GEORGE

Next generation multiplatform ocean observing technologies for research infrastructures

D5.1 | Technology validation and prototyping SOP and trials project plan

GEORGE project received funding from European Union's Horizon Europe programme under grant agreement no. 101094716

GEORGE

- √ Appearance follows the GEORGE template and visual guidelines.
  Cover page has been updated with Deliverable details.
- √ The executive summary provides a short description of the deliverable.
- √ All abbreviations are explained in a separate list.
- √ References are listed alphabetically at the end of the document.
- √ The deliverable identifies all contributions from partners and justifies the resources used.
- √ The deliverable has been checked for spelling and grammatical errors.
- √ If the deliverable contains data, a DOI is provided.

Dissemination level

- √ Public
- Restricted to other programme participants (including the Commission Services)
- Restricted to a group specified by the consortium (including the Commission Services)
- Confidential, only for members of the consortium (including the Commission services)

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Table of content

1. Executive summary

D5.1 results from the coordination of technology development and integration across participants carried out between the 1st and the 12th month of the project. **D5.1 is a first release of the work plan intended for adjustment, even for strong modifications as the project progresses**.

D5.1 will be the road map for the WP and project leaders to coordinate the integration across the sensors, platforms and stage-gates (deployments leading to TRL7, TRL8 and sea trials in a multi RI). Task 5.2, covering the deployments to TRL6 to TRL8 will be led by UiB and EMSO (M12-36). Task 5.3 and the field trials in a multi RI context will be led by EMSO and NOC (M30-54).

The deployment (modification of the work plan, preparation and operation) will be the responsibility of the tasks leader in close coordination with WP2, WP3, WP4 and WP5 leaders.

After a short introduction to the project and to the context, this document presents the method and successive steps established to carry out the validation of WP2, WP3 and WP4 developments (platforms, sensors and processes). The document includes:

- a table presenting a short description of each development carried out and tested at sea during the project
- a schedule showing the period envisaged for the deployment at sea
- the list of equipment required and its affectation to the various deployments
- an in-depth description of each deployment including all aspects: objectives, coordination, equipment provision, operation at sea, expected results and risk assessment

2. Introduction

2.1. The project GEORGE

The aim of the GEORGE project is to develop and test a cutting-edge biogeochemical, multi-platform marine technology sensors for ocean observation systems that works across three ERICs it is EMSO, EurArgo and ICOS, and can perform integrated measurements to characterise the ocean carbon system. The project aims to improve the technology readiness level of advanced sensors, which will allow for the first time systematic autonomous, *in situ*, seawater CO_2 system characterisation and CO_2 fluxes determination on moving and fixed platforms throughout the water column from benthos to sea surface.

Together with sensor manufacturers, GEORGE will optimise sensor technologies for measurements on platforms operated by the three mentioned ERICs and according to their operational requirements. Technology will be co-developed between industry and ERICs ensuring direct route to market and potential for scalability. The technologies will be validated according to a rigorous TRL progression engineering process and demonstrated at sea as an integrated multi-platform observing system during several field campaigns where ERICs are active.

Additionally, we are going to advance the integration and interoperability of measurements gathered within GEORGE and between EMSO, EuroArgo and ICOS ERICs. This work includes streamlining the integration of different data formats originating from the various sensor/platform combinations.

2.2. The developments in GEORGE

The **letter in this table** will be used in the entire document to refer to the development items

Item		Development by	Contact person	Description of the development	TRL now	TRL by end of the project
[A]	Adaptive strategy for multiplatform deployments	MyOcean Resources	U.Schuster@exeter.ac.uk john@myocean.co.uk	Real time optimization of the observation strategy, using neural network approach		TRL8
[B]	Argo float PROVOR CTS5 with passive acoustic	SU/LOV	edouard.leymarie@imev-mer.fr	Firmware integration of a COST passive acoustic recorder on the CTS5.	TRL5	TRL8
[C]	Argo float PROVOR CTS5 with Linux CPU	SU/LOV	edouard.leymarie@imev-mer.fr	Implementation of a new CPU on the CTS5's acquisition board (USEA). Firmware integration and development of a dedicated software on the Linux CPU.	TRL4	TRL6 or TRL7
[D]	ARVOR_C Updated Coastal profiler	Nke	jerome.sagot@nke.fr romain.cancouet@euro-argo.eu	Updated version of the ARVOR_C, Argo float designed to operate in shallow waters 6 prototypes	TRL6	TRL8 or TRL9
[E]	CaPASOS CO_2 flux sensor	Uni Exeter	U.Schuster@exeter.ac.uk w.tatkiewicz@exeter.ac.uk	Improve performance and ruggedisation and integrate in Sailbuoy	TRL6	TRL8
[F]	Chlorination on LoC sensors	CSW and Ifremer	pip.simpson@clearwatersensors.com nlanteri@ifremer.fr	Evaluate protection of the LoC sensor filters with chlorine generated in situ If conclusive, set the legal context for progression to TR8		TR6
[G]	Chlorination on membrane sensors	4H Jena and Ifremer	seelmann@4h-jena.de nlanteri@ifremer.fr	Evaluate resistance of new membrane to chlorination Depending on the evaluation results, integration in the COTS	TR6	TRL8

				sensors		
[H]	EGIM Lander	Ifremer	nlanteri@ifremer.fr	Develop a compact lander to deploy and recover the EGIM from the surface Analyze the technical specifications from maintenance and industrial point of view Document deployment and recovery procedures If required, design titanium battery tanks for 6000 m depth		TRL8
[I]	EGIM Upgrade	Ifremer	nlanteri@ifremer.fr adrien.chauvet@ifremer.fr	Integrate new electronic boards Complement software to interface the sensors used on the EGIM (pH, TA, DIC and TADIC LoC sensor, 4H Jena pCO2 and CH_4 sensors) Develop new component to provide 48 V power voltage to sensors of the EGIM	TRL5	TRL8
[J]	EGIM Rechargeable batteries packs	Ifremer	nlanteri@ifremer.fr julien.legrand@ifremer.fr	Testing an alternative to non-rechargeable battery packs		TRL7 or TRL8
[K]	HydroC CO_2 FT Hybrid	-4H-JENA	seelmann@4h-jena.de	Implementation of reference gas measurements on the HydroC CO_2 FT sensor		TR8
[L]	HydroC Combi CO_2/CH_4 FT	-4H-JENA	seelmann@4h-jena.de	Combining the HydroC CO_2 and CH_4 FT sensors in one sensor; WP4.2 Task ii: To add -4H-Jena Contros HydroC FT CO_2 on SOOP		TR8
[M]	HydroFIA TA	-4H-JENA	seelmann@4h-jena.de	Mainly for WP4.2 Task ii		TR8

				Testing new indicator (bromocresol purple) for extending the salinity range to lower salinities (5 < S < 29)		
[N]	Integrated microsens ISFET pH sensor	CWS	alex.beaton@clearwatersensors.com pip.simpson@clearwatersensors.com	Integrate Microsens ISFET pH sensor with auto-calibration from CWS LoC pH sensor for rapid sampling without drift Integration on the Sea-Explorer		TR8
[O]	Iridium Certus Test Bench	Nke	adavid@nke.fr	Bench test of the new Iridium Certus modem and protocol	TRL2	TRL4
[P]	LoC DIC	NOC	s.loucaides@noc.ac.uk	Characterize, design and test new integrated detector Implement new calibration procedure and new temperature measurement Develop data processing algorithm	TRL 6	TRL 8
[Q]	LoC TA	NOC	s.loucaides@noc.ac.uk	Characterize pH dye indicators Modify fluidic design to shorten measurement Improve gas exchange Reduce on-board reagent volume Increase analytical performance	TRL6	TRL 8
[R]	LoC TADIC	NOC	s.loucaides@noc.ac.uk	Test and optimize new pumps Implement temperature measurement on detector Develop measurement state machine Implement improvements from DIC and TA sensors above	TRL 6	TRL 8

[S]	Membrane sensors behaviour with regard to pressure and temperature	Ifremer	nlanteri@ifremer.fr seelmann@4h-jena.de	Tests the response of membrane sensors in various temperature, pressure condition, oxygen and concentration Recommend best practices for the use of mobile platforms		
[T]	Sampler for fixed ocean stations	NOC	ksw@noc.ac.uk	Sampler development: Design and manufacture sampler for gas-tight carbon samples with poisoning capability	TRL5	TRL8
[U]	Sampler for ships of opportunity	ULPGC and OCEOMIC	melchor.gonzalez@ulpgc.es ialonso@oceomic.com	Sampler development: Integrated Temperature and Salinity measurements • Gas-tight sample storage • Automated sample storage • Automation of bottle sealing	TRL6	TRL8
[V]	Sea-Explorer Acoustic Purpoise	SU/LOV	laurent.coppola@imev-mer.fr	Sea-Explorer glider payload extension	TRL9	TRL9
[W]	Sea-Explorer with pCO2 mini-Pro	SU/LOV	laurent.coppola@imev-mer.fr	Sea-Explorer glider payload extension	TRL9	TRL9
[X]	Sea-Explorer with RBR (CTD LEGATO + DO CODA)	SU/LOV	laurent.coppola@imev-mer.fr	Sea-Explorer glider payload extension	TRL9	TRL9
[Y]	Spectrophotometric pH sensor	CWS	alex.beaton@clearwatersensors.com pip.simpson@clearwatersensors.com	Commercial sensor ; brand new sensor which has never been used for carbon observation		TRL8
[Z]	Wireless Communication Infrastructure	Wsense	eric.delory@plocan.eu michele.nati@wsense.it	Collection of pCO2 data, using sensors and wireless underwater connections. Exchange of messages between interoperable platforms		TRL8

3.1. TRL scale

TRL, standing for Technology Readiness Level, provides a framework to evaluate the technological development and progression. The TRL scale helps to assess the readiness and maturity of a technology at different stages of development. It provides a common language for researchers, engineers, decision-makers, government agencies, research institutions and private companies to communicate the level of technological advancement, evaluate risks and make informed decisions regarding further development, testing, funding or commercialization.

The definition of the various TRL stages are quite general and the translation into precise objectives and tests strongly depends on the domain and object. Some, for instance GOOS's definition { 1 }, emphasizes the final goal, while others, mostly in use within the EU projects scenario, focus on the validation process to reach the TRL { 2 }.

When applying TRL to ocean technologies, the scale should reflect the specific challenges and requirements of working in the marine environment and sustain the entire life cycle. For example, TRL assessments for underwater robots might consider factors like pressure resistance, corrosion resistance, navigational capabilities, and power efficiency. The qualification in simulated condition and the multiple mission in real conditions are of major importance.

Consequently, the guidelines to evaluate the TRL will be:

Development phases	TRL	Definition by the European Union { 2 }	TRL examples { 3 }
MATURE Deployed and ready for commercialization	9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)	System/model proven and ready for commercial deployment. An example includes the actual system/model being successfully deployed for multiple missions by users.
	8	System complete and qualified	System/model produced and qualified. An example might include the knowledge generated from TR7 being used to manufacture and actual system/model, which is subsequently qualified in an operational environment. In most cases, this TRL represent the end of the development.
	7	System prototype demonstration in operational environment	A major step increase in technological maturity. Example could include a prototype/system being verified in an operational environment.
PILOT Development with system design, testing, demonstration…	6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Prototype system verified. Examples might include a prototype system/model being produced and demonstrated in simulated environment

	5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Reliability of technology significantly increases. Examples might involve validation of semi-integrated system/model of technological and supporting elements in **a simulated environment.**
	4	Technology validated in lab	Technology validated through designed investigation. Examples might include analysis of the technology parameter operating range. The result provide evidence that envisioned application performance requirements might be attainable.
CONCEPT Different research levels to determine the technology's feasibility	3	Experimental proof of concept	Effective research and developments initiates. Examples include studies and laboratory measurement to validate analytical predictions.
	2	Technology concept formulated	Envisioned applications are speculative at this stage. Examples are often limited to analytical studies.
	1	Basic principles observed	Scientific observation made and reported. Example could include paper-based studies of a technology's basic properties.

{ 3 } TRL illustrated with examples

3.2. Qualification in simulated condition

The qualification of equipment for the environment, by systematic lab tests, is a part of the TRL progression that will be requested before any deployment at sea. These situation for this tests should cover the entire life cycle of the equipment.

Actually, depending on the domain, the situation and the equipment, there are various standards, best practices and labels to be complied with. For example, in France, there is the standard NF X10-812 (2013) - Marine Environment - Oceanographic Instrumentation - Guide for Environmental Tests, Association Française de Normalisation (AFNOR), developed by academics and industrial companies. The document is available to users and manufacturers likely for oceanographic equipment likely to be produced in large or small runs, intended to be sold “off the shelf”. It gives the series of tests to be performed and the corresponding severity for environmental factors, namely cold, damp and saline atmospheres, salt spray, solar radiation and heat, vibrations, shocks, platform motion, electromagnetic compatibility, hydrostatic pressure[1], thermal shocks upon immersion, shock due to

[1]) With respect to the hydrostatic pressure tests, it is worth reminding the relationship between pressure for tests and depth: in sea water, Pressure (bar) = (0.101 x depth (m) + 0.0000005 x depth(m)²) and for deep-sea condition, the error of assimilating 10 m to 1 bars is significant.

Maximal operating depth	Service pressure	Test pressure recommended by NFX10-812
6000 m	625 bar	750 bar
4830 m	500 bar	600 bar

swinging. This standard is used to qualify equipment produced in France such as NKE floats, acoustic releasers, COSTOF2, etc... It was the basis for the EMSO ESONET Label and, more recently, the EMSODEV partners adopted this standard for the development of the EGIM. In rare cases (e.g., cables for observatories), to ensure a longer life span and a better resistance, the reference is made to oil and gas standards but the consequences on the cost are extensive.

In GEORGE, the partners will encounter various environmental conditions (depth, temperature, concentration range), use various platforms (mobile and fix with various amount of power available and different payload capacities), act in various sites around Europe (various environmental situations) and manage various access to COTS products. **We will follow the rules in force on each platform and test (or provide the documents attesting to compliance) the resistance of the equipment to the environment, accordingly.**

The information gained from all the deployments carried out during the project will provide an opportunity for compiling a policy recommendation, and for launching the process required to establish a common standard, at least at European level. It would be available for the international oceanographic community including the International Ocean Carbon Coordination Project (IOCCP) and the Global Ocean Observing Systems (GOOS).

3.3. The test plan in GEORGE

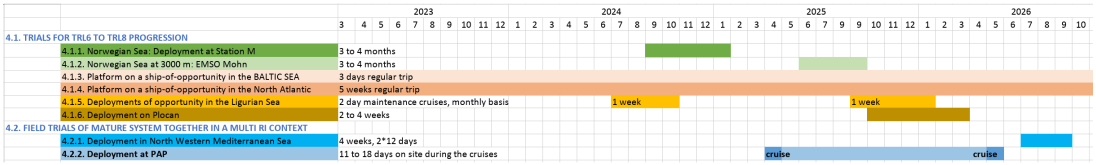
The developments in George range from completely new solutions to evolutions or integrations based on existing solutions.

For some developments, the initial plan is limited to preliminary laboratory tests (TRL 4) with the ambition of setting the background for further collaboration and there will be no TRL6 to TRL8 demonstration at sea in GEORGE. It is the case for Chlorination on LoC sensors **[F]**, Chlorination on membrane sensors **[G]**, Iridium Certus Test Bench **[O]**.

Most of the developments will match TRL 7 and 8 at the end of the project thanks to the multiple deployments in operational conditions presented in 4.1 TRIALS FOR TRL6 TO TRL8 PROGRESSION and 4.2 FIELD TRIALS OF MATURE SYSTEM TOGETHER IN A MULTI RI CONTEXT

4. The deployments in GEORGE

Within the project, there are eight deployments planned: six trials for TRL6 to TRL8 progression and two trials for the systems matured, deployed together in a multi RI context:



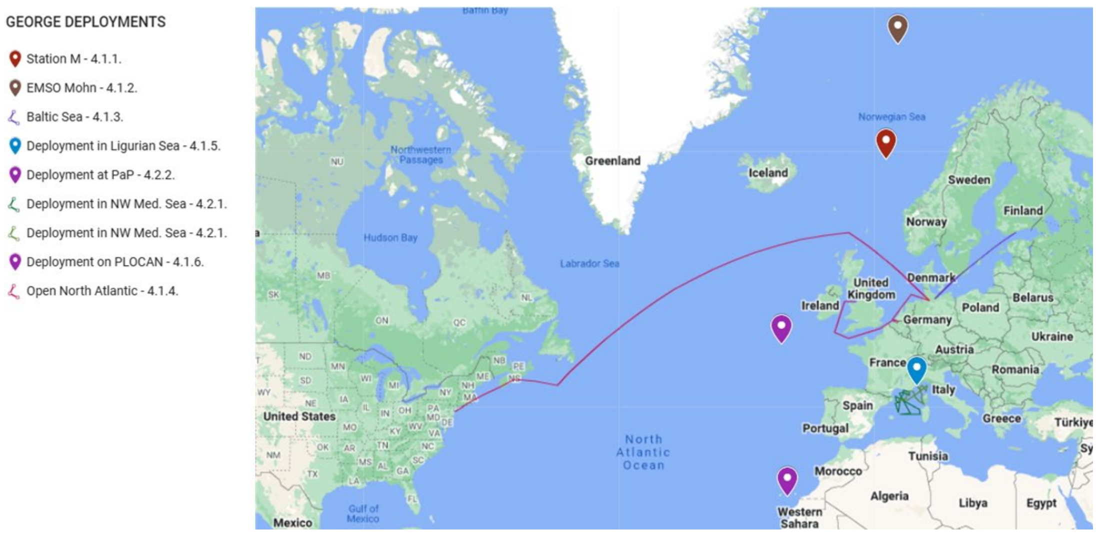


Figure 1: GEORGE deployments on a map

The following sections presents the deployments, one by one. Each presentation starts with a short **reference to GEORGE Proposal** Part B. Then, the **main objective** is detailed in a **work plan** described **step-by-step** with the results expected. The table, listing the **equipment required** , clarifies who will be in charge of the equipment provision,of the operation at sea and of the data assessment. The description gives the information available at the time of writing about the **cruise, place, date, teams involved, ship and accommodation**. The final part is related to the **major risks** and their mitigation.

The **global schedule** gathers all the information in a synthetic view, giving the type of equipment and number of units required to fulfil the program.

Responsibilities are proposed as follow:

Deployment coordination

The coordinator will lead the preparation and the deployment with the help of the task and WP leaders. He will consider logistics, authorizations, certificates and safety aspects. He will gather the participants, get the relevant authorizations, check the time lines, etc... He will establish a detailed at-sea operation plan using D5.1 and the equipment deployment procedures.

For referral, the following table lists the task and WP leaders of the deployments:

DEPLOYMENT	TASK	TASK LEADER(S)	WP LEADER(S)
Norwegian Sea: Deployment at Station M	5.2.1	UiB/EMSO	EMSO ERIC
Norwegian Sea at 3000 m: EMSO Mohn	5.2.1	UiB/EMSO	
Platform on a ship-of-opportunity in the BALTIC SEA	5.2.2	IOW/ICOS	
Platform on a ship-of-opportunity in the North Atlantic	5.2.3	UiB/EMSO	
Deployments of opportunity in the Ligurian Sea	Additional	IMEV-MER	SU
Deployment on PLOCAN	3.2	PLOCAN	SU
Deployment in North Western Mediterranean Sea	5.3	EMSO/NOC	EMSO ERIC
Deployment at PAP	5.3	EMSO/NOC	

Personnel legal coverage

Personnel due to embark on ships for the Project are covered by their employer's insurance, provided that their travel order correctly specifies the dates and places of travel and the ship concerned.

Equipment insurance

The recipient Party cannot be considered liable of the loss or damage of the equipment except if resulting from a willful act and/or gross negligence.
The Parties have signed a Consortium Agreement (CA) that details liability conditions. This agreement is wholly applicable to the deployments made for the GEORGE project but the Parties have given no warranties to each other regarding materials and equipment (incl. Results and Background) supplied by one Party to another under the Project.
For the deployments, the Party providing the equipment and the recipient Party should agree on the procedures and conditions to use the equipment (correct usage and safety rules). Insuring the equipment is strongly recommended, but remains the choice and the financial responsibility of the sole owner.

Obligations under the CA

Provided that the Party has used reasonable efforts to fulfill its tasks and applied for any necessary license or authorization properly and in due time, a party, prevented from fulfilling its obligations due to a restriction resulting from import / export laws and regulations or any delay of granting / extension of the import / export license or any other governmental authorization, shall not be considered in breach of the CA.

4.1. Trials for TRL6 to TRL8 progression

4.1.1. Norwegian Sea: Deployment at Station M

Reference to the project: this deployment is part of task 5.2.1 - Lead: UiB/EMSO. First step of the demo following pCO_2 and CH_4 sensor integration to EGIM (WP3, IFREMER), including deep-sea improvement for sensor membrane (WP2, IFREMER)

Coordinator: Ilker Fer, ilker.fer@uib.no

Main objective: The main objective is to measure pCO2 in a deep-sea environment, in-mooring behaviour

Work plan:

Objectives	Description of the operation	Result expected
1) Measurement of pCO2 using a 4H-Jena sensor in a deep-sea environment (2000 m), in-mooring behaviour	An EGIM will be included in a deep-sea mooring, 15 m above seabed. The subsurface mooring, which covers the deepest layer at Station M can benefit from one of the cruises operating the Nordic Seas Facility node at Station M. The deployment at Station M will last for several (2-4) months and will be coordinated with the regular section cruises run by the Institute of Marine Research, Norway.	The equipment is recovered in normal condition (visual inspection) The data sets are complete DOI published with metadata and data sets
2) Check the power consumption of the sensor	Calculation of the consumption expect according to the sensors present and the duty cycle	Program carried out to the end
3) Data curation, pressure influence, quantify an eventual drift	Test of the sensor in lab simulating real deployment conditions Collect water sampling at the depth of measurement during the deployment and during the recovery Analyse the water samplings on-board the vessel or, if not possible, in lab Compare the measurements against the water samplings carried out Test of the sensor in lab (temperature, pressure ant pCO2) after the deployment	Addition to the DOI data sets (information in the landing page of the DOI and data sets) of • the sampling analyse reports • the calibration reports Addition of the curated data set to the DOI (WP4)
4) TRL Progression for the EGIM with pCO2 sensor	Qualification to environment of the different parts Deployment at sea: the EGIM will be put on-board in Bergen early August or delivered to Bergen no be later than first week of September 2024 in order to be sent over to Tromsø in due time	Documentation of the deployment and recovery process Documentation of the pCO2 sensor calibration process (EMSO context) TRL8
5) Data quality and scientific analysis of the observations		Chapter in the report D5.2

Place and date: Station M { 4 } (See MAP in Figure 2: Map of station M area), September 2024 to January 2025 (3 to 4 months)

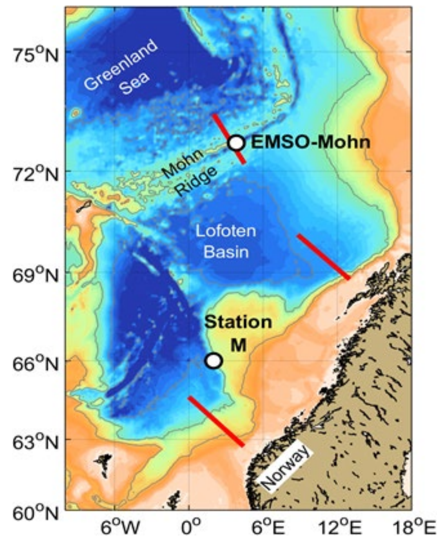


Figure 2: Map of station M area

Condition expected on the site

Maximal depth	2050 m
Conductivity	C = 2.92 S/m
Salinity	S = 34.913 +/- 0.003
Temperature	T = -0.80 +/- 0.03 °C
Dissolved oxygen	DO = 290 µmol/kg
pCO_2	pCO_2 = 323 +/-14 µatm
Sea bed temperature	T = 0.75 to -0.7 °C

Platforms, equipment and sensors required

Platform		Team in charge	Provision by
EGIM [I], { 5 }		Ifremer and/or UPC	NOC
1 Battery pack (non-rechargeable, 5 kWh)		Ifremer	Ifremer

Sensors on the EGIM	Duty cycle	Principal Investigator	Provision by ; Operation by
SeaBird SBE37-SIP*	3 seconds per acquisition Measurement duration: 1 min (minimum 15 sec) Sleeping periods: 9 min (maximum 3h)	UiB	NOC; Ifremer and UPC
AADI-3005214831 DW4831*	3 seconds per acquisition Measurement duration: 1 min (minimum 30 sec) Sleeping periods: 9 min (maximum 3h)	UiB	
Wetlabs NTUrdt*	Measurement duration: 10 s (minimum 10 sec*) Sleeping periods: 15 min (maximum 3h*)		
Teledyne Workhorse monitor ADCP 300 kHz*	Measurement duration*: 15 min (minimum 10 min) Sleeping periods*: 45 min	UiB	

	(maximum 1 day minus 10 min) Proposition for this deployment: Measurement duration: 10 min Sleeping periods: 2 hours		
SeaBird SBE54 Tsunami*	***Not requested***		
Ocean Sonics icListen SB60L-ETH*	***Not requested***		
CONTROS HydroC CO_2 with SBE-5T [I], [S]	The sensor measures once every 48 hours and for each "wake up", the sensor measures every 2 seconds for 10 minutes, and then go to sleep.	UiB	4H-Jena
CONTROS HydroC CH_4 with SBE-5T [I], [S]	***Not requested***		

**) Sensor already available on the EGIM; Recommended duty cycle are the specifications of the EGIM*

Other equipment	Team in charge	Provision by
Water sampling device	UiB	UiB
Analyse of the water samplings in lab	UiB	UiB
Deep sea mooring line	UiB	UiB

Teams involved

Ingunn Skjelvan (NORCE), Tor de Lange (UiB), Ilker Fer (UiB), Beatrice Tomasi (UiB)
Adrien Chauvet (Ifremer)
Enoc Martinez (UPC)

Information about the cruise, ship and accommodation

GO SARS { 6 } or Johan Hjort { 7 }

One person for the EGIM

In 2024, Station M cruise is scheduled on-board GO SARS, 18-30 September. The trip is Tromsø-Bergen. The ship is leaving Bergen on 15 August 2024. The 2025 cruise calendar is not set yet but the EGIM will most probably be recovered mid Jan 2025, back to Bergen by February and shipped back to Brest early Feb 2025.

Risk assessment

Risk	Mitigation
The EGIM are not updated in due time for the deployment in September 2024. The update and tests were to start in September 2023 and the equipment has not been delivered yet.	The deployment would be postponed. As a last resort, the deployment could be limited to 4 or 5 days during a maintenance cruise.
The equipment is not recovered	EGIMS will be packed in wooden boxes for shipping. There will

or damaged during deployment of transportation	be a few spare parts available.
The quantity of power available is limited on-board the EGIM	The sensor consumption will be evaluated from previous experiences, measured or provided by the supplying company. Information will be used to set up the consumption balance sheet. The duty cycles will be adjusted to reach the best compromise between scientific requirement and technical constrain. As an example, for a 5 months period, the pCO_2 sensor could measure once every 48 hours, and for each "wake up", the sensor measures every 2 seconds for 10 minutes, and then go to sleep. To afford this duty cycle, the power needs is equivalent to one HydroB battery pack, which equals 84 Lithium batteries, each of 3.6V and 13.0 Ah. An increased frequency could be achieved with increased power.

4.1.2. Norwegian Sea at 3000 m: EMSO Mohn

Reference to the project: This deployment is part task 5.2.1 - Lead: UiB/EMSO. Second step of the demo following pCO_2 and CH_4 sensor integration to the EGIM (WP3, IFREMER), including deep-sea improvement for sensor with membrane (WP2, IFREMER)

Coordinator: Ilker Fer

Main objective: Measure pCO2 and CH_4 in a deep-sea environment, seabed behaviour

Work plan:

Objectives	Description of the operation	Result expected
1) Demonstration in a deep-sea environment (3000 m), seabed behaviour	The EGIM sensors will be calibrated in Brest. The equipment will be mounted in the lander and tested then sent to Norway for deployment Deployment and recovery will be coordinated with the EMSO Mohn cruises. In a period between mid-2025 to early 2026 (The dates are not secured for the 2025 cruises), the EGIM will be deployed at 3000 m using the lander developed in WP2. The EGIM will be recovered in the subsequent deployment cruise for EMSO Mohn. During the deployment, data will be transferred through acoustic communications and pre-cruise tests can be run at halve one month before deployment.	The equipment is recovered in normal condition (visual inspection)
2) Measurement of pCO2 and CH_4	pCO_2 and CH_4 sensors will integrated in the EGIM.	The data sets are complete DOI published with raw

		datasets
3) Power consumption monitoring	Calculation of the consumption expect according to the sensors present and the duty cycle	Program carried out to the end
4) Pressure influence, eventual drift	Test of the sensor in lab (temperature, pressure and pCO_2) before deployment. Collect water sampling at the depth of measurement during the deployment and during the recovery Analyse the water samplings in lab Compare the measurements against the water samplings carried out Test of the sensor in lab (temperature, pressure and pCO_2) after the deployment	Pressure influence, eventual drift Addition of the results of the sampling analyse to the metadata (landing page of the DOI) Addition of the cured datasets to the DOI
5) TRL Progression for the EGIM with pCO2 sensor	Qualification to environment of the different parts Documentation of the deployment and recovery process Documentation of the pCO_2 sensor calibration process	TRL8 attribution
6) Data quality and scientific analysis of the observations		Report in D5.2

Place and date: EMSO Mohn { 8 }, deployment in 2025-2026 (3 to 4 months)

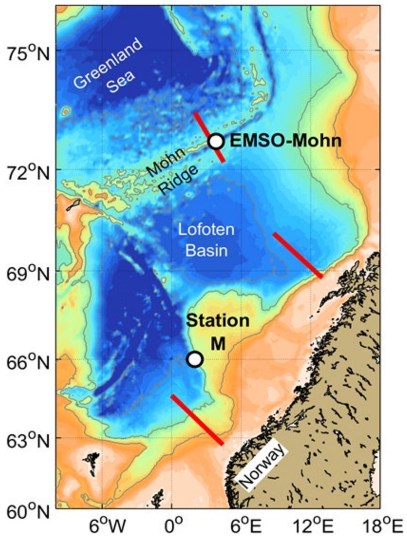


Figure 3: Map of EMSO Mohn area

Condition expected on the site

Maximal depth	3000 m
Conductivity	C = 2.92 S/m
Salinity	S = 34.913 +/- 0.003
Temperature	T = -0.80 +/- 0.03 °C
Dissolved oxygen	DO = 280 µmol/kg
pCO2	At Fåvne, in hydrothermal vents, CO_2 is a few mmolar; 15 m above would be scaled 100-1000 down, so around 10 s of micromolar of CO_2

Platforms and sensors required

Platforms	Team in charge	Provision by

EGIM [I], { 5 }	Ifremer and/or UPC	NOC
Lander [H]	Ifremer	Ifremer

Sensors on the EGIM (platform1)	**Duty cycle**	**Principal Investigator**	**Provision by; Operation by**
SeaBird SBE37-SIP*	3 seconds per acquisition Measurement duration: 1 min (minimum 15 sec) Sleeping periods: 9 min (maximum 3h)*	UiB	NOC; Ifremer or UPC
SeaBird SBE54 Tsunami*	Measurement duration: 15 sec (minimum 15 sec) Sleeping periods: none*	UiB	
AADI-3005214831 DW4831*	3 seconds per acquisition Measurement duration: 1 min (minimum 30 sec) Sleeping periods: 9 min (maximum 3h)*	UiB	
Wetlabs NTUrdt*	Measurement duration: 10 s (minimum 10 sec)* Sleeping periods: 15 min (maximum 3h)*		
Teledyne Workhorse monitor ADCP 300 kHz*	Measurement duration*: 15 min (minimum 10 min) Sleeping periods*: 45 min (maximum 1 day minus 10 min) Proposition for this deployment: Measurement duration: 10 min Sleeping periods: 2 hours	UiB	
Ocean Sonics icListen SB60L-ETH*	***Not requested***		
CONTROS HydroC CO_2 with SBE-5T [I], [S]	The sensor measures once every 48 hours, and for each “wake up”, the sensor measures every 2 seconds for 10 minutes, and then go to sleep.	UiB	4H-Jena
CONTROS HydroC CH_4 with SBE-5T [I], [S]	The sensor measures once every 48 hours, and for each “wake up”, the sensor measures every 2 seconds for 10 minutes, and then go to sleep.	UiB	4H-Jena

**) Sensor already available on the EGIM; Recommended duty cycle are the specifications of the EGIM*

Other equipment	**Team in charge**	**Provision by; Operation by**
Water sampling device	UiB	UiB
Analyse of the water samplings in lab	UiB	UiB
Battery units	Ifremer	Ifremer

Team involved

Steffen Jørgensen (UiB), Beatrice Tomasi (NORCE), Rune Øyerhamn (NORCE)
Adrien Chauvet (Ifremer)
UPC

Information about the cruise, ship and accommodation

GO SARS { 6 }, two people

Risk assessment

Risk	Mitigation
The lander is not ready for the deployment	The system will be deployed on an existing lander. The experience will be valuable to validate or change the design of the lander dedicated to the EGIM. The demonstration with the lander specifically design for the EGIM would be postpone to the deployment in PAP or Western Mediterranean.
The equipment is not recovered or damaged during deployment of transportation	EGIMs will be packed in wooden boxes. There will be a few spare parts available.
The quantity of power available is limited on-board the EGIM	Measurement of the sensor consumption will be evaluated from previous experiences or measured or provided by the supplying company. Data will be used to set up the consumption balance sheet. The duty cycles will be adjusted to reach the best compromise between scientific requirement and technical constrains. As an example, for a 5 months period, the pCO_2 sensor could measure once every 48 hours, and for each "wake up", the sensor measures every 2 seconds for 10 minutes, and then go to sleep. To afford this duty cycle, the power needs is equivalent to one HydroB battery pack, which equals 84 Lithium batteries, each of 3.6 V and 13.0 Ah. An increased frequency could be achieved with increased power.

4.1.3. Platform on a ship-of-opportunity in the BALTIC SEA

Reference to the project: This deployment is part task 5.2.2 - Lead: IOW (ICOS RI). The SOOP programme on the Finnmaid operated by ICOS ERIC as a platform to evaluate the ability of the sensors developed in WP2 to characterise the carbonate system across a range of salinities. The Baltic Sea area will also allow the evaluation of the ARVOR (T, S, P), Argo float adapted for shallow water.

Coordinator: Henry Bittig, henry.bittig@io-warnemuende.de

Main objective: Evaluation of sensors developed in WP2 and COTS sensors and their ability to characterize the carbonate system in **coastal Baltic Sea** across a range of salinities.

Workplan:

Objectives	Description of the operation	Result expected
1) Integration of new sensors on the line • HydroC Combi CO_2 / CH_4 FT • SOOP sampler from OCEOMIC (option; or SOOP North Atlantic)	The figures below show the SOOP line Finnmaid, the ship, and the installation on board. Water is pumped from ca. 3 m depth to the system. It passes a thermosalinograph and is directed through a manifold to two equilibrator-based trace gas systems for pCO_2, CH_4, and N_2O, to a pair of PreSens oxygen optodes, and to a HydroFIA instrument measuring pH. As for now, there is no real-time data transmission to shore. This might be implemented, depending on funding. Data can be retrieved every 3 days when the ship is in port. For the integration of new sensors, new secured seawater channels need to be built, which is funded through GEORGE and available in early 2024.	Sensors made available Sensor integrations complete
2) Evaluation of the sensors developed in WP2 to characterize the carbonate system	Sensor operating during the transit.	The data sets are complete DOI with raw dataset
3) Evaluation of the sensors developed in WP2	Compare the measurements against the reference instrumentation.	Addition of the curated dataset to the DOI TRL8 for HydroC Combi CO_2/CH_4 FT and SOOP sampler from OCEOMIC

Place and date: 3 day round trip Lübeck-Travemünde – Helsinki – Lübeck-Travemünde.

Figure 4: SOOP ICOS-DE Finnmaid

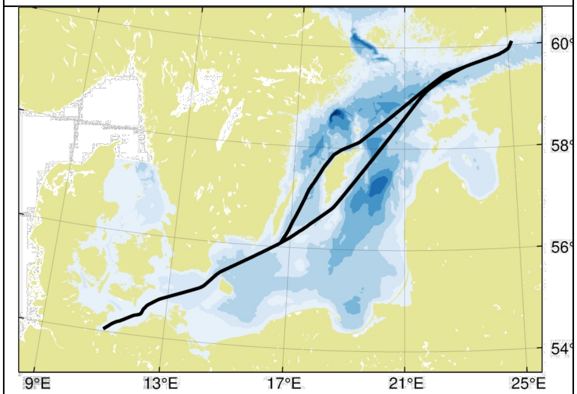


Figure 6: Round trip track

Figure 5: Installation on-board

Condition expected on the site

Water depth	Pump intake at ca. 3 m water depth
Temperature	0 - 25 °C
Salinity	5 - 19
Oxygen saturation	80 - 150 %
pCO_2	80 - 800 µatm
pH	7.5 - 8.7

Platforms, equipment and sensors required

Platforms	Team in charge	Provision by
Installations on SOOP ICOS-DE Finnmaid { 9 }	IOW	IOW

Sensors on the platform	Duty cycle	Principal Investigator	Provision by; Operation by
Dissolved oxygen*: PreSens Oxygen Optode Q=2	1 Min.	H. Bittig	IOW
pH*: -4H-Jena Contros HydroFIA pH	15 Min.		IOW
pCO2*: 2x equilibrator-based reference systems (with Picarro / Los Gatos instruments)	1 Min.		IOW
Methane*: 2x equilibrator-based reference systems (with	1 Min.		IOW

Picarro / Los Gatos instruments)			
Alkalinity (AT): via WP4.2 Task ii: To add -4H-Jena CONTROS HydroFIA TA [M]	15 Min		-4H- Jena (Spring/Summer 2024)
CONTROS HydroC Combi CO_2/CH_4 FT [L]	1 Min.		-4H-Jena (December 2023)

**) Sensors present on the experiment under way*

Other equipment	Team in charge	Provision by; Operation by
SOOP sampler [U] (or SOOP Atlantic)	M. González Dávila H. Bittig	OCEOMIC-ULPGC (2025)

Teams involved

IOW is operating all equipment in connection with ICOS SOOP.

Information about the cruise, ship and accommodation

Easy possibility to join the ship (ferry line)
The SOOP line is part of ICOS Ocean (DE-SOOP Finnmaid). It is a ferry running between Lübeck-Travemünde (Germany) and Helsinki (Finland) with a round trip of 3 days.

Risk assessment

Risk	Mitigation
Late availability of SOOP sampler for D5.2 (M36)	Evaluation of SOOP sampler on VOS line Gran Canaria - Barcelona

4.1.4. Platform on a ship-of-opportunity in the North Atlantic

Reference to the project: This deployment is part task 5.2.3 - Lead: UiB/EMSO. SOOP programme operated by GEOMAR as part of ICOS is used to evaluate the ability of the sensors developed in WP2 to characterise the carbonate system in the open N Atlantic.

Coordinator: Tobias Steinhoff, tsteinhoff@geomar.de

Main objective: Evaluation of the sensors developed in WP2 to characterize the carbonate system

Workplan:

Objectives	Description of the operation	Result expected
1) Integration of new sensors • HydroC CO_2 FT Hybrid • OCEOMIC SOOP sampler (or SOOP Baltic Sea)	The figures below show the SOOP line Atlantic Sail and the installation on-board. Water is pumped from the sea chest (ca. 10 m depth) to the system. First, it enters a thermosalinograph (SBE21) which also acts as manifold. Then, part of the water goes through an Aanderaa oxygen optode and	

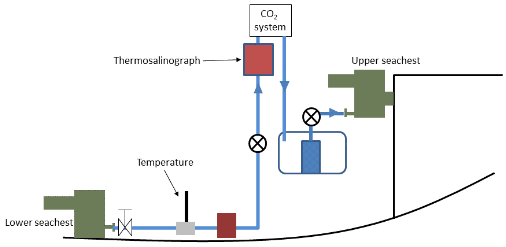
<table>
<tr><td></td><td>then through the GO 8050 pCO_2 system. A second bypass goes through a cross-flow filter and feeds the two Hydro FIA instruments measuring pH and TA.
As for now, there is no real-time data transmission to shore. This might be implemented in the next years, depending on funding. Data can be retrieved every 5 weeks when the ship is in port in Europe.</td><td></td></tr>
<tr><td colspan="3">

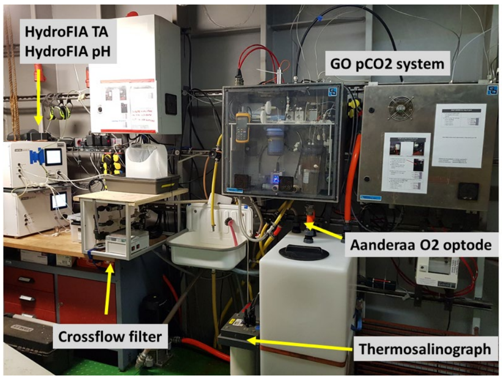
Figure 7: Schematic of installation in the engine room on-board the SOOP line Atlantic Sail


Figure 8: Installation of underway system on-board SOOP line Atlantic Sail.</td></tr>
<tr><td>2) Evaluation of the sensors developed in WP2</td><td>Sensor operating during the transit</td><td>The data sets are complete
DOI published with raw dataset</td></tr>
<tr><td>3) Evaluation of the sensors developed in WP2 to characterize the carbonate system</td><td>Compare the measurements against the reference measurement</td><td>Addition of the cured datasets to the DOI</td></tr>
</table>

Place and date: 5 weeks round trip, Europe – North America – Europe / departure twice a month

The SOOP line is part of ICOS Ocean (DE-SOOP-Atlantitoc Sail. It is a combined car/container ship having regular port calls in Europe (Liverpool, Antwerp, Hamburg, see cruise track below) and North America (Canada: Halifax, US: New York, Baltimore, Norfolk). The easiest access to the ship is during the port call in Hamburg (regular maintenance). The ship is in Europe every 5 weeks.

Figure 9: SOOP line Atlantic Sail

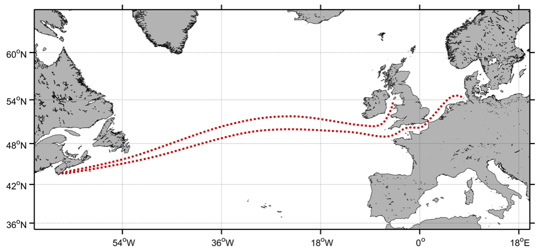


Figure 10: Approximate cruise track of SOOP line Atlantic Sail

Condition expected on the site

pH	7.6 - 8.1
pCO2	250 - 500 µatm
Alkalinity	2100 - 2600

Platforms, equipment and sensors required

Platforms	**Team in charge**	**Provision by**
1- Equipment on a ship of opportunity { 10 }	GEOMAR	GEOMAR

Sensors on the platform	**Duty cycle**	**Principal Investigator**	**Provision by; Operation by**
Dissolved oxygen (Aanderaa 4330)*	1 min	T. Steinhoff	GEOMAR
pH (4H-Jena HydroFIA pH)*	15 min		GEOMAR
pCO_2 (GO 8050)*	1 min		GEOMAR
Alkalinity (4H-Jena HydroFIA TA)*	15 min		GEOMAR
HydroC CO_2 FT Hybrid [K]			4H Jena (December 2023)

**) Sensors present on the experiment under way*

Other equipment	**Team in charge**	**Provision by; Operation by**
SOOP sampler [U] (or SOOP Baltic Sea)	M. González Dávila H. Bittig	OCEOMIC-ULPGC (2025)

Team involved

GEOMAR team is operating all the equipment.

Information about the cruise, ship and accommodation

Possibility to join the ship between Europe and Halifax/Canada. One crossing takes around 10 days. In principle, it is possible to send a person with the ship during an Atlantic crossing. This needs to be negotiated every time, but this opens the opportunity to install new equipment and operate it under supervision.

Risk assessment

Risk	Mitigation
Late availability of SOOP sampler for D5.2 (M36)	Evaluation of SOOP sampler on VOS line Gran Canaria - Barcelona

4.1.5. Deployments of opportunity in the Ligurian Sea

Reference to the project: This deployment is an addition to the project proposal. The frequent and short maintenance operations at sea are valuable opportunities to carry out George experiments. - Lead: WP3

Coordinator: Laurent Coppola, laurent.coppola@imev-mer.fr; Edouard Leymarie, edouard.leymarie@imev-mer.fr

Main objectives: Deploy and test over a few days including various sensors developed or improved in WP2 on mobile platforms (Argo floats and gliders)

Work plan:

Objectives	Description of the operation	Result expected
1) Tests the new sensor on gliders and floats • acoustic, • pCO_2, • TA-TC-pH	Deploy various platforms (gliders and Argo floats) with new sensors during a few days: sensors, communication, data	The data sets are complete DOI with raw dataset
2) Inter-comparison with *in situ* sampling	The samplings are carried out during MOOSE monthly cruises at DYFAMED fixed station and/or coastal station in Villefranche bay. Recover the platforms and the data for delayed mode verification	Addition of the cured dataset to the DOI Report

Place and date: 2024, during one of the cruises in Villefranche/Mer

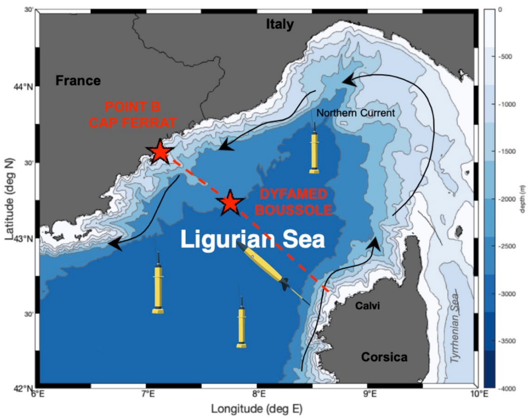


Figure 11: Cruises to DYFAMED

Environmental conditions expected on the site, for the gliders (platform 1.1, 1.2) and the floats (platform 2.1, 2.2)

Dissolved oxygen	150-320 µmol/kg
pH	8-8.15 (total scale)
pCO_2 (surface)	380-420 µatm
TA, DIC	TA: 2500-2620 µmol/kg; TC: 2150-2350 µmol/kg
Depth	0-2000 m
Temperature	10-28 °C
Marine traffic	Quiet from Nov to May
Security intervention	With private rapid boats

Platforms and sensors required

Platforms	Team in charge	Provision by
1.1 and 1.2 - Sea-Explorer { 11 }	LOV + ALSEAMAR	ALSEAMAR
2.1 and 2.2 - PROVOR CTS5 { 12 }	LOV + NKE	NKE

Sensors on the Sea Explorer (platform 1.1)	Duty cycle	Principal Investigator	Provision by; Operation by
DO (AROD JFE)*	1 s, multi-yo 0-500/1000 m, 3-5 km	L. Coppola	ALSEAMAR; LOV + ALSEAMAR
FLBBCD (Wetlabs)*	4 s, multi-yo 0-500/1000 m, 3-5 km		ALSEAMAR; LOV + ALSEAMAR
Integrated microsens ISFET+LoC pH sensor [N]	1s		CWS
Acoustic Purpoise [V]		L. Coppola	SU/LOV
pCO2 Min-Pro [W]		L. Coppola	ALSEAMAR; LOV + ALSEAMAR
CTD RBR LEGATO [X]	1s, multi-yo 0-500/1000m, 3-5km	L. Coppola	ALSEAMAR; LOV + ALSEAMAR

**) Sensors already available on the Sea-Explorer*

Sensors on the Sea	Duty cycle	Principal	Provision by;

Explorer (platform 1.2)		Investigator	Operation by
Integrated microsens ISFET+ LOC pH sensor [N]	1s		CWS
LoC TADIC [R]	Every ~10 minutes	L. Coppola, S. Loucaides	NOC; LOV + ALSEAMAR
Sensors on the Provor CTS5 (platform 2.1)	**Duty cycle**	**Principal Investigator**	**Provision by; Operation by**
CTD (SBE)*	2s, 0-2 000m. Profile every 3 days TBD	L. Coppola	LOV
Passive Acoustic [B]	5 min during parking @ 1 000m	E. Leymarie	NKE; LOV

**) Sensors already available on the PROVOR CTS5*

Sensors on the Provor CTS5 (platform 2.2)	Duty cycle	Principal Investigator	Provision by; Operation by
Linux Core [C]	2 s, 0-2000 m. Profile every 3 days TBD	E. Leymarie	NKE; LOV

Team involved

ALSEAMAR: L. Beguery, F. Margirier

LOV: L. Coppola, E. Leymarie, A. Poteau, C. Desjardins, P. Stil

NOC: S. Loucaides

Information about the cruise, ship and accommodation

For deployments in open sea, there are 11 cruises to DYFAMED { 13 } on board RV TETHYSII planned for 2024. One of them will host George experiments. For coastal waters there are cruises on a weekly basis on-board SAGITTA III (in Villefranche/Mer).

SAGITTA III { 14 }, TETHYSII { 15 } and PELAGIA, a free-access barge (5 m, 80 HP).

Risk assessment

Risk	Mitigation
The equipment is not ready for the planned deployment.	Deployment opportunities are multiple.
Laboratory vessels not available or unable to retrieve the equipment.	Rent a commercial vessel.
Collision between autonomous platform and ship.	Minimize surface time. Choose the safer areas and deployment periods (with the minimum traffic).

4.1.6. Deployment on PLOCAN

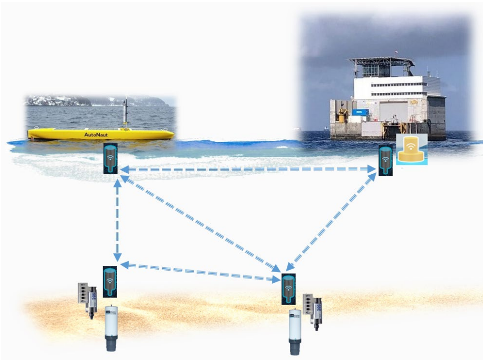
Reference to the project: This deployment will demonstrate capabilities of a novel underwater acoustic communication system in the context of multi-platform observations using IoT (Internet of

Things); this will enable communications between sensors and platforms underwater and ultimately real-time data transmission from underwater infrastructure to shore. Task 3.2 Novel communication systems, Lead: WP3, SU.

Coordinator: Eric Delory, eric.delory@plocan.eu

Main objective: Demonstrate enhanced communications between platforms underwater through acoustic and continuous real-time transmission and control

Work plan:

Objectives	Description of the operation	Result expected
1) Functional testing of an underwater-based communication system for the underwater Internet of Things	A multi-nodes system (up to 6 nodes, realistically 2-3 nodes + 2-3 for replacement if needed) and gateway will be deployed at the PLOCAN test site. The performance (e.g. bandwidth with regard to distance) will be evaluated vertically (from seabed to surface), with various inclination and horizontally.  Figure 12: Communication between nodes	Communication reports on functionality and performances of the WSense wireless system in the field. Recommendations to prepare for deployments in various platform situations
2) Sensor integration	In lab, virtual sensors (simulators) will be interfaced with Wsense platform to ensure the system is fit for purpose.	Integration and communication between the sensor and Wsense platform
3) Test with sensors in real conditions	Integration real sensors on the platform to measure pCO2, preferably WP2 sensors if available.	Transmission of sensor data

Place and date: 2025, PLOCAN test site { 16 }

Figure 13: Plocan platform

Conditions expected on the site:

Depth	0 – 600 m

In progress, sea surface:

Dissolved oxygen	200-290 umol/L
Temperature	18ºC – 24ºC

More data (physics and chemistry) available at depth at several locations down to 600 m (for example, sound velocity profiles can be provided), surface and underwater

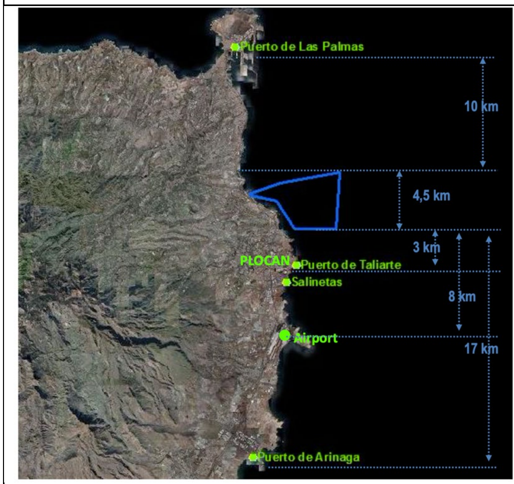


Figure 14: Map of the area

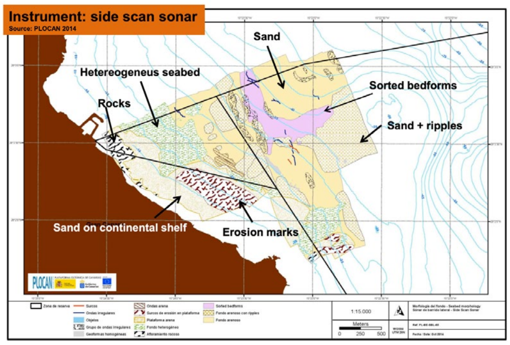


Figure 15: Bathymetry map

Platforms, equipment and sensors required

Platforms	Team in charge	Provision by
1- Communication Gateway [Z]	WSense	WSense
2- Coastal instrument platform sensor cabled to PLOCAN platform { 16 }	PLOCAN	PLOCAN
3- Autonaut { 17 }	PLOCAN	PLOCAN

Sensors on Autonaut (platform 3)	Duty cycle	Principal Investigator	Provision by; Operation by
LoC sensor pH [Y]		S. Locaides	CWS
LoC sensor TA [R]			NOC
CTD (temperature, salinity)			PLOCAN

Other equipment	Team in charge	Provision by; Operation by
Coastal instrument platform sensor cabled to PLOCAN	PLOCAN	PLOCAN

platform { 16 }		

Teams involved:

PLOCAN: Eric Delory, Manuel Batista, Rayco Moran, Vidina Monagas.

WSense: Michel Nati, Chiara Petrioli, Daniele Spaccini, Georgia Koutsandria

Information about the cruise, ship and accommodation

PLOCAN owns small boats (inflatable and rigid) and subcontracts larger work vessels equipped with cranes, for its day to day sea operations, deployments, recovery of equipment, and access to the offshore platform, with capacity to welcome personnel on-board, such as the ones below. Offshore platform can welcome personnel, access conditions depend on wave height (1,1 m max), and timing limited to 09h00 to 14h00, leaving Taliarte harbour at 08h00, back at 15h00. Staying overnight on platform is not yet formally in place.

Risk assessment

Risk	Mitigation
Limited budget for moorings, acoustic release needed at depth	Reduce the number of nodes to 2-3 Avoid depths greater than 100 m requiring costly acoustic release systems.
Test site / offshore platform availability (maintenance / overload) for time period Probability: low, impact: high	Ensure platform/test site space time window is secured ahead of time (1 year min.) and reserved for time periods Fall back plan: other PLOCAN sites available, and synergies with other projects on Tenerife or La Palma island
Delay / availability of nodes / gateway / sensors for integration and validation time periods. Probability: low; Impact: medium	Ensure components are secured ahead of time (1 year min.) and reserved for time periods Fall-back plan (sensors): reserve extra sensors, even on different variables
The Autonaut platform is not available	We will find another platform within George (ARGO float, Sea-Explorer, Sailbuoy or EGIM) depending on the schedule, availability of the equipment and on technical aspects In a last resort we would limit the demonstration to the communication between the 2 platforms (node and gateway) provided by Wsense
The WP2 sensors are not available	We will use off the shelf sensors or just demonstrate the feasibility using simulators

4.2. Field trials of mature system together in a multi RI context

Task 5.3: We will bring together the sensors developed in the programme to undertake a full characterisation of the carbonate system using the multiple platforms operated by the three RIS.

4.2.1. Deployment in North Western Mediterranean Sea

Reference to the project: This deployment is part task 5.3 - Lead: EMSO/NOC. Step 1 of the field trials to demonstrate the operation of the mature systems together in a multi RI context in the North Western Mediterranean Sea

Coordinator: Laurent Coppola, EMSO, laurent.coppola@imev-mer.fr

Main objective: What optimal array of platform do we need to measure carbon? Full characterization of the carbonate system using the multiple platforms operated by the 3 RIs

Work plan:

Objectives	Description of the operation	Result expected
1) Measurement in the full water column	Two North-South sections of CO_2 (TA-DIC-pH) are regularly visited every year during the MOOSE-GE cruises in the Mediterranean Sea NW basin. During these sections, GEORGE platforms (gliders, Sailbuoy, Argo floats) will be deployed to augment the capacity to observe the CO_2. We will validate and qualify the sensors and the data that will be provided by the platforms. In addition, the EGIM equipped with pCO_2 sensors will be deployed at the beginning of the cruise and recovered at the end of the cruise. It will be installed on the seabed with the lander or on a dedicated mooring, It is also planned to install a pCO_2-pH autonomous system on-board to measure continuously the surface water during the cruise.	Recovery of the systems No damage (visual inspection) Data sets with DOIs
2) Inter-comparison between platforms, route and meeting points	Sea-Explorer, Argo floats, Sailbuoy, EGIM: similar sensor variables (e.g. pCO2, AT-CT, pH) will be mounted on the different platforms. Different reference stations will be planned to cross-validate dataset for different platforms like gliders and Sailbuoy. The number of meeting point during the cruise will depend on the number of stations and weather conditions.	
3) Evaluation of the performance of the sensors by data comparison against bottle samples collected from ships and with on-board measurements	Data provided by the different sensors will be compared with *in situ* sampling at the different stations during the cruises. A calibration system will be installed on-board to inter-compare pCO2 sensors. Thanks to the facilities on-board the RV vessel, we plan to analyse DO by Winkler	Addition to the DOI data sets (information in the landing page of the DOI and data sets) of • the sampling analyse reports

	technique, TA by titration, pH by spectrophotometry. The labs and the facilities on-board will provide the opportunity to analyse a large amount of samples for TA-DIC-pH-DO and nutrients in order to compare the different dataset.	• the calibration reports Addition of the QC'd dataset to the DOI
4) Estimation of air-sea fluxes	The estimation of air-sea fluxes during the period of deployment will be based on data collected *in situ*, model products and machine learning predictions (linked to WP4)	
5) Demonstration of adaptive sampling strategy [A]	At the scales of the open sea trials, an adaptive optimal sampling technique will be used to provide alternative observational strategies based on maximizing observational skill. Modelled fields and/or near real-time satellite data will be sub-sampled in simulated sea trials. The geographical and temporal parameters of the simulated sea trials will be varied, within realistic limits, and the resulting observations and Modelled fields and/or near real-time satellite data quantitatively compared with respect to one or more cost functions (e.g. the error in a surface chlorophyll map). The variation in the geographical and temporal parameters of the simulated sea trials will continue following a simple neural network style approach at each iteration until the cost-function is at a minimum, which will define a maximum in observational skill. The result will be an optimized alternative observational strategy for informing those in charge of the trials programme. This will be repeated at regular intervals during the sea trial programme.	
6) What optimal array of platform do we need to measure carbon?	Using the multiple platforms operated by the 3 RIs during described	Final report including • Recommendations of sensors and practices for various platforms and deployment situations

		• Recommendation about the sampling strategy to achieve the full characterization of the carbonate system

Place and date: Summer 2026; 2 x 12 days on board RV Pourquoi Pas? { 18 }; EMSO-LION { 19 }, EMSO-LO { 20 } and EMSO-DYFAMED { 13 }

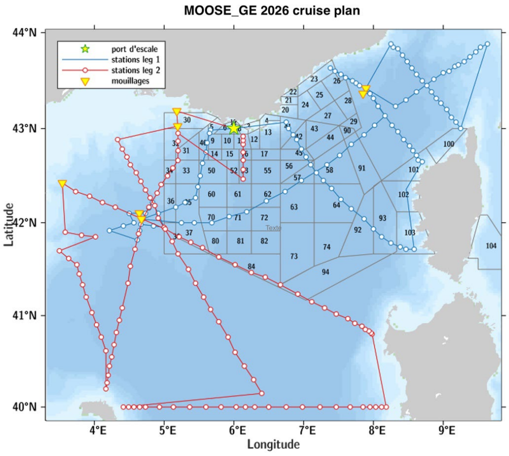


Figure 16 MOOSE_GE cruise stations planned for 2026

Blue dots leg 1 and red dots leg2. The yellow triangles represent the fixed mooring from EMSO (open sea) and ILICO-RI (coastal)

Environmental conditions expected on the EGIM (Platform 1)

Dissolved oxygen	150-320 µmol/kg
pH	8-8.15 (total scale)
pCO2	380-420 µatm
TA, DIC	TA: 2500-2620 µmol/kg; TC: 2150-2350 µmol/kg

Platforms and sensors required

Platforms	Team in charge	Provision by
1- EGIM [I] { 5 }	Ifremer and/or UPC	NOC
2.1 - PROVOR CTS5 with Passive acoustic [B]	LOV	LOV (1 unit)
2.2 - PROVOR CTS5-DO (up to 3 units, the number of floats and package of sensors) { 12 }	Euro-Argo	Euro-Argo
2.3 - ARVOR (T,S,P) ARGO Floats for shallow water (up to 2 unit) { 21 }	Euro-Argo	Euro-Argo
3- Sea-Explorer { 11 }	LOV	ALSEAMAR
4- Sailbuoy { 22 }	EXETER	Operation shared between Norway and Ireland
5 – RV Pourquoi Pas ?	LOV	FOF

Sensors on EGIM (platform 1)	Duty cycle	Principal Investigator	Provision by; Operation by
SeaBird SBE37-SIP*	3 seconds per acquisition Measurement duration: 1 min (minimum 15 sec) Sleeping periods: 10 min (maximum 3h)	L. Coppola E. Leymarie	NOC; Ifremer or UPC
SeaBird SBE54 Tsunami*	***Not requested***		
AADI-3005214831 DW4831*	3 seconds per acquisition Measurement duration: 1 min (minimum 30 sec) Sleeping periods: 9 min (maximum 3h)		
Wetlabs NTUrdt*	Measurement duration: 10 s (minimum 10 sec*) Sleeping periods: 15 min (maximum 3h*)		
Teledyne Workhorse monitor ADCP 300 kHz*	Measurement duration: 15 min (minimum 10 min) Sleeping periods: 45 min (maximum 1 day minus 10 min)		
Ocean Sonics icListen SB60L-ETH*	Duty cycle to be defined in accordance with deployment type, sleeping period are to be defined in accordance with A6 (ADCP) to avoid perturbation	E. Leymarie	
CONTROS HydroC CO_2 with SBE-5T [I], [S]	***To be confirmed***		4H-Jena; Ifremer or UPC
CONTROS HydroC CH_4 with SBE-5T [I], [S]	***Not requested***		
Loc pH sensor [H]		S. Loucaides	CWS
LoC TA [H], [Q]		S. Loucaides	NOC
LoC DIC [H], [Q]		S. Loucaides	NOC

**) Sensor already available on the EGIM; Recommended duty cycle are the specifications of the EGIM*

Sensors on ARGO Float CTS5-Acoustic (platform 2.1)	Duty cycle	Principal Investigator	Provision by; Operation by
CTD (SBE)*	2s, 0-2 000m. Profile every 3 days TBD	L. Coppola	LOV; LOV

DO AADI*	2s, 0-2 000m. Profile every 3 days TBD	L. Coppola	LOV; LOV
Passive acoustic [B]	5 min during parking @ 1 000m	E. Leymarie	NKE; LOV

**) Sensors already available on ARGO Floats CTS5*

Sensors on PROVOR CTS5-DO (platform 2.2)	Duty cycle	Principal Investigator	Provision by; Operation by
CTD*	2s	L. Coppola	Euro-Argo
DO AADI*	2s, 0-2 000m. Profile every 3 days	L. Coppola	Euro-Argo

**) Sensors already available on ARGO Floats CTS5*

Sensors on ARGO Float Arvor (platform 2.3)	Duty cycle	Principal Investigator	Provision by; Operation by
CTD*	2s	L. Coppola	
DO*		L. Coppola	

**) Sensors already available on ARGO Floats Arvor*

Sensors on Sea-Explorer (platform 3)	Duty cycle	Principal Investigator	Provision by; Operation by
DO (CODA RBR)*	4s 0-1000m	L. Coppola	ALSEAMAR; LOV
pCO2 (Pro-Oceanus)*		L. Coppola	ALSEAMAR; LOV
LoC TADIC [R]		L. Coppola	NOC
Integrated microsens ISFET + pH sensor [N]	1s		CWS

**) Sensors already available on the Sea-Explorer*

Sensors on Sailbuoy (platform 4)	Duty cycle	Principal Investigator	Provision by; Operation by
CTD*			Offshore Sensing Exeter
CaPASOS [E]		U. Schuster	Offshore Sensing Exeter

**) Sensors already available on the Sailbuoy*

Equipment on-board the PP ? (platform 5)	Duty cycle	Principal Investigator	Provision by; Operation by
Tank of water on board the ship	Calibration of pCO2 on board before deployment	M. Becker, T. Steinhoff	UiB; GEOMAR
HYDROC FT (optional,	pCO2 surface measurements	K. Seelman	4H-JENA

tbc)		L. Coppola	
CTD SBE911 (profiler)		L. Coppola	LOV
DO (SBE43/RINKO and Winkler)		L. Coppola	LOV
pH (spectrometry)		T. Wagener	MIO
TA, TC (in situ)		L. Coppola	LOV
Nutrients (colorimetry)		T. Wagener	MIO

Other equipment	Team in charge	Provision by; Operation by
EGIM Lander [H]	Ifremer	Ifremer
Battery units (rechargeable batteries) [J]	Ifremer	Ifremer

Teams involved

LOV, EURO-ARGO, EMSO, NOC, ICOS, MIO, ALSEAMAR, EXETER

Ifremer, UPC

Information about the cruise, ship and accommodation

The cruise will take place in summer 2026, on the RV Pourquoi Pas? { 18 } or another French Vessel. It will be a joint operation with MOOSE-GE cruise, LOV (MOOSE/ILICO-RI). The call for the ship time, 2 x 12 days on board, will be in summer 2024. The size of the ship and the organisation in 2 legs will open the door to large participation of the partners.

Risk mitigation

Risk	Mitigation
RV Pourquoi Pas ? not available for the cruise in 2026	Another French vessel can replace the RV Pourquoi Pas ? Small vessel are also available.
Agreement for deployment of the platforms Sailbuoy	Integration of AIS on the ASV platform Use of GPS position as a virtual AIS
Rechargeable battery units are not available	Use non rechargeable batteries
EGIM Lander is used on another site at the moment of this deployment	The EGIM would be included in a deep-sea mooring, possibly in DYFAMED, weight permitting. In this configuration, the EGIM would be installed at 100 m depth to enable a comparison with the other sensors present in the line.
The equipment is not recovered or damaged during deployment of transportation	EGIMS will be packed in wooden boxes. There will be a few spare parts available.

4.2.2. Deployment at PAP

Reference to the project: This deployment is part task 5.3 - Lead: EMSO/NOC. It is the second step of the final field trials to demonstrate the operation of the mature systems together in a multi RI context. The deployment at PAP will demonstrate operation of all GEORGE technologies in a **deep open ocean environment**.

Coordinator: Socratis Locaides, s.loucaides@noc.ac.uk ; Andrew Gates, arg3@noc.ac.uk

Main Objectives: Full characterization of the carbonate system using the multiple platforms over a deep long-term deployment.

Results will be used in WP4 for observing system design.

Work plan:

Objectives	Description of the operation	Result expected
1) Complementary data series from PAP mooring with seabed information	PAP site is an ICOS site for surface CO_2 data, with a long time series of data in very deep sea (5480m). Complement the data series and document the oceanic processes near the sea bottom was anticipated at the early stage of the FixO3 project (https://en.wikipedia.org/wiki/European_Multidisciplinary_Seafloor_and_water_column_Observatory) and carried out in PLOCAN during EMSODEV project. Contribution of GEORGE to the PAP long-term data series.	Data series from the seabed. Deep-sea data from turbidity and ADCP will be especially useful for PAP, to be used alongside the Bathysnap camera at depth. Other deep ocean EGIM sensor data will be validated against the annual deep CTD samples taken on the PAP process studies. GEORGE will also complement to surface CO_2 data collected at PAP, especially with the Sailbuoy and the CaPASOS data will add on-board standards to the ProOceanus data collected on the PAP1 mooring.
2) Evaluate long-term performance of sensors over 1 year deployment in open ocean and at depth (> 5000 m)	The deployment on PAP will be the only long term and very deep-sea deployment of the project. The mooring line and the EGIM lander will be on site over one year at near 5000 m depth. The EGIM sensor package will be integrated to a lander and deployed from the surface in free fall or attached to a cable. An acoustic signal will trigger the recovery after 1-year deployment. Evaluate performance of membrane sensors at 1 and 30 m depth from samples collected by the GEORGE sampler.	Recovery of the systems No damage (visual inspection) 1-year long dataset of carbonate system from the seabed with complimentary bathysnap data. Evaluation of autonomous sampler and performance of antifouling system on membrane sensors. DOI published with the

		raw data set
3) Evaluation of the performance of the sensors by data calibration against bottle samples taken from ships	Sensor calibration (or test in lab) before the deployment using the calibration rig developed through GEORGE WP4 Collect water samples from the full profile depth for validation of the sensors on the EGIM and shallow mooring sensors. Water samples are routinely collected on PAP process studies for all core oceanographic variables including carbonate chemistry. Take and preserve water samples using the sampler developed in WP2 over a year (2025-2026). The sampler will be at 1 m or 30 m depth to collect calibration data for the membrane sensors. All measurements will be compared with on-board analysis (TA/DIC/pH) of samples collected on site by the ship (DIC/TA/pH routinely measured at PAP, along with O_2, salinity, nutrients, chl, organic material). Sensor calibration (or test in lab) after deployment	Addition to the metadata (information in the landing page of the DOI and data sets) • the sampling analyse reports • the calibration reports Addition of the QC'd dataset to the DOI Validation of sensor output and auto-sampler measurements to CTD samples taken each year at the PAP-SO (comparison with previous time series) Inter-calibration of surface measurements.
4) Determination of the optimal set of observations to describe air/sea flux with high precision	There are atmospheric and in water (1 m and 30 m) sensors measuring surface pCO_2 year round at PAP-SO The CaPASOS instrument has on-board standards and should achieve grade A measurements in SOCAT. This would be a good opportunity to compare the data with the membrane systems on both the EGIM and the PAP1 mooring.	Recommend cross comparison with membrane (Pro-Oceanus) sensors used at PAP1.
5) Communication between platforms	There have been some trials of acoustic data transmission at PAP but it has not been successful to date. An umbilical connects the 30 m frame on PAP1 to ensure NRT transmission of subsurface data. The purpose can be various: getting the data from the autonomous equipment deployed to check that everything is working properly before leaving the site for a long time, getting data samples to check if the system is drifting... We will test the transfer through acoustic communication of data from the EGIM to a glider and to a surface vehicle. How long ? what data ?	Progress towards transmission of any deep data to the surface for iridium transfer, transposition of the way it worked the on Azores with the surface buoy

6) Deployment and recovery of floats ?	The floats will be deployed on the site during the cruise in 2025 and recovered in 2026.	BGC floats and gliders have been deployed at PAP-SO before (EXPORTS, iFADO, GOCART projects), but they do not tend to have carbonate chemistry aside from pH on the Argo floats. With a move to net zero it would be good for PAP if this could be demonstrated as an option for the future.
7) Deployment and recovery of ASV and gliders	In the iFADO project a glider was deployed from deep waters off Ireland (by the MI) to circle PAP (December 2022). The glider did not have carbonate chemistry so this would be especially useful to see if deployment from shore is feasible in delivering high quality CO_2 data at PAP-SO. Sailbuoy and the Sea-Explorer might travel from the shore and the site in surface and between surface and 1000 m depth. Restrictions may be battery power and number of sensors that can be carried.	
8) Full characterization of the carbonate system using the multiple platforms	Currently pCO2 (and sometimes pH) is measured year round at PAP in the surface ocean. GEORGE would potentially add year round DIC sampling. Full carbonates system characterisation will be achieved by EGIM alone but possibly by the shallow sensor frame if LoC TA sensor is added. Inter-comparison between float-mooring-glider-ASV measurements	Final report
9) Test of rechargeable batteries in deep sea operational conditions	PAP1 technical team will be interested in use and development of rechargeable batteries – it is especially difficult to find a reliable long term solution for this Deploy a prototype of the rechargeable batteries at 4850 m depth and use it to power an equipment, possibly an EGIM	TR7 or TR8

Place and date: The PAP site { 23 } is located 2.5 days trip from shore, at 1000 km from Ireland. The maintenance campaign is 14 days long. PAP is only visited once a year. The only possible time slot for the deployment is April / May 2025 to April / May 2026.

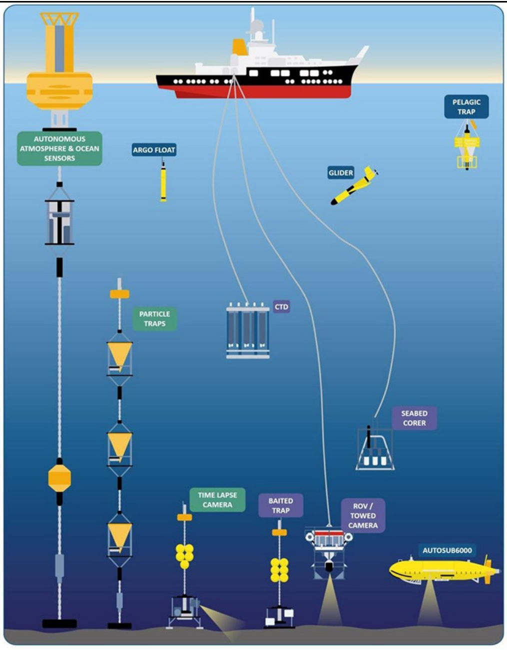


Figure 17: Instrumentation on PAP

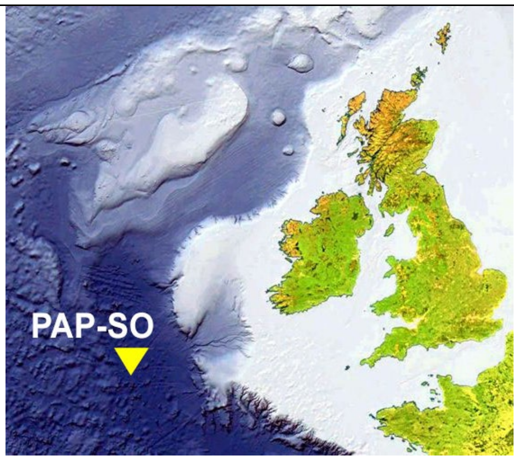


Figure 18: PAP-SO location

Environmental conditions expected on the site

Depth	4850 m

Salinity	35.5-35.8
SST	14-20 C
pCO_2	300-410 ppm
Nitrate	0.5-6uMol/kg

Depth	4850 m
Salinity	35.5-35.8
SST	14-20 C
pCO2	300-410 ppm
Nitrate	0.5-6uMol/kg

Platforms and sensors required

Platforms	**Team in charge**	**Provision by**
1- Mooring (PAP) { 23 }	NOC	PAP
2- EGIM [H] { 5 }	Ifremer/ UPC	NOC Modem from Ifremer (TBC)
3- Sailbuoy (ASV) { 22 }	Offshore sensing	Offshore sensing
4- Sea Explorer (glider) { 11 }	ALSEAMAR	ALSEAMAR
5- Float Provor CTS5-DO { 12 }	Euro-Argo	Euro-Argo

Sensors on PAP mooring (platform 1)	**Duty cycle**	**Principal Investigator**	**Provision by; Operation by**
ODO microcats at 1m and 30 m*	30 minutes	S. Hartman A. Flohr	NOC
Pro-Oceanus atmospheric and water samplers (1 m, 30 m)*	6 hourly	S. Hartman A. Flohr	NOC
Wetlabs fluorimeter at 30 m in the chlorophyll	4 hourly	S. Hartman A. Flohr	NOC

maxima*			
Sampler for fixed ocean stations, DIC/pH sampler [T]			NOC

) Sensors already available on PAP Mooring

Sensors on the EGIM (platform 2)	**Duty cycle**	**Principal Investigator**	**Provision by; Operation by**
SeaBird SBE37-SIP*	3 seconds per acquisition Measurement duration: 1 min (minimum 15 sec) Sleeping periods: 10 min (maximum 3h)		NOC; Ifremer or UPC
SeaBird SBE54 Tsunami*	Measurement duration: 15 sec (minimum 15 sec) Sleeping periods: none		
AADI-3005214831 DW4831*	3 seconds per acquisition Measurement duration: 1 min (minimum 30 sec) Sleeping periods: 9 min (maximum 3h)		
Wetlabs NTUrdt*	Measurement duration: 10 s (minimum 10 sec*) Sleeping periods: 15 min (maximum 3h*)		
Teledyne Workhorse monitor ADCP 300 kHz*	Measurement duration: 15 min (minimum 10 min) Sleeping periods: 45 min (maximum 1 day minus 10 min)		
Ocean Sonics icListen SB60L-ETH*	Duty cycle to be defined in accordance with deployment type, sleeping period are to be defined in accordance with A6 (ADCP) to avoid perturbation		
CONTROS HydroC CO_2 with SBE-5T [I], [S]	TBD		4H-Jena
CONTROS HydroC CH_4 with SBE-5T [I], [S]	***Not required***		4H-Jena
LoC pH sensor [H]	Integration to EGIM (COSTOF2) for power and comms.	S. Loucaides	CWS
LoC TA [H], [Q]	1-2 measurements per day Integration to EGIM (COSTOF2)	S. Loucaides	NOC

	for power and comms.		
LoC DIC [H], [P]	Integration to EGIM (COSTOF2) for power and comms.	S. Loucaides	NOC

) Sensor already available on the EGIM; Recommended duty cycle are the specifications of the EGIM

Sensors on Sailbuoy (platform 3)	Duty cycle	Principal Investigator	Provision by; Operation by
CaPASOS CO_2 [E]		U. Schuster	Uni Exeter
LoC TA [Q]		S. Loucaides	NOC
Wind speed		U. Schuster	Uni Exeter

Sensors on Sea-Explorer (platform 4)	Duty cycle	Principal Investigator	Provision by; Operation by
LoC TA [Q]			NOC
Integrated microsens ISFET+ LOC pH sensor [N], [Y]	1 s		CWS

Sensors on PROVOR CTS5 (platform 5)	Duty cycle	Principal Investigator	Provision by; Operation by
pCO2 (commercial sensors)			4H Jena
Acoustic	5 min during parking @ 1 000 m		NKE

Sensors on-board	Duty cycle	Principal Investigator	Provision by; Operation by
CTD samples on annual PAP process studies	All depths – chl, O2, salinity, DIC, TA, pH, nutrients	S. Hartman A. Flohr	NOC
Underway CO_2 from the ships	GO system will be fitted on both the Discovery and the Cook (with optional SubCtech system) along with under TSG and associated sampling	Hartman A. Flohr	NOC

Other equipment	Team in charge	Provision by; Operation by
EGIM Lander [H]	Ifremer	Ifremer
Battery units (rechargeable batteries) [J]	Ifremer	Ifremer

Team involved

S. Loucaides (NOC), Ifremer

Information about the cruise, ship and accommodation

The maintenance cruise on PAP takes place on-board the RSS James Cook { 24 }. The cruise is 3 or 4 weeks with extra days possible with GEORGE co-funds. The transit is 5 days (both ways, Southampton to Southampton). The number of berths available, less than 10, is to be define in accordance with the operation planned.

Risk mitigation

Risk	Mitigation
Depth	Select the equipment (foam, sensors...) accordingly Adapt the operation if possible
The rechargeable batteries rated 6000 m are not delivered on due time	Design, manufacture and qualify battery housing for 4850 m ; adapt the measurement strategy to the quantity of energy available ; test the rechargeable batteries during the recovery cruise
The data transmission between the seabed and the surface is not possible with the equipment present on PAP buoy	Ifremer might be able to provide an acoustic modem Evologics which was used on Azores for real time data transmission. A theoretical evaluation should be carried out to determine the feasibility in this range of depth. The task was not included in the grant and the resource availability must be confirmed. PAP1 data are sent in NRT for comparison with the GEORGE data
Ship time not available	There is a CLASS annual process study at PAP which will continue under the new NC funding Atlantis so the risk is low There are 2 4.2. Field trials of mature system together in a multi RI context planned. If required, a fall back solution could be envisaged on PLOCAN, Western Ligurian Sea or another EMSO site, with similar conditions and operations.
Biofouling or drift of sensors	The project is designed to account for the fouling and sensor drift on an year long deployment. PAP scientists would also be interested in any new methods to counter biofouling and to distinguish it from other drift (e.g.: through use of an auto-sampler)
Sailbuoy / CaPASOS system and Sea-explorer might not be capable of travelling from the shore; additionally, we might not get permission under the UK law on novel vessels (the UK MCA MGN 664 process)	Sailbuoy and Sea-explorer will be deployed from the vessel during the cruise

4.3. GLOBAL SCHEDULE

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Abbreviations

ADCP Acoustic Doppler Current Profiler
ASV Autonomous Surface Vehicle
BGC Biogeochemistry
C Carbon
CaPASOS Calibrated pCO2 in air and surface ocean Sensor
CH_4 Methane
chl Chlorine
CO_2 Carbon dioxide
COTS Commercial Off The Shelf
CPU Central Processing Unit
CTD Conductivity Temperature Depth
DIC Dissolved Inorganic Carbon
DO Dissolved Oxygen
DOI Digital Object Identifier
EGIM EMSO Generic Instrument Module
ENVRI European Research Infrastructures in the environmental domain
EOOS European Ocean Observing System
EOSC European Open Science Cloud
ERIC European Research Infrastructure Consortium

EU European Union
FAIR Findable, Accessible, Interoperable, and Reusable
FIA Flow Injection Analysis
FOF Flotte Oceanographique Française
GOOS Global Ocean Observing System
ILICO Infrastructure de recherche littorale et côtière
IoT Internet of Things
ISFET Ion Sensitive Field Effect Transistor
LOC Lab-on-Chip
N_2O Nitrous oxide
O_2 Oxygen
PAP Porcupine Abyssal Plain observatory, Ligurian Sea, Baltic Sea
pCO2 Partial pressure of carbon dioxide
QC Quality Control
RI Research Infrastructure
RV Research Vessel
S Salinity
SOCAT Surface Ocean CO2 Atlas
SOOP Ships Of OPportunity
SOP Standard Operating Procedure
TA Total Alkalinity
TBC To Be Confirmed
TBD To Be Determined
TC Total Carbon or Thematic Centre, depending on content
TRL Technology Readiness Level