PLOCAN CAMPAIGN REPORT (ADF19/1222)

Version 1

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1. Overview

The EU-funded TechOceanS project has developed and demonstrated through several underwater vehicles nine pioneering technologies for ocean biology, chemistry and plastics monitoring. The novel solutions comprise five sensors, two imaging systems targeting seabed and pelagic biology and plastics, a sampler that will collect particle samples and a new AI-based image processing method for data compression and information transmission.

To test the technology, a set of experiments and integration on a suit of platforms have been organised. The final tests were carried out in Gran Canaria in March 2024 where 7 new technologies developed in this project were combined and integrated in 4 different autonomous vehicles. This unique opportunity was also used to provide a multidisciplinary practical training with students directly involved in the preparation (i.e. calibration/validation of sensors, preparation of the platforms) and management of deployments and included students and technicians from ODA recipient states.

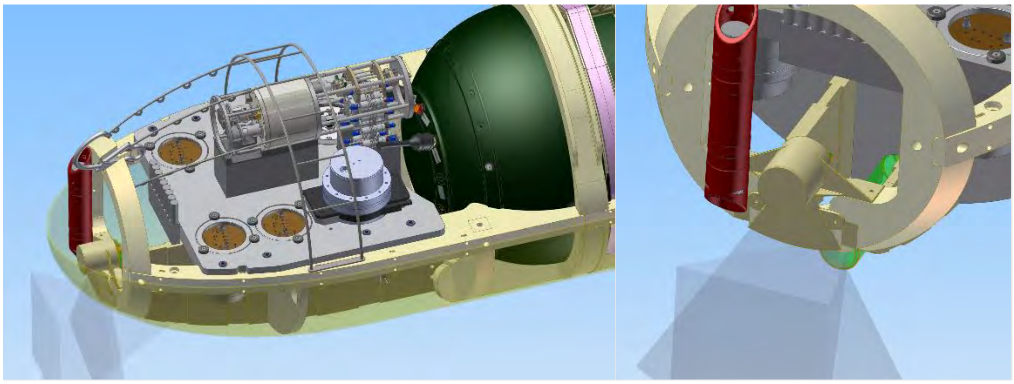


Figure 1.1. Diagrams of ALR5 and different sensors and samplers integrated.

1.1. Objectives

Core objective for this campaign was:

- Tests a suit of sensors developed in the project in MARS autonomous underwater vehicles (AUV) developed at NOC, UK.

2. Campaign Narrative

Day by day breakdown of key activities:

2.1. Monday 4/3/24:

AM

- MARS+OTE arrive at PLOCAN - Samuel and Eduardo provide site briefing and tour of PLOCAN facilities.
- Unloading of NOC containers, ALRs moved into PLOCAN Glider Lab
- Procurement of sim cards for C2iab (Piloting laptop for ALRs)

PM

- ALR1500 (ALR5) battery on charge
- Show and Tell / Equipment Safety Briefing for ALR and associated sensors
- RoCSI Testing onboard ALR5
- Swap TA/DIC Unit onboard ALR5
- Review of ALR5 Pre-Mobilisation Checklist
- C2iab configuration preparation
- Prepping of reagents for LoC sensors on ALR5
- ALR5 OCS (Onboard Control System) software build overnight.
- ALR5 on charge

2.2. Tuesday (5/3/24)

Productive day yesterday preparing the eddy chasing biogeochemistry ALR1500 (ALR5) and sensors and undertaking an initial harbour dunk:

AM

- ALR5 OCS Build Complete
- ROCSI Commissioned in ALR5
- mSTAF unit for ALR5 not arrived on site (stuck in customs) - blanked off the non-functioning unit in ALR5
- Reagents added to LoCs in ALR5 (TA/DIC + nutrients)
- LoCs commissioned in ALR5
- C2iab installed on support vessel
- ALR5 wheeled outside for comms checks (Iridium and xeos confirmed to be working)
- ALR5 Missions Calibration Missions Reviewed
- Started ALR Pre-Deployment Checklist
- Inspect hired support vessel – discuss operations with boat driver.
- C2 Release

PM

- Planned inspection of proposed work area by rib postponed as weather too rough.
- Pre-deployment checklist run through for ALR5.
- Toolbox talk prior to transporting and launching ALR in Harbour
- ALR5 crane dunk in dock to confirm launch process and rehearse pre-deployment checklist.
    - check leak and ground faults.
    - Recover ALR5

- Signed off all outstanding items on pre-mobilisation checklist ready to begin pre-deployment checklist first thing on Wednesday.
- RoCSi/ LoC prepped ready for deployment.

2.3. Wednesday (6/3/24)

AM

- Arrived on site - still force 4 and 2m waves so no on-water AUV operations.
- Reconnaissance of work area by support vessel - wave conditions far too rough for safe AUV operations - no new hazards identified but potential sheltered recovery location found.
- ALR5 in the lab - debugging activities for one of the nutrient sensors.
- ALR3/BioCam on charge.

PM

- mSTAF units located in Gran Canaria expecting them to be available Thursday.
- Quayside missions with ALR5 running the RoCSI and LOC sensors
- C2iab end to end testing of commands.
- Remaining equipment arrived for Seaglider preparation.
- OCS Build on ALR3 / ALR5 overnight.

2.4. Thursday (7/3/24)

Wind and wave conditions too high for in-water AUV operations. Good progress on preparation and testing of ALR5 and sensors.

AM

- Continued prep ALR3/BioCam
- Continued quayside testing of ALR5 and LoC sensors.
- Issued identified with RoCSi pumping too much water when commanded by ALR5 - under investigation.

PM

- Tested UVP6 in ALR5 all seems to be working
- Filming comms material for PLOCAN and TechOceanS
- Testing of new ALR Localisation Package (running in the background for this trial)
- ALR Piloting - issue identified with old plans not being usable - C2 team investigating.
- Good progress with cytochip
- mSTAF units arrived at PLOCAN

2.5. Friday (8/9/24)

- Firmware update on mSTAF unit then installation and testing on ALR5 - not complete so sensor will be disconnected for first deployment.
- Nutrient LoC on ALR5 was seizing on one of the pumps - issue fixed ready for first deployment.
- TA/DIC LoC on ALR5 sensor ready for first deployment.
- Issue identified with RoCSi configuration onboard ALR5 - work complete to rectify this issue – ready for first deployment.
- Finalised ALR towing plans.
- Finish the day with ALR5 ready to go on deployment on Saturday.
- NTM to issued to cover duration of trial with details for upcoming 24/48/72 hours.
- Continued prep work on ALR3.
- Continue work on cytochip.
- Review plan for later science missions considering adverse weather conditions. Discussions continuing.

2.6. Saturday (9/9/24)

Arrived at PLOCAN wind and wave conditions significantly reduced - some residual swell proceeded with initial tests of ALR5 (Pictures attached)

- Pre-deployment checklist for ALR5
- Launch ALR5
- Tow to Work Area
- Mission/Command Sequence for ALR5
    - ALR5M101: C01 Surface Run - Complete
    - ALR5M102: C01a 10min Test Dive (15 m)
    - Command: Turn Sensors On (5 mins)
    - ALR5M103: C02a Compass Cal + Rocsi
    - Command: Turn Sensors On (5 mins)
    - ALR5M104: C03 Alignment (Northward)
    - Turn Sensors On (5 mins)
    - ALR5M105: C04b Endurance Run + Rocsi
    - Turn Sensors Off (5 mins)
    - CTD OFF
- Recovered ALR5 to PLOCAN
- Co-sampling along line of calibration missions by OTE in second boat
- Testing of ALR3+BioCam in the Lab and testing of lasers systems - all OK

Initial analysis of ALR data looks promising, flight characteristics are a little jittery (in roll, pitch and surge), but it is unclear if this is a function of poorly tuned controllers for the extended vehicle length or a function of operating at a shallow depth (15m) with a 1m swell. Suspicion is the later but need data from a deeper mission to confirm. Straight line navigation error post calibration missions was 40m on a 2km run (2% of distance travelled). This is at the high end of acceptable but given fluctuations in speed over ground measurements this is not unexpected. Given ALR5 will mostly be operating without bottom lock this is less critical. RoCSI sampled as planned in the missions using the new commands in the mission script functionality. Initial analysis suggests TA/DIC LoC performed as expected, one nutrient LoC worked as expected the other needs to be swapped out.

2.7. Sunday (12/3/24)

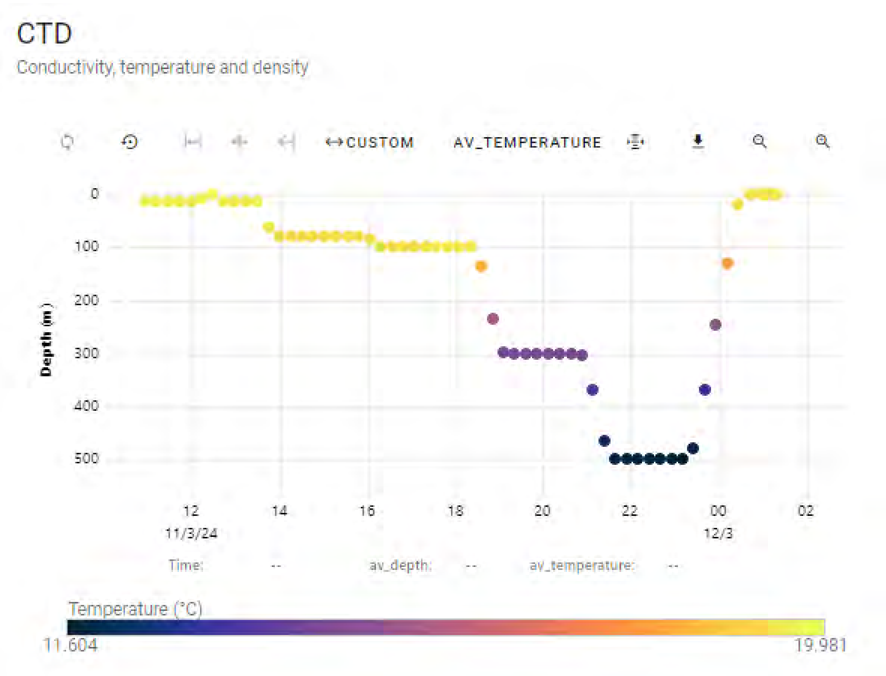
Weather conditions on site a little rougher than Saturday - team went to review conditions in the support vessel, large 2m swell and force 4 so launch of ALR5 postponed till Monday first thing.

- Fuller review of data from ALR5+Sensors.
- mSTAF in-rush current incompatible with ALR5 12v supply. Dummy system fitted to ALR5.
- Swapped one of the LoC nutrient sensors.
- Harbour test on crane of ALR3/BioCam and associated NRT data features. BioCam mapping worked as expected but poor iridium in harbour meant it was not possible to demonstrate the NRT data flow - work ongoing to show this in the lab/quayside.
- Reconnaissance of work area to the south of PLOCAN in support vessel - co-ordinates of several fish farms collected and mission plans adapted to provide a greater clearance between AUV ops and these hazards.
- ALR5 and sensors prepped ready for deployment on Monday.

2.8. Monday (11/3/24)

Weather conditions on site good, 0.75m waves with some larger swell, wind force 2-3.

- Launched ALR5 for 24 hour deployment heading east into deep water assuming.
    - ALR5M106 (Head east - staircases with loiters and ROCSI samples at the start of each step)
    - ALR5 surfaced 10km south of the target waypoint – not unexpected as operating outside bottom lock and there is a strong southerly current.
    - LOC sensors reporting back data over Iridium (data being reviewed)
    - Co-sampling by OTE at intermediate surfacing point

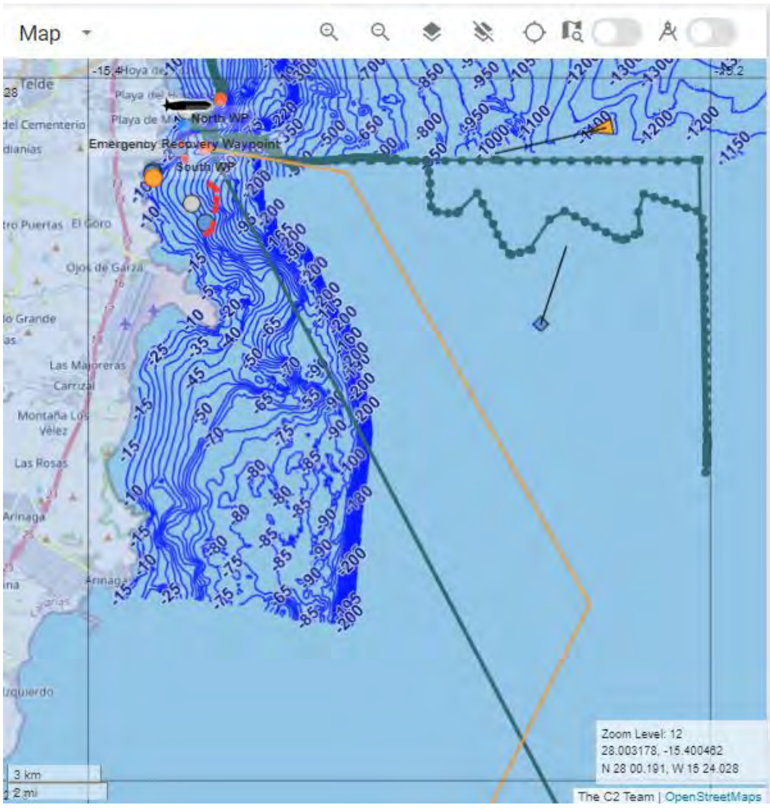


- Confirmed NRT functioning as expected for ALR3/BioCam data
- Cytochip harbour test

2.9. Tuesday (12/3/24)

- ALR5 PLOCAN Deployment 2 (Sensor Test Run1 Continued):

- ALR5M107:ST1a Sensor Tests Inbound Profiles sent at circa 0130 to start bringing ALR back in towards PLOCAN - initial phase profiling then constant depth at 30m. Due to southerly current AUV tracked to the south of intended track but slowly converged to the track line by increasing the number of surfaces. LOC turned on for initial dive but off for later dives due to mission plan length constraints.
- Mission terminated approximately 5km offshore to swap to a more conservative approach into PLOCAN.
- ALR5M108: 2 hour Surface Loiter at Tanker WP
- ALR5M109: ST1b Tanker WP towards recovery 45min timeout
- ALR5M1010: ST1c Final leg to recovery 45min timeout
- AUV surfaced within 200m of intended waypoint and recovered and back at PLOCAN 1545



- LoC and RoCSi data analysis
  - 5 samples taken as planned for RoCSI
  - TA/DIC looking ok some niggles to work through.
  - Nitrate Phosphate LoC looking good – need to look at the polling speed between the ALR and the hub to ensure all measurements captured
  - Silicate Phosphate some niggles to work through on the sensor side
- Prepared ALR3 for calibration runs tomorrow.

- More cytochip work in the harbour – longest test yet.
- Prepare ALR3 for calibration work first thing Wednesday.

This was the first long mission with ALR intended to operate outside of bottom lock so it has been a bit of a learning exercise of how to best pilot. For future deployments of this nature, we will probably look to surface circa every 4 hours to minimise the surfacing error. The approach for coming back to shore without bottom lock where navigational error provides the biggest risk (collision with headland, fish farms etc) worked well, surfacing regularly (1hr) as we came within 10km towards shore. Then loitering at a safe waypoint a couple of km of shore then making short 30m dive in to bottom lock and the recovery location.

2.10. Wednesday 13/3/24

Conditions calm with force 1 breeze and very small waves, plus very sunny.

- Reviewing data from ALR5/RoCSi/LoC/UVP6 24hr deployment underway
    - Niggles with TA/DIC worked through.
    - Good progress with nutrient sensors.
- On ALR5 changed the Wetlabs ECO-FLCDRTD CDOM Sensor for a Wetlabs ECO-FLNTURTD Chlorophyll/Turbidity Sensor
- AL3/BioCam commissioning missions (compass cal, compass alignment)
    - ALR deployed at 1015
    - Towed to Northern Waypoint
    - ALR3M127:C01 Surface Run
    - ALR3M128:C01a 10 min Test dive (15m)
    - ALR3M129: C02 Compass Calibration - AUV appeared to be loitering at depth at the end of mission rather than loitering on the surface - Mission ended, AUV surfaced unpowered with a reported depth of circa -4.5m. Issue suspected with CTD unit so AUV recovered for further investigation.
    - Further investigation of the AUV log shows a drift on the depth (pressure) read by the CTD of circa 10 m/hr when on the surface- unit swapped for the spare (NOCALR-1310)
- CytoChip testing in the dock continued good progress made.
- Science planning for ALR5 southern mission.

Other than the issue with the pressure sensor on ALR3 everything else seems nominal on the vehicle, so hopeful for good progress.

2.11. Thursday 14/3/24:

- ALR3/BioCam Deployment 2

- ALR3M130:C01a 10 min Test dive (15m)
- ALR3M131:C03a BioCam Alignment + FLS On
- ALR3M132:S0a BioCam Survey (10m alt) + FLS On
- ALR altitude control looks good at 10m altitude, NRT pipeline worked as planned, SBD with low-res images (see attached) and summary statistics sent successfully, visibility very good even at 10m, we were not expecting to see anything in the NRT data.

- Rebuilt software on ALR5 (includes fix to conductivity NRT pipeline)

- Had confirmation from Marc that UVP6 is collecting data on ALR5
- Confirmed Wetlabs ECO-FLNTURTD Chlorophyll/Turbidity Sensor on ALR5 is providing NRT Data
- Finalized preparation of ALR5+sensors for southern mission.
- Cytochip team working in lab today.

2.12. Friday (15/3/24):

- ALR5 was launched from the harbour at about 1100 for the southern mission.
  - On arriving at the southern waypoint the AUV was reporting a negative conductivity by the CTD sensor (NOCALR-1314).
  - A short 10m 10min test dive (ALR3M111) was completed which cleared the fault - suspect bubble in the CTD tubing
  - The Eco-Puck/UVP6 were turned on and LoCs on standby.
  - At 13:10 ALR5M112: T0a Transit South Profiling was sent. AUV observed diving and boat crew returned to the harbour
  - At 14:45 the AUV sent and Iridium message (SBD 9572) stating the AUV was stationary on the surface in a Safety Stop condition a contingency behaviour that is triggered by a number of unusual events: under minimum altitude, stuck trying to descend etc. AUV was reporting being only a short distance from the initial dive location (NOCALR-1313)
  - A resume command was sent over Iridium to clear the contingency behaviour and get the AUV back into its idle state (sat on the surface waiting for new instructions). No persistent fault was present.
  - Whilst waiting to receive the mission logs the AUV was tasked with holding station on the surface which demonstrated the thruster was functioning.
  - Initial analysis of the decimated mission log sent over iridium identified odd surfacing behaviour and suspicion of AUV being tangled in a ghost line, but data was inconclusive.
  - A short dive to 30m was undertaken (ALR5M113) which confirmed the AUV was operating correctly in the vertical plane, while waiting for the support boat

to be available to recover the AUV to access the full data set and check for damage.
   - Analysis of full data set indicates the AUV was caught by something leading to a rapid de-acceleration, increase in roll and inability to control speed, depth and heading. The combination of these behaviours is very difficult to explain through anything but external factors - such as getting caught on a line.
   - Co-sampling by OTE at start locations.
- Preparation of ALR3/BioCam

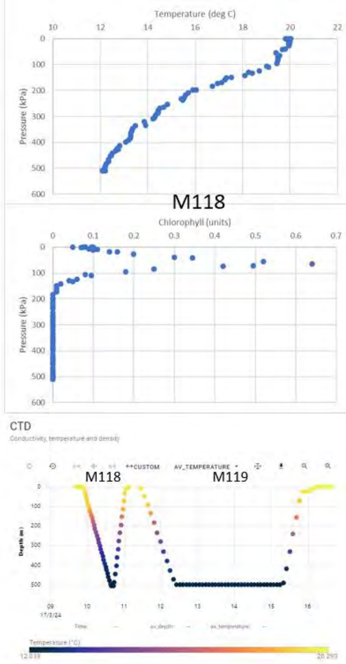
2.13. Saturday 16/03/24:

Yesterday was likely to be the last day we can operate from PLOCAN, weather conditions look unfavourable into next week. We also had the added complication that access to the harbour was restricted between 0800 and 1600 so the MARS team got both ALRs down to the harbour for 0745.

- ALR3 with BioCam was deployed first: and towed to the North Waypoint
   - ALR3M133:C01a 10 min Test dive (15m)
   - ALR3M134:S1 BioCam Survey (5m alt) + FLS On - Mission planning error meant the command to start mapping with BioCam was not sent so no images were captured so near real time data was sent back
   - ALR3M135:S1 BioCam Survey (5m alt) + BioCam On FLS On sent - this follows the same initial trajectory but cuts out the last two survey lines - unfortunately due to time constraints unable to redo the whole survey - images captured on survey but NRT pipeline has some gremlins that are being explored.
- ALR5 was deployed (once ALR3 was underway) and towed to the South waypoint. Once a flotilla of yachts had cleared the work area the AUV was released and sent on its transect to the South of the Island, see annotated figure below. Note: Transit missions modified to try and avoid point of suspected entrapment yesterday.

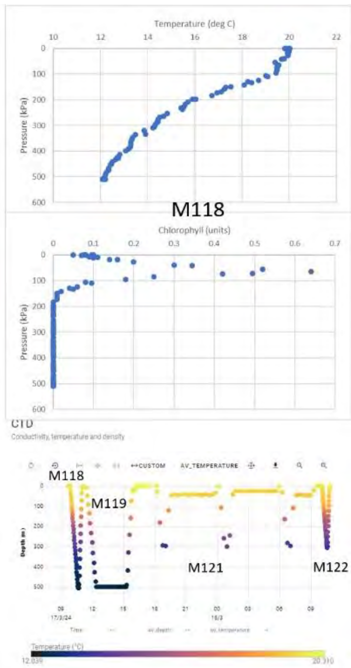
2.14. Sunday 17/03/24:

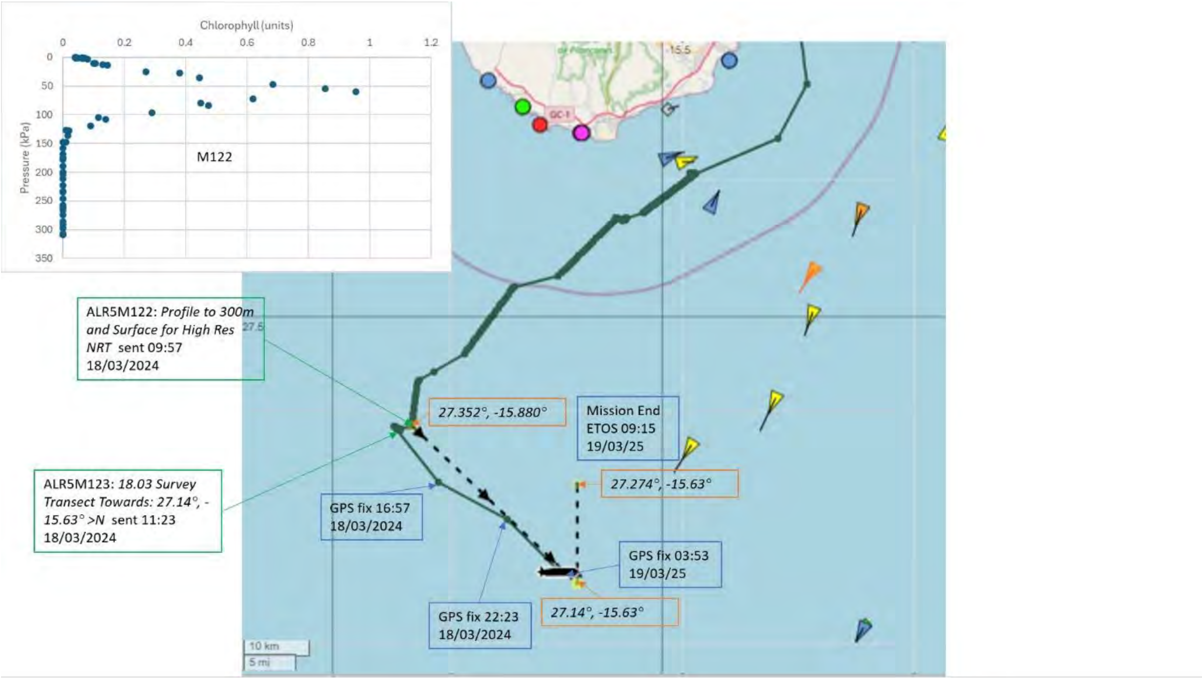
ALR5 continued its Southern Deployment, see below:



2.15. Monday 18/03/2024:

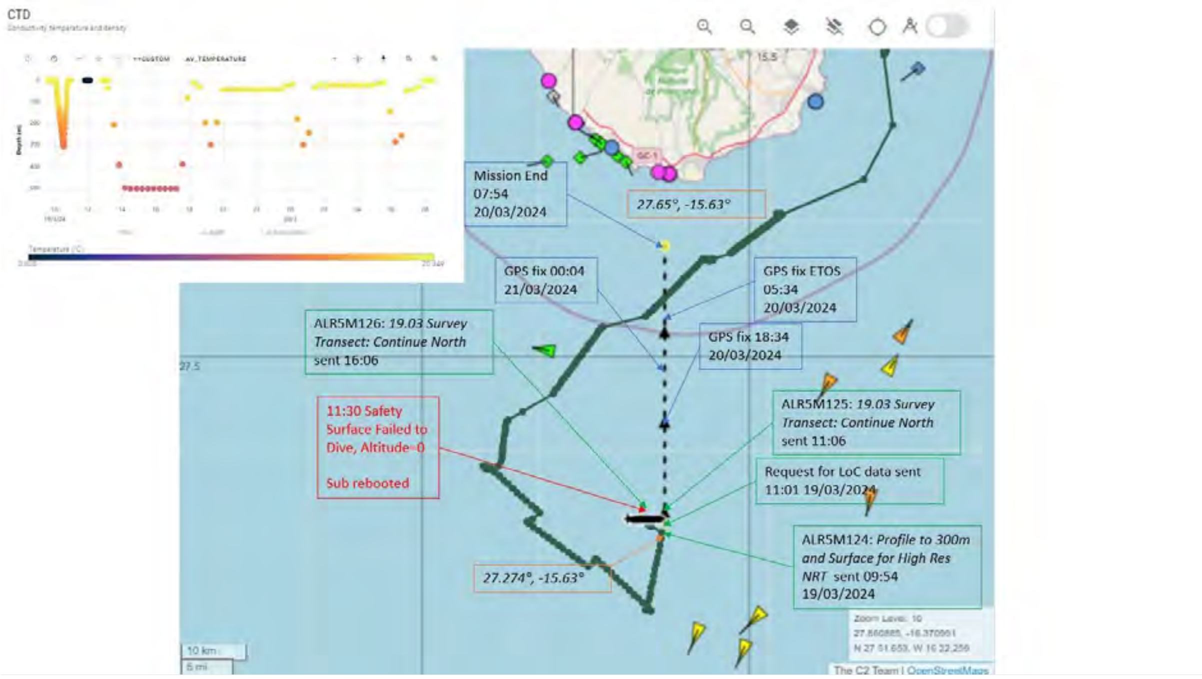
ALR5 is continuing its southern deployment, it surfaced for a GPS fix at the southerly waypoint at roughly 4 am this morning.





2.16. Tuesday 19/03/24:

- ALR5 continued to transit North throughout the day surfacing approximately 10km South of the island at 07:54 this morning.



- ALR5 was requested to send back NRT data from the LoCs going back to the start of the deployment. Data was received as it being reviewed by the sensor teams.

- ALR team visited Puerto Rico harbour to finalise planning for recovery.
- Work underway to review and process the BioCam imagery taken with ALR3. Below are a couple of example images taken at approximately 5m altitude on Saturday afternoon.

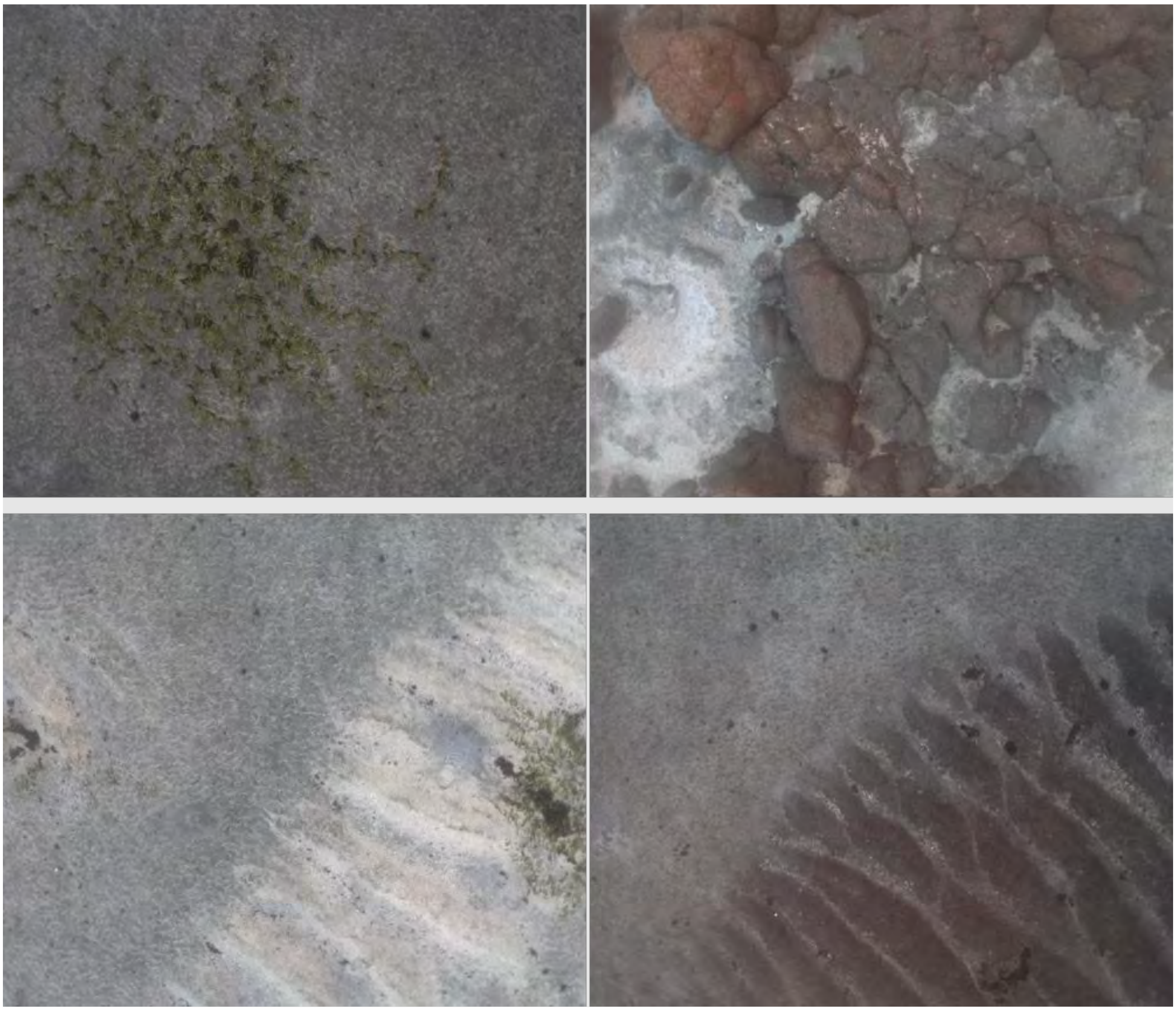
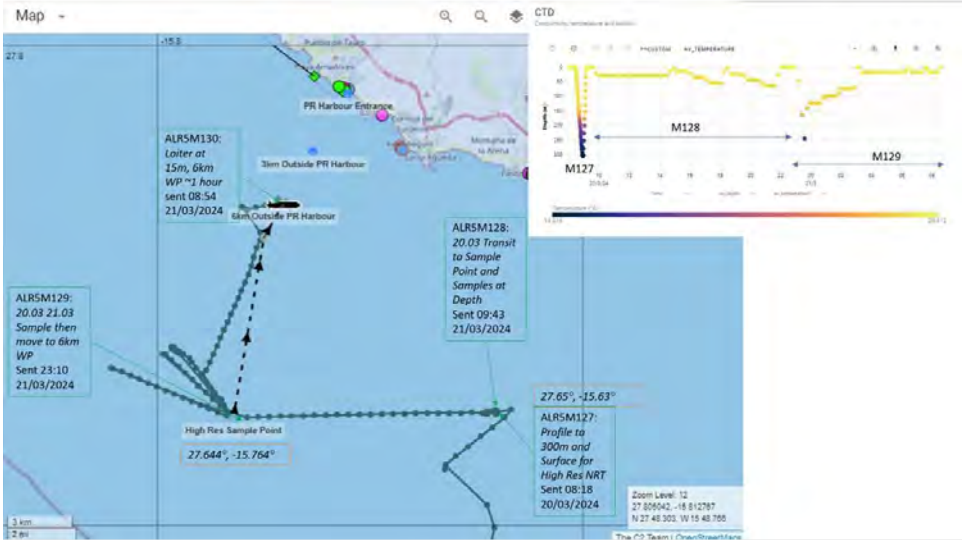


Figure 2.16: Examples of post-processed full resolution images showing volcanic rock, sand ripples, transition between hard substrate and sand, and probably sea grass acquired from 5m altitude.

2.17. Wednesday 20/3/2024:

ALR5 continued its Southern deployment, spending most of the day at the High Res Sample Point taking RoCSi and LOC measurements at a range of depths in the mixed layer.



2.18. Thursday 21/03/2024:

ALR5 was bought close to shore, where it rendezvoused with the rib and was put on tow at 11:30. Team recovered it to Puerto Rico and then transported it back to the PLOCAN site to downloaded data, removed samples and washed the sub down.

3. PLOCAN Facilities

PLOCAN gave us access to laboratories, workshops, offices and parking areas for the containers (see images below).

Figure 3.1. Onshore facilities.

We also had access to Taliarte harbour and PLOCAN's pontoon (see images below).

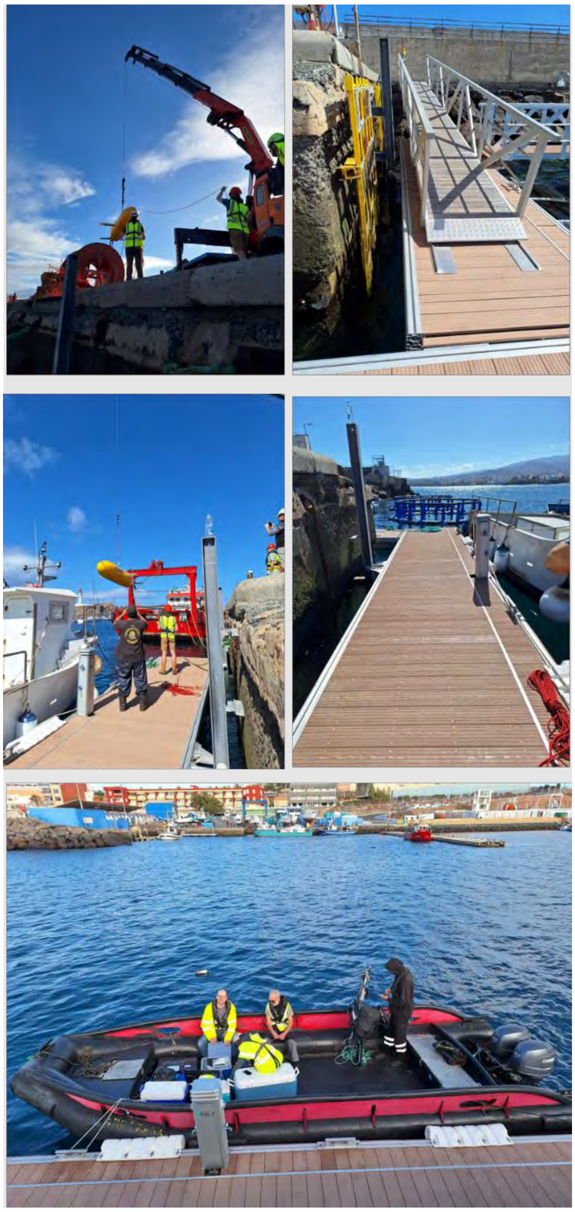


Figure 3.2. Work at Taliarte harbour.

4. TechOceanS Sensor Technologies

The list of sensors are samplers can be found in the following table.

Table 4.1. Technology metadata.

Sensor	*S/N*	*Platform*	*Comments*
RoCSI	*4*	*ALR5*	
TADIC	*6*	*ALR5*	
TADIC	*8*	*PLOCAN Lab*	
Dual Nut NP	*3*	*ALR5*	

Dual Nut SiP	*3*	*ALR5*	
Dual Nut NP	*1*	*PLOCAN Lab*	
Dual Nut SiP	*4*	*PLOCAN Lab*	
Cytochip	*1*	*PLOCAN Lab/ Taliarte Pontoon*	*With Pump S/N 1*
Cytochip	*2*	*PLOCAN Lab*	*With Pump S/N 4*
Underwater Vision Profiler 6 (UVP6)	*000218lp*	*ALR5*	
LabSTAF	*N/A*	*PLOCAN Lab*	
mSTAF	*N/A*	*ALR5*	*Dummy*
Oceanids Sensor Hub A7055	*16*	*ALR5*	
BioCam	*BioCam4k_15C*	*ALR3*	*Include strobe and laser*
BioCam	*BioCam4k_5C*	*PLOCAN Lab (spare)*	*Include strobe and laser*

4.1. mSTAF

The lead up to the trial

A number of factors had led to significant delays in the construction of the first batch of MicroSTAF units. The end result was that meaningful testing didn't start until early February. Pressure testing of two MicroSTAF systems (main units plus SPAR sensors) was performed at Sonardyne on 20/02/2024. One of these systems were allocated to ALR5.

Figure below provides an overview of the firmware and software package for MicroSTAF, as outlined within the design specification. At the start of the PLOCAN trial, the FPGA and SetSTAF elements were still going through testing. The MicroSTAF version of RunSTAF (hereafter RunMSTAF) had largely been developed without access to a complete set of MicroSTAF electronics and was going through a phase of integration with the embedded SetSTAF code. The OpSTAF element provides a pass through to the SetSTAF functions, to allow RunMSTAF to set all FPGA functions. During the tests, it also allowed the pump to be turned on and off and the humidity and pressure sensors to be read.

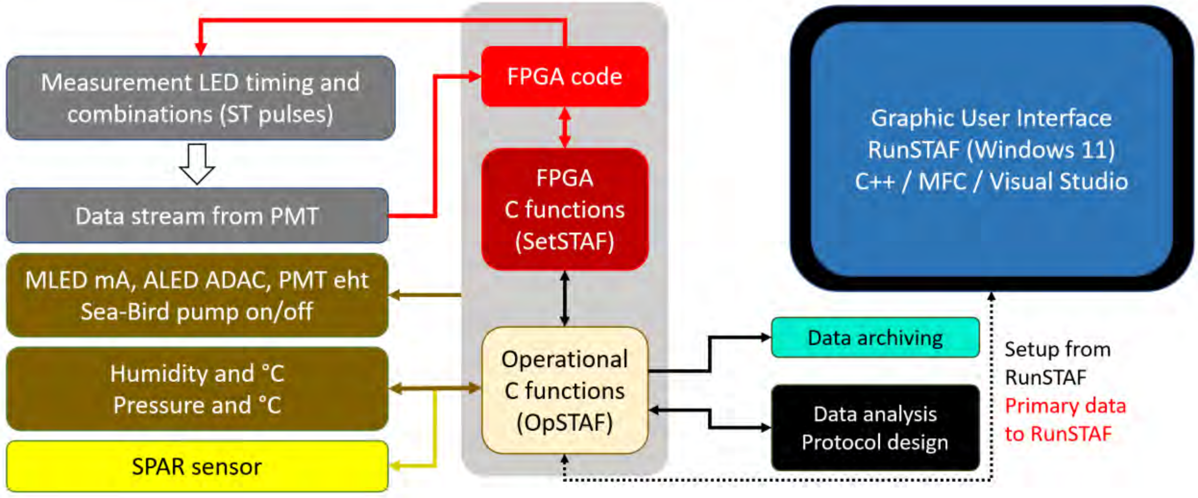


Figure 4.1.1: Overview of the firmware and software package for MicroSTAF

A fourth MicroSTAF unit was constructed without the pressure housing, to allow for continued development of the FPGA and SetSTAF code. This unit remained in the UK. A fifth complete MicroSTAF system was also put together for software development by KO during the PLOCAN test.

A LabSTAF unit fitted with the same measurement LEDs as the MicroSTAF units was shipped to PLOCAN to provide a reference.

During testing at PLOCAN, three technical issues with MicroSTAF were identified.

1. Significant filter breakthrough
2. A small but consistent artefact during the first two microseconds of each ST pulse
3. A high inrush current requirement

These three issues are covered within Section 4 of this document.

Deployment of MicroSTAF

Mechanical integration of MicroSTAF within ALR5 was straightforward and allow for simple exchange of the unit used for ballasting at NOCS before shipping to PLOCAN and the working unit shipped separately to PLOCAN during the first week of March. At the time, the MicroSTAF unit required 1.6 A at 12 V to get over the inrush phase, before dropping to between 160 and 200 mA at 12 V. The ALR5 could only provide 1 A at 12 V and, as a result, could not power up the MicroSTAF unit. After working through the limited options, it was decided to reinstall the original non-working unit that had been used for ballasting.

Figure 4.1.2: View of the MicroSTAF integrated in the ALR.

Data collected during the PLOCAN trial

The LabSTAF unit was used to run Fluorescence Light Curves (FLCs) on samples collected from offshore and the harbour. Most of the measurements were from Julie Robidart's samples. Additional measurements were made on samples collected from the harbour, next to the flow cytometer setup.

Samples were run on the 10th, 11th, 12th, 13th and 15th March. Photochemical Excitation Profiles (PEPs) were run on all samples. This step is required for spectral correction and also provides qualitative information on phytoplankton community structure.

LabSTAF and MicroSTAF include automated PEP protocols that are optimised for phytoplankton groups that include chlorophyll *b* or *c* within the PSII light harvesting system (PEP-bc) or cyanobacteria (PEP-cy). All samples were interrogated using a 'standard' combination of PEP-bc and FLC. However, the expectation was that the samples collected would include significant levels of *Synechococcus* sp. With that in mind, a PEP-cy was run on all samples between the 12th and 15th March, in addition to the standard combination of PEP-bc and FLC.

Figure below shows an example of the difference between PEP-bc and PEP-cy from the same sample. The ALED flat white coefficient has a proportional impact on the calculation of PSII photochemical flux (J_{PII} and JV_{PII}). In this example, the difference is around 12% (higher for the PEP-bc). This is at the high end of the difference observed across all samples. Figure below shows the FLC generated with the PEP-bc.

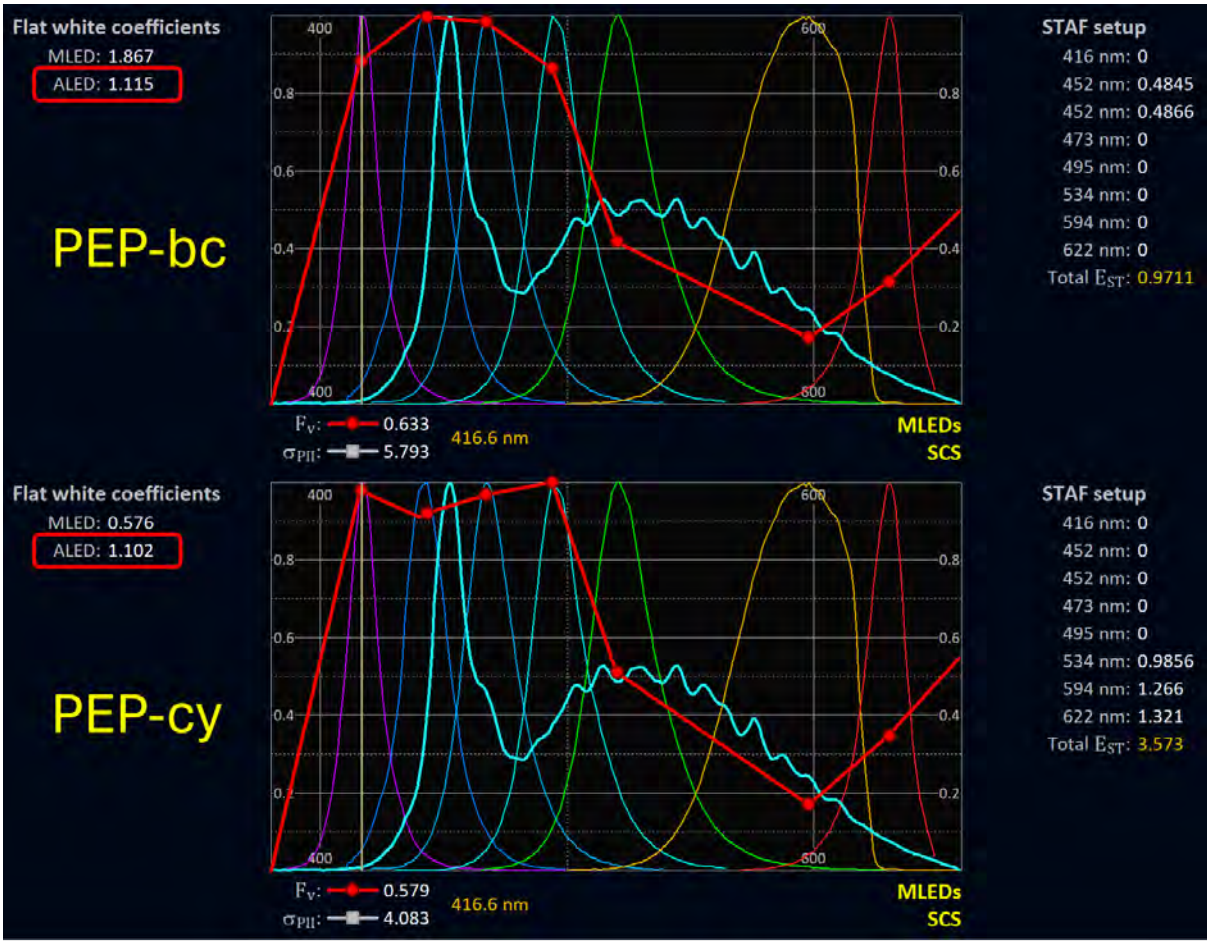


Figure 4.1.3: Comparison of PEP-bc and PEP-cy from a sample collected from 15 m depth at Site 1 (site defined by Julie Robidart) on 12th March 2024.

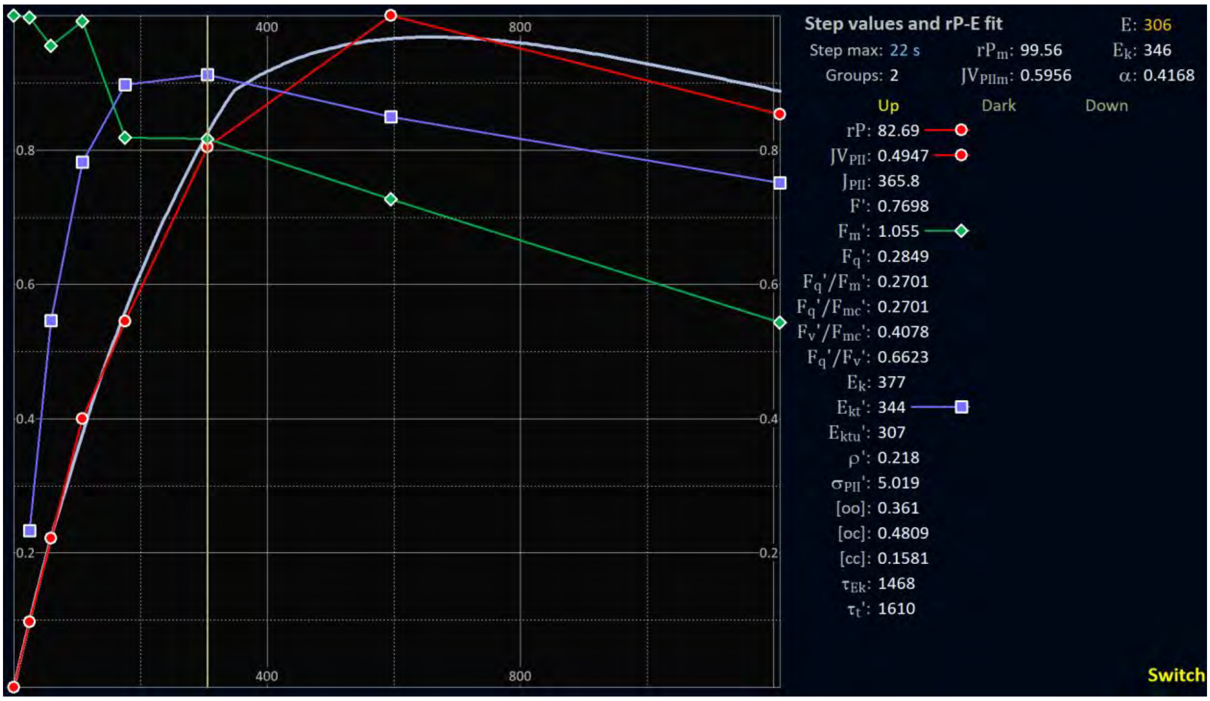


Figure 4.1.4: FLC generated by sample collected from 15 m depth at Site 1 (site defined by Julie

Robidart) on 12th March 2024. The MLEDs were as set for PEP-bc in Figure 5.1 (both 452 nm channels).

4.2. RoCSI

The Robotic Cartridge Sampling Instrument (RoCSI) is an environmental DNA and RNA autosampler. It filters particles >0.2 um from the environment and preserves them for later in-lab molecular biological analyses, to learn about marine life using environmental DNA and microbiology tools. For this fieldwork, we deployed RoCSI with in situ biogeochemical sensors to understand the activities of photosynthesising and other biogeochemically-important microbes, in relation to environmental change.

Understanding the links between microbial biogeochemistry and ocean physics decreases uncertainty in projected changes associated with warming and acidifying oceans. This was the first time that the RoCSI was deployed with lab-on-a-chip wet chemical sensors, which will deliver high resolution datasets on these links, at adequate scales to understand the microbial functional responses to physics and associated nutrient provision and carbonate system change.

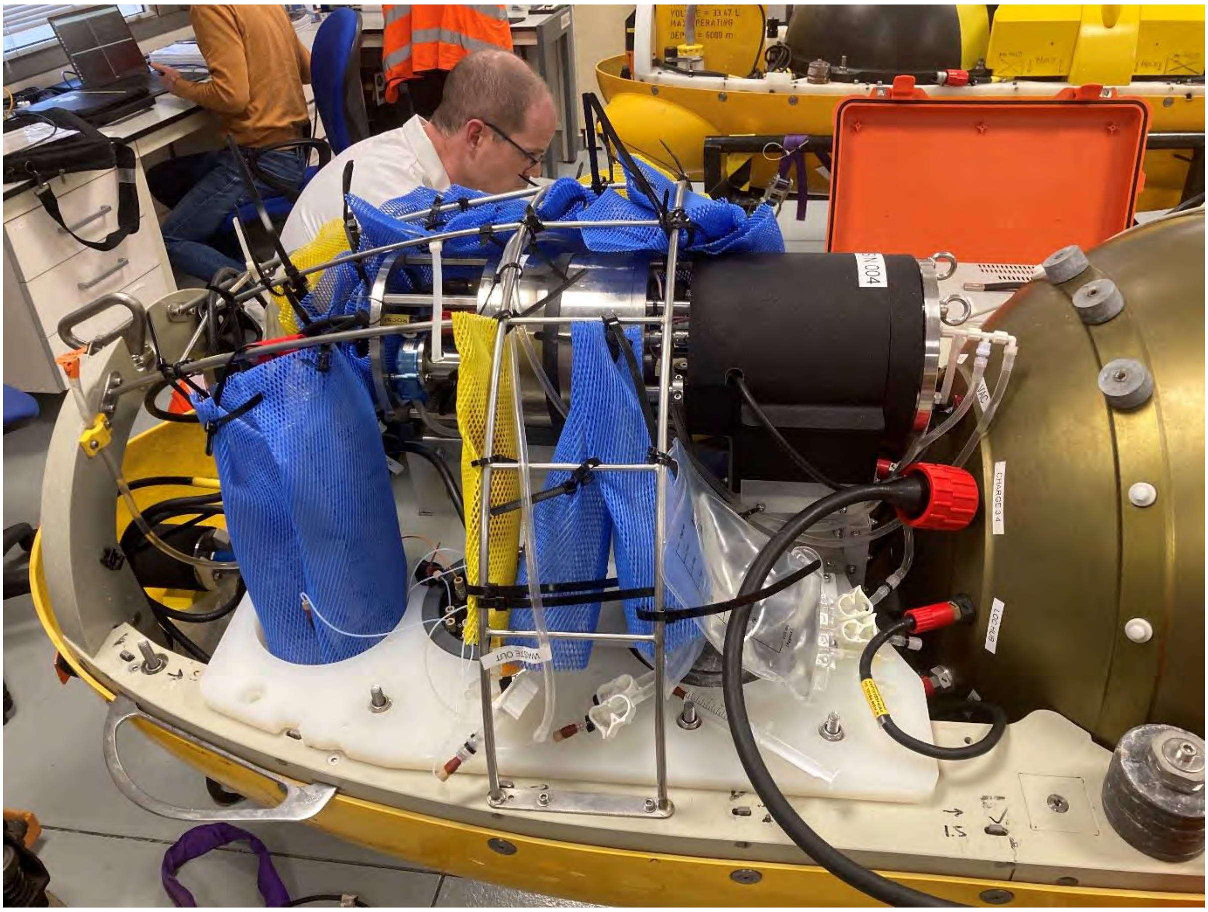


Figure 4.2.1: RoCSI (the metal cylinder with a black protective case over the sample reel) integrated into the ALR 5.

The RoCSI successfully collected samples during the ALR 5 Compass Calibration run, the Sensors Test run and the mission to the south of Gran Canaria. It captured 10 samples in total, ranging from 15m to 500m depth, for microbial RNA analyses. The sampler had a fault in the last transit to the south, and it stopped after sampling twice. After discussions with the NOC engineers leading the development, we think that water got into the Hall Effect sensor. As a result, the sensors are not reading their positions properly, and failing to move the flow nozzles to the 'engaged' and 'disengaged' positions, even after reconfiguration. In addition, on recovery of RoCSI, the cartridge in the stabilizer position was misaligned with the outflow nozzle, which would have prevented sample preservation and downstream operations. This might have been due to an error in construction of the filter cartridges. After recovery, we measured the 46 cartridges and found 3 that were slightly too long, which can be problematic with engaging the nozzles before flowing seawater or stabilizer. We aren't yet sure if these errors were related but we don't think they were. We have updated the pre-deployment checklist to prevent this from happening again.

Future plans are to sequence the RNA from the microbial community from the RoCSI samples and interpret these in relation to the nutrient concentrations from the same environments. We additionally took a variety of 'paired' (RoCSI + traditional benchtop) samples in order to evaluate RoCSI's performance relative to gold standard microbial ecological techniques, which has not been done for mRNA yet. Within 12 months of sequencing, data will be uploaded to an open nucleic acid data repository such as the European Nucleotide Archive (ENA).

4.3. Lab on Chip

4.3.1. TA/DIC

Introduction

The ocean is becoming increasingly acidic due to the dissolution of CO2 which has resulted in an average pH drop of 0.1 pH unit. Investigation of the carbonate system in marine waters requires knowledge of at least two out of the four measurable parameters $_pCO_2$, pH, TA and DIC.

In order to measure 2 of these properties, Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC), we have combined two of our existing technologies, developed at OTE, and combined them into a single sensor, known as the TADIC.

This will be its first test in the field in order to (a) measure its mechanical and electronic robustness and (b) to be able to measure the precision and accuracy of the sensor when compared to the bottled samples.

Description of the Sensor

The sensor is based on microfluidic Lab on a Chip technology and combines an optical and a conductivity detector so that TA and DIC can be measured simultaneously. Fluids are pumped through the microfluidic channels via individually addressable pumps and controlled by miniature solenoid valves. A gas permeable membrane (tube in a tube system) where the TA sample is acidified pH3.5 with a solution of acid and a pH sensitive indicator dye. This generates gaseous CO_2 which is removed across a gas-permeable membrane made of Teflon AF2400 tubing. The solution's pH is determined optically via the dye. The sample TA is calculated from the pH. The DIC sample is acidified which generates gaseous CO_2 , which is collected in a solution of 7mM NaOH across a gas permeable membrane made of Teflon AF2400 tubing. The changes in the conductivity of the NaOH as a result of the absorption of the CO_2 is measured via a four electrode glass conductivity detector.

Deployment of TADIC sensor at PLOCAN

The TADIC sensor was fitted to ALR 5 and tested pre-deployment in the PLOCAN workshop to check its functionality and operation.

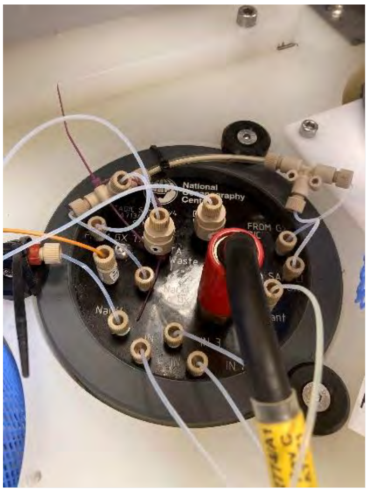


Figure 4.3.1 The TADIC dual parameter sensor

Day 6 to Day 9 we took bottled TADIC seawater samples in the ALR5 work areas.

On Day 6 the ALR was towed out for the compass calibration and Day 8 the ALR was launched on its 24 hour mission heading East into deep water. Data was recorded on the TADIC sensor for both of these runs but the TA data was of poor quality due to a faulty check valve preventing the dye entering the optical cell. This was replaced with a new check valve and the sensor was tested again in the PLOCAN workshop. The data showed a change in the optical output when the dye was injected confirming that the check valve was working properly again. The tube in tube was also checked to make sure it was functioning properly.

Preparations were made for the Southern Mission making sure there were enough reagents to cover continuous sampling from the TADIC sensor over several days.

On Day 12 the ALR 5 was deployed on its Southern Mission. TADIC seawater sample bottles were also collected at the same time as the deployment.

On Day 16 we received live TA data from ALR 5 that showed that it was operating correctly.

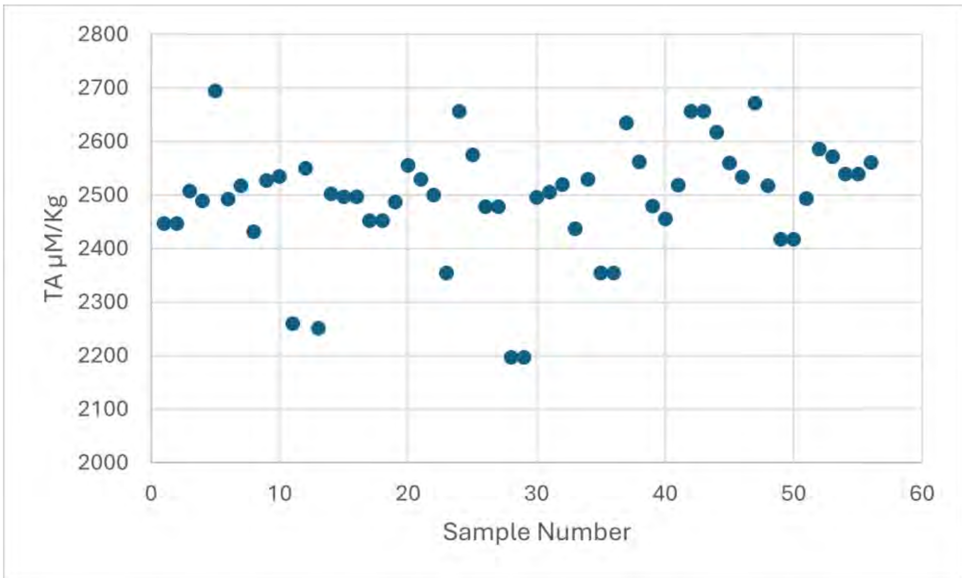


Figure 4.3.2 Graph showing live TA data recorded on the ALR during its Southern Mission

On Day 17 only several short files were recorded. This was apparently due to a hub fault that was rectified in time for Day 18 when several hours of data from the TADIC sensor was successfully recorded.

The ALR was retrieved on Day 18 and bottled seawater samples were also taken at the same time.

On Day 19 the data was downloaded and both DIC and TA data had been successfully recorded. This data has not been analysed yet or compared to the bottled samples taken at the beginning and end of the ALR 5 mission.

4.3.2. Dual nutrient sensors

Introduction

Dissolved macronutrients (which includes dissolved nitrate, phosphate and silica, among other species) are among the most fundamental water column parameters for natural waters and are routinely monitored in a number of different contexts, including oceanography, water quality and fisheries management.

In recent years, the NOC has been developing in-situ chemical analysers to measure these parameters to eliminate the need to collect water samples and analyse them in a laboratory. For this project, TechOceanS, NOC has developed technology to combine the measurement of 2 separate analytes in a single, integrated device. We have produced two prototypes to demonstrate the new technology: one that combines measurements of nitrate and phosphate (N/P), and another measuring both phosphate and dissolved silica (Si/P).

This will be its first test in the field in order to (a) measure its mechanical and electronic robustness and (b) to be able to measure the precision and accuracy of the sensor when compared to the bottled samples.

Description of the Sensor

The sensor is based on microfluidic Lab on a Chip technology and features a shared optical cell that can operate at two distinct wavelengths (optimised for each assay). Fluids are pumped through the microfluidic channels via individually addressable pumps and controlled by miniature solenoid valves. The system is based on the classic spectrophotometric methods, whereby the analyte of interest is reacted with chemical reagents to produce a coloured product, of which the absorbance is measured to determine the concentration of the analyte originally present in the sample.

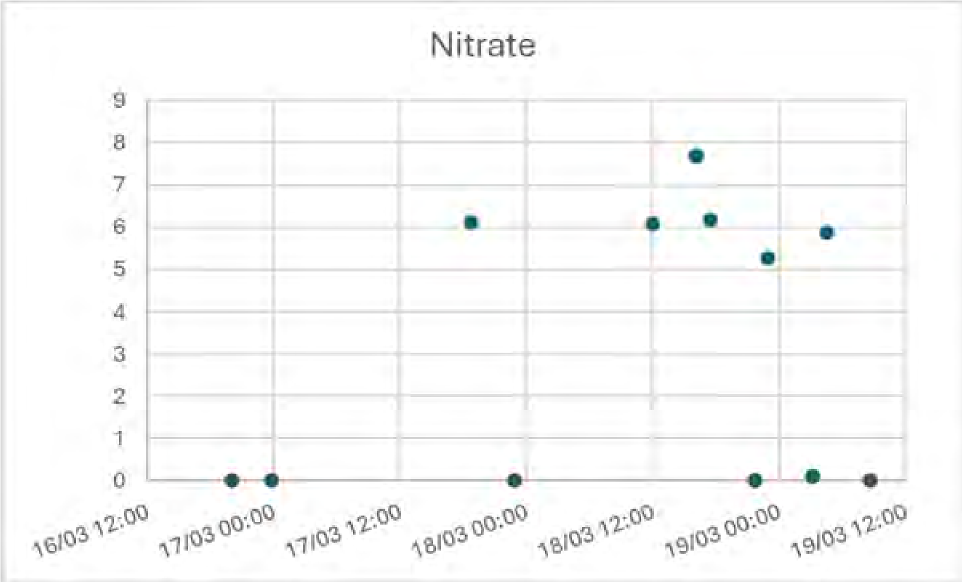
Deployment of dual nutrient sensors at PLOCAN

Two dual nutrient sensors (N/P and Si/P) were fitted to ALR 5 and tested pre-deployment in the PLOCAN workshop to check their functionality and operation.

The ALR was deployed with the sensors operating on three separate occasions: a short deployment on 9th March for compass alignment; an overnight deployment from 11th to 12th March; then a final long-distance deployment from 16th to 21st March. Post processing of the data generated has not yet been completed, so detailed knowledge of the number and quality of measurements is currently unclear.

During the first deployment limited data was obtained due to the short length of operation and the slow nature of the sensor (which requires around 1 hour of continuous operation to make a single measurement of both parameters). Some technical difficulties were encountered with the sensors, particularly the Si/P sensor, so data may not be available for all parameters during all of the deployments.

Error! Reference source not found.4.3.3 shows some preliminary data obtained during one o f the dives during the third (extended deployment) for the N/P sensor.



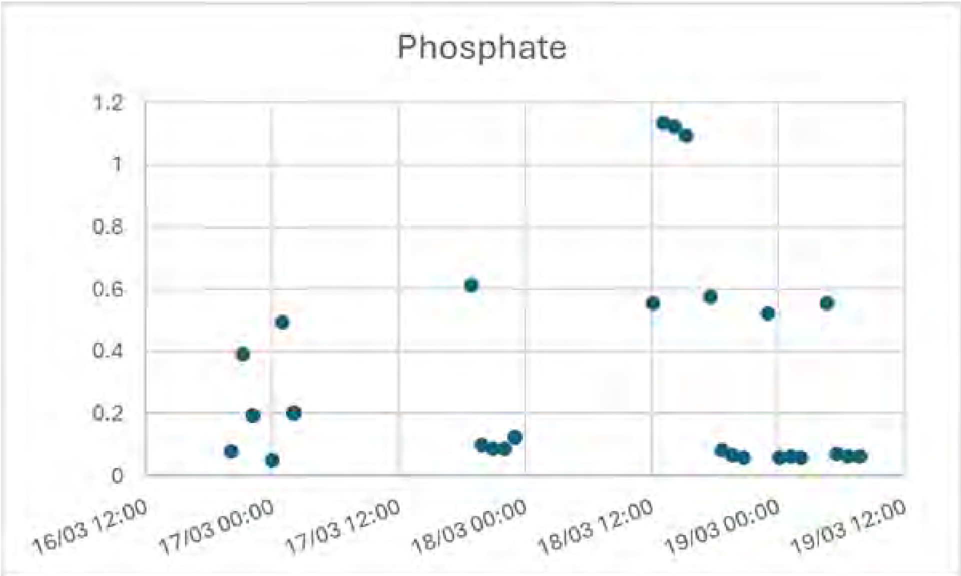


Figure 4.3.3: Examples of nitrate and phosphate data generated during extended ALR deployment. The vertical axis gives the concentration of the nutrient as reported by the sensor (in micromol / L)

4.4. Cytochip

4.4.1. Introduction and aim

The deployable cytometer also known as cytochip is a flow cytometer which can be fully submerged and autonomously to characterise the phytoplankton and microplastics content of seawater. Assessing phytoplankton numbers and type is important for understanding of ecosystem dynamics as phytoplankton form the base level of the food web. Microplastics levels are also of concern in due to their unknown effects on the ecosystem and human health. The technology uses a microfluidic chip which uses impedance measurements for particle size and fluorescence measurements to quantify chlorophyll and phycoerithrin. The cytometry modules tested on this deployment are submersible up to 4m depth and are powered by a 12V battery. The aim of this deployment for the cytometer was to test the prototype cytometer immersed over the side of a pontoon over a period of days to assess reliability, produce optimised sampling protocols and compare the cytometry results to a lab-based cytometer.

4.4.2. Deployment timeline

- Monday 4th March: Assembly of cytometry modules 1 and 2 and preparation of reagents in the lab.
- Tuesday 5th March Lab based assembly of cytometry modules and programming of autonomous sampling routines on module 1. Programming of data analysis.
- Wednesday 6th March Lab calibrations on module 1 using calibration beads. Optimisation of device gain settings and signal processing based on calibration data.
- Thursday 7th March Lab based programming and testing of autonomous sampling routines using module 1. Working on stalling problems with autonomous sampling from module 1 Calibration of module 2.
- Friday 8th March. 50 ml water sampled from Taliarte docks and analysed on cytometry module 1 and BD flowflex Assembly and calibration of module 2. Trouble shooting of low signal on module 2 inconclusive

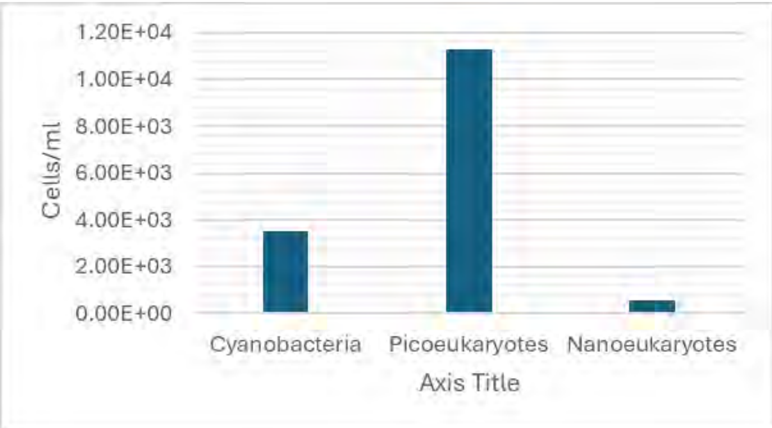


Figure 4.4.1: Phytoplankton concentrations from Taliarte dock water measured on BD flowflex cytometer on 8th March 2024.

- Saturday 9th March: Lab based finalising autonomous sampling routines on module 1. Final preparations of module 1 for submerged deployment. 50ml of seawater sampled from Taliarte docks and tested on module 1 to set detector gain.
- Monday 11th March. Cytometer module 1 deployed submersed at 30 cm depth from the side of the PLOCAN pontoon in Taliarte docks. Deployed for 2 hours submerged running two sample cycles analysing 1.2 ml of water with 2x two-minute acquisitions.

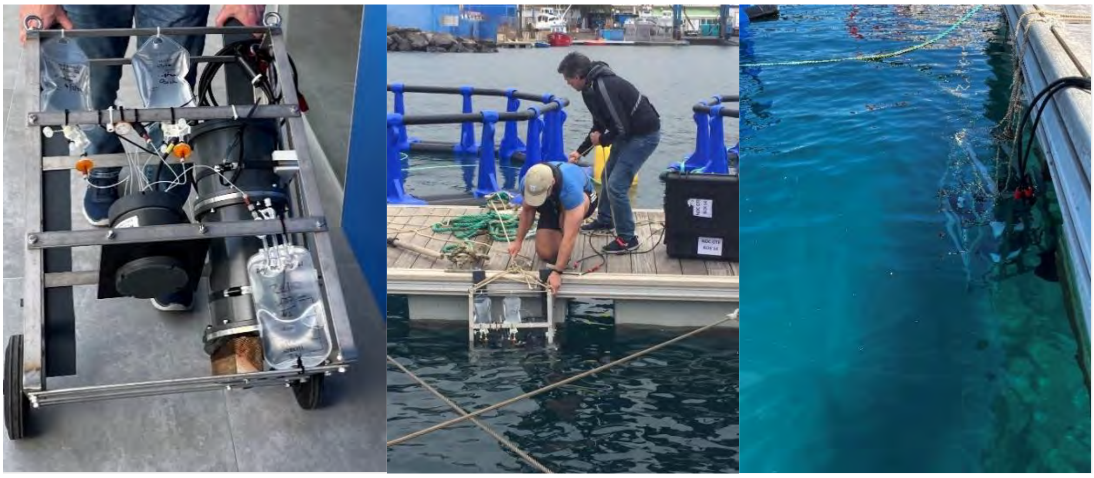


Figure 4.4.2: (Left) Cytometer module 1 on frame ready for deployment. (Middle) Lowering cytometer into dockside water. (Right) Deployed cytometer sampling autonomously powered by shore based battery.

- Tuesday 12th March: Cytometer module 1 deployed submerged again in Taliarte docks for three hours. Sampling set for longer acquisition of 10 minutes each however programming error resulted in only 10 seconds of data per sample. Programming fixed. 50ml sample also analysed on the BD flowflex showing similar numbers of phytoplankton groups to the 8th March. Analysis of filtered sample revealed that device 20 um filters were cutting out a significant proportion of 3 um sized particles.
- Wednesday 13th March: Lab based analysis of 50ml sample from docks on Cytometer module 1. Cytometer module 1 deployed submerged in Taliarte docks for 3 hours recording 20 minutes of cytometry data. 50ml sample also analysed on the BD flowflex showing similar numbers of phytoplankton groups to the 8th March. Chlorophyll signal low suggesting the chip in module 1 needed realigning or changing.
- Thursday 14th March: Optical alignment and testing of new chips in the lab. Modification of filters with new 50 um mesh design filter.
- Friday 15th March. Alignment of original chip improved and installed in module 1. Module 1 calibrated and prepared for deployment. Tested 50 ml sample from Taliarte docks in the lab on the cytometer.
- Monday 18th March: Preparation of course training talks.
- Tuesday 19th March: Training talks and lab tours
- Wednesday 20th March: Sampled 50 ml from Taliarte dock and analysed in the cytometer in the lab. Cytometer module 1 deployed in the docks for 3 hours sampling 20 minutes of data autonomously (1.2 ml volume).
- Thursday 21st March: Sampling water from 3 Km offshore Puerto Rico, Gran Canaria. 1 litre taken at 15m and 1 litre taken at approximately 30 m. Water analysed on cytometer module 1 in the lab.

- Friday 22nd March.: Further lab analysis on module 1 in the lab of Puerto Rico water sample. Packing away of modules and equipment for shipment back to Southampton.

4.4.3. Conclusion

The field campaign in Grand Canaria allowed in the field testing of the reliability, ease of use and performance of the cytometer. On the whole the cytometer unit performed automated sampling well with few issues and was able to detect particles within the 2-50 um size range. We identified some key weak points which will require more development. Occasionally the control software would crash the cytometer on successive measurements and required the power to be recycled. The fluidic flow paths require frequent washing and flushing to remain clear, this would also improve the longevity of the pump. The excitation optics require a more rugged alignment method. The chip needs to be positioned in an easier position to allow easy changing. The cytometry module should be mounted on a lighter and more compact frame. A waterproof pressure tolerant battery will allow easier deployment. A smaller and lighter frame will also allow easier deployment and integration with CTD frames.

4.5. BioCam

BioCam is a visual mapping system developed in partnership of the University of Southampton and Sonardyne International Ltd. that generates 3D reconstructions of the seafloor along the trajectory scanned by an AUV. The device consists of a stereo camera and logging unit, two line lasers and two LED strobes. The laser, strobes and cameras are mounted downward looking on the AUV (ALR for this deployment), offering an unobstructed view to the seafloor, as shown in Figure 1.24.A. It should be operated from an altitude above the seafloor of 4 to 10m. BioCam can communicate with the AUV either via Ethernet or serial (RS232) communication. Time is synchronized using NTP if Ethernet is used. Data is extracted via the same Ethernet cable post recovery of the AUV. BioCam can send information about the quality and the type of collected data during the mission that can be forwarded to the operators by the AUV over satellite communication, if the AUV supports that. Table 1.24.A summarises the most important properties of the device.

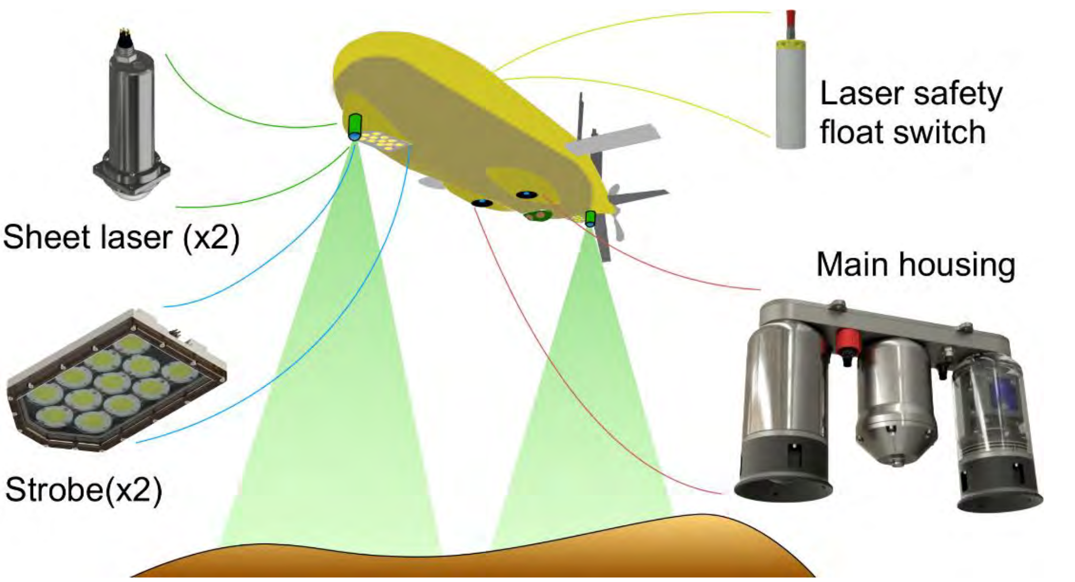


Figure 4.5.1: Illustration of BioCam components mounted on ALR. © A. Bodenmann et al., "High-resolution visual seafloor mapping and classification using long range capable AUV for ship-free benthic surveys," 2023 IEEE Underwater Technology (UT), Tokyo, Japan, 2023, http://doi.org/10.1109/UT49729.2023.10103421

Table: BioCam properties

Mass	35.9kg (in air), 20.2kg (in water)
Depth rating	4000m
Power consumption	48V, 1.2A (typical)
Communication with AUV	Ethernet or RS232
Mapping altitude	4m to 10m
Maximum speed when mapping from 6m alt.	1.5 m/s
Data acquisition rate	30 GB/h
Storage	2 TB (2.5 days of continuous mapping)
Swath, resolution at 6m mapping altitude	Swath: 8.4m, resolution: 3mm
Line lasers	525nm, 1W
Laser safety	Float switch (-> disabled when out of water), watchdog timer

5. Autosub Long Range Vehicles

Long Range Autonomous Underwater Vehicles (LRAUVs) offer the potential to monitor the ocean at higher spatial and temporal resolutions compared to conventional ship-based techniques. The multi-week to multi-month endurance of LRAUVs enables them to operate independently of a support vessel, creating novel opportunities for ocean observation. The National Oceanography Centre's Autosub Long Range is one of a small number of vehicles designed for a multi-month endurance.

NOC currently operate six Autosub Long Range (ALR) vehicles three 1500m depth rated and three 6000m depth rated (see Figure 5.1). All the vehicles are 3.6m long, 0.9m diameters and displace 1.2m3 in water (see Figure 5.2). Each vehicle is equipped with a single thruster at the stern and three movable control surfaces: one rudder and two jointly actuated sternplanes completing the aft arrangement is a fixed vertical fin which houses secondary relocation beacons. For primary navigation the vehicles are equipped with a down DVL (Nortek 500 or RDI Workhorse 500), a MEMS compass and orientation sensor (PNI) and an acoustic modem for acoustic aided navigation. For further details see Roper et al. 2021 and Phillips et al. 2023.

Figure 5.1: Autosub Long Range Variants, 6000m depth rated behind, 1500m in front

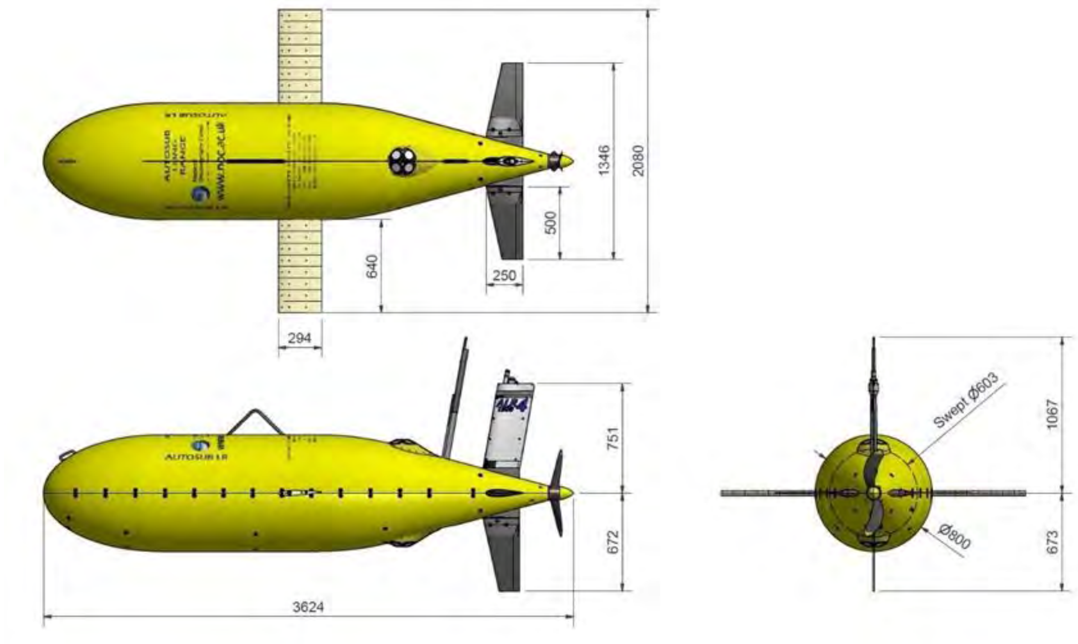


Figure 5.2: ALR Dimensions

The design of the platform is such that there is a significant payload space at the nose and tail which are routinely equipped with mission specific payloads (discussed in more detail below). The ALR platforms are designed to be remotely piloted from shore using the Oceanids C2 system Harris et al. 2020. The vehicles typically surface every 24 hours to receive new piloting instructions and upload decimated near real-time data sets. The nature of the platforms is they are flexible to utilising multiple comms channels depending on the use case. Specific interrupts can be programmed to enable the vehicle to surface and send back data due to pre-defined triggers (e.g. identification of a target). Figure 4 illustrates the mission planning tool component of the NOCs Oceanids C2 tool. Missions are created from a series of mission primitives which include:

- Track Follow – the AUV will track follow between to waypoints at a pre-defined depth/altitude and speed
- Loiter At Depth – the AUV will circle at a pre-defined waypoint at a specific depth/altitude demand
- Profile Track – the AUV will profile through the water column between pre-defined water depths
- Loiter on Surface – the AUV will maintain station at a fixed waypoint on the surface

Composite behaviours such as lawnmower surveys can be created by combining these primitives. More advanced mission primitives are available for under ice operation.

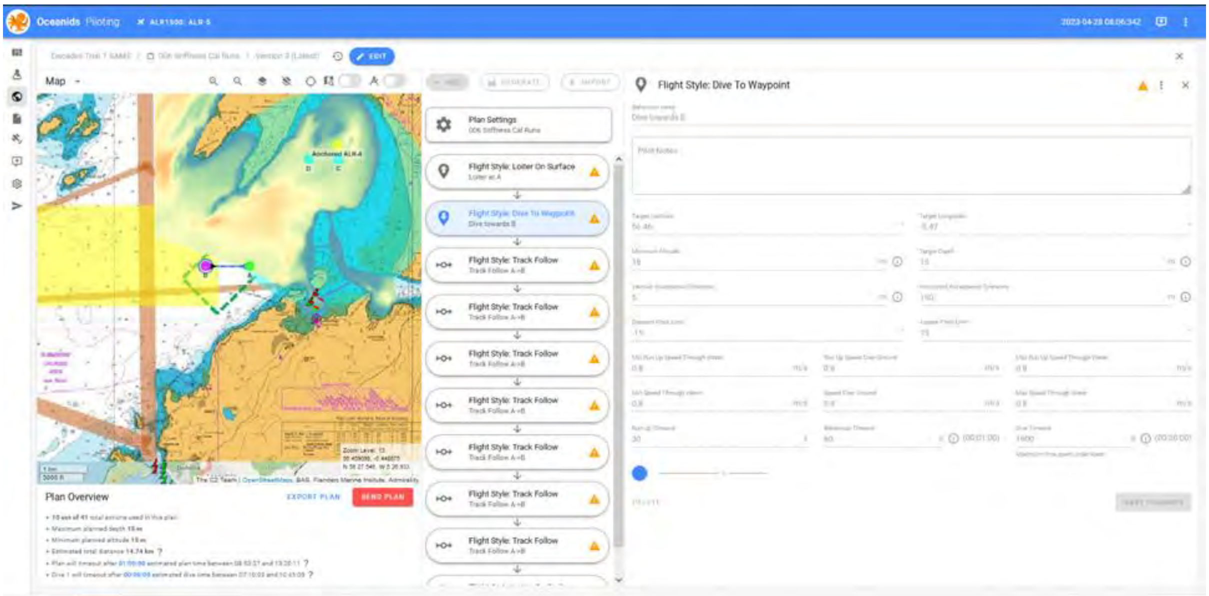


Figure 5.3: *Autosub Mission Planning Tool*

Figure 5.3 illustrates the web-based mission monitoring infrastructure used to review decimated data as it is sent back by the vehicle.

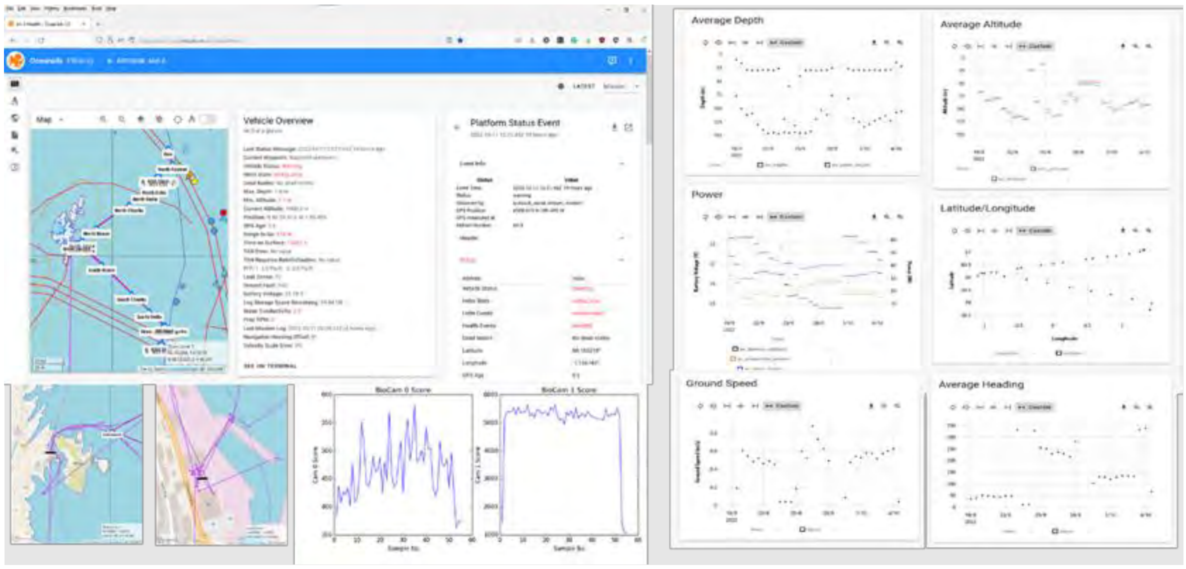
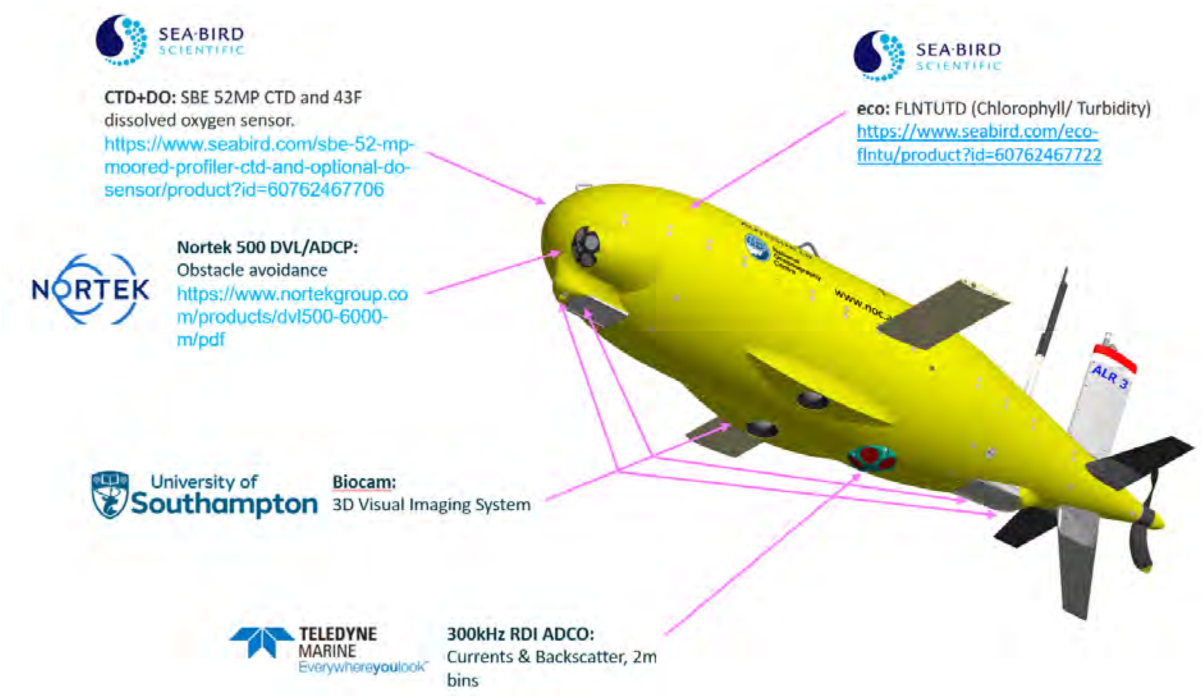
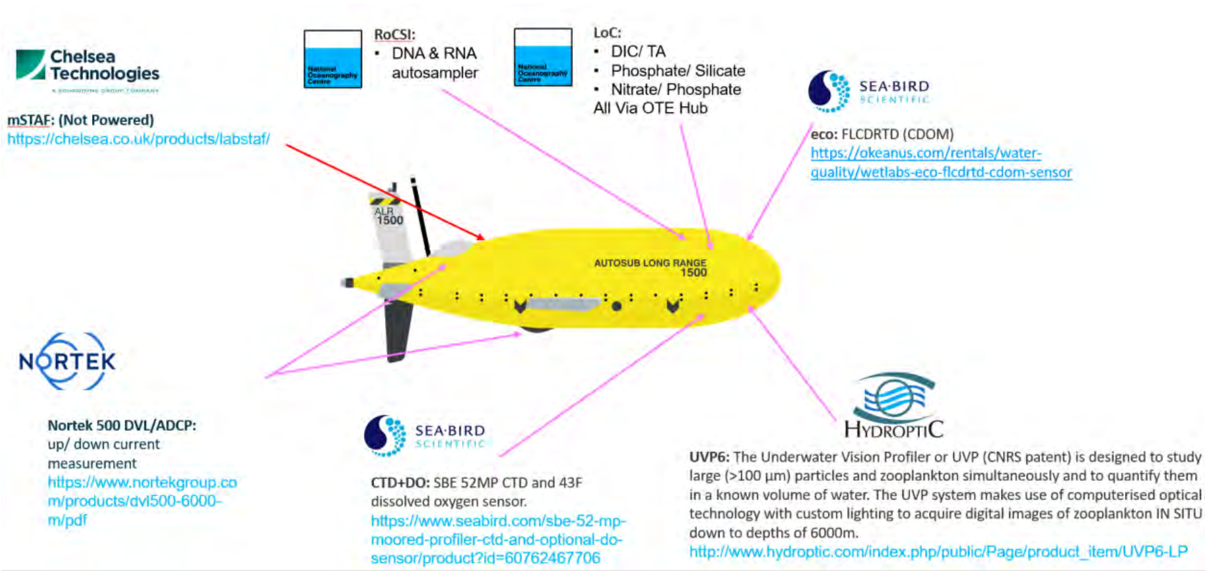


Figure 5.4: Autosub Mission Monitoring

5.1. ALR3 Configuration



5.2. ALR5 Configuration



6. **Deployment Summaries**

6.1. ALR5 Calibration Missions (ALR5M101 to ALR5M105)

At the start of any campaign with an ALR vehicle it is necessary to undertake a sequence of calibration missions to ensure:

- The vehicle is operating as expected;
- That the magnetic compass on ALR is well calibrated (see Figure 6.1.1);

- The alignment between the DVL and compass is known (see Figure 6.1.2);
- The AUVs propulsion power requirements are well understood (see Figure 6.1.3).

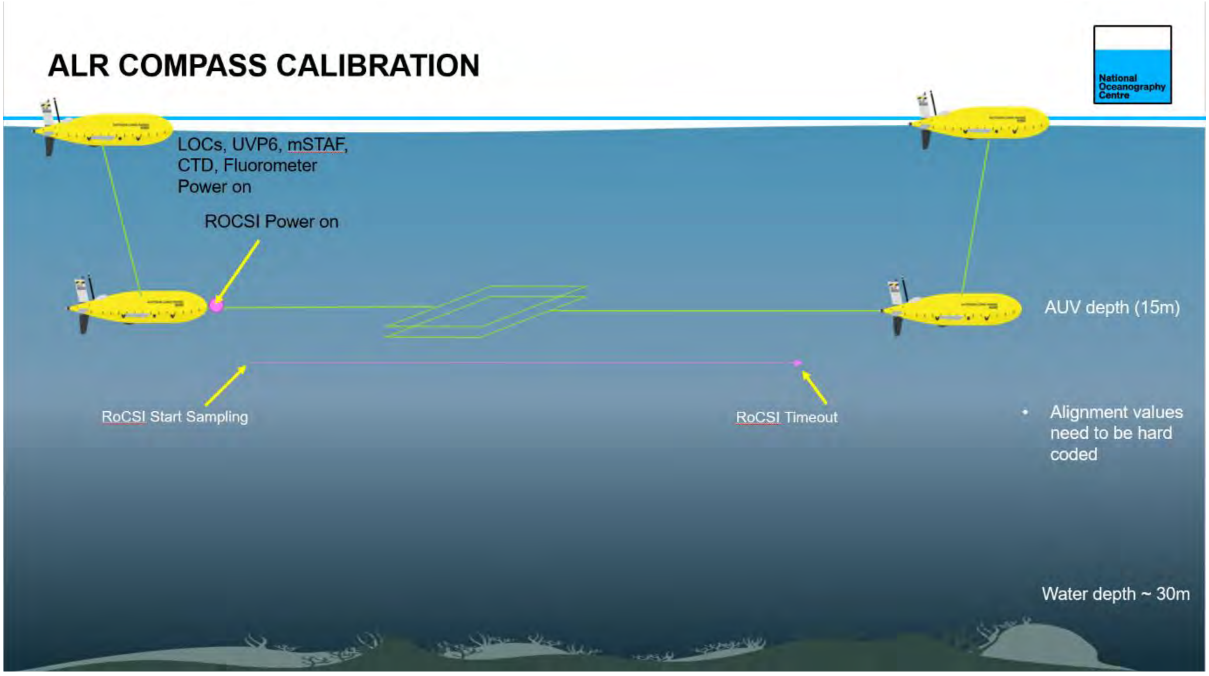


Figure 6.1.1. ALR compass calibration

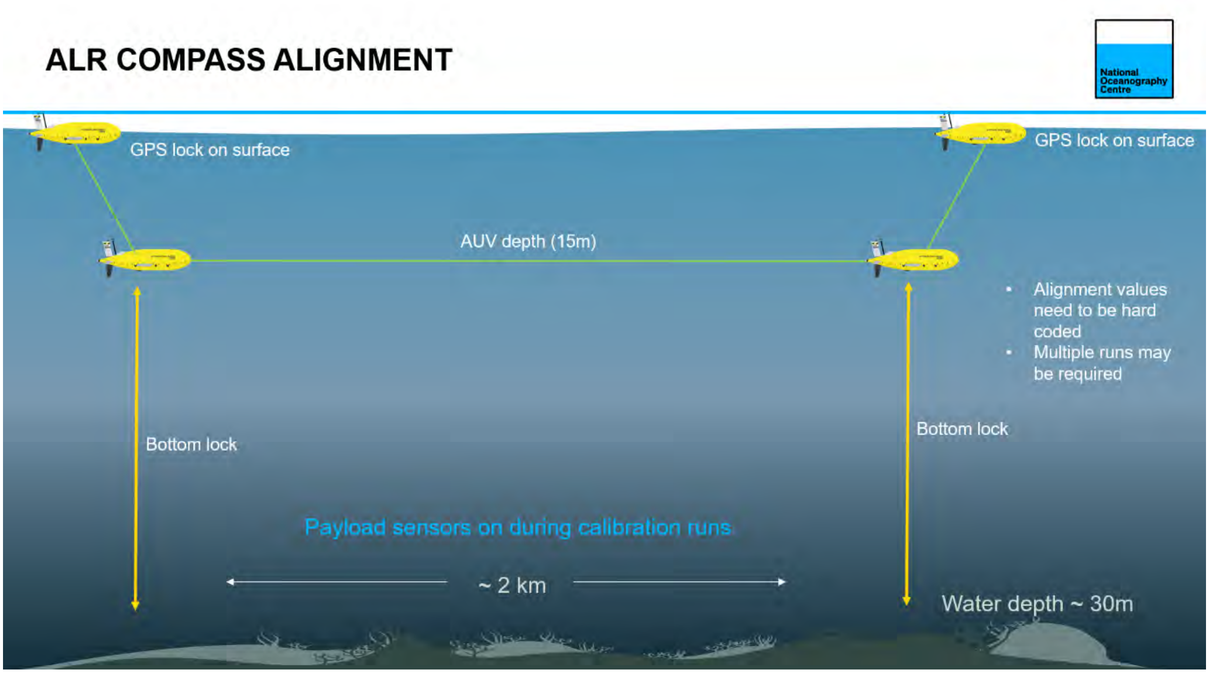


Figure 6.1.2. ALR Compass Alignment

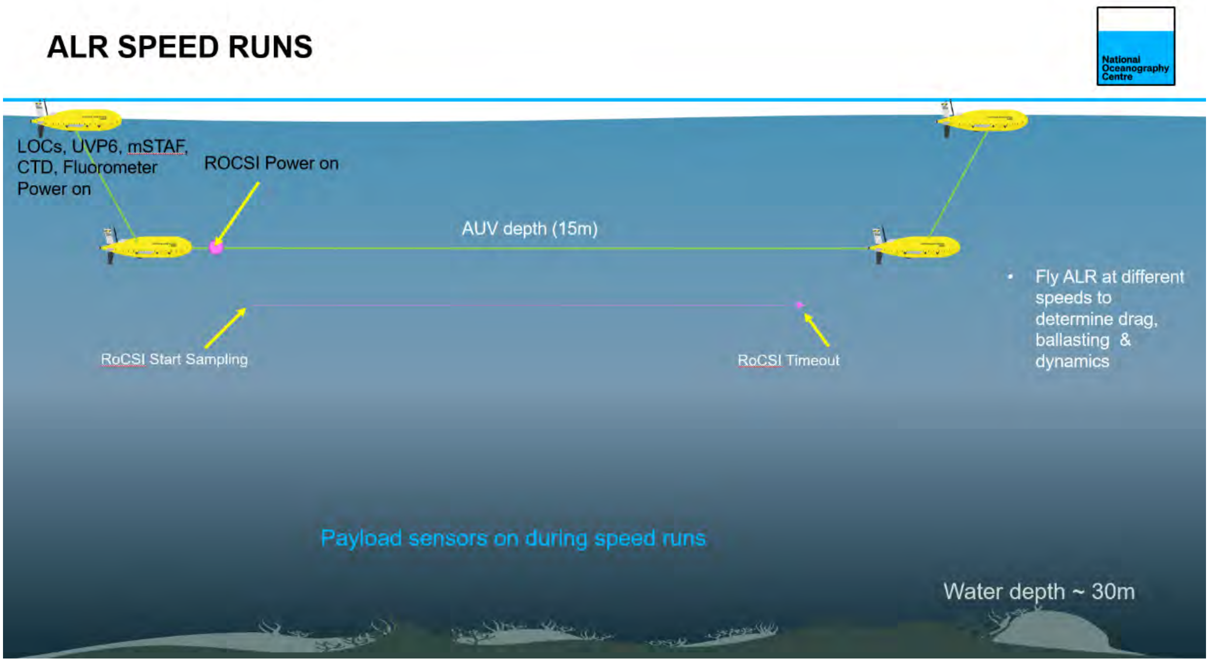


Figure 6.1.3 ALR Speed Runs

To achieve this, we undertake a sequence of standard missions. Calibration activities for ALR5 took place on the 9/3/24. The Mission/Command Sequence for ALR5 was as follows

- ALR5M101: C01 Surface Run - Complete
- ALR5M102: C01a 10min Test Dive (15 m)
- Command: Turn Sensors On (5 mins)
- ALR5M103: C02a Compass Cal + Rocsi
- Command: Turn Sensors On (5 mins)
- ALR5M104: C03 Alignment (Northward)
- Turn Sensors On (5 mins)
- ALR5M105: C04b Endurance Run + Rocsi
- Turn Sensors Off (5 mins)
- CTD OFF

6.2. ALR5 Sensor Test Deployment (ALR5)

To perform initial test of the TechOceanS sensors a sensor test mission was undertaken in the waters East of PLOCAN. During the outward mission the ALR loitered at a series of set depths to allow a suitable period for LoC and RoCSI samples to be taken. On the return leg the ALR performed a profiling behaviour with all sensors operational (apart from RoCSI) to further test the sensors. The profiling behaviour would be used for the later Southerly missions and these test provided a good opportunity to ensure ALR performed as expected in the environmental conditions experienced off Gran Canarias.

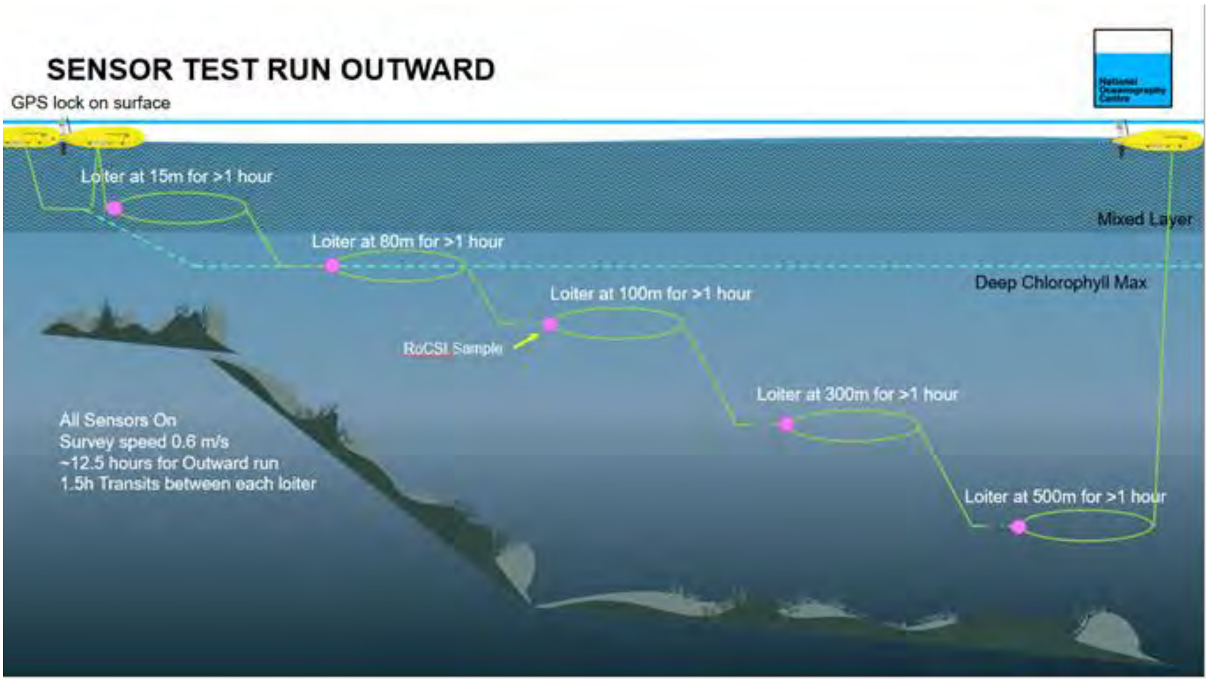


Figure 6.2.1. Faulty conductivity measurement

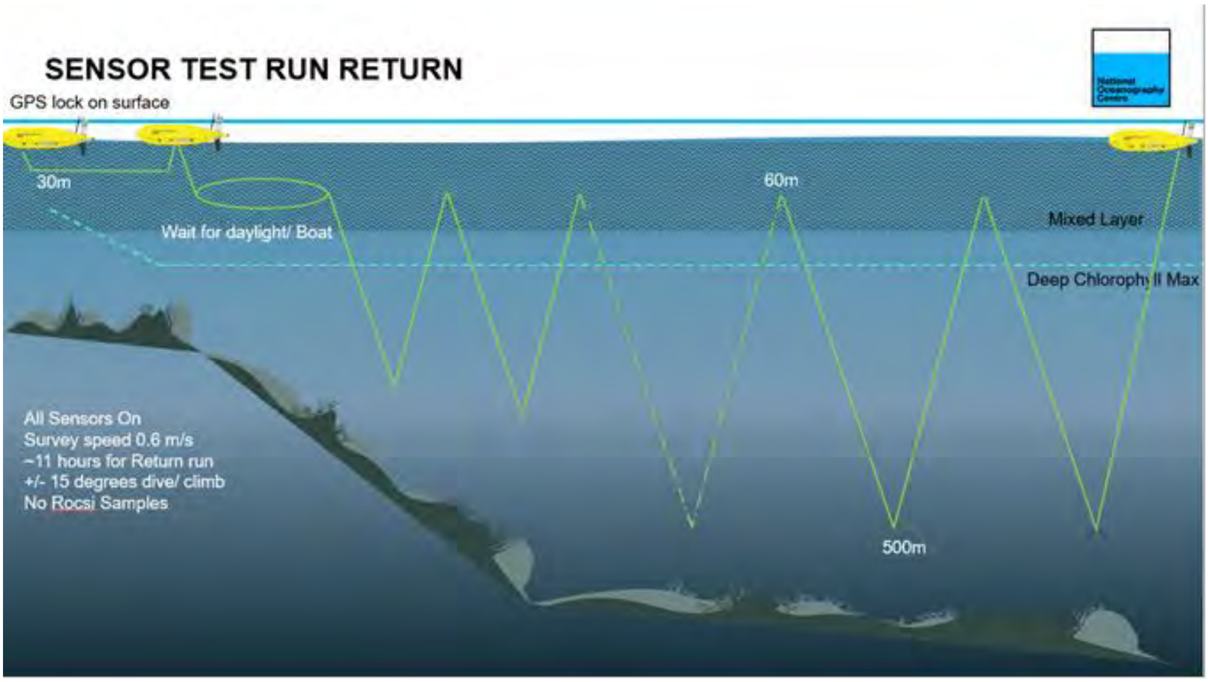


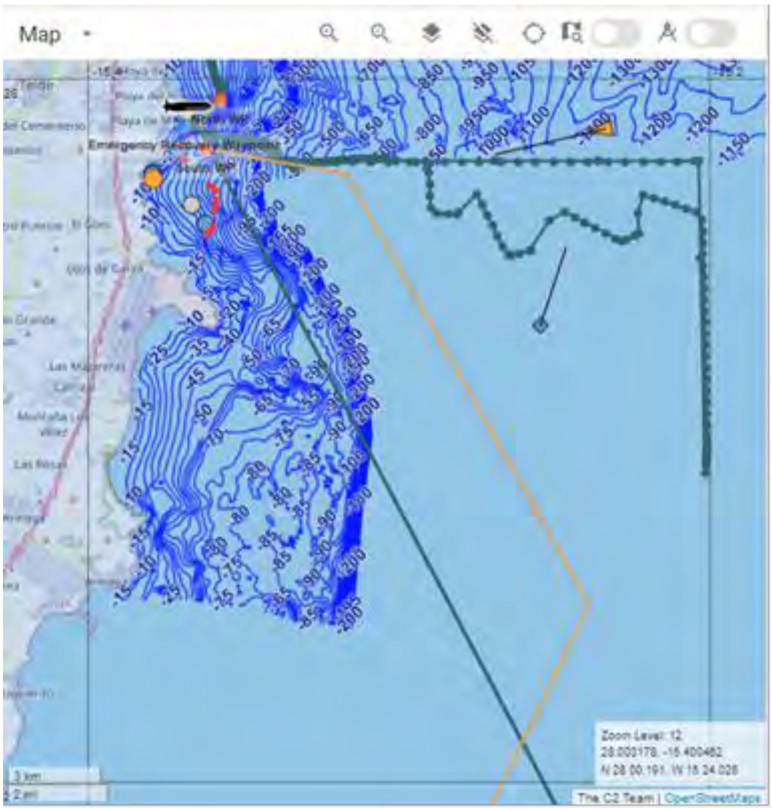
Figure 6.2.2. Faulty conductivity measurement

- ALR5M106 (Head east - staircases with loiters and ROCSI samples at the start of each step)
- ALR5M107:ST1a Sensor Tests Inbound Profiles sent at circa 0130 to start bringing ALR back in towards PLOCAN - initial phase profiling then constant

depth at 30m. Due to southerly current AUV tracked to the south of intended track but slowly converged to the track line by increasing the number of surfaces. LOC turned on for initial dive but off for later dives due to mission plan length constraints.

- Mission terminated approximately 5km offshore to swap to a more conservative approach into PLOCAN.
- ALR5M108: 2 hour Surface Loiter at Tanker WP
- ALR5M109: ST1b Tanker WP towards recovery 45min timeout
- ALR5M1010: ST1c Final leg to recovery 45min timeout
- AUV surfaced within 200m of intended waypoint and recovered and back at PLOCAN 1545

- LoC and RoCSi data analysis
  - 5 samples taken as planned for RoCSI
  - TA/DIC looking ok some niggles to work through.
  - Nitrate Phosphate LoC looking good – need to look at the polling speed between the ALR and the hub to ensure all measurements captured
  - Silicate Phosphate some niggles to work through on the sensor side



6.3. ALR5 Abandoned Southern Deployment (ALR5M111 to ALR5M113)

On Friday 15/3/24 ALR5 was launched from the harbour at about 1100 for a first attempt at the Southern Deployment.

- On arriving at the southern waypoint, the AUV was reporting a negative conductivity by the CTD sensor (NOCALR-1314).
- A short 10m 10min test dive (ALR5M111) was completed which cleared the fault - suspect bubble in the CTD tubing
- The Eco-Puck/UVP6 were turned on and LoCs on standby.
- At 13:10 ALR5M112: T0a Transit South Profiling was sent. AUV observed diving and boat crew returned to the harbour
- At 14:45 the AUV sent and Iridium message (SBD 9572) stating the AUV was stationary on the surface in a Safety Stop condition a contingency behaviour that is triggered by a number of unusual events: under minimum altitude, stuck trying to descend etc. AUV was reporting being only a short distance from the initial dive location (NOCALR-1313)
- A resume command was sent over Iridium to clear the contingency behaviour and get the AUV back into its idle state (sat on the surface waiting for new instructions). No persistent fault was present.
- Whilst waiting to receive the mission logs the AUV was tasked with holding station on the surface which demonstrated the thruster was functioning.
- Initial analysis of the decimated mission log sent over iridium identified odd surfacing behaviour and suspicion of AUV being tangled in a ghost line, but data was inconclusive.
- A short dive to 30m was undertaken (ALR5M113) which confirmed the AUV was operating correctly in the vertical plane, while waiting for the support boat to be available to recover the AUV to access the full data set and check for damage.
- Analysis of full data set indicates the AUV was caught by something subsea leading to a rapid de-acceleration, increase in roll and inability to control speed, depth and heading. The combination of these behaviours is very difficult to explain through anything but external factors - such as getting caught on a line. See Figure 6.3.2.

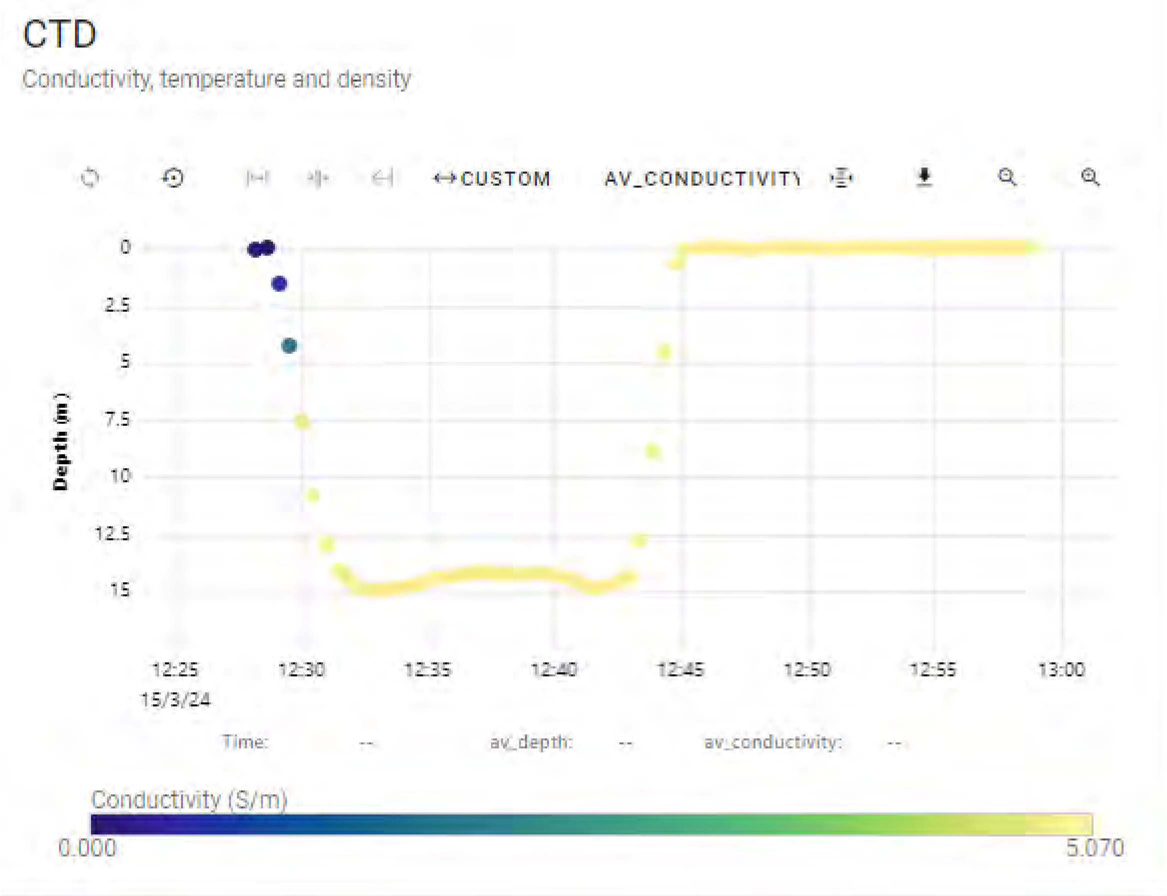


Figure 6.3.1. Faulty conductivity measurement

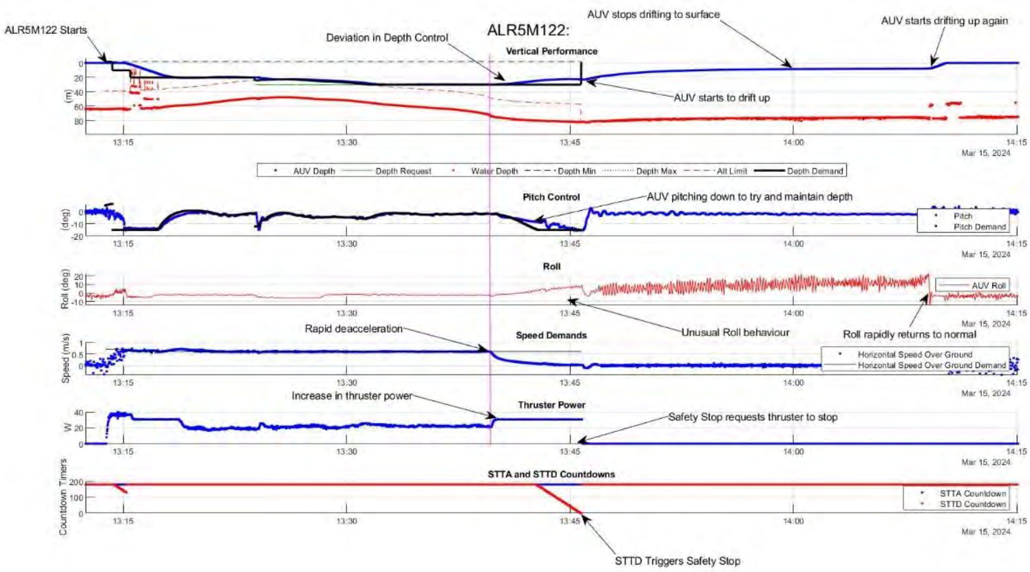


Figure 6.3.2. ALR5M112 underwater collision.

6.4. ALR5 Southern Deployment (ALR5M114 – ALR5M130)

ALR5 was deployed for its southern deployment on Saturday the 16/3/24 from Taliatre harbour then transited south, operating south of the island for a period of 6 days before recovery to Puerto Rico harbour on the 21/3/24. This deployment comprised of missions ALR5M114 to ALR5M130. Figure 6.4.1 through Figure 6.4.4 illustrate the path, individual missions, surfacing locations and key results from this deployment.

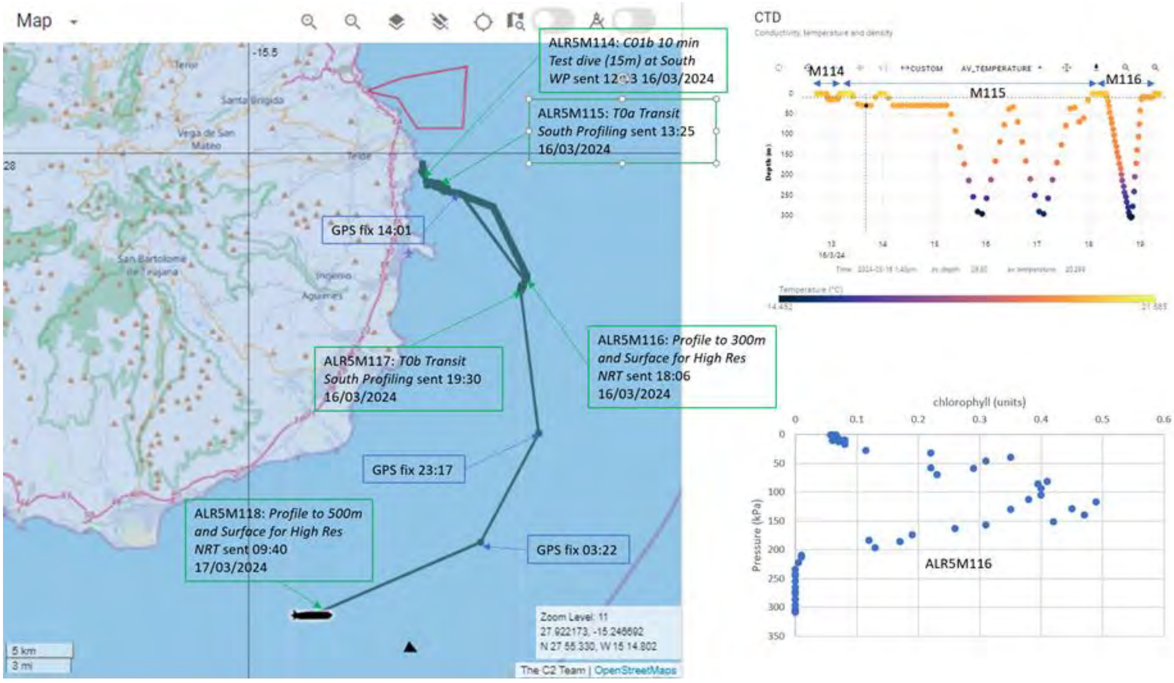


Figure 6.4.1. ALR5 Southern Deployment 17/3/24

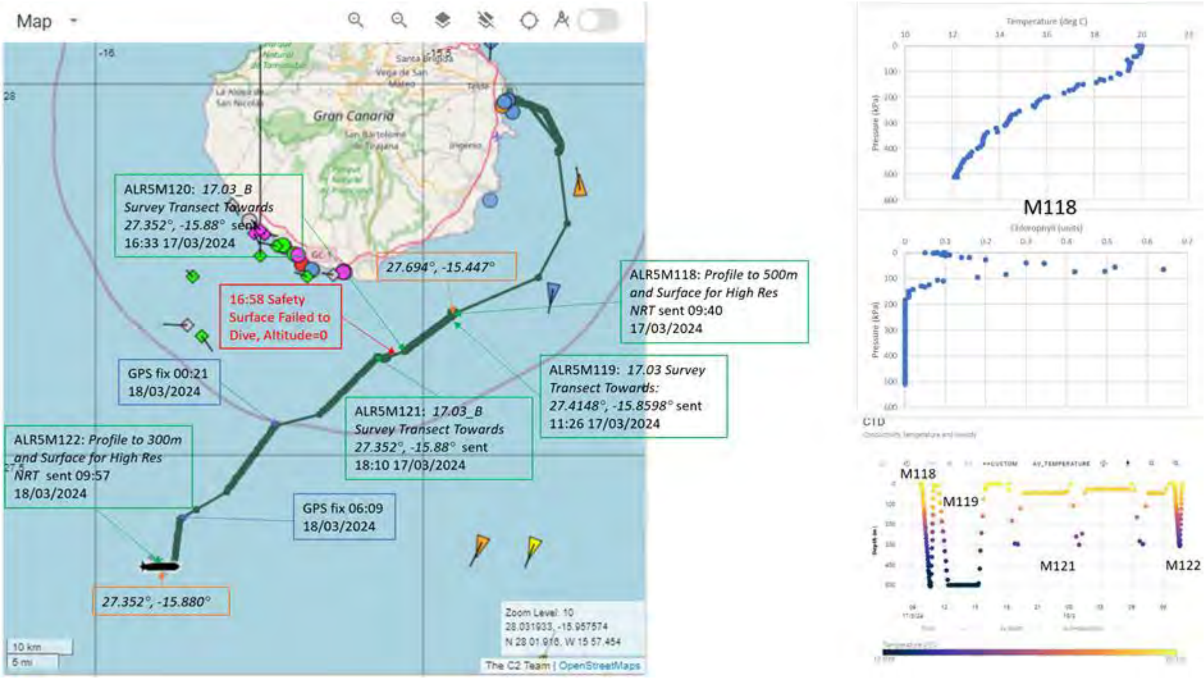


Figure 6.4.2. ALR5 Southern Deployment 18/3/24

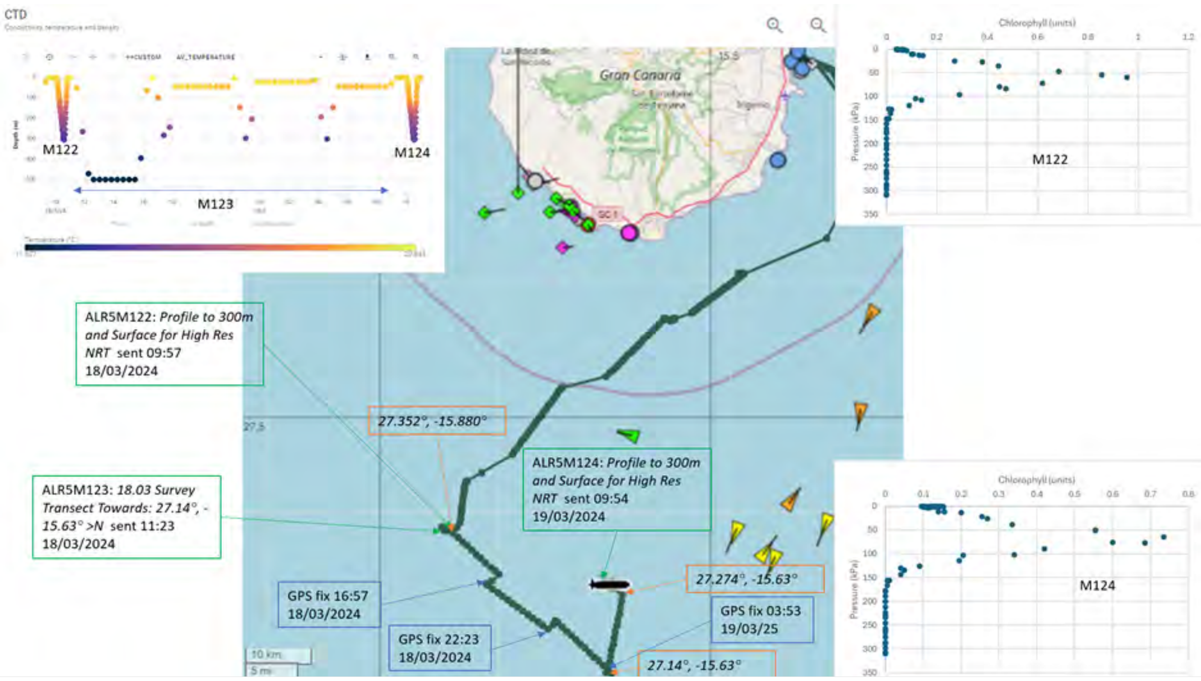


Figure 6.4.3. ALR5 Southern Deployment 19/3/24

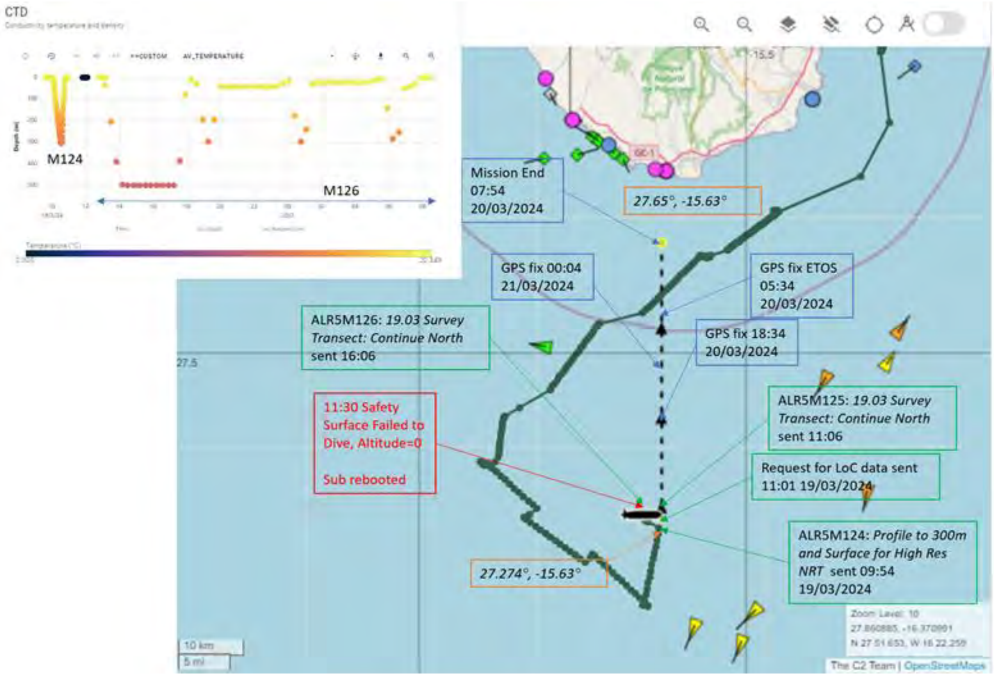


Figure 6.4.4. ALR5 Southern Deployment 20/3/24

6.5. ALR3 Calibration Missions

The calibration procedure is the same as ALR 5 and has been described in Section 6.1. During this process we observed an issue with ALR 3 CTD pressure sensor which resulted in the calibration process being abandoned after the compass calibration mission. The ALR was recovered and returned to PLOCAN where the CTD was replaced. Details and analysis of this initial calibration attempt are detailed in APPENDIX C – ALR 3 Mission summary table and APPENDIX D – ALR 3 Mission Detail.

6.6. Take 2 and Initial BioCam Survey with NRT Data Pipeline Deployment

ALR ran a compass alignment mission, followed by the grid survey. Both missions were run at a constant altitude of 10m above the seafloor, and ALR surfaced briefly between the two missions. BioCam continuously collected images throughout two dives. At the end of the 2nd dive the near real-time remote awareness algorithm classified the collected images and sent a compressed version of the 16 most representative images over satellite communication, along with the latent space representation of the other images. Figure 6.6.1 shows the latent space representation of the collected images, with the different colours indicating the clusters the algorithm has identified. Figures 6.6.2, 3 and 4 show where these types of images geographically occur. Figure 6.6.5. shows the representative images.

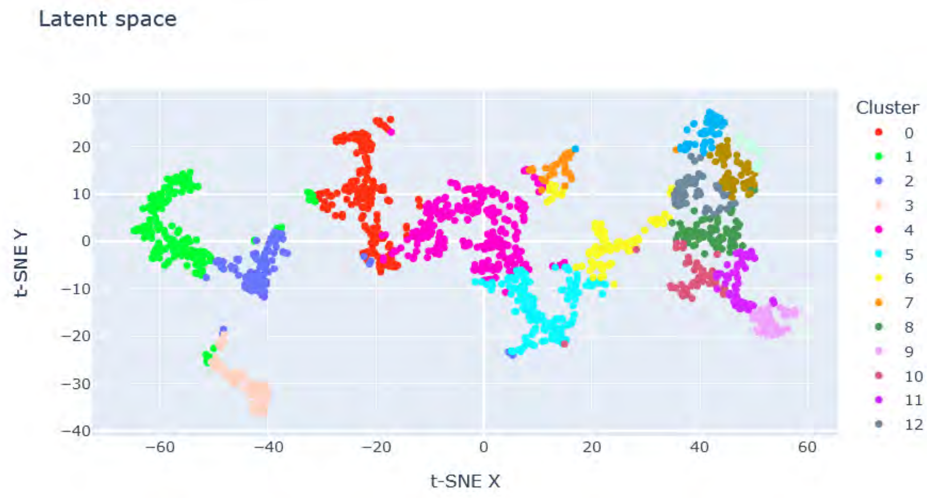


Figure 6.6.1: Latent space representation of all the collected images.

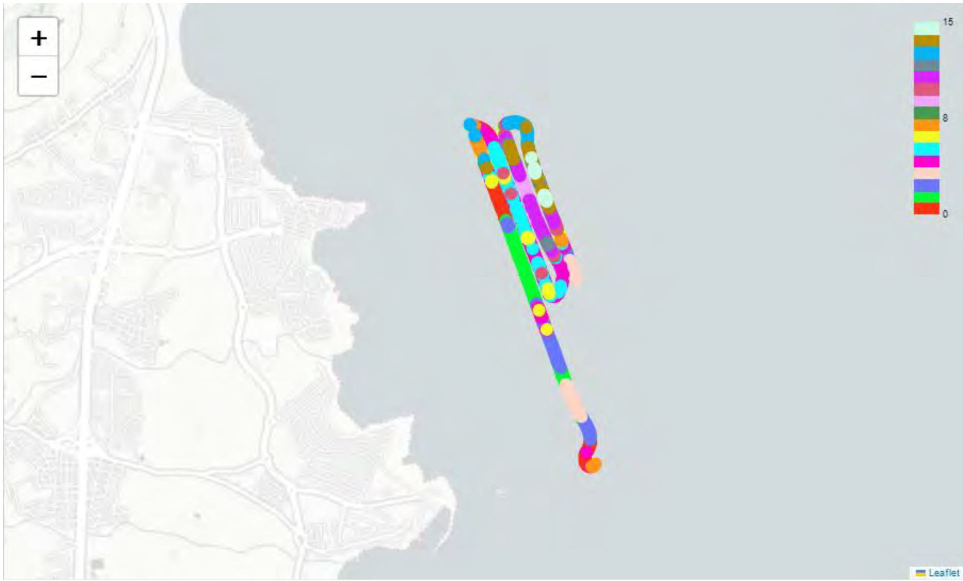


Figure 6.6.2: Representation of the types of images on a map.

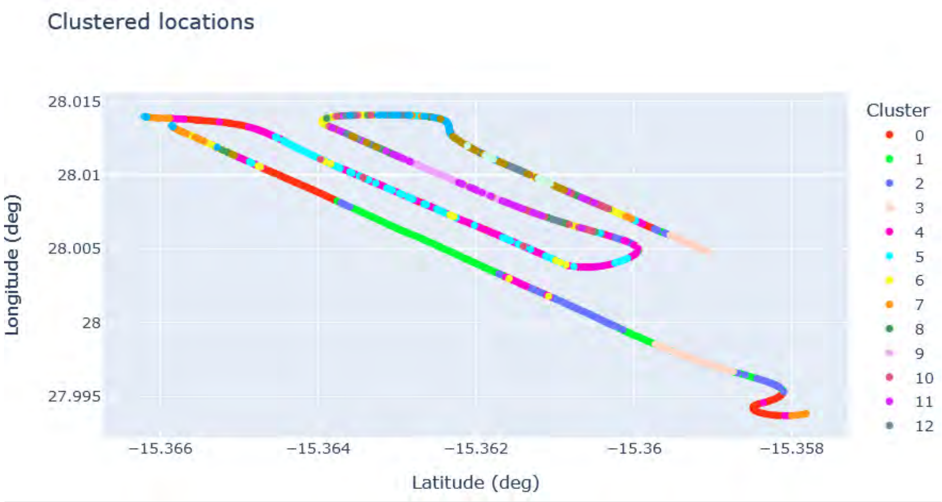


Figure 6.6.3: Georeferencing of the types of images, where the colour represents the cluster they belong to.

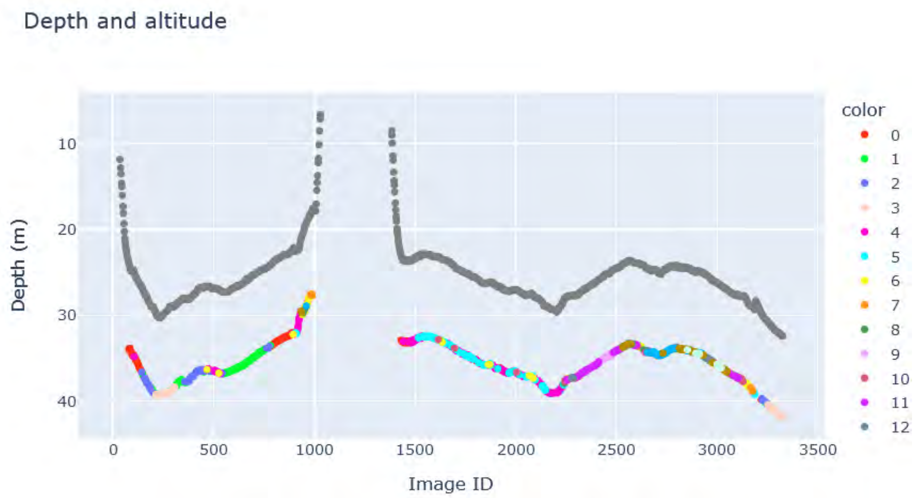


Figure 6.6.4: Depth vs. image index plot, where the colours represent the clusters the images belong to.

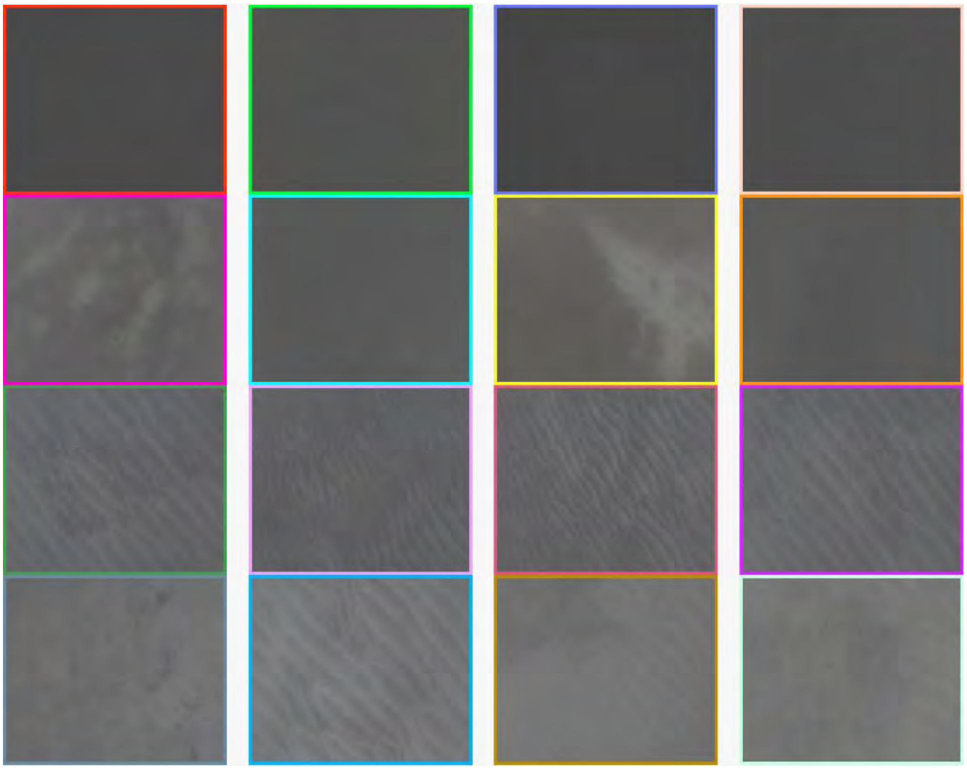


Figure 6.6.5: Images corresponding to each of the clusters, transmitted over satellite communication

Figure 6.6.6 shows full resolution images downloaded and processed after recovering the AUV. Despite the high acquisition altitude of 10m the images are clear, even if the colours are washed out due to the strong absorption of the red component of light.

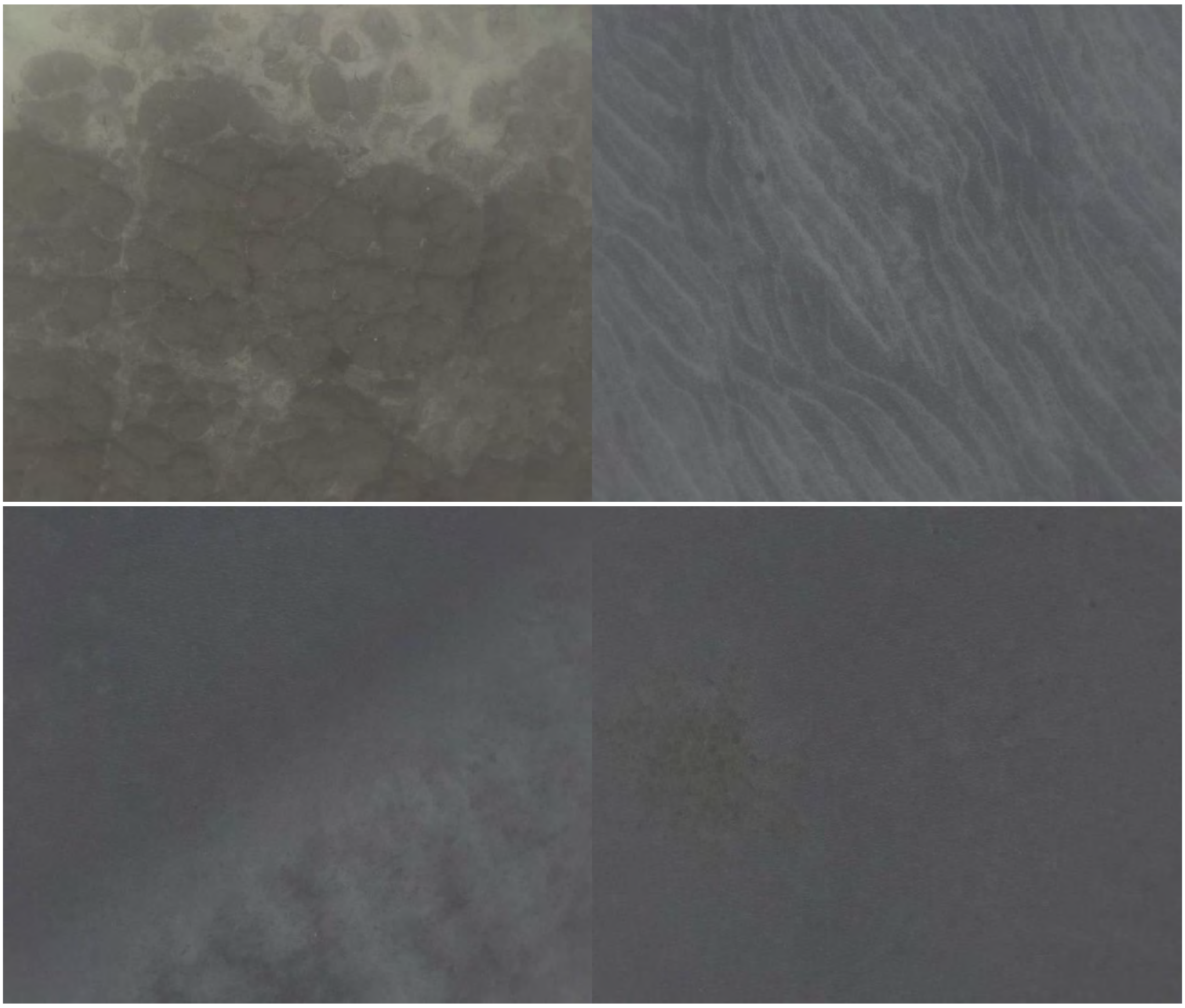


Figure 6.6.6: Examples of post-processed full resolution images showing volcanic rock, sand ripples, transition between hard substrate and sand, and sea grass acquired from 10m altitude.

Table 6.6.1. Stats of the data collected by BioCam during the "ALR3 Calibration Missions Take 2 and Initial BioCam Survey" mission

Number of colour images collected	3326
Size of colour images	34.3GB
Total size of imagery data	75.6GB
Size of data transmitted via satcom	90.5KB
Time taken to transmit data via satcom	34min 39s

6.7. ALR3 BioCam Survey

During the "ALR3-BioCam mission" part of the same area as during the "ALR3 Calibration Missions Take 2 and Initial BioCam Survey" mission was mapped but, from a lower altitude of

5m. Figure 6.7.1 shows a few full resolution images that were colour and attenuation corrected after recovering the AUV. Due to the lower mapping altitude and so shorter distance the light travelled, the colours are more vivid than those acquired during the "ALR3 Calibration Missions Take 2 and Initial BioCam Survey" mission. Due to operational issues it was not possible to run the near real-time remote awareness pipeline. However, all data had been successfully recorded and all processes can be run in post-processing.

Figure 6.7.1: Examples of post-processed full resolution images showing volcanic rock, sand ripples, transition between hard substrate and sand, and probably sea grass acquired from 5m altitude.

Table 6.7: Stats of the data collected by BioCam during the ALR3 BioCam survey

Number of colour images collected	1885
Size of colour images	19.4GB
Total size of imagery data	42.8GB

7. Other Sampling

7.1. Co-sampling with ALR5 Calibration Missions

Samples to validate sensor data were taken in the vicinity of the area where ALR5 was working. Samples were taken using a 5L Niskin bottle. Dissolved oxygen and DIC samples were fixed immediately after collection.

Figure 7.1.1: Sampling team during one 21st March 2024 near Puerto Rico, Gran Canaria.

In the following table, we can find the list of samples collected during the experiment:

Table 7.1. List of samples collected and identification numbers.

		Bottle Label								
Date	**Location**	**Niskin ID**	**Depth (m)**	**DO**	**Nut**	**Chl-a**	**Sal**	**DIC**	**Cyto**	**DNA**
9/3/24	North End of Alignment run; 28° 0' 51",-15° 21' 52"	1	12	146	1 (2x)	1	No sample	1		(1+2)
9/3/24	North End of Alignment run; 28° 0' 51",-15° 21' 52"	2	12	181						
9/3/24	North WP; 27° 59' 37" -15° 21' 28	3	4	139	2 (2x)	2	2	2		(3+4)
9/3/24	North WP; 27° 59' 37" -15° 21' 28	4	4	134						
11/3/24	27.58'35; -15.20'02	1	15	102	1 (2x)	1	1	3		(1+2)
11/3/24	27.58'35; -15.20'02	2	15	179						
11/3/24	27.58'37; -15.20'42	3	15	104	2 (2x)	2	2	4		(3+4)
11/3/24	27.58'37; -15.20'42	4	15	141						
11/3/24	27.58'45; -15.21'14	5	15	115	3 (2x)	3	3	5		(5+6)
11/3/24	27.58'45; -15.21'14	6	15	130						
11/3/24	27.58'47; -15.21'44	7	15	119	4 (2x)	4	4	6		(7+8)
11/3/24	27.58'47; -15.21'44	8	15	107						
12/3/24	27.58'47''; -15.21'44.6''	1	15	100	1 (2x)	1	1	7		(1+2)
12/3/24	27.58'47''; -15.21'44.6''	2	15	182						
15/3/24	South WP 27.58'48''; -15.21'45''	1	15	123	1 (2x)	1	1	8		(1+2)
15/3/24	South WP 27.58'48''; -15.21'45''	2	15	126						
15/3/24	Upstream AQ 27.58'58''; -15.22'11''	3	15	185	2 (2x)	2	2	9		(3+4)
15/3/24	Upstream AQ 27.58'58''; -15.22'11''	4	15	183						

15/3/24	Downstream AQ 27.58'54''; -15.21'79''	5	15	122	3 (2x)	3	3	10		(5+6)
15/3/24	Downstream AQ 27.58'54''; -15.21'79''	6	15	184						
15/3/24	East AQ 27.58'54''; -15.21'79''	7	15	118	4	4	4	11		(7+8)
15/3/24	East AQ 27.58'54''; -15.21'79''	8	15							
15/3/24	South WP 27.58'48''; -15.21'45''	9	5						1	
21/3/2024	Puerto Rico Harbour; 27º45'17.2"N, 15º42'28.9"W	1	15	187	1 (2x)	1	2	12		(1+2)
21/3/2024	Puerto Rico Harbour; 27º45'17.2"N, 15º42'28.9"W	2	15	9						
21/3/2024	Puerto Rico Harbour; 27º45'17.2"N, 15º42'28.9"W	3	32	28	2 (2x)	2	1	13		(3+4)
21/3/2024	Puerto Rico Harbour; 27º45'17.2"N, 15º42'28.9"W	4	25							
Total Number of samples		**27**		24	25	13	12	13	1	13
Total Vol collected (L)		**135**		5	0.5	15	7	7	1	104

Some samples were analysed at PLOCAN, the rest are going to be measured back at NOC, UK. Some preliminary results can be found in the following table:

Table 7.2: Results for some of the samples collected.

Date	Location	Depth (m)	DO (µmol/L)	NO3+NO2 (µmol/L)	PO4 (µmol/L)	Si (µmol/L)	Chl-a (µg/L)
9/3/2024	North End of Aligment run; 28° 0' 51",-15° 21' 52"	12	229.25	<LD	0.14	0.62	1.06
9/3/2024	North End of Aligment run; 28° 0' 51",-15° 21' 52"	12	230.45				

9/3/2024	North WP; 27° 59' 37" -15° 21' 28	4	227.86	<LD	0.13	0.51	0.96
9/3/2024	North WP; 27° 59' 37" -15° 21' 28	4	228.8				
11/3/2024	27.58'35; -15.20'02	15	229.15	<LD	0.14	0.46	0.53
11/3/2024	27.58'35; -15.20'02	15	229.89				
11/3/2024	27.58'37; -15.20'42	15	228.11	<LD	0.14	0.56	0.47
11/3/2024	27.58'37; -15.20'42	15	228.22				
11/3/2024	27.58'45; -15.21'14	15	227.52	<LD	0.13	0.62	0.56
11/3/2024	27.58'45; -15.21'14	15	227.79				
11/3/2024	27.58'47; -15.21'44	15	229.33	0.12	0.18	0.61	0.91
11/3/2024	27.58'47; -15.21'44	15	229.23				
12/3/2024	27.58'47''; -15.21'44.6''	15	226.64	<LD	0.14	0.49	1.03
12/3/2024	27.58'47''; -15.21'44.6''	15	226.93				
15/3/2024	South WP 27.58'48''; -15.21'45''	15	232.28	<LD	0.14	0.5	0.41
15/3/2024	South WP 27.58'48''; -15.21'45''	15	233.65				
15/3/2024	Upstream AQ 27.58'58''; -15.22'11''	15	232.37	<LD	0.14	0.55	0.52
15/3/2024	Upstream AQ 27.58'58''; -15.22'11''	15	232.72				
15/3/2024	Downstream AQ 27.58'54''; -15.21'79''	15	232.56	<LD	0.12	0.46	0.45
15/3/2024	Downstream AQ 27.58'54''; -15.21'79''	15	233.19				
15/3/2024	East AQ 27.58'54''; -15.21'79''	15	232.7	<LD	0.13	0.46	0.55
15/3/2024	East AQ 27.58'54''; -15.21'79''	15					
21/3/2024	Puerto Rico Harbour;	15	240.32				0.24

	27º45'17.2"N, 15º42'28.9"W						
21/3/2024	Puerto Rico Harbour; 27º45'17.2"N, 15º42'28.9"W	15	238.9				
21/3/2024	Puerto Rico Harbour; 27º45'17.2"N, 15º42'28.9"W	32	240.43				0.41

Samples have been analysed following gold standard protocols:

- Dissolved oxygen: Winkler method (Langdon et al., 2010)
- Inorganic dissolved nutrients: SKALAR San+ system, following Hansen and Koroleff (1999)
- Chlorophyll-a: Method 445.0 In Vitro Determination of Chlorophyll a and Pheophytin ain Marine and Freshwater Algae by Fluorescence, Arar et al., (1997)
- Salinity: Autosal Salinometer 8400B - OSIL
- DIC method: Total dissolved inorganic carbon (DIC) is determined by IR gas analysis following acidification with 10% phosphoric acid and stripping of the generated CO_2 with pure nitrogen gas. The DIC determination is conducted on an AIRICA® DIC Analyser (Marianda, Kiel, Germany) coupled with a LICOR 840A IR CO_2/H_2O Analyser (Goyet and Snover 1993; O'Sullivan and Millero 1998; Call et al. 2017). The analytical system is calibrated daily with CO_2-in-seawater Certified Reference Materials (CRMs, Scripps Institution of Oceanography, USA). The DIC concentration in all samples is determined from $n = 2 – 3$ repeat measurements from the same 250 mL sample bottle, each measurement consisting of integrated CO_2 peaks from 4 repeat injections of 1.2 mL of sample, with repeatability better than 6 µmol kg^{-1} (average = 3 µmol kg^{-1}, 1σ = 2 µmol kg^{-1}).

8. **Conclusion**

Overall the experiment went well. Despite of the weather and some technical problems, both ALRs equipped with sensors and samplers developed in the project TechOceanS managed to complete all tests and missions planned. The south mission (called Eddies mission) demonstrated the capacity of the technology to detect biogeochemical gradients, this mission was shorter in time but this was due to weather conditions. Moreover, the BioCam ALR also produced good results, demonstrating the near real-time remote awareness algorithms.

9. References

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10. APPENDIX A: ALR 5 Mission Summary Table

MISSION DETAILS				SENSOR STATUS										MISSION METRICS											
ALR5 Mission Number	Mission Segment	Start Date & Time (UTC)	End Date & Time (UTC)	CTD + DO	ADCP Up/Down	FLCDRTD	HUB	LoC DIC/TA	LoC Phosphate Silicate	LoC Nitrate Phosphate	UVP6	mSTAF	RoCSI samples	Duration (Days)	Distance Travelled Underwater (km)	Average Power (W)	Energy Used (kWh)	Percent of Pack Used	Average SOG (m/s)	Max Depth (m)	Min Altitude (m)	Percent Bottom Lock	Average Surfacing Error (m)	Percent Error of DT	Mission Log MTSN
	Calibration Missions																								
ALR5M101	C01 Surface Run	09/03/2024 09:12	09/03/2024 09:22	**ON**	**ON**	OFF	OFF	OFF	OFF	OFF	OFF	OFF	-	0.01	-	39.93	0.01	0.04%	0.55	0.91	38.9	100.00	-	-	9089
ALR5M102	C01a 10min Test Dive (15 m)	09/03/2024 09:24	09/03/2024 09:42	**ON**	**ON**	OFF	OFF	OFF	OFF	OFF	OFF	OFF	-	0.01	0.46	38.86	0.01	0.07%	0.53	15.59	26.8	100.00	16.29	3.5%	9091
	>>Sensors On Mission																								
ALR5M103	C02a Compass Cal + Rocsi	09/03/2024 09:49	09/03/2024 11:11	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	-	0.06	1.60	48.66	0.07	0.40%	0.53	16.1	24.3	99.92	26.57	1.7%	9102
	>>Sensors On Mission																								
ALR5M104	C03 Alignment (Northward)	09/03/2024 11:22	09/03/2024 12:46	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	-	0.06	2.01	46.38	0.07	0.40%	0.53	15.54	19.2	99.81	46.67	2.3%	9112
	>>Sensors On Mission																								
ALR5M105	C04b Endurance Run + Rocsi	09/03/2024 12:54	09/03/2024 13:48	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	1	0.04	2.50	48.77	0.04	0.27%	0.79	15.56	19.1	99.97	39.37	1.6%	9117
	>>Sensors Off Mission																								
	Recover & Recharge ALR											**Totals:**	**1**	**0.17**	**6.58**		**0.19**	**1.18%**					**Average:**	**2.3%**	
	Sensor Test Runs																								
	>>Sensors On Mission																								
ALR5M106	ST0 Sensor Tests Outbound Staircase	11/03/2024 10:57	12/03/2024 00:57	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	5	0.58	28.79	45.97	0.64	3.90%	0.60	500.6	35.7	4.37	10310.31	35.8%	9392
	>>Sensors On Mission																								
ALR5M107	ST1a Sensor Tests Inbound Profiles	12/03/2024 01:38	12/03/2024 10:58	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	-	0.39	16.86	41.88	0.39	2.37%	0.59	501.2	-	0.10	965.26	5.7%	9420
ALR5M108	Loiter on Surface	12/03/2024 10:58	12/03/2024 12:38	**ON**	**ON**	**ON**	**ON**	**Idle**	**Idle**	**Idle**	**ON**	OFF	-	0.07	-	36.19	0.06	0.37%	0.50	0.17	0.0	5.97	-	-	9442
ALR5M109	Trackfollow and Loiter (should have included a dive)	12/03/2024 12:38	12/03/2024 13:22	**ON**	**ON**	**ON**	**ON**	**Idle**	**Idle**	**Idle**	**ON**	OFF	-	0.03	0.40	39.75	0.03	0.18%	0.54	30.19	0.0	7.38	86.66	21.7%	9451
ALR5M110	ST1c Final leg to recovery 45min timeout	12/03/2024 13:30	12/03/2024 14:18	**ON**	**ON**	**ON**	**ON**	**Idle**	**Idle**	**Idle**	**ON**	OFF	-	0.03	1.23	37.29	0.03	0.18%	0.55	30.23	0.0	99.59	261.65	21.3%	9456
	>>Sensors Off Mission																								
	Recover & Recharge ALR											**Totals:**	**5**	**1.11**	**47.28**		**1.15**	**6.99%**					**Average:**	**21.1%**	
	Abandonned Southern Deployment																								
	>>15.03 OCS Def - Turn Sensors On (5 mins)																								
ALR5M111	C01b 10 min Test dive (15m) at South WP	15/03/2024 12:28	15/03/2024 12:53	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	-	0.02	0.62	42.76	0.02	0.11%	0.58	15.09	27.4	99.78	8.48	1.4%	9563
	>>15.03 OCS Def - Turn Sensors On (5 mins)																								
ALR5M112	T0a Transit South	15/03/2024 13:13	15/03/2024 14:51	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	-	0.07	1.05	31.88	0.05	0.31%	0.15	30.01	25.0	97.62	9.07	0.9%	9582
	>>15.03 OCS Def - Turn Sensors On (5 mins)																								
ALR5M113	30m test dive	15/03/2024 15:36	15/03/2024 16:06	**ON**	**ON**	**ON**	**ON**	**Sampling**	**Sampling**	**Sampling**	**ON**	OFF	-	0.02	0.63	44.7	0.02	0.14%	0.59	30.65	39.7	96.53	8.46	1.3%	9601
	>>15.03 OCS Def - Turn Sensors On (5 mins)																								
	Surface mission to South WP for recovery																								
	Recover & Recharge ALR											**Totals:**	**0**	**0.11**	**2.30**		**0.09**	**0.56%**					**Average:**	**1.2%**	

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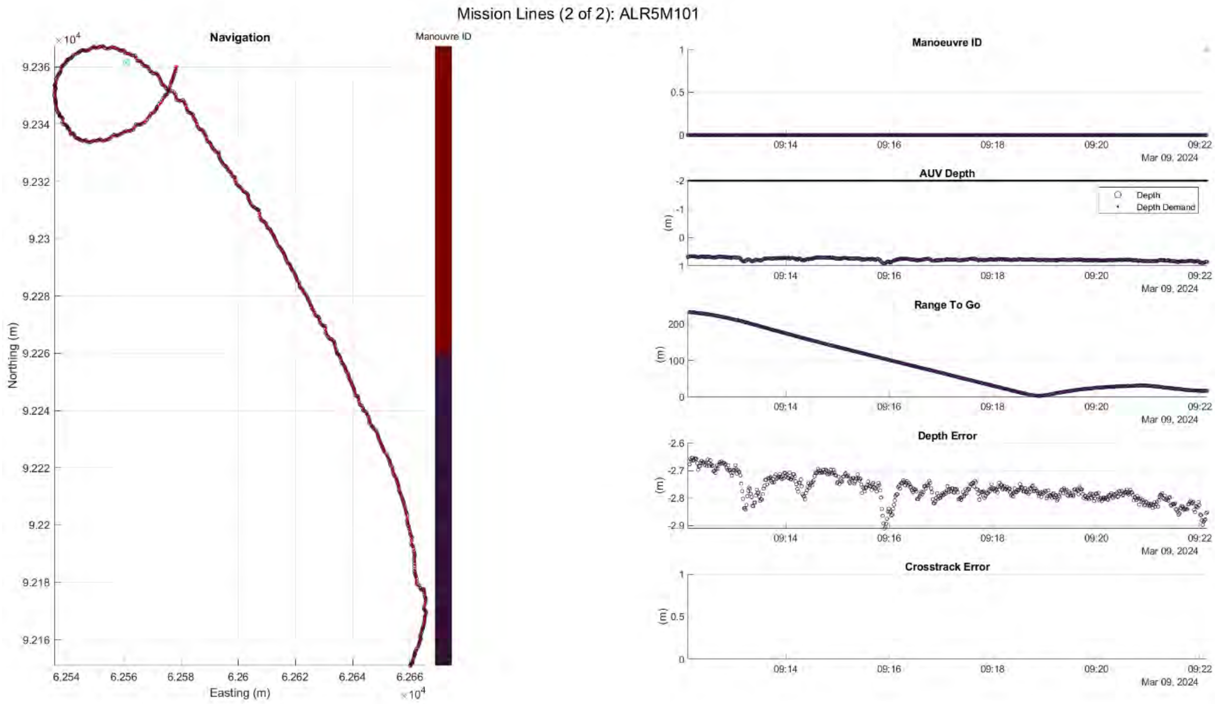
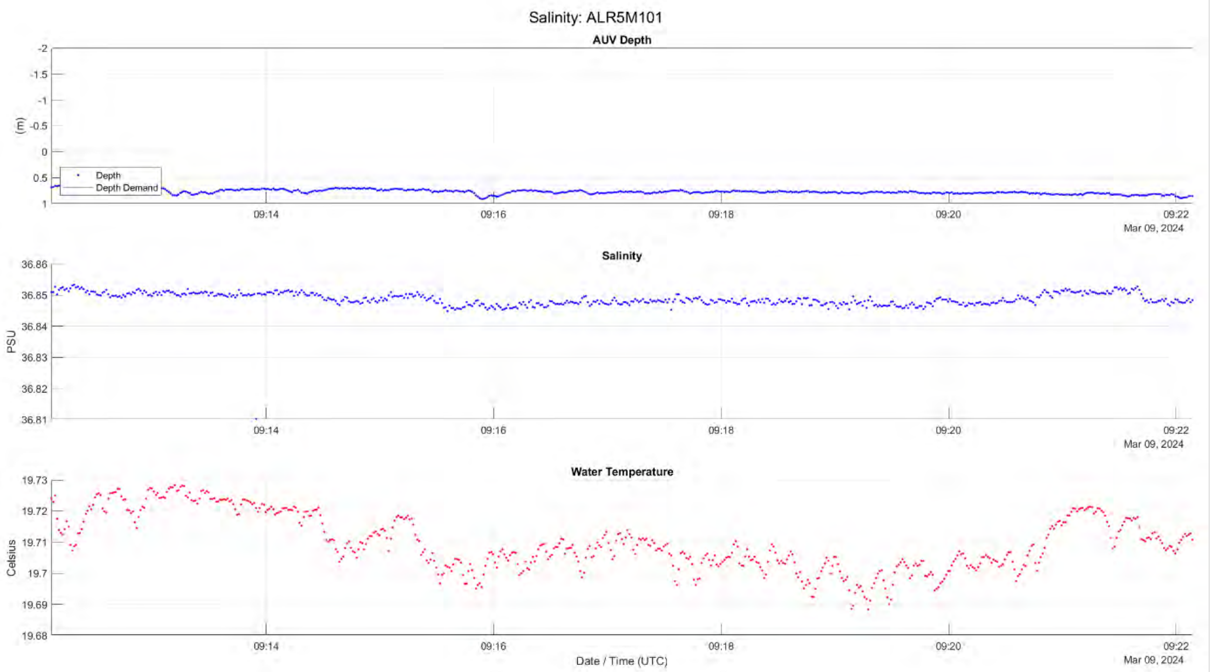
MISSION DETAILS				SENSOR STATUS										MISSION METRICS											
ALR5 Mission Number	Mission Segment	Start Date & Time (UTC)	End Date & Time (UTC)	CTD + DO	ADCP Up/Down	FLCDRTD	HUB	LoC DIC/TA	LoC Phosphate Silicate	LoC Nitrate Phosphate	UVP6	mSTAF	RoCSI samples	Duration (Days)	Distance Travelled Underwater (km)	Average Power (W)	Energy Used (kWh)	Percent of Pack Used	Average SOG (m/s)	Max Depth (m)	Min Altitude (m)	Percent Bottom Lock	Average Surfacing Error (m)	Percent Error of DT	Mission Log MTSN
	Southern Deplpoyment																								
	>>Sensors On - 15.03 OCS Def - Turn LoC Sensors On (5 mins)																								
ALR5M114	C01b 10 min Test dive (15m) at South WP	16/03/2024 12:53	16/03/2024 13:18	ON	ON	ON	ON	ON	ON	ON	ON	OFF	-	0.02	0.59	44.97	0.02	0.11%	0.58	15.59	46.1	67.41	15.75	2.7%	9863
	>>Sensors On - 15.03 OCS Def - Turn LoC Sensors On (5 mins)																								
ALR5M115	T0a Transit South Profiling	16/03/2024 13:25	16/03/2024 18:10	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	1	0.20	9.92	46.09	0.22	1.33%	0.62	300.95	0.0	0.54	183.39	1.8%	9875
ALR5M116	Profile to 300m and Surface for High Res NRT	16/03/2024 18:10	16/03/2024 19:17	ON	ON	ON	ON	Idle	Idle	Idle	ON	OFF	-	0.05	2.17	49.52	0.06	0.34%	0.68	305.33	0.0	0.06	265.7	12.2%	9879
	>>Sensors On - 15.03 OCS Def - Turn LoC Sensors On (5 mins)																								
ALR5M117	T0b Transit South Profiling	16/03/2024 19:31	17/03/2024 09:42	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	3	0.59	28.37	44.39	0.63	3.82%	0.59	301.24	0.0	0.07	3329.45	11.7%	-
ALR5M118	Profile to 500m and Surface for High Res NRT	17/03/2024 09:42	17/03/2024 11:09	ON	ON	ON	ON	Idle	Idle	Idle	ON	OFF	-	0.06	2.79	48.94	0.07	0.43%	0.67	506.21	0.0	0.00	726.89	26.1%	9900
	>>Sensors On - 15.03 OCS Def - Turn LoC Sensors On (5 mins)																								
ALR5M119	17.03 Survey Transect Towards: 27.4148°, -15.8598°	17/03/2024 11:27	17/03/2024 16:18	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	-	0.20	10.73	46.81	0.23	1.37%	0.63	500.95	0.0	0.06	2432.88	22.7%	9908
	>>Misson Log - Loiter on surface for 2 hours																								
ALR5M120	17.03_B Survey Transect Towards 27.352°, -15.88° / V 9	17/03/2024 16:38	17/03/2024 17:28	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	6	0.03	-	39.33	0.03	0.20%	0.54	1.1	0.0	-	-	-	9926
	>>Sensors On - Turn Sensors On (5 mins)																								
ALR5M121	17.03_B Survey Transect Towards 27.352°, -15.88° / V 9	17/03/2024 18:13	18/03/2024 09:36	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	-	0.64	31.72	44.35	0.68	4.13%	0.60	301.37	0.0	0.17	5233.46	16.5%	9950
	>>Misson Log - Loiter on surface for 2 hours																								
ALR5M122	Profile to 300m and Surface for High Res NRT	18/03/2024 10:01	18/03/2024 10:53	ON	ON	ON	ON	Idle	Idle	Idle	ON	OFF	-	0.04	1.12	49.18	0.04	0.26%	0.67	306.36	0.0	0.00	357.51	31.9%	9961
	>>15.03 OCS Def - Turn ALL Sensors On (5 mins)																								
ALR5M123	18.03 Survey Transect Towards: 27.14°, -15.63° Version 8	18/03/2024 11:27	19/03/2024 09:24	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	6	0.91	36.39	12.215	0.27	1.62%	0.64	500.89	3.3	0.20	2085.73	5.7%	9988
	>>Misson Log - Loiter on surface for 2 hours																								
	>>Command: sensor_hub > send_summary																								
ALR5M124	Profile to 300m and Surface for High Res NRT	19/03/2024 09:59	19/03/2024 10:51	ON	ON	ON	ON	Idle	Idle	Idle	ON	OFF	-	0.04	1.72	48.72	0.04	0.26%	0.67	305.95	0.0	0.07	294.13	17.1%	10003
	>>15.03 OCS Def - Turn ALL Sensors On (5 mins)																								
	>>option to clear sensor_summary																								
ALR5M125	19.03 Survey Transect: Continue North	19/03/2024 11:07	19/03/2024 11:40	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	6	0.02	-	40.01	0.02	0.13%	0.57	1.2	0.0	NaN	-	-	-
	>>Misson Log - Loiter on surface for 2 hours																								
	>>Command: sensor_hub > send_summary																								
ALR5M126	19.03 Survey Transect: Continue North (2nd attempt)	19/03/2024 13:08	20/03/2024 07:56	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	6	0.78	38.13	42.72	0.80	4.86%	0.60	501.2	2.8	0.06	1967.28	5.2%	10053
	>>Misson Log - Loiter on surface for 2 hours																								
ALR5M127	Profile to 300m and Surface for High Res NRT	20/03/2024 08:21	20/03/2024 09:13	ON	ON	ON	ON	Idle	Idle	Idle	ON	OFF	-	0.04	1.72	49.03	0.04	0.26%	0.67	306.1	0.00	0.00	326.29	19.0%	10063
	>> Request LoC NRT Summary...																								
	>>15.03 OCS Def - Turn ALL Sensors On (5 mins) / LOCs only																								
ALR5M128	20.03 Transit to Sample Point and Samples at Depth	20/03/2024 09:47	20/03/2024 22:03	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	6	0.51	25.20	41.95	0.51	3.12%	0.60	65.5	0.00	0.10	4945.32	19.6%	10088
	>>15.03 OCS Def - Turn ALL Sensors On (5 mins) / LOCs only																								
ALR5M129	21.03 Sample then move to 6km WP	20/03/2024 23:14	21/03/2024 08:43	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	9	0.40	19.53	45.66	0.43	2.63%	0.62	251.3	32.6	27.75	1177.31	6.0%	10119
	>>Loiter at depth till recovery team give go																								
ALR5M130	Move to 3km WP for recovery	21/03/2024 08:58	21/03/2024 10:01	ON	ON	ON	ON	Sampling	Sampling	Sampling	ON	OFF	-	0.04	1.84	38.14	0.04	0.24%	0.56	15.3	38.4	100.00	9.49	0.5%	10127
	On tow at 1130 earliest																								
	>>Turn off all sensors for recovery																								
												Totals:	43	4.6	211.9		4.1	25.1%					Average:	13.26%	
												Mission used equivalent energy stored within					0.39	Litres of Diesel							

11. APPENDIX B: ALR 5 Mission Detail

11.1. ALR5M101: C01 Surface Run:





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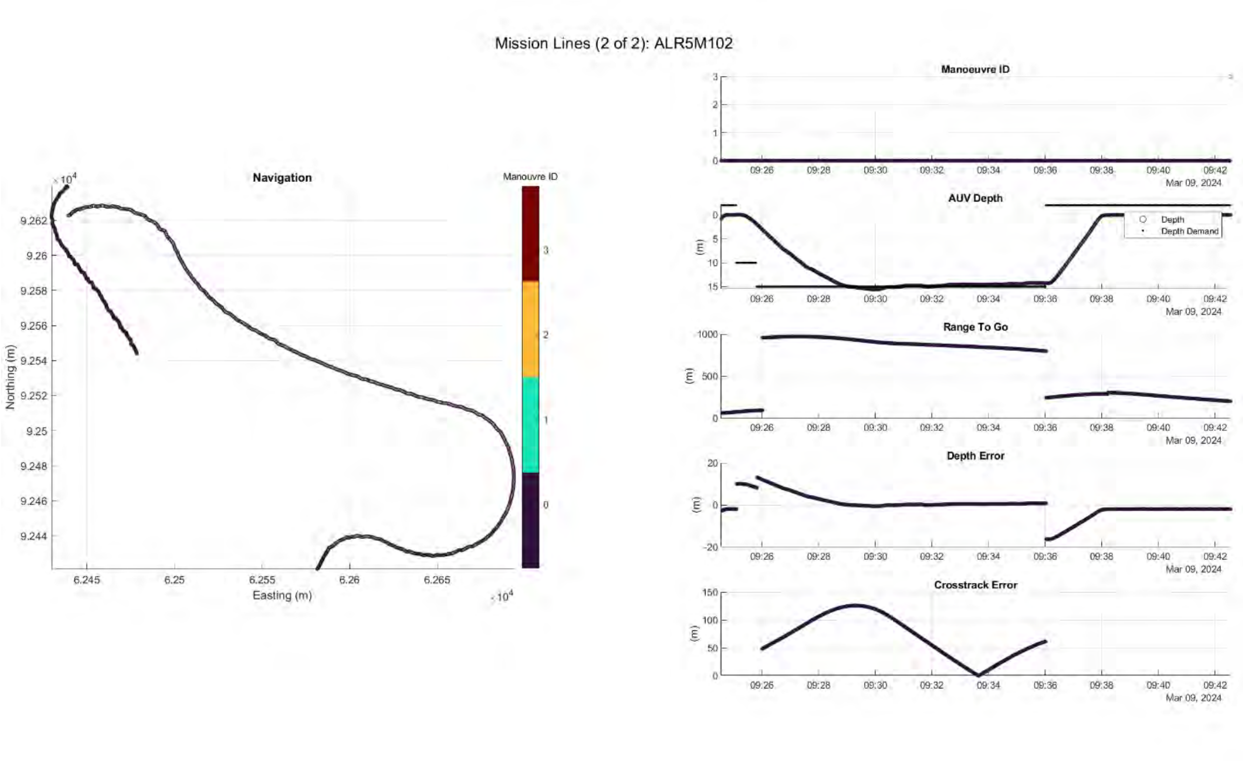
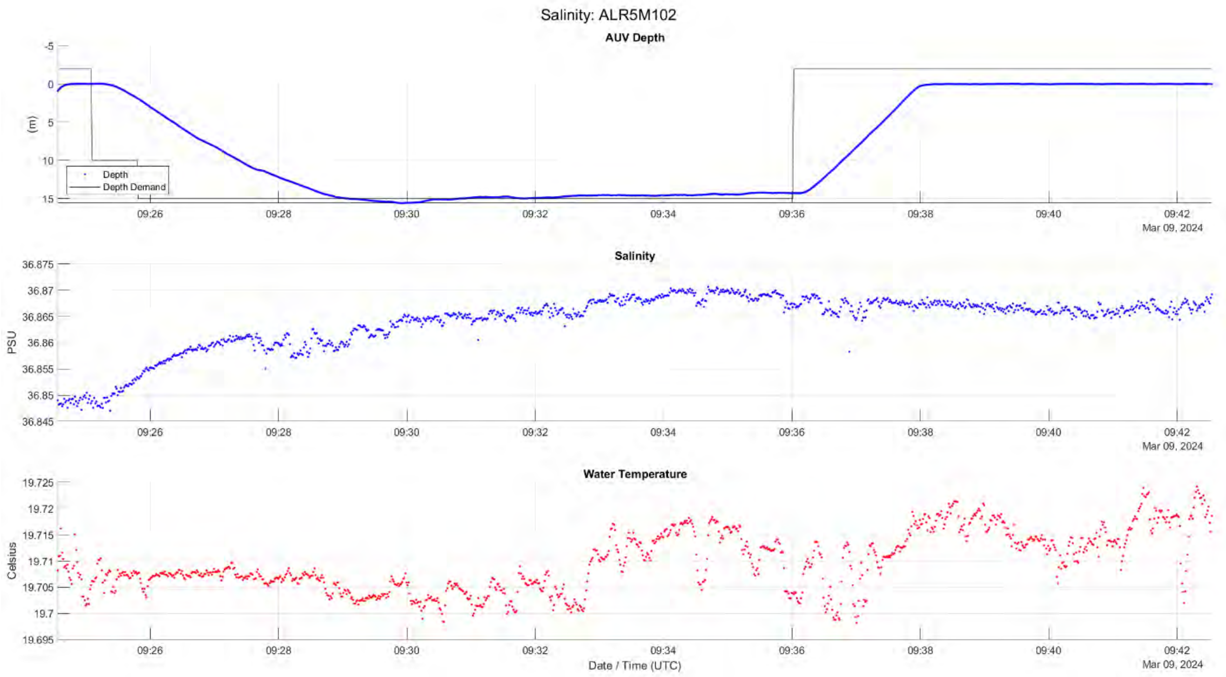
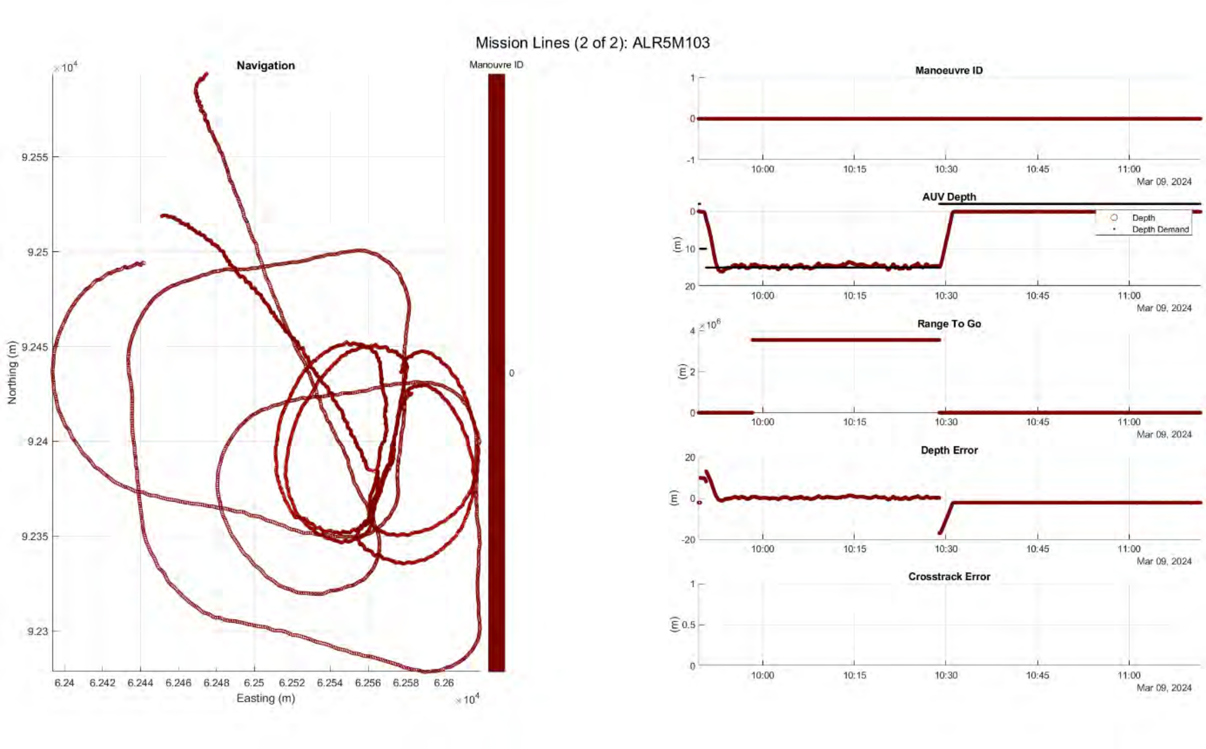
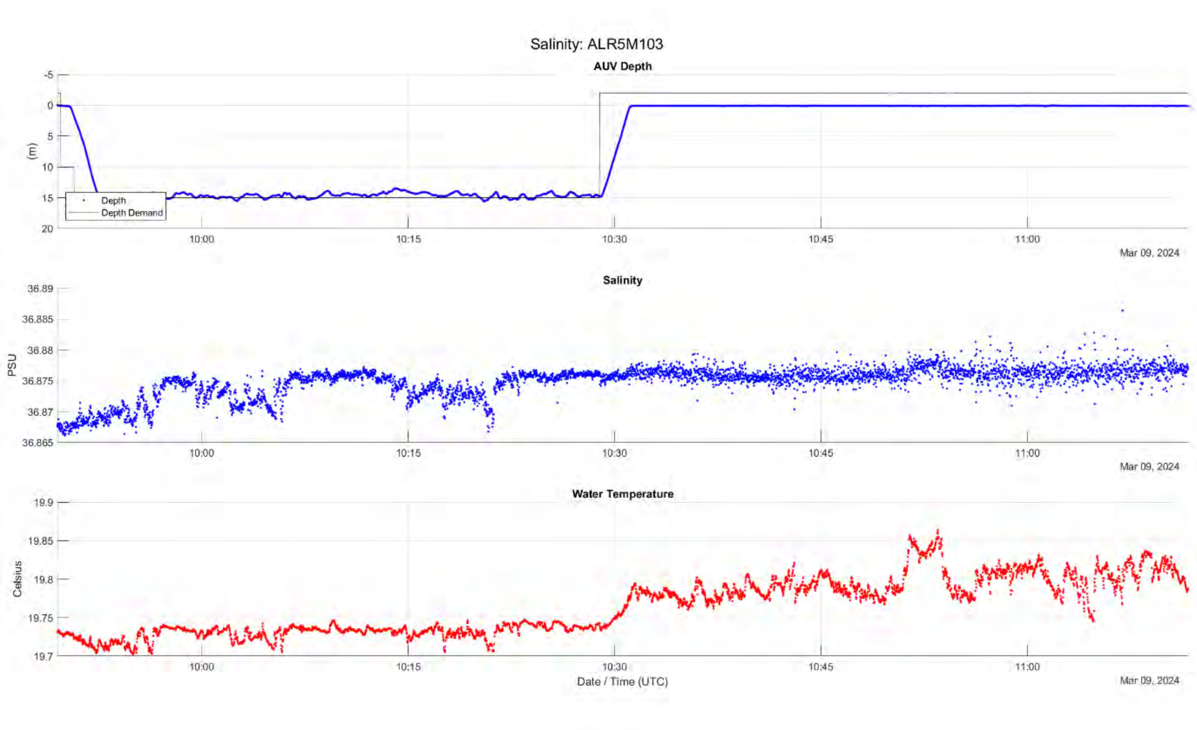
11.2. ALR5M102: C01a 10min Test Dive (15 m):



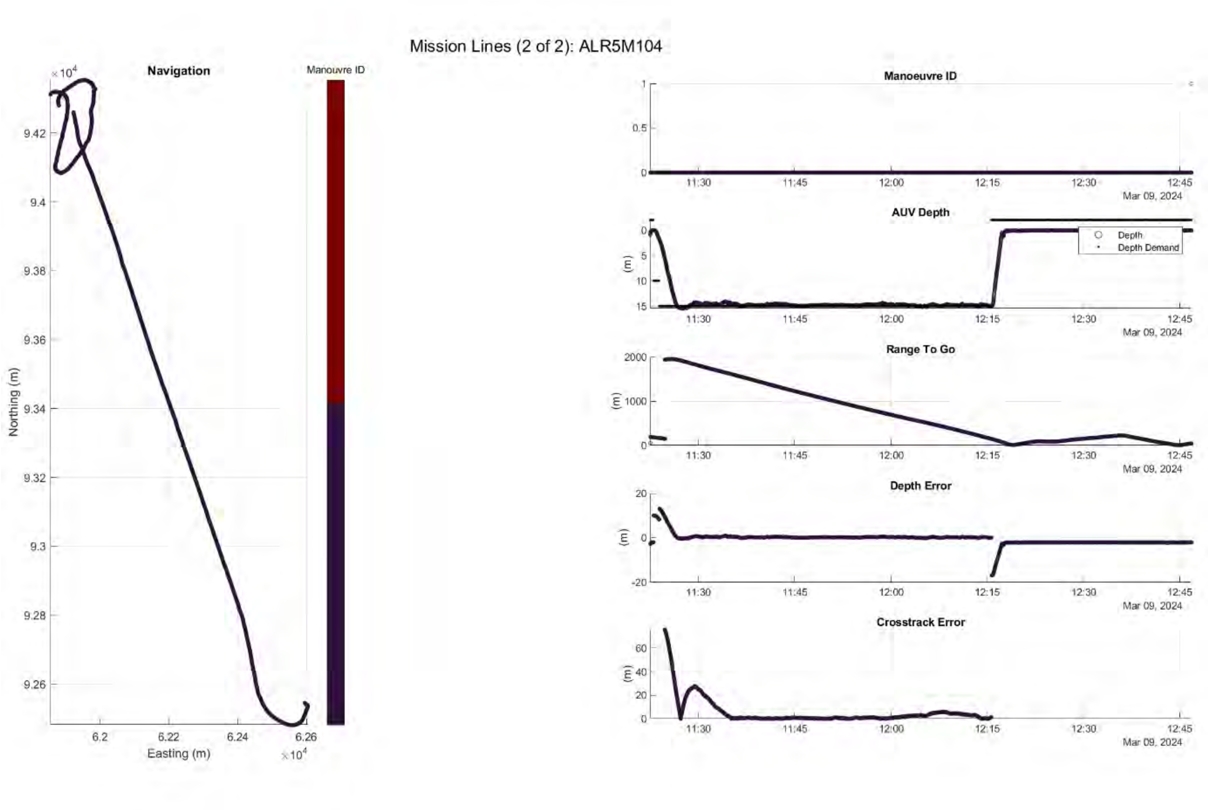


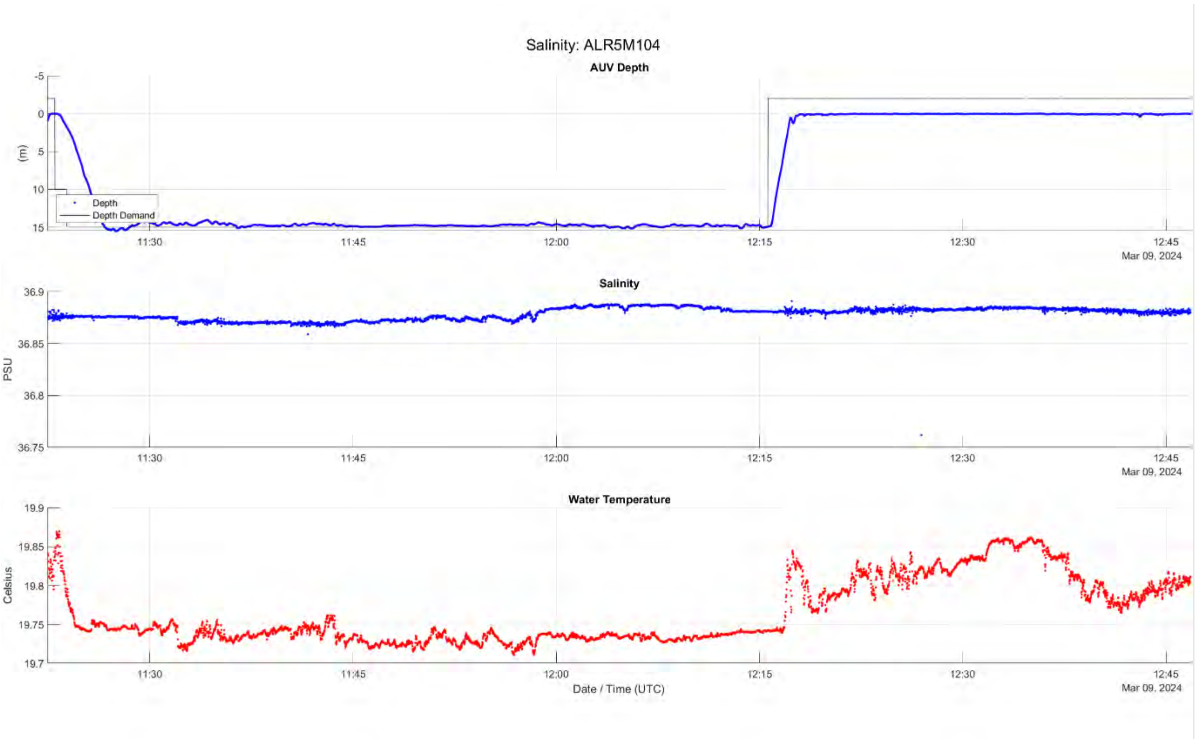
11.3. ALR5M103: C02a Compass Cal + Rocsi



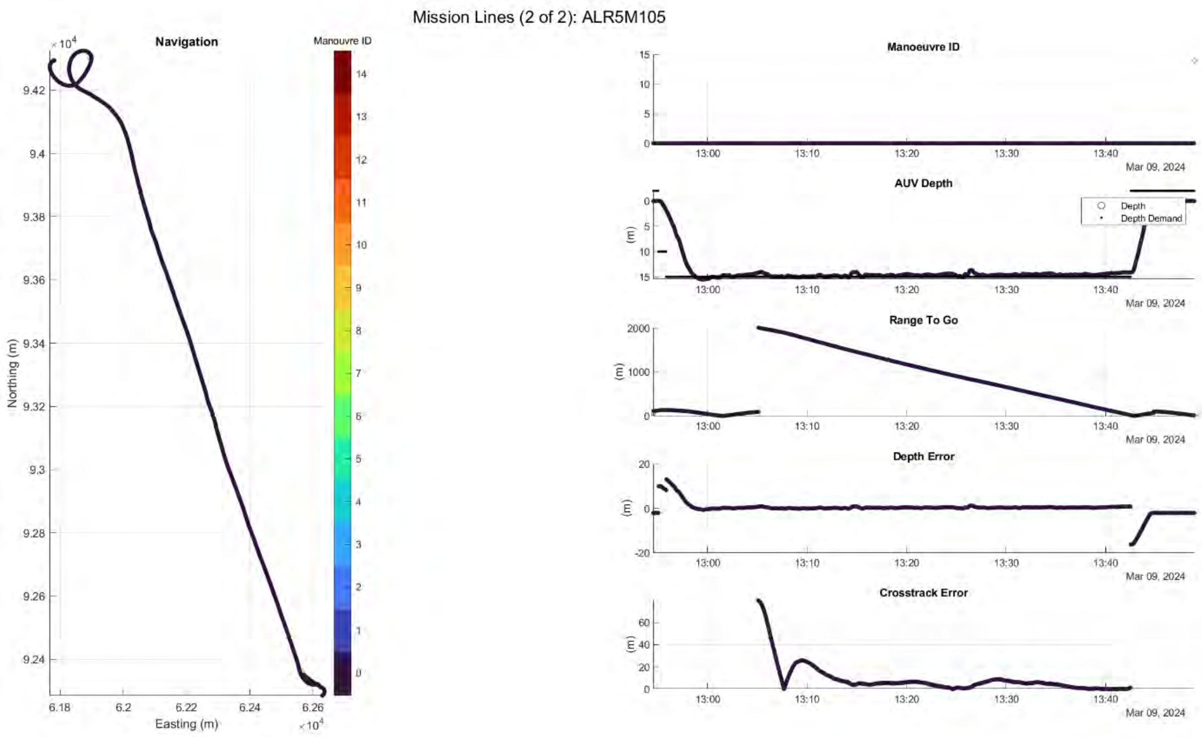


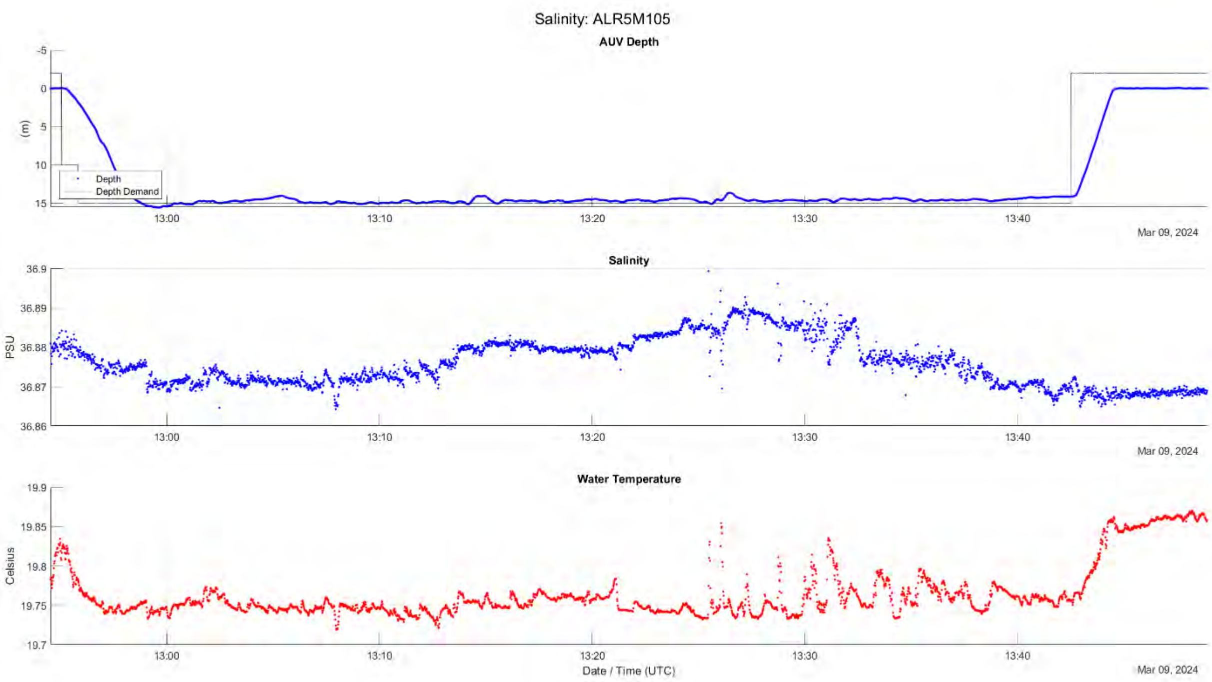
11.4. ALR5M104: C03 Alignment (Northward)



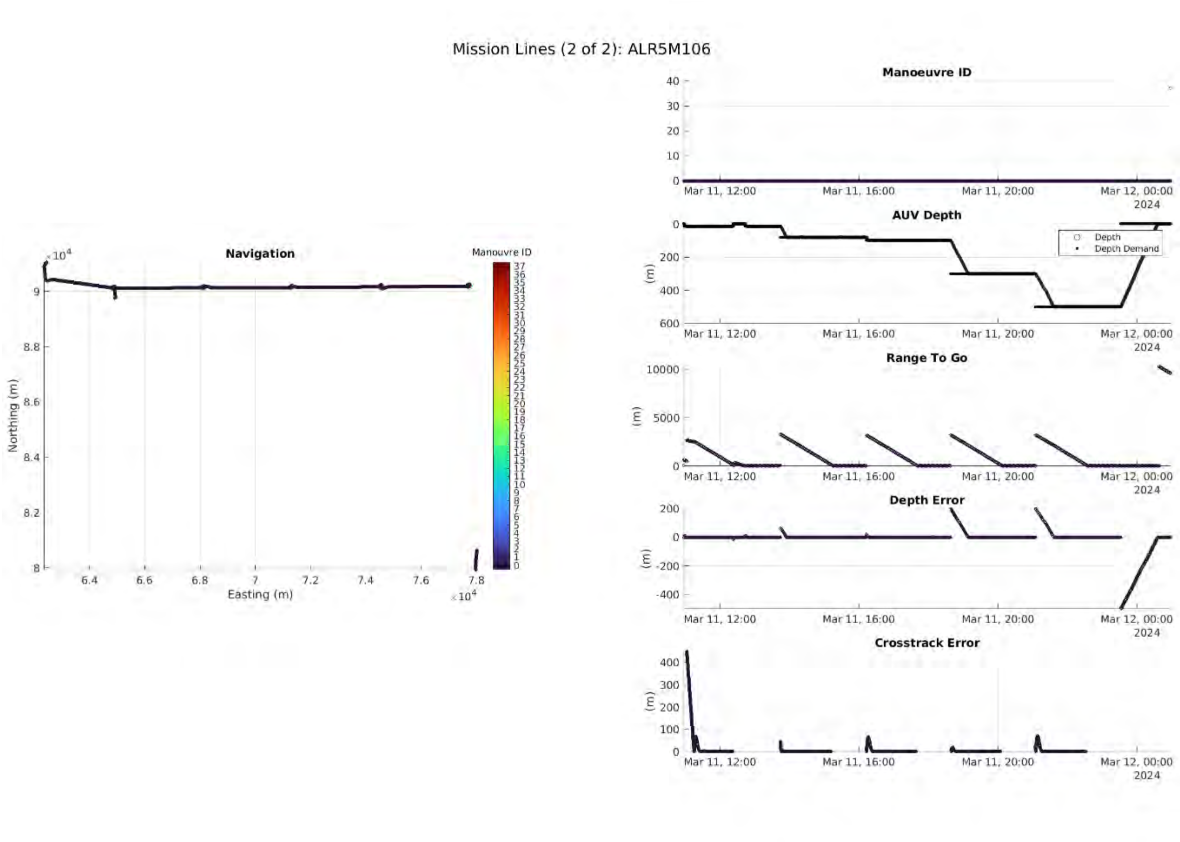


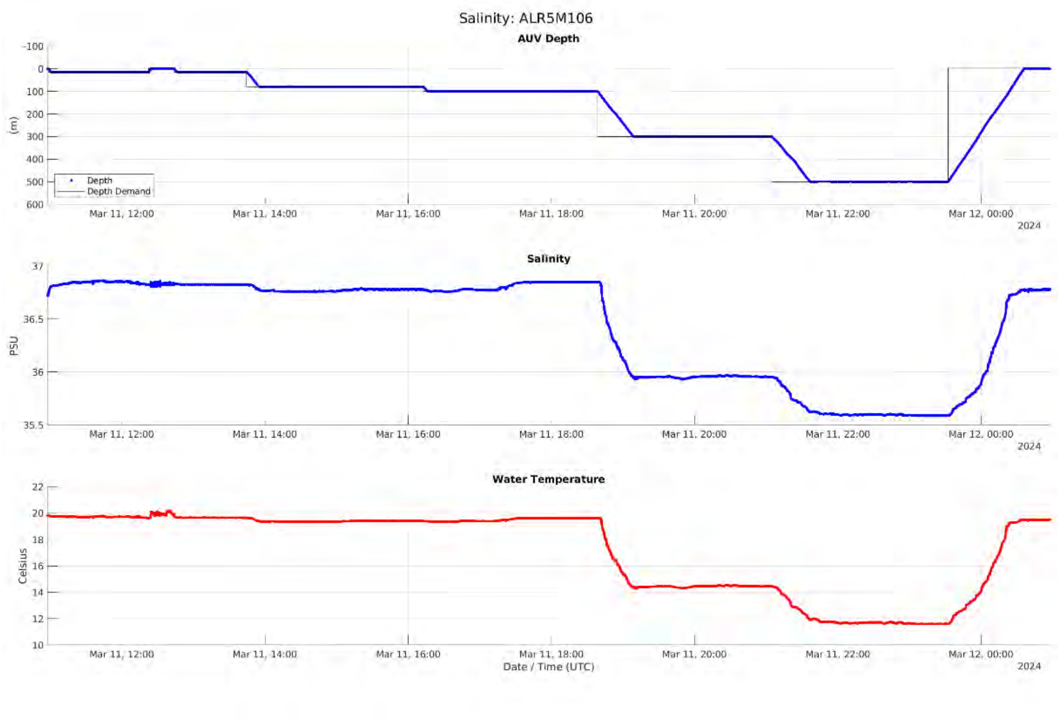
11.5. ALR5M105: C04b Endurance Run + Rocsi



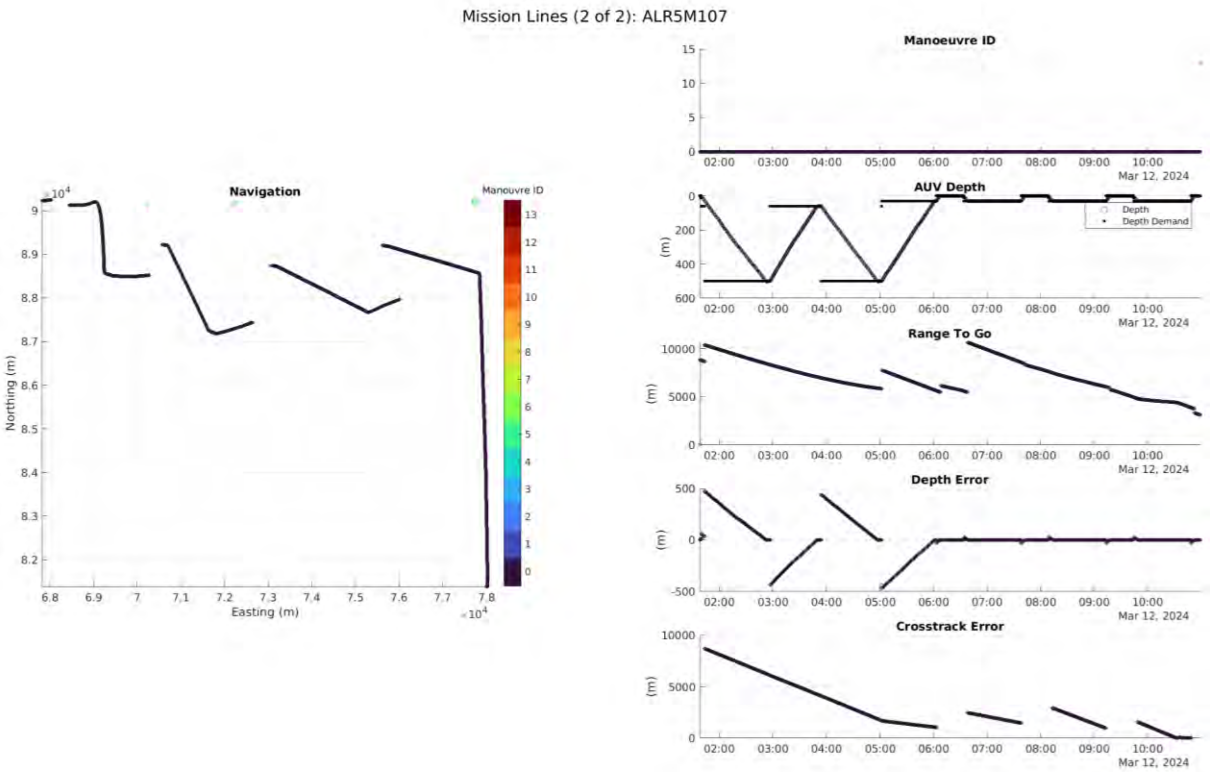


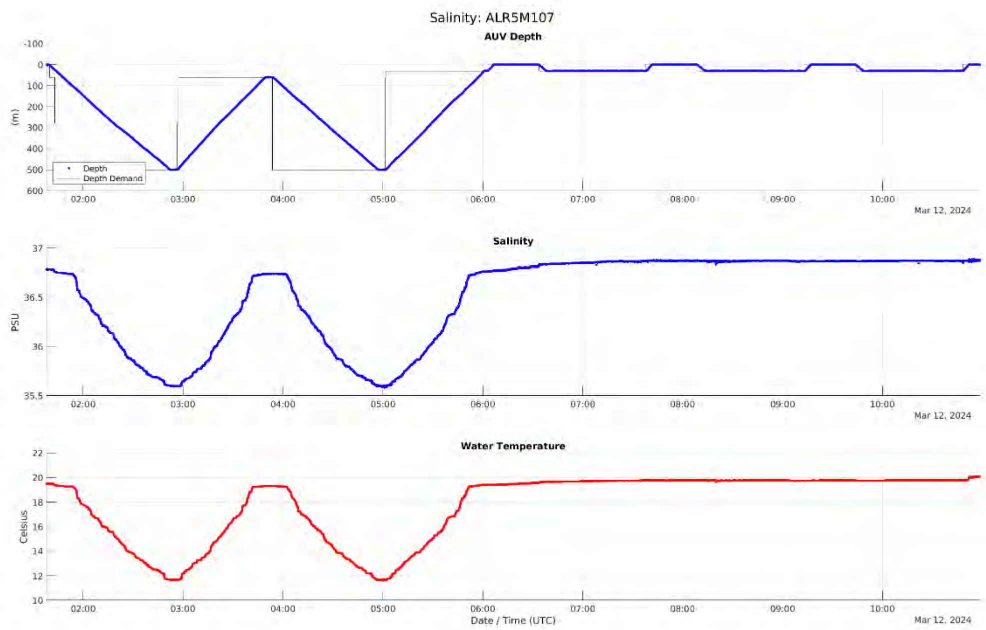
11.6. ALR5M106: ST0 Sensor Tests Outbound



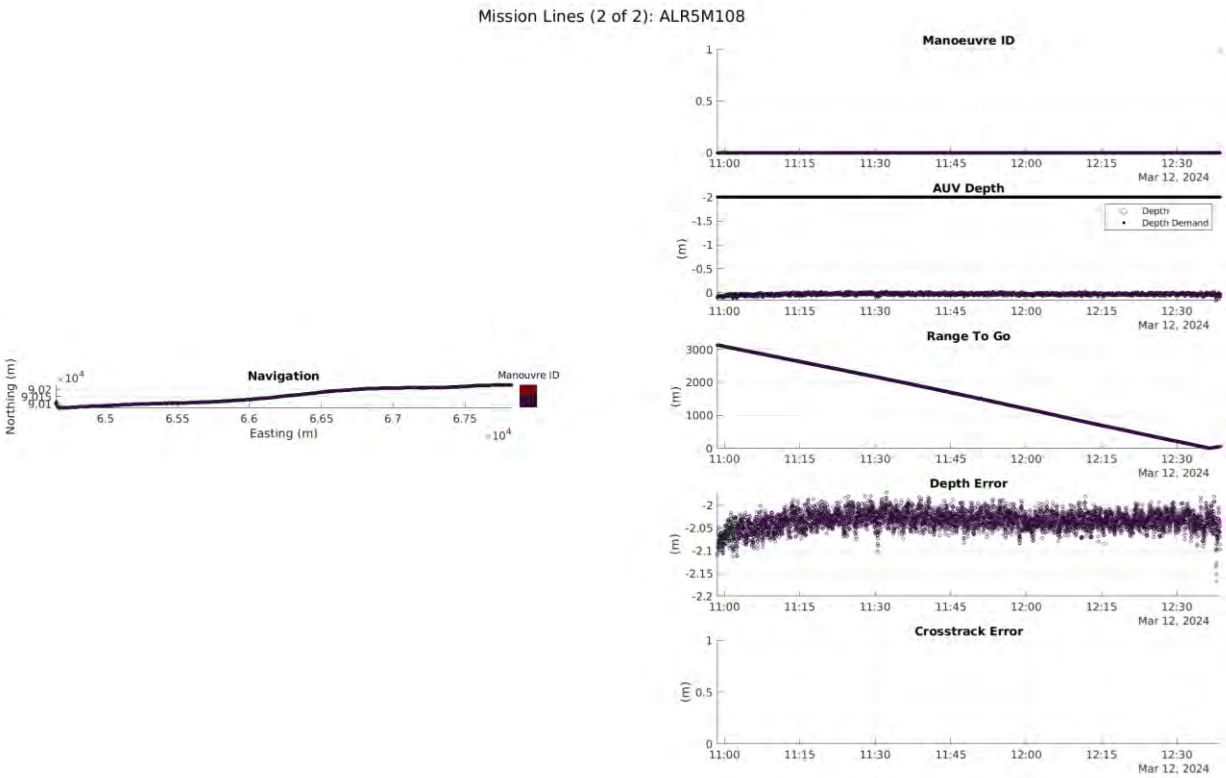


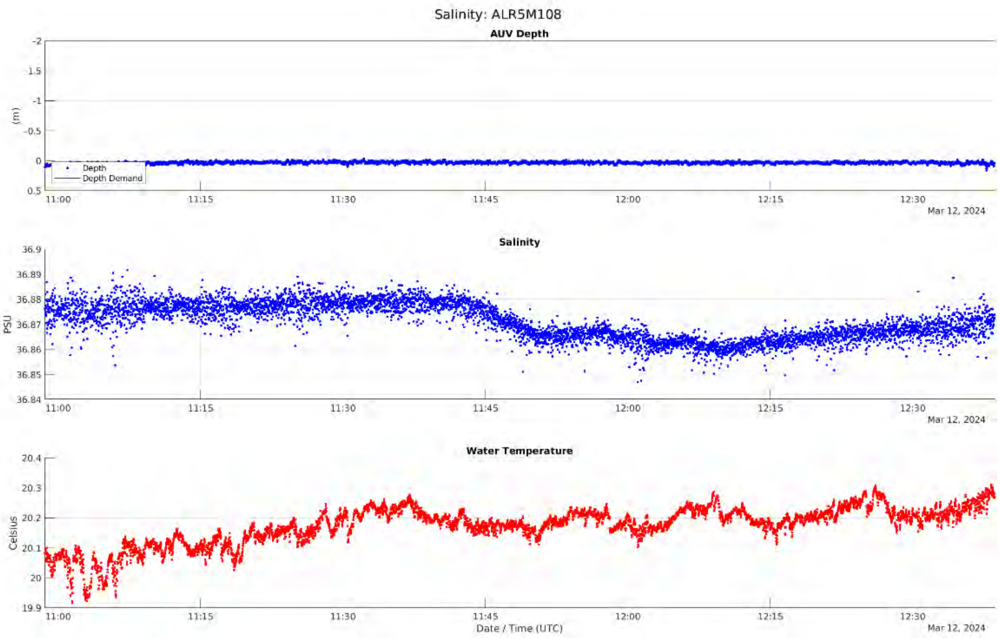
11.7. ALR5M107: ST1a Sensor Tests Inbound Profiles



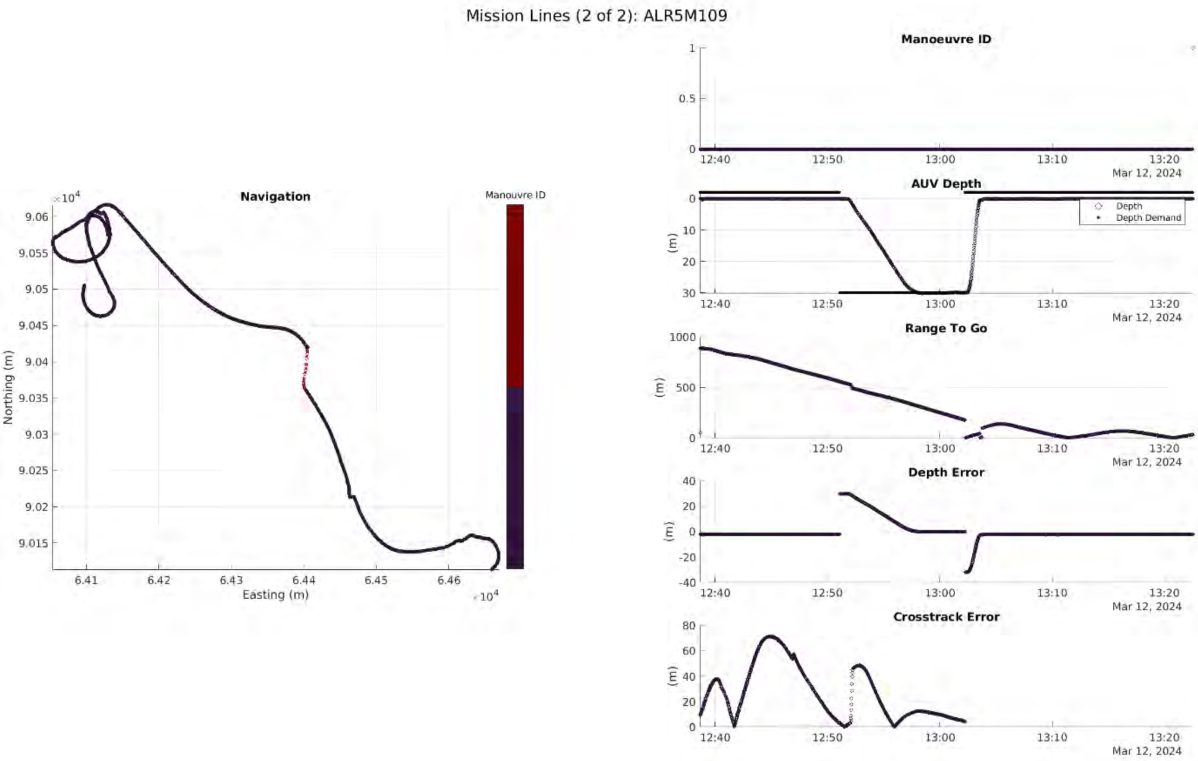


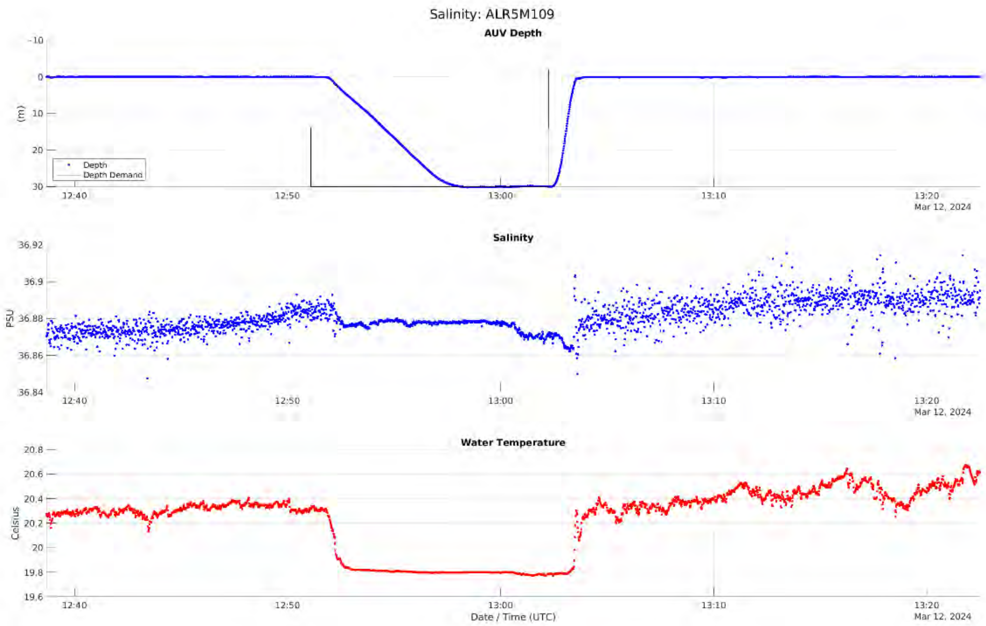
11.8. ALR5M108: Loiter on surface

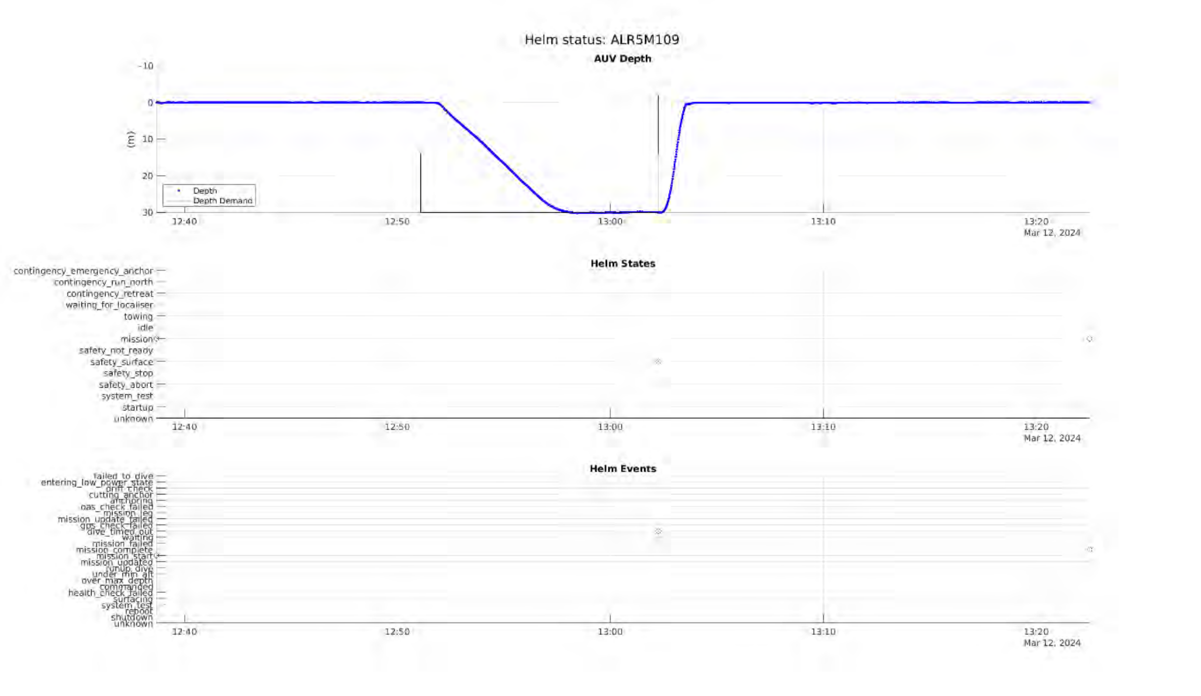


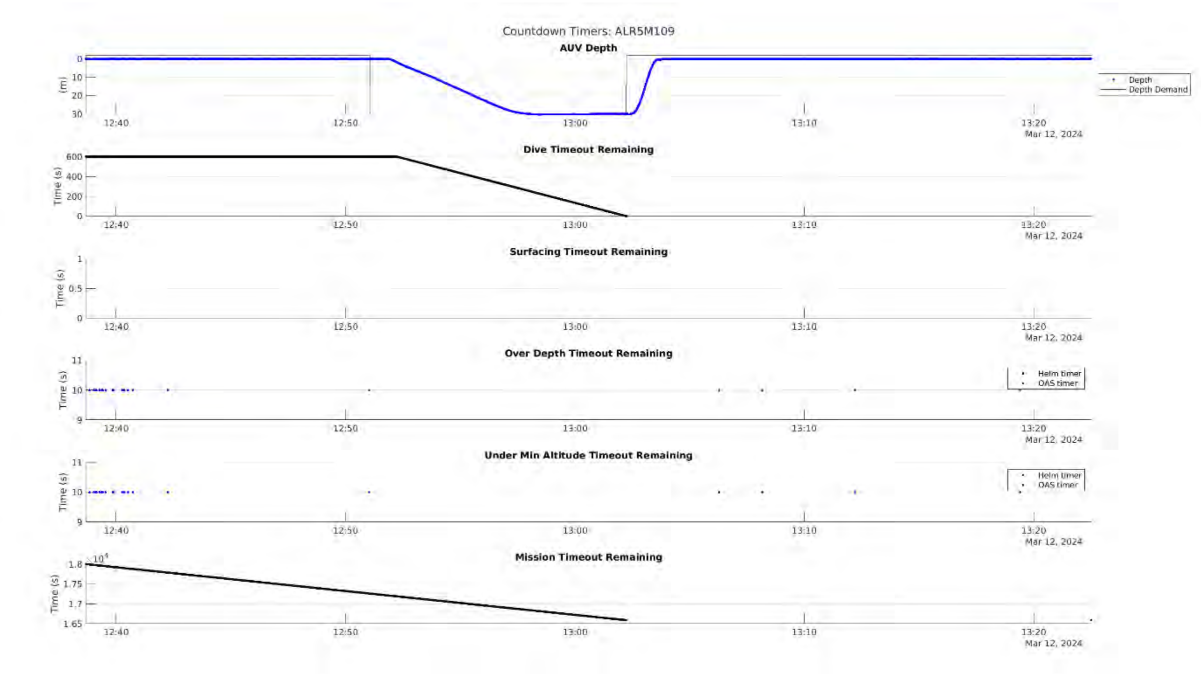


11.9. ALR5M109: Track follow & Loiter (missing dive command)



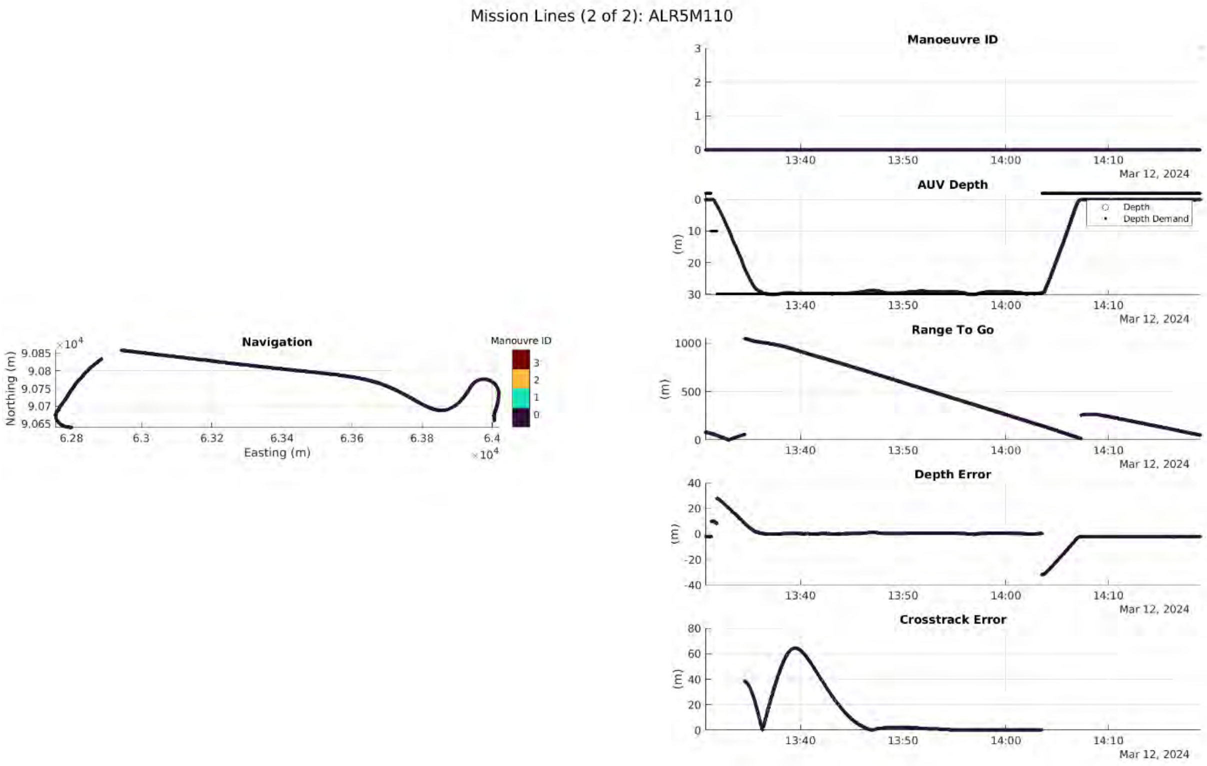


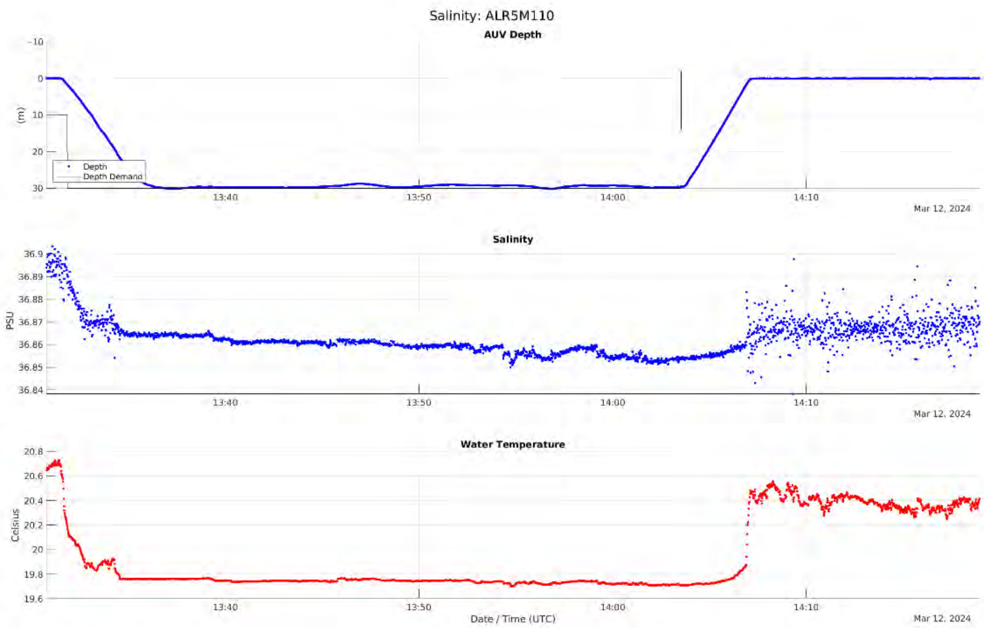




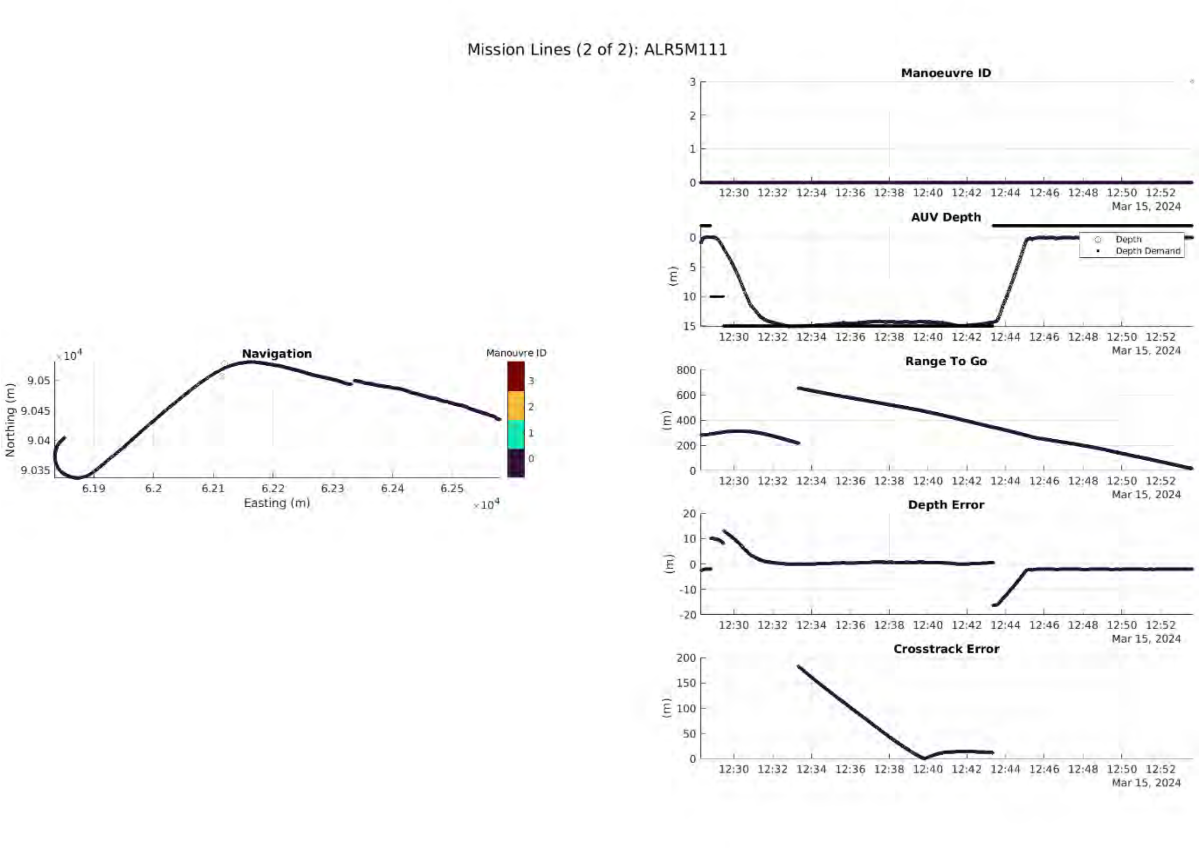
Dive incorrectly omitted from command script, resulting in a dive timeout and safety surface. Resume sent to return the vehicle to idle.

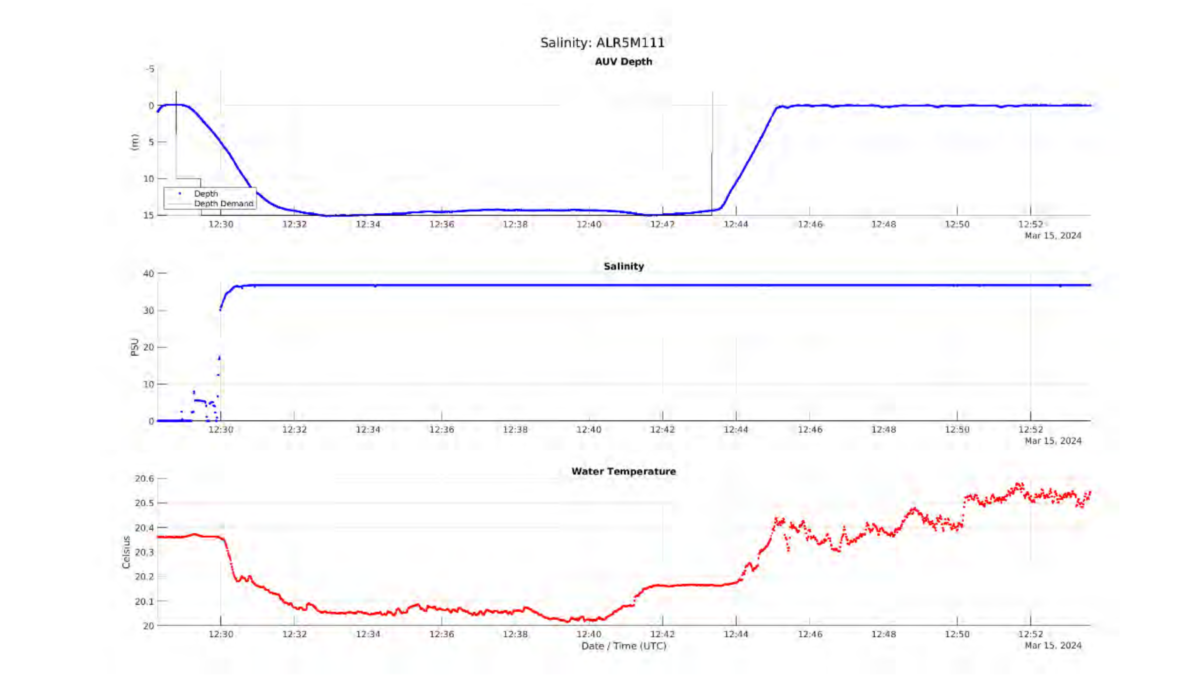
11.10. ALR5M110: ST1c Final Leg to Recovery 45min Timeout



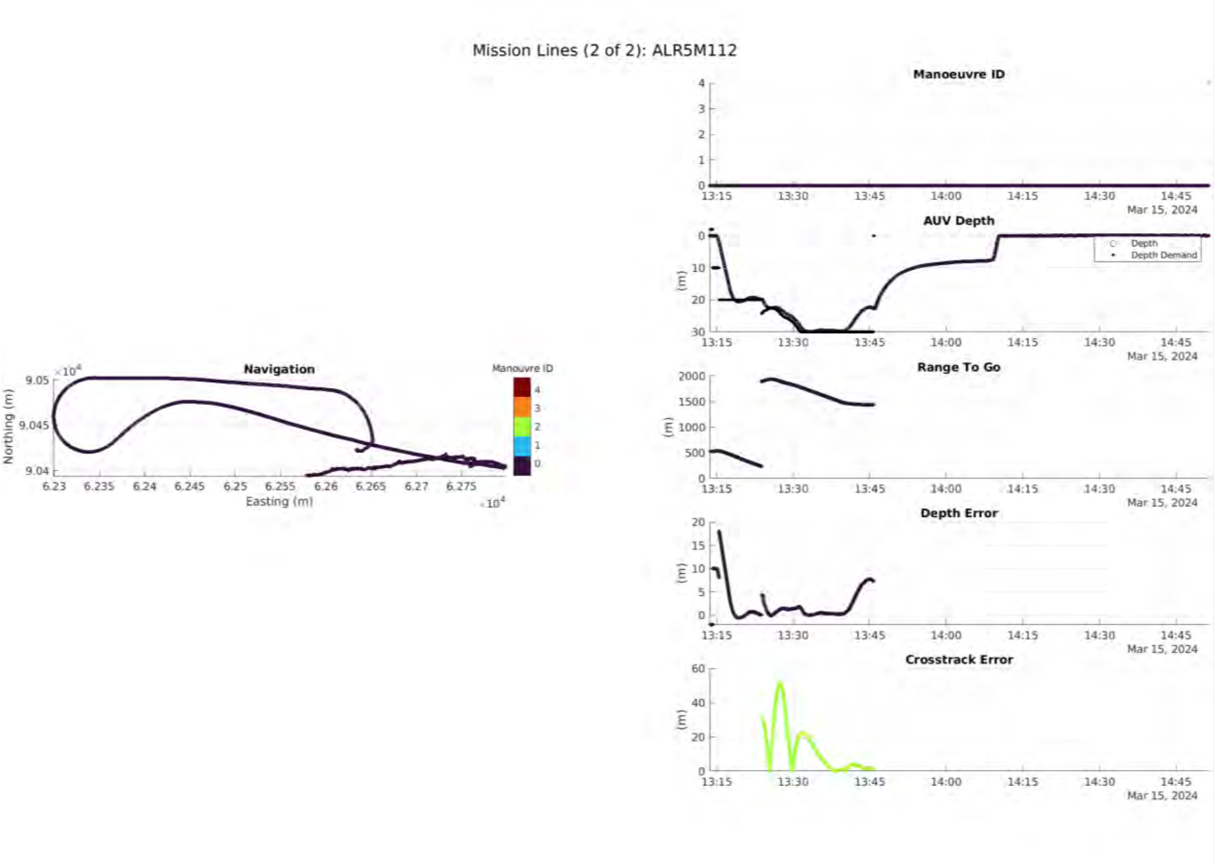


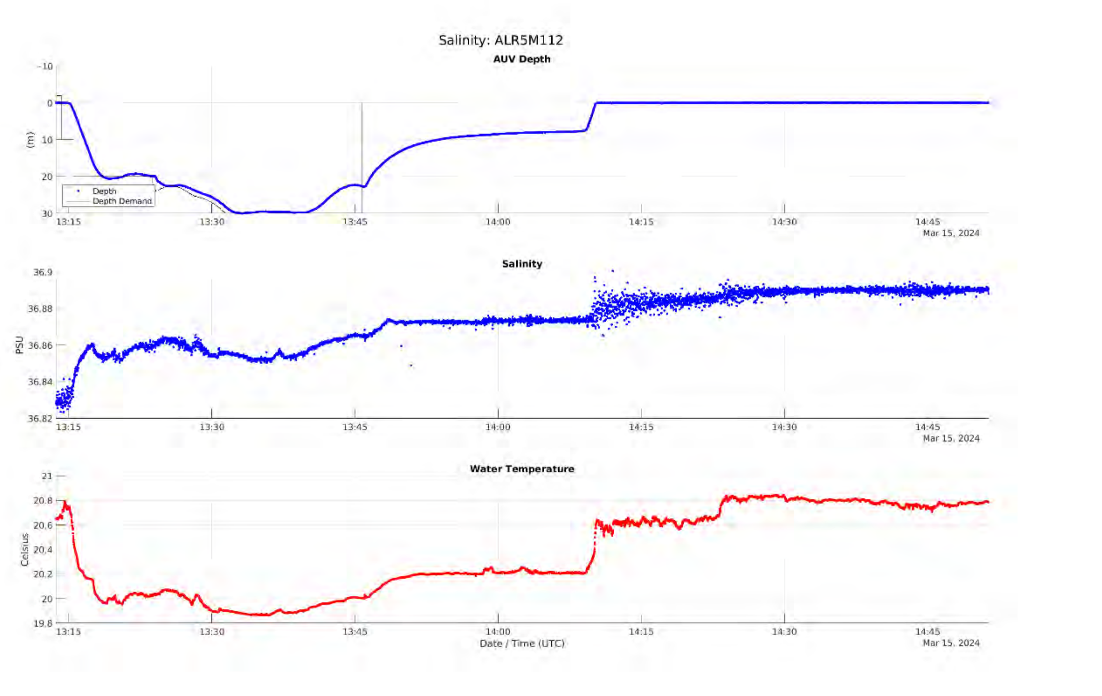
11.11. ALR5M111: C01b 10 min Test dive (15m) at South WP

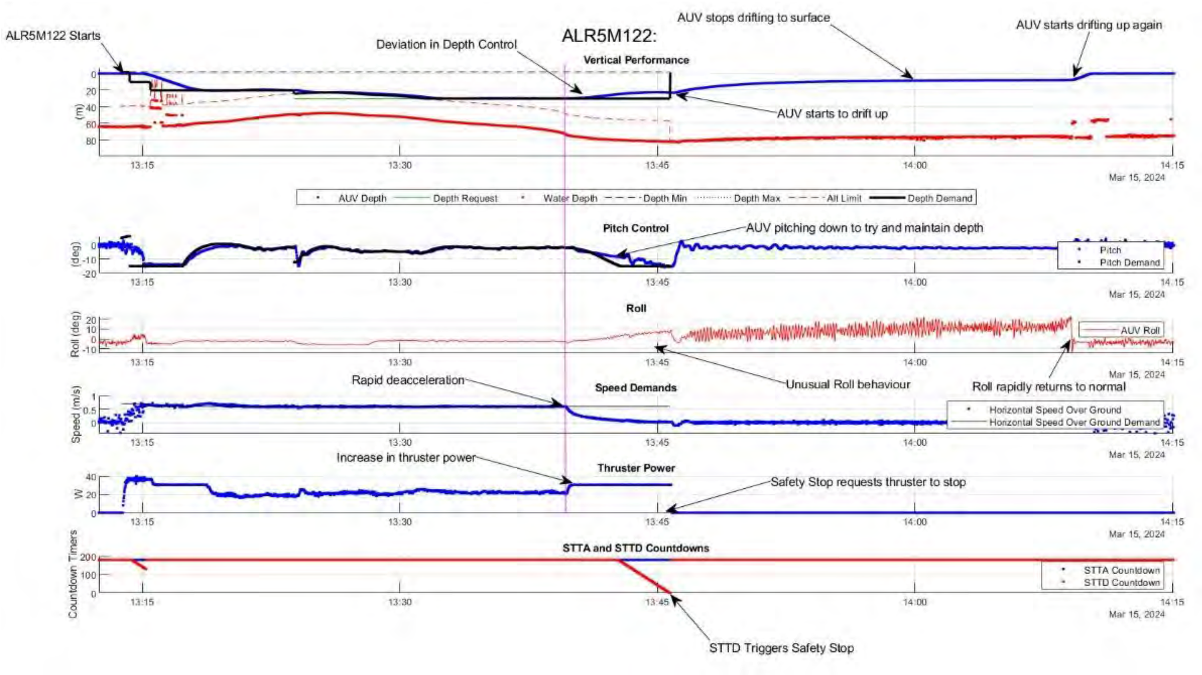




11.12. ALR5M112: T0a Transit South

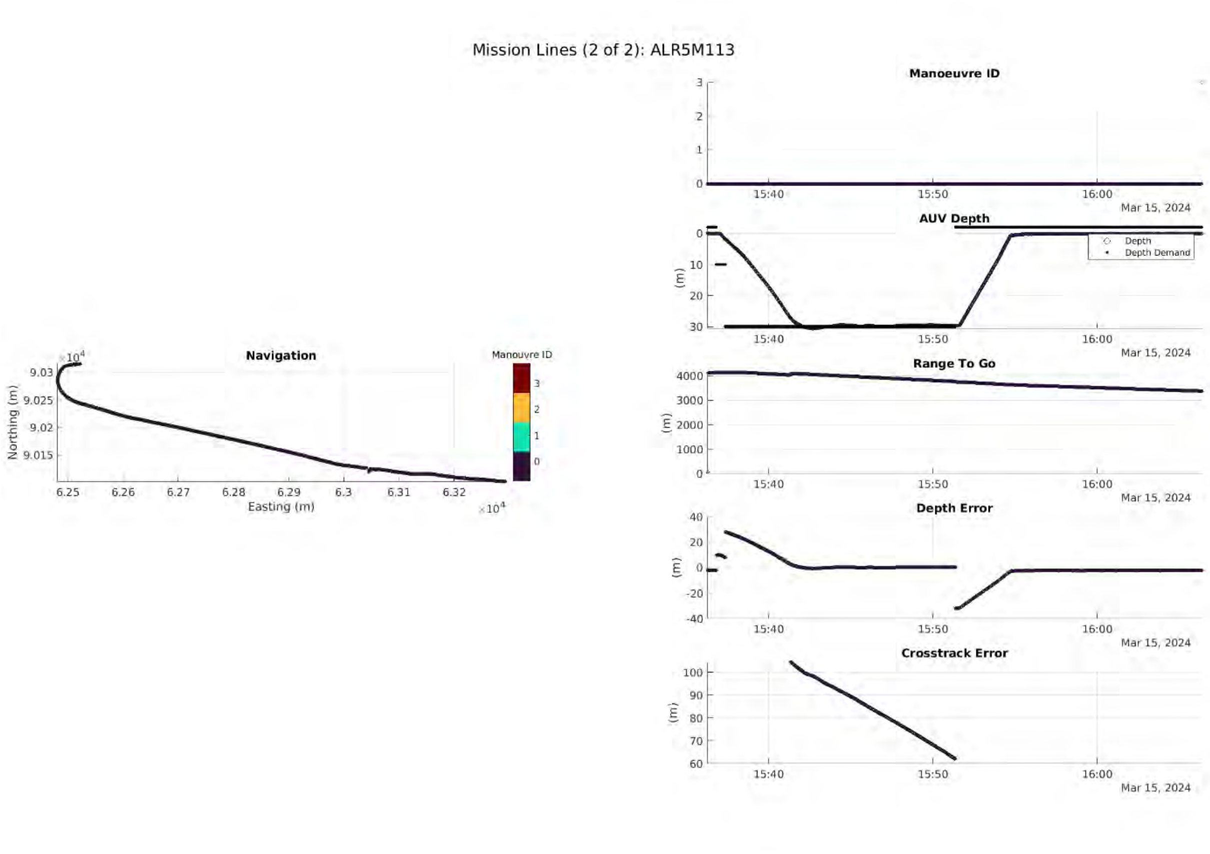


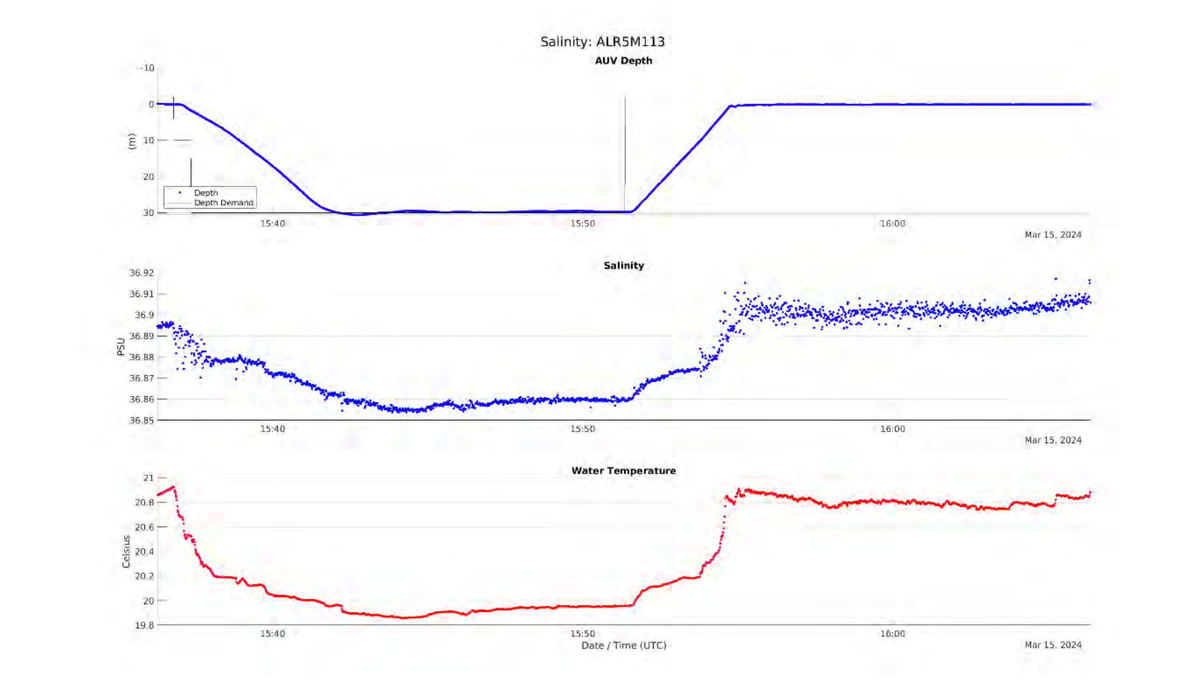




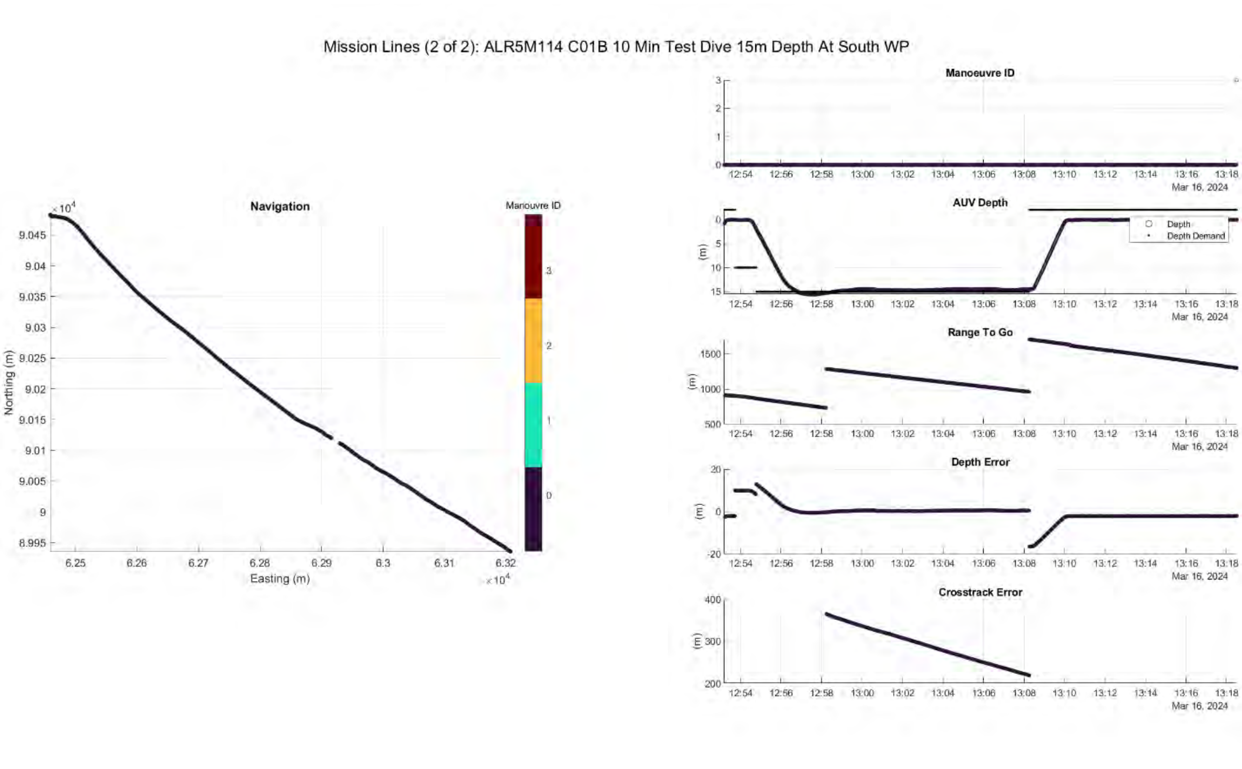
The ALR surfaced in a safety stop configuration, having not made much progress on its journey South. Post deployment analysis suggested the ALR hit an underwater obstruction (such as a ghost mooring line) and failed to reach the commanded dive depth, triggering a stuck trying to decent fault condition. This condition turns off the prop and angles the control surfaces to return the ALR to the surface. However, as the ALR started to drift towards the surface it was held for a period at approximately 8m depth before the strong changing currents allowed the ALR to release from the obstruction and return to the surface. These data above confirm the ALR experienced a rapid deceleration and pitch compensation behaviour consistent with hitting a submerged obstruction, and then unusual roll behaviour until it became disentangled and returned to the surface.

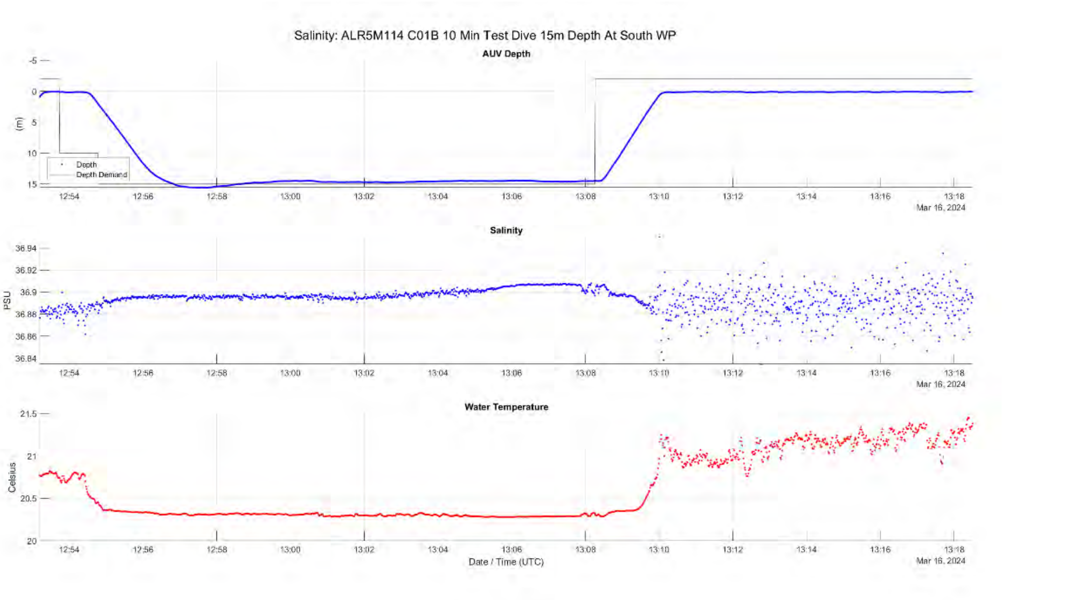
11.13. ALR5M113: 30m Test Dive



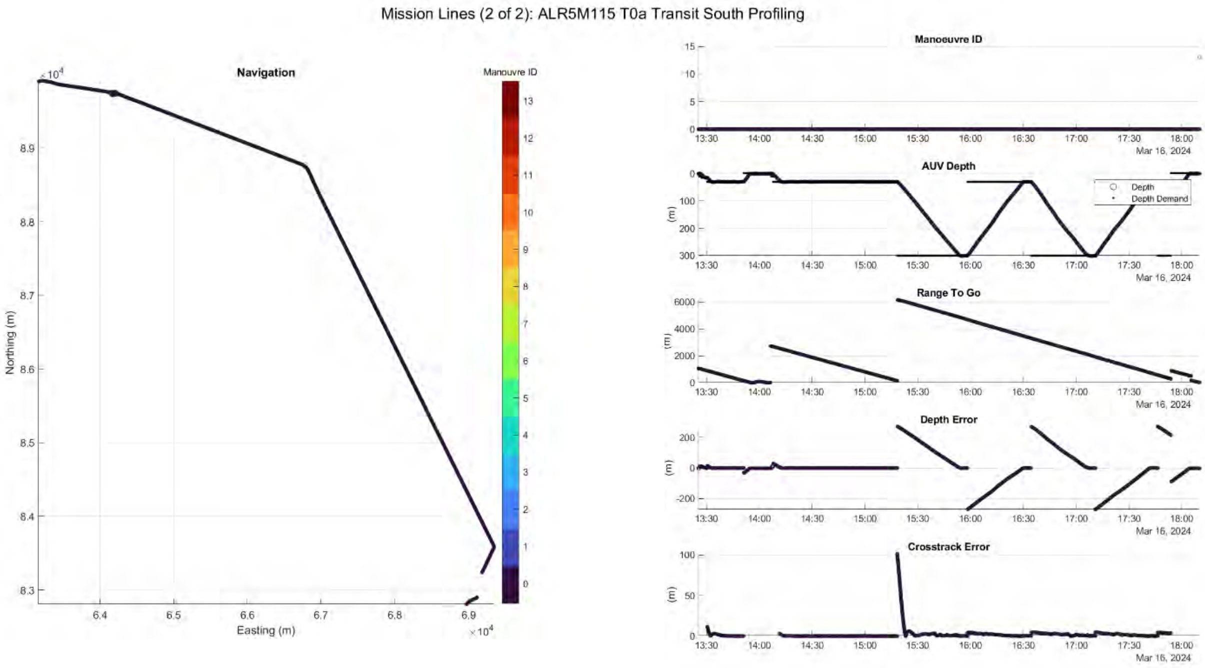


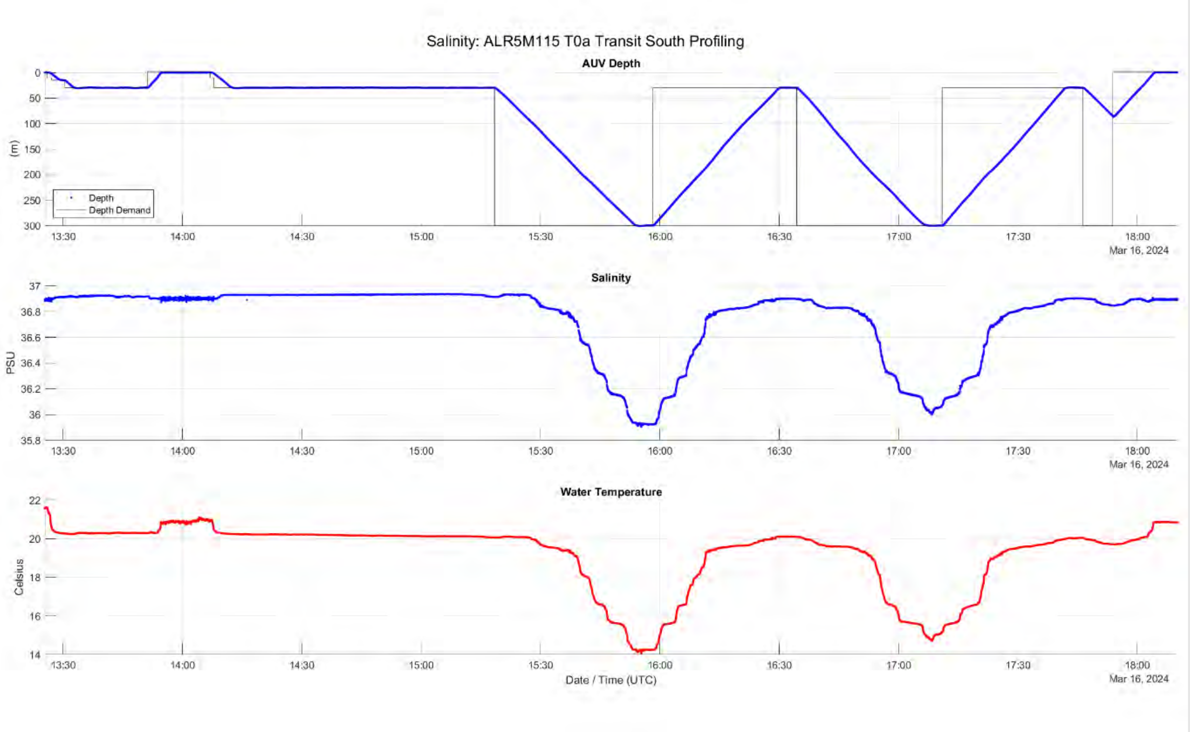
11.14. ALR5M114: C01b 10 min Test dive (15m) at South WP



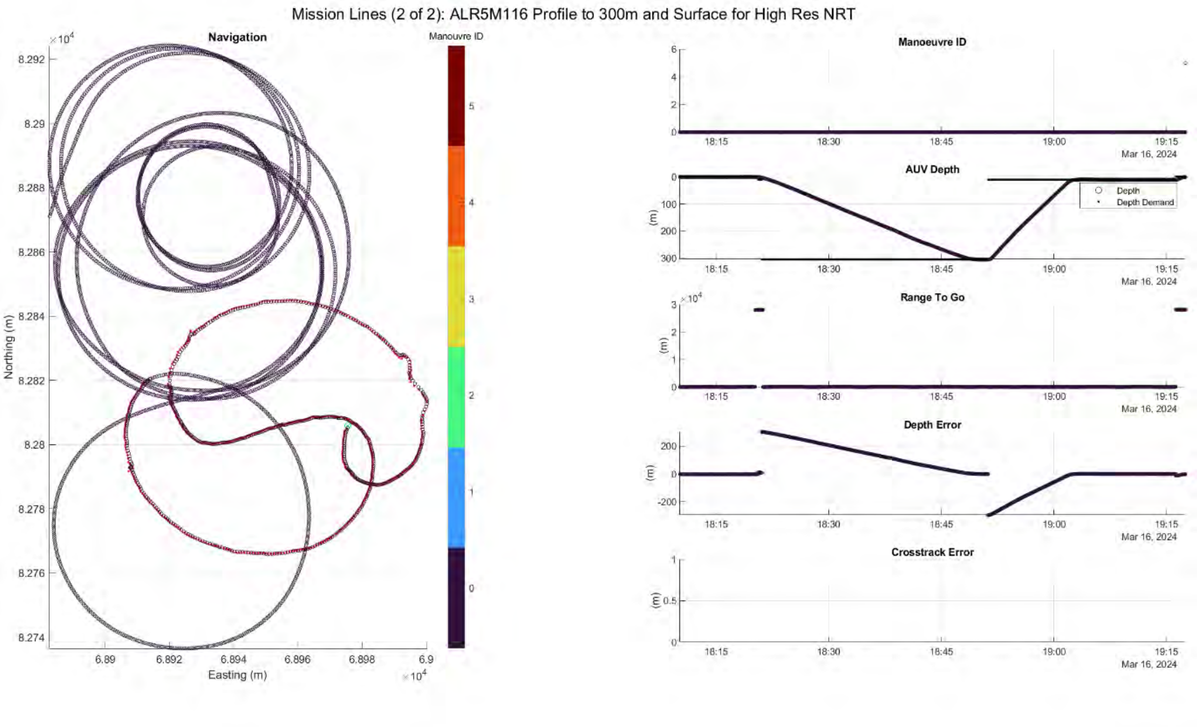


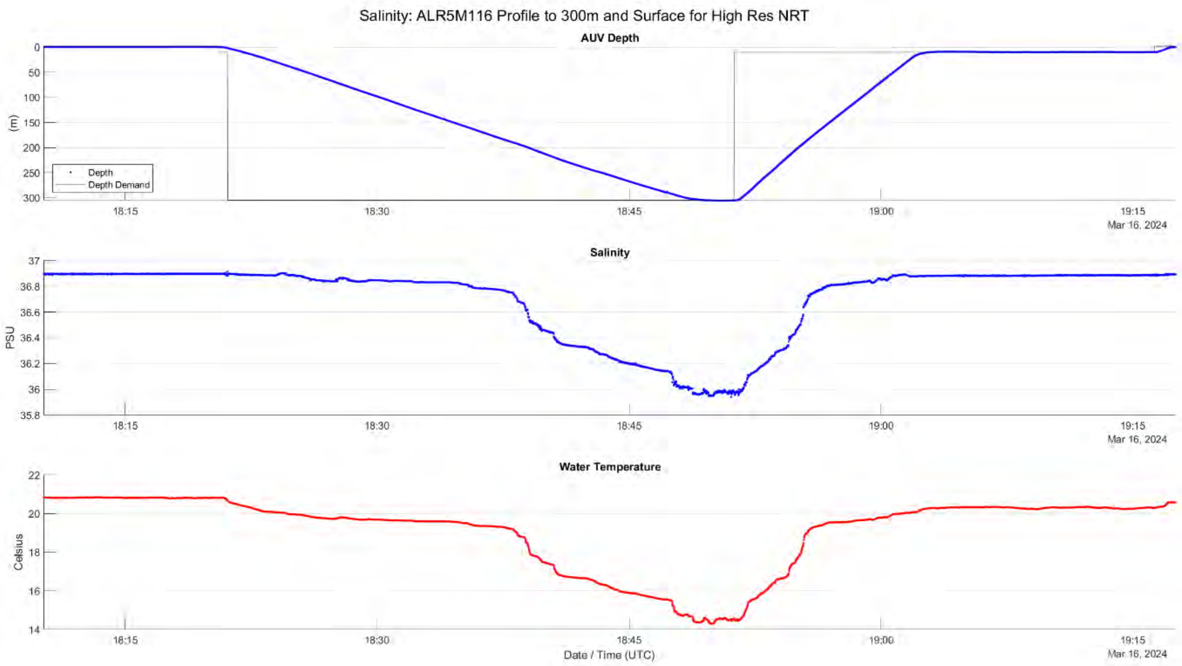
11.15. ALR5M115: T0a Transit South Profiling



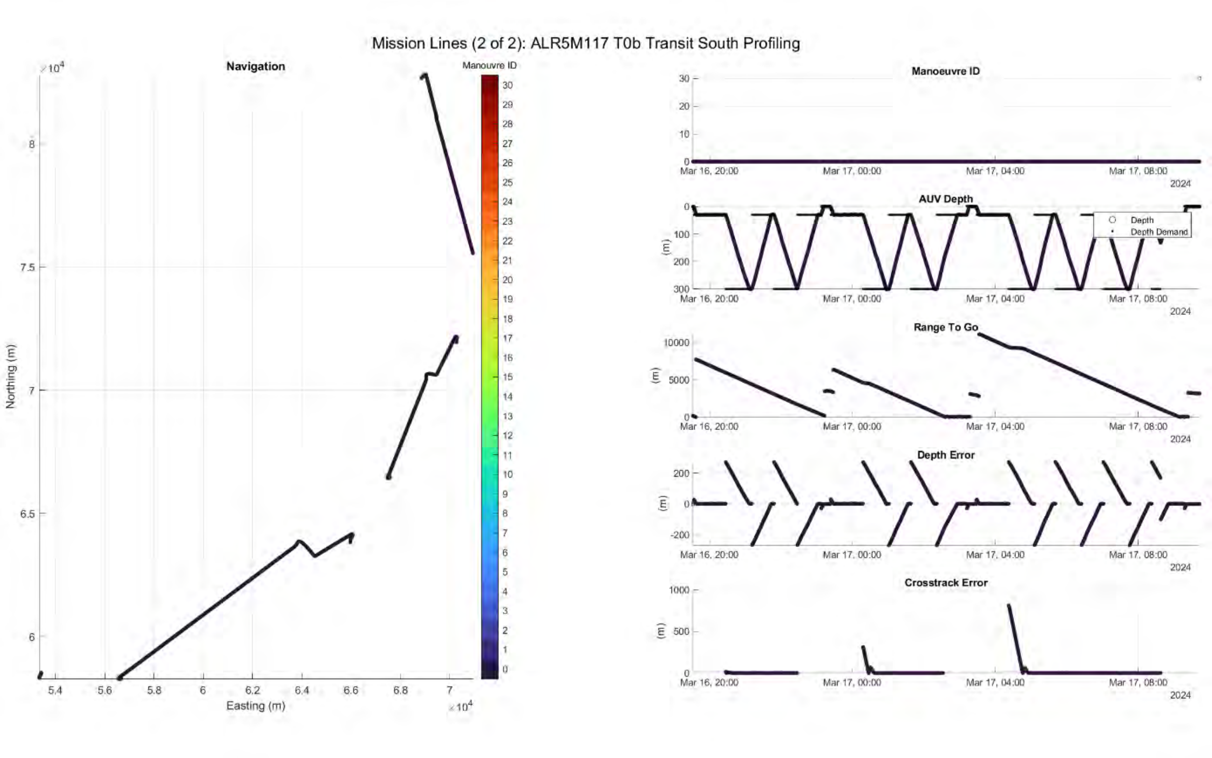


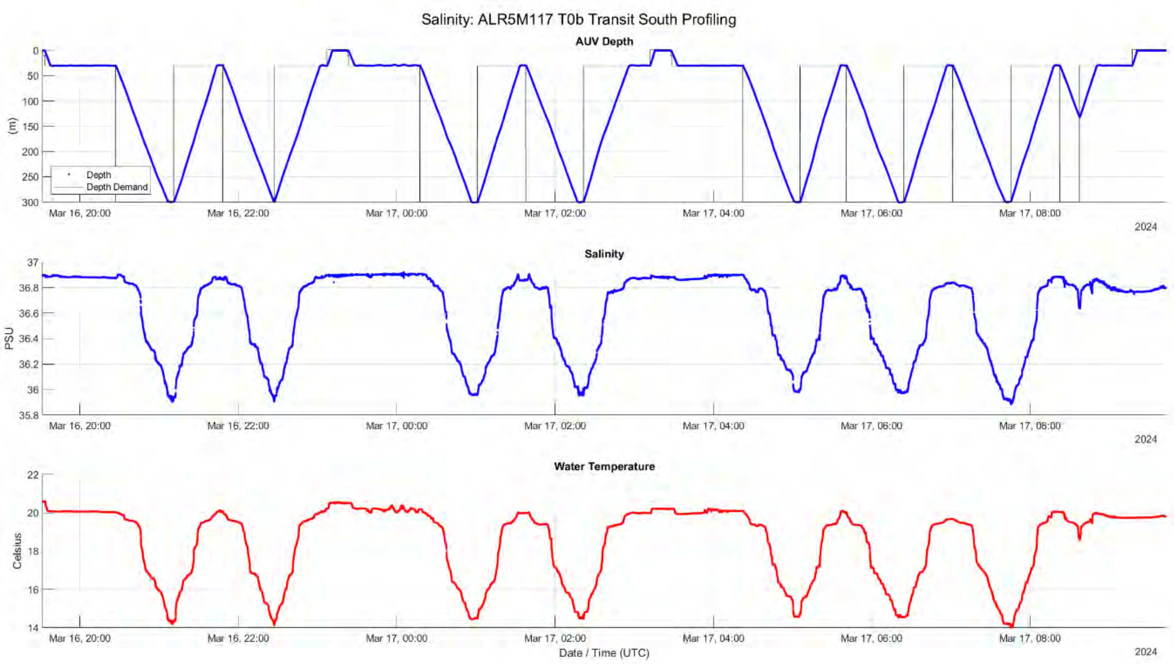
11.16. ALR5M116: Profile to 300m and Surface for High Res NRT



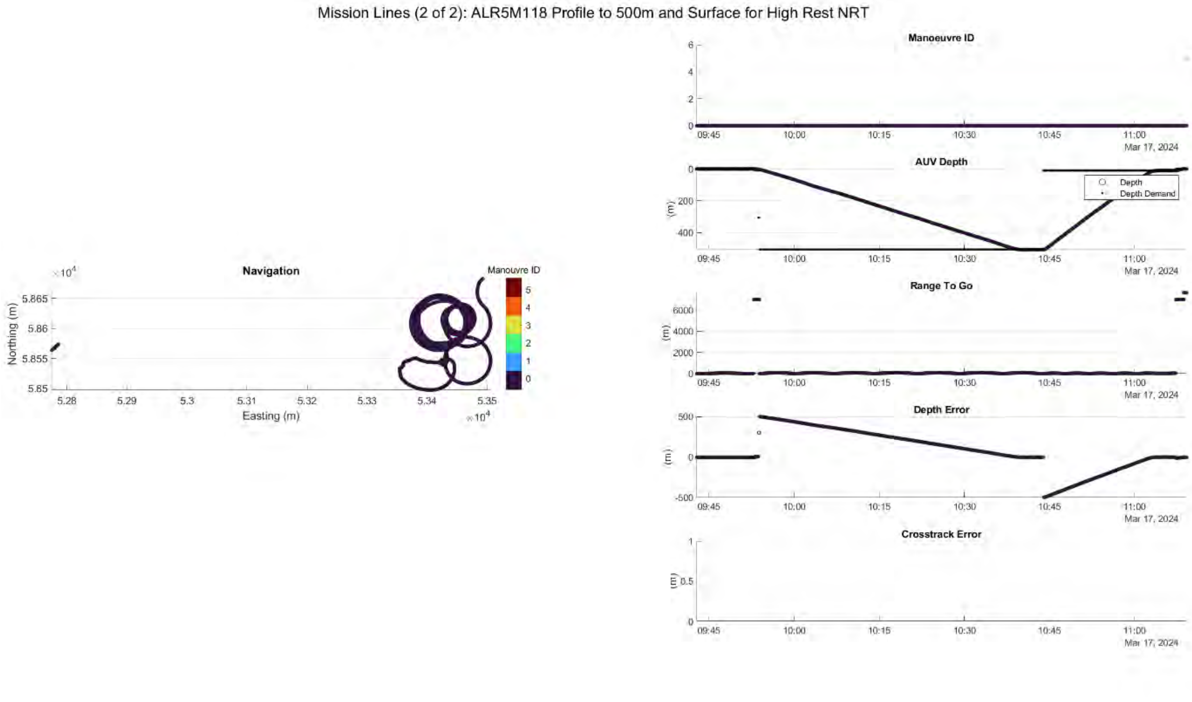


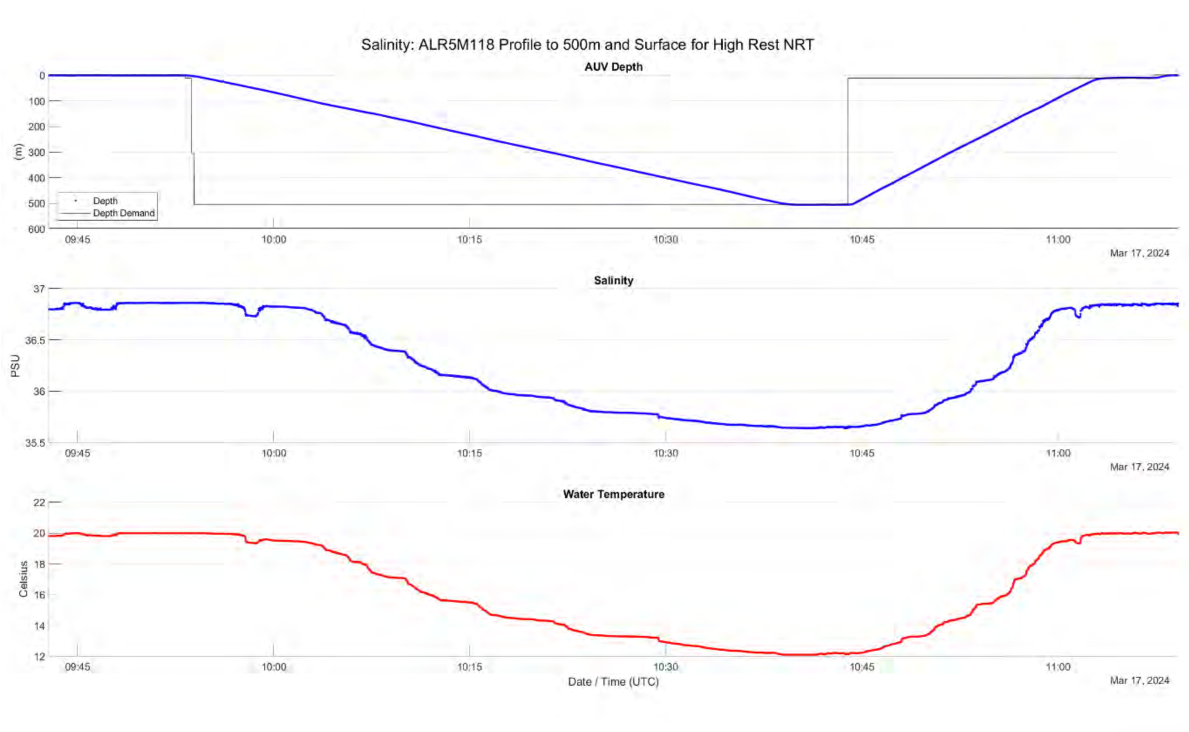
11.17. ALR5M117: T0b Transit South Profiling



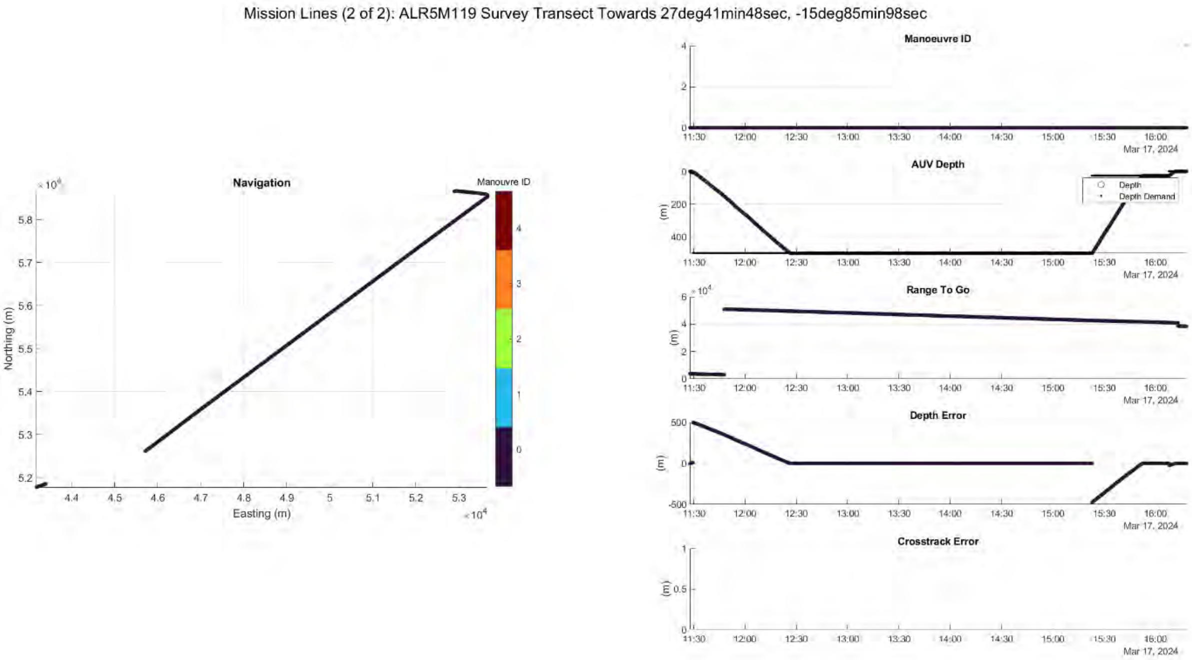


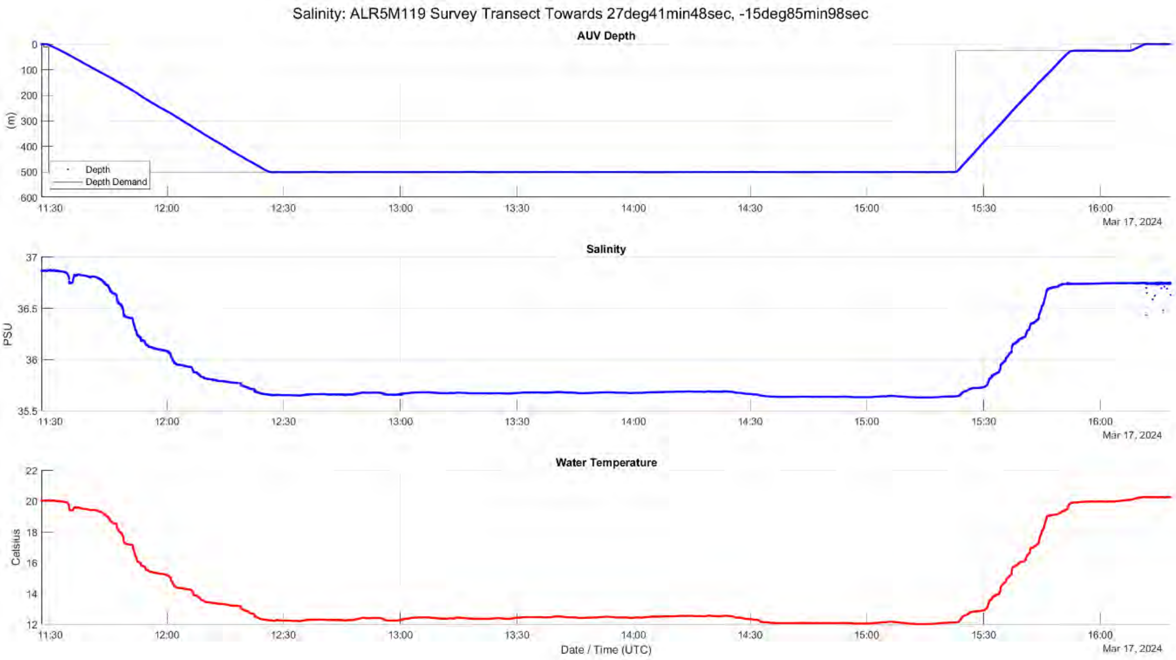
11.18. ALR5M118: Profile to 500m and Surface for High Res NRT



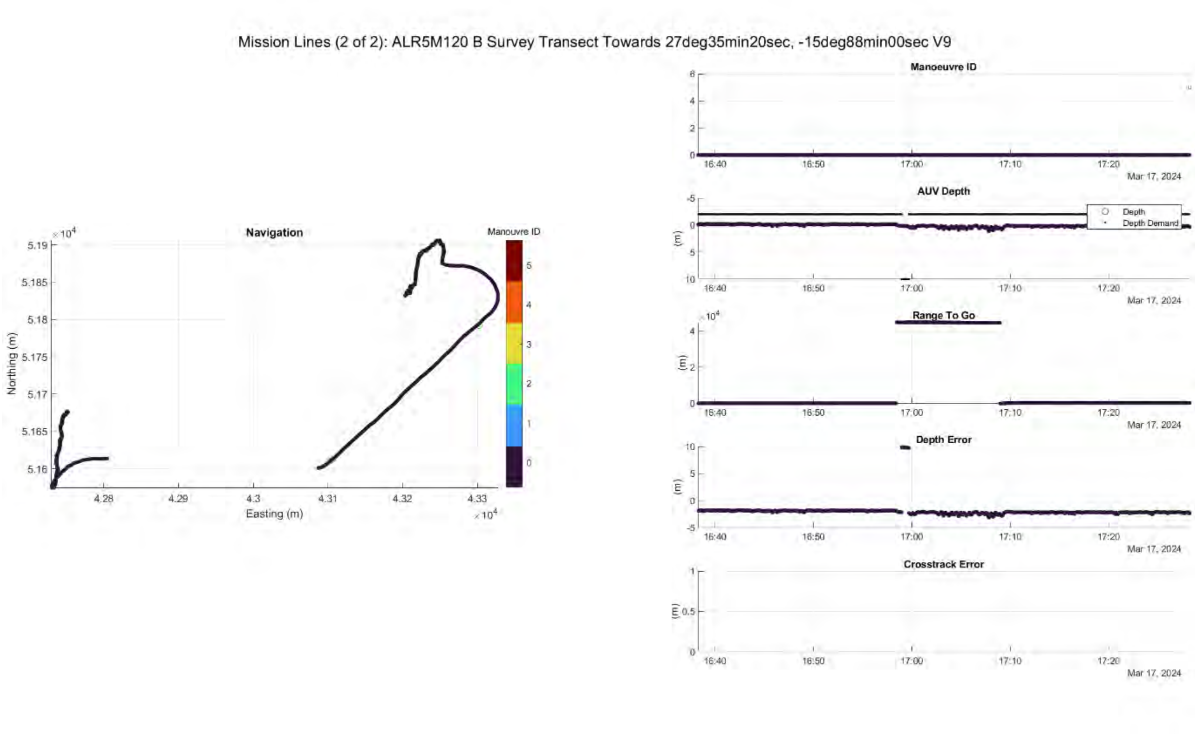


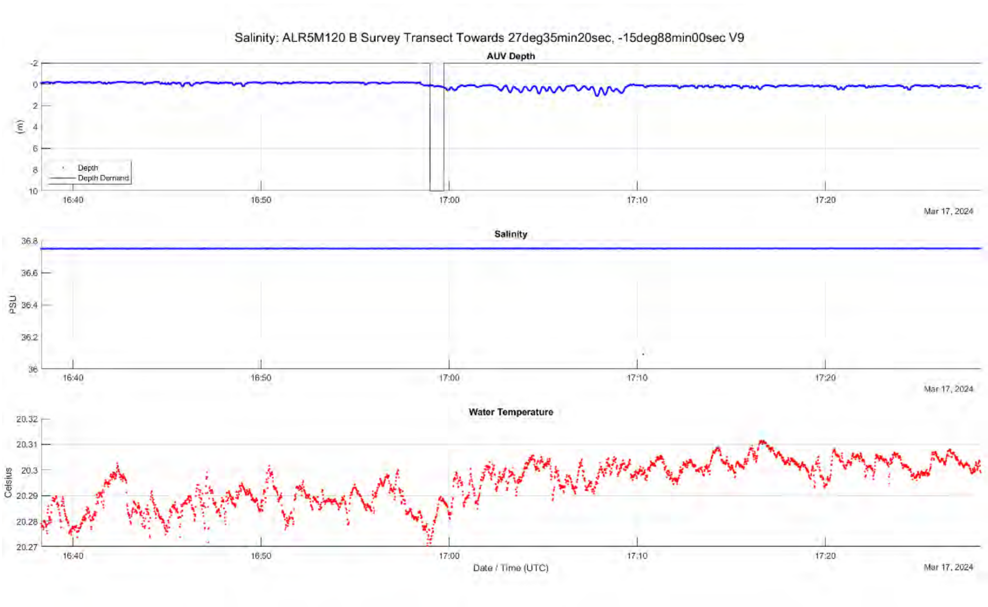
11.19. ALR5M119: Survey Transect Towards: 27.4148°, -15.8598°





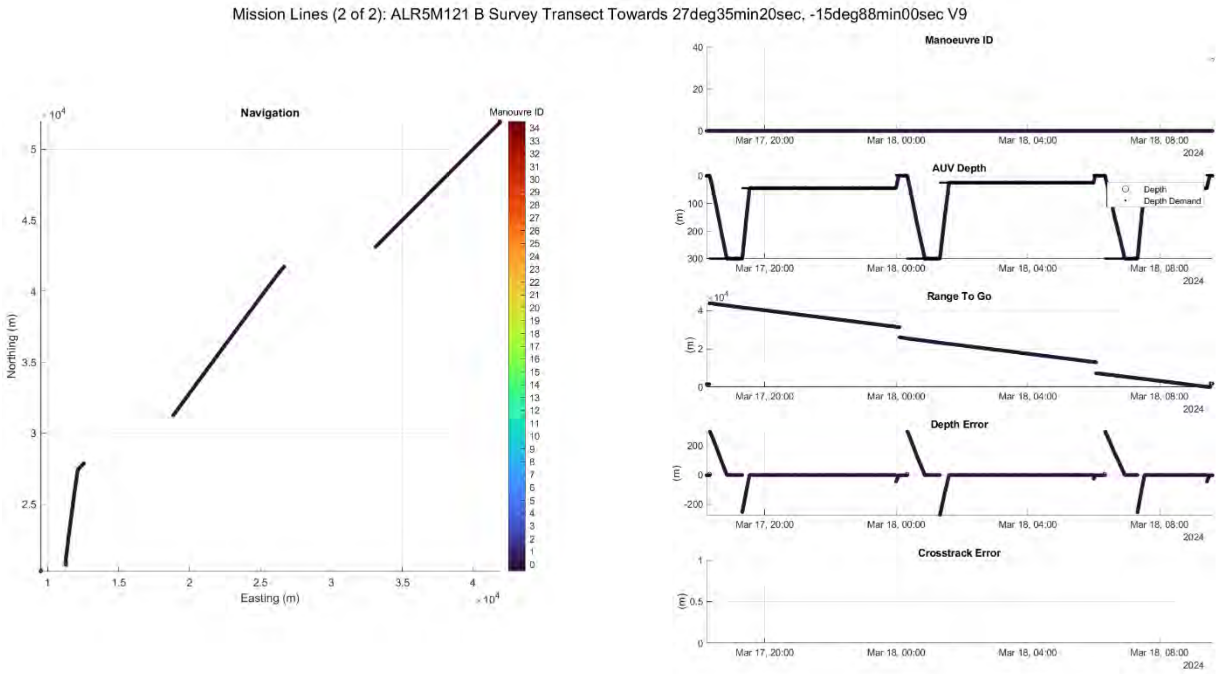
11.20. ALR5M120: 17.03_B Survey Transect Towards 27.352°, -15.88° / V 9

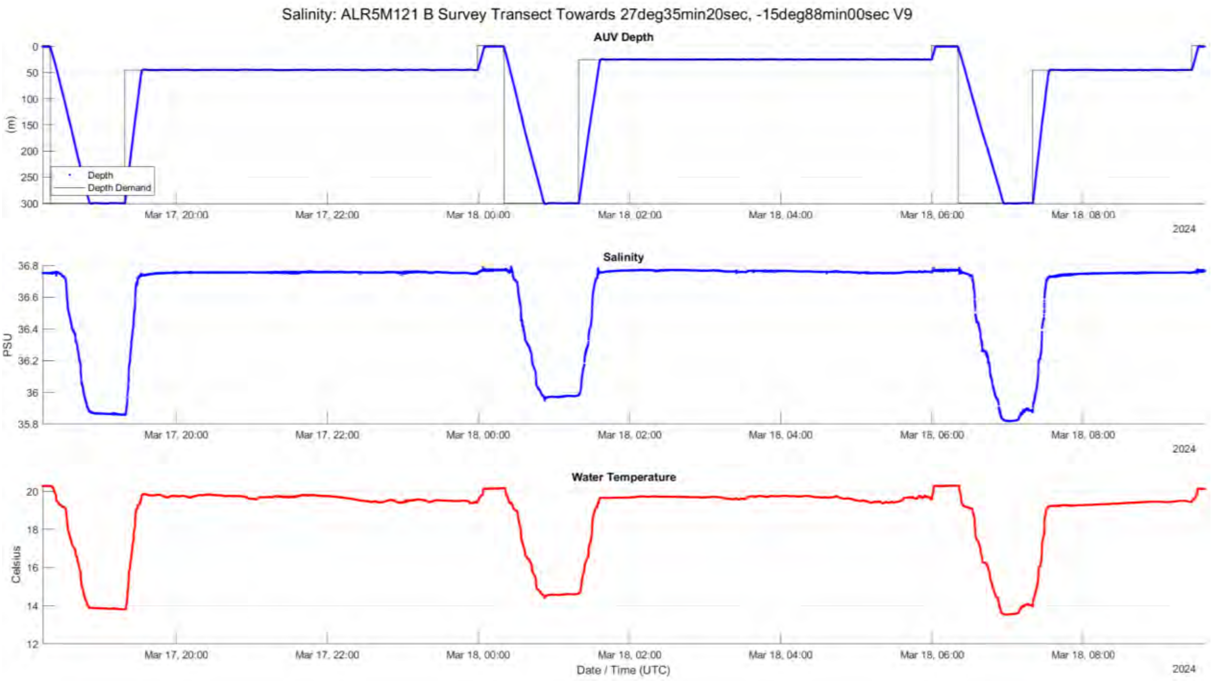




Issue where the ALR altitude was latched at 0m preventing the ALR from diving. This error reappeared during mission ALR5M125. The issue was resolved by loading a new mission . Post campaign analysis is continuing however seems to be related to different software threads accessing the same memory.

11.21. ALR5M121: 17.03_B Survey Transect Towards 27.352°, -15.88° / V 9





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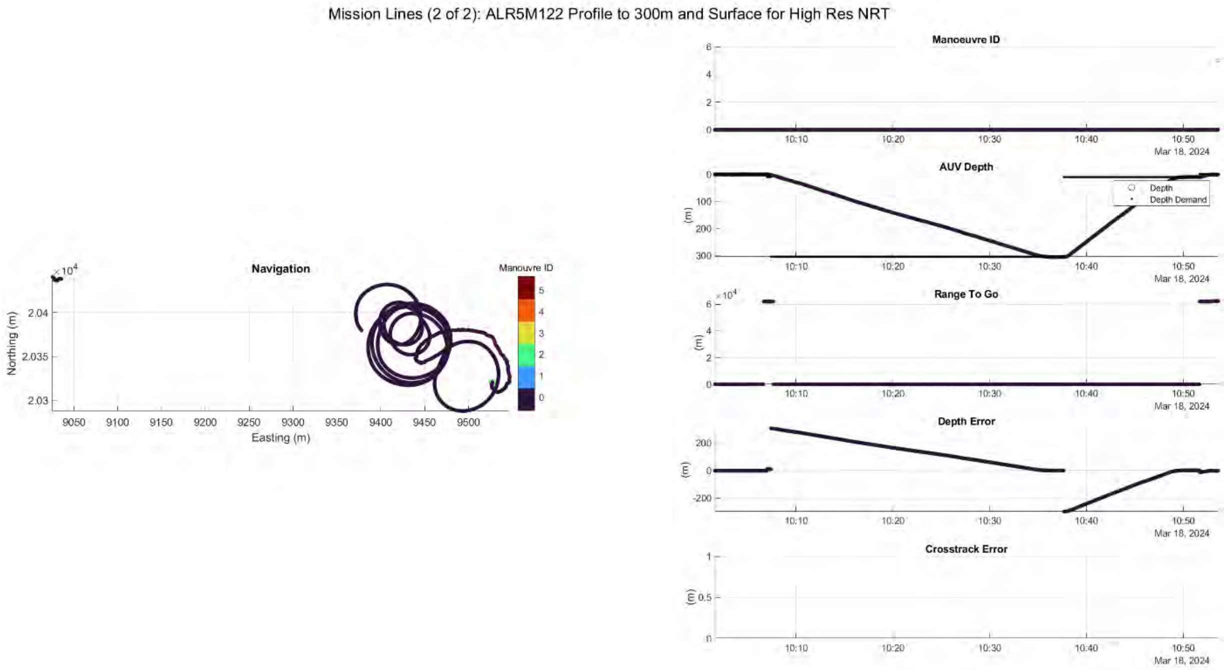
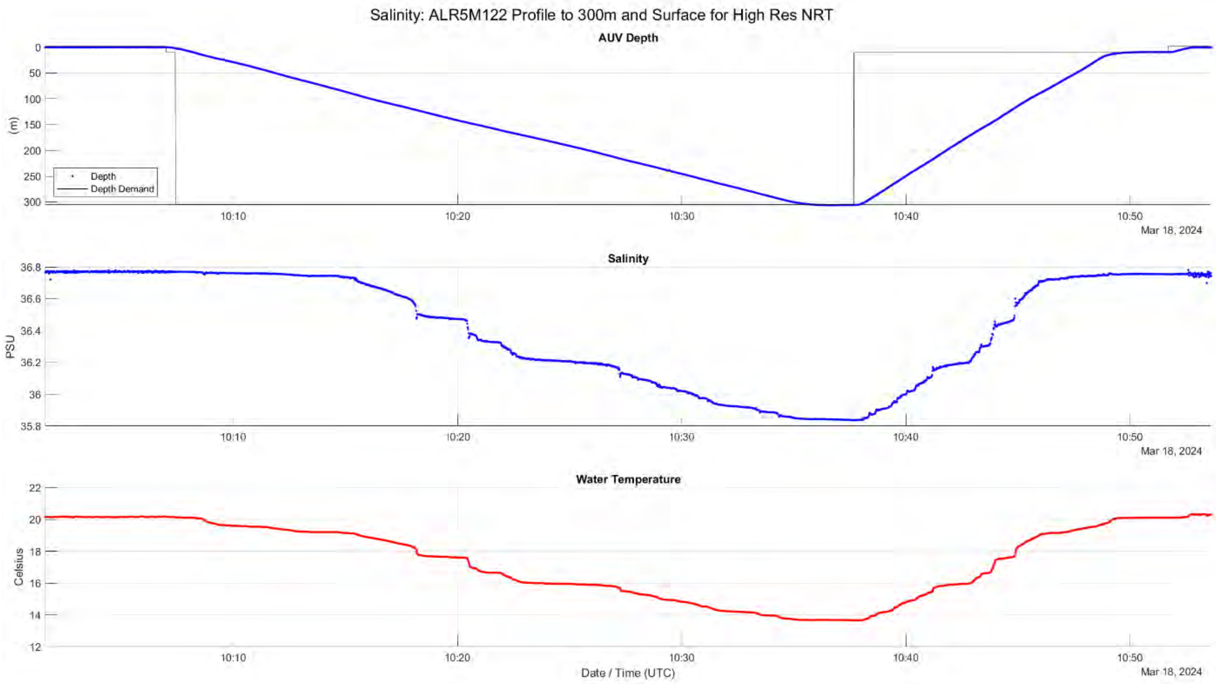
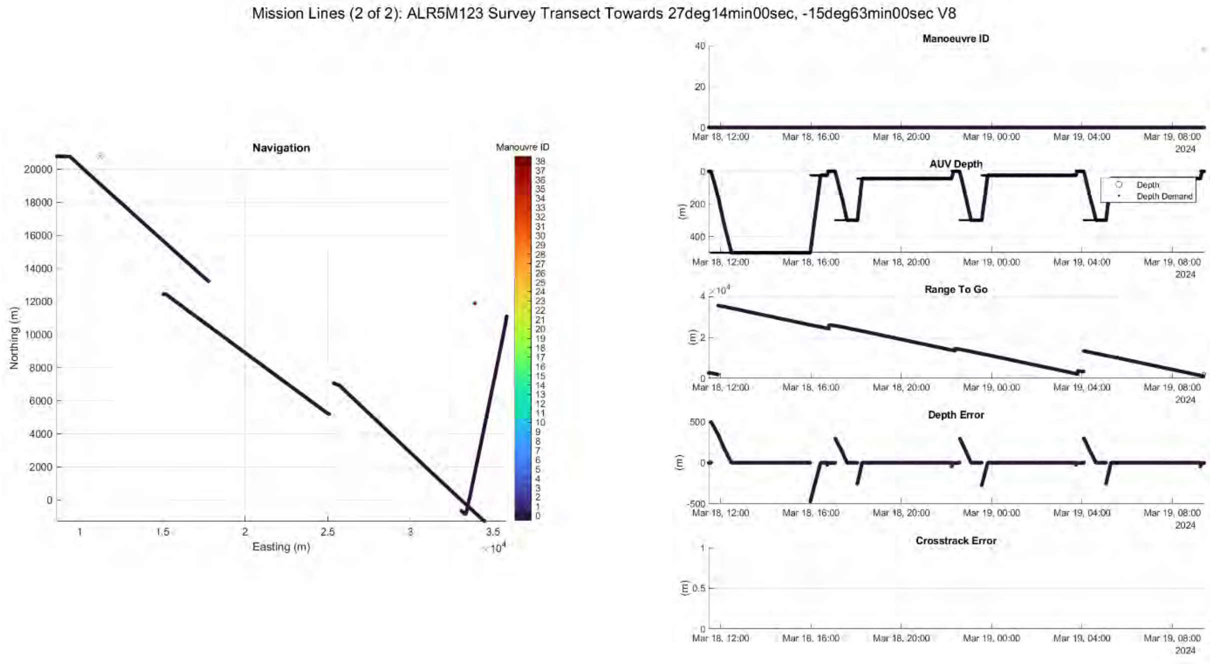
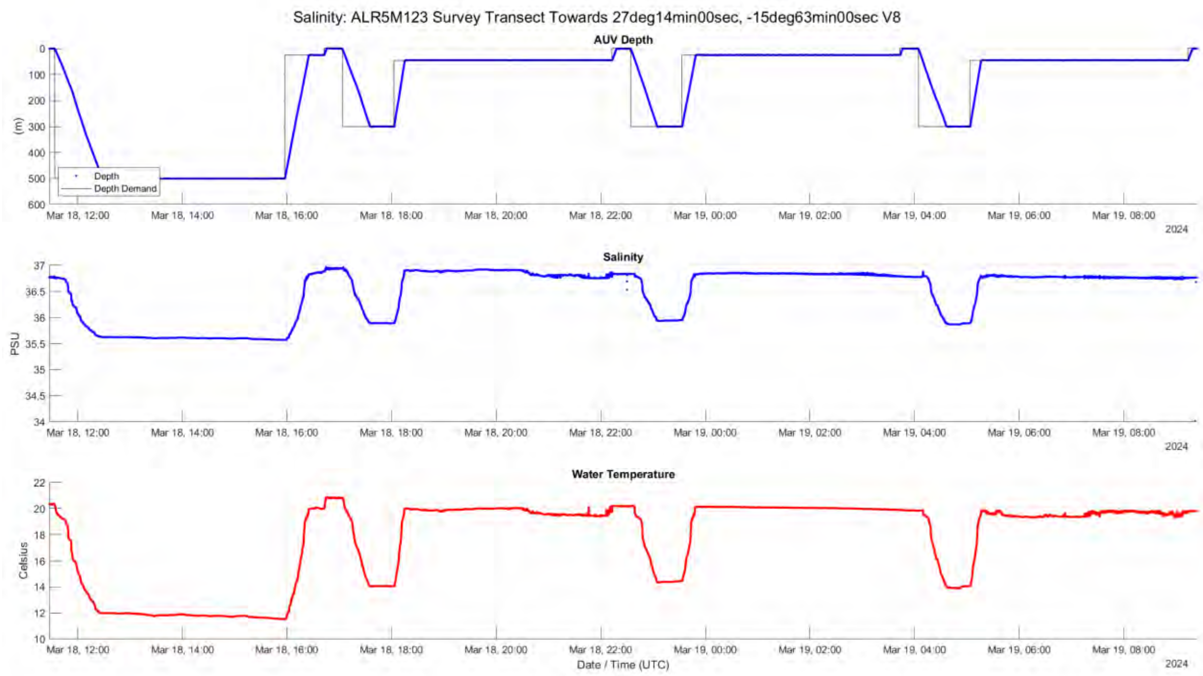
11.22. ALR5M122: Profile to 300m and Surface for High Res NRT



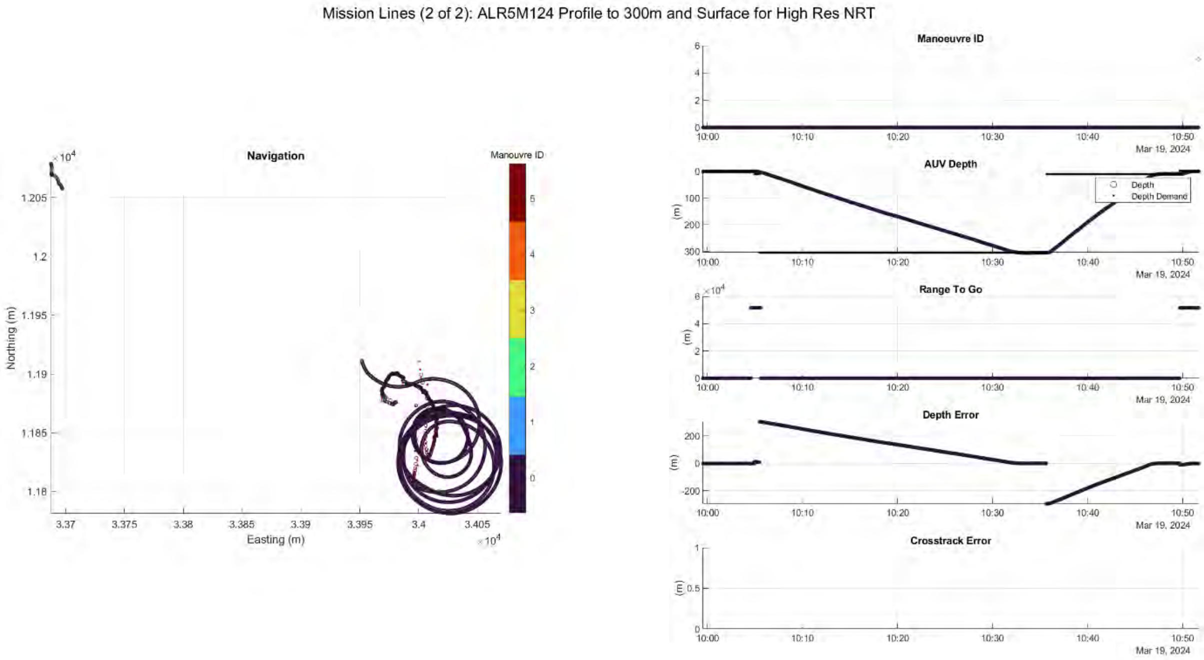


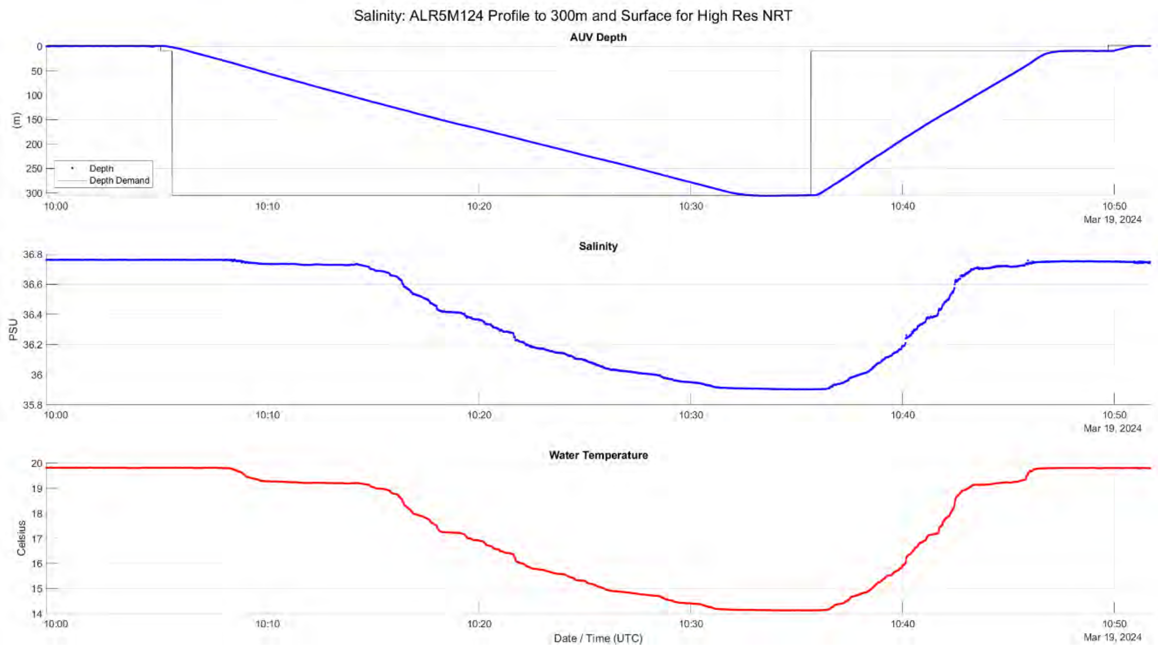
11.23. ALR5M123: 18.03 Survey Transect Towards: 27.14°, -15.63° Version 8



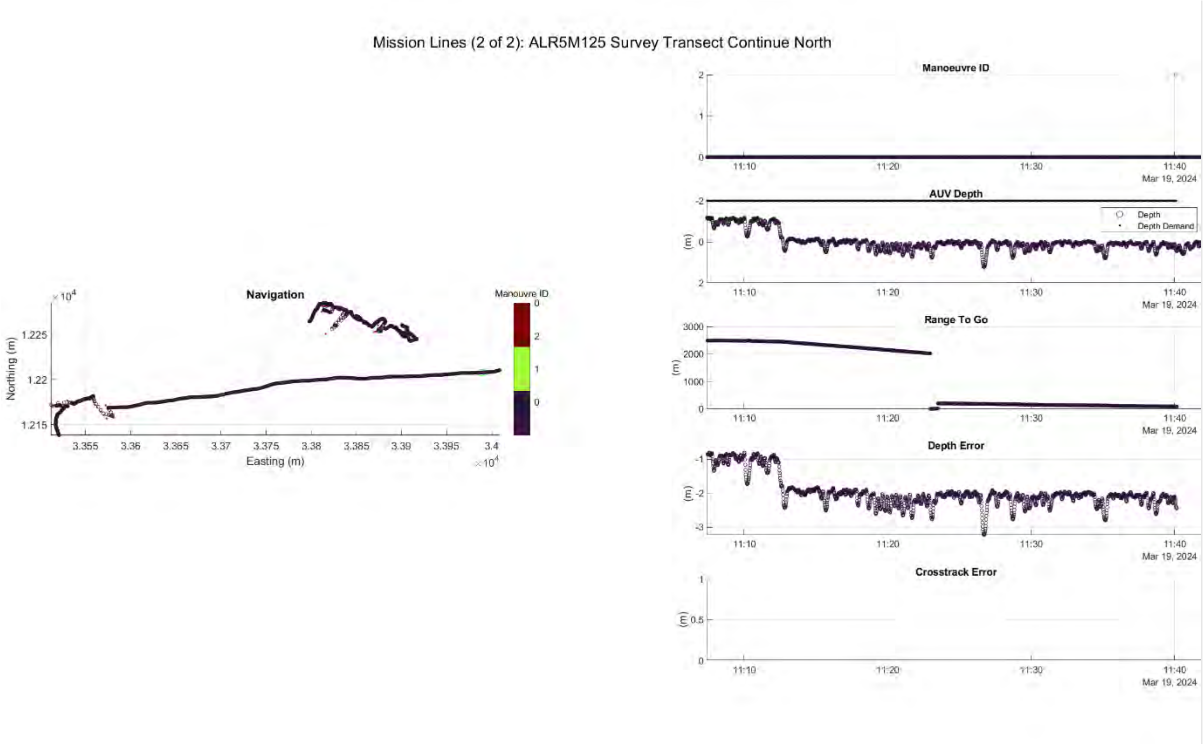


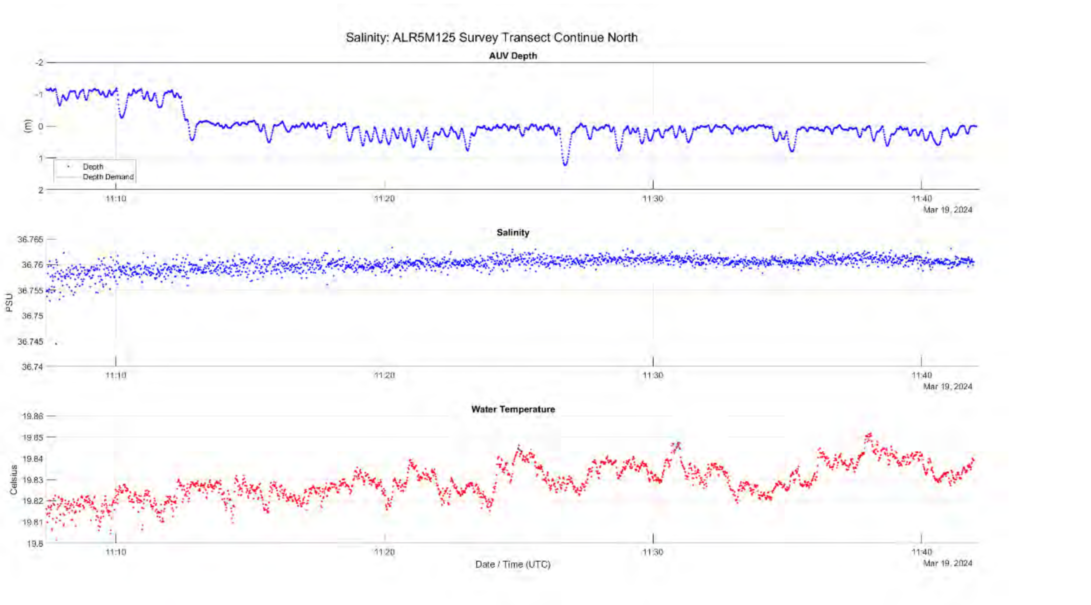
11.24. ALR5M124: Profile to 300m and Surface for High Res NRT





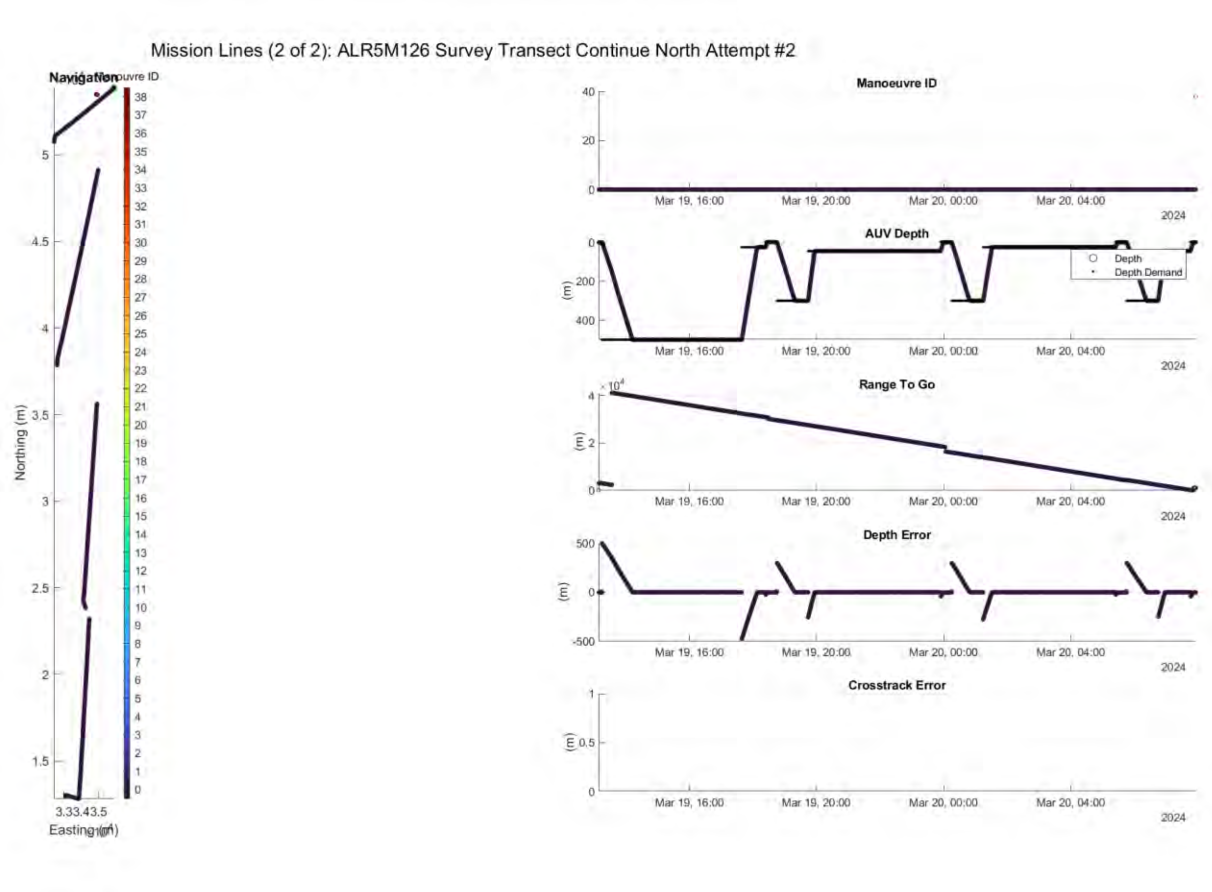
11.25. ALR5M125: 19.03 Survey Transect: Continue North

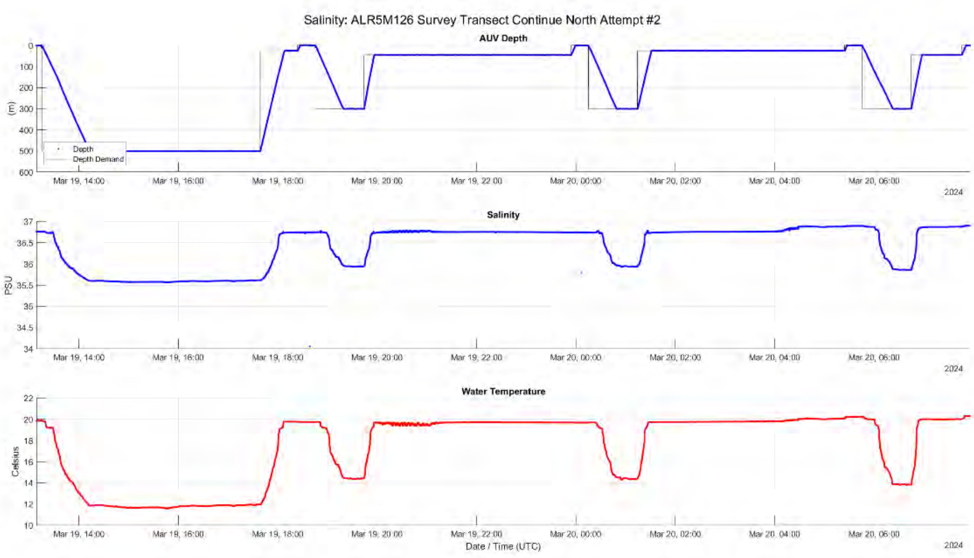




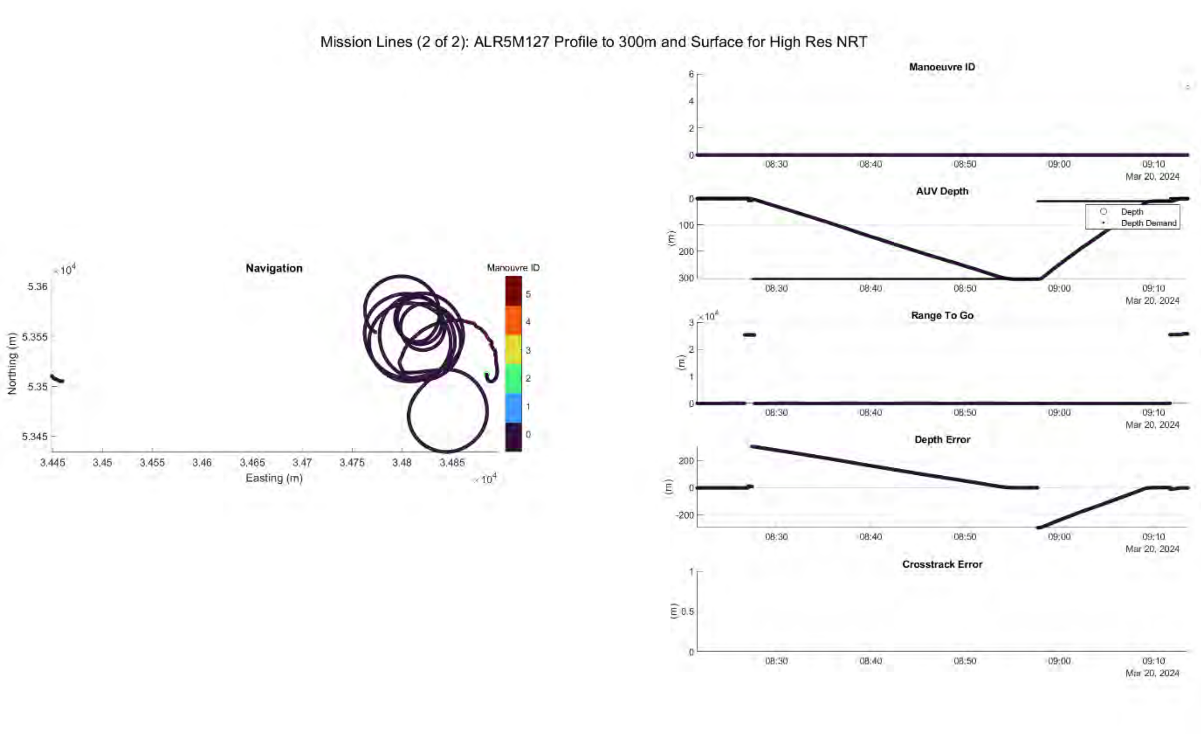
Issue where the ALR altitude was latched at 0m preventing the ALR from diving., despite being in deep water. DVL was rebooted which caused an unscheduled ALR reboot. Post mission investigations continuing however the error seems related to two different software threads trying to access the same memory. Rebooting the ALR returned the vehicle to a normal state (Idle) allowing the next mission to continue.

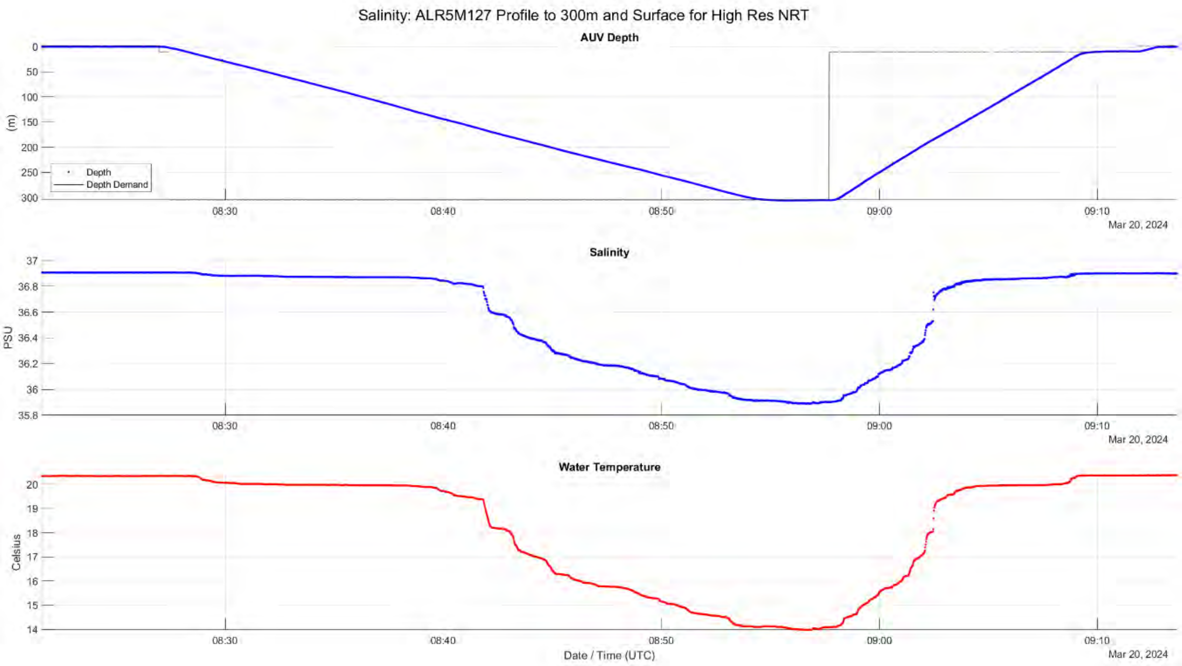
11.26. ALR5M126: 19.03 Survey Transect: Continue North (2nd attempt)



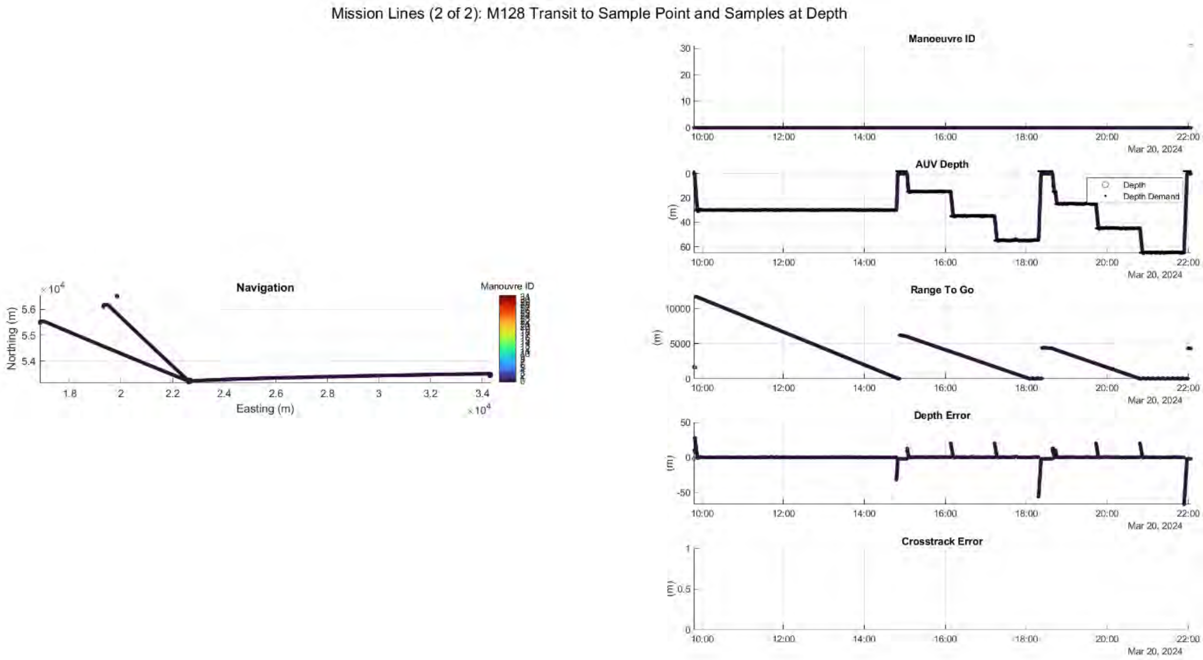


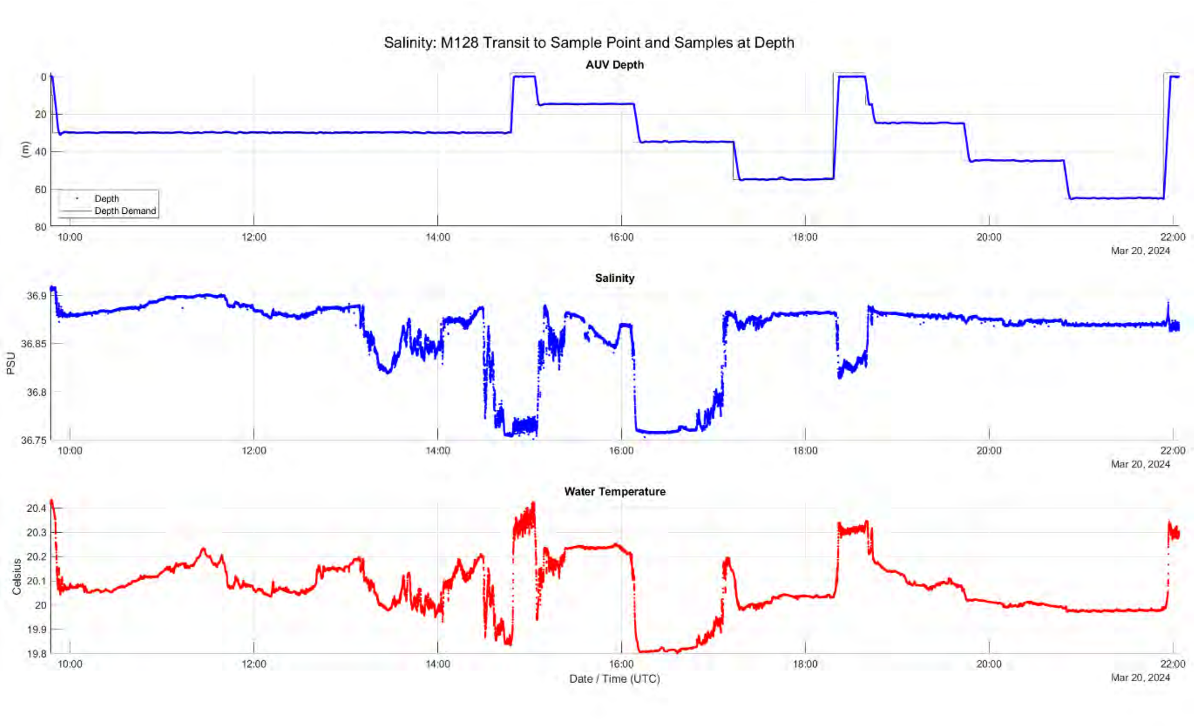
11.27. ALR5M127: Profile to 300m and Surface for High Res NRT



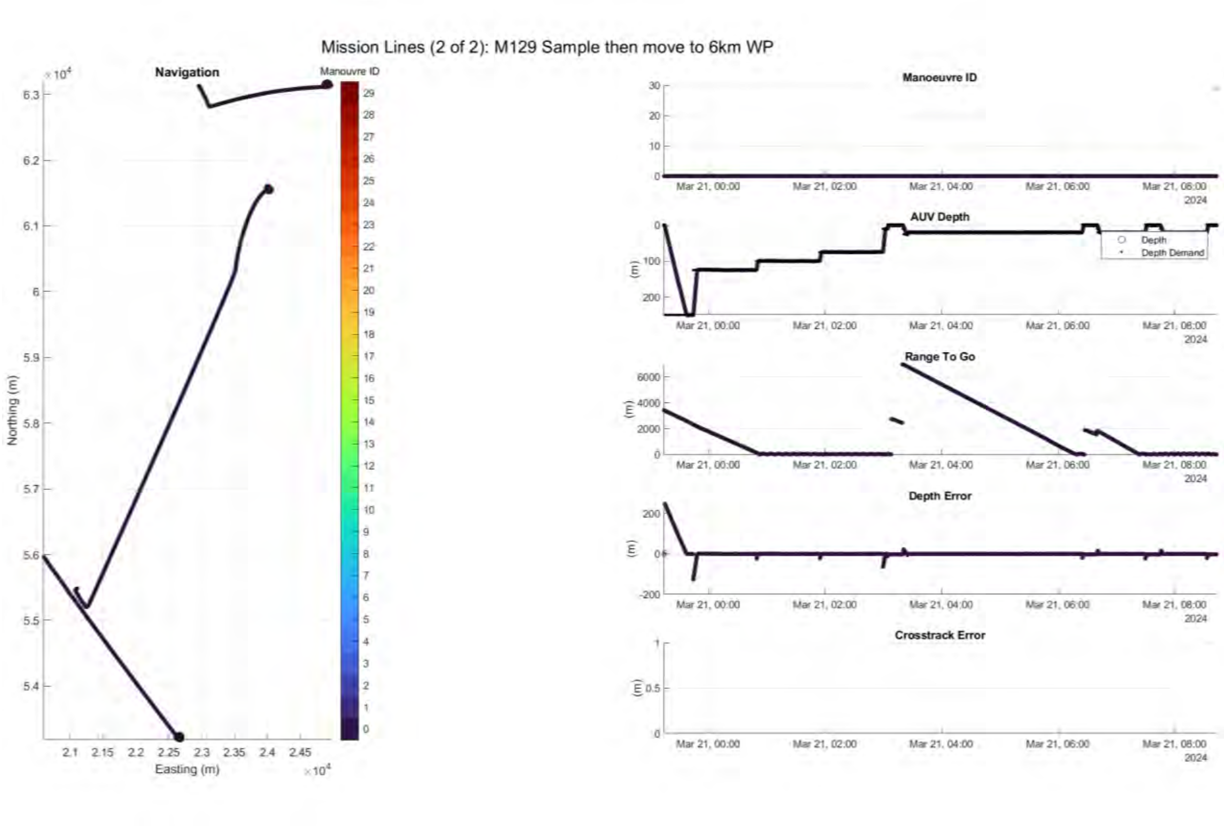


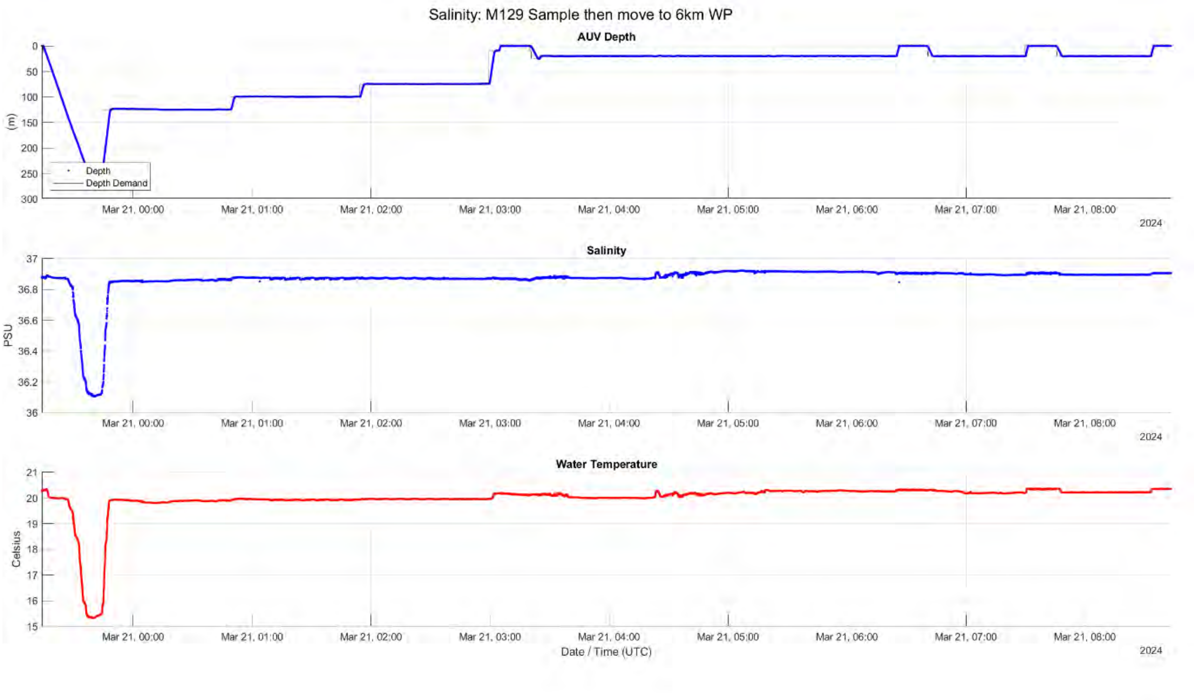
11.28. ALR5M128: 20.03 Transit to Sample Point and Samples at Depth



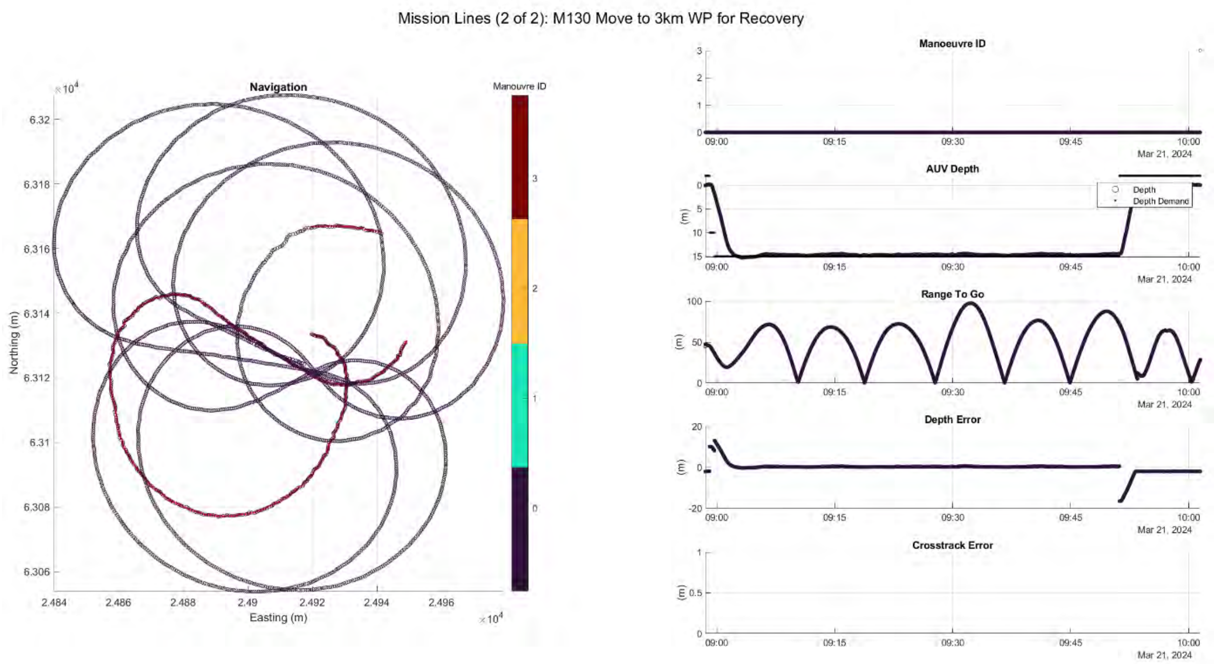


11.29. ALR5M129: 21.03 Sample then move to 6km WP





11.30. ALR5M130: Move to 3km WP for recovery



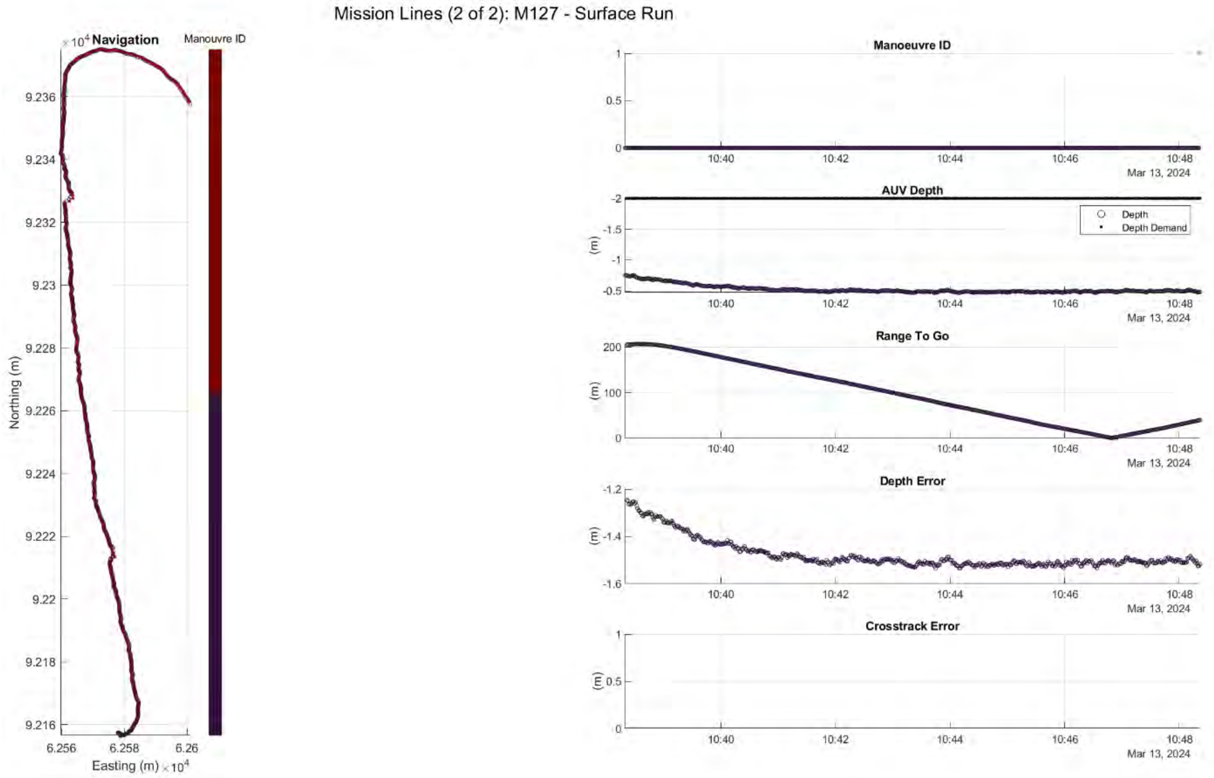
12. APPENDIX C: ALR 3 Mission Summary Table

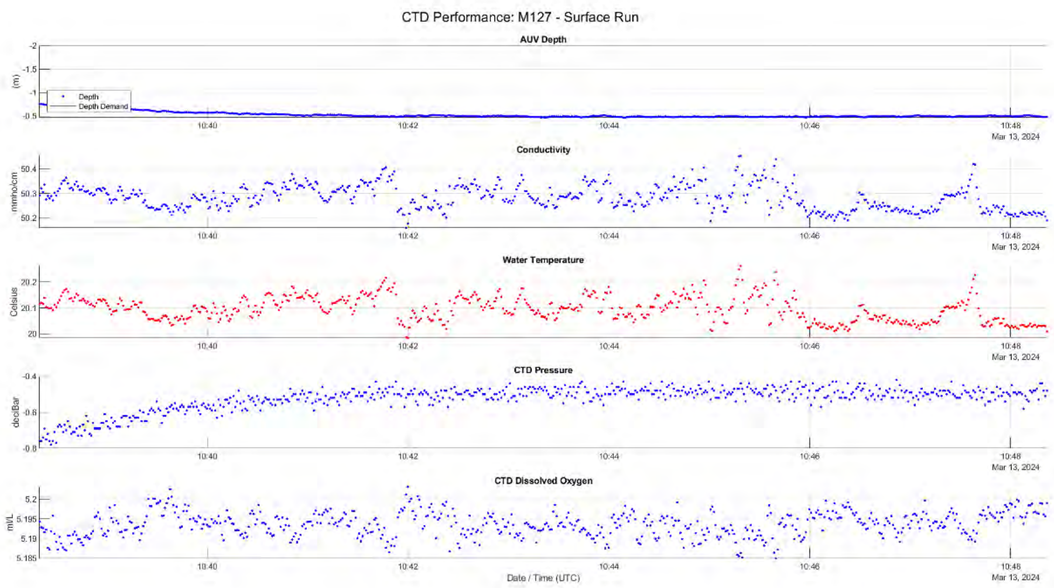
MISSION DETAILS				SENSOR STATUS				MISSION METRICS											
ALR3 Mission Number	Mission Segment	Start Date & Time (UTC)	End Date & Time (UTC)	CTD + DO	ADCP Up/Down	FLNTUTD	Biocam	Duration (Days)	Distance Travelled Underwater (km)	Average Power (W)	Energy Used (kWh)	Percent of Pack Used	Average SOG (m/s)	Max Depth (m)	Min Altitude (m)	Percent Bottom Lock	Surfacing Error (m)	Percent Error of DT	Mission Log MTSN
	Calibration Missions																		
ALR3M127	C01 Surface Run	13/03/2024 10:38	13/03/2024 10:48	**ON**	**ON**	**ON**	OFF	0.01	-	46.36	0.01	0.05%	0.44	-0.46	36.7	-	-	-	5964
ALR3M128	C01a 10 min Test dive (15m)	13/03/2024 10:50	13/03/2024 11:19	**ON**	**ON**	**ON**	OFF	0.02	-	26.71	0.01	0.08%	0.40	15.79	23.3	100.00	-	-	5970
ALR3M129	Compass Cal	13/03/2024 11:28	13/03/2024 13:00	**ON**	**ON**	**ON**	OFF	0.06	-	34.71	0.05	0.32%	0.59	15.65	16.1	100.00	-	-	-
	Recover & Recharge ALR						**Totals:**	**0.09**	-		**0.07**	**0.45%**					**Average:**	-	
ALR3M130	C01a 10 min Test dive (15m)	14/03/2024 10:46	14/03/2024 11:14	**ON**	**ON**	**ON**	OFF	0.02	0.63	36.92	0.02	0.11%	0.59	15.64	18.4	100.00	21.03	3.4%	6049
ALR3M131	C03a Biocam Alignment + FLS On	14/03/2024 11:14	14/03/2024 12:18	**ON**	**ON**	**ON**	**ON**	0.04	2.49	40.21	0.04	0.26%	0.73	30.3	8.8	100.00	93.17	3.7%	6052
ALR3M132	S0a Biocam Survey (10m alt) + FLS On	14/03/2024 12:23	14/03/2024 14:57	**ON**	**ON**	**ON**	**ON**	0.11	3.94	46.35	0.12	0.72%	0.60	32.6	9.7	100.00	3.86	0.1%	6120
	Recover & Recharge ALR						**Totals:**	**0.17**	**7.06**		**0.18**	**1.09%**					**Average:**	**2.4%**	
	Surevy Missions																		
ALR3M133	C01a 10 min Test dive (15m)	16/03/2024 10:28	16/03/2024 10:57	**ON**	**ON**	**ON**	OFF	0.02	0.58	38.32	0.02	0.11%	0.56	15.5	24.5	100.00	**3.02**	0.5%	6238
ALR3M134	S1 Biocam Survey (5m alt) + FLS On	16/03/2024 11:01	16/03/2024 14:43	**ON**	**ON**	**ON**	**ON**	0.15	6.29	37.24	0.14	0.84%	0.60	36.83	4.8	99.96	**6.90**	0.1%	-
ALR3M135	S1 Biocam Survey (5m alt) + BioCAM On FLS On	16/03/2024 14:43	16/03/2024 18:24	**ON**	**ON**	**ON**	**ON**	0.15	3.89	27.97	0.10	0.62%	0.53	35.62	4.8	100.00	**7.58**	0.2%	6279
							Totals:	**0.3**	**10.8**		**0.26**	**1.6%**					**Average:**	**0.28%**	
							Mission used equivalent energy stored within				**0.02**	**Litres of Diesel**							

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101000858 (TechOceanS). This output reflects only the author's view and the Research Executive Agency (REA) cannot be held responsible for any use that may be made of the information contained therein.

13. APPENDIX D: ALR 3 Mission Detail

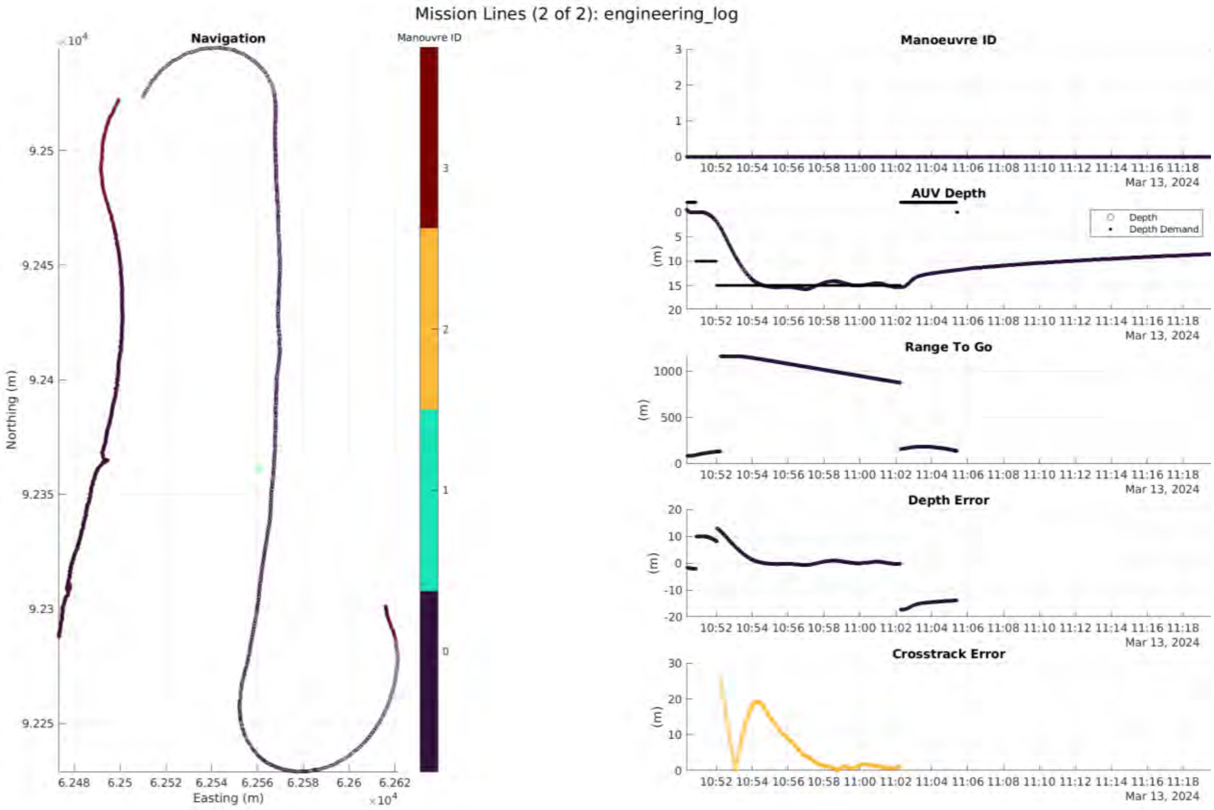
13.1. ALR3M127: C01 Surface Run

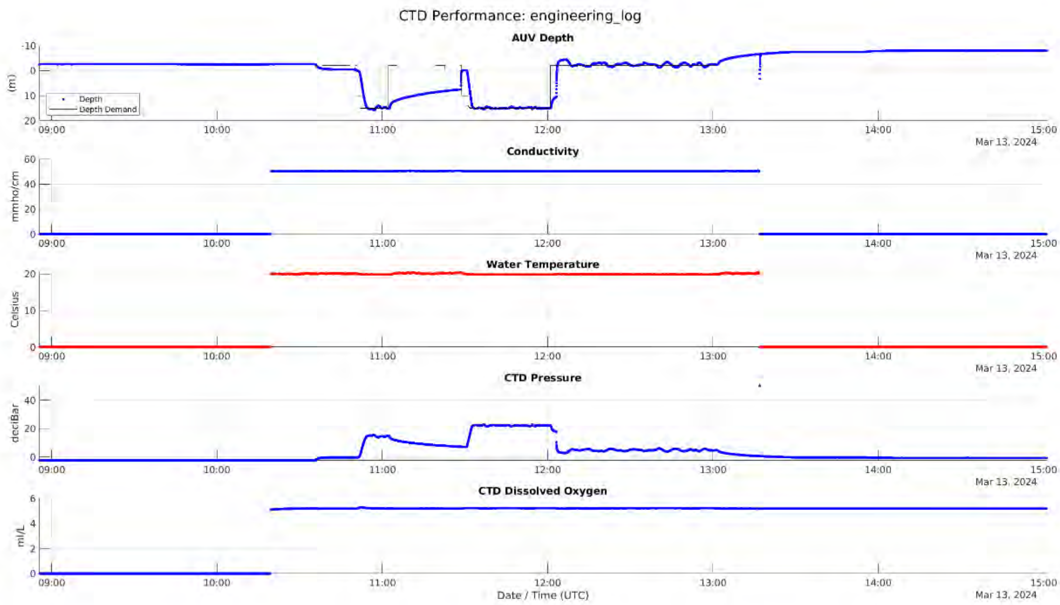


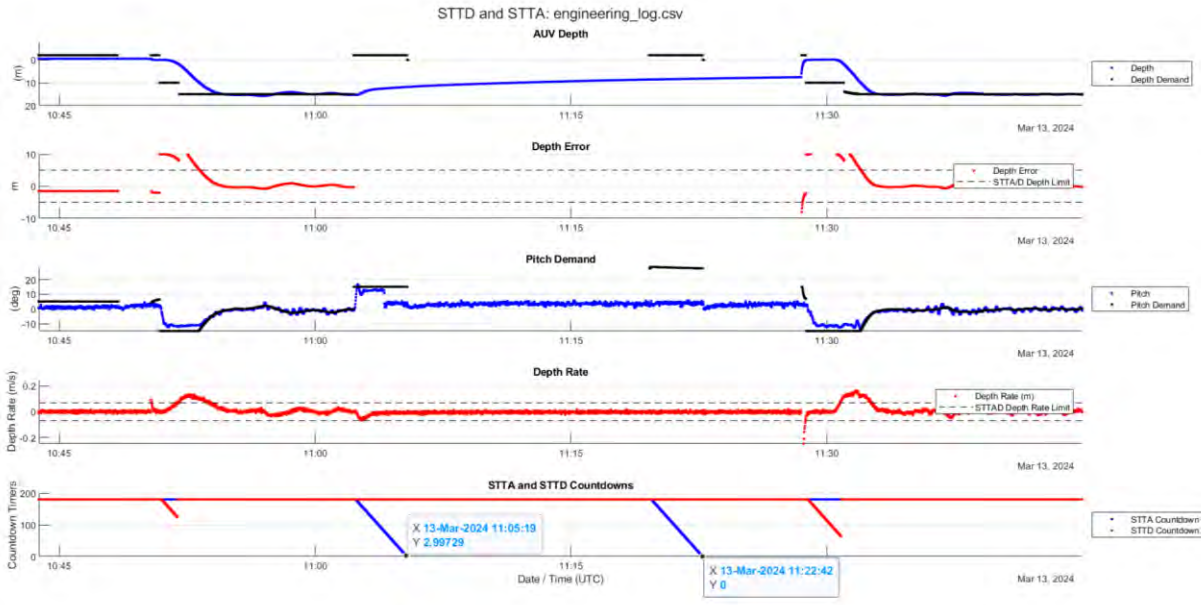


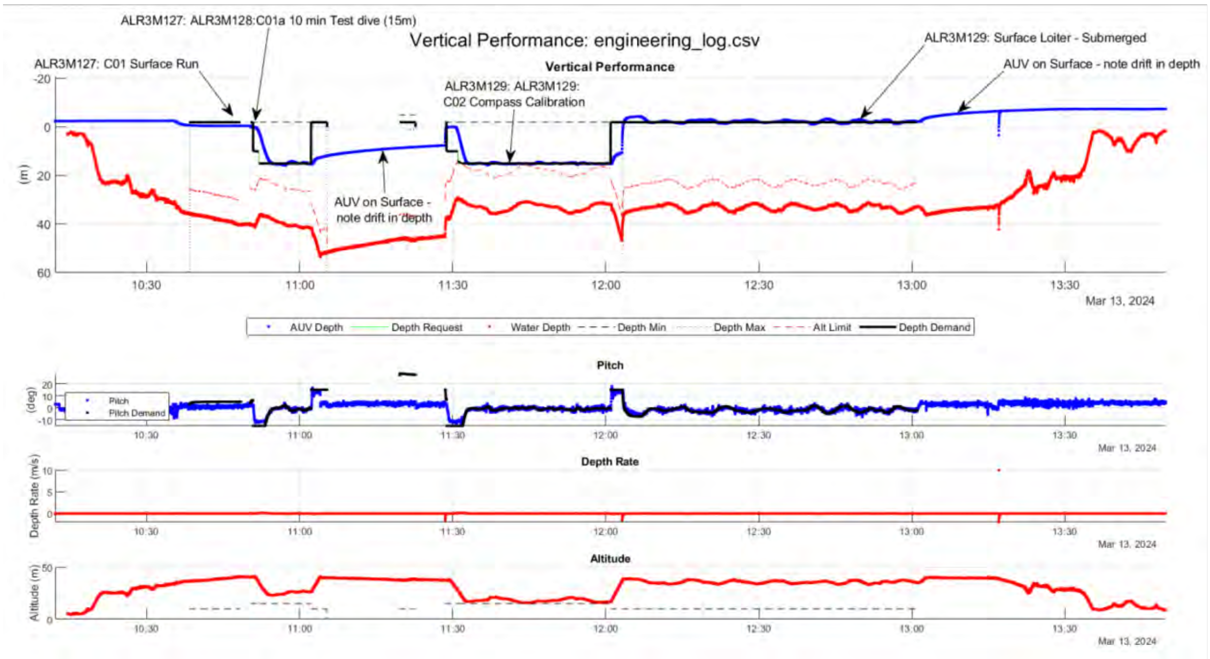
This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101000858 (TechOceanS). This output reflects only the author's view and the Research Executive Agency (REA) cannot be held responsible for any use that may be made of the information contained therein.

13.2. ALR3M128: C01a 10 min Test dive (15m)







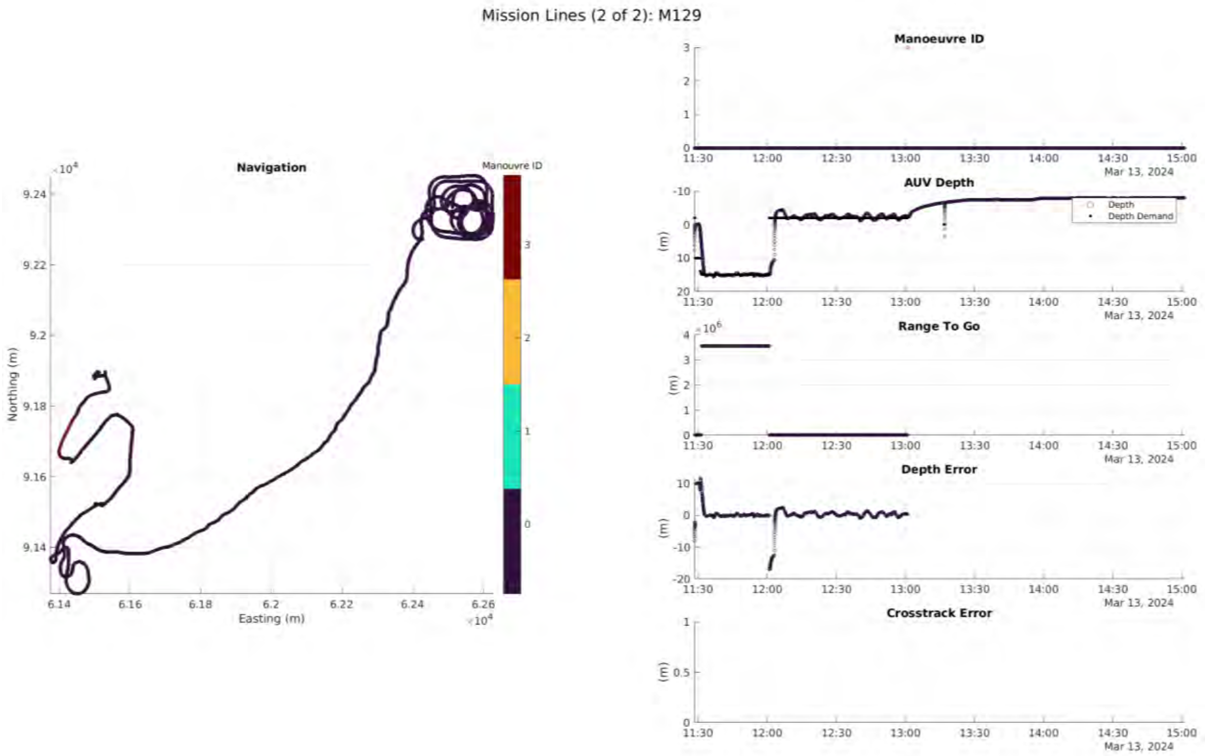


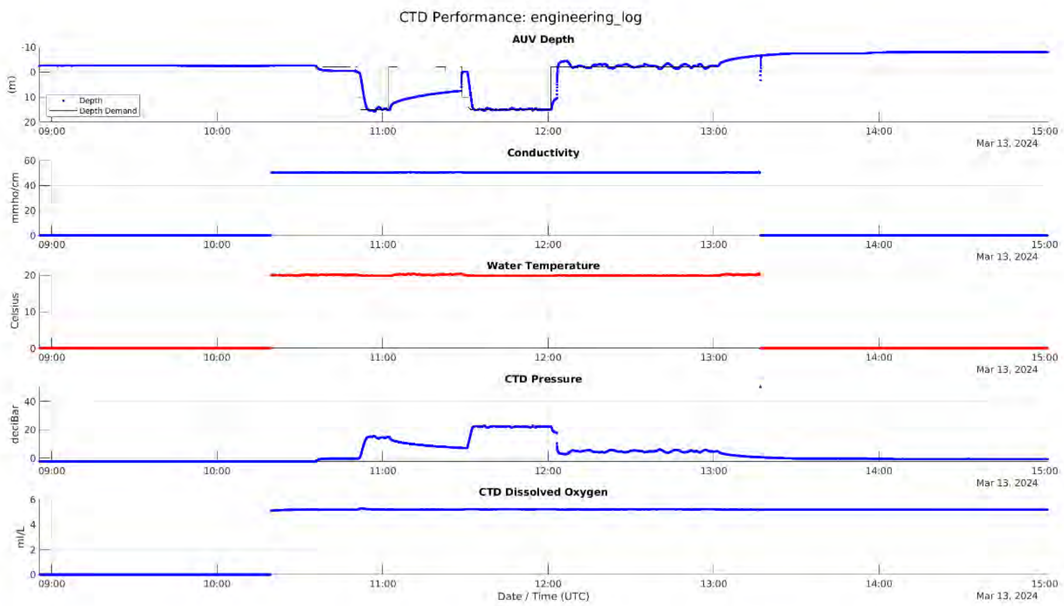
First Indication of CTD Issue:

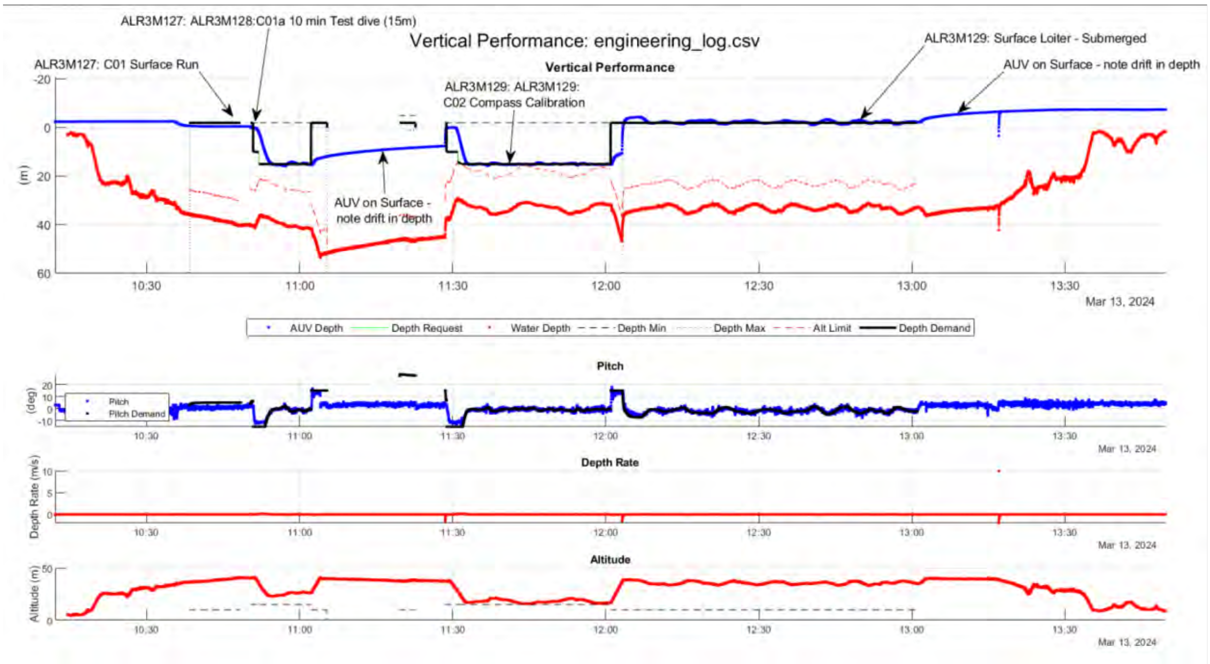
- Vehicle already in the water
- Mission sent via C2IAB and vehicle dived
- Vehicle surfaced in a safety stop, unclear from the C2IAB what had caused it but assumed as there was no health event it must have been STTA/D. Was unable to confirm this by wifi-ing in and checking the nhs log.

- A resume was sent, as the vehicle didn't think it was on surface the dive timeout triggered (this can be seen in the helm ros log) and a safety surface was entered, this triggered another STTA which caused another safety stop.
- Resume was sent again and the vehicle returned to being in idle

13.3. ALR3M129: C02 Compass Calibration



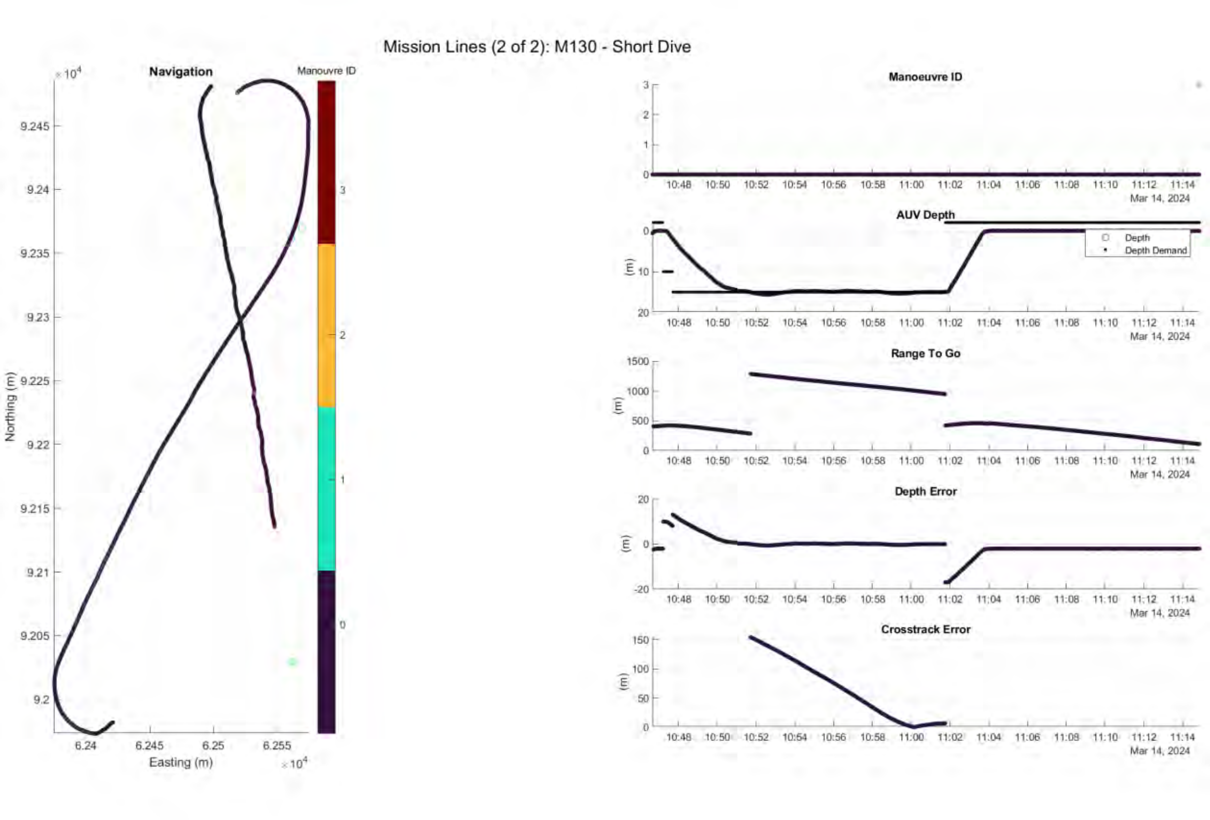


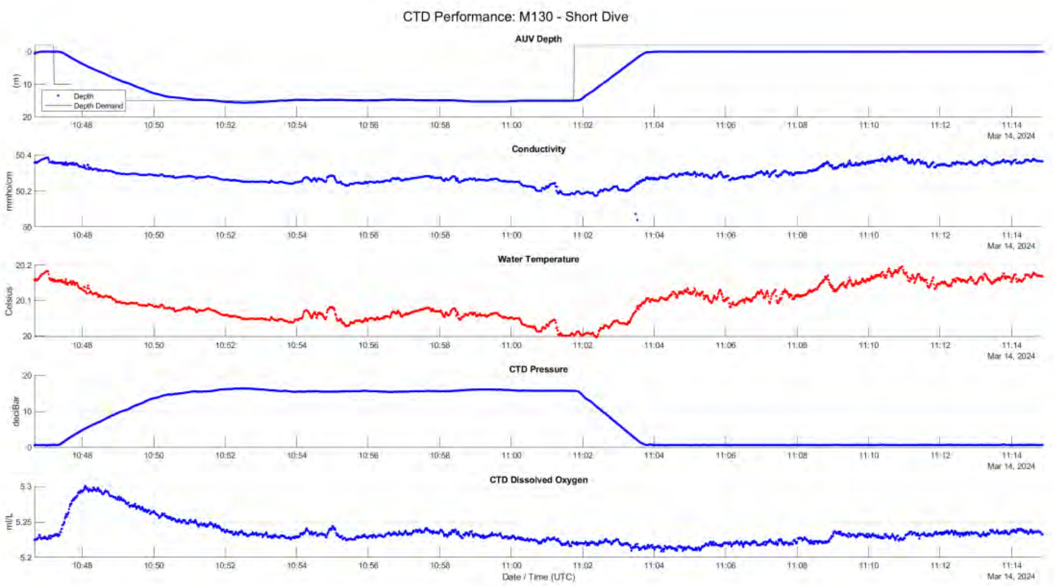

Vertical Performance: engineering_log.csv
Vertical Performance
ALR3M127: ALR3M128:C01a 10 min Test dive (15m)
ALR3M127: C01 Surface Run
ALR3M129: ALR3M129:
C02 Compass Calibration
AUV on Surface - note drift in depth
ALR3M129: Surface Loiter - Submerged
AUV on Surface - note drift in depth
Mar 13, 2024
AUV Depth
Depth Request
Water Depth
Depth Min
Depth Max
Alt Limit
Depth Demand
Pitch
Pitch Demand
Depth Rate
Depth Rate (m/s)
Altitude
Altitude (m)

ALR did not surface after successful compass calibration:

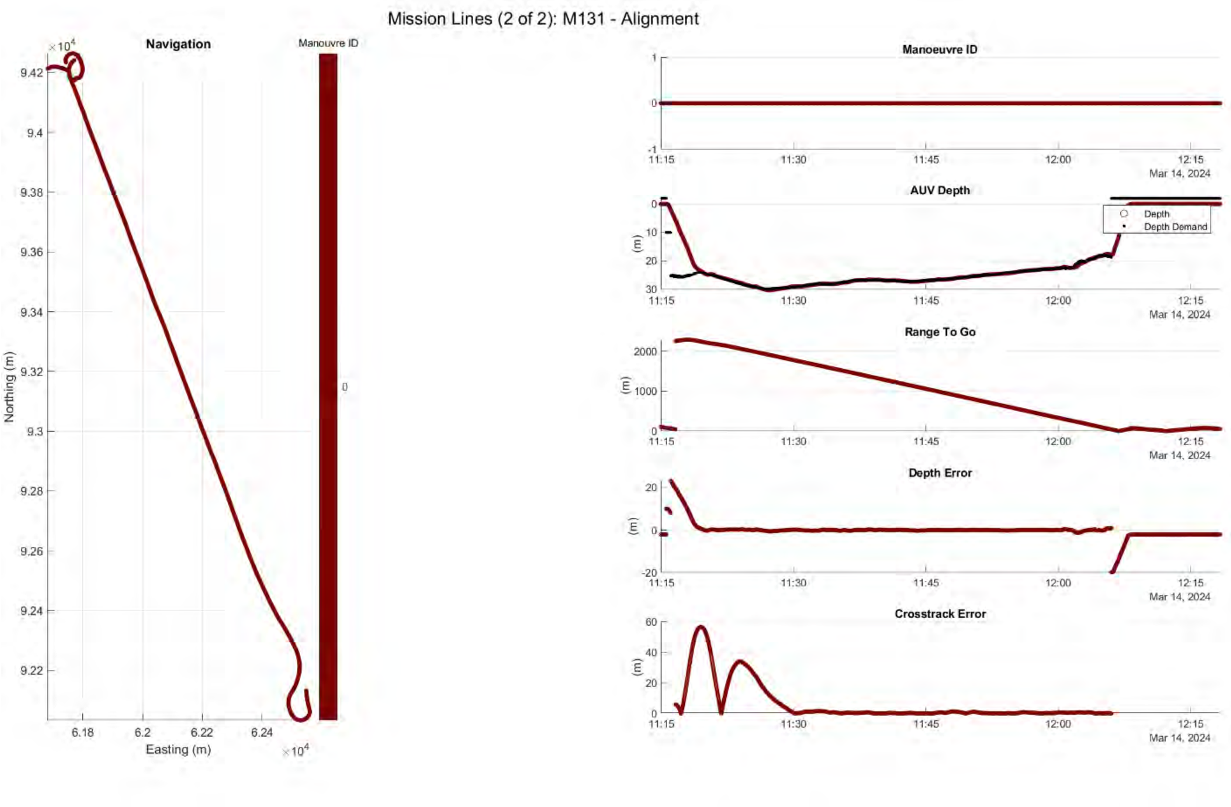
- Vehicle already in the water
- Compass calibration mission sent via C2IAB, acknowledged and vehicle dived
- After the expected time for the compass calibration to be completed the boat crew slowly approached the compass calibration point expecting it to be on the surface or about to surface. Boat crew discovered that it appeared to be loitering some way under the surface. Fortunately, very clear water allowed the boat crew to safely follow it until it surfaced
- On surfacing and inspecting the status it appeared that “time on surface” was ~3600s indicating that it thought it had been on the surface for the last hour doing the “loiter on surface” part of the mission, the depth also indicated that it thought it was at ~-4.8m.
- Boat crew decided to put the vehicle on tow and recover to shore.

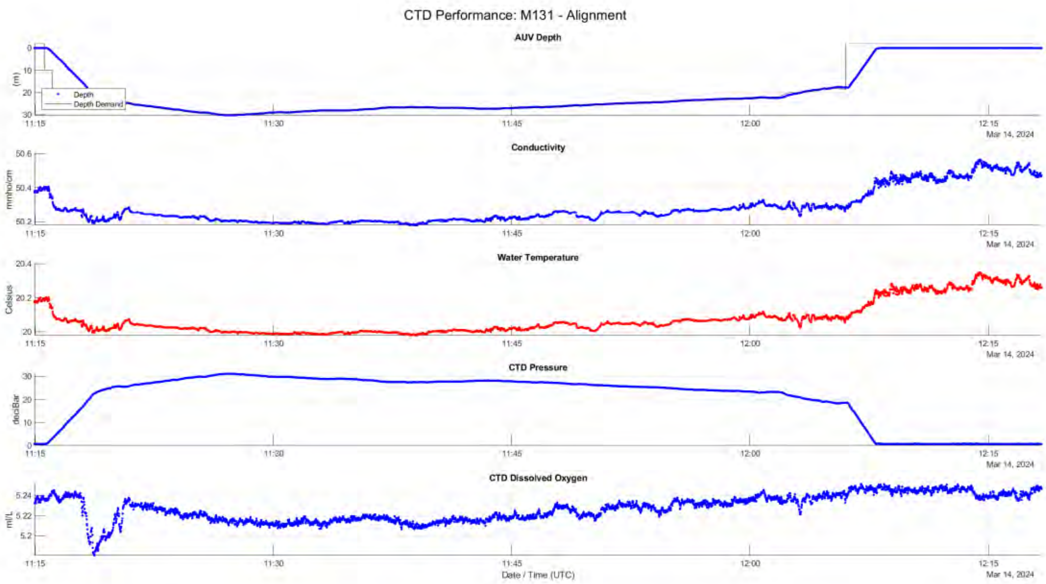
13.4. ALR3M130: C01a 10 min Test dive (15m)



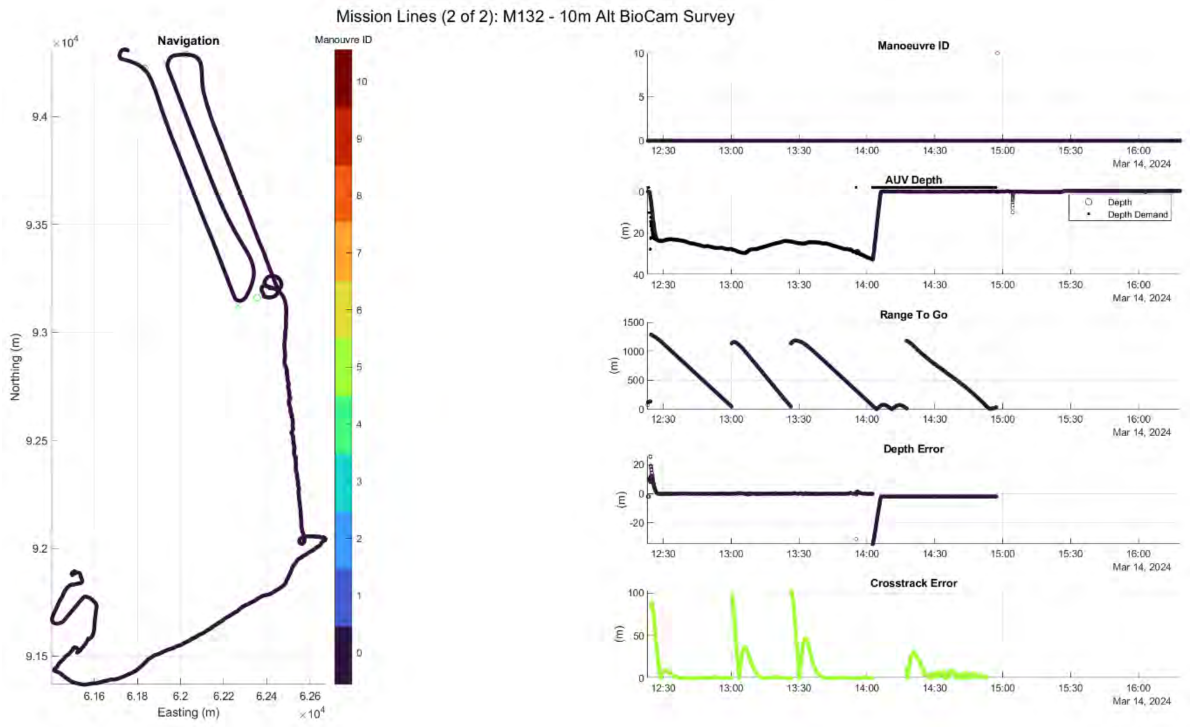


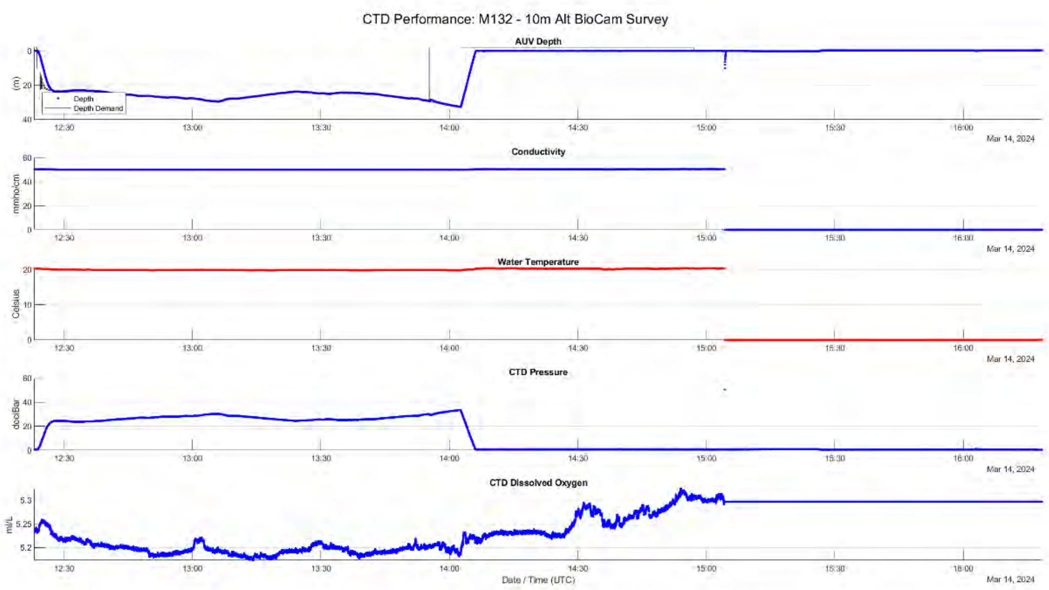
13.5. ALR3M131: C03a BioCam Alignment + FLS On



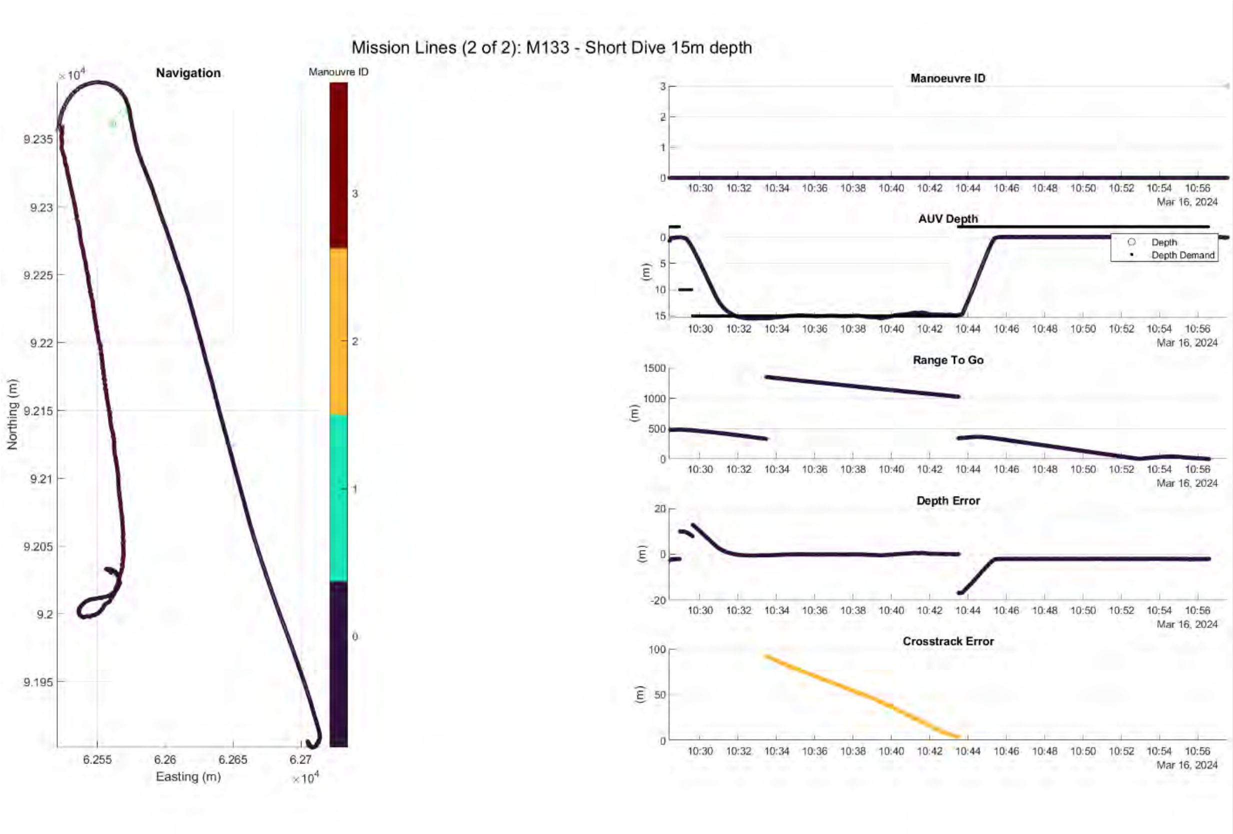


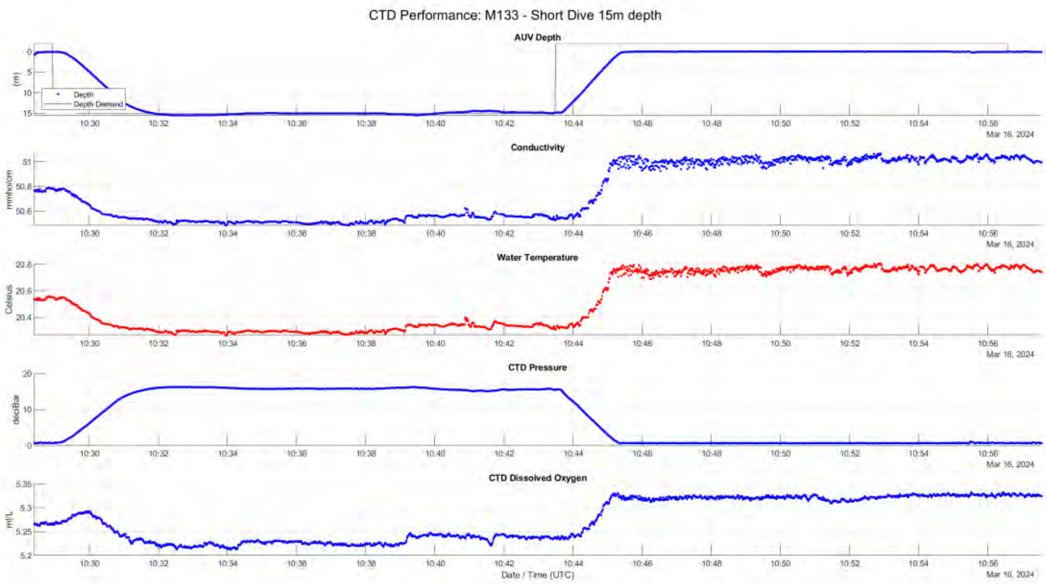
13.6. ALR3M132: S0a BioCam Survey (10m alt) + FLS On



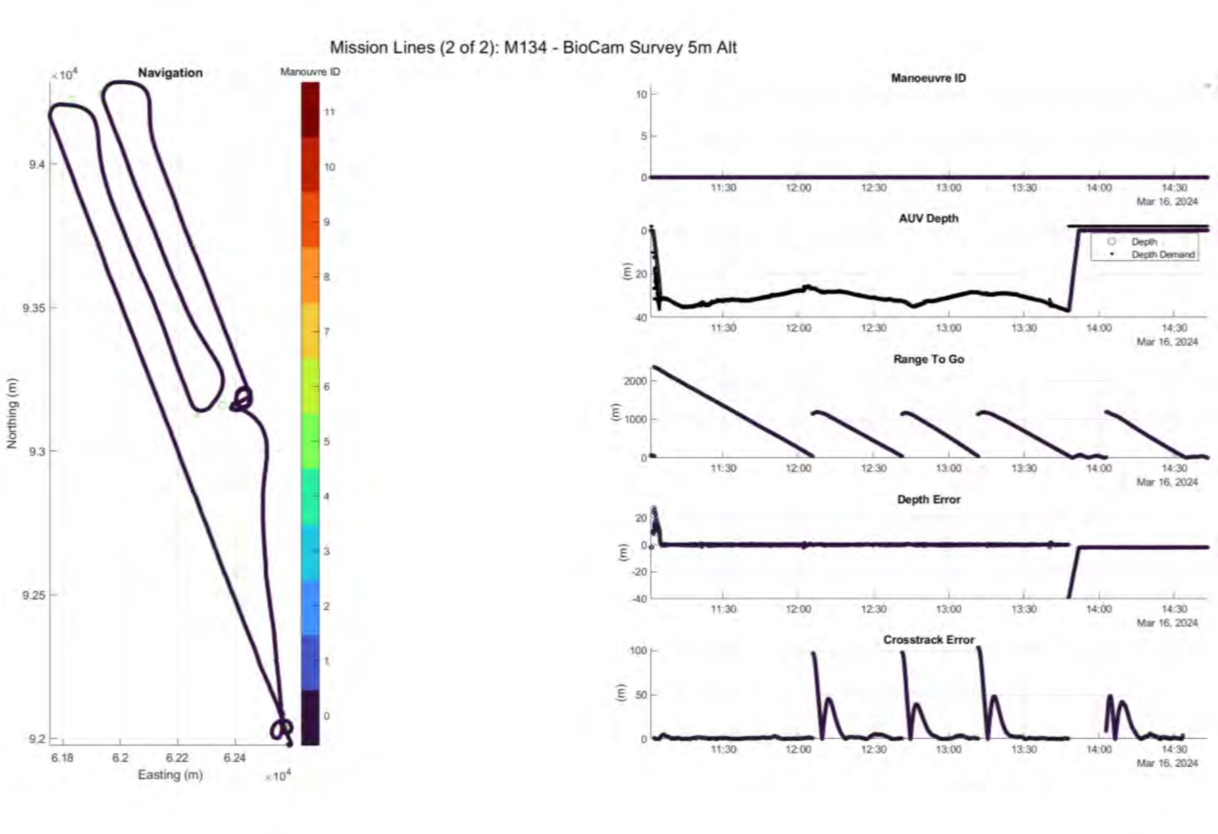


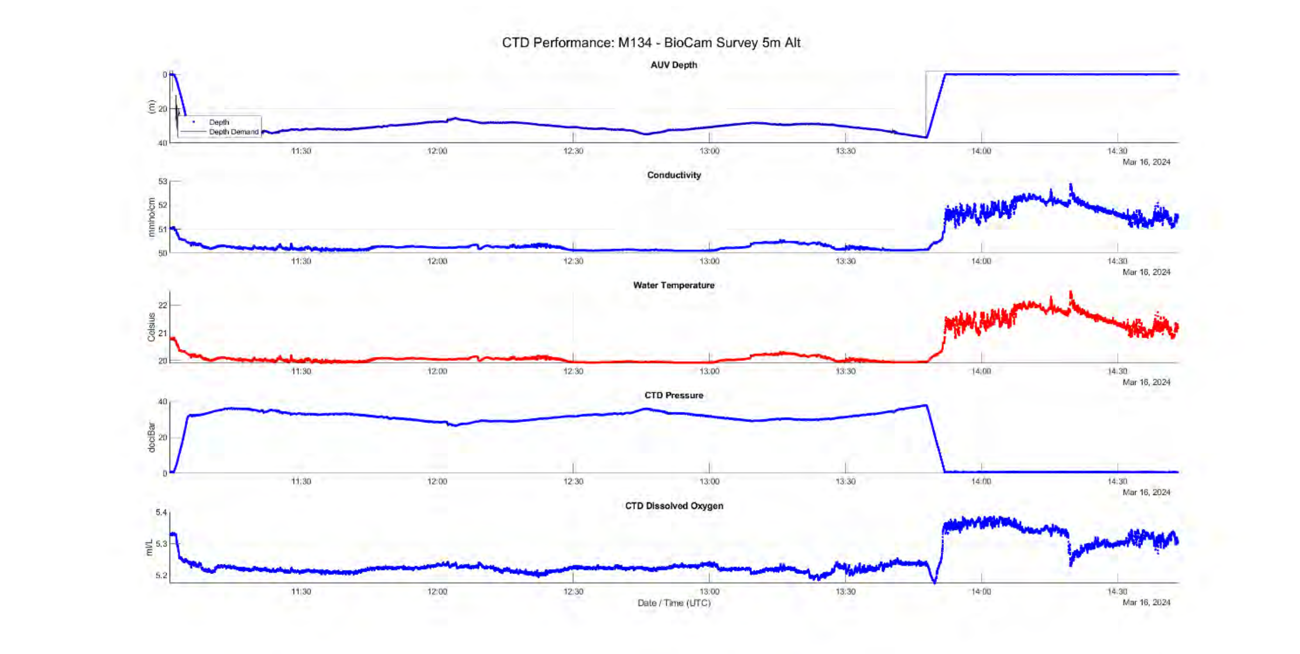
13.7. ALR3M133: C01a 10 min Test dive (15m)





13.8. ALR3M134: S1 BioCam Survey (5m alt) + FLS On

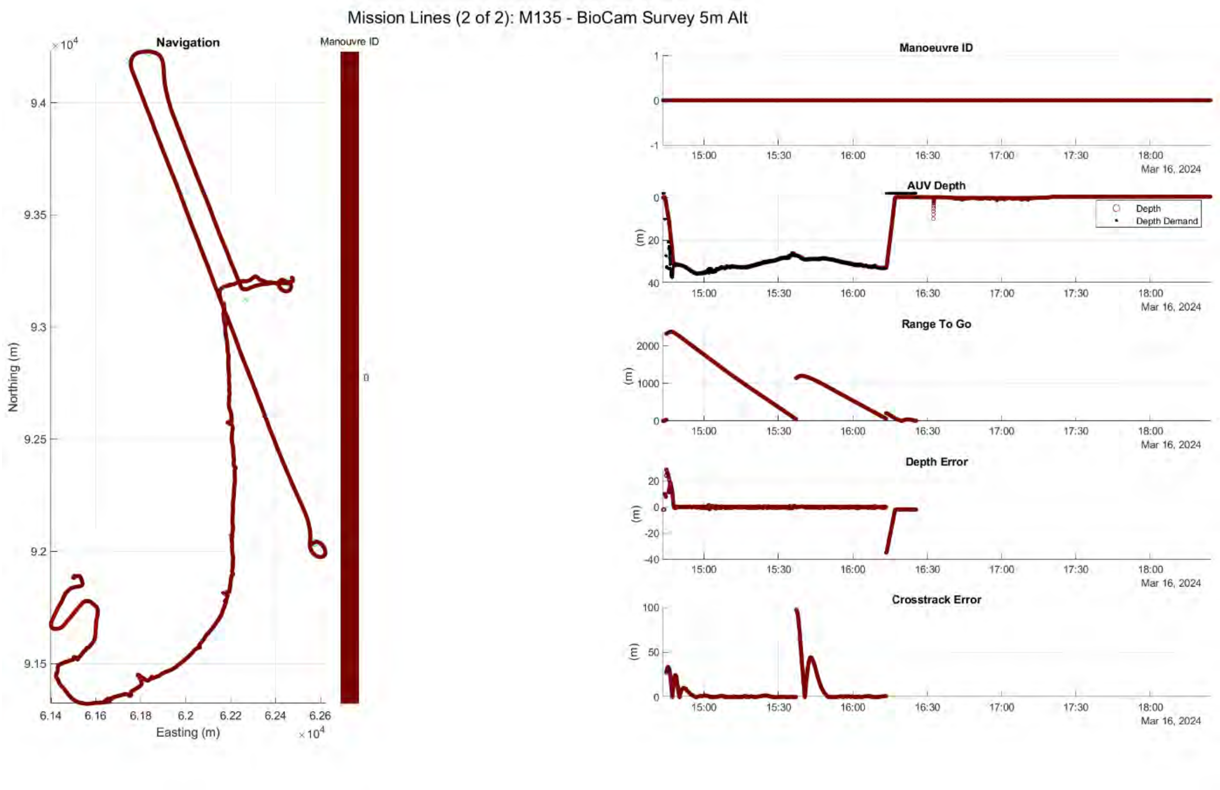


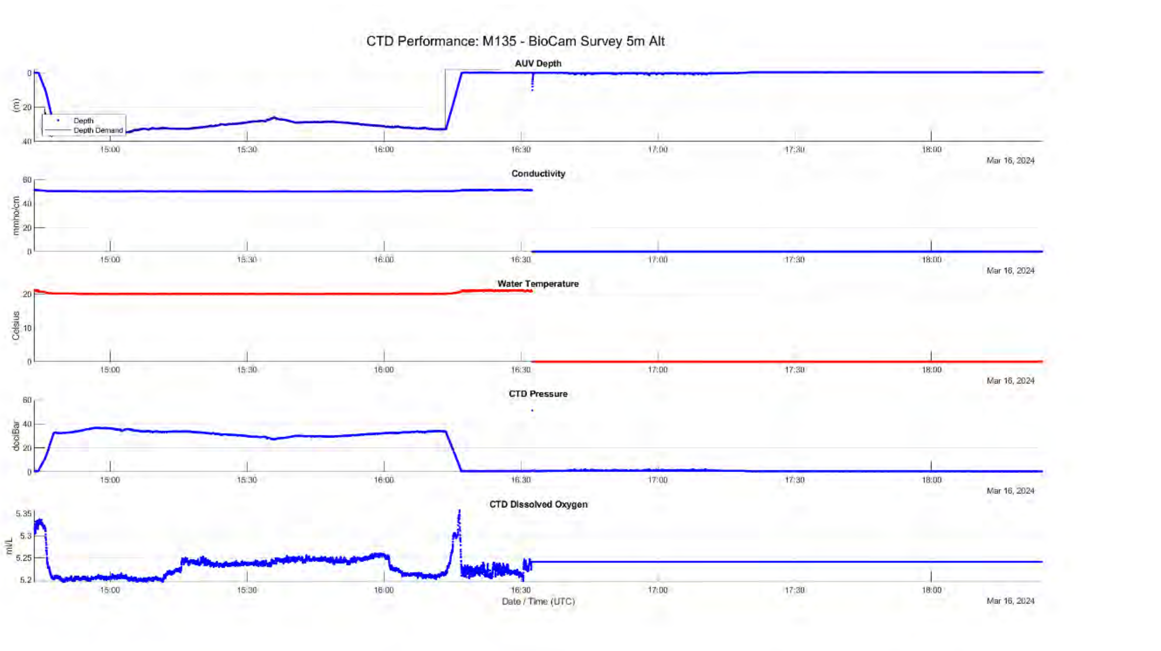


On surfacing and transiting back to the north waypoint no NRT sbd messages were received, on investigation it appeared that when merging the two previous missions (alignment and

10m altitude ADCP) to make the 5m altitude BioCam plan an error was made in the mission plan, the start mapping command was omitted meaning that the BioCam was not put into mapping mode and therefore no data was collected and no NRT data messages sent.

13.9. ALR3M135: S1 BioCam Survey (5m alt) + BioCam On FLS On





On surfacing no BioCam NRT data messages were received, later investigations suggest that the BioCam was in an unknown state due to the sequence of start, stop, send summaries commands?

14. **Document Information**

EU Project	No 101000858	Acronym	TechOceanS
Full Title	Technologies for Ocean Sensing		
Project website	www.techoceans.eu		

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Reviewers	All

Version log			
Issue Date	Revision N°	Author	Change
29.04.2024	1	All	Final version to submit to Spanish authorities