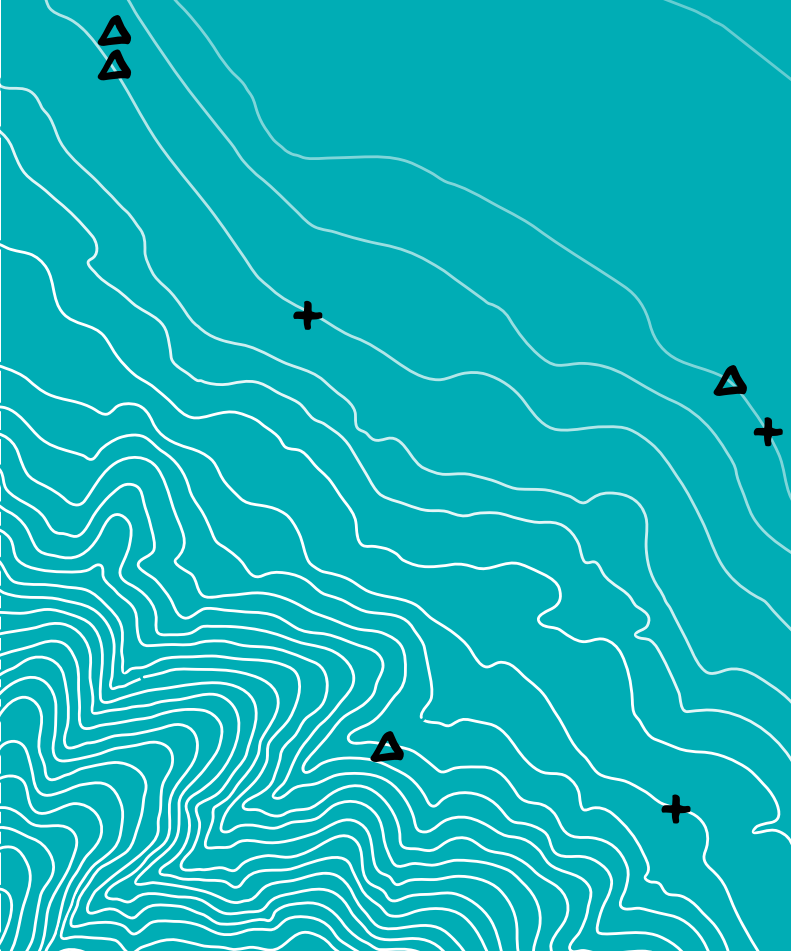
NAOS

Novel Argo Ocean observing System

Equipex Project



OBSERVING
THE WORLD OCEAN
PREPARING ARGO'S NEXT DECADE

The international Argo network

AN OCEANOGRAPHIC REVOLUTION

4 000
profiling floats
make up an international network that measures temperature and salinity in every sea on the planet, down to a depth of 2 000 m.

Argo cycle

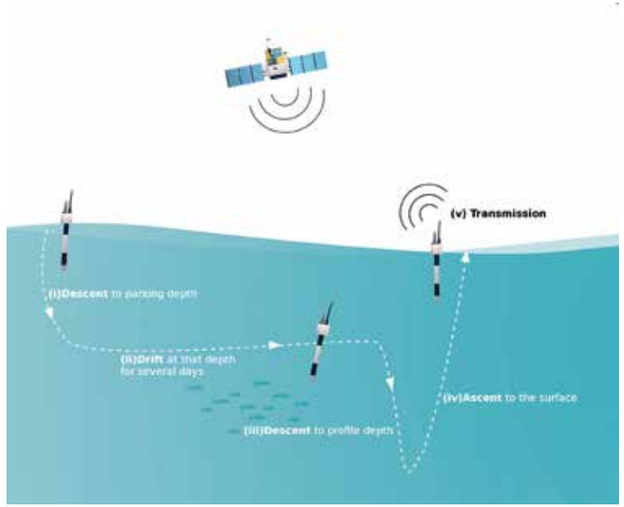
Argo has revolutionized ocean observation by permitting worldwide monitoring, in quasi-real time, of both the ocean surface and its depths.

Argo is a crucial component of the global ocean and climate observation system. Argo provides essential data:

To constrain ocean analysis and forecasting models, to initialize ocean-atmosphere models for seasonal and decadal forecasts, and to validate climate models.

For sensor calibration and the validation of satellite data.

To detect climate variability on seasonal and decadal scales, and for long-term observation of climate-change and its impacts on the oceans.



The Argo cycle of a profiling float typically lasts 10 days, and consists of 5 stages: (i) descent, (ii) drifting at depth over 9 days, (iii) descent to the profiling depth (2,000 m for Argo or BGC-Argo, 4,000 to 6,000 m for Deep-Argo), (iv) profiling along the ascent, during which scientific data are acquired, and (v) satellite transmission. © Euro-Argo

France has played an important role in the Argo program ever since its launch at the end of the 1990s. **France accounts for nearly 10 % of the international effort.**

Ifremer through the Coriolis data center coordinates one of Argo's two Global Data Assembly Centers as well as a Data Assembly Center (DAC) for data from France and several other European countries.

Thanks to a public/private partnership between Ifremer and the SME nke Instrumentation, France is a **European leader** in the **development of Argo floats** (Provor and Arvor floats).

The international Argo Information Center (AIC), part of the JCOMMOPS structure, is also hosted by Ifremer.

12 European countries
in 2020

Ifremer site
Brest

Oversees and federates European contributions to Argo.

France coordinates the **European research infrastructure Euro-Argo,** a long-term European legal structure and organization (Euro-Argo ERIC).

France's contribution to Argo (Argo-France) is organized through the Coriolis partnership which draws together the major French institutions involved in ocean observation.

Argo-France is included in the French Ministry of Research's national roadmap on very large-scale research facilities (TGIR). On a regional scale, Argo-France is supported by the IUEM and Villefranche-sur-Mer Observatories (IUEM and OOV OSU).

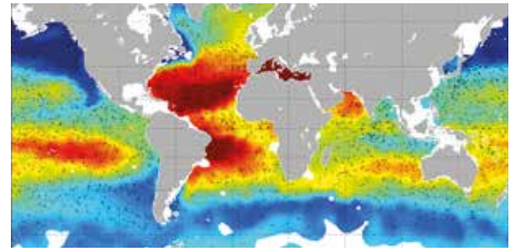
The NAOS Equipex project

PREPARING NEW CHALLENGES FOR ARGO

NAOS Novel Argo Ocean Observing System
was selected to participate in the French government's Equipex "Investissement d'avenir" Investing in the Future **program**

To understand and predict climatic and oceanic evolutions
maintaining the Argo network in the coming decades and ensuring its evolution are vital.

NAOS Equipex float coverage



Objectives

#1

To consolidate France's contribution to Argo's core mission: temperature and salinity measurements down to a depth of 2 000 m.

#2

To develop the future generation of French Argo profiling floats: higher-performance, "smarter," with a capacity to integrate biogeochemical sensors, reach greater depths (4 000 m) and observe polar regions.

#3

To prepare the next stage of the Argo program with an extension to the deep sea (Deep-Argo), to biogeochemistry (BioGeoChemical-Argo) and to the polar seas. Three pilot experiments were carried out:

- floats with biogeochemical sensors in the Mediterranean Sea,
- floats with biogeochemical sensors in the Arctic Ocean,
- deep-sea floats with oxygen sensors in the North Atlantic.

Sponsors

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

INVESTIR L'AVENIR

Scientific partners

Ifremer
SORBONNE UNIVERSITÉ
SHOM
cnrs
UNIVERSITÉ LAVAL
UBO
iuem

Industrial partners

CLS
Satellite telecommunication

nke INSTRUMENTATION
Argo floats industrialization and marketing

WP1
Consolidation of France's contribution to Argo
Led by Ifremer
2012 > 2019

5 workpackages
2011 → 2020

WP2
Development of the new generation of Argo floats
Led by Ifremer
2011 > 2016: technological developments and at-sea tests

WP3
Floats with biogeochemical sensors in the Mediterranean
Led by UPMC/LOV
2012: launch of scientific experiments

WP4
Floats with biogeochemical sensors in the Arctic
Led by Takuvik (CNRS/Université Laval)
2015/2016: launch of scientific experiments

WP5
Deep-sea floats with oxygen sensors in the North Atlantic
Led by IUEM/LPO
2015 > 2016: launch of scientific experiments

New-generation of French Argo floats

Deployment of a Deep-Arvor float.
© Kevin Balem/LOPS

4 000 m
depth

88 %
of the ocean's volume monitored

Deep-Arvor profiling Float

In 50 years, the ocean has absorbed over **90 % of excess heat accumulating on Earth due to human activities,** causing heating of the global ocean that extends far below a depth of 2 000 m.

To track this signal of climate change in the ocean depths, the NAOS project developed the Deep-Arvor profiling float.

The technological developments carried out as part of the NAOS project meet the need to **consolidate France's contribution to Argo,** and to **develop extensions** for Deep-Argo and BGC(bio-geo-chemistry)-Argo.

Arvor launch. © Hanna Leniec-Koper

Arvor profiling Float

The NAOS project has opened the way for unprecedented work on **upgrading and increasing the reliability** of the Arvor float produced by nke Instrumentation.

The world's most deployed float in 2018 and 2019

96 %
of Arvor floats are still active after 1 000 days at sea, compared to 76 % in the past.

French BGC profiling Float

Provor BGC profiling floats integrate a growing number of **biogeochemical sensors,** which require a flexible hardware and software architecture.

The Provor CTS5-*Payload* was developed with this need in mind and comprises:
- an electronic board dedicated to managing the float's movement,
- a *Payload* board dedicated to managing the sensors.

ProVal float during the Sagitta 2017 mission.
© Edouard Leymarie/LOV

The ProVal is an example of a float designed in partnership with the CNES (French Space Agency) to carry out in-situ radiometric measurements in order to validate satellite "ocean color" products.

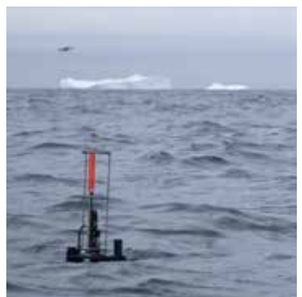
Deployment of a Pro-Ice (equipped with BGC sensors) in Baffin Bay (BB2 site, July 2017, from the Amundsen, AN1702 mission). © Claudie Marec

Under-ice profiling Floats

Polar regions play a key role in climate regulation, but observing them is a complex challenge.

The NAOS project has enabled numerous experiments in these regions, thanks to an **Ice-Sensing Algorithm** (ISA), embedded in the Provor CTS5-Payload and validated in the course of several deployments in Baffin Bay (Arctic). This algorithm now equips Arvor and Deep-Arvor profiling floats.

Pro-Ice float during the 2016 Green Edge campaign.
© Pascal Bourgain



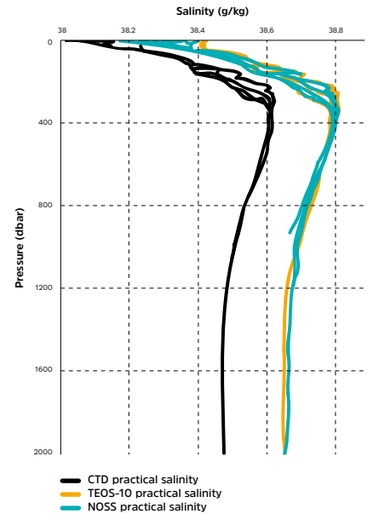
NOSS sensor. © nke Instrumentation

NOSS sensor

Classic CTD (conductivity, temperature, depth) measurements fail to take into account the influence of non-ionic compounds in seawater.

The NOSS sensor measures **absolute salinity,** thanks to a **refractometric measurement technique.**

The NAOS project has led to:
- the sensor's miniaturisation and increased reliability,
- its integration into the Provor float for testing at sea over numerous profiles at 2 000 m.

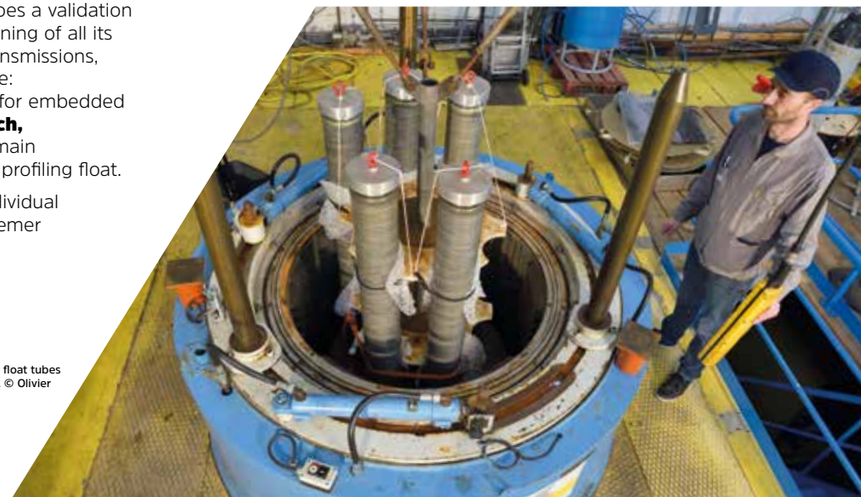


Testing means

Each profiling-float prototype undergoes a validation procedure to check the sound functioning of all its subassemblies (sensors, hydraulic, transmissions, electronics, etc.). Of particular note are:
- an elaborate validation procedure for embedded software on a laboratory **test bench,**
- hyperbaric-chamber tests for the main subassemblies, then the complete profiling float.

During the production stage, each individual float is **trialed in the test pool** at Ifremer before being launched at sea.

Validation of Deep-Arvor float tubes in a hyperbaric chamber. © Olivier Dugornay/Ifremer



Floats with biogeochemical sensors

IN THE MEDITERRANEAN

Objective

To demonstrate the feasibility of a network of BGC-Argo floats on the scale of an ocean basin, and its capacity to increase our knowledge about the ocean's physico-biogeochemical interactions.

With the exception of a thin surface layer observed by satellite, oceanic biogeochemistry is drastically under-sampled, and remains, as a result, poorly understood. And yet, the risks that societies face due to climate-change impacts on marine ecosystems raise an alert for emergency action:

→ ***Improving our observational capacities*** to identify the key processes that control the dynamics of the oceanic biosphere.

The Mediterranean Sea stood out as an ideal candidate for the implementation of this pilot network. As a small-scale ocean basin, the Mediterranean is characterized by several important processes such as:

- the formation of deep and intermediate waters,
- the existence of the three active thermohaline circulation cells.

At the outset of NAOS, the PROVBIO platform (developed by Ifremer and industrialized by nke Instrumentation as part of the ERC remOcean project) demonstrated its capacities over a number of deployments carried out in different and contrasting oceanic regions.

In 2010, there was still no pluriannual **observation system** based on BGC-Argo floats on the scale of an ocean basin.

In 2010, the international community recommended that a pilot experiment of this type be carried out as a necessary step before the implementation of a truly global network.

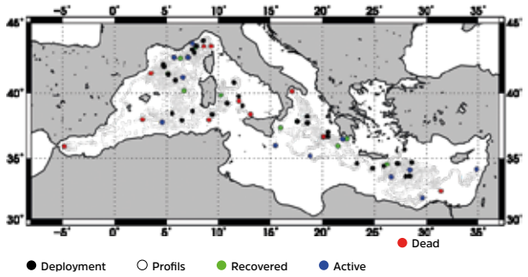
The Mediterranean Sea, a pilot region

Situated within a relatively limited latitudinal band, the Mediterranean comprises **immensely varied trophic regimes,** ranging from extreme oligotrophy in its easternmost region to the seasonality typical of temperate zones in the basin's northwest sector.

This range of seasonal variations, summed up by Mediterranean biogeographical data derived from 20 years of satellite observations, helped to steer the deployment and sampling strategy used for

26 NAOS BGC-Argo Floats

Positions of BGC-Argo profiles from the NAOS network in the Mediterranean.



3 waves of deployment

one wave roughly every 3 years (2012-2013, 2015, 2018)

→ NAOS WP3 :

constant observation of the basin over approximately 8 years.

Retrieval and redeployment

Over 4 000 profiles obtained

from throughout the basin at the start of 2020

6 floats retrieved

then successively redeployed

5 floats still active

Over 65 % of the floats deployed have notched up more than

250 days of at-sea operation

with a success rate comparable to that of Argo's "Core" floats.

1/3 of floats redeployed

Over 30 publications

2010 > 2020

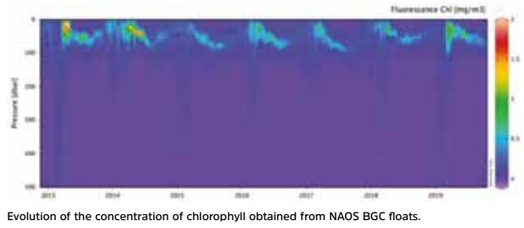
Usage

Exploitation of the data gathered (and made freely accessibly in accordance with the Argo policy) is already underway, namely through lively interaction with the scientific community involved in INSU's "MISTRALS" program and its biogeochemical component "MERMEX".

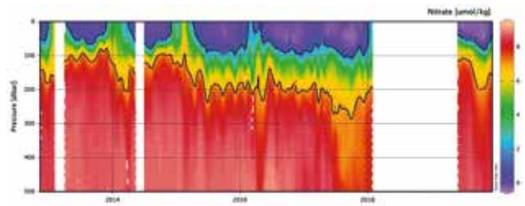
↓

NAOS floats have contributed to experimental studies in the DEWEX, PEACETIME and PERLE campaigns. They were also instrumental in one of the earliest projects **to integrate BGC-Argo floats in an operational physico-biogeochemical model.**

Chlorophyll and nitrate in the northwestern Mediterranean



Evolution of the concentration of chlorophyll obtained from NAOS BGC floats.



Evolution of the concentration of nitrates obtained from NAOS BGC floats.

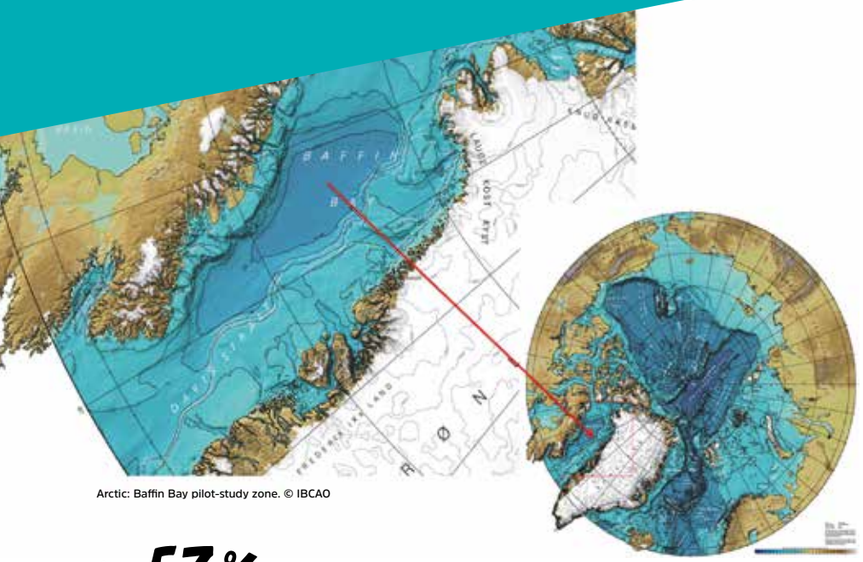
↑

Long-term monitoring yielding time series of nitrates and chlorophyll-a profiles in the northwestern Mediterranean.

Not only has the NAOS WP3 demonstrated the **feasibility of a BGC-Argo network** on a basin scale, it has also made a strong contribution to **understanding of the physico-biogeochemical processes that control Mediterranean ecosystems.**

Floats with biogeochemical sensors

IN THE ARCTIC OCEAN



Arctic: Baffin Bay pilot-study zone. © IBCAO

The Arctic, a pilot-project region for NAOS

Climate change has triggered **fundamental modifications to marine biotopes** in the Arctic Ocean. For this reason, this site was selected for a pilot study.

BGC-Argo floats constitute a tool that supplements remote sensing and oceanographic missions in this pilot-project.

Growth of French involvement in the international Argo network

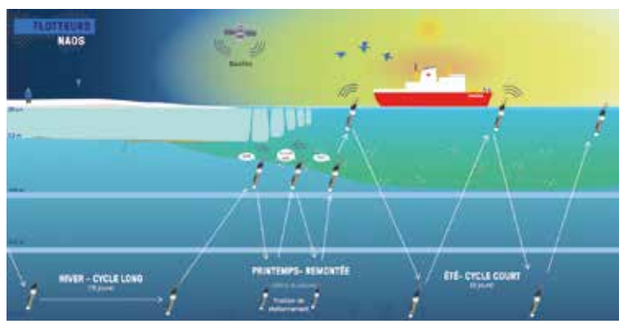
Over 57 % of pan-Arctic primary production

is due to the diminution of summer ice-cover in the Arctic Ocean in the last two decades.

One important element of primary production in the Arctic Ocean is the **phytoplankton spring bloom** which develops at the edge of ice, both under sea ice and in ice-free water: growth that represents a large proportion of yearly primary production.

Study of the **dynamics of spring blooms** requires the availability of year-round high-frequency time series on phytoplankton phenology and growth factors.

Pro-Ice cycle



Pro-Ice cycle. © J. Sansoulet

Deployment of a Pro-Ice float. © P. Bourgain

New-generation BGC Float

Thanks to NAOS and the development of a **new generation of BGC floats** (Pro-Ice), Takuvik succeeded in conducting its study in Baffin Bay from 2016 onwards.

These float deployments were carried out as a NAOS pilot experiment, within the program framework of the **Green Edge research project:** www.greenedgeproject.info

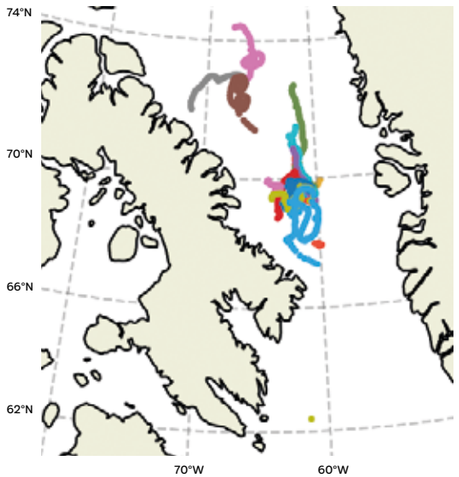
The **BGC floats** (Pro-Ice), relying on Provor CTS5-Payload technology, are equipped with biogeochemical sensors:

- dissolved oxygen,
- nitrate,
- chlorophyll-*a* fluorescence,
- fluorescence of dissolved organic matter (CDOM),
- suspended particles,
- radiometry.

They have been **adapted to navigate in icy zones** and postpone surfacing for data transmission if they detect surface ice.

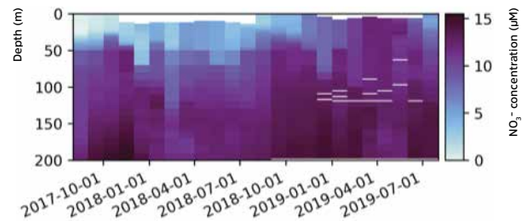
Pro-Ice trajectories

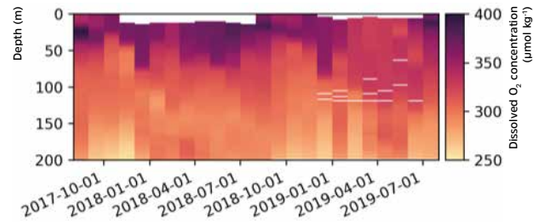
Between 2016 and mid-2020 in Baffin Bay.



Nitrate and oxygen in Baffin Bay

Concentrations obtained by under-ice BGC profiling floats.





These unprecedented data have offered the means to **analyze full annual cycles** of phytoplankton biomass, hydrography, light availability and sea-ice coverage to **decipher the environmental factors** that influence the onset of spring blooms.

Deep Floats with oxygen sensors

IN THE NORTH ATLANTIC

The deep ocean, an unknown realm

Due to a limited number of observation data, **the ocean depths** below 2 000 m remain **largely unknown** to date. It is nevertheless necessary to quantify the mean currents and mean properties of deep water masses as well as their variabilities in order to assess:

- their role in the storage of excess heat accumulating on Earth as a result of human activities,
- the sea level rise due to the ocean's expansion as a consequence of warming,
- the spread of climatic anomalies in the ocean.

Such information is crucial for ***improving climate-projection models.***

23 Deep-Arvor Floats

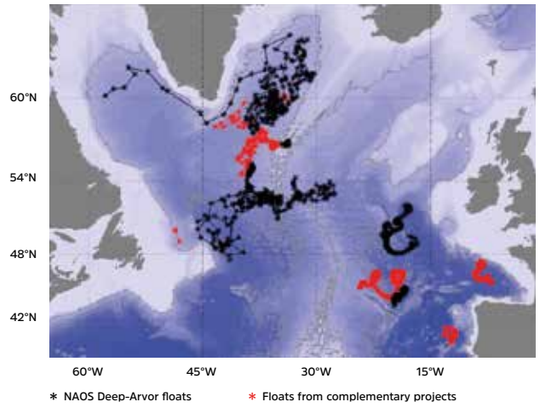
acquired by the NAOS project

These were mainly deployed in the Subpolar North Atlantic Ocean to demonstrate the technical feasibility and scientific interest of making measurements at depths beyond 2 000 m (Figure 1).

The Subpolar North Atlantic Ocean is a region where surface waters coming from the south densify and plunge down to great depths. As these surface-water masses have had contact with the atmosphere, they transport **traces of the recent climate,** and by plunging, contribute to the deep ocean's sequestration of climate signals (such as excess heat or CO_2 due to human activities).

French Floats in the North Atlantic

Figure 1



Objective #1

To understand how climate signals penetrate and travel through the ocean

Objective #2

To launch a Deep-Argo network in this basin

Discovery of new routes

Surprisingly, the floats, deployed in a fracture zone of the Mid-Atlantic Ridge near 50°N latitude, did not follow the northward trajectory of the dominant currents. One of them even revealed the existence of a **new deep route towards the south** which had never been observed directly until now (Figure 2).

Figure 2a. Map of deep mean currents (Daniault et al. 2016).

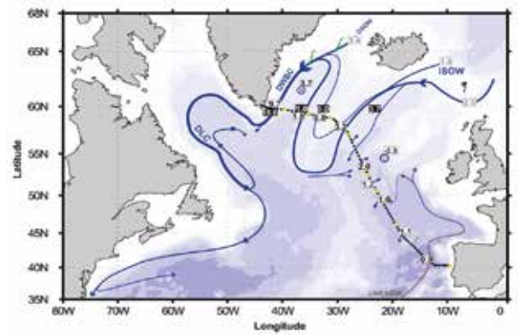
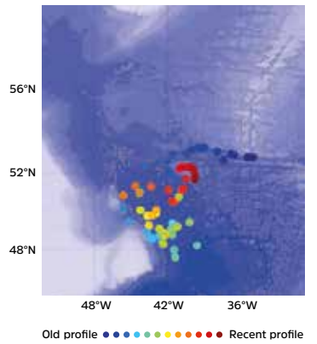


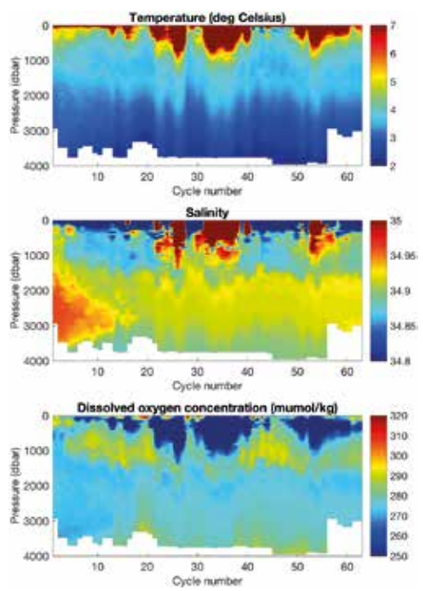
Figure 2b. Trajectory of float 6901758 deployed in the Charlie Gibbs Fracture zone.



Thanks to data from NAOS Deep-Arvor floats, scientists participating in the NAOS project also observed **the mixing of a young water mass, recently formed near Iceland and circulating at 2,750 m in a deep channel, with an older water mass as a result of particularly energetic surface currents** at this location.

To obtain these results, they relied on data on the dissolved oxygen concentration data acquired by Deep-Arvor floats (Figure 3). From these data, it was possible to **deduce the relative age of a water mass** corresponding to the time elapsed since the water mass's last contact with the atmosphere. In this way, the younger a water mass, the higher its oxygen concentration, and vice versa.

Figure 3: Temperature, salinity and dissolved-oxygen concentration data along the trajectory of Deep-Arvor float 6901758.



On the strength of the **success of the NAOS project** and other pilot experiments carried out in other oceanic regions (such as the southwest Pacific), the Argo program is expanding to incorporate a long-term Deep-Argo component, with the aim of:

maintaining in operation 1 250 deep floats

uniformly spread out throughout the oceans.

Following on from the NAOS project, France has committed to contributing to the Deep-Argo network and its implementation.

Deep-Arvor float. © P. Rousseaux / Ifremer

French contribution

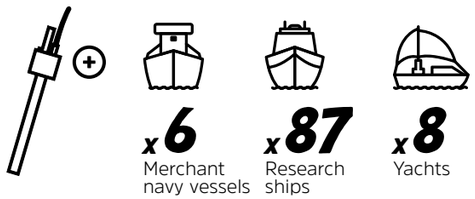
TO THE GLOBAL ARGO MISSION

Standard CTD floats purchased in the framework of the NAOS project have boosted **a rise in France's contribution to Argo** from 65 to 80 floats per year.

France now represents 1/4 of the European effort and 10% of the global effort during the period between 2012 and 2017.

101 floats launched
between 2012 and 2019

Number of NAOS Floats deployed



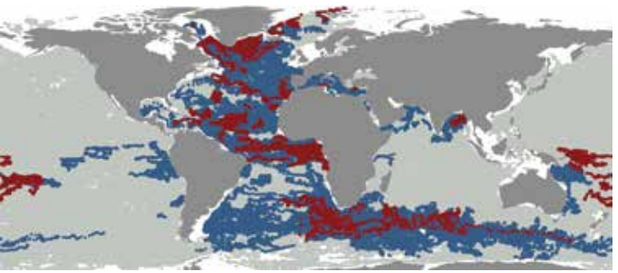
x6 Merchant navy vessels

x87 Research ships

x8 Yachts

French contribution on a global scale

Cartography of Argo observations over the period 2012-2019 (1 million profiles)



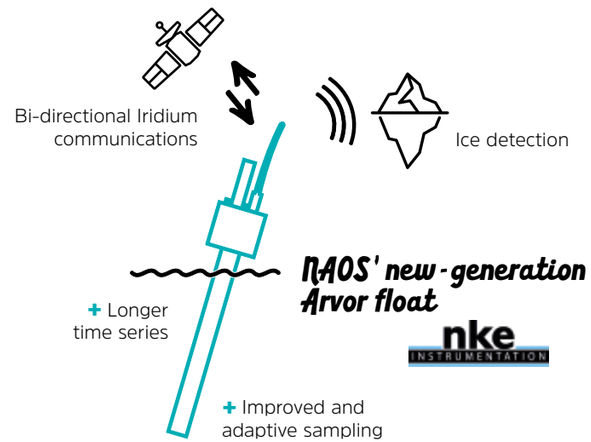
● 10% of observations by Argo-France ● 1% of observations by NAOS floats

Over 10 000 CTD profiles collected
thanks to NAOS floats

= 1%
of one million Argo observations

One of the first NAOS Arvor floats ready for a second life after being retrieved and reconditioned – July 2020 © Boris Hermann

Expanded mission capacities



NAOS' new-generation Arvor float

nke INSTRUMENTATION

180 Argos cycles
5 years

250 Iridium cycles
7 years

1/3 of NAOS floats
still active in 2020

Over 400 French contributions
to Argo publications

The last NAOS WP1 Arvor, #6902727, just prior to its deployment in Baffin Bay – July 2019 © Claudie Marec

Socio-economic impacts

Benefits that far outweigh costs

Given Argo's key importance for climate change research plus its role in and influence on climate forecasts, the socio-economic impacts generated by Argo and NAOS are very significant in the long term. These also include the wide range of ocean services offered by operational oceanography:

- maritime transport,
- maritime security,
- fishing management,
- monitoring and forecasting of accidental pollution,
- ...

Today, over 24 000 subscribers
to the Marine Service of the European Union Copernicus program can take advantage of high quality global ocean analyses and forecasts thanks to the real-time observations of Argo and NAOS.

© Mercator Ocean International

Applications of the Copernicus Marine Service:
1 Polar environment monitoring 2 Marine conservation & policies
3 Science & climate 4 Natural resources & energy 5 Water quality
6 Coastal monitoring 7 Society & education 8 Marine food
9 Marine navigation 10 Safety & disaster

NAOS, a technology and economy booster

NAOS has had a catalyst effect in **strengthening the international competitiveness of nke Instrumentation** and opening up new business opportunities. Indeed, nke Instrumentation has become the **number 2 industrial manufacturer of Argo profilers** in terms of the number of active floats. This excellent growth corresponds to a twofold increase in nke Instrumentation's market share compared with the pre-NAOS period.

Over 20 % of active Floats
in 2020 were delivered by nke Instrumentation.

250 nke Instrumentation floats
were deployed in 2019

> "NAOS has allowed us to improve our floats and to provide an operational guarantee to the international clients who, as a result, have placed their trust in us. The program has also led us to develop new functions such as biogeochemical, deep-sea and under-ice measurements, and to widen our market offer."

Jean-Claude Le Bleis
CEO of nke Instrumentation

CLS, the operator of the Argos system, identified NAOS as offering a unique opportunity to test and validate **new Argos-3 satellite-communication techniques** for the ocean-instrumentation industry.

NAOS' usage of Argos-3 technology has helped to fuel:

- definition of the current system's capacity limits,
- the gathering of **feedback from experienced users** to feed the design of the next-generation Argos instrument (Argos-4).

The next French constellation of nano-satellites (Kinéis), scheduled to be launched in 2022, fully takes into account NAOS feedback.

25 satellites

Optimized high-speed link

> "Thanks to NAOS, we received the first user feedback on Argos-3 technology very soon after the launch of the satellites, allowing us to tune the specifications for the next generation of Argos instruments in order to best meet the needs of operational oceanography in terms of data collection via satellite. For me, NAOS is a genuine booster for French science and technology in its field."

Yann Bernard
Director, Environment and Climate CLS

The future of NAOS

NEW CHALLENGES

Objectives

Improve its coverage

Sustain the network

Set up its global extensions

Strategy

- Consolidating France's **key role** in Argo
- Contributing to an **optimized and global network** via international and European collaborations
- Maintaining leadership in the **management of Argo data**
- Playing a leading role in the **scientific validation** of BGC-Argo data
- **Integrating Argo data** with satellite observations and models
- Deploying Argo floats in **priority areas of interest** for the French scientific community: the North Atlantic, the Mediterranean, tropical regions (PIRATA, TPOS2020), the Arctic and Antarctic

Scientific stakes

Climate change

Rising sea levels

Ocean deoxygenation and acidification

Carbon cycle

Oceanic and climatic forecasts

80 Argo floats/year

- **30** standard floats — Temperature and Salinity
- **20** floats — with oxygen sensors
- **15** deep-sea floats — (Deep-Argo)
- **15** floats — with biogeochemical sensors (BGC-Argo)

= **30 %** of European contribution

Technological developments

- **Deep-Arvor float** 6 000 m depth
- **New-generation BGC-Argo**
  - + imaging
  - + active acoustics

© GOOS/IOC - Getty Images

2030 objective

→ **4 700 floats**

including 1 000 BGC-Argo and 1 200 Deep-Argo floats

French contribution of 10 %

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Main NAOS publications

- Lavigne H. et al. (2013), **Enhancing the comprehension of mixed layer depth control on the Mediterranean phytoplankton phenology**, Journal of Geophysical Research.
- D'Ortenzio F. et al. (2014), **Observing mixed layer depth, nitrates and chlorophyll concentrations in the North Western Mediterranean: a combined satellite and NO_3 profiling floats experiment**, Geophysical Research Letters.
- André X. et al. (2015), **Argos3 Satellite Communication system: Implementation on the Arvor Oceanographic Profiling Floats**, Journal of Atmospheric and Oceanic Technology
- Lavigne H. et al. (2015), **On the vertical distribution of the chlorophyll-a 1 concentration in the Mediterranean Sea: a basin scale and seasonal approach**, Biogeosciences.
- Sauzede R. et al. (2015), **Vertical distribution of chlorophyll a concentration and phytoplankton community composition from in situ fluorescence profiles: a first database for the global ocean**, Earth System Science Data.
- Pasqueron de Fommervault O. et al. (2015), **Atmospheric input of inorganic nitrogen and phosphorus to the Ligurian Sea: Data from the Cap Ferrat coastal time-series station**, Deep-Sea Research.
- Pasqueron de Fommervault O. et al. (2015), **Temporal variability of nutrient concentrations in the northwestern Mediterranean sea (DYFAMED time-series station)**, Deep-Sea Research.
- Pasqueron de Fommervault O. et al. (2015), **Seasonal variability of nutrient concentrations in the Mediterranean Sea: Contribution of Bio-Argo floats**, Journal of Geophysical Research.
- Cabanes C. et al. (2016), **Improvement of bias detection in the conductivity sensor of Argo float. Application to the North Atlantic Ocean**, Deep-Sea Research.
- Le Reste S. et al. (2016), **Deep-Arvor: A New Profiling Float to Extend the Argo Observations Down to 4000-m Depth**, Journal of Atmospheric and Oceanic Technology.
- Organelli E. et al. (2016), **A novel near real-time quality-control procedure for radiometric profiles measured by Bio-Argo floats: protocols and performances**, Journal of Atmospheric and Oceanic Technology.
- Mayot N. et al. (2016), **Interannual variability of the Mediterranean trophic regimes from ocean color satellites**, Biogeosciences.
- Sauzede R. et al. (2016), **A neural network-based method for merging ocean color and Argo data to extend surface bio-optical properties to depth: Retrieval of the particulate backscattering coefficient**, Journal of Geophysical Research.
- Houpert L. et al (2016), **Observations of open-ocean deep convection in the northwestern Mediterranean Sea: Seasonal and interannual variability of mixing and deep water masses for the 2007–2013 period**, Journal of Geophysical Research.
- Piron A. et al. (2016), **Argo float observations of basin-scale deep convection in the Irminger sea during winter 2011–2012**, Deep-Sea Research.
- Bosse A. et al.(2016), **Scales and dynamics of Submesoscale Coherent Vortices formed by deep convection in the northwestern Mediterranean Sea**, Journal of Geophysical Research.
- Estournel C. et al. (2016), **High resolution modeling of dense water formation in the north-western Mediterranean during winter 2012–2013: Processes and budget**, Journal of Geophysical Research.
- Le Menn M. et al. (2016), **Développement et essais d'un salinomètre optique, I2M (Lavoisier)**, Méthodes optiques, Vol. 15.
- Piron A. et al. (2017), **Gyre-scale deep convection in the subpolar North Atlantic Ocean during winter 2014–2015**, Geophysical Research Letters.
- Testor P. et al. (2017), **Multiscale Observations of Deep Convection in the Northwestern Mediterranean Sea During Winter 2012-2013 Using Multiple Platforms**, Journal of Geophysical Research.
- Lagunas J. et al. (2018), **Sea-ice detection for autonomous underwater vehicles and oceanographic lagrangian platforms by continuous-wave laser polarimetry**, SPIE Proceedings Vol. 10631, Ocean Sensing and Monitoring.
- Le Menn M. (2018), **Calibration and temperature correction of a V-block refractometer**, Measurement Science and Technology.
- Leymarie E. et al. (2018), **ProVal: A New Autonomous Profiling Float for High Quality Radiometric Measurements**, Frontiers in Marine Science.
- Taillandier V. et al. (2018), **Hydrography and biogeochemistry dedicated to the Mediterranean BGC-Argo network during a cruise with RV Tethys 2 in May 2015**, Earth System Science Data.
- Testor P. et al. (2018), **Multiscale Observations of Deep Convection in the Northwestern Mediterranean Sea During Winter 2012-2013 Using Multiple Platforms**, Journal of Geophysical Research.
- Wolf M. et al. (2018), **Oxygen saturation surrounding Deep Water formation events in the Labrador Sea from Argo-O_2 data**, Global Biogeochemical Cycles.
- Barbieux M. et al. (2018), **Assessing the variability in the relationship between the particulate backscattering coefficient and the chlorophyll a concentration from a global Biogeochemical-Argo database**, Journal of Geophysical Research.
- Barbieux M. et al. (2019), **Bio-optical characterization of subsurface chlorophyll maxima in the Mediterranean Sea from a Biogeochemical-Argo float database**, Biogeosciences, European Geosciences Union.
- Bellacicco M. et al. (2019), **Global variability of optical backscattering by non-algal particles from a Biogeochemical-Argo dataset**, Geophysical Research Letters.
- Cossarini G. et al. (2019), **Towards operational 3D-Var assimilation of chlorophyll Biogeochemical-Argo float data into a biogeochemical model of the Mediterranean Sea**, Ocean Model.
- Mignot A. et al. (2019), **Quantifying observational errors in Biogeochemical-Argo oxygen, nitrate, and chlorophyll a concentrations**, Geophysical Research Letters.
- Smith G. et al. (2019), **Polar Ocean Observations: A Critical Gap in the Observing System and Its Effect on Environmental Predictions From Hours to a Season**, Frontiers in Marine Science.
- Racapé V. et al. (2019), **ISOW Spreading and Mixing as Revealed by Deep-Argo Floats Launched in the Charlie-Gibbs Fracture Zone**, Journal of Geophysical Research.
- Roemmich D. et al. (2019), **On the Future of Argo: A Global, Full-Depth, Multi-Disciplinary Array**, Frontiers in Marine Science.
- Terzić E. et al. (2019), **Merging bio-optical data from Biogeochemical-Argo floats and models in marine biogeochemistry**, Biogeosciences.
- André X. et al. (2020), **Preparing the new phase of Argo: technological developments on profiling floats in the NAOS project**, Frontiers in Marine Science.
- Babin M. et al. (2020), **The role of light and mixing in triggering and stopping the phytoplankton fall bloom in the Arctic Ocean**, Proceedings of the National Academy of Sciences (submitted).
- D'Ortenzio F. et al. (2020), **Biogeochemical Argo: the test case of the NAOS Mediterranean array**, Frontiers in Marine Science.
- Le Traon P.Y. et al. (2020), **Preparing the new phase of Argo: scientific achievements of the NAOS project**, Frontiers in Marine Science.
- Randelhoff A. et al. (2020), **Arctic mid-winter phytoplankton growth revealed by autonomous profilers**, Science Advances.
- Randelhoff A. et al. (2020), **Pan-Arctic Ocean Primary Production Constrained by Turbulent Nitrate Fluxes**, Frontiers in Marine Science.
- Zunino P. et al. (2020), **Why did deep convection persist over four consecutive winters (2015–2018) southeast of Cape Farewell?**, Ocean Science.

Steering Committee

Pierre-Yves Le Traon
Coordinator,
Ifremer

Marcel Babin
WP4 leader,
CNRS/INSU

Fabrizio D'Ortenzio
Co-coordinator
& WP3 leader,
Sorbonne Université

Claudie Marec
Steering Committee WP4,
CNRS/INSU

Edouard Leymarie
Steering Committee WP3,
Sorbonne Université

Virginie Thierry
WP5 leader,
Ifremer

Sylvie Pouliquen
WP1 leader,
Ifremer

Serge Le Reste
and **Xavier André**
WP2 leader, Ifremer

Governing Board

Patrick Vincent
Chairman of the
Governing Board,
Ifremer

Yann Bernard
CLS

Etienne Balan
Sorbonne Université

Jean-Claude Le Bleis
Nke Instrumentation

Bruno Blanke
CNRS

Frédéric Jean
IUEM

Laurent Kerleguer
SHOM

Project Office

Virginie Le Saout
Ifremer/Altran

Project Team

Ifremer: Martin Amice, Alexandre Beauguion, Vincent Bernard, Tanguy Bescond, Thomas Bouinot, Thierry Carval, Christine Coatanoan, Damien Desbruyères, Vincent Dutreuil, Fabienne Gaillard, Catherine Lagadec, Sylvie Le Bras, Yannick Lenault, Guillaume Maze, Bertrand Moreau, Noé Poffa, Corentin Renaut, Coralie Trautmann

Sorbonne Université: Hervé Claustre, Loïc Le Ster, Nicolas Mayot, Alexandre Mignot, Christophe Migon, Orens Pasqueron du Fommervault, Christophe Penkerc'h, Antoine Poteau, Louis Prieur, Vincent Taillandier

CNRS / INSU: Catherine Schmechtig, Herlé Mercier, Virginie Racapé, José Lagunas, Achim Randelhoff, Xiaogang Xing (Takuvik - CNRS/Université Laval)

SHOM: Eric Duporte, Nathanaële Lebreton, Marc Le Menn

UBO / IUEM: Cécile Cabanes, Nicolas Kolodziejczyk, Sabrina Speich

CLS: Michel Guigue, Stéphan Lauriol, Jean-Pierre Malardé, Philippe Schwab

nke Instrumentation: Patrice Brault, Arnaud David, Benoît Jugeau, Damien Malardé, David Nogré, Jérôme Sagot, Christophe Schaeffer

Thank you!

The NAOS project received support from the French Ministry of Research under the **"Investissements d'avenir" (Investing in the Future) program**. This support, managed by the French National Research Agency (ANR), is referred to as ANR-10-EQPX-40.

RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité