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Report on testing results of the joint operations of sensors, buoy, lander and ASV

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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

This deliverable details the activities undertaken in sub-task (ST) 6.3.1, titled "Controlled scenario testing of sensors, buoy, lander, and ASV joint operations" a part of WP6 Task 6.3. The primary focus of these activities was on testing and validating the NAUTILOS sensors and hosting platforms in coastal environments. The NAUTILOS instrumentation, developed in WP3 and WP4, along with Commercial Off-The-Shelf (COTS) instrumentation, was integrated into an Autonomous Surface Vehicle (ASV) (T4.1: Carbonate system/ocean acidification sensors, T3.3: Passive Acoustic Sensors) and a Lander platform (T4.5: Deep-ocean CTD) as part of the WP5 activities.

During the task activities, CEiiA deployed the ASV, equipped with installed payloads, in Portugal and on a coastal mission near the HCMR facilities in Gournes, Crete. This deployment aimed to coordinate efforts in a novel way, fostering collaboration between CEiiA ASV, the HCMR diving team and HCMR aerial drone for habitat monitoring. A sampling campaign was conducted to validate the pH sensor, while the passive acoustic sensor was set to collect data throughout the mission.

The lander deployment in Portugal tested CTD data logging on ATLANTIS lander platform provided by CEiiA and acoustic modems communication to enable quasi real-time status data transmission from seabed to surface. The tests conducted in T6.3.1 not only provided technological validation but also offered insights into improvements and tuning activities required for achieving the necessary operational status for the project's demonstration phase (WP7).

LIST OF FIGURES

List of Acronyms and Abbreviations

ASV	Autonomous Surface Vehicle
CTD	Conductivity, Temperature, and Depth
DPGS	Distributed Programmable Grid System
GNSS	Global Navigation Satellite System
GPS	Global Position System
LTE	Long-Term Evolution
NTRIP	Networked Transport of RTCM via Internet Protocol
ReNEP	Rede Nacional de Estações Permanentes
RHIB	Rigid-Hull Inflatable Boat
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SIM	Subscriber Identity Module
SIR	Sensor Interface Relay
SVP	Sound Velocity Profiler
UAV	Unmanned Aerial Vehicle

I. ASV MISSION - INTRODUCTION TO TECHNOLOGIES AND OBJECTIVES

1. INTRODUCTION

This part of the deliverable reports on the joint operations of the ASV and sensors coupled with other surveying and sampling methodologies aiming to assess the performance of this novel scheme in data collection.

With a few exceptions (i.e. reef forming organisms such as corals, or densely aggregating species such as shellfish), most biological attributes on the seafloor are not directly measurable using remote survey techniques. To produce a benthic habitat map, it is therefore always necessary to measure the biological characteristics of the seafloor using *in situ* ground-truthing methods, which can then be linked in some way to the environmental data layers. The choice of *in situ* sampling techniques will depend on a large number of factors (e.g. purpose of the survey, availability of gear, survey platform, cost etc.), but ultimately this will have a profound effect on the ability to characterize the biology of an area in a way that can be linked to the remotely sensed data sets. Regardless of the specific sampling technique used (e.g. grab sampling, trawls, underwater photographs or video), the multivariate nature of the biological data is usually reduced in some way to a single site-specific category that represents a summary of the physical and biological characteristics when describing a habitat. No matter how the environmental data layers are analyzed, it is still necessary at some point to incorporate biological information in order to create a benthic habitat map. The term "habitat" is often used in an ambiguous way, and we need to address this point carefully. In our case we use this term in a way to characterize the distribution of different types of ecosystems (i.e. soft bottom, shallow reefs, seagrass meadows).

Advancements in floats, profilers, and autonomous vehicles are improving the monitoring of marine environments by increasing observation numbers and reducing costs. Central to these innovations are autonomous sensors that offer high quality and cost-effectiveness, performing comparably to traditional lab or already existing technologies with efficient *in situ* quality control. Moreover, these sensors must support extended deployments, requiring *in situ* calibration, anti-biofouling materials, and low power consumption. The integration of modern platform and instrumentation technologies enhances information gathering with heightened spatiotemporal resolution. In applications experiencing growing data demands, such as measuring coastal zone pH, contributing to ocean carbon uptake and noise related to anthropogenic activities, traditionally performed by fixed point stations or sampling surveys, technological upgrades can significantly boost data availability.

2. TECHNOLOGIES TO BE TESTED

The ORCA Autonomous Surface Vehicle (ASV), developed by CEiiA (Figure 1.1), is a versatile unmanned vehicle designed for inland and coastal applications, demonstrating proficiency in scientific missions. Notable for its expandable payload and modular configuration, the ORCA

ASV excels in adapting to diverse scenarios and missions—a crucial feature aligned with the dynamic requirements of the NAUTILOS project.

Figure 1.1 ORCA ASV

The ORCA ASV was equipped with a multibeam sonar from Imagenex (Figure 1.2). The model used is the DT101Xi, that is a single instrument integrating the sonar, motion reference unit (MRU) and sound velocity into one sleek and compact unit. This model is compatible with the DT100 SIR (Sensor Interface Relay) power supply/timing box, simply connecting a dual antenna GNSS/GPS receiver is all that is required to perform bathymetric surveys. Data acquisition is controlled with Imagenex's software.

Figure 1.2. Multibeam sonar head (left), and acquisition and synchronization system (right).

NAUTILOS pH Sensor – NIVA

Figure 1.3. NAUTILOS pH Sensor

The pH sensor package, developed by NIVA in T4.1, encompasses the Honeywell Durafet pH sensor, with integrated temperature-sensing capabilities. This system has been paired with additional hardware and electronics for data acquisition and storage, developed during NAUTILOS activities. These supplementary components are designed to enhance sensor performance and usability while concurrently minimizing costs for the end user.

NAUTILOS Click & Sound recorder – AQUATEC

Figure 1.4. NAUTILOS Click & Sound recorder

The Click & Sound recorder is an advanced device designed for observing echo-locating marine mammals. Equipped with a 150 kHz bandwidth sound recorder, it captures the full waveform of frequency-modulated whale clicks, broadband dolphin clicks, narrowband high-frequency porpoise-like clicks, and dolphin communication whistle sounds, facilitating improved species classification. Developed and provided by AQUATEC in T3.3, this recorder integrates two NAUTILOS sensors: a passive broadband acoustic recording sensor for noise monitoring and a passive acoustic event recorder. It includes a custom-made hydrophone with a flat frequency response over the entire recording bandwidth. The design covers deployment, data uploading, and post-processing, supported by user-friendly software. This functional device serves the purpose of efficient marine mammal observation, contributing to advancements in acoustic monitoring and species identification.

3. OBJECTIVES

The primary objective of this task was to conduct large-scale mapping of critical seabed habitats within designated marine areas. This mapping process utilizes novel equipment and Unmanned Vehicles to assess biodiversity and other non biotic parameters in shallow habitats. The methodology involves field-testing, cross-evaluation, and validation through comparison with assessments conducted by divers. Diver assessments encompass visual census over predetermined transects, non-destructive photographic sampling, and rigorous quantitative image processing techniques. This integrated approach aims to leverage technological advancements for comprehensive and accurate evaluations of marine biodiversity in shallow ecosystems. A second objective related to the NAUTILOS developed sensors, following the integration of both sensors on the ASV platform, was to validate the performance of the pH sensor with sampling and test the passive acoustic instrumentation deployed in a realistic sea environment.

II. ASV OPERATIONS

1. PREPARATION AND VALIDATION MISSIONS – PORTUGAL

This section delineates the field tests conducted for Autonomous Surface Vehicle (ASV) operations, with multibeam sonar from Imagenex and NIVA pH sensor, emphasising both laboratory bench tests and practical sea environment tests. Notably, the focus here is on sea tests, in order to confirm findings derived from bench testing and platform and sensors operational readiness up to a full working day before the mission in Crete (mechanical integration endurance and battery considering multibeam and pH power requirements)

The selected test site, Porto de Leixões in Porto (Portugal, Figure 1.5a and b), has served as the location for numerous ASV missions and technology evaluations. Its controlled environment, and minimal sea wave interference, has facilitated thorough testing of the ORCA ASV.

Figure 1.5a. Porto de Leixões, Portugal testing site

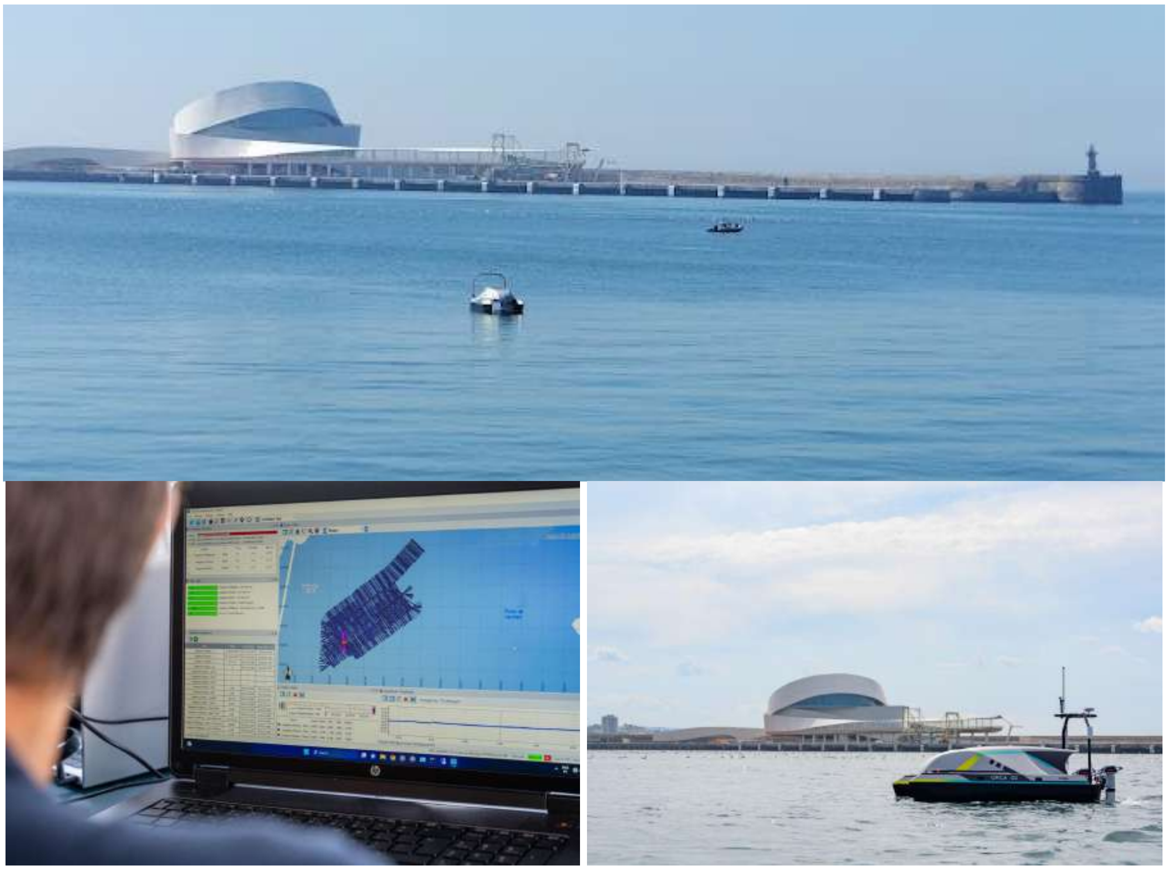


Figure 1.5b: ASV operations at Porto de Leixões

Equipped with a multibeam sonar, the ASV mapped the seafloor topography within the testing site at Porto de Leixões. The resulting bathymetric data provides detailed information on underwater terrain, aiding in the identification of subsea features, potential hazards, and habitat characteristics. Figures 1.6 and 1.7 below shows some results of the bathymetric survey from the testing campaign in Portugal.

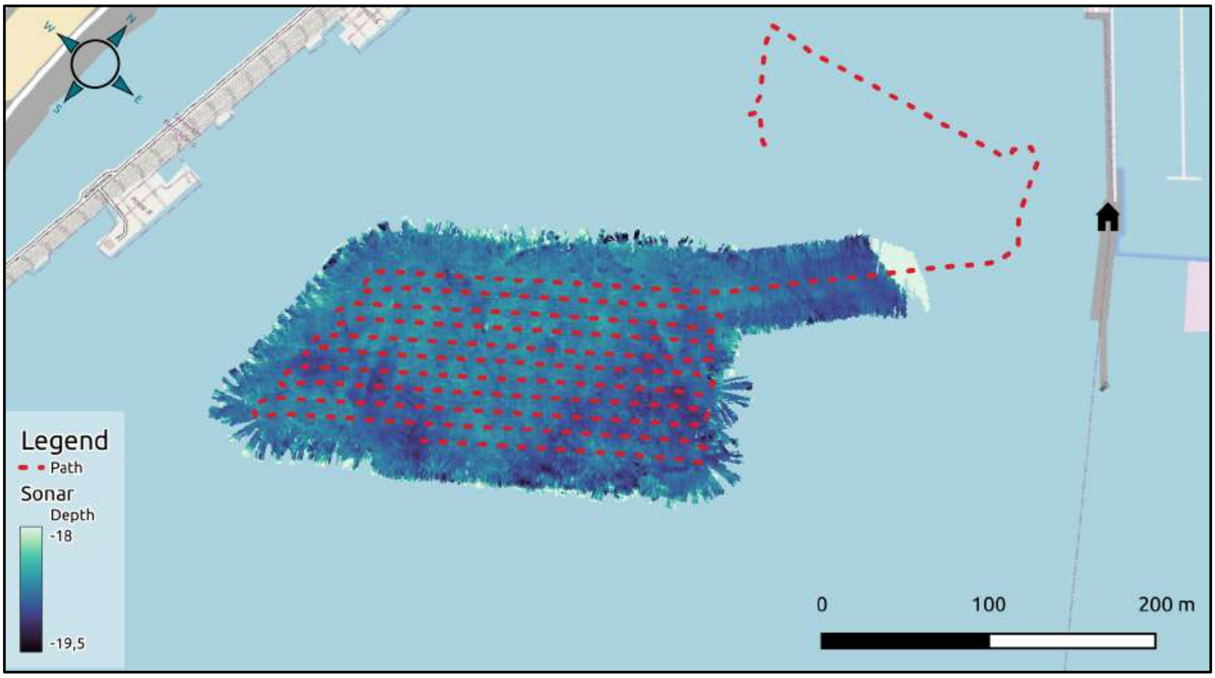


Figure 1.6. Porto de Leixões bathymetry survey. Depth.

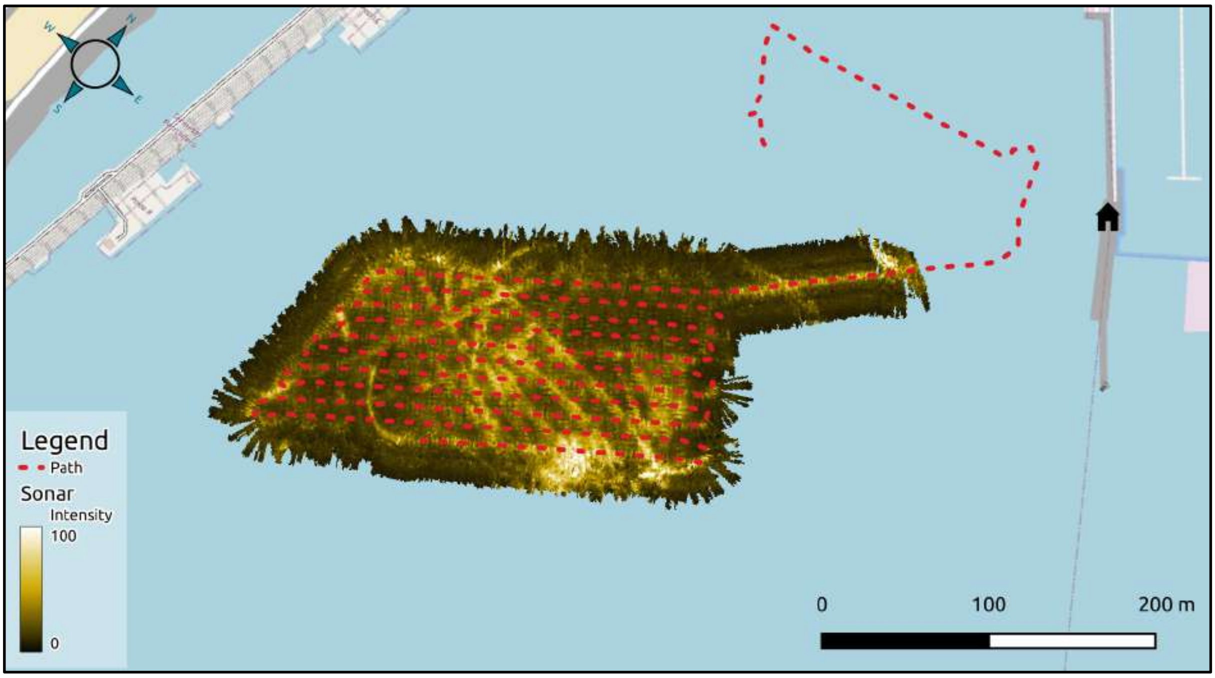


Figure 1.7. Porto de Leixões bathymetry survey. Backscatter intensity.

Concurrently, the ASV was outfitted with NIVA's pH sensor to measure seawater acidity levels. pH, a critical parameter reflecting ocean acidity or alkalinity, holds pivotal importance in marine ecosystem health. The sensor's real-time pH measurements contribute to our understanding of ocean acidification.

Figure 1.8 below shows the results of pH measurement from the testing campaign in Portugal.

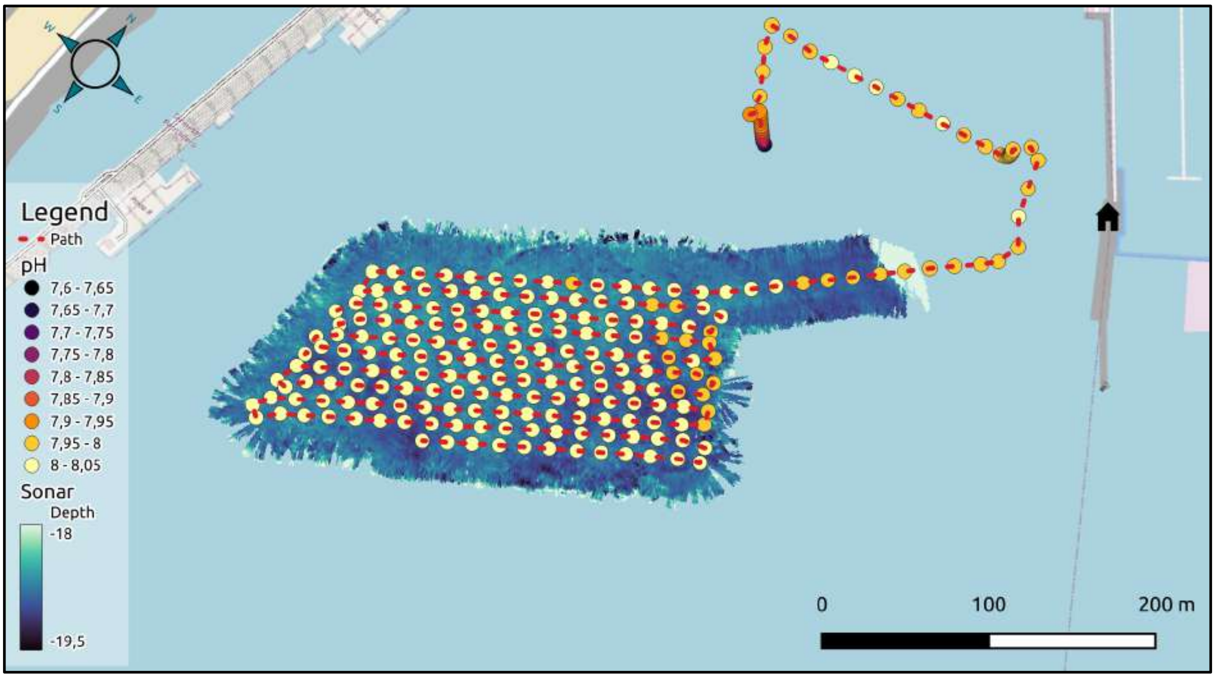


Figure 1.8. Porto de Leixões pH sampling map.

The tests ensured the successful integration of diverse systems within the ASV, and proved ASV system autonomy to operate up to 8 hours. Reliable communication among sensors, navigational tools, and data recording mechanisms demonstrated the robustness of autonomous technology and assured the quality of collected data.

2. CONTROLLED SCENARIO OPERATION – CRETE

The T6.3.1 ASV and Sensors operation activities occurred from October 19th to October 26th, 2023, with land-based activities taking place at the HCMR Thalassocosmos complex in Crete, and coastal operations carried out in the Gournes area (35.335488, 25.280327) near HCMR. These activities were facilitated by the support of HCMR laboratories such as the Poseidon Sensor Lab and infrastructure resources like the HCMR machinery lab, Scientific diving lab, and Cretaquarium lab, all of which are located within the Thalassocosmos complex in Gournes (Heraklion, Crete). Additionally, HCMR vehicles and the "IOLKOS" RHIB were utilised for the field operations.

2.1. Challenges and solutions

Operating a platform like the ORCA ASV necessitates specialized equipment and logistics. Conducting operations thousands of kilometres away from the home base demands rigorous procedures and careful planning. Factors such as shipping, border controls, weather conditions, and financial transactions all introduce complexity and can impact even the most well-thought-out plans.

Upon CEiiA's operations team arrival in Crete, they swiftly unloaded the ASV and necessary equipment, preparing for the planned tasks. However, the mission faced technical and operational challenges, requiring quick resolution, to avoid delays that could compromise this mission (mission & logistics - 6 working days). This section will detail the equipment checks, operational issues, and solutions encountered during the mission, emphasizing the importance of adaptability in international contexts.

2.1.1. Internet and RTK corrections

For applications that require higher accuracy on positioning, such as surveying bathymetry, it is common to use a Real-Time Kinematic (RTK) technique. The basic concept is to reduce and remove errors common to a base station and rover pair. Since we do not have a base station of our own, we use the Networked Transport of RTCM via Internet Protocol (NTRIP), that is a protocol for streaming differential GPS (DPGS) corrections over the internet for RTK positioning.

In Portugal, the team uses a national public service called Rede Nacional de Estações Permanentes (ReNEP) that provides users with GPS equipment with data that allows them to determine geographic coordinates with an accuracy of better than 10 cm. To use this service, it is necessary to have internet access on the ASV system, to connect to a server that sends the correction over the NTRIP protocol.

Internet access on the ASV system is provided by an LTE modem with a SIM card. Data roaming with the Portuguese SIM card was prepared beforehand, but upon arrival in Crete, it was not possible to establish a connection. After several failed attempts at getting data access, the decision was made to purchase a Greek SIM card. It was then possible to establish internet access. Regrettably, this setback led to a substantial delay (1 day) in the mission.

Instead of the Portuguese service for RTK corrections, ReNEP, the team used a Greek service called Uranus[1], to obtain RTK positioning corrections for the ASV system.

[1] https://www.uranus.gr/

2.1.2. Multibeam cable issues

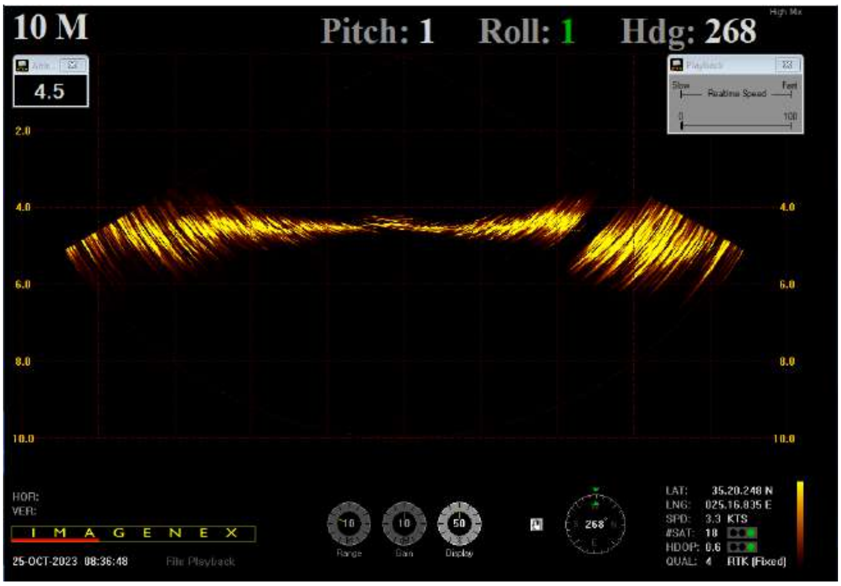


Figure 1.9. Multibeam's Imagenex interface

Despite meticulous pre-deployment testing of the ASV and multibeam sonar, adhering to operational checklists, challenges emerged during navigation, specifically with sonar data acquisition (Figure 1.9). Upon retrieval, a faulty cable connector was pinpointed as the root cause of the issue. Swift corrective action was taken, with a new cable prepared (merged and sealed with a spare connector from HCMR), resolving the problem. Regrettably, this setback led to a substantial delay (1 day) in the mission.

2.1.3. Click & Sound recorder

For this mission, CEiiA integrated the AQUATEC Click & Sound recorder, a standalone sensor tested for the first time in Greece (delivered directly to HCMR due to some logistics issues that delayed delivery) but we faced a data acquisition challenge.

Mechanical integration of the Click & Sound recorder into ASV worked as expected. For that purpose, CEiiA's mechanical engineering team created fixed support brackets capable of holding the sensor on the ASV so that it does not interfere with the correct functioning of the ASV, and does not suffer damage during the mission, as described D5.3.

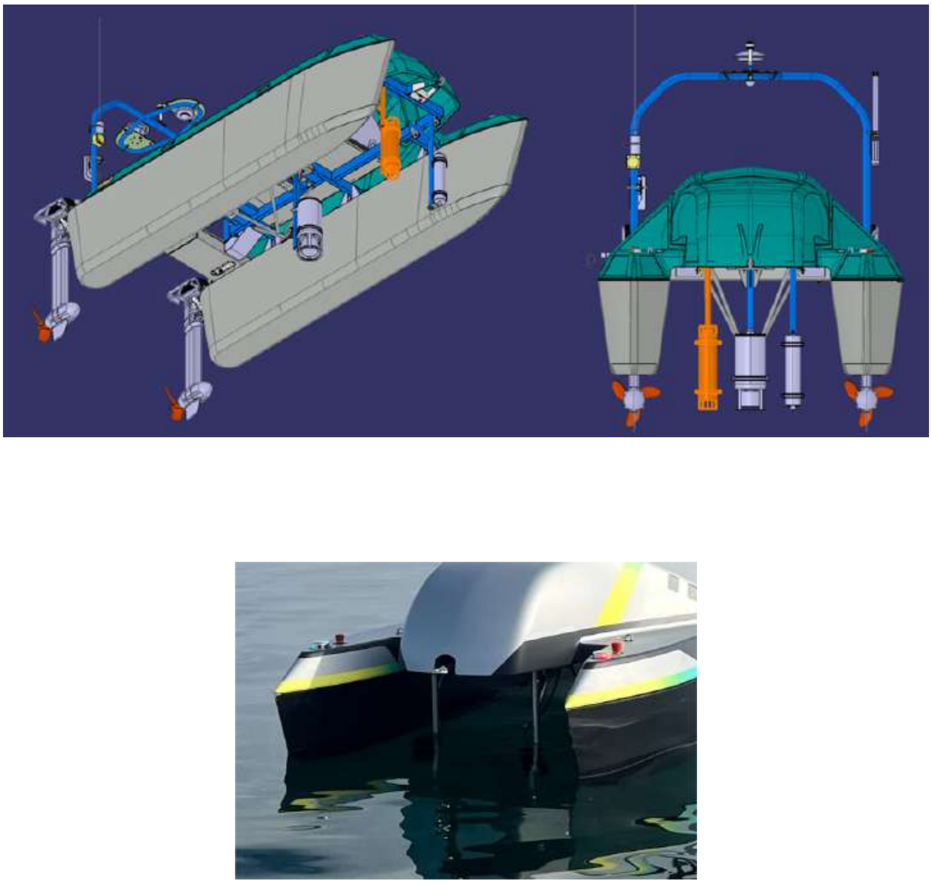


Figure 1.10. ORCA ASV Click & Sound recorder mechanical integration

No electrical or data logging integration was required for this system.

The subsequent task involved configuring the Click & Sound Recorder and acquiring data from it. Utilizing the software provided by AQUATEC, namely AQUAtalk and UnifiedHost, the sensor was configured for optimal performance. AQUATEC also supplied the necessary firmware version for a successful sensor update (upon arrival to Greece). Following the completion of the firmware update, conducted at the request of AQUATEC, the CEiiA ASV operation team initiated sound recording. The settings recommended by AQUATEC for this phase were:

- Gain Control (Ratio) – 1:1
- Sampling Frequency – 384 kHz

After configuring, CEiiA started the first tests in the laboratory, recording 3 seconds every 10 minutes. The first tests were successful, providing some recordings. After this, the goal was acquiring recordings in the Cretan Sea with the Click & Sound Recorder device attached to the ASV. To achieve this, it was again necessary to set up the Click & Sound recorder and start the timer for the recordings before placing the sensor in water.

Unfortunately, after performing the suggested procedure, it was noticed that the sensor only recorded a limited number of data samples, and none of them in water. After this problem, the CEiiA team repeated recording tests in the laboratory, but this time without success. CEiiA started debugging this issue with AQUATEC support, doing more tests, recordings and repeating the firmware update, but without success. A FW/SW update was deemed necessary by AQUATEC, which immediately started to work on solving all issues for the next mission.

2.1.4. Drone interference

After starting the autonomous operation of the ORCA ASV successfully, as planned during the mission briefing, HCMR's team deployed their drone to do the Aerial Survey of the area of interest. After the drone's launch, both vehicles lost communication to their respective ground station. This phenomenon occurred due to both systems' high RF power output and operational frequency band being too close to each other. Both operations paused and ASV restarted to conclude the survey as planned for ST 6.3.1. No major delay resulted from this issue.

2.1.5. Weather forecast

The operational efficiency remained largely unaffected by weather conditions such as wind and waves on most days. Nonetheless, on the final day of the mission (25/10/2023), we encountered worsening weather conditions. The subsequent day (26/10/2023) witnessed a drastic shift in weather patterns, with high winds making navigation challenging (Figure 1.11).

Figure 1.11. Weather forecast for 26/10/2023 (@Crete)

3. HABITAT MAPPING SURVEY

3.1. ASV Multibeam sonar survey

3.1.1. Sound Velocity Profiles data collection

A sound velocity measurement is essential for bathymetry operation. The multibeam has an integrated SVP, however it only measures from the surface of the seabed. To obtain a high-resolution bathymetric map of the seabed of the monitored area, it is required to acquire a representative distribution, both temporally and spatially, of the sound velocity profiles.These should be recorded in an organized way for later application for data processing.

CEiiA uses an SVP from Valeport, model SWiFT SVP that has Bluetooth connectivity, rechargeable batteries and a GPS module (Figure 1.12). In addition to the directly measured sound speed, temperature and pressure observations, Conductivity, Salinity, and Density are calculated using Valeport's proprietary algorithm.

Figure 1.12. Valeport SVP sensor

Before and after a survey, the team in the RHIB made several SVP casts (Figure 1.13 a and b), following directions from the team on the ground who had all the coordinates from the survey area of interest.

All data collected using Valeport software allows us to visualize all the graphs of each measurement, and all the location of each cast. Those data were used to post-process the bathymetry results, using the BeamworX software, AutoClean, to correct the data from multibeam.

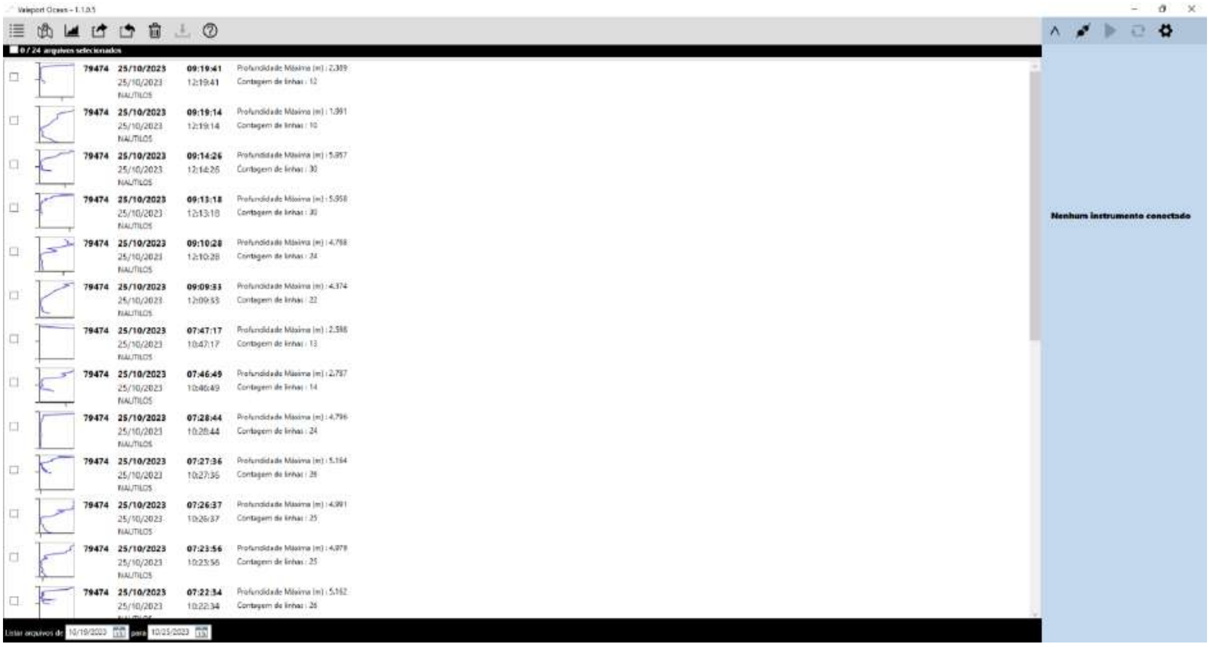


Figure 1.13a. SVP recorded data

Figure 1.13b. SVP profiles sites displayed on a map

3.1.2. Multibeam

Data from multibeam sonar is logged using Imagenex software, and the output is recorded in a profile point data format (d1p). This data combines all the information of sonar beams, attitude and heading, sound velocity from the head and GPS position. The d1p output data is used as an input on the BeamworX software, called NavAQ. This is a hydrographic data acquisition program that can calculate live Multibeam Echo Sounder result footprints.

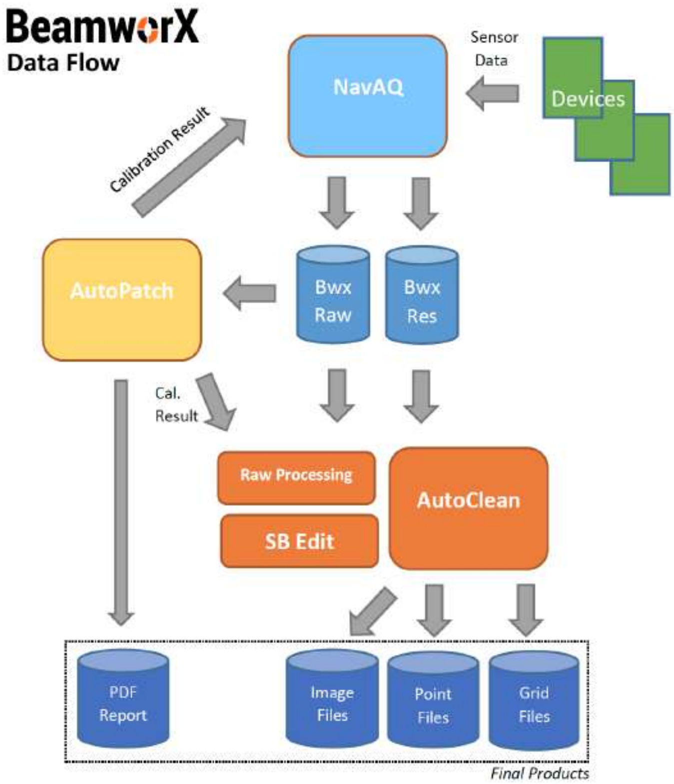


Figure 1.14: BeamworX workflow (beamworx.com/autoclean)

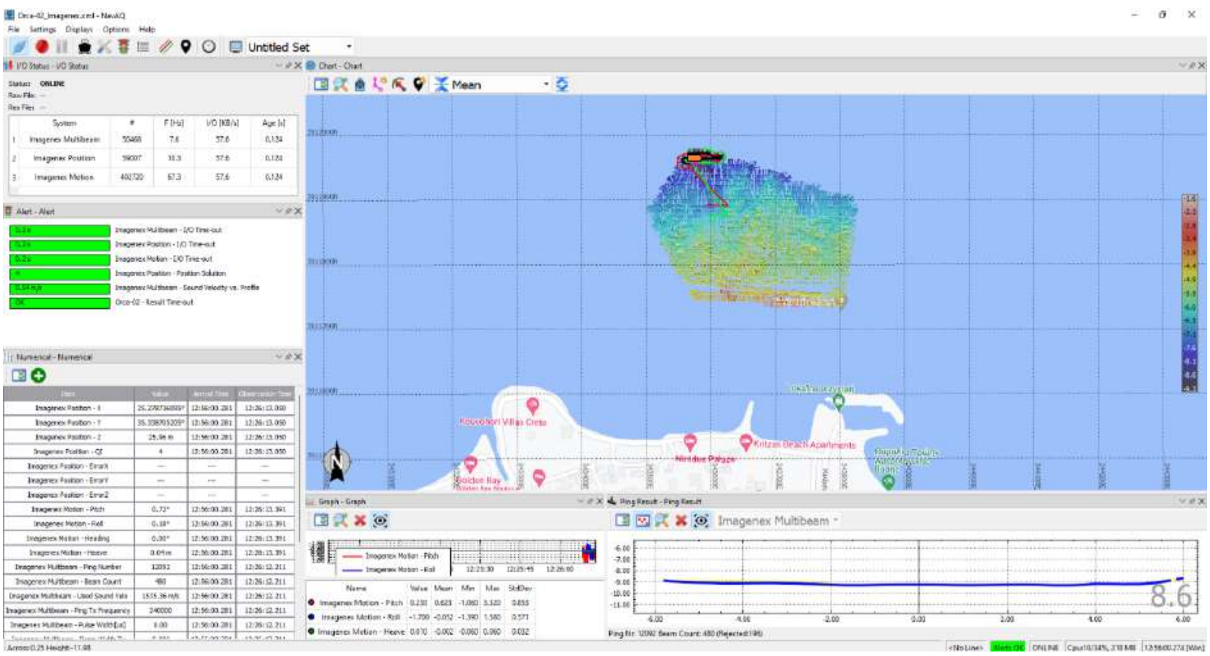


Figure 1.15. Real-time multibeam data acquisition

In the NavAQ it is necessary to set up the Survey Configuration, that has all the information about the vessel and the sensors used for this operation, and additional information about geodetic, clock synchronisation and offsets configurations. The result output of the NavAQ is a proprietary data format from BeamworX and it is used as an input for other software from them, called AutoClean.

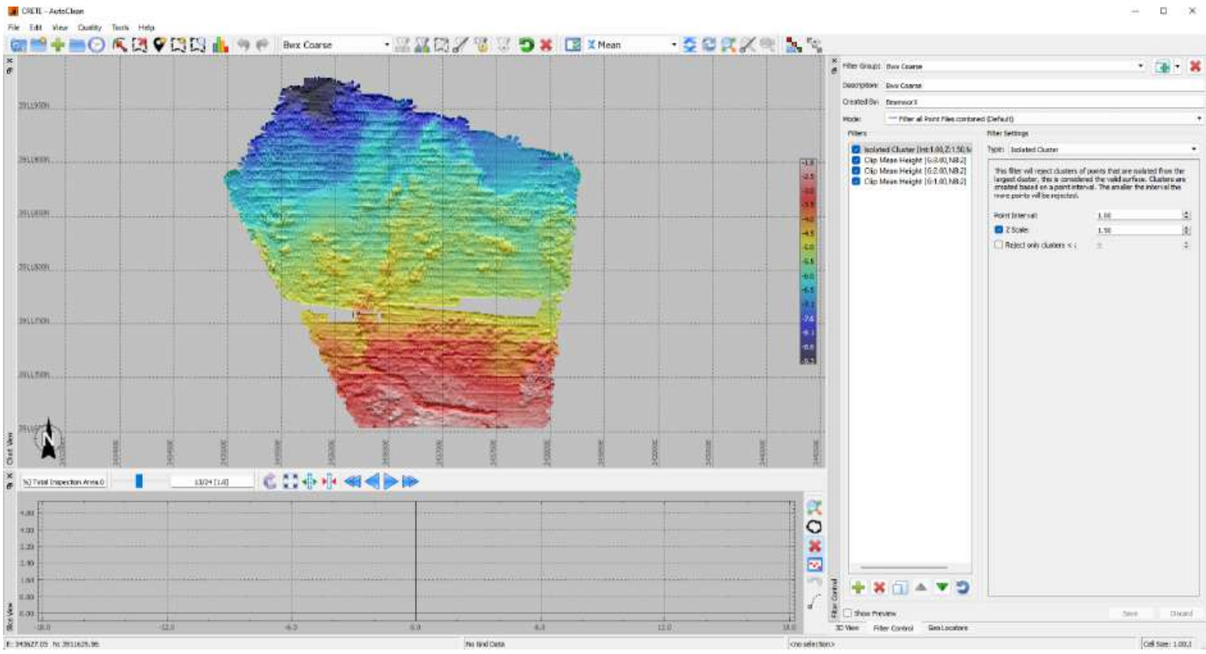


Figure 1.16. Processed multibeam data

AutoClean is designed to quickly process point data sets. It can automatically load and clean data, in a preliminary way. The main features used in our scenario are SVP corrections, filtering (clean outliers) and interpolation, filling the holes in the grid with “virtual” points. The results can be exported to grid data to various file formats, in this case we used the GeoTiff format, with height values and intensity values.

3.2. Visual census with divers – Ground truthing

During the activities of sub-Task 6.3.1 and the CEiiA mission in Crete (20-26/10/2023), the ASV was equipped with a multibeam and performed a survey in the coastal area of Gournes (see map in Figure 1.17). In parallel, the HCMR Scientific Diving Team (SDT) performed ground-truthing in the same area using geotagged underwater photographs and video. The divers carried a surface GPS, an underwater camera (Sony RX100V) and an underwater video system (GoPro ver11). The divers from HCMR visited the test site and performed horizontal and vertical visual census transects. One transect was selected, along which the divers took photographs at certain points focused on a variety of locations and habitats. In total 104 photographs were taken in 65 minutes of diving time (Figure 1.18) along the transect.

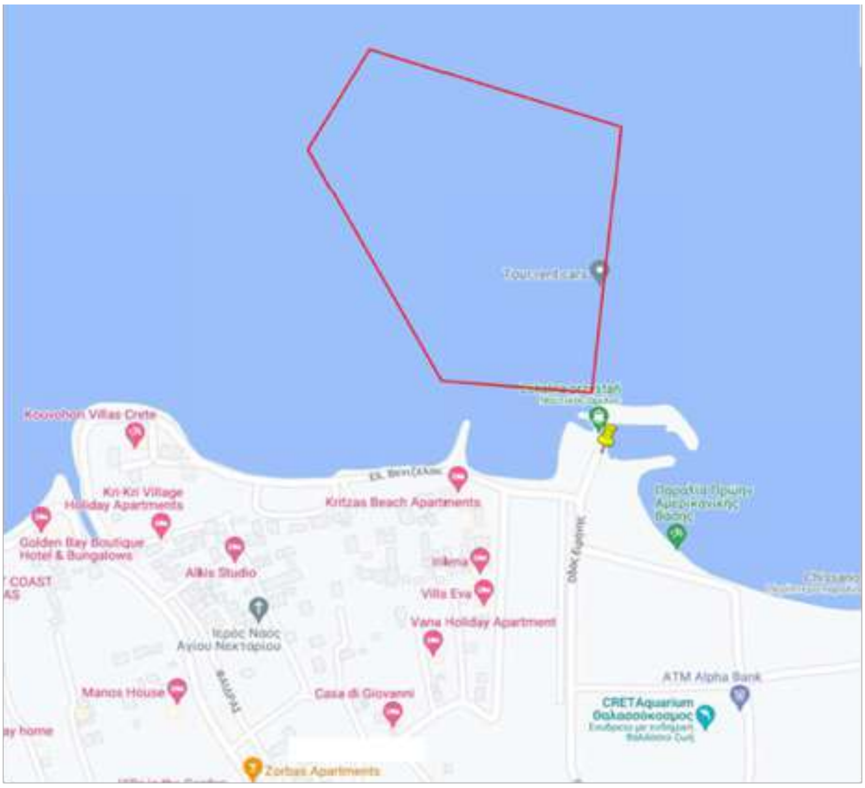


Figure 1.17. Map of the area surveyed by the ASV and where the habitat mapping was performed by HCMR divers.

Figure 1.18. Ground truthing diving track (blue line) in the area of interest.

3.3. Aerial drone images

Besides the underwater diving mission for the visual census, high-resolution optical aerial images were acquired by the HCMR team using a modified DJI Mavic 2 Pro quadcopter. This consumer-grade UAV is a lightweight (0.9 kg) and easy-to-carry drone equipped with a fully stabilized 3-axis gimbal Hasselblad L1D20c camera with a 1-inch CMOS RGB sensor with a resolution of 5472 × 3648 (20 MP). Considering a GPS flight speed of 5 m/s and a flight height of 40 m above mean sea level, to maintain a sufficient overlap (>70%) between images, photos were taken every 5 m by using the space-lapse mode with auto white balance and shutter priority (1/400 sec) to avoid motion blur in the acquired imagery.

The UAV-based imagery was processed using Pix4Dmapper 4.4.12, ver.12. With this low-cost SfM software package, 3D models and 2D raster products can be generated in a fully automated five-step process, comprising: (i) alignment of the photographs, (ii) calculation of a sparse point cloud, (iii) calculation of a dense 3D, (iv) polygonal mesh model generation and texture mapping, (v) generation of Digital Surface Models (DSMs) and ortho-rectification of the imagery (De Reu et al., 2013). Firstly, we performed the alignment of images with the parameter accuracy set to 'high'. After the photo-alignment, this initial bundle adjustment created sparse point clouds from overlapping digital images. The sparse point clouds included the position and orientation of each camera position and the 3D coordinates of all image features. The internal camera geometry was modelled by self-calibration during the bundle adjustment (Price et al., 2019). Subsequently, dense point clouds were built based on multi-view stereopsis (MVS) algorithms with high-quality and mild depth filtering. After filtering the dense point clouds according to points of confidence (points with values less than three were removed), these were used for producing polygonal meshes and DSMs using an Inverse Distance Weighting (IDW) interpolation. Finally, the DSMs generated ortho-rectified RGB photomosaics of submerged habitats.

Orthophoto mosaics and DSMs generated in Metashape were exported as raster images (GeoTIFF format, in the reference systemWGS84/UTM zone 35 N, EPSG:4326) and transferred to a geographical information system (GIS) using QGIS 3.12 software for subsequent Object-Based Image Classification (OBIA) processing. At this stage, classification methods based only on pixel information are time-consuming and limited due to the spectral similarities. Therefore, we are aiming to reduce the pixel complexity by segmenting the orthophotos into more meaningful objects to speed up the aerial and underwater imagery classification.

4. RESULTS

4.1. Multibeam data

The habitat mapping mission conducted with the ORCA ASV equipped with a multibeam sonar system has yielded significant and insightful results for the assessment of underwater environments. The collected data were preliminary processed using advanced software called AutoClean from BeamworX.

One of the essential steps in this mission involved the incorporation of data from a Sound Velocity Profile (SVP). This data was utilized to correct the multibeam sonar data, compensating for variations in sound velocity through the water column. The SVP data helped in ensuring that the acoustic signals generated by the sonar accurately represented the seafloor and underwater structures, thus minimizing errors and uncertainties in the dataset.

AutoClean from BeamworX was instrumental in processing the collected data. It included the application of filtering techniques to remove noise, artefacts, and outliers from the dataset. This step was vital in ensuring that only high-quality and relevant data points were used in subsequent analyses.

Furthermore, the software also performed interpolation on the data. Interpolation aided in filling gaps and irregularities in the dataset, creating a more comprehensive and continuous representation of the seafloor. The combination of data filtering and interpolation enhanced the overall dataset quality, making it suitable for habitat mapping applications.

To obtain results for habitat mapping, the processed multibeam data, which included both depth (Figure 1.19) and intensity (backscatter) information (Figure 1.20), were utilised. Backscatter data is valuable for habitat mapping as it provides insights into the type and texture of the seafloor, allowing for the identification of different habitat types.

The processed multibeam data was used to generate grid files in the form of GeoTIFF (tiff) files. These grid files represent the seafloor and the associated intensity values, which can be indicative of habitat characteristics. By creating these grid files, we were able to transform the raw sonar data into visual and quantitative representations of the underwater landscape.

The preliminary results of the habitat mapping mission have provided valuable insights into the distribution of seafloor features sharing similar acoustic responses within the surveyed area. The GeoTIFF files generated from the multibeam sonar data allow for the creation of zone maps, helping to identify areas with distinct habitat characteristics (e.g. soft versus hard substrate) .

Figure 1.19. Bathymetry Data displayed on a map

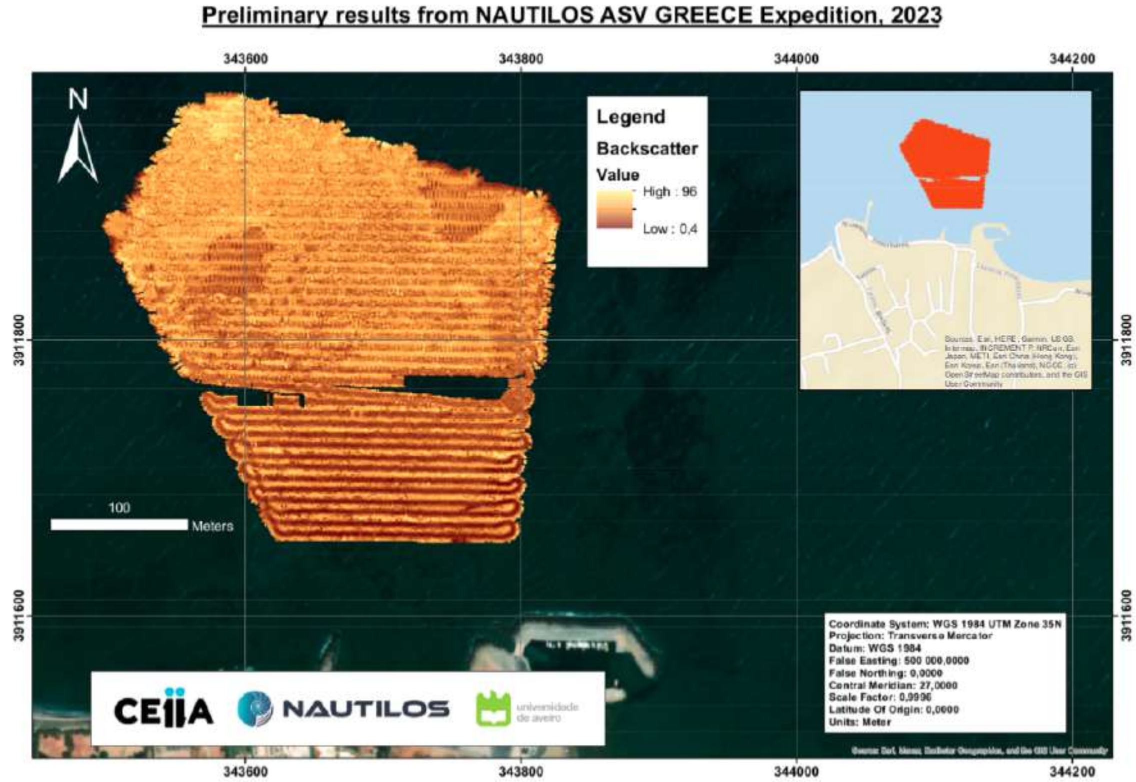


Figure 1.20. Intensity (backscatter) Data displayed on a map

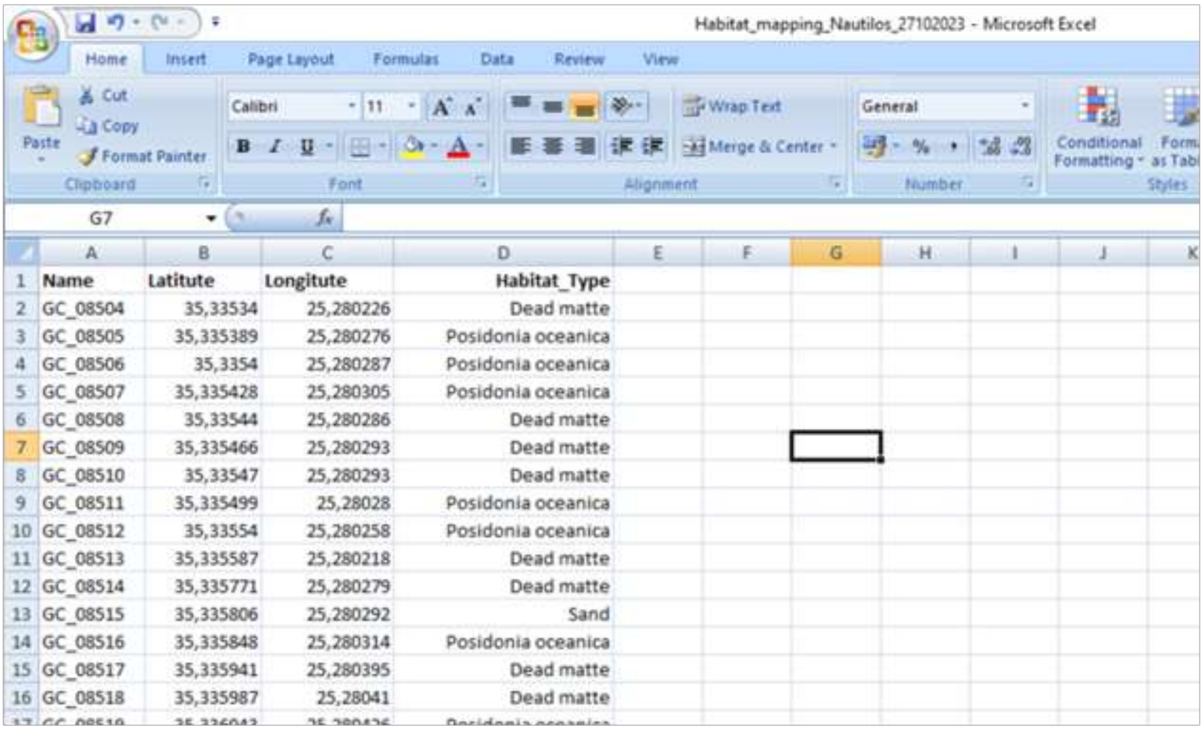
4.2. Visual census with divers – Ground truthing

Photographs from the diving survey were geotagged using the surface GPS track and the free software GEOSETTER. In order to perform an accurate geotagging, the camera time was aligned with the GPS time. After that a new track was created including the position of each photograph (Figure 1.21).

The analysis of the photographs and video in the studied area indicated that the shallow infralittoral rocky bottoms at depths from 0.1 m up to 6 m are characterised by complex communities constituting of seagrass patches of *Posidonia oceanica* (L.) Delile, as well as brown (Phaeophyta), red (Rhodophyta), and green (Chlorophyta) photophilous algal assemblages, which host a large number of endemic faunal species (Gravina et al., 2020). In total, three types of habitats are present in the area of interest: *Posidonia oceanica* meadows, *Posidonia* dead matte and sand. In addition, bare shallow reefs are present in the nearby area. Therefore, it was concluded that the selected area was indeed an appropriate selection for the habitat mapping mission, since it was characterized by a complex landscape, shallow water and high heterogeneity of benthic habitats.

Each seabed photograph was associated with the respective positional data (GPS coordinates) and was related to one of the 3 identified habitats/substrate types (*Posidonia oceanica* meadows, dead matte and sand) in order to create the geo-referenced habitat mapping dataset from the visual census (Figure 1.22).

Figure 1.21. Geotagged photographs on survey track.



Habitat_mapping_Nautilos_27102023 - Microsoft Excel

	A	B	C	D
1	Name	Latitute	Longitute	Habitat_Type
2	GC_08504	35,33534	25,280226	Dead matte
3	GC_08505	35,335389	25,280276	Posidonia oceanica
4	GC_08506	35,3354	25,280287	Posidonia oceanica
5	GC_08507	35,335428	25,280305	Posidonia oceanica
6	GC_08508	35,33544	25,280286	Dead matte
7	GC_08509	35,335466	25,280293	Dead matte
8	GC_08510	35,33547	25,280293	Dead matte
9	GC_08511	35,335499	25,28028	Posidonia oceanica
10	GC_08512	35,33554	25,280258	Posidonia oceanica
11	GC_08513	35,335587	25,280218	Dead matte
12	GC_08514	35,335771	25,280279	Dead matte
13	GC_08515	35,335806	25,280292	Sand
14	GC_08516	35,335848	25,280314	Posidonia oceanica
15	GC_08517	35,335941	25,280395	Dead matte
16	GC_08518	35,335987	25,28041	Dead matte

Figure 1.22. The geo-referenced habitat mapping data from the visual census transect performed by the HCMR scientific divers.

The whole study area (5 Ha) was mapped after a flight time of 27’36’’ from a height of 100 m, leading to the acquisition of 210 aerial images (Figure 1.23). Based on the combination of two techniques (diving and aerial photos), four major seabed cover classes representing broad benthic community-level categories were identified: *Posidonia oceanica* meadows, dead *Posidonia* matte, soft bottoms (sand) and bare shallow reef.

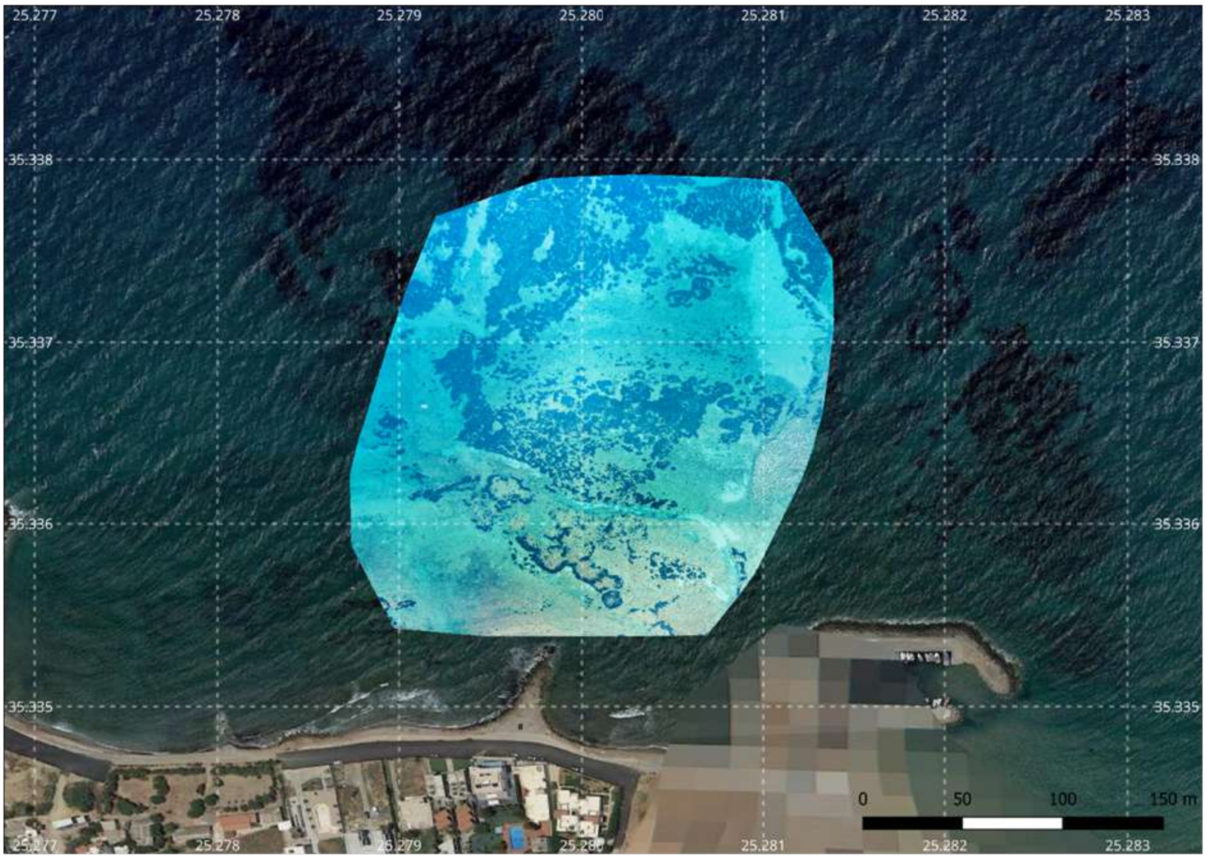


Figure 1.23. Aerial image from UAV.

The visual census data (diving) will be used as a quality control point system for the acquisition of ground-truth data in order to test the veracity of the map product based on the remotely sensed data as they are derived by the multibeam sensor of ASV.

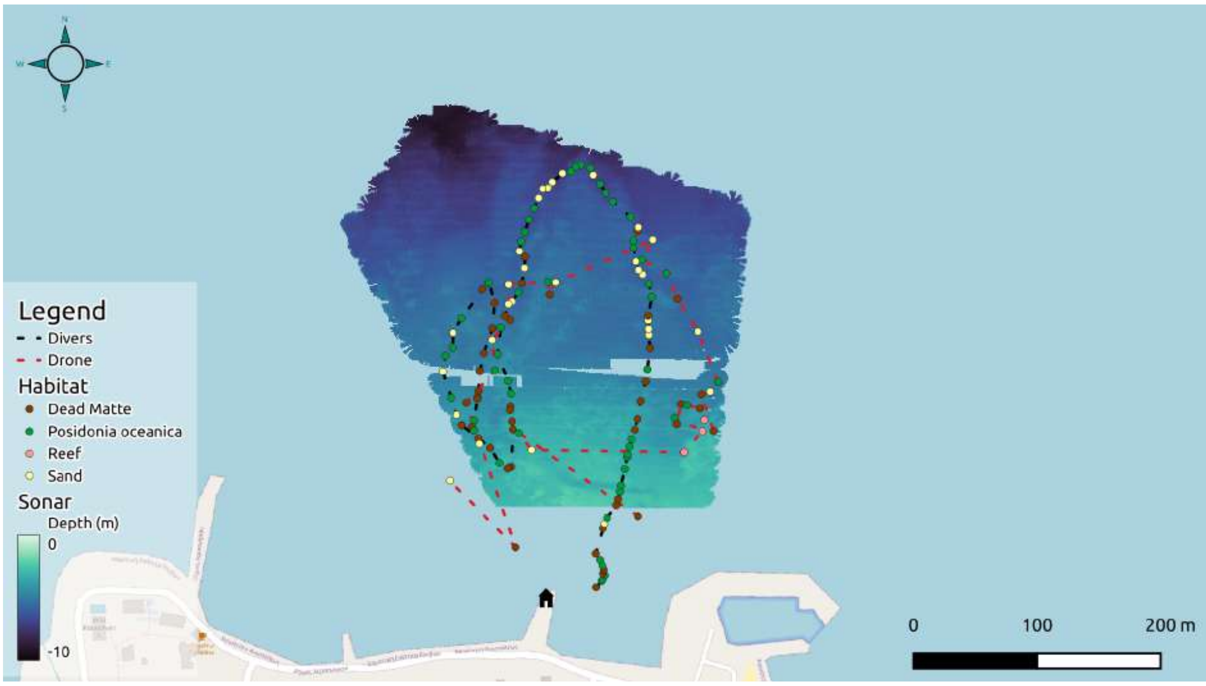
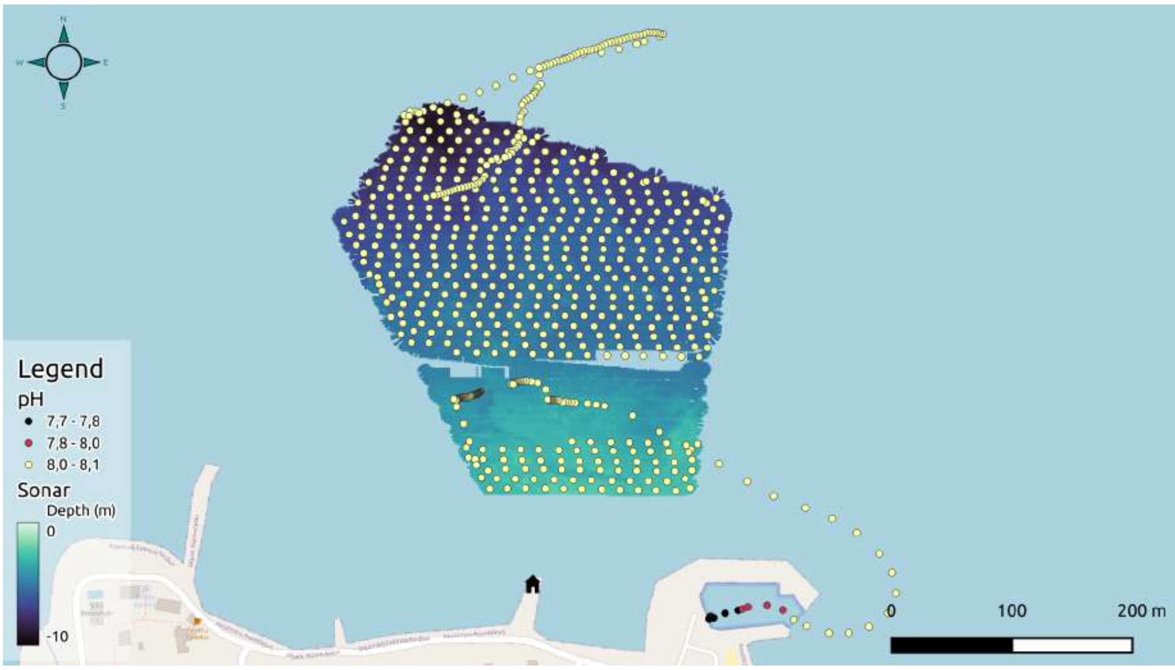


Figure 1.24.: The geo-referenced habitat mapping data (seen in Figure 1.22), displayed on top of the bathymetry map.

4.3. Sampling and CTD data for the pH sensor validation

Due to the technical issues that delayed the habitat mapping mission, it was not possible to plan and execute safe navigation (weather conditions and ASV specifications) with the ASV to the POSEIDON HCB buoy (expected for 26th of October) where relative instrumentation is installed. In order to validate data sampling from the NIVA pH sensor water samples collected on the area of the coastal habitat mapping mission were used (Figure 1.25). Prior to the Crete mission the NIVA pH sensor was also tested in Portugal and provided data continuously for a mission duration of about 5 hours (Figure 1.8).



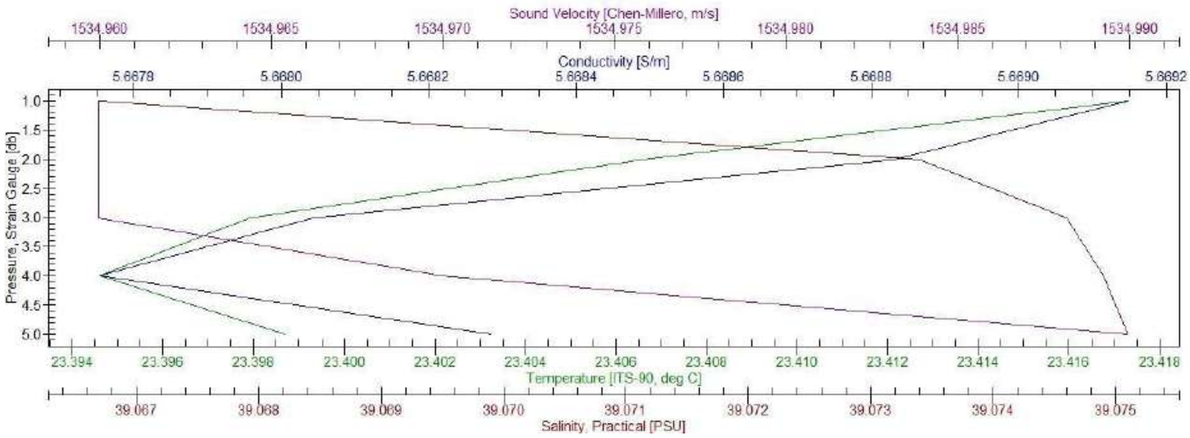
	A	B	C	D	E
1	timestamp	latitude	longitude	pH	temperature
2	2023-10-25 06:51:47	35.3350324071365	25.2814103741747	7.742	22.75
3	2023-10-25 06:51:58	35.3350323739957	25.281410412876	7.749	22.75
4	2023-10-25 06:52:08	35.3350324438175	25.2814103797111	7.752	22.74
5	2023-10-25 06:52:18	35.3350323619294	25.2814104017512	7.758	22.74
6	2023-10-25 06:52:29	35.335032386405	25.2814103727334	7.76	22.76
7	2023-10-25 06:52:39	35.3350324196987	25.281410420943	7.76	22.75
8	2023-10-25 06:52:49	35.3350324077636	25.2814103952853	7.762	22.76
9	2023-10-25 06:52:59	35.3350324505571	25.281410398329	7.766	22.75
10	2023-10-25 06:53:10	35.3350324254704	25.2814103794783	7.766	22.76
11	2023-10-25 06:53:20	35.3350323792145	25.2814103948723	7.769	22.75
12	2023-10-25 06:53:30	35.3350323927203	25.2814103824182	7.768	22.75
13	2023-10-25 06:53:41	35.3350323908048	25.2814103790652	7.77	22.76
14	2023-10-25 06:53:51	35.3350323613999	25.2814104221763	7.777	22.75
15	2023-10-25 06:54:01	35.3350324178434	25.281410431026	7.771	22.75
16	2023-10-25 06:54:12	35.3350324060571	25.2814104230101	7.775	22.75
17	2023-10-25 06:54:22	35.3350323577484	25.2814104291476	7.774	22.76

Figure 1.25. The upper panel presents a map with the averaged pH measurements, the lower panel is a snapshot of the georeferenced pH sensor data as retrieved from the ASV data logger.

The RHIB of HCMR “IOLKOS” was deployed to support the tests and the ASV mission (Figure 1.26) (22-25/20/2023) and collect surface water samples and CTD casts inside the area of the mission grid (25/10/2023).

Figure 1.26. The ORCA ASV and the HCMR “IOLKOS” depart from the Gournes at 25/10/2023.

The CTD unit used in the survey was a SBE 19 plus (Figure 1.27) and the seawater pH samples were measured in the Creta Aquarium laboratories on the same day. The equipment used to measure the pH samples was a Hana HI- 98127 lab pH/temperature bench device calibrated with buffer solutions provided by the manufacturer.



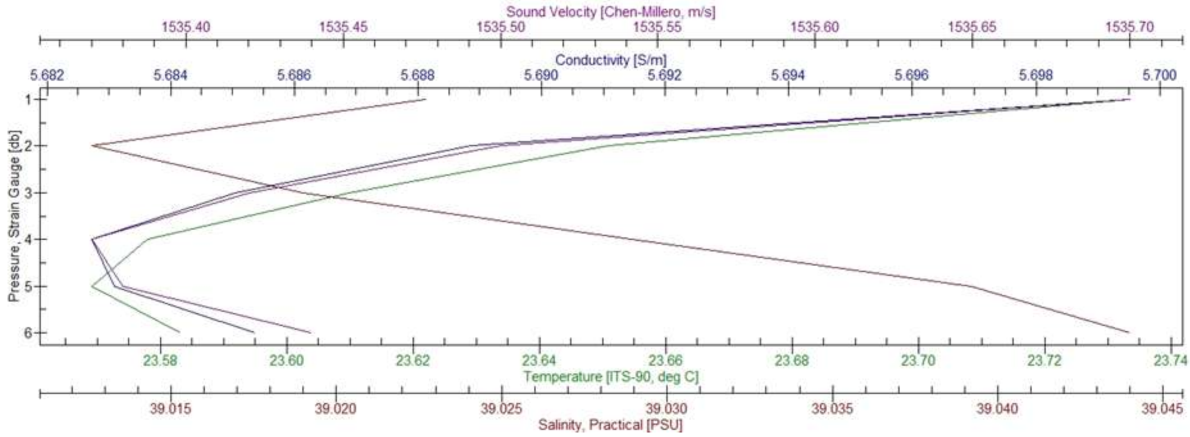


Figure 1.27: The CTD profiles in the beginning (upper panel) and at the end (lower panel) of the ASV mission**.**

Because of the limited size of the ASV operation's sampling area, no variations in pH were observed among the three replicate samples. The pH value obtained from the sample analysis, adjusted for temperature and salinity using the CTD data, was 8.17. Furthermore, the mean difference between the sensor readings and the actual sample values was determined to be 0.07 (Figure 1.28). This difference is comparable to the results of the T6.2 laboratory calibrations experiments for the sensor reported in D6.2.

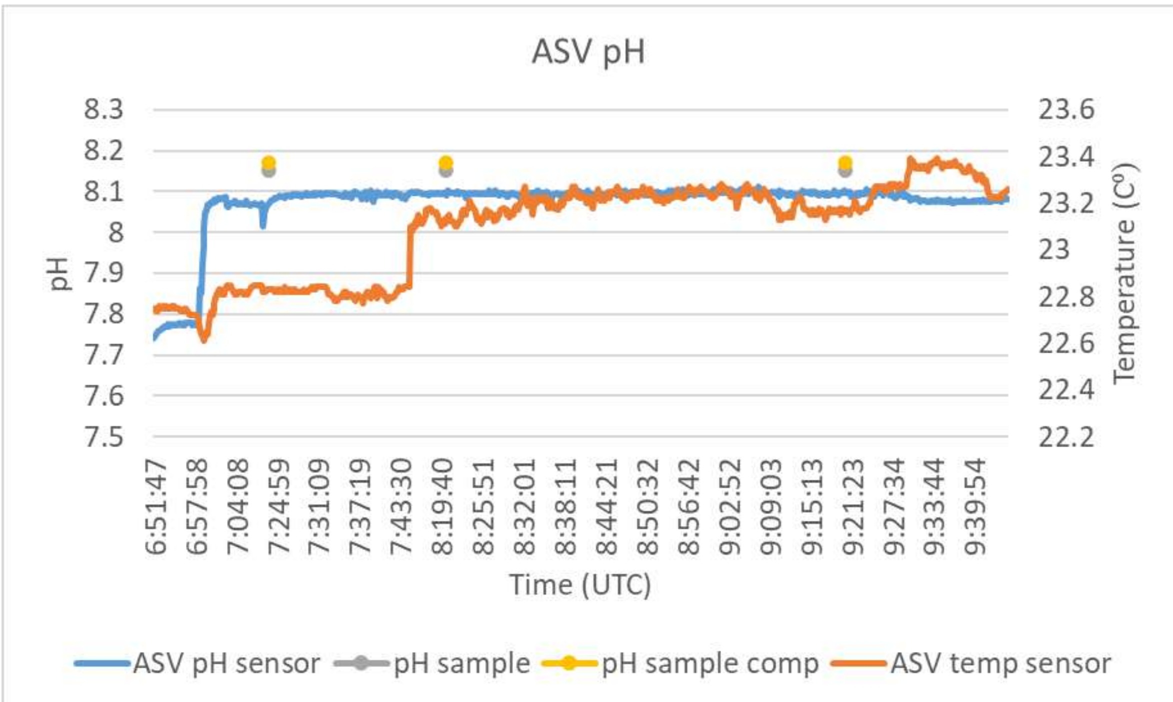


Figure 1.28: The time series data for pH and temperature collected during the ASV mission are paired with the pH sample and pH sample compensated data. The initial rise in pH on the graph coincides with the ASV's departure from the harbour area into the coastal sea.

III. LANDER OPERATIONS

1. INTRODUCTION

Seabed platforms as landers, operating independently and situated on the ocean floor, serve the purpose of continuously gathering high-resolution observations of the seabed. These observations are crucial for marine geosciences as well as long-term physical and biochemical observations. Equipped with oceanographic sensors, these platforms come in various structures, ranging from individual instruments grouped together to extensive networks of cabled connected multi-parametric observatories. They can be deployed in both coastal and offshore waters. The elements of stand-alone seabed platforms exhibit variations in design and dimensions. However, the fundamental components include:

- Frame: The frame, hosting scientific equipment, may differ in material and shape. In areas with intense fishing activities, the frame needs to be trawl-resistant to prevent accidents.
- Transmission System to the Sea Surface: Facilitating communication between the seabed platform and the sea surface.
- Battery Pack: This component must provide sufficient power to the instrumentation on an annual basis. Given the critical nature of power consumption, careful consideration is essential when selecting platform components.
- Electronic Front-end: Responsible for collecting data from the instruments, distributing energy, and storing/transmitting data.

Traditionally, the transmission of data from underwater instrumentation to the surface relied on direct cable connections. Nevertheless, these cables were characterized by their bulkiness, high cost, and unreliability. Additionally, once the cable was designed and manufactured, the positions and number of individual sensors were fixed. Acoustic telemetry emerged as an alternative to direct cables, but in early stages introduced a more costly and complex system. This method required additional battery packs, faced depth restrictions due to limited transmission range, and was susceptible to various sources of errors and failure modes. The development of modern acoustic modems aimed to address the three main challenges in underwater communication: poor reliability, low data rate, and high power consumption.

Owing to the considerable costs associated with specialized logistics, particularly for the ASV's transport from Portugal to Greece, a decision was made to relocate CEiiA's Lander exercises in WP6 to Portugal. Such costs were unforeseen at this scale at the time of the GA drafting. This adjustment, mutually agreed upon by CEiiA and HCMR in March 2023, was prompted by a time and cost-effectiveness evaluation.

Furthermore, this decision has proven advantageous for the project, as it facilitated the timely conclusion of UL-FE's CTD sensor integration on the Lander platform. The delivery of the sensor to CEiiA experienced significant delays, and the revised location for Lander deployments in Portugal has provided a valuable opportunity to address these delays and streamline the integration process. This adjustment aligns with project timelines and resource considerations, contributing to the overall efficiency and progress of the NAUTILOS project.

2. TECHNOLOGIES TO BE TESTED

The ATLANTIS Lander, developed by CEiiA is a highly adaptable modular platform designed to function effectively at depths of up to 2000 meters (Figure 2.1). Its primary mission is to facilitate deep-sea observation and the monitoring of both chemical and biological parameters, in addition to various other physical variables of the profound ocean environment. The platform offers extensive versatility, allowing the seamless integration of a wide array of sensors and other electronic devices.

Figure 2.1. ATLANTIS Lander

NAUTILOS Deep Ocean CTD – UL-FE

The CTD instrument, developed by UL-FE, is a fundamental tool in oceanography (Figure 2.2). This instrument precisely measures conductivity, temperature, and pressure, with depth derived from the pressure readings. These parameters are processed to derive salinity values, allowing for the accurate monitoring of temporal variations in seawater conditions. The NAUTILOS CTD comprises an integrated MEMS-based Au thin film electrode conductivity cell and thin film Ti temperature sensor on the common substrate (CT chip), a separate OEM Keller pressure sensor and electronic circuitry for control and signal processing. All components are assembled in a watertight pressure resistant SS 316L housing suitable for deep sea environments (UL-FE proprietary design).

NAUTILOS Active acoustic backscatter profiler – AQUATEC

Lander payload for ST 6.3.1 expected to include the active acoustic sensor from AQUATEC. Due to unexpected delays internally and mainly with PCBs production, the sensor was unfortunately not available for Lander missions described in the present deliverable. Sensor expected to be delivered in early 2024, when new Lander tests in Portugal will be performed to confirm correct function, prior to deep ocean mission in 2024. A dummy sensor with identical dimensions was provided by AQUATEC and used to test the geometry of the integration affecting the buoyancy of the lander.

3. OBJECTIVE

The main objective of this work was to test the integration of the hydroacoustic telemetry system and the sensors in the lander platform. This test performed in a controlled environment (coastal site) focused, apart from testing the functionality, on fine tuning the equipment and the instrumentation in order to proceed to the demonstrations of WP7.

4. LOCATION

The controlled scenario tests took place in Porto de Leixões, near the shore with depths up to 30 meters. During these tests, the lander platform successfully logged Conductivity, Temperature, and Depth (CTD) data. This is the same location where the Orca ASV was initially tested. See Figure 1.5a and 1.5b.

5. INTEGRATION

5.1. CTD sensor

Prior to the controlled testing scenario, several short data transmissions were performed, to validate the CTD sensor integration and the ability of the Lander data logger to acquire data. As described in D5.7 – "Report on integration of payloads/sensors on Lander platform", interactions with UL-FE were crucial to ensure proper integration with the Lander platform during these tests (Figure 2.2).

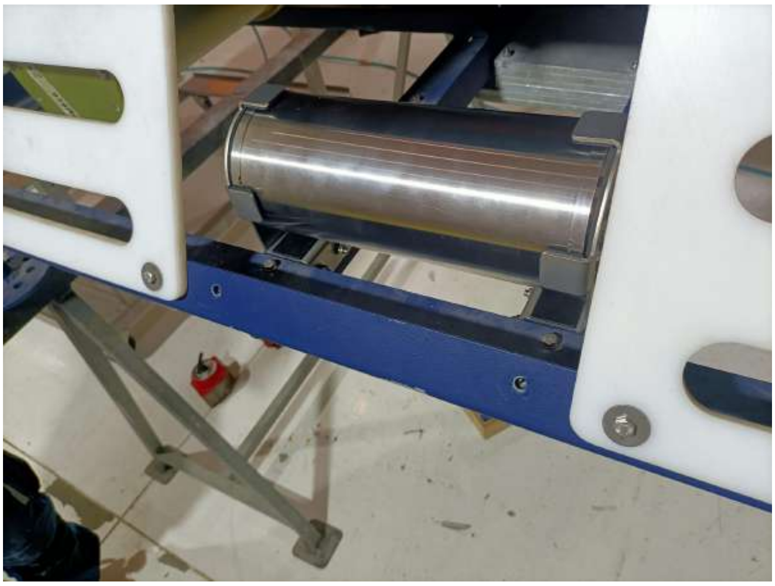


Figure 2.2: CTD sensor (UL-FE) installed on the ATLANTIS Lander (CEiiA).

In the initial deployments of the CTD, a challenge surfaced where the pressure readings consistently registered as 0 (zero). Subsequent investigation revealed a sensor calibration issue, necessitating a recalibration. Collaboratively debugging the problem with UL-FE, the partner responsible for CTD development, CEiiA successfully addressed the issue after receiving the calibration procedure document from UL-FE. This collaborative troubleshooting process ensured the optimal functionality of the lander CTD for subsequent deployments.

5.2. Acoustic modem – AQUAmodem 1000

The AQUAmodem 1000 functions as the primary communication link between the Lander, positioned in the seabed, and the surface. Given its low bandwidth, this acoustic communication channel is dedicated exclusively to system telemetry, handling critical information such as battery charge status, mission execution state, and internal error notifications. Additionally, the acoustic modem is also used to issue short commands from the surface, such as mission control (start/stop) or to initiate the ballast weight release process (Figure 2.3). Sensor data is stored onboard and transmitted through alternative channels to optimize efficiency.

Figure 2.3: AQUAmodem 1000 (AQUATEC) installed on the ATLANTIS Lander (CEiiA).

6. DEPLOYMENT CONFIGURATION

The ATLANTIS Lander was deployed in the configuration illustrated below (Figure 2.4). The optical modem (AQUAmodem Op2) was not active during this experiment.

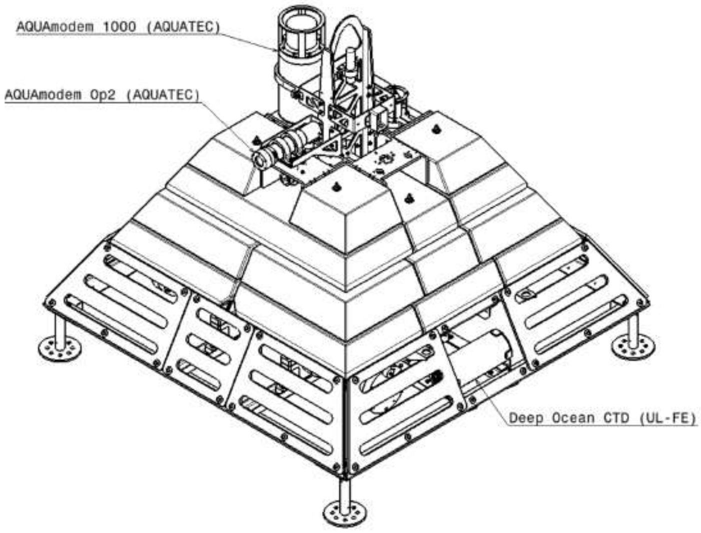


Figure 2.4: ATLANTIS Lander (CEiiA) configuration.

7. Deployment / recovery

The deployment of the Lander is executed utilizing a crane, which lowers the Lander gently to the water's surface (Figure 2.5). With a weight of approximately 15 kg when submerged in water, the Lander is manageable manually by a person on board a support RHIB once disconnected from the crane. Subsequently, it can be manually released, descending at a slow pace.

Figure 2.5: Left: After lifting the Lander with a crane, the CTD sensor is visible from underneath. Right: Final checks before deployment.

The recovery process initiates with the activation of the release system for the ballast weight by the Lander's computational system. Once the ballast weight is released, the Lander gradually ascends to the surface, completing the recovery phase.

8. RESULTS

Here we present the outcomes of the initial controlled scenario deployments. In the first set of deployments, CTD data acquisition took place without the use of acoustic communication. The focus was to test data acquisition post-sensor calibration, ensuring the reliability of the collected information. The second set of tests was aimed at testing acoustic communication of status and mission command messages.

Below are samples of CTD data collected on 3 November, in the initial set of deployments. Readings were acquired in groups of 5 samples every 2 seconds, spaced by intervals of 1 minute. See Figure 2.6 for an example. Sampling rate and intervals can be configured when planning a deployment.

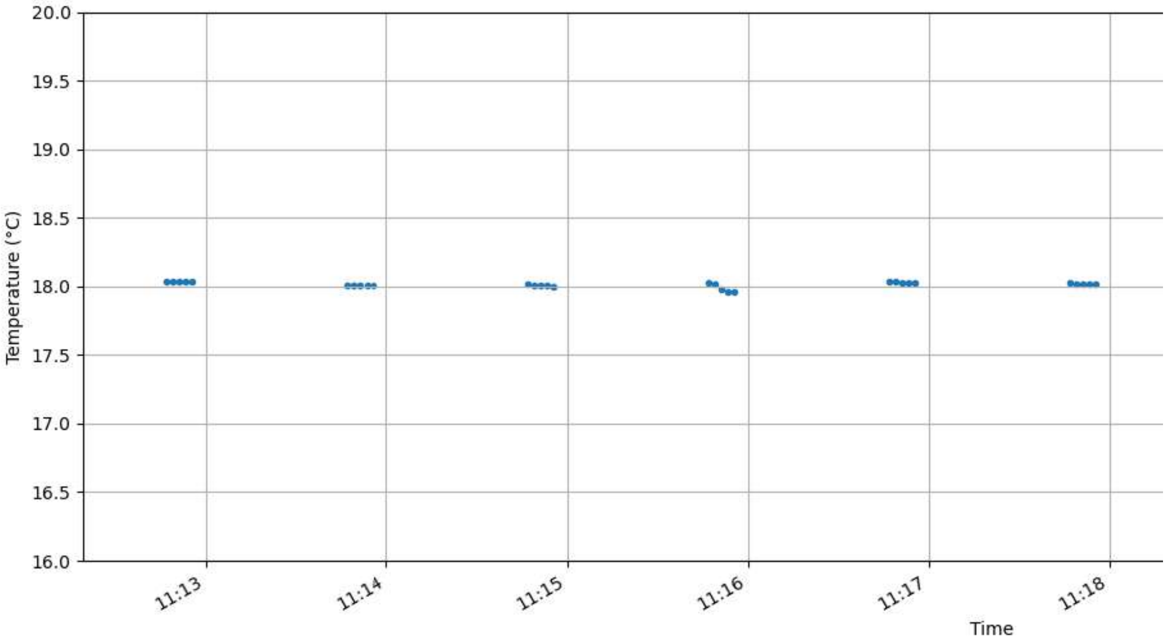


Figure 2.6: Sampling rate and intervals. 5 minutes window of temperature data.

The CTD sensor data samples are displayed as blue dots in figures 2.7, 2.8 and 2.9. The red line is the output of Savitzky–Golay filtering of the raw data points (Savitzky and Golay, 1964).

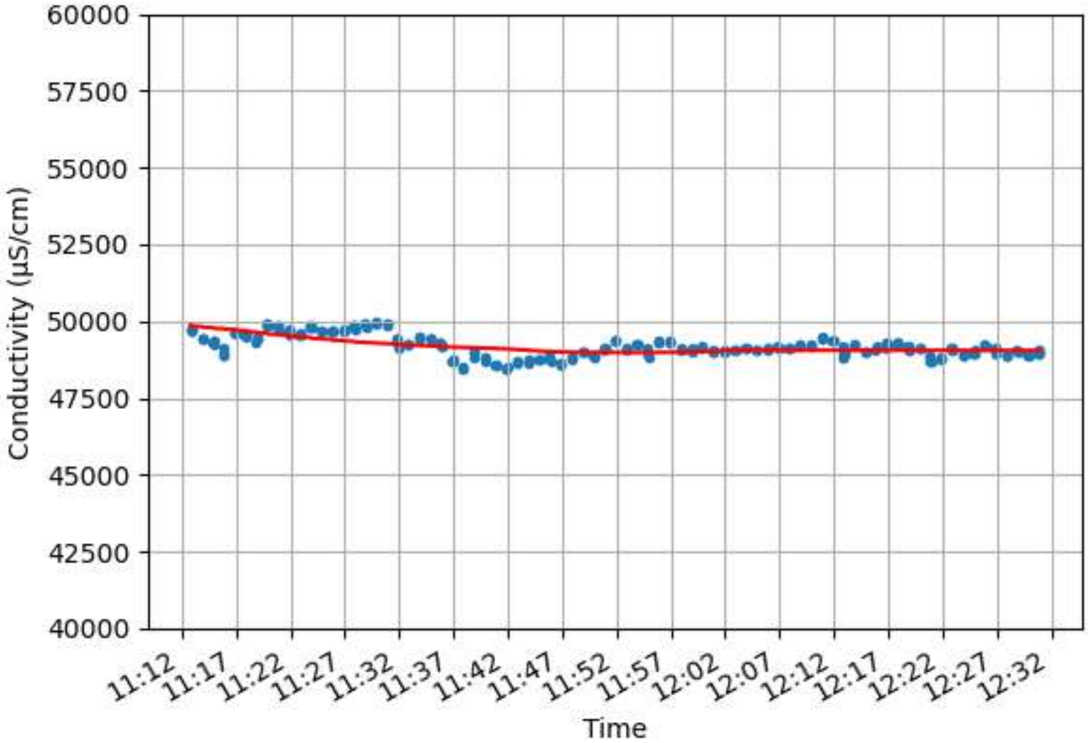


Figure 2.7: Conductivity data collected during the tests

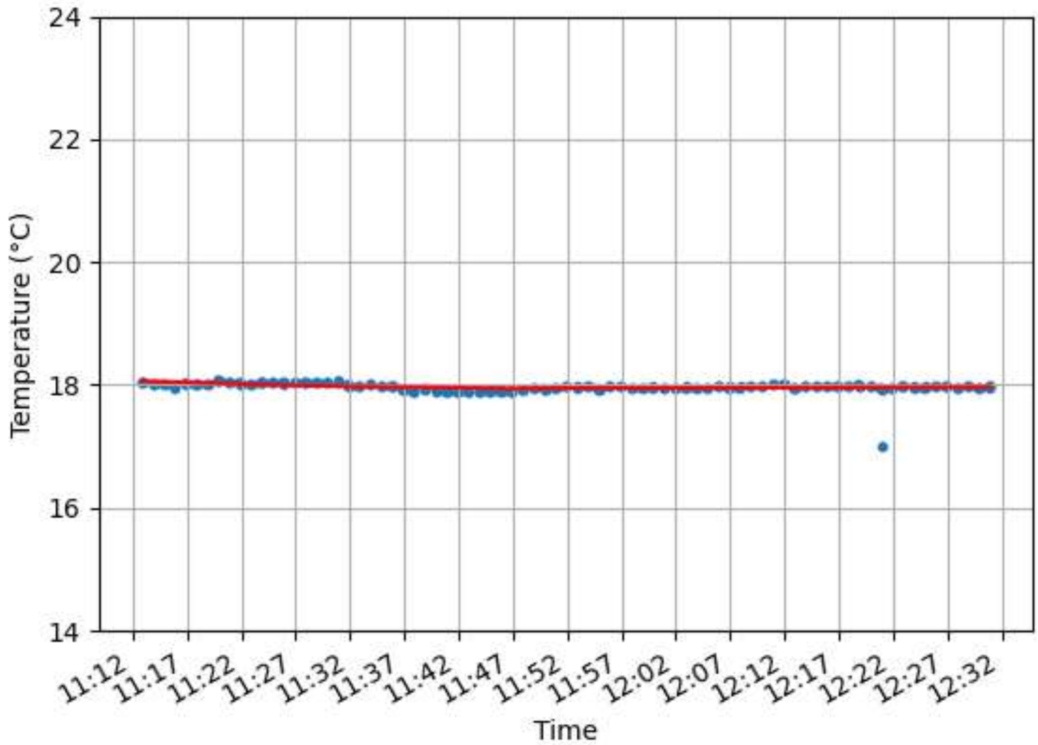


Figure 2.8: Temperature data collected during the tests

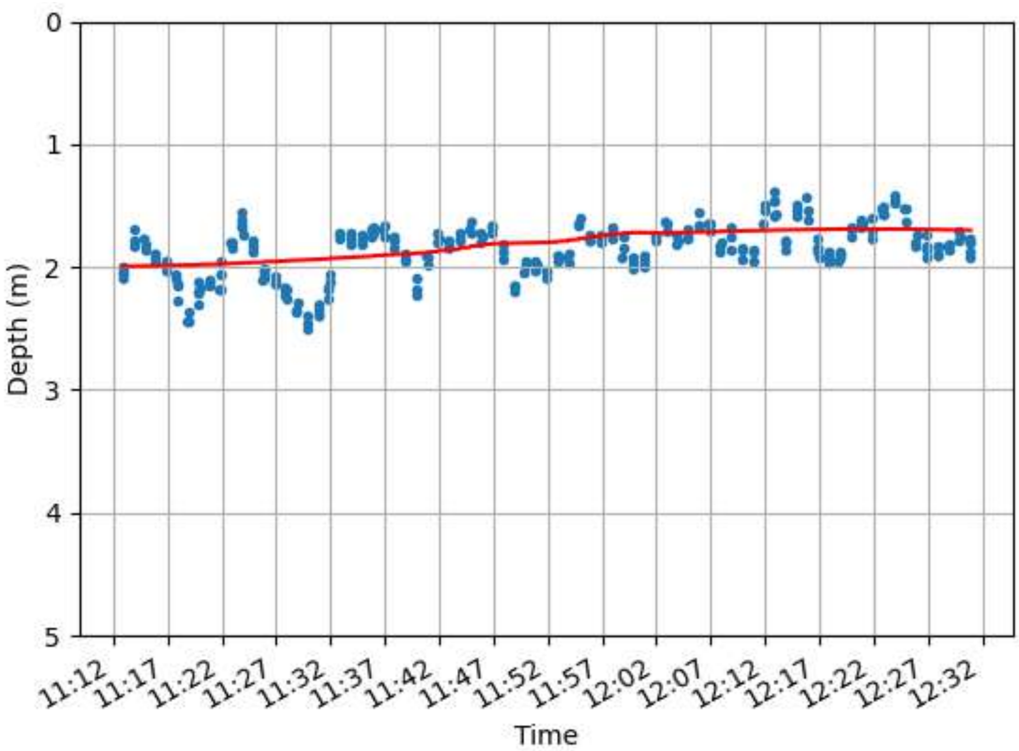


Figure 2.9: Depth (derived from Pressure measurement) data collected during the tests

During the second set of tests, the acoustic modems were used to transfer telemetry – battery, system, and mission status. See figure 2.10 below.

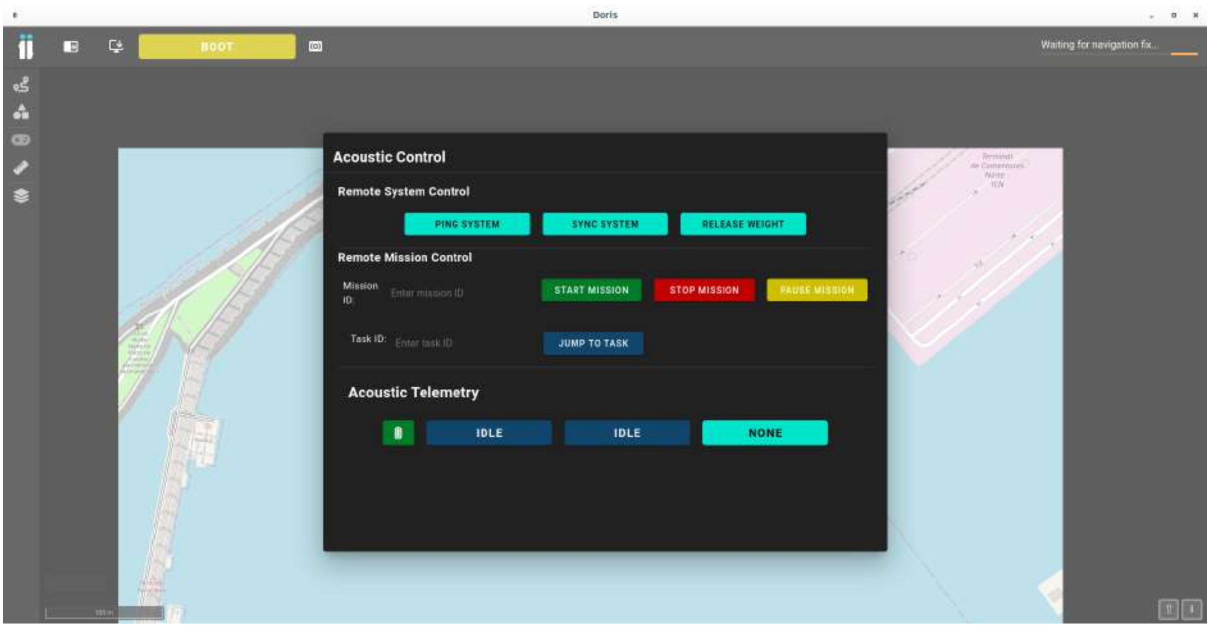


Figure 2.10: Lander is IDLE, waiting for a mission start command.

In addition to receiving Lander status updates, acoustic communication is used to issue commands, such as mission start/stop, or ballast release, as seen in Figure 2.11, below.

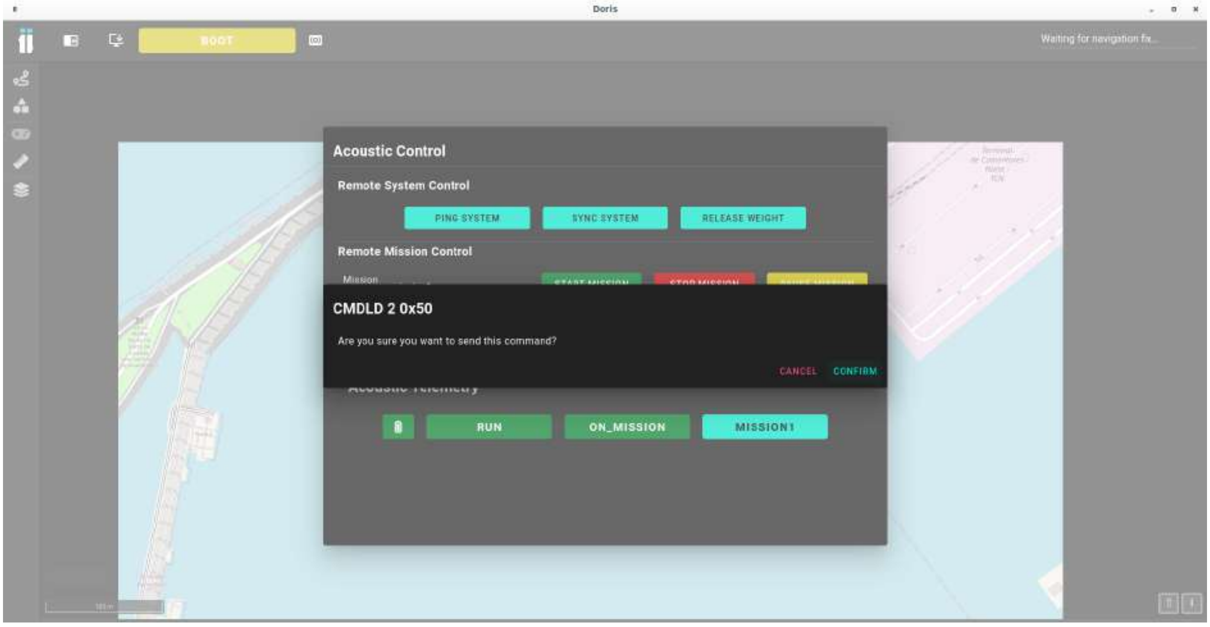


Figure 2.11: Sending a CMDLD 0x50 (Ballast release command).

After receiving the ballast release command, the Lander returns to the surface (Figure 2.12).

Figure 2.12: Lander returning to surface after receiving “ballast release” command.

IV. SUMMARY

During the first part of T6.3.1 activities a novel combination of data collected by two unmanned vehicles (ORCA ASV and HCMR aerial drone) was validated and enriched with scientific diving observations through visual census. This three-layer approach (aerial, surface, underwater) provides valuable insights into the distribution of habitats and seafloor features sharing similar habitat characteristics within the surveyed area. The habitat mapping mission has provided a valuable dataset and preliminary results for habitat assessment and conservation efforts in the surveyed area. These results could serve as a foundation and hold great promise for the scientific community, environmental agencies, and organizations dedicated to the conservation of marine habitats and the sustainable management of marine resources.

The sensor payload of the ASV was also tested in realistic conditions. The pH sensor mechanical, electrical and data logging integration was successfully tested in both the preparatory missions in Portugal and in the coastal scenario mission in Greece. The sensor data stored in the ASV data logger was retrieved totally and no loss was noticed. The measurements were compared with samples collected *in situ* and the overall dataset will contribute to the sensor field calibration before the WP7 demonstration activities. After the field testing the pH sensor has reached a TRL of 5. The passive acoustic sensor was mechanically integrated to the ASV platform but no valid data was obtained during the sea trials. The misfunction was caused by the sensor firmware that needs to be improved, updated and tested before moving to demonstration activities.

The second part of the T6.3.1 activities conducted in Porto de Leixões by CEiiA involved testing the UL-FE CTD integration and the acoustic telemetry (AQUAmodem 1000) of the ATLANTIS lander in a realistic environment. The power and data acquisition of the CTD were successfully executed by the lander power module and data logger. The status and operation commands/controls related to the lander's operation were effectively transmitted and received by the submerged modem and the surface unit. The Nautilos instrumentation and technologies involved in these tests have progressed to a technology maturity level of TRL 6.

APPENDIX 1: REFERENCES AND RELATED DOCUMENTS

ID	Reference or Related Document	Source or Link/Location
1	*Gravina, M. F. M. F., Bonifazi, A., Del Pasqua, M., Giampaoletti, J., Lezzi, M., Ventura, D., et al. (2020). Perception of changes in marine benthic habitats: The relevance of taxonomic and ecological memory. Diversity 12, 480*	*doi: 10.3390/d12120480*
2	De Reu, J., Bourgeois, J., Bats, M., Zwertvaegher, A., Gelorini, V., De Smedt, P., Chu, W., Antrop, M., De Maeyer, P., Finke, P., Van Meirvenne, M., Verniers, J., Crombé P. 2013. Application of the Topographic Position Index to Heterogeneous Landscapes. Geomorphology. 186: 39–49.	doi:10.1016/j.geomorph.2012.12.015
3	*Price, D. M., Robert, K., Callaway, A., Lo lacono, C., Hall, R. A., and Huvenne, V. A. I. (2019). Using 3D photogrammetry from ROV video to quantify cold-water coral reef structural complexity and investigate its influence on biodiversity and community assemblage. Coral Reefs 38, 1007–1021.*	*doi: 10.1007/s00338-019-01827-3*
4	*Coppola, L., Ntoumas, M., Bozzano, R., Bensi, M., Hartman, S. E.,Charcos Llorens, Mi., Craig, J., Rolin, J-F., Giovanetti, G., Cano, D., Karstensen, J., Cianca, A., Toma, D., Stasch, C., Pensieri, S., Cardin, V., Tengberg, A., Petihakis, G., Cristini, L. (2016). Handbook of best practices for open ocean fixed observatories. European Commission, FixO3 Project*	*doi: 10.25607/OBP-1488*
5	Savitzky, A., Golay M. J. E. (1964). Smoothing and Differentiation of Data by Simplified Least Squares Procedures. Analytical Chemistry 36 (8), 1627-1639	doi: 10.1021/ac60214a047