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E-AIMS

Euro-Argo Improvements for the GMES Marine Service

R&D on float technology
Synthesis
D2.6.1

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Table of Content

1. Introduction

1.1. General presentation

This document is the synthesis of the results of WP2 work, obtained from the five experiments that were conducted with the floats deployed at sea. Task 2.1 concerns the comparison of two oxygen sensors, Task 2.2 has to test new deep floats, Task 2.3 evaluates bio-geochemical floats, Task 2.4 is decated to satellite transmission performance assessment and task 2.5 concerns Arctic floats. It is the deliverable D2.61 identified in the description of work DA-1, in the table WT 2, which was initially due by the end of June 2015 (T0+30), but which was postponed to October 2015 (T0+34) (see minutes of 5th steering committee meeting), T0 being the 1st of January 2013.

1.1.1. *Reminder of the WP2 objectives (DOW, WT3, Work package 2 description)*

"The continued improvement and evolution of float technology is crucial to answer existing and new GMES Marine Service requirements, to develop new capabilities for seasonal and decadal forecasting, to better serve satellite Cal/Val activities and to answer science requirements to further explore the oceans. Technological innovation is also needed to improve reliability, lifetime, energy savings and to reduce costs and size/weight. This is a key aspect of long term sustainability. There are several important on going float technology R&D activities and new Argo floats are or will soon be available from float manufacturers (in particular from the European SMEs NKE and Optimare). They require, however, extensive testing before they can be used for operational monitoring. E-AIMS WP2 will organize an end-to-end test of these new floats (float design, float procurement, float deployment and float data analysis) and will analyze the actual performances at sea. This will be done in close collaboration with float manufacturers in Europe."

1.1.2. *Reminder of Task 2.6 objectives*

Main findings of tasks 2.1 to 2.5 will be summarized. Feasibility and readiness for operational monitoring of the new Argo floats will be discussed and recommendations for future technological R&D activities for Euro-Argo will be given.

It is the deliverable D2.61 identified in the description of work DA-1, in the table WT 2, which was initially due by the end of June 2015 (T0+30), but which was postponed to October 2015 (T0+34) (see minutes of 5th steering committee meeting), T0 being the 1st of January 2013.

1.2. Overview of the at sea experiment progress

First of all, a description of the objectives of the experiment and the way to reach them was delivered (T0+10): floats to be used, initial sensor check / calibration, specifications of the mission, deployment plan, reference measurements.

Then all floats were purchased except one deep float (IEO, T2.2). Five types of floats, manufactured by three companies, were funded by E-AIMS (see figure 1): The Arvor (NKE) and the Navis (Seabird) for task 2.1, The Deep-Arvor (NKE) for task 2.2, The "Bio-Argo CTS4" (NKE) for task 2.3, The Navis and the Arvor for task 2.4 and the Nemo (Optimare) for task 2.5. Two additionnal Apex (Teledyne) floats (non E-AIMS funding) were also tested in task 2.4.

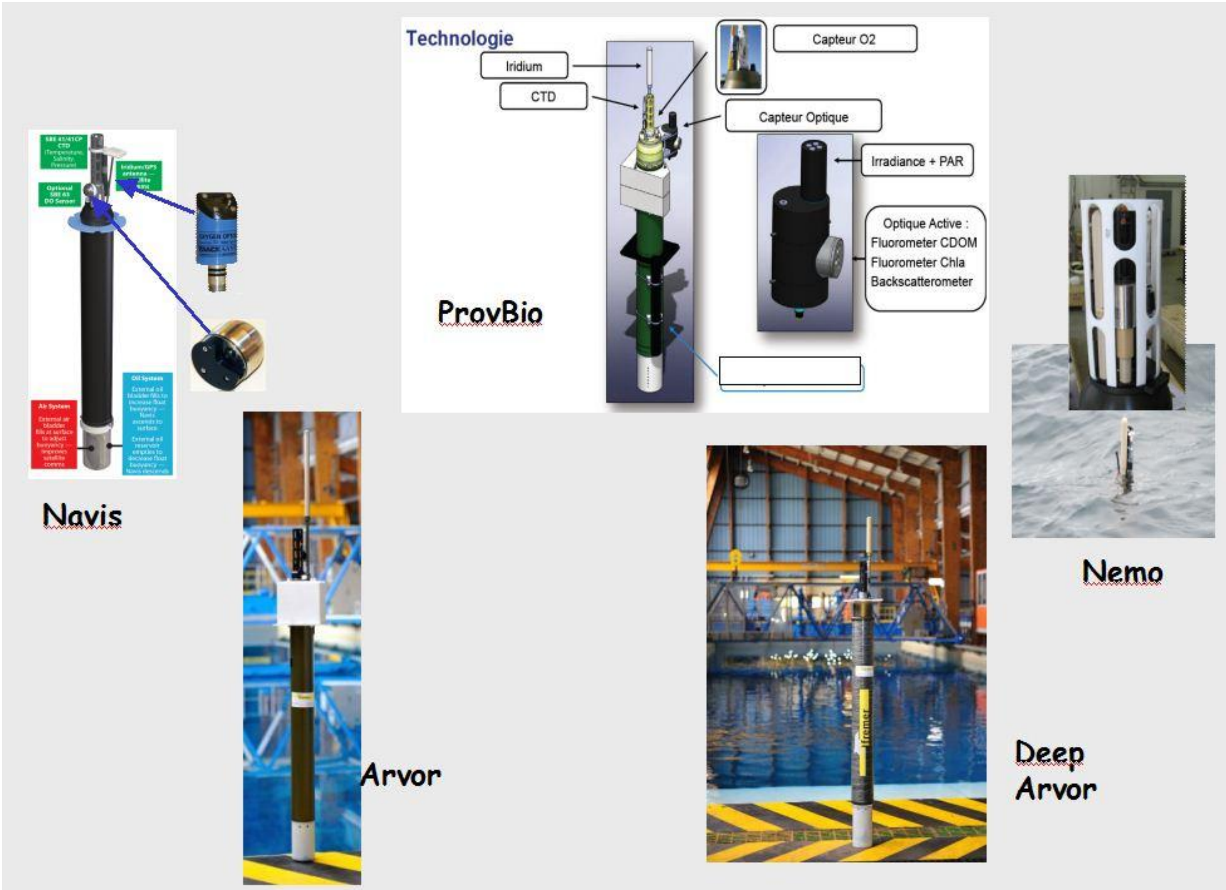

Figure 1: presentation of the new float tested at sea (E_AIMS funded)

Several regions were choosen for these experiments, depending on scientific interests (see figure 2).

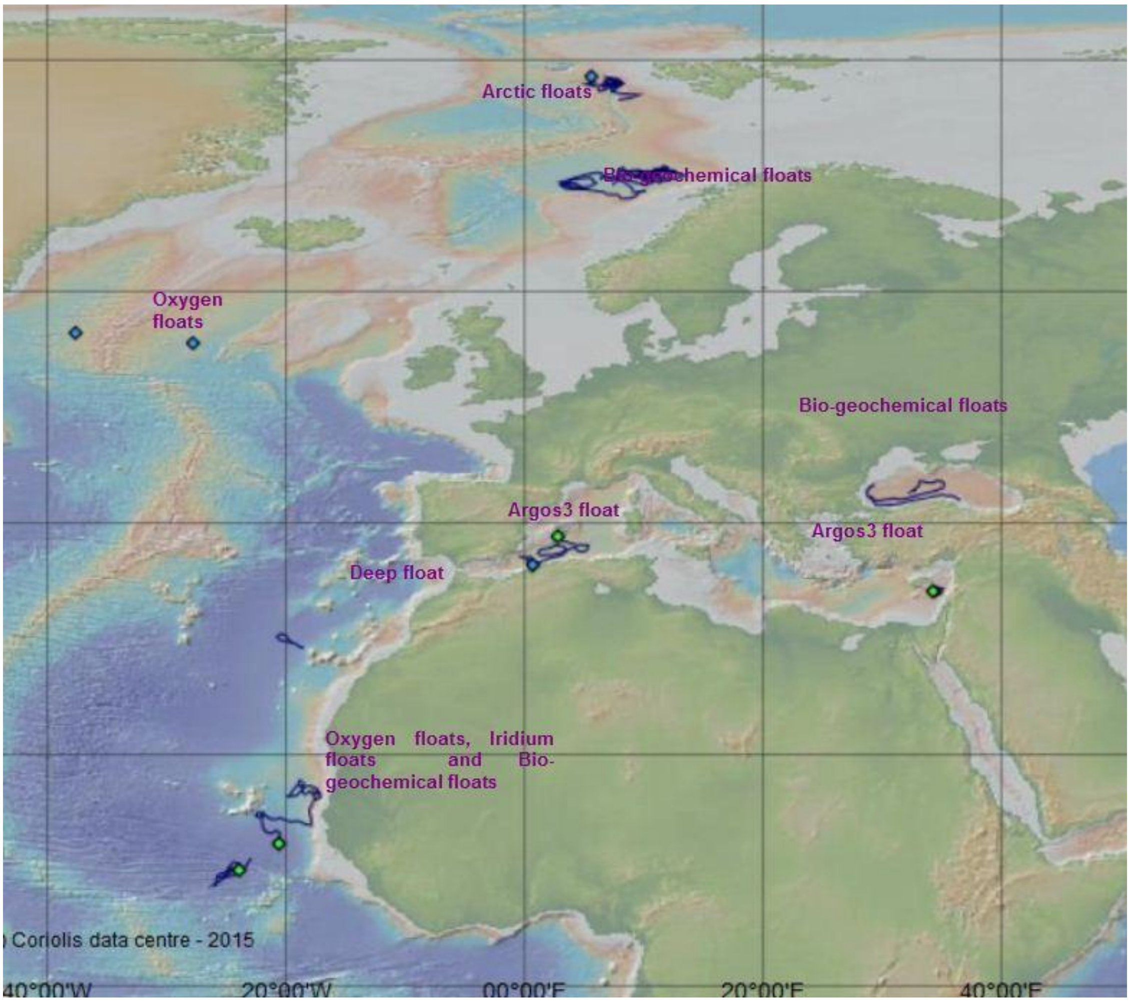

Figure 2: Map of the deployed floats

The main deployments were done in 2013, others in 2014 and three in 2015 (see figure 3). The spreading of the deployments was explained by several factors: the delay in availability of certain floats from the manufacturers, the need to do extra testing on floats, the wish to find the best cruise, offering the possibility of conducting scientific complementary measurements at deployment, or the need to return floats to the manufacturers for reparation.

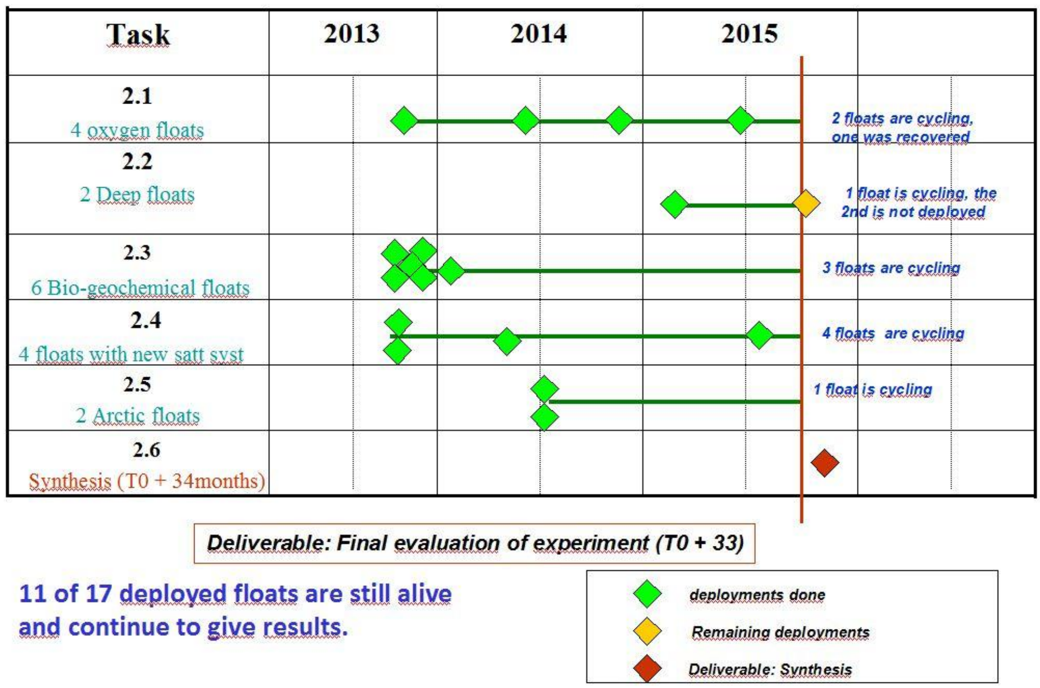

Figure 3: Deployment status of the floats. The deployments were spread into the time between the end of 2013 and the middle of 2015.

2. The five experiments: results and conclusions.

2.1. Test of new oxygen sensors: Geomar + Ifremer.

The purpose was to compare the performance of the Aanderaa optode (model 4330) and the Seabird optode (SBE63). The two sensors were mounted on three Navis floats (Seabird manufacturer) and two Arvor floats (NKE Manufacturer). The Navis were deployed in the OMZ region (off West African coast), whereas the Arvor were launched in the North Atlantic. All the floats were configured to do in-air measurements at the end of the ascent.

2.1.1. *Main findings*

Regarding the **floats reliability** aspects, despite of some early problems (pre-deployment tests and buoyancy), the two Navis floats showed good results after several months of working at sea (70 and 152 cycles at Sept 2015). The first Arvor float performed 126 cycles before it was recovered whereas the second one was lost after seven cycles for an unkown reason. The floats were fitted with a two-way communication that demonstrated their efficiency to allow tests to identify possible cause of a SBE63 failure (see below), to improve the mission parameters, to easily recover the float.

Concerning the **oxygen sensors reliability**, some points were noticed. On the Navis floats, the SBE63 sensors performed well except some invalid readings that appeared more frequently after cycle 100 that may indicate an issue with a connector. On one Arvor float, the SBE63 failed at the first descending profile (no more data were delivered by the sensors). This float was recovered in September 2015 and the sensor will be returned to Seabird for repairing. The Aanderaa 4330 was also subject to anomalies. On the Arvor floats, random spikes appeared during the profiles, whose origin was detected (restart of the optode after switch off) and resolved for further manufacturing. For the SBE63, on all the floats, the first data point of the profile is frequently biased low, probably caused by a too short flushing time at the beginning of the profile. For the 4330, on the Arvor floats, oxygen profiles were not biased low, unlike on other NKE floats were it is frequently noticed.

Analysis of **oxygen sensor calibration issue** has shown that for both optode models, considerable drifts appear during the months before the deployment of the float. Thus, individual factory or laboratory calibrations are not sufficient, and in-situ references are essential. Calibration was done by using in-air measurements (*Bittig & Körtzinger, 2015*). Recent laboratory and field results on pressure correction for oxygen optode calculations (*Bittig et al, 2015*) have been used and these methods are submitted to Coriolis for inclusion into the public delayed-mode dta files.

From the **oxygen sensors stability** point of vue, the experiment has proven a small and systematic downward drift of the 4330 optode (using in-air measurements), whereas the SBE63 was not evaluated because it cannot measure in air.

The SBE63 is integrated in the pumped flow path of the CTD and thus exhibits most of the time a better **time-response** than the 4330. Pumping significantly improves the resolution of fin structure and the localization of gradients in the profile.

Concerning the **sensor stability**, both optode models were calibrated at deployment, but the difference between them increased over the time. This is probably caused by the difference between the foils of the sensors. On aanderaa optode, a "burn-in" routine is applied to the foils, causing a pre-aging which offers a better stability. This is not the case for the SBE63 foils.

For **science** aspects, this work showed high quality observations in an Oxygen Minimum Zone (OMZ) and contributed to the on-going pilot study in the North-Atlantic and thereby fill gaps in the global Argo Array. It also contributed to several scientific peer reviewed publications (*Geomar et al.*)

2.1.2. *Feasibility and readiness for operational monitoring*

Both floats have demonstrated that they are able to deliver profiles of temperature, salinity and oxygen measurements for periods compatible with Argo requirements. However, some early problems have been encountered on the Navis float and one Arvor float was lost prematurely and one SBE63 optode failed. Thanks to these experiments, improvements have been proposed: revision of SBE63 electric connexion on the Navis, better managing of the O_2 sensor by the Arvor float electronics to cancel the spikes on the data.

2.1.3. *Recommendations for future technological R&D activities*

Based on the E-AIMS project floats, an in-situ calibration method using in-air measurements was established (*Bittig & Körtzinger, 2015*) to improve the accuracy of autonomous O_2 observations. Such measurements are proposed to become a standard feature on O_2 floats (see details on SCOR WG142 recommendation). This is possible with the Aanderaa optode. By pre-aging the foils (done by Aanderaa), the data are more stable. It would be very interesting to know why a SBE63 failed on the Arvor that was recovered. The question has to be asked to Seabird. Seabird and other optode manufacturers are encouraged to explore the possibility to propose in-air measurements and to apply "pre-aging" on their optodes.

The question of the oxygen profiles that are frequently low biased when the Aanderaa optodes are mounted on NKE floats (other than Arvor used for E-AIMS) is not understood for the moment.

2.2. Test of New deep floats: IEO

The regular Argo float perfoms profiles from 2000m depth to the surface. The objective of this task was to test a float that was able to do profiles down to 4000m depth. The new "Deep-Arvor" model was used, fitted with a SBE41CP.

The intention was to order two Deep-Arvor floats to be delivered in June-July 2014, and to deploy them at the following Autumn on a cruise around the Canary Islands after mid-October. Additional delays appeared: production delays by the manufacturer combined with additional problems related to administrative complications due to the budget restrictions imposed by the Spanish government in relation with the austerity measurements. Finally, the first float was purchased in January 2015, and this float was deployed in March 2015 in the Canary basin. The purchase order of the second float was still in process in Autumn 2015, and this float should have been deployed in July 2015 in the same area than the first one.

2.2.1. *Main findings*

The first float was programmed for a five day cycle, a parking depth of 1000m, a profile depth of 3000dbar. It was then deployed near Canary Islands on March 3rd 2015, just after a CTD cast at station n°25 which has been sampled (with station 24 nearby), since 2006, at least once a year. CTD were done using SBE911+ with redundant TC sensors and autosal calibrations. A second configuration (after profile 5) was remotely sent to the float to modify its profile depth to 4000dbar. Regarding the **float reliability** aspects, by November 19th 2015, the float had done three cycles at 3500dbars and 49 cycles at 4000 dbars. There is a good reproducibility of the float behavior. The regularity of the cycles along time, the stability of the float at parking depth and the quality of data transmission are very satisfying. The parking depth and the starting profile depth were reached with very few overshoots, indicating a good control of the descent phase. The drift at the parking depth interval (+/- 50m) is particularly stable. The ascendent profile is done at a steady speed of 9 cm/s. The analysis of the satellite communication shows that the system spends less than five minutes to transmit a low resolution profile (~200 CTDO samples). The total time spent at surface, including buoyancy management, is approximatively 35 minutes. The bidirectional communication with the float was also satiying, since in was reprogramed.

Concerning the **sensors reliability and stability**, the temperature measurements are accurate and no drift in time was observed. However, from the first profile, an evident fresh bias salinity (-0.25 PSU!) was observed. During the profiles 1-4 there was also a strong and irregular drift salinity that modified the initial bias to 0.22 PSS78. Probably this behavior during the first 5 profiles was due to TBNO that was washed off. After the 5th profile, the observed drift was constant in time (0.0003/day). According to the manufacturer, this bias could be due to technological issues on the conductivity sensor: a degradation of the "platine-black" coating of the cell could lead to such a bias**. After correction of the drift in salinity, 0.0074 PSU variability was found during the 10 months of data, which is a similar variability found during 20 years of measurements in the area**. IEO has a planned cruise in February 2016, when the float could be recovered. Although the recovery would be after the end time of the project, it would be valuable information in order to improve the performance of the floats

In term of power consumption, using a model based on the voltage drop for the regular Arvor-2000 Argo floats, it was possible to demonstrate that the life of the Deep Arvor was proportional to the vertically climbed km, since the mayor contribution to the power consumption is the pump during the ascend of the float. Using this model, it is possible to estimate the decrease in lifetime expectancy for a deep Arvor based on the number of deep (4000dbar) profiles.

2.2.2. *Feasibility and readiness for operational monitoring*

Until now, the float has shown a good behavior. Elsewhere, to complete this analysis, the results of another experiment that use Deep-Arvor (NAOS French project) report that deployed floats have also good behaviors (capacity to do reproductible cycles with same performance, including grounding management). A particularly good result can be noticed: one float achieved 142 cycles between 3500 to 4000m with oxygen measurements and with its CTD pump running continuously (lifetime expected is 150 cycles with CDT only). However, few early prototypes were lost without understanding why.

Concerning the salinity sensor issue, in the NAOS experiment like in the E-AIMS one, we can noticed that a high fresh bias (~ -0.4 PSU) was also observed on one float at cycles 29 and 30, before losing it at cycle 32. Moreover, on several floats we were able to identify a salinity bias of 0.01 psu, which were not pressure dependant. Such results were also mentioned by Jamstec on Deep Ninja profiling floats fitted with the same CTD.

Concerning the sampling, the recommendations, in order to sample properly the scales in the deep ocean and avoid aliasing, would be to perform, at least 1 deep 4000 dbar profile every 5 standards 2000 dbar profiles. This sampling scheme would imply a reduction in the lifetime expectancy of the float, if compared with the standard 2000m Argo floats, of 17%.

2.2.3. *Recommendations for future technological R&D activities*

Recommendations mainly concern the salinity sensor accuracy and stability. The specifications of the CTD 41CP is given in table 1. Seabird is encouraged to help users to resolve the issues of the 0.01 constant bias and to understand the high bias observed on the E-AIMS float.

	Accuracy	Stability

Conductivity	0.002 S/m (equivalent salinity)	0.001 S/m per year (equivalent salinity)
Temperature	0,002 °C	0.0002 °C per year
Pressure	7 dbars	3.5 dbars per year

Table 1. Accuracy and stability of the Deep-Arvor SBE-41CP-CTD sensor.

2.3. Test of new geochemical floats: IMR+ UKMO/PML+ IO-BAS/USOF.

The purpose was to test six Argo floats fitted with new bio-geochemical sensors. Three experiments were conducted in three different areas: Atlantic Ocean off West African coasts, Black Sea and Nordic Seas. The float chosen for this experiment was the Provor named "Bio-Argo CTS4" manufactured by NKE. This float is equipped with the Seabird 41CP for pressure, salinity, temperature, multipoint calibrated Aanderaa optode 4330 for dissolved oxygen, Satlantic optical pack "Rem-A". This optical pack contains i) a OCR503 Irradiance system which delivers measuments in 3 wavelenghts (380, 412, 490 nm) and integrated measurements between 400 and 700 nm thanks to a "Photosynthetical Available Radiation" (PAR), ii) a Wetlabs ECO triplet (CHL-A, and backscattering 532 and 700nm wavelenghts).

2.3.1. *Main findings*

Regarding the **floats reliability** aspects, of the six floats one float was lost after one profile, while two floats transmitted intermittent GPS data. Also, one of the latter stopped transmission after 78 profiles. Another float stopped transmitting in August 2015, after nearly two years operation. Thus, four floats have cycled (period of five days) for two years, and by September 2015, three floats, one in each region, were still active.

Concerning the **sensors reliability and stability**, some points were noticed. The temperature and salinity performed well. One Wetlabs ECO-triplet failed at the 4th cycle, when it was exposed to pressures greater than 1000dbars, and remained failed. At parking depth, data given by the Eco-triplets showed significant drifts (with opposite trends in the 532 and 700 nm optical backscattering channels for one of them), after less than one year of operation. This might be caused by instrumental drift and /or bio-fouling that may have covered the light sources. A decrease of an oxygen measurement was also revealed at parking depth, suggesting a drift of the optode. Large peaks were observed on chl-a at parking depth, but were unlikely caused by a sensor issue.

The bbp (532)/ bbp(700) ratio varied over a restricted range, suggesting that the **sensitivity** of the Eco-triplet was insufficient for detecting changes in spectral backscattering in oligotrophic area.

From the **scientific outcomes** aspects, this experiment showed that the biogeochemical floats deliver novel data that improve our understanding of the biogeochemical ocean, but has also pointed few questions that need further investigations. The data from these floats have also already been used in several other studies which also have resulted into submitted peer-review manuscripts.

2.3.2. *Feasibility and readiness for operational monitoring*

Even so the whole fleet of the bio-geochemical floats does not work at this day; some significant results have shown that this technology is mature for the Bio-Argo needs. Among the six floats deployed in 2013, four of them have worked two years and three were still working by early November. The batteries embedded in the floats are well adapted to cover all the requirements (cycling, acquisition of all the sensors, transmission of the data). The deployment phases were successful since all the floats performed at least one cycle. The transmission system has performed well: no loss of data was mentioned and remote commands were successfully sent to the floats. However, two floats were affected by intermittent failures in GPS reception and the ECO-triplets sensors were subject to significant instrumental drifts and one failed.

2.3.3. *Recommendations for future technological R&D activities*

Here are some recommendations on how to handle the biogeochemical floats and sensors to get optimal quality of the biogeochemical data.
Concerning the **float** itself, NKE is encouraged to improve the antenna or the electronics of the GPS.

Regarding the **sensors**, a particular care have to been taken by Satlantic / Wetlabs with the tests of the ECO-triplet before delivery, in order i) to be fully functional at the operational pressure ii) to calibrate and verify the stability of the instrument. In oligotrophic regions the particulate optical backscattering (bbp) sensors should have higher instrumental sensitivity. As demonstrated, in the oligotrophic North Atlantic sub-tropical gyre the sensitivity of the sensor was insufficient to detect significant bbp changes. On-going discussions are engaged with the manufacturer with respect to these various issues.

The **instrument preparation phases,** before and during deployment, are recommended:

- ✓ The sensors should be calibrated and tested before deployment. For instance, the dark counts for the optical sensors should be measured and compared with that from the manufacturer. If possible, relevant in-situ (ship) measurements during deployment should be taken for comparison with data from the float profiles.
- ✓ If no air measurements of oxygen is available, deep dissolved oxygen measurements (below the seasonal thermocline) realized by the sensor, and the subsequent calculation of Apparent Oxygen Utilization (AOU), can help to detect drift in this sensor. Another way to get a reference is to request to the float an in-air oxygen measurement prior to deployment (this needs to connect a computer).

The **programming of the float** mission and the **method to correct drifts** may influence the results. Due to possible peaks in the fluorescence near the parking depth care should be taken if the deepest measurement is used as a reference to correct each profile. Some prior analysis is consequently needed. Deep bbp measurements are affected by bbp of “pure” sea water. Drift in deep bbp could reflect both instrumental changes in offset (dark counts) or gain (scaling factor). This needs to be considered when using deep bbp data for drift corrections.

Further investigations are needed to explain the slightly increase in the calculated chl-a in the deep layers of the Black Sea (~0.02 mg/m^3/100m). Suggested explanations are either insufficient calibration of the sensor, its malfunction in the H_2S environment, or that the chl-a sensor reacts to other substances (for example yellow substances or bacteria).

2.4. Test of floats with Iridium and Argos3 transmission capability: OGS/CSIC + UKMO

The purpose of this test is to determine the readiness of the Iridium and Argos-3 satellite communication systems for an implementation on the profiling floats. Using such systems would allow transmitting a data profile in a short time, in order to reduce surface risks (such as biofouling, drift, thefts, etc.). Moreover, these new generations of satellite systems allow the user to send remote commands to the floats and to change their mission configuration.

2.4.1. *Main findings*

<u>Iridium</u>

Two Iridium modes are now available: Short Burst Data (SBD) and Router-Based Unrestricted Digital Internetworking Connectivity Solutions (RUDICS). Only the RUDICS mode was evaluated, with two SeaBird Navis floats and two Webb Apex floats that were deployed in the North Atlantic Ocean in October 2013.

When the float surfaces at the end of a profile the transceiver registers with the Iridium system, the float then disconnects from Iridium and acquires a GPS position fix. The float then reconnects to Iridium, uploads its hydrographic and engineering data and downloads any changes to its mission parameters. For both the Apex and Navis floats such changes can be achieved by placing an updated mission configuration file on the host server.

Many configuration changes were successfully tested: number of samples acquired per profile, period of cycles, time at surface. These instructions were correctly received by the floats, but led to problems in the data processing at BODC, which requires a migration to NetCDF v3 to be solved. Consequently, data had sometimes to be processed by hand. Moreover, some changes were (successfully) rejected by the floats as two parameters were not self-consistent, which shows the importance of a validation utility before changing the parameters of the floats.

<u>Argos-3</u>

Two Argos-3 modes are available: the "interactive low-data rate" mode and the "high-data rate" mode. Qualifications in laboratory proved that the latter is highly sensitive to the continental electromagnetic noise, and cannot be used in operational conditions. Consequently, only the low-data rate mode has been evaluated. Two Arvor NKE floats were fitted with the Argos-3 telemetry developed by Ifremer, and deployed in the Mediterranean Sea in 2014 and 2015.

The float arrives at surface at a time in accordance with the ephemeredes of the Argos satellite passing. Then the float registers to the Argos system. Data is uploaded and commands are downloaded at the same time. The positioning is done with the Argos system itself, which simplifies the design of the antenna. Changes of mission parameters are done via sending commands through the CLS-Argos website.

In Argos-3 interactive low data rate mode, the transmission of a dataset was successfully done in less than one satellite pass: about 3.5 min in the western part of the Mediterranean Sea, and about 7.5 min in the eastern part, more subject to the electromagnetic noise. In comparison, a float fitted with the Argos-2 system requires ten hours at surface in the Mediterranean Sea to send its data! The downlink capability has been successfully used too. However, eight percents of the profiles were not located with the Argos positioning system.

Regarding the **reliability aspects** of the floats, the whole of E-AIMS fleet were still working in September 2015

2.4.2. *Feasibility and readiness for operational monitoring*

The profiling floats using RUDICS are now operational. The **utility of this mode of transmission has been proven at sea for high resolution profiles**, where Argos and Iridium-SBD modes are too restrictive. The demonstration of their uplink and downlink capabilities was done successfully. To be fully integrated in the Argo data processing chain, the problems encountered in the data processing at BODC have to be solved first, but this issue is not related to the technology of the floats. These trials showed the importance of the validation of the remote commands before sending them to the float, with an utility onboard the float, in order to avoid conflict or hazardous programmings.

The **profiling floats fitted with Argos-3 proved to be operational** in the low data rate mode. The downlink capability has been demonstrated to change the mission configuration. A typical Argo dataset can be transmitted in a few minutes, where more than eight hours were required with the Argos-2 generation. However, eight percents of the profiles are not located. This issue can be addressed by selecting satellites passes with an elevation lower than 80° or 85°, by changing this parameter with the downlink.

We recommand to use the RUDICS transmission system when a high quantity of data is required: high resolution profiles, multi-sensors profiles. We may also recommend to use Argos-3 to transmit standard Argo profiles in marginal seas (where it is essential to shorten the stay at surface) as an improved solution compared to Argos-2, or as an alternative way to Iridium. A paper was published about Argos3 embedded on floats (André et al, 2015).

2.4.3. *Recommendations for future technological R&D activities*

The satellite transmission system is a key technology on instruments such as profiling floats. It is important to continue to evaluate new emerging systems. For example, Iridium is moving to its second generation, called Iridium Next. It should be operational in 2017 and will offer more flow rate for transmissions. At the same time, the fourth generation of Argos, named Argos-4, will be launched, with a high data rate link that will not be affected by the electromagnetic continental noise. Moreover, many projects are currently under development to offer satellite transmission capabilities, with the technology of nano satellites.

The Argo community should remain up-to-date and close to these technologies, and evaluate the opportunity to implement them on the profiling floats.

2.5. Test of new Artic floats: IOPAS

Two Nemo floats, manufactured by Optimare, were used for this Arctic experiment. These float were adapted to Ice covered area by means of some modifications. They were fitted with a shorter antenna for satellite communications and a protection against shocks when the float ascent under Ice. Avoiding contact with ice was done by the so-called algorithm ISA (Ice Sensing Algorithm) and the transmission of collected data in the float memory was postponed if ice was detected. Such data are not so valuable because the geographical position of profiles are inaccurate. That is why IOPAN developed an Inertial Navigation System (INS) using recent advances in miniaturization of MEMS technology. One of the two floats was used to embed the INS, in order to assess this technology for a potential future use in Argo floats. The two floats were deployed in summer 2014.

2.5.1. *Main findings*

Regarding the **reliability** aspects, one float encountered technical problems, and sent incomplete data 59 days after its deployment. Among 33 profiles that had been done, only ten profiles were built with the data, and the float disappeared. However, the second float had sent data from 83 profiles and 16 datasets from the INS at the end of June 2015, and was still working in Early November 2015 (109 profiles). At this date where it was situated not far from the Arctic Ocean drifting sea ice. Elsewhere, the energy consumed by the INS was higher than expected and it was decided to switch off the navigation system several weeks, ~80 kms drift after deployment. This was made by the Iridium downlink.

High accurate INS are very expensive systems. With a low cost system, used in the float, the error in position is due to a bias in the accelerometer and has a quadratic growth with time. From the **sensors reliability and stability** aspects, the INS returned mostly zeros and incorrect numbers, incompatible with the surfacing positions of the float. Most likely, the accuracy of the sensors was not sufficient to provide good information about the instrument displacement.

2.5.2. *Feasibility and readiness for operational monitoring*

This experiment shows that one float survived in the harsh environment of these regions, even so it did not encountered ice covered areas.

2.5.3. *Recommendations for future technological R&D activities*

The technology to do inertial navigation on floats is not mature. Today, there is no solution that satisfies at a time the accuracy needs, the mechanical size, the energy consumption, the cost. However, efforts should be continued to get an alternative way for under-ice navigation.

Sophisticated floats, with more sensors or devices, need better capacity batteries but high energy densities, and particularly Lithium batteries, are expensive and difficult to transport.

The costs of Arctic experiments by floats are rising, similarly to gliders, because they need a permanent supervision by a staff.

Another idea is to construct a new, less sophisticated and cheaper float, assigned for short missions. This kind of float should be designed for missions shorter than one year, for operation in shallow waters (big part of the Arctic Ocean and subarctic seas are shelves). Compact construction (spherical shape?) should prevent from getting damaged by floating ice or getting stuck on bottom. A simple cheap electronic module should contain the bathymetry map, which would also help in preventing contact with the bottom. Floats for shallow seas must meet very similar conditions, and efforts towards constructing a cheap float for the Arctic and shallow seas should be joined. Such floats may be much more attractive for potential users. By using both kinds of floats (sophisticated ones for long missions under sea ice and cheaper ones for short missions in ice free regions) may improve coverage of the Arctic by the Argo floats.

But only a revolution in the development of efficient, stable and cheap sources of energy will enable using all the technological advances, such as the active ice and bottom detection, inertial navigation, wide spectrum of sensors, big amount of data processed by intelligent floats.

3. General conclusions

These experiments were very helpful for the assessments of new floats, new sensors, new devices and new methods. Even though some of these experiments were shortened, they were carried out over several months on average and more than two years for the major part. Early November, 11 of 17 deployed floats were still active.

Overall WP2 achieved or ever exceeded all its initial objectives. Highly valuable results have been obtained. Task 2.1 showed that oxygen measurements could be considerably improved by adding in-air measurements when the float is at surface and that thanks to these improvements operational monitoring of oxygen with Argo float can now be implemented. Task 2.2 assessed the performance of new deep floats. It showed that deep floats are ready for operational implementation but it also highlighted the issue of the quality of sensor measurements in the deep ocean. The successful test of six Bio-Argo floats within the task 2.3 demonstrated the maturity of the float technology, even though some work remains to be done on validation of the different sensors. The two satellite communication systems tested in task 2.4 demonstrated the feasibility and benefits of these improved telecommunication techniques; the evolution of these satellite systems towards new capabilities should be considered in the future. The test of Arctic floats showed the difficulties encountered and the technological and financial limitations to navigate in ice covered regions. Finally, several of the WP2 results led to peer reviewed publications.