Project	AtlantOS – 633211
Deliverable number	D3.12
Deliverable title	Eastern boundaries survey
Description	Report on glider surveys in eastern boundary regions, key regions for the Atlantic fishery and connected with the WP4. Survey, sampling and data delivery in these regions is investigated and reported in here.
Work Package number	WP3
Work Package title	Enhancement of autonomous observing networks
Lead beneficiary	GEOMAR
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Submission data	Final Draft: 14 November 2018 – additional revised input Draft 1: 3 November 2018
Due date	30 September 2018 (PM 42)
Comments	Late delivery due to capture evolving input from the International Conference on Glider Data Management in Genoa, Italy, 18-20 September 2018, and the preparation of the Community White Paper for the OceanObs'19 conference in Honululu, Hawaii, 16-20 September 2019.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 633211.

Last updated: 19 November 2018

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

WHO are your most important stakeholders?	**X** Private company If yes, is it an SME **X** or a large company **X**? **X** National governmental body **X** International organization ☐ NGO **X** others Please give the name(s) of the stakeholder(s): Marine research institutes, Scientific and technological infrastructures, Glider/sensor manufacturers
WHERE is/are the company(ies) or organization(s) from?	**X** Your own country **X** Another country in the EU **X** Another country outside the EU Please name the country(ies): Spain, Germany, France, United Kingdom, Norway, Brazil, Canada, USA, South Africa and others out of the AtlantOS scope
Is this deliverable a success story? If yes, why? **If not, why?**	**X** Yes, because this report emphasizes the importance of gliders in filling the observational gaps in Eastern Atlantic boundary regions as well as supporting the scientific assessment of fisheries. ☐ No, because …..
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	**X** Yes, by the glider community in order to share best practices and foster joint glider projects. ☐ No, because …..

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.

Contents

Executive summary

The review of the AtlantOS eastern boundaries survey covers three main aspects concerning glider observations in the Atlantic Ocean: the scientific contribution based on the use of underwater gliders, their role in fisheries assessment and its importance in filling observational gaps in the transition region between the open ocean and the coast. Based on the findings of our task partners, which conducted several glider missions in different locations in eastern boundary regions, we provide some recommendations to further foster glider activities in these critical regions. The main recommendations are summarized here.

- Gliders should be considered as a key technique to minimize the well known observing gap between the coast and the open ocean, particularly in the eastern boundary of the Atlantic Ocean.
- Since the observational gaps in the South Atlantic are larger than in the North Atlantic, gliders could serve as an appropriate technology to overcome this discrepancy and to contribute to the cross-cutting GOOS (Global Ocean Observing System) targets climate, operational services and ocean health.
- The development of a sustained multi-platform observing system needs to be encouraged in eastern boundaries to take full advantage of the capacity of continuous ocean observing that gliders can provide.
- The rapid development of sensors (e.g. biogeochemical and biological sensors) will enhance the use of gliders with regard to the assessment of fisheries, particularly in regions that are at risk by anthropogenic pressure and therefore depend on marine resources.
- Free access of glider data in a specifically defined format must be promoted and controlled to guarantee an optimal exploitation of glider observations.
- A technical coordinator should be in charge of the enhancement of the glider network in terms of collecting, harmonizing and promoting best practices and common data management processes.

1. Introduction

The AtlantOS WP3 “Enhancement of autonomous observing networks” aims to organize, reinforce and demonstrate the importance of a well developed network of autonomous observing platforms in the Atlantic Ocean. Task 3.4 “Glider” is dedicated to the glider network that was in a critical phase of development at the beginning of the project in 2015. The task was designed to structure and strengthen the Atlantic glider network, to develop tools that are relevant for the glider community, and to illustrate the essential role autonomous platforms play in observing eastern boundary regions of the Atlantic Ocean.

1.1 Objectives

This report will provide a comprehensive summary of the glider activities carried out by the following task partners in the Eastern Atlantic boundary region: PLOCAN, GEOMAR, CNRS, NOC, SAMS and UiB. In order to present a short overview about the conducted missions, a selected number of regional glider lines and networks are summarized here.

- PLOCAN: The Canary Island oceanic platform (PLOCAN) operates gliders mainly in the Macaronesian area. It provides support for marine research and technological developments.
- GEOMAR: The GEOMAR Helmholtz Center for Ocean Research Kiel is leading frontiers science with gliders since 2003. During the AtlantOS project, the GEOMAR glider group has undertaken several surveys in the eastern tropical Atlantic with a primary goal of observing upwelling regions and oxygen minimum zones.
- CNRS: The French National Scientific Research Center (CNRS) is supporting the National Glider Pool (NGP). The NGP operate gliders in the Atlantic boundaries through national and international calls.
- NOC: The National Oceanography Center (NOC) hosts the Marine Autonomous and Robotic Systems (MARS) facility that comprises the largest and most diverse research fleet of marine autonomous systems in Europe. More than 30 underwater gliders are operated by MARS and accessible to several research institutes in the United Kingdom.
- SAMS: The Scottish Association for Marine Science (SAMS) is operating gliders across the AMOC (Atlantic Meridional Overturning Circulation) in the eastern subpolar North Atlantic on the Extended Ellett Line (EEL) between Scotland and Iceland.
- UiB: The University of Bergen (UiB) is one of the contributors to the Norwegian National Facility for Ocean Gliders (NorGliders). They operate long-term monitoring lines along the Norwegian coast particularly suited to survey the northern extension of the Gulf Stream.

The report will point out the crucial role of coordinated networks in monitoring Eastern Atlantic boundary regions while ensuring data access, data quality and data harmonization. Links between fishery and eastern boundaries will be established and the necessity of a better understanding of the biogeochemical dynamics achieved by long-term glider monitoring will be demonstrated. Existing observational gaps will be revealed and assessed, particularly focusing on the eastern boundary regions in the South Atlantic. We present how gliders can be used to overcome these gaps, especially in combination with other observing platforms.

Following a more theoretical background specifying the definitions of gliders, platforms and networks, a brief introduction into eastern boundary currents and fishery will be given. Section 2 comprises the scientific and technical achievements that resulted from different glider missions conducted by our task partners since the start of the AtlantOS project in 2015 until summer 2018. Advantages using gliders when observing fish abundance will be presented afterwards, including a case study of promoting the use of gliders in Nigeria. Section 3 describes the links established with WP4 "Interfaces with coastal ocean observing systems", before summing up the findings of this report and pointing out future perspectives in section 4.

1.2 Concept

In the following, a brief theoretical input with regard to underwater gliders, observational platforms, and networks will be presented. Furthermore, the importance of active upwelling and strong eddy activity in eastern boundaries for fish stocks, ecosystems and biodiversity will be highlighted.

1.2.1 Definitions of gliders, platforms and networks

Underwater gliders are of low energy consumption, remote controlled, autonomous platforms particularly suited to sample mesoscale and submesoscale ocean processes. These processes are key to the physical, chemical and biological oceanography close to ocean boundaries, while they are still very difficult to observe in the long-term (Testor et al., 2010).

Gliders measure Essential Ocean Variables (EOVs) continuously at high resolution along their sawtooth trajectory from the surface down to generally 1000 m. The standard resolution of less than a few kilometers between two surfacings allows an adequate monitoring of the ocean dynamics in boundary regions that are key to understand the mixing between the coastal shelf and the adjacent open ocean. Glider tracks of hundreds of kilometers length can fill the gaps left by other observing platforms such as Argo's open ocean profiling floats and coastal observing systems like High Frequency Radar (HF Radar). Even the OceanObs'09 decadal conference on ocean observing highlighted the importance of gliders to provide higher spatial resolution and coverage than other existing observing platforms and programs (Lindstrom et al., 2012).
Following the OceanObs'09 requirement, the community of glider users, from operators to scientific principal investigators (PIs), should organize themselves on the European and global level to initiate international coordination, to enhance global data management and to share common best practices within the community. The EuroGOOS glider task team and the recent OceanGliders program are promoting, monitoring and reporting glider activities worldwide. In this framework, ocean boundaries have been identified as strategic regions, where observing activities need to be strengthened.

1.2.2 Eastern boundary currents

The ocean's influence on the coast is most perceivable in boundary regions. These regions contain the most intense currents that flow along the continental slopes. Eastern boundary currents are relatively slow, shallow, and wide. They transport colder waters into the tropics, where they are heated and transported toward the poles. Furthermore, eastern boundary currents are often upwelling systems with nutrient-rich water that contain some of the most biologically productive regions around the globe. Hence, good fishing grounds occur in upwelling regions as for example, along the west coasts of Africa due to year-round coastal upwelling. Besides fisheries, boundary regions generate other socio-economic benefits as derived from transportation and recreation (Rudnick et al., 2016).

Since boundary currents are small-scale and relatively complex to capture, global ocean observing systems are not well suited for their monitoring. In addition to the physical parameters, biogeochemical as well as biological parameters need to be assessed, which can be done by gliders. Also, merged hybrid approaches are conceivable (Send et al., 2010) such as suggested by the OceanGliders Boundary Ocean Observing Network (BOON).

BOON proposes a global network of underwater gliders that monitors boundary current variability within a multi-platform observing system. By coordinating and linking the global glider activities, BOON aims to improve regional models of coastal ocean circulation and therefore, enhance regional forecasts. Improving the quality of glider data from regional networks will lead in the end to the ultimate objective of enabling glider monitoring across international borders and all seasons, in real-time and in difficult conditions and locations. BOON will build on historical records and combine Argo's observations, OceanSites mooring data and ship surveys. Particular emphasis will be put in filling existing gaps in observation data with the most appropriate technology (Rudnick et al., 2016).

1.2.3 Fishery in the Eastern Atlantic Ocean

Climate change poses a growing threat to key commercial species. Significant shifts in their range, distribution, abundance, and productivity are expected (Burden et al., 2007). Sustainable Development Goal (SDG) 14 "Conserve and sustainably use the oceans, seas and marine resources" brought prominence to the issue that marine areas need to be protected and effectively managed. Negative impacts such as overfishing, marine pollution, and ocean acidification can only be reduced when regulations are in force (United Nations, 2018a).

Especially in the North East Atlantic region, institutions create rigid rules that hinder adaptive management. Tensions have already resulted from variations in fish stocks that endanger the long-term conservation of fish species and consequently, the socioeconomic benefits that can be gained from fishing. Since fish species move across geo-political borders, the question arises of how to share them. The trend of overfishing and illegal discarding has already been a response to it (Burden et al., 2007).

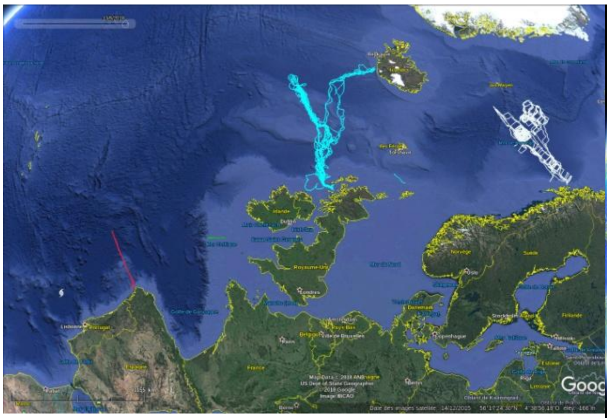
In order to adequately deal with the transboundary nature of fish species, scientific surveys should be conducted at the most appropriate spatial and temporal scales (Burden et al., 2007). Since along the eastern boundaries active upwelling and strong eddy activity is prevailing, they provide a habitat for the world's most important fisheries. Therefore, observational data indicating fish abundance provide essential information that is necessarily needed for the management of fisheries (Send et al., 2010). In other words, effective management that is based on a reliable database might result in positive impacts on socio-economic (generating income, sustaining livelihoods) and ecological dimensions (preserving biodiversity).

Gliders are able to detect zooplankton and/or fish abundance by acoustic backscatter strength (Send et al., 2010). Thus, gliders could serve as a basis for collecting data that can be used to determine how fisheries will be managed in the future. Here, one key point is to create linkages between science and decision-making, hence, the collaborative dialogue between all stakeholders, especially science and policy actors, needs to be strengthened (Burden et al., 2007).

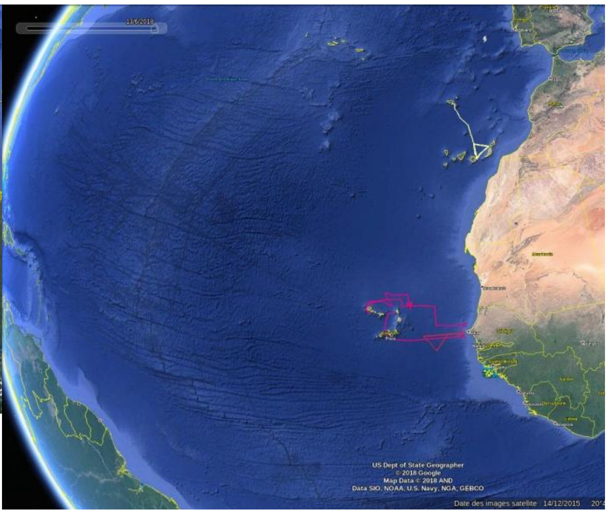
Assuming that climate change may have negative impacts on the fisheries in the Eastern Atlantic, it is vital to collect oceanographic data to further minimize the gap of uncertainties and increase the data input for developing models and scenarios. This will help to build a more resilient, sustainable fisheries management. Furthermore, a strong continuous outreach to industry might be another key component in achieving a more adaptive framework for the Eastern Atlantic (Burden et al., 2007).

2. Eastern glider activities during the AtlantOS project

The three maps bellow display eastern boundary glider deployments from our task partners funded by the AtlantOS project from 2015 until summer 2018.



European eastern boundary glider deployments of SAMS (cyan), NOC (green), UiB (white), and CNRS (red).



North African and Canarian eastern boundary glider deployments of GEOMAR (red) and PLOCAN (yellow).

South African eastern boundary glider deployments of GEOMAR (red).

The map below displays all AtlantOS deployments that are available on the EGO/Coriolis Global Data Assembly Center (GDAC) under the common European glider format.

Accessible glider data sets from the GDAC EGO/Coriolis in the common European glider format.

2.1 Scientific and technical achievements

This section comprises a review of the glider deployments and a compilation of scientific publications dealing with different gliders missions operated by our AtlantOS task partners. We will extract the key points from the publication's abstracts that emphasize the use of gliders in ocean boundary regions.

2.1.1 PLOCAN

PLOCAN: The R3M initiative as an example for building up a regional ocean monitoring system based on gliders

Glider deployment	**Deployment date**	**Description**	**Sensor payload**
ESTOC2015_1	20 days from Aug 28 - Sep 16, 2015	Water masses / Time Series	CTD[1], Fluorescence, DO[2]
ESTOC2015_2	21 days from Oct 27 - Nov 16, 2015	Water masses / Time Series	CTD, Fluorescence, DO
MADEIRA_2016	63 days from Apr 11 - July 12, 2016	Water masses / Time Series	CTD, Fluorescence, DO
ESTOC2016_1	12 days from Mar 02 - Mar 14, 2016	Water masses / Time Series	CTD, Fluorescence, DO
ESTOC2016_2	23 days from Nov 05 - Nov 28, 2016	Water masses / Time Series	CTD, Fluorescence, DO
ESTOC2017_1	19 days from Mar 08 - Mar 27, 2017	Water masses / Time Series	CTD, DO
ESTOC2017_2	18 days from June 19 - July 07, 2017	Water masses / Time Series	CTD, Fluorescence, DO
ESTOC2018_1	19 days from May 25 - June 13, 2018	Water masses / Time Series	CTD, Fluorescence, DO
8 deployments	**190 days at sea**	**One section repeated twice a year and one transect from the Canarian Island to Madeira**	**CTD, Fluorescence, DO**

PLOCAN eastern boundary region glider deployments (yellow).

The Macaronesian Marine and Maritime Network (R3M) is a regional initiative aimed to increase the quantity and quality of marine environment observations across its four main archipelagos in order to understand and predict the local phenomena and their environmental and socioeconomic impact. R3M makes all the marine environment observations compatible and accessible to potential end-users (e.g. navigation, harbors, safety and security, oil and gas, aquaculture, wastewater,

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[1] CTD = Conductivity, temperature and depth

[2] DO = Dissolved oxygen

tourism, marine research, marine energies, weather agencies, national and regional governments), regardless of the institution or company that carries out them (PLOCAN, n.d.). In this context, PLOCAN develops a long-term monitoring program with gliders, which is called "European Station for Time series in the Ocean Canary Islands" (ESTOC), and a testing infrastructure to increase the capability of gliders and enhance the access of fit-for-purpose data for the users (Barrera et al., 2018).

PLOCAN: The role of gliders in the development of a boundary region observing network

Eastern boundary regions are characterized by a strong need for more appropriate ocean data. The high resolution data acquisition and the new capabilities offered by gliders transform this technology into an essential element of regional ocean observing networks.

2.1.2 GEOMAR

GEOMAR: Assessing strong eddy activity and oxygen minimum zones

Glider deployment	Deployment date	Sensor payload
imf02_depl23	14 days from Nov 09 - Nov 24, 2015	CTD, DO, FLNTU[3], Turbulence
Ifm03_depl13	10 days from Oct 21 - Nov 26, 2016	CTD, DO, FLNTU, Turbulence
Ifm03_depl12	28 days from Oct 31 - Nov 27, 2015	CTD, DO, FLNTU, Turbulence
Ifm09_depl07	8 days from Oct 21 - Oct 28, 2016	CTD, DO, FLNTU, Turbulence
Ifm09_depl06	38 days from Nov 16 - Dec 24, 2015	CTD, DO, FLNTU, Turbulence
Ifm09_depl08	8 days from Nov 08 - Nov 15, 2016	CTD, DO, FLNTU, Turbulence
Ifm09_depl12	5 days from June 18 - June 23, 2018	CTD, DO, FLNTU, Turbulence
Ifm12_depl05	88 days from Mar 05 - June 01, 2015	CTD, DO, FLBBCD[4]
Ifm13_depl03	18 days from Nov 07 - Nov 25, 2015	CTD, DO, FLNTU, Nitrate
Ifm13_depl04	7 days from Oct 21 - Nov 27, 2016	CTD, DO, FLNTU, Nitrate
Ifm13_depl06	5 days from June 18 - June 23, 2018	CTD, DO, FLNTU, Nitrate
Ifm14_depl03	38 days from Jan 13 - Feb 20, 2017	CTD, DO, FLBBCD
Ifm14_depl04	14 days from Feb 26 - Mar 11, 2017	CTD, DO, FLBBCD
13 deployments	**281 days at sea**	**CTD, DO, FLNTU, Turbulence, FLBBCD, Nitrate**

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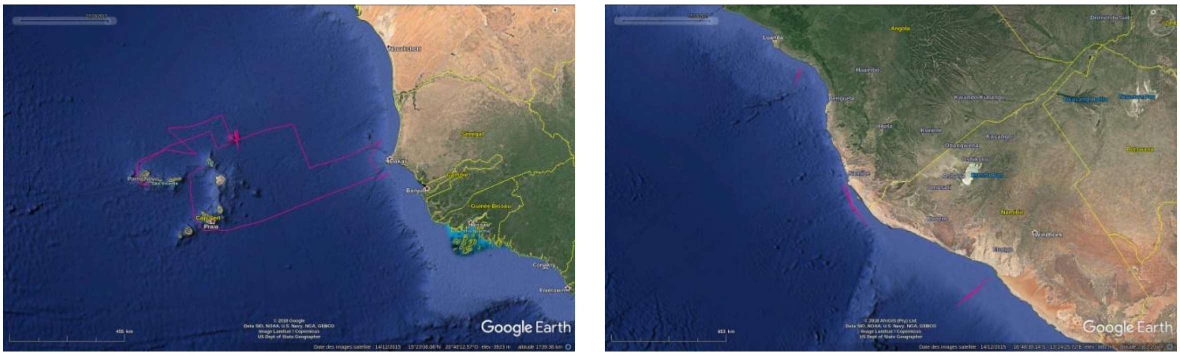
[3] FLNTU = Fluorescence and turbidity

[4] FLBBCD = Fluorescence, backscatter and CDOM



GEOMAR Eastern Atlantic boundary region glider deployments (red).

Upwelling and isolation in oxygen-depleted anticyclonic modewater eddies and implications for nitrate cycling

The temporal evolution of the physical and biogeochemical structure of an oxygen-depleted anticyclonic modewater eddy (ACME) in the eastern tropical North Atlantic was investigated over a 2-month period using high-resolution glider and ship data. In late December 2013, a candidate eddy in the eastern tropical North Atlantic was identified and in late January 2014, a pre-survey was initiated making use of autonomous gliders. After confirmation that the candidate eddy was indeed a low oxygen ACME, two ship surveys and further glider surveys followed (Karstensen et al., 2017).

Data from the GEOMAR glider IFM12 and glider IFM13 were used. Glider IFM12 surveyed temperature, salinity, and oxygen to a depth of 500 m as well as chlorophyll a fluorescence and turbidity to 200 m depth. Glider IFM13 surveyed temperature, salinity, and oxygen to a depth of 700 m as well as chlorophyll a fluorescence and turbidity to 200 m depth. Glider IFM13 was also equipped with a nitrate sensor that sampled to 700 m depth. Additionally, data from two ship surveys have been used, surveying about 6 weeks after the first glider survey (and 3 weeks before the last glider survey) on the same eddy. High-resolution underwater glider and ship data allowed to describe the eddy structure at submesoscale resolution. Thus, characteristics of a low oxygen ACME found in the eastern tropical North Atlantic could be provided (Karstensen et al., 2017).

Subsurface fine-scale patterns in an anticyclonic eddy off Cap-Vert peninsula observed from glider measurements

In the last decades, the development of autonomous observing platforms, such as underwater gliders, paved the way to observe and study eddy regimes in greater details. GEOMAR conducted a study, where subsurface thermohaline and dissolved oxygen fine-scale structures observed within an Eastern Tropical North Atlantic (ETNA) anticyclonic eddy are characterized for the first time using high-resolution glider observations along a cross-shore transect between Dakar (Senegal) and Cape Verde Archipelago along 14.7°N (Kolodziejczyk et al., 2018).

Gliders were deployed to enhance the observational database in the still poorly sampled ETNA and Senegal-Mauritanian Upwelling System (SMUS) off Senegal. The experiment aimed to conduct a detailed survey of the large as well as fine-scale thermohaline and biogeochemical tracer structure along the 14.7°N latitudinal transect in order to better document the circulation and water masses structure in this region. Two gliders were deployed: a French glider off Cap-Vert Peninsula

(Senegal) and a second German glider. Both gliders are so-called deep (i.e., able to dive to 1000-m depth) gliders and operated between 12 March 2014 and 13 May 2014. They provided unprecedented high-resolution insight into the processes involved in thermohaline and dissolved oxygen layering and stirring, induced by mesoscale eddies (Kolodziejczyk et al., 2018).

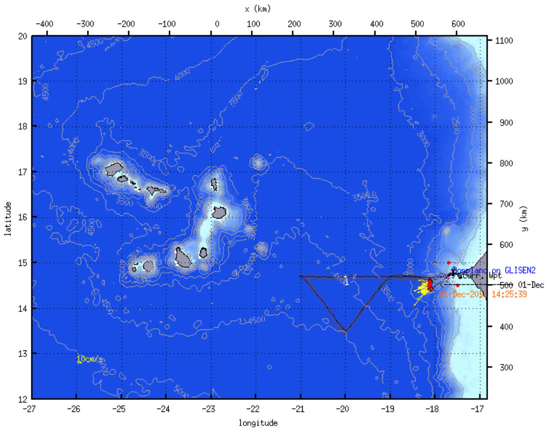
GEOMAR: Efficient monitoring of regions characterized by strong variability at scales less than the mesoscale

Gliders are capable to investigate the hydrography, currents, and biogeochemical characteristics of a low oxygen anticyclonic modewater eddy and its temporal evolution. They can be used for identifying eddies as part of a pre-survey as well as for the survey itself. Additionally, glider technology may enable an efficient monitoring of regions of the ocean characterized by strong variability at scales less than the mesoscale. This makes a glider deployment strategy complementary to other observing platforms especially relevant in boundary current regions.

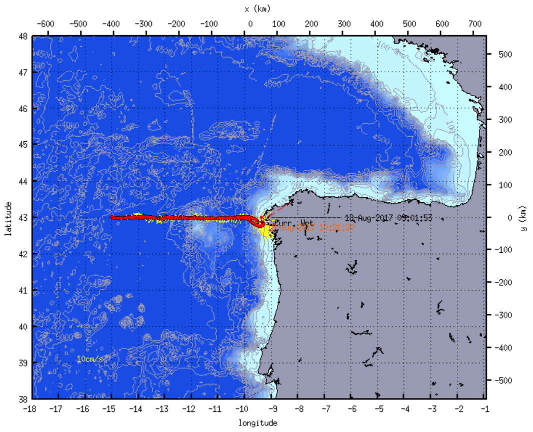
2.1.3 CNRS

CNRS: Submesoscale dynamic studies of the North Atlantic Ocean boundaries

Glider deployment	Deployment date	Description	Sensor payload
FinisGlider	21 days from June 29 - July 19, 2017	250 NM/ about 450 km perpendicular to the coast	CTD, DO, Fluorescence, CDOM, Turbidity, Backscatter
Glisen2	58 days from Oct 04 - Dec 01, 2016	750 km perpendicular to the coast with a detour of about on degree South and back to the starting point	CTD, DO, Fluorescence, CDOM, Turbidity, Backscatter
2 deployments	**79 days at sea**	**Two repeated transects over 1100 km**	**CTD, DO, Fluorescence, CDOM, Turbidity, Backscatter**



GLISEN deployment trajectory (red).



FinisGlider deployment trajectory (red).

FinisGlider – a submesoscale study of the ocean variability along a ship ctd transect

A primary scientific target of the first glider mission was to quantify short-term variability influence on the representativeness of an annual hydrographical cruise series. Thus, it was considered convenient to perform inter-calibration dives for a direct comparison of CTD casts from the annual oceanographic cruise along this transect. The cruise started on July 3, 2017, and was navigated to the last known glider position to make an initial inter-calibration profile. The first CTD cast was performed on July 3, 2017, at 20:57 UTC at 42°59.95'N, 010°19.80'W matching with the glider dive #52 (43°00.05'N, 010°21.16'W, 22:50 UTC), i.e. separated by 2.5 km and less than two hours. Three days later, the cruise overtook the glider close to 11°W providing a second inter-calibration dive (with a difference of 2.5 km and four hours). After finishing the sampling, the ship returned taking the same line while recording velocity measurements. The inter-calibration dive shows a clear matching of the samplings but also highlights the need to carefully calibrate the oxygen and chlorophyll sensors. Vertical displacement that occurred in the chlorophyll-fluorescence sensor is consistent with a vertical shift of the overall hydrographical structure due to the local internal wave field (González-Pola Muñiz, 2017).

The current assumption of a precise estimation of the hydrographical state of regional water masses based on a typical one-per-year CTD section seems obsolete. The glider measurements reveal strong mesoscale and submesoscale activities due to the Mediterranean water flow in the deeper layers. The differences between the cruise and the glider sections (forward and back tracks) need to be analyzed, which allows to quantify the influence of mesoscale structures and short-term variability of the hydrographical properties of regional ocean dynamics (González-Pola Muñiz, 2017).

The FinisGlider mission was a unique occasion of overlapping a ship cruise with a glider mission. It provided a rare opportunity to make the same estimates for biogeochemical variables (e.g. dissolved oxygen and chlorophyll), whose spatial structure depends strongly on the hydrography but also on biological factors. Considering that shelf-slope dynamics as well as mesoscale structures evolve in time frames of weeks, it is anticipated that the outcome will vary between the different records with regard to the recirculation structures. The differences concerning the geostrophic circulation will be explored in the analysis, taking into account regional meteorological forcing and altimetry (González-Pola Muñiz, 2017).

CNRS - FinisGlider: Continuous observation of key areas and moving to biogeochemical long-term observations

The first conclusions from the FinisGlider mission recommended a more frequent sampling along the trajectory. It clearly demonstrates the capacity and efficiency of underwater gliders to capture mesoscale ocean variability. Furthermore, gliders can carry large sensor payloads which make them an adequate tool to observe biogeochemical activities in boundary regions. Regional multi-platform observing systems appear to be the most appropriate solution for the long-term monitoring of ocean boundary regions in general, measuring physical, biogeochemical, and biological processes.

Glisen2 – The use of gliders to monitor and understand ocean circulation in oxygen minimum zones

The GLISEN project was a joint glider experiment of the GEOMAR and the IRD[5]-AWA[6] campaign (from February to March 2014). It was devoted to the physical and biogeochemical observations within the SMUS (Senegal-Mauritanian Upwelling System). The GLISEN project's main purpose was the documentation of the large- to fine-scale circulation off Cape Verde, and to provide a comprehensive description of the thermohaline and tracer ventilation processes of the Guinea Dome in the upper ETNA (Kolodziejczyk et al., 2015).

The upper ETNA is characterized by the Dome of Guinea centered around 10°N to 23°W. This region is of importance for climate studies because of its strong air-sea coupling. The coupling in turn is believed to be strong during boreal winter and spring and controls the northward excursion of the inter-tropical convergence zone during boreal spring and summer (Doi et al., 2010), impacting the Western African Monsoon (Chang et al., 2008). The ETNA is also characterized by oxygen minimum zones and very old water masses (Karstensen et al., 2008, Brandt et al., 2014) observed at shallow and intermediate level (100-800 m) within the fresh North Atlantic central water. In spite of zonal tropical jets, which transport saline and oxygenated water from the western tropics, the transport of water masses in the ETNA and the supply of dissolved oxygen might be due to eddy transport and mixing (Brandt et al., 2014). In this study, measurements from a joint French and German glider transect along 14.7°N between Dakar (Senegal) and the Cape Verde archipelago from March to April 2014, are used to investigate the traversal structure of an anticyclonic eddy as well as hydrological and dynamical associated features (Kolodziejczyk et al., 2015).

CNRS - Glisen2: Assessing the role of the ocean in regional climate variability while providing a tool to enhance the observational data base in low sampled areas of the Tropical and South Eastern Atlantic

The glider deployments have strongly contributed to a better understanding of the regional dynamic nature of water masses that strongly influence the regional climate and the biological activity. Since the West African region is only poorly sampled by oceanographic techniques, the need to standardize data acquisition and to make the data publicly available is crucial. Gliders as part of the OceanGliders program seem to be the most appropriate technique to improve the conditions in the ETNA, especially with respect to society needs (marine dependent livelihoods). The German-French joint deployments demonstrated the capacity of gliders to acquire ocean data that is needed for a better monitoring and understanding of regional ocean processes.

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[5] IRD = Institut de recherche pour le développement

[6] AWA = Ecosystem approach to the management of fisheries and the marine environment in the West African waters

2.1.4 NOC

NOC: Sustained multi-glider deployments operated in the North Atlantic shelf

Glider deployment	**Deployment date**	**Description**	**Sensor payload**
Mission 2015_1	1st quarter 2015	Off-shelf transect	CTD, DO, CDOM, BBP, Fluorescence
Mission 2015_2 (lost at sea)	2nd quarter 2015	Off-shelf transect	CTD, DO, CDOM, BBP, Fluorescence
Mission 2015_3	2nd quarter 2015	Off-shelf transect	CTD, DO, CDOM, Fluorescence
Mission 2015_4	3rd quarter 2015	Off-shelf transect	CTD, DO, CDOM, BBP, Fluorescence
Mission 2015_5	1st quarter 2015	In between mooring transect	CTD, DO, CDOM, BBP, Fluorescence
Mission 2015_6	2nd quarter 2015	In between mooring transect	CTD, DO, CDOM, BBP, Fluorescence
Mission 2015_7	2nd quarter 2015	In between mooring transect	CTD, DO, CDOM, BBP, Fluorescence
Mission 2015_8	3rd quarter 2015	In between mooring transect	CTD, DO, CDOM, BBP, PAR[7], Fluorescence
Mission 2015_9	2nd quarter 2015, 21 days	Mooring mode	CTD, DO, Turbulence
Mission 2015_10	2nd quarter 2015	Mooring mode	CTD, DO, CDOM, BBP, Fluorescence, Nitrate
Mission 2015_11	3rd quarter 2015, 7 days	Mooring mode	CTD, DO, Turbulence
Mission 2015_12	3rd quarter 2015	Mooring mode	CTD, DO, CDOM, BBP, Fluorescence, Nitrate
Mission 2015_13	2nd quarter 2015, 21 days	Mooring mode	CTD, DO, Turbulence
Mission 2015_14	3rd quarter 2015, 8 days	Mooring mode	CTD, DO, Turbulence
Mission 2015_15	3rd quarter 2015	Mooring mode	CTD, DO, Fluorescence, CDOM
Mission 2015_17	2nd quarter 2015	Off-shelf transect	CTD, DO, CDOM, BBP, Fluorescence
Mission 2015_18	3rd quarter 2015	Off-shelf transect	CTD, DO, CDOM, BBP, Fluorescence
17 deployments	**618 days at sea**	**27 repeated transects over 100 km**	**CTD, DO, CDOM, BBP, Fluorescence, Turbulence, Nitrate, PAR**

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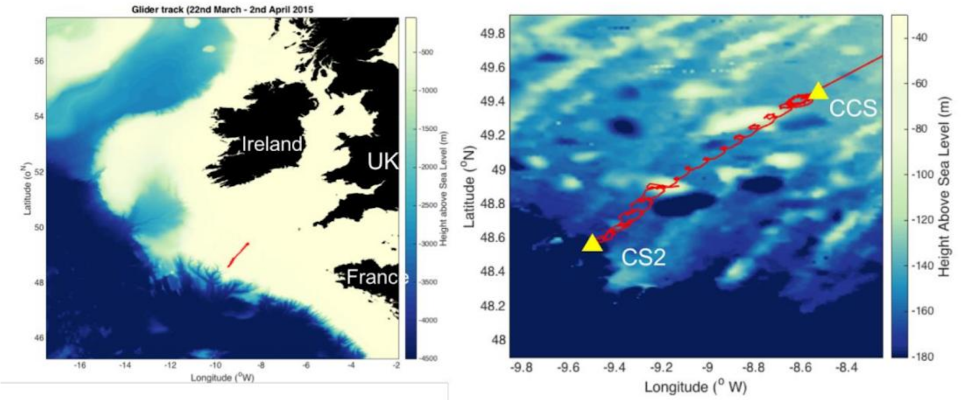
[7] PAR = Photosynthetically Active Radiation



NOC's multiple glider transects (red) between two moorings (yellow triangles) since the AtlantOS project started.

This section summarizes the AtlantOS D4.3 produced by Matthew Palmer from NERC (Natural Environment Research Council) that analyses sustained multi-glider deployments operated in the North Atlantic shelf across the Celtic seas. The analysis aims to deliver methods for the synoptic interpretation of all ocean variables over multiple timescales (Palmer et al., 2018).

Long-term, multiple vehicle deployments should test the capability of ocean gliders to provide a synoptic study of the physical and biogeochemical functioning in a temperate shelf sea with the aim of providing a framework for operational coastal oceanography that is transferable and can be used globally. 22 autonomous gliders were deployed over a 17-month period. D4.3 focuses on the on-shelf component of this operation, which includes a repeated 120 km long transect between the Atlantic shelf break and the inner shelf, and a series of short-term deployments of specialized gliders that provide additional parameters at fixed locations. The experiment was successful providing an extensive, high-resolution, multi-variable dataset that captures the key components of the seasonal cycle of stratification and associated biogeochemical responses (Palmer et al., 2018).

The deployment of specialized Ocean Microstructure Gliders (OMGs) that sample small-scale turbulence as well as Nutrient Sensor Enabled Gliders (NSEGs) that measure in situ nitrate concentrations were successful and highlight the capacity of gliders to open the scope of long-term autonomous measurement of biogeochemical processes (Palmer et al., 2018).

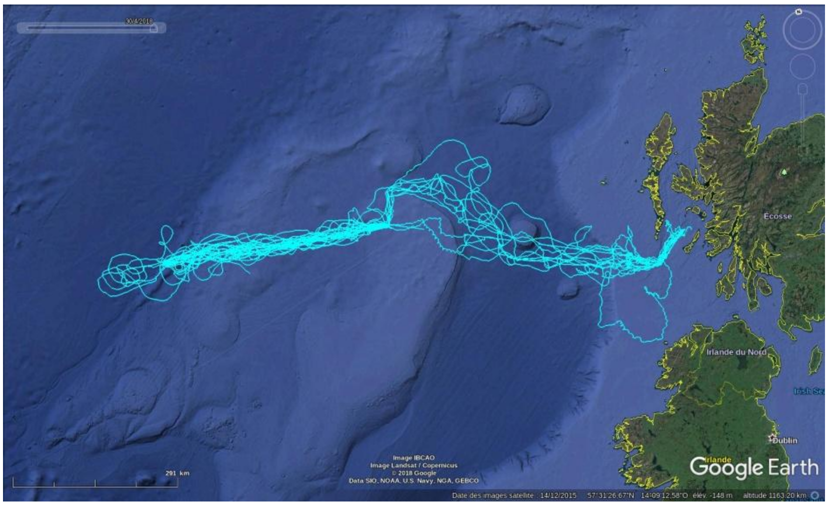
NOC: Interfacing coastal ocean observing systems with the GOOS

Gliders can complement existing sustained ocean observing systems (e.g. moorings) with new observations and sensors. Maintaining such efforts on the long term could certainly contribute to better connect coastal and open ocean observations.

2.1.5 SAMS

SAMS: Sustained endurance lines across boundary regions

Glider deployment	Deployment date	Description	Sensor payload
EEL #4	193 days from Feb 06 - Aug 18, 2015	Long-term monitoring	CTD, DO, Optical Sensor
OSNAP #3	137 days from Feb 06 - June 24, 2015	Long-term monitoring	CTD
FASTNEt Greenland	104 days from June 03 - Sep 14, 2015	Deep ocean to shelf exchange study	CTD, DO, Optical Sensor
OSNAP #4	175 days from June 08 - Dec 01, 2015	Long-term monitoring	CTD
EEL #5	107 days from Feb 11 - May 29, 2016	Long-term monitoring	CTD, DO, Optical Sensor
OSNAP #5	145 days from Feb 11 - July 05, 2016	Long-term monitoring	CTD
OSNAP #6	17 days from Aug 23 - Sep 09, 2016	Long-term monitoring	CTD
OSNAP #7	132 days from Oct 01 - Feb 10, 2017	Long-term monitoring	CTD
EEL #6	105 days from Feb 10 - May 26, 2017	Long-term monitoring	CTD, DO, Optical Sensor
OSNAP #8	144 days from Feb 10 - July 04, 2017	Long-term monitoring	CTD
OSNAP #9	177 days from May 21 - Nov 14, 2017	Long-term monitoring	CTD
OSNAP #10	167 days from Nov 14, 2017 - Apr 30, 2018	Long-term monitoring	CTD
OSNAP #11	166 days from Apr 30 - Oct 13, 2018	Long-term monitoring	CTD
COMPASS #1	67 days from Aug 13 - Oct 19, 2018	Combined coastal MPA surveys / cross-shelf transects	CTD, DO, Optical Sensor, PAM
14 deployments	**1836 days at sea**	**31 transects, total distance 22000 km**	**CTD, DO, Optical Sensor, PAM**



SAMS' deployments during the AtlantOS project.

North Atlantic endurance line to monitor eastern ocean circulation for climate and biogeochemical transport and biology

Extended Ellett Line

Flow in the eastern subpolar North Atlantic is an important component of the global thermohaline circulation and thus has an important role in regulating climate. Around 90 % of the upper ocean inflow to the Nordic Seas passes between Iceland and Scotland, whilst almost 50 % of the cold dense outflow returns through the same area. The Extended Ellett Line (EEL) is a standard hydrographic section between Scotland and Iceland designed to monitor these critical flows. It measures regularly nutrients, oxygen, temperature, and salinity. Furthermore, the annual cruises provide a platform for additional science as well as training for the next generation of marine scientists and engineers. Since research cruises are naturally biased towards the summer months when the weather in the region tends to be better, SAMS has been using autonomous gliders to sample along the EEL transect during the under-sampled autumn, winter and spring months. This provides valuable data to supplement that obtained from the annual cruises (SAMS, 2018b).

UK-OSNAP (Overturning in the Subpolar North Atlantic Programme)

The transport of heat and freshwater by the North Atlantic Subpolar Gyre greatly affects the climate of the North Atlantic and Europe through its impact on air temperature, precipitation and wind strength. It is highly significant to the region's marine ecosystems, the formation of hurricanes, and rainfall in places like the Sahel, the Amazon and parts of the USA. However the Subpolar Gyre is presently inadequately measured, and no ocean general circulation or climate model represents it accurately. UK-OSNAP will deliver enhanced understanding of processes critical to the improvement of physics in climate models through sustained observation of ocean circulation and fluxes together with modelling and analysis (UK-OSNAP, 2018).

UK-OSNAP is a partnership between SAMS, NOC, and the Universities of Oxford and Liverpool. The UK-OSNAP team is developing a new observing system and innovative modelling techniques to characterize the circulation and fluxes of the North Atlantic Subpolar Gyre. The first aim is a continuous record for four years (2014–2018) of full-depth, trans-basin mass, heat, and freshwater fluxes in the Subpolar Gyre. The second aim is to quantify and understand the response of circulation, and heat and freshwater fluxes to local (e.g. Greenland ice sheet melting) and remote forcing (e.g. Agulhas leakage), within the conceptual framework of the AMOC (UK-OSNAP, 2018).

UK-OSNAP is part of an international collaboration to establish a transoceanic observing system in the subpolar North Atlantic (the OSNAP array). International OSNAP is led by the USA and includes ten further partners in Canada, France, Germany, the Netherlands and China. SAMS is responsible for maintaining the Rockall Trough array of moorings, as well as the continuous monitoring of the Hatton-Rockall Plateau with autonomous gliders (UK-OSNAP, 2018).

FASTNEt (Fluxes Across Sloping Topography of the North-East Atlantic)

The FASTNEt consortium was funded to deliver NERC's Ocean Shelf-Edge Exchange programme. Commencing in October 2011, this four-year study combined traditional observing techniques such as moorings and CTDs with autonomous ocean gliders. The FASTNEt observational data set spanned all four seasons to highlight any inter-annual variability in localised exchange processes (including eddying and internal tide transport) at varying ocean shelf edge environments. In addition to the ambitious use of autonomous platforms, FASTNEt also exploited the latest computer modelling capability to integrate the data and develop a new parameterisation of shelf edge exchange that is appropriate for regional scale modelling exercises. Three survey locations on the UK shelf edge have been selected for FASTNEt; the Celtic Sea, Malin and North Scotland shelves. Each location was selected for distinctive bathymetric and oceanographic regimes known for influencing the shelf edge exchange. A fourth site was selected on the other side of the basin off the Greenland coast and surveyed by a glider in 2015 (BODC, 2016).

COMPASS (Collaborative Oceanography and Monitoring for Protected Areas and Species)
The COMPASS project is a 5-year project, which will establish a network of oceanographic and acoustic moorings, ship-based measurements, and glider surveys within and adjacent to cross-border marine protected areas (MPAs). Glider missions will also include cross-shelf transects into the North-Eastern Atlantic on an opportunistic basis. These measurements will produce new marine monitoring data for emerging areas of environmental concern including ocean acidification and the long-term impacts of anthropogenic noise on marine life. It will also help fulfill international, European and national biodiversity obligations. Additionally, COMPASS will deliver a clearer understanding of what changes in the oceanographic climate have on underwater habitats, fauna and flora across the region. The project will also develop an innovative acoustic tag programme to understand the migration patterns, the behaviour and mortality of salmon and sea trout in the North Western part of the Irish Sea. The interregional perspective will allow data to be captured and shared across Northern Ireland, the Border Region of Ireland and Western Scotland and help in the development of effective future monitoring programs for MPAs (SAMS, 2018a).

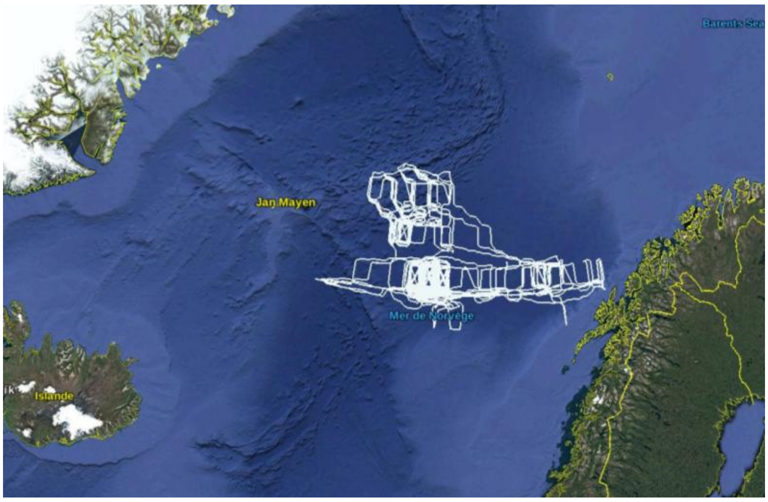
SAMS: Multipurpose benefits of long-term monitoring of boundary regions with gliders
SAMS' glider projects are maintained in the long-term to monitor different scientific biogeochemical processes. Several scientific publications demonstrate that observations in the Northern Atlantic boundary region lead to an increase in reliability when continuous glider observations are combined with other observing platforms over the long-term.

2.1.6 UiB

UiB: Sustained endurance lines across the boundary region

Glider deployment	Deployment date
AGF311_811_2016	9 days from Nov 09 - Nov 18, 2016
RETROSPECT_Lofoten_2016	61 days from May 04 - July 04, 2016
NACO_Lofoten_2014_2	211 days from Dec 18, 2014 - July 18, 2015
Provolo_MohnRidge_1	218 days from June 09, 2016 - Jan 13, 2017

IcelandSea_1516	19 days from Aug 17 - Sep 05, 2015
Provolo_LofotenBassin	253 days from May 04, 2016 - Jan 13, 2017
IcelandSea_1516	21 days from Aug 15 - Sep 05, 2015
NACO_Lofoten_2014_3	211 days from Dec 18, 2014 - July 18, 2015
Provolo_MohnRidge_2	240 days from Jan 13 - Sep 12, 2017
Provolo_LofotenBassin_2	161 days from Jan 13 - July 24, 2017
20170907_1	70 days from Sep 07 - Nov 16, 2017
20170907_2	25 days from Sep 07 - Oct 02, 2017
12 deployments	**1299 days at sea**



UiB glider deployments (white) during the AtlantOS project.

The warm and salty Atlantic water is an important component of the ocean conveyor belt transporting heat from the equator to the pole. Substantial transformations of this water mass occur along its poleward transit across the Nordic Seas. The transformed waters, in response to winter cooling from the atmosphere, become denser and can be tracked by following the properties of seawater along surfaces of the same density. The Lofoten Basin is a region, where warm and salty Atlantic Water accumulates within a 500-m-thick layer. Intense atmospheric cooling in winter is able to mix Atlantic Water all the way down to 500 m, thus playing a crucial role in its transformation. The area west of Bear Island also plays an important role in this process. The transformed Atlantic Water has a vertical structure allowing for slow diffusive processes to occur farther downstream in the Arctic. The Atlantic water properties at the entrance of the Nordic Seas are correlated with the Lofoten Basin and further north toward the Arctic with a lag of 1 to 1.5 years (Bosse et al., 2018).

UiB: Endurance lines to monitor long-term hydrodynamic changes
Gliders are used in boundary regions to monitor long-term variations of water masses. The maintenance of endurance lines in such areas gives access to oceanographic data at a high spatial and temporal resolution to better understand the regional dynamics and inter-annual variability of key oceanographic processes.

2.2 Fishery and gliders in boundary regions

The relationship between biological production (including fish) and its oceanic environment has been studied since the development of a profitable fish industry in the 1930ies (Radovich, 1982) and the development of modern oceanography (McErlean et al., 1973). Considering an increasing number of people relying on marine resources for food and economic prosperity, it becomes critical to better understand the physical, biogeochemical and biological ocean processes. Assessing fish distribution, the development of larvae, and the growth of pelagic juveniles in boundary regions are some examples of biological parameters that can be monitored by using glider measurements.

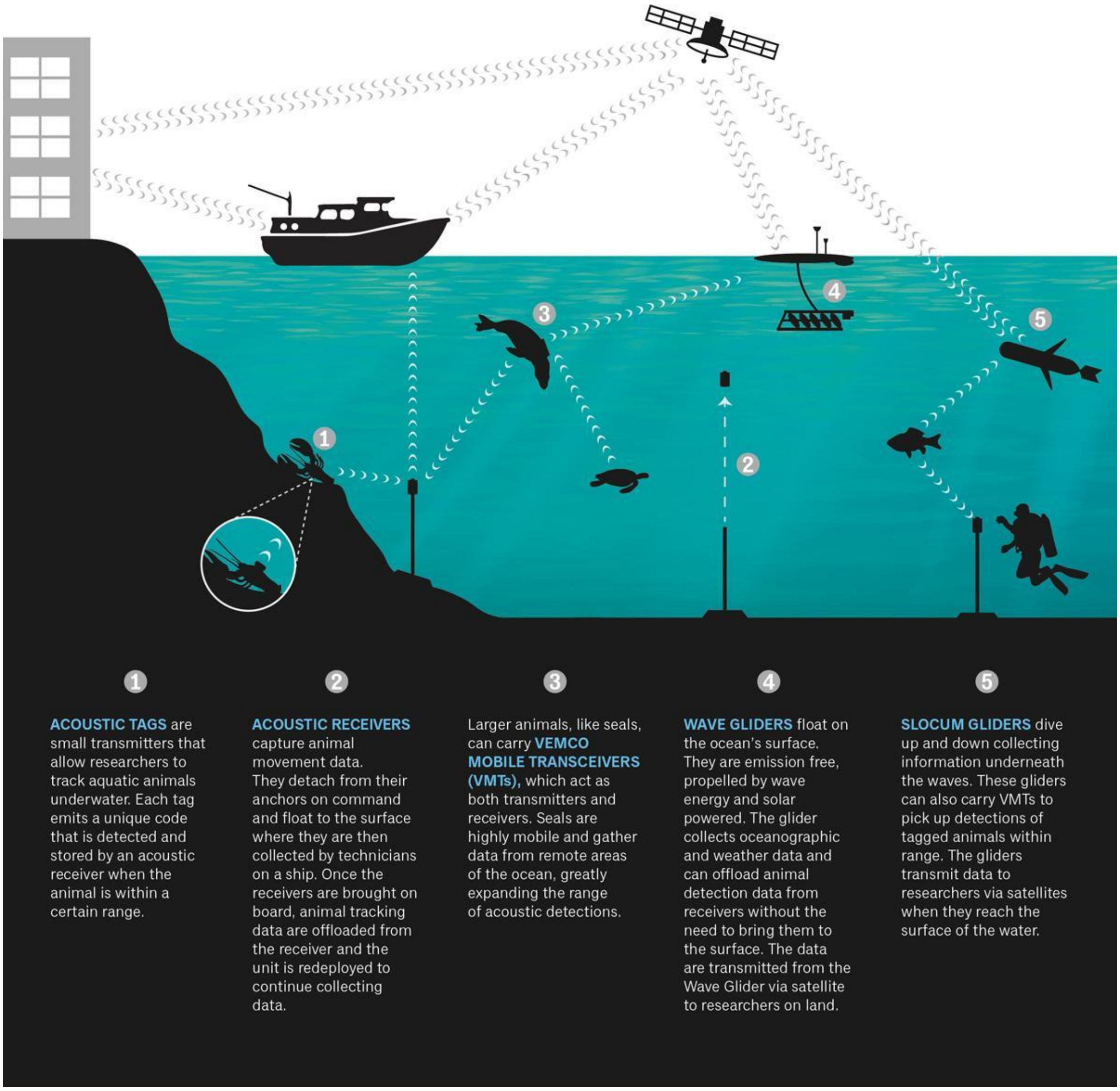
The development of new monitoring technologies allows a more accurate understanding of the physical, biogeochemical and biological ocean processes. For example, the impacts of small-scale dynamics and seasonal ocean variability on the biological productivity in boundary regions represent a major research field within the Atlantic community (Vikebø et al., 2005, Porter et al., 2016). The importance of gliders in observing and assessing ocean processes has matured in the last decades.

In the following, we will try to demonstrate how gliders currently contribute to the development of biological assessments of fisheries in the Eastern Atlantic boundary region. We will review recent projects and programs related to fisheries and gliders. We will also draw attention to the needs of developing countries located at the West African coast to access glider technology in order to pave the way for a sustainable use of their marine resources.

2.2.1 Use cases of glider surveys connected with fishery

Use case 1: The glider program of the Ocean Tracking Network (OTN)
The Ocean Tracking Network (OTN) is developing a global infrastructure to collect comprehensive data on sea animals in relation to the ocean's changing physical properties. A wide range of aquatic species (e.g. salmon, tuna, whales, sharks, penguins, crabs, and seals) will be tagged with small electronic transmitters that are surgically implanted or attached externally, and can operate for up to 20 years. Acoustic receivers will be arranged 800 m apart in invisible "listening lines" at strategic locations along the sea floor in 14 ocean regions off all seven continents. These receivers will pick up coded acoustic signals identifying each tagged sea creature that passes within half a kilometre. As a tagged animal swims over a line, it is recorded. The data are subsequently uploaded to a central database resulting in current and reliable global records that can be analyzed and applied to many different environmental research efforts (OTN, 2018).

The OTN deploys two gliders (OTN200 and OTN201) continuously along the Halifax Line, running from Chebucto Head (Nova Scotia, Canada) to approximately 250 km offshore. Others are deployed in the Gulf of St. Lawrence and Cabot Strait regions. Their mission is to provide oceanographic context for the animal tagging and monitoring efforts of the OTN. Data from the gliders will provide foundations for models of ocean dynamics that will be related directly to the activities of tracked species (OTN, 2018).



① **ACOUSTIC TAGS** are small transmitters that allow researchers to track aquatic animals underwater. Each tag emits a unique code that is detected and stored by an acoustic receiver when the animal is within a certain range.

② **ACOUSTIC RECEIVERS** capture animal movement data. They detach from their anchors on command and float to the surface where they are then collected by technicians on a ship. Once the receivers are brought on board, animal tracking data are offloaded from the receiver and the unit is redeployed to continue collecting data.

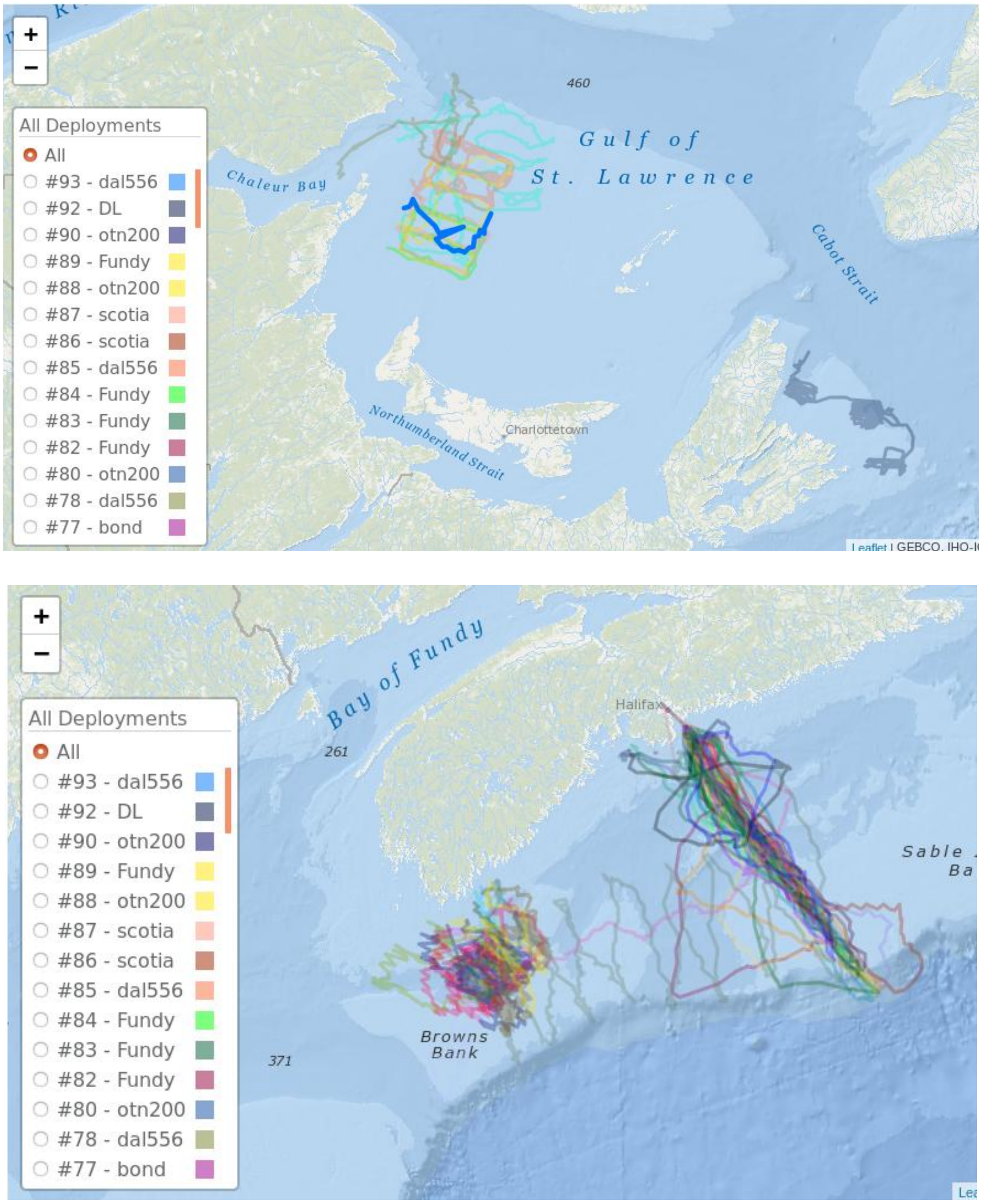
③ Larger animals, like seals, can carry **VEMCO MOBILE TRANSCEIVERS (VMTs),** which act as both transmitters and receivers. Seals are highly mobile and gather data from remote areas of the ocean, greatly expanding the range of acoustic detections.

④ **WAVE GLIDERS** float on the ocean's surface. They are emission free, propelled by wave energy and solar powered. The glider collects oceanographic and weather data and can offload animal detection data from receivers without the need to bring them to the surface. The data are transmitted from the Wave Glider via satellite to researchers on land.

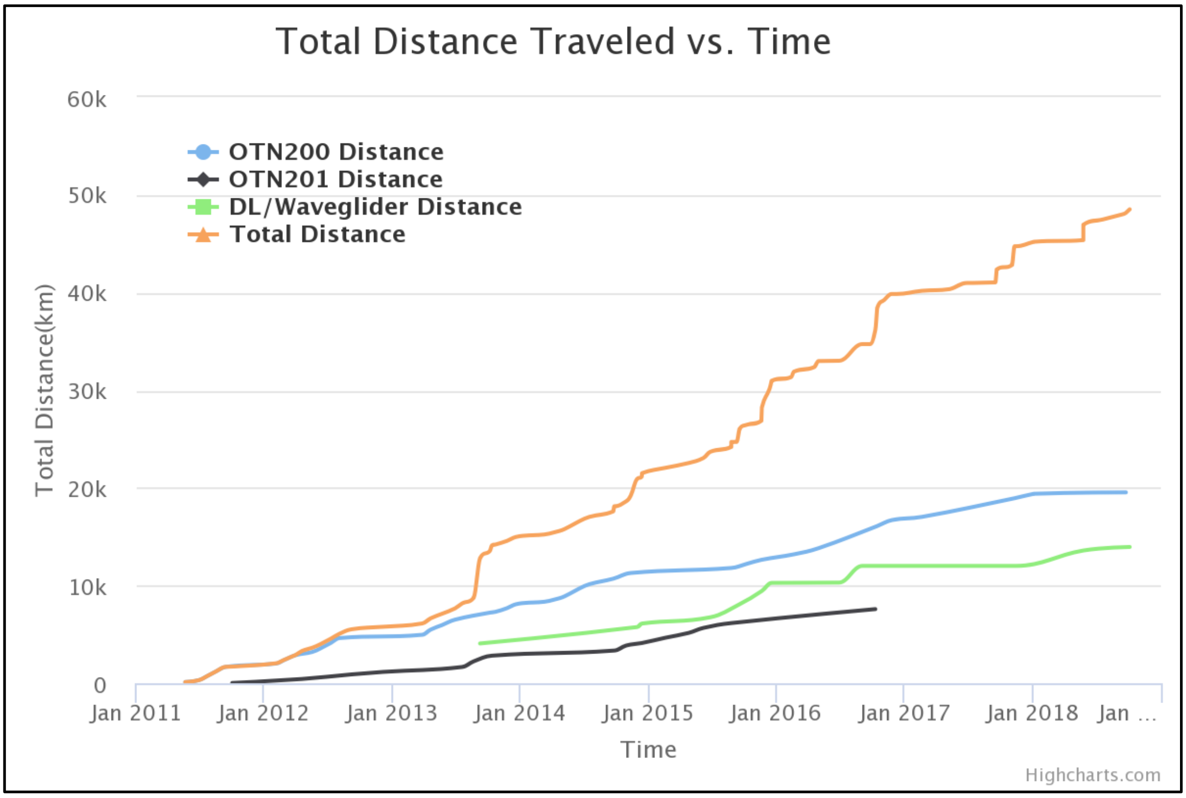
⑤ **SLOCUM GLIDERS** dive up and down collecting information underneath the waves. These gliders can also carry VMTs to pick up detections of tagged animals within range. The gliders transmit data to researchers via satellites when they reach the surface of the water.

OTN's data collection methods (source: OTN, 2018).

The image below summarizes the OTN glider activities and demonstrates the capability of gliders to contribute to advanced environmental research efforts and fisheries assessment.



Tracks of glider missions supported by OTN (source: OTN website)



Monitoring index of OTN glider missions (including wave gliders) since 2012 (source: OTN website)

Since 2011, OTN gliders have completed 75 missions, travelling over 46617 km (630 km per mission on average) in the same three regions of the western coast of the north Atlantic and in the Gulf of Saint Laurent. Currently, three gliders are deployed.

Use case 2: The Norwegian development of wildlife monitoring with gliders

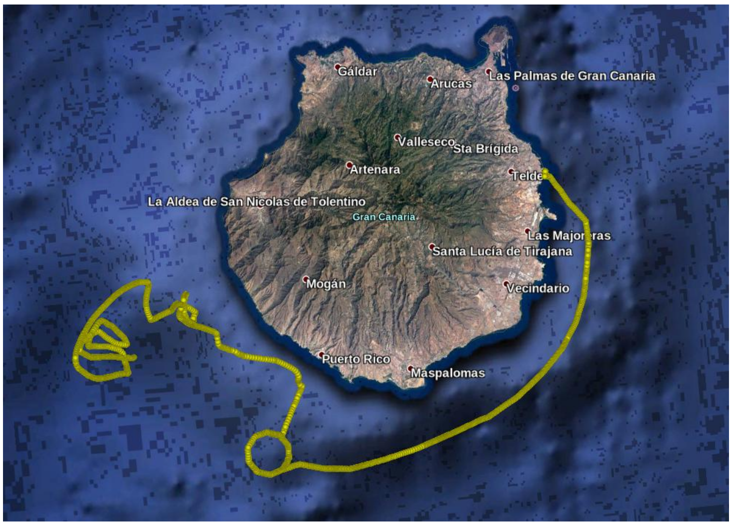
In the context of increased industrial activity in the Arctic, much attention is given to the potential effects on ecosystems considered sensitive. Among these areas we find the Lofoten-Vesterålen islands on the Norwegian continental shelf, known for their highly productive fisheries and tourism industry, and the North East part of the Barents Sea which is close to the productive polar front and the ice edge. As exploration licenses have been awarded in these areas, there is a demand from Norwegian authorities for a thorough characterization of these ecosystems and for data for environmental risk and impact assessment, impact prediction models, net environmental benefit analysis and finally for biomonitoring throughout the lifetime of industry projects (Liquid Robotics, 2018).

The primary objective of the “GLIDER Unmanned Ocean Exploration – Advancing Knowledge of Arctic Marine Ecosystems” project, managed by Akvaplan-niva, is to demonstrate a cost-effective observation program for real-time and long-term integrated environmental monitoring in sensitive areas over a large spatial scale. Included in this is the goal of increasing the amount of high quality ocean data and facilitating more flexible sampling methods compared to traditional concepts (Liquid Robotics, 2018).

The operation of three autonomous gliders that were deployed at the coast west of Bodø (Norway) in the beginning of March 2018 has been a success. The aim of this mission is to collect environmental data that can increase our knowledge about the marine ecosystem during the spawning season of the Atlantic cod. Some of the data have been received in real time via satellite (temperature, oxygen, salinity, chlorophyll a, turbidity) whilst echo sounder and hydrophone data are stored on the gliders. The sensors on the vehicles have been calibrated and a data portal has been developed to visualize data in real time as well as to perform data quality control (Dahle, 2018)

Use case 3: Hydrophon test by PLOCAN

The Macaronesia Inter-Regional and Multi-Disciplinary Network of Knowledge and Technological Transfer (MARCET) protects and monitors cetaceans while analyzing associated tourist activities. The project brings together public and private agencies from the Azores, Madeira, Senegal, Cape Verde and Canaries. The operational trial, co-ordinated by PLOCAN (with the collaboration of other institutes and local companies) aims to assess the scientific-technical and socio-economic feasibility of the use of new autonomous observation technologies specifically designed for monitoring cetaceans. PLOCAN's fleet of autonomous gliders and its array of meteorological and oceanographic sensors includes a system of passive hydrophones (PAM) aimed at picking up acoustic traces of cetaceans in the south of Gran Canaria (Spain). The Macaronesia research network spans several stakeholders involved in studying marine mammals in the region of Macaronesia. Transferring knowledge plays a key component within the newly established network (PLOCAN, 2018).



Track of the hydrophone (PAM) test at PLOCAN (yellow).

2.2.2 Case study: Promoting the use of gliders in Nigeria

In the following, an exemplary pilot study of deploying gliders in the Gulf of Guinea under the umbrella of transnational collaboration between European and African partners will be presented. The pilot study was part of a proposal for transnational access to coastal observatories. Even though the proposal was not accepted and thus the study has not been conducted yet, it demonstrates how gliders can be used for monitoring EOVs as well as sustaining food security in West African coastal nations.

The main objective of this study is to monitor the dynamics of EOVs in the Gulf of Guinea by using gliders. Additionally, the coupling between coastal ocean circulation and the biological response should be assessed. Also, sustainable management strategies based on investigations concerning the fish stocks should be initiated to enhance food security in the region. Beyond that, international collaboration between African and European researchers will be promoted.

The Gulf of Guinea is a very dynamic and complex system, where the linkages with its biodiversity and ecosystems are still poorly understood. As part of the eastern tropical Atlantic Ocean off the western African coast the Gulf of Guinea is characterized by coastal upwelling, warm tropical waters and an abundance of light that promotes the growth of plankton. This in turn provides a crucial source of food to many large aquatic organisms, such as fish. Fishing in turn generates income for the local population and therefore, estimating the exploitation of fish stocks and sustaining them in this area is of immense importance for the socioeconomic development of the West African countries along the Gulf of Guinea.

Nigeria, for example, is experiencing the challenges of food scarcity. Marine fisheries are found to play an important role in providing food, employment and income. Management of the fish stock is key for a sustainable development within this region. Filling the existing gap of ocean data has already been identified as a strong need for environmental decision making in Nigeria. At present, the country's oceanographic data is collected conventionally during ship cruises. Since this is very cost- and personnel-intensive, the coverage of oceanographic data is underrepresented. Using gliders instead of ships will significantly increase the number of data available.

This project will provide the first pilot study for a sustained long-term observing program to better support the understanding of the physical and biological dynamics in the Gulf of Guinea and provide advanced information for environmental issues related to fisheries. The success of this project therefore has the potential to secure future jobs and to develop alternative livelihoods for the young and unemployed population of the West African countries along the gulf. Besides creating a strong link with industry, the project will also provide the next steps for advancing research and building future partnerships between African and European partners.

Behind this call for transnational access there is a strong demand from ocean scientists in Nigeria to access coastal ocean data. The gap in data acquisition and data access in developing countries, in particular in ocean boundary regions, where the anthropogenic pressure is increasing, has been highlighted by the AtlantOS D1.3 "Capacities and gap analysis" (Buch et al. 2017). Gliders should be seen as key observing systems to fill that gap in the future.

3. Gliders to connect open ocean and coastal observatories: Linkage with WP4

The WP4 “Interfaces with coastal ocean observing systems” aims to link ocean observing activities in AtlantOS with coastal ocean observing initiatives in Europe and across the wider Atlantic. The previous review in section 2 clearly demonstrates the important role gliders play in this respect. In consideration of an increasing number of inhabitants living along the Atlantic coast, Eastern Atlantic boundary regions are exposed to multiple threats. On the one hand, coastal ecosystems are endangered, since the exploitation rate will keep pace with increasing anthropogenic pressure. On the other hand, more people will depend on marine resources. The need for sustaining ocean observing in these regions needs to become a priority to better understand its oceanographical functioning and contribute to improve marine resources management. In addition, as a part of the ocean conveyor belt, that transports heat from the equator to the pole, eastern boundary regions are often characterized by poleward currents. Long-term monitoring of the evolution of such a region will contribute to the understanding of global warming. These two examples explain why eastern boundaries are so important that the observational efforts need to be extended in a sustained way for ensuring ocean health, operational services and the understanding of climate processes.

At this point it should be referred to D4.3 and D4.5 of the AtlantOS WP4 that underline the potential of gliders to fill the observational gap between the open ocean and coastal seas while pointing out the associated difficulties:

- D4.3 “Synoptic multi-variable multi-glider study”: Analysis and report of sustained multi-glider deployments, providing detailed methodology of the deployment strategy, piloting, and calibration process. The analysis will deliver methods for the synoptic interpretation of all ocean variables over multiple timescales (Palmer et al., 2018).
- D4.5 “Gap analysis of links between coastal and open ocean networks”: Report setting out recommendations to re-plan and optimize current observational strategies for continental shelf observing networks; and improve their connection with wider ocean observing networks (Akpinar and Charria, 2018).

The D4.3 reports that NOC deployed gliders across the shelf in the Celtic Sea equipped with standard sensors (CTD, dissolved oxygen, optical backscattering) and less conventional sensors (photosynthetically active radiation (PAR), nitrate, turbulence) between two moorings in 2014 and 2015. This multi-platform experiment (involving gliders, moorings and oceanographic cruises) offered the possibility to access a valuable data set that enabled investigations of the physical and biogeochemical functioning of a typical shelf sea system in temperate latitudes. It was the first experiment of its kind that integrated multiple gliders with different configurations and objectives towards a common goal in a coordinated way over a longer period. The lessons learned are reported in the D4.3 (Palmer et al., 2018).

The D4.5 presents a gap analysis of the Atlantic Ocean observing system based on EOVs (e.g. temperature, salinity, oxygen, waves, sea level, and chlorophyll). The analysis is based on the Coriolis data set (www.coriolis.eu.org) which serves as the reference data set for the European Glider Community. D4.5 reports data made available during 2017 (Akpinar and Charria, 2018).

Two conclusions can be drawn from the approach underlying the D4.5. The first conclusion concerns the methodology for the gap analysis between coastal and open ocean data. As described in the D4.5, the distinction between the open and coastal ocean is made along the 200 m depth contour line. Gliders are designed to either navigate from 50 m to 1000 m depth (deep type) or from 15 m to 200 m depth (shallow type). These characteristics make gliders a unique tool for connecting the coastal and open ocean. Another factor can be found in the methodology used concerning the EOVs. The most common sensor payload of gliders consists of CTD, dissolved oxygen and optical backscattering covering three wavelengths. Gliders can also compute the average current during the dive from the surface to the bottom. The conventional payload and the capacity to retrieve information about currents cover five out of the seven EOVs used to assess the North Atlantic Ocean observation gap between coastal and open ocean data in 2017. This strategy demonstrates the relevance of gliders in enhancing the measurement of EOVs. The second conclusion can be derived from the low number of gliders considered in D4.5. It points out the critical need for a better data management system for glider deployments.

4. Conclusion and perspectives

This report provides a comprehensive overview of the observing efforts in Eastern Atlantic boundary regions achieved by the partners of Task 3.4 “Gliders” during the start of AtlantOS in 2015 until summer 2018. Overall, 4304 days of glider missions were conducted, equipped with a minimum sensor payload of CTD, dissolved oxygen and optical backscattering. This is equivalent to 12 years of continuous glider operation over the whole project and about three gliders on average that were dedicated at any time to the AtlantOS project.

The various underlying purposes combined with an increasing capability of gliders to integrate additional sensors (e.g. acoustic, nutrient, and microstructure) highlight the importance of using gliders in observing Eastern Atlantic boundaries. Their use becomes crucial in order to understand the physical, biogeochemical and biological ocean processes. Therefore, gliders equipped with multiple sensors are particularly suitable to be deployed for long-term high-resolution surveys.

In this report, we also point out the difficult task of connecting coastal and open ocean observing systems. Despite the obvious physical connection, a profound gap exists in the current observing continuum. The increasing number of coastal inhabitants inevitably leading to an increasing dependence on marine resources makes coastal observing a key element of the future GOOS. That gliders are able to fill observational gaps, also in combination with other observing platforms, is well documented in this report.

Furthermore, we analyzed recent glider surveys connected with fishery. This analysis emphasizes how the development of gliders may support the scientific monitoring and assessment of fisheries. In order to effectively protect fishery resources and enhance its sustainable exploitation, reliable data is needed that serves as a basis for developing an appropriate fisheries management that in turn is based on defined objectives. Gliders could carry out monitoring control and surveillance that are key instruments for a proper implementation of management rules. Having access to glider technology is of major importance for African coastal states, which the report has also referred to. The use of gliders in providing multi-purpose ocean data contributes to several benefits for eastern boundary regions, in particular filling observational gaps in South East Atlantic regions.

Underwater gliders should be considered as key platforms to support ocean observing in eastern boundary regions. Their capabilities make them a suitable tool for various observing purposes. The network of multi-platform observatories in the Atlantic eastern boundary region needs to be further developed. Ideally, such a network would benefit from a set of technical tools and the documentation of best practices regarding operation and data management. Here, a technical coordinator, who organizes and develops tools and documentation, brings stakeholder together and collect and shares the requests from the glider community, is highly desirable. Finally, following a long-term vision becomes inevitable in addressing the issues arisen in eastern boundary ocean observing and in targeting SDGs[8] 2 “Zero Hunger”, 13 “Climate Action” and 14 “Life Below Water” to protect marine and coastal ecosystems, regulate fishing and increase scientific knowledge.

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[8] United Nations, 2018b

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