIC concentrations and consequently, the components of the biological carbon pump
	Chlorophyll a	Photosynthesis and phytoplankton dynamics
The other parameters used in combination with the BGC parameters	Bioptical sensors	New carbon-export pathways and mechanisms
	Ocean colour	• Models estimation of oxygen, nutrients and carbon throughout the water column • Models mitigation on seasonal and vertical dynamics of Chlorophyll a (e.g. in the Mediterranean Sea)
The specific location of the BGC Argo floats	In eddies	Remineralization process and carbon export
	In mesopelagic zones	The major part of the ocean's carbon cycle
	In OMZs	Long-term trends in the ocean's carbon cycle
	In anoxic basin	The structure of the anoxic interface

Table 4. The main conclusions scientists can reach thanks to BGC parameters.

Summary

Long-term observation of ocean biogeochemistry helps to broaden understanding of the evolution of the marine ecosystem → see Table 4, including the ocean carbon pump and the coupling of physics and biology. Long-term observation also provides data for assessments on the impact of climate change on ocean chemistry and ecosystems. BGC-Argo floats expose the state of ocean health through direct observation of its absorption/production of various parameters (oxygen, pH and nitrate) across seasons.

Long-term observation of ocean biogeochemistry helps to understand the evolution of the marine ecosystem and the impact of climate change.

The two sustainable-development strategies that focus on the ocean.

Monitoring of changes in the ocean, mainly due to human influence and ranging from climate change to pollution, is central to the definition of sustainable-development strategies. Several United Nations Sustainable Development Goals (SDGs) focus on the ocean and hinge on its continuous and long-term monitoring. SDG14 for example, refers to sustainable use of the ocean while SDG13 aims at combating climate change, goals that both directly relate to the good health of the oceans. Euro-Argo contributes to addressing these challenges through its global coverage of the oceans and its production of time series of physical, as well as biogeochemical parameters.

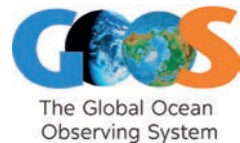# 9 EURO-ARGO, PART OF THE INTEGRATED OCEAN OBSERVING SYSTEM

An integrated observing system is the crux of a holistic scientific understanding of the Earth system. It relies on synergies between marine research programmes, infrastructures and projects. It inspires a more coherent, interdisciplinary and interoperable cluster of marine initiatives by creating new innovative solutions for observational and data-management challenges. Euro-Argo is a major actor in this integrated ocean-observing system.

The Global Climate Observing System (GCOS)-WMO and the GOOS of IOC-UNESCO are collaborative systems of sustained ocean observations encompassing *in situ* networks, satellite systems, governments, UN agencies, RIs and individual scientists. The GOOS and its European component – Euro-GOOS – provide a forum for observing-platform networks and regional systems, as well as cooperation to unlock quality marine data and deliver common strategies, priorities and standards. Task Teams have been implemented to promote scientific synergy and technological collaboration among European ocean-observing infrastructures. Euro-Argo is identified as one of the Euro-GOOS observation Task Teams, stressing the importance of Argo observations in the European Ocean Observing System (EOOS).

Euro-Argo ERIC works with other marine based RIs as well as related programmes to contribute efficiently to a new integrated and sustained EOOS, with the aim of extending the Argo array. EOOS is a joint initiative between Euro-GOOS and the European Marine Board (EMB), with which Euro-Argo is also linked. This multidisciplinary approach is a strategy used in relation to answering various questions on ocean and climate evolution, and for coordinated focus on Essential Ocean Variables (EOV).

Studies have demonstrated that the integration of ocean-observing efforts with necessary data analysis and product distribution, implemented at the global, ocean basin and regional scales, generate far more economic benefits than costs (OECD Study - 2018). Despite their key role in *in situ* ocean observations, Argo services still require promotion in order to reach new users and partners. The public needs to gain an awareness of Argo's critical importance for meeting challenges such as observing and predicting the ocean's response to climate change.
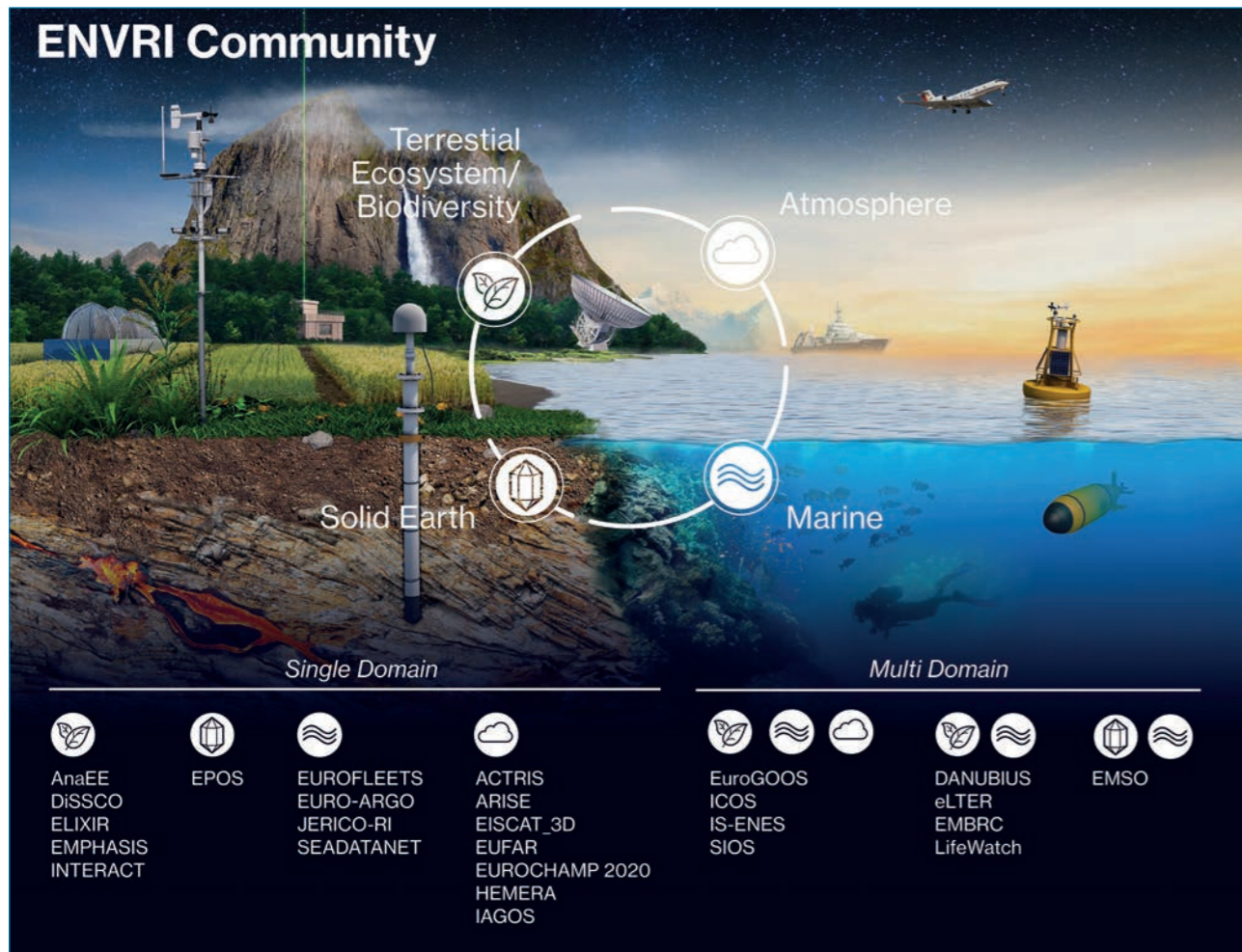
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ENVRI Community

Terrestrial Ecosystem/ Biodiversity

Atmosphere

Solid Earth

Marine

Single Domain

AnaEE
DiSSCO
ELIXIR
EMPHASIS
INTERACT

EPOS

EUROFLEETS
EURO-ARGO
JERICO-RI
SEADATANET

ACTRIS
ARISE
EISCAT_3D
EUFAR
EUROCHAMP 2020
HEMERA
IAGOS

Multi Domain

EuroGOOS
ICOS
IS-ENES
SIOS

DANUBIUS
eLTER
EMBRC
LifeWatch

EMSO
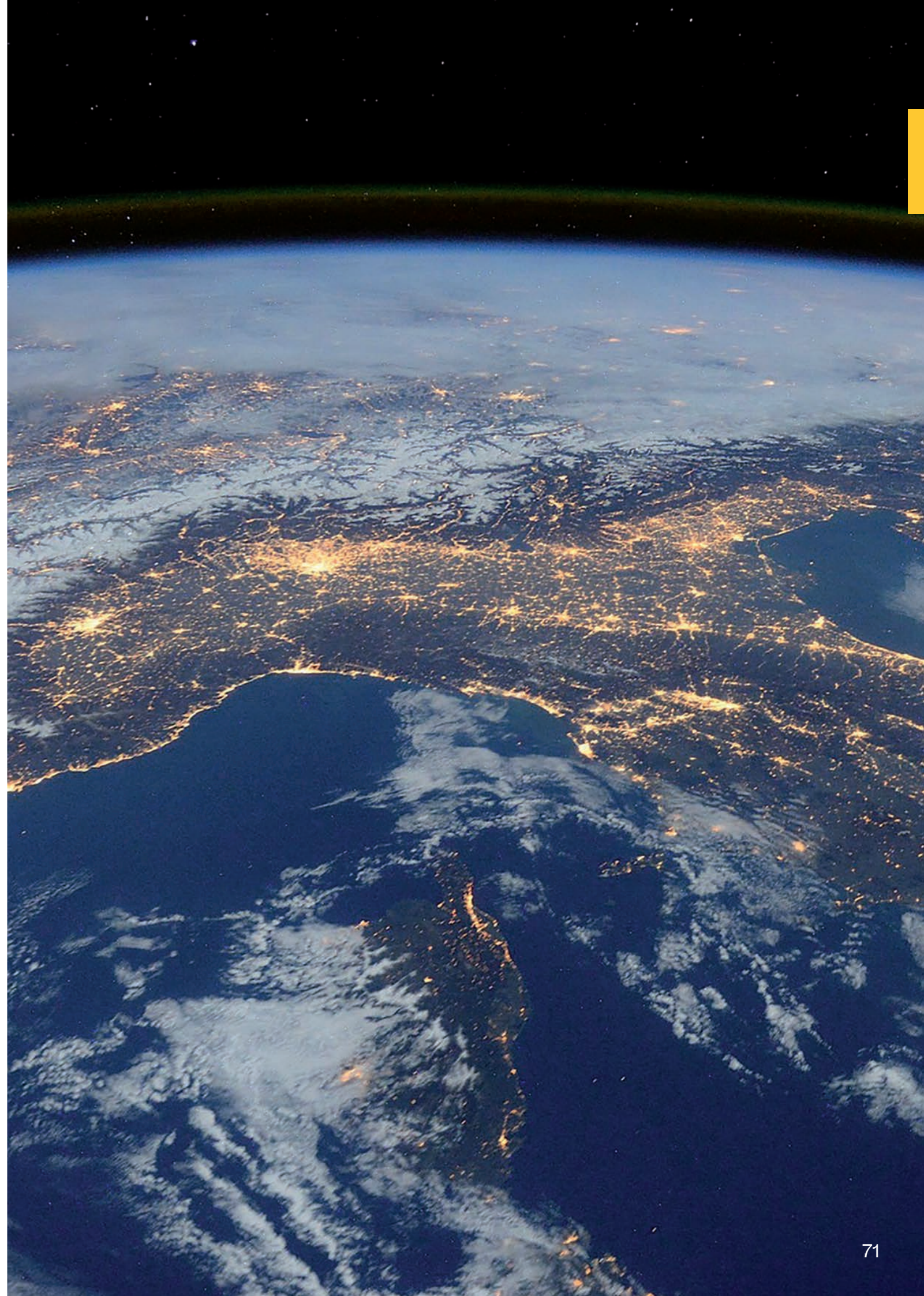
© ENVRI Community

Figure 23: Earth science domains covered by ENVRI Community.

COLLABORATION WITH ENVIRONMENT RESEARCH INFRASTRUCTURES (ERIs)

The Euro-Argo ERIC's collaboration with other European RIs is assisted via its participation in the H2020 ENVRIplus project, a cluster of environmental and Earth system RIs, built around the ESFRI roadmap. The project brings together all domains of Earth System science covering the atmosphere, ocean biosphere and solid Earth → Figure 23.

ENVRIplus offers a direct interface to capitalise on the progress made in various disciplines and strengthen interoperability amongst RIs and domains. Participation in such clusters encourages cross-fertilisation in terms of technological developments, data-system inter

-operability, communication/outreach actions and across domain strategic developments through the Board of European Environmental Research Infrastructures (BEERI), in which the Euro-Argo ERIC is represented. Technical tasks such as the integration of a prototype pCO2 sensor on a Argo float were achieved thanks to joint activities between European Multidisciplinary Seafloor and Water Column Observatory (EMSO) and Integrated Carbon Observing System (ICOS). ENVRIplus also facilitates collaboration in specific areas, as demonstrated by the deployment of Argo floats at the EMSO Hellenic site, in the South Ionian area, reinforcing observation of this site, as well as providing cross-validation possibilities. Common data principles and guidelines were agreed on within

ENVRIplus. In the meantime, concrete actions to further implement Findable, Accessible Interoperable and Reusable (FAIR) principles in the Euro-Argo data system, will be pursued through the ENVRI-FAIR project, launched in early 2019.

Euro-Argo has been requested to advise the INTAROS H2020 project on the long-term design of the Arctic observing system.

## INTEGRATION WITHIN REGIONAL OBSERVING SYSTEMS

Integration is fostered at the regional level thanks to Euro-Argo, together with EMSO and FerryBox lines, contributing to the regional observing system in the Aegean Sea. Argo data is assimilated on a weekly basis in the different modelling/forecasting components of the POSEIDON operational system. It allows assessment of the impact of remote-sensed and FerryBox sea-surface salinity data on the Aegean Sea hydrodynamic model. In the Southern Oceans, BODC and BSH are also integrated into the international initiative Southern Ocean Observing System

(SOOS), whose mission is to facilitate the collection and delivery of essential observations on dynamics and changes in Southern Ocean systems.

The Euro-Argo ERIC, together with FerryBox, tide gauges and moorings, contributes to the Baltic Sea monitoring programme Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM), providing essential data for Baltic applications. With the recent development of the ice-avoiding Argo floats in the Arctic, Euro-Argo has been requested to advise the INTAROS H2020 project on the long-term design of the Arctic observing system, as a member of the project's Advisory Board.

The Euro-Argo ERIC has developed links with the glider community for the homogenisation of data processing and reprocessing between Euro-Argo, OceanGliders, EMSO and FixO3. At national level, there is also cross-collaboration with the ocean glider community, for example in the UK (BODC-NOC), or in France (CNRS, Ifremer/ Coriolis). Links with other observing platforms such as Drifters, Oceansites, and GOSUD are sustained thanks to the Coriolis partnership in France (see Box 9).

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Géovide campaign, 2014.
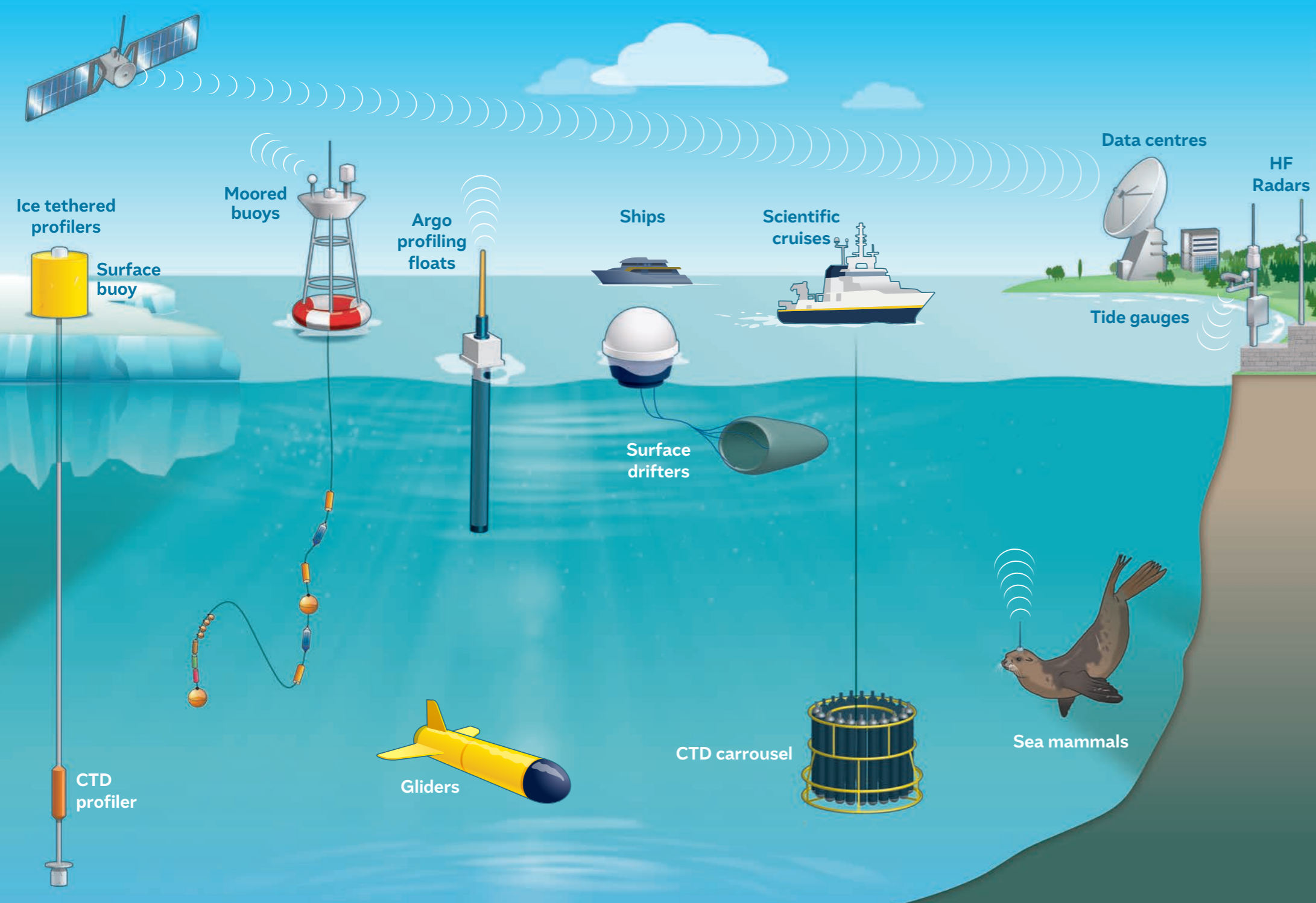
Figure 24:
The integrated ocean observing system is composed of different ocean observing platforms, whether autonomous or ship-based. Argo floats are identified as a major observing component.

© Thomas Haessig

Collaboration across various observing networks was one of the objectives of the H2020 AtlantOS project (see Box 10). Within AtlantOS, Argo – specifically BGC and Deep Argo – has been collaborating with other autonomous platforms (e.g. drifters, gliders, fixed point biogeochemistry mooring, Prediction and Research Moored Array (PIRATA) in the Tropical Atlantic) and ship-based (e.g. GO-SHIP, SOOP and VOS) programmes to enhance the observing system in the Atlantic Ocean → Figure 24.
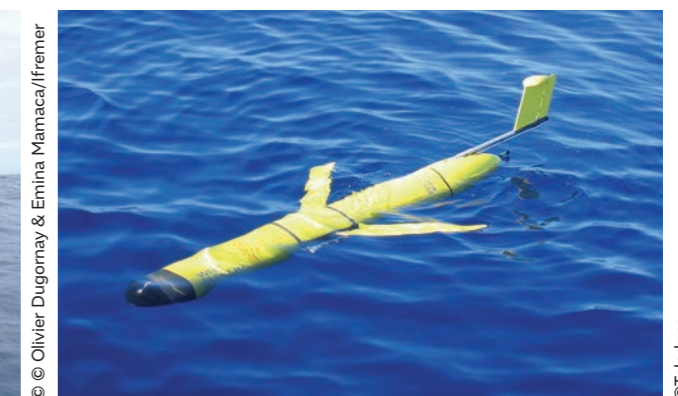

Pirata buoy.

© M. Maupas/Genavir

Vessel with a CTD carrousel.

© Ifremer

Argo profiling float.

© © Olivier Dugornay & Emina Mamaca/Ifremer

Glider.

©Teledyne

Argo

National contributions - 3895 Operational Floats
Latest location of operational floats (data distributed within the last 30 days)

December 2018

ARGENTINA (1)	EUROPE (123)	INDIA (126)	KENYA (1)	PERU (3)	USA (2190)
AUSTRALIA (353)	FINLAND (4)	INDONESIA (2)	MEXICO (1)	POLAND (9)	
BRAZIL (3)	FRANCE (275)	IRELAND (11)	NETHERLANDS (24)	KOREA, REPUBLIC OF (44)	
CANADA (93)	GERMANY (154)	ITALY (60)	NEW ZEALAND (11)	SPAIN (16)	
CHINA (99)	GREECE (4)	JAPAN (147)	NORWAY (9)	UK (146)	

Generated by www.jcommops.org, 10/01/2019

Figure 25: Argo National contributions.

FLOAT DEPLOYMENTS: A COLLABORATIVE WORK

The Argo community relies on vessels to deploy floats, from different countries → Figure 25: normally Research Vessels (RVs) are used, but naval merchant or leisure vessels may also be used to deploy floats.

Euro-Argo succeeded in testing and deploying 12 out of 13 new AtlantOS (BGC and Deep-Argo) floats primarily due to collaboration with several European and non-European research institutes operating large RVs. These opportunities were identified through regular contact with ship operators, as well as operations planning between Euro-Argo Members and international partners, that were coordinated by JCOMMOPS. Euro-Argo also collaborates with Eurofleets, the alliance of European research vessel operators.

In addition to standard deployments from RVs, Euro-Argo has benefited from other types of collaborations – the personnel in charge of deployment are trained by Euro-Argo members or by the Euro-Argo Office – such as:
– Dutch co-financed MOCCA floats that were successfully deployed off the South American coast, from the passenger ship M/V Plancius, on its way to Antarctica (2016);
– working relationship (IOPAN) with a private ship company **(see Box 11)** who perform cruises in the Atlantic sector of the Southern Ocean, and who raised the potential for a float deployment opportunity;
– within the MOCCA project, deployments in remote areas have been possible due to an ongoing partnership with Orange Marine, who operate cable ships **(see Box 12)**.

Some ships of opportunity ready to deploy floats.

© Euro-Argo

GLOBAL SOCIETAL IMPACT

The Argo programme and Euro-Argo provide the infrastructure and data to assist the public and industry in making marine related decisions based on current and future sea conditions.

IMPACT ON SOCIETY

Monitoring global climate change and ecosystem health

The ocean's temperatures have an influence on weather and their continuous monitoring is key to a more accurate weather forecast, including the prediction of hurricanes and monsoon rainfall.

> Society can indirectly find Argo data in their daily lives, such as within weather models.

A better understanding of the ocean is a means to fine-tune weather forecasts for the next season, as ocean and atmosphere are closely linked. Argo is essential for ocean observations, complementing satellite observations, that are limited to measuring the ocean's surface only a few meters just below the surface. Different national meteorological centres rely on Argo data (see Chapter 8 p. 56) and society can indirectly find Argo data in their daily lives, such as within weather models (e.g. Meteo France and Met Office, respectively French and British forecast centres). The Met Office UK interacts with the atmospheric community, who uses Argo data to validate the output from the Met Office's OSTIA (see Box 8 p. 60), as well as ECMWF operational forecasts, that aim to show how weather is most likely to evolve.

Inundation.

© Pexels

© Pxabay

© Ifremer

Improving maritime transport and safety

International commerce and transportation rely on the ocean, with commercial ships representing more than 90% of global vessels. Assimilated in models, Argo data enable better ocean circulation forecasts used by shipping companies, to better route their ships and ensure the safety of personnel and cargo. Although maritime transport has already made significant strides in terms of safety at sea, it is continuing to develop this practice, while also seeking to optimise fuel consumption.

Emerging use for marine resources and fishery management

Observation of the ocean is also beneficial for fishery management, as greater understanding of the fish habitat nurtures the development of better policies for sustainable management and regulating fishery activities. As aquaculture and fish farming spread, it is important to monitor the ocean environment in order to assess the impact of such activities on the environment. In Finland, guidelines on ocean monitoring have been issued for the fish-farming industry, and bottom-parking Argo floats have been identified as one solution for cost-effective environmental monitoring. The Plymouth Marine Laboratory (PML), in the UK, uses Argo data to describe the physical environment in the context of biological studies, for example when mapping eel migration routes.

© Unsplash

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Monitoring European water-quality

Monitoring water quality, whether coastal or offshore, is vital. The EU's Marine Strategy Framework Directive (MSFD) → Figure 26 requires a good knowledge of the environmental status of European marine waters. This Directive establishes a framework for actions in the field of marine-environmental policy, with the aim of achieving and maintaining Good Environmental Status (GES) of the EU marine environment by 2020, and protecting the resource base upon which marine-related economic and social activities depend. Focusing on the Baltic Sea, the northeast Atlantic Ocean, the Mediterranean Sea and the Black Sea, the MSFD has established criteria, methodological standards, specifications and standardised methods for monitoring and assessing the predominant pressures and impacts. Euro-Argo data has proven extremely useful in assessing changes in hydrological conditions (Fabri et al. 2018). The H2020 EA-RISE project will investigate how the Argo observing network

can help to address several MSFD indicators, such as hydrographic changes (D7) and eutrophication (D5) in complement of other observing networks.

> The H2020 EA-RISE project will investigate how the Argo observing network can help to address several MSFD indicators.

Euro-Argo contributes to ocean observation by providing data usable for monitoring pollution, coastal environments, weather, seasonal forecasts and long-term climate, maritime safety (marine operations, ship routing, incident response), offshore activities, fishery activities and their sustainable management and for discovering the unknown marine resources in the planet's deepest depths.

Figure 26: The 11 qualitative descriptors for determining good environmental status as presented in Directive 2008/56/EC of the European Parliament and the Council.

Bio-geochemical floats for Soclim cruise - R/V Marion-Dufresne, in Kerguelen Islands, 2016.

PROVOR-CTS5 float on the icebreaker CCGS Amundsen - GreenEdge Cruise, in Baffin Bay, 2016.

© Pascaline Bourguain

© Julien Boulanger

A STRONG IMPACT ON EUROPEAN INNOVATION AND ECONOMY

The Euro-Argo ERIC develops close collaborations with the private industry for sensor or float development. Innovation is an important aspect of these partnerships.

Some examples of collaborations with private companies to improve Biogeochemical-Argo float capabilities by adapting new sensors are:
– a pH sensor has been integrated for the first time on a European float, in partnership with the private company Sea-Bird, Inc. (USA);
– an Aanderaa/Xylem (Norway) pCO_2 sensor has been integrated on an Argo float through a collaboration between the Ifremer R&D department and the French float manufacturer, NKE Instrumentation. The overall collaboration with NKE Instrumentations has resulted in this company becoming a major international manufacturer;
– in Germany, the SME, TriOS, is collaborating with the University of Oldenburg for the development of hyperspectral sensors;

– transmission capabilities, with improvement of the RUDICS (Router-based Unrestricted Digital Interworking Connectivity Solution) performed by NKE Instrumentation (France), are now required on each BGC float purchased.

Some examples of strong interactions with manufacturers to work on Deep Argo float capabilities and technology are:
– in the UK, extensive interaction with the manufacturer was necessary for improvements of the Deep APEX floats;
– in France, Deep Arvor was developed by Ifremer and NKE Instrumentation in the framework of NAOS Equipex project.
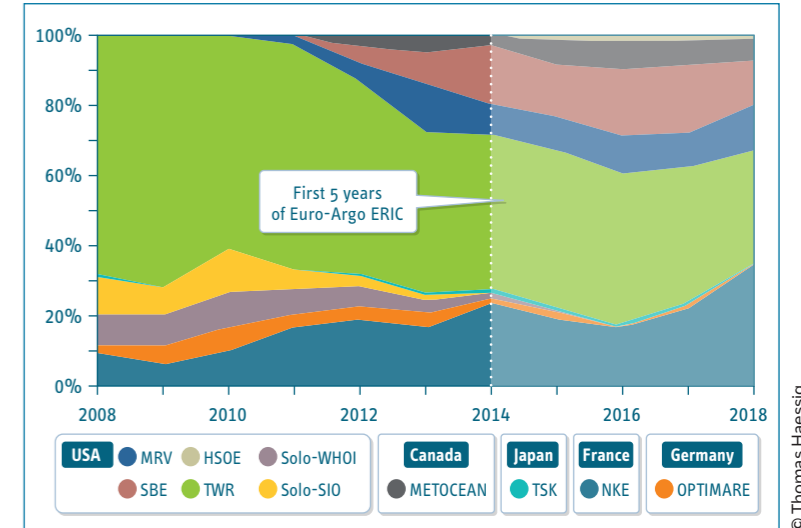
Some other examples of innovations relying on partnerships with private companies to implement the floats:
– two prototypes have been deployed at Ifremer to develop an Autonomous System for Argo float Release (ASFAR);
– the increased ice-resilience of Argo floats was achieved in Germany, by the Alfred Wegener Institute (AWI) in cooperation with the German float manufacturer, Optimare;
– the ice-sensing algorithm (ISA) for Arctic conditions: BSH developed ice-sensing algorithms which have been implemented on Arvor floats by NKE instrumentation.

Eventually, a collaboration is ongoing with private partners in France for data quality control and software development (Glazeo, ACRI, Altran).

This range of activities has helped to develop the float market in Europe, with NKE Instrumentation, a European company, becoming the primary Argo float provider in 2018, responsible for 32.5% of the floats deployed at international level → Figure 27. NKE Instrumentation is an alternative to US providers, helping to maintain and even reduce platform and sensor costs. This private company has demonstrated a prospering presence on the market. Innovation in this sector continues to thrive and opportunities for future developments look promising for example:
– development and improvement of quality-control procedures through machine learning in France (via collaboration with the mathematics and statistics community);
– preparation of the future generation of sensors and floats to monitor their lifetime: the UVP (Under Vision Profiler) is an *in situ* image sensor that can be deployed to depths of 6000m to process images, in order to quantify and deter-
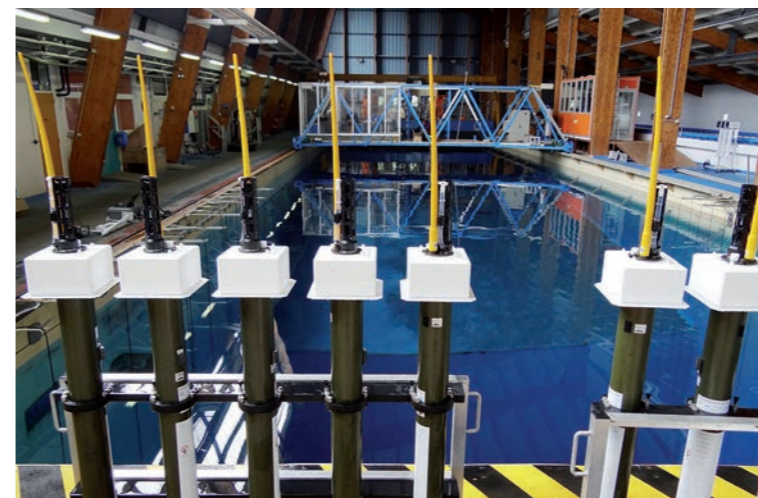
mine the size of marine particles and to identify and quantify zooplankton. Floats with video cameras are being tested to study macro and mega fauna in the Mediterranean Sea, such as jellyfish, via a collaboration with Italian and Spanish institutes. The new generation of BGC-floats aims to provide monitoring tools to cover extensive areas and for extended periods of time, like never before;
– improvement of electronics, communication systems and float lifetimes in ongoing French projects (NAOS, RemOcean);
– underwater positioning remains a challenge although some methods have been tested or may be developed in the future.

Figure 27: Market evolution for SMEs developing ocean-observation technologies (JCOMMOPS AIC).

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Float tests in the Ifremer pool.

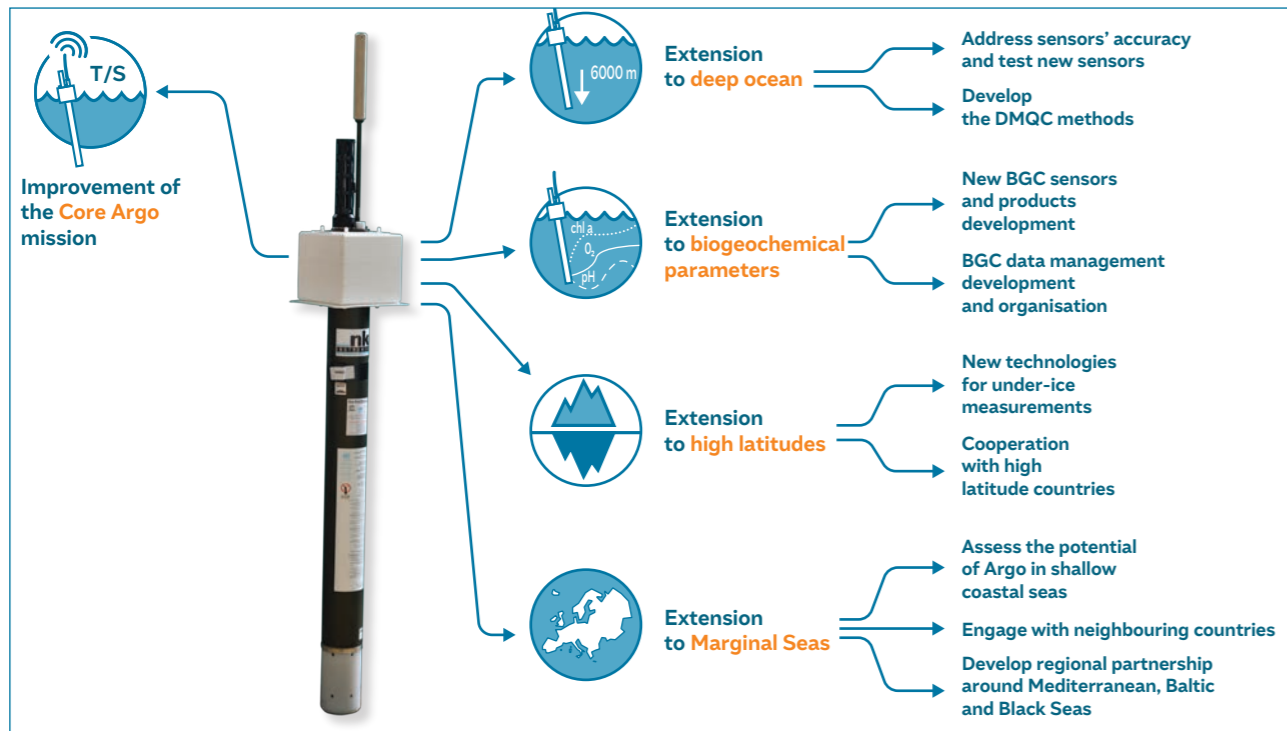© Euro-Argo ERIC

© Olivier Dugornay/Ifremer

Figure 28: The Euro-Argo RISE main objetives.

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In the framework of EA-RISE → Figure 28 (see Box 13), the new phase of Euro-Argo will be developed, with two main objectives: 1) sustain the existing global array and 2) extend its capabilities to greater depths (at least 4000m) and to biogeochemistry (i.e. adding new sensors such as oxygen, nitrate, chlorophyll a, optics and pH). The present target is to maintain a network of at least 4000 floats, with ¼ carrying biogeochemical parameters and ¼ going to abyssal depths.

TOWARDS DECISION MAKING AND POLICY SUPPORT

Euro-Argo has provided support to European and regional decision makers in the field of Marine Environment and Security (EC Directorate, European Agencies and Regional Conventions). Three particular major events are worth noting.
The COP21 in 2015 (United Nations Conference on Climate Change for the 21st Century) ended with a historical agreement to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C. This agreement was based on an unambiguous diagnostic of climate change, supported by a century of ocean observations. Observing the ocean in a sustained manner is now mandatory, and Argo plays a crucial role in this monitoring. In this context, Euro-Argo's role in sustaining ¼ of the Argo network is fundamental, and Euro-Argo partners, having defined a strategy for the next decade, are presently working on an implementation plan. Argo was present at the COP21 via partners/Member States.

© Olivier Dugornay/Ifremer

Guillaume Maze (Argo-France) presents the Argo Programme to the G7 delegates, in Ifremer premises.

The G7 in 2016 and in 2017. For years, Euro-Argo has been developing ocean-observing capacities at global and European scales and promoting synergy and cooperation across both European and global actors. However, high level political commitment to sustained observations and free and open data sharing is a cornerstone to fully unlock the substantial economic value of ocean knowledge and to help protect ocean health. The ministers' communiqué to the G7 Leaders' Summit in Ise-Shima on 26-27 May 2016 included a strong emphasis on sustained and enhanced global ocean observing, data sharing and capacity building, critically required for the ocean's future. Through the involvement of its Members, Euro-Argo contributed to the recommendations to G7 countries, in particular the importance of sustaining and further developing BGC and Deep Argo. Based on these recommendations, actions are being carried out with the Euro-Argo ministries and the EC to implement these recommendations in the next decade.
In 2015, Argo, along with IOCCP and GO-SHIP, contributed to the International Workshop for "Sustained ocean observing for the next decade". One of the outcomes of the workshop was the signature of the Galway Statement on Atlantic Ocean Cooperation, thus launching an Atlantic Research Ocean Alliance (AORA), uniting Europe, Canada and the United States of America. Today, there are more than 500 research teams working in the Atlantic Ocean. Transatlantic cooperation has been embraced by the scientific teams working together in Atlantic-wide field campaigns on seabed mapping, ocean observation, seafood, weather and climate, polar research, marine biotechnology and marine spatial planning.

> Observing the ocean in a sustained manner is now mandatory, and Argo plays a crucial role in this monitoring.

Work performed in the course of MOCCA and AtlantOS projects has fostered collaborations with countries bordering the South Atlantic in Africa and South America. Such activities will be pursued in the future covered by the so-called Belem statement, an agreement on research and innovation in the Atlantic Ocean. The statement was signed in Lisbon on 13 July 2018.

MEMBERS TESTIMONIES

The Euro-Argo ERIC relies on the synergy between 12 European Members and helps them at every single step, from the purchasing of floats to the data processing.
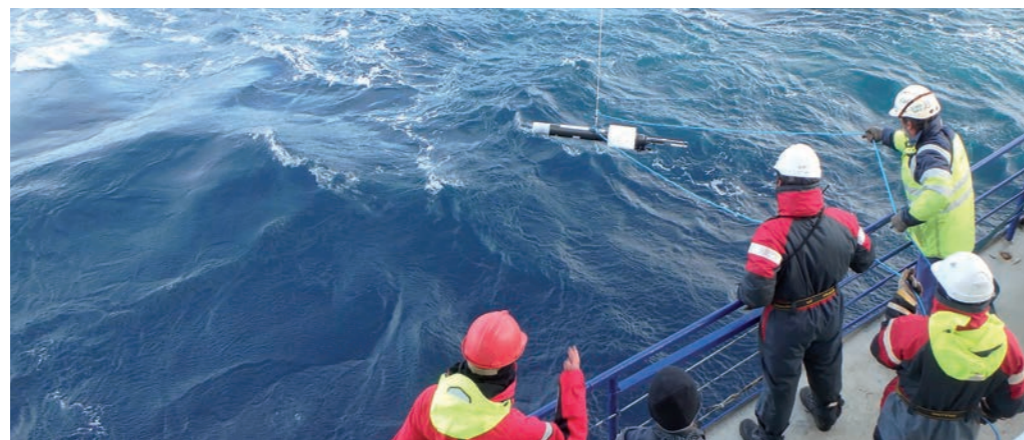
Guillaume Maze, Argo-France (Ifremer): "Euro-Argo ERIC and Argo-France is a win-win relation".

Euro-Argo ERIC and Argo-France is a win-win relation. Argo-France has brought expertise and leadership to the ERIC, with several decades of experience in float developments through industrial partnerships and floats handling, through in-house tests and deployments. Since the beginning of the Argo programme, Argo-France has also played a leading role in Argo Data Management at international level. More recently, France has strongly been involved in scientific leadership for the new Argo missions: Deep and BGC. In addition, France hosted the ERIC for its first 5 years phase.

The ERIC has actively contributed to the sustainability of the Argo-France programme and provided new opportunities to strengthen Argo-France activities: EU-funded projects coordinated by the Euro-Argo ERIC (E-AIMS, MOCCA, EA-RISE) have led to new technological developments and tests to improve the historical Argo mission and to allow the new one. The ERIC has also led a strong reinforcement of European industry through new opportunities for manufacturers and improvement of catalogues.

Funds for floats procurement have been secured and new opportunities for deployments emerged. Argo-France also benefited from improved coordination with international partners, as well as development and sharing of good practices, in order to prepare floats before deployments and better monitor fleet performances. Funds to operate the French Data Centre (Coriolis) have also been secured, with a better coordination with European partners for the BGC data stream development, and closer interactions with European users on priorities for data services improvement, at GDAC level.

The ERIC has strengthened French national research activities in terms of:
1) strategic planning for the new Argo mission on biogeochemical measurements and full-depth sampling, with the delivery of a European Argo roadmap (SIDERI project) and a stronger voice at international level;
2) visibility and valorisation of results through new dissemination means (news briefs, social networks and science workshops);
3) new collaborations with European partners.

Float deployments in the Austral Ocean during the OISO cruise onboard Research Vessel Marion Dufresne II, 2015.

© G. Obolensky/CNRS

Andreas Sterl, KNMI, Argo-Netherlands: "The Euro-Argo ERIC enables knowledge sharing and helps with national issues by providing a European perspective".

For the Netherlands and other Euro-Argo members with a small Argo contribution – less than 10 floats deployed per year – benefits from being part of the Euro-Argo ERIC are multiple, ranging from help with float procurement, to an easier collaboration with other scientists.

Since 2017, the Euro-Argo ERIC offers the possibility of centralised float purchase at significant discount rates. For floats purchased through this contract, the ERIC Office technical team undertakes the whole logistic chain from ordering the floats, via performing an acceptance test in the Ifremer testing facilities, to the shipment of the floats to the purchasing institutes, or directly to the deployment ports of call. Furthermore, Euro-Argo ERIC provides technical advice on float parameter settings and the characteristics of sensors. After deployment, it also allows the access to DMQC and monitoring tools. Together, these services make it much easier for small partners to buy, launch and operate their floats.

The ERIC membership is helpful in strengthening and sustaining national Argo programmes, and makes access to national funds easier. It offers the possibility to take part in EU projects (e.g. E-AIMS for Netherlands) to complement national funding. The Euro-Argo ERIC enables knowledge sharing and helps with national issues by providing a European perspective.

Through organizing workshops (e.g. training workshop on Argo data Delayed Mode Quality Control) and user meetings, Euro Argo enhances the exchange of knowledge between the partners. In particular, bi-annual science meetings provide opportunities for new scientific collaborations, especially for young researchers. The experience of the scientific and technical staff of all European partners is brought together by, and discussed within, the Euro-Argo ERIC, allowing for a fast exchange of views and reactions to emerging issues.

Kjell Arne Mork, IMR, NorArgo: "Norway benefits from the expertise of the Euro-Argo ERIC, in terms of technical advises on floats and sensors, purchase of floats, and data processing and Quality Control".

Norway became a major contributor to Euro-Argo in 2018. The Norwegian contribution to Argo is focused on the Nordic Seas, and also aims at extending towards the Arctic and the Barents Sea. Starting as a small contributor (15 floats deployed between 2002 and 2011), Norway has entered the Euro-Argo ERIC in 2014 with the status of Observer, thanks to the national programme NorArgo funded by the Research Council of Norway (400 k€, 2012-2016).

Partly through Norway's involvement in Euro-Argo and the scientific collaborations that resulted (e.g. E-AIMS project), NorArgo2 project was successfully granted in 2017,

providing secured funds for 5 years, and involving 6 Norwegian partners. This new project enables Norway to operate 30 Argo floats (including BGC and Deep Argo floats) in the Nordic Seas, the Arctic Ocean and the Barents Sea, thus significantly contributing to the implementation of the European strategy for Argo. In 2018, thanks to the NorArgo2 project, Norway changed its status from Observer to full Member. Norway benefits from the expertise of the Euro-Argo ERIC, in terms of technical advises on floats and sensors, purchase of floats, and data processing and Quality Control.

KEY PERFORMANCE INDICATORS

Since its creation, the Euro-Argo ERIC has defined Key Performance Indicators (KPIs) to assess the European contribution to the international network. The enhanced role of Europe in the international Argo programme and the heightened Europe-wide visibility of the research is monitored each year through two types of indicators: KPIs in relation to the Argo network implementation and user specific KPIs.

KPIS REGARDING FLOATS

A growing fleet

The overall objective of the Euro-Argo ERIC in terms of float deployments is to provide, deploy and operate an array of around 800 to 1000 floats, maintaining a European contribution of ¼ of the global array, with enhanced coverage in the European regional seas. At the beginning of the period, in 2014, the array was around 3000 active floats. This translated into a target of 800 new floats per year at global scale, 250 to be deployed by the Euro-Argo ERIC each year (¼ of the global effort and 50 additional floats in European marginal seas). At the end of the period, in 2018, the array is around 4000 active floats, which requires the deployment of 1000 floats per year, with a new target for Euro-Argo of 350 floats deployed, including 50 biogeochemical floats and 50 deep floats. → Figure 29 shows the evolution of Euro-Argo partners' contribution to the global Argo network.

Figure 29: Number of operational floats (colour, left axis) and in the percentage of the total number of active floats in the array (blue dashed line, right axis) (© JCOMMOPS/AIC).

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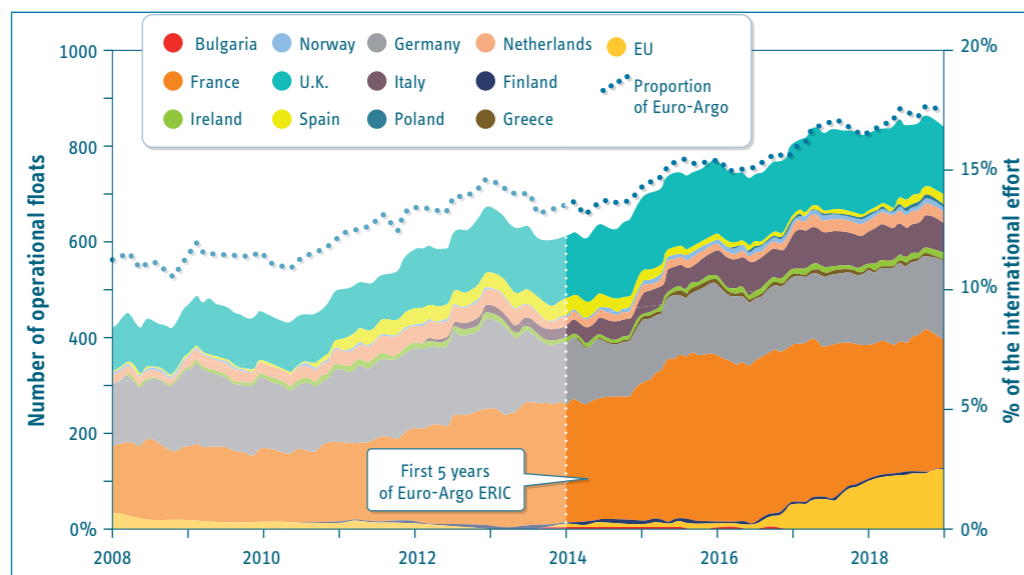
© Thomas Haessig
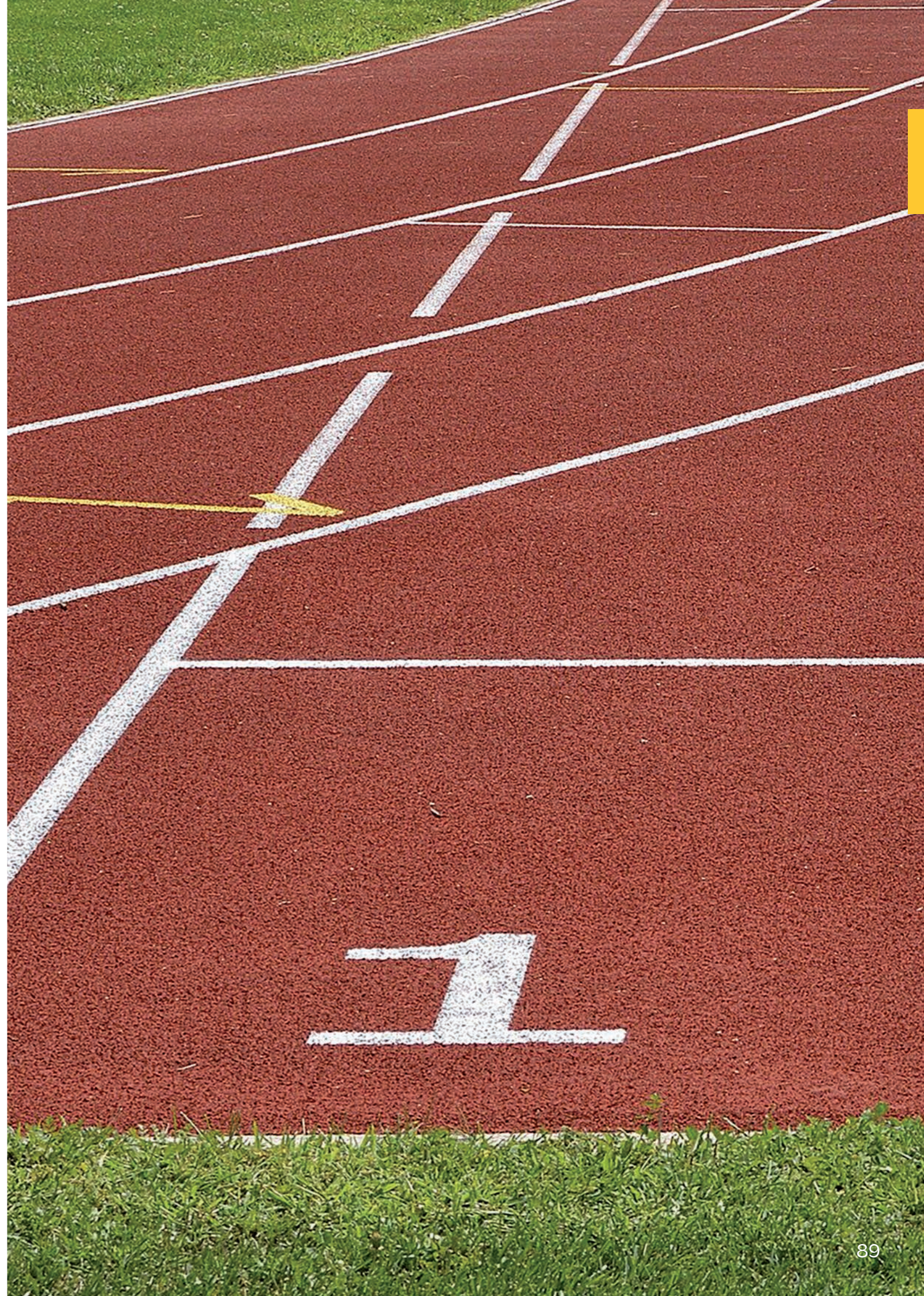
Greenedge
ice camp first
BGC float with
ISA algorithm
tested under ice,
Qikiqtarjuaq,
Nunavut 2015.

© Claudie Marec/CNRS

In 2018, 279 European floats were deployed, including 66 floats on the extension to biogeochemical and deep oceans. This is still below the target of 350 new floats/year, but above the 25% mark of the global effort in term of deployment. The → Figure 29, p. 86 describes the evolution of the European contribution to the network in terms of active floats, at any time. The number of European Argo floats has been increasing since the beginning of the project. The percentage of European active floats has slowly increased from around 17% in 2014 (ERIC creation) to 22% in 2018. The → Figure 29, p. 86 also shows the importance of the "European Union" contribution (in yellow) in the last 3 years through H2020 and EMODnet projects.

The score of the Euro-Argo fleet reading 100 cycles shows impressive progress in past years, reaching the 75% threshold.

Impressive progress for float performance

The life expectancy of European floats is improving and the target of 4 years – around 150 cycles for a standard float cycling with a 10 days-period – has been achieved in average. Compared to the rest of the Argo fleet, the percentage of floats reaching the 50 cycles target → Figure 30 shows that on recent deployments the Euro-Argo fleet has a similar score than the rest of the fleet (about 90%). Of the 100 cycles target, the score of the Euro-Argo fleet has nearly reached the level of the Argo fleet and shows impressive progress in past years, reaching the 75% threshold.

The increasing visibility of Europe in the Argo network is also reflected looking at the evolution of the number of floats deployed per float manufacturer → Figure 31. In 2018 for the first time, a European manufacturer (NKE, delivering ARVOR and PROVOR float models) is number 1, ahead of US manufacturers (e.g. Teledyne Webb Research (TWR) providing the APEX).
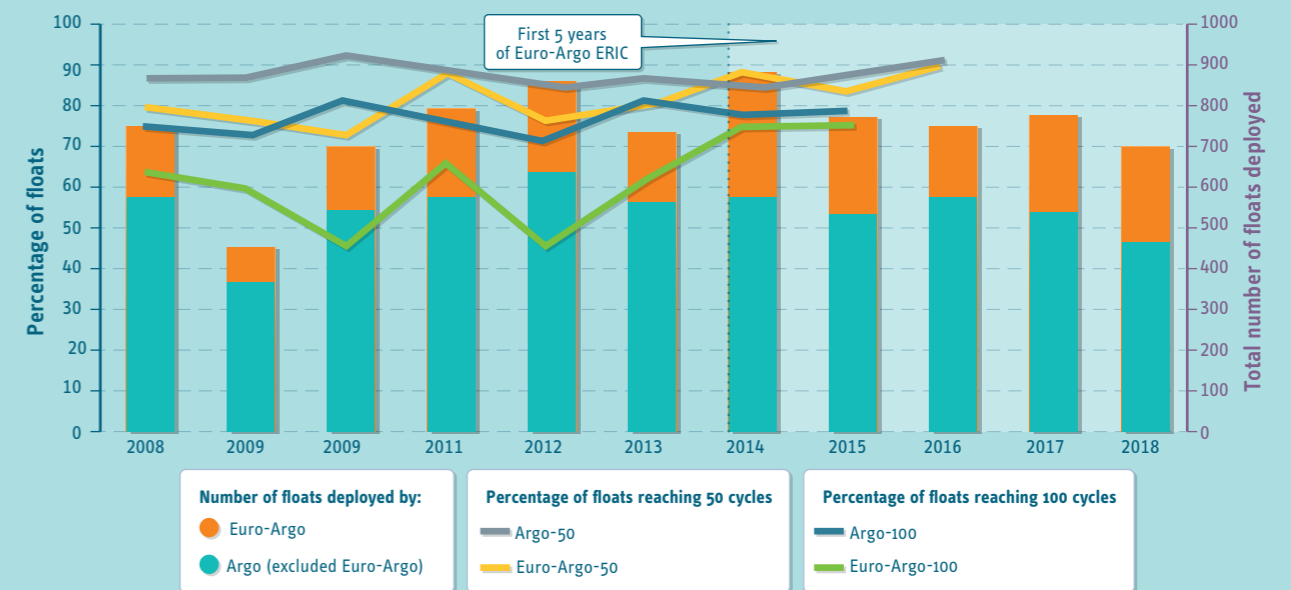

Figure 30: Percentage of floats from the Euro-Argo fleet reaching the 50 cycles or 100 cycles target compared to the rest of the Argo fleet (coloured lines, left axis). In grey, the total number of floats deployed for Euro-Argo and the rest of the fleet (right axis) (© JCOMMOPS/AIC).
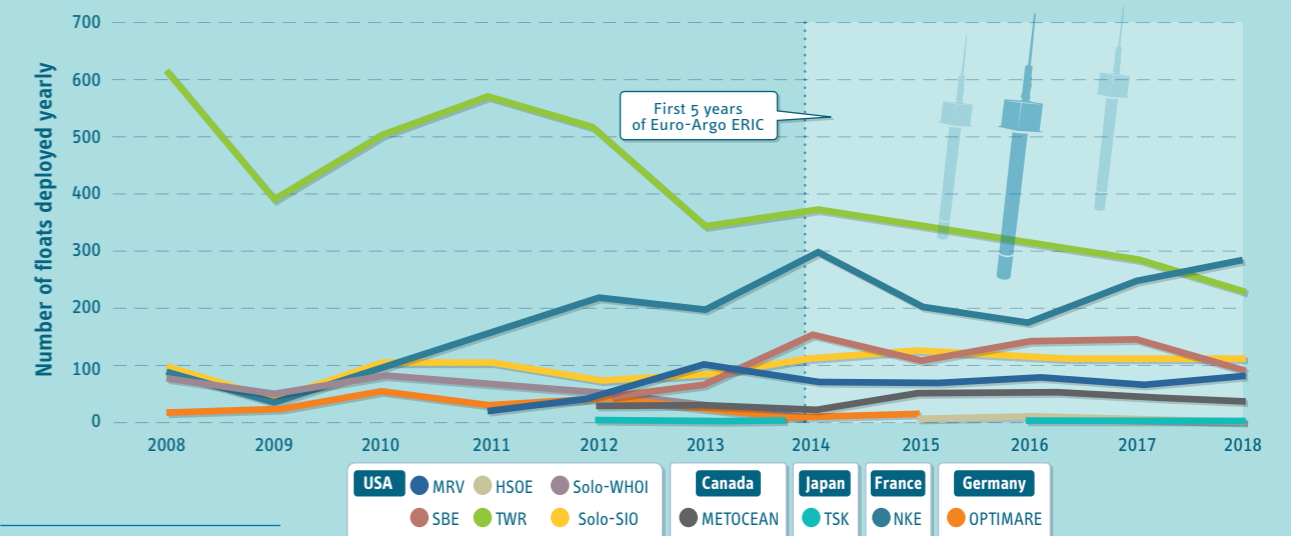

Figure 31: Evolution of number of floats deployed per year, grouped by float manufacturer. (© JCOMMOPS/AIC).
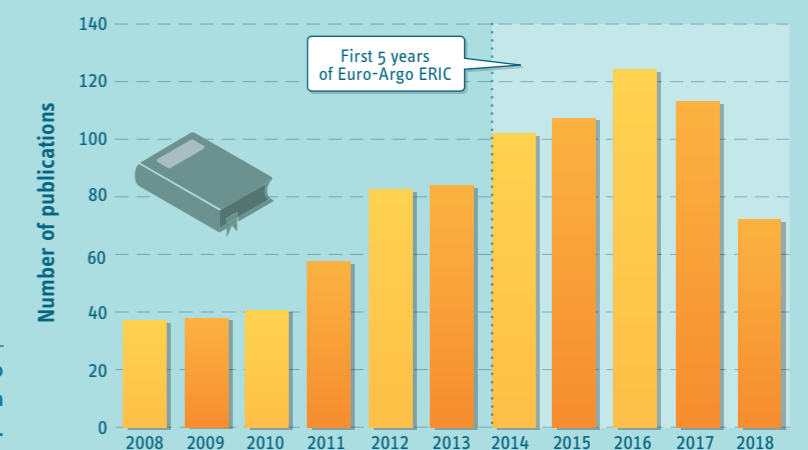

Figure 32: Number of Argo publications from European researchers per year since 2008.

KPIS REGARDING USERS

One of the overall objectives of the Euro-Argo ERIC is to provide quality-controlled data and reliable data services for the research (climate and oceanography) and operational (e.g. Copernicus Marine Service and weather forecasts services) communities.

Euro-Argo bibliography

Euro-Argo monitors each year the number of publications using Argo observations from European users → Figure 32. A publication is defined as "from Europe" based on first author affiliation's country. Similar to Argo international, Argo publications from the Euro-Argo community reached its highest record in 2016, with 125 papers published. Since 2008, the European contribution has been slightly below 30% of the total number of publications, which is better than the initial target of 25% (not shown). The decrease in 2017 and 2018 is also observed at international level (not shown) and could be explained, at least partly, due to the omission of the "Argo" word in some publications using Argo-derived products.

Argo Data

Europe (Coriolis, France) hosts one of the two Global Data Assembly Centres (GDAC) for Argo that contains the whole official Argo dataset. The number of users that access, visualise and download Argo data sets is monitored each year from the Coriolis Argo GDAC portal.

In November 2018, more than 2 million Argo profiles were available on Coriolis GDAC, 14.5% of them coming from Coriolis and 3.9% from BODC, the two European DACs. The → Figure 33 shows the number of profiles increase during the 2008-2018 period, which emphasises a significant contribution of the Coriolis and BODC DACs, reaching more than 24% of the total number of profiles available on the GDAC in 2018.

Twitter followers

Since its creation in July 2016, the Euro-Argo twitter account has continuously gained new followers, reaching a total of 573 followers in December 2018 → Figure 34.

SUMMARY

The Euro-Argo ERIC has now existed for 5 years and has reached its overall objective of operating ¼ of the global network while enhancing coverage of the European seas. On average, the European fleet has reached the same level of performance as that of the global international Argo fleet and a European manufacturer became one of the main float providers. The use of Argo data for science has increased overall despite a decrease in 2018. The contribution of Europe in providing data to users has also increased, with 22% of the total number of available Argo profiles processed by Coriolis and BODC Data Assembly Centres.
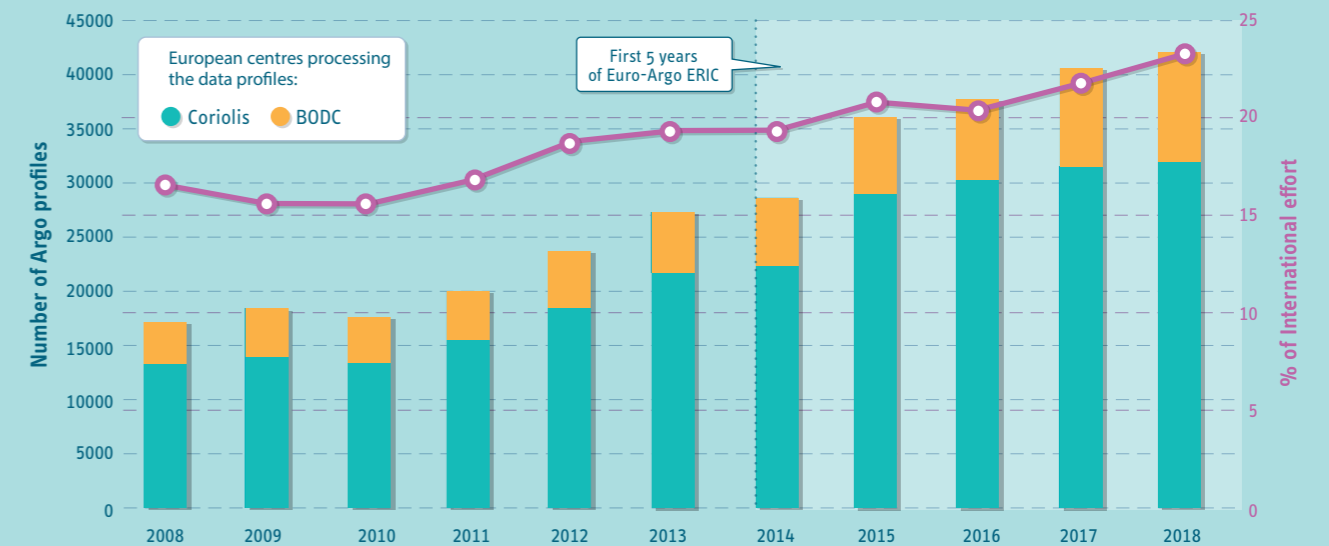

Figure 33: Argo data profiles available on Coriolis and BODC DACs: in number of profiles (left axis, blue: Coriolis and orange BODC) and in percentage of the total number of profiles available on the Coriolis GDAC (right axis).
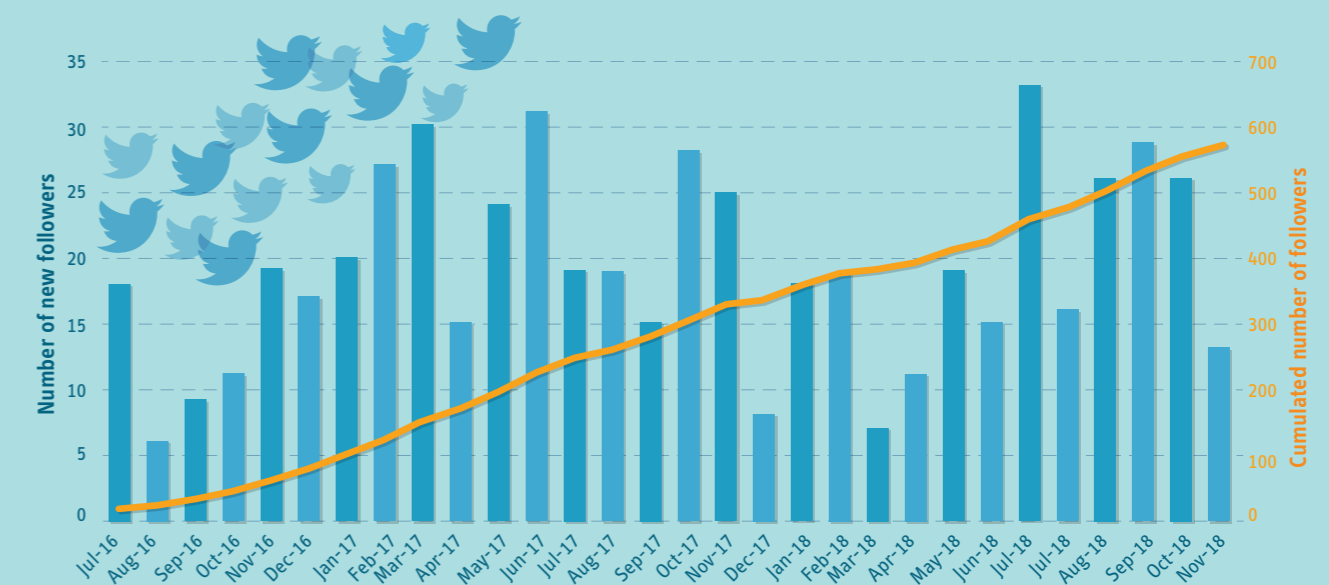

Figure 34: Evolution of the number of new (left axis, in blue) and cumulated (right axis, in orange) followers on the Euro-Argo ERIC twitter account.

CONCLUSION

**OPERATIONAL
SERVICES**

CLIMATE

**OCEAN
HEALTH**

The Euro-Argo ERIC is now an operational distributed research infrastructure with activities that are managed both at national level and at the ERIC Office level. The Euro-Argo ERIC provides continuous monitoring of new areas of interest (marginal seas, high-latitude seas and the deepest part of the ocean) as well as new biogeochemical parameters. Offering free access to regular and accurate data, the Euro-Argo ERIC has proven its capacity to conduct R&D driven by research and operational needs, including Copernicus requirements. Euro-Argo offers insight into scientific marine research, for improved understanding of the evolution of the marine ecosystem, including the ocean carbon pump and the coupling between physics and biology, and for more accurate assessments of the impact of climate change on ocean dynamics, chemistry and ecosystems.

Euro-Argo is an integrated European research infrastructure dedicated to ocean observation, providing services to its members thanks to close coordination with the Argo international programme. The data management system has been improved by the ERIC to provide researchers and operational oceanography with accurate real-time quality-controlled data. Euro-Argo has advanced the ocean-observing system as a whole thanks to the geographic extension of Argo observation to marginal seas and high latitudes, through close collaboration with oceanographic research campaigns. It also provides training when needed (for users to manage data or for float deployment). Argo's thematic extension to the deep sea and to biogeochemical variables has been supported by Euro-Argo's National Members and scientists who have contributed to designing innovative instruments. Euro-Argo's visibility is boosted by activities dedicated to education, to the society at large and to policy makers. Its profile is set to rise further as it continues to stand out as an important ocean-observing infrastructure, highlighting Europe's significant contribution to better knowledge about the ocean, and as a result, the climate and ocean forecasting. **(→ Figure 35, p. 96)**
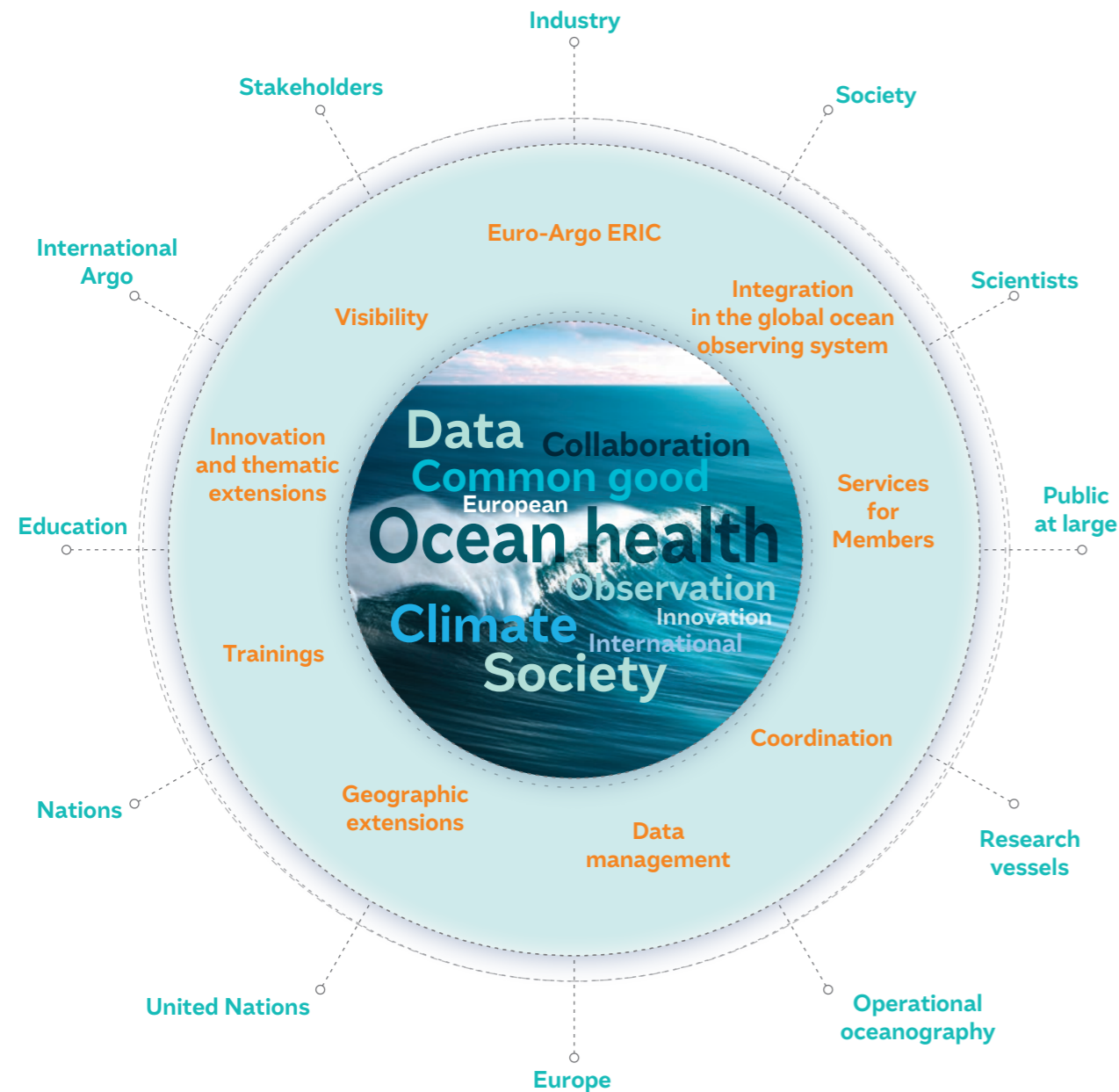
Figure 35: Euro-Argo ERIC, an integrated European research infrastructure.

Now thanks to the new H2020 European projects Euro Argo RISE, ENVRI-FAIR and EuroSea, the Euro-Argo ERIC can pursue its objective to enhance and extend the capabilities of the Argo network, focusing on the following objectives:

• **Improve the accuracy of the Essential Ocean Variables** (EOV as defined by GOOS) measured by Argo (temperature, salinity, oxygen, chlorophyll-a, suspended particles, downwelling irradiance, nitrate and pH).
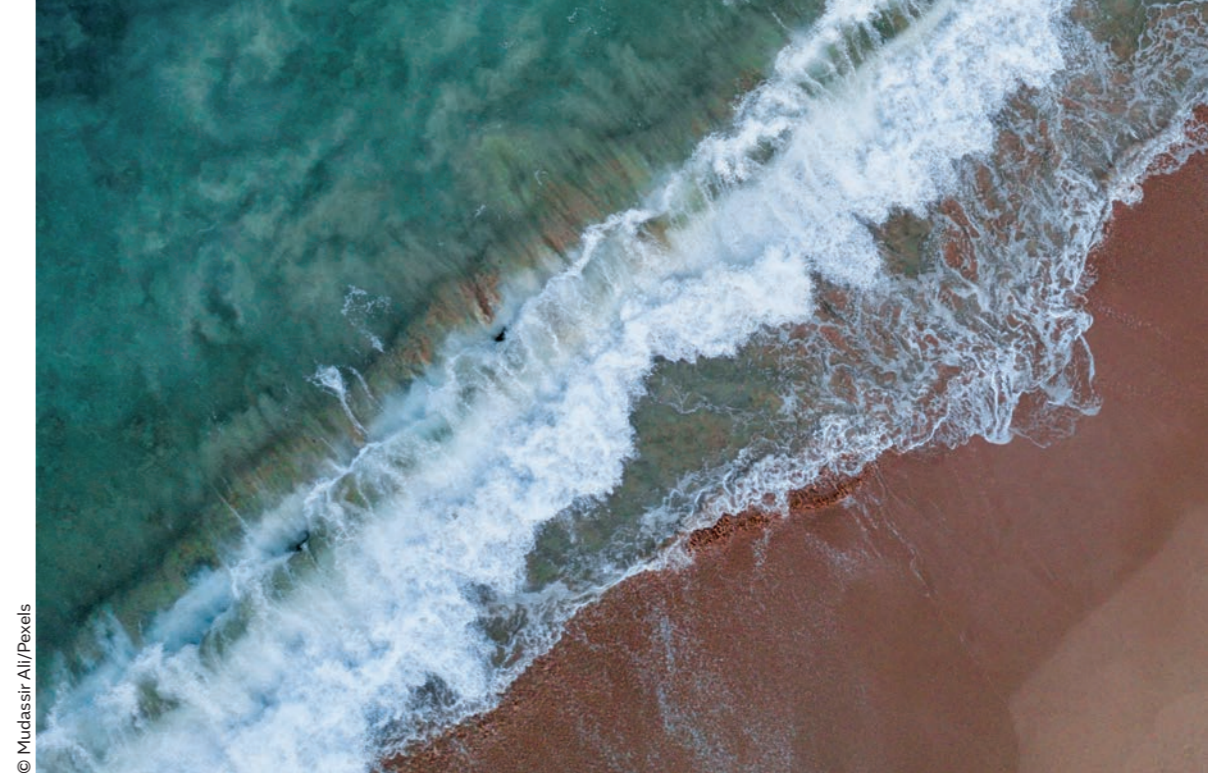
© Mudassir Ali/Pexels

• **Guarantee the long-term technological sustainability of the European contribution to Argo**, by qualifying new sensors and providing opportunities for new European SMEs, to enter the Argo float market, ensuring competition among float and sensor manufacturers.

• **Develop and sustain the Biogeo-chemical-Argo extension**, from data acquisition to data management, including quality control, and develop products for users, so consolidating Argo's contribution to biogeochemical and ecosystem ocean research.

• **Develop and sustain Argo's extension towards the deep ocean.**

• **Increase usability and lifetime of Argo floats in partially ice-covered areas.**

• **Investigate the potential of Argo profiling floats in shelf area.**

• **Investigate the potential of Argo profiling floats in shelf areas** to close the gap between open-ocean and shallow waters.

• **Increase Euro-Argo's integration within the European Ocean Observing System (EOOS)**, in particular by fostering links with other ESFRI Marine Research Infrastructures.

• **Enhance services to Argo users** (research, regulatory and operational systems).

• **Promote the importance of Argo to different types of stakeholders**, including the general public, and develop awareness among new Argo data users.

• **Improve the technological and financial sustainability of Euro-Argo** implementation through the development of Argo innovation potential by fostering relations between researchers and the private sector (SMEs and industry).

• **Develop a Long-Term sustainability plan** with Member and Observer countries, as well as the European Commission, to sustain ¼ of the "Global, full-depth and multidisciplinary" Argo network.

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ANNEX I - LIST OF INSTITUTIONS

COUNTRY	PARTNERS	EURO-ARGO COUNCIL	CONTRIBUTION FROM
Bulgaria	Ministry of Education and Science	IO-BAS	University of Sofia National Institute of Meteorology & Hydrology
Finland	Ministry of Transport and Communication	FMI	
France	Ministry of Research	Ifremer	SHOM INSU-CNRS-SU / LOV
Germany	Federal Ministry of Transport and Digital Infrastructure	BSH	Geomar University of Hamburg ICBM/ University of Oldenburg AWI
Greece	Ministry of Education	HCMR	
Ireland	Department of Agriculture, Food and the Marine (DAFM)	Marine Institute	
Italy	Ministry for Education	OGS	
Netherlands	Royal Netherlands Meteorological Institute	KNMI	
Norway	Ministry of Trade, Industry and Fisheries	IMR	
UK	Department for Business, Energy & Industrial Strategy (BEIS)	Met Office NERC-BODC	NERC-NOC PML
Spain	Ministerio de Economía y Competitividad	IEO SOCIB	

OBSERVERS

Poland	Ministerstwo Nauki i Szkolnictwa Wyższeg	IOPAN	

CANDIDATE MEMBERS

Portugal		IH IPMA	

LIST OF ACRONYMS

AIC
Argo Information Centre

ANR
Agence Nationale de la Recherche (French National Agency for Research)

AORA
Atlantic Ocean Research Alliance

ARC
Argo Regional Centre

Arctic-ROOS
Arctic Regional Ocean Observing System

ASFAR
Autonomous System For Argo float Release

AtlantOS
Atlantic ocean Observing System

AWI
Alfred Wegener Institut

BEERI
Board of European Environmental Research Infrastructures

BGC
BioGeoChemical

BODC
British Oceanographic Data Centre

BOOS
Baltic Operational Observing System

BSH Bundesamt für Seeschifffahrt und Hydrographie (German Federal maritime and hydrographic agency)

C3S
Copernicus Climate Change Service

CEREMA
Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (French Centre for studies and expertise on risks, the environment, mobility and development)

Chla
Chlorophyll a

CLIVAR
CLImate and ocean VARiability, predictability, and change

CMEMS
Copernicus Marine Environment Monitoring Service

CNES
Centre National des Etudes Spatiales (French spatial agency)

CNRS
Centre National de la Recherche Scientifique (French national centre for scientific research)

CO2
Carbon Dioxyde

COP21
21th Conference of the Parties

CPER
Contrat de Plan Etat-Région (contract between French State and Region)

CSIRO
Commonwealth Scientific and Industrial Research Organisation

CTD
Conductivity, Temperature, Depth

DAC
Data Assembly Centre

DBCP
Data Buoy Cooperation Panel

DG MARE
Directorate-General for Maritime Affairs and Fisheries

DIC
Dissolved Inorganic Carbon

DMQC
Delayed Mode Quality Control

E-AIMS
Euro-Argo Improvements for the Copernicus Marine Service

EA RISE
Euro-Argo Research Infrastructure Sustainability and Enhancement

ECMWF
European Centre for Medium range Weather Forecasting

EMB
European Marine Board

EMFF
European Marine and Fisheries Fund

EMODnet
European Marine Observation and Data network

EMSO
European Multidisciplinary Seafloor and water column Observatory

ENVRI FAIR
ENVironmental Research Infrastructures building FAIR services accessible for society

ENVRIplus
ENVironmental and earth system Research Infrastructures

EOOS
European Ocean Observing System

EOV
Essential Ocean Variables

ERA
European Research Area

ERC
European Research Council

ERIC
European Research Infrastructure Consortium

ESFRI
European Strategy Forum on Research Infrastructures

EU
European Union

EuroGOOS
European regional alliance of GOOS

FAIR
Findable Accessible Interoperable Reusable

FixO3
Fixed-point Open Ocean Observatory

FMI
Finnish Meteorological Institute

FOAM
Forecasting Ocean Assimilation Model

FP7
7th Framework Programme

GAIC
GO-SHIP/Argo/IOCCP

GCOS
Global Climate Observing System

GDAC
Global Data Assembly Centre

GEO
Group on Earth Observations

GES
Good Environmental Status

GOOS
Global Ocean Observing System

GODAE
Global Ocean Data Assimilation Experiment

GO-SHIP
Global Ocean Ship-based Hydrographic Investigation Programme

GOSUD
Global Ocean Surface Underway Data

GSSL
Global Steric Sea Level

GTS
Global Telecommunication System

H2020
Horizon 2020

HCMR
Hellenic Centre for Marine Research

HELCOM
Baltic Marine Environment Protection Commission - Helsinki Commission

ICBM
Institut für Chemie und Biologie des Meeres (German Institute for Chemistry and Biology of the Marine Environment)

ICOS
Integrated Carbon Observation System

ICTP
International Centre for Theoretical Physics

IEO
Instituto Español de Oceanografía (Spanish institute of oceanography)

Ifremer
Institut Francais de Recherche pour l'Exploitation de la MER (French institute for Marine Research)

IMR
Institute of Marine Research

INTAROS
INTegrated ARctic Observing System

IO-BAS
Institute of Oceanology – Bulgarian Academy of Sciencel

IOCCP
International Ocean Carbon Coordination Project

IOC-UNESCO
Intergovernmental Oceanographic Commission – United Nation Educational Scientific and Cultural Organisation

IOPAN
Institute of Oceanology of the Polish Academy of sciences

IPEV
Institut polaire français Paul-Émile-Victor (French polar institute)

IPMA
Instituto Português do Mar e da Atmosfera (Portuguese institute for sea and atmosphere)

IRD
Institut de Recherche et Dévelopement (French institute for research and development)

ISA
Ice-Sensing Algorithm

JCOMMOPS
Joint technical Commission for Oceanography and Marine Meteorology in situ Observing Platform Support

KNMI
Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)

LOPS
Laboratoire d'Océanographie Physique et Spatiale (Laboratory for Ocean Physics and Satellite remote sensing)

LOV
Laboratoire d'Océanographie de Villefranche-sur-Mer (Laboratory of Oceanography of Villefranche-sur-Mer)

MBARI
Monterey Bay Aquarium Research Institute

Med-ARC
Mediterranean and Black Seas ARC

MEFS
Marine Environment and Food Safety

METno
Norwegian Meteorological Institute

MI
Marine Institute

MOCCA
Monitoring the Oceans and Climate Change with Argo

MSFD
Marine Strategy Framework Directive

NA-ARC
North Atlantic ARC

NAOS
Novel Argo Ocean observing System

NCEI
National Centre for Environmental Information

NEMO
Nucleus for European Modelling of the Ocean

NERSC
Nansen Environmental and Remote Sensing Center

NGO
Non-Governmental Organisation

NIMH
National Institut of Meteorology and Hydrology (Bulgaria)

Niva
Norsk institutt for vannforskning (Norwegian institute for water research)

NOC
National Oceanography Centre

NODC
National Oceanographic Data Centre (now called NCEI)

NCEI
National Centre for Environmental Information)

NORCE
Norwegian Research Center AS

O₂
Oxygen

OCB
Ocean Carbon & Biogeochemistry

OECD
Organisation for Economic Co-operation and Development

OGS
istituto nazionale di Oceanografia e di Geofisica Sperimentale (Italian institute of oceanography and applied geophysics)

OMI
Ocean Monitoring Indicator

OMZ
Oxygen Minimum Zone

OSIS
Ocean Science and Information Services

OSSE
Ocean System Simulation Experiment

OSTIA
Operational Sea surface Temperature and sea Ice Analysis

pCO2
partial pressure of carbon dioxide

pH
potential Hydrogen

PIRATA
PredIction and Research moored Array in the Tropical Atlantic

PML
Plymouth Marine Laboratory

remOcean
remotely-sensed biogeochemical cycles in the Ocean

RI
Research Infrastructure

RVs
Research Vessels

R&D
Research & Development

SDG
Sustainable Development Goal

SHOM
Service Hydrographique et Océanographique de la Marine (French hydrographic service)

SIDERI
Strengthening International Dimension of Euro-Argo Research Infrastructure

SMEs
Small and Medium Enterprises

SOARC
Southern Ocean ARC

SOCCOM
Southern Ocean Carbon and Climate observations and Modelling project

SOCIB
Coastal Ocean observing and forecasting System - Balearic Islands

SOOP
Ship Of OPportunity

SOOS
Southern Ocean Observing System

STAG
Scientific and Technical Advisory Group

TMA
Transport Mooring Arrays

UH
Universität Hamburg

UiB
Universitetet i Bergen (University of Bergen, Norway)

USOF
Sofia University St. Kliment Ohridski

UVP
Under Vision Profiler

VOS
Voluntary Observing Ship programme

WMO
World Meteorological Organization

WMOP
Western Mediterranean OPerational forecasting system