Project	AtlantOS – 633211
Deliverable number	D 3.14
Milestone title	Enhancement of the Argo core mission: Deployment of Bio-Argo and O2-deep floats and improvement of the network capabilities
Description	7 Deep floats and 6 Biogeochemical floats purchased and deployed in Atlantic and Southern Ocean
Mean of verification	Real-time data are available on the data assembly centre.
Work Packages involved	WP3
Lead beneficiary	Euro-Argo ERIC
Lead authors	Grigor Obolensky – EURO-ARGO ERIC
Contributors	Herve Claustre – SU Virginie Thierry – IFREMER Arne Koertzinger – GEOMAR
Submission date	01st of March 2019
Due date	01st of January 2019
Comments	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 633211.

Stakeholder engagement <u>relating to this task</u>*

WHO are your most important stakeholders?	☒ Private company If yes, is it an SME ☒ or a large company ☐? ☐National governmental body ☐International organization ☐NGO ☐others Please give the name(s) of the stakeholder(s): NKE Instrumentations (FR), Kongsberg Maritime Contros GmbH (GER)
WHERE is/are the company(ies) or organization(s) from?	☒ Your own country ☒ Another country in the EU ☐Another country outside the EU Please name the country(ies): France, Germany
Is this deliverable a success story? If yes, why? **If not, why?**	☒ Yes, because all developments intended to be done have been finally implemented or initiated with excellent future perspectives for those not achieved due to technical reasons ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	☒ Yes, because it represents a state-of-the-art of the technological developments at the end of the AtlantOS project, that will further evolve during the years to come to their operational achievements ☐ No

NOTE: This information is being collected for the following purposes:

1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult D10.5 Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.

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1 Executive Summary

In September 2018, a major milestone was achieved when the Argo programme delivered its two millionth profile of physical and chemical data from the world's oceans, quadrupling the number collected by ships over the previous 100 years. Across the globe, about 4,000 Argo floats continuously collect data on the physical state of the ocean. The project has been revolutionising oceanography for nearly 20 years.

With the emergence of stable and improved technologies allowing to build long lasting platforms, able to reach greater depths, to carry additional sensors and to better transmit their data to shore, the international Argo Steering Team has strongly recommended scientists, institutions, funding agencies, ministries of involved countries to foster the extensions of the Core Argo program (temperature and salinity of the upper 2000m of the ocean) to greater depths (4000m to 6000m) and to the measurements of Biogeochemical parameters (dissolved oxygen, chlorophyll, particulate backscattering, radiometry, nutrients and pH).

The deepest parts of the oceans play an important role in the evolution of the surface temperature on Earth through its capability to store and transport gases and heat. The technological developments in the recent years have made it possible to test Argo floats which probe the abyssal ocean. Measuring T/S below the first 2000m will provide new information on ocean circulation and water mass formation and properties. Finally, it will also mitigate the lack of observations of deep ocean for data assimilation and modelling.

Over the last 30 years, the ocean colour remote sensing has been widely used to understand, assess and model the biogeochemical processes of the upper ocean. Coupling and assimilating in-situ data from oceanographic cruises has allowed to refine the remote sensing algorithms, to build accurate datasets for calibration and validation of satellite products, and to understand the main processes coupling physics, chemistry and biology at regional scales of the global ocean. For parameters hardly measured from satellite and required to assess the global climate change process such as the ocean acidification, deoxygenation, the carbon sequestration and oceanic carbon biological pump cycle, the international scientific community requires the implementation of a global network of autonomous platforms equipped with biogeochemical sensors, and to link their data with ocean colour remote sensing and ecosystem models.

Based on the results of recent pilot projects enabling the use of deep Argo floats and biogeochemical ones, AtlantOS is integrating the "Argo Evolution" task 3.1 of the WP3 aiming to provide among the first deep concomitant measurements of temperature, salinity and dissolved oxygen and enhancing the array for biogeochemical parameters.

The overall goal of the AtlantOS technical WP3 is to build on existing capacities for autonomous observing networks on both sides of the Atlantic Ocean for filling the observational gaps for certain under-sampled areas (e.g. Southern Atlantic, Equatorial regions), measuring during some key periods (e.g. harsh winter conditions in sub-polar North Atlantic).

Within this task, the Euro-Argo ERIC is in charge to specify, purchase, perform acceptance test and finally deploy seven Deep O_2 floats, and six BGC floats for the upper ocean. The data flow has been organised, implemented and monitored by the Euro-Argo ERIC Office team in partnership with IFREMER and NERC/BODC.

Complementary to this implementation of extensions to the Core Argo program, the task 3.1 is also dedicated to develop new platforms to fulfil the goal of undisrupted time series for the core Argo parameters. The "Autonomous System For Argo floats Release" has thus been designed, tested in IFREMER tank, and finally successfully deployed at sea by IFREMER.

The need for new sensors dedicated to ocean acidification and global carbon cycle assessment required the implementation of novel technologies on profiling floats. SU has been in charge of the integration on a standard European profiling float of a commercially available pH sensor, and German manufacturer KM CONTROS (Kongsberg Maritime Contros GmbH) for the quality assessment of novel optode technology (for O_2) and the development of a suitable pCO_2 sensor for profiling float autonomous network. This document relates the successes and failures experienced during these two extremely challenging research and development actions.

2 General scope of the document

This report overviews the progress from the beginning of the project schedule concerning:

Argo Network Enhancement

1. Float specification and procurement
2. Acceptance tests and derived actions
3. Deployment plans and achievements
4. Data management, quality control and delivery to end-users

New systems and sensors development

1. Achievements
2. Failures
3. Deployment of prototypes

In particular, this report will explain the reasons for the delays in float procurement, the technical issues occurred in these challenging developments and the actions undertaken to keep the achievements of the task as close as possible of its initial target.

It will also explain the actions undertaken to develop a new pCO2 sensor for profiling floats, and how this development will get to its end in the project's timeline.

3 Argo network enhancements

3.1 Rationales

3.1.1 Deployment areas

The deployment's zones of BGC-Argo AtlantOS float have been chosen as to fill in the observation gaps in the Atlantic, in particular the South Atlantic which is critically under sampled. Therefore, four floats were deployed there. Two of them were deployed in the core of South Atlantic sub-tropical gyre as a way to continue the time-series initiated in fall 2012 through ERC RemOcean project and later continued through the UK Argo program. Two additional floats were deployed within the southern limit of the subtropical gyre with the additional goal of possibly characterizing the biogeochemical fields associated to eddies originating from the Agulhas current and crossing the southern Atlantic. Finally, two floats were deployed in the sub-equatorial waters of the Guinea Dome, an under-sampled structure too with expected interesting physical-biogeochemical coupling.

3.1.2 Data flow

AtlantOS BGC-Argo float data are Quality-Controlled (QC) in Real-Time through agreed international procedure and made available thanks to CORIOLIS Global Data Assembly Centre (GDAC). Delayed-mode qualification of data requires the analysis of long time-serie for producing data of "climatic quality". It will rely on the expertise of the various AtlantOS scientific PIs with respect to the core variables (LOV-UPMC: Chla, radiometry, NO3; GEOMAR: O2; PML: backscattering coefficient). This delayed-mode quality control will start in 2019 and will be subsequently performed yearly until the float death. Data will become available through the GDAC.

3.1.3 BGC-Argo data usage

The data are already public available in Real-Time and therefore potentially usable by any operational agency or scientific PI. Presently, and to our best knowledge, these data are at least used in a more global context, in particular to address the dynamic and the drivers of the so-called Deep Chlorophyll Maximum, a permanent structure in the highly stratified environments where all AtlantOS BGC-Argo floats have been deployed.

3.1.4 pH and pCO_2

AtlantOS has contributed to the operational implementation of the pH sensor on BGC-Argo floats provided by the NKE SME, one of the three main float providers to the Argo/BGC-Argo programs. In parallel and as part of WP5, transfer functions have been developed (Bittig et al., 2018) to retrieve, on the basis of historical databases (GLODAP V2) and the implementation of machine learning methods, pCO2 vertical profile from pH and O2 measurements which both are core BGC-Argo variables. The development of such a so-called pCO2 "virtual" product with a very acceptable accuracy can be considered as a promising alternative waiting on pCO2 sensors will get the sufficient maturity and readiness level to become core BGC-Argo sensors.

3.2 Floats specifications and procurement

At the writing time of the AtlantOS proposal, the unitary price for BGC floats was evaluated at 50k€ based on the experienced amounts for the recent projects, mainly sustained by the LOV laboratory in France. The unitary price for Deep float was stated at 30k€.

The global amount for floats purchases within task 3.1 of AtlantOS was thus fixed to 560 k€. The first call for tender released by Euro-Argo ERIC for AtlantOS concerned both BGC and Deep floats, in two lots of a common open call.

The results obtained from the competing manufacturers showed that the price for Deep floats was correctly evaluated, but for BGC floats the increase in the prices for additional sensors combined to a disadvantageous USD/EUR rate lent to minimum prices raise up to 85K€ per float.

Euro-Argo ERIC then decided do have a discussion in the partner's consortium to decide:

- If we were continuing with the proposed prices and reducing the scientific goals of the project
- If we were able to rearrange the budgets among the partners trying to lower the budgets for BGC purchases: In fact, LOV was holding a framework contract with SeaBird Inc. who is the manufacturer for all BioGeoChemical sensors approved at this time for BGC network, with a 30% discount on sensor's prices.

The second option was approved, with the consequence of pursuing with the awarding process for Deep floats – 7 floats purchased within this first batch and disrupting the first call for tender for BGC floats.

The budget transfer from Euro-Argo ERIC was accepted by the AtlantOS management, and a second call for tender was opened for BGC floats.

This second call was successful and as a final result, 6 complete BGC floats have been purchased within this second batch.

The table below summarizes the calls for tender published by Euro-Argo ERIC:

OJEU CFT reference	Date of publication	Date of awarding	Awarded Company	Number and type of floats
2015-150346	09/11/2015	22/03/2016	NKE Instrumentations	7 Deep Arvor
2016-043861	07/04/2016	21/06/2016	NKE Instrumentations	6 BGC Provor CTS4

Table 1. Call for tenders published for AtlantOS purposes

3.3 Acceptance tests and derived actions

Following the awarding to *NKE Instrumentations* for both BGC and Deep floats manufacturing, the Euro-Argo ERIC technical team has performed several pressure tests and acceptance tests on the provided equipment. Strong misfunctioning on hydraulic groups of the deep floats, and obsolete software version on BGC floats have been discovered, requiring the manufacturer to upgrade all the floats delivered at this time.

Finally, all floats have been upgraded, tested and accepted.

3.4 Deployment plans and achievements

The deployment plan for both Bio-geochemical and Deep floats has been discussed between the task partners, taking into account the scientific programs and the deployment opportunities for years 2017 and 2018:

- Two BGC floats for LOV (PI Hervé Claustre), two BGC floats for PML (PI Giorgio Dall'Olmo), two BGC floats for NOC (PI Brian King)
- Two Deep floats for NOC (PI Brian King), two Deep floats for IEO (PI Pedro Velez), two Deep floats for IRD (PI Bernard Bourles) and one Deep float for LOCEAN (PI Jean Baptiste Sallée)

12 floats were deployed in the Atlantic Ocean, both in the southern and northern basins, according to the AtlantOS area of interest and reinforcing the tropical network of observations PIRATA jointly operated by France, US and Brazil. One deep float is deployed in the Austral Ocean, fulfilling one goal of the task 3.1 aiming at integrate new features on profiling floats: the concerned Deep float has been upgraded with a prototype version of its software allowing the Ice detection, bringing the ability to maintain the operational life of the float under sea-ice covered ocean.

All deployments have been successfully executed between October 2017 and August 2018.

Cruise Name	Ship	Start Harbour	Date	Country
AMT27	RRS Discovery	Immingham	23/09/2017	UK
CAPRICORN	RV Investigator	Hobart	09/01/2018	AUS
JC159	RRS James Cook	Rio de Janeiro	28/02/2018	UK
PIRATA	NO Thalassa	Mindelo	28/02/2018	FR
RAPROCAN 0418	BO Angeles Alvarino	Tenerife	09/04/2018	SP
RADPROF 0818	BO Ramon Margalef	Gijon	17/08/2018	SP

Table 2. Deployment cruises for AtlantOS floats

Figure 1. Deployment of a BGC float onboard AMT27 cruise

Figure 2 Night deployment of a Deep float onboard PIRATA cruise

Figure 3. Deployment of a Deep float onboard PIRATA cruise

Figure 4. Deployment of a Deep float onboard RAPROCAN cruise

A summary of deployment positions is outlined on the following map.

Figure 5. Deployment positions of AtlantOS floats

Finally, the following chart summarizes the overall manufacturer (■), Euro-Argo ERIC (■ and ■), joint (■) and deployment (■ for BGC and ■ for Deep floats) activities:

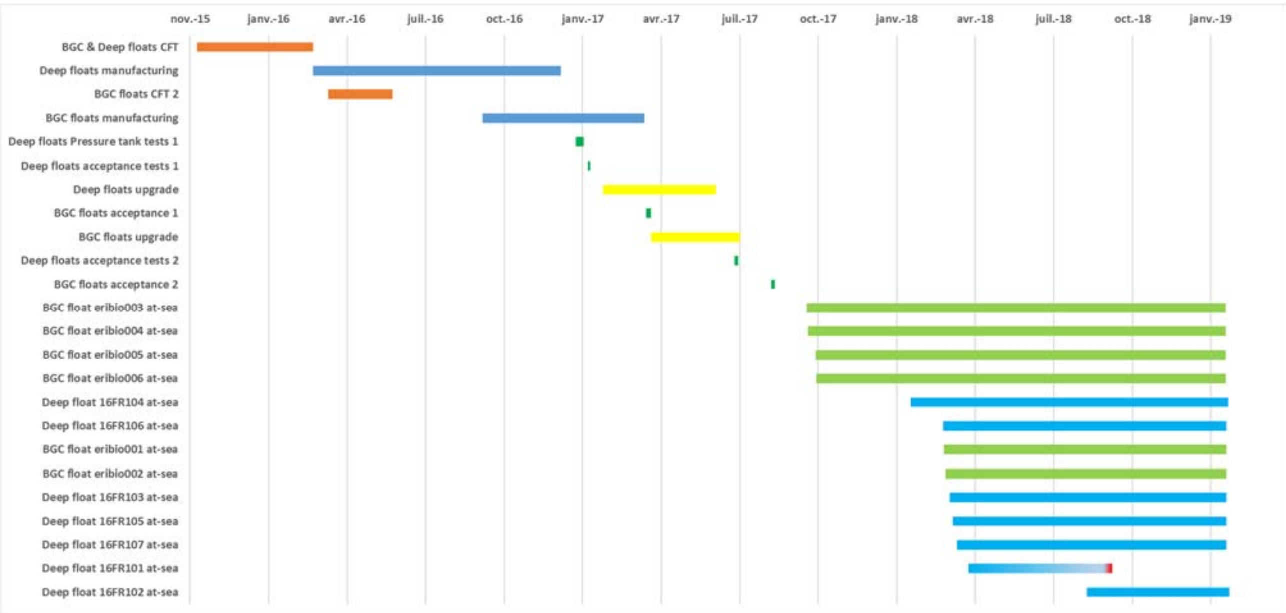


Figure 6. Time schedule of procurement, manufacturing, test phases and deployment at sea for AtlantOS floats

3.5 AtlantOS fleet status – February 2019

All AtlantOS floats are operating nominally at sea.

The BGC floats are programmed with various cycling schedules, according to the requirements for scientific purposes. They are profiling on 5 days or 10 day-cycle period, diving alternatively to 1000 and/or 2000m. Their surfacing time is automatically scheduled at each surfacing to cover all the circadian cycle patterns.

The Deep floats are programmed to drift at 3000m and profile at 4000m. The low drift depth ensures that the grounding risk of the floats is securely controlled, minimizing the risk for the float to be landed on the sea-bed, cause of the majority of Deep floats losses occurred in the past years.

A summary of the AtlantOS fleet health can be assessed from the float's anomalies monitored in the ArgoMonitoring tool (http://www.ifremer.fr/argoMonitoring/floatMonitoring/650) , with an excellent behaviour at sea for all floats still profiling.

Two active floats (WMO 3902130 and 3902128 - Deep floats) have one lost profile each, probably due to communication issues (under investigation).

One deep float died prematurely after 56 cycles (WMO 3902126) after having entered in the continental shelf area off the Canarias Islands coast. This loss is probably due to repeated grounding on the sea bed and corresponding technical issues occurring in such cases.

One Deep float (WMO 3902129 - deployed in the Austral Ocean) is flagged with anomalies at this date, due to entering in a sea-ice covered area. Thanks to the Ice Sensing Algorithm implemented on this unique platform, the float has pursued its operational life under sea-ice and reappeared in the charts in November 2018 after 7 months under the Ice. 10 under the Ice profiles have been recovered, 11 profiles have been lost due to memory overflow because of a too high-resolution sampling strategy.

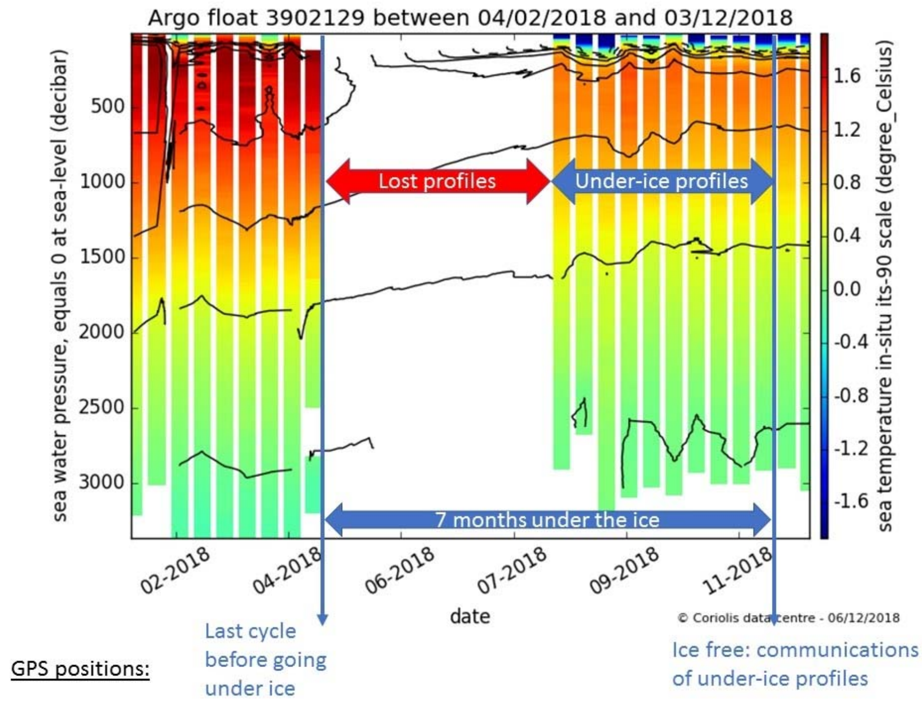


Figure 7. Vertical Temperature section of float 3902129 (Deep) with under-ice profiles

3.6 Availability of float's data

All data are available from the Coriolis DAC, and fully integrated in the Argo Data distribution system from GDACs.

The interested user may download data from each individual float in Ascii or NetCDF format using the dedicated links on individual float pages as shown below, or request a complete dataset on the Argo webpage http://www.argodatamgt.org/Access-to-data/Description-of-all-floats2

Float WMO	Float type	Status	Age	# profiles	# anomalies
3902120	BGC	Active		70	0
3902121	BGC	Active		68	0
3902122	BGC	Active		120	0
3902123	BGC	Active		119	0
3902124	BGC	Active		110	0
3902125	BGC	Active		64	0
3902126	ARVOR DEEP	Inactive		56	2
3902127	ARVOR DEEP	Active		16	0
3902128	ARVOR DEEP	Active		68	1
3902129	ARVOR DEEP	Active		26	21
3902130	ARVOR DEEP	Active		67	1
3902131	ARVOR DEEP	Active		85	1
3902132	ARVOR DEEP	Active		77	1

Table 3 . AtlantOS floats fleet status

The status of the AtlantOs profiling float's fleet can be summarized in term of data availability and anomalies on the data flow as reported here below:

Figure 8. Number of cycles performed for each deployed AtlantOS float, showing anomalies (in yellow and red)

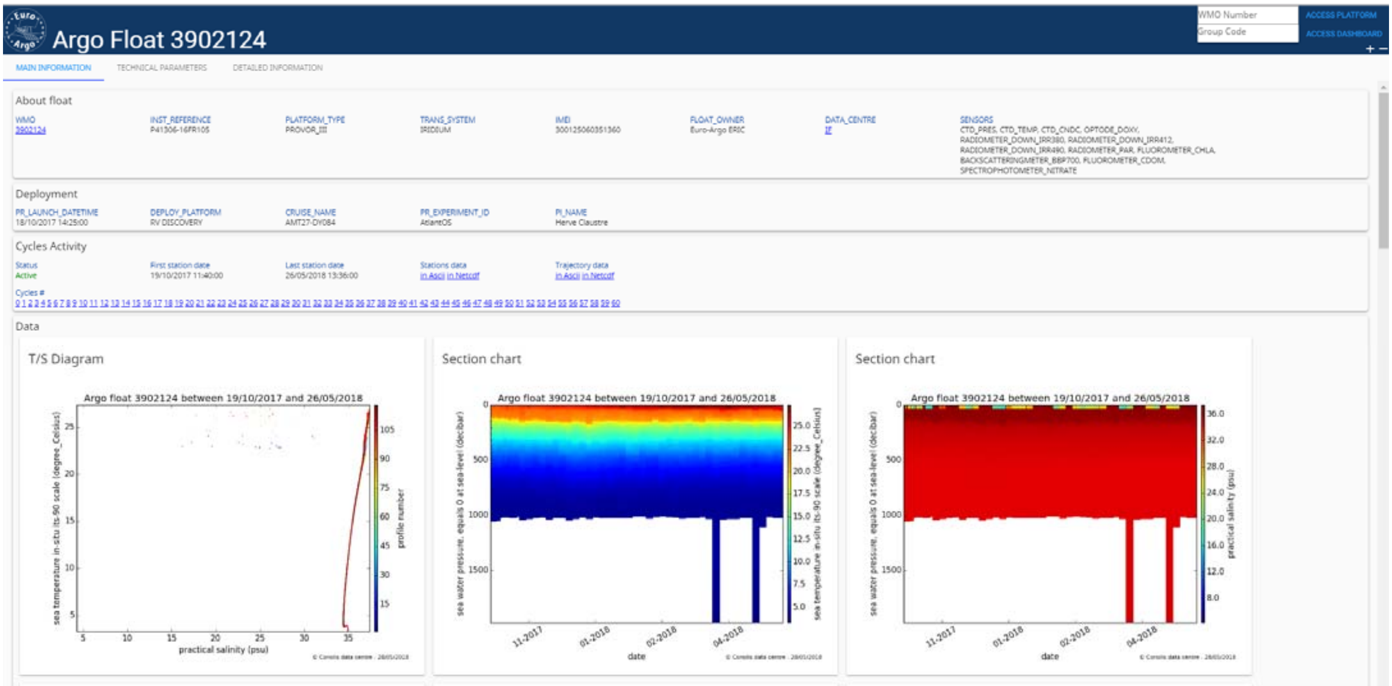


Figure 9. Screenshot of a dedicated data webpage for an AtlantOS float (WMO 3902124)

4 Development of an Autonomous System for Argo Floats Release – ASFAR (IFREMER)

4.1 System description and developments

To ensure a regular seeding of Argo floats in regions of interest, we have developed the ASFAR system (Autonomous System For Argo FloatsRelease). ASFAR is a recoverable frame equipped with 4 Argo floats. The frame is moored at the ocean bottom for typically 1 year. ASFAR ejects the 4 Argo floats at predetermined dates to maintain Argo float seeding throughout the year in a given region.

Besides the development of the frame itself, we modified the software of the Argo floats mounted on ASFAR. Contrary to the regular deployment of an Argo float, the float is switched on in the water and released at depth. We thus had to modified the sequence of tests done prior to deployment and to disactivate for instance the satellite transmission test. We also had to ensure that the float rises to the surface once released, instead of diving to its parking depth.

The ASFAR frame developed and funded by AtlantOS complemented three other ASFAR frames acquired by Ifremer as part of the RREX project on complementary national funds.

4.2 System deployments (BOCATS / RREX)

Owing to the four ASFAR frames available at Ifremer, we maintained since 2015 two ASFAR frames at sea, one on each side of the Reykjanes Ridge. The Reykjanes Ridge is a major topographic feature that lies south of Iceland in a central position in the subpolar gyre and greatly influences the top to bottom large scale circulation there as well as water mass exchange and transformation between the eastern and western part of the subpolar gyre (Petit et al., 2018). The regular float released by the two ASFAR frame will allow the investigation of seasonal to interannual variability of the circulation and water masses on both sides of the ridge. This analysis is currently conducted as part of Ivane Salaun pHD thesis (LOPS, Brest, France).

The first two ASFAR frames were deployed in July 2015 as part of the RREX2015 cruise. Then, the ASFAR were recovered and two other frames were re-deployed at the same position in 2016 as part of the BOCATS cruise. Then again in 2017 and 2018 as part of the RREX2017 and OVIDE2018 cruises, respectively.

The frames were programmed to release floats every 2,5 months, that is 1st of September, 15th of November, 1st of February and 15th of April. Complementary float deployment was done at the ASFAR frame moored position in summer during the ASFAR deployment/recovery cruises, allowing a regular float release throughout the year.

Note that the ASFAR were moored at depths shallower than 2000m because the floats don not support pressure greater than 2000 dbar.

The two tables below provide the WMO number of the floats deployed over 2015-2019 on the two sides of the Reykjanes Ridge by the ASFAR frames.

Years	Cruise	Float released 1 September	Float released 15 November	Float released 1 February	Float released 15 April
2015/2016	RREX15 June-July 2015	Float not released	Float not released	6901721	Float not released
2016/2017	BOCATS June-July 2016	6902706	6902707	6902708	6902709
2017/2018	RREX17 July-August 2017	6902753	6902754	Float not released	6902756
2018/2019	OVIDE18 June-July 2018	6902786	6902787	6902788	6902789 (expected 15 April 2019)

Table 4: WMO number of the floats released by the ASFAR frame located west of the Reykjanes Ridge.

Overall, 21 floats were released by the throw ASFAR between the 1st of November 2015 and the 1st of February 2019. Two more floats should be released the 15th of April 2019. The ASFAR frames failed to release 9 floats because of an incorrect timing for the activation of the release system. Based on tests in the Ifremer pool, the release system was activated during 2 hours, while in some cases the release system needs to be activated during more than 12 hours. This is now modified and the ASFAR frame works well. Note that the floats that were not released by ASFAR were recovered afterwards when the ASFAR frame was recovered.

All the floats are still active and provide good data, which show that ASFAR deployment do not alter the behaviour of the platform and of the sensors.

The two ASFAR that are still in the water will be recovered in 2020 as part of cruises conducted as part of the international OSNAP project (Lozier et al. 2019).

4.3 Perspectives

We plan to continue using the ASFAR system in the North-Atlantic as part of the OVIDE and OSNAP projects to maintain the seeding of Argo floats in this basin that are crucial for Meridional Overturning Cell estimates (Mercier et al., 2015; Lozier et al., 2019).

The ASFAR system could also be used in boundary currents to maintain a sufficient number of Argo floats there as they are rapidly ejected from this region. This could help fulfil the new Argo mission that requires enhance coverage in critical regions such as the western boundary regions where mesoscale 'noise' is high (Roemmich et al, 2019).

We plan to adapt ASFAR to Deep-Arvor floats (Le Reste et al., 2016), one of the Deep-Argo float type. ASFAR deployment with Deep-Argo floats are expected in 2021 in the Southern Ocean as part of the SOCHIC project (PI JB Sallée) and in 2022 in the North-Atlantic Ocean.

We envision two additional developments:

- float release on event like eddy or deep convection for instance, based on temperature, salinity or dissolved oxygen concentration anomaly;

- ASFAR mounted on a mooring to allow float release in basin with bottom deeper than 2000m.

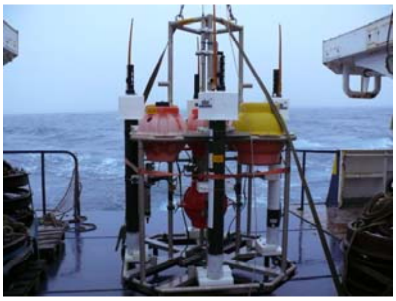


Figure 10. ASFAR system with four Argo floats onboard RREX cruise

Figure 11. Night deployment of the ASFAR system onboard RREX cruise

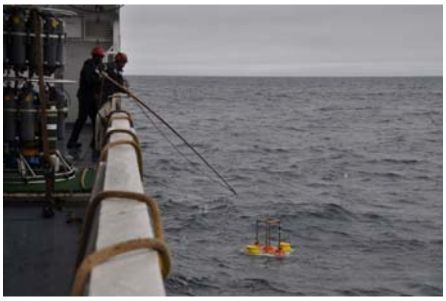


Figure 12. Recovery of the ASFAR system during the RREX cruise realized in 2017.

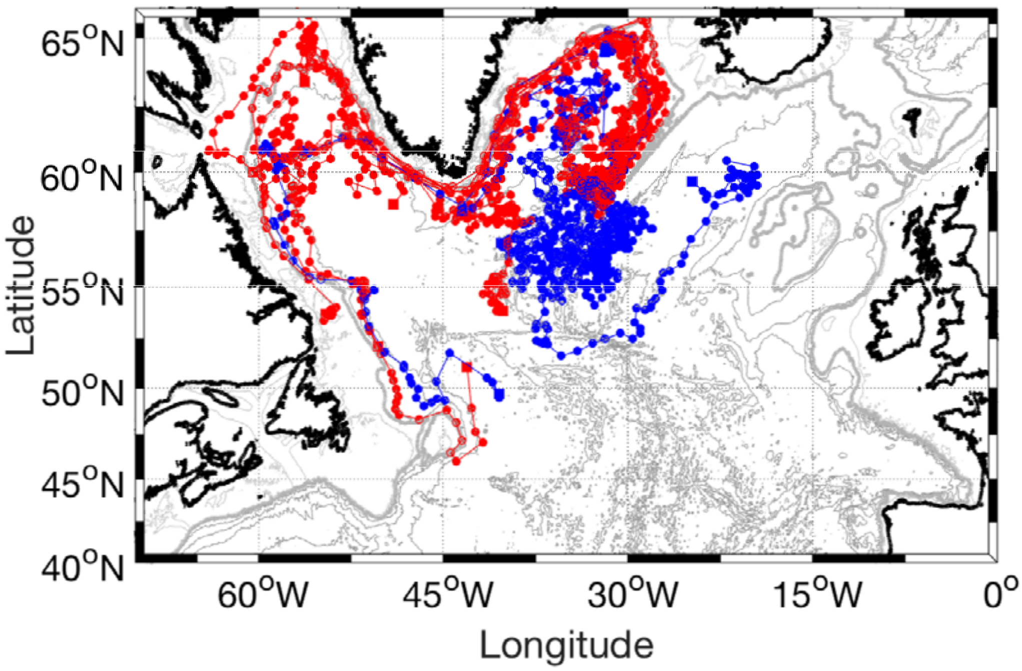


Figure 13. Trajectories of Argo profiling floats released from ASFAR systems on the western side of the ridge (red dots) and on the eastern side of the ridge (blue dots).

5 Development of the ability of floats to measure pH (SU) and pCO2 (GEOMAR)

5.1 Seabird SeaFet pH sensor integrated to NKE Instrumentations profiling float (SU)

The choice for measuring technology of Oceanic pH from profiling floats is driven both by the ability of sensor to achieve a four years at sea lifetime without any human handling, and by the capacity to answer to strong scientific request in term of accuracy and precision of the measure. Following the outcomes of the US SOCCOM project, during which the MBARI has integrated pH sensors on US floats, firstly developing an in-the-lab version of Honeywell DURAFET Ion Sensitive Field Effect Transistor material and secondly transmitting the commercial implementation to Sea-Bird Inc., the same technology has been retained for the integration of pH on the European NKE Instrumentations Provor CTS5 float.

5.1.1 Developments

As a consequence, an three parties agreement has been set between SU, NKE Instrumentations and Sea-Bird Inc. to integrate the OEM version of the SeaFET pH sensor. The hardware developments required

- a modification on the float's head, with a complete simulation of the materials strength performed at SU
- The adapting of OEM version of the SeaFET sensor to communicate both with the science and technical payload of the float, and allowing the sensor to be continuously powered to maintain its reference electrode calibration – development by Sea-Bird Inc.
- the development of a new controlling board and its associated drivers for the specific piloting of the pH sensor: the previous payload board of the CTS5 float became obsolete, inducing the designing of a completely new PCB (USEA board), work shared between SU and NKE Instrumentations

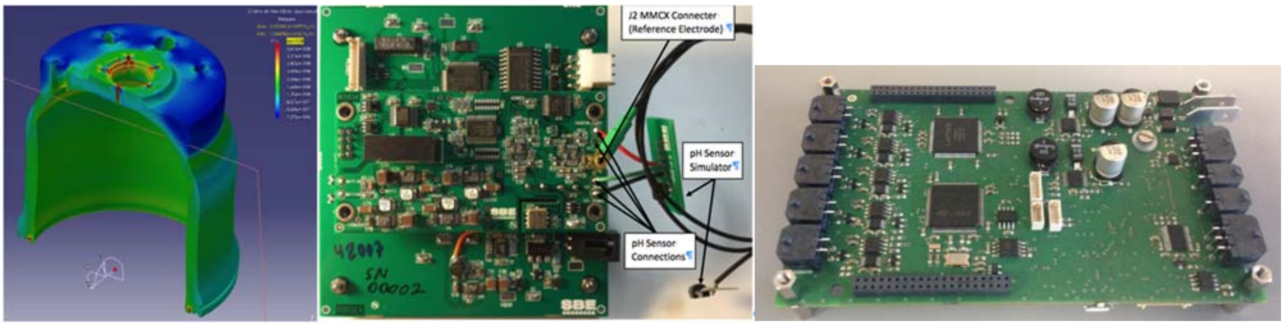


Figure 14. (left)The float's head strength simulation, (middle) the Sea-Bird Inc. interfacing board for SeaFET pH, (right) The USEA multisensory board developed by SU and NKE Instrumentations

Summer 2017 – December 2017: firsts bench tests on the prototype

These first steps allowed to solve many issues on the interfacing of the various elements (sensors, communications module) and to validate the transition from older OSEAN science payload board to the updated USEA board

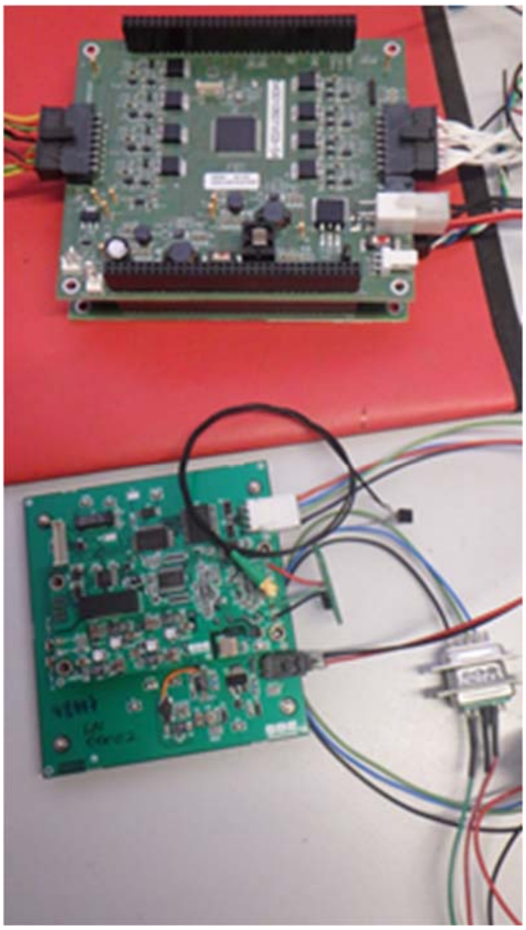


Figure 15 Bench testing of the OEM SeaFET PH sensor attached on OSEAN board

Figure 16. SeaFET pH sensor integrated on a NKE Instrumentations Provor CTS5 profiling float equipped with the OSEAN board.

5.1.2 Deployments and results

The profiling float equipped with pH and O2 sensors has been deployed during a 4 months campaign in the Ligurian Sea, from 4th of December 2017 to 17th of April 2018.

This at-sea validation has showed that the pH sensor was not mature enough to function nominally at depth, presenting a pressure induced effect on the measurements between 1000 and 2000dbars, and a bad calibration pattern in the surface layer (lack of calibration steps). A comparison with reference measurements of pH by spectrophotometric method showed also a large shift , which was confirmed for the majority of DURAFET sensors deployed in the same period in the Austral Ocean by the SOCCOM group.

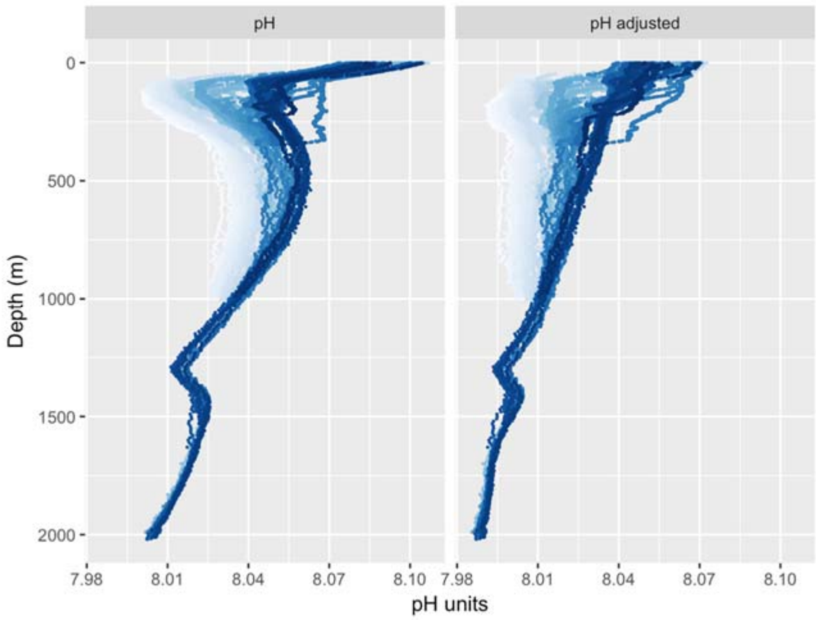


Figure 17. First deployment in Ligurian Sea. Vertical distribution of pH in (left) raw and (right) after adjustment proposed by the manufacturer. The data between 1200 and 1700 m are suspicious even after alignment.

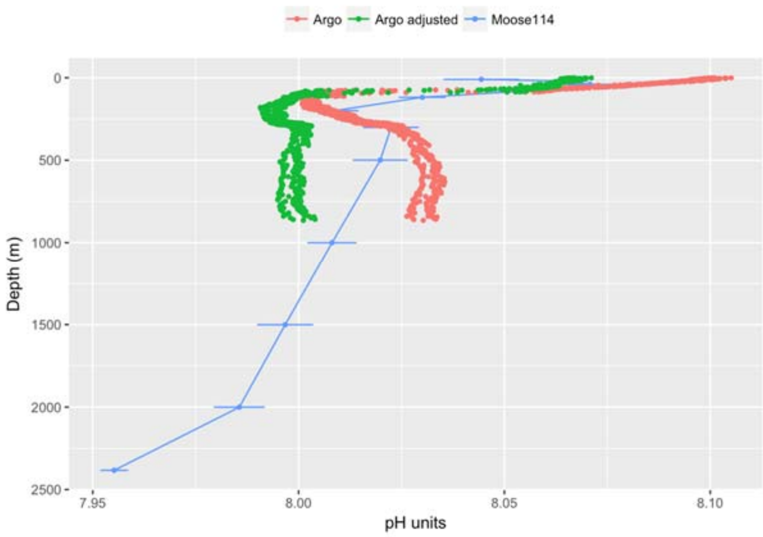


Figure 18. Comparison between in-situ (red), in-situ adjusted (green) and reference measurements (blue) at the deployment profile

The material has been recovered from sea, send back to the manufacturers for upgrade (hardware and software), and a second deployment has been scheduled from 1st of July 2018 to 01st of August 2018 in the same Area.

The pH sensor presented a nominal behaviour at each pressure level, though its measurements show a slight shift compared to the reference data. The shift stabilized after the first week at sea, and the offset remained stable after the transition period.

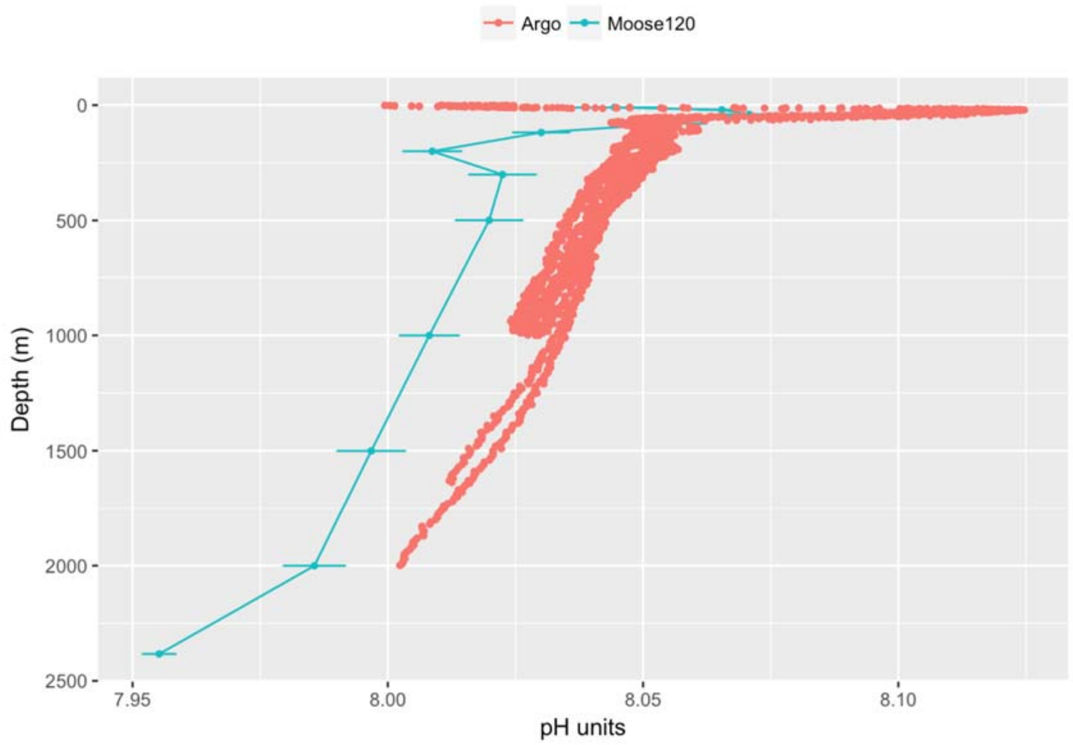


Figure 19. Second deployment at sea – July 2018. Vertical distribution of pH by the float (red) and reference curve (blue). After a one-week stabilization, a constant offset of about 0.03 pH units is remaining.

Spring 2019 – Future deployment

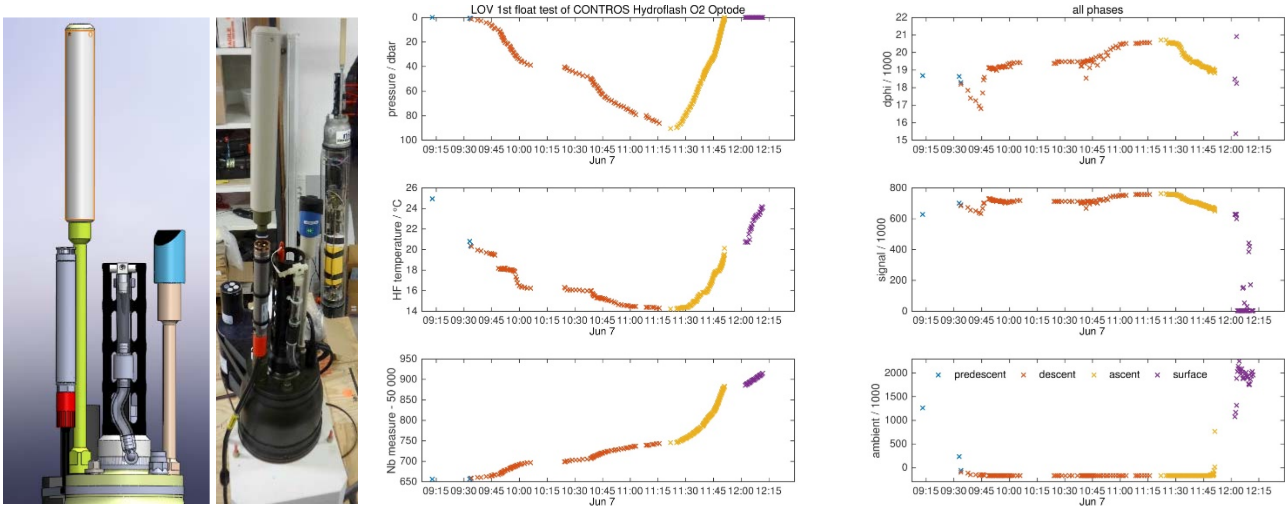
The acceptance of the new USEA board is in strong progress, and a float equipped with the full updated hardware will be deployed for a long term period in spring 2019.

5.2 pCO2 Optode development for autonomous platforms (GEOMAR)

In collaboration with the Laboratoire d'Océanographie de Villefranche-sur-Mer (LOV), a proof-of-concept float (PROVOR) implementation of a CONTROS HydroFlash® O_2 optode was successfully achieved (see Fig. 20.A and 20.B). This step was necessary as a precursor for planned field work on pCO_2 optodes from CONTROS at that time, as those were meant to be based on the same instrument type. Therefore, the CONTROS HydroFlash® O_2 optode was entirely integrated in the top structure, power supply and data string transmission of the float besides the other sensors, namely a CTD and Aanderaa optode.

This dual-oxygen float was then deployed in the morning of 7th June 2016 in the Mediterranean Sea off the coast of Villefranche-sur-Mer. This test profile can be seen in Fig. 20.C, where data is shown for pressure (dbar, from CTD) as well as temperature (°C), number of measurements, phase shift (°), signal intensity (mV) and ambient light (mV; all from HydroFlash® O_2 optode). Generally, data points are shown for 4 different phases of the floats cycle, i.e. pre-descent, descent, ascent and surfacing. While all measurements show normal behaviour before the float's full ascent, the optode revealed a strong cross-sensitivity of the sensor spot when exposed to direct solar irradiation at the surface at about 12:00 pm.

Overall, the collaboration with the LOV and results from the test gained important information for both GEOMAR scientists and CONTROS developers. This test revealed an issue with the sun-shading of HydroFlash® O_2 optode, while for the rest of the profiles data was successfully recorded without peculiarities. Further tests could not be carried out.



(A) (B) (C)

Figure 20: (A) Schematic arrangement of the CONTROS HydroFlash® O_2 optode next to the CTD and Aanderaa optode on a PROVOR float. (B) Successful proof-of-concept float (PROVOR) implementation of a CONTROS HydroFlash® O_2 optode as a precursor for further work on *p*CO_2 optodes. (B) First profile of the CONTROS HydroFlash® O_2 optode recorded during the test deployment (Drawing and figures kindly provided by Christoph Penkerc'h/LOV and Henry C. Bittig/LOV).

A first prototype of a planar *p*CO_2 mini sensor spot optode (SN DCO2-1116-001) provided by CONTROS, was initially tested in the course of a research cruise (R/V Meteor cruise M133) across the South Atlantic (15.12.2016 – 13.1.2017). The spot optode was integrated in a custom-made flow-through chamber with simultaneous temperature recording. Fig. 21.A schematically shows all underway measurements during M133 in which the *p*CO_2 prototype was integrated (flow line 5d, red box). Optical, continuous *p*CO_2 measurements with this prototype were carried out throughout the cruise using a measuring interval of 30 seconds. In total, data were recorded for 17 days. For comparison, an Aanderaa *p*CO_2 optode sensor (model 4797) was installed in the flow-through chamber SOOGuard. Part of the full setup is shown in Fig. 21.B. Further information is available in the M133 cruise report (provided on request).

(A)

(B)

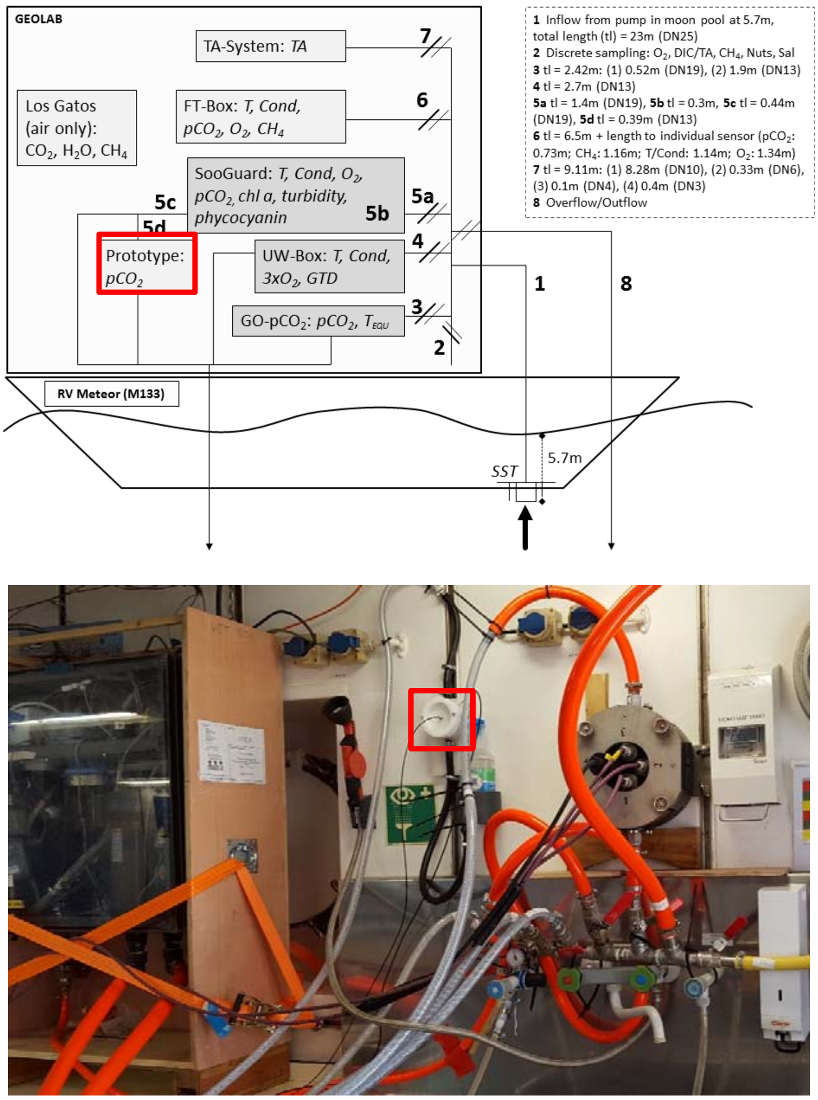


Figure 21 : (A) Schematic overview of all underway measurements carried out during the research cruise M133 of R/V Meteor. The CONTROS *p*CO_2 prototype (flow line 5d, red box) was arranged directly behind optical *p*CO_2 measurements from an Aanderaa *p*CO_2 optode (model 4797). (B) Arrangement of the *p*CO_2-GO-system (left), CONTROS *p*CO_2 prototype sitting in a flow-through chamber (middle, red box) and the SOOGuard system (right; picture and figure by Tobias Hahn/GEOMAR).

The data acquired both from the Aanderaa *p*CO_2 optode sensor (see Fig. XX.A) as well as the CONTROS prototype of a planar *p*CO_2 mini sensor spot optode (not shown here) did not provide useful data as compared to the reference GO underway *p*CO_2 system (see Fig. XX.B). After a trans-Atlantic section along 34.5°S (departure from Cape Town/South Africa) with relative stable *p*CO_2 in the 370-410 µatm, a generally lower and more variable *p*CO_2 of 220-360 µatm was encountered on the Patagonian Shelf from Jan 4th onwards. The Aanderaa *p*CO_2 optode does detects *p*CO_2 features qualitatively, particularly towards the end of the cruise. However, the *p*CO_2 data show a (i) a rather long conditioning phase (> 2 days), (ii) very long response times that do not allow to resolve the *p*CO_2 variability in the open South Atlantic, and (iii) a large drift pattern towards higher *p*CO_2. The data acquired with this optode therefore do not meet minimum quality requirements even for underway work.

Similar observations have been made elsewhere and points at the not satisfactory level the optode technology has reached with respect to pCO_2. The problem lies mostly with the properties of the sensing foil. A new foil type with largely improved properties is needed but apparently not within reach of the major manufacturers. This has led to severe delays with the development of a CONTROS pCO_2 optode up to a point where it remains questionable to the manufacturer, whether a pCO_2 optode product could actually meet the user demands concerning measurement performance. Aanderaa has already announced to withdraw their pCO_2 optode.

Without a major break-through in pCO_2 sensing foil technology, no further improvement in pCO_2 optodes is to be expected. For measurement of the carbon parameter pCO_2 one therefore has to resort to the established planar membrane sensor technology with NDIR detection, which is not suitable for integration into BGC-Argo floats due to their current specifications (size, power demands).

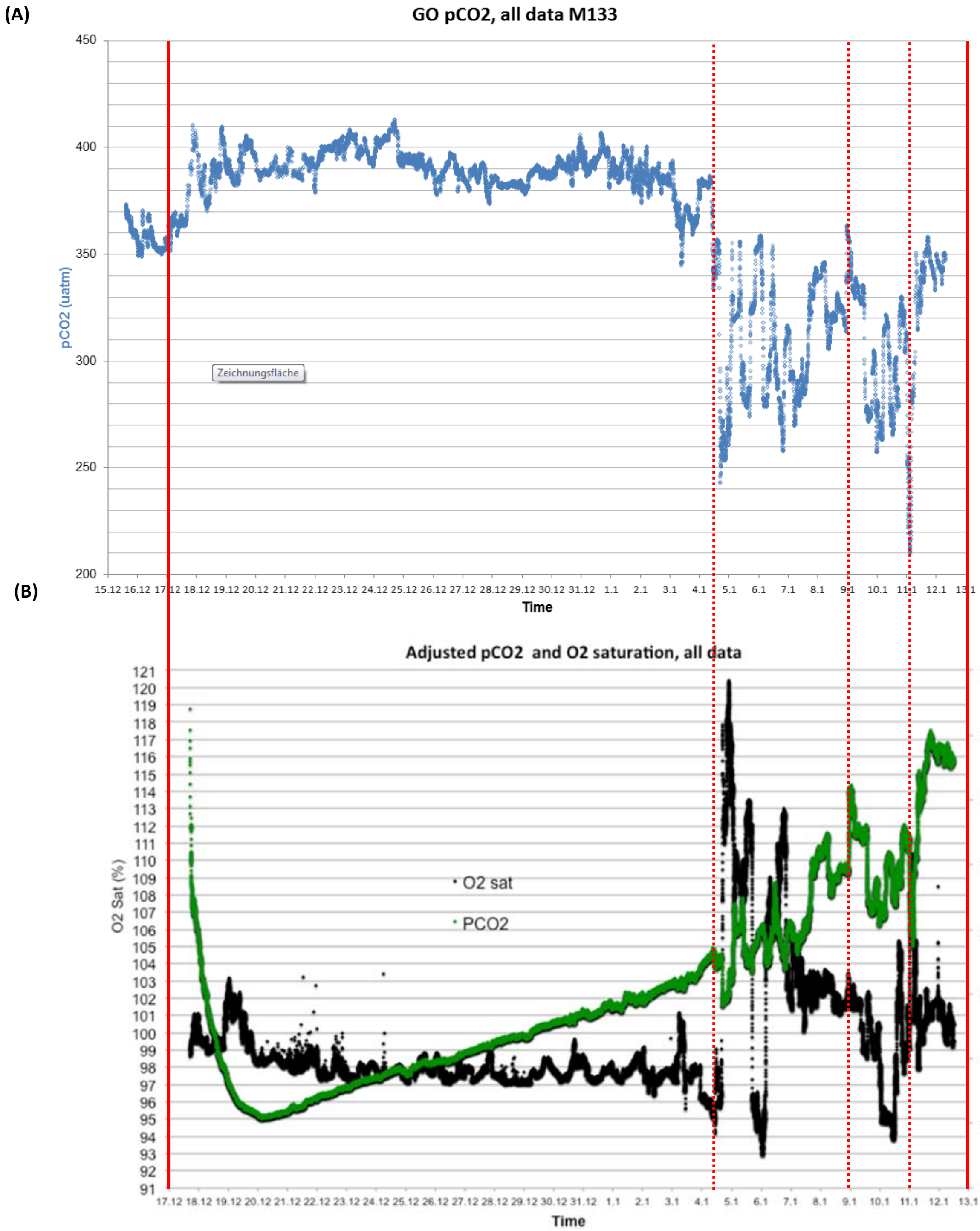


Figure 22. **Reference pCO_2 data from the GO underway pCO_2 system (A) and the Aanderaa pCO_2 optode (B, green symbols) as recorded between 15.12.2016 and 13.1.2017 over the course of the M133 cruise of R/V Meteor. After a trans-South Atlantic section along 34.5°S (departure from Cape Town/South Africa), data were recorded over the Patagonian Shelf from Jan 4th onwards.**

6 List of acronyms

BGC	Biogeochemistry
DAC	Data Assembly Centre
GDAC	Global Data Assembly Centre
IOC	Intergovernmental Oceanographic Commission
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JCOMMOPS	JCOMM in-situ Observing Programmes Support Centre
NRT	Near Real Time
QC	Quality Control
PI	Principal Investigator
KM CONTROS	Kongsberg Marine Contros Gmbh
IFREMER	Institut Français de Recherche pour l'Exploration de la Mer
NERC	Natural Environment Research Council
NOC	National Oceanography Centre
BODC	British Oceanographic Data Centre
PML	Plymouth Marine Laboratory
LOV	Laboratoire d'Oceanographie de Villefranche
IEO	Instituto Espanol de Oceanografia
GEOMAR	Helmholtz Centre for Ocean Research Kiel
SU	Sorbonne Université
PIRATA	Prediction and Research Moored Array in the Tropical Atlantic
ASFAR	Autonomous System for Argo floats Release
RREX	Reykjanes Ridge Experiment