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Stakeholder engagement relating to this task*

WHO are your most important stakeholders?	☑ National governmental body ☑ International organization ☑ NGO ☑ others Please give the name(s) of the stakeholder(s): A list of the key MS contact points responsible for national funding are held by EuroGOOS [Email: Erik Buch at erik.buch@eurogoos.eu]
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): All countries involved in the AtlantOS project.
Is this deliverable a success story? If yes, why? If not, why?	☑ Yes, because this was the first time a concerted effort was made to collect financial data on the Atlantic Ocean Observing Networks with significant input from network representatives including AtlantOS partners in WP2 & WP3 and the wider community. There was also collaboration with WP6 regarding the feasibility of new and emerging technologies. ☐ No
Will this deliverable be used? If yes, who will use it? If not, why will it not be used?	☑ Yes, the findings of this study will be presented to funding agencies from around the Atlantic at a workshop in early 2019. ☐ 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

The purpose of this report was to provide, for the first time, an initial overview of the estimated running costs of a selection of Ocean Observing Networks in the Atlantic. This financial data is required to assist funding agencies to make informed decisions on the allocation of future funding for ocean observations. The cost accounting data provided can be used to estimate the cost of filling gaps in the capacities of open ocean observing in the Atlantic. This data is a vital component of an advanced framework for an integrated Atlantic Ocean Observing System, as outlined in the vision of the AtlantOS project. Considerable effort was extended to ensure the financial information provided in this report is as accurate as possible. The methodology presented involved the collection of financial data on ocean observing activities with input from network representatives. Cooperation from the networks was very positive with significant input in terms of the information provided. Time constraints and budget inhibited an in-depth analysis of each network. The financial data presented in this report is therefore incomplete and gaps remain. However, the financial figures gathered provide an indication of the level of funding required to operate the observing networks outlined. From the analysis, the annual estimated total running cost of these existing networks is €35,922,392 plus 137.3 Full Time Equivalent staff (estimated average of €10,297,500). These figures on expenditure are conservative and for a number of the networks the financial figures are likely a gross underestimate. For example, the CPR costs were only available for activities in the northern hemisphere and for the Ship of Opportunity Programme only the cost to run the European FerryBox system was estimated. Similarly, the GO-SHIP costs only included lines surveyed that submitted open data and not the expected frequency of line occupation and the daily costs used were based on costs from the 2017 A02 GO-SHIP transatlantic survey. Research vessel hire is one of the most expensive components of ocean observations for many of the networks.

The **Main Conclusions** are:

- There is a requirement for more up-to-date and accurate data on the expenditure of ocean observing systems in the Atlantic.
- The observing networks investigated in this study are currently funded through a combination of national governmental and research project funds.
- All networks involved in the study have plans to upgrade and expand their present system and to address gaps in their capacities for ocean observations.
- Many of the networks investigated in this study are reliant on time-limited research funds since sustained funding is currently unavailable.

The **Key Recommendations** are to:

- **Establish a common cost accounting approach** to allow a more detailed analysis of the financial expenditure of the Atlantic Ocean observing networks.
- **Use the financial data gathered in this study to inform discussions** on sustained funding for Atlantic Ocean observing networks.
- **Provide the required (personnel and financial) resources to allow a more in-depth study** of all operating and delayed mode *In Situ* activities in the Atlantic.
- **Enable an international body, of repute in Ocean Observation, to lead and coordinate** the continuation of **annual reporting on the costs** (CAPEX and OPEX) to run the networks.

The development of a standardised cost accounting methodology would enable a more optimal allocation of resources and facilitate informed requests for financial assistance from funding authorities (Government, Research and Private funding sources). This would also help networks to plan upgrades to systems and determine the needed investment to fill identified gaps. This report is a first step to create a consistent cost accounting framework for ocean observing networks in the Atlantic. The methodologies employed in this study provide a starting point for the development a common methodology. This will help to strengthen the knowledge acquired in this study and prevent the potential duplication of effort in future studies.

Acronyms

Abbreviation	**Description**
Argo	Array for Real time Geostrophic Oceanography
ATN	Animal Telemetry Network
BGC	Biogeochemical
CAPEX	Capital Expenditure cost of non-consumable essentials (e.g. equipment)
CLIVAR	Climate and Ocean - Variability, Predictability, and Change
CMEMS	Copernicus Marine Environmental Marine Service
CPR	Continuous Plankton Recorder
DBCP	Data Buoy Cooperation Panel
EMODnet	European Marine Observation and Data Network
EMSO	European Multidisciplinary Seafloor and water column Observatory
EOOS	European Ocean Observing System
EOV(s)	Essential Ocean Variable(s)
EuroGOOS	European Global Ocean Observing System
FTE	Full Time Equivalent
GCOS	Global Climate Observing System
GEO-BON	Group on Earth Observations Biodiversity Observation Network
GOOS	Global Ocean Observing System
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Programme
GROOM	Gliders for Research Ocean Observation and Management
ICES	International Council for the Exploration of the Sea
IOC	International Oceanographic Commission
IOOS	Integrated Ocean Observing System
JCOMMOPS	Joint Commission for Oceanography and Marine Meteorology *In Situ* Observing Programmes Support Centre
OOI	Ocean Observatories Initiative
OPEX	Operating Expenditure (ongoing costs)
OTN	Ocean Tracking Network
PAP	Porcupine Abyssal Plain
PICES	North Pacific Marine Science Organisation
PIRATA	Prediction and Research Mooring Array in the Tropical Atlantic
POGO	Partnership for Observation of the Global Oceans
SCOR	Scientific Commission on Oceanic Research
SOOP	Ships Of Opportunity Programme
TMA	Transport Moored Arrays
WOCE	World Ocean Circulation Experiment

2. Introduction

2.1 Background

The numerous and varied open ocean observing platforms active today are an integral part of the Atlantic Ocean monitoring programme. These ship-based and autonomous platforms are organised into "Networks" (listed in Table 2.1). Networks collect data (e.g. on Essential Ocean Variables) to identify and monitor ocean phenomena at space-time resolutions and accuracies adequate for scientific research (e.g. to advance knowledge of oceanic processes) and to facilitate the operational needs of policy makers (e.g. ocean assessments and inventories) and marine sectors (shipping, offshore operations, tourism, fisheries management, etc.). This report seeks to estimate the cost of a number of networks in the present-day Atlantic Ocean Observing System, in order to help identify funding deficits. We also highlight and assess the readiness and feasibility of implementation of different observing technologies that can potentially enhance and improve Atlantic Ocean monitoring.

This report follows work done in AtlantOS D1.3 Capacities and Gap analysis (Buch *et al*. 2017). Deliverable 1.3 identified generic gaps existing in the current ocean observing system in the Atlantic. Further work in this area is required to provide a more accurate account of the specific technologies (sensors, samplers, platforms, etc.) needed by each network to fill the gaps in observation capabilities. Following this, the financial figures provided in this "Cost and feasibility" study can be used to help estimate the expected cost to fill these capacity gaps once they have been determined. Where possible, information is provided (mostly from the mature networks) on potential upgrades that would enhance Atlantic Ocean monitoring efforts.

Table 2.1 Atlantic Ocean Observing Networks examined in this study.

Ship Based **AtlantOS WP2**	**Autonomous Based** **AtlantOS WP3**
1. GO-SHIP Network - Global Ocean Ship based Hydrographic Investigations Programme [1]	4. Argo Network[1]
	5. OceanSITES Network[1]
	6. Glider Network
2. SOOP - Ships Of Opportunity Programme[1, 2]	7. Surface drifting buoy Network
3. CPR - The Continuous Plankton Recorder[2]	8. Ocean Tracking Network
	9. PIRATA - Prediction and Research Mooring Array in the Tropical Atlantic

[1] JCOMM *In Situ* Observations Programme Support Centre (JCOMMOPS) are involved in the operational coordination of research and observation activities. [2] SOOP and CPR include ship-based observations from merchant vessels.

2.2 Objectives

The objectives of this AtlantOS deliverable are to:

- Provide actionable information on the estimated current cost of a number of networks in the Atlantic Ocean Observing System.
- Provide information to help identify investment gaps (e.g. recommended upgrades) required to adequately monitor important Atlantic phenomena.
- Evaluate the feasibility of implementing different observing technologies to guide the observing system design.

2.3 Scope of the cost and feasibility study

- Produce a cost estimate report based on available information from existing Atlantic Open Ocean Observing Networks with a focus on AtlantOS ship-based (WP2) and autonomous (WP3) networks (i.e. the capital and operational costs of established networks).
- Focus on *In Situ* Atlantic Ocean Observing System activities - specifically related to data collection through to submission to international databases. The cost of data management and other costs (e.g. development of data products) along the Ocean Observing value chain are beyond the scope of this study.

- Produce an assessment of the technology readiness level (TRL) of emerging ocean observing technologies. This task was done in collaboration with AtlantOS WP6 (cross-cutting issues and emerging networks).
- Summarise the available estimated costs of ocean observing activities in Atlantic shelf seas, provided by other studies (e.g. reports produced on U.S. IOOS).

2.4 Purpose of the report

The purpose of this exercise was to estimate the cost of the present-day Atlantic Ocean Observing System, in order to highlight current running costs and help to identify funding deficits. In 2019, AtlantOS partners plan to present the findings of this report to European funders of Ocean Observing Systems, in particular to key contact points of member states responsible for national funding.

2.5 Region of interest

Figure 2.1 AtlantOS boundaries map redrawn from the JCOMMOPS operational centre for IOC-UNESCO and its WMO partner (https://twitter.com/jcommops/status/808307281045680128)

3. Cost Accounting Exercise

A standardised "one size fits all" methodology to describe the costs of each network was not identified for use in this study. However, the costs incurred by each "network platform type" were separated into a number of high-level categories. To allow transparent reporting and to assist future ocean observing cost studies, the steps followed to cost each Atlantic Ocean Observing Network are explained in detail in this report. Where possible, weblinks are provided to files where the calculated numbers are stored. Expertise and knowledge from the networks involved in this costing exercise were used to ensure the accounting inventories in the report were as detailed and recent as possible.

3.1 GO-SHIP Network

3.1.1 Background Information

The Global Ocean Ship-based Hydrographic Investigations Programme (GO-SHIP) is a global ship-based ocean observing network that collects high spatial (~ 30 nautical miles) and vertical resolution data related to physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems. GO-SHIP monitors the ocean/climate and contributes to the global efforts of the Global Climate Observing System (GCOS)/Global Ocean Observing System (GOOS) by providing international coordination of sustained decadal hydrographic sections (61 worldwide, including 16 core sections in the Atlantic Ocean). GO-SHIP provides approximately decadal resolution information related to heat, freshwater, carbon, oxygen, nutrients and transient tracers, covering the ocean basins from coast to coast and full depth (top to bottom), with water column and surface water measurements of the highest required accuracy to detect changes. Detailed information about the GO-SHIP network can be found on their webpage and Talley *et al.* (2016) demonstrate how the network has advanced our scientific understanding of the ocean. JCOMMOPS provides a focal point to GO-SHIP for coordination, implementation, monitoring, and assessment of the status of the programme.

There are 16 core GO-SHIP hydrographic sections in the Atlantic Ocean (AtlantOS domain, Figure 3.1, Table 3.1) that sustain measurements of GOOS Essential Ocean Variables. All GO-SHIP surveys must collect, at a minimum, all Level 1 parameters. This suite of core variables include at least two of Dissolved Inorganic Carbon (DIC), Total Alkalinity (TAlk) and/or pH, as well as CTD pressure, temperature, salinity (calculated), CTD oxygen (sensor), Bottle Salinity, Nutrients by standard auto analyser (NO3/NO2, PO4, SiO3), Dissolved Oxygen, Chlorofluorocarbons (CFC-11, -12, -113) and SF6, Surface underway system (T, S, pCO2), ADCP shipboard, ADCP lowered, Underway Navigation and Bathymetry and Meteorological data.

GO-SHIP is the only network that measures the full water column with the high accuracy measurements critical to monitor changes in the deep ocean (> 2,000m) of particular relevance to climate science (e.g. long-term changes in heat content and anthropogenic carbon sequestration). GO-SHIP provides a baseline to validate and quality control (QC) new sensors and also assists other networks with the deployment of their instruments. For example, GO-SHIP cooperates with and supports the Argo network by deploying floats and sharing its high quality water property measurements to QC and validate the physical and chemical data collected by Argo and BGC-Argo (Biogeochemical-Argo) floats. Data collected by GO-SHIP is open access and free, and contributes to International Scientific Assessments of basin scale and regional inventories on a decadal scale related to anthropogenic carbon, ocean acidification, nitrates, ventilation, dissolved oxygen, organic matter recycling etc. GO-SHIP lines are typically occupied once a decade at a minimum with some lines occupied more frequently, especially in areas with high variability in ocean phenomena (e.g. ocean ventilation or transport).

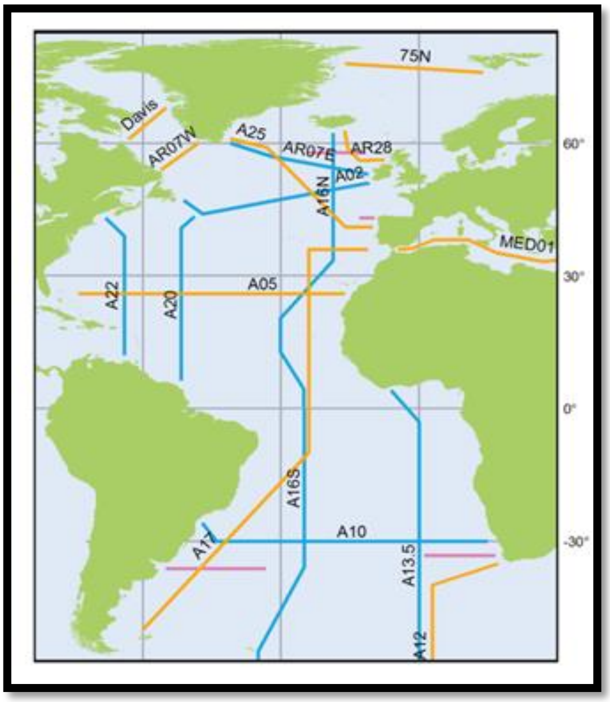

Figure 3.1 GO-SHIP lines in the Atlantic Ocean target region (AtlantOS) - planned missions for the decade 2012 to 2023. There are 16 core sections in the defined Atlantic boundary map. Where blue lines = Level 1 data requirements met at a decadal frequency; Orange lines = High frequency occupation (annually or biennial) with reduced data requirements and a Level 1 data requirements met at a minimum once a decade. Pink lines = associated lines with decadal or greater occupation and similar data requirements to GO-SHIP. Note: pink lines are not included in this cost accounting study.

Table 3.1 GO-SHIP line names in the Atlantic target region. See Figure 3.1 to view the geographic location of the Atlantic lines.

No.	GO-SHIP Line (code)	Historical Names, e.g. when line was part of WOCE, CLIVAR efforts
1*	Davis	Davis, Baffin Island to Greenland*
2*	75N	75N / GNS / CARINA line, Iceland – Greenland*
3	AR07E	A01E / AR07E, Greenland to Ireland
4	AR28	AR28, Scotland to Iceland (extended Elliot line)
5	AR07W	A01W / AR07W: 53°N, Labrador to Greenland
6	A02	A02 / AR19 (SFB-460): ~ 48°N, Ireland to St John's Bay
7	A05	A05: 24°N, this line is part of the UK RAPID programme
8	A10	A10 / A9.5 / A095 / A09 / A09.5: 30°S
9	A12	A12, Cape Town to the Antarctic continent along the prime meridian
10	A13.5	A13.5, 0°, Cape Town to Ghana
11	A16N	A16N: 20 – 25°W, Iceland to 5°S
12	A16S	A16S: 25 - 35°W, 5°S to 60°S
13	A17	A17 (FICARAM), Ushuaia – Cartagena (Spain)
14	A20	A20: 52°W
15	A22	A22: 66°W
16	A25	A25 (OVIDE), Iberian Peninsula – Greenland

*considered the Arctic region by GO-SHIP

3.1.2 Cost accounting methodology for GO-SHIP network

All GO-SHIP surveys collect Level 1 parameters. According to the GO-SHIP data policy, cruise data must be submitted to the Clivar & Carbon Hydrographic Data Office (CCHDO) data portal within six months upon completion of the survey. The CCHDO data portal was used to calculate the estimated costs of the current GO-SHIP network monitoring programme for the Atlantic AtlantOS domain. GO-SHIP data was extracted from CCHDO to get an estimate of costs over one decade. Search words used included "GO-SHIP", "Atlantic", CLIVAR", "IIOE", and "GEOSECS". Since the recent planned missions run from 2012 to 2023 in the Atlantic Ocean target region, the previous decade was analysed to ensure the community had time to upload data collected into the international CCHDO database; GO-SHIP surveys that neglected to submit data were considered void. Each survey track was checked manually to ensure only surveys carried out in the AtlantOS domain were used in this study. CCHDO Metadata was extracted in September 2017. All costs are linked to 2017 expenditures. The 2017 A02 survey was used to calculate the typical GO-SHIP survey costs (Level 1 parameters) and the person hours invested by the partner organisations since the A02 partners had the necessary data for this cost accounting exercise. Cost details and calculations can be found by clicking here.

Costs were simplified into three categories: start-up costs and maintenance; ship-based network costs and person hours.

(a) Start-up Costs and Maintenance [Capital Equipment & Annual Depreciation cost of equipment]

Capital Equipment identifies start-up costs (i.e. the purchase of all equipment costing > €1,000 needed for a GO-SHIP survey). In this study, the start-up cost was calculated to be €1,418,557, however most national oceanographic centres already have the necessary equipment in place and ready to use on Research Vessels that carry out the GO-SHIP network survey work.

Annual Capital Depreciation cost of equipment depends on the type of equipment and is based on either a five or fifteen-year depreciation model, with the life expectancy based on "expert" opinion and experience. A daily rate of €564 for Capital Depreciation Cost was used in this study.

(b) Ship-based Network Costs [Research Vessel hire, CTD Rosette Sensor Calibration Cost, Scientific Consumables and Other]

Research Vessel (RV) hire: The scientific RV hire daily rate was collected from RV operators and an average daily rate was used to estimate the ship time costs for each GO-SHIP cruise. Contacts around the Atlantic were approached by email to get the daily rate to hire a RV for deep ocean scientific surveys. Note: Information from all the participating GO-SHIP countries was not readily available for this study – it is recommended that missing daily RV hire rates are added in future cost accounting studies. The daily rate used is based on numbers received from operators in September 2017. **A daily rate of €25,052 for RV hire** was used in this study.

CTD Rosette Sensor Calibration Cost: An estimated Daily Calibration Cost for the CTD rosette sensor package (Temperature, Conductivity, Oxygen, Fluorometer, Turbidity Meter, Transmissometer, Thermosalinograph, shipping costs) was included in this study since many countries use their own CTD rosettes on GO-SHIP surveys. However, please note that calibration costs are included with RV hire in some countries such as Ireland. **A daily rate of €23 for CTD Rosette Sensor Calibration Cost** was used in this study.

Scientific Consumables: This refers to the cost of chemicals, tubing, bottles, etc. used on the survey. **A daily rate of €2,295 for Scientific Consumables Cost** was used in this study.

Other: all other costs incurred, including Van Rental, Courier & Carriage, Waste Removal, General Equipment <€1,000, Maintenance - Service Contracts, Carriage Inwards/Outwards, Import duty and VAT costs, Outsourced Work, T&S Domestic Subsistence, T&S Public Transport, T&S Foreign Flights, Expense Claims, T&S Foreign Subsistence and travel, T&S Misc. Costs, Training, protective clothing, Days at Sea Allowance, IT Consumables, Bank Charges, etc. **A daily rate of €4,012 for "OTHER" Costs** was used in this study.

(c) Personnel

Since the cost of personnel and salaries vary greatly from country to country and between scientific career grades, only Person Hours are reported. Person hours were calculated using information obtained from the 2017 A02 GO-SHIP cruise. Members of the A02 scientific team were asked to provide estimates of time spent preparing for the cruise. A total of **6,320 hours for pre-survey activities was calculated**. On completion of the survey, the team was also asked to provide an estimate of the time spent on data QC checks, sample reanalyses (QC check and sample analyses in delayed mode) and potential time writing up the results to disseminate findings to a variety of audiences. This amounted to **4,100 hours for post cruise activities.** Data Management and Data QC activities are taken account of in this section. However, post cruise time is likely underestimated as it is very difficult to quantify. The estimated number of person hours per day on-board the RV during the cruise includes the daily number of hours worked by the scientists on the survey. The salaries of the crew are included in the hire of the RV. The 2017 A02 expedition had only 18 scientists on-board with a total of 5,160 person work hours (**198 hours/day**) calculated - this accounts for 17 on-board scientists and 1 scientist on-land who carried out data QC. Since one of the 18 scientists on-board was subcontracted, their work time on-board was excluded from the person hour calculation to avoid a double accounting error.

Accounting Method used to calculate the ESTIMATED DECADAL COST from 2002 to 2011 in the AtlantOS domain

a) The JCOMMOPS GO-SHIP 2012-2022 decadal ship line map of planned surveys was used (Figure 3.1). The four associated lines with decadal or greater occupation and similar data requirements to GO-SHIP were not included in this cost accounting study.

b) The number of days for each cruise was calculated from available CCHDO metadata (the start and end dates of each completed survey were used).

c) The average RV hire daily rate was multiplied by the number of days for each cruise. This provided the estimated RV cost for each survey carried out in the AtlantOS domain from 2002 to 2011.

d) A daily rate for Capital Depreciation (equipment) cost was multiplied by the number of days for each cruise carried out in the AtlantOS domain from 2002 to 2011.

e) A daily rate for CTD Rosette Sensor Calibration costs was multiplied by the number of days for each cruise carried out in the AtlantOS domain from 2002 to 2011.

f) A combined daily rate calculated for Scientific Consumables & OTHER costs was multiplied by the number of days for each cruise carried out in the AtlantOS domain from 2002 to 2011.

g) Daily on-board Person Hours was multiplied by the number of days for each cruise carried out in the AtlantOS domain from 2002 to 2011. An estimated pre- and post- cruise person time was added to give the total estimated person hours per cruise.

Accounting Method to calculate the EXPECTED DECADAL COST in the AtlantOS domain

The JCOMMOPS GO-SHIP decadal ship-line map of planned surveys for the decade 2012-2022 was used to calculate the expected costs and followed a similar cost accounting methodology as above for the previous decade. However, the expected time in days to complete each planned line was calculated based on the average number of days for each line historically recorded in the CCHDO database.

3.1.3 Issues/Limitations

The results presented are a conservative estimate for the cost of the GO-SHIP network in the AtlantOS domain. There are many other hidden costs not covered. An example is the cost to operate on-land laboratories for pre- and post- QC parameter checks on methods used and confirmation of results. The calibration costs of specialised equipment on-land were not included in this study.

3.1.4 Estimation of current GO-SHIP network costs

Table 3.2 Estimated Costs for GO-SHIP lines completed from 2002 to 2011 in the Atlantic sector.

GO-SHIP line	Expected Frequency (no. years)	No. Surveys on Line (2002-2011)	CTD Sensor Calibration (€)	RV COST 2002-2011 (€)	COST of Scientific Consumables & OTHER (€)	Capital Depreciation (equipment) Cost (€)	Total person hours
1*	High (5-10)	0	-	-	-	-	-
2*	High (5-10)	3	1,399	1,528,171	384,681	34,379	43,366
3	Decadal (1)	1	596	651,352	163,963	14,653	15,580
4	High (5-10)	0	-	-	-		-
5	High (5-10)	14	6,971	7,615,804	1,917,100	171,332	206,212
6	Decadal (1)	2	1,192	1,302,703	327,925	29,307	31,160
7	High (5-10)	2	1,857	2,029,211	510,806	45,651	36,915
8	Decadal (1)	3	2,568	2,805,823	706,300	63,122	53,488
9	High (5-10)	4	5,687	6,212,893	1,563,950	139,771	90,898
10	Decadal (1)	1	527	515,108	145,044	12,963	14,985
11	Decadal (1)	2	2,064	2,254,679	567,563	50,723	38,702
12	Decadal (1)	3	2,201	2,404,991	605,400	54,105	50,312
13	High (5-10)	1	848	926,924	233,331	20,853	17,763
14	Decadal (1)	1	665	726,508	182,881	16,344	16,175
15	Decadal (1)	1	504	551,144	138,738	12,399	14,786
16	High (5-10)	0	-	-	-	-	-
		Estimated 2002-2011	€27,082	€29,525,310	€7,447,682	€665,603	630,343
		Total Decadal	**€37,665,678**		**Total Annual**	**€3,766,567**	

*considered the Arctic region by GO-SHIP; Note: Some lines only partially completed

Sponsorship contribution (Government, Research Project, Private)

The percentage contribution of funding from sponsors was estimated (based solely on the 2017 GO-SHIP A02 transatlantic survey cost) as:

- Government - 87 %
- Research - 13 %
- Private - 0 %

3.1.5 Estimation of future GO-SHIP network costs

The future GO-SHIP network costs are estimated using the current network costs and applying this to the future planned GO-SHIP lines.

Table 3.3 Expected Costs for GO-SHIP lines (maximum of 88 cruises) from 2012 to 2023 in the Atlantic sector; eight lines are High Frequency.

GO-SHIP line	No. Days **	Period 2002-2011: Max no. of expected surveys	CTD Sensor Calibration Cost (€)	RV COST 2002-2011 (€)	COST of Scientific Consumables & OTHER (€)	Capital Depreciation (equipment) Cost (€)	Total person hours
1*	29	10	6,650	7,265,077	1,828,813	163,442	161,754
2*	21	10	4,701	5,135,658	1,292,781	115,536	144,885
3	25	1	562	613,774	154,503	13,808	15,282
4	15	10	3,379	3,691,872	929,342	83,056	133,447
5	22	10	4,942	5,398,703	1,358,997	121,454	146,968
6	32	1	732	799,576	201,275	17,988	16,754
7	39	10	8,943	9,770,275	2,459,438	219,801	181,600
8	37	1	848	926,924	233,331	20,853	17,763
9	60	10	13,759	15,031,193	3,783,750	338,156	223,277
10	25	1	562	613,774	154,503	13,808	15,282
11	38	1	868	947,800	238,586	21,323	17,928
12	39	1	891	973,449	245,043	21,900	18,132
13	56	10	12,727	13,903,854	3,499,969	312,794	214,346
14	27	1	619	676,404	170,269	15,217	15,778
15	22	1	512	559,494	140,840	12,587	14,852
16	42	10	9,631	10,521,835	2,648,625	236,709	187,554
		Expected 2013-2023	€70,327	€76,829,661	€19,340,066	€1,728,431	1,525,604
		Total Decadal	**€97,968,484**		**Total Annual**	**€9,796,848**	

*considered the Arctic region by GO-SHIP

**Expected time to complete line (DAYS) based on average number of days in the database CCHDO for each survey documented

3.2 Ship of Opportunity Programme - European FerryBox

3.2.1 Background Information

The Ship of Opportunity Observing Programme (SOOP) facilitates the use of commercial ships, which routinely transit strategic shipping routes. Some routes have been frequently sampled for over 30 years. A cost estimate for the entire SOOP network is currently unavailable. However, an example of the cost of FerryBox observations in Europe is provided. The principal idea behind the FerryBox Observation System is to use ships of opportunity, like ferries on fixed routes, to make automatic measurements of important oceanographic parameters. These measurements are made in a flow-through system where different sensors are applied to continuously measure parameters like water temperature, salinity, turbidity as a measure of the amount of suspended matter, and fluorescence as a measure of the amount of microalgae. In comparison to other *In Situ* measurement systems, the reliability and data availability of FerryBoxes is higher and maintenance costs are significantly lower. FerryBox systems have reached a state of maturity and the number of measured parameters is still increasing with focus on more biogeochemical variables. The systems are extended with new sensors and analysers, e.g. microalgal composition, pH, carbon budget (pCO_2, alkalinity) and on some ferry routes nutrients such as phosphate, nitrate and silicate.

Long-term observations on fixed transects are a powerful mechanism to detect long-term trends in coastal and oceanographic waters. Furthermore, the continuous measurements, repeated along a certain transect within days or at higher frequencies, are also very helpful to detect short-term events (e.g. phytoplankton blooms, Harmful Algal Blooms, etc.) that could be missed by research cruises with limited ship time.

The FerryBox time series can be further used to validate and improve physical models and the increasing number of biogeochemical variables measured will be very useful for further development and improvement of ecosystem models. Real-time transmitted FerryBox data can assist in data assimilation efforts to support and enable better estimates in operational models. Furthermore, the high spatial and temporal frequency of data collected by FerryBox systems can provide real-time information for nearby aquaculture and fishing operations including early warning indicators, e.g. toxic algal blooms. With the introduction of new sensors to measure total alkalinity and pH, ocean acidification and the special behaviour of the coastal ocean as a highly dynamic component of the global carbon budget can be followed in detail. The diverse sources and sinks of carbon and their complex interactions in these waters are still poorly understood.

Most FerryBox systems in operation today, are equipped with automated water samplers that facilitate the regular collection of targeted water samples from key regions of interest for subsequent laboratory analyses. Early pilot studies have highlighted the feasibility for both target and non-target exploratory screening of trace contaminants. This type of targeted water sampling could assist with investigations of the steadily growing abundance of microplastics in the ocean, once suitable analytical techniques are agreed.

The first step toward a European system of FerryBoxes was taken during the EU-funded project "FerryBox" (2002-2005) focused on helping to optimise the use of these systems for automated measurements and water sampling on ships of opportunity, e.g. merchant vessels and ferries. The European FerryBox community has further increased cooperation through the establishment of a FerryBox Task Team under EuroGOOS (http://eurogoos.eu/ferrybox-task-team). Currently, FerryBox systems are installed on ships connected to a network of European FerryBox contributors of mainly national marine research institutes and environmental agencies.

Task Team members exchange open source tools, collaborate on areas of common interest, and jointly make collected European data openly available to the EuroGOOS Regional Operational Oceanographic system data portals across all European maritime regions, which in turn provide data to the European Marine Observation and Data Network (EMODnet) and Copernicus Environmental Marine Service (CMEMS) initiatives. Figure 3.2 below, from the FerryBox EuroGOOS task team, shows 17 FerryBox operational lines in the AtlantOS coverage area.

More information on FerryBox systems can be found by clicking here.

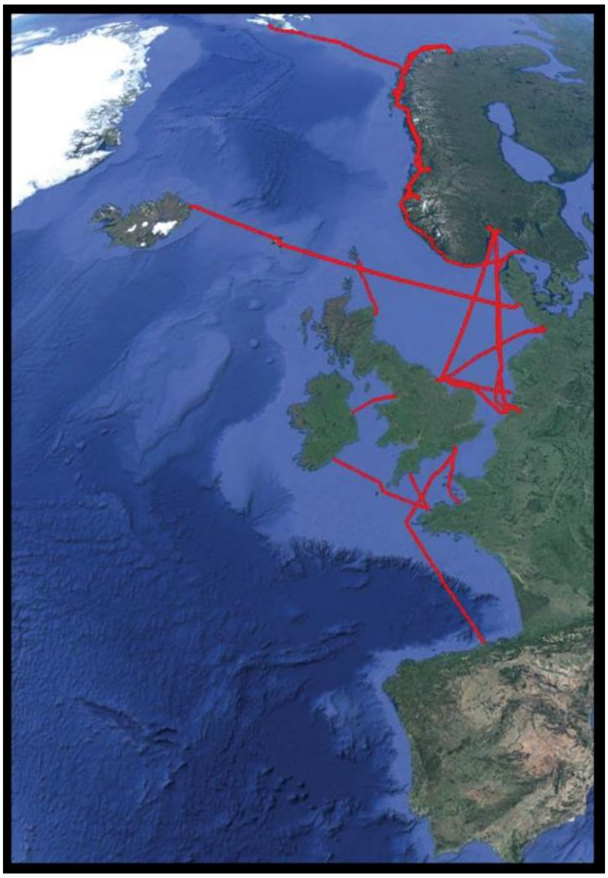

Figure 3.2 European FerryBox lines in the AtlantOS region (Source: EuroGOOS FerryBox Task Team: www.ferrybox.org/routes_data/routes/index.php.en).

3.2.2 Cost accounting methodology for FerryBox systems

FerryBox systems include either commercial systems or custom-made systems installed on ships of opportunity or research vessels. Costs for the FerryBox system were estimated using replies returned from questionnaires sent to project partners in the FP7 project JERICO (www.jerico-fp7.eu, see Greenwood *et al.* 2014; JERICO deliverable D4.5 for details). The initial investment required and the estimated cost to run a permanent FerryBox line was calculated using the JERICO results in combination with information provided by the FerryBox EuroGOOS Task Team. The initial investment to set-up a permanent FerryBox line is approximately €110,298 with an annual operating cost of €84,729. The operating cost is highly dependent on the institute managing the FerryBox. The total cost estimated for the AtlantOS area comes from multiplying the estimated cost per line by the total number of current operational lines.

3.2.3 Issues/Limitations

The yearly routine costs described above can vary quite widely, especially if one institute runs several FerryBox lines. As a result, the numbers presented are just an estimate of the overall cost. The estimated cost presented only includes European FerryBox lines and does not provide a cost estimate for the entire SOOP network.

3.2.4 Estimation of a single FerryBox line

3.2.4.1 Cost of initial investment per FerryBox

The average initial investment per FerryBox line is €110,298 (Table 3.4) although there is a wide range of investment options (determined by the type of sensors and instruments included). The cost of purchasing the system and other capital costs dominate the initial investment (Table 3.5).

The cost of initial investment for the entire European AtlantOS region (17 lines) is €1,875,066.

Table 3.4 Summary of initial investment and annual running costs per FerryBox system.

Expenditure Item	Average Initial Investment to set-up 1 X FB line* (€)	Average Routine Cost to run 1 X FB line (€)	Average Total Cost including emergencies to run 1 X FB line (€)
Investment per FerryBox line	110,298		
Operations per year- variable (data processing and storage, insurance, maintenance)		17,214	21,027
Operations per year-fixed (consumables, sensor repair, calibration)		19,937	19,937
Personnel costs		47,578	49,565
Total	**110,298**	**84,729**	**90,529**

*The length of a FerryBox line varies from approximately 100km to 1,000km

Table 3.5 A breakdown of the investment associated with running FerryBox systems.

Expenditure Item	Mean (€)
Purchase of FerryBox system (Frame, pipes, electrical wiring, sensor housings, valves, etc.)	53,365
Purchase of sensors	20,069
Purchase of FerryBox infrastructure (e.g. Pressure chamber)	4,166
Purchase of FerryBox equipment (e.g. tools, R&D, launch)	4,548
Purchase of safety equipment	125
Initial set up costs (Capital)	28,025
Total	**110,298**

3.2.4.2 Running costs related to Operations and Personnel

The average annual routine running cost is €84,729 and the average annual total cost (routine plus emergency) for operating a FerryBox system is €90,529 due to the additional variable and personnel costs associated with responding to emergencies (Table 3.4). An emergency cost refers to a contingency for unforeseen costs beyond the fixed and variable costs. An example of this is a sensor malfunction during an important observing period that needs to be repaired before the next scheduled maintenance. The amount spent on non-routine operations is much smaller for FerryBox systems than for fixed platforms. Personnel costs (€49,565) account for 55% of the total running costs with variable costs (€21,027) and fixed costs (€19,937) accounting for 23% and 22% respectively (Table 3.4). The personnel costs equate to an annual average of 125 days for total operations. Based on 225 working days per year, the personnel input is 0.56 FTE per line or 9.5 FTE for 17 lines in the AtlantOS region.

The yearly cost for operational expenditure to run the 17 lines in the AtlantOS region is €1,538,993.

3.2.5 Estimation of future FerryBox network costs

Future costs of the Atlantic FerryBox network would include the costs related to increasing the observational capacity of the existing network. This includes improving the sensor and sampler types currently in use by the FerryBox system to enhance Essential Ocean Variable knowledge, especially those relevant to Water Quality Directives, Ocean Climate Change studies and scientific research.

The following objectives are envisioned for the next 10 years:

- Some network funding is needed to keep the 17 lines in operation and to standardise the operating sensor package.

- Add 2-3 new lines in regions that lack coverage (e.g. the North Atlantic) using the same cost basis of establishment and annual maintenance.
- Add carbonate chemistry sensors to a minimum of ten (based on expert opinion) FerryBoxes to measure variables related to changes in ocean acidification (pH, pCO2, total alkalinity sensors) - establishment cost of ~ €30,000 per line an increase of the annual maintenance cost by ~ €3,000 per line.
- Add sensors and samplers to measure phytoplankton in order to monitor biodiversity, eutrophication and harmful algal bloom events (PSICAM, FRRF/PAM, nutrient analysers, flow cytobots) - ~ €100,000 per line to set up and an increase in the cost of annual maintenance by ~ €10,000 per year line with a minimum of five lines (based on expert opinion).
- Add sensors/samplers for microplastics and contaminants - ~ €50,000 per line and increase of the annual maintenance cost by ~ €4,000 with three to five lines suggested to begin a pilot study.
- Have a FerryBox system with relevant sensors that can be deployed quickly to a ship operating in a region of sudden need - oil spill, volcanic eruption, abnormal bloom conditions, etc. - €200,000.

3.3 Continuous Plankton Recorder

3.3.1 Background Information

The North Atlantic Continuous Plankton Recorder (CPR) survey, managed by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) in the UK, is a ship based ocean observing network that collects high temporal and spatial biological data related to planktonic organisms in surface waters. Data collected provides essential information on biodiversity and ecological changes in time and space. The North Atlantic CPR survey is a good example of a collaborative effort between scientists and industry, with shipping companies providing the platform, in-kind, to deploy the CPR scientific monitoring units along multiple routes. Today, a well-established biological time series exists in the region dating back to 1931. Twenty core CPR survey lines are operational in the N Atlantic Ocean.

Scientific data information products produced by the CPR network support improved scientific understanding of marine ecosystems and give policymakers information needed to monitor the effects of climate change, help identify the impacts of ecosystem change to fisheries (e.g. EU Common Fisheries Policy) and determine baselines and changes of healthy ecosystems (e.g. EU Marine Strategy Framework Directive). The societal drivers and pressures, and scientific questions addressed by the CPR network are listed and discussed in Edwards *et al.* 2017.

The CPR network produces scientific assessments and data that feed into several international bodies, including the International Council for the Exploration of the Sea (ICES), the North Pacific Marine Science Organisation (PICES), the Global Ocean Observing System (GOOS), the Group on Earth Observations Biodiversity Observation Network (GEO-BON), the International Oceanographic Commission (IOC), the Scientific Commission on Oceanic Research (SCOR) and the Partnership for Observation of the Global Oceans (POGO), and are relevant to the G7 Future of the Seas and Oceans Working Group.

In recent years, the CPR survey has expanded globally to include the South Atlantic and other ocean basins worldwide. For the purpose of this cost accounting exercise, the well-established N Atlantic programme was used to determine the estimated and future expected costs to run an efficient, enhanced and fit-for-purpose CPR monitoring programme in the N Atlantic. Results presented should help determine future resources needed in the whole Atlantic (e.g. S Atlantic and upgrades to the existing N Atlantic programme) to fill existing gaps and mature efforts in the region. Cost options to enhance and improve the existing N Atlantic CPR survey (e.g. the measurement of other essential ocean variables with state of the art technologies) are also presented.

More detailed information about the CPR network is available by clicking here.

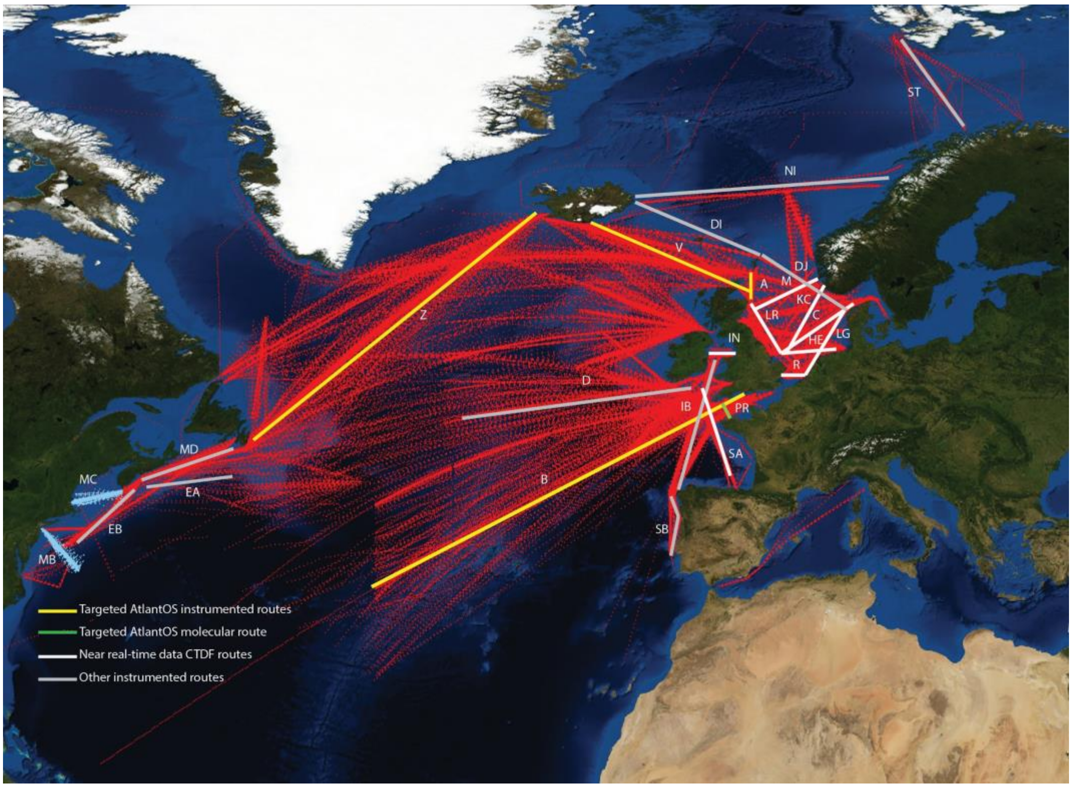

Figure 3.3 North Atlantic CPR survey lines. Where historic CPR routes = red lines, AtlantOS instrumented routes = yellow lines, AtlantOS molecular routes = green lines, near real-time data CTD fluorescence = white line and other CPR instrumented routes = grey lines. Note: letters listed in Table 3.6 below identify the CPR route. Map Source: AtlantOS plankton Report Deliverable 2.1 (Edwards *et al.* 2017).

3.3.2 Cost accounting methodology for CPR network

Accounting Method used to calculate the Existing annual COST in the N Atlantic

Note: a currency convertor dated 27th February 2018 was used to convert GBP values to Euros, where £ 1 = € 1.1323

a) The SAHFOS ship line map, in Figure 3.3, presents the current 20 CPR survey routes used to calculate existing operational costs. Standard operations in the N Atlantic coverage includes some instrumented routes (based on 2016 financial figures) with ~ 20,000km (~ 10,799nm) of coverage per month. All CPR surveys collect planktonic samples - a sample covers 10 nautical miles (18.5km) of the ship line. Temperature, salinity and fluorescence are measured on a number of ship lines. Water samples are collected on some lines and used for molecular studies.
b) A minimum of 20 CPR machine units and 36 internal mechanisms are required to run 20 CPR survey routes.
c) The set-up cost of a new route with a length of 500 nautical miles (~ 926km) is estimated at €34,592 (UK sterling £30,550).
d) Costs are presented by route and include staff costs, overheads, capital equipment depreciation cost. The staff costs cover the cost to analyse all biological samples on each route, collected on a monthly basis.
e) A five-year equipment depreciation model was used with an annual estimated cost of €120,477 (UK sterling £106,400).

3.3.3 Issues/Limitations

The results presented here are a conservative estimate for the cost of the CPR surveys in the North Atlantic. There are many other hidden costs not covered. An example is the cost to operate on-land laboratories (CPR microscopes, dissection microscopes, equipment to meet health and safety requirements, e.g. suitable fume hoods, calibration costs of equipment IT equipment - hardware and software to process tow and plankton information).

3.3.4 Estimation of current CPR network costs in the North Atlantic

Table 3.6 annual operational costs of standard CPR network routes in the N Atlantic.

Route Code	Expected No. Samples	Salaries €	Overheads €	Equipment Depreciation €	Annual Running Cost €	Total €
A	108	21,821	9,673		31,495	
AT	576	107,071	47,467		154,537	
B	306	289,905	128,521		418,426	
C	213	40,524	17,965		58,490	
D	258	85,386	37,853		123,240	
E	286	118,862	52,694		171,557	
HE	168	31,715	14,060		45,774	
IB	282	42,287	18,746		61,032	
IN	90	16,671	7,391		24,061	
KC	210	45,404	20,128		65,532	
LG	282	45,811	20,309		66,118	
LR	222	52,858	23,433		76,291	
M	156	29,817	13,218		43,035	
NI	384	63,565	28,180		91,745	
PR	96	22,092	9,793		31,886	
R	106	15,993	7,090		23,083	
ST	300	30,766	13,640		44,405	
V	276	53,807	23,853		77,660	
VJ	390	71,833	31,845		103,677	
Z	897	169,145	74,985		244,131	
TOTAL	**5,606**	**€1,355,331**	**€600,844**	**€120,477**	**€1,956,175**	**€2,076,652***

*This total is the sum of the Equipment Depreciation and the Annual Running Cost
Note: Routes are divided into 500 nautical mile segments with a maximum tow per internal mechanism. For example, B route is made up of 'BA' 'BB' 'BC' and BD but it is still the B route. Click here for detailed costing sheets.

Sponsorship contribution (Government, Research Project, Private)

Historically, the Sir Alister Hardy Foundation for Ocean Science running costs were covered by a private donor and an "in-kind" contribution of the deployment platforms was provided by the shipping industry. Today, financial support comes primarily from government and research projects (see UNESCO 2017 for a detailed breakdown). Presently, it is difficult to calculate the "in-kind" cost contribution from the private shipping sector. However, based on the GO-SHIP survey cost accounting exercise in this report, where ship-time accounts for approximately 78% of the total monetary cost to run a survey, the contribution from the shipping industry to the CPR monitoring programme is likely significant. Private contributions for the CPR are not accounted for in this report.

The percentage contribution of funding from sponsors was estimated as follows:

- Government - 35%
- Research - 65%
- Private - Unknown; this is likely very high as the shipping industry provides the CPR deployment platform.

It is important to note that the percentage estimates of sources of financial support are based solely on the CPR survey costs related to the unit, payload and sample analyses.

3.3.5 Estimation of future CPR network costs

A number of improvements and enhancements could be made to the existing N Atlantic CPR surveys that would add value to the existing observing system. Details on current options available are listed in Table 3.7 below. Some upgrade examples include the addition of nutrient sensors to the CPR unit to complement and enhance data collected by biogeochemical Argo floats (BCG–Argo) and the use of molecular biological methods to increase biodiversity resolution of samples examined. Upgrades to the existing N Atlantic network and filling gap areas monitored will allow a deeper understanding of ecoregions sensitive to environmental change and those considered as "hotspots". Examples of how to add value to the N Atlantic CPR surveys include:

- Biogeochemical sensors to link with BGC-Argo in key N Atlantic regions
- Additional sensors for ecoregions undergoing rapid climate change
- Molecular sensors used in areas of particular high biodiversity or used to act as early warning systems for the presence of HABS in aquaculture regions
- Nutrient sensors to pick up eutrophication in the southern North Sea

Table 3.7 Potential Future Costs required to upgrade the existing N Atlantic CPR monitoring programme. Detailed costs can be viewed by clicking here. The annual running cost will vary depending on the sensor payload chosen to include in the CPR units. New EcoRegions line costs presented below only relate to the standard measurements (i.e. they exclude new sensors related to molecular, BGC, pCO2, optics, etc.).

	Annual Running Cost			Start-up Cost	
	Existing Programme	New Eco Regions	Molecular Biology	New Sensors	New Sensors
Description	€	€	€	€	€
Existing CPR Routes					
20 x CPR route	1,956,175				
Annual depreciation	120,477				
Gap Areas (300 nm lines)					
Labrador Basin		154,537			34,592
Azores Current		154,537			34,592
Rockall Trough		154,537			34,592
Irminger Basin		154,537			34,592
Norwegian Sea		154,537			34,592
Barents Sea		154,537			34,592
Annual Depreciation		30,119			
Molecular (20 routes)					
Molecular biologists x 2 FTE			215,703		
Molecular Biology Consumables			1,132,300		
Sensor Upgrade Options					
(20 routes; includes 2 FTE)					
CTDF*				139,022	280,491
WaMS**				280,189	593,235
pCO2				302,699	484,921
BGC***				655,032	1,718,577
Optics****				61,391	985,164
Total	**2,076,652**	**957,344**	**1,348,003**	**1,438,332**	**4,269,938**

Where * = Conductivity, Temperature, Depth and Fluorescence; ** = Water and Molecular Sampler (WaMS): Independent Water Sampler for Flow Cytometry, Molecular & other analyses; *** = Full suite of Biochemical sensors replicating Argo/biological sensors; **** = Optical plankton sensors (for automated zooplankton analysis.

Figure 3.4 Infographic with a selection of recent technological advances on the type of sensors that can fit into the traditional CPR unit. Source: SAHFOS.

3.4 Argo Network

3.4.1 Background Information

The global Argo network is an array of approximately 4,000 floats that provide 140,000 temperature and salinity (T&S) profiles, as well as velocity measurements per year and are distributed over the global oceans at an average 3-degree spacing. Core Argo profiling floats cycle to a depth of 2,000m every 9-10 days with each float having a 4-5 year lifetime. Purchase and deployment of Argo floats is funded via a mix of national and EU funding programmes. In the AtlantOS domain, there are currently ~ 850 active Argo floats. This requires the deployment of between approximately 250 new floats each year, to maintain coverage in the AtlantOS region. Figure 3.5 below, from JCOMMOPS, shows the active Argo floats in the AtlantOS domain for January 2018.

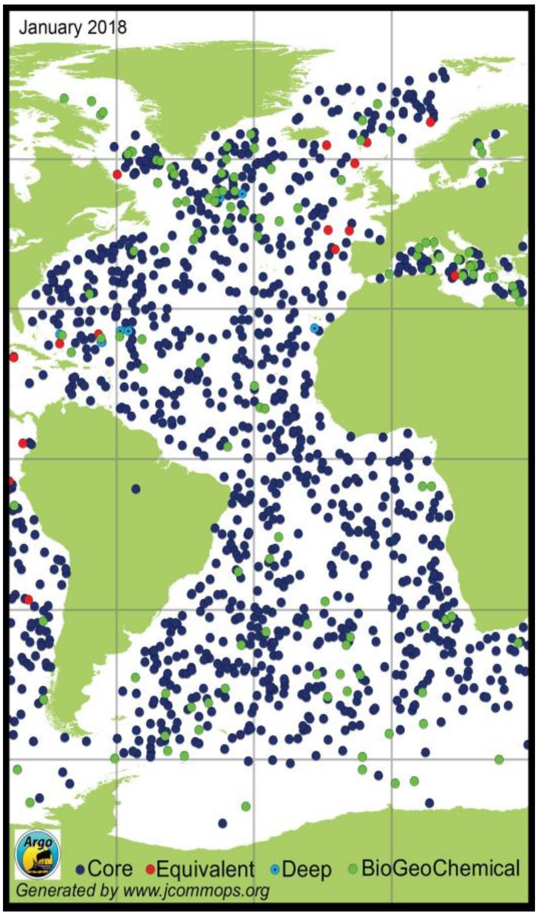

Figure 3.5 Active Argo floats in the Atlantic, January 2018. The colours of the dots represent the different Argo float and sensor types. Source: JCOMMOPS (www.jcommops.org).

3.4.2 Cost accounting methodology for Argo network

This section of the report aims to assess the cost of running the Argo network within the AtlantOS domain. This includes both capital expenditure (CAPEX), i.e. the cost of procuring an Argo float and operational expenditure (OPEX), i.e. the recurring costs associated with deploying an Argo float.

The average unit cost price of an Argo float was estimated based on the 2017 cost price of a float in each of the countries active in the AtlantOS domain. Three types of Argo float were considered for this study – a standard core Argo float, a biogeochemical float and a deep Argo float that has standard CTD sensors. The estimated cost of an Argo float was calculated in consultation with the Argo network contacts. Additional costs associated with deploying an Argo float were then added to this cost. The additional costs include transmission, calibration and logistics.

Available data on the number of Argo floats deployed in the AtlantOS domain for each year was obtained from the JCOMMOPS data portal. The portal provides information on the number of Argo floats deployed in any given year. There is a variance in the number of floats deployed each year, i.e. in 2012 there were 252 floats deployed whereas in 2016 there were 195 floats deployed, therefore a five-year period was used to calculate an average number of floats deployed. The most recent five-year period, for which deployment numbers were available, was used to calculate the average. The total number of Argo floats deployed within the AtlantOS domain from 1/1/2012 to 31/12/2016 was 1139. The average number of core Argo floats deployed annually between 2012 and 2016 was 229. The deployment of deep and BGC floats is relatively low in comparison to what is planned in terms of increased BGC float deployment over the coming years. For this report, the target numbers of deep and BGC floats was used. The target annual deployment numbers for deep and BGC Argo floats are, therefore, 35 and 38 respectively.

The estimated cost of each type of Argo float (plus the additional costs) was multiplied by the average number of Argo floats deployed annually by each country in the AtlantOS domain during the five-year period 2012 to 2016. This provides an estimate of the average annual cost to run the Argo network in the Atlantic. Cost details and calculations can be found by clicking here.

For the European Argo network, the sponsor finance contribution is approximately 25% from government funding (with a five-year commitment), 40% from research funding (with a five-year commitment) and 35% from shorter-term research projects. All deep and BGC floats are currently funded through research projects, but this is likely to change for future deployments.

3.4.3 Issues/Limitations

It should be noted that this is a conservative estimate for the cost of the Argo network in the AtlantOS domain. Furthermore, costs for personnel and research vessel hire are excluded in this estimate. The inclusion of these costs would add considerably to this financial figure.

3.4.4 Estimation of current Argo network costs

3.4.4.1 Cost of procurement for an Argo float

The cost to procure a core Argo float for a member country of the Euro Argo ERIC is €14,280. This price excludes Value Added Tax (VAT). In the US, the estimated average cost of procurement for a core Argo float is €17,500. Based on these financial figures, the average cost to purchase an Argo float within the AtlantOS domain is €15,890. This financial figure is only for a standard core (T&S) Argo float. The purchase cost of a biogeochemical (BGC) Argo float is estimated at €85,000 and an Arvor Deep Argo float, which can profile to a depth of 4,000m, is estimated at €30,000. The cost price for an Apex Deep Argo float, which can descend to a depth of 6,000m, is approximately €65,000. Note that in this study, only the Arvor Deep Argo float financial figure was used.

3.4.4.2 Additional costs

There are additional costs accumulated before an Argo float is ready for deployment and these costs were also estimated. The costs associated with the deployment of an Argo float includes assembly, testing, logistics, transmission and other overheads. The testing and calibration costs are estimated at €300 per sensor. The costs of logistics (including transport of the Argo float) are estimated at €500 per float. Transmission costs per float are €30 per month for core and deep Argo floats and €80 per month for BGC floats. Based on a four-year life expectancy for core Argo floats, the annual transmission costs were calculated as €1,440 per float for core and deep Argo floats. Based on a two-year life expectancy for a BGC float, the transmission costs were calculated as €1,920 per float. However, this depends on the sampling frequency of the sensors on the BGC float. Note that these financial figures are based on the deployment of large numbers of Argo floats and they may cost considerably more for countries that only deploy a small number of Argo floats. These costs are also likely to vary considerably among countries.

Table 3.8 Annual estimated cost of running the Argo network in the AtlantOS domain.

Description of costs	Core Argo float (€)	BGC Argo float (€)	Deep Argo float (€)	Total (€)
Argo float average purchase cost	15,890	85,000	30,000	
Transmission costs	1,440	1,920	1,440	
Testing/calibration costs	300	300	300	
Logistics and transport/shipment	400	600	400	
	18,030	87,820	32,140	
	No. Floats	**No. Floats**	**No. Floats**	
Average floats deployed in AtlantOS domain annually	229			
Annual target deployments		38	35	
Average Annual Cost of Argo floats Deployed (€)	**€4,128,870**	**€3,337,160**	**€1,124,900**	**€8,590,930**

3.4.4.3 Personnel

Personnel, in the form of coordination, data management (processing and quality control), project management and a technician are likely to form a significant part of the cost for running an Argo programme. The monetary cost in Euros of scientific or technical time is not included in this cost accounting exercise. Instead, time invested is included as Full Time Equivalent (FTE) and person months since salaries vary greatly from country to country as does the scientific career grade of the cruise participants.

Full Time Equivalent refers to the time worked by an individual on a full-time basis. FTE information was obtained from the 2016 Euro-Argo annual activity report and was used to calculate the person months. FTE in France includes coordination and management of Euro-Argo. This also includes an additional four FTE that are required for real time and delayed mode quality control of the BGC floats that is estimated for Europe. A spreadsheet, reproduced below in Table 3.9, was created to allow new updates of these time resource figures.

Table 3.9 Personnel input for the Euro Argo programme.

Country	FTE	Person months
Finland	0.21	2.5
France	13.83	166.0
Germany	2.50	30.0
Greece	0.42	5.0
Ireland	0.38	4.5
Italy	0.58	7.0
Netherlands	0.08	1.0
Norway	0.38	4.5
Poland	0.42	5.0
Spain	0.50	6.0
United Kingdom	3.33	40.0
Total	**22.63**	**271.5**

Note: Non-EU countries actively deploying floats in the Atlantic are missing from the table.

3.4.4.4 Research vessel hire

Additional overhead costs may include vessel hire, where applicable. For this assessment, the cost of vessel hire was excluded. For many Euro Argo members, Argo floats are often deployed by "piggybacking" (free of charge) on existing planned cruises via national Research Vessels (RVs), ships of opportunity, etc. Details of the daily chartered vessel hire cost was collected for some countries active in the AtlantOS domain and an average daily cost to hire a vessel was then calculated. Such chartered vessel costs should be added when applicable.

3.4.5 Estimation of future Argo network costs

To fulfil future scientific needs, the Argo community is developing an extension of the network towards high latitudes, biogeochemistry measurements, and greater depths. Considerable future investment is required to fulfil these needs. To estimate the future network expenditure, the cost of each type of Argo float (plus the additional costs) can be multiplied by the average expected number of floats deployed by each country annually within the AtlantOS domain.

3.5 OceanSITES Network

3.5.1 Background Information

The mission of OceanSITES is to collect, deliver and promote the use of high quality data from long-term, high-frequency observations at fixed locations in the open ocean. OceanSITES typically aim to collect physical, biogeochemical, and biology/ecosystem data worldwide in the open-ocean, full-depth water column as well as the overlying atmosphere and from the seafloor.

The OceanSITES network of stations or observatories measures many aspects of the ocean's surface and water column using, where possible, automated systems with advanced sensors and telecommunications systems, yielding high time resolution, often in real-time, while building a long temporal record. The sites serve multiple purposes and the scientific motivation for the observatories can be categorised into three groups (a site may be a composite of any of the three):

- Group 1: Air/Sea flux reference sites – these sites have complex surface buoys accompanied by upper ocean instrumentation and serve as calibration/validation sites, e.g. for satellite derived products. Notably the tropical moored arrays (PIRATA in the AtlantOS context, WP3) include Air/sea flux sites. (The cost to run the PIRATA network has been estimated separately in section 3.7. Where possible, these costs have not been included in the OceanSITES network cost estimate in order to avoid the inclusion of the cost to run these observatories twice). These sites are typically equipped with real-time data telemetry, which is globally coordinated by the DBCP JCOMM network. In addition, the Air/Sea flux sites in the Atlantic are the Porcupine Abyssal Plain (PAP) and the Ocean Observatories Initiative (OOI), Irminger Sea.
- Group 2: Transport Moored Arrays (TMA) – these sites are often comprised of an array of moorings that monitor the transport and, the physics, biogeochemical and ecosystem characteristics. The platforms have an ocean physics backbone that includes current sensors (profilers, single point) and T/S recorders. In AtlantOS WP3, Task 3.3, additional biogeochemical sensors (oxygen optode) were installed on nine platforms in the subpolar North Atlantic.
- Group 3: Global Ocean Watch – these sites aim for long time series of water properties across disciplines (physics, biology/ecosystem, biogeochemistry). The sites are equipped with an ocean physics backbone and, include additional sensors and samplers such as sediment traps, oxygen and pCO2 sensors, passive acoustics, optical properties.

One of the main drivers for time series is to provide both monitoring and process observations to detect, understand, and predict regional physical, biogeochemical and ecosystem state and changes, including ocean warming, ocean carbon uptake/storage and acidification. The role of and impact on ecosystems are also considered. The combination of the regional efforts creates a global network.

Figure 3.6, below, from JCOMMOPS shows the total number of OceanSITES observatories that are registered in the system for March 2018. Currently, the OceanSITES network is integrating the sites/platform metadata information into the JCOMMOPS system and the picture shown below is uncertain in respect to completeness.

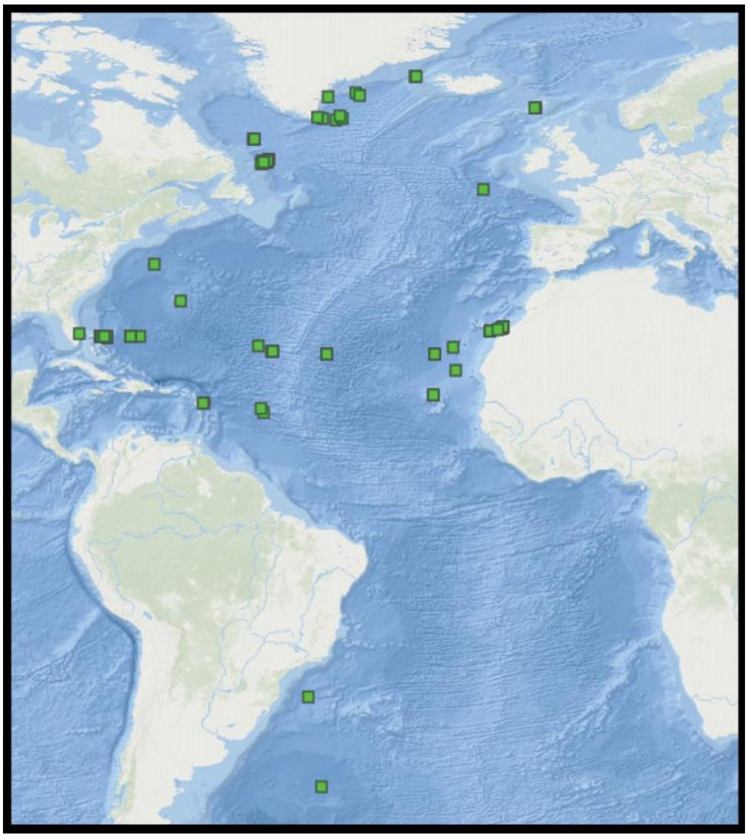

Figure 3.6 Active OceanSITES platforms in the AtlantOS domain.

3.5.2 Cost accounting methodology for the OceanSITES network

This section of the report aims to assess the cost of running the OceanSITES network in the AtlantOS domain. This includes both capital expenditure (CAPEX), i.e. the cost of procuring sensors and equipment for a fixed-point observatory and operational expenditure (OPEX), i.e. the recurring costs associated with running the observatory, such as consumables. For this analysis, it was assumed that the capital equipment purchased has a useful life of five years and therefore, an annual depreciation rate of 20% was used.

The average running cost for a "standard observatory" as defined in the framework of the European Union FP7 funded project on Fixed-Point Open Ocean Observatories (FixO3 - Grant Agreement number 312463) was estimated and documented in their deliverable D6.6 (Cost-benefit analysis report) and in Cristini *et al.* (2016). The observatory under discussion had the characteristics of two OceanSITES science objective groups: Group 3 (Global Ocean Watch site) and some characteristics of Group 2 (Air/sea flux site). The configuration of a FixO3 "standard observatory" was summarised as:

- moored in water depth of 3,000m
- constructed of a steel wire and rope (50:50) combination
- has a commercially available surface buoy with standard meteorological sensor package –e.g. wind speed and direction, humidity, air and sea surface temperature, atmospheric pressure, wave height/period
- uses an Iridium telemetry system
- has full biogeochemical sensor packages at two key depths, one near the surface in the mixed layer and one in the permanent thermocline
- has twenty physical sensors (temperature, salinity, pressure) used to resolve the seasonal evolution of the mixed layer and to obtain a suitable amount of observations below 2,000m water depth
- a minimum of one annual research cruise (five days on site) is required to maintain the standard infrastructure.

For such an observatory, the CAPEX (for five years) was estimated to be €501,000 – (including approximately €180,000 for biogeochemical sensors (fluorescence, oxygen, nutrient analyser, pCO2, pH, Irradiance) and €170,000 for physical sensors (T/S and current profilers)). The annual CAPEX therefore was estimated to be approximately €100,200. An additional €32,800 for sensor and mooring consumables (batteries, wire, shackles, etc.) and €6,000 telecommunication costs for real-time data access also need to be considered on an annual basis. The FIxO3 D6.6 (and likewise Cristini et al. 2016) also included an amount of €108,000 for "operational costs per sensor". Therefore, in total the sensor and mooring infrastructure CAPEX and sensor consumables and servicing amounts to €247,000 per year. By adding ship time, shipping and personnel the total annual expenditure was estimated at €731,000 per year (Cristini et al. 2016).

It is important to note that these financial figures are based on the "standard FixO3 observatory", as defined above. The CAPEX and OPEX for a typical OceanSITES observatory are different and strongly depend on the individual configuration. For this report, the costs are estimated using the science objective groups (1, 2 and 3) outlined in section 3.5.1. In the context of this report, the annual cost for the OceanSITES observatories in the AtlantOS region was calculated by multiplying the mean annual cost of running an observatory of each Group 1, Group 2 and Group 3 by the number of such observatories active in the AtlantOS domain. The number of OceanSITES platforms currently active in the AtlantOS domain was obtained from the JCOMMOPS data portal, with the limitations as indicated previously. Cost details and calculations can be found by clicking here.

3.5.3 Issues/Limitations

This is a high-level assessment of the CAPEX and OPEX for OceanSITES observatories and it provides a basic estimate of this expenditure. OceanSITES is a very diverse and heterogeneous network in terms of the complexity of installations. In addition, the configurations tend to change from year to year. Each observatory in the OceanSITES network will incur different expenditure costs. CAPEX depends strongly on the configuration and sensor payload. OPEX is likely to vary considerably, e.g. a Group 2 "Transport Moored Array" platform requires approximately half a day of ship time for a complete redeployment while a FixO3 type observatory type requires five days. For this example, there is a difference in costs of a factor of ten for ship time and personnel.

It is also difficult to capture the personnel required for an OceanSITES observatory. For example, a technician employed by the organisation operating the observatory may not work solely on the observatory. In a case like this, it is necessary to estimate the proportion of time spent working on the facility.

3.5.4 Estimation of current OceanSITES network costs

This section provides an estimation of costs for each of the three main OceanSITES categories – Group 1: Air/sea-flux reference sites, Group 2: Transport Moored Array and Group 3: Global Ocean Watch. The cost estimate provided by Cristini *et al*. (2016) was used as a reference point but is not entirely applicable for the OceanSITES cost estimate provided in this report. The overall cost to run the OceanSITES network was estimated to be approximately €3,664,000 per year (excluding personnel and ship time).

3.5.4.1 CAPEX and OPEX for OceanSITES Group 1: Air/Sea flux platform

Table 3.10 shows the estimated cost information for a range of sensors that operate on an OceanSITES Air/Sea flux platform. The annual depreciation amount is also included. The unit price of a number of sensors is listed in Table 3.10 along with the estimated number used on a platform.

Table 3.10 CAPEX for OceanSITES Group 1: Air/Sea flux platform.

Item	Unit cost per item (€)	Number	Capital Investment (€)	Annual Depreciation of 20% (€)
Meteorological package	14,000	1	14,000	2,800
Surface buoy	30,000	1	30,000	6,000
T/S/P	7,000	5	35,000	7,000
ADCP current profiler	30,000*	1	30,000	6,000
Acoustic release	5,000	3	15,000	3,000
Buoyancy	500	30	15,000	3,000
Telecom	6,000	1	6,000	1,200
Additional CAPEX			100,000	20,000
Total			**245,000**	**49,000**

*ADCP is only present at a small number of sites

Table 3.11 below provides a summary of the CAPEX depreciation and OPEX of an OceanSITES Air/Sea flux platform. There are 20 known platforms in the AtlantOS domain. Table 3.11 excludes the costs of personnel input and research vessel use.

Table 3.11 Annual CAPEX and OPEX for OceanSITES Group 1: Air/Sea flux platforms in the AtlantOS region.

Expenditure	Euros (€)
Capital expenditure depreciation	49,000
Operational expenditure (Batteries, wire, anchor, sensor maintenance)	36,000
	85,000
Number of observatories active in AtlantOS domain	20
Annual Cost of running the OceanSITES sites Group 1: Air/Sea flux	**1,700,000**

3.5.4.2 CAPEX and OPEX for OceanSITES Group 2: Transport Moored Array

TMA OceanSITES platforms primarily gather data on physical ocean variables and may also include some multidisciplinary sensors. In terms of instruments, they generally carry ten MicroCat CTDs and either a long ranger ADCP or five single point current meters. The infrastructure consists of a large buoyancy (approximately 40 inches), twenty 17-inch glass spheres and an acoustic release element. The cost of each of these sensors and the infrastructure is presented in Table 3.12.

Table 3.12 CAPEX for OceanSITES Group 2: Transport Moored Array.

Item	Unit cost per item (€)	Number	Capital Investment (€)	Annual Depreciation of 20% (€)
MicroCat CTD	6,000	10	60,000	12,000
Long range ADCP*	60,000	1	60,000	12,000
Large buoyancy	20,000	1	20,000	4,000
Glass spheres	800	20	16,000	3,200
Acoustic release element	17,000	1	17,000	3,400
Total			**173,000**	**34,600**

*Alternatively, five single point current meters can be used (€12,000 each)

The operational expenditure for a TMA OceanSITES platform generally consists of mooring wire, batteries for instrumentation, telemetry costs (data, mooring finder), shackle/rings, etc. There are approximately 40 TMA OceanSITES platforms in the AtlantOS domain. This consists of five overflow sites, ten Lab Sea platforms and five Tropical Atlantic platforms and 20 other TMA platforms. Table 3.13 below shows the annual depreciation on CAPEX and the OPEX of mid-range complexity TMA OceanSITES platforms in the AtlantOS region.

Table 3.13 Annual CAPEX and OPEX for OceanSITES Group 2: Transport Moored Array in the AtlantOS region.

Expenditure	Euros (€)
Annual depreciation on Capital expenditure	34,600
Operational expenditure	4,000
	38,600
Number of observatories active in AtlantOS domain (RAPID; OSNAP; 53N; MOVE, Overflows)	40
Annual Cost of running TMA OceanSITES	**1,544,000**

3.5.4.3 CAPEX and OPEX of OceanSITES Group 3: Global Ocean Watch

Global Ocean Watch OceanSITES platforms primarily gather data on physical ocean variables and may also include some multidisciplinary sensors. The sites are established in regions that are deemed to be representative of larger geographical areas. In terms of instruments, they generally carry six MicroCat CTDs and either a WorkHorse ADCP or three single point current meters. The infrastructure consists of a large buoyancy (approximately 40 inches), forty 17-inch glass spheres and an acoustic release element. Additional biogeochemcial sensors may include: pCO2, pH, Sediment trap, fluorescence and turbidity, irradiance, nutrient analyser, oxygen optode with logger. The cost of each of these sensors and the infrastructure is presented in Table 3.14.

Table 3.14 CAPEX for OceanSITES Group 3: Global Ocean Watch.

Item	Unit cost per item (€)	Number	Capital Investment (€)	Annual Depreciation of 20% (€)
MicroCat CTD	6,000	6	36,000	7,200
WorkHorse ADCP*	35,000	1	35,000	7,000
Large buoyancy	20,000	1	20,000	4,000
Glass spheres	800	40	32,000	6,400
Acoustic release element	17,000	1	17,000	3,400
pCO2 sensor	15,000	2	30,000	6,000
pH	15,000	2	30,000	6,000
Sediment trap	30,000	2	60,000	12,000
Fluorescence and turbidity	10,000	2	20,000	4,000
Irradiance and Nutrient analyser	40,000	2	80,000	16,000
Oxygen optode with logger	15,000	2	30,000	6,000
Total			**390,000**	**78,000**

*Alternatively, three single point current meters can be used (€12,000 each)

The operational expenditure for a Global Ocean Watch OceanSITES platform generally consists of mooring wire, batteries for instrumentation, telemetry costs (data, mooring finder), shackle/rings, etc. There are approximately five Global Ocean Watch OceanSITES platforms operational in the AtlantOS domain. Table 3.15 below shows the annual depreciation on CAPEX and the OPEX of mid-range complexity OceanSITES platforms of the Global Ocean Watch category in the AtlantOS domain.

Table 3.15 Annual CAPEX and OPEX for OceanSITES Group 3: Global Ocean Watch in the AtlantOS region.

Expenditure	Euros (€)
Annual depreciation on Capital expenditure	78,000
Operational expenditure	6,000
	84,000
Number of observatories active in AtlantOS domain	5
Annual Cost of running the Global Ocean Watch OceanSITES	**420,000**

3.5.4.4 Personnel

Personnel in the form of a technician, data management (processing and quality control) and coordination/project management is likely to form a considerable part of the cost of running an OceanSITES platform. The monetary cost in Euros of scientific or technical time is not included in this cost accounting exercise. Instead, time invested is included as FTE and person months since salaries vary greatly from country to country as does the scientific career grade of the cruise participants. Based on consultation with observatory operators in the AtlantOS domain, Table 3.16 below shows the personnel input for an OceanSITES site in terms of full time equivalent (FTE), person months and person hours under three main headings.

Table 3.16 Personnel input for an OceanSITES site.

Personnel	FTE	Person months	Person hours per annum
Technician	1	12	1755
Data management	0.5	6	878
Coordination and project management	0.5	6	878

3.5.4.5 Research vessel hire/use

Additional overhead costs may include research vessel (RV) hire. A ship is always required to service moorings and their sensors, and a cost is incurred as a result, i.e. an RV hire cost inclusion is always applicable for the OceanSITES network. For this assessment, the cost of research vessel hire was not included due to the differing requirements of each OceanSITES group. The use of a research vessel and the duration is likely to be determined by the distance of the fixed-point observatory from the shoreline. For example, it was estimated that five days of ship time per annum is required to carry out maintenance on the PAP observatory. For the TMA sites, each platform requires a maximum of one day for redeployment and calibration measurements. For a Global Ocean Watch site such as the Cape Verde CVOO-mooring, it was estimated that the redeployment would also take approximately one day. The ship transit time also needs to be considered. Details on the cost of RV hire per day was collected in this study for several countries active in the AtlantOS domain.

3.5.5 Concluding remarks

The cost estimate of €3,664,000 provided in this report is for 65 platforms of the three main OceanSITES groups outlined above. This is a lower estimate than reported previously (Cristini *et al*. 2016) which was approximately €17,000,000 per year for 23 sites. The estimate by Cristini *et al.* (2016) was also used in subsequent assessments such as the EU publication "Study on costs, benefits and nature of an extended European Ocean Observing System" (O'Kane *et al.* 2018). The estimate in this current study updates previous estimates in that it takes the various site characteristics into account. The improvement of the site metadata management via the JCOMMOPS observing networks metadata base will enable a more accurate calculation of CAPEX for future reports.

3.6 Glider Network

3.6.1 Background Information

Today, autonomous underwater gliders are more advanced and technologically developed than earlier versions of the infrastructure. Gliders now operate on a routine basis over repeatable deployment tracks and have fleet numbers able to continually provide gliders on a given mission (i.e. the ability to replace gliders for sensor calibration, battery renewal, while keeping another glider on-mission and in some cases also have another glider on stand-by). Unlike the first gliders ever produced, technological advancements facilitate longer missions and support abilities for these autonomous platforms to routinely complete repeat-sections collecting essential ocean measurements throughout the water column in regions of importance. Gliders can collect fine scale resolution physical and BGC water properties in the coastal ocean, the shelf seas and in the deep open ocean. In 2016, a Global Glider Programme was established, as part of the Global Ocean Observing System, to provide international coordination and scientific oversight of the global glider monitoring array set up to investigate ocean boundary circulation and to identify and document key links between the coastal and open ocean.

Sensors on gliders routinely measure physical variables such as pressure, temperature, salinity, and current speed and direction, and biogeochemical variables (oxygen, relative fluorescence and nitrate) relevant to plankton abundance and distribution. As new technologies develop (e.g. pH sensors mature), gliders will provide an excellent platform to monitor important ocean phenomena such as ocean acidification.

Pilots can fly gliders into shallow water (50 m) and direct their flight path toward the shore to facilitate recovery (similar to deployment) from a wide range of platforms, including small boats and chartered fishing vessels. The glider programme is designed as an array of long-term repeat-sections across important ocean phenomena, e.g. boundary circulation pathways in key areas all over the world.

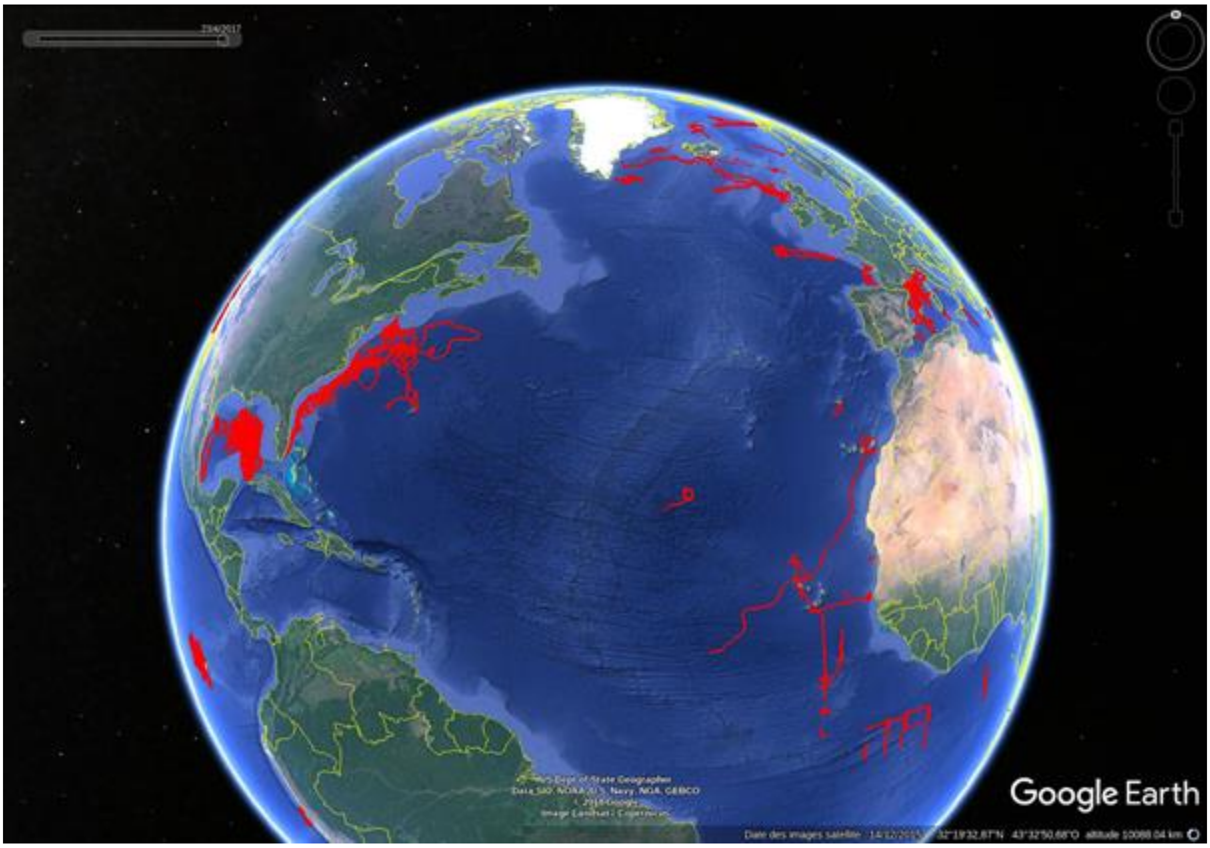

Figure 3.7 European and US Gliders repeat sections in the Atlantic. Source: EGO website (www.ego-network.org).

3.6.2 Cost accounting methodology for Glider network

The cost to run a Glider fleet to monitor the ocean varies greatly. Costs depend on the aim of the study in question, e.g. coastal vs. open ocean; multi gliders vs. single glider; monitoring line ('repeated' section) vs. specific ocean process experiment. Therefore, a simplified cost accounting method was used to estimate the actual cost based on information provided by the EuroGOOS Glider Task Team, which focuses on European glider activities in the Atlantic. The approach taken below to estimate the cost to run the European Glider fleet is easily adaptable to other fleets operated in the Atlantic and globally.

For this study, a permanent line is represented schematically as a section between two waypoints that is continuously sampled by a glider. A minimum of three gliders are required to maintain a section (line) with one glider at sea, one glider in the refurbishment facility (maintenance requires a new battery, sensor calibration, repairs, logistic planning etc. before redeployment), and one glider in preparation for an upcoming deployment (ballast checks, sensor installation, transportation, etc.).

With knowledge of the number of gliders available from Europe, US, Canada, Brazil and South Africa, and the cost of operating each line, a good estimate of the cost of the observing activity in the Atlantic is provided.

A minimum cost estimate of €150,000 per year to facilitate one continuously monitored line was calculated based on available information from the GROOM project (Grant Agreement number 284321, www.groom-fp7.eu) and the expert knowledge of the European Glider Task Team.

3.6.3 Issues/Limitations

An approximate estimation of the cost of the sustained lines in the Atlantic is provided above. There is not yet a mature, organised observing component under GOOS to monitor more precisely such costs, and therefore, the costs are based on fragmented information and estimations of the cost of glider lines, not in the cost of recurrent lines and individual glider missions. The information has been collected, in the case of Europe, on an institutional basis rather than a nationwide audit.

3.6.4 Estimation of current Glider network costs

3.6.4.1 Cost to procure a standard Glider

The average cost of a glider equipped with standard sensors (CTD, Oxygen and optical sensors) is €150,000 (www.groom-fp7.eu).

3.6.4.2 Running costs

Table 3.17 below shows the annual estimated running cost of a glider permanent line, based on cost estimates from the European GROOM project (www.groom-fp7.eu).

Table 3.17 Annual estimated running cost of a permanent glider line (source: GROOM project).

Item	**Glider line cost per year (€)**
Salaries (average EU MS salary)	50,000
Running cost (replacement batteries, communications, calibration, shipping)	70,000
Depreciation (including sensors)	30,000
Average Annual Cost of a Glider Line (based on European Estimations)	**150,000**

Table 3.18 below shows the annual cost of the maximum glider observing capacity in the Atlantic considering only permanent lines or repeated sections where scientists and operators maintain glider observations. This does not take into account other days at sea for gliders used for specific ocean process studies.

Table 3.18 Annual cost of the maximum glider observing capacity (if all lines were exploited).

Region/Country	# Gliders (Atlantic)	# potential permanent lines	Cost per year (€)
Europe	40	13	1,950,000
US	40	13	1,950,000
Canada	6	1	150,000
Brazil	4	2	300,000
South Africa	3	1	150,000
Total	**83**	**27**	**4,500,000**

The total estimated cost of the Atlantic glider fleet, if run at 100% current capacity, is approximately €4.5 million. However, due to a lack of funding, the nature of research projects with a finite life etc., the lines listed in Table 3.18 above are, unfortunately, not fully operational and the current cost invested in this network is only approximately €2 million.

3.6.4.3 Personnel

Although salaries vary greatly from country to country, the running costs presented in section 3.6.3.2 includes an estimate of the average total cost of personnel in Euros. However, the Full Time Equivalent (FTE) information, i.e. the time worked by an individual on a full-time basis, was obtained from the EuroGOOS glider Task Team.

Table 3.19 Annual FTE by country (from the EuroGOOS glider Task Team).

Country	FTE	Person Months
Brazil	2	24
Canada	2	24
Finland	0.5	6
France	3.5	42
Germany	2	24
Ireland	0.25	3
South Africa	1	12
Norway	2.5	30
Spain	2	24
United Kingdom	4	48
USA	10	120

3.6.4.4 Research vessel hire

These costs of hiring support vessels for the deployment of gliders are included in the running cost. However, gliders can be deployed from a rubber boat when reaching 50m depth and there is no need for a large boat or a long cruise.

3.6.5 Estimation of future Glider network costs

As the glider international coordinated observation network is still at a very early stage, there is not yet a detailed international programme for glider activity for the next ten years. However, sustainable glider observations for the next five years were discussed within the G7 Ocean Action and the agreed plan is to maintain operationally 20 permanent boundary lines, three Arctic lines and three Antarctic lines.

3.7 PIRATA

3.7.1 Background information

PIRATA was designed to study ocean-atmosphere interactions in the tropical Atlantic that affect regional weather and climate variability on seasonal, inter-annual and longer time scales. Ocean-atmosphere interactions in this region influence the development of droughts, floods, severe tropical storms and hurricanes, with impacts felt by millions of people in the Americas and Africa. PIRATA was first established in the mid-1990s and has undergone expansions and enhancements since 2005 to improve its utility for ocean and climate research and forecasting. To reflect the design improvements, the original PIRATA acronym was changed in 2008, from "Pilot Research Moored Array in the Tropical Atlantic" to "Prediction and Research Moored Array in the Tropical Atlantic". PIRATA is supported by France (IRD, Meteo-France, CNRS and IFREMER), Brazil (INPE and DHN) and the USA (NOAA).

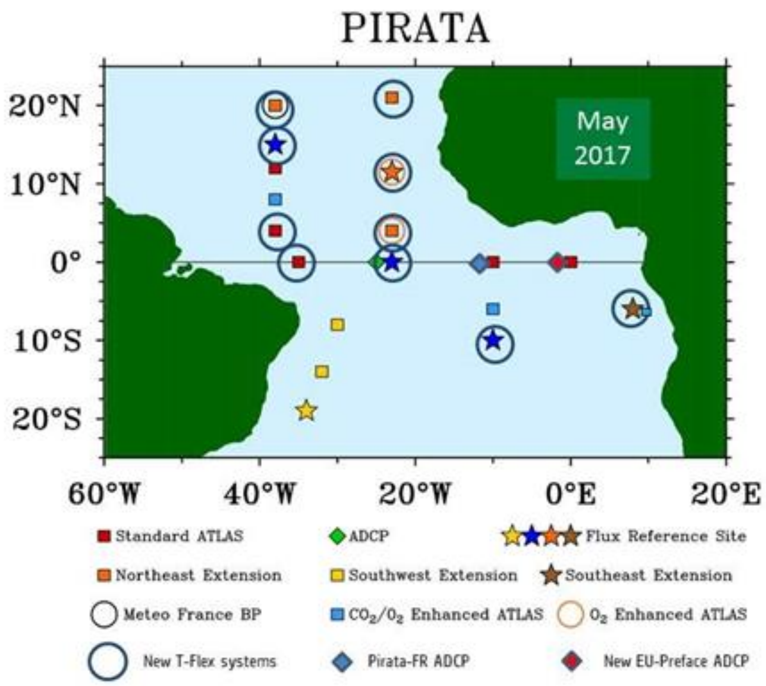

Figure 3.8 PIRATA Meteo-oceanographic buoys of the PIRATA backbone of ATLAS buoys (red), Northeast Extension (orange), Southwest Extension (yellow), Southeast Extension pilot project (brown). Stars represent the Flux Reference sites, where buoys are equipped with longwave radiometer & current meter. Black circle buoy is equipped with a barometer (Meteo-France). Blue squares are buoys with CO2 sensors (IRD). Orange circles are buoys with O2 sensors (at 300m & 500m; GEOMAR). The three ADCP moorings are represented by diamonds (at 23°W, 10°W and 0°E, along the equator; IRD). T-Flex systems are surrounded by a blue circle.

3.7.2 Cost accounting methodology for the PIRATA network

3.7.2.1 Capital costs

PIRATA is organised such that buoy systems purchased by the partners via national or project funding are "leased" to NOAA/PMEL. The estimate of capital costs is therefore, based on numbers delivered by NOAA/PMEL. The present PIRATA network is composed of eight ATLAS and ten T-FLEX systems. PIRATA is in the process of renewing the buoys and the future programme will consist entirely of T-FLEX systems. The capital cost calculation presented is, therefore, based on a total renewal of all buoys in 2017 (i.e. the purchase of a total of 36 T-FLEX systems at a price of €120,000 each). Additionally, PIRATA operates three current meter (ADCP) moorings along the equator (maintained by France).

3.7.2.2 Annual PIRATA network servicing

All the buoys of the PIRATA network are replaced on an annual basis, with 18 systems in operation and 18 systems on land. PIRATA buoys are furnished and refurbished by NOAA/PMEL.

France (IRD), USA (NOAA/AOML) and Brazil (INPE) are in charge of yearly cruises for buoy servicing. Yearly costs include:

- material transports for cruises,
- functioning including travel and subsistence for the scientific teams participating on the cruises, and
- cruise costs (vessel time), material for ADCP moorings (France), and costs for yearly refurbishing of the buoys and related material (cable, mooring weights), sensors calibrations etc. (NOAA/PMEL).

Each year, Brazil replaces eight buoys, the USA replaces four buoys and France replaces six buoys. This explains the different demands on vessel time (cruise duration is based on 2017 values), which also includes the transit time. The cost per day to hire a Research Vessel in each PIRATA network participating country is €20,000 in France; €33,300 in the USA and €35,000 in Brazil. Usually, a cruise duration is 60 days per year for France, 40 days for the USA and 60 days for Brazil.

All partners are funded by their Governments through national research organisations, i.e. NOAA in USA, IRD (3/4 of functioning) & Meteo-France (1/4 of functioning) and the French Research Ministry (vessel time) in France and MCTIC (through INPE) & DHN (vessel time) in Brazil.

Since the servicing work is similar every year, the annual cost displayed in the following section will also be valid for the coming years, since no changes in the PIRATA programme are planned.

3.7.3 Estimation of current PIRATA network costs

3.7.3.1 Cost of procurement of equipment

All instruments in the PIRATA network are replaced once a year, meaning that two sets of instruments are required. Procurement calculations are based on:

- the purchase of new instruments in 2017: 18 T-Flex Moorings x 2 =36 mooring systems and three ADCPs.
- straight-line depreciation cost assuming 50% salvage value after 1 year only for cost of single set of 18 moorings (i.e. 50% of 18 moorings = 25% salvage of 36 moorings).

The cost of procurement for the existing PIRATA system amounts to €4,800,000 and the annual depreciation is €1,200,000.

3.7.3.2 Additional costs

The cost of operating the PIRATA network are separated among the participating countries/institutions as outlined in section 3.7.2 and are composed of:

- Equipment - instrument and mooring hardware plus equipment technology upgrade
- Logistics – shipping, travelling, overhead etc.
- Functioning – instrument calibration, satellite telemetry service fees and software licensing
- Ship time – includes transit to and from working area.

The annual additional costs are displayed in Table 3.20.

Table 3.20 Annual additional cost of operating the PIRATA network (€).

Expenditure Item	**USA** (NOAA/PMEL)	**USA** (NOAA/PMEL)	**Brazil** (INPE, DHN)	**France** (IRD, MF, National Fleet)	**Total**
		2017	2017	2017	
		30 days/cruise	60 days/cruise	60 days/cruise	
	(€)	**(€)**	**(€)**	**(€)**	**(€)**
Equipment	375,000	27,500	0	30,000	432,500
Logistics	110,000	22,500	75,000	55,000	262,500
Functioning	62,500	2,100	12,500	15,000	92,100
Ship Time	0	1,020,000	2,100,000	1,200,000	4,320,000
Total per organisation	547,500	1,072,100	2,187,500	1,300,000	
Total per country		1,619,600	2,187,500	1,300,000	
GRAND TOTAL					**5,107,100**

3.7.3.3 Personnel

The labour input was estimated in person months and was divided into four categories: coordination, instrument and cruise preparations, cruises and data management. Table 3.21 shows the use of person months for each participating country.

Table 3.21 Personnel input for each participating country.

Expenditure Item	**USA** (NOAA/PMEL)	**USA** (NOAA/AOML)	**Brazil**	**France**	**Total**
Coordination	16	2	3	7	28
Preparing instruments and cruises	22	1.5	1	5	29.5
Cruises	2	4	7	12	25
Data management	28	5.5	2	6	41.5
Total per organisation	68	13	13	30	
Total per country		81	13	30	
GRAND TOTAL					**124**

3.7.4 Estimation of future PIRATA network costs

A new Memorandum of Understanding between the partners will be signed in 2019. The partners of the PIRATA consortium have a strong commitment to sustain the PIRATA network in the coming years at the same level as today. Expansion of the network is foreseen to happen only if partners can attract additional funding via research projects. The addition of biogeochemical sensors is of particular interest to the network.

3.8 Surface Drifting Buoy Network

3.8.1 Background Information

Lagrangian drifting buoys (drifters) are equipped with a thermistor on the base of the surface hull to measure sea surface temperature (SST) and a drogue centred at 15m below the surface such that enables the drifters to follow the surface circulation. Around half of the drifter array, mainly in mid-latitudes, are equipped with barometers to measure sea-level atmospheric pressure. The objectives of the global drifter network are to:

- Maintain a global 5x5 degree array of satellite-tracked surface drifting buoys to provide an accurate and globally dense set of observations of mixed layer currents, sea surface temperature and atmospheric pressure, and
- Provide a data processing system to deliver the data to operational and research users.

The Surface Drifting Buoy Network is funded mainly (approximately 95%) through contributions from the government, with the remaining 5% from research projects. Figure 3.9 shows the total number of drifters that were active in the AtlantOS region in December 2017.

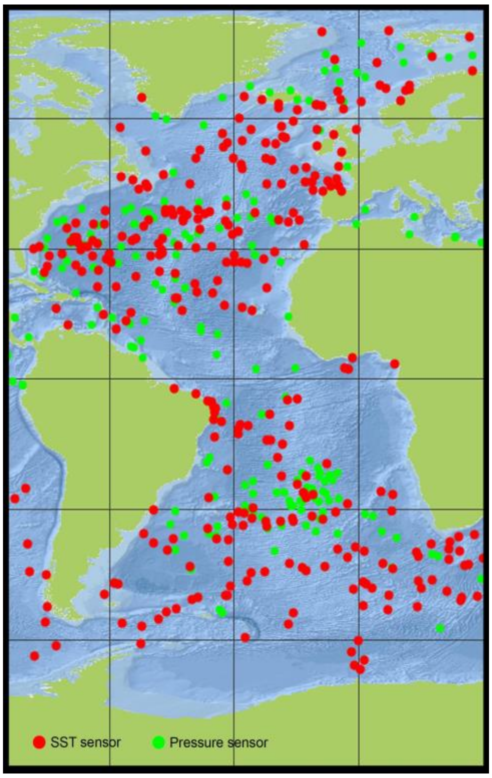

Figure 3.9 Active drifting buoys in the AtlantOS domain. The red dots represent drifting buoys with sea-surface temperature (SST) sensors and the green dots represent drifting buoys with SST and pressure sensors.

3.8.2 Cost accounting methodology for Drifter network

This section of the report aims to assess the cost of running the drifter network in the AtlantOS domain. This includes both capital expenditure (CAPEX), i.e. the cost of procuring a drifter and operational expenditure (OPEX), i.e. the recurring costs associated with deploying a drifter.

Three main types of drifter were considered for this study - a core Surface Velocity Programme Barometer (SVP-B) drifter that measures sea surface temperature and atmospheric pressure, a SVP-B drifter that also measures surface salinity and a SVP-B drifter that also measures wind speed. Wave drifters were also considered as they offer the possibility to make *In Situ* wave measurements in future from the open ocean. However, as they are still at a prototype stage, they were not included in this study but will likely contribute to future costs of the network.

The average unit cost price of each drifter was estimated based on the 2017 cost price of a buoy in each of the countries active in the AtlantOS domain. The cost of a standard SVP-B drifter buoy was estimated to be €2,605. The cost of additional sensors required to measure surface salinity and wind were estimated to be €1,195. The estimated cost of each of the three types of drifter buoy was multiplied by the average number of drifters deployed annually by each country in the AtlantOS domain. As there is a variance in the number of buoys deployed each year a five-year period (2012-2016) was used in order to get an average figure. The available data on the number of drifters deployed in the AtlantOS domain for each year was obtained from contacts in the drifter network.

The additional costs associated with deploying a drifter and data transmission and processing were then added to this, as explained in the section 3.8.4. Cost details and calculations can be found by clicking here.

3.8.3 Issues/Limitations

It should be noted that this is a conservative estimate for the cost of the Drifter network in the AtlantOS domain. Furthermore, the inclusion of personnel costs and research vessel hire or ship time would add considerably to this figure.

3.8.4 Estimation of Current Drifter Network costs

3.8.4.1 Cost of procurement of a Drifting buoy

The cost of procurement for a standard SVP-B drifter for a country in the EU Meteorological Services Network (EUMETNET) is €2,605. The cost of procurement for a drifter with an additional wind or salinity sensor for a country in EUMETNET can be as much as €3,800.

3.8.4.2 Additional costs

The additional costs incurred before a drifter is ready for deployment include logistics, coordination and other costs. Other costs refer to Iridium transmission and communication costs, transport, travel and subsistence costs, etc. For the entire drifter network, these additional costs are estimated to be €332,751 annually. Table 3.22 below shows the estimated annual running cost of core drifters in the AtlantOS domain.

Table 3.22 Estimated annual running cost of drifters in the AtlantOS domain.

Expenditure Item	SVP drifter buoy (€)	SVP drifter plus salinity sensor (€)	SVP drifter plus wind sensor (€)	Total (€)
Drifter buoy average unit cost	2,605	2,605	2,605	
Salinity sensor		1,195		
Wind measurement sensor			1,195	
Unit cost	**2,605**	**3,800**	**3,800**	
Average number of drifters deployed in AtlantOS domain annually	300	3	3	
	781,500	**11,400**	**11,400**	**804,300**
Additional costs				332,751
Average Annual Cost of drifters deployed (2012-2016)				**1,137,051**

3.8.4.3 Personnel

Personnel input is likely to form a significant part of the cost of running the drifter programme. The monetary cost in Euros of scientific or technical time is not included in this cost accounting exercise. Instead, time invested is included as FTE and person months since salaries vary greatly from country to country as does the scientific/engineer career grade of the programme participants.

Full time equivalent (FTE) refers to the time worked by an individual on a full-time basis. Table 3.23 shows the FTE and person months for the drifter network for France, the UK and EUMETNET countries. Table 3.23 is incomplete but provides an indication of the personnel input for France, the UK and the EUMETNET countries.

Table 3.23 Personnel input per annum.

Country	FTE	Person Months
France	0.25	3
United Kingdom	0.10	1.2
EUMETNET	0.50	6

3.8.4.4 Research vessel hire

Additional overhead costs may include research vessel (RV) hire, where applicable. For this assessment, the cost of research vessel hire is only included if an RV is chartered specifically for the deployment of drifter buoys. It has been assumed that there are no RV hire costs as most drifting buoys are deployed on existing planned cruises, ships of opportunity, etc.

3.8.5 Estimation of future Drifter network costs

Considerable future investment will be required to fulfil the scientific and operational needs of the user community for drifter data. To estimate the future network costs, the cost of each type of drifter buoy can be multiplied by the average number of floats expected to be deployed by each country annually in the AtlantOS domain.

3.9 Ocean Tracking Network

3.9.1 Background Information

The Ocean Tracking Network (OTN) is a global aquatic animal tracking, technology development, and partnership platform headquartered at Dalhousie University in Halifax, Canada. OTN and its partners use electronic tags to track more than 150 keystone, commercially important, and endangered species across 280 projects in over 30 countries. Despite their importance, little is known about the survival, movements and migrations, habitat use, and response to anthropogenic impacts on aquatic species. Since its inception in 2008, OTN has worked with partners in all of the world's five oceans to deploy acoustic receivers and oceanographic monitoring equipment. OTN has built a global receiver infrastructure and data system to comprehensively examine the local-to-global movements of tagged marine animals such as sharks, sturgeon, eels, and tuna, as well as other marine and freshwater species including squid, trout, sea turtles and marine mammals.

OTN's underlying concept is to share costs, resources, expertise and data with global partners to enable the creation of a global acoustic telemetry network. OTN researchers also work with other technologies, including satellite telemetry and accelerometer data storage tags, which can contribute knowledge about animal movements, energy efforts, and their environmental correlates. More than 400 international researchers including trainees, graduate students and postdoctoral fellows participate in the global network. OTN hosts an internationally certified data warehouse (over 300 million detection records and growing) that serves as a repository for data collected by OTN researchers and associated data nodes. OTN is also developing interpretation and visualisation tools for analysis of tracking data. OTN operates a fleet of autonomous marine gliders in support of oceanographic and tracking research.

The first phase of infrastructure development (Phase 1), including the creation of the OTN Data Centre to manage, synthesise, analyse, and visualise data generated by OTN and independent Canadian and international scientists within the network, ended in 2016. During this time, partnerships were developed with researchers and networks in Canada (including the Arctic), the United States (numerous individual efforts as well as the Animal Tracking Network [ATN] component of IOOS), a number of nations in Europe (including the formation of EATN, the European Animal Tracking Network), as well as Australia, Brazil and South Africa. Phase 2 (2017-2022) support for the core infrastructure operations is secured for an additional five years (renewable), and partners are currently establishing new research funding initiatives. During this second phase, OTN will seek to develop additional global partnerships, including in Asia, to expand the research infrastructure and data sharing capacities. Continued development of the OTN-Brazil infrastructure and data node will be a particular focus.

3.9.2 Cost accounting methodology for OTN

Detailed sources of funding are not publicly available, although OTN's literature (its website and latest annual report) provides an overall picture. The Canada Foundation for Innovation (CFI; $35M, all funds in Canadian dollars) provided support for the global acoustic receiver infrastructure and core operations in its first phase, and renewed its operations and maintenance support through the Major Sciences initiative in 2018 ($11.4M). The Nova Scotia Research and Innovation Trust (NSRIT) provides matching funding to CFI support, primarily for the salaries of HQ personnel. The Natural Sciences and Engineering Research Council of Canada (NSERC; $10M) funded Canadian scientists conducting research using the acoustic infrastructure within Canada, and the Social Sciences and Humanities Research Council of Canada (SSHRC; $0.3M) funded participation of social scientists in OTN work. NSERC-supported research addressed key questions by focusing on Canada's ocean and aquatic ecosystems. OTN also relies on in-kind support from its many international partners to develop and maintain local aspects of monitoring receiver lines.

Estimates of costs were obtained through discussions with OTN leadership. Section 3.9.3 (below) provides an indication of current costs, broken down by category. The cost to develop the network, including the OTN data Centre, were significant: in the eight years since its inception in 2008, over $135M (Canadian) in cash and in-kind support.

3.9.3 Issues/Limitations

It is an annual challenge for OTN staff to collate detailed and accurate costs associated with the in-kind operations of international partners, both for the development of animal tracking programmes (some of which existed, at least in earlier stages of maturity, prior to OTN) and their maintenance and integration with other observing programmes and networks. In some cases, the incremental cost of collaborating with existing programmes (e.g. the PIRATA network) is minimal, at least in terms of data capture. As with many programmes, scientist, technician, and vessel time serve multiple uses at the same time, and are difficult to assign to individual networks such as the OTN.

3.9.4 Evaluation of maintenance costs

Table 3.24 Summary of Annual Costs for Maintenance of System.

Category	**$CAD (2017-2018)**	**Euros (€) (2017-2018)**
International Operations*	1,550,000	990,683
Infrastructure Operations (OTN equipment and arrays)	550,000	351,533
Gear Upgrades	300,000	191,745
Services (consultants, fees, security, telecommunications, glider operations)	943,300	602,910
Supplies (oceanographic equipment, batteries, tags)	250,000	159,788
General Administration (communications, outreach, travel)	145,000	92,677
Training	120,000	76,698
Total	**3,858,300**	**2,466,032**

* In-kind contributions from international partners, not OTN
Note: a currency convertor dated 4th April 2018 was used to convert CAD values to Euros, where CAD$1 = €0.63915

As the number of international partners rises, and as the programmes and monitoring capability of existing partners grow, costs in each of these categories will increase, although it is expected to be at a reduced rate due to economies of scale. There will also be a need for capital / infrastructure funding to bridge networks and to purchase compatible acoustic receivers, which cost between $1,000 and $16,000 each, depending on model and capability.

OTN estimates that the global network currently requires between $5-6M annually to operate at a minimal level (i.e. foregoing expansion and possibly some needed maintenance). About 50% of the current maintenance costs relate to data, including telecommunications, storage, autonomous marine vehicle operations, and visualisation.

3.9.5 Personnel

Personnel input forms a considerable part of the cost to run the OTN. This equates to €784,022 (CAD$1,226,664). The monetary cost in Euros of scientific or technical time is not included in Table 3.24. Instead, time invested is used as FTE and person months since salaries vary greatly depending on the scientific/engineer career grade of the programme participants. There are 16 permanent staff in the OTN headquarters and this equates to 192 person months.

3.10 Support and Coordination costs

This section provides an overview of the costs associated with running JCOMMOPS. These costs are not included in the analysis; however, it is a vital component of the ocean observing networks. The costs refer to coordination support for global ocean observing activities.

3.10.1 JCOMMOPS

The Joint WMO-IOC Technical Commission on Oceanography and Marine Meteorology (JCOMM) is an intergovernmental body of technical experts that provides a mechanism for international coordination of oceanographic and marine meteorological observing, data management and services, combining the expertise, technologies and capacity development capabilities of the meteorological and oceanographic community. The JCOMM Observing Programme Area includes representation from several networks who focus on ways to improve the existing ocean observing system. The observing networks (e.g. DBCP, OceanSITES, GO-SHIP, and Argo) receive essential support from a centralised information and technical support facility called the JCOMM *In Situ* Observations Programme Support Centre (JCOMMOPS). The centre facilitates inter-network communications, the development of management tools to track network performance, new sensor development and logistical support.

3.10.2 JCOMMOPS operational budget

The 2016 JCOMMOPS operational budget was costed at US$667,000 per year (www.jcommops.org/ftp/JCOMMOPS/Presentations/JCOMMOPS_OCG2017_BudgetSummary_revision.pptx). The costs were mainly related to staff costs of the Technical Coordinators (TC), mission costs, rent, other activities and overheads. The cost per year for each category are listed in Table 3.25 below.

Table 3.25 JCOMMOPS operational budget.

Costs	$	€
Staff		
TC Argo/JCOMMOPS	160,000	130,734
TC DBCP/OceanSITES	130,000	106,222
TC SOT/GO-SHIP	110,000	89,880
Engineer	60,000	49,025
TC Science Communication staff	50,000	40,855
TOTAL STAFF	**510,000**	**416,716**
Mission		
TC Argo/JCOMMOPS	20,000	16,342
TC DBCP/OceanSITES	20,000	16,342
TC SOT/GO-SHIP	15,000	12,256
Engineer	5,000	4,085
TC Science Communication staff	5,000	4,085
TOTAL MISSION	**65,000**	**53,111**
Rent (IT Hosting)	30,000	24,513
Activities*	20,000	16,342
Overhead**	42,000	34,318
TOTAL INFRASTRUCTURE	**92,000**	**75,173**
IT Developments***	**90,000**	**73,538**
TOTAL OPERATIONAL BUDGET	**667,000**	**545,000**
TOTAL BUDGET	**757,000**	**618,538**

*$20,000 is the minimum evaluated for miscellaneous activities and include: JCOMM Report Card, meeting organisation, administrative/secretarial/minor material needs.
**Additional IT Development (subcontracted) costs may vary on a yearly basis between $20,000 and $100,000.
*** Average overhead is around 6%, as funding is channelled through different organizations with different overhead costs.
Note: a currency convertor dated 4th April 2018 was used to convert USD values to Euros, where USD$1 = €0.81709

4. Summary of Costs

This section provides a high-level summary of the cost accounting research carried out for each ocean observing network in the report. Table 4.1 summarises the current annual cost of running the networks presented. Where possible, costs were divided into CAPEX and OPEX. In addition, personnel costs are highlighted when reported by a network. It is important to note again that the financial figures provided in the table likely underestimate the expenditure of the networks.

Table 4.1 Estimated annual running costs of Atlantic Ocean observing networks.

Network	Maturity level (status)	Annual CAPEX (€)	Annual OPEX (€)	Total Annual Running Cost (€)
GO-SHIP	Mature	N/A	N/A	3,766,568
SOOP - European FerryBox	Pilot	1,875,066	1,538,993	3,414,059*
Continuous Plankton Recorder	Mature	N/A	N/A	2,076,652*
Argo	Mature	7,918,810	672,120	8,590,930
OceanSITES	Mature	2,754,000	910,000	3,664,000
Glider	Pilot	N/A	N/A	4,500,000*
PIRATA	Mature	1,200,000	5,107,100	6,307,100
Surface Drifter	Mature	804,300	332,751	1,137,051
Ocean Tracking Network	Pilot	N/A	N/A	2,466,032
Total				**35,922,392**

*Personnel cost included
Where OPEX = Operating Expenditure and CAPEX = Capital Expenditure; N/A = Not Available

Table 4.2 below provides an estimate of the annual personnel input associated with each network in terms of Full Time Equivalent (FTE) and person months.

Table 4.2 FTE and person months of Atlantic Ocean observing networks.

Network	FTE	Person months
GO-SHIP	35.9	431
SOOP - European FerryBox	9.5	114
Continuous Plankton Recorder	N/A	N/A
Argo	22.6	272
OceanSITES	20.0	240
Glider	23.0	276
PIRATA	10.3	124
Surface Drifter	N/A	N/A
Ocean Tracking Network	16.0	192
Total	**137.3**	**1,649**

Where N/A = Not Available

To provide a conservative estimate of the value of the personnel input the total FTE figure for all networks was multiplied by a figure of €75,000. This refers to a €50,000 salary plus overheads, insurance and pension contributions. This provides an estimated total of €10,297,500. While this figure is likely inaccurate, due to the difference in salaries in the Atlantic countries and the different scientific pay grades, it provides an indication of the personnel cost for ocean observing systems in the Atlantic.

Table 4.3 shows the estimated percentage financial sponsorship of the networks in terms of Government, Research Project and Private funding. The percentages provided in this table are merely an initial indication of the sponsorship contribution and further research is required to gain a more accurate assessment of how the networks are funded.

Table 4.3 Estimated percentage contribution by sponsors to each network.

	Percentage Funding Contribution (%)		
Network	**Government**	**Research Projects**	**Private Parties**
GO-SHIP	87	13	0
SOOP - European FerryBox	N/A	N/A	N/A
CPR	35	65	N/A*
Argo	25	75	0
OceanSITES	90	10	0
Glider	N/A	N/A	N/A
PIRATA	100	0	0
Surface Drifter	95	5	0
Ocean Tracking Network	N/A	N/A	N/A

*The Private percentage funding contribution for the CPR network is currently unavailable as the “in-kind” contribution in terms of ship-time is unknown. This is likely a significant percentage of the overall cost to run the network.
Where N/A - Not Available.

5. Regional cost estimate initiatives

This section provides details of initiatives that were carried out, external to the AtlantOS project, to estimate the cost of ocean observing networks (with many observing activities in the Shelf Seas).

5.1 USA Integrated Ocean Observing System (IOOS)

5.1.1 Background Information

The Integrated Ocean Observing System (IOOS) in the United States is an umbrella organisation comprising the IOOS Central Function and the oceanographic capabilities of 17 Federal agencies and 11 Non-Federal Regional Associations. The Central Function is responsible for coordinating and overseeing the development and integration of the capabilities of six IOOS subsystems: observing; data management and communications; modelling and analysis; governance and management; research and development; and training and education – the objective is to take maximum advantage of existing capabilities among the partners and to identify opportunities for incorporation and collaboration.

5.1.2 Cost accounting methodology for IOOS network

The methodology used and financial figures obtained for IOOS come directly from an Independent Cost Estimate (ICE) which was the response to American legislation - the Integrated Coastal and Ocean Observation System Act of 2009 - to examine the IOOS Central Function and the partnering oceanographic capabilities of 17 Federal agencies and 11 non-Federal Regional Associations who together comprise IOOS. Full cost accounting was employed to include the value of all U.S. oceanographic and Great Lakes observing assets. The IOOS Central Function, Federal, and Non-Federal contributions were assessed over a 10-year buildout followed by a 5-year sustainment period with both 50% and 80% confidence levels.

Full details are available in "Volume II: Detailed Cost Analysis" of the Independent Cost Estimate available on the IOOS website, but a few important points are listed here. All Regional Associations along with three Federal agencies provided asset inventories and buildout plans to help determine the programme cost. In addition, IOOS was itself conducting a cost review and where numbers differed, methodologies were compared and updated, yielding very similar results. The report (Volume II) also provides a detailed look at the cost breakdown and its associated drivers.

5.1.3 Issues/Limitations

As noted above, vessel time is not accounted for separately, and for the non-federal partners, is not included. Furthermore, as detailed in Volume II, a number of federal agencies (including the Office of Naval Research, NASA, the U.S. Coast Guard, and the Department of Transport) with oceanographic interest did not provide costs estimates of the equipment and personnel they are using.

5.1.4 Evaluation of development costs

The ICE summary of costs for the 10-year development of IOOS (see Table 5.1) indicates that 2.8% of the total development cost was borne by the Central Function in its coordinating role – and most of this in establishing an interoperable data management system, which includes cataloguing, searching, modelling, analysis, dissemination, and education. The rest was spent by federal and non-federal partners in establishing observation programmes for their regular mandates.

Capital expenditures on observational and support equipment (excluding data management) are counted in the Observing Subsystems element (Table 5.1); the $10.78 billion over 10 years represents 53% of the total costs. Other costs include building data management and communication systems, modelling and analysis, governance and management, research and development and training and education.

Table 5.1 Summary of Costs for Development of System.

Element	Central (US$ million)	Federal (US$ million)	Non-Federal (US$ million)	Total (US$ million)
Observing Subsystems	13	7,843	2,926	**10,782**
DMAC*	337	2,289	248	**2,873**
Modelling & Analysis	60	2,289	327	**2,675**
Governance & Management	110	1,526	643	**2,279**
Research & Development	20	763	70	**853**
Training & Education	34	458	217	**709**
Total	**574**	**15,166**	**4,432**	**20,172**

* Data Management and Communication

5.1.4.1 Personnel

Person years (FTEs) were not broken down for federal partners. Note that these are totals over the 10-year period, and the associated costs (salary and overhead) are included in Table 5.1 above.

Table 5.2 Summary of Person-Years for Development of System.

Element	Central	Federal	Non-Federal	Total
Observing Subsystems	28	-	6,423	**6,451**
Data Management and Communication (DMAC)	820	-	716	**1,536**
Modelling and Analysis	159	-	928	**1,087**
Governance and Management	239	-	1,332	**1,571**
Research and Development	44	-	42	**86**
Training and Education	75	-	582	**657**
Total	**1,365**	**-**	**10,023**	**11,386**

5.1.4.2 Research vessel hire

As noted in Table 7.2-1 of Volume II of the ICE, "there is no comprehensive inventory of identified non-federal ships that contribute to U.S. IOOS. To meet ship time requirements, NOAA uses, in addition to its own fleet, chartered ships from the University National Oceanographic Laboratory System (UNOLS) fleet, ships of opportunity, and ships provided by its foreign partners. Regional Alliances use ships and small boats for sampling, for observing asset maintenance, and to deploy and recover observational assets. This includes UNOLS ships, ships owned by various institutions such as oceanographic research institutes, and workboats and fishing boats chartered for operations and maintenance of in water instrumentation."

5.1.5 Evaluation of maintenance costs

Table 5.3 Summary of Costs for Maintenance of System

Element	Central (US$ million)	Federal (US$ million)	Non-Federal (US$ million)	Total (US$ million)
Engineering and Programme Management	21	0	0	**21**
System Operations*	352	15,256	3,575	**19,183**
Maintenance	12	9,861	0	**9,872**
Sustaining Support and Engineering	0	2,465	0	**2,465**
Indirect Continuing Support	0	1,233	0	**1,233**
Continuing System Improvement	27	1,233	0	**1,260**
Total	**412**	**30,047**	**3,575**	**34,035**

* Replication of all functions in Table 5.1

Note that costs shown as zeros indicate that the work breakdown from federal and non-federal partners was not detailed enough; the costs for these entries are included in System Operations line.

Table 5.4 Summary of Person-Years for Maintenance of System.

Element	Central	Federal	Non-Federal	Total
Engineering and Programme Management	15	-	-	**15**
System Operations*	687	-	5,005	**5,692**
Maintenance	5	-	-	**5**
Sustaining Support and Engineering	-	-	-	**-**
Indirect Continuing Support	-	-	-	**-**
Continuing System Improvement	25	-	-	**25**
Total	**732**	**-**	**5,005**	**5,737**

* Replication of all functions in Table 5.1

Note, again, that for non-federal partners, the work breakdown was not detailed enough to separately account for Person-Years in each category, but the total in the System Operations line accounts for these. The same is true for two categories in the Central Function.

5.2 Study on costs, benefits and nature of an extended European Ocean Observing System

The European Commission funded a study to provide evidence to help guide options for the creation of an extended European Ocean Observing System (O'Kane *et al.* 2018). The report provides useful information on the estimated expenditure on ocean observation activities in EU Member States and Norway. The detailed report prepared by MRAG can be found by clicking here.

The methodology used involved:

- online search for financial reports from EuroGOOS members and private companies
- requests for information from identified organisations
- analysis of data from the Euro Ocean Marine Infrastructure database

The report acknowledges that it was difficult to disaggregate by ocean observing activity the data gathered on Member State expenditure activity. As such, the information provided in the report on expenditure for ocean observation activities is fragmented. Input from ocean observing networks was sought to increase the accuracy of estimates on expenditure.

5.3 GMES *In Situ* Coordination (GISC) project

For the GMES *In Situ* Coordination (GISC) project (GA 249327), a global ocean observing system position paper was prepared for the European Environment Agency workshop on GMES *In Situ* data requirements. The paper provided an estimate from NOAA of the cost to build a sustained ocean observing system. It was estimated that to provide complete global ocean coverage would require an annual operating budget (maintenance and operation) of approximately €120 million (excluding ship time). The Atlantic Ocean would account for approximately 25% of this amount, i.e. €30 million per year. This estimate is somewhat in line with the financial figures provided in this current cost and feasibility study.

6. Feasibility

Since cost and resources are key to successful ocean observing efforts, it is important that the scientific and operational communities continue to work toward optimising the existing ocean observation programmes. The Global Ocean Observing System (GOOS) has addressed this issue by approaching ocean observations with a focus on Essential Ocean Variables (EOVs). The EOVs identified by the three GOOS Expert Panels, Physics, Biogeochemistry and Biology and Ecosystems, are selected based on the following criteria:

- **Relevance:** The variable is effective in addressing the overall GOOS three main themes of Climate, Operational Ocean Services and Ocean Ecosystem Health.
- **Feasibility:** Observing or deriving the variable on a global scale is technically feasible using proven and scientifically understood methods.
- **Cost effectiveness:** Generating and archiving variable data is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

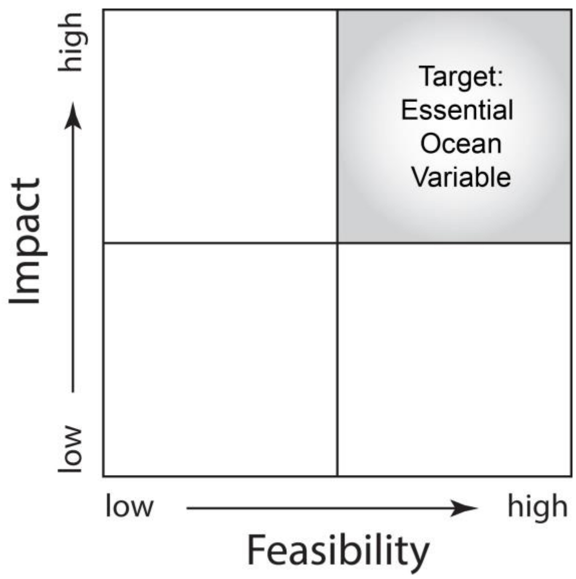

Figure 6.1 The concept of Essential Ocean Variables – EOVs in terms of feasibility and impact (source: GOOS).

Further details on this effort are available on the GOOS webpage.

To deem an observing technology 'feasible' several steps of development are followed; these are clearly defined in the Framework for Ocean Observations - FOO (UNESCO, 2012).

The steps, shown in Figure 6.2 below, are split into three broad categories:

1. **Concept** - ideas are articulated and peer-reviewed
2. **Pilot** - aspects of the system are tested and made ready for large-scale implementation
3. **Mature** - they become a sustained part of the global ocean observing system

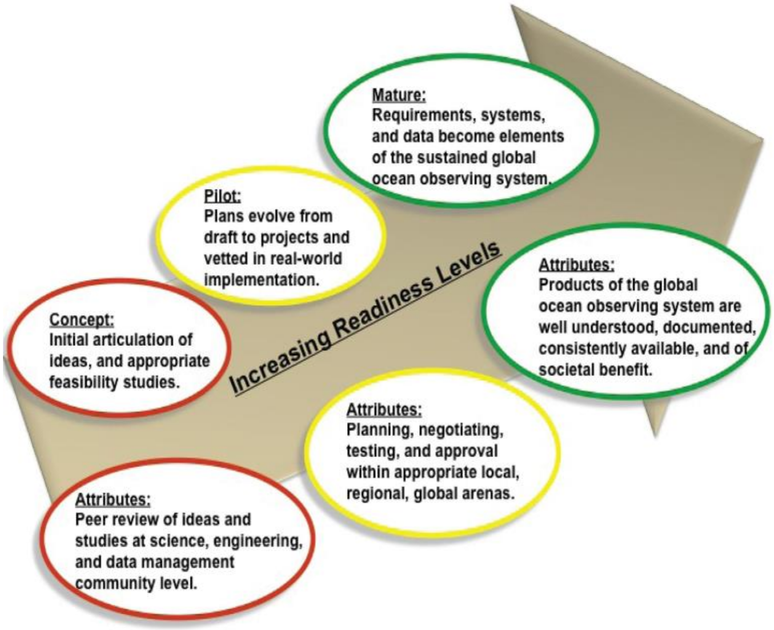

Figure 6.2 The three steps of readiness level (source: Framework of Ocean Observing).

Many of the Atlantic Ocean observation networks, for which costs were evaluated in this report, are well established, well functioning and regarded as mature from a technological point of view, while the networks themselves operate at different levels of coordination. There is, however, a need to continuously develop new instruments, sensors and technology to address new requirements for ocean observation (new parameters e.g. those related to biology, better resolution in time and space, higher precision and accuracy, etc.) as well as improved cost efficiency and, affordable sensors and instruments.

Developing new technologies is an iterative process. Those seeking to incorporate a new parameter and/or associated variable(s) into the observing system need to:

1. assess the stakeholder requirements to ensure acceptance
2. develop the associated measurement technology to an adequate Technology Readiness Level (TRL)
3. ensure data and information products are appropriate, accessible and fit for purpose for the targeted scientific and societal benefit area.

In FOO (UNESCO, 2012) this process has been streamlined by defining nine readiness levels linked to the above mentioned three steps: concept, pilot and mature (Figure 6.3).

FRAMEWORK PROCESSES BY READINESS LEVELS

Readiness Levels	Requirements Processes	Coordination of Observational Elements	Data Management & Information Products
Mature			
Level 9 "Sustained"	Essential Ocean Variable: • Adequate sampling specifications • Quality specifications	System in Place: • Globally • Sustained indefinitely • Periodic review	Information Products Routinely Available: • Product generation standardized • User groups routinely consulted
Level 8 "Mission qualified"	Requirements "Mission Qualified:" • Longevity/stability • Fully scalable	System "Mission Qualified:" • Regional implementation • Fully scalable • Available specifications and documentation	Data Availability: • Globally available • Evaluation of utility
Level 7 "Fitness for purpose"	Validation of Requirements: • Consensus on observation impact • Satisfaction of multiple user needs • Ongoing international community support	Fitness-for-Purpose of Observation: • Full-range of operational environments • Meet quality specifications • Peer review certified	Validation of Data Policy • Management • Distribution
Pilot			
Level 6 "Proven capacity"	Requirement Refined: • Operational environment • Platform and sensor constraints	Implementation Plans Developed: • Maintenance schedule • Servicing logistics	Demonstrate: • System-wide availability • System-wide use • Interoperability
Level 5 "Verification"	Sampling Strategy Verified: • Spatial • Temporal	Establish: • International commitments and governance • Define standardized components	Verify and Validate Management Practices: • Draft data policy • Archival plan
Level 4 "Trial"	Measurement Strategy Verified at Sea	Pilot project in an operational environment	Agree to Management Practices: • Quality control • Quality assurance • Calibration • Provenance
Concept			
Level 3 "Proof of concept"	Proof of Concept via Feasibility Study: • Measurement strategy • Technology	Proof of Concept Validated: • Technical review • Concept of operations • Scalability (ocean basin)	Verification of Data Model with Actual Observational Unit
Level 2 "Documentation"	Measurement Strategy Described • Sensors • Sensitivity • Dependencies	Proof of Concept: • Technical capability • Feasibility testing • Documentation • Preliminary design	Socialization of Data Model • Interoperability strategy • Expert review
Level 1 "Idea"	Environment Information Need and Characteristics Identified: • Physical • Chemical • Biological	System Formulation: • Sensors • Platforms • Candidate technologies • Innovative approaches	Specify Data Model • Entities, Standards • Delivery latency • Processing flow

Figure 6.3 A detailed view of varying levels of readiness.

The focus of this section is on the feasibility of the existing and, in particular, the emerging technologies (sensors and instrumentations) to measure EOVs. AtlantOS project WP6 partners carried out a task to catalogue instrument development and monitor the readiness levels for a great number of sensors and instrumentation. A detailed list is available in the sensors and instrumentation roadmap deliverable.

The ambition of the AtlantOS WP6 activity is to provide an open access technology roadmap for research centres surrounding the Atlantic Ocean, with the objective to both engage and improve collaboration, and integrate efforts across all stakeholders. The roadmap constitutes a tool from which the oceanographic community can learn of current and upcoming technology to better inform grant proposals, to improve engagement with technology providers and to help focus integrated efforts on the most important science questions. The work in AtlantOS WP6 has resulted in a ten-year technology roadmap for existing and for emerging sensors and instrumentation for oceanographic research in and around the Atlantic Ocean. The level of readiness is reported as Technology Readiness Levels (TRLs). Whenever available, further parameters detailing the capabilities and specifications of submitted sensors and instrumentation are also made available on the accessible roadmap for emerging networks.

The online technology roadmap, in the form of an Excel file, is updated regularly to display TRL developments for individual sensors and instruments. An example of the type of information available in the Excel file is provided in Figure 6.4 below.

Company/Institute (project affiliation)	Sensor or instrument name	Application/target/technology	TRL1	TRL2	TRL3	TRL4	TRL5	TRL6	TRL7	TRL8	TRL9	Operational demo	Commercial release
Aanderaa	Aanderaa optode (4797)	pCO2	met	met	met	met	met	met	met	met		complete	
Airmar	Ultrasonic weather station	liquid robotics waveglider sensor package	met	met	met	met	met	met	met	met	met	complete	available
AML Oceanographic	Minos CTD	deployment metadata	met	met	met	met	met	met	met	met	met	complete	available
AML Oceanographic	UV Xchange (XCH-UV-U)	Anti-fouling	met	met	met	met	met	met	met	met	met	complete	available
AML Oceanographic	Cabled UV (PDC-CUV-V-05-3M)	Anti-fouling	met	met	met	met	met	met	met	met	met	complete	available
CEFAS (COMMON SENSE Project)	Cefas Noise Sensor (pre-production prototype)	hydrophone	met	met	met	met	met	met	met				
COMMON SENSE Project	Microplastic sensor	microplastics	met	met	met	met							
COMMON SENSE Project	Nutrient Sensor	nutrients	met	met	met	met	met						
Flydog Solutions LLC	Profiler buoy 'Mona'	profiler	met	met	met	met	met	met	met	met	met	complete	available
Flydog Solutions LLC	Submersed profiler 'Salla'	profiler	met	met	met	met	met	met	met	met	met	complete	available
KM Contros GmbH / GEOMAR (AtlantOS project)	HydroFlash O2	dissolved oxygen	met	met	met	met	met	met	met	met		complete	available
KM Contros GmbH / GEOMAR (AtlantOS project)	HydroFlash CO2	carbon dioxide	met	met	met	met				Dec-17	Jul-19	Aug-19	Mar-20
LOSEM University of Tuscia	TFLaP	physical-chemical-biological parameters	met	met	met	met	met	met	met	met			
LOSEM University of Tuscia	Spectra (derived from TFLaP)	physical-chemical-biological parameters	met	met	met	met	met	met	met	met			available
National Oceanography Centre	Chemical Sensors: Nitrite	nitrite	met	met	met	met	met	met	met	met	Mar-20		
National Oceanography Centre	Chemical Sensors: Phosphate	phosphate	met	met	met	met	met	met	met	met	Mar-20		
National Oceanography Centre	Chemical Sensors: Ammonia	ammonia	met	met	met	met	Dec-17						

Figure 6.4 Example of the TRL status for a number of instruments under development. Source: http://noc.ac.uk/files/documents/science/WP6_Roadmaps_(S%2BI_and_Emerging_networks)V4.xlsx.

7. Conclusions & Recommendations

The main aim of the present study was to provide a cost estimate for the operation of existing Atlantic Ocean observing activities. The focus was to collect information from as many ocean observing networks as feasible within the timeframe allocated to the task. A significant input from network representatives was required to carry out the exercise.

A number of key conclusions from the analysis can be made:

- There is a need for more accurate financial data on the cost of running ocean observing networks.
- The observing networks investigated in this study are currently funded through a combination of national governmental and research project funds.
- All networks involved in the study have plans to upgrade and expand their present system and to continue to complement, support and integrate with other networks where possible.
- Many of the networks are reliant on time-limited research funds since sustained funding is currently unavailable for upgrades.

Based on these conclusions the key recommendations from this study are to:

- Develop a standardised methodology to enable the provision by the networks of more accurate information on expenditure.
- Use the methodologies employed in this study as a starting point to develop a common methodology.
- Use the financial data gathered in this study to inform discussions on sustained funding for Atlantic Ocean observing networks.
- Provide adequate and sustained funding to enable regular and updated cost accounting reports for Atlantic Ocean observing networks.
- Enable an international body, of repute in ocean observation, to lead and coordinate the continuation of annual reporting on the costs to run the networks.

This report is a first step to develop a consistent cost accounting framework for ocean observing networks in the Atlantic. The financial figures gathered provide an indication of the level of funding required to operate the observing networks outlined. There are a number of limitations with the financial data gathered for each network; these are addressed specifically in the relevant sections of the report. In many cases, the level of detailed cost information provided – capital investments as well as annual operational costs – depended on the maturity of the network. As such, it was impossible to estimate the expenditure of all ocean observing networks in the AtlantOS domain; more work is required to achieve a fully comprehensive report. As a result, the estimated total running cost of the existing system of €35,922,392 plus 137.3 FTE staff (estimated average of €10,297,500) is likely a considerable underestimation of the actual costs.

The decision to keep personnel costs as a separate number was due to the variance in salaries in countries surrounding the Atlantic Ocean. Including the estimated financial cost of personnel input in the analysis could increase the expenditure considerably. However, despite these limitations the cost estimation provided can help guide funders with regard to sustained funding for the Atlantic Ocean observing networks.

The cost accounting process needs refinement and standardisation across the networks. A common approach could involve the classification of costs into capital and operational expenditure (CAPEX and OPEX), as demonstrated in this study. This would help inform national policy discussions and reports regarding the allocation of funding for ocean observing networks. For this to occur it is recommended that institutes in all countries around the Atlantic Ocean collaboratively work together to collect data on investments in ocean observations. Increased cooperation and integration between the networks would help to provide assessments that are more accurate. The extent to which the networks currently report expenditure is varied. In some cases, this depends on the network's maturity level. For example, the networks that are separate legal entities are required to produce annual financial activity reports. They also operate a centralised procurement process for the purchase new assets; this can have an added benefit of lower prices when buying in bulk. Centralised procurement is a useful process that enables the networks to make cost savings.

Research vessel hire is one of the most expensive components of ocean observations for many of the networks. This affects some of the networks more so than it affects others. The availability of ship time on research vessels capable of mooring operations is crucial for some of the networks. Increased cooperation with ship operators in terms of using regular commercial ships for ocean observations, where possible, would also save costs for the networks.

This study was limited by time and resources and as such is viewed as a first step in developing a cost accounting methodology for ocean observing networks in the AtlantOS region. The study relied on the significant goodwill, effort and contribution of the network representatives, which was provided as a courtesy. Adequate resources and funding are required to build on the data gathered in this initial study. Future work should focus on addressing the limitations of this study and help to enhance the provision of more accurate financial data for the ocean observing networks in the Atlantic.

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