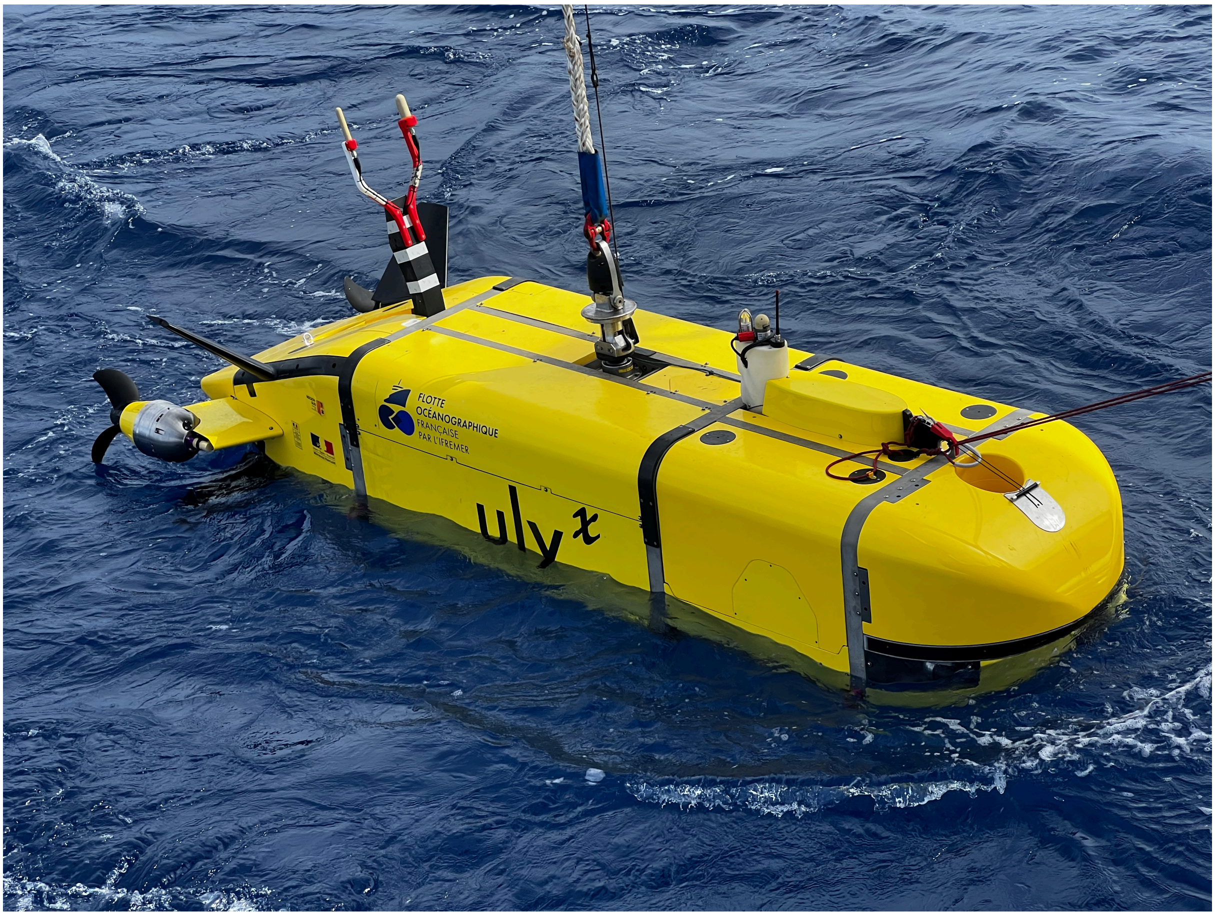
*Preliminary Scientific Report*
***v.2024/07/04***

# *Ulyx Demo'24 test cruise*

*PI: Ewan Raguel*
*Scientific co-PI: Javier Escartín*
*PI of 'PI school': B. Ildefonse*




*Leg#1: La Seyne – Palermo, 29 Mai – 4 Juin 2024*
*Leg#2: Palermo - La Seyne, 5-19 Juin 2024*

**Preamble**

This preliminary report has been redacted in coordination and with the science party of the second leg of the Uly$^{X}$Demo cruise, and includes results from both Leg#1 and Leg#2. The synthesis, conclusions and recommendations also include feedback from both the IFREMER/FOF and GENAVIR teams onboard, and reflects on a cruise that benefitted greatly of the open communication, exchanges and shared experiences of all participants. This format of hybrid engineering-science cruises can be extremely valuable, providing scientifically relevant data, optimizing ship time and operations, and educating scientists on the requirements and limitations of vehicles and instruments.

The data acquired onboard, together with that of prior Uly$^{X}$ test cruises, will be publicly available post cruise, with submissions to SEANOE of different datasets scientifically validated both by the onboard participants and members of the Working Group. The timing will be determining by the required processing and validation. This report will be made publicly available via ARCHIMER. A full cruise report will be compiled post-cruise and made publicly available before the end of the year 2024. All data will be available by request and for unrestricted use prior to open access publication online.

To better capitalize on the scientific data acquired, the science party will coordinate to submit a publication in a 'data type' journal (e.g., *Journal of Maps*), that will showcase the capabilities of Uly$^{X}$ as of the end of the Uly$^{X}$Demo cruise.

The science party benefitted from the participation of 5 young scientists that participated in the PI School conducted during the Leg #2. They were key to the success of the missions and the validation of scientific data onboard. The science party thanks the French Oceanographic Fleet for facilitating this experience. A report has been distributed by the participants to the PI school by B. Ildefonse.

The science party thanks the Commandant, Enora Person, the officers and crew of L'Atalante, and the GENAVIR and IFREMER/DFO and IFREMER Teams, and the leadership of Ewan Raugel (PI of the Uly$^{X}$Demo cruise), Patrick Jaussaud (head of Uly$^{X}$ project), Jan Opderbecke (head of the Submarine Systems Unit), and Lorenzo Brignone (prior head of Uly$^{X}$ project).

The contributors for this preliminary report are, in alphabetical order:

Tristan BRIARD (École PI, Univ. Littorale Côte d'Opale/LOG)
Catherine BORREMANS (GT Uly$^{X}$, IFREMER/LEP)
Javier ESCARTIN (scientific co-PI, GT Uly$^{X}$, ENS Paris/CNRS)
Ridha FEZZANI (SMF, IFREMER/DFO)
Virginie DURAND (École PI, GéoAzur/IRD)
Aurélie FELD (DFO/PON, Flotte Océanographique Française)
Arnaud GAILLOT (SMF, IFREMER/DFO)
Charline GUERIN (GT Uly$^{X}$, IFREMER/GM)
Benoit ILDEFONSE (Chef École PI, U. Montpellier/CNRS)
François LALLIER (GT Uly$^{X}$, U. Sorbonne/Roscoff Biological Station)
Séverine MARTINI (École PI, MIO/CNRS)
Margaux MATHIEU-RESUGE (École PI, IFREMER/LEP)
Olivier SULPIS (École PI, CEREGE/CNRS)

Coordinated onboard with:
Ewen RAUGEL (**PI**, IFREMER/DFO)
and
Xavier SAINT-LAURENT (responsible Équipe Uly$^{X}$ – GENAVIR).

## 1.- Summary

The Uly$^{X}$Demo-24 technical cruise was conducted in the Thyrrenian sea to a) transfer the AUV Uly$^{X}$ to the GENAVIR for routine operations by the French Oceanographic Fleet, to b) test and evaluate the conditions, performances, and limits of operation to achieve scientific goals defined by a science Party while c) scientifically validate its sensors and acquired data. **The mission modes tested during the cruise may differ from those finally validated by GENAVIR after the AUV Uly$^{X}$ transfer, based on the analysis of cruise results, vehicle security, and other constraints, resulting in different limitations.** The interactions and team work between the GENAVIR, IFREMER and Science Teams was key cruise success, advancing on Uly$^{X}$ improvements while gathering scientifically valuable data. A hybrid mode of scientific/engineering cruise is viewed as optimal to accelerate and facilitate the evolution of Uly$^{X}$ to achieve its full capacity (instrument integration, and full-depth operations to 6000m).

Uly$^{X}$ is equipped with instrumentation for acoustic surveying (multibeam, reflectivity, water column), optical inspection (APN, i.e., still camera with flashes; Figures 2,5), and other physico-chemical sensors (oxygen, pH, redox, magnetometers (3), fluorimeter, nephelometer). At the time of its transfer, Uly$^{X}$ has not integrated yet two core instruments, the interferometric sonar system (SAMS) and the sediment profiler (ECHOES). The sonar requires a flight mode of 20-30 m for the interferometric sonar (on flat seafloor). The integration of these two instruments remains a priority for the scientific community so that the French Oceanographic Fleet provides an AUV that is both operational and flexible for a wide range of scientific missions (including P1 and future scientific cruises, as well as other operations).

The Uly$^{X}$ Demo-24 cruise targeted areas in three types of terrain (Figure 1), with depth of test sites ranging between 500 and ~3700 m, for Uly$^{X}$ dives including both inspection and survey modes:

a) Sedimented areas with gentle relief (e.g., abyssal plain, Italian margin), <10°,
b) Areas with relief typically <20°,
c) Rugged terrain with scarps, slopes (>30° locally) and complex morphology.

Some of these areas also host hydrothermal vents and gas plumes, that allowed the development and evaluation of different surveying and inspection strategies, as well as the data acquired during the dives.

AUV Uly$^{X}$ conducted 17 dives (Table 1). Dives during Leg 1 included several technical and engineering operations to correct issues with the AUV and improve performance and reliability. From dive #93-07, the AUV operated in what can be considered a nominally routine mode, with dives typically lasting about 14h (deck to deck), conducting surveying and seafloor inspection in proportions depending on scientific objectives, and with no dive interruption for technical issues.

Regarding the navigation over different kinds of terrain the Uly$^{X}$Demo-24 cruise confirms the capacity of the AUV Uly$^{X}$ to conduct multibeam acoustic surveying under all terrain conditions (including the most extreme) at a nominal altitude of ~70 m above seafloor at 3 knots (Figure 3, 4).

Analyses onboard show that the bathymetry is of high quality, owing to vehicle dynamics, high-quality navigation, and improvements implemented to solve prior problems (e.g., pitch/heave noise, DVL problems, etc.) In this configuration, bathymetric grids have a resolution of ~1 m. Bathymetry from optical inspections (9-6 m of altitude) also yield excellent bathymetry (10 cm resolution).

Optical seafloor inspection with parallel tracks can be done in flat zones (slopes <10° at the scale of the inspection). Optical inspection in rugged areas was tested successfully with a hover mode that provides ground-truthing over areas of ~100-200 $m^2$ or more; <u>this mode of inspection (Figure 7) is extremely promising and of interest for ground-truthing in all types of terrain</u>. Systematic inspections (mosaicking) in extremely complex terrains (e.g., hydrothermal field with chimneys >5 m-high, large boulder files) are more suited for ROV, complementing the hover mode of AUV successfully conducted during Uly$^{X}$Demo.

Optical inspection at 6 m altitude provides high-quality data. Dives at 9m altitude provided under-exposed images that are exploitable scientifically (Figures 5,8). The APN camera shows several issues (Figure 9): it does not trigger consistently; interrupts acquisition; shows uneven shooting intervals (PL#16). AUV immersion at 6m was not maintained in some inspections, flying instead at 9m. Unmounting of the APN in PL#16 revealed scaling of the dome. The APN was removed for security on PL#17. Reliability of the APN and solving the dome fitting are highest priorities for Uly$^{X}$ in the immediate time.

The multibeam system records the water column return for plume detection at all altitudes (including inspections 6-9m above seafloor, Figures 5,6). This allows a multi-scale, nested survey strategy combining large area acoustic surveys (~70 m altitude) and optical inspection (6-9 m altitude), correlating imagery and water column data to pinpoint plume sources in optical mosaics and 3D reconstructions (Figures 5,6). This survey strategy was particularly successful for sites in flat-lying areas (e.g., gas plumes, pock mark fields, etc.).

All sensors recorded data that were validated onboard, within the limitations of the Science Party expertise. The Science Party also evaluated and improved the protocols for some of the instruments (e.g., pH, Eh), to establish the mode of operation during cruises, with calibrations secured by the science team (for all Uly$^{X}$ science cruises as an obligation of the PI). A communalized instrumentation and associated protocols at the level of the FOF and the deep submergence vehicles would greatly facilitate interoperability, management, and data consistency among platforms. Ascent and descent may show an offset for given sensors; similar offset is observed in the CTD acquisitions from the board.

Deployment and recovery operations were efficient and well-run. AUV operations are intended in tandem with ROV or HOV, one of the main assumptions and requirements of the CORAL/ Uly$^{X}$ Working Group. These operations cannot be conducted simultaneously onboard L'Atalante. This inability to operate two deep-sea submersibles will impact the flexibility of future operations for the French National Fleet, as only Pourquoi Pas? can conduct these operations. Cruises on L'Atalante would require instead two legs in the case of a two-vehicle strategy, which is not sustainable nor optimal.

During Uly$^{X}$Demo-24, L'Atalante escorted the AUV through almost all the dives. The scientific community requests operations conducted during AUV dives, as conducted in the past with an external AUV and ROV Victor diving simultaneously. As a preliminary test of this type of strategy, we conducted two CTD casts during AUV dives. L'Atalante was also positioned away from the AUV during a survey to test the range limit to position the AUV (~3 km at 700 m immersion, >4 km at 3000m immersion) and to get telemetry (~1.5 km at 700m immersion). Operations during AUV dives remains a priority of the science teams.

At the end of the Uly$^{X}$Demo Cruise, the preliminary analysis of dives and operations shows that AUV Uly$^{X}$ can fly multibeam survey missions in all kinds of terrain. Optical inspection can be conducted with strategies tailored for the terrain conditions so as to secure the AUV, but require further reliability of the camera system as a priority. Future operations and field experience, together with feedback from operators and scientists, will surely result in improving its capacities and reliability in coming years, and hopefully developing the possibility to carry out operations during AUV dives (e.g., CTD, coring, dredges, ROV deployment, etc).

AUV Uly$^{X}$ requires in the short-term a) securing the reliability of the optical payload, b) the integration of the sonar and sediment profiler instruments, identified by the CORAL/Uly$^{X}$ Working Group as key for polyvalent scientific operations, and c) tests at >5000 m in 'routine mode' to confirm its full depth operability: King's Trough dives (ESSULYX23B) did not operate Uly$^{X}$ in fully scientific mode, and maximum depths in the Thyrrenian (Uly$^{X}$Demo) are limited to <3800 m).

**2.- Project context**

The main goal of the Uly$^X$Demo -24 technical cruise was the deployment of the AUV Uly$^X$ in science-like operations, to:

a) validate the data acquired by different sensors onboard (CTD, Redox, O2, pH, turbidity, magnetometers),
b) test and develop different dive strategies based on scientific objectives, instrumental capacity and needs, and vehicle constraints (e.g., terrain, etc.),
c) explore the limits and conditions of use under different scenarios, in particular linked to the seafloor morphology (e.g., from rough terrain to flat areas),
d) transfer the AUV to GENAVIR for French Oceanographic Fleet (FOF) operations

The Uly$^X$ project was followed by a Working Group (WG) established after the definition of the vehicle architecture with the ECA solution. This WG has operated for more than 6 years, following the development and tests, and defining the sensors to be deployed. It was populated with members of the Submarine Unit at IFREMER that carried the project, and members of the scientific community (IFREMER, CNRS, Universities). After a series of test and other cruises (e.g., Hermine), Uly$^X$ conducted its deepest dive to ~6000 m in 2023 in the King's Trough area in the North-Western Atlantic. For the Uly$^X$Demo-24 cruise, the WG requested a cruise for 'regular scientific operations' along the Mid Atlantic Ridge, based on the need for an area of operations with a wide range of terrains and sites for detailed studies (e.g., hydrothermal systems). Owing to budget constraints, the cruise was eventually scheduled in the Thyrrenian Sea by the FOF. The WG identified targets in this area that cover a wide spectrum of terrain conditions (from rugged, volcanic terrain that is equally or more abrupt than that at the Mid-Atlantic Ridge), sites of interest (hydrothermal vents, gas plumes, detachment faults, abyssal plain), and hence dive strategies to be tested. Despite the site change the working area is suitable to test the AUV in a variety of terrain conditions.

The Uly$^X$Demo-24 cruise was conducted in two legs. Leg #1 (La Seyne sur Mer-Palermo) was dedicated to dives for engineering, reliability, and training towards the transfer of Uly$^X$ from IFREMER to GENAVIR. Dives were conducted on transit, in the Vavilov Basin area, and near the island of Ustica near Palermo. This Leg acted the transfer of Uly$^X$ to the French Oceanographic Fleet, and its operation in the future by GENAVIR.

For Leg#2 (Palermo-La Seyne sur Mer) a science party embarked to conduct dives at different sites in the Thyrrhenian Sea, and Uly$^X$ conducted 11 dives, typically ~14h long (deck to deck), and reaching nominally routine operation. Between dives #7 and #16 all dives were fully completed. Issues remain on the reliability of the APN camera (inspections when the camera does not start). A dive testing a 9m flight mode over moderate terrain for inspection in transects resulted in a collision, but the dive was pursued after resurfacing and followed up with a multibeam survey. Dive #17 was conducted without APN (see below).

Terrains in the Thyrrenian Sea include flat or low-relief areas (abyssal plains and Propellor basin), moderate terrains (slopes <20-25°, Vavilov detachment and abyssal mounds), and high-relief areas (Vavilov, Marsili and Palinuro volcanic ridges and somital cones, slopes >30°). The test of different AUV mission plans in these 3 terrains is discussed below.

One of the main scientific needs for future Uly$^X$ scientific operations, and to complete the acoustic surveying capabilities of Uly$^X$, is the integration of the interferometric and regular synthetic aperture sonar and sediment sounder, that will complement the multibeam system.

**3.- Uly$^X$ reliability and endurance**

During the DemoUly$^X$-24 cruise the AUV conducted 17 dives (also 17 in the "*Dossier de Préparation de Campagne*", DPM), with only one dive aborted providing no data (PL#91-05). Some of the early dives resulted in the AUV resurfacing and diving after re-programming to re-initiate the mission. From Dive #92-06 onwards (11 dives) the AUV completed all the missions and achieved most of the science and technical objectives. One mission in this series had the AUV resurface following a collision during a test of an inspection mode, but proceeded with multibeam surveying.

Time length of a mission will depend on the operations planned during the dive, with hovering and surveying being among the most power-hungry. PL#14 was the longest dive (18h, deck to deck), and excluding technical and short dives imposed by transits, the standard dive length for Uly$^X$Demo-24 has been ~14h (deck to deck). Bottom time is highly dependent on mission planning (>85% bottom time, for dives PL#11-15, that are primarily scientific) but improved over other deep-sea vehicles of the FOF owing to speeds of descent/ascent.

AUV collided with the seafloor in two occasions (dive #4 and #15, see technical report). The second contact occurred testing an inspection mode with terrain follow-up at 9m over rugged terrain, owing to a local slope of ~50°, thus testing the limits of this inspection mode. Despite the collision the dive completed a subsequent multibeam survey.

AUV Uly$^X$ thus shows reliability for routine operations during scientific cruises, and will require specification of conditions for optical inspection modes in sloping and rugged terrain, and in particular the implementation of hovering in routine mode.

## 4.- Data and sensors

### 4.1. – Bathymetry, water column, and backscatter

Bathymetry surveys were conducted in all terrain types. Performance of the vehicle allowed navigation following the terrain at ~70 m above seafloor with pitch reaching up to 60°. This allows bathymetry acquisition in all terrain conditions, including the most rugged terrain. Terrain conditions encountered in the Thyrrenian Sea are comparable, or even more extreme (e.g., ruggedness, slope), than those typically found at faulted slow-spreading mid-ocean ridges or complex volcanic areas. Bathymetry data benefits from excellent navigation; numerous surveys required no navigation shifts, and data are processed using the raw navigation. Noise and artifacts in the bathymetry data are primarily associated to abrupt changes in pitch and/or heave of the AUV, that cannot be corrected at this time, and navigation errors across tracks. While these problems are more pronounced in surveys conducted in rugged terrain (e.g., summit of volcanoes), the overall performance of Uly$^X$ even at these conditions surpasses that of AsterX and IdefX and can be considered of excellent quality and perfectly exploitable for scientific purposes. Associated backscatter data is of good quality.

All dives recorded the water column during multibeam surveys. This allowed us to identify a modest plume at Marsili seamount in an area where active venting had been previously identified. The water column data also allowed the mapping of plumes during surveys both at 70 and 9-6 m altitude, showing an excellent integration and correlation of bathymetry, backscatter, optical imagery and water column data, in addition to the sensor data (see below). Uly$^X$ also conducted a test survey at 30m altitude (800x100m) at Propellor basin flying at 3kt. The community is also interested on a mode of surveying with auto-immersion for specific scenarios, that could also minimize problems of pitch/heave noise/artifacts.

AUV Uly$^X$ can provide high-quality scientific bathymetry, water column (and associated backscatter) at most if not all terrain conditions that may be encountered during scientific missions.

### 4.2. – Photography

Optical seafloor inspections with Uly$^X$ were conducted in all terrain types, at altitudes varying between 9 m and 6m, which is the nominal altitude for this type of missions. The APN failed acquiring data at the start of several surveys, acquired images at irregular rates, and missed acquisition during certain inspections (Figure 9). This may be mitigated with more reliability of the system, and a procedure to verify the acquisition and re-start it if necessary. We conducted several tests of different acquisition modes under different conditions that will be analyzed in depth post-cruise to inform the final conditions of optical inspection to be validated for routine operations by GENAVIR. The tested inspection modes associated to different terrains are as follows:

Flat terrain (<10°): Uly$^X$ can perform inspections using parallel tracks ('mowing the lawn').

Moderate terrain (<20°): The AUV can follow the terrain in inspection mode and at an altitude of 9 m, provided that high resolution bathymetry (AUV) is available to avoid impact and collision with the seafloor, following the collision during PL#15.

Imagery acquired at 9 m is exploitable (e.g., identification of type of terrain, presence of ecosystems), but systematic 'mowing the lawn' surveys will require further tests to determine if they are a possibility and under which conditions.

Rugged terrain: For rugged terrain with slopes steeper than 30°, a surveying strategy was developed during the cruise with hovering maneuvers over selected spots to acquire imagery at 9 m over the seafloor, and covering areas of up to 300-700 m$^2$ (Figure 7). This 'hover' inspection mode provides the possibility to conduct systematic inspections (e.g., profiles or grids of spots) in rugged terrain. Its implementation for routine operations may require high resolution multibeam bathymetry in some scenarios.

Inspections at 9m of altitude are not well lit, and provide exploitable but suboptimal image quality. AUV Uly$^X$ should benefit from an evolution allowing inspections at a somewhat lower altitude (e.g,, 7 or 7.5 m if 6m inspections are not possible) in moderate slope track inspection and hovering modes.

AUV Uly$^X$ can conduct optical inspection in all type of terrains, with inspection strategies tailored on a case-by-case basis (e.g., track surveys in flat areas at 6 m, terrain follow in moderate terrain, and spot inspections with hovering in rugged terrain at 9m). The possibility to do hovering is particularly promising as it would allow optical inspection in all types of terrain, subsidiary to vehicle security.

### 4.2. – Other sensors

AUV Uly$^X$ is equipped with several physicochemical sensors, including a fluorimeter, oxygen, Eh, pH, nephelometer and magnetometer, in addition to the AUV's CTD. Fluid sources in the area are limited to weak low-temperature hydrothermal activity (Palinuro, Marsili) and degassing (Propellor basin), that were preferential targets.

CTD: The AUV's CTD has been validated against CTD data acquired with a sbe19plus CTD deployed from the L'Atalante; with matching data at depths >200 m. However, we noticed major differences between downcast and upcast in both CTDs (as expected for a standard CTD-rosette cast). Therefore, we recommend using downcast data for the AUV's CTD for analyses of water-column parameters. Upcast data should be preserved as well in case of downcast errors.

Magnetometer: Magnetic data from 3 sensors were inspected onboard, lacking an expert in magnetic processing. All sensors worked correctly, and recorded data consistent with attitude changes of the vehicle. All dives include a set of surface navigation circles that may be exploitable for diving. A full magnetic calibration was conducted during dives PL#15-17, for later data exploitation.

Eh and Ph: These sensors recorded correctly during the dives, with data consistent with variations in the shallow water column (surface to ~200 m). The pH sensor recorded a modest pH anomaly associated with degassing at Propellor basin, with a pH reduction of ~0.2 thus suggesting $CO_2$ rich degassing.

Nephelometer: The sensor recorded correctly during the dives, but values of the area were typically low ranging from 0 to 20 FTU (excluding dives where Uly$^X$ collided with the seafloor in dives 4 and 14, values > 500 FTU). Negative values were also recorded (especially when pitch was around 0), but this was probably linked to the low observed FTU data. Qualitative calibration improvised onboard with a range of dilution of turbid water showed a consistent response of the sensor on-deck. Therefore, the lack of turbidity signal is attributable to the absence of turbidity sources (e.g., black smokers) in the area; fluids in volcanic fields of Palinuro and Marsili are reported to be clear and low-temperature, and there is no turbidity associated with degassing. When data where > to 5FTU, we observed differences between data acquired when Uly$^X$ is pitching down or up (e.g., dive 15). As for CTD, we recommend to use data recorded when Uly$^X$ is pitching down.

Fluorimeter and O2: These sensors recorded data during all successful dives. Records showed variations associated primarily to the sub-surface layer, with an increase of both $O_2$ and fluorimeter values near-surface associated frequently characterizes the vertical distribution of phytoplankton chlorophyll in the Mediterranean Sea.

**5.- Operations during AUV dives**

AUV autonomy can be exploited through simultaneous operations during dives, with the ultimate goal of deploying two deep sea vehicles at the same time if in accordance with scientific objectives (e.g., AUV Uly$^X$ and ROV Victor). This mode of operation has not been implemented by the French Oceanographic Fleet and its vehicles, but it was fully tested during a prior cruise (ODEMAR) that deployed the AUV Abyss (GEOMAR, Germany) and VICTOR.

During Uly$^X$Demo-24 we conducted the following simultaneous operations, in chronological order:

- CTD casts during AUV dive, in close proximity.
- Increasing the ship distance to the AUV, losing telemetry at 1.5 km and at the limit of USBL positioning at >3km, during dives at 700 m and >3000m immersion.

AUV dives in autonomy are a priority identified by the WG, and requested by the scientific community. Tests towards this goal should be included in future technical cruises, and tested at sea during regular scientific cruises in accordance with AUV security and science goals. This can significantly increase the science output of a cruise.

**6.- AUV navigation**

AUV Uly$^X$ relies for navigation on the PHINs system, a DVL that provides vehicle speed when there is a bottom lock (<90 m), a sonar that provides information of terrain ahead, and acoustic positioning from the ship via an USBL system. During the Uly$^X$Demo-24 cruise, offsets between the vehicle and USBL navigation varied from dive to dive, with accuracies of <10 m achieved at ~3100 m (PL#89-03) m and exceeding >20 m at ~700 m.

A critical part of a dive mission is the descent to the seafloor. During descent, calculated AUV positions (USBL) are transmitted from the ship to the AUV through the acoustic modem (x, y and z positions with a time stamp) that allows the AUV to update his position continuously and accurately. Problems in this positioning during descent may result in a descent without repositioning and relying on inertial navigation with neither DVL nor USBL, and hence prone to drift.

During the surveys and inspections, navigation relies on the DVL information. Prior DVL issues have been solved with a fusion of sensor data and applying machine learning techniques that allow Uly$^X$ to navigate despite these DVL glitches that are filtered. In rugged terrain, DVL may lose bottom momentarily, resulting in drift and inaccurate navigation that is then propagated along the SMF survey or optical seafloor inspection.

**7.- Tested mission modes**

Based on the results summarized above, and pending an analysis of both technical and scientific dive information, the Uly$^X$Demo-24 cruise tested the following mission types, on three types of terrain as originally defined by the WG:

a) Missions on flat terrain (<10°):
   Bathymetry surveying at ~70 and ~6 m (auto-altitude)
   Optical inspection at ~6 m to 8m (parallel tracks) depending on local relief/slope
b) Missions on moderate terrain (<20° over a track/survey length):
   Bathymetry surveying at ~70m (auto-altitude)
   Optical inspection along tracks with slopes <20° (track/exploration mode, 9m) with mitigated results (successful tracks vs. collision, PL#15, after encountering slopes of ~50°)
c) Missions on rugged terrain (>30°):
   Bathymetry surveying at ~70m (auto-altitude)
   Optical inspection at spots (hover/spot mode, 9m)

**8.- Preliminary conclusions**

The Uly$^X$Demo cruise thus tested a wide range of mission plans, with different surveying and inspection modes. These dives demonstrated that some missions such as multibeam mapping were conducted in routine mode over all kinds of terrain. Optical inspection requires strategies adapted to the terrain. **The final conditions, requirements, specifications and limitations on modes of survey and inspection type will be defined post-cruise, between the IFREMER and GENAVIR.** These specifications, and the addition of new modes of inspection in particular (some tested during this cruise) may require further tests before being proposed in routine operation (e.g., relief tracking in moderate slopes).

Bathymetry data is of good quality in all modes, but noisier and with artifacts in rugged terrain owing to heave issues. A possible cause linked to limits in the limits of vehicle navigation has been identified onboard but the remediation will be post-cruise.

All sensors recorded correctly, although some of them (e.g., nephelometer) did not encounter water column anomalies, and hence are lacking significant signals during this cruise.

With immersions to a maximum of ~3700 m, validation of the various mission modes at full depth (e.g., >5000 m) is pending.

The AUV navigation is at this stage reliable and suitable overall, and for all type of terrains, and of better quality than that of Aster$^X$ and Idef$^X$. Errors in navigation are accentuated during descents to the seafloor that lack USBL positioning communicated by acoustic modem, or during DVL loss in rough terrain (also associated with bathymetry artifacts).

Imagery is optimal at 6 m of altitude, and underexposed but exploitable at 9 m.

Modes and conditions of optical inspection that are of interest for science projects (e.g., hovering, tracks evolving over moderate terrain) may require further tests and data analyses (e.g., increase the slope thresholds, reduce inspection altitude in some of the modes now tested at 8-9 m).

Additional acoustic survey modes that may be of interest to the scientific community include a) auto-immersion surveys that may be useful for rugged terrain so as to minimize artifacts (heave/pitch), or to fly over extremely complex and rugged areas where auto-altitude may be difficult, and b)

**9.- Ship operations during AUV cruises**

During the Uly$^X$Demo-24 cruise we conducted both CTD casts with the lateral winch, and rock dredges through the A-frame. CTD operations can be conducted without interference with AUV operations, including during AUV dives.

Two dredges were carried out during the cruise (Palinuro, Vavilov). The feasibility of this operation is greatly hindered by the latch system of the AUV Uly$^X$, and in the present configuration probably cannot be carried out in bad weather. All operations conducted during the UlyXDemo-24 cruise benefitted of optimal weather conditions, with flat or state-1 seas, and wind <30 km/h and typically <20 km/h. These operations (dredging, coring, etc.) are often secondary objectives to cover down-time of the deep-sea vehicles (bad weather, technical problems), and the set up must evolve so that operations can be carried out during a cruise deploying Uly$^X$ or Uly$^X$+ROV/HOV. L'Atalante cannot provide this critical flexibility to account for contingencies with the deep-sea vehicles. An identified possibility to improve this interoperability is a modification of the Uly$^X$ latch system, with foldable wings that do not interfere with the cabling required during dredges.

**10.- Data transfer and volume**

Data volume varies depending on the mission planning. Optical inspection operations can produce large volumes of data, and the acquisition of the water column during multibeam surveys increases the data volume by >200%. As a result of the large data volume, the transfer to the science party and subsequent processing onboard can constrain the operations during AUV/ROV cruises. Future science cruises using Uly$^X$ may benefit from a streamlined data transfer that minimizes the time between AUV arrival on deck, delivery of data to the chief scientist, and the processing for subsequent operations, hence optimizing ship time use.

**11.- Onboard network and external connectivity**

The Uly$^X$Demo-24 cruise relied on the ship's network for data transfer and access, cooperative work, and access to internet (scientific papers, databanks, transmission of files and information, etc.)

The recent evolution of the network/internet onboard system was clearly unsuitable for Uly$^X$Demo-24, and more critically so for future routine science operations and achieving scientific goals, during a cruise with a full scientific staff and 24/24 operations. Any solution implemented on the French Oceanographic Fleet should facilitate:

- Seamless access to online resources through the science network (i.e., databases such as gmrt.org, scientific journal, institutional websites required to work, etc.),
- Access to file transfer facilities,
- Removal of 1h timeouts in the network that do not allow or interrupt data access or processing, with the implications regarding lost time and work,
- Speed of network required for scientific operations involving Uly$^X$ (and other similar vehicles)

A list of sites to be declared accessible is not a workable solution as the practices and needs of access change both among scientific and technical communities, and evolve with time; a list of allowed sites would be impossible to establish.

**12.- School of PIs**

The Uly$^X$Demo-24 cruise offered an opportunity for a pilot PI school. A group of 5 early career scientists boarded as full members of the Science party. During the cruise, participants had access to information on different aspects of the cycle of a cruise in the French Oceanographic Fleet, including proposal preparation, evaluation, post-cruise science, management of a cruise including operations at sea, associated tasks and obligations of the PI (e.g., reporting, cruise preparation, logistics, administration, etc.). The feedback and experience acquired during this pilot experiment may facilitate the implementation of a regular PI school by the French Oceanographic Fleet, responding to a demand of the scientific community.

They also provided a precious and key support for the analysis and validation of the AUV data and vehicle.

**13.- Glossary:**
APN: Digital still camera (*appareil photo-numérique*)
AUV: Autonomous Underwater Vehicle
DVL: Doppler velocity Lock
HOV: Human-operated vehicle
ROV : Remotely Operated Vehicle
SDS: Sediment sounder (*sondeur de sediments*)
SMF : Multibeam system (*système ulti-faisceaux*)
USBL: Ultra-short base line

**14. Science Party (both Legs #1 and #2):**

| | |
|---|---|
| Aurelien ARNAUBEC | Équipe Uly$^{X}$ - IFREMER/DFO |
| Tim AUTIN | Équipe Uly$^{X}$ - IFREMER/DFO |
| Nathan BARTOLINI | Équipe Uly$^{X}$ - GENAVIR |
| Sébastien BELL | Équipe Uly$^{X}$ - IFREMER/DFO |
| Rémy BENEJEAN | Équipe Uly$^{X}$ - GENAVIR |
| Tristan BRIARD | École PI – Ecologist – Univ. Littorale Côte d'Opale/LOG |
| Loic BONNET | Équipe UlyX - GENAVIR |
| Catherine BORREMANS | GT Uly$^{X}$ –Biologist – IFREMER/LEP |
| Prune BRENGUIER | Journaliste |
| Tanit DE DIESBACH | Équipe Uly$^{X}$ - GENAVIR |
| Virginie DURAND | École PI – Sismologue – GéoAzur/IRD |
| Etienne DUTTO | Équipe Uly$^{X}$ - GENAVIR |
| Javier ESCARTIN, **co-PI** | GT Ulyx – Geologist – ENS Paris/CNRS |
| Marie-Noelle FABRE | Équipe Uly$^{X}$ - IFREMER/DFO |
| Ridha FEZZANI | SMF – IFREMER/DFO |
| Aurèlie FELD | DFO/PON – Flotte Océanographique Française |
| Gino FABBRI | Équipe Uly$^{X}$ - GENAVIR |
| Arnaud GAILLOT | SMF – IFREMER/DFO |
| Benjamin GASQ | Équipe Uly$^{X}$ - IFREMER/DFO |
| Cyrille GOMEZ | Équipe Uly$^{X}$ - IFREMER/DFO |
| Jennifer GREER | Équipe Uly$^{X}$ - IFREMER/DFO |
| Charline GUERIN | GT Uly$^{X}$ – Carthographe et chaire « Marie Tharp » – IFREMER/GM |
| Benoit ILDEFONSE | Chef École PI - Geologist – U. Montpellier/CNRS |
| François LALLIER | GT Uly$^{X}$ – Biologist – U. Sorbonne/Roscoff Biological Station |
| Thomas LEFEVRE | Équipe UlyX - IFREMER/DFO |
| Pauline LE PECULIER | Journaliste |
| Stéphane LESBATS | Communication - IFREMER |
| Anthony MARINELLI | Équipe Uly$^{X}$ - GENAVIR |
| Thibault MARTIN | Équipe Uly$^{X}$ - IFREMER/DFO |
| Séverine MARTINI | École PI – Biologist – MIO/CNRS |
| Margaux MATHIEU-RESUGE | École PI –Biologist – IFREMER/LEP |
| Xavier MORIN | GENAVIR |
| Pierre PASCAL | Équipe Uly$^{X}$ - GENAVIR |
| Thomas PELLIESSIER | Communication - IFREMER |
| Romain PIASCO | Équipe Uly$^{X}$ - IFREMER/DFO |
| Cyrille PONCELET | SMF – IFREMER/DFO |
| Ewen RAUGEL - **PI** | Équipe Uly$^{X}$ - IFREMER/DFO |
| François ROLAND | Équipe Uly$^{X}$ - IFREMER/DFO |
| Xavier SAINT-LAURENT | Équipe Uly$^{X}$ - GENAVIR |
| Remy SUDA | Équipe Uly$^{X}$ - GENAVIR |
| Olivier SULPIS | École PI – Geochemist – CEREGE/CNRS |

***Leg#2: Board & Science Team***

## 15.- Figures & Tables

| Dive (abs) | Dive (rel) | Date | Dive lenght | Distance parcourue sur le fond | Location | Bathy | Imagerie | Capteurs Physico-chimique | CTD profils |
|---|---|---|---|---|---|---|---|---|---|
| # 87 | #01 | 20240530 | 08h32:25 | 16,6 km | Large de Propriano | Tech | | X | |
| # 88 | #02 | 20240531 | 13h59:41 | 18,4 km | Site IODP | X | X | X | |
| # 89 | #03 | 20240601 | 14h19:12 | 32 km | Ride Nord Ouest Vavilov (VD_C) | X | Tech | X | |
| # 90 | #04 | 20240602 | 11h46:24 | 5,5 km | Ride Nord Ouest Vavilov | Tech | | X | |
| # 91 | #05 | 20240603 | 02h12:18 | 0 km | Basin Marsili | | | | |
| # 92 | #06 | 20240604 | 07h51:48 | 12,66 km | Zone de repli à l'est de l'Isola di Ustica | Tech | X | X | |
| # 93 | #07 | 20240606 | 05h44:52 | 61,8km | Volcan Marsili | X | | X | |
| # 94 | #08 | 20240607 | 07h18:06 | 5,98 km | Zone de repli Est de l'ile de l'Ustica | | Tech | X | |
| # 95 | #09 | 20240608 | 15h28:08 | 61,16km | Volcan Marsili | X | X | X | |
| # 96 | #10 | 20240609 | 10h40:17 | 39,8km | Propeller Bassin zone Sud | X | X | X | |
| # 97 | #11 | 20240610 | 14h52:47 | 41,5 km | Propeller Bassin | X | X | X | 2 |
| # 98 | #12 | 20240611 | 14h04:49 | 27,6 km | Propeller Bassin | X | X | X | 2 +2 (afer dive) |
| # 99 | #13 | 20240612 | 13h29:00 | 51,7 km | Palinuro | X | Tech | X | 2 |
| # 100 | #14 | 20240613 | 18h13:60 | 79,7 km | Palinuro | X | Tech | X | |
| #101 | #15 | 20240615 | 16h02:12 | 25,8 km | Transition flan ouest mont Vavilov – Ride volcanique | X | Tech | X | |
| #102 | #16 | 20240616 | 14h21:27 | 25 km | Vavilov - ride N detachement | X | X | X (lack depth) | |
| #103 | #17 | 20240617 | 14h45:35 | 24.9 km | Vavilov - ride S detachement | X | | X | |

Table 1: List of AUV Uly$^X$ dives and associated information

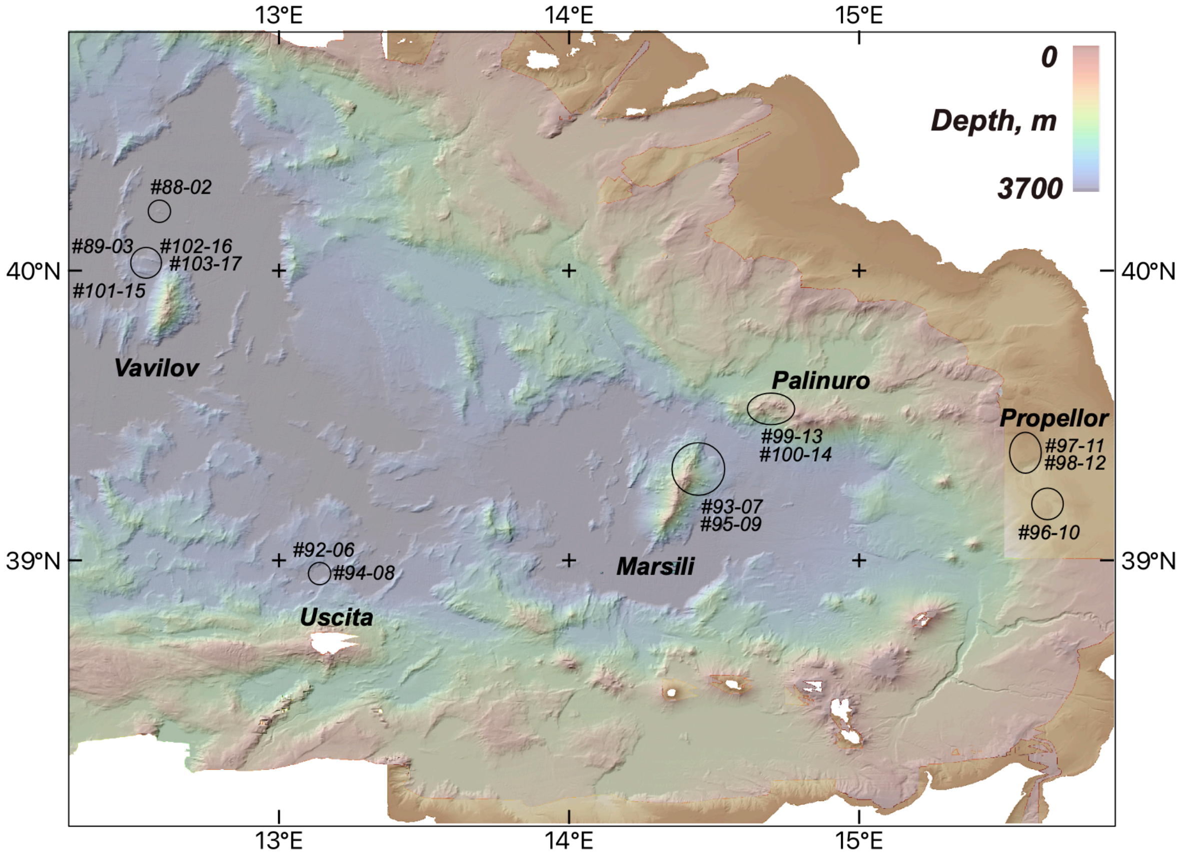



Figure 1 : Map locating the study areas and Uly$^X$ dives conducted (dive #87-01 off Corsica is not shown).

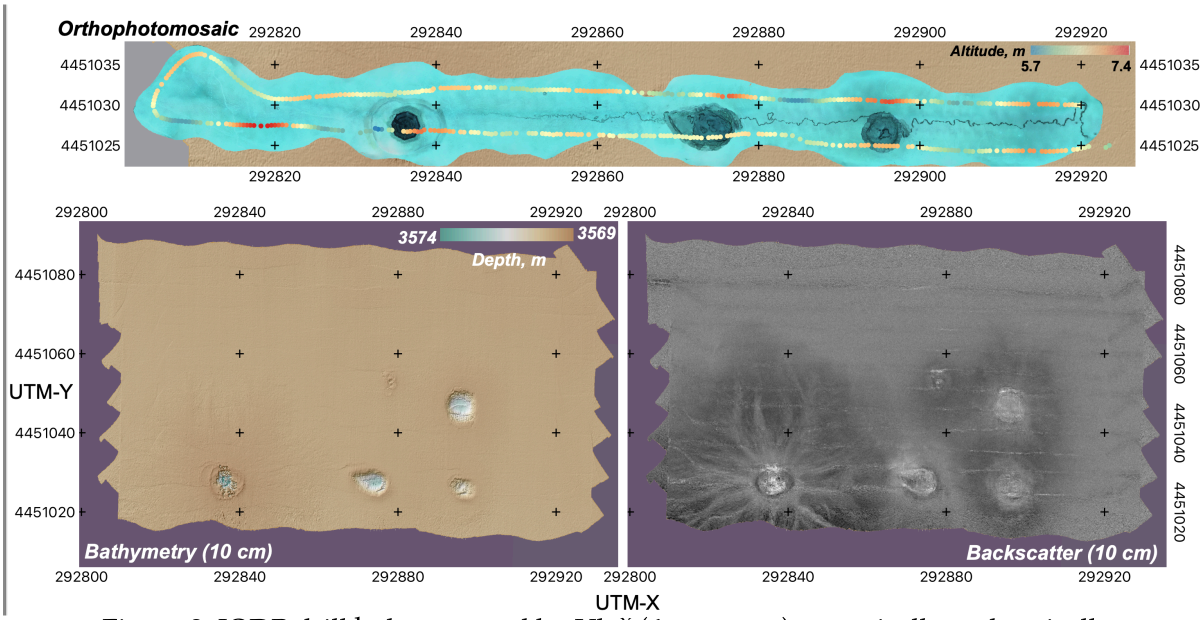



Figure 2: IODP drill holes mapped by Uly$^X$ (6m-survey) acoustically and optically (orthophotomosaic from 3D reconstruction), with raw navigation (uncorrected).

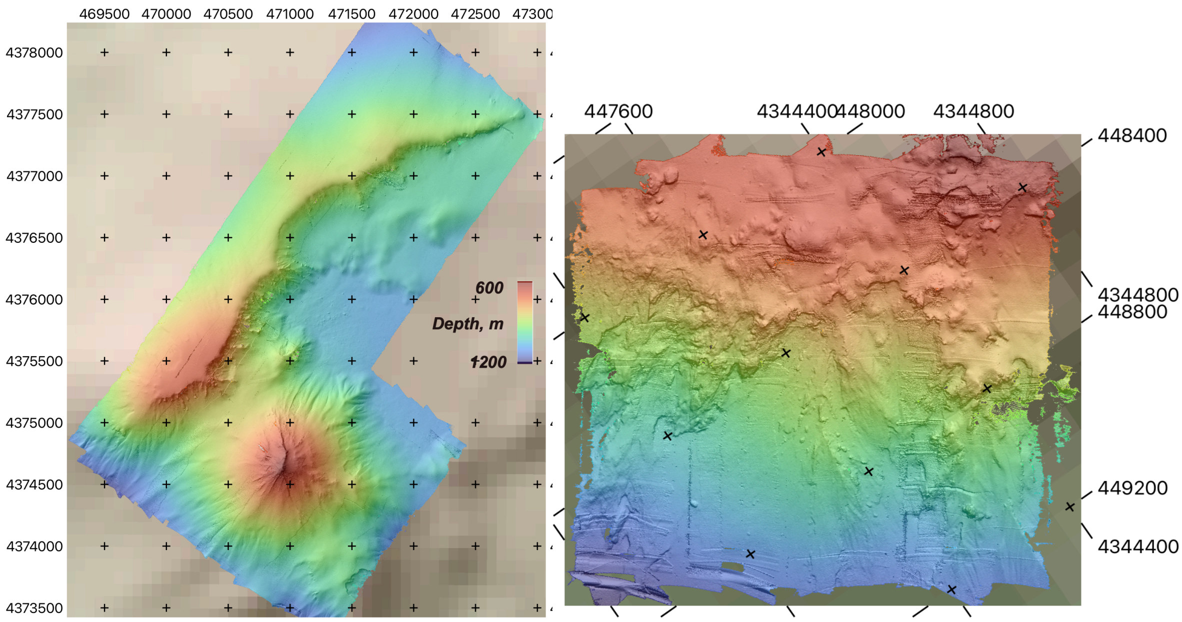



Figure 3: Examples of bathymetry (not processed, raw navigation), on a volcanic area (Palinuro, PL14) and a volcanic flank with an average slope >30° (Marsili seamount).

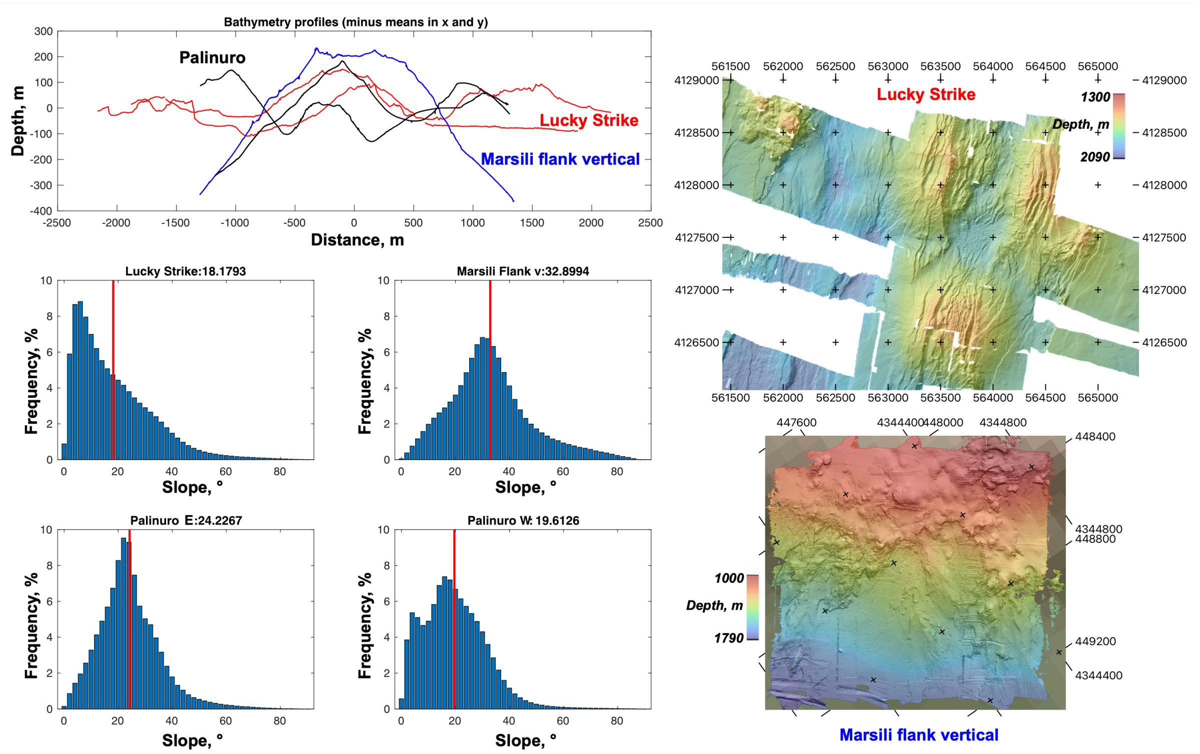



Figure 4: Top left: profiles across volcanic terrain at the ridge axis at Lucky Strike (Mid Atlantic Ridge), Masili flank and Palinuro seamounts (see Figure 3). The average slope of surveys in volcanic terrain in the Thyrrenean are more rugged and show more slope than the Lucky Strike area. Right: maps comparing Lucky Strike (top) and Marsili seamount flank (bottom); maps have a color bar with the same dynamic range (790m) showing the more subdued topography at Lucky Strike than in the Thyrrenian.

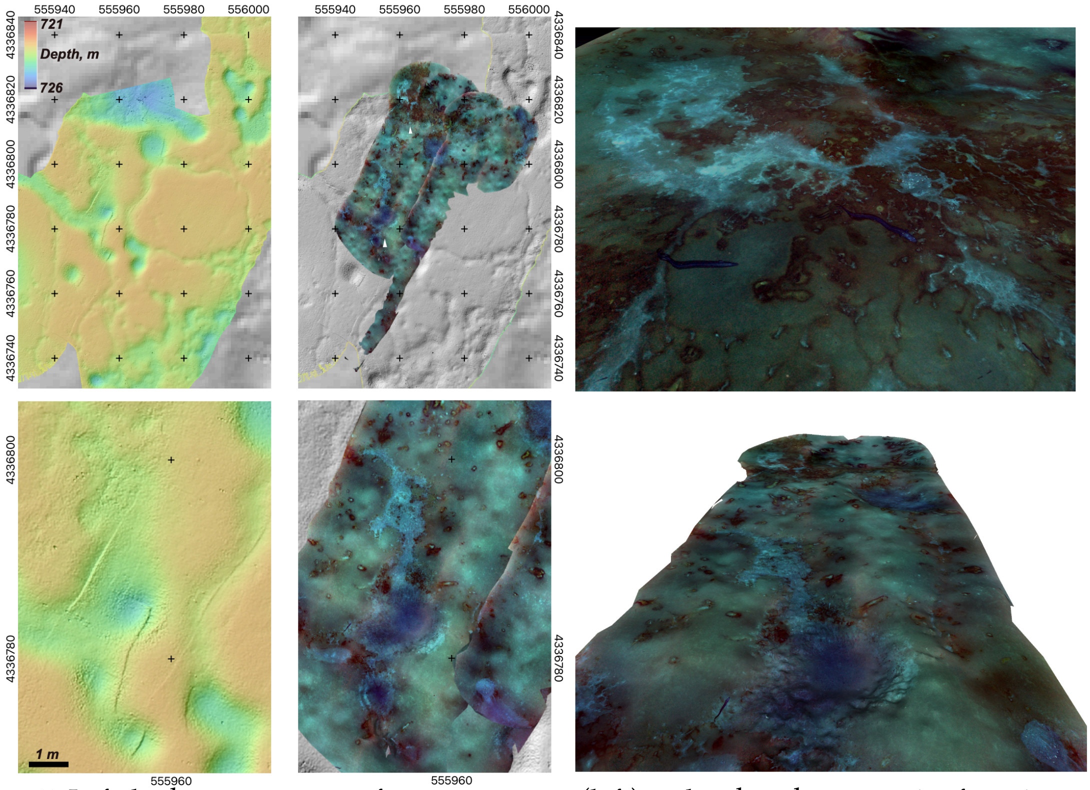



Figure 5. Left: bathymetry maps of a gas seep area (left) and ortho-photomosaics from inspection at 9m (center) obtained from 3D models (right) showing the bacterial mats at depressions where gas plumes emanate (left).

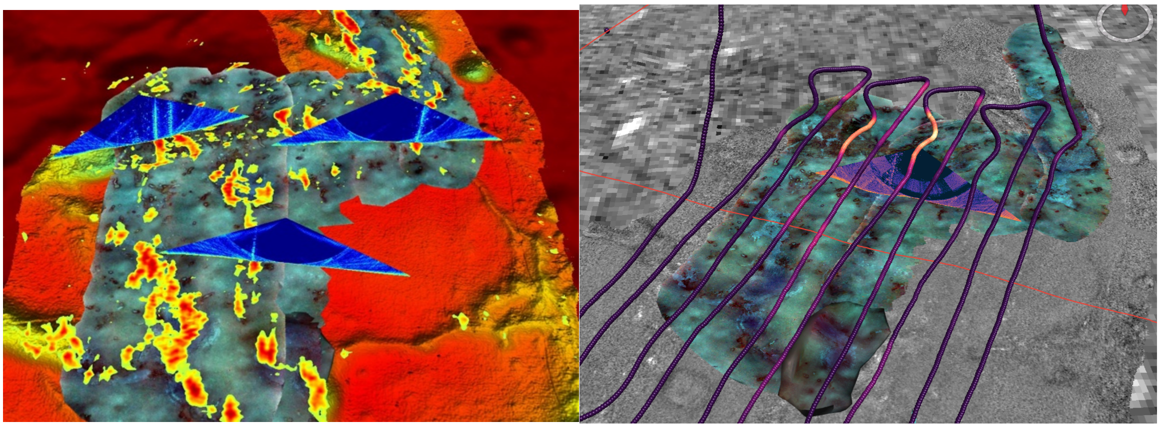


Figure 6: Mapping of gas plumes in the water column and swaths showing the plumes over a gas seep, over both shaded terrain and ortho-photomosaics (top; see also Figure 5) and pH anomaly recorded by Uly$^X$ during the dive (colored track, bottom) at Propellor basin (PL#10).

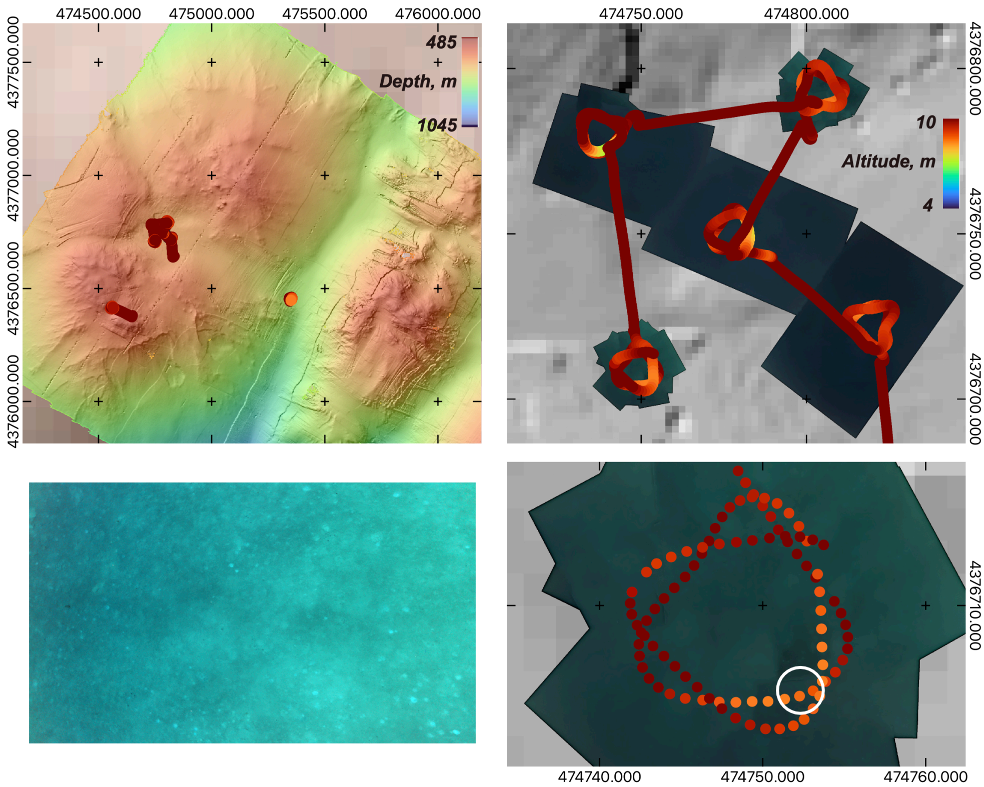



Figure 7: Optical inspection over the summit of a rugged and complex volcano (top left, Palinuro), with 7 hovers (5 shown on top-right). The AUV inspects an are delimited by a circle (bottom right) providing imagery usable for ground truthing (bottom left).

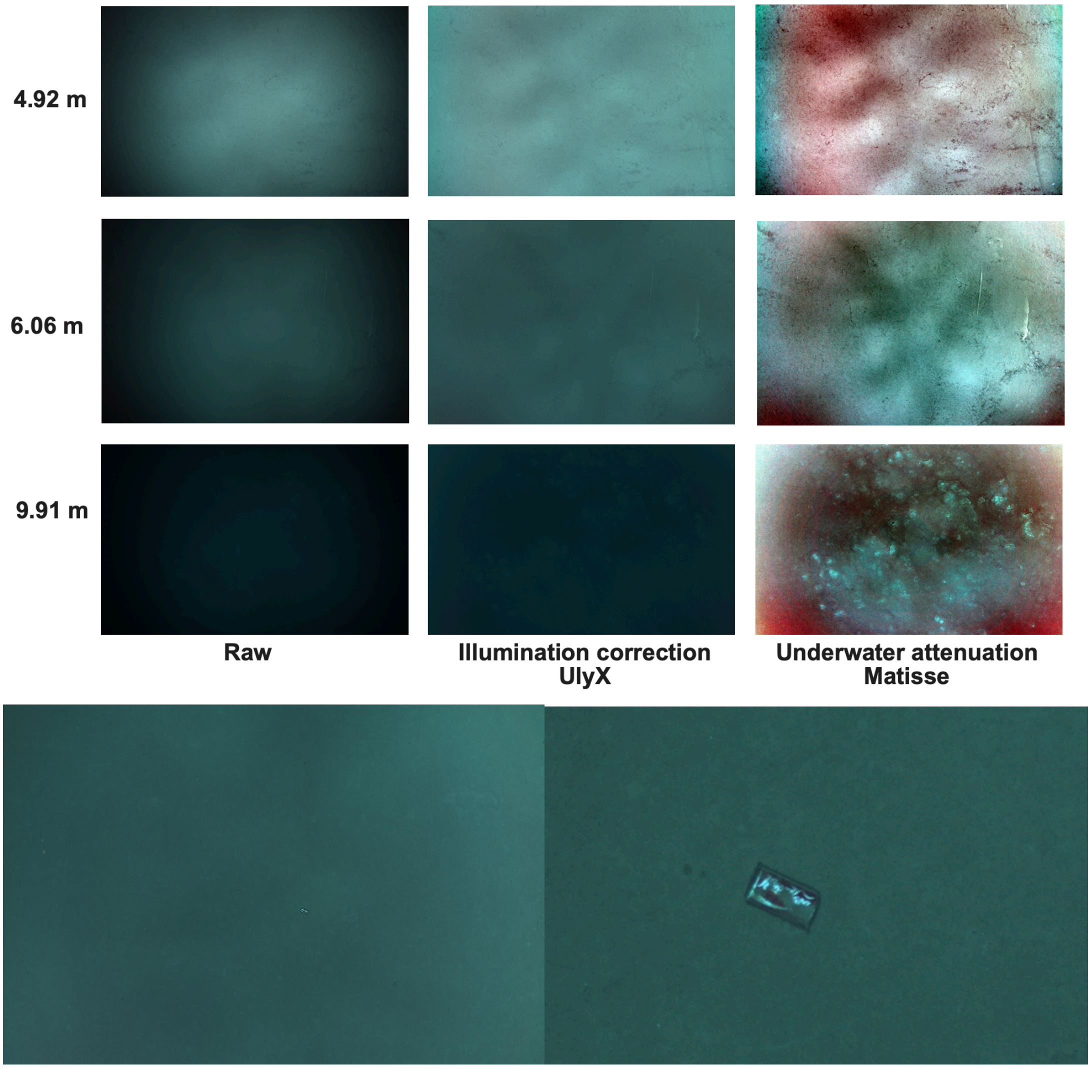



Figure 8: Images from texture-less sedimented seafloor: raw images (left), corrected for illumination (provided with Uly$^X$ data) and corrected for underwater attenuation using Matisse (right). At >6 m images are underexposed but exploitable scientifically (see Figure 5), particularly in textured seafloor. The images show a pattern of uneven illumination after corrections, likely due to an uneven illumination (4 flashes) that a parabolic illumination correction does not correct. Image of litter (soda drink can, unfortunately) allows identification of letters 3-4 cm high (PL#06 off Ustica, 6.9 m altitude, full image left, blown up image right with readable lettering).

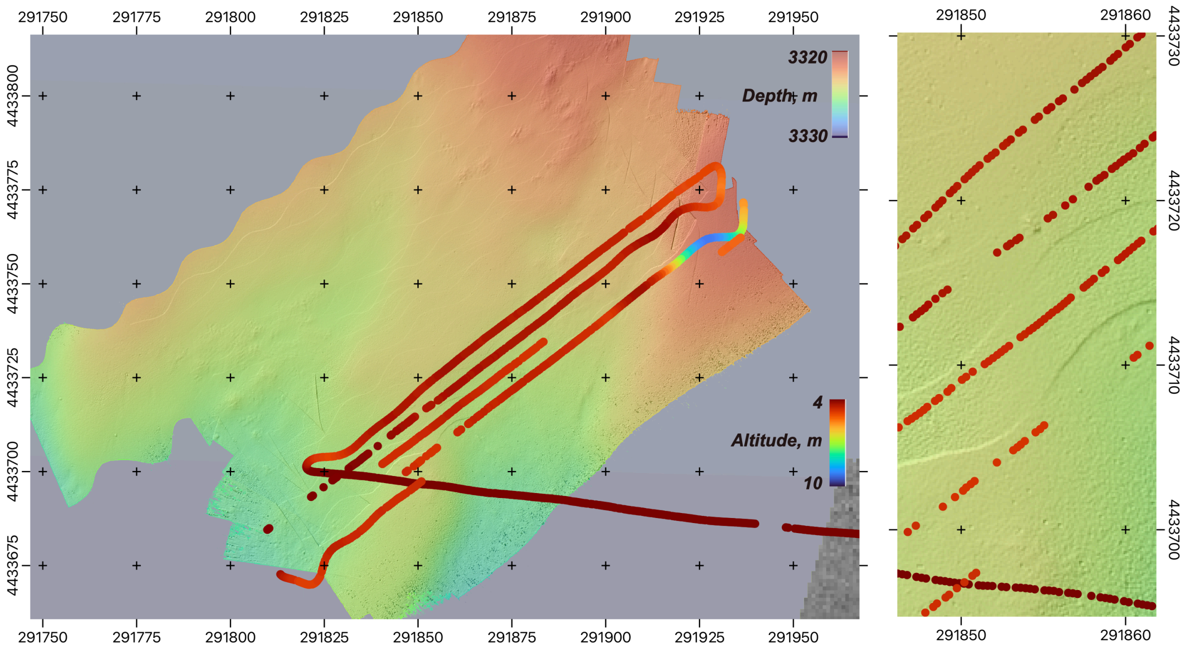



Figure 9: Optical survey and associated bathymetry (PL16) and position of acquired images color-coded by altitude. The APN failed at the start of the survey, and was re-started but acquired data at 9m instead of 6, above seafloor, did not record over significant track sections, and shows irregular recording of images instead of a constant rate of 3s (left).

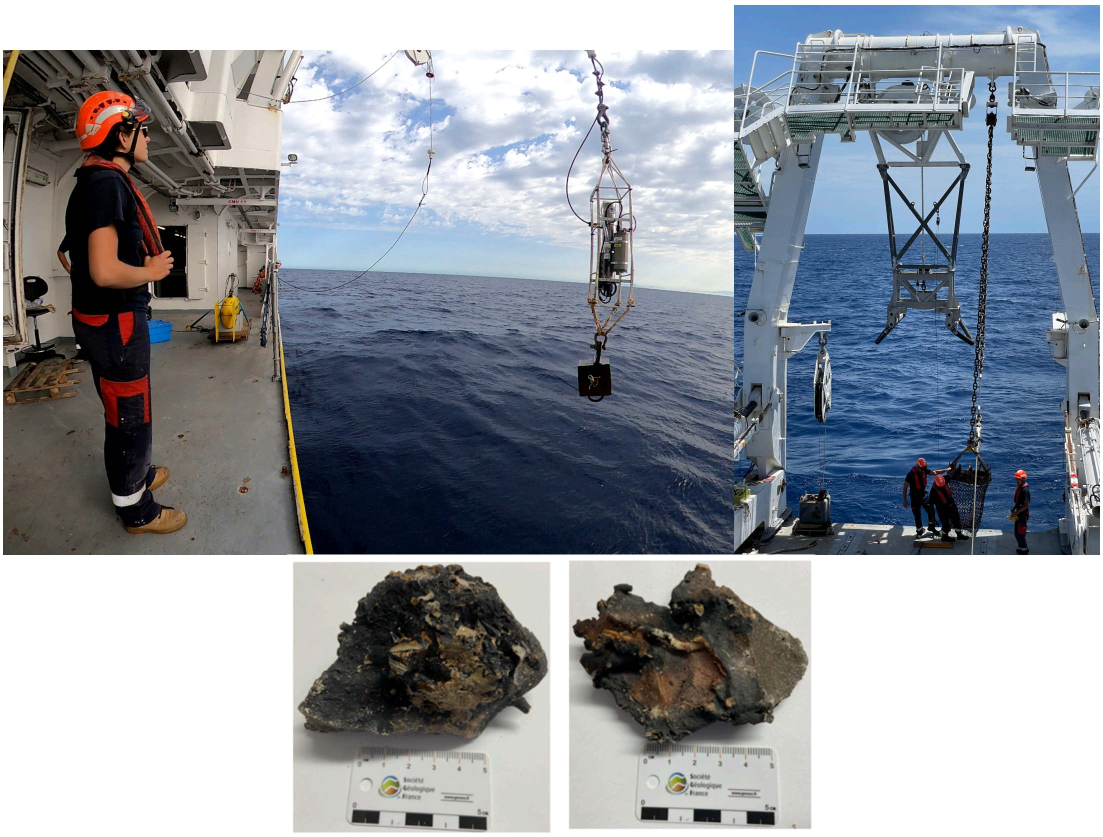


Figure 10: Ancillary operations included, in addition to multibeam mapping and sediment echosounder profiles (see Figure 1), CTD casts (top left) and dredges (top left) at Palinuro (no samples) and Vavilov (basalts, bottom, and carbonates).