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Report on the testing results of the joint operations of sensors, buoy and AUV in ST6.3.2

Date: 06/12/2023
Doc. Version: Rev. 1.7
doi : 10.5281/zenodo.10694761

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101000825 (NAUTILOS). This output reflects only the author's view and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Document Control Information

Settings	Value
Deliverable Title	Report on the testing results of the joint operations of sensors, buoy and AUV in ST6.3.2
Work Package Title	WP6 – Calibration, Validation and Scenario Testing
Deliverable number	6.4
Description	Report on the testing results of the joint operations of sensors, buoy and AUV in ST6.3.2. The report describes results of field measurement carried out in the experimental site of Capo Tirone (Cosenza, Italy) using an AUV, a Buoy and a RHIB.
Lead Beneficiary	EDGELAB
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Submitted by	Anna Mori
Doc. Version (Revision number)	1.7
Sensitivity (Security):	Public
Date:	06/12/2023
Doi:	10.5281/zenodo.10694761

Document Approver(s) and Reviewer(s):

NOTE: All Approvers are required. Records of each approver must be maintained. All Reviewers in the list are considered required unless explicitly listed as Optional.

Name	Role	Action	Date
PIERLUIGI PENNA	Reviewer CNR IRBIM	*Review & Approve*	05/12/2023
PIERLUIGI PENNA	Reviewer CNR IRBIM	*Review*	21/11/2023

Document history:

The Document Author is authorized to make the following types of changes to the document without requiring that the document be re-approved:

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Revision	Date	Created by	Short Description of Changes
1.7	6/12/2023	MICHELE COCCO-EDGELAB	Generation of the final release
1.6	5/12/2023	MICHELE COCCO-EDGELAB	Text adaption after comments from reviewer
1.5	27/11/2023	ANNA MORI-EDGELAB	Updated paragraph of results and data analysis
1.4	25/11/2023	ANNA MORI-EDGELAB	Updated paragraph of results and data analysis
1.3	23/11/2023	ANNA MORI-EDGELAB	Updated paragraph of results and data analysis
1.2	21/11/2023	ANNA MORI-EDGELAB	Elimination of extremely detailed descriptive parts of the platforms. Updated description On field Test

			Location Insertion of figures
1.1	07/11/2023	ANNA MORI-EDGELAB	Modification of table of contents. Adapting text content to paragraphs.

Configuration Management: Document Location
The latest version of this controlled document is stored in <location>.

Nature of the deliverable		
R	Report	X

Dissemination level		
PU	Public	X

ACKNOWLEDGEMENT

This report forms part of the deliverables from the NAUTILOS project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101000825. The Community is not responsible for any use that might be made of the content of this publication.

NAUTILOS - New Approach to Underwater Technologies for Innovative, Low-cost Ocean observation is an H2020 project funded under the Future of Seas and Oceans Flagship Initiative, coordinated by the National Research Council of Italy (CNR, Consiglio Nazionale delle Ricerche). It brings together a group of 21 entities from 11 European countries with multidisciplinary expertise ranging from ocean instrumentation development and integration, ocean sensing and sampling instrumentation, data processing, modelling and control, operational oceanography and biology and ecosystems and biogeochemistry such, water and climate change science, technological marine applications and research infrastructures.

NAUTILOS will fill-in marine observation and modelling gaps for chemical, biological and deep ocean physics variables through the development of a new generation of cost-effective sensors and samplers, the integration of the aforementioned technologies within observing platforms and their deployment in large-scale demonstrations in European seas. The fundamental aim of the project will be to complement and expand current European observation tools and services, to obtain a collection of data at a much higher spatial resolution, temporal regularity and length than currently available at the European scale, and to further enable and democratise the monitoring of the marine environment to both traditional and non-traditional data users.

NAUTILOS is one of two projects included in the EU´s efforts to support of the European Strategy for Plastics in a Circular Economy by supporting the demonstration of new and innovative technologies to measure the Essential Ocean Variables (EOV).

More information on the project can be found at: http://www.nautilos-h2020.eu.

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Executive Summary

Deliverable D6.4 concerns the report detailing the results of joint tests conducted on the collaborative functionality of sensors, a buoy and an autonomous underwater vehicle (AUV). This evaluation took place in the Gulf of La Spezia, organized by EDGELAB.

The examination involved data acquisition via three distinct platforms: an AUV, an unmanned surface vehicle (USV-CAT) functioning as a buoy, and a rigid-hull inflatable boat (RHIB) equipped with a multiparameter probe.

The AUV performed navigation manoeuvres, ranging from surface level to a depth of 8 meters, following an orbital trajectory around the water column beneath the catamaran when submerged and around the catamaran itself while navigating on the surface. The AUV was equipped with a fluorometer and a broadband passive acoustic sensor for monitoring environmental noise.

The surface catamaran was equipped with a fluorometer and a broadband passive acoustic sensor for noise monitoring.

The RHIB was equipped with a multi-parameter probe designed to measure temperature, conductivity, turbidity, pH, ORP and dissolved oxygen. Notably, each platform operated independently, with data collection being done individually for each.

The final result goes beyond data collection and includes an analysis of test results and their subsequent statistical evaluation.

Originally intended for the Capo Tirone site in Cosenza, Italy, the tests were moved to La Spezia, due to the convergence of problems caused by weather conditions and on-site logistics, occurred in the planned framework windows of the test activities (Autumn 2023). The need to conclude the activities in time for the project deadline required the execution of a bailout scenario, with the headquarters of operations being moved from Capo Tirone (Cosenza-Italy), to La Spezia (Italy).

The initial test configuration involved the deployment of a moored buoy, equipped with a fluorometer, multi-parameter probe and passive acoustic sensor. To compensate for the unavailability of the same, a remotely controllable catamaran) (USV-Unmanned Surface Vehicle) was used, which simulates the buoy as a sensor platform. The USV is equipped with a data transmission system equivalent to that of the buoy, making the two platforms practically identical in terms of both communications infrastructure and on-board sensors.

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviation	Definition
AUV	Autonomous Underwater vehicle
USV-CAT	Unmanned Sufface Vehicle Catamaran
RHIB	Rigid Hull Inflatable Boat
GIS	Geographical Information System
DoF	Degree of Freedom
HD	High Definition
USBL	Ultra Short Baseline Acoustic Positioning System
RF	Radio Frequency
SAT	Satellite
GUI	Graphic User Interface
MMS	Mission Management System
HDD	Hard Disk Drive
LiPo Battery	Lithium-ion-polymer battery
WiFi	Wireless Fidelity

DO	Dissolved Oxygen
CSSN	Centro di Supporto Sperimentazione Navale

I. DELIVERABLE OBJECTIVES

The objectives of deliverable 6.4 "Report on the testing results of the joint operations of sensors, buoy and AUV in ST6.3.2" are to describe the results of Field measurements conducted in the experimental site of Gulf of La Spezia (Italy).

The objective of the deliverable is to report the results of the simultaneous data collection of three platforms, using an autonomous underwater vehicle (AUV), a USV Catamaran operating as a buoy and a RHIB with a multiparametric probe. The document reports the results of simultaneous data gathering from the three systems and related sensors, and the calculation of some main statistical parameters related to the acquired data. All acquired data are georeferenced and ready to be imported into a GIS infrastructure.

The initial plan for conducting tests at the Capo Tirone site in Cosenza, Italy had to be reconsidered due to a confluence of challenges. These challenges included adverse weather conditions, logistical difficulties at the on-site location, and the emergence of more favourable weather conditions in La Spezia. To ensure the timely completion of project activities aligned with the impending deadline, a decision was made to relocate the testing operations to La Spezia.

The relocation was prompted by a need to overcome the unfavourable circumstances at the original site. Weather conditions posed a significant obstacle, and logistical challenges on-site further complicated the feasibility of executing the planned tests. Simultaneously, the availability of more favourable weather in La Spezia presented an opportunity for a smoother and more reliable testing environment.

To execute this change in plans and meet the project deadline, a bailout scenario was implemented. The operations headquarters were shifted from Capo Tirone in Cosenza to La Spezia, facilitating the continuation of testing activities in the new location.

The initial test configuration involved the deployment of a moored buoy at Capo Tirone. This buoy was equipped with essential instruments, including a fluorometer, multi-parameter probe, and passive acoustic sensor. However, due to the unavailability of the moored buoy apparatus in La Spezia, an alternative approach was devised.

In lieu of the moored buoy, a remotely controllable catamaran, referred to as the Unmanned Surface Vehicle-Catamaran (USV-CAT), was employed in La Spezia. This USV-CAT was strategically designed to simulate the buoy's function as a sensor platform. Crucially, the USV-CAT was equipped with a data transmission system equivalent to that of the original buoy, ensuring a seamless transition between the two platforms. This equivalence extended to both the communications infrastructure and the on-board sensors, maintaining a consistent testing framework despite the change in locations. This adaptation allowed for the successful continuation of testing activities and the collection of valuable data in the new testing environment in La Spezia.

II. PLATFORMS DESCRIPTION

1. NAUTILOS AUV

1.1. Description

In pursuit of evaluating on-site communication capabilities, EDGELAB conceived and implemented an Autonomous Underwater Vehicle (AUV). The primary objectives were to conduct communication tests with a Lander in Porto, Portugal, and EDGELAB's Unmanned Surface Vehicle (USV-CAT) Catamaran in La Spezia, Italy. The AUV selected for these endeavors is a derivative of the EDGELAB U_Tracker AUV, specifically tailored for the initiatives undertaken within the framework of the NAUTILOS Project. The adaptation and utilization of the EDGELAB U_Tracker AUV platform serve as a strategic choice to meet the communication testing requirements integral to the project's objectives.

The U_Tracker AUV (see fig. 1), characterized by its compact design, cost-effectiveness, diminutive stature, and user-friendly interface, emerges as a versatile and proficient autonomous underwater vehicle. Despite its relatively modest size and economical nature, this AUV demonstrates a capacity to undertake tasks akin to larger and more intricate counterparts, often surpassing them in certain scenarios. The inherent modularity of the U_Tracker allows for customization in line with precise customer specifications, enabling the provision of various configurations. This adaptability extends to the seamless installation or removal of sensors, facilitating the AUV's utilization in diverse underwater activities such as general submersible operations, seafloor surveys, bathymetric mapping, and other relevant applications. The U_Tracker's modular design not only enhances its flexibility in addressing distinct customer needs but also underscores its efficiency and efficacy across a spectrum of underwater tasks.

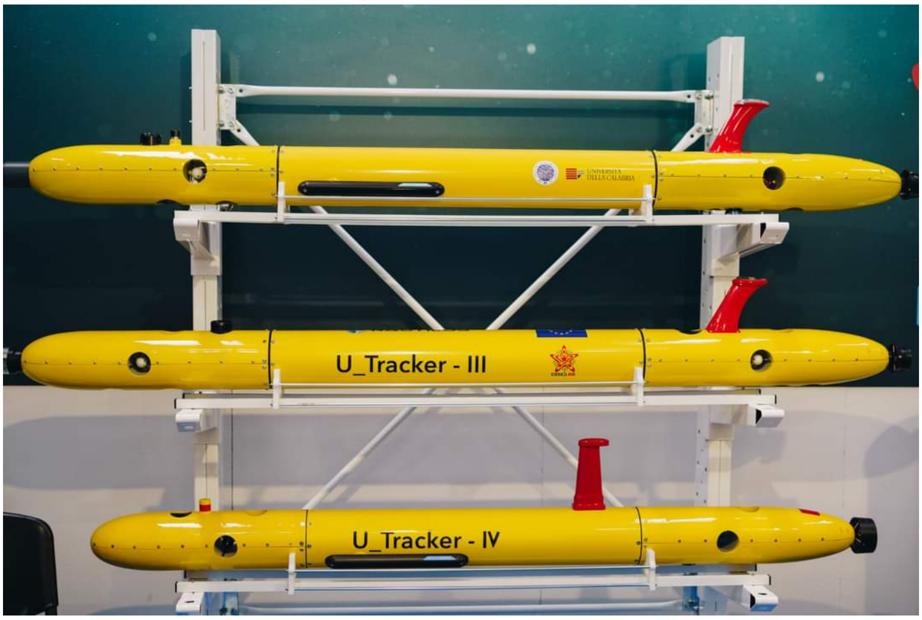

Fig. 1 – EDGELAB U_Tracker AUV

The Autonomous Underwater Vehicle (AUV) under consideration boasts a set of technical specifications that position it as a versatile and capable instrument for underwater exploration. With an operational endurance of 8 hours, the AUV can reach a maximum operating depth of 300 meters and achieve a maximum speed of 5 knots, while maintaining a cruise speed of 3 knots. Its 5 Degrees of Freedom (5DoF) control capability, inclusive of hovering and point rotation, enhances its manoeuvrability.

The AUV's propulsion system is composed of one main stern propeller, complemented by two horizontal thrusters and two vertical thrusters. Its compact dimensions, with a length of less than 230 cm, a diameter of 20 cm, and a weight of under 25 kg, contribute to its ease of deployment and handling. The payload capacity of the AUV includes scientific probes, a side-scan sonar, and an HD camera, offering a comprehensive suite of observational tools.

In terms of communication, the AUV is equipped with Ethernet/Wi-Fi or similar socket capabilities, an integrated underwater acoustic modem with a USBL (Ultra-Short Baseline) device, a radio link for data download and system recovery, and an RF module. The communication range exceeds 2 km with a full frequency range and transmit power, with the option for customization to 500 m or other specifications as per customer requirements. Additionally, a SAT Comm link is incorporated for extended communication capabilities.

Various accessories accompany the AUV, including a test transmitter, waterproof Pelican Case, external speaker, professional-quality headphones, autopower battery cable, and a Ground Control System for efficient operation.

The software suite, represented by the JDeMoN Graphic User Interface (GUI) developed by Edgelab, provides a user-friendly interface for mission planning, optional monitoring, and post-mission analysis. The GUI allows for control settings of RF and optional Acoustic Data Link with the vehicle. The Mission Management System (MMS) within the GUI permits dynamic adjustments, including mission modifications decided by the operator and adaptations to environmental changes detected by the AUV or external sensors.

For testing purposes, the AUV was equipped with a specific payload, including a fluorimeter sensor and a Passive Broadband Acoustic Sensor. This integrated payload aligns with the AUV's capability to accommodate various scientific instruments, showcasing its adaptability for diverse underwater research tasks.

2. USV-CAT

The USV-CAT (see fig.2), a highly versatile autonomous surface platform, has been engineered to excel in a spectrum of applications encompassing hydrography, oceanography, and monitoring. Its adaptability is a result of a modular design that allows for the integration of additional modules tailored to the specific requirements of each mission. Figure 2 showcases the EDGELAB USV-CAT Catamaran, representing the standard configuration of USV-CAT when assembled as a stand-alone unit.

In its conventional form, USV-CAT integrates a comprehensive array of systems crucial for autonomous functionality. These include control computers, embedded programming units, navigation instrumentation such as an inertial platform and pressure sensor, navigation and mission software, HDD memory, and LiPO batteries. The LiPO battery configuration consists of 1x 24V @ 20Ah, providing an operational duration of approximately 8 hours, and 2x 12V @ 90Ah. Further enhancing its capabilities, USV-CAT incorporates WiFi technology for mission data exchange and long-range communication systems that facilitate remote control on the surface through a gamepad or joystick.

The autonomous configuration empowers USV-CAT to execute preprogrammed missions or routes independently, enhancing operational efficiency. One of its distinctive features is the modular structure that allows users to customize the vehicle according to their unique needs. This customization extends to easy access to various payloads and working modules, including batteries, electronics, and sensors.

For the testing phase, the USV-CAT was equipped with a specific payload, showcasing USV-CAT's adaptability and versatility. The integrated payload comprised a fluorimeter sensor and a Passive Broadband Acoustic Sensor, underscoring USV-CAT's capacity to seamlessly accommodate diverse scientific instruments for comprehensive testing and operational scenarios.

Fig. 2 – EDGELAB USV-CAT Catamaran

3. RHIB – RIGID HULL INFLATABLE BOAT

In the course of the testing procedures, a Rigid Hull Inflatable Boat (RHIB), depicted in Figure 3, was deployed for specific operational tasks. Notably, a multi-parameter probe, specifically the B&C Electronics model SA 8060.10X equipped with a built-in data logger, was manually lowered into the sea from the RHIB.

The RHIB served as a platform for conducting the required tests, facilitating the controlled deployment of the multiparametric probe for data collection purposes.

This collaborative setup, involving the RHIB and the multiparametric probe, contributed to the comprehensive nature of the testing activities, ensuring a holistic assessment of the marine environment under scrutiny.

Fig. 3 – RHIB-Rigid Hull Inflatable Boat used for test experiment

III. PAYLOAD

1. OPTICAL DISSOLVED-OXYGEN SENSOR

1.1. Description

This sensor measures the dissolved oxygen in the water. The measuring principle is optical and is based on an LED that excites an oxygen-reactive membrane and detects its oxygen-dependent luminescence emission by means of a photodiode.

Measurements of Dissolved Oxygen concentration have been achieved using as a fluorescence-based optical sensor, i.e NKE-HESSO Fluorimeter. This type of sensor is able to quantify the concentration of dissolved oxygen in the water measuring the time-decay of luminescence.

The relationship between Oxygen concentration and decay of luminescence is well known in literature; this principle is described by the Stern and Vomer equation:

$$\frac{I_o}{I} = \frac{t_o}{t} = 1 + K_{sv} * [O_2]$$

where
I: Luminescence intensity in presence of oxygen
I_o**:** Luminescence intensity in the absence of oxygen
t: Luminescence decay time in the presence of oxygen
t_0**:** Luminescence decay time in the absence of oxygen
K_{sv}**:** Stern-Volmer constant (quantifies the quenching efficiency and therefore the sensitivity of the sensor)
$[O_2]$**:** oxygen content

The formula indicates that the luminescence decay of the medium is faster in presence of a quencher like the oxygen. The dynamically evolution of the Time decay ration (t0/t or I0/I) can be considered linear, under certain assumption, with a different response (slope of linear distribution) as function of the KSV.

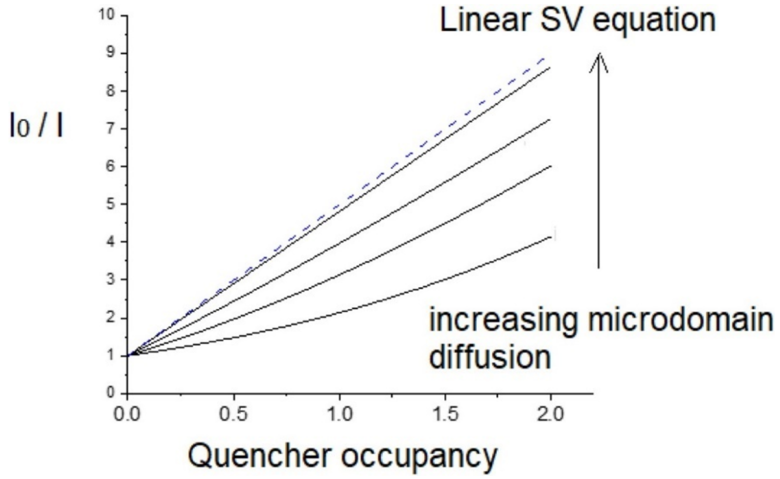

Fig. 4 – Relationship between Oxygen concentration and decay of luminescence, from Stern and Vomer equation (ref.: Gehlen M., Journal of Photochemistry and Photobiology C: Photochemistry Reviews - Volume 42, March 2020)

In this specific optical DO sensor (see fig. 5) the measurement is obtained the sensor the fluorophore via the UV_LED and then measuring the exponential decay via the photodiode.

Fig. 5 – NKE-HESSO optical DO sensor integrated on AUV and USV-CAT

Fig. 6 – Optical DO sensor integrated on the AUV

2. PASSIVE BROADBAND ACOUSTIC SENSOR FOR NOISE MONITORING

2.1. Description

The Passive Broadband Acoustic Sensor (see Fig. 7) used for noise monitoring operates as an independent and self-contained sensor within the system, drawing power from either the Autonomous Underwater Vehicle (AUV) or the Unmanned Surface Vehicle Catamaran (USV-CAT). This sensor is designed to capture ambient noise levels when the AUV is deployed in the sea and the Catamaran USV-CAT is either navigating or stationed in a moored position within the bay.

Passive Broadband Acoustic Sensor records the noise data onto a datalogger during its operation. Subsequently, this recorded data is retrieved during the recovery process of both the AUV and the USV-CAT. This methodology allows for a comprehensive post-mission analysis of the acoustic environment. The Passive Broadband Acoustic Sensor is manufactured by AQUATEC.

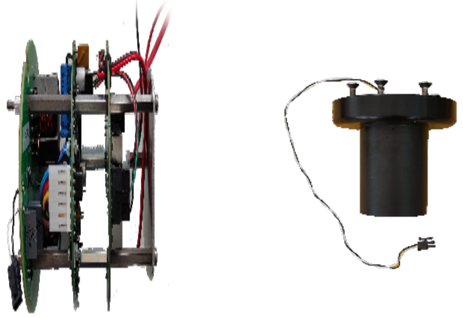

Fig. 7 – AQUATEC Passive Broadband Acoustic sensor for noise recording integrated on AUV and USV-CAT

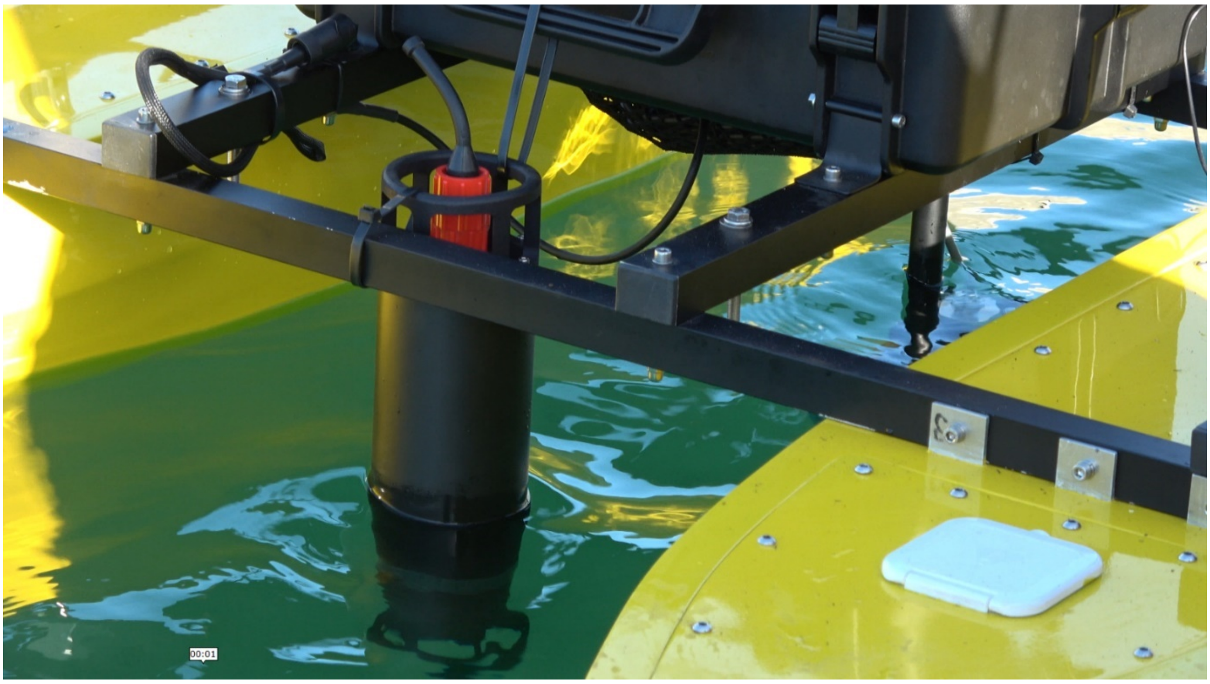

Fig. 8 – AQUATEC Passive Broadband Acoustic sensor for noise recording integrated on the USV-CAT

3. OTHER SENSORS NOT PROVIDED BY NAUTILOS

The Multiparametric Probe (see Fig. 9), manufactured by B&C Electronics in Italy and commercially available, is a versatile instrument employed for data collection, notably deployed from the Rigid Hull Inflatable Boat (RHIB).

In its comprehensive configuration, the Probe encompasses measurement sensors, electronic circuitry, a serial communication interface, datalogger, and rechargeable batteries. It continuously transmits data to a Personal Computer and can be configured for scheduled acquisitions at specific time or depth intervals, even in unattended mode. The probe's functionality is extended by interfacing it with a GPRS Modem, allowing for remote connectivity and real-time data acquisitions, data interrogation, and parameter adjustments.

The gathered data from the Multiparametric Probe includes essential environmental parameters such as temperature, conductivity, pH, redox, dissolved oxygen (measured optically or polarographically), turbidity, and last calibration. Additionally, the data format encompasses geospatial information, including UTC, latitude, latitude direction, longitude, longitude direction, GPS quality, satellite number, and horizontal dilution of precision (HDOP).

The feature includes a RS 485 output communication. It plays the role of reference in simultaneous measurements acquisition experiment

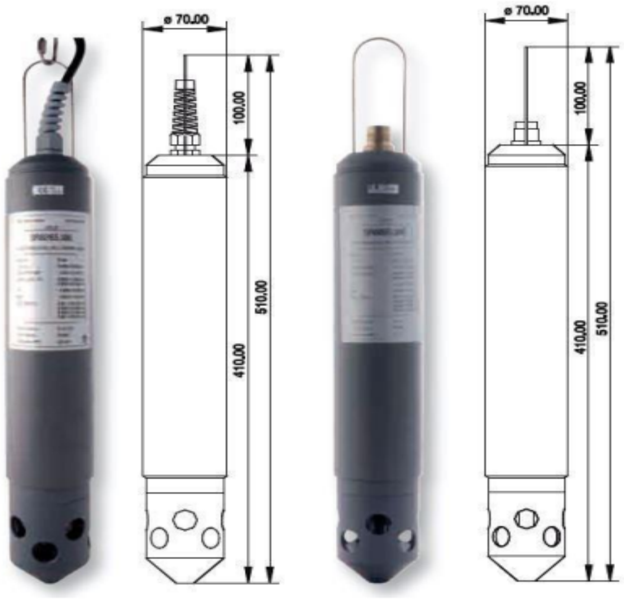

Fig. 9 – Multiparametric Probe

Fig. 10 – Multiparametric probe plunged from the RHIB

IV. FIELD TEST

1. Description

1.1. Location

The NAUTILOS Project's Subtask 6.3.2 was originally formulated to conduct on-field tests at Capo Tirone in Cosenza, Italy. However, the project encountered a series of interconnected challenges that necessitated a reassessment and modification of the initial plan that forced the replanning of the activity in the backup area test site.

The gulf of La Spezia (see fig. 11) is oriented along a north-west/south-east axis, is protected by a chain of mountains all around and is bordered by the promontory of Porto Venere (and the islands of Palmaria, Tino and Tinetto) to the west and the Lerici coast to the east. For this reason, the waters of the gulf are only exposed to sirocco winds and partially to tramontana winds, while they are sheltered from libeccio winds.

At the mouth of the gulf is a 2210-metre-long breakwater that cuts the gulf from Punta S. Maria in the west to Punta S. Teresa in the east, leaving two passages (400 and 200 meters long, respectively) open at either end.

The gulf measures approximately 4.5 km in length and an average of 3-3.5 km in width.

The La Spezia roadstead extends from Punta Calandrello, to the east, to Punta Pezzino, along the west coast, on a water mirror, inside the breakwater dam, of about 15 square kilometres and a coastal development of about 12 km.

Fig. 11 – Gulf of La Spezia – Detail of the on-field test location- CSSN-Centre of Support and Naval Experimentation of the Italian Navy.

Inside the water area of the gulf, which is protected by the breakwater, the isobaths reveal depths that, for the area affected by port activities, generally do not go below seven meters, while in the areas excavated for the access and manoeuvring of oil tankers, two channels and an evolution area, they reach a depth of -11.50. This corresponds to berthing possibilities for ships of up to 50-60,000 gt. It is planned, in connection with the future development of the port, to further deepen the seabed in the newly constructed docks (up to 13 meters at the head of the piers).

Neither the currents within the gulf nor the tides constitute serious difficulties for the regular manoeuvring of ships. The former, derivations of the main ones established offshore, follow the South/North direction along the east coast and the North/South direction along the west coast, with speeds not exceeding the knot. The latter, with values of no more than 0.4 meters at the leeward and 0.3 meters at the squares, do not pose any particular difficulties or obstacles to the performance of port activities. On the whole, therefore, optimal conditions for carrying out the complex work of anchoring in roadstead, approaching quaysides and loading and unloading goods.

The test was carried out in the marina of the CSSN-Centre of Support and Naval Experimentation of the Italian Navy, where the depth ranged from 6 to 12 meters. Being inside the marina, it is a fairly quiet area in terms of wave disturbance and vessel traffic..

1.2. Deployment procedures

On Friday, 17 November 2023, EDGELAB conducted on-site tests (see fig. 12) aimed at the simultaneous collection of data from three platforms (AUV, USV-CAT operating as a buoy, RHIB with multiparametric probe).

Figure 12 – Ground Control Station of the Test experiment

Measurements of dissolved oxygen were obtained using the optical DO sensor deployed from both the AUV (see fig. 14) and the USV-CAT. Simultaneously, the Passive Broadband Acoustic Sensor on both the AUV and the USV-CAT captured sound data for noise monitoring. Additionally, a comprehensive set of environmental data, including temperature, conductivity, turbidity, pH, dissolved oxygen, and Redox, was collected utilizing the multiparametric probe deployed from a RHIB (see fig. 15).

parameters	AUV	USV-CAT operating as a buoy	RHIB with multiparametric probe
Optical Dissolved Oxygen	X	X	X
PASSIVE BROADBAND ACOUSTIC (noise monitoring)	X	X	
temperature, conductivity, turbidity, pH, and Redox			X

Table 1.- Parameters measured on each platform

Edgelab's catamaran moored in the middle of the harbour (see fig. 13), simulating a buoy, was used to carry out the test. The passive broadband acoustic sensor for noise monitoring and the optical, DO sensor that were intended for the buoy were integrated on board. In order to carry out further tests, the catamaran was also unmoored at times and made to move slightly.

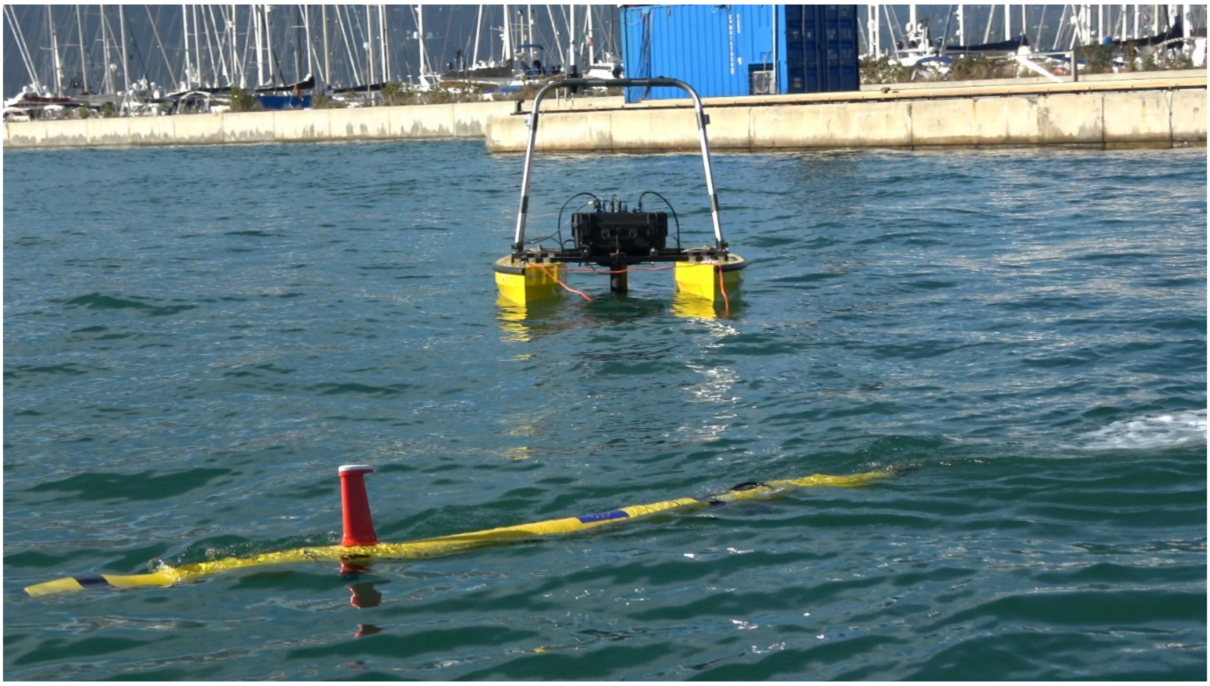

Fig. 13 – USV CAT moored at the centre of the test field operating as a buoy

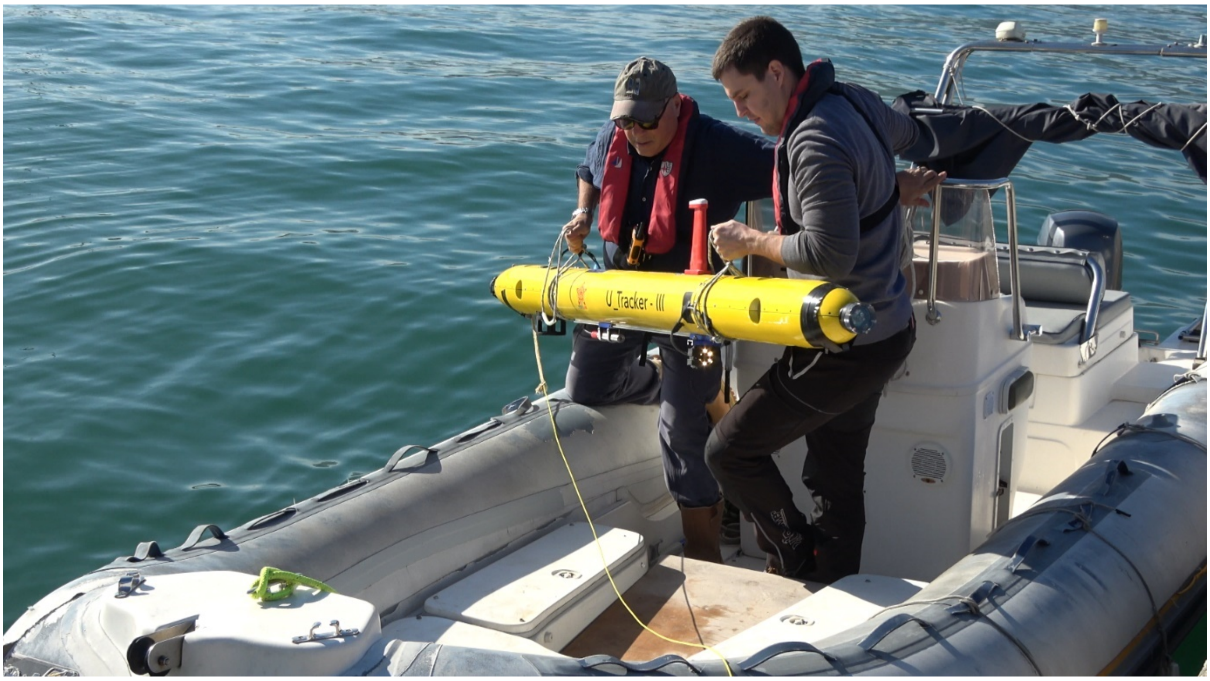

Fig. 14 – AUV launching

Fig. 15 – Multiparametric probe manually lowered in the sea

Once the preliminary site preparation activities had been carried out, the platforms were started up and data collection began. As for the AUV's navigation, it was set up so that the vehicle would orbit the catamaran at different depths, from the surface to a maximum of 8 meters.

The orbital trajectory of the AUV (see fig. 16) around the catamaran, ranging from the surface to a maximum depth of 8 meters, was strategically chosen to enhance the comprehensiveness of data collection. While the catamaran features sensors primarily situated on the surface, extending the AUV's trajectory to deeper depths serves several purposes.

1.- Vertical Data Profiling: by navigating at various depths, the AUV creates a vertical profile of the water column. This profiling allows for a more detailed understanding of the environmental parameters at different layers, contributing to a more comprehensive analysis of the aquatic ecosystem.

2.- Cross-Sectional Insights: the orbital trajectory at different depths facilitates the acquisition of cross-sectional data. This is particularly valuable for understanding variations in parameters such as dissolved oxygen, temperature, and acoustic signals across different horizontal layers of the water column.

3.- Environmental Stratification: water bodies often exhibit stratification, where distinct layers with different properties (temperature, salinity, etc.) exist. By navigating at multiple depths, the AUV can capture variations in these stratifications, providing insights into the vertical structure of the water column.

4.- Sensor Calibration and Validation: the AUV's orbital trajectory allows for calibration and validation of the surface sensors on the catamaran. By comparing readings from both platforms at different depths, it becomes possible to assess the reliability and accuracy of the surface sensors under varying conditions.

In summary, the chosen orbital trajectory extending to -8 meters offers a more nuanced and thorough exploration of the aquatic environment, enabling a holistic understanding of the water column and providing valuable cross-sectional insights for the study.

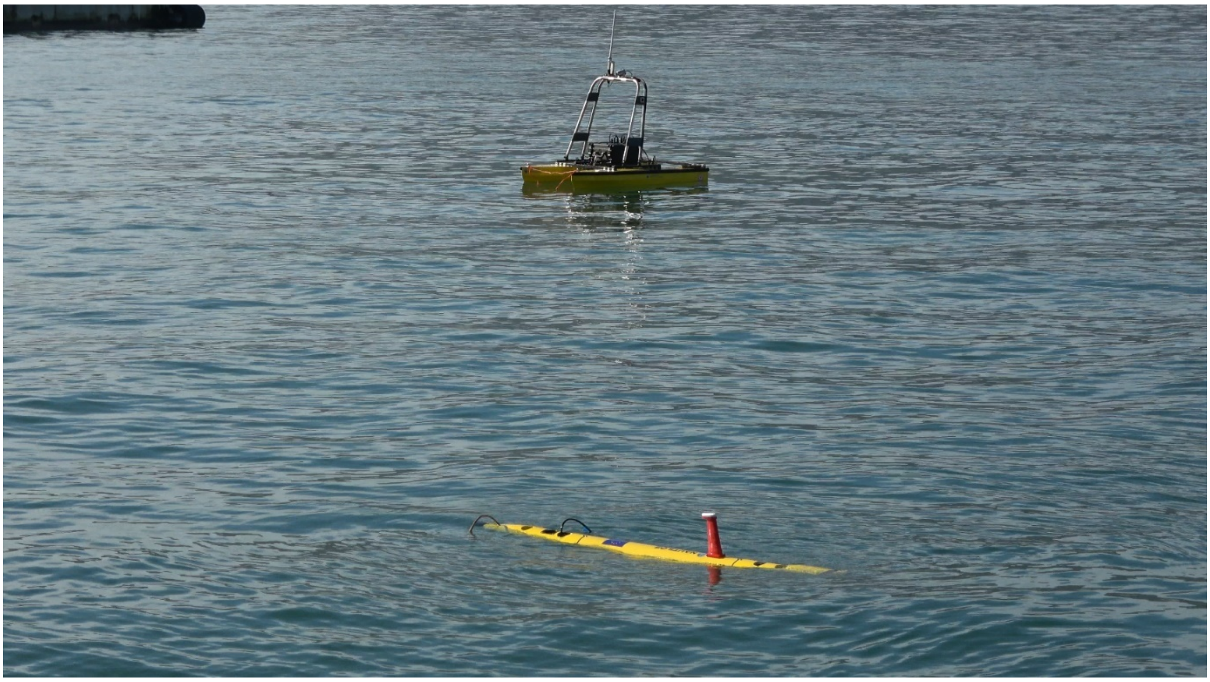

Fig. 16 – AUV navigating with orbital route around the catamaran

2. ON FIELD TEST RESULTS

2.1. Results

During the test, following data has been collected:

Optical DO Sensor (integrated both on the AUV and on the USV-CAT)
Data received and sent by the system followed the NMEA protocol. No standards identifier was found for the system type, so the following identifier have been used:

- DORAW : Raw data sent by the system
- DOTAU : Calculated Tau value sent by the system
- ttDOQ : Identifier to send to demand a measurement

String sent by the system:
$DORAW,<Time>,S,<Temp>,T,<UStart>,V,<UStop>,V*hh
└ <Time>: Measured time on the decadence in picoseconds (S) of type uint32_t
└ <Temp>: Measured temperature on the PT1000 in Celsius (T) of type float
└ <UStart>: DAC voltage used to generate the start signal in millivolt (V) of type uint16_t
└ <UStop>: DAC voltage used to generate the stop signal in millivolt (V) of type uint16_t
└ hh: Checksum

$DOTAU,<Tau_Value>,S,<Temp>,T,<UStart>,V,<UStop>,V*hh
└ <Tau_Value>: Calculated Tau value in picoseconds (S) of type uint32_t

$$Tau = \frac{Time}{\log\left(U_{Start}/U_{Stop}\right)} = \frac{ps}{\log(mV/mV)}$$

└ <Temp>: Measured temperature on the PT1000 in Celsius (T) of type float
└ <UStart>: DAC voltage used to generate the start signal in millivolt (V) of type uint16_t
└ <UStop>: DAC voltage used to generate the stop signal in millivolt (V) of type uint16_t
└ hh: Checksum

As mentioned, the optical DO Sensor was set to take a measurement for 10 seconds followed by a 10-minute pause. Below are some of the results of the 8 measurements taken, showing data format. The full file will be attached to this document as Annex 1.

Column1	Column2	Column3	Column4	Column5	Column6	Column7	Column8	Column9
$DORAW	14120086	S	-1	T	1320	V	400	V*68
$DOTAU	11826635	S	-1	T	1320	V	400	V*68
$DORAW	14212287	S	-1	T	1320	V	400	V*69
$DOTAU	11903860	S	-1	T	1320	V	400	V*60
$DORAW	14107551	S	-1	T	1320	V	400	V*62
$DOTAU	11816136	S	-1	T	1320	V	400	V*6F

Table 2 - Optical DO Sensor Measurement Data Format

We performed 8 casts of fluorescent measurement of Dissolved Oxygen (see fig.17) in the same test-Bay of CSSN, Gulf of La Spezia. At the contrary of CTD casts, which were performed along a vertical profile, the fluorimeter was placed to acquire in stationary mode at approx. 20cm below the sea-level. The acquired time series varied from 100 to 500 samples. The specific sensor provides a raw-values of time decadence of luminescence (in Picosecond) and an additional measurement (TAU) obtained as difference of time decadence normalized for the difference of voltage between start and stop of the measurement. We used the TAU values because they are less scattered than the raw dataset. The choice to utilize TAU values instead of the raw dataset was driven by the inherent characteristics of the TAU values. Specifically, TAU values demonstrated a notable advantage in terms of reduced variability compared to the raw dataset. This reduction in scatter enhances the reliability and consistency of the dataset, making TAU values a preferable metric for our analysis.

By opting for TAU values, we aimed to mitigate the impact of potential noise or fluctuations in the raw data, providing a more stable and discernible representation of the luminescence decay over time. This decision contributes to the overall accuracy and robustness of our Dissolved Oxygen measurements in the test-Bay environment, allowing for more confident interpretations of the collected fluorescence data.

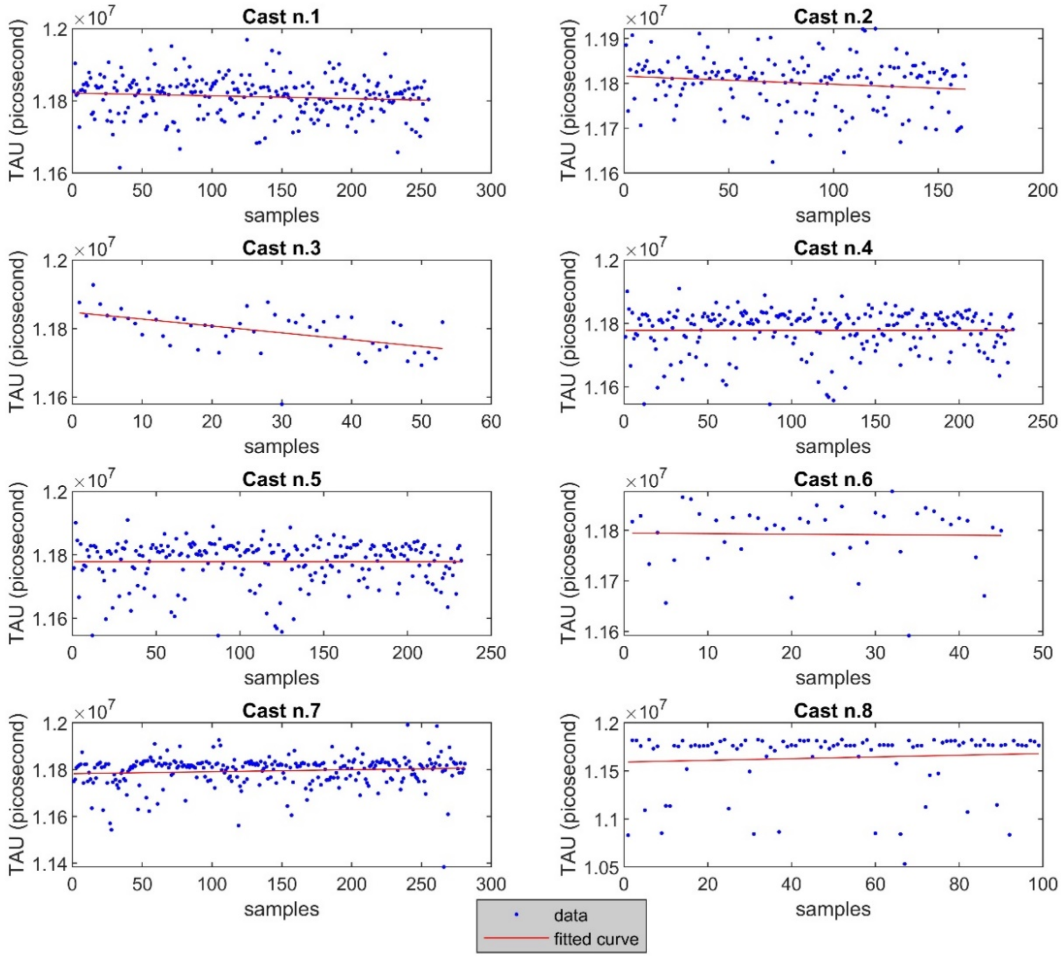

Fig. 17 – nr. 8 casts of fluorescent measurements of Dissolved Oxygen

Although in the all plots the data seem quite scattered, the linear fitting (1st degree polynomial) a quasi-flat pattern placed around 1.18 x10^7 which could represent the luminescence time decay typical of the water-air interface (the water layer placed few centimetres below the sea) of the test-site. the cast 3 reveals a fast time decay of the fluorescence indicating thus relative higher concentration of dissolved oxygen in this specific site.

Passive Broadband Acoustic Sensor for Noise Monitoring (Integrated both on the AUV and on the USV-CAT):

The sensor was configured to record data for 10 seconds, followed by a 10-minute pause. The sampling frequency was set to 48 KHz, gain 1:1.The format of the acquired data is in Waveform Audio File Format (WAV).

The marina where the test was carried out is located in a military area with moderate levels of vessel traffic. The audio files are uploaded on NAUTILOS' data sharing platform.

Multiparametric Probe (hand lowered into the sea from the RHIB)

Data collected with the multi-parameter probe concerned temperature, turbidity, dissolved oxygen, redox, pH and conductivity.

We performed a CTD measurement in the test–bay area of CSSN (Centro supporto e Sperimentazione Navale) of Italian Navy, inside the Gulf of La Spezia. This area is deputed for experimental trials and is featured by a very shallow water (max 12 meter). We used the

CTD probe SA8060 by B&C Electronics equipped by turbidimeter and optical sensor for direct measurement of dissolved Oxygen. The probe records data with a maximum sampling rate of 1Hz (1 data per second). The cast was recorded around the noon (UTC time), from the dock reaching maximum depth of 2.8 meter.
We report the main statistic parameter of the CTD cast and several graphical distributions of the recorded chemical physical parameters

	Temp (*c)	Condu. (mS)	Ph	Eh (mV)	Diss.Ox (%)	Torb (NTU)
Minimum	18.6	7.197	6.794	170.8	119	2.4
maximum	18.8	46.045	7.438	188	123.61	4200
Average	18.64286	40.12848	7.25919	182.2857	121.0738	449.2667
St. Deviation	0.059761	12.03737	0.157238	3.512874	1.138369	1250.534
Variance	0.003571	144.8983	0.024724	12.34029	1.295885	1563834

Table 3 - Statistics of downward CTD profiling

Statistical analysis of CTD data has been computed for the down warding profiles (table 3). As general observation, we note that the down cast shows a more stable data with lower standard deviation values respected the upward one, except for the Ph which shows a clear countertrend.

Below we report the different plots showing the distribution of the different parameter as function of the depth. For this purpose, we selected just the down subset of data except for the pH that was plotted using the upward sub-cast (see statistic above).

Multiparametric probe raw data table are uploaded on NAUTILOS' data management infrastructure.

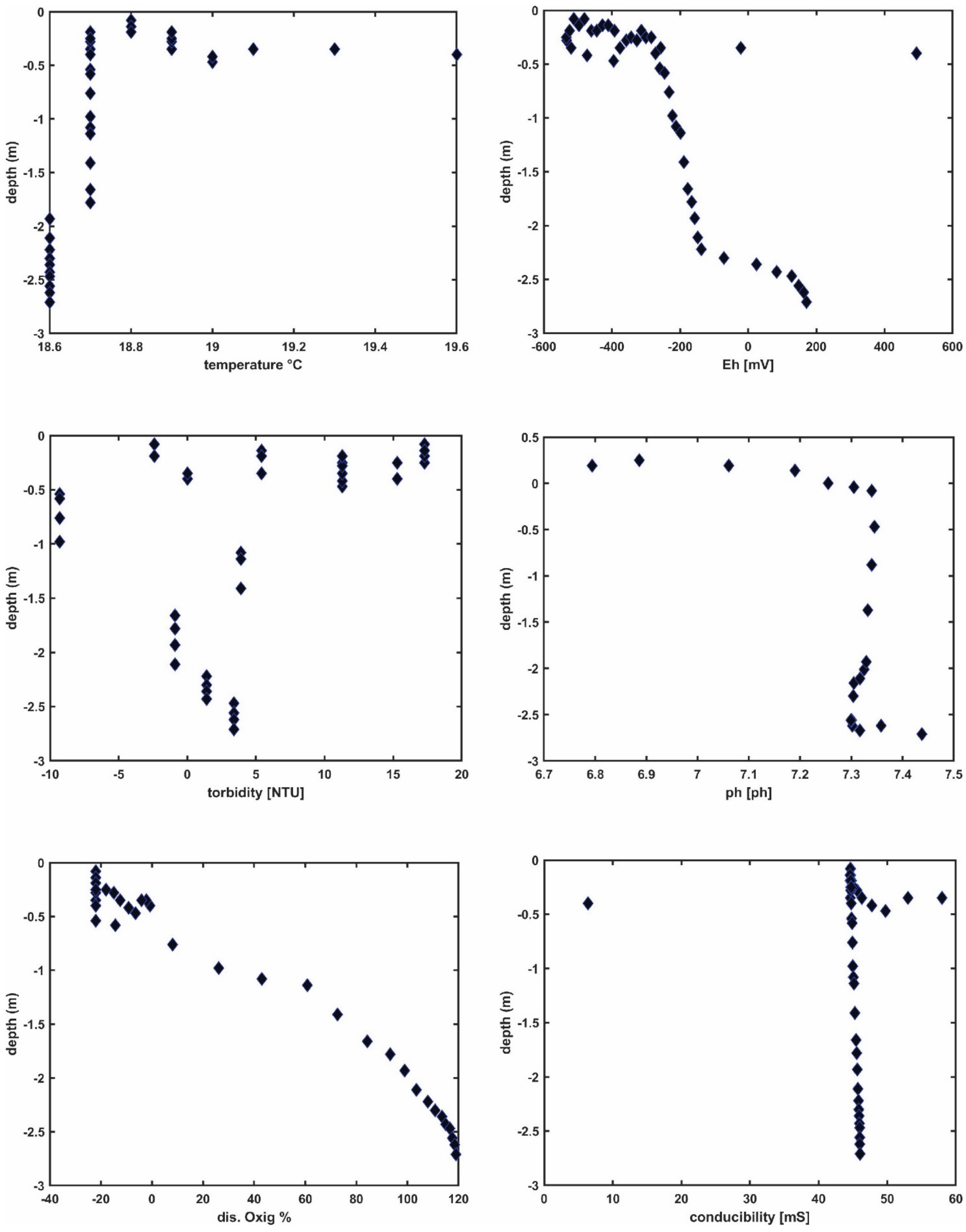

Figure 18 - 6 plots related the variation of chemical-physical parameter vs depth

GPS LOG

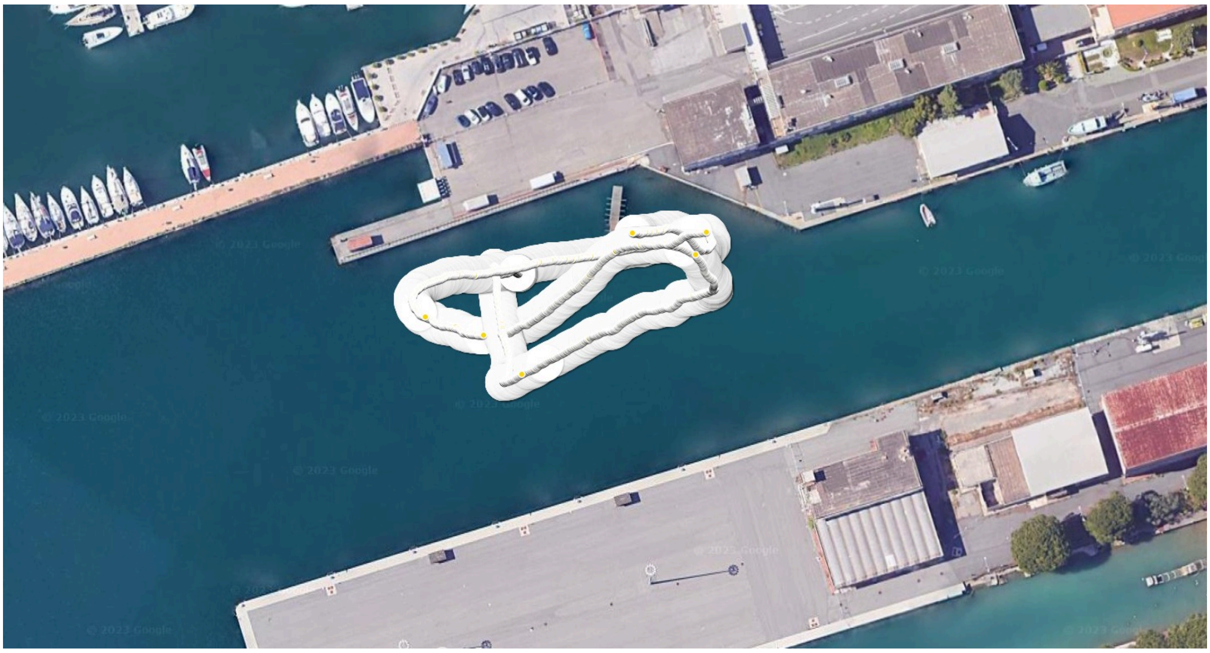

Figure 19 – AUV route geo-localization

The AUV GPS Log Table details data covering 10 seconds AUV route. Basing on GPS data, an instantaneous speed of 1.6 knots on average and a peak at 3.66 knots was reported.
The file with all data covering the whole test, which took place from 12.10'.56'' am to 12.17'.33'' am.

The test results will be further processed within the framework of the activities of WP7 (Task 7.4), where the data of the two Optical DO sensors will be correlated with those of the multi-parametric probe, acquired at the same altitude (surface).
In addition, the acoustic spectrograms of the two passive sensors will be analysed, trying to detect a common target (e.g. AUV propeller noise).
Finally, the GPS map will be compiled with the oxygen values spatially mapped during the AUV's navigation.

V. Summary

On Friday, 17 November 2023, EDGELAB conducted on-site tests aimed at the simultaneous collection of data from three platforms (AUV, USV-CAT operating as a buoy, RHIB with multiparametric probe). The test was conducted in a small harbour overlooking the Gulf of La Spezia, in a fairly quiet area in terms of wave disturbance and vessel traffic.

Data were collected on dissolved oxygen from the Fluorimeter on the AUV and the USV-CAT, on sounds from the Passive Broadband Acoustic Sensor for noise monitoring on the AUV and the USV-CAT, data on temperature, conductivity, turbidity, pH, dissolved oxygen and Redox from the multiparametric probe on the RHIB.

Appendix 1: References and Related Documents

ID	Reference or Related Document	Source or Link/Location
1	**Optical DO sensor measurements datasheets**	On field EDGELAB test
2	**Multiparametric probe raw data table**	On field EDGELAB test
3	**AUV route GPS Log D**atasheets	On field EDGELAB test