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Critical marine environment observation: measurement problems, technological solutions and procedural methods

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Abstract – **This paper focus on the observation of critical marine environments, pointing out the difficulties that these kinds of dynamic, sensitive and fragile environments create for monitoring operations. The technological solutions adopted, through the use of robotic vehicles, and the operating procedures implemented are also described. The data acquired in two particular critical environments, the front of tidewater glaciers in Svalbard and an area in the northern Tyrrhenian Sea affected by submarine gas emissions allow us to identify and characterise phenomena strongly localised and requiring very high resolutions, both in space and time. This result can be useful to obtain environmental indicators that can be used as hazard precursors and, eventually, to implement alarm procedures.**

I. INTRODUCTION

This paper focus on the development of methodologies and procedures to carry out observing operations of critical marine environments through the use of autonomous robotic platforms for the acquisition of bio-geo-chemical and physical parameters and for the seabed characterisation.

The use of autonomous vehicles is spreading in a wide variety of marine geoscience studies, originally focused on seafloor mapping but more recently expanding into water column physical, biogeochemical and dynamic measurements, favored by the increase of the quality and accuracy of the data collected thanks to the ability of autonomous vehicles to execute fully autonomous and very precise motion over a predefined area of interest [1]. Based on the data request, selections of platforms, sensors and parameters are set within appropriate temporal and spatial ranges, coverage and resolutions. Selection of parameters to measure should fit the investigated environment and the aim of the mission. Based on the environment, there will be a minimum set of parameters that always should be measured, either as an essential or supporting parameter for interpretation of other data gathered. In addition to measurements of essential parameters, the quality of the data interpretation is dependent on the spatial and temporal resolution and coverage of the data [2].

The particularity of this work consists in adapting the observing methodologies, based on robotic platforms, according to the marine environment being studied in order to obtain results that are reliable, reproducible and comparable with those obtained through the classic monitoring methodologies. The environments in which the tests were executed are particularly dynamic, sensitive and fragile areas where it is necessary to study and apply particular methodologies to observe phenomena strongly localised in space and requiring very high resolutions, in time. Moreover, the critical conditions may present some risks not only for the data acquisition but also for the instrumentation and the operators.

Polar marine areas and marine areas characterised by seabed degassing activities are examples of these environments where it is difficult to acquire data using traditional methods and it is advantageous to apply monitoring methods using robotic platforms.

II. OBJECTIVES

These marine environments can be considered critical from different points of view:

- because they are difficult or impossible to reach (such as the area in front of the glacier front);
- because the instrumentation must operate in extreme conditions (very low temperatures at the pole, very high in the case of submarine emissions of volcanic origin);
- because the event to be observed is not repeatable and not completely predictable.

For all these reasons, it is necessary to implement observation solutions that are adapted to the particular operating environment in order to acquire data that can be interpreted both instantaneously, possibly for alert purposes in the event of a hazard, and inserted in a more general context of time series, to derive long-term trends. Two case studies are described below, where different critical issues are present and for which different technological solutions and procedural methods were implemented.

A. Observation of tidewater glacier fronts in Svalbard

The first study case concerns different campaigns carried out in the Svalbard Archipelago by the Institute of Marine engineering (CNR-INM) [3]. The goal of the campaigns was to perform repetitive sampling of water in the surface and and to characterise the physical and bio-geo-chemical parameters of the water and air column close to the front of tidewater glaciers in the Kongsfjorden [4], [5]. In this paper the focus is on the 2018 data acquisition campaign, when valuable scientific data were obtained, as well as important operative indications on the procedures to be followed to observe this critical environment.

B. Observation of seabed gas emissions in the northern Tyrrhenian Sea

The second study case concerns the campaign for the identification, localisation and characterisation of gas emission (mainly methane) from the seabed in the area surrounding the Scoglio d'Affrica, Tuscan archipelago, in the northern Tyrrhenian Sea. This area, due to its geological structure, is subject to numerous gas emissions from the seabed. In particular, those in the area of the Scoglio d'Affrica are studied since the sixties [6] and recently they return to great interest due to an episode that occurred in March 2017, when fishermen reported that an outburst of gas rose about 10 m near their boat. Following this event, numerous data acquisition campaigns were carried out in the area [7] and, among these, the paper focuses on the one carried out by the Italian Hydrographic Institute (IIM) with the National Institute of Geophysics and Volcanology (INGV), the Institute of Marine Engineering (INM) Genoa of the CNR, University of Ferrara (UniFe) and University La Sapienza (Roma1) in June 2019 [8],[9]. The survey has highlighted the presence on the bottom of numerous emission points, sometimes intermittent, located at different depths. The purpose of the investigation by ROV was the collection of video images of the gaseous emissions from the seabed to be integrated with the acoustic morphological survey done with a multibeam sonar.

III. METHODS

The environmental constraints and the specific outputs to be obtained in term of temporal and spatial resolutions, are the leading factors towards the definition of technological tools and monitoring procedure. Hence, autonomous operations in hardly accessible areas, such as Polar Regions or gaseous emissive seabed, require specific designs and ad-hoc studied solutions.

To perform the measurements in the Svalbard campaigns, the unmanned vehicle named PROTEUS (Portable RObotic TEchnology for Unmanned Surveys) was developed and used as USSV (Unmanned Semi-Submersible Vehicle) with remote control. As the purpose of the Svalbard campaigns was to capture measurements of bio-geo-chemical and physical parameters variations with respect to the distance of tidewater glacier front, PROTEUS was equipped with different sensons (CTD, turbidimeter, fluorimeter, etc...) and all the data collected were integrated in real-time with PROTEUS telemetry (for having all data synchronised and geolocalised). The acquisitions were performed in the stretch of sea facing different glaciers of the Kongsfjorden (i.e. Blomstrandbreen, Kongsbreen, Kronebreen, and Conwaybreen), with the robot moving away from the glacier along paths almost perpendicular to the glacier fronts. During the 2018 campaign data were collected not only on the surface but also along the water column, in order to understand the complex phenomena that occur near the front of the glaciers. From an operational point of view, the first phase of data acquisition involved the approach of PROTEUS to the front of the glacier, until it touched it. Reached this point the vehicle was stopped and made sure that it maintained its position. While the vehicle was in position, measurements of bio-geo-chemical and physical parameters along the water column were performed releasing the set of instruments by means of a winch, down to depth of 35-40 m. This operation was used to record the variation of the parameters as a function of the depth, in a fixed point, and therefore to study possible effects due to currents, to the introduction of substances by the water coming from the glacial ice melting and to characterize the area near the front of the glacier from a physical point of view. Once the measurements along the water column were completed, the winch was rewound and PROTEUS was directed to the next sampling point, at a distance gradually greater from the front of the glacier. Even during the transfer phases from one sampling point to the next, the measurements of bio-geo-chemical and physical parameters were recorded in the surface layer of the water [5].

For the Scoglio d'Affrica campaign, due to the complexity of degassing events from the seabed, an integrated study is necessary: acquiring data from different points of view (geological, morphological and chemical-physical) and video images is necessary in order to characterise the site being tested in an interdisciplinary way. The coordinated action between the different entities took place with the goal of 3D mapping the area with the identification of targets of interest and of classifying the nature of the seabed, developing a rapid environmental characterisation procedure in case of exceptional events, environmental monitoring and risk management, also in support of Civil Protection. To this end, the ROV e-URoPe (e-Underwater Robotic Pet) of the CNR-INM has been embarked on the ITS Magnaghi (Italian Navy Ship), and was used to investigate shallow water areas, which couldn't be reached by the ship itself. e-URoPe instrumentation included sensors needed for underwater vehicle navigation (attitude and orientation, velocimeter, heading, CTD, altimeter), three analog cameras, mounted to frame the environment from different points of view, and an Ethernet camera (Bullet Network Camera VIVOTEK IB8168), mounted vertically under the vehicle.

Data acquisition was divided in classic hydro-oceanographic mapping of the whole area of interest using the high resolution multibeam echosounder (MBES) mounted on the ITS Magnaghi and on its support boats and video inspections of a sub-set of the area with e-URoPe. The use of the ROV allowed the observation of the underwater sites of gaseous emissions and demonstrated the possibility of carrying out long-lasting missions, considerably longer than those performed by divers.

IV. DATA ANALYSIS

In the following subsections examples of the data collected during the campaigns at Svalbard and Scoglio d'Affrica are shown.

A. Water mass stratification near the Kongsbreen glacier

The execution of the measures following "data-driven" procedures allowed to collect useful data for the characterisation of the environment from physical, chemical, biological point of view, coping with the hostile working conditions typical of the areas close to the fronts of tidewater glaciers. The Kongsfjorden is characterised by five tidewater glaciers which, together with the Atlantic current, influence the physical-chemical-geological and biological characteristics of the waters of the fjord and therefore of the entire system connected to them. The Kongsbreen glacier is located in the innermost part of the Kongsfjorden [10], [11]. As already described, data were collected not only on the surface but also along the water column, in order to detect effects due both to currents and to the introduction of substances by the water coming from the glacial ice melting.

The graph in Fig. 1 characterises the area near the front of the Kongsbreen glacier from a physical point of view: Temperature (°C) and Salinity (PSU - Practical Salinity Unit) are plotted as a function of the distance from the glacier front (m). To measure these parameters the OCEAN SEVEN 305Plus CTD was employed, which guarantees 0.005 °C of accuracy and 0.001 °C of resolution on the Temperature measure. Salinity data are obtained using the algorithms described in the UNESCO technical papers in marine science no. 44 "Algorithms for computation of fundamental properties of sea water" starting from Conductivity measures (accuracy 0.007 mS/cm and resolution 0.001 mS/cm in salt water, as tabulated in the data-sheet). The presence of a water mass characterised by lower values of temperature and salinity at about 200-300 meters from the front of the glacier is evident (green/light blue dots). This can be an indicator of the presence of a plume of meltwater coming from the glacier which has physical characteristics different from the surrounding water mass and which, thanks to the lower density, is going up the water column towards the surface to then disperse and mix with the water of the fjord. This is an example of temperature and salinity gradients used as indicators of water mass stratification produced by glacier melting.

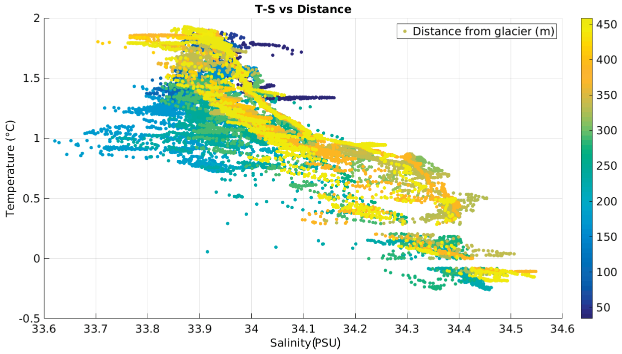

Fig. 1. T-S diagram: temperature (°C, y-axis) is plotted versus salinity (PSU, x-axis). The color scale is proportional to distance from the glacier front (m): yellow = far; blue = near.

The variations in water mass stratification, highlighted by temperature and salinity gradients, are only some of the effects produced by glacier melting; increase in turbidity and chlorophyll-a concentration, which directly affects primary productivity and the trophic chain, are other consequences generated by the introduction of meltwater and sediments from the glacier in the form of plume [12]. The following graph (Fig. 2) shows turbidity distribution near the Kongsbreen glacier front, as a function of depth (m, y-axis) and distance (m, x-axis).

Turbidity data were acquired using a Turner Cyclops-7F sensor, with a 0.05NTU resolution. The values of the turbidity in the graph are expressed in arbitrary units since they are raw data, read directly from the sensor and not calibrated. This is neither a problem nor a limitation: since in this type of analysis what we focus on are the gradients and the variations in space of the measured quantities and not their absolute value.

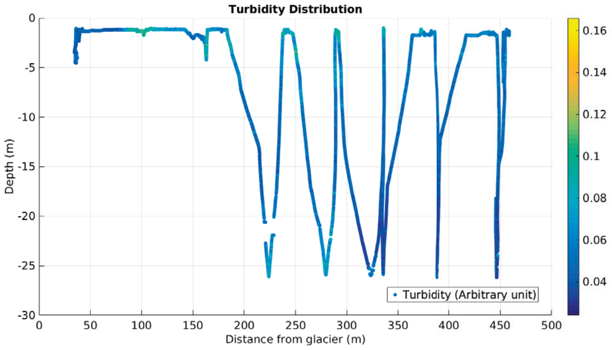

Fig. 2. Variation in Turbidity (arbitrary unit; yellow = high turbidity; blue = low turbidity) as a function of depth (m, y-axis) and distance from the front of the glacier (m, x-axis).

Turbidity data acquired during our surveys (Fig. 2) show an upwelling of suspended matter at about 220 m from the glacier front, corresponding to a cold-water rising zone also visible in the T-S graph (Fig. 1). Moreover, turbidity values show a concentration of suspended matter below the plume, at a depth of about 25 m, and also in the rest of the water column values. This process could be due to the re-precipitation of the sediments brought to the surface by the plume. Higher turbidity values are also visible in correspondence with the upper layer near the water surface, indicating the dispersion of the suspended matter of the plume, once it has reached the surface. High turbidity values, might have a negative impact on phytoplankton growth due to the light absorption, and therefore studying how the physico-chemical characteristics of water masses vary is also of fundamental importance for the study of the trophic chain.

B. Mapping of seabed gas emission points near the Scoglio d'Affrica

The data collected using the e-URoPe ROV were acquired in a sub-area of the area investigated by the ITS Magnaghi, for which high-resolution multibeam acoustic data are available. This area is part of an elongated main NNW-SSE ridge that rises 30 m from the surrounding seabed, already observed in the high-resolution bathymetric data collected subsequently to the 2017 gas outburst. The ridge is made up of two mounds whose tops are located at about 8 m and 10 m water depths, respectively [13]. The ROV collected video images of the gaseous emissions from the seabed (methane gas) during five dives in as many points of interest as possible, for the study of gaseous emissions. Once synchronised the video times with the vehicle telemetry times, the data analysis involves the identification of the gaseous emissions from the seabed in order to create a map. At this point, the question of underwater positioning of the vehicle arises. During the operations, e-URoPe was used with the surface console installed on the ITS Magnaghi and, due to the configuration of the ship, it was not possible to mount the system for underwater acoustic positioning. Thus a localization of the ROV with respect to the ship was not available during the underwater phases. However, during the post-processing of the data, the ROV track was inferred from the GPS data available during the phases on the surface and measured using the Microstrain 3DM-GX3-35 (Horizontal position accuracy <2.5 m), integrated with the data from the DVL (Doppler Velocity Logger – ExplorerDVL TELEDYNE) that measures how fast the vehicle is moving and in what direction and with the heading data from the FOG (Fiber Optic Gyro - QUADRANS iXBlue). Applying algorithms of dead reckoning on these data, it was possible to reconstruct the possible routes followed by the vehicle during the diving phases. The vehicle's positions obtained were subsequently integrated with video and multibeam data, allowing the different seafloor features observed in the videos to be associated with the distinct morphologies acoustically identified on the seabed, verifying the correctness of the results. In this way, the video acquired were georeferenced and a preliminary map of gas emission points was created, as shown in Fig.3.

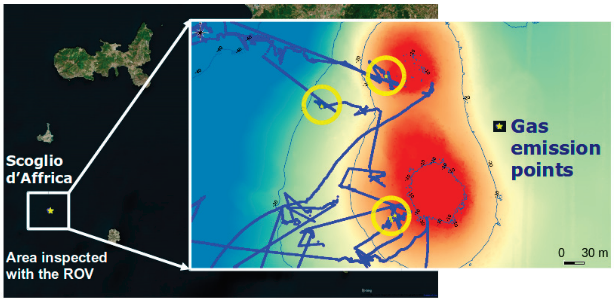

Fig. 3. Preliminary map of gas emission points obtained from the georeferenced video acquired by e-URoPe.

From the video images, it was observed that the degassing activity is weak with small bubble columns that are emitted intermittently; the emissions are punctual and come out of small chimney of centimetric dimensions; the type of emission depends on both the porosity of the bottom and the amount of gas in the substrate.

Moreover, integrating data from different sources (video images, telemetry of the robotic platform and acoustic multibeam data) it is possible to identify different types of seabed and observe whether there are associated gaseous emissions or not. In Fig. 4 there are some examples of observed seabed types and associated phenomena. In this area, the seabed varies from areas whose bottom is covered with sand on which large blocks and masses (up to metric sizes) are scattered, to completely rocky areas. These rocks are often covered with algae, indicating that their presence dates back many years, even before the 2017 event. Numerous active emission points and also holes in the seabed identified as emission points not active during the investigation with the ROV were observed in the sandy seabed. From the images collected, it was noted that some gaseous emission events occur at the contact points between rocks and sand.

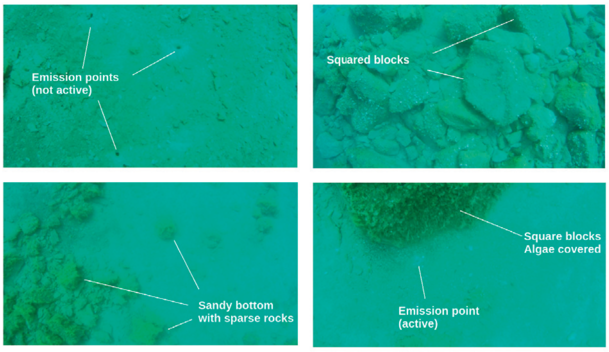

Fig. 4. Pictures of examples of seabed encountered during e-URoPe dives. Numerous emission points are showed (both active and not active) together with different types of seabed (sandy, rocky)

Beside the information coming from the video, it is possible to use the basic instrumentation package mounted on-board e-URoPe, in particular the altimeter (Tritech Micron echosounder) and the depth sensor of the OCEAN SEVEN 305Plus multi-parameter CTD, to obtain the profile of the seabed overflown by the robotic vehicle. By putting together the data of the reconstructed route with the calculated depths, it is possible to obtain an indication of the bathymetry of the seabed in the area investigated with the ROV. This exercise of estimating the bathymetry of the seabed starting from data collected using sensors commonly available as basic equipment of the ROV (altimeter and depth gauge) and the comparison of the results with the high resolution data obtained with more sophisticated (and expensive) instrumentation, such as the multibeam, was done to demonstrate that in critical or emergency situations it is possible to intervene in a short time with a robotic vehicle, even if not equipped as necessary, but it is still possible to obtain data that are fundamental to characterise the environmental situation of the operations. With these kind of procedures, the precisions and accuracies can be limited but the data is available in a short time. This is a fundamental aspect for systems which aim to have a first knowledge of the environment through data that are easy to interpret and characterised by the immediacy of information, in order to study an intervention strategy [14].

V. DISCUSSION

The two cases described above, although they may seem very different, actually have a common nature: both foresee the study of events strongly localised in space and time, with observation operations that take place in critical environments. These complex environmental situations are typical examples in which measurements must be made systematically to avoid the risk of missing to record the event (plume of meltwater from the glacier or the emission of gas from the seabed) before it ends due to the mixing with the water of the environment. To be able to operate in these conditions and with procedures that ensure both the safety of the operators and the integrity of the data collected, the use of robotic platforms is necessary.

In this context, two aspects are fundamental:

- the choice of the instruments and sensors to be mounted on the robotic platforms which must be able to guarantee certain performances (in time and space) and at the same time must be able to operate even in demanding conditions and with power requirements that are sustainable;
- the implementation of sampling procedures that are flexible and that can be adapted according to the specific working environment and the measure to be obtained.

In conclusion, the focus of this work is the measurement and its interpretation: the preliminary results described above are very important because show that, even in situations far from the “ideal operating conditions”, it is still possible to obtain indicators that can be interpreted as hazard precursors and, eventually, implement alarm procedures.

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