DY149 Cruise Report

RRS Discovery

14th March – 30th March 2022

PS: Prof. Mark Moore

University of Southampton

Contents

1. General Information

Mark Moore – University of Southampton

1.1 Cruise Personnel

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DY149 Cruise personnel

From left: Front row: Mary, Patry, Nina, Rudi. Middle row: Jade, Emily, Boaty. Third row: Paul, Neil, Alan, Ed, Alberto, Chris, Simon. Back row: Mark, Socratis, John, Martin, Matt, Phil, Jacob, Nick, Jack

1.2 Scientific background

Cruise DY149 was the trials cruise for 3 of the 5 sensor development projects within the NERC funded OCEANIDS programme. The overall aim of the cruise was to trial and demonstrate capability for a suite of in situ biogeochemical sensors developed to measure: the inorganic carbon system (CarCASS, led by the National Oceanography Centre, (NOC)); a series of inorganic nutrients (AUTONUTS, led by NOC) and phytoplankton primary production (STAFES, led by the University of Southampton (UoS)), all deployed on the Autosub Long Range (ALR) platform (aka ‘Boaty McBoatface’). The cruise was undertaken on the *RRS Discovery* within the Celtic Sea and adjacent shelf break/slope and near-slope North East Atlantic Ocean from 14th – 30th March 2022.

The main objectives of the cruise were:

1. To demonstrate each of the sensor packages working in situ on ALR, including over their full depth range on the platform;
2. To collect validation / comparison data for the variables measured in situ with the sensors on ALR;
3. To develop an understanding of mission and deployment profiles for ALR and the sensor suite which can provide high quality biogeochemical data;
4. To demonstrate capabilities of the ALR and sensor suite in the investigation of biogeochemical processes during the early development stages of the spring bloom at towards and across the shelf break of the Celtic Sea;

At the point of docking the cruise could be considered highly successful. The ALR platform performed very well, achieving over 8.5 days of deployment in the open ocean including one >4 day individual deployment. All 11 of the new sensors across the 3 sensor projects (AUTONUTS, CarCASS and STAFES) deployed on ALR were demonstrated to work *in situ* on the platform at some stage during the cruise, with multiple individual missions and deployments demonstrating all sensors working simultaneously. There were inevitably some problems identified with individual sensors at certain stages, but the majority of the issues were either known or identified at sea with subsequent workable solutions found. A number of mission profiles were tested with the whole system (sensors plus platform), with the aim of identifying mission modes applicable to generating high quality biogeochemical oceanographic data. Co-sampling performed using the CTD system (Figure 1.1) should enable both data for sensor validation and overall comparison data for validation / comparison with the biogeochemical information provided by the ALR / Sensor platform. The final 4 day deployment from the shelf across the shelf edge (Figure 1.3) sampled the beginning of the spring bloom towards the shelf edge (Figure 1.2) and the clear oceanographic gradients apparent within this data are likely to provide both a good demonstration of system capabilities and valuable scientific data.

All of the crew, technicians and scientists are thanked for their hard work and professionalism throughout. Thanks are also due to all of the shore based staff who helped in preparing platforms, instruments and in organising and supporting a very successful cruise.

DY149 main sampling locations

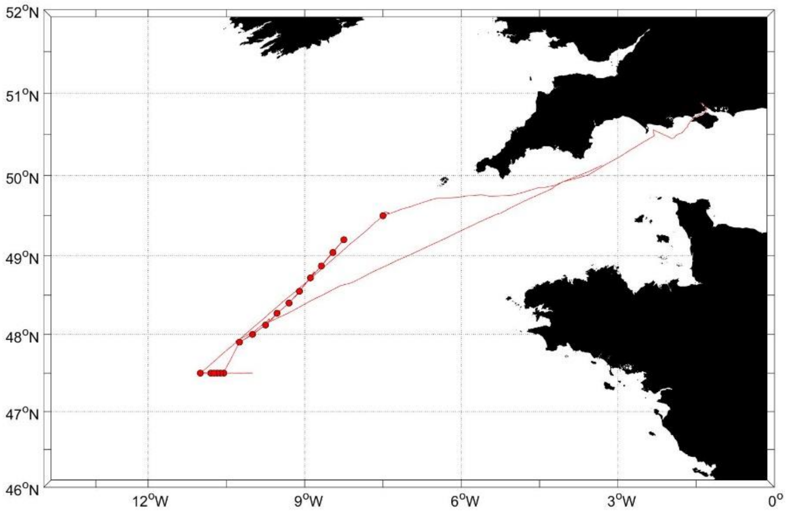


Figure 1.1: *Cruise track with main sample locations*

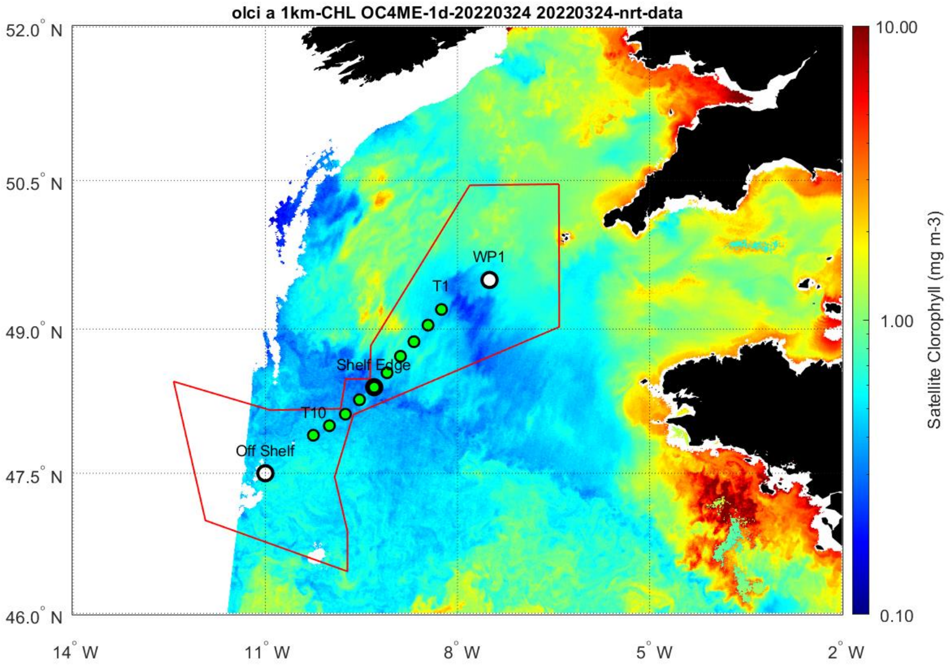


Figure 1.2: *Main sampling locations for DY149 superimposed on satellite ocean colour chlorophyll image from 24/03/2022*

1.3 Day-by-day overview

Date	**JD**	**Location**	**Activities**
10/03	68	Southampton	Mobilisation
11/03	69	Southampton	Mobilisation
12/03	70	Southampton	Mobilisation
13/03	71	Southampton	Mobilisation
14/03	72	Sail, Transit	Sail from Southampton (1430)
15/03	73	Transit + W1	Transit. Arrive W1 1830, CTD01
16/03	74	W1	Working W1, ALR Deployment 1, CTD02, CTD03
17/03	75	Transit + OS	CTD04, survey along 47.5N
18/03	76	OS transect	Working OS_A – OS_B
19/03	77	OS transect	Working OS_A – OS_B
20/03	78	OS transect	Working OS_A – OS_B
21/03	79	OS transect	Working OS_A – OS_B
22/03	80	OS transect	Working OS_A – OS_B, in transit to T1
23/03	81	T transect	On station T1, working on ALR
24/03	82	T transect	‘T’ Transect, T1, T2
25/03	83	T transect	‘T’ Transect, T3, T4
26/03	84	T transect	‘T’ Transect, T5, T6
27/03	85	T transect	‘T’ Transect, T7, T8
28/03	86	T transect	‘T’ Transect, T9, T10
29/03	87	T transect	‘T’ Transect running back T9 – T7, steaming Southampton
30/03	88	Transit	Steaming Southampton
31/03	89	Departure	Demob

Table 1.1: *Overview of general activities on day-by-day basis*

1.4 DY149 Cruise narrative

Date	**Time (GMT)**	**Time (ships)**	**Activity/event**	**Site/Location**
10/7	ALL UTC	ALL UTC	Alongside at NOCS Science and technical parties joining ship throughout day. Some initial 'issues' with lateral flow tests in use at the beginning of the day were sorted by switching to different tests. All joiners undertook PCR tests. Science and technical party isolating in cabins until result of tests available. First day of mobilisation. Containers loaded.	
11/03			Alongside at NOCS PCR tests returned late morning (all negative!). Second day of mobilisation. All remaining equipment loaded. Laboratory setup commenced.	
12/03			Alongside at NOCS Joining and orientation meeting at 1000 for science compliment Laboratory setup continues	
13/03			Alongside at NOCS Science meeting at 1000 for scientists and technicians Laboratory setup continues	
14/03	0000 1430 2100 2130		Alongside at NOCS am **Sailed** Transit to Weymouth to drop off engineer In transit	
15/03	0000 0830 1830 1837		On transit First morning meeting On station W1 **Event 01**: Shakedown CTD (CTD 01) Stainless	
16/03	0712 1500 1718 1843		**Event 02**(a): ALR Deployed **Event 03**: Stainless CTD (CTD 02) **Event 02**(b): ALR recovered **Event 04**: Titanium CTD (CTD 03) Overnight incident with lithium battery pack. Investigation performed following morning. Likely water ingress caused failure. On transit to 'Off shelf' (OS)	W1 49.5N, 7.5W
17/03	 1530 1541 1655		On transit to OS On station at OS **Event 05**: Stainless CTD (CTD 05) to 1000m	OS OS (47.5N, 11W)

			Event 06: Survey along 47.5N Survey overnight to identify region of maximum chlorophyll gradient to east of OS	
18/03	0743 1048 1706		**Event 07**: Stainless CTD (CTD 06) to 1000m at OS_A **Event 08**(a): ALR deployed ALR deployment delayed due to GPS failure **Event 09**: Stainless CTD 06 to 100m	OS_A (47.5N, 10.8W) Midpoint OS_A – OS_B
19/03	0140 0857 1112 1435		ALR sighted on surface **Event 10**: Stainless CTD (CTD07) to 1000m **Event 08**(b): ALR recovery **Event 11**: Titanium CTD (CTD08) to 1000m ALR aborted during dive to 250m at OS_B. Discovered to be due to system reboot while diving. Recovery was better than first. ALL sensors found to have worked on run! 20% battery used to this point	OS_B (47.5N, 10.55W)
20/03	0823 1257 1513 1725 2019		**Event 12**: Stainless CTD (CTD09) to 1000m **Event 13**(a): ALR deployment #3 ALR deployed to do OS_A to OS_B transect again in ‘reverse order’, 600m run first (B-A), then 250m (A-B), then 20m (B-A) Reposition to 47.5N, 10.61 W (3 quarters distance along OS A-B line, OS_AB_2), arrive 1456 **Event 14**: Stainless CTD (CTD 10) to 1000m **Event 15**: Titanium CTD (CTD 11) to 1000m Move on to OS_A (ALR at 600m) Picked up ALR on USBL (both running out to OS_A and back following overshoot)	OS_B (47.5N, 10.55W) OS_AB_4 (47.5N, 10.61W) OS_A (47.5N, 10.8W)

			Acoustic transducer used to talk to ALR Ship and ALR proceed return leg (250m) back to OS_B	
21/03	0611 1435		Standing by ALR in wifi range at OS_B ALR dived for return to OS_A at 20m Reposition to ¼ way along OSA – OS_B (OS_AB_2, 47.5N, 10.74W) **Event 16**: Stainless CTD (CTD12) to 1000m ALR sent new mission (staircase back to OS_B), dived at 2009 Ship repositions to OS_B	OS_B (47.5N, 10.55W) OS_AB_2 (47.5N, 10.74W)
22/03	0704 1137		**Event 17**: Stainless CTD (CTD 13) to 1000m **Event 13**(b): ALR recovery Transit to Station T1 via stations T10, T9 etc. Swath running to collect good bathymetry along run line.	OS_B (47.5N, 10.55W)
23/03	0906 1027		On station at T1 **Event 18**: Stainless CTD (CTD 14) to 100m **Event 19**: Titanium CTD (CTD 15) to 100m STAFES swapped out on ALR. Required removal of CarCASS sensors. All replaced by end of day. Pub Quiz during the evening (PS in team that came last…)	T1
24/03			Problem with AUTONUTS tests overnight, required re-flushing and tests delaying ALR deployment.	

	0840 1251 1757		**Event 20**: Stainless CTD (CTD 16) to 110m (T1) **Event 21**: ALR deployed (Deployment 4) ALR required reboot on deployment. STAFES restarted Clear evidence of spring bloom commencing on shelf alongside weak near surface stratification Commence 'Line T' with ALR and parallel CTD stations. **Event 22**: Stainless CTD (CTD 17) to 110m (T2)	T1 T2
25/03	0617 1010 1211		**Event 23**: Stainless CTD (CTD 18) to 110m (T3) Move to T4 **Event 24**: Titanium CTD (CTD 19) to 110m (T4) **Event 25**: Stainless CTD (CTD 20) to 110m (T4) ALR transect and Line T continue	T3 T4
26/03	0814 1550		**Event 26**: Stainless CTD (CTD 21) to 110m (T5) Move to T6 **Event 27**: Stainless CTD (CTD 22) to 110m (T6) ALR transect and Line T continue	T5 T6
27/03	0702 1403 1534 1652		**Event 28**: Stainless CTD (CTD 23) to 110m (T7) Move to T8 **Event 29**: Titanium CTD (CTD 24) to 110m (T8) **Event 30**: Stainless CTD (CTD 25) to 110m (T8) **Event 31**: Titanium CTD (CTD 26) to 500m (T8) test cast with sensors only ALR transect and Line T continue	T7 T8

28/03	0609		**Event 32**: Stainless CTD (CTD 27) to 1500m (T9), long stops for sensors ALR found to not have CTD running during mission during the previous day. Move to T10	T9
	1132		**Event 33**: Stainless CTD (CTD 28) to 3000m (T10), long stops for sensors	T10
	1641		**Event 21**(cont): ALR recovered. ALR deployment 4 ends Decided to do one more ALR transect along line T in order to test revised STAFES sampling system and to fill in gap in CTD data	
	1939		**Event 34**: ALR Deployed	48.0414 N, 9.9454 W
	2024		**Event 35**: Stainless CTD (CTD 29) deployed to unspool wire to point where lay uneven	
29/03	0549		**Event 34**(cont): ALR recovered Off station on transit for Southampton	48.1883 N, 9.6612 W

Table 1.2: *Daily cruise narrative*

1.5 Main station locations

Note, locations are the reference point, refer to individual logs for details of deployment / recovery locations. All locations below are decimal degrees

Station ID	**Latitude N**	**Longitude W**	**Comments**
W1	49.5	7.5	Test station, first ALR deployment
OS	47.5	11.0	Reference station off shelf
OS_A	47.5	10.8	Station at west end of ‘OS transect’
OS_B	47.5	10.55	Station at east end of ‘OS transect’
OS_AB2	47.5	10.6125	Stations along OS transect
OS_ABmid	47.5	10.6750	Stations along OS transect
OS_AB4	47.5	10.7375	Stations along OS transect
T1	49.2	8.25	‘Line T’
T2	49.04	8.46	‘Line T’
T3	48.87	8.68	‘Line T’
T4	48.72	8.89	‘Line T’
T5	48.55	9.10	‘Line T’
T6	48.40	9.30	‘Line T’
T7	48.27	9.53	‘Line T’
T8	48.12	9.75	‘Line T’
T9	48.00	10.00	‘Line T’
T10	47.90	10.25	‘Line T’

Table 1.3: *Main sample locations during DY149*

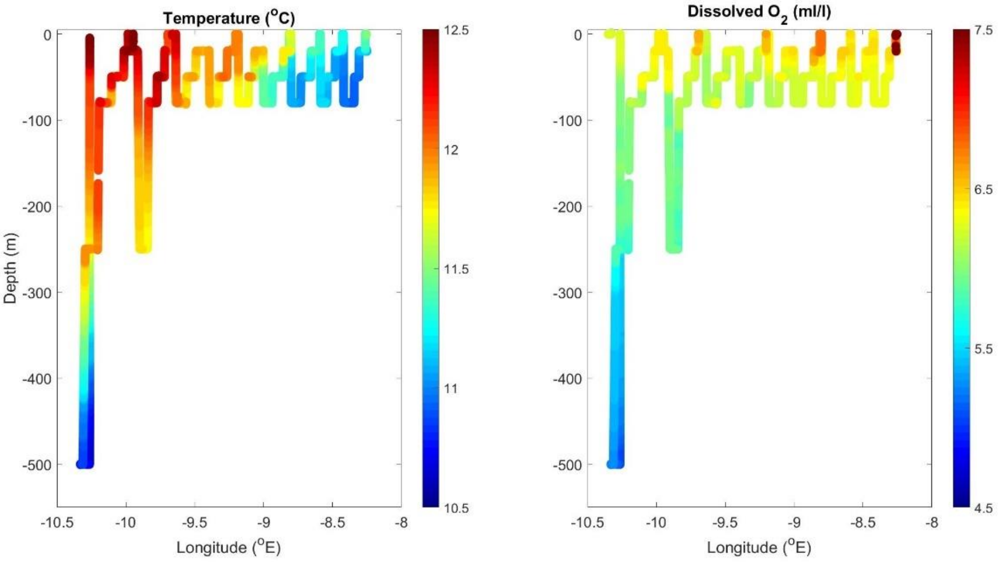


Figure 1.3: *Example data from ‘Transect T’ collected with ALR.*

2. ALR-2 Operations

Ed Chaney, Alberto Consensi, Phil Bagley (NOC)

2.1 Introduction

2.1.1 Document Description

This is the Technical cruise report for Autosub Long Range (ALR) operations during DY149

2.1.2 Aim of ALR Operations

The primary objective of the cruise is to demonstrate Oceanids funded sensors Autonuts, CarCASS, and STAFES-APP) in a representative environment on a MARS vehicle (ALR2) and cross calibrate sensors with water samples from the both the normal and metal free CTD.

2.2. ALR Mission List

2.2.1 Mission List

Table 2.1 shows a summary of ALR missions undertaken during DY149, and Figure 2.1 shows the general layout of the ALR with sensor locations

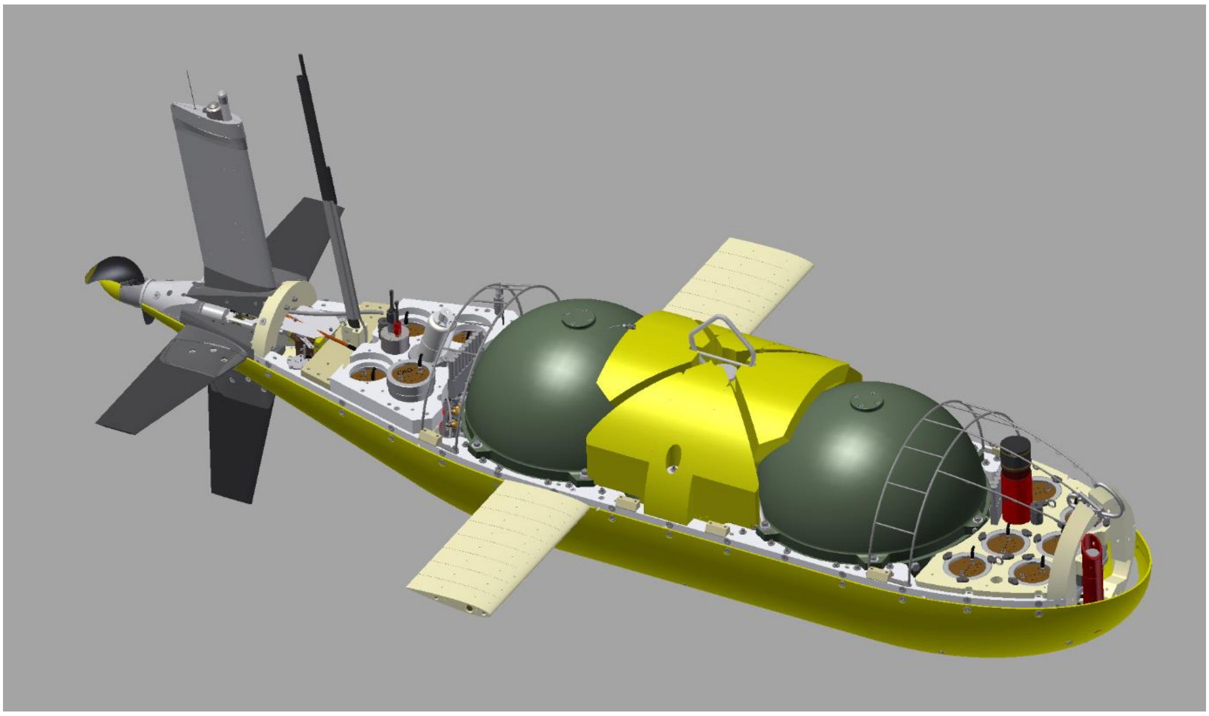


Figure 2.1: *ALR-2 with CarCASS sensors in the bow and AutoNuts and STAFES-APP in the aft.*

Ships Station Number	ALR Mission Number	Start		End		Plan Name	Plan Start Location (decimal degrees)	Depth (m)	Description
		Date	Time (GMT)	Date	Time (GMT)				
2	M55	16/3/2022	07:15	16/3/2022	07:20	DY149-ALR-2-ENG02-SouthOnSurface	Relative to Ship	Surface	Five-minute surface track heading south from deployment location
	M56	16/3/2022	07:35	16/3/2022	07:56	DY149-ALR-2-ENG03-SouthDived10m-Potter	Relative to Ship	10	Short safety dive to 10m then potter on surface
	M57	16/3/2022	08:41	16/3/2022	11:25	DY149-ALR-2-ENG04-CompassCal-LOS-A-B	49.4955, -7.5000	30	Line of sight from current location to Calibration start, then calibration boxes
	M58	16/3/2022	14:10	16/3/2022	14:46	DY149-ALR-2-ENG10-Alignment to E	49.5119, -7.5132	30	Compass alignment run to Waypoint E
	M59	16/3/2022	14:57	16/3/2022	15:53	DY149-ALR-2-ENG11-Alignment East from E	49.5269, -7.5037	50	Sensors On: STAFES-APP, Autonuts, CarCASS Compass alignment run East from waypoint E
2	M60	16/3/2022	15:53	16/3/2022	162:7	DY149-ALR-2-ENG12-Speed Test	49.5083, -7.4353	80	Sensors On: STAFES-APP, Autonuts, CarCASS Compass alignment run at different speeds (40W, 30W, 20W, 10W) to check buoyancy

Ships Station Number	ALR Mission Number	Start		End		Plan Name	Plan Start Location (decimal degrees)	Depth (m)	Description
		Date	Time (GMT)	Date	Time (GMT)				
8	M61	18/3/2022	10:55	18/3/2022	11:07	DY149-ALR-2-SCI-01-South-on-Surface Potter	Relative to Ship	Surface	Five-minute surface track heading south from deployment location
	M62	18/3/2022	11:20	18/3/2022	16:49	DY149-ALR-2-SCI-02A-FeatureTransect-A-to-MAB Cal	47.5000, -10.8008	20	Sensors On: STAFES-APP, Autonuts, CarCASS Compass calibration then track to Mid AB waypoint
	M63	18/3/2022	17:28	18/3/2022	21:37	DY149-ALR-2-SCI-02B-FeatureTransect-MidAB to B	47.5000, -10.6750	20	Sensors On: STAFES-APP, Autonuts, CarCASS Track from Mid AB to B
	M64	19/3/2022	00:49	19/3/2022	02:00	DY149-ALR-2-SCI-03-FeatureTransect-B to A 250m	47.5000, -10.8000	250	Sensors On: Autonuts, CarCASS Dive Aborted
13	M65	20/3/2022	13:05	21/3/2022	05:30	DY149-ALR-2-SCI-05- B to A 650m A to B 250m	47.5000, -10.5500	600, 250	Sensors On: Autonuts, CarCASS Track OS_B to OS_A at 650m, then OS_A to OS_B at 250m
	M66	21/3/2022	08:35	22/3/2022	17:49	DY149-ALR-2-SCI-02-FeatureTransect B to A 20m	47.5000, -10.8000	20	Sensors On: STAFES-APP, Autonuts, CarCASS Track OS_B to OS_A at 20m

Ships Station Number	**ALR Mission Number**	**Start**		**End**		**Plan Name**	**Plan Start Location (decimal degrees)**	**Depth (m)**	**Description**
		Date	**Time (GMT)**	**Date**	**Time (GMT)**				
	M67	21/3/2022	20:06	22/3/2022	08:34	DY149-ALR-2-SCI-06-Staircase A to B	47.5000, -10.5500	20, 100, 250, 600	Sensors On: STAFES-APP, Autonuts, CarCASS Staircase mission from OS_A to OS_B
21	M68	24/3/2022	13:45	25/3/2022	00:03	DY149-ALR-2-SCI-07-Staircase T1 to T2	49.1957, -8.2307	20,50,80	Sensors On: STAFES-APP, Autonuts, CarCASS Staircase mission from T1 towards T2 on shelf
	M69	25/3/2022	00:42	25/3/2022	07:20	DY149-ALR-2-SCI-08-Staircase T2 to T3	49.0542, -8.4406	20,50,80	Sensors On: STAFES-APP, Autonuts, CarCASS Staircase mission through T2 towards T3 on shelf
21	M70	25/3/2022	08:43	25/3/2022	17:00	DY149-ALR-2-SCI-09-Staircase T3 to Mid-T3	48.9372, -8.5951	20,50,80	Sensors On: STAFES-APP, Autonuts, CarCASS Staircase mission through T3 towards T4 on shelf
	M71	25/3/2022	18:37	26/3/2022	13:51	DY149-ALR-2-SCI-10-Staircase Mid-T3- T5	48.7866, -8.8038	20,50,80	Sensors On: STAFES-APP, Autonuts, CarCASS Double Staircase mission through T4 towards to Mid T5,T6 on shelf
	M72	26/3/2022	15:00	27/3/2022	09:55	DY149-ALR-2-SCI-11-Staircase Mid-T5 mid T7	48.4768, -9.1981	20,50,80	Sensors On: STAFES-APP, Autonuts, CarCASS Double Staircase mission start mid T5-T6 to Mid T7-T8 on shelf
	M73	27/3/2022	11:15	27/3/2022	22:41	DY149-ALR-2-SCI-12-Staircase Mid-T5T7 T9	48.174812, -9.665043	20,50,80,250	Sensors On: STAFES-APP, Autonuts, CarCASS Single staircase mission from mid T7 towards T9 No ALR CTD data
	M74	27/3/2022	23:49	28/3/2022	14:59	DY149-ALR-2-SCI-13-Staircase T9- Past T10	48.027762, -9.981463	20,50,89,250 ,500	Sensors On: STAFES-APP, Autonuts, CarCASS Single staircase mission from mid T9 to T10

Ships Station Number	ALR Mission Number	Start		End		Plan Name	Plan Start Location (decimal degrees)	Depth (m)	Description
		Date	Time (GMT)	Date	Time (GMT)				
34	M75	28/3/2022	19:47	29/3/2022	04:51	DY149-ALR-2-SCI-14-Staircase T9- T7	48.04199, -9.942497	20,250,80,50,20	Sensors On: STAFES-APP, Autonuts, CarCASS Single staircase mission from mid T9 to T7

Table 2.1: ALR-2 Missions

2.2.2 Station #2 Mission Summary

Ship Station Number: 2	**ALR Mission Numbers: M55 to M60**
Deployment Start: 16/3/2022 07:15	**Deployment End: 16/3/2022 16:27**
Weather Conditions: 20kn wind, 3m swell	
General Location: Shelf	

The main objective of these first missions were to perform standard ALR compass calibration and alignment runs. The compass calibration runs are required to recalibrate the compass to the suite of OTE sensors installed in the vehicle. Whilst the alignment runs account for any misalignment between the (Doppler Velocity Log) DVL and compass. Once complete these missions improve the navigational accuracy of the ALR. The final mission in this series, enabled the ALR to run at different power levels to confirm the power required to maintain the ALR depth (Figure 2.4). With the large number of sensors and associated fluid bags, it was difficult to precisely alter the ballast of the ALR pre-cruise (Figure 2.2, Figure 2.3).

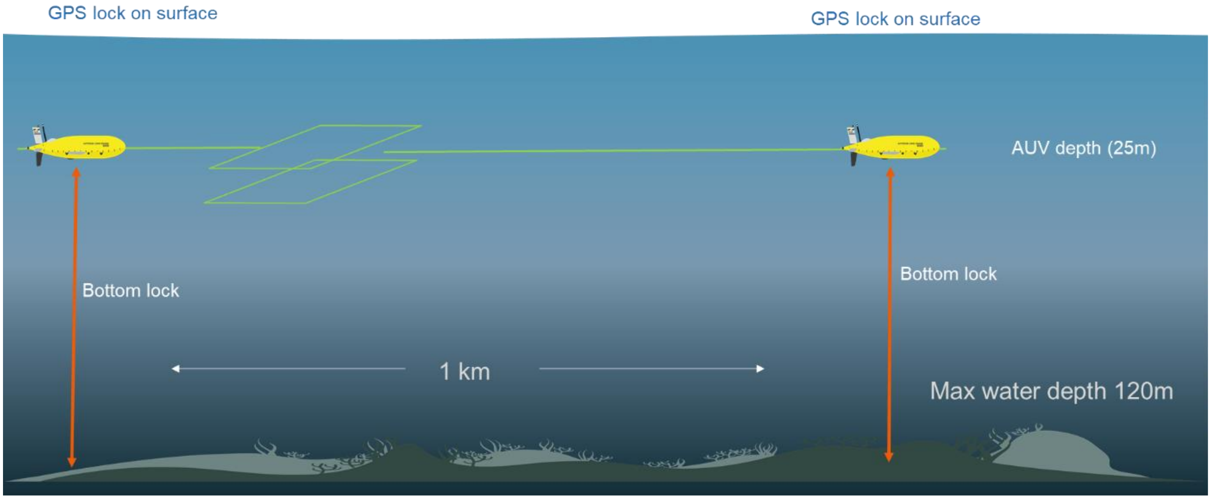


Figure 2.2: *Compass Calibration Plan*

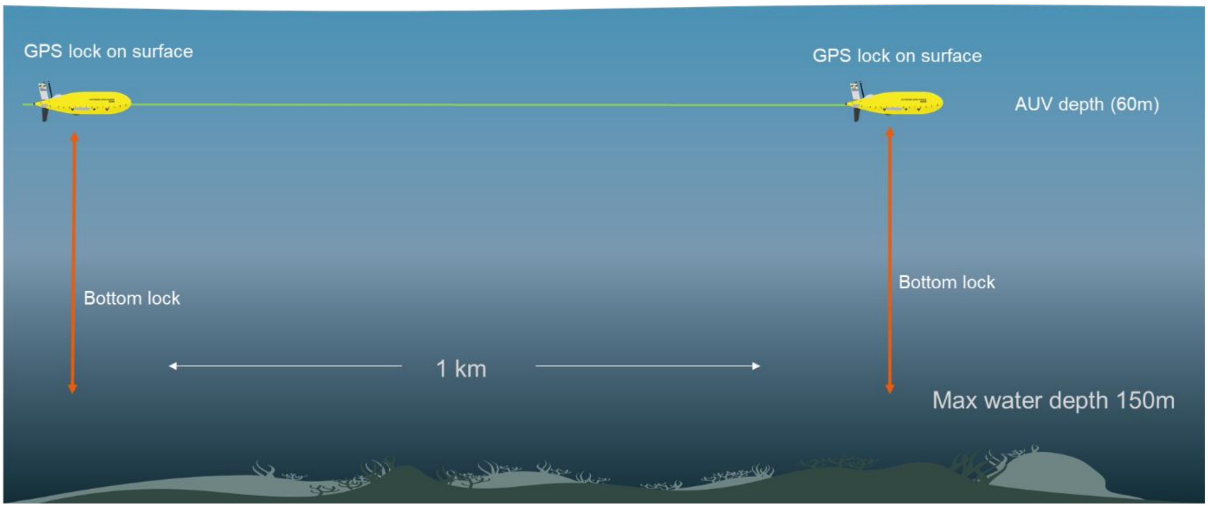


Figure 2.3: *Compass Alignment runs with sensors also switched on*

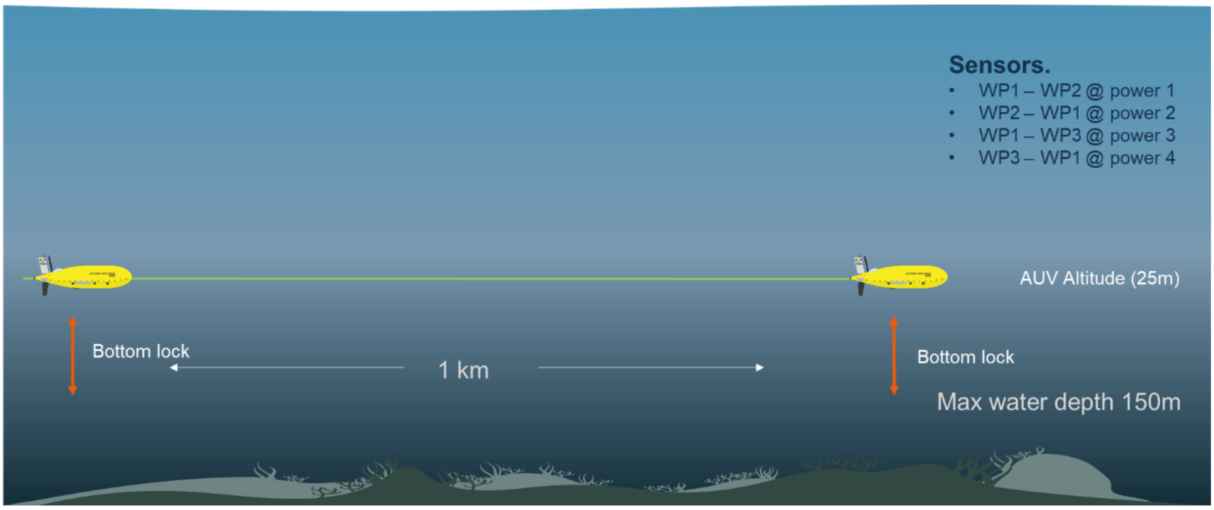


Figure 2.4: *ALR power runs with sensors also switched on.*

To make the most of these engineering runs during the alignment and power runs all sensors were powered on to check they were working and integrated correctly into the ALR control architecture.

Results:

- Compass calibration and alignment runs completed successfully. Power runs showed the ALR in its current ballasting condition needed more than 20W to maintain depth. Correct depth (at 80m) was maintained at 25W.
- All sensors integrated correctly within the ALR and were controllable via the ALR command and control system (Autonuts and CarCASS), or via command line (STAFES-APP).

Issues:

- The WiFi setup on the ship is not ideal. Although, we see high quality signal strength for various antennas around the ship, we observe poor WiFi communication with ALR. In previous setups (in Loch Ness with ALR, and at sea on the same ship with Autosub 6000) we have seen WiFi rages out to 800m. Here we achieve poor WiFi reception at 150m.
- Recovery was challenging, and some damage was caused during the recovery phase (Wing and fairing damage). For following recoveries as soon as the Templeton hook has engaged and the pole is clear the winch will be hauled to clear the ALR from the sea surface. Although this may result in the ALR swinging in air, this will prevent any impact against the side of the ship.

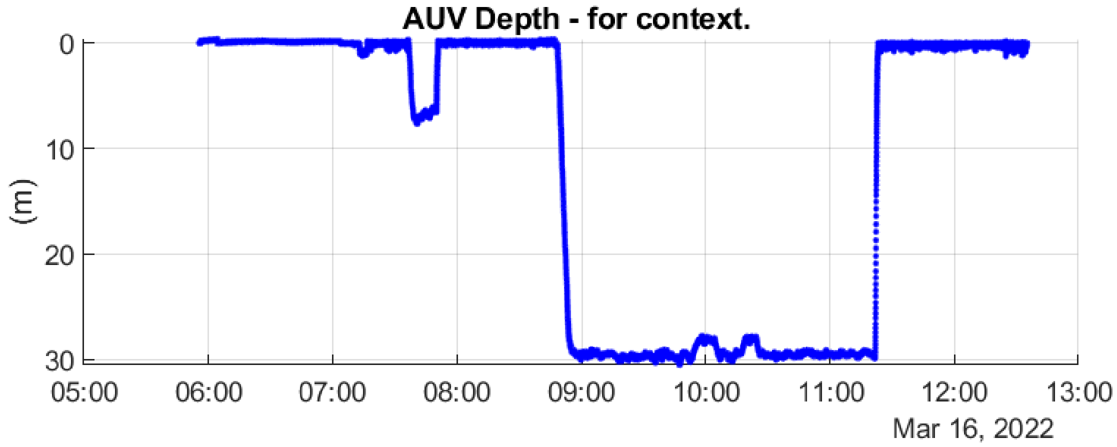


Figure 2.5: *Mission 55 to 57 AUV Depth*

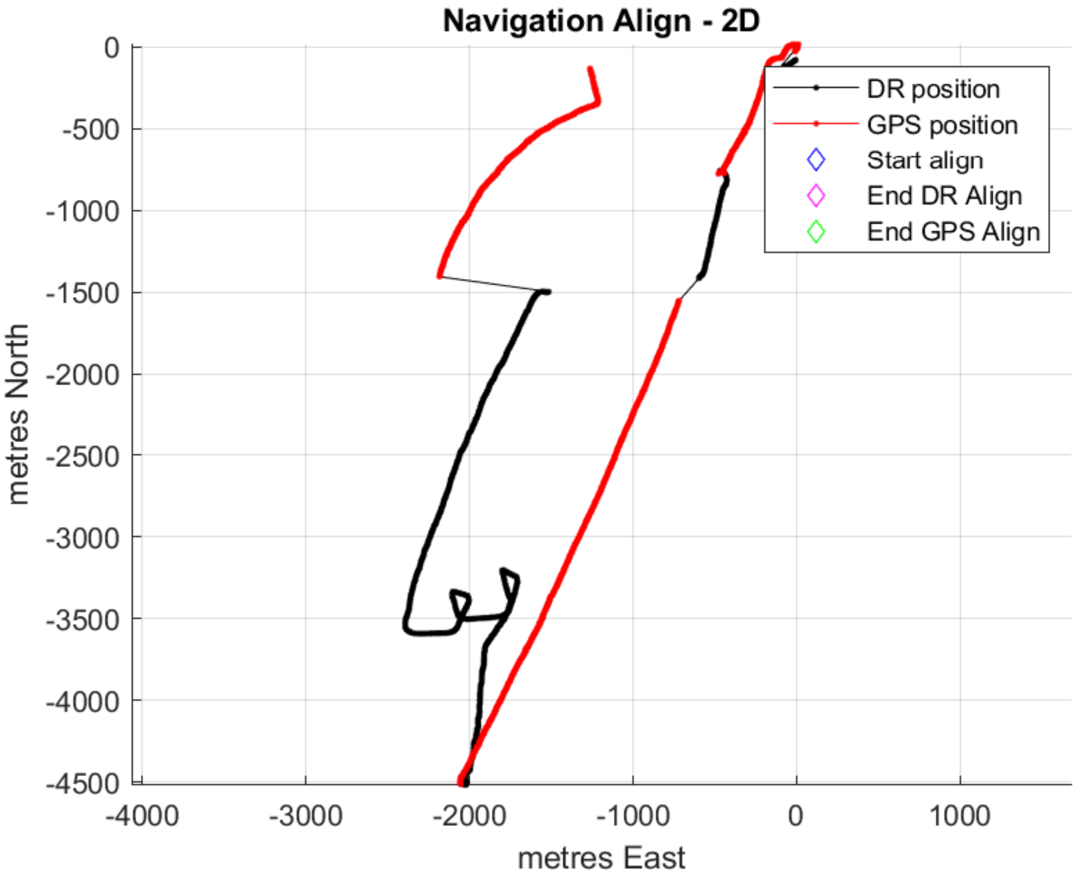


Figure 2.6: *Mission 55 to 57 Navigation*

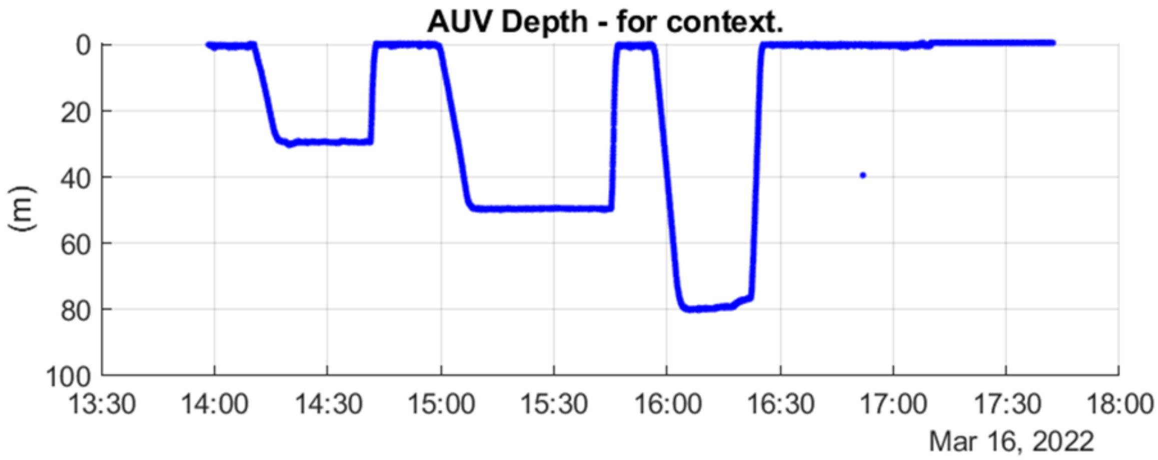


Figure 2.7: *Mission 58 to 60 AUV Depth*

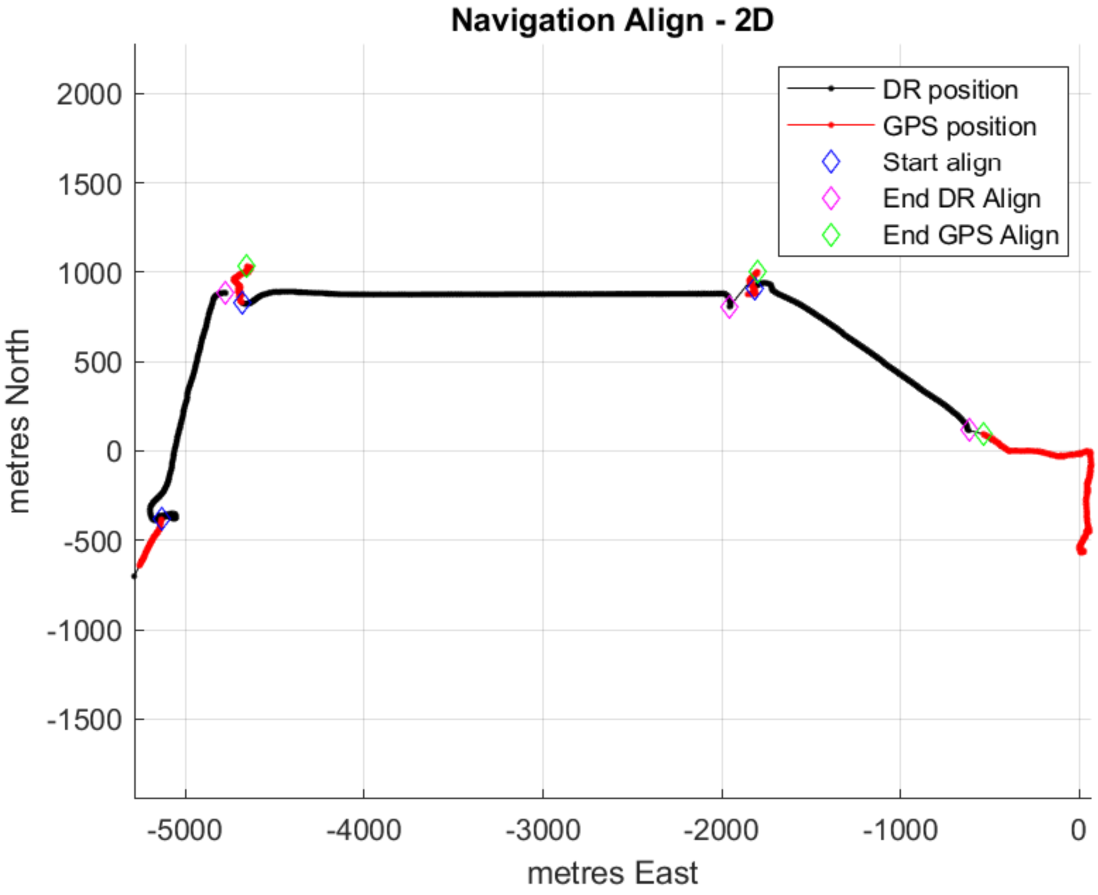


Figure 2.8: *Mission 58 to 60 AUV Navigation*

2.2.3 Station #8 Mission Summary

Ship Station Number: 8	**ALR Mission Numbers: M61 to M64**
Deployment Start: 18/3/2022 10:55	**Deployment End: 19/3/2022 02:00**
Weather Conditions: 25 knot wind, 2m swell	
General Location: Off Shelf	
Waypoints: OS_A: 47.5N, 10.8W OS_B: 47.5N, 10.55W	

These first set of science missions were aimed at transiting across an ocean feature/ front to determine if the sensors aboard ALR could detect the front and compare ALR sampling with underway and CTD sampling at representative points along the mission track (Figure 2.9).

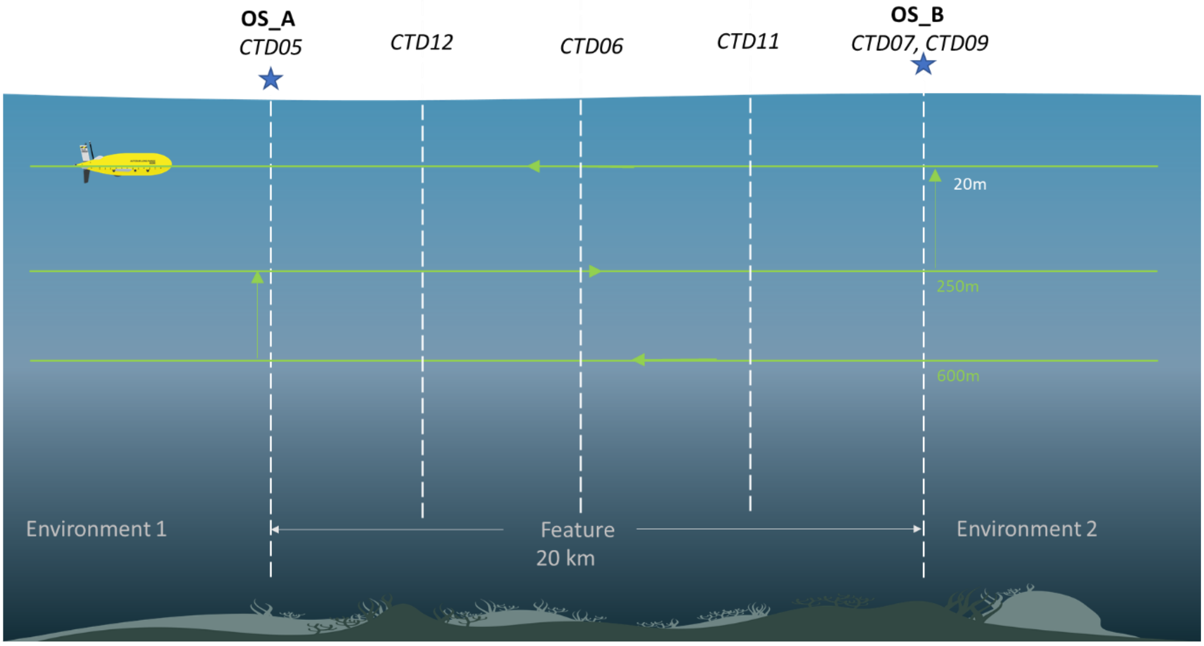


Figure 2.9*:Ocean feature transects*

Missions M62 & M63

Sensors On: STAFES-APP, Autonuts, CarCASS

Mission M62 followed a track approximately 20km long heading from Waypoint OS_A to a waypoint midway between OS_A and OS_B, followed by mission M63 which then continued from the midway point to OS_B. At the mid-point ALR surfacing allowed checks and to download ALR logs including Autonuts and CarCASS instrument logs.

Results:

- Successful missions with data from all 3 sensors. ALR surfaced 600m from the mid waypoint and 2km from the final waypoint at OS_B. Bottom lock was not possible running so shallow in deep waters, therefore navigation is based on speed through the water speed from ADCP and prop dynamics. This is not as accurate as bottom locked ADCP data and this a larger navigational accuracy is expected (Figure 2.10, Figure 2.11).

Mission M64

Sensors On: Autonuts, CarCASS

Mission 64 aimed to continue the feature tracking with a further 250m dive from OS_B to OS_A. However, the mission aborted on the initial dive phase to 250m (Figure 2.12). Analysis of the logs showed the ALR suffered a PIC reset during the dive phase. The ALR has a distributed control system where PIC based microprocessors control key elements of the ALR system. If any of the PIC microprocessors become unresponsive, the ALR control system reset the PIC processors to regain control. PIC resets are infrequent in the ALR Onboard Control System (OCS) version 2 (used in ALR-2) and almost non-existent on OCS version 3 (all other ALRs operate OCS version 3). A PIC reset has the effect of temporarily switching off key control elements such as the CTD. During this dive the CTD stopped working for 1 min 40 seconds as the PIC reset. During this reset period no depth data was being produced and the ALR assumed it was stuck trying to descent. This could be a serious (in other situations) and is an abort condition which resulted in the drop weight being released, and the ALR surfacing. Once the abort weigh has been dropped the ALR cannot dive and must be recovered.

A further consequence of a PIC reset, results in the actuators that operate the rudder and stern planes also becoming temporarily unresponsive. This is typically only for a short period of around 30 seconds. As the vehicle is travelling slowly this short period of unresponsiveness does not significantly affect ALR control. However, we have seen during bench testing that occasionally the actuators do not recover after a PIC reset and remain unresponsive.

The abort condition occurred at 02:00 so the ship stood watch over the ALR until daylight and weather conditions improved.

Mitigations:

As we are operating in deep water some of the safety timings associated with a PIC reset could be relaxed. Therefore, a number of changes were made to the ALR configuration:

- The STTD/ STTA timers were increased from 3 mins to 10 mins. Giving more time for the CTD to recover after a PIC reset. This is equivalent to 60m depth at our current descent rate of 0.1m/s, which is acceptable in deep water
- Max depth now set to 800
- Max depth offset set to 100
- The actuator issue will be mitigated by moving rudder and stern plane abort conditions to safety stops conditions. So, an actuator remaining unresponsive after a PIC reset, will allow the ALR to return to the surface to enable a reboot to correct the issue without the need to recover the ALR. Ultimately, if this stuck rudder/ stern plane

condition is dangerous to the vehicle, it will lead to a different abort condition, thus protecting the ALR.

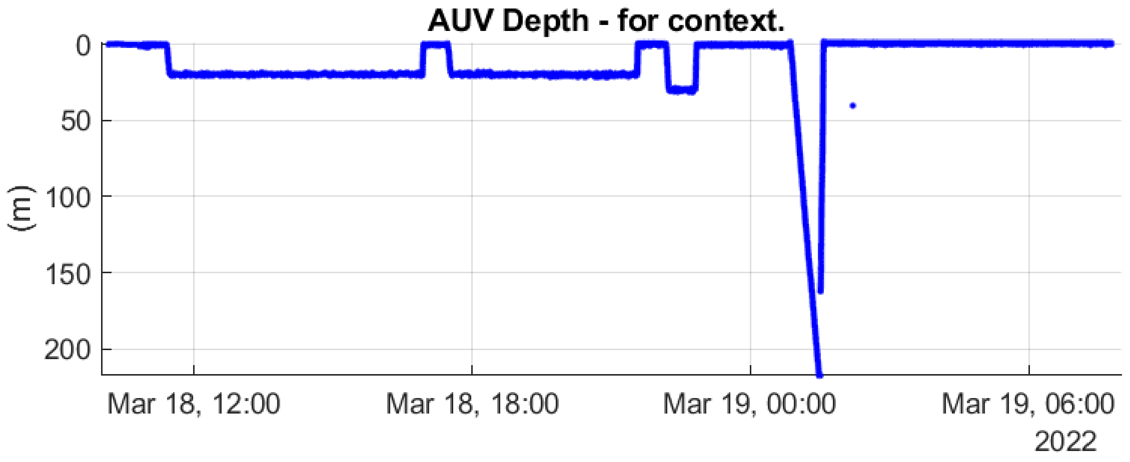


Figure 2.10: *Missions 61 to 64 AUV depth*

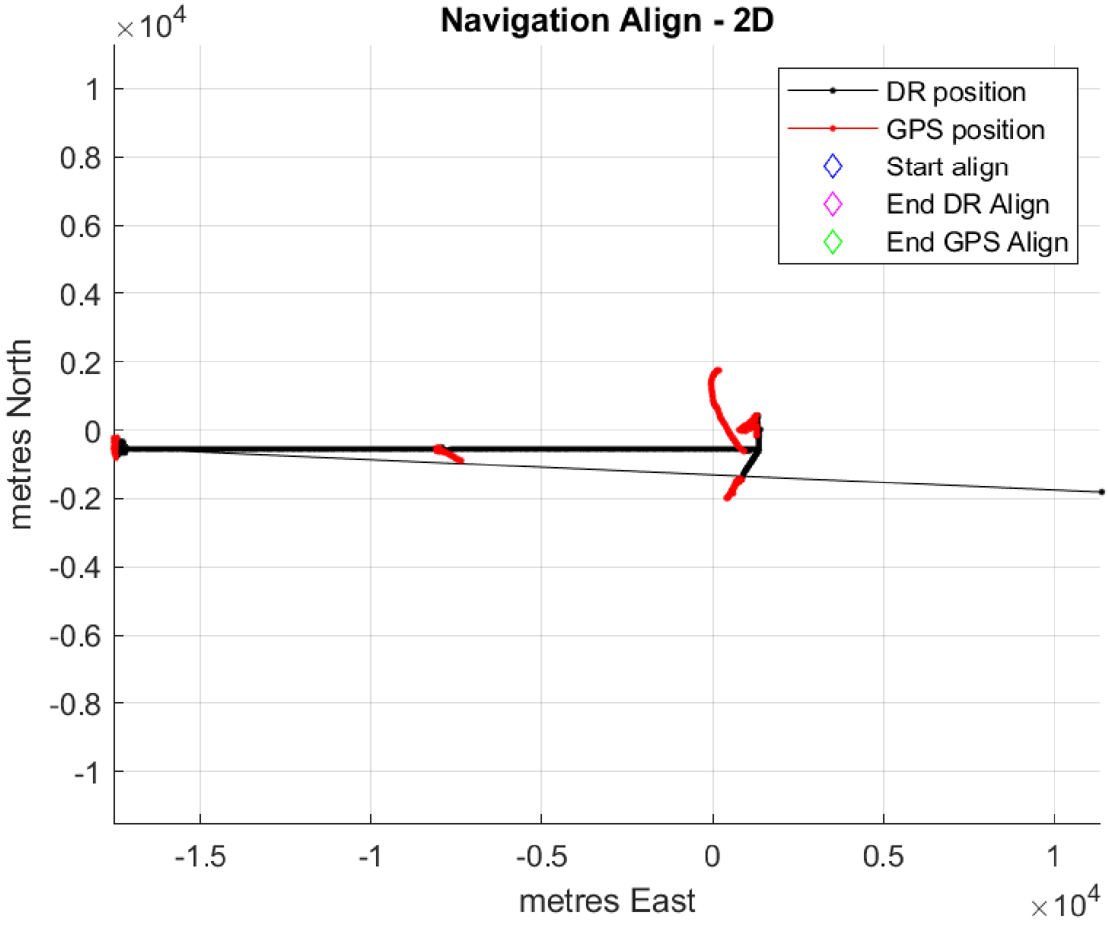


Figure 2.11: *Missions 61 to 64 AUV navigation*

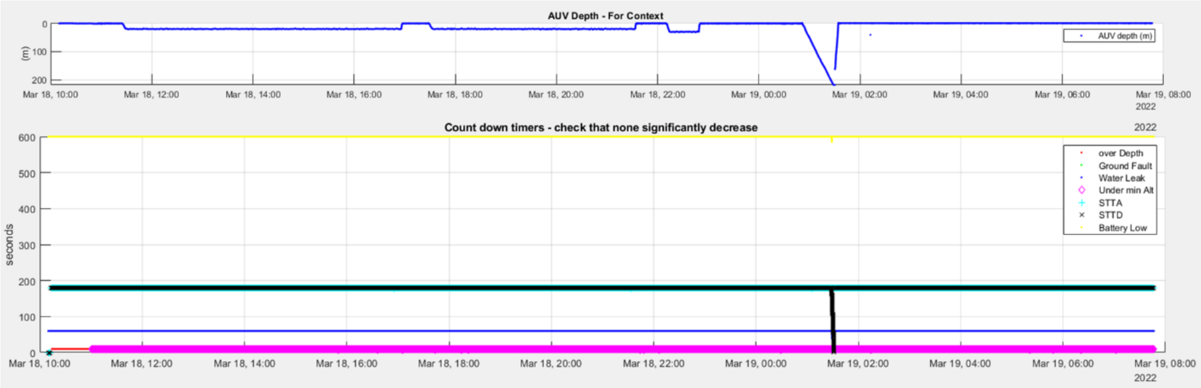


Figure 2.12: *Stuck Trying to descend abort condition (black line bottom trace)*

2.2.3 Station #13 Mission Summary

Ship Station Number: 13	**ALR Mission Numbers: M65 to M67**
Deployment Start: 20/3/2022 13:05	**Deployment End: 22/3/2022**
Weather Conditions: 15 knots 1 to 2m swell	
General Location: Off Shelf	
Waypoints: OS_A: 47.5N, 10.8W OS_B: 47.5N, 10.55W	

Mission M65

Sensors On: Autonuts, CarCASS

This mission continued the survey of the front by first transiting from OS_B to OSA at 600m depth, then returning to OS_B at 250m. The aim was then to surface and extract vehicle and sensor logs (Figure 2.13).

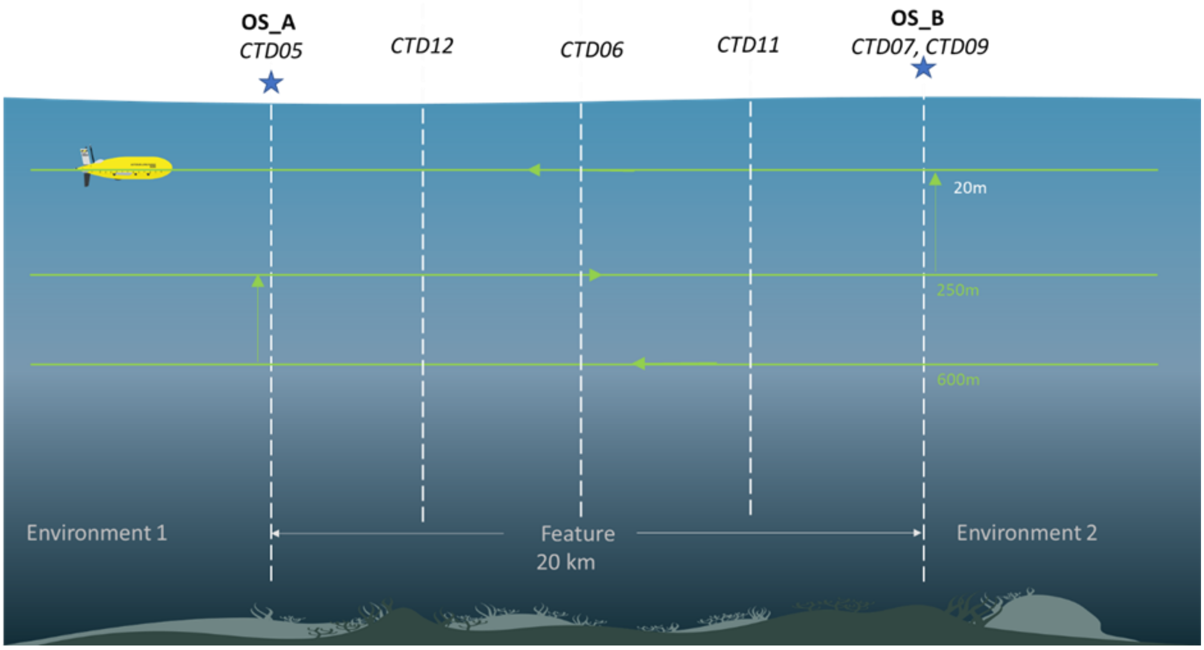


Figure 2.13: *Mission 65 & M66 plan*

Results:

- Successful mission. ALR was observed (using USBL tracking) transiting West past the OS_A waypoint at 600m, then returning past the same waypoint as it returned on the second leg of the mission back to OS_A at 250m. The ALR flew faster than expected and turned approximately 2km West of OS_A (Figure 2.14, Figure).
- The ALR surfaced at OS_B the following day approximately 3km from the waypoint.
- We positioned the ship within WiFi range and extracted vehicle and sensor logs.
- CarCASS successfully operated.

Issues:

- Autonuts Nitrate sensors did not operate. They were powered and switched on by the vehicle but the Nitrate sensors failed to start.
- The ALR experienced 3 PIC resets however, the mitigations put in place meant the mission completed successfully.

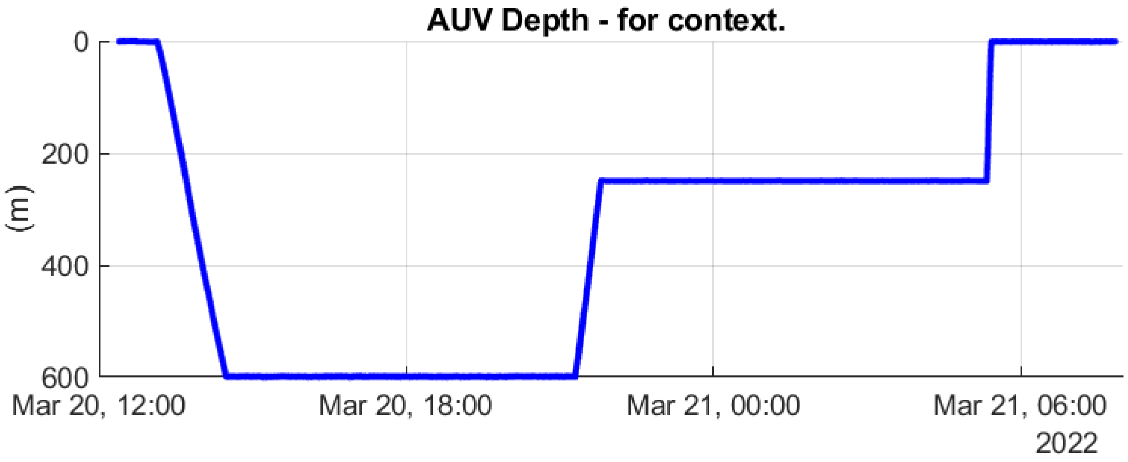


Figure 2.14: *Mission 65 AUV Depth*

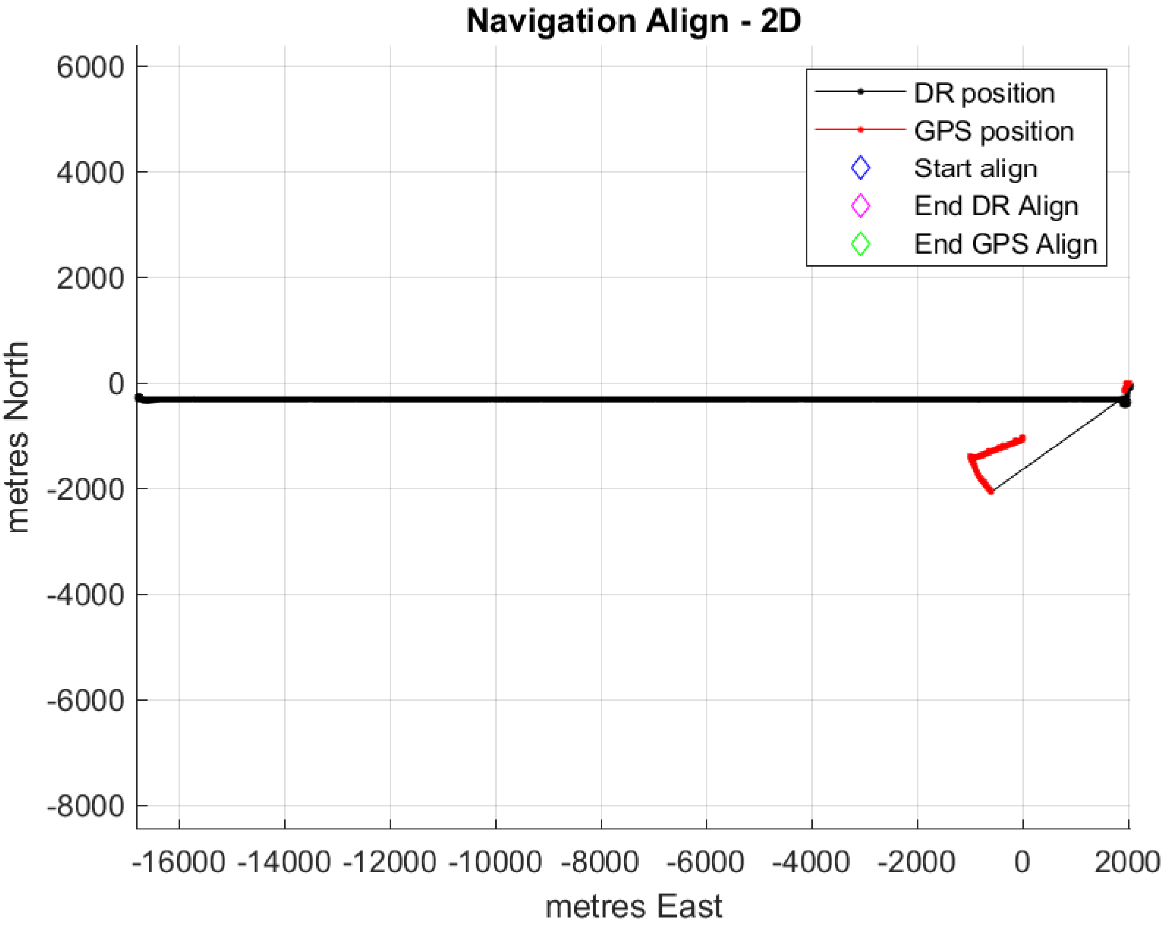


Figure 2.15: *Mission 65 AUV navigation*

Mission M66

Sensors On: STAFES-APP, Autonuts, CarCASS

All sensors were switched on with the ALR transiting between OS_B to OS_A at 20m. A Stainless CTD would co sample a similar area just after the ALR passed a point ¾ the way along the track (Figure 2.13).

Results

- Successfully completed mission.
- CarCASS SPD shows data
- No data in Autonuts SBD

Mission M67

Sensors On: STAFES-APP, Autonuts, CarCASS

This mission started at OS_A, on a staircase mission at 4 depths (20m, 100m, 250m, and 600m) keeping at each depth for approximately 2 hours to allow the sensors to sample. At the end of the staircase the 600m track was extended by double backing West to complete the mission near OS_B (Figure 2.15).

The ALR then stood by whilst a CTD at OS_B was completed before ALR was recovered to deck.

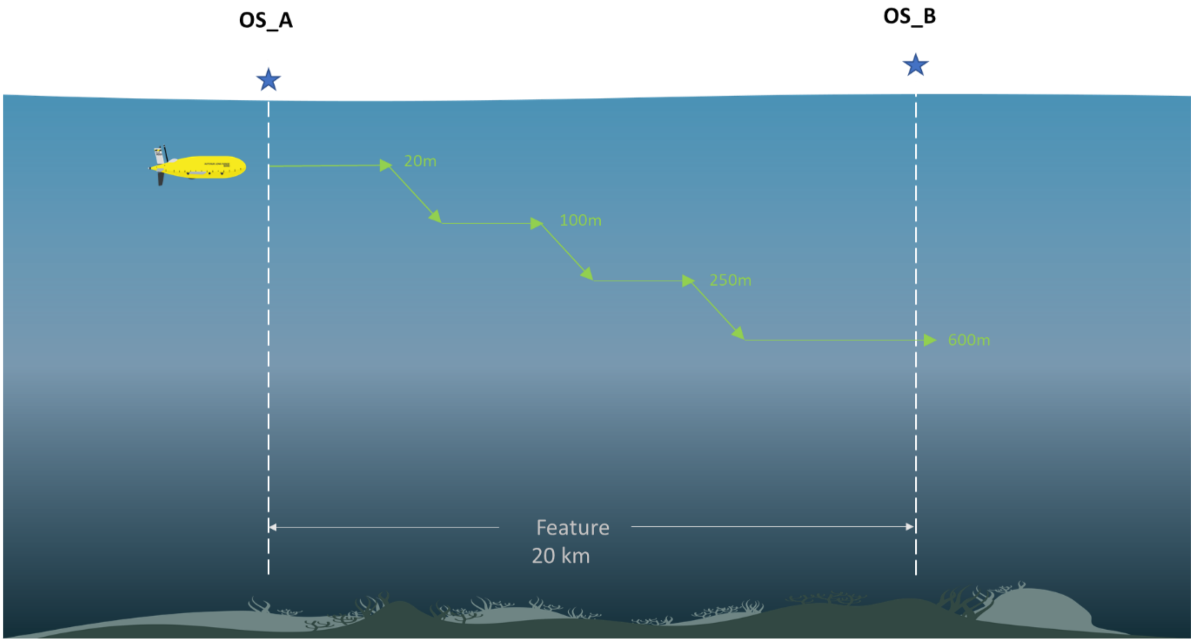


Figure 2.15: *Staircase mission through ocean feature*

Results:

- The mission completed successfully (Figure 2.16, Figure 2.17). ALR did experience 3 PIC resets however the previous mitigations (described above in section 2.3) allowed the ALR to handle the situation and the mission completed as programmed.
- The Navigation error at the end of the mission was approximately 2km. Without bottom lock for the duration of the mission this error is expected.
- There was still an issue with AutoNuts communications between the ALR and the AutoNuts hub. Investigations (after recovery) showed the AutoNuts system was not moving out of bootloader mode resulting in any communications from the ALR being ignored. The AutoNuts enters Bootloader mode when the system thinks a USB cable is inserted. Leaking blanking plugs appear to have fooled the AutoNuts into thinking a USB cable was inserted, preventing normal AutoNuts operations. Mitigations put in place for the next deployment.
- Although STAFES-APP recorded data the quality of the results was a concern. Therefore, the next ALR deployment was delayed to allow time for STAFES-APP to be removed from the ALR and bench testing.

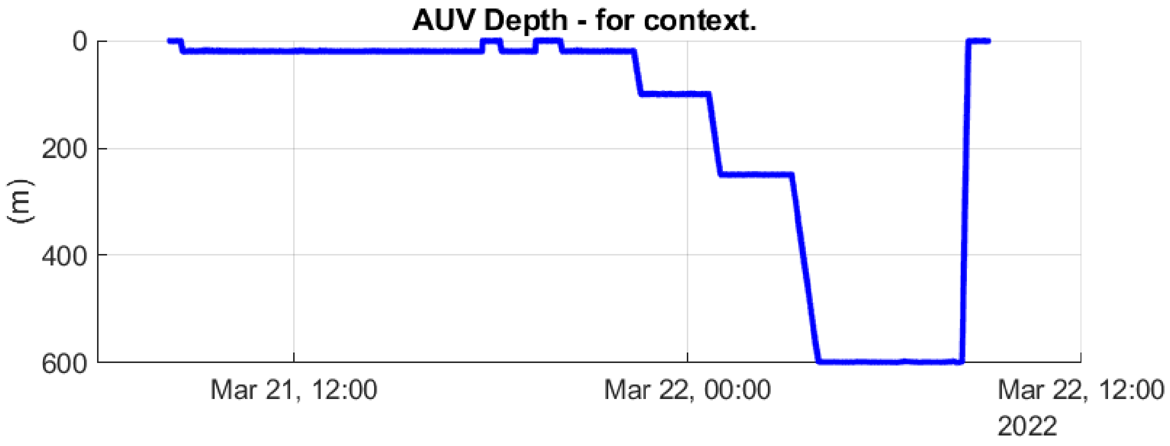


Figure 2.16: *Mission 67 AUV Depth*

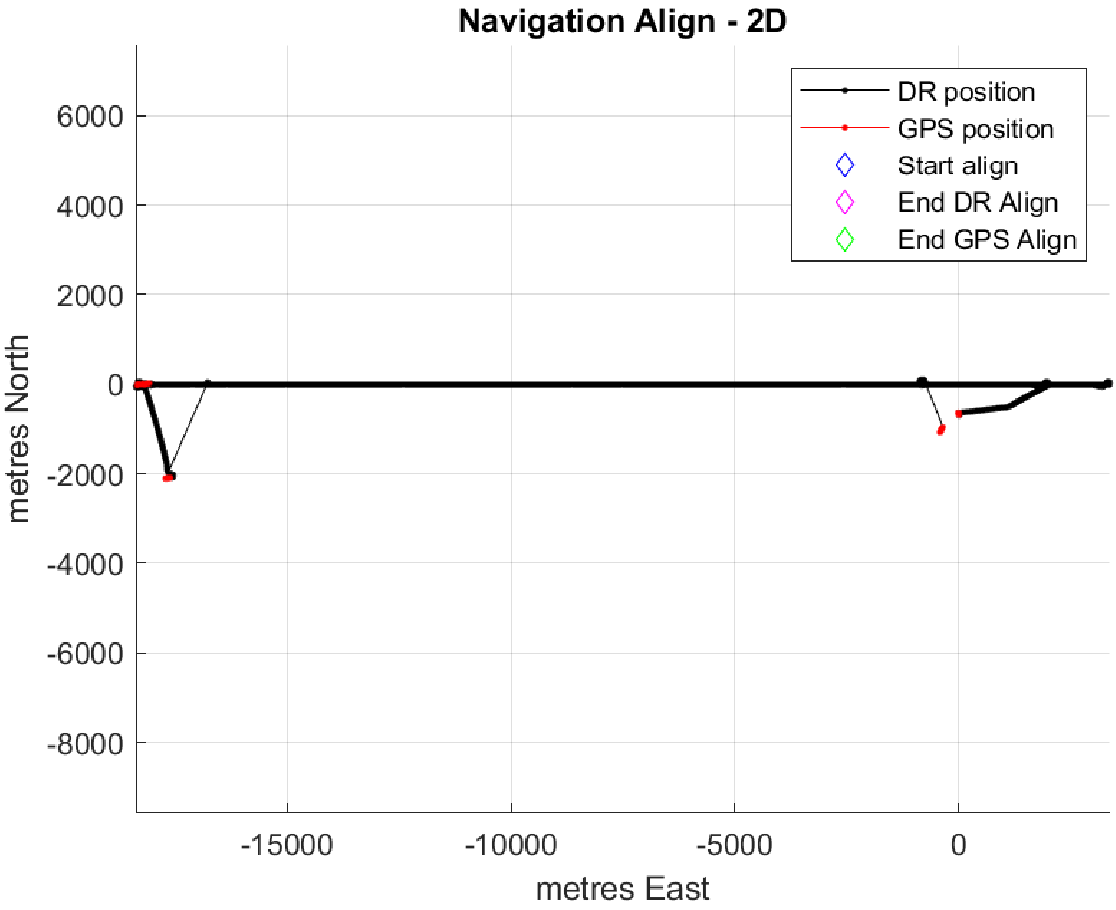


Figure 2.17: *Mission 67 AUV Navigation*

2.2.4 Station #21 Mission Summary

Ship Station Number: 21	**ALR Mission Numbers: M68 to M74**
Deployment Start: 24/3/2022 13:45	**Deployment End: 28/3.2022**
Weather Conditions: Generally, 15 knots 1 to 2m swell	
General Location: Transect from Shelf, over slope into deep water	
Waypoints: T1 to T10 (see APENDIX A for waypoints)	

Mission M68

Sensors On: STAFES-APP, Autonuts, CarCASS

Relocating to the shelf edge the plan for the remainder of the cruise was to perform repeated staircase missions from waypoints T1 to T10. As the tracks progress over the shelf into deeper waters to staircase depths would increase. For this staircase mission, there were 3 tracks each 3 hours long with depths of 20m, 50m, and 80m (Figure 2.18).

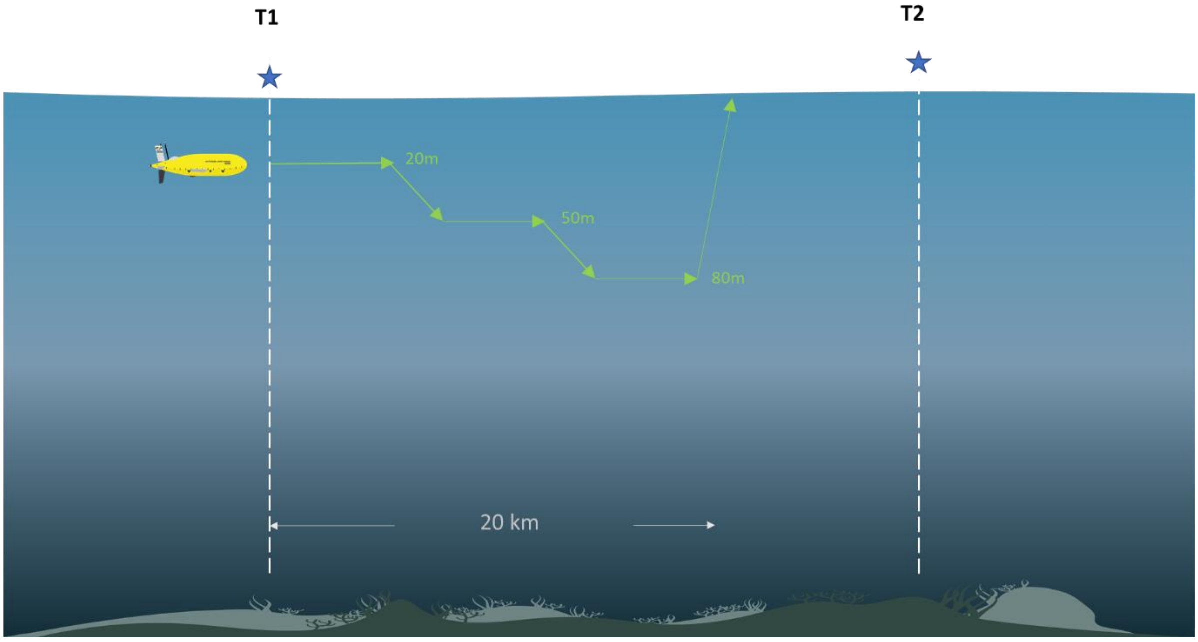


Figure 2.18: *M68 Staircase mission from T1 towards T2*

Results (Figure 2.21, Figure 2.22):

- Successful mission.
- We saw strong currents (0.8 Knots observed on ships CTD) however the Autosub managed to keep to track quite well. There was a slight divergence from the mission path, which will be resolved by using a higher propulsion power.

Mission 69

Sensors On: STAFES-APP, Autonuts, CarCASS

This mission starts where M68 finished, enabling the ALR to travel through T2 and towards T3 (Figure 2.19). Propulsion power increased from 25W to 30W and speed over the ground increased to 1 ms^{-1}. The ALR will not achieve this speed but is a way to make sure propulsion power is kept at 30W.

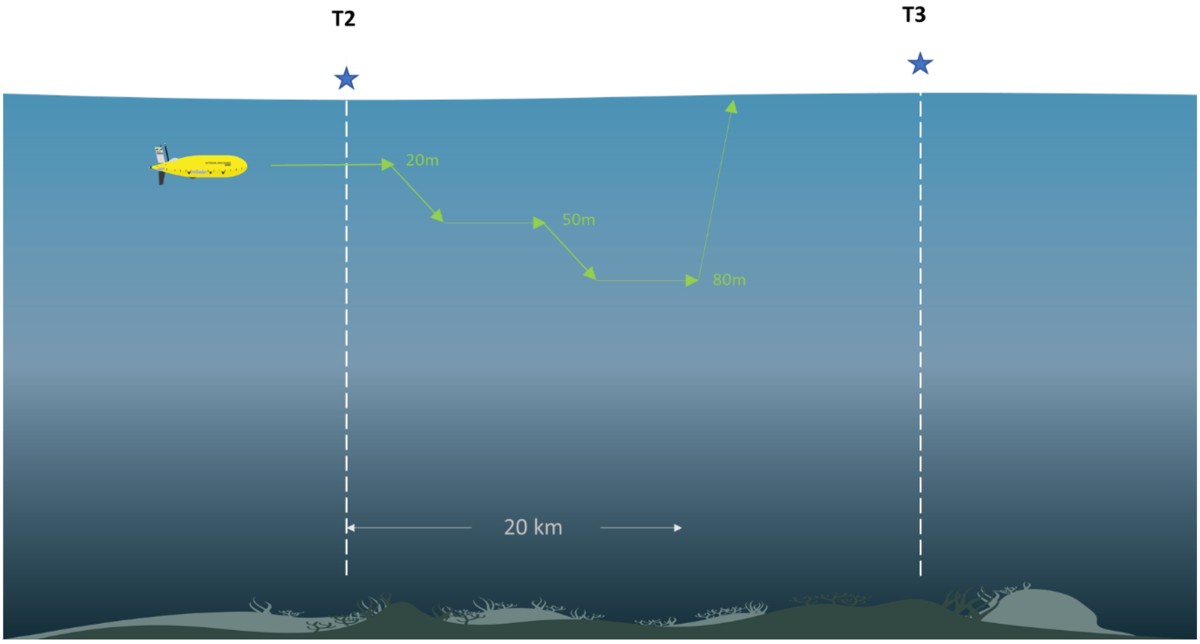


Figure 2.19: *M69 mission through T2 towards T3*

Results (Figure 2.21, Figure 2.22):

- Successful mission
- This time the ALR achieved the waypoints faster than planned as a result of the higher requested propulsion power. To ensure we get at least 2 hours at each depth the propulsion power was kept at 30W but the speed over ground was reduced to 0.9 ms^{-1}.
-

Mission 70

Sensors On: STAFES-APP, Autonuts, CarCASS

This mission was similar to M69 just transposed along the survey line to start at the end of M69 (midway between T2 and T3 to end midway between T3 and T4 (Figure 2.20)

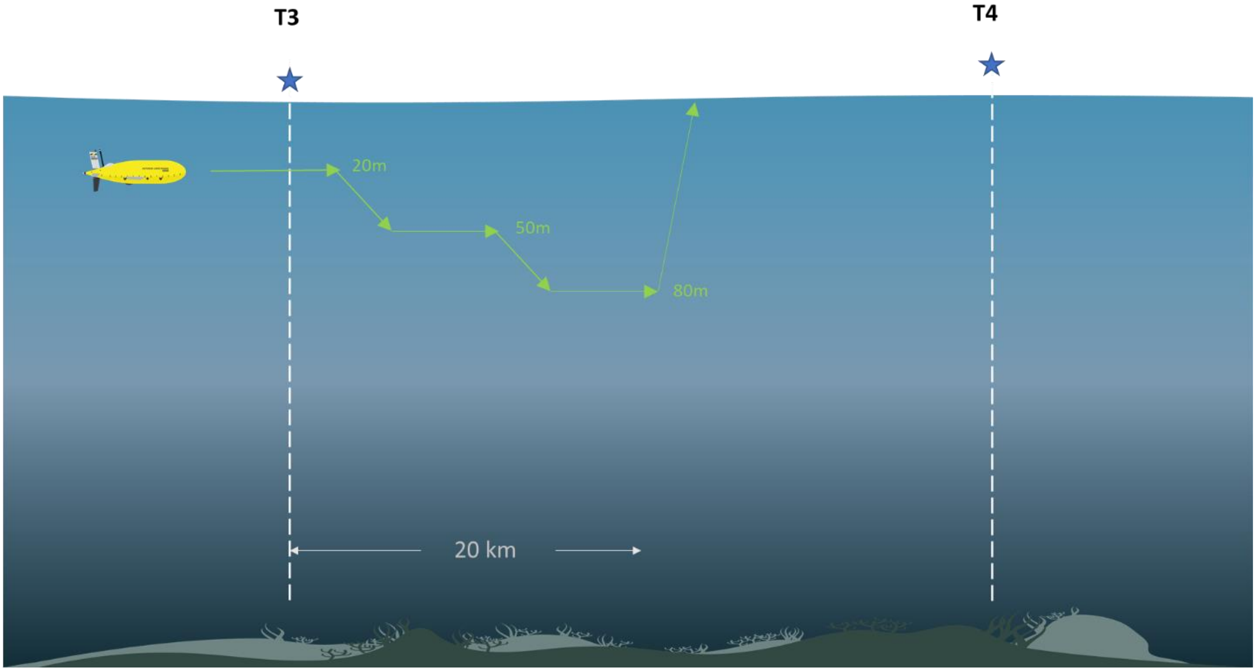


Figure 2.20: *M70 mission through T3 towards T4*

Results (Figure 2.21, Figure 2.22):

- Successful mission
- ALR surfaced approximately 500m North West of the desired location

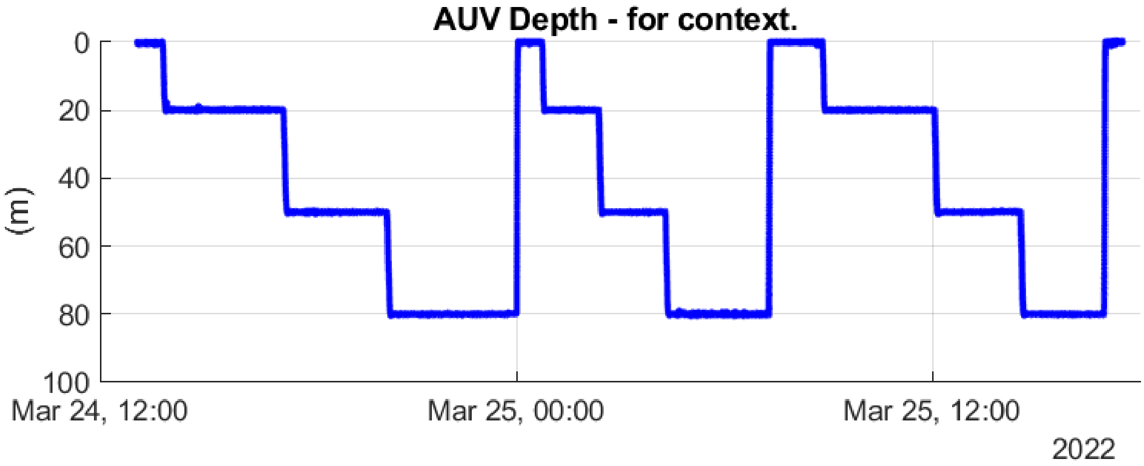


Figure 2.21: *AUV Depth (Missions M68, M69, M70)*

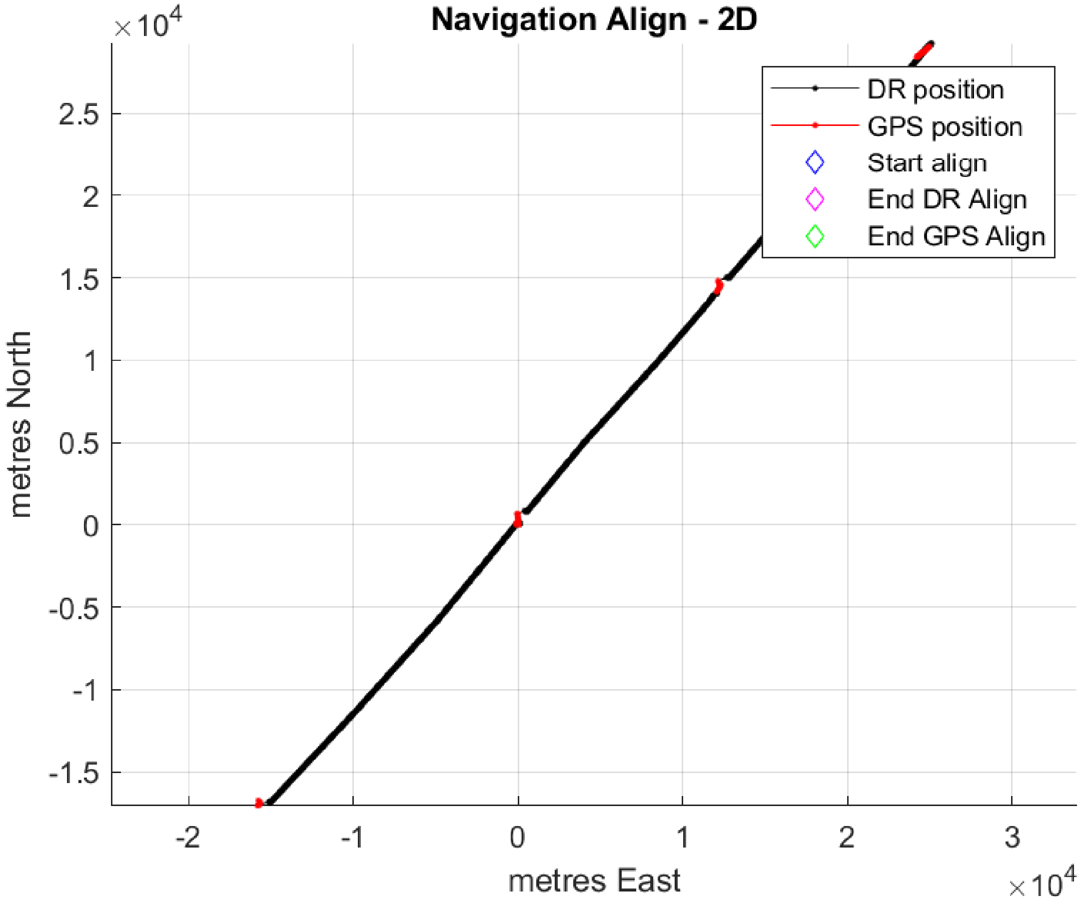


Figure 2.22: *AUV Navigation (Missions M68, M69, M70)*

<u>Mission M71</u>

Sensors On: STAFES-APP, Autonuts, CarCASS

Double staircase mission from midway between T3 and T4 to midway between T5 and T6 (Figure 2.23). Before executing this mission, we rebooted the vehicle to enable an extension of the “no contact” timer from 24h to 36h. This emergency system aboard the ALR causes an abort should no communication occur for the programmed no contact period. As this mission was a double staircase it was possible for the ALR to be dived and out of contact for a period approaching 24h. Therefore, the no contact timer was extended.

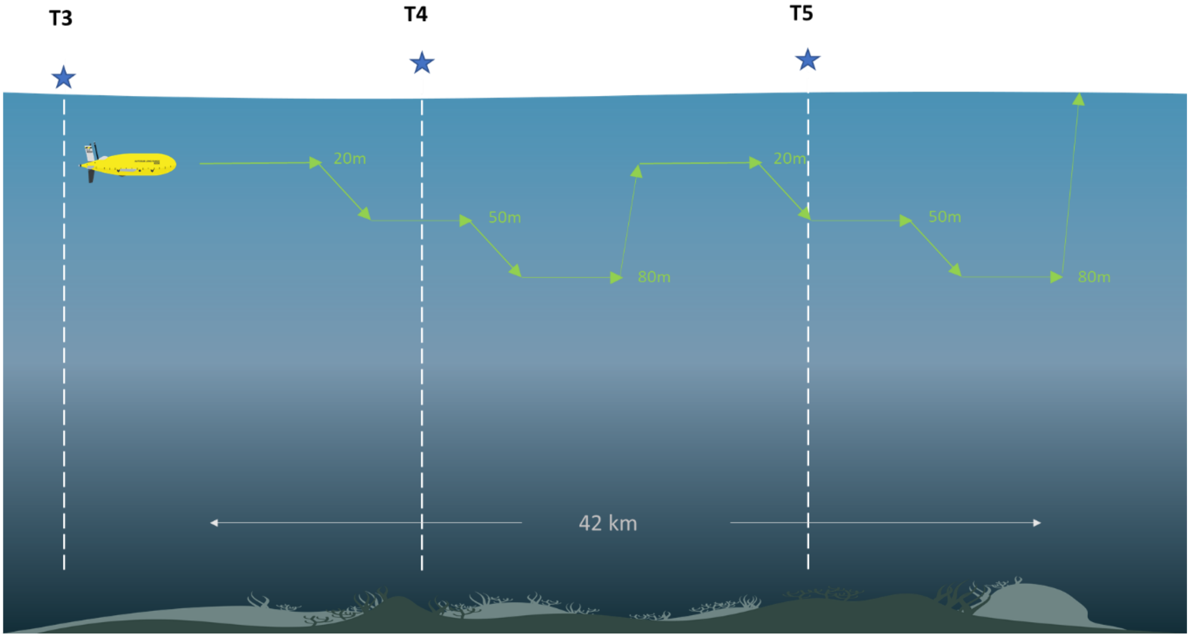


Figure 2.23: *Mission M71 Double staircase, surfacing midway between T5 and T6.*

Results (Figure 2.24, Figure 2.25):

- Successful mission
- Surfaced approximately 500m off track.
- Full data set for AutoNuts and CarCASS

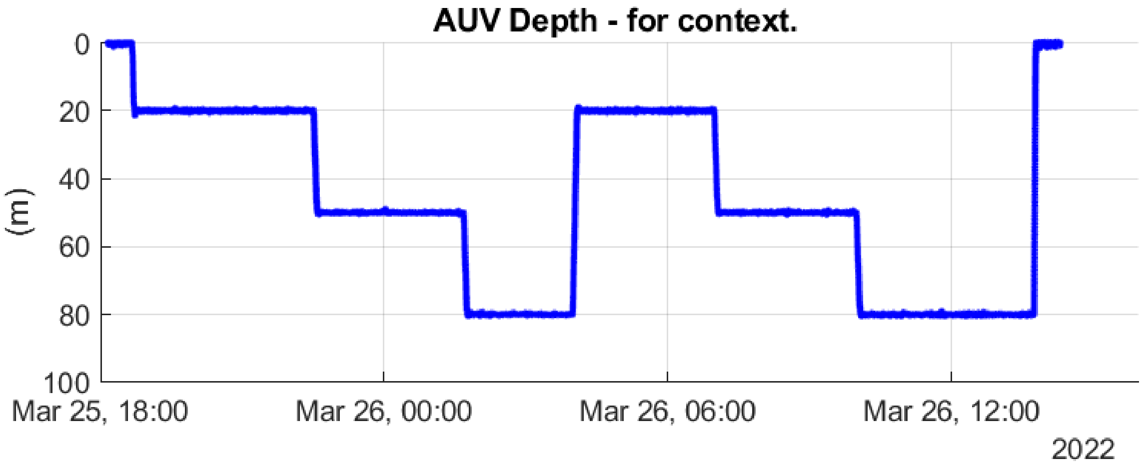


Figure 2.24: *Mission M71 AUV Depth*

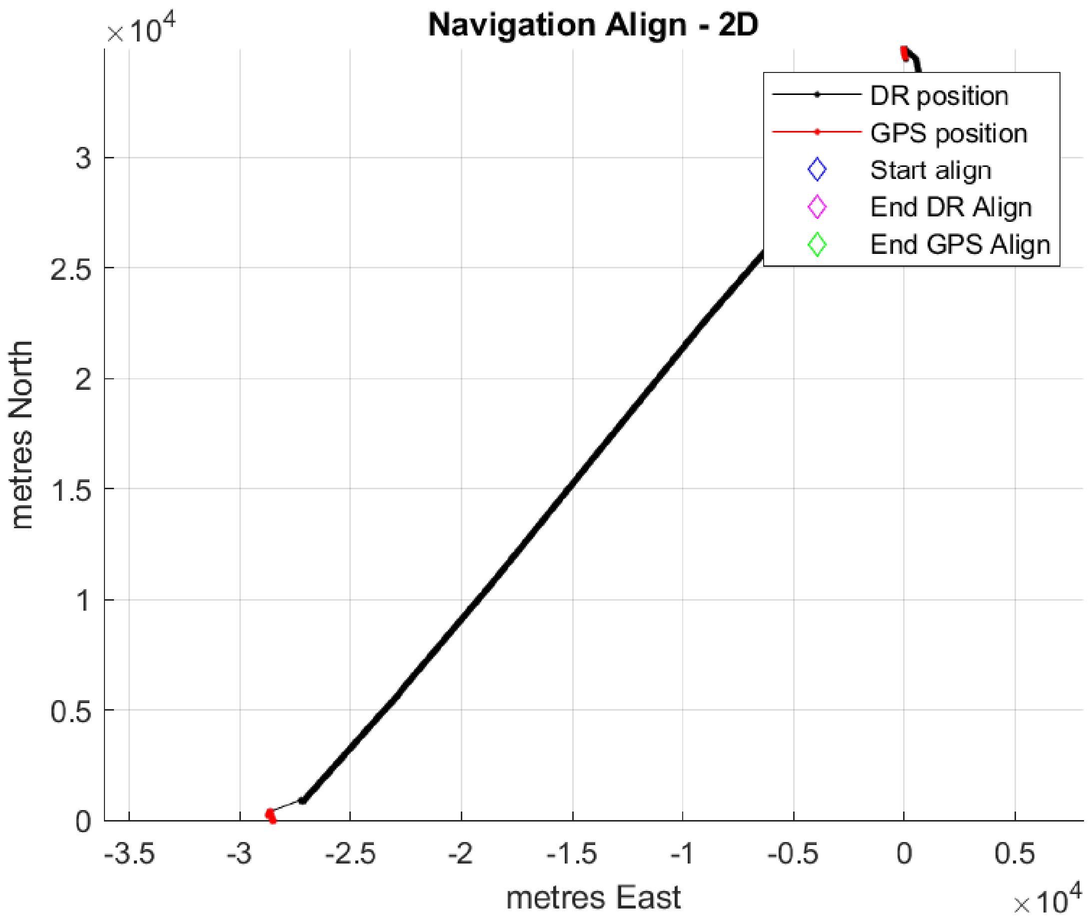


Figure 2.25: *Mission M71 AUV navigation*

<u>Mission M72</u>

Sensors On: STAFES-APP, Autonuts, CarCASS

A repeat of the double staircase mission, surfacing midway between T7 and T8.STAFES-APP power cycled.

Results (Figure 2.27, Figure 2.28):

- Successful mission
- Surface 2.5km past surface waypoint but on track.
- Full CarCASS and AutoNuts data files

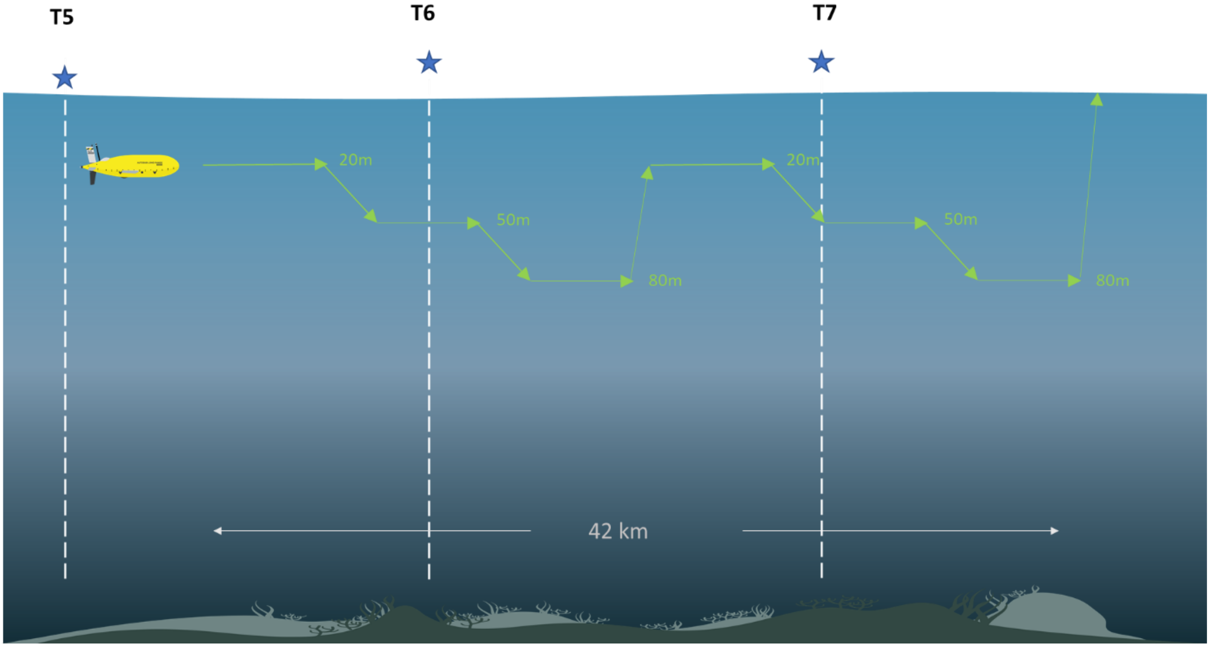


Figure 2.26: *Mission M72, Double staircase*

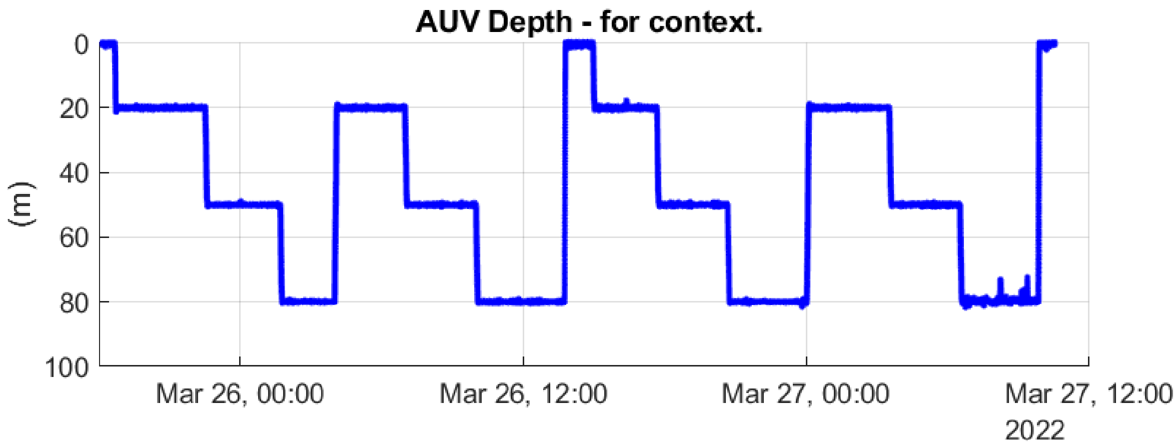


Figure 2.27: *Missions M71 and M72 AUV depth*

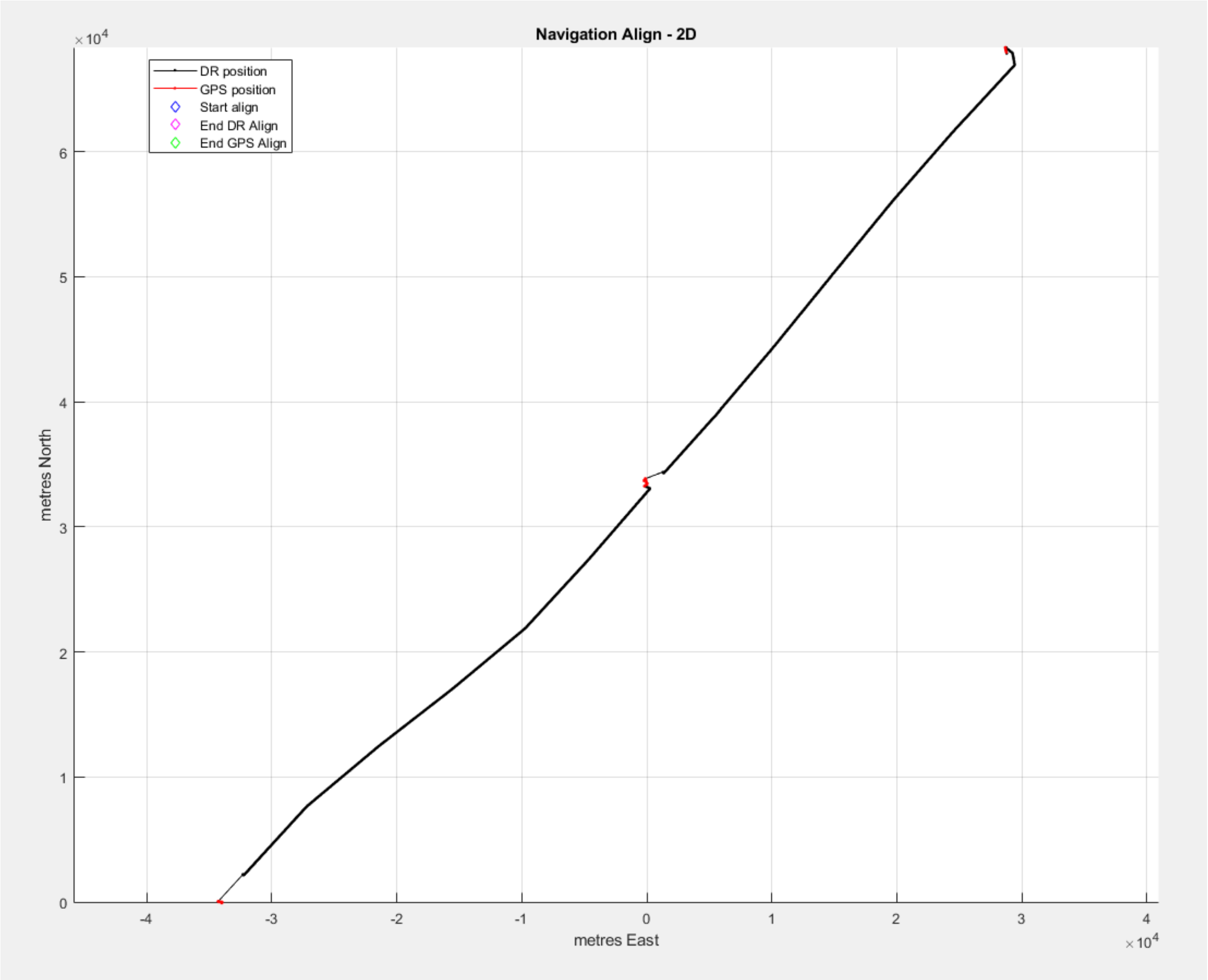


Figure 2.28: *Mission M71 and M72 AUV Navigation*

Mission M73

Sensors On: STAFES-APP, Autonuts, CarCASS

Returning to single staircase, however with an added 250m depth (Figure 2.29). The ALR was rebooted to install new vehicle safety parameters to compensate for the off slope deeper water conditions. STAFES-APP power cycled. The power available to the ALR was increased from 30W to 35W to allow the ALR to handle the stronger currents expected.

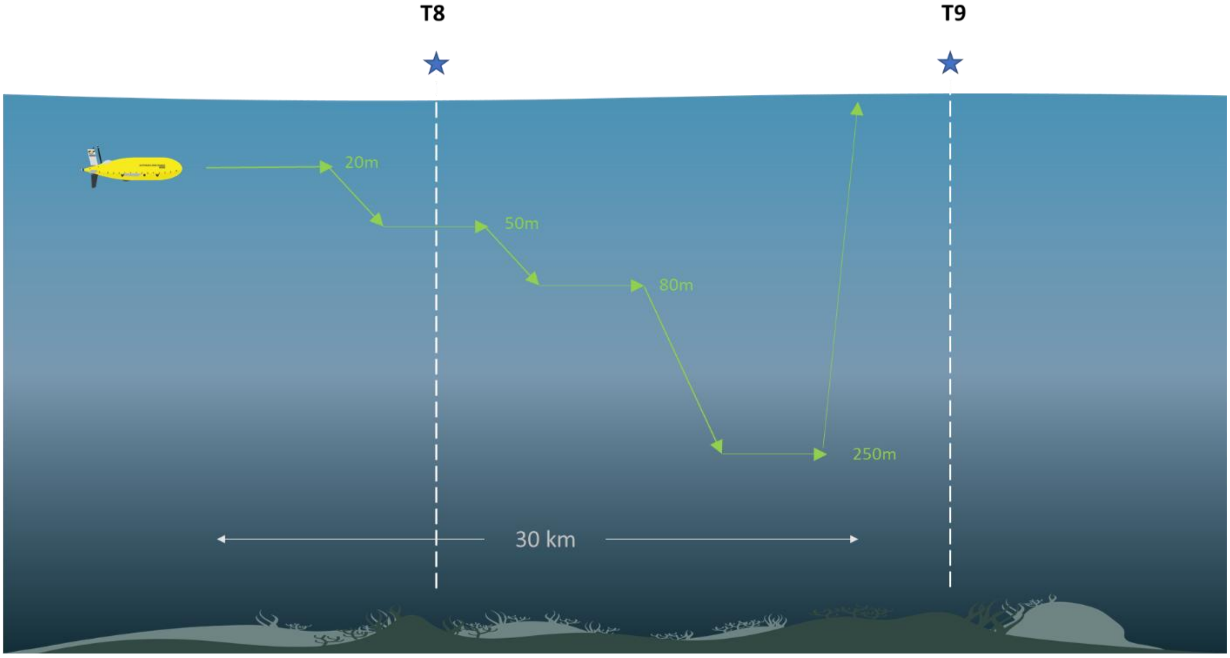


__Figure 2.29:__ Mission M73, Four depth staircase.

Results (Figure 2.30, Figure 2.31):

- Successful mission
- ALR surfaced 1.63nm West of waypoint
- There was no CTD data provided by the ALR. Starting the CTD pump requires a manual instruction after the ALR has been deployed and before the mission started, which we forgot to do. Apologies all.

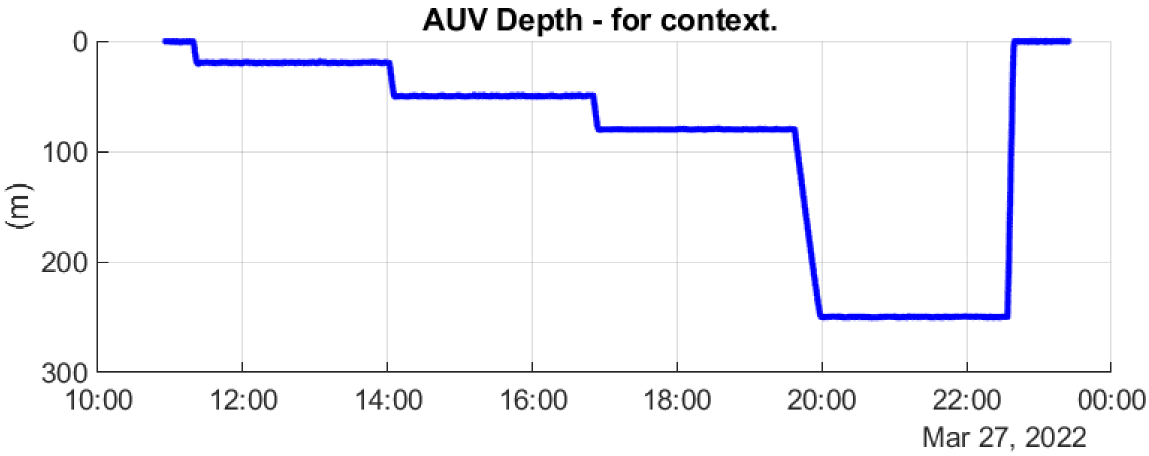


__Figure 2.30:__ Mission M73 AUV Depth

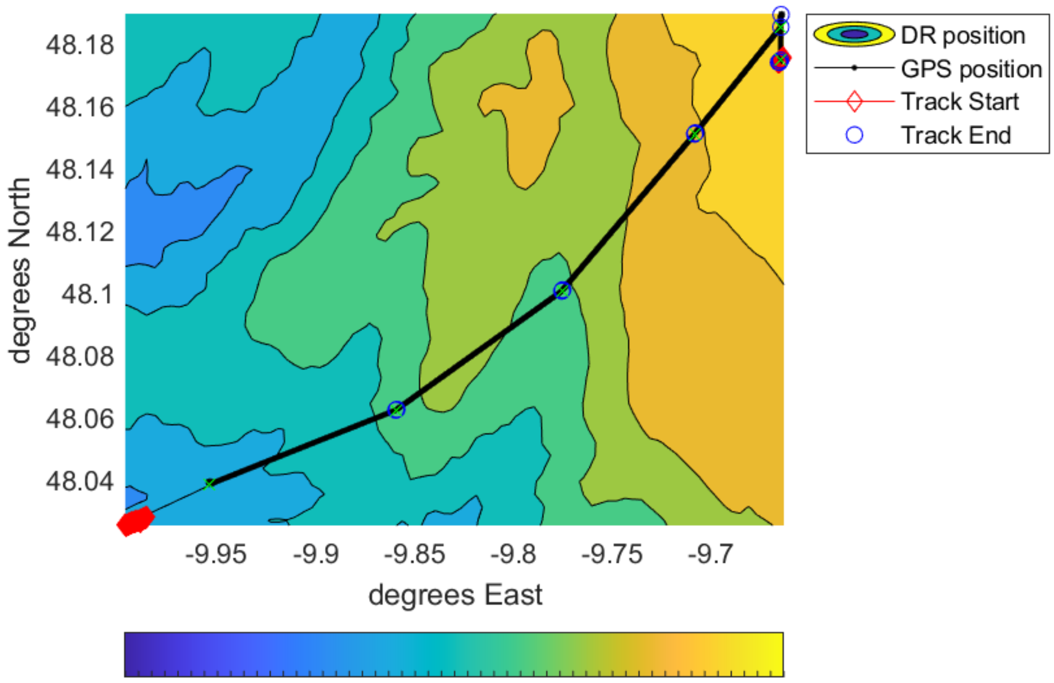


Figure 2.31: *Mission M73 AUV Navigation*

<u>Mission M74</u>

The final mission along the T1 to T10 transect included a further survey depth (20m, 50m, 80m, 250m and 500m). All other parameters remained the same as the previous mission (Figure 2.32).

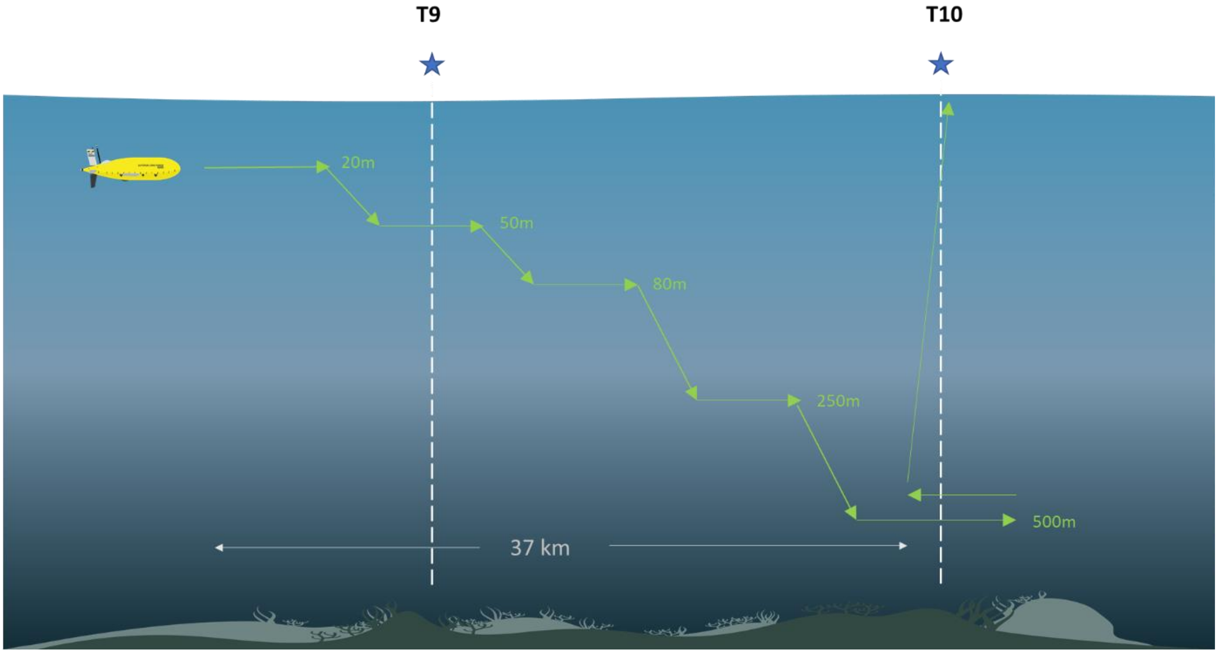


Figure 2.32: Mission M74 five depth staircase

Results (Figure 2.33, Figure 2.34):

- Successful Mission
- CarCASS stopped operating at 07:49, and STAFES-APP stopped working at 08:53.

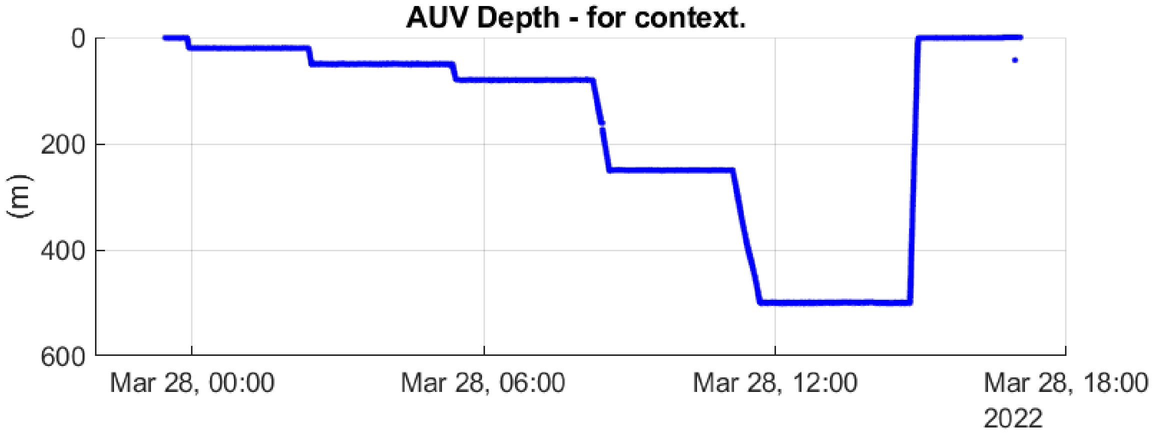


Figure 2.33: *Mission M74 AUV Depth*

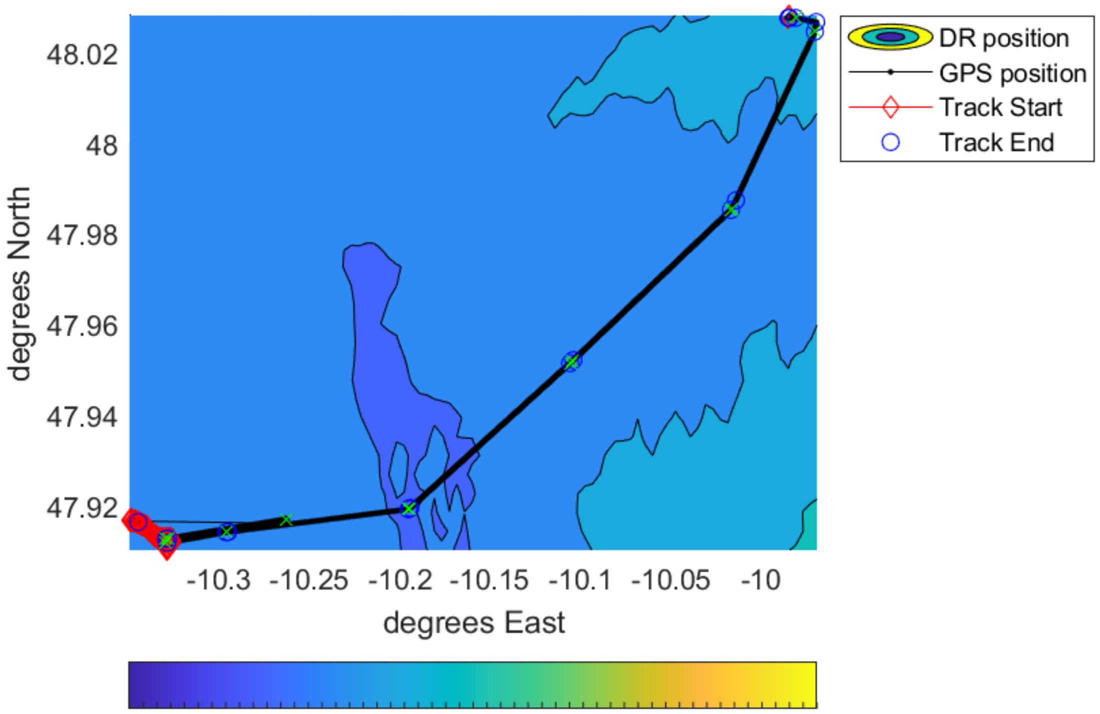


Figure 2.34: *Mission M74 Navigation*

2.2.5 Station #34 Mission Summary

Ship Station Number: 34	**ALR Mission Numbers: M75**
Deployment Start: 28/3/2022 19:47	**Deployment End: 29/3/2022 04:51**

Weather Conditions: Generally, 15 knots 1 to 2m swell
General Location: Up shelf
Waypoints: T8 to T7 (see APENDIX A for waypoints)

Mission 75

To allow the test dive with STAFES-APP valve arrangement and fill in a sampling gap caused by not having the ALR CTD operating during mission M73, on the steam back to port we stopped and deployed the ALR for one last mission (Figure 2.35).

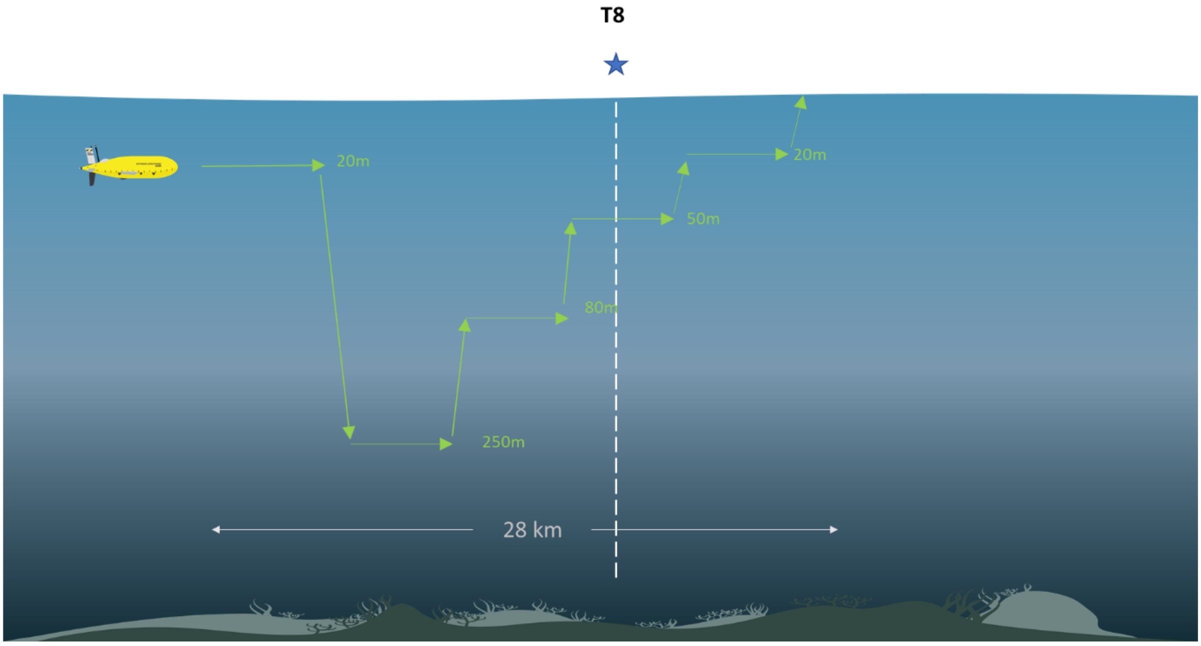


Figure 2.35: *Mission M75 Reverse staircase*

The STAFES-APP non-return valve was designed and constructed by Ed and Simon to prevent water exchange occurring in the STAFES-APP measurement cell. Constructed from a welded Yorkshire tea plastic container retained within a syringe, the ingenious design was similar to a whoopie cushion rasp valve, letting water flow in one direction but preventing flow in the opposite direction. On ship testing proved fruitful and was deployed during this last mission (Figure 2.36).

Figure 2.36: *Ed and Simon's Whoopie Valve*

Results (Figure 2.37, Figure 2.38):

- Successful Mission
- On initial investigation it appears the STAFES-APP worked and the valve arrangement retained the water sample within the measurement cell providing an expected reading.

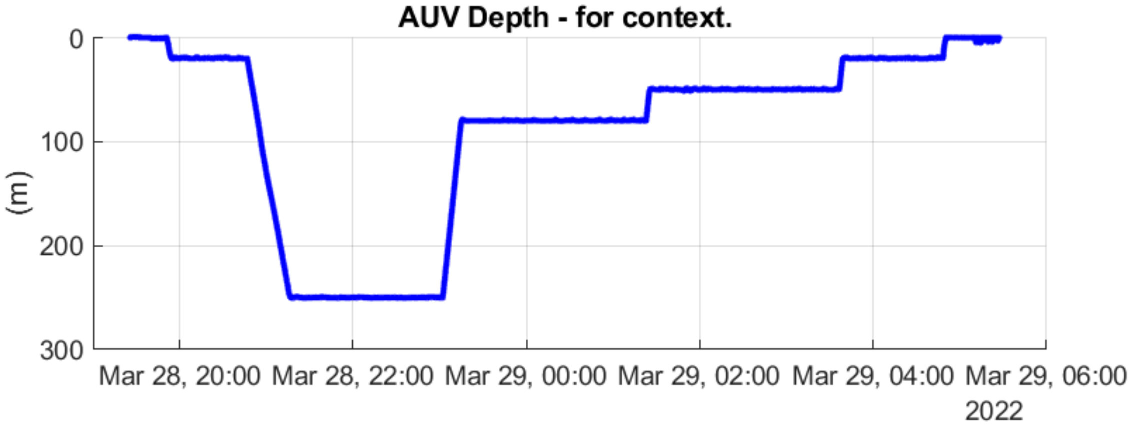


Figure 2.37: *Mission M75 AUV depth*

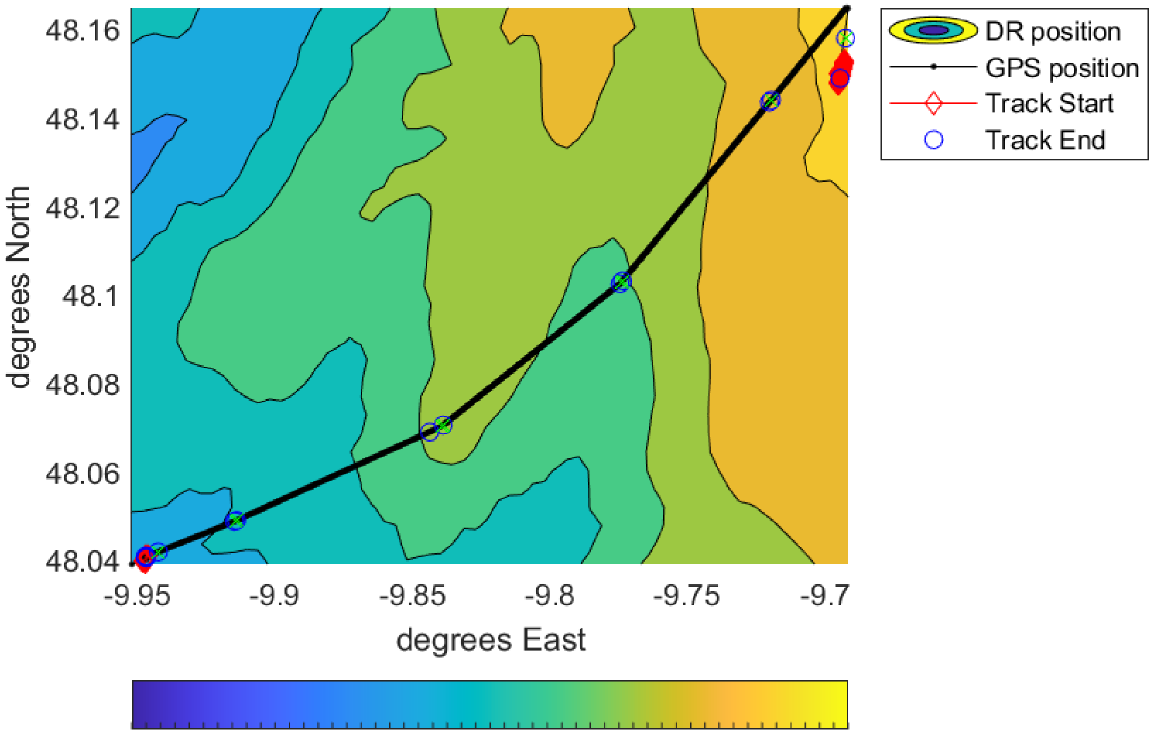


Figure 2.38: *Mission M75 AUV navigation*

2.3. WiFi Setup

The ALR can be controlled via 3 communication systems:

- Iridium Satellite network
- Wi-Fi
- Acoustics

With this version of the command and control architecture WiFi networking is controlled via the C2 in a box system (C2IAB) as well as the backup Linux GUI. The GUI is also capable of communicating via a Sonardyne topside and the “Bagley Box” acoustically with the ALR. A later version of the C2IAB system (currently deployed in Antarctica) incorporates all three communications alternatives in one C2IAB system. During DY149 the WiFi system was the preferred communication method, with Iridium used when not in WiFi range. Figure 2.39 shows the network setup in the RRS Discovery.

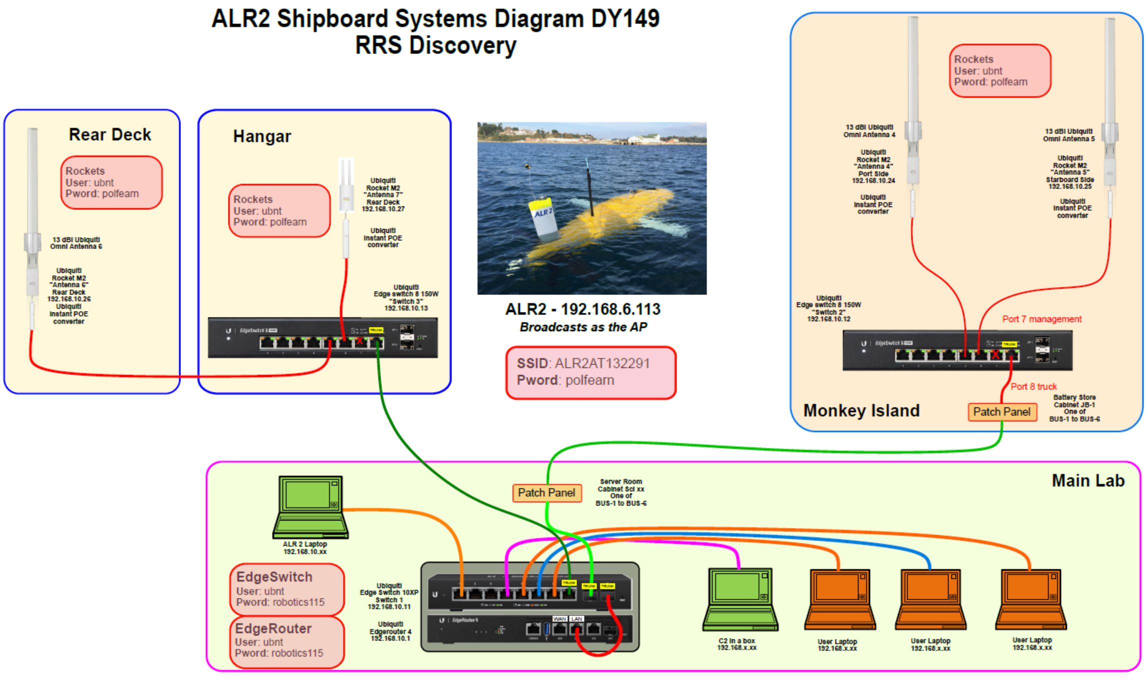


Figure 2.39: *ALR WiFi Setup*

We had some issues with this setup and further testing should be carried out before DY152 trials cruise:

- Although good WiFi communication was achieved with the ALR on-board the Discovery, once deployed, the WiFi network was of poor quality and inconsistent. Typically, we achieved poor but usable connection with the ALR sat on the starboard side of the ship at a maximum 150m range, with no communication possible at approximately 200m.

- Reviewing the Ubiquiti Rocket web interface, we could see very strong signal from all outside antennas, yet communication with the ALR was poor and intermittent.
- We reduced the data rate to MCS 3 (26/ 28.9) which was the fastest speed available that would still generate the maximum 28 dBm transmit power. However, this did not resolve the issue.
- Using the standard ping 192.168.6.113 command to check communications with the ALR we occasionally received a DUP error, indicating duplicate packets were received by the ALR.

Mitigations:

Having seen the same issues as described above in different sea conditions over several ALR deployments the following change made a significant quality and range improvement

- It appeared as if all antennas that were in range of the ALR (regularly all three outside antennas) were causing network collisions and “fighting” each other resulting in poor WiFi communications
- Therefore, turning all but one antenna off significantly improved the quality and range of WiFi communications with the ALR. We typically used just the starboard monkey Island antenna operating at full power (28dBm) and on WCS 3 data rate. This regularly achieved good useable communications at 500m range with WiFi communications starting at about 700m (but initially at a lower quality).
- The ships preferred approach to the ALR was on the starboard side and thus we almost exclusively used the starboard monkey island antenna.
- Anecdotally, on one occasion we tried a different antenna (back deck) when the ALR was behind the ship and again good WiFi communications were achieved as long as only one antenna was powered.
- Using the Starboard Monkey Island antenna, we also obtained good WiFi communications even when the ALR was in the hanger. However, it should be noted that mostly the starboard side hanger doors were open and we did not test wifi communications will all hanger doors shut.
- For the later third of the cruise we exclusively used the starboard monkey Island antenna which proved reliable while the ALR was in the hanger, and offered good and reliable communications at approximately 500m range when the ALR was deployed.

APPENDIX 2.1: Working Area

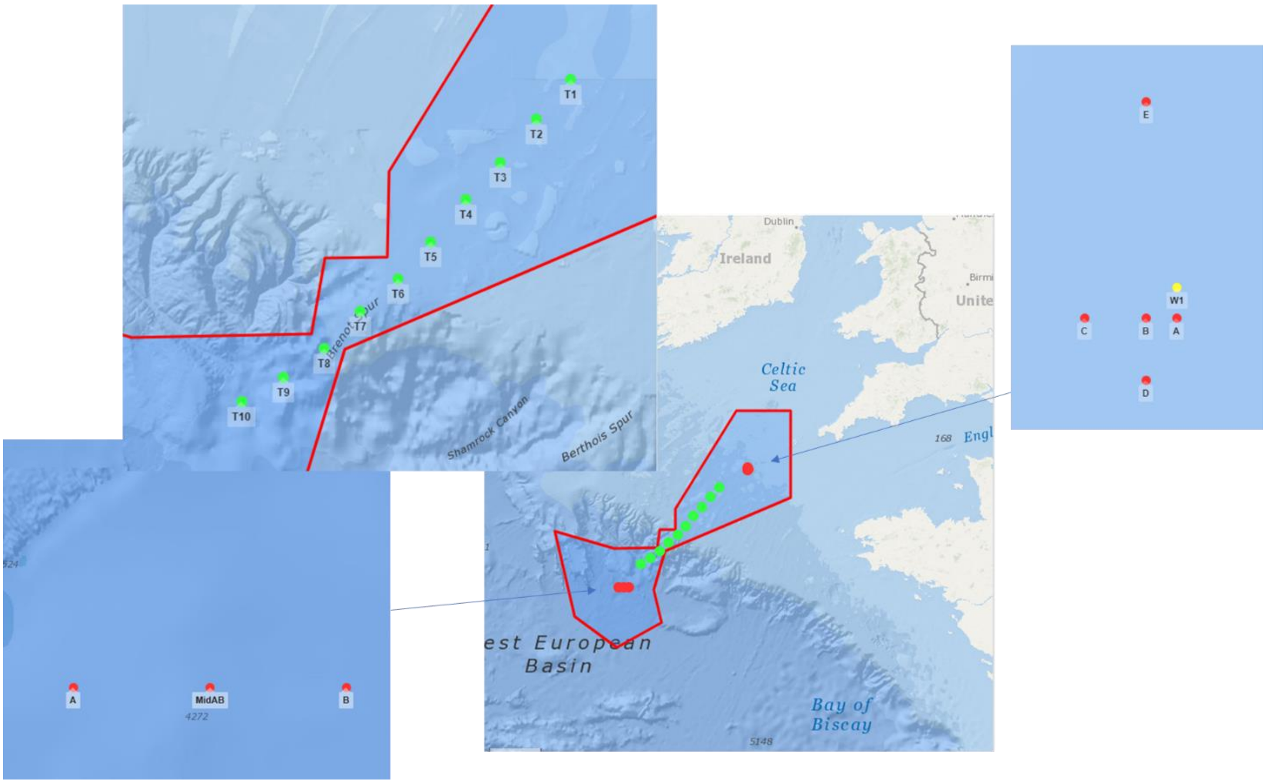


Figure 2.40: *DY149 Working Area*

WP	LAT N	LONG E
W1	49.5000000	-7.5000000
A	49.4955050	-7.5000000
B	49.4955050	-7.5069033
C	49.4955050	-7.5207083
D	49.4865133	-7.5069033
E	49.5269750	-7.5069033
OS_A	47.50000	-10.80000
MID	47.50000	-10.67500
OS_B	47.50000	-10.55000
T1	49.20000	-8.25000
T2	49.04000	-8.46000
T3	48.87000	-8.68000
T4	48.72000	-8.89000
T5	48.55000	-9.10000
T6	48.40000	-9.30000
T7	48.27000	-9.53000
T8	48.12000	-9.75000
T9	48.00000	-10.00000
T10	47.90000	-10.25000

APPENDIX 2.2: Battery Usage Record

Mission/ Test	Description	Vehicle On	Vehicle Off	Average Power (W)	Total on time (dd hh:mm:ss)	Energy Used (Wh)
Hanger Test	Test of all sensors + Quayside	15/03/2022 08:56	15/03/2022 12:42	88.00	00 03:46:00	331.47
Cal runs & Sensor shakedown	Cal runs & Sensor shakedown	16/03/2022 05:54	16/03/2022 17:55	88.00	00 12:01:00	1057.47
SAFESApp Hanger tests	Hanger Tests	17/03/2022 13:50	17/03/2022 15:50	88.00	00 02:00:00	176.00
M61 partial M64	20m runs + overnight abort	18/03/2022 08:41	19/03/2022 12:44	88.00	01 04:03:00	2468.40
M65, M66	OS_B to OS_A 600m, OS_A to OS_B 250m	20/03/2022 12:20	22/03/2022 12:05	88.00	01 23:45:00	4202.00
Slope Transect	T1 to T10 Missions	24/03/2022 11:54	28/03/2022 16:00	88.00	04 04:06:00	8808.80
STAFESApp Featuring the Whoopie Valve	Uop slope transect T9 to T7	28/03/2022 16:00	29/03/2022 06:00	88.00	00 14:00:00	1232.00
			Totals		**08 15:41:00**	**18276.13**
			Energy Usage Limit			18585.60
			Energy Left			309.47
			Percentage Battery Used			98.33%
			Percentage Battery Remianing			**1.67%**

APPENDIX 2.3: Daily logs

Daily Log 13/3/2022

Summary

Plan:
• Acoustic test – topside Avtrak, ALR Avtrak & Marker6 • Update configuration • Test on battery power • Plan shake down missions • Complete recovery plan and discuss with crew • Final sensor test
Conditions:
Alongside in Southampton. Fair.
Operations:
Issues:

Log

Time	Action	Detail	Initial
0905	Updated config on ALR	Config based on meeting at NOC before mob	EC
0910	Rebooted		EC
0920	Depth threshold disabled	Depth threshold for AutoNuts and Carcass disabled so that sensors can be tested on the deck	EC
0920	Rebooted		EC
1112	Test mission	DY149-ALR-2-ENG01-Dummy 30 seconds at min power - Forgot to untick do dive runup Edited and resent	EC
1124	Test mission	Quayside test long Interrupt with STOP command Send Dummy mission Send RESUME Result: seems as if the dummy mission is not required – returned to idle straight away	EC
1230	Test mission	Further testing confirmed that after sending RESUME, ALR will return to IDLE	EC
15:43	Rebooted	Investigating Avtrak	AC
15:52	Rebooted	Enabling DEBUG logging level for the AvTrak	AC

Daily Log 14/3/2022

Summary

Plan:
• Acoustic test – topside Avtrak,

- Batteries test - Sensors test
Conditions:
Alongside in Southampton. Sailing at 2:30 pm.
Operations:
Issues:

Log

Time	Action	Detail	Initial
08:30	Reboot	Sub is aborting due to no contact timeout expired overnight	AC
08:38	Configuration updated	AvTrak node verbosity reverted back to WARN. AvTrak added to nocs_status_channel.yaml file with a perios of 5 seconds. This represent the period the status node will update the internal buffer. It does not represent the transmission period. The device needs to be pulled in order to transmit.	AC
08:41	OCS killed, extract logs	The OCS has been killed. Toggling the watchdog, extracting the logs	AC
08:45	Logs cleared		AC
08:46	Reboot		AC
14:30	Sail		PB
16:00	SAFESAPP tests	Setup millique loop and ran STAFES App several times. Some issues, however eventually appeared to work.	PB

Daily Log 15/3/2022

Summary

Plan:
- Batteries Tet - Sensor Test
Conditions:
Steaming to W1
Operations:
Issues:

Log

Time	Action	Detail	Initial
08:56	Battery connected	Start test all sensors on and long Quayside	PB
09:12	CARCUS on		
09:14	Autonuts on		
09:15	Long Quayside sent	Quayside Test 2hr 20w/ 10w	
09:16	Quayside started		
09:31	STAFES off	Issues with STAFES not starting	
09:32	STAFES on	Now working	
09:50	Quayside mission finished early		
09:57	Quayside mission resent		
09:59	Quayside started	Vehicle in warning	
10:00	Go sent	Mission started	
10:01	On mission		
10:25	Stop command sent	(on Quayside mission depth demand set by mistake, stuck trying to descend warning)	
10:25	Resume sent		
10:26	Updated long Quayside sent	Quayside Test 2hr 20w/ 10w	
10:28	Go sent	Still in warning after stop, go tells it to go anyway	
10:28	Quayside started		
10:30	Boat drill		
11:00	Mission complete, helm state Idle	Not sure why? No GPS	
11:10	STAFES off		
11:17	CARCUS off		
	Autonuts Off		
11:20	Quayside test	Sent over iridium	
11:25	Quayside started		
11:27	Mission complete		
12:42	ALR Outside on shore power	AutoSTAFES tests	
12:44	XEOS operation confirmed		
14:14	10 min Quayside sent	Quayside Test 10 min	
14:17	Mission end		
14:29	10 min Quayside sent from Iridium via mail		
18:00	C2IAB Quayside short timeout resolved	C2IAB Quayside track length was set as zero, causing odd behaviour. Timeouts are ok with a track length greater than zero	
19:45	Acoustic status, abort and resume sent and operational	All operated correctly from Avtrack topside dunker	

Daily Log 16/3/2022

Summary

Plan:
• Ships station number 2 • M55 – M62 • Compass call, compass alignment, power runs & sensor tests
Conditions:
20kn wind, 3m swell
Operations:
Issues:
• Poor WiFi range (150m just useable). • Long timeout on calibration runs

Log

Time	Action	Detail	Initial
05:54	ALR on	Primary Batteries	PB
06:03	Quayside mission	10min mission from C2iAB	EC
06:14	Mission complete		
07:12	Launched		
07:15	Mission	South on Surface	
07:35	Mission	South Dived 10m Potter	
07:56	On Surface via email	Lat = 49.48940 Long = -7.70049	
08:06	Mission C2 Online	ENG-04-CompassCal-LOS-A-B. ETOS	
08:17	Autonuts on command sent	All the sensors on	AC
08:22	Status message received		
08:26	CARCUS on Command sent		
08:33	Pump On sent		
08:41	Mission	ENG-04-CompassCal-LOS-A-B. ETOS 10:15-11:00	
08:46	SBD ack		
11:25	surface	On surface from email	
11:57	In wifi range	About 300m first contact, just about usable at 150m (distances estimated)	
12:00	Extracting logs	Poor Wifi connection - manoeuvring ship	
12:20	Stop sent C2IAB		PB
12:22	Stop sent C2IAB		
12:23	Stop sent C2 Iridium		
12:35	Logs extracted		
13:58	Sub rebooted	Reboot the sub to load the new compass cal values	AC
14:01	Rebooted ok		
14:04	CTD on sent C2IAB		

14:10	Mission sent C2IAB	ENG 10 Alignment to E ETOS 15:00	
14:33	Acoustics tracking	Looks on track. Marker6 2204 working Avtrack 2212 not visible	EC
14:42	Acoustic tracking on Marker 6, not avtrack		
14:46	Surface, mission log received		
14:51	STAFES-APP on		
14:52	Autonuts on sent C2iab		
14:52	CARCUS on sent C2iab		
14:57	Mission C2IAB	ENG11- Alignment- East from E ETOS 15:58	
15:50	Queue Mission C2 Iridium	ENG 12 – Speed Test	
15:53	Surface and on next mission from queued C2 mission	ENG 12 – Speed Test ETOS 14:23	
16:27	Surface		
17:15	Recovered	Recovery Conditions:- 15 knots wind, 2m to 3m swell • Vehicle spotted and alongside after approximately 15 mins LR pointing head to wind but when in the lee of Discovery turned right angles propeller toward the ship. • Templeton pole extended and after some initial difficulty hooked successfully. • Held ALR on crane whilst ALR still in water with slack crane line whilst connecting handling lines to bow. • P frame fully extended • Successfully attached bow line, however it became twisted around lifting line as ALR rotated. ALR experienced occasional impacts with the ship (prop, wing, bow, actuator). • Second line attached to rear handling ring, but hook did not release from pole. • Winch hauled and ALR recovered from the water • Once stable a further handling line attached to the bow handline ring and ALR successfully recovered. • Damage Cracked bow faring Lost wing, damaged wing pin Impact on prop, initial inspections shows no damage however further analysis required	

		Lessons Learnt • Initial hook using Templeton pole was reasonably successful, although took several attempts before successful engagement. • Once connected leaving the ALR in the water leaves the ALR free to move and potentially impact the ship. • The main issue was leaving the ALR in the water too long. We should for the next recovery haul as soon as connected to the lifting line. Attaching handlings lines as appropriate when the ALR is in the air on a short line to reduce any pendulum effect.	
17:55	Power Off		

Daily Log 17/3/2022

Summary

Plan:
• Passage
Conditions:
Operations:
Issues:
• Poor WiFi range (150m just useable). • DO reading zero • Wing actuator damage • Inconsistent WEOS beacon • SBD Hubs • Check Motor and actuators

Log

Time	**Action**	**Detail**	**Initial**
08:00	Checks an fixes on ALR	After previous days mission and rough eecovery	
		• Motor replaced • Broken actuator bearing – replaced • Configuration change to DO, now works • Spare wings used, one remaining wing repaired, • Control surfaces checked – ok • Abort weight fizz link replaced with cable tie for long upcoming mission	

		• Restricted Monkey Island TX/RX rate to MCS3 (58.5 Mbps TX/ 43 Mbps RX. This enables the Rocket to provide full 28dBm Tx power at all times, also uses 16QAM which is more robust than larger constellations. See how it goes…. • Avtrack stopped responding replaced with Avtrack 2211	
13:50	ALR on Battery power		
14:13	STAFES-APP tests		

Daily Log 18/3/2022

Summary

Plan:
• Science missions between OS_A and OS_B • Ship Station number 8
Conditions:
25knot wind, 2m swell
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
07:30	ALR on Bench power		
07:42	STAFES-APP on		
08:28	STAFES Off	Did not work	
08:41	ALR on	Battery power	
08:53	STAFES-APP on		
10:08	Reboot	Reboot to have the sub getting GPS	
10:15	Added 250g	Top of syntactic, under lifting eye	
10:26	Quayside sent		
10:28	Quayside complete		
10:53	ALR Deployed		
10:55	Mission M61	SCI-01-South-on-Surface Potter	
11:01	CTD Pump on		
11:03	Mission compl		
11:04	Stop Sent	Email by mistake	
11:06	Stop sent	By Wifi	
11:10	Resume sent		
11:10	Stop potter sent		
11:12	Autonuts on sent	confirmed	
11:12	CARCUS on	confirmed	

11:20	M62 Mission sent	**By WiFi Sci-02A- FeatureTransect-A-to-MAB cal ETOS 15:05 to 16:50**	
16:49	M62 surface	• SBD data confirming Autonuts and Carcuss • Surfaced approx. 600m from MidAB waypoint • Average battery voltage 21.98V	
17:09	Autonuts on sent	Sent by Iridium - acknowledges	
17:17	CARCUSS on sent	(STAFES-APP still on) - acknowledges	
17:23	Mission M63 sent	**Iridium SCI-02B-FeatureTransect-MidAB-to-B**	
17:28	Mission acknowledged	ETOS 21:30	
21:37	M63 On the surface	• Average battery volts 22.07v • 2km off position to SW of OS_B • SBD message from CARCUS • CRC error on CARCUSS •	
22:03	**Mission Sent via Iridium**	Dive to miss shipping Track 1 km north of OS_B **DY149-ALR2 Dive to B**	
22:08	Mission acknowledged		
10:59	Extract logs		
11:02	Stop sent over wifi		
11:07	STAFES-APP off		
00:01	Stafes app on		
00:02	Autonuts on		
00:03	Carcass on	acknowledged	
00:05	Stafes app off		
00:07	Stafes app on		
00:24	Resume sent		
00:25	M64 Mission sent wifi	SCI-03-feature transect B to A 250m	
00:32	Stop sent		
00:47	Mission 64 sent Iridium	SCI-03-FeatureTransect B to A 250m	
00:49	Acknowledged		

Daily Log 19/3/2022

Summary

Plan:
•
Conditions:
20 knots 2m swell (at 07:00) 30 knots 3m swell (02:00)
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
02:00	Bridge reported ALR on surface	• Safety abort •	
02:00	Standby until first light	• Rudder health events triggered • Poor wifi unable to extract logs • ALR team have been awake for a long time, reassess in morning	
07:00	Ship standing by ALR still on surface		
08:47	Logs extracted	Using C2IAB laptop • Analysis suggests we had a PIC reset whilst diving • Resulting in the CTD turning off for 1 min 49 secs triggering a stuck trying to descend causing the abort • During the PIC reset the actuators also reset but did not return. This is a known issue with the new actuators on v2. Aold actuators do not exhibit this behaviour however the old actuators we have here are mechanically noisy. Mitigations • Change STTD/ STTA timers increased to from 3 mins to 10 mins. Giving more time for the CTD to recover after a PIC reset. This is equivalent to 60m depth at out current descent rate of 0.1m/s • Max depth now set to 800 • Max depth offset set to 100 • The actuator issue will be mitigated by moving rudder and stern plane aborts to safety stops. This will allow the ALR to return to the surface to enable a reboot to correct the issue. Ultimately, is this stuck rudder/ stern plane condition will still lead to one of the other aborts if the condition is dangerous to the vehicle.	
12:30	SttafesApp off		
12:44	Battery disconnected		
12:45	On shore power		

Daily Log 20/3/2022

Summary

Plan:
• M65 (Ship station number) OS_B to OS_A 600m, OS_A to OS B at 250 • Ships Station Number 13

Conditions:
15 knots 1 to 2m swell
Operations:
Issues:
• Avtrack 2211 showing hardware error and was replaced with 2211. 2211 was the subject of a previous similar problem and dent back to manufacturer who reported no error (see Jira NOCALR-1008)

Log

Time	Action	Detail	Initial
08:00	Applying changes to mitigate PIC reset issues	Pulled a new config, applied Rachels minor alterations	
08:26	Reboot		
08:34	Quayside		
09:53	Quayside		
09:58	Quayside		
11:00	Avtrack Failure	2211 did not respond during in air test. Replaced with 2212. We previously changed out 2212 because of poor performance in air, but potentially we were unable to get a good acoustic coupling. 2212 tested in air – ok. See Jira NOCALR-1008 for Avtrack 2211	
12:20	Battery connected		
12:43	Quayside		
12:56	Launched		
12:59	CTD on C2IAB		
13:00	Checklist complete		
13:01	AutoNUTS on	Confirmed	
13:02	Carcass	Confirmed	
		STAFES-APP not powered for these deep missions	
13:05	**Mission sent - WiFi**	**M65 SCI-05- B to A 600m A to B 250m**	
14:30	Confirmation of position on UBL	500 depth continuing dive	
15:30	Test acoustic comms from topside dunker using Bagley box and GUI	Failed, however ALR had moved 600m West. Also dunker cable too short and dunker although below the waterline was still against the side of the ship.	
20:05	First USBL contact	850m 11 deg behind ship	
20:30		Parallel with ship, position error of 400m	
20:30	Dunker test	Status messages received	
21:51	USBL Hit	515m behind ship, at 250m depth on its return journey. Sip positioned 47 deg 29.548; 10 deg 48.472	

Daily Log 21/3/2022

Summary

Plan:
- M65 (Ship station number) OS_B to OS_A 600m, OS_A to OS B at 250 - continued - Ships Station Number 13
Conditions:
15 knots 1m swell
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
05:30	Surface	M65	
06:00	Ship heading over to ALRs position		
06:30	Visual of ALR2		
06:42	First wifi contact at 400m range	Extracting logs Wifi Updates that improved connection • Hanger and rear deck antennas were specified incorrectly Hanger rocket was expecting Rear deck antenna and rear antenna was specified as having hanger (internal antenna) • Still getting wifi inconsistences so switched off hanger wifi AP. • Improved wifi resulted	
		WE SAW 3 PIC RESETS DURING MISSION	
06:59	Surface mission to return APR to OS_B	DY149-ALR2-Surface to B • Autonuts Nitrate did not work, although ALR powered and controlled them correctly.	
07:36	Stop Sent		
08:12	Reboot sent		
08:24	CTD On		
08:234	STAFES-APP On		
08:25	Carcuss on sent	Acknowledged	
08:26	Autonuts on	Acknowledged	
08:31	**M66 Mission sent**	**DY149-ALR2-SCI-02- FeatureTransect-B to A 20m** **ETOS 18:00**	
08:35	ALR dived		
15:00	Turned on USBL to try to observe ALR transiting past CTD location	ALR not seen. At 20m depth unlikely to be able to see the ALE via the USBL.	

16:00	CTD Sampling along the ALR track		
17:49	**M66 surface**	**Mission log ok** **CarCASS SBD shows data** **No data shown in Autonuts SBD**	
18:12	Sent mission	Dive 20m LOS to west of AS_A Still CTDing so send Sub on short dive mission to align to the West of OS_A	
18:16	M66 acknowledged	ETOS 19:16	
19:23	M66 On surface	Ship still heading to ALR location from CTD site	
19:30	First time WiFi in range	All antennas apart from starboard monkey Island switched off. Appears to give much better WiFi range and quality	
20:01	Carcass on	acknowledged	
20:03	Autonuts on	Port 1 and 3 off - acknowledged	
20:03	**M67 sent wifi**	**SCI 06 Staiarcase A-B**	
20:06	Mission started		
		Autonuts may not have switched off due to comms error with Autonuts, we sent a new bitmask (port 1 and 3 off) but this may not have been registered.	

Daily Log 22/3/2022

Summary

Plan:
• Recover from M67 and steam to shelf region • Ships Station Number 13
Conditions:
15 knots 2m swell
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
08:34	M67 Surfaced	CarCASS SBD full but corrupt Autonuts SBD empty as before	
09:00	Slow C2 response	Approximate 30 min Delay on C2	
09:30	Drifting SW	Ship performing CTD until 10:30, will move over to recover ALR2 when CTD on board	
10:00	C2 showing ALR in warning at 09:11 with a large GPS age	ALR seems to have rebooted	
12:00	Recovered to deck		

12:05	Battery disconnected and on shore power		
13:00	Logs extracted	3 PIC RESETS	
16:00	Reboot and issues with Autonuts investigated	Approx times	
17:00	STAFES-APP issues investigated	Aoorox times	

Daily Log 23/3/2022

Summary

Plan:
• Recover from M67 and steam to shelf region • Ships Station Number 13
Conditions:
15 knots 2m swell
Operations:
Issues:
•

Log

Time	**Action**	**Detail**	**Initial**
08:00	Remove, test and reinstall SAFESApp	Requires removing AutoNuts	
19:30	Reboot	Reboot Hubs before two hour tests of Autonuts and CarCASS	
19:35	CarCASS on	Acknowledged, (10m depth threshold disabled)	
19:35	AuroNuts on	Acknowledged	
21:35	CarCASS off		
21:35	AuroNuts off		

Daily Log 24/3/2022

Summary

Plan:
• Staircase Mission from T1 to T10, starting at T1 today • Ship Station 21
Conditions:
10 knots 1m swell
Operations:
Issues:
•

Log

Time	**Action**	**Detail**	**Initial**
07:00	Problems with Autonuts	After removal for STAFES-APP change	
08:00	Change vehicle parameters as we are on the shelf	• No contact timer 24h and results in an abort • Max depth 120m • Depth offset 40m • STTD 4 mins • All other abort conditions (apart from no contact timer) set to safety stops	
08:32	125g removed from lift point	Slightly less buoyant at this shelf site so removing a little ballast. Buoyancy 25Nm (calculated)	
08:15	Slow comms to ALR	Were extracting logs overnight, all ok. As soon as the process stopped we saw very slow comms.	
08:56	Reboot	Comms speed back to normal…. (We wonder about CPU usage…)	
10:22	Started AutoNuts end to end test		
11:13	AutoNuts power off		
11:54	Battery connected		
12:50	Pump on		
12:57	CARCUSS sent		
13:00	CatCASS off		
13:02	STAFES-APP Off		
13:03	Reboot	Needed to pull down new configuration values • C2 needs to tell us the what the current configuration is, Alberto only caught this by chance	
13:07	STAFES-APP On		
13:08	CTD Pump on		
13:10	CarCASS on	Acknowledged	
13:11	AutoNuts On	Acknowledged	
13:22	STAFES-APP off		
13:23	STAFES-APP on	Acknowledged	
	Mission sent	SCI-07-Staircase T1 – T2	
13:45	**M68 Mission sent by WiFi**	**SCI-07-Staircase-T1-T2**	
13:47	On mission		
00:03	On surface	500m away (10h 18min duration)	
00:11	Stop potter sent - Iridium	Acknowledged	
00:38	AutoNuts on	Acknowledged	
00:38	CarCASS on	Acknowledged	
00:42	**M69 Mission sent**	**SCI-08-Staircase-T2-T3**	
00:45	**Mission started**		

Daily Log 25/3/2022

Summary

Plan:
• Staircase Mission from T1 to T10, starting • Ship Station 21
Conditions:
10 knots 1m swell
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
07:20	Surface	M69 Ended	
08:35	AutoNuts on sent	By Iridium	
08:39	Autonuts acknowledged		
08:39	CarCASS on	By Iridium	
08:43	CarCASS Acknowledged		
08:43	**Mission sent by Iridium**	**M70 SCI-09-Staircase T3 – Mid T3**	
08:48	Mission Acknowledged		
17:00	Surface	M70, approx. 500m off course	
17:05	Occasional WiFi	Possibly at 700m	
17:11	Stop Potter sent WiFi		
17:12	Extract logs		
18:04	No contact timer changed to 36h	Confirmed	
18:09	STAFES-APP Off		
18:09	Reboot		
18:12	Awake on system test		
18:14	CTD pump on		
18:16	Autonuts on	Acknowledged	
18:17	CarCASS on	Acknowledged	
18:19	STAFES-APP on		
18:34	STAFES-APP off		
18:35	STAFES-APP on		
18:37	**M71 Sent over Wifi**	**SCI-10- Staircase T3mid – T5**	

Daily Log 26/3/2022

Summary

Plan:

• Staircase Missions from T1 to T10 • Ship Station 21
Conditions:
20 knots 1m swell
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
13:51	Surface M71	From XEOS no response from ALR2 yet	
14:01	Stop potter sent	Iridium	
14:08	Acknowledged	Stop potter	
14:12	Ship manoeuvring to wifi range	First wifi comms at 800m (occasional)	
14:12	Extracting binary and sensor logs		
14:33	STAFES-APP off		
14:35	STAFES-APP on		
14:50	STAFES-APP Off		
14:51	STAFES-APP on		
14:52	Autonuts on	Acknowledged	
14:52	CarCASS on	Acknowledged	
14:54	**Mission sent by wifi**	**SCI-11-starcase T5-Mid T7**	
14:56	On mission		

Daily Log 27/3/2022

Summary

Plan:
• Staircase Missions from T1 to T10 • Ship Station 21
Conditions:
20 knots 1m swell
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
08:39	Changing Vehicle parameters	• No contact timer 24h • Max depth 700m (going over slope)	
09:55	Surface	M72, 1.63nm west of waypoint	
10:20	Stop potter sent	Iridium, Bridge has visual.	
10:26	Good wifi connection	0.35nm	

10:36	STAFES-APP off		
10:53	Reboot		
10:56	STAFES-APP on		
10:58	CarCASS on	Acknowledged	
10:58	Autonuts on	Acknowledged	
11:12	STAFES-APP off		
11:13	STAFES-APP on		
11:15	**Mission sent**	**SCI-12-staircase midT7 to T9**	
11:17	Dive runup		
22:41	Surface	Ave Voltage 22.17v	
22:52	3.5km SW of waypoint		
23:19	Bridge has visual		
23:24	STAFES-APP off		
23:24	Reboot	Question about sensor SBD, so reboot to be sure	
23:28	STAFES-APP on		
23:38	CTD Pump on	(**Forgot to turn CTD on Last time**)	
23:39	CarCASS on	Acknowledged	
23:40	Autonuts on	Acknowledged	
23:43	STAFES-APP off		
23:45	STAFES-APP on		
23:48	**Mission Sent**	**WiFi SCI-013-Staircase T9-Past T10**	
23:51	Dive runup		

Daily Log 28/3/2022

Summary

Plan:
• Staircase Missions from T1 to T10 • Ship Station 21
Conditions:
10 knots 1m swell
Operations:
Issues:
•

Log

Time	Action	Detail	Initial
14:59	Surface	4 nm away	
15:20	Surface mission	Bring it back towards waypoint as we CTD By email C2 not working	
15:27	Belived on mission	Range to go 1200m	
16:28	Stop sent	Via email and wifi	
1628	1000m away		
16:28	Stop command sent		
16:56	CTD off sent	Wifi – confirmed	
17:00	On board		

17:01	STAFES-APP off		
		• CarCASS stopped working at 07:49 • STAFES-APP stopped working at 08:53 • AutoNuts ok • ALR PIC reset at 08:25 seems unrelated	
18:37	STAFES-APP on		
19:06	STAFES-APP Power cycled		
19:20	Reboot		
19:31	Quayside sent		
19:41	CTD pump on		
19:42	CarCASS on	acknowledged	
19:43	AutoNuts on	acknowledged	
19:43	STAFES-APP on	acknowledged	
19:47	**Mission sent wifi**	**SCI 14 staircase T9-T7**	
19:49	Dive run up		

Daily Log 29/3/2022

Summary

Plan:

- Staircase Missions from T1 to T10
- Ship Station 34

Conditions:

10 knots 1m swell

Operations:

Issues:

-

Log

Time	Action	Detail	Initial
04:51	Surface	3nm away, ship moving	
04:58	Resume sent by email		
05:03	Surface mission sent by email.	Towards ship 15min timeout	
05:18	Bridge eyes on	Flasher vis	
05:18	Stop sent by email		
05:24	Stop sent by c2iab	ALR nearly alongside	
05:26	Abort sent by c2iab	It wasn't stopping	
05:27	Reboot sent wifi		
06:24	On deck heading home	😊	

3. Oceanids Sensors Integration

Chris Cardwell & John Walk (NOC)

3.1 Objectives for DY149

Mechanical, fluidic, electrical and software integration of the Oceanids AutoNutS, CarCASS and STAFES sensors with the Autosub Long Range (ALR) vehicle, and the AutoNutS and CarCASS sensor with the stainless steel CTD frame and the underway system.

Out of scope for DY149

The cancelled JC220 cruise had intended to demonstrate the integration of the Oceanids AutoNutS, CarCASS and CAPASOS sensors with the Liquid Robotics Waveglider vehicle. The integration was completed prior to JC220 and demonstrated in The Solent but the Waveglider vehicle was not included in this cruise. The Oceanids BioCam sensor was also not included in this cruise.

3.2 Equipment

The AutoNutS sensors deployed on this cruise were all NOC Wet Chemical sensors each measuring a single nutrient (nitrate, nitrite, phosphate, silicate and iron). All of the sensors consisted of an oil-filled, pressure-balanced plastic cylindrical housing (size 149mm diameter x 191mm length, weight in air 3.6kg, weight in water 0.85kg, rated for 6000m) with electrical and chemistry-specific fluidic connections to the top end-cap only. Reagents and waste were housed in external blood bags connected to the housings with Tygon Microbore tubing. The NOC sensors deployed in this cruise had either IE55 1206 connectors (older sensors) or Subconn MCBH8M connectors (newer sensors) for power and communications. Six AutoNutS sensors were deployed on the ALR, including two silicate sensors, and except for the phosphate which was swapped out mid-cruise, all the others remained in the vehicle for the whole cruise. A further three AutoNutS sensors were deployed on the CTD frame in various groups. Additional sensors were deployed on the ship’s underway system.

The CarCASS sensors deployed on this cruise were NOC Wet Chemical sensors each measuring a single assay (pH, Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC)) and an S1100 electrochemical pH sensor from ANB Systems. The Wet Chemical sensors have the same external design as the AutoNutS Wet Chemical sensors except that the DIC sensor is currently divided between two housings with electrical and fluidic connections running between them (second oil-filled C4D housing 149mm diameter and 355mm long). The ANB sensor has a pressure-tolerant housing (size 90mm diameter x 285mm long, weight 3.8Kg, rated for 1000m) and a single Subconn MCBH4M connector for power and communications. A full set of CarCASS sensors (NOC pH, ANB pH, TA and DIC) were deployed on the ALR and remained in the vehicle for the whole cruise although the entire tray containing them was removed (after the bags were detached) on one occasion to allow the STAFES sensor mounted below the tray to be replaced. A subset (NOC pH and TA) was deployed on the CTD frame and a spare ANB pH sensor was deployed both on the CTD frame and on the underway system.

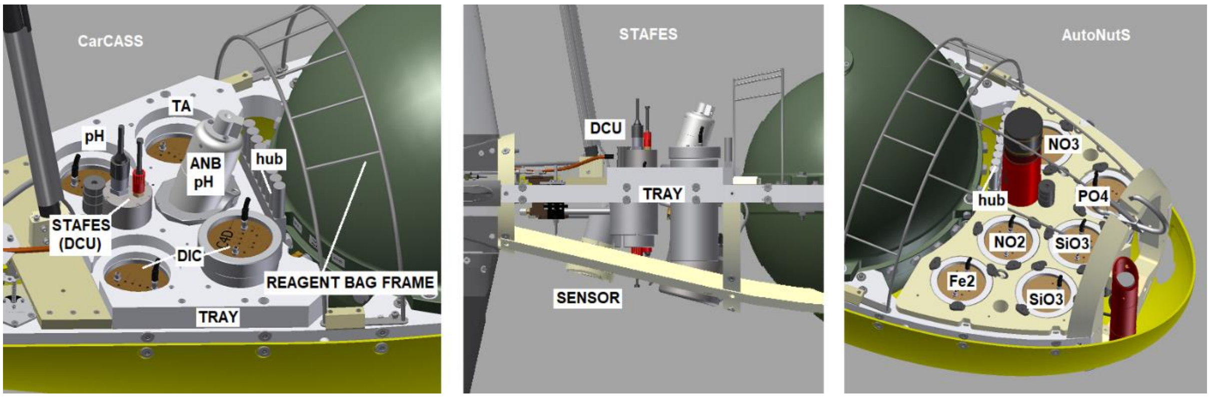
The STAFES sensor is a fluorescence sensor for measuring primary production. It is divided between two pressure-tolerant housings, a control unit (DCU size 88mm x 245mm long, weight 3.8kg) and the sensor itself (size 188mm diameter x 226mm long, weight 9kg, rated for 600m). A single unit was deployed on the ALR and it was replaced by a second unit mid-cruise. Other units ran on the ship’s underway system.

On the ALR, three pumps (2 x Sea-bird SBE-5T, 1 x Sea-bird SBE-5M (STAFES)) were used to ensure the sensors were sampling from outside the vehicle. The exact arrangement is described later.

Two pressure-tolerant Oceanids hubs (size 155mm or 198mm x 110mm x 21mm, weight 500g, rated for 6000m) were used on the ALR to integrate power and communications for the AutoNutS and CarCASS sensors with the vehicle. Two further hubs were carried as spares but one was subsequently deployed on the CTD frame to distribute CTD power to two AutoNutS and CarCASS Wet Chemical sensors (which two varied between CTD casts) and the other was deployed on the CTD frame initially to distribute battery power, control and logging for an ANB pH sensor and subsequently to distribute battery power to a third NOC sensor. It was also used in the laboratory to automatically control a pump to stress-test an improvised valve for the STAFES sensor with a small Windows application controlling the hub in place of the ALR. The hubs were identical except in the number of sensor ports available and the software they were running.

3.3 Mounting

The picture below (based on CAD images supplied by Ed Chaney) shows the general location of the CarCASS and STAFES and AutoNutS sensors on the ALR.



On the ALR the CarCASS sensor housings (including the ANB sensor) were mounted into a tray located in the ALR's rear payload bay using the same fittings designed by Rob Templeton (MARS Group, NOC) for the Oceanids Loch Ness trials in 2019. The STAFES DCU was also mounted in the same tray, with the STAFES sensor itself mounted below the tray. The Wet Chemical sensors' blood bags were sheathed in plastic netting to allow them to be fixed with cable ties to a metal hoop running across the vehicle behind the rear sphere (see the photographs). The AutoNutS sensors were mounted similarly in the ALR's forward payload bay.

On the CTD frame the CarCASS and AutoNutS Wet Chemical sensor housings and their blood bags were mounted individually in free-flooding plastic housings fixed to bottle clamps and clipped onto the frame in place of bottles, an arrangement used on several previous cruises (see the photographs). Initially the sensors were powered by batteries in their own cylindrical battery housings sufficient for 4 D-cells end-to-end clamped to the outside of the sensor housings. These were later removed when the sensors were powered directly from the CTD's own power supply (see later). The spare ANB sensor was occasionally mounted directly to the CTD frame using jubilee clips and a XEOS battery housing (rated for 11000m) filled with 5 CR123A batteries cable-tied to the frame for power.

The sensors deployed on the ship's underway system were placed in the sinks in the laboratories and tied down as necessary.

3.4 Sampling Arrangement

All of the sensors analyse water samples and to provide this from outside of the vehicle body (reducing dead volumes to a minimum in an aid to reduce flushing required) the manifolds used were electrically pumped. CarCASS and AutoNutS used a Seabird SBE-5T pump (one per system) and STAFES used a Seabird SBE-05M. The AutoNutS Wet Chemical sensors each sampled from tappings in a single 12.7mm diameter manifold line (see the photographs). The CarCASS Wet Chemical sensors sampled from tappings in a single (and separate) 12.7mm diameter manifold tube and the electrochemical pH sensor had a flow cell in line to the same tube. The STAFES system is a single flow cell in line to a third 12.7mm tube.

The requirements on the pump were as follows:

- Turbid flow (Reynolds number > 3000).
- Manifold refresh every 1s (volume in manifold before final sensor tap).

Flow rate vs power testing was performed after the pre-cruise Technology Trial in Loch Ness where it was deemed that pump power should be reduced and it was calculated that to meet the manifold refresh time AutoNutS needed a pump rotational speed of 1500rpm and CarCASS needed a pump rotational speed of 2000rpm. For simplicity and interchangeability of parts, both AutoNutS and CarCASS pumps were set to 2000rpm.

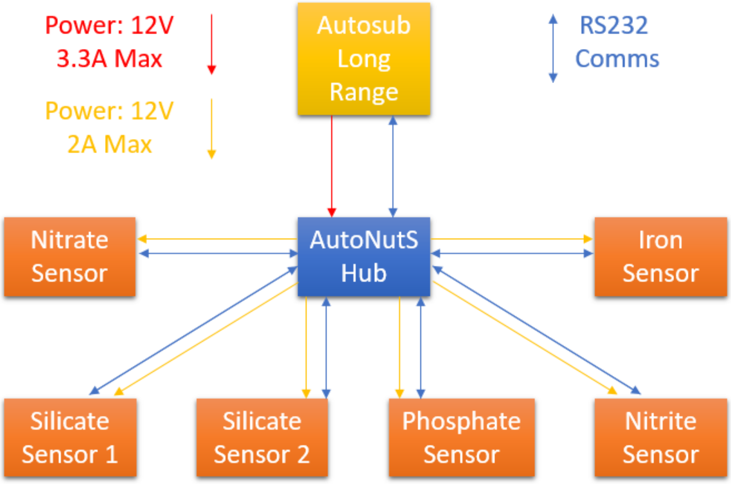
STAFES sensors weren't available for this testing and pumps were fitted by the STAFES system by the sensor team with 9.8mm tubing provided in the vehicle.

On the CTD frame the Wet Chemical sensors drew their samples through filters located external to plastic housings in which they were mounted to the bottle clamps and used only their internal pumps to draw in a sample. The ANB sensor's electrodes were open to the sea and the sensor was located 100mm clear of any metal parts in front of the electrodes. The STAFES sensor was not deployed on the CTD.

For the CarCASS and AutoNutS Wet Chemical sensors on the ship's underway system the flow from the clean sea water taps in the laboratories was led into a constantly overflowing cylinder and the Wet Chemical sensors drew their samples through filters inserted into the side walls of the cylinder. The ANB sensor was occasionally deployed on the underway system simply by placing it in a tray in the sink with the water led into the tray through a hose and constantly overflowing. The arrangements for running the STAFES sensors run in the laboratory will be covered elsewhere in this document.

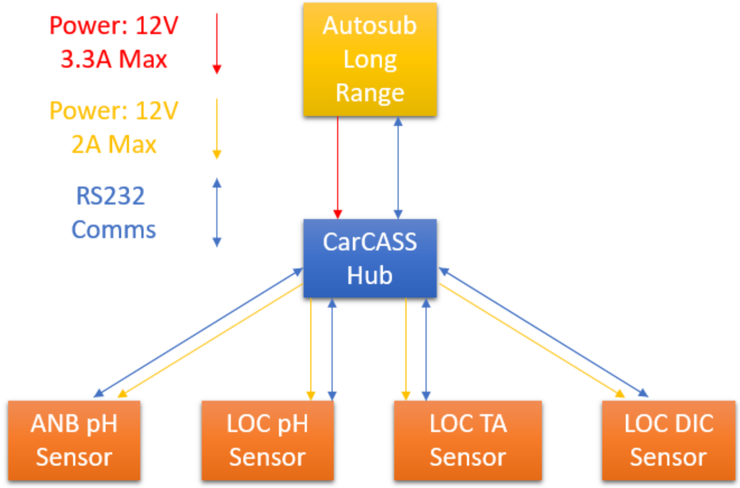
3.5 Power & Communications

The six AutoNutS sensors and their Sea-bird pump were connected for power and communications to a single ALR device port (MCBH4F connector, powered from a TracoPower TMDC 40-2412 12V 3.3A DC/DC convertor) via a 7+2 port Oceanids hub as shown below.



The hub consists of a single printed circuit board encapsulated in polyurethane attached to a plastic bulkhead fitted with 9 Subconn connectors, 7 MCBH4F connectors for sensors, one MCBH4M connector for the ALR and one MCBH6M connector to connect the hub to a PC for configuration or re-programming. A short (~500mm) terminated USB cable was deployed with the hub making it much easier to connect to a PC when the vehicle was on deck. The hub is completely waterproof and is rated for 6000m depth. The hub distributes power and RS232 communication from the vehicle to the individual sensor ports. The power is switched but not regulated (max 16V 2A continuous with 4A software re-settable e-fuses). The primary purpose of the hub is to provide a translation service between vehicles and sensors that are capable of communicating over RS232 serial connections but do not share a common communications protocol. Replacement hub firmware can be uploaded over the hub's USB port to expand the translation capability as necessary. The firmware in the AutoNutS hub for DY149 was the same as designed – along with the hub's physical design and its electronics - by Jake Ludgate (OTE Group, NOC) for the Loch Ness trial. When running the AutoNutS firmware, the hub effectively gives the ALR individual control over each attached sensor, allowing the ALR to power the sensor on or off and to send commands to the sensor (start, stop, set time, get status, get sample and send CTD). The logic of which commands to call when during an ALR mission and what to do if they fail was in the ALR itself implemented by Alberto Consensi (MARS Group, NOC): the AutoNutS hub just relays the commands from the ALR to the individual sensors and their responses back to the ALR. The Autonuts hub ran without fault for the whole cruise.

The four CarCASS sensors and their Sea-bird pump were connected to another ALR device port (MCBH4F connector, with a second TracoPower TMDC 40-2412 12V DC/DC converter) via a second 5+2 port Oceanids hub as shown below.

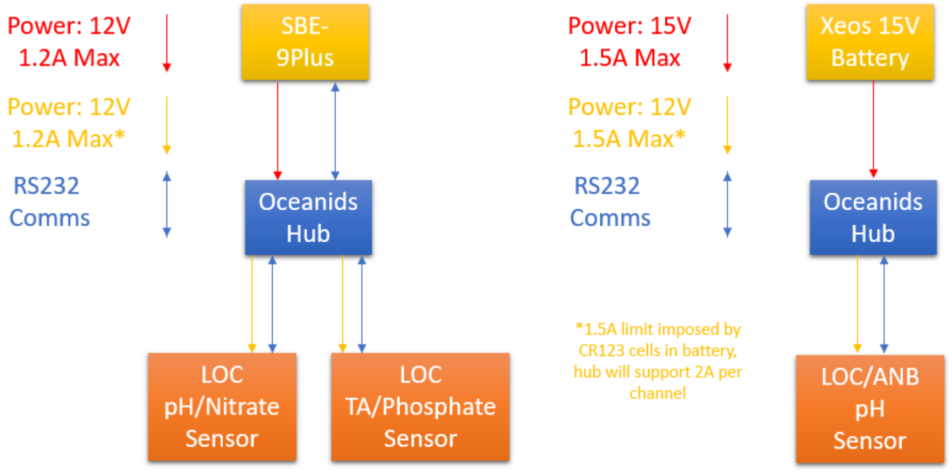


As with the AutoNutS hub it was deployed with a short, terminated USB cable attached. Except for the number of bulkhead connectors for sensor ports, the AutoNutS and CarCASS hubs are identical and can even be interchanged just by loading the correct firmware. The firmware in the CarCASS hub is significantly different from that in the ALR hub because the CarCASS hub firmware implements an entire carbonate measurement system, so the hub itself is responsible for controlling the individual sensors. It is seen by the ALR as a single sensor with the power on, power off, start, stop, get status, get sample and set CTD commands implemented by the hub, not passed through to the sensors attached to it. The sample returned by the CarCASS hub is the output from the carbonate calculation that in turn takes inputs from the two pH sensors, the TA sensor and the CTD data from the ALR itself. The CarCASS DIC sensor also runs but the DIC reported by the CarCASS sensor is actually an output from the carbonate calculation. For debugging purpose the CarCASS firmware did also give the ALR limited direct access to the individual sensors and logged raw data from all four sensors into its internal 8G SD card from which the data was downloaded via the hub's USB connection when the vehicle was on deck. The CarCASS hub ran without fault for the whole cruise except for one unexplained restart which occurred around the same time as an unexpected restart of the STAFES sensor and may perhaps have been caused by a glitch in the power supply to the hub.

The STAFES sensor was connected to a third ALR 12V device port (MCBH4F connector, with a third TracoPower TMDC 40-2412 12V DC/DC) with its Sea-bird 4M pump powered from the sensor's DCU. The STAFES sensor was designed for 24V but ran fine on 12V. It did not have any communications with the ALR, the data were downloaded on the occasions that the ALR was recovered to the ship.

On the CTD frame the CarCASS and AutoNutS sensors were initially powered by individual pressure-tolerant battery units containing 4 SAFT LSH-20 3.6V cells each. Unfortunately one of these battery units leaked (cause to be investigated after the cruise) and the sea-water ingress to one or more of the cells, perhaps under pressure, resulted in the unit exploding overnight while it was still mounted to the CTD frame. The remaining three units were removed to safe storage by the ship for the rest of the cruise. Subsequently pairs of CarCASS or AutoNutS sensors were deployed on the CTD frame powered from a spare sensor port (Port ID JT5, supplying 15V, about 1.2A max continuous) on the CTD's own Sea-bird 9Plus CTD control unit, itself powered from the 250V supply in the CTD cable thanks to a kind offer from Paul Henderson (NOC, Sensors and Moorings Group). A spare

Oceanids hub was used to distribute the single power source to both sensors as shown on the left below.



*1.5A limit imposed by CR123 cells in battery, hub will support 2A per channel

*1.2A limit imposed by 9Plus, hub will support 2A per channel

The ANB sensor was also deployed occasionally on the CTD frame using a battery unit intended as a spare for the XEOS GPS beacon on the ALR. The battery unit was loaned by Ed Chaney (MARS Group, NOC). Designed to hold 9x3V “CR123” Lithium cells this was reduced to 5 cells using a conductive spacer manufactured by Jack Arnott and Simon Jones (OE Group, NOC) to provide 15V for the ANB sensor. On the last deep (3000m) CTD cast the same battery was used instead to power an AutoNutS silicate sensor allowing it to be deployed alongside phosphate and nitrate sensors on the same cast. On both occasions the sensors were powered from the Xeos battery via a second spare Oceanids hub as shown on the right above. In the case of the ANB deployment the hub (originally intended as a spare for AutoNutS) was programmed with the CarCASS firmware to control the sensor and log the sample data from it in addition to providing power.

On the underway system the sensors were powered from benchtop power supplies.

3.6 Telemetry

Telemetry from the AutoNutS and CarCASS (but not STAFES) sensors was provided by the ALR (Alberto). This provides both a summary SBD message (sent via Iridium each time the ALR surfaced) and fuller logs (equivalent to the “processed data logs” on the sensors themselves) whenever the ship was able to get within WiFi range of the ALR on the surface. The satellite SBD messages were limited to just under 2KB for each of AutoNutS and CarCASS which made them necessarily brief but allowed for summary data at 10 minute intervals for a max 12 hour mission (occasionally exceeded) which on this cruise gave a very good indication of the health of all of the sensors. Many of the satellite messages were corrupted during transmission but, perhaps helped by the good weather, the WiFi logs were usually successfully retrieved, providing both early access to summary results while the ALR was still deployed and also enough information to diagnose occasional faults that allowed us to take some remedial action (on one occasion requesting a remote reboot of the ALR) when we saw something had gone wrong. All of the AutoNutS and CarCASS telemetry is available in their respective folders in the DY149 folder of the cruise data and the file format definitions and a graphical viewer (ALRLOG.EXE) are available in the DY149/integration folder.

3.7 Integration Issues

As with previous missions the IE55 connectors used on the older Wet Chemical sensors were found to be hard to use in the field and prone to deterioration and failure. Most of the IE55 blanking plugs and two of the sensor cables were replaced due to either actual failure or the potential for it (identified by resistance measurements across the pins) probably due to water uptake.

The USB cable between the STAFES DCU and its sensor failed probably due to strain on the potted joint that was very close (perhaps too close) to the connector at one end. Separately, the limited clearance between the AutoNutS and CarCASS blood bags and their respective hubs caused the cable connections to the hubs to be bent over probably beyond their minimum bend radius. They did not fail but this should be addressed in other deployments, perhaps by deploying the hub horizontally. Access to the hub would and the sensors' own connectors would ideally be improved.

Wet Chemical sensors with a single 8-way MCBH8M connector would benefit either from a deployable Y-cable to provide an easy USB connection or from a pass-through GUI via the Oceanids hub to make it easier to control the sensors (e.g. for configuration or flushing) when they are powered by the ALR.

The battery unit explosion is the subject of a separate investigation but a side-effect of that incident was that all identical battery units were removed and stored safely by the ship as a precaution. That left all of the CarCASS and AutoNutS deployments on the CTD frame in jeopardy and only the kind assistance of others on the ship and some ingenuity saved them. It highlights perhaps an unexpected single point of failure (the same battery units on all the sensors), although conversely the near universal use of Subconn cables made the electrical integration much easier with only two ends requiring soldering and potting.

On one occasion the ALR chose not to run an AutoNutS (silicate) sensor due to a communications time-out on the Stop command sent to that sensor via the hub on the previous mission. The sensor itself had been powered down at the end of that mission. In a subsequent deployment any CarCASS or AutoNutS sensor error that doesn't compromise the operation of the vehicle itself should be considered to be cleared by a power-cycle of the sensor.

The satellite summaries from the ALR were very helpful and on longer deployments where the ship can't be on WiFi range would be invaluable. If anything can be done to increase the reliability of transmission that would be helpful.

The ALR missions were numbered by the ALR team and whilst all the log data is timestamped it would be helpful if the ALR mission number was communicated to the sensors (as it is with some other vehicles). A difficulty is that the mission number isn't currently known even to the ALR but it's probably worth pursuing.

The Wet Chemical sensors' blood bags, while lending themselves to be being arranged in tight spaces, do tend to make access to the sensors difficult (either for downloading data or swapping them out). The blood bags themselves don't generally need much access (except sometimes to close them) so perhaps access to the sensors could be given priority over access to the blood bags by some alternative arrangement.

3.8 Overall Assessment

Mechanical, fluidic, electrical and software integration of the sensors to the ALR and the other systems worked consistently and well through the whole mission such that the integration effort was largely invisible (as it should be). There were a few issues noted above but generally the approach taken has proven to be sound. The Oceanids hubs worked without fault through the whole trip and their versatility was shown by the deployment of the spare units in laboratory testing and deep ocean CTD casts. This has been a very successful cruise.

Acknowledgements

The original mechanical integration of the sensors to the ALR was carried out by Rob Templeton (MARS Group, NOC). The Oceanids hub was designed and built by Jake Ludgate (OTE Group, NOC) who also wrote all of the hub software. The assistance of the Phil, Ed, Alberto, Paul, Jade, Jack, Simon and Nick in helping us solve integration issues throughout the cruise is also gratefully acknowledged.

Figures

All photographs Chris Cardwell.

Figure 3.1: *AutoNutS sensors showing reagent bags and manifold pump/outlet*

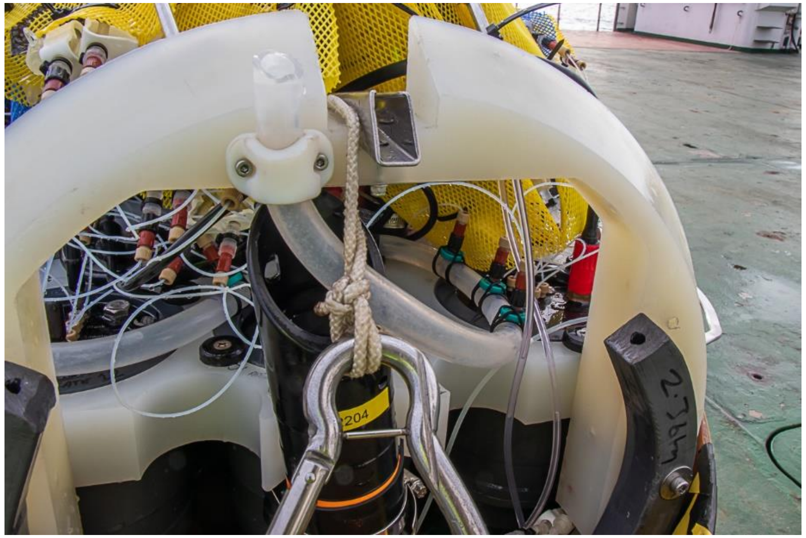


Figure 3.2: *AutoNutS manifold, inlet in centre of image*

Figure 3.3: *CarCASS and STAFES sensors showing CarCASS reagent bags*

Figure 3.4: *CarCASS manifold and pump (inlet top), into ANB pH sensor and outlet to rear. Large red cable connecting to STAFES DCU*

Figure 3.5: *STAFES inlet hose (to the left of CarCASS reagent bag frame)*

Figure 3.6: *STAFES outlet hose position (2 cable ties to rear)*

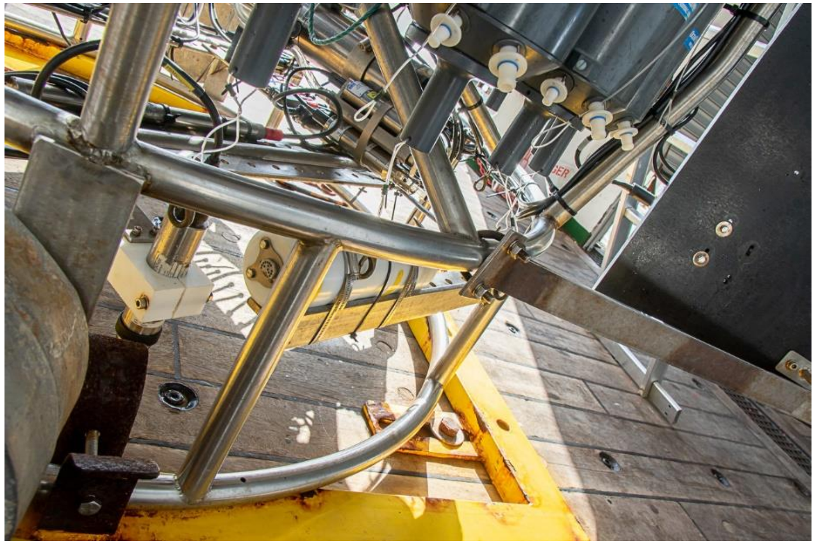


Figure 3.7: *ANB pH sensor fitted to CTD carousel*

Figure 3.8: *View of Xeos battery pack (left side of centre structure), Oceanids Hub (far structure under SBE-9plus) and ANB sensor to right of picture*

Figure 3.9: *Installation of Oceanids Hub on CTD frame, taking power from CTD SBE-9Plus*

Figure 3.10: *From the Oceanids Hub individual cables run to the two Wet Chemical sensors*

4. STAFES-APP project

Jacob Harper, Neil Wyatt, Mark Moore, Alan Wright (University of Southampton)

Mary Burkitt-Gray, Nina Schuback (Chelsea Technologies)

4.1 Introduction

The physiology and composition of upper ocean plankton communities has a strong influence on the magnitude of marine primary production (MPP). MPP is not like temperature, salinity or the concentration of nutrients, which can in principle be measured exactly. It is a biological process and. although artefacts are unavoidable, MPP data has been central to our understanding of marine ecology and biogeochemical cycles (Cullen 2001).

4.2 The STAFES-APP development project

STAFES-APP (Single Turnover Active Fluorometry of Enclosed Samples – for Autonomous Primary Productivity) is part of the NERC-funded OCEANIDS programme (NE/P020844/1). The purpose of this work package on DY149 is the final trials cruise of this grant, enabling the first real time MAS based MPP measurements, and thus revolutionising our observation and understanding of oceanic systems.

To examine relationships between surface plankton elemental stoichiometry, community structure and community iron status a series of samples and measurements were collected on DY149 to assess levels of phytoplankton biomass (chlorophyll-*a*), community composition (preserved and filtered water samples for microscopy, diagnostic pigments via high performance liquid chromatography (HPLC)), particulate absorption spectra (PABS), biomineral standing stocks (biogenic silica) and total particulate organic carbon and nitrogen standing stocks. The physiological state of near surface phytoplankton communities was assessed using single turnover active fluorescence (STAF) techniques applied to water collected from the ship's underway sampling system, alongside underway chlorophyll measurements. Furthermore, a STAF instrument was deployed on board an Autosub Long Range 2 submersible to gather real time data on unprecedented spatial and temporal scales.

4.3 Active chlorophyll fluorescence measurements.

Chlorophyll active fluorescence analysis, specifically Single Turnover Active Fluorometry (STAF), can provide a useful non-destructive and rapid index of the physiological status of phytoplankton (e.g. Moore et al. 2007). STAF is capable of measuring a suite of parameters pertaining to the photosynthetic physiology of the entire phytoplankton community, most commonly including the photosynthetic energy transfer efficiency (Fv/Fm) which can provide a proxy of the overall photosynthetic ‘health’ of the community. The STAFES technique measures in real time, in situ and at high sensitivity. Multiple STAFES instruments were deployed in a range of modes during DY149.

4.3.1 Instruments summary

Six STAF instruments were used during DY149, four LabSTAFs and two AutoSTAFs. The four LabSTAFs and one AutoSTAF were used for laboratory-based measurements, and one AutoSTAF was in the ALR2. Lab books for each instrument are in
STAFES/Instruments/Lab books

The instruments are identified by their serial number, with the final three digits of the serial number used as a shorthand name in listed in Table 4.2.

Instrument type	Serial number	Name	Work locations
LabSTAF	19-0105-004	LabSTAF-004	RN lab
LabSTAF	19-0105-005	LabSTAF-005	Deck lab bench/underway
LabSTAF	19-0105-006	LabSTAF-006	Deck lab underway
LabSTAF	19-0105-008	LabSTAF-008	RN lab
AutoSTAF	21-1834-001	AutoSTAF-001	Deck lab underway (until 23/03) ALR2 (from 23/03)
AutoSTAF	21-1834-002	AutoSTAF-002	ALR2 (until 23/03) Deck lab underway (from 23/03)

Table 4.2: *STAF instruments on DY149*

4.3.2 Calibration

Parallel measurements of a fixed fluorescein sample in a scintillation vial were taken using all four LabSTAF units to verify the calibration between instruments. LabSTAF-004 and LabSTAF-008 were calibrated by Chelsea Technologies immediately prior to the cruise and were used as the reference instruments to check whether calibration drift had occurred on LabSTAF-005 or LabSTAF-006. These test measurements of fluorescein are saved in the folder location: **STAFES\Data\Testing_LabSTAF\fluorescein**

LabSTAF-005 required a calibration update and a new calibration spreadsheet was generated, which is saved at: **STAFES\Instruments\LabSTAF\new_calibrations\19-0105-005**. These calibration values were updated prior to the start of other measurements.

On 2022-03-21, LabSTAF-006 was found to have a single incorrect value in the actinic light calibration, likely due to a mistake in typing during the initial calibration procedure. This was clearly identifiable by a kink in the rPE curves and in the calibration slope stored internally. The actinic light curve was remeasured using a Walz quantum sensor (SQS A0295) and multimetre and the single incorrect calibration value corrected. All RunSTAF files were reprocessed with the new calibration values, and all files referenced here use these new correct values. The test measurements and new actinic calibration values are located at **STAFES\Instruments\LabSTAF\new_calibrations\19-0105-006\Actinic ReCal 19-0105-006.xlsx.**

4.3.3 Maintenance

The sample chambers and all connective tubing were cleaned with MilliQ on the following occasions:

LabSTAF-005 and LabSTAF-006
2022-03-17 at 9am
2022-03-21 at 9am
2022-03-24 at 11am

2022-03-27 at 3pm
LabSTAF-005 was additionally cleaned with MilliQ prior to every discrete CTD sample.

AutoSTAF-001
In the lab:
2022-03-17 at 9am
2022-03-21 at 9am
2022-03-22 at 7pm
2022-03-23 at 7am

In the ALR2:
2022-03-24 Flushed with MilliQ before deployment 4
2022-03-28 Flushed with MilliQ before deployment 5
2022-03-30 Flushed with MilliQ after deployment 5

AutoSTAF-002

In the ALR2:
2022-03-14 Flushed with MilliQ
2022-03-15 Flushed with MilliQ
2022-03-16 Flushed with MilliQ before and after deployment 1
2022-03-17 Sample chamber cap removed and chamber thoroughly cleaned during DCU swap
2022-03-18 Flushed with MilliQ before deployment 2
2022-03-19 Flushed with MilliQ after deployment 2
2022-03-20 Flushed with MilliQ before deployment 3
2022-03-23 Flushed with MilliQ after deployment 3

In the lab:
2022-03-23 Thoroughly cleaned in the lab during testing
2022-03-24 at 11am
2022-03-27 at 3pm

4.3.3 Autosub Long Range 2 deployments

Multiple deployments were made with STAFES installed in the ALR2. The details of each deployment and mission (depth, location etc) are available from the ALR section of this report. As will be clear by reading the details below, after every retrieval multiple changes and tests were carried out. This section of the report is an attempt to describe that in chronological order. Detailed descriptions of all activities and all data files are available upon request

Pre-deployment tests

A range of pre-deployment power tests were conducted prior to deployment. See folders 2022-03-14 ALR2 Powering tests MilliQ, and 2022-03-15 ALR2 Powering tests MilliQ.

Deployment	**From**	**to**	**DCU**	**AutoSTAF**
1	**15 March 2022**	**15th March**	**Primary**	**21-1834-002**

Deployment details	Protocol / set up	Changes from last mission	Pre-launch checks	Data received
Launch @ 0712 on 15th March 2022 See ALR data for retrieval time.	12 step FLC Auto PEP Auto DWM Auto LED Auto PMT Auto FLC off Max E = 1500 Software (8.5.6) Pump time 20s	N/A	Attachment verified Pump primed - milliQ	No data received See folder 2022-03-16 deployment1 NO DATA

Post deployment tests

Following the lack of data collection, multiple checks were carried out.

Running from the ALR battery;

AutoSTAF was restarted five times without issue, on the fifth restart it was left running to establish if a data file was created. The result shows that all data files were created.

Additionally, from the log;

17 March 2022 – 1414. AutoSTAF turned on and DCU attaches to instrument. AutoSTAF in ‘starting’ mode for 10 minutes. In an attempt to reduce the time before data was collected, the following was tried. **See folder 2022-03-17 ALR2 powering tests MilliQ and empty chamber**

21-1834-001 connected to primary DCU – run staf successfully opened and attached, acquired data to light step 2. This was repeated successfully four more times.

21-1834-002 reconnected. However, secondary DCU replaced the primary. Run staf opened and DCU immediately attached to AutoSTAFES, pump switched on, but not acquiring data.

This was repeated 4 more times with the same result – with a variety of no sample, underway and milliQ in the sample chamber – all resulting in no data being acquired.

Upon inspection of the existing USB cable, it became clear that some connections were damaged, there was also visible excess loading on the pins. Attempts were made to try and change the angle of connecting cables to reduce strain, in case a bad connection was the reason for the issues described. A wedge was installed under AutoSTAF to reduce the angle of the USB cable, furthermore, mechanical support (in the form of half a measuring cylinder) was applied where the USB cable enters the DCU – again to reduce strain.

On reconnect there were still connection issues, with the ADC stuck on 121 (max) and the PMT on 360V (min), with no reading from the RH sensor. Eventually attachment was made and data collection started.

Deployment	**From**	**to**	**DCU**	**AutoSTAF**
2	**18 March 2022**	**19 March 2022**	**secondary**	**21-1834-002**

Deployment details	Protocol / set up	Changes from last mission
18 March @ 1049 ALR2 launch 19th March @11.15 ALR2 leaves the water. 19th March @12.25 AutoSTAF shut down.	Software Version 8.5.3 High E 1500 Auto FLC Off 12 up steps, no pre E, no pre-dark, step 1 (E=0) 180s DCU set up: Depth delay N/A Pump delay N/A Pump time 20s Seq/Acq 8	USB cable replaced.

Pre-deployment 2 tests

The following power cycles were tested prior to deployment.

1, (Hanger) powered on, attached, but took 15 minutes to begin data acquisition.

2, (Deck) powered on, attached, then crashed, not clear if data acquisition had started

Both 1 and 2 had sea water flushed through the sample chamber.

3, (Deck) powered on, attached immediately, ADC within range and proceeded to data acquisition.

Post deployment observations and data

A range of data was collected, although unusual findings were observed (Figure 4.1)

See Folders 2022-03-18_to_2022-03-19_deployment2_NOTE-sample_exchange_20s

And **See folder 2022-03-19 MilliQ**

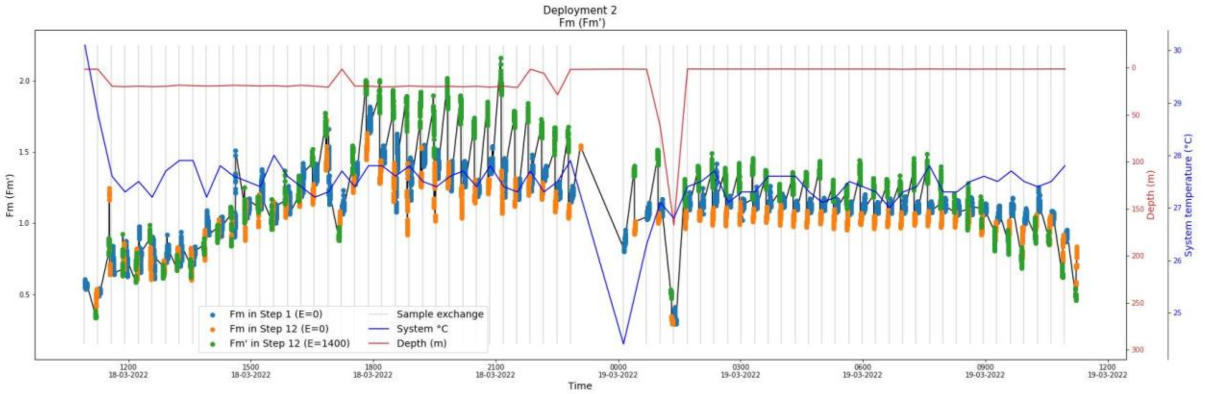


Figure 4.1: *Analysis of Fm and Fm' by time, depth and system temperature for deployment 2.*

Deployment	**From**	**to**	**DCU**	**Auto STAFES**
3	**20 March 2022**	**22 March 2022**	**Secondary**	**21-1834-002**

Deployment details	Protocol / set up	Changes from last mission
20 March 2022 @ 0800 ALR2 launched 21 March 2022 @ 0825 AutoSTAF turned on 22 March 2022 @ 0324 AutoSTAF stopped acquiring data 22 March 2022 @ ALR2 retrieved	Software Version 8.5.6 High E 1400 Auto FLC Off 12 up steps, no pre E, no pre-dark, step 1 (E=0) 180s DCU set up: Depth delay N/A Pump delay N/A Pump time 60s Seq/Acq 16	Pump changed to 60s Gap steps 11 Seq/Acq now 16 Group time 22s Settings file copied from 001. RunSTAF 8.5.6 High E 1400

Pre-deployment 3 tests

The following power cycles were tested prior to deployment.

Power on test with new settings. DCU and instrument attach, with a 9-minute delay until data acquisition begins. The instrument was acquiring data successfully until circa 60 minutes prior to launch, then powered down.

Post deployment 3 observations / tests and data collection

AutoSTAF stopped acquiring data at 03:24 on 22 March 2022. This was logged in Windows error reports as due to 'The program RunSTAF stopped working'. RunSTAF error reports from the same time suggest that the software failed while trying to acquire a PEP measurement. This time coincided with the ALR2 diving from 250 to 600 m (depth of last datafile at 0319 was 360m).

22/03/22 @1424 discrete underway sample ran in instrument 002. See folder 220322-1419_discrete_cross_comparison_AutoSTAF-002_1

AutoSTAF-002 removed from ALR2 after deployment 3 and replaced with AutoSTAF-001 before deployment 4. Pump also replaced.

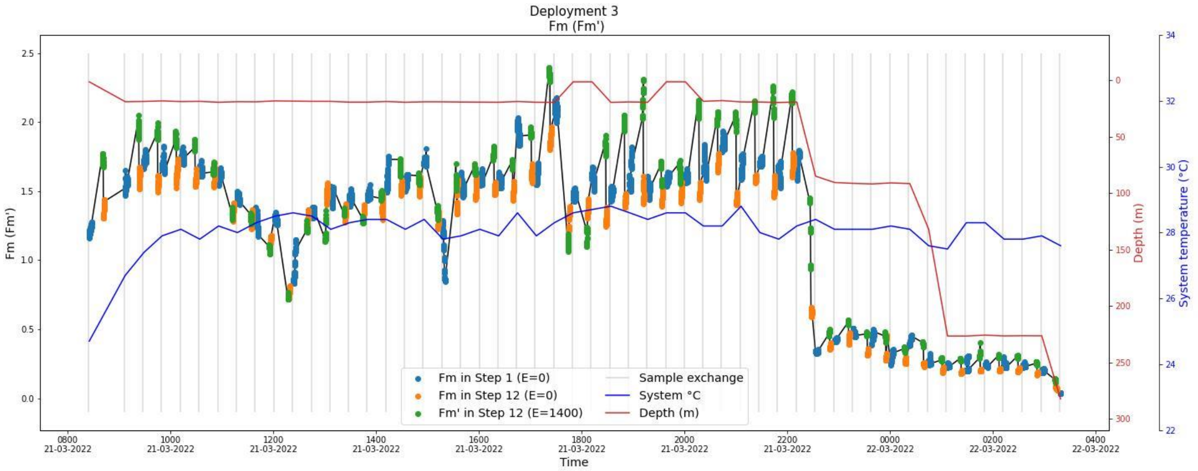


Figure 4.2: *Analysis of Fm and Fm' by time, depth and system temperature for deployment 3.*

Deployment	**From**	**to**	**DCU**	**AutoSTAF**
4	**24 March 2022**	**28 March 2022**	**Secondary**	**21-1834-001**

Deployment details	Protocol / set up	Changes from last mission
24 March 2022 @ 1253 launched 28 March 2022 @ 0853 RunSTAF failed and AutoSTAF stopped acquiring data 28 March 2022 @ 1700ish ALR2 retrieved	Software Version 8.5.3 High E 1000 Auto FLC Off 12 Up steps, no pre E, No pre-dark, step 1 (E=0) 180s DCU set up: Depth delay N/A Pump delay N/A Pump time 60s Seq/Acq 24 Gap Steps 11	AutoSTAF-001 now in ALR2 Pump reserve now in ALR2 Settings file copied from computer. High E now 1000 Seq/Acq now 24

Pre deployment activity log

1225 Flushed unit through with MilliQ on deck to prime pump. Took 9 minutes to obtain 'ready' from ADC. Only observed detectable ADC reading when System temperature reached 22C.
1240 Reached step 2 UP
1250 ALR deployed (@ T1)
1300 ALR experienced problems with Wifi and needed to be powered down, AutoSTAF powered off.
Power cycled. Off, on for 15 minutes, off, and on again

Post deployment 4 observations / tests and data collection

AutoSTAF stopped working at 0853 with Windows reporting the error 'RunSTAF stopped working'. The ALR2 was stable at 250m during this period so unlikely related to diving.

While ALR2 had been out on deployment, the source of the erroneous FLC data was identified as the sample chamber continuously flushing during the measurement procedure. Immediately after deployment 4, the pump was replumbed to fit a no-return valve, in the form of a duckbill valve made from Yorkshire Tea teabag bag ('Yorkshire B' valve from tests) fitted inside the chamber from a 60ml syringe. This was fitted on the outlet of the pump to allow discharge when the pump ran while preventing backflush while it was off. The pump outlet was relocated to discharge inside the ALR2 so that outlet should not experience current. The sample chamber inlet tube, on the side of the ALR2, has moving water going past it and as such experiences negative pressure. These combined effects should prevent flushing of the sample chamber except when the pump runs, allowing a discrete sample to be held inside the chamber throughout the measurements.

FLC data was checked immediately post deployment 4 and confirmed that the sample flushing was still observed in this deployment. A snapshot of the deployment 4 Fm data is included below.

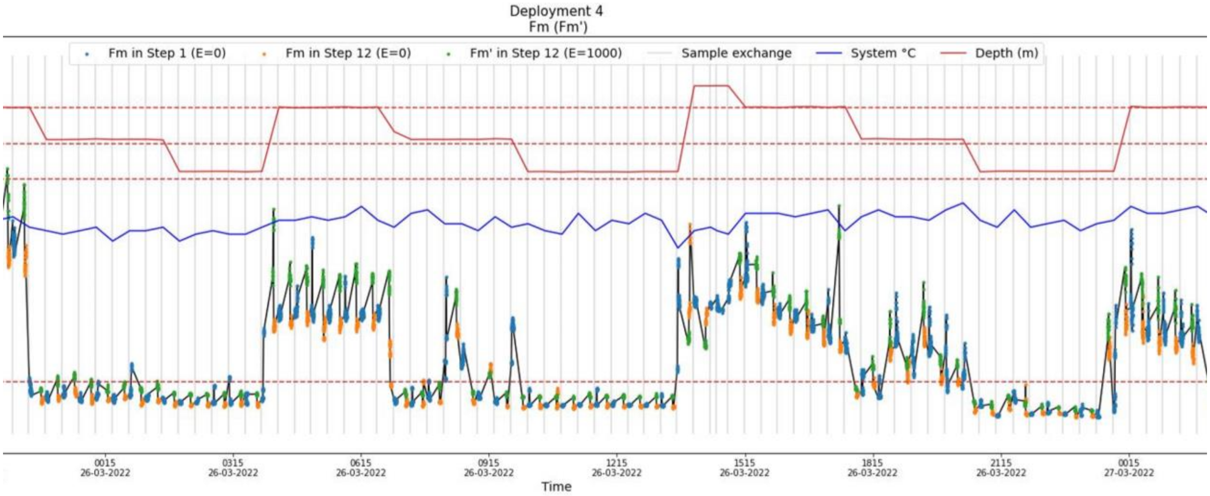


Figure 4.3: *Snapshot of analysis of Fm and Fm' by time, depth and temperature for deployment 4*

Deployment	**From**	**to**	**DCU**	**AutoSTAF**
5	**28 March 2022**	**29 March 2022**	**Secondary**	**21-1834-001**

Deployment details	Protocol / set up	Changes from last mission

28 March 2022 @ 1940 ALR2 launched 28 March 2022 @ 1945 AutoSTAF powered on and began acquiring data 29 March 2022 @ 0600 ALR2 retrieved	Software Version 8.5.3 High E 1000 Auto FLC Off 12 Up steps, no pre E No pre-dark, step 1 (E=0) 180s DCU set up: Depth delay N/A Pump delay N/A Pump time 60s Seq/Acq 24 Gap Steps 11	'Yorkshire B' no return valve fitted on pump outlet. Pump outlet rerouted to discharge inside the ALR2.

Pre deployment activity log

DCU refitted into AutoSTAF. System flushed with MilliQ to prime pump and prime new valve.

1840 AutoSTAF powered on, ADC signal in range when system temperature reached 22°C. AutoSTAF then powered down.

1940 ALR2 launch, AutoSTAF powered on in the water.

Post deployment 4 observations / tests and data collection

RunSTAF acquired data continuously for deployment. No return valve worked exactly as intended – static sample held in chamber throughout acquisition. Good FLCs obtained up til final ascent to 20m, when the AutoSTAF linear actuator (switches between 685 and 730nm emission filters) failed. Low fluorescence readings observed for the final 20m run because the filter was not located in correct position for the 685nm filter, resulting in partial blocking of the PMT.

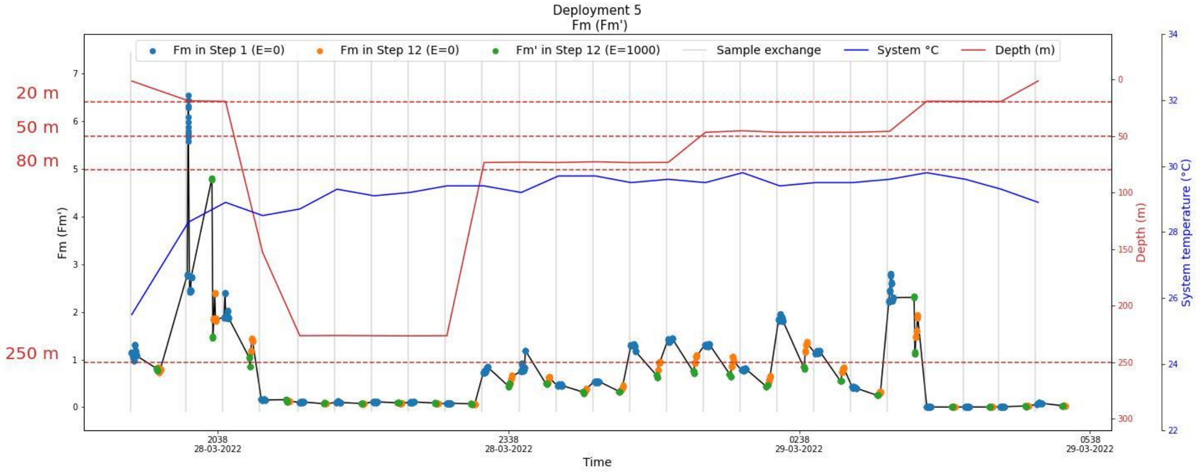


Figure 4.4: *Analysis of Fm and Fm' by time, depth and system temperature for deployment 5*

4.3.4 Continuous underway measurements

Hardware set-up

Chelsea Technology LabSTAF and AutoSTAF systems were connected to the ship's non-toxic underway supply within the Deck Lab to assess and monitor the physiological state of Photosystem II (PSII) within the surface phytoplankton population of the study area.

The STAFES instruments were controlled by RunSTAF software (versions listed in the table below). Data were stored on an external data logger and backed up every 1-4 days throughout the cruise. The instrument optics were cleaned periodically with MilliQ. Data will be analysed using custom software in a Matlab^{TM} environment

LabSTAF-006 was acquiring measurements on automatically exchanging underway samples in the Deck Lab for the duration of cruise using the LabSTAF flow unit and stirrer unit.

LabSTAF-005 was acquiring underway measurements intermittently, when it was not being used for CTD analysis or for cross-comparison to ^{14}C samples.

For LabSTAF underway measurements, the system temperature was controlled by continuously pumping underway water through the temperature control ports. The internal system temperature was recorded by RunSTAF.

AutoSTAF-001 was installed in the Deck Lab sink acquiring underway measurements from 2022-03-15 until 2022-03-23, at which point it was transferred into the ALR2. From 2022-03-15 until 2022-03-17, AutoSTAF-001 was fully submerged in a bucket of constantly flowing underway water. On 2022-03-17, the depth-rated USB cable was removed from AutoSTAF-001 and used in the ALR2; from this point onwards, AutoSTAF-001 was in underway water flowing through a shallow pelicase, and the top few centimetres of AutoSTAF-001 remained dry. AutoSTAF-001 was removed from the underway on 2022-03-23 and transferred to the ALR2.

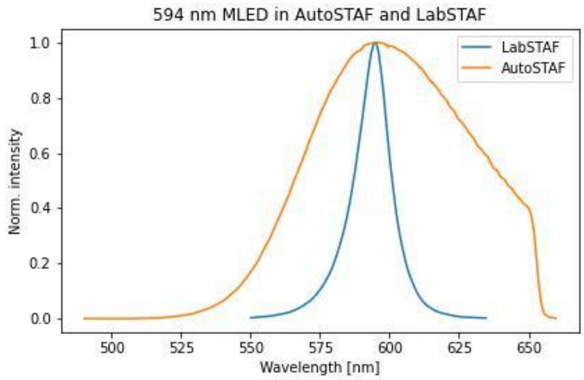
AutoSTAF-002 was acquiring underway measurements in the Deck Lab sink from 2022-03-23 until 2022-03-29.

For AutoSTAF underway measurements, the system temperature was controlled by immersion in constantly flowing underway water.

Instruments

There are two significant differences between the underway data acquired by the LabSTAF and AutoSTAF instruments:

- The 594 nm MLED (position 7) is centred at the same wavelength in both instruments, but has a much broader bandwidth and greater total intensity in AutoSTAF than LabSTAF. This will only affect the PEP measurements during DY149, because only 452 nm MLEDs were used during FLC measurements.



- The signal calibration is approximately a factor of two higher in LabSTAF than AutoSTAF, likely due to an error during the initial calibration of AutoSTAF. This will be corrected in later analysis through cross-calibration measurements taken on all instruments during the cruise.

FLC protocol

Where possible, the measurements parameters (including the FLC setup and the single turnover protocol) were identical in LabSTAF-006, the ALR AutoSTAF (002 until 23/03 and 001 from 23/03), and the lab-based AutoSTAF (001 until 23/03 and 002 from 23/03). This provided matched datasets between the instruments.

The FLC protocol was varied on LabSTAF-005 using the built-in AutoFLC option to compare how the calculated primary productivity parameters varied with experimental conditions. Additional Down Steps were also included on the FLC protocol, after any Up and Dark Steps, to provide information on hysteresis.

STAF protocol

AutoLED and AutoPMT were activated on all instruments throughout the cruise to ensure an appropriate signal throughout. AutoDWM and AutoPEP were activated throughout to acquire data to correct for variations in fluorescence reabsorption and spectral effects.

The STAF protocol was optimised throughout the cruise based on the signal:noise ratio observed, with Seq/Acq gradually increased from 8 to 24. The Gap Steps were also increased throughout the cruise to provide higher-resolution tau data, from 6 at the start to 11 by the end. The specific STAF protocols are listed for each instrument and folder in the following section.

Data location

All underway data is stored in the folder location: **STAFES\Data\Underway**

A separate folder contains the data for each individual STAF instrument, e.g. **’19-0105-005 (LabSTAF)’**.

Each instrument-specific folder contains folders sorted by date and experimental protocol. For example **‘STAFES\Data\Underway\19-0105-006 (LabSTAF)\2022-03-15 to 2022-03-18 FLCs HighE=1500 Gap steps=6**’ contains underway FLC data where the HighE was 1500 and the STAF protocol has 6 gap steps.

Underway STAFES operational details

LabSTAF-006

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
1	2022-03-15	18:46	2022-03-18	12:39	Off	0	12	1500	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	6	8	1	90
Folder path:	Folder path: Data\Underway\19-0105-006 (LabSTAF)\2022-03-15 to 2022-03-18 FLCs HighE=1500 Gap steps=6														
Notes:	LabSTAF plumbed in with mix unit and solenoid valves with a 90s exchange time followed by an 8s air purge. The sample was mixed with air for 600 ms air mix between Steps. AutoPMT, AutoLED, AutoPEP, and AutoDWM all active. RunSTAF version was 8.5.1.														

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
2	2022-03-18	13:00	2022-03-20	09:46	Off	0	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	6	16	1	90
Folder path:	Folder path: Data\Underway\19-0105-006 (LabSTAF)\2022-03-18 to 2022-03-20 FLCs HighE=1400 Gap steps=6														
Notes:	FLC protocol the same as that running on AutoSTAF-002 in the ALR2 and AutoSTAF-001 in the sink. The mix unit was replaced with a stir unit to more closely replicate the sample conditions inside AutoSTAF, which does not have resuspension between Steps. AutoPMT, AutoLED, AutoPEP, and AutoDWM all active.														

Experiment no.	**Protocol start**	**Protocol end**	**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
				Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	

3	2022-03-20	0953	2022-03-21	09:31	Off	0	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	16	1	180
Folder path:	Folder path: Data\Underway\19-0105-006 (LabSTAF)\2022-03-20 to 2022-03-21 FLCs HighE=1400 Gap steps=11														
Notes:	Gap steps increased to 11. Sample exchange time increased to 180s. AutoPMT, AutoLED, AutoPEP, and AutoDWM all remain active.														

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
4	2022-03-21	12:01	2022-03-22	11:00	Off	0	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	16	1	180
Folder path:	Data\Underway\19-0105-006 (LabSTAF)\2022-03-21 to 2022-03-22 FLCs HighE=1400 PEP and DWM off														
Notes:	AutoPMT, AutoLED, AutoPEP, and AutoLED all turned off due to a software glitch. FLCs acquired throughout this period but some measurements may be out of range. This likely occurred because the actinic LED was recalibrated at 11:30 on 2022-03-21, and the calibration mode settings may have overwritten the acquisition mode settings. DWM and PEP measurements can be used from LabSTAF-005 which was running the same underway samples.														

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
5	2022-03-22	11:10	2022-03-23	19:24	Off	0	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	16	1	240
Folder path:	Data\Underway\19-0105-006 (LabSTAF)\2022-03-22 to 2022-03-23 FLCs HighE=1400														
Notes:	AutoPMT, AutoLED, AutoPEP, and AutoDWM all active. Exchange time increased to 240s to match the exchange volume of the pump in the ALR2, which has a higher flow rate and an exchange time of 60s. At end of this dataset, a test was run to compare AutoFLC on LabSTAF-005 and a fixed FLC protocol on LabSTAF-006. The initial starting protocol was identical for LabSTAF-005 and LabSTAF-006, and FLC acquisition was begun at the same time for the same sample. Start file for this test: 220323-1545 HighE=1400 comparison start.rsf.														

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
6	2022-03-23	19:35	2022-03-24	08:40	Off	0	12	1000	50	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	16	1	240
Folder path:	Data\Underway\19-0105-006 (LabSTAF)\2022-03-23 to 2022-03-24 FLCs HighE=1000 SeqAcq 16														
Notes:	FLC protocol same as in AutoSTAF in ALR2 deployment 4 except for Seq/Acq. Push up reduced to 50 to decrease spacing between datapoints at low E values and improve resolution in this region, with the aim to improve analysis of the low-Ek curves observed in the ALR2. FLCs acquired by LabSTAF-006 have matched start points and samples as in LabSTAF-005 to observe the divergence in PP parameters between AutoFLC mode and a fixed FLC protocol. Starting files with identical sample/time are identified by the suffix “HighE=1000 comparison start” in the filename after the timestamp.														

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
7	2022-03-24	09:18	2022-03-30	06:46	Off	0	12	1000	50	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	24	1	240
Folder path:	Data\Underway\19-0105-006 (LabSTAF)\2022-03-24 to 2022-03-30 FLCs HighE=1000 SeqAcq 24														
Notes:	Seq/Acq increased to 24 to match the protocol used in the ALR. FLCs acquired by LabSTAF-006 have matched start points and samples as in LabSTAF-005 to observe the divergence in PP parameters between AutoFLC mode and a fixed FLC protocol. Starting files with identical sample/time are identified by the suffix “HighE=1000 comparison start” in the filename after the timestamp. NOTE: clock on computer updated to BST. Files from 1am to 7am on 2022-03-27 have been renamed so the timestamped file name corresponds to the correct ship time, but internally the original BST time may be saved.														

Underway STAFES operational details

AutoSTAF-001

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	
8	2022-03-15	18:46	2022-03-17	07:30	Off	0	12	1500	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	6	16	1	60
Folder path:	Data\Underway\21-1834-001 (AutoSTAF in bucket til 03-23)\2022-03-15 to 2022-03-17 FLCs Emax=1500														
Notes:	AutoSTAF in the Deck Lab sink fully immersed in continuously flowing underway water (tall white bucket). All cables used were depth-rated and the pump was also fully immersed. The system temperature was controlled though this underway exchange. FLC protocol matched to that running in LabSTAF-006. AutoPMT, AutoLED, AutoPEP, and AutoDWM all active. RunSTAF software version was 8.5.0 until 20:50 on 2022-03-16, when 8.5.9 was added. The FLC and STAF protocol remained the same. Both software versions displayed the same problems: • Sample exchange pump timings. The pump ran much longer than it has been set to, somehow connected to the Pre Dark and Pre E steps. For example, the pump time was set to 20s and the pump would run for over two minutes. AutoLED would initiate and initial ST measurements would begin to acquire while the sample was still exchanging, resulting in frequent crashes. • Frequent failures to connect to the AutoSTAF on start-up. • Settings files were overwritten every time the AutoSTAF failed to connect or the DCU restarted. RunSTAF frequently reverted to AutoFLC mode, rather than AutoFLC+DCU mode, and would no longer look for an instrument on Start Up or automatically run an acquisition. These problems compounded to make both software versions unusable in the ALR2. • RunSTAF would also revert to a Pre dark time of 120s when this occurred, resulting in recurring problems with the sample exchange and AutoLED as described above. • 8.5.9 crashed while running overnight. Decision made to revert to 8.5.6 for subsequent tests (see Experiment no. 10, below).														

Experiment no.	Protocol start	Protocol end	Auto FLC on/off	FLC summary						STAF summary			Exchange time
				Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	

9	2022-03-18	12:42	2022-03-19	13:57	Off	0	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	6	16	1	20

Folder path: Data\Underway\21-1834-001 (AutoSTAF in bucket til 03-23)\2022-03-18_to_2022-03-19_FLCs_Emax=1400_NOTE-bad_pump_setup_as_top_plate_no_longer_waterproof_has_poor_sample_exchange

Notes: DCU Primary removed from the ALR2 and swapped with DCU Reserve. DCU Primary now used for underway measurements in the Deck Lab connected to AutoSTAF-001. The depth-rated USB cable was removed from the AutoSTAF-001 in the Deck Lab setup and used in the ALR2 (the previous one in the ALR2 had internal damage from cable strain and likely caused the failed to acquire data during Deployment 1). As a result, AutoSTAF-001 no longer had watertight connectors on the top plate (non-watertight AutoSTAF-to-USB cable used instead). For this experiment series, AutoSTAF-001 was therefore not immersed in the underway water, but instead was on the edge of the sink and only the pump fully immersed. The setup was altered numerous times during this measurement series to try to get the pump to stay primed, including locating the sample chamber inlet directly by the underway outlet.

Significant flow, sample exchange, and overheating problems were observed during these experiments. The overheating problems were identified by the System Temperature parameter saved in RunSTAF. Some FLC files displayed the same trends in data as observed with the AutoSTAF in the ALR2 (very low Ek and higher Fm during the light steps than in the Dark Steps). These almost certainly arose because the sample was constantly exchanging throughout the measurement procedure due to the proximity of the sample chamber inlet to the underway outlet (this had been implemented to try and prevent the pump from becoming unprimed). For some periods in this experiment series, the sample also failed to exchange at all when the pump took on air and was no longer primed.

RunSTAF software used was version 8.5.6 throughout these tests, and for all subsequent AutoSTAF measurements for the remainder of DY149. The following known changes were implemented by this software version:

- The Default settings loaded automatically by RunSTAF are:
    - Acquisition mode: AutoFLC+DCU
    - FLC HighE: 1400, Push Up 80, 12 Steps. Step 1 Up (E=0) is 180s and Step 2 Up is 120s.
    - 60s Dark Step after Step 12 Up.
    - AutoFLC: Inactive
    - Pre Dark and Pre E both zero
    - Look for STAF system: On
    - Run acquisition on start-up: On
    - STAF parameters now 11 Gap Steps, with Gap Times from 200 to 6400 µs.
- In RunSTAF 8.5.6 the ability for RunSTAF to overwrite the default settings parameters has been disabled, to prevent the software from reverting to any settings which would hinder autonomous data acquisition in the ALR2.

These FLC parameters matched the updated protocol running in AutoSTAF-002, in the ALR, and LabSTAF-006, which was simultaneously acquiring underway data.

	Protocol start		**Protocol end**			**FLC summary**						**STAF summary**			

Experiment no.					Auto FLC on/off	Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	Exchange time
10	2022-03-19	17:30	2022-03-20	08:39	Off	0	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	6	16	1	60
Folder path:	Data\Underway\21-1834-001 (AutoSTAF in bucket til 03-23)\2022-03-19 to 2022-03-20 FLCs Emax=1400 Gap steps=6 NOTE- good pump setup again														
Notes:	AutoSTAF-001 now fully immersed in constantly flowing underway water in a pelicase, except for the top plate which remained dry above the waterline (connectors not watertight). Sample exchange pump also full immersed in the pelicase, and the rise from the pump to the sample chamber exchange minimised to only ~20cm. Good temperature control and good sample exchange obtained. The pump time was at 60s to test whether the bad FLC shape observed in the ALR2 arose due to insufficient sample exchange (pump time in ALR2 only 20s). FLC protocol matched to that in ALR2 for deployment 2.														

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	
11	2022-03-20	09:35	2022-03-22	13:36	Off	0	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	16	1	60
Folder path:	\Data\Underway\21-1834-001 (AutoSTAF in bucket til 03-23)\2022-03-20 to 2022-03-22 FLCs Emax=1400 Gap steps=11 Good pump setup														
Notes:	Same setup as Experiment No. 10 but Gap Steps increased to 11. The settings files (stored in the App folder on the DCU) were copied from AutoSTAF-001 to AutoSTAF-002 (in the ALR2) for Deployment 3.														

Underway STAFES operational details

AutoSTAF-002

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
12	2022-03-23	16:50	2022-03-29	06:00	Off	0	12	1000	50	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	24	1	60
Folder path:	Data\Underway\21-1834-002 (AutoSTAF in bucket from 03-23)\2022-03-23 to 2022-03-29 FLCs HighE=1000														
Notes:	AutoSTAF-002 removed from the ALR2 and installed for continuous acquisition of underway measurements. The general setup was the same as in Experiment 11, above (peli case with exposed top plate, same connectors and cables, same DCU Primary). The pump was swapped from the ALR2, so underway measurements now using the reserve pump (no observable difference in flow rate). High E 1000 and the Push Up reduced to 50 to give higher resolution measurements at the low E values, in an attempt to better capture the shape of the FLC curves with very low Ek values. Events of note: 2022-03-25: the water trap by the underway sink leaked and emptied into the container of continuously flowing underway water containing the AutoSTAF. Files from 220325-1236 may have contamination from water trap. Files up to 220323-1213 and later than 220323-1321 definitely not contaminated. 2022-03-29: the continuously flowing underway was reduced to a very low flow rate overnight, noticed in the morning of 29/03. The sample exchange rate in the pelicase containing the AutoSTAF was reduced compared to previous measurements. Should check the datafiles from this timepoint to determine how significant this affect is.														

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
13	2022-03-29	08:32	2022-03-29		On	0	12	1000	50	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60 120	11	24	1	60

										Down Step 8 Down Step 7 Down Step 6 Down Step 2: Down Step 1	60 60 60 60				
Folder path:	Data\Underway\21-1834-002 (AutoSTAF in bucket from 03-23)\2022-03-29 to 2022-03-30 AutoFLC														
Notes:	AutoFLC mode activated for underway measurement on journey back towards Southampton. Default Down Steps protocol implemented to match the underway measurements acquired on LabSTAF-005.														

Underway STAFES operational details

LabSTAF-005

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	
14	2022-03-15	20:11	2022-03-16	13:21	On	0	12	1500	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12 Down Step 10 Down Step 7 Down Step 6 Down Step 5	180 120 60 60 60 60 60 60	6	16	1	90
Folder path:	Data\Underway\19-0105-005 (LabSTAF)\2022-03-15 to 2022-03-16 AutoFLC no PreE														
Notes:	AutoFLC acquisitions with stirrer unit to monitor deviation between variable and fixed experiment parameters. Down cycle to monitor hysteresis. Attempt to implement a PreE of 10 for 600s for two RunSTAF files (220316-0816 and 220316-0909, saved in a separate folder ‘with_PreE_no_exchange’ in the same location), but activating the PreE meant that the pump didn’t run during sample exchange due to a software bug.														

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	
15	2022-03-16	13:53	2022-03-23	09:23	On	10, 600s	12	1000	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12 Down Step 8 Down Step 7 Down Step 6 Down Step 2 Down Step 1	180 120 60 60 120 60 60 60 60	11	24	1	90
Folder path:	Data\Underway\19-0105-005 (LabSTAF)\2022-03-16 to 2022-03-23 AutoFLC with 600s PreE														

Notes:	RunSTAF updated to 8.5.9 to fix pump issues. AutoFLC acquisitions with stirrer. Down steps increased, PreE of 10 for 600s, Gap Steps increased to 11 and Seq/Acq to 24. RunSTAF was updated on the following occasions: 2022-03-16 to 5.8.9, 2022-03-18 to 8.6.0. The Exchange time was 90s until 2022-03-20, then increased to 180s, then increased to 240s on 2022-03-23.

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre E	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
16	2022-03-17	18:57	2022-03-18	07:17	On	10, 600s	12	1000	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12 Down Step 2 Down Step 1	180 120 60 60 60 60	11	24	1	90
Folder path:	Data\Underway\19-0105-005 (LabSTAF)\2022-03-17 to 2022-03-18 AutoFLC 600s PreE short down steps														
Notes:	AutoFLC acquisitions with stirrer, same settings as Experiment 15 but Down Steps reduced.														

Experiment no.	**Protocol start**		**Protocol end**		**Auto FLC on/off**	**FLC summary**						**STAF summary**			**Exchange time**
						Pre Dark	**Steps**	**High E**	**Push Up**	**Steps**	**Time**	**Gap steps**	**Seq/Acq**	**Acq/Saq**	
17	2022-03-21	21:09	2022-03-22	05:40	On	Pre E off. 120s Pre Dark active.	12	1000	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12 Down Step 8 Down Step 7 Down Step 6 Down Step 2 Down Step 1	180 120 60 60 120 60 60 60 60	11	24	1	180
Folder path:	Data\Underway\19-0105-005 (LabSTAF)\2022-03-21 to 2022-03-22 AutoFLC with 120s Pre Dark														
Notes:	Same settings as Experiment 15 but PreE replaced with 120s Pre Dark.														

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	
18	2022-03-23	15:44	2022-03-23	19:06	On	Off	12	1400	80	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	24	1	180
Folder path:	Data\Underway\19-0105-005 (LabSTAF)\2022-03-23 AutoFLCs HighE=1400														
Notes:	Comparison study to compare AutoFLC on LabSTAF-005 and a fixed FLC protocol on LabSTAF-006. Starting protocol identical for LabSTAF-005, LabSTAF-006, and both AutoSTAFs. The FLC acquisition begun at the same time for the same sample in both LabSTAF-005 and 006, but AutoFLC was activated on LabSTAF-006 to document divergence in calculated PP parameters between a fixed FLC protocol (LabSTAF-006) and a variable AutoFLC protocol (LabSTAF-005).														

Experiment no.	Protocol start		Protocol end		Auto FLC on/off	FLC summary						STAF summary			Exchange time
						Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	
19	2022-03-23	19:34	2022-03-27	18:54	On	Off	12	1000	50	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12	180 120 60 60	11	24	1	240
Folder path:	Data\Underway\19-0105-005 (LabSTAF)\2022-03-23 to 2022-03-27 AutoFLCs HighE=1000														
Notes:	FLC protocol same as for AutoSTAF in ALR2 deployment 4 and LabSTAF-006, except with AutoFLC active. Push up reduced to 50 to decrease spacing between datapoints at low E values and improve resolution in this region. FLCs acquired by LabSTAF-006 and LabSTAF-005 have matched starting HighE values (1000), but LabSTAF-006 has AutoFLC active to compare directly to fixed FLC protocl. FLC files with highE=1000 identified by the suffix “HighE=1000 comparison start” in the filename after the timestamp. NOTE: clock on computer updated to BST. Files from 1am to 7am on 2022-03-27 have been renamed so the timestamped file name corresponds to the correct ship time, but internally the original BST time may be saved.														

Experiment no.	Protocol start	Protocol end	Auto FLC on/off	FLC summary						STAF summary			Exchange time
				Pre E	Steps	High E	Push Up	Steps	Time	Gap steps	Seq/Acq	Acq/Saq	

20	2022-03-27	20:19	2022-03-30	06:21	On	Off	12	1000	50	Up Step 1 Up Step 2 Up Steps 3 to 12 Dark Step 12 Down Step 8 Down Step 7 Down Step 6 Down Step 2 Down Step 1	180 120 60 60 120 60 60 60 60	11	24	1	240
Folder path:	Data\Underway\19-0105-005 (LabSTAF)\2022-03-27 to 2022-03-29 AutoFLC HighE1000 default Down steps														
Notes:	Up protocol and Dark protocol maintained but default Down Steps added in. This protocol also used by AutoSTAF-002 for underway samples on return journey to Southampton (Experiment 13).														

4.3.5 LabSTAF measurements of stainless steel CTD samples

LabSTAF-005

FLCs were acquired of samples from CTD casts throughout DY149 for two purposes:

- To correlate between ^{14}C primary production estimates and STAF-based primary production estimates on the same CTD samples;
- To corroborate AutoSTAF measurements acquired on ALR2 deployments *in situ* from the same depths.

LabSTAF-005 with the stir unit fitted was used for all CTD sample measurements. Samples were transferred to 50ml shot bottles immediately after collection from the CTD and stored in continuously flowing underway water in the sink with low light conditions until analysis. RunSTAF files acquired for CTD samples are at the location: **Data\CTDs_stainless_steel_all**.

CTD samples for corroboration of AutoSTAF

For comparison to AutoSTAF measurements from deployment, the CTD samples were run with the same FLC and STAF protocol as on the ALR2. This is referred to in Table 4.3 as **AutoSTAF** protocol and is listed below.

Pre E: 0s
Pre Dark: 0s

Step	**E**	**Time (s)**
1	0	180
2	16	120
3	37	60
4	65	60
5	101	60
6	150	60
7	213	60
8	297	60
9	408	60
10	554	60
11	746	60
12	1000	60
12 (dark)	0	60

CTD samples for correlation to 14C PP estimates

For comparison to 14C estimates the protocol was applied to match the conditions of the photosynthetron. This is referred to in Table 4.3 as **14-C** protocol and is listed below.

Pre E: 10 for 600s
Pre Dark: 0s

Step	**E**	**Time (s)**
1	0	180
2	26	120
3	59	60
4	104	60
5	162	60
6	239	60
7	341	60
8	475	60
9	652	60
10	886	60

11	1194	60
12	1600	60
12 (dark)	0	60

A complete listing of STAFES CTD samples follows.

CTD ID	Date	Lat.	Long.	Station	Depth (m)	Protocol
2	2022-03-16	49 30.547	07 30.522	W1	7	14-C
					30	14-C
5	2022-03-18	47 30.101	10 48.029	OS-A	20	14-C
6	2022-03-18	47 31.048	10 40.556	OS mid A-B	20	14-C
7	2022-03-19	47 31.411	10 33.653	OS-B	20	14-C
9	2022-03-20	47 30.012	10 33.006	OS-B	20	14-C
10	2022-03-20	47 30.136	10 36.635	OS-AB4	10	14-C
					20	14-C
					75	14-C
12	2022-03-21	47 30.000	10 44.400	OS-AB2	20	14-C
13	2022-03-22	47 30.265	10 33.041	OS-B	20	14-C
14	2022-03-23	49 12.197	8 15.218	T1	20	14-C
16	2022-03-24	49 12.010	8 14.987	T1	20	14-C
					20	AutoSTAF
					50	14-C
					50	AutoSTAF
17	2022-03-24	49 02.425	8 27.604	T2	20	14-C
					20	AutoSTAF
					50	AutoSTAF
18	2022-03-25	48 52.199	8 40.818	T3	20	14-C
					20	AutoSTAF
					50	AutoSTAF
20	2022-03-25	48 43.205	8 53.444	T4	20	14-C
					20	AutoSTAF
					50	AutoSTAF
21	2022-03-26	48 32.588	8 5.444	T5	20	14-C
					20	AutoSTAF
					50	AutoSTAF
22	2022-03-26	48 24.005	9 16.036	T6	20	14-C
					20	AutoSTAF
					50	AutoSTAF
23	2022-03-27	48 16.198	9 31.818	T7	20	14-C
					20	AutoSTAF
					50	AutoSTAF
25	2022-03-27	48 7.206	9 45.008	T8	20	AutoSTAF
					50	AutoSTAF
27	2022-03-28	48 0.000	10 0.018	T9	20	14-C
					20	AutoSTAF
					50	AutoSTAF
28	2022-03-28	47 54.008	10 15.030	T10	20	AutoSTAF
					50	AutoSTAF

Table 4.3: FLC data acquired on LabSTAF-005 of samples from CTD casts

4.3.6 Discrete underway samples for ^{14}C comparison

LabSTAF-005

FLCs were acquired of discrete, stirred samples of underway water to correlate between ^{14}C primary production estimates and STAF-based primary production estimates. Samples were collected from the underway sampling room at the same time for ^{14}C and LabSTAF analysis. LabSTAF-005 was used for all measurements.

The 14-C RunSTAF protocol (listed in the previous section) was used for analysis to match the conditions of the photosynthetron.

All RunSTAF datafiles for these discrete underway comparative samples are stored in the location: **STAFES\Data\C14_experiments\Underway_discrete_samples**

The following samples were analysed:

UW ID	Date	Time	FLC protocol
10	2022-03-17	18:00	14-C
28	2022-03-22	06:00	14-C
32	2022-03-23	06:00	14-C
36	2022-03-24	06:00	14-C
40	2022-03-25	06:00	14-C
42	2022-03-25	18:00	14-C
44	2022-03-26	06:00	14-C
48	2022-03-27	05:00	14-C
49B	2022-03-27	13:15	14-C
52	2022-03-28	06:00	14-C

Table 4.3: *Underway samples collected in association with CTD data*

Note: UW48 was sampled at 05:00 because the clocks changed. The file name has been edited to the ship time but the internal timestamp data stored in the RunSTAF file will still be BST.

4.3.6 LabSTAF analysis of trace metal CTD samples

LabSTAF-005

Samples from TM CTDs were analysed with the LabSTAF, primarily to obtain basic fluorescence parameters such as Fv/Fm, and secondarily for comparative primary productivity data. For these measurements, LabSTAF was run on manual mode to acquire PEPs and DWM measurements and then dark dual-pulse ST measurements obtained with 11 Gap steps, with Gap times from 200 to 6400 µs and 24 Seq/Acq. This protocol is referred to in Table 4.4 as ‘Basic’.

When a full FLC was run, the protocol used matched that of the AutoSTAF on deployment and is referred to as ‘AutoSTAF’. The STAF protocol was the same as in the Basic protocol, and the FLC parameters were:

Pre E: 0s
Pre Dark: 0s

Step	E	Time (s)
1	0	180
2	16	120
3	37	60
4	65	60
5	101	60
6	150	60
7	213	60
8	297	60
9	408	60
10	554	60
11	746	60
12	1000	60
12 (dark)	0	60

All RunSTAF files for these measurements can be found at the location: **Data\CTDs_trace_metal**.

The following samples were analysed:

CTD ID	Date	Lat.	Long.	Station	Depth (m)	Protocol
8	2022-03-16	47 30.811	10 33.708	OS-B	20	Basic
					30	Basic
					50	Basic
					100	Basic
					150	Basic
11	2022-03-18	47 30.140	10 36.630	OS-AB4	20	Basic
					30	Basic
					50	Basic
					100	Basic
					150	Basic
19	2022-03-18	48 43.204	8 53.444	T4	10	AutoSTAF
					20	AutoSTAF
					50	AutoSTAF
24	2022-03-19	48 7.206	9 45.008	T8	20	AutoSTAF
					30	AutoSTAF
					50	AutoSTAF

Table 4.4: *Trace metal CTD samples*

4.3.7 Troubleshooting

Instrument cross comparisons between LabSTAF-005, AutoSTAF-001, AutoSTAF-002

To diagnose the origin of the bad FLC dataset acquired by AutoSTAF during ALR2 deployments, matching discrete samples were analysed with multiple instruments at the same time with the same protocol, to identify any instrument error, software error, or other issues.

These cross-comparison datafiles are stored in Data\Instrument_cross_comparisons.

No instrument or software-based issues were identified during these tests.

Other testing

During this troubleshooting, tests were also run with:

- Empty sample chamber
- MilliQ
- Power cycling
- Analysing the same discrete sample overnight, to determine if pump failure could be causing the bad FLC dataset from the ALR2
- Testing for scatter and filter breakthrough with milk in the sample chamber

These files are stored in: **STAFES\Data\Testing_AutoSTAF** and **STAFES\Data\Testing_LabSTAF**.

4.4 ^{14}C- uptake experiments

Single-turnover active fluorometry (STAF) measurements can provide estimates phytoplankton photosynthetic activity which are directly related to rates of primary production. To allow conversion of electron transport in photosystem II - the rate derived at high resolution and autonomously from STAF instruments - to ecologically more relevant rates of carbon fixation, parallel measurements of STAF and ^{14}C-uptake are required. Large datasets of such parallel measurements will be needed to characterize and constrain the conversion factor between the two rates.

During DY149 a range of parallel measurements of STAF and ^{14}C-uptake were acquired. In particular, the cruise provided the opportunity to perform ^{14}C-uptake measurements directly in the sampling chamber of two LabSTAF instruments. This approach minimizes the apparent decoupling of the two rates which is due to methodological bias (e.g. difference in light sources or incubation time used), which in past experiments has proven difficult to distinguish from true physiological effects.

The experimental approaches used for ^{14}C-uptake experiments performed during DY149 are described in more detail below.

4.4.1 Productivity vs Light (PE) curves

PE curves of ^{14}C-uptake were measured in a custom-built incubator holding 12 60 mL polycarbonate bottles, cooled by water from the continuous seawater supply. Each of the 60 mL polycarbonate bottles was rinsed three times with sample water then filled to the shoulder in a low-light environment. Each bottle was spiked 10 µCi ^{14}C sodium bicarbonate solution (100 µl of stock solution) and incubated in a light gradient provided by white LEDs for 2 hours. A single dark bottle was also placed in the incubator to measure ^{14}C incorporation in the dark.

Total activity in the incubation bottles were determined from 100 µL of spiked sample pipetted into scintillation vials containing 500 uL 0.1M NaOH. Carbon fixation in the incubation bottles was determined by filtering the sample through 25 mm GF/F filters and placing the filters into scintillation vials containing 500 uL 2M HCl over night under a fume hood. 5 mL scintillation cocktail (Ultima Gold) were added to each scintillation vials and counts obtained by the shipboard liquid scintillation counter in disintegrations per minute (DPM).

PE curves were measured at 21 sampling points throughout DY149 (Table 4.5). A STAF based PE curve (FLC) was run on the same sample each time.

cruise	*year*	*month*	*day*	*hour*	*minute*	*station*	*CTD*	*UW*	*depths*	*Lat*	*Long*
DY149	2022	3	16	15	40	W1	2		7	49,5286	-7,5091
DY149	2022	3	17	18	0		uw	10	7	47,4994	-10,7669
DY149	2022	3	18	19	15	OS_A	5		20	47,5175	-10,6002
DY149	2022	3	18	18	10	Osmid A+B	6		20	47,5174	-10,6759
DY149	2022	3	19	10	10	OS_B	7		20	47,5235	-10,5609
DY149	2022	3	20	10	55	OS_B	9		20	47,5001	-10,5501
DY149	2022	3	20	16	40	OS_AB4	10		20	47,5023	-10,6106
DY149	2022	3	21	18	30	OS_AB2	12		20	47,5000	-10,7401
DY149	2022	3	22	6	0		uw	28	7	47,5044	-10,5507
DY149	2022	3	22	9	50	OS_B	13		20	47,5044	-10,5507
DY149	2022	3	23	6	0		uw	32	7	49,2028	-8,2436
DY149	2022	3	23	9	40	T1	14		20	49,2003	-8,2514
DY149	2022	3	24	6	0		uw	36	7	49,2058	-8,2467
DY149	2022	3	24	9	11	T1	16		20	49,2002	-8,2498
DY149	2022	3	25	6	0		uw	40	7	48,8700	-8,6803
DY149	2022	3	25	12	40	T4	20		20	48,7201	-8,8907
DY149	2022	3	26	6	0		uw	44	7	48,5490	-9,1006
DY149	2022	3	26	9	10	T5	21		20	48,5432	-9,0907
DY149	2022	3	27	5	0		uw	48	7	48,2684	-9,5317
DY149	2022	3	27	7	30		23		20	48,2700	-9,5303
DY149	2022	3	28	6	0		uw	52	7	48,0000	-10,0003

Table 4.5: *Sampling points for ^{14}C-uptake vs light (PE) curves during DY149.*

4.4.2 ‘RAD-STAF’ ^{14}C incubation

In parallel with each PE curve, ^{14}C-uptake experiments were performed directly in two LabSTAF instruments (serial numbers 008 and 004). Samples were inserted into the LabSTAF sampling chamber inside a 24 mL scintillation vial surrounded by MQ water and held in place by a custom-made sample chamber cap. A blank of 0.2µm filtrate was first run on each instrument. Then, unspiked samples were exposed to a sampling protocol to determine a photosynthetic excitation profile (PEP), dual wavelengths correction (DWC) factor, and single-turnover parameter in the dark-regulated state. After this ‘dark acquisition’, the samples were spiked with 20-30 µCi ^{14}C sodium bicarbonate solution and incubated with background irradiances switched on to determine single-turnover parameters in the light-regulated state. Light intensities were selected to be below light saturation (30 or 50 µmol quanta m^{-2} s^{-1}) in one instrument and above light saturation (200 or 300 µmol quanta m^{-2} s^{-1}) in the other instrument. One additional vial was spiked and incubated in the dark. Incubation times were either 3 time-points (0,5 hr, 1 hr, 2 hr) or 2 hr only. Carbon fixation was determined by filtering sample (7 – 10 mL) onto 25mm GF/F filter and placing the filter into a scintillation vial containing 500 µL 2M HCl over night to remove all inorganic carbon. Total ^{14}C spike in each incubation vial was determined from triplicate 100 µL aliquots pipetted into scintillation vials containing 500 µL 0.1M NaOH. 5 mL scintillation cocktail (Ultima Gold) were added to each scintillation vials and counts obtained by the shipboard liquid scintillation counter in disintegrations per minute (DPM).

In addition, ^{14}C-uptake experiments within the LabSTAF instruments were performed on samples taken from the continuous seawater supply at three hour intervals over a diurnal cycle on 21 March. Here, the incubation light level in one instrument was kept constant at 50 µmol quanta m^{-2} s^{-1}, while the light level in the second instrument was set to the estimated light intensity experienced by phytoplankton at the time and depths of sampling. In total, 54 ^{14}C-incubations within LabSTAF instruments were performed of which approximately half were at sub-saturating and saturating light intensities.

cruise	***year***	***month***	***day***	***hour***	***minute***	***station***	***CTD***	***UW***	***depths***	***Lat***	***Long***	***light level (uE m-2 s-1)***		***incubation time (hr)***		
												A	***B***	***A***	***B***	***C***
DY149	2022	3	15	18	0		uw	2	7	49,5221	-7,3944	50	200	0,5	1	1,5
DY149	2022	3	16	15	40	W1	2		7	49,5286	-7,5091	50	300	1	2	4
DY149	2022	3	17	18	0		uw	10	7	47,4994	-10,7669	50	300	0,5	1	2
DY149	2022	3	18	19	15	OS_A	5		20	47,5175	-10,6002	50	300	0,5	1	2
DY149	2022	3	18	18	10	Osmid A+B	6		20	47,5174	-10,6759	50	300	0,5	1	2
DY149	2022	3	19	10	10	OS_B	7		20	47,5235	-10,5609	50	300	0,5	1	2
DY149	2022	3	20	10	55	OS_B	9		20	47,5001	-10,5501	50	300	0,5	1	2
DY149	2022	3	20	16	40	OS_AB4	10		20	47,5023	-10,6106	50	300	0,5	1	2
DY149	2022	3	21	6	0		uw	24	7	47,5171	-10,5518	50				2
DY149	2022	3	21	9	0		uw		7	47,4935	-10,5740	50	20			2
DY149	2022	3	21	12	0		uw	25	7	47,4998	-10,5941	50	330			2
DY149	2022	3	21	15	0		uw		7	47,5001	-10,7400	50	300			2
DY149	2022	3	21	18	0		uw	26	7	47,5000	-10,7401	50	100			2
DY149	2022	3	21	21	0		uw		7	47,5069	-10,7905	50				2
DY149	2022	3	22	6	0		uw	28	7	47,5044	-10,5507	30	200			2
DY149	2022	3	22	9	50	OS_B	13		20	47,5044	-10,5507	50	300			2
DY149	2022	3	23	6	0		uw	32	7	49,2028	-8,2436	30	200			2
DY149	2022	3	23	9	40	T1	14		20	49,2003	-8,2514	50	300			2
DY149	2022	3	24	6	0		uw	36	7	49,2058	-8,2467	30	200			2
DY149	2022	3	24	9	11	T1	16		20	49,2002	-8,2498	50	300			2
DY149	2022	3	25	6	0		uw	40	7	48,8700	-8,6803	30	200			2
DY149	2022	3	25	12	40	T4	20		20	48,7201	-8,8907	50	300			2
DY149	2022	3	26	6	0		uw	44	7	48,5490	-9,1006	30	200			2
DY149	2022	3	26	9	10	T5	21		20	48,5432	-9,09074	50	300			2
DY149	2022	3	27	5	0		uw	48	7	48,2684	-9,5317	30	200			2
DY149	2022	3	27	7	30		23		20	48,27	-9,53031	50	300			2
DY149	2022	3	28	6	0		uw	52	7	48	-10,0003	30	200			2

Table 4.6: *Sampling points, incubation light levels and incubation times for ^{14}C-uptake experiments performed within the LabSTAF sampling chamber during DY149.*

4.4.3 ‘RAD-STAF’ ^{14}C incubation PE curves and FLCs

Two kinds of additional experiments were run at two sampling points each:

At uw 42 and ctd 22 entire PE curves were run as ^{14}C-incubations in the LabSTAF instruments. Samples were inserted into the LabSTAF sampling chamber inside a 24 mL scintillation vial surrounded by MQ water and held in place by a custom-made sample chamber cap. A blank of 0.2 µm filtrate was first run on each instrument. Then, unspiked sample were exposed to a sampling protocol to determine a photosynthetic excitation profile (PEP), dual wavelengths correction (DWC) factor, and single-turnover parameter in the dark-regulated state. After this 'dark acquisition', the samples were spiked with 30 µCi ^{14}C sodium bicarbonate solution and incubated with background irradiances switched on to determine single-turnover parameters in the light-regulated state. Light levels were 600, 300, 200, 100, 50, 30 µmol quanta m^{-2} s^{-1} and incubation time was 30 min each. Incubations were run staggered on both instruments, starting with the highest irradiance. Samples not processed immediately were kept at low light and sea surface temperature for a maximum duration of 2 hr after initial sample collection. One additional vial was spiked and incubated in the dark and an additional unspiked sample was run without background irradiance after the ^{14}C incubations. Carbon fixation was determined by filtering sample (2 x 10 mL) onto 25 mm GF/F filter and placing the filter into a scintillation vial containing 500 µL 2M HCl over night to remove all inorganic carbon. Total ^{14}C spike in each incubation vial was determined from triplicate 100 µL aliquots pipetted into scintillation vials containing 500 µL 0.1M NaOH. 5 mL scintillation cocktail (Ultima Gold) were added to each scintillation vials and counts obtained by the shipboard liquid scintillation counter in disintegrations per minute (DPM).

At uw 49b and ctd 27 entire fluorescence light curves (FLC) were run on 23 mL samples spiked with 30µCi ^{14}C. Samples were filtered (2 x 10 mL) immediately after the FLC protocol finished. Samples were processed as described for samples above.

cruise	*year*	*month*	*day*	*hour*	*minute*	*station*	*CTD*	*UW*	*depths*	*Lat*	*Long*	*experiment*
DY149	2022	3	25	18	0		uw	42	7	48,7902	-8,8114	7 light-level PE run with 14C in LabSTAF
DY149	2022	3	26	16	40	T6	22		20	48,4001	-9,3006	7 light-level PE run with 14C in LabSTAF
DY150	2022	3	27	13	15	T7	uw	49b	7	48,1372	-9,7241	FLC with 14C in LabSTAF
DY149	2022	3	28	12	0		uw	53	7	47,9002	-10,2505	FLC with 14C in LabSTAF

Table 4.7: *Sampling points and experiment kind performed in addition to 'standard' ^{14}C-uptake experiments during DY149.*

5. Autonomous vehicle Nutrient Sensors (AutoNutS) Project

Matt Patey, Rudi Hanz, Patricia López-García (NOC)

5.1 Overview

Targeting nutrients, one of the two highest scientific priorities for chemical measurement in ocean waters, this project has optimised the performance of existing NOC sensor technology to produce six new operational devices for measuring macro and micronutrients. The data gathered using these sensors will be crucial to advancing our knowledge of how marine ecosystems work, how productive they are and how they respond to a changing climate, exploitation and ecosystem management. These 'lab-on-chip' miniaturised laboratories are able to perform seawater chemical analysis using small amounts of seawater samples and chemical reagents to help create more complete low-cost ocean chemistry datasets.
The project has developed sensors that can be deployed on the National Marine Equipment Pool Autonomy fleet for Phosphate, Silicate and Iron to TRL (Technology Readiness Level) 7 (i.e. mature and doing science) and created new sensors for ammonia (TRL5: prototype in simulated environment). This builds on the existing mature Nitrate/Nitrite sensors (TRL9) enabling a very comprehensive measurement of nutrients and micronutrients on autonomous vehicles or in low infrastructure settings.

5.2 Autonuts Lab on Chip Sensors on ALR, CTD and Underway System

Matt Patey, Rudi Hanz (NOC)

Equipment Description

The Autonuts project deployed several nutrient chemistry lab-on-chip (LOC) sensors. Developed and built by the Ocean Technology and Engineering Group at the National Oceanography Centre, these in-situ devices autonomously measure a single chemical parameter. The devices are attached to a series of reagents and standards allowing laboratory-like methods and calibration. Pumps and valves move reagents, standards and seawater through microfluidic channels and mixers before being colourimetrically (Nitrate, Nitrite, Phosphate, Silicate) or flourometrically (Ammonia) analysed.

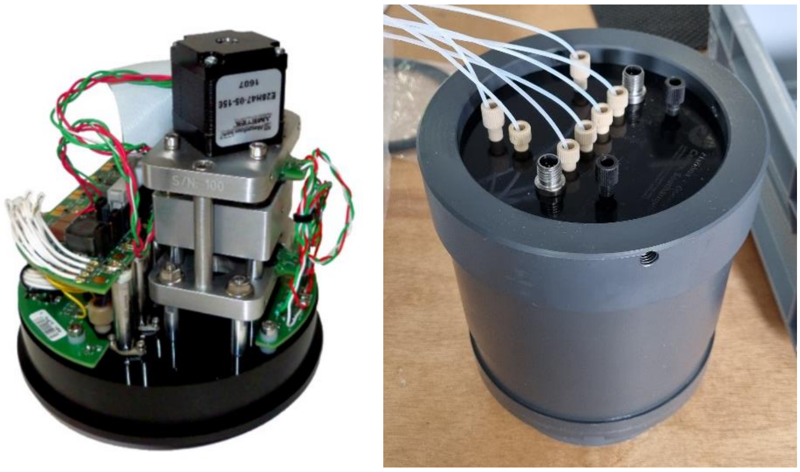


***Figure 5.1:** 1- LOC sensor out of (Left) and inside (Right) a housing*

Parameter	Number	Serial Numbers
Ammonia	1	7
Nitrate + Nitrite	4	84, 97, 110, 115
Phosphate	3	57, 58, 65
Iron	2	10, 13
Silicate	3	2, 9, 12

***Table 5.1:** 13 nutrient sensors were brought on this cruise.*

ALR AutoNutS configuration during DY149

The Autonuts sensors were housed in the front section of the Autosub Long Range (ALR). One sensor of Iron, Nitrate, Nitrite and Phosphate and two of silicate were mounted to a tray. A cage was mounted above to allow for the securing of Sartorius Flexboy bags. In order to provide fresh seawater to the sensors, a Seabird SBE-5T pump was used to pump seawater through a manifold. The pump was mounted after the manifold to not contaminate the water prior to sampling. For further information regarding the mechanical and electrical systems see the ALR and Integration section.

Seawater used for analysis by the sensors was filtered through a 0.45 µm filter.

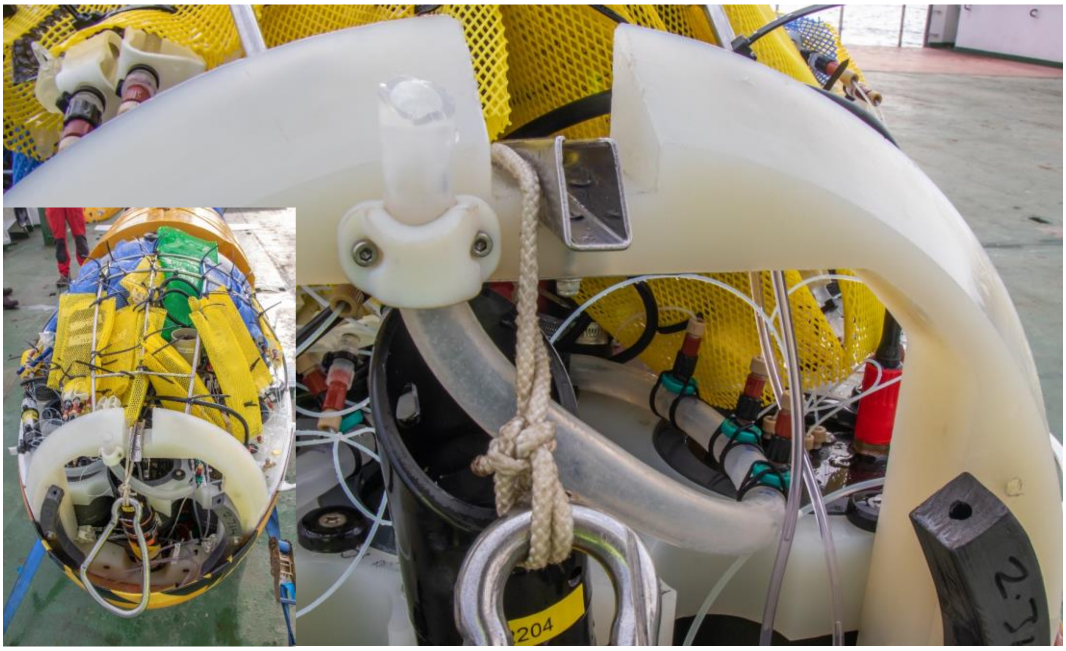


Figure 5.2: *Sampling manifold for Autonuts. Inlet is in the top centre and SBE-5T pump and outlet is to the left of the image. Insert: Installation of Autonuts sensors in front of ALR.*

ALR Mission	Fe	NO_3 + NO_2	NO_2	PO_4	Si (9)	Si (12)
55	ALR Test Mission					
56	ALR Test Mission					
57	X	X	X	X	X	X
58						
59		X	X	X*	X*	X*
60						
61						
62	X	X	X	X	X	X
63	X	X	X	X	X	X
64			X	X*	X*	X*
65					X*	X
66	X	X		X	X	X
67	X	X		X	X	X
68	X	X	X	X	X	X
69		X	X	X	X	X
70	X	X	X	X	X	
71	X	X	X	X	X	X
72	X	X	X	X	X	X
73	X	X	X	X	X	X
74	X	X	X	X	X	X
75	X	X	X	X	X	X

Table 5.2: *Times sensors successfully ran on the Autosub Long Range. Asterisk indicates that the sensor run was not long enough (or it stopped shortly after starting) and no samples were measured for this leg*

CTD Integration

When running on the CTD, the sensors were clipped in via a standard CTD bracket. Depending on power availability, power was supplied either by a 15V supply from the CTD electronics or a battery housing to an Oceanids hub. This in turn supplied power to the sensor.

Figure 5.3: *On the left, sensors battery powered, on the right, sensors powered from the Oceanids hub.*

The sensors ran a modified state machine which ran fewer standards but more samples due to the much faster speed of the CTD rosette relative to the sensors. Extended stops were also incorporated in particularly interesting parts of the water column. These extended stops also included CTD bottle firings which will be later analysed onshore. See section *Dissolved Inorganic Nutrients Analysis for Sensor Validation* for detailed sampling methodology for these samples.

Underway sampling

Underway measurements were collected in the underway system in the chemistry laboratory. The AutoNutS sensors used for underway measurements were the NOCS Nitrate+Nitrite, Nitrite, Phosphate, Silicate and Ammonia. The sensors were connected to the ships underway system via a custom made underway device that had connecting filters fitted at the bottom and a water feed from the top to avoid problems with air bubbles entering the chemical sensors, as shown in Figure 5.5. This system worked well throughout the cruise. Samples for validation were also collected three times a day, 6.00 am, 12.00 pm and 6.00 pm, from the same underway system.

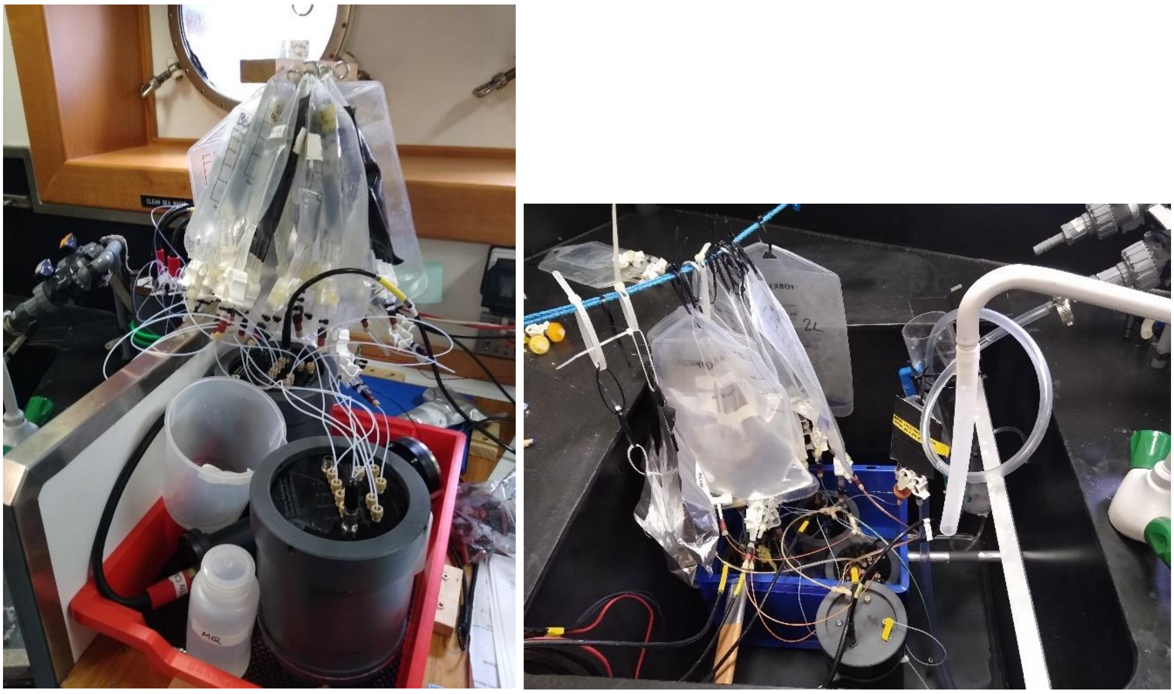


Figure 5.4: *Setting the sensors in the underway system.*

Nutrient Sampling

In order to monitor contamination, faults in the production and any drift in the concentration, at least one sample of all the blanks and standards were taken during the cruise. See section *Dissolved Inorganic Nutrients Analysis for Sensor Validation* for methodology.

During and adjacent to the ALR missions, CTD deployments took place. After shore-based analysis of these samples, the results will be used to validate the nutrient measurements made by the NOC LOC sensors.

Underway samples were also collected.

5.3 Sensors performance and preliminary results

Ammonia

A prototype ammonia sensor was brought on board to measure samples from the ship’s underway system. This sensor is based on the NOC LOC platform but uses a fluorometric detector and incorporates the OPA assay.

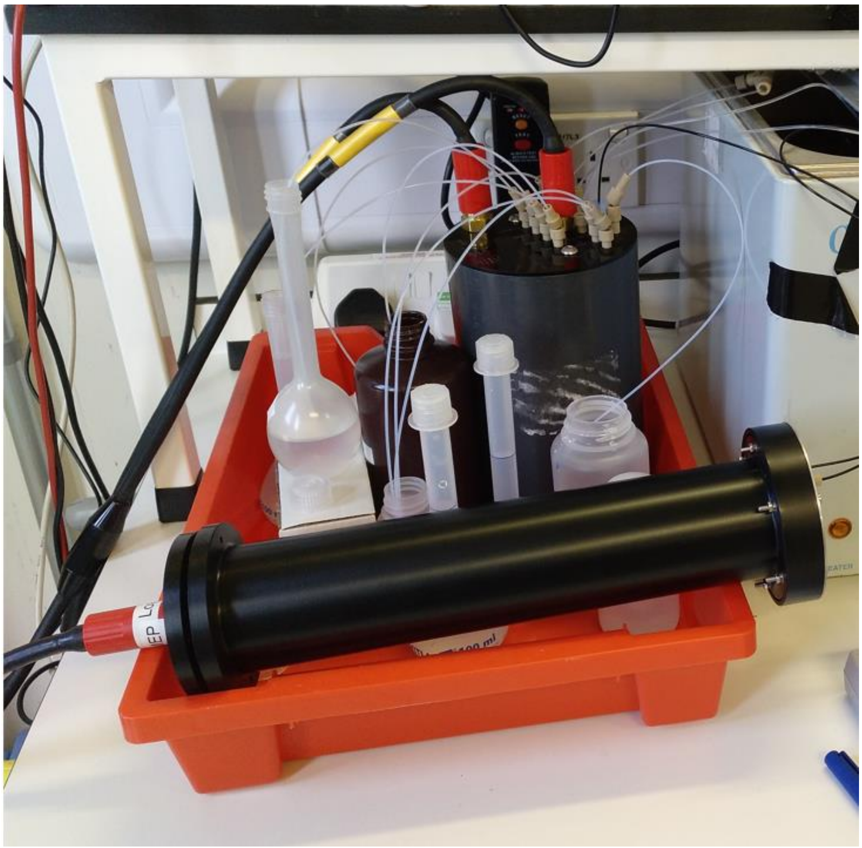


Figure 5.5: *Ammonia sensor used to sample underway during DY149*

Discrete samples were taken from both the underway and CTD profiles to verify the ammonia sensor. These were analysed on board according to the protocol described by Holmes et al. (1999) using a portable Trilogy Fluorometer. Standard additions were prepared in deep seawater collected during the cruise (1000 m) in order to match the matrix of the samples and standards.

Ammonia concentrations were extremely low throughout most of the cruise (< 20 nmol / L), which was challenging to measure using the experimental sensor. In addition, the sensor uses a gas diffusion membrane to extract the ammonia from the seawater samples, thus eliminating matrix effects and some interferences and some problems were encountered with this membrane which led to a loss of precision and sensitivity. During the last 2 days of the cruise it was decided to remove the membrane and mix the sample directly with the OPA reagent. Ammonia levels also increased slightly during this time, so some useful data was collected to examine the performance of the instrument. Data analysis will be done after the cruise. An example of an ammonia profile from late in the cruise is shown below (measured by manual analysis).

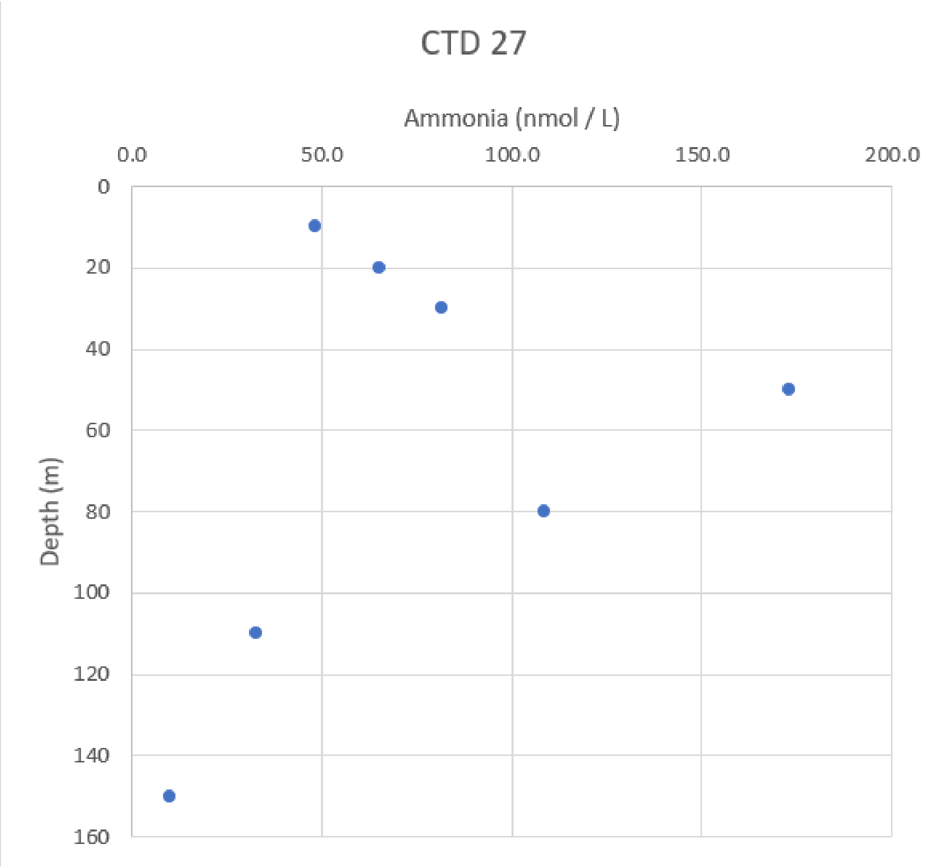


Figure 5.6: *Example profile of ammonia concentration from CTD 27. Measured by standard benchtop analysis.*

Nitrate + Nitrite (NO_3+NO_2) Sensor

The nitrate and nitrite (referred to as nitrate) sensor works using the colorimetric measurement of nitrite with the Griess assay (Beton et al.). The sample and Imidazole buffer (pH 7.8) is mixed and passed through an external cadmium column where nitrate is reduced into nitrite. The blank and 10 µM potassium nitrate standard was prepared prior to the cruise with artificial sea water (35 g/L sodium chloride and 0.5 g/L sodium hydrogen carbonate) and preserved with 0.1% chloroform. For this location the sensor's long measurement channel (~10 cm) was used rather than the medium (~1 cm) or short (~0.1 cm) channel.

This sensor was installed on the ALR, one CTD to 3000m and for several days on the underway system. The nitrate sensor was able to successfully measure during many of the ALR missions, the CTD and the underway. On the ALR sensor, after the 25th of March (Mission 70), an optical or fluidic blockage was seen in the raw data. This dramatically altered the range of the sensor. Further analysis and troubleshooting on shore will be required to determine the quality of the later nitrate measurements and the repairs necessary.

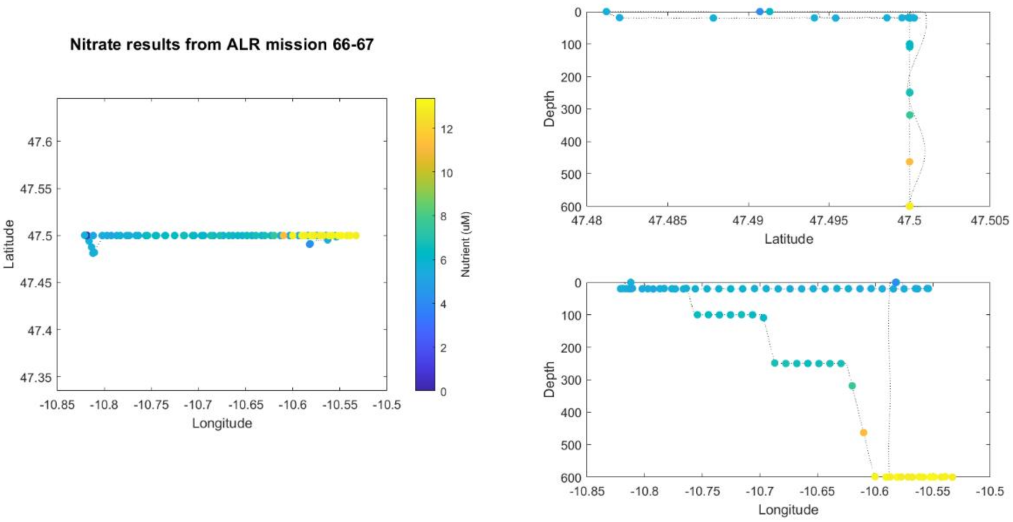


Figure 5.7: *Nitrate values during ALR Mission 66 and 67 off the shelf following a "Staircase" profile*

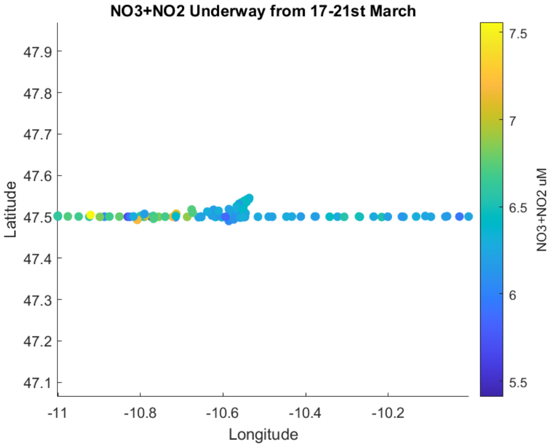


Figure 5.8: *Surface nitrate results while transecting the off shelf location*

Nitrite (NO_2) Sensor

The nitrite sensor operates following the same methodology as the Nitrate + Nitrite sensor but without a cadmium column and imidazole buffer. Due to the lower concentration of nitrite in seawater only a 1 µM sodium nitrite standard was used.

This sensor was only installed on the ALR. While at low concentrations for most of the missions, there were measurable concentrations for much of the time. There is some indication of degradation of the standard which we hope to rectify by benchtop analysis of the standard when back in Southampton.

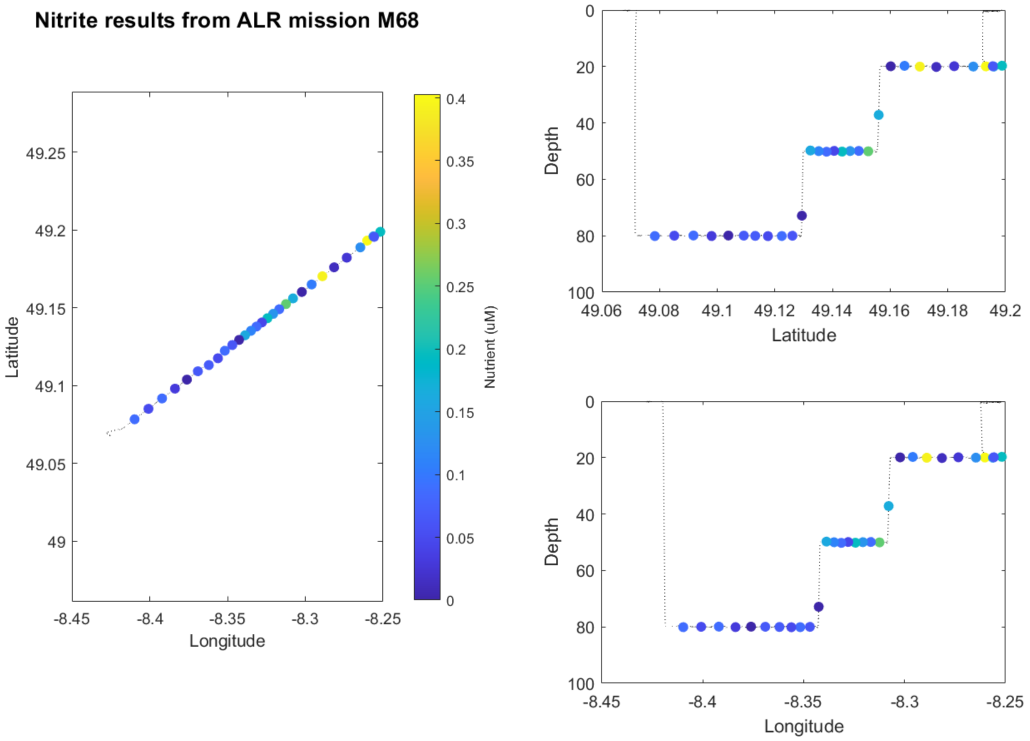


Figure 5.9: *Nitrate results from a shallow staircase mission (No 68)*

Ferrozine Iron Sensor

The iron sensor uses the colorimetric determination of iron with ferrozine to determine iron concentrations through an approximately 10 cm long measurement channel. Two standards, 5 and 20 nM Fe^{+3} calibrate the sensor. The ferrozine based iron sensor was not able to measure the iron concentrations in this part of the ocean.

Phosphate Sensor

The phosphate sensor uses a modified version of the Molybdenum Blue assay to measure soluble reactive phosphate (Clinton-Bailey et al., 2017). Phosphate sensors were deployed in the ALR (on all dives), on the CTD (profile 13 – to 1000 m), and on the underway supply (between 17th and 22nd March). A phosphate sensor was included on the CTD for profile 28, but unfortunately stopped measuring about 60 seconds into its measurement cycle and so no data was collected.

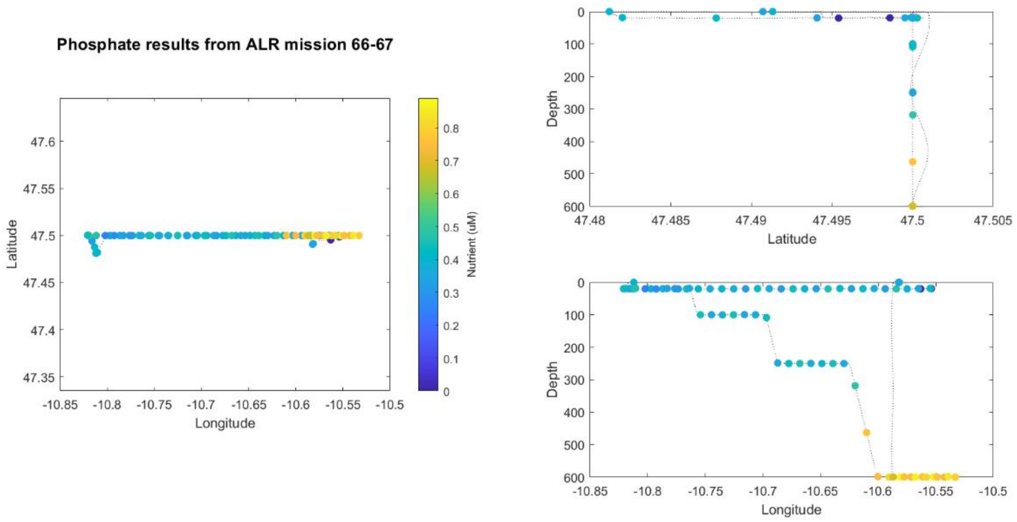


__Figure 5.10:__ Example of phosphate results from the ALR - a deep staircase mission (no 66-67)

The phosphate is calibrated by a sequence of two external standards. For this cruise standard concentration used was 1 and 3 µmol / L. With the ALR and underway measurements, an alternating measurement sequence was used to increase the sampling frequency where every other measurement was of a sample, with a single calibration solution solution being measured in between sample measurements, cycling between the blank solution, the lower standard and the higher standard.

Some carry over from the higher standard solutions to the sample solutions is noticeable in the sample measurements (ie. a clear pattern is apparent of sample concentrations varying by the concentration of the preceding standard solution). This pattern is very regular and it should be possible to correct for this interference.

When deploying on the CTD, the sensor was configured to run some calibration solutions on the descent and then measure only samples as the CTD ascends. Since more calibration of sample measurements is preferable, the sensor was immediately removed from the rosette once it was back on deck and it was immersed in a bath of continuously running seawater from the underway system (to maintain a stable temperature as far as possible) while further calibration solutions were measured.

Silicate Sensor

The silicate sensor uses a version of the Molybdenum Blue assay to measure dissolved silica (Clinton-Bailey et al., 2019). Two silicate sensors were deployed in the ALR (on all dives), on the CTD (profiles 10, 13 and 28), and on the underway supply (between 17th and 22nd March).

As with the phosphate sensor, clear carry over is noticeable in the data and will be corrected for after measurements have been made back in the laboratory.

References

A. D. Beaton et al., “Lab-on-Chip Measurement of Nitrate and Nitrite for In Situ Analysis of Natural Waters,” Environ. Sci. Technol., vol. 46, no. 17, pp. 9548–9556, Sep. 2012.

Clinton-Bailey, Geraldine S., Maxime M. Grand, Alexander D. Beaton, Adrian M. Nightingale, David R. Owsianka, Gregory J. Slavik, Douglas P. Connelly, Christopher L. Cardwell, and Matthew C. Mowlem. 2017. 'A Lab-on-Chip Analyzer for in Situ Measurement of Soluble Reactive Phosphate: Improved Phosphate Blue Assay and Application to Fluvial Monitoring'. Environmental Science & Technology 51 (17): 9989–95. https://doi.org/10.1021/acs.est.7b01581.

Clinton-Bailey, Geraldine S., Alexander D. Beaton, Matthew D. Patey, Emily L. Davey, Sara E. Fowell, Adrian P. Martin, Sheri N. White, Antony Birchill J., and Matthew C. Mowlem. 2019. '"Lab-on-Chip" Sensor for in Situ Determination of Silicate in Natural Waters'. In . Barcelona, Spain. https://goldschmidt.info/2019/abstracts/abstractView?id=2019004010.

Holmes, Robert M, Alain Aminot, Roger Kérouel, Bethanie A Hooker, and Bruce J Peterson. 1999. 'A Simple and Precise Method for Measuring Ammonium in Marine and Freshwater Ecosystems'. Canadian Journal of Fisheries and Aquatic Sciences 56 (10): 1801–8. https://doi.org/10.1139/f99-128.

5.4 Dissolved Inorganic Nutrients analysis for sensor validation: CTD rosette, underway system and STD samples.

Patricia López García, Rudolf Hanz, Matthew Patey (NOC)

5.4.1 OBJECTIVES:

- To investigate the spatial and temporal variations of the micromolar nutrient (nitrate, nitrite, phosphate, silicate and ammonia).
- Validate AutoNutS sensors: ammonia, nitrate+nitrite, nitrite, phosphate, silicate.

5.4.2 SAMPLING and ANALYTICAL METHODOLOGY:

Sample preparation and procedure
Samples were taken from the stainless-steel Sea-Bird CTD systems on-board the RRS Discovery.

50 mL acid clean (10% HCl) falcon tubes were used to collect duplicate samples from the CTD rosette and Underway system. Ammonia was analysed the same day, samples were kept in the fridge at 5 C.

Nutrient analysis for nitrate, nitrite, phosphate and silicate will be carried out at NOC so samples are kept at -20 C until then.

Lab on Chip Standard Samples
Prior to use and after the cruise, samples of all the blanks and standards used by the sensors were taken directly from the reagent bags they were stored in. 15 mL acid clean (10% HCl) falcon tubes were used to store the samples. Nutrient analysis for nitrate, nitrite, phosphate and silicate will be carried out at NOC so samples are kept at -20 C until then.

Sample Analysis

Ammonia analysis was carried out using the protocol described by Holmes et al. (1999) as described above.

As we mentioned previously, the rest of the inorganic nutrients will be analysed at NOC after the cruise. A SEAL AutoAnalyzer3 High Resolution (AA3HR) will be used (Aminot et al., 2009; Nagul et al., 2015; Grasshoff, k. 1976):

- Nitrate+nitrite: Nitrate is reduced to nitrite at pH 8 in a copperized cadmium reduction coil. The nitrite reduced from nitrate plus any nitrite react under acidic conditions with sulfanilamide to form a diazo compound that then couples with N-1-naphthylethylenediamine dihydrochloride (NEDD) to form a reddish-purple azo dye measured at 520 nm.
- Phosphate: Determination of phosphate is based on the colorimetric method in which a blue color is formed by the reaction of phosphate, molybdate ion and antimony ion followed by reduction with ascorbic acid. The reduced blue phospho-molybdenum complex is read at 880 nm.
- Silicate: Determination of soluble silicates is based on the reduction of a silicomolybdate complex in acid solution to molybdenum blue by ascorbic acid. For silicate, oxalic acid is added to minimize interference from phosphate. The absorbance is measured at 820 nm.

References:

Aminot, A.; Kerouel, R.; Coverly Stephen. Nutrients in Seawater Using Segmented Flow Analysis. n book: Practical Guidelines for the Analysis of SeawaterChapter: Nutrients in seawater using segmented flow analysis. Publisher: Taylor & FrancisEditors: Wurl.

Grasshoff K., 1976. Methods of seawater analysis. Verlag Chemie, Weinheim and New York, 317pp.

Nagul, E. A., McKelvie, I. D., Worsfold, P., & Kolev, S. D. (2015). The molybdenum blue reaction for the determination of orthophosphate revisited: Opening the black box. *Analytica chimica acta*, *890*, 60–82. https://doi.org/10.1016/j.aca.2015.07.030

Holmes, Robert M, Alain Aminot, Roger Kérouel, Bethanie A Hooker, and Bruce J Peterson. 1999. 'A Simple and Precise Method for Measuring Ammonium in Marine and Freshwater Ecosystems'. Canadian Journal of Fisheries and Aquatic Sciences 56 (10): 1801–8. https://doi.org/10.1139/f99-128.

CTD Samples

Date	CTD	Event	Position	CTD bottle collected
16/3/22	2	W1	49 31.71N 07 30.55W	Bottles 1, 5, 9, 13, 17, 21 (depths: 100, 75, 50, 30, 10, 7 m)
18/3/22	5	OS-A	47 30.00N 10 48.03W	Bottles 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 75, 50, 30, 20, 10 m)*

18/3/22	6	MID-AB	47 31.05N 10 40.56W	Bottles 1, 3, 6, 7, 9, 11, 13, 15, 17, 19, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 75, 50, 30, 20, 10 m)*
19/3/22	7	OS-B	47 31.41N 10 33.65W	Bottles 1, 3, 6, 7, 9, 11, 13, 15, 18, 19, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 75, 50, 30, 20, 10 m)*
20/3/22	9	OS-B	47 30.01N 10 33.01W	Bottles 1, 3, 6, 7, 9, 11, 13, 15, 18, 19, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 75, 50, 30, 20, 10 m)*
20/3/22	10	OS-AB4	47 30.13N 10 36.63W	Bottles 1, 3, 6, 7, 9, 11, 13, 15, 18, 19, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 75, 50, 30, 20, 10 m)*
21/2/22	12	OS-AB-2	47 30.00N 10 44.40W	Bottles 1, 3, 6, 7, 9, 11, 13, 15, 18, 19, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 75, 50, 30, 20, 10 m)*
22/3/22	13	OS-B	47 30.27N 10 33.04W	Bottles 1, 3, 6, 7, 9, 11, 13, 15, 18, 19, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 75, 50, 30, 20, 10 m)*
23/3/22	14	T1	49 12.02N 08 15.08W	Bottles 1, 5, 9, 13, 17, 21 (depths: 100, 75, 50, 30, 20, 10 m)
24/3/22	16	T1	49 12.01N 08 14.99W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
24/3/22	17	T2	49 02.43N 08 27.61W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
25/3/22	18	T3	48 52.20N 08 40.82W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
25/3/22	20	T4	48 43.20N 08 53.44W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
26/3/22	21	T5	48 32.59N 09 05.44W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
26/3/22	22	T6	48 24.01N 09 18.04W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
27/3/22	23	T7	48 16.20N 9 31.82W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
27/3/22	25	T8	48 07.21N 09 45.01W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
28/3/22	27	T9	48N 10 0.018W	Bottles 1, 3, 5, 6, 7, 8, 9, 10, 12, 13, 17, 19, 21, 23 (depths: 1500, 1200, 800, 600, 500, 400, 250, 150, 110, 80, 50, 30, 20, 10 m)

28/3/22	28	T10	47 54.01N 10 15.03W	Bottles 1, 3, 4, 6, 8, 10, 12, 15, 19, 21, 23 (depths: 3000, 2000, 1000, 500, 250, 150, 100, 80, 50, 30, 20, 10 m)

**Ammonia samples only in the first 400 m.*

Underway Samples

Sample number	**Date**	**Time**	**Nutrient bottle (duplicated)**
1	19/03/2022	12:00	U14
2	19/03/2022	18:00	U15
3	20/03/2022	06:00	U16
4	20/03/2022	12:00	U17
5	20/03/2022	18:00	U18
6	21/03/2022	06:00	U19
7	21/03/2022	12:00	U20
8	21/03/2022	18:00	U21
9	22/03/2022	12:00	U22
10	22/03/2022	18:00	U23
11	23/03/2022	06:00	U25
12	23/03/2022	12:00	U26
13	23/03/2022	18:00	U27
14	24/03/2022	06:00	U28
15	24/03/2022	12:00	U29
16	24/03/2022	18:00	U30
17	25/03/2022	06:00	U31
18	25/03/2022	12:00	U32
19	25/03/2022	18:00	U33
20	26/03/2022	06:00	U34
21	26/03/2022	12:00	U35
22	26/03/2022	18:00	U36
23	27/03/2022	08:00	U37
24	27/03/2022	12:00	U38
25	27/03/2022	18:00	U39
26	28/03/2022	06:00	U40
28	28/03/2022	18:00	U42
29	29/03/2022	06:00	U43
30	29/03/2022	12:00	U44
31	29/03/2022	18:00	U45

Lab on Chip Standard Samples

Date Taken	Platform	Nutrient	Nominal Concentration (μM)
15/03/2022	ALR	NO2	1
15/03/2022	ALR	NO3	0
15/03/2022	ALR	NO3	10
15/03/2022	ALR	PO4	0
15/03/2022	ALR	PO4	1
15/03/2022	ALR	PO4	3
15/03/2022	ALR	Si	0
15/03/2022	ALR	Si	10
15/03/2022	ALR	Si	30
17/03/2022	ALR	NO2	1
17/03/2022	ALR	Si	0
21/03/2022	UWAY/CTD	PO4	0
21/03/2022	UWAY/CTD	PO4	1
21/03/2022	UWAY/CTD	PO4	3
15/03/2022	ALR	Si	30
17/03/2022	ALR	NO2	1
17/03/2022	ALR	Si	0
21/03/2022	UWAY/CTD	PO4	0
21/03/2022	UWAY/CTD	PO4	1
21/03/2022	UWAY/CTD	PO4	3
27/03/2022	CTD	NO3	0
27/03/2022	CTD	NO3	10

Preliminary Results

Data for nitrate, nitrite, phosphate, silicate and ammonia requires further data processing and will be made available once this has been completed.

Cruise Summary:

No preliminary results for nitrate, nitrite, phosphate, silicate and ammonia.

5.5 Dissolved Oxygen (Winkler method).

Patricia López García (NOC)

5.4.1 OBJECTIVES:

- Calibrate oxygen sensors from the CTD rosette and ALR.

5.4.2 SAMPLING and ANALYTICAL METHODOLOGY:

Samples were taken from the stainless-steel Sea-Bird CTD systems on-board the RRS Discovery using ~120 mL borosilicate bottles. Winkler method was used to determine the concentration of oxygen in the samples collected (Carpenter, J. 1965, Langdon, C. 2010).

Samples were analysed the same day of collection and a 794 Basic Titrino (Metrohm) was used for the titration (Figure 5.11).

Titrant solution was calibrated at the beginning of the run and some standard was also run the end in order to detect any variation. Differences between the starts and ends were lower than

Figure 5.11: *Winkler titration set up (794 Basic Titrino, Metrohm) and an oxygen sample after collection.*

References:

Carpenter, J. The Chesapeake Bay Institute Technique for the Winkler Dissolved Oxygen Method. Limnology and Oceanography, 1965.

Langdon, C. (2010) Determination of Dissolved Oxygen in Seaweater By Winkler Titration using Amperometric Technique. In, The GO-SHIP Repeat Hydrography Manual: A Collection of Expert Reports and Guidelines. Version 1, (eds Hood, E.M., C.L. Sabine, and B.M. Sloyan). 18pp.. (IOCCP Report Number 14; ICPO Publication Series Number 134). DOI: https://doi.org/10.25607/OBP-1350.

CTD Samples

Date	CTD	Event	Position	CTD bottle collected
16/3/22	2	W1	49 31.71N 07 30.55W	Bottles 1, 5, 9, 13, 17, 21 (depths: 100, 75, 50, 30, 10, 7 m)
18/3/22	5	OS-A	47 30.00N 10 48.03W	Bottles 1, 3, 5, 7, 9, 11, 13, 17, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 50, 20, 10 m)
18/3/22	6	MID-AB	47 31.05N 10 40.56W	Bottles 1, 3, 6, 7, 9, 11, 13, 17, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 50, 20, 10 m)
19/3/22	7	OS-B	47 31.41N 10 33.65W	Bottles 1, 3, 6, 7, 9, 11, 13, 18, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 50, 20, 10 m)
20/3/22	9	OS-B	47 30.01N 10 33.01W	Bottles 1, 3, 6, 7, 9, 11, 13, 18, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 50, 20, 10 m)
20/3/22	10	OS-AB4	47 30.13N 10 36.63W	Bottles 1, 3, 6, 7, 9, 11, 13, 18, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 50, 20, 10 m)
21/2/22	12	OS-AB-2	47 30.00N 10 44.40W	Bottles 1, 3, 6, 7, 9, 11, 13, 18, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 50, 20, 10 m)
22/3/22	13	OS-B	47 30.27N 10 33.04W	Bottles 1, 3, 6, 7, 9, 11, 13, 18, 21, 23 (depths: 1000, 800, 600, 400, 250, 150, 100, 50, 20, 10 m)
23/3/22	14	T1	49 12.02N 08 15.08W	Bottles 1, 5, 9, 13, 17, 21 (depths: 100, 75, 50, 30, 20, 10 m)
24/3/22	16	T1	49 12.01N 08 14.99W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
24/3/22	17	T2	49 02.43N 08 27.61W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
25/3/22	18	T3	48 52.20N 08 40.82W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
25/3/22	20	T4	48 43.20N 08 53.44W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
26/3/22	21	T5	48 32.59N 09 05.44W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)

26/3/22	22	T6	48 24.01N 09 18.04W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
27/3/22	23	T7	48 16.20N 09 31.82W	Bottles 1, 5, 9, 13, 17, 21 (depths: 110, 80, 50, 30, 20, 10 m)
27/3/22	25	T8	48 07.21N 09 45.01W	Bottles 1, 3, 5, 7, 9, 13, 15,17 (depths: 500, 350, 150, 110, 80, 50, 30, 20, 10 m)
28/3/22	27	T9	48 N 10 0.018W	Bottles 1, 3, 5, 6, 7, 8, 9, 10, 12, 13, 19, 21 (depths: 1500, 1200, 800, 600, 500, 400, 250, 150, 110, 80, 30, 20 m)
28/3/22	28	T10	47 54.01N 10 15.03W	Bottles 1, 3, 4, 6, 8, 10, 12, 15, 19, 21,23 (depths: 3000, 2000, 1000, 500, 100, 80, 50, 30, 20, 10 m)

Preliminary Results

Data will be analysed after the cruise in order to calibrate the CTD and ALR oxygen sensors.

As preliminary results, winkler values were compared with values from the CTD oxygen sensor, in average a difference of 11 µmol/kg was found in all samples (Figure 5.12). First cast (CTD 2, JDay 75) might need to be considered unreliable.

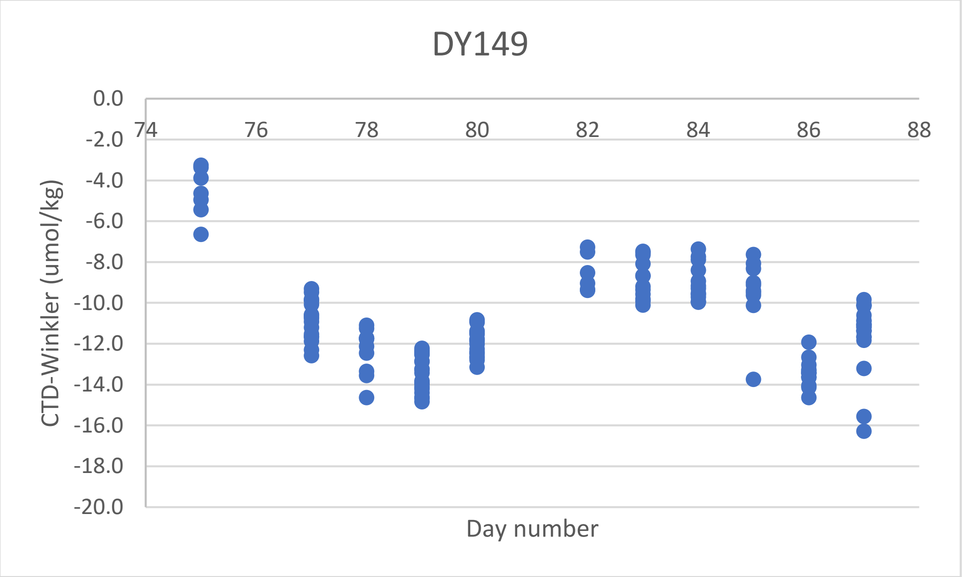


Figure 5.12: *Preliminary results: difference between values of oxygen concentration given by the CTD oxygen sensor and Winkler samples analysed during the cruise.*

Cruise Summary:

Almost samples from all depths from the CTD were analysed since the oxygen bottles had some problems and we wanted to be sure that we had at least 6 good samples from each cast. Some duplicates were taken and a good reproducibility was found.

Nest steps: analysed data and calibrate CTD oxygen sensor and ALR oxygen sensor.

Summary & Acknowledgements

We would like to thank the crew for all their support with the deployments and Profesor Mark Moore for his management of the activities.

This deployment was a success. The integration worked well and through the hard work of the Integration and ALR team the process was not much different than running a sensor in the lab. The sensors were able to measure differences in the waters we measured and we are returning with plenty of data. We also need to thank the other members of the Ocean Technology and Engineering Group, who helped immensely with cruise preparation in and amongst the two other cruises that will or did take place in the first half of this year.

We would like to thank Sue Hartman for providing the equipment for Winkler analysis and Rudi for helping during sampling and measuring of oxygen.

6. Carbonate Chemistry Autonomous Sensor System (CarCASS)

Emily Hammermeister, Martin Arundell and Socratis Loucaides (NOC)

6.1 Overview

The CarCASS project aims to advance the technology readiness level (TRL) of carbonate sensor technology and integrate them into a carbonate chemistry autonomous sensor system (CarCASS) capable of determining the full seawater carbonate speciation onboard Marine Autonomous Systems (MAS). The CarCASS device offers high performance, high spatial and temporal resolution complete carbonate chemistry characterization with full ocean depth capability over long-term deployments. CarCASS addresses, at unprecedented resolution from MAS, the metrology of the carbonate system which the Global Ocean Observing System (GOOS) community have judged is the highest impact biogeochemical EOV. This new technology will help improve our understanding of the inorganic carbon cycle in the ocean and monitor ocean acidification. It will also present a powerful tool for monitoring sub-seafloor carbon sequestration and storage (CCS) sites for detection of CO2 leaks during and after gas injection and seawater acidification in shell fishing areas and mariculture establishments.

Carcass is a combination of three autonomous Lab-on-chip (LOC) sensors measuring pH, Total Alkalinity (TA) and Dissolved Inorganic Carbon (DIC) and an electrochemical pH sensor (developed by ANB sensors). All four devices are connected to a communications hub which manages sensor operation and data communication between platform and sensors. The pH sensor is based on the benchtop seawater spectrophotometric pH assay using purified meta-cresol purple indicator dye. The measurement uncertainty is better than 0.010 pH units and measurement resolution is better than 0.001[1]. The TA sensor is based on the single step titration method[2] and it involves sample degassing, followed by spectrophotometric pH determination. The current accuracy of the measurement is in the order of 10 µmol Kg^{-1}. The DIC sensor is based on the benchtop DIC flow injection analytical method[3] and it involves extraction of DIC from the sample by acidification and into a NaOH solution. DIC is calculated by monitoring the change in conductivity of the NaOH solution. The ANB sensor is an electrochemical pH sensor developed by ANB sensor LTD.

Figure 6.1: *The tree LOC sensor for the measurements of pH, TA and DIC*

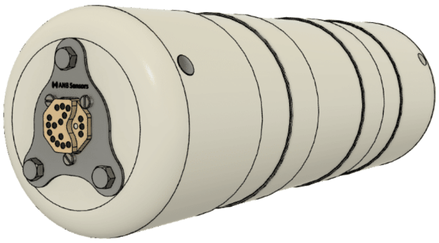


Figure 6.2. *The ANB electrochemical pH sensor*

The electrochemical voltammetric sensor utilsies two redox active species, the first is an innovative polymer embedded thiol which permits the voltammetric determination pH with a Nerstein response (GB GB1609669.5). This is coupled with redox active reference couple which sets the chemistry local to the electrode surface to ensure a constant and stable redox potential.

Purpose

The purpose of this field trial was to demonstrate the CarCASS system at sea integrated on a marine autonomous platform in an operational setting (TRL8). Through a series of ALR missions, the objective was to test sensor operation at different depths, across gradients of carbonate chemistry variables and over long deployments while operating continuously. Sensor analytical performance was to be validated through co-sampling using the ship's CTD frame and Niskin bottles and later analysis for TA and DIC using standard methods.

CarCASS configuration during DY149

The 4 sensors were integrated within the aft sensor bay of the Autosub Long Range (ALR). The 3 LOC sensors' inlets withdrew sample from a pumped seawater line running through the vehicle and flowing though the ANB sensor's flow cup.

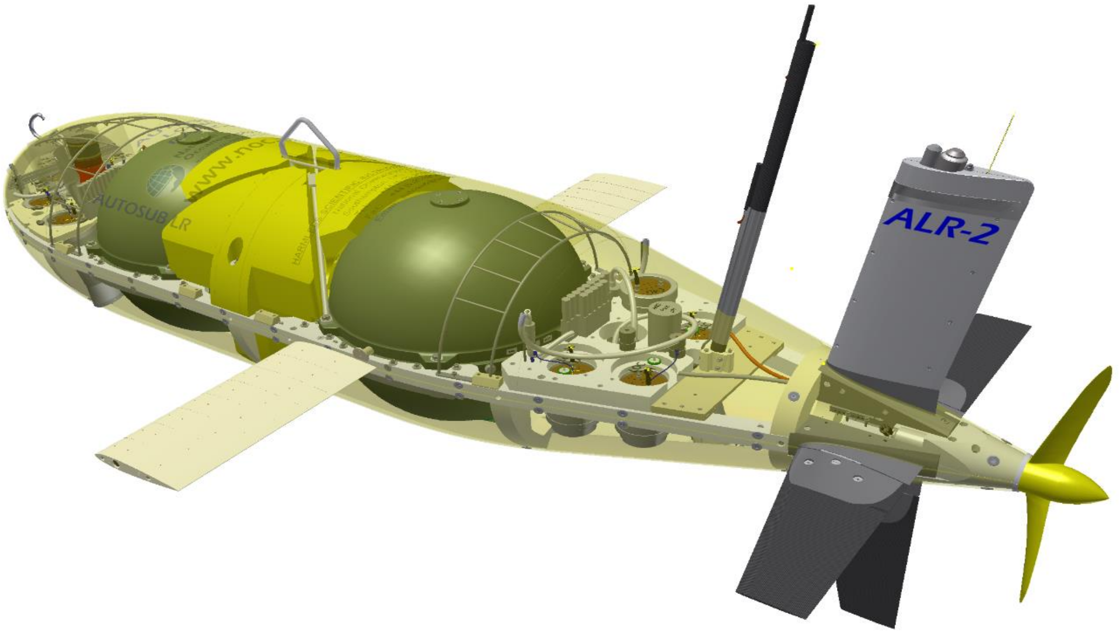


Figure 6.3: *CarCASS sensor configuration on the ALR 2. The three LOC sensors and the ANB sensors at the AFT of the vehicle.*

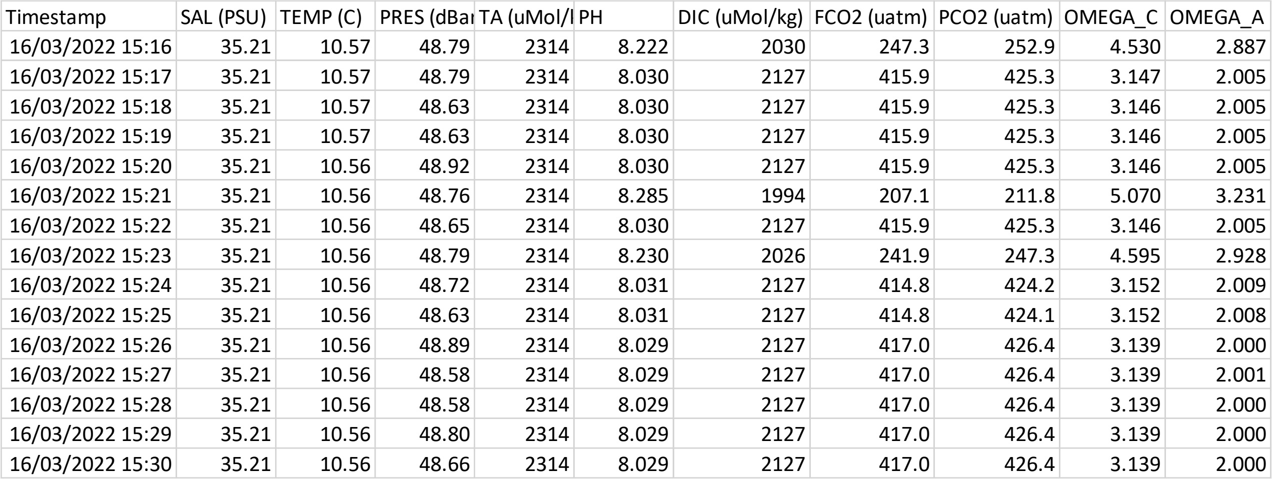
Each LOC sensor made a measurement every 10-14 minutes during ALR missions and the ANB measured every 20 seconds. All sensors were connected to a communications hub which provided power and communication between sensors and the vehicle. The hub collected temperature (T), salinity (S), pressure (P) and dissolved oxygen (DO) data from the ALR's CTD and provided T and S to the LOC pH sensor which was used for the calculation of pH at in situ T and S. In situ LOC sensor pH was used to periodically baseline correct the high resolution ANB sensor pH. The hub also produced high resolution TA values from S data (from the ALR's CTD) and known S/TA relationships[4]. The relationship was validated using direct TA measurements by the TA LOC sensor. Using the high resolution pH and TA measurements, the hub used thermodynamic carbonate chemistry calculations to calculate the rest of the carbonate system parameters at high resolution. An extract from the CarCASS output is presented in Figure 6.4.

6.2 Missions during DY149

The CarCASS system was switched on for 14 ALR missions (see ALR mission table in ALR section). CarCASS produced good data on 13 missions out of 14. CTD was not switched on during mission 74 therefore CarCASS produced no valid data.

Data post-processing

Post processing is required for TA and DIC measurements. TA data are corrected based on periodic measurements of certified reference materials (CRM) carried by the sensor onboard the ALR. Two CRMs with distinctly different TA values are used (CRM1 TA=2205.26 µmol Kg^{-1}, CRM2 TA=2495.8). The CRM measurements are used to constrain the titrant molarity and the acidity constant of the dye which are recalculated every 3 TA measurements. The DIC data is corrected post-deployment based on periodic measurements of CRM carried onboard the ALR. The DIC sensor measures the CRM in triplicate every 12 seawater measurements. The CarCASS CO_2 system algorithm will be rerun after DIC and TA measurement correction. DO sensor data from ALR's SBE43F sensor will be calibrated using Winkler DO analysis on samples collected from the Niskin bottles at corresponding depths.



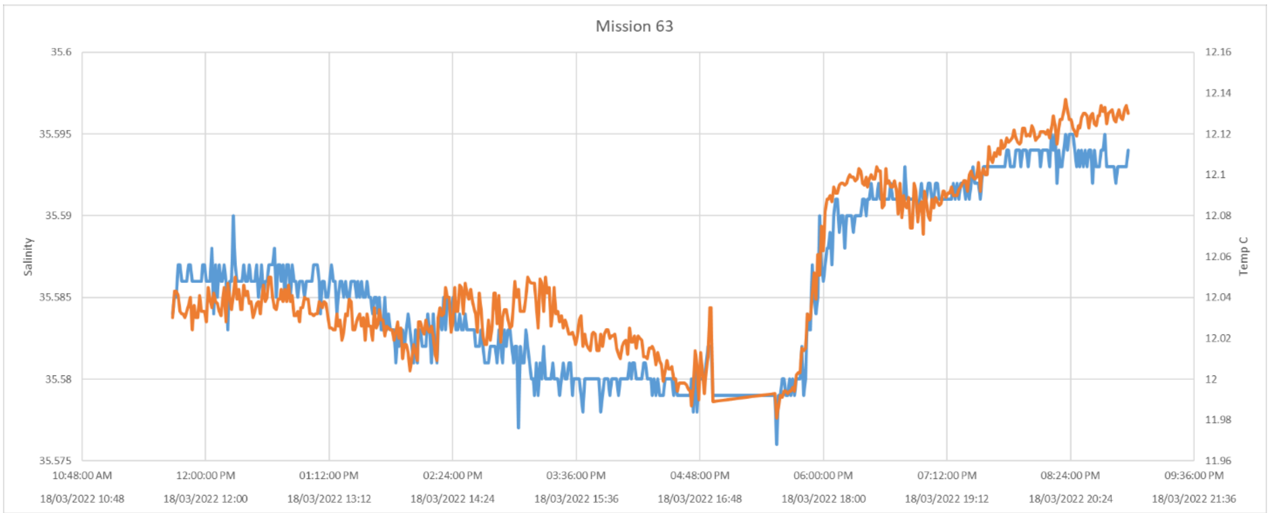
Timestamp	SAL (PSU)	TEMP (C)	PRES (dBar	TA (uMol/l	PH	DIC (uMol/kg)	FCO2 (uatm)	PCO2 (uatm)	OMEGA_C	OMEGA_A
16/03/2022 15:16	35.21	10.57	48.79	2314	8.222	2030	247.3	252.9	4.530	2.887
16/03/2022 15:17	35.21	10.57	48.79	2314	8.030	2127	415.9	425.3	3.147	2.005
16/03/2022 15:18	35.21	10.57	48.63	2314	8.030	2127	415.9	425.3	3.146	2.005
16/03/2022 15:19	35.21	10.57	48.63	2314	8.030	2127	415.9	425.3	3.146	2.005
16/03/2022 15:20	35.21	10.56	48.92	2314	8.030	2127	415.9	425.3	3.146	2.005
16/03/2022 15:21	35.21	10.56	48.76	2314	8.285	1994	207.1	211.8	5.070	3.231
16/03/2022 15:22	35.21	10.56	48.65	2314	8.030	2127	415.9	425.3	3.146	2.005
16/03/2022 15:23	35.21	10.56	48.79	2314	8.230	2026	241.9	247.3	4.595	2.928
16/03/2022 15:24	35.21	10.56	48.72	2314	8.031	2127	414.8	424.2	3.152	2.009
16/03/2022 15:25	35.21	10.56	48.63	2314	8.031	2127	414.8	424.1	3.152	2.008
16/03/2022 15:26	35.21	10.56	48.89	2314	8.029	2127	417.0	426.4	3.139	2.000
16/03/2022 15:27	35.21	10.56	48.58	2314	8.029	2127	417.0	426.4	3.139	2.001
16/03/2022 15:28	35.21	10.56	48.58	2314	8.029	2127	417.0	426.4	3.139	2.000
16/03/2022 15:29	35.21	10.56	48.80	2314	8.029	2127	417.0	426.4	3.139	2.000
16/03/2022 15:30	35.21	10.56	48.66	2314	8.029	2127	417.0	426.4	3.139	2.000

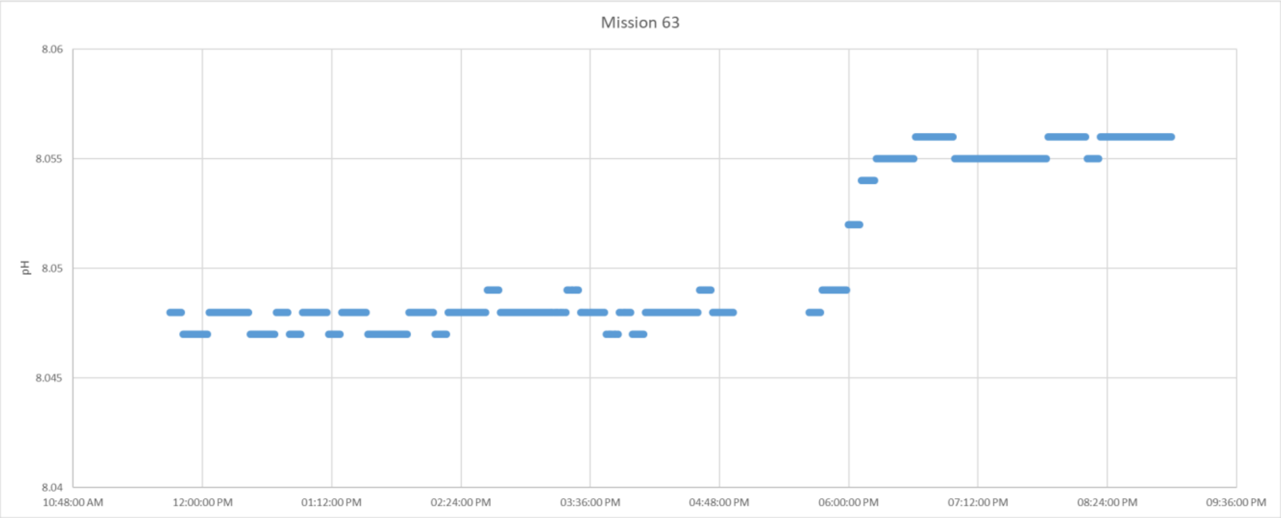
Figure 6.4: *Example output from the CarCASS sysrtem during DY149*

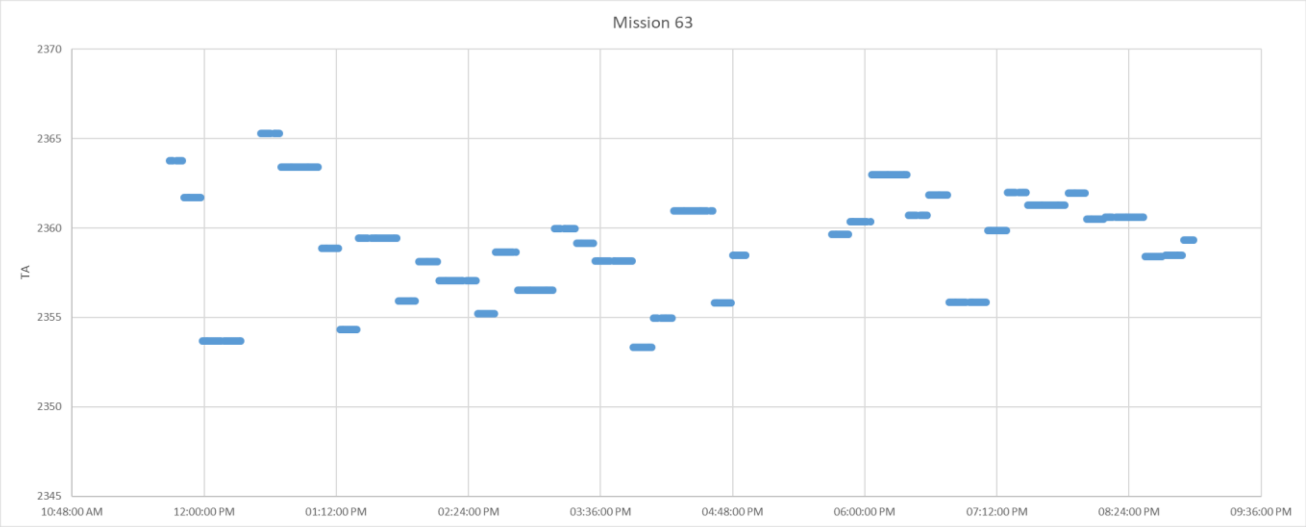
Data collected by the CarCASS system on the ALR.

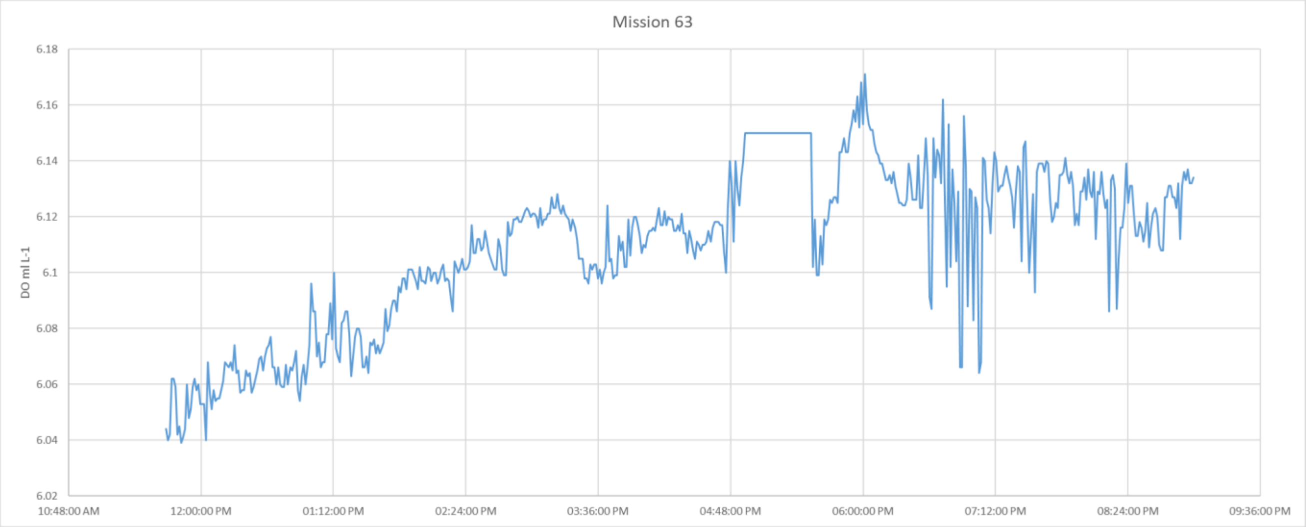
Below is a summary of the uncorrected data collected by the CarCASS sensors integrated on the ALR organised per mission.

MISSION 63

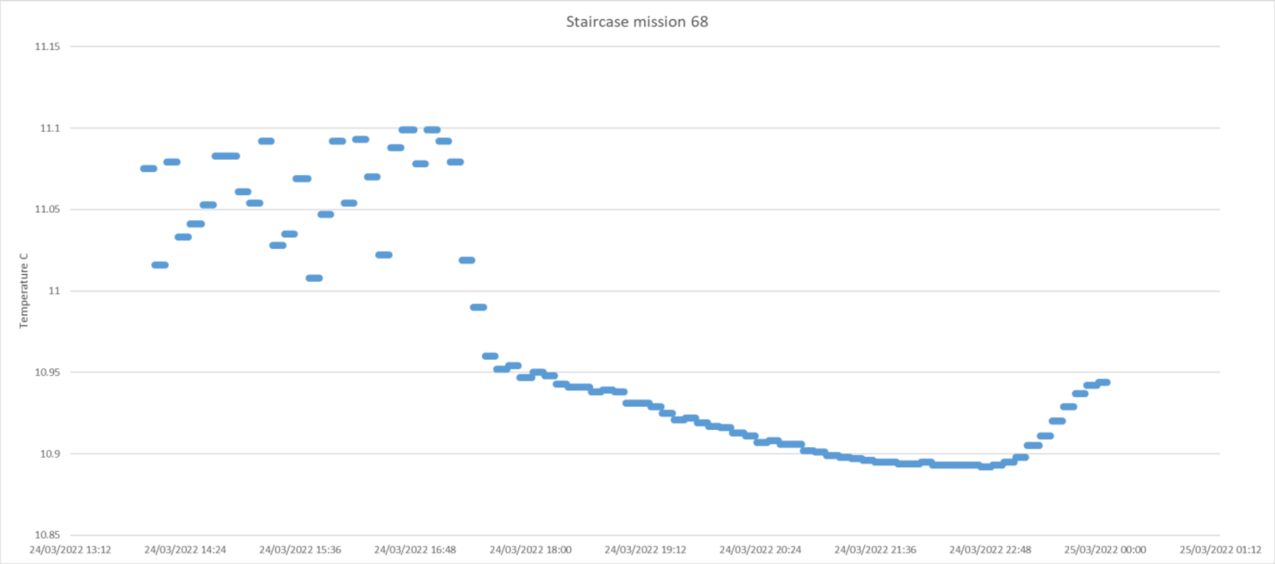


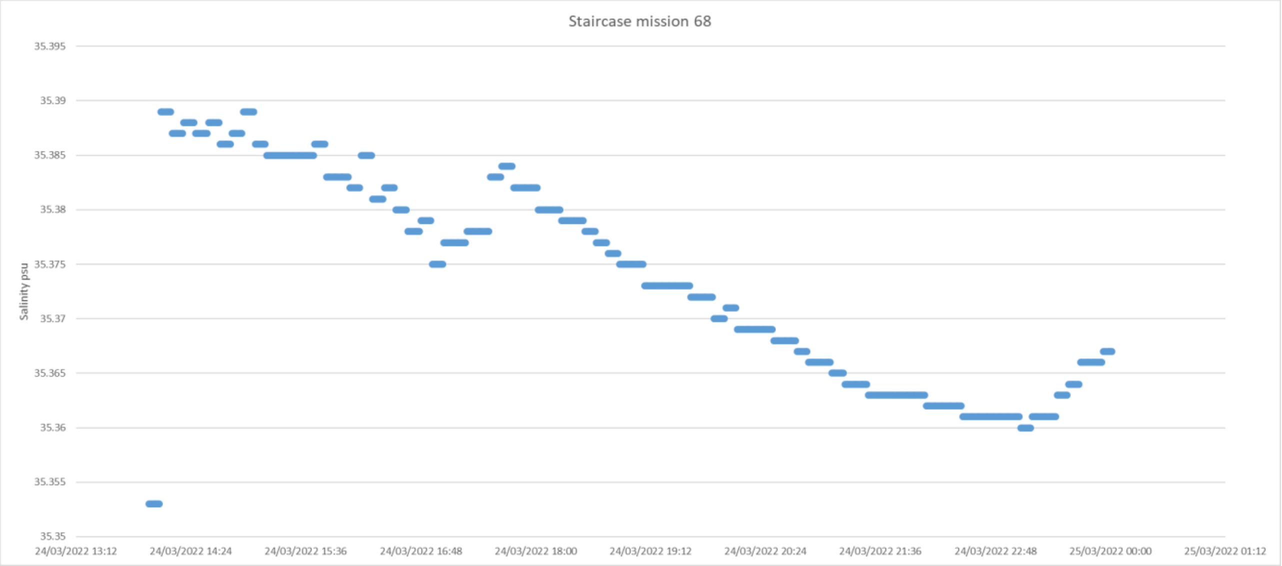


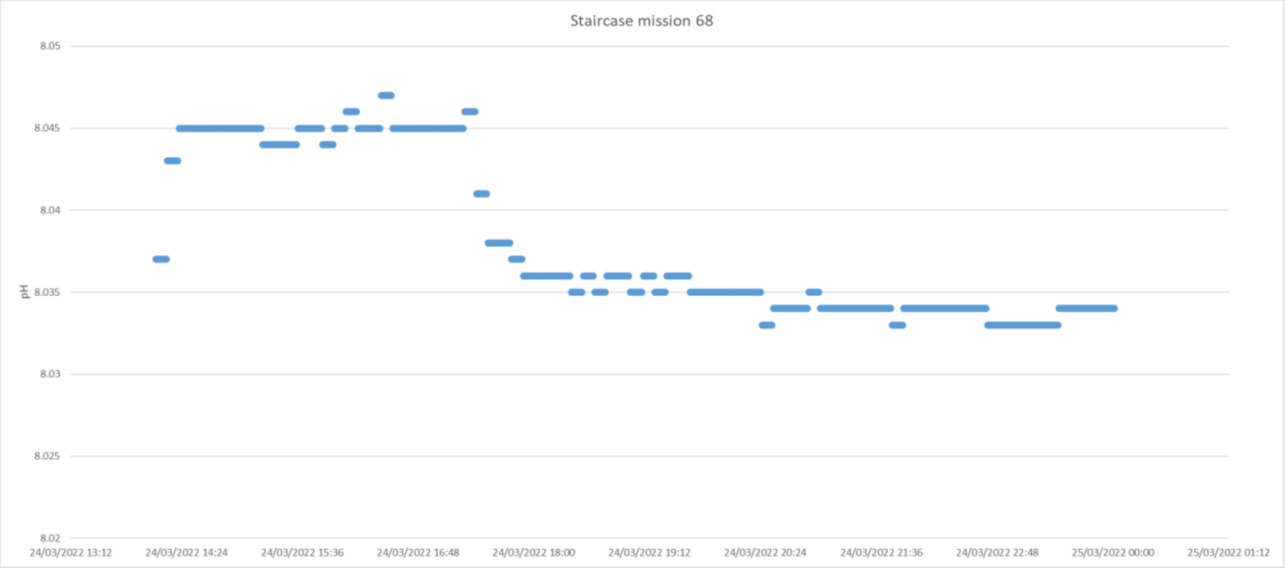


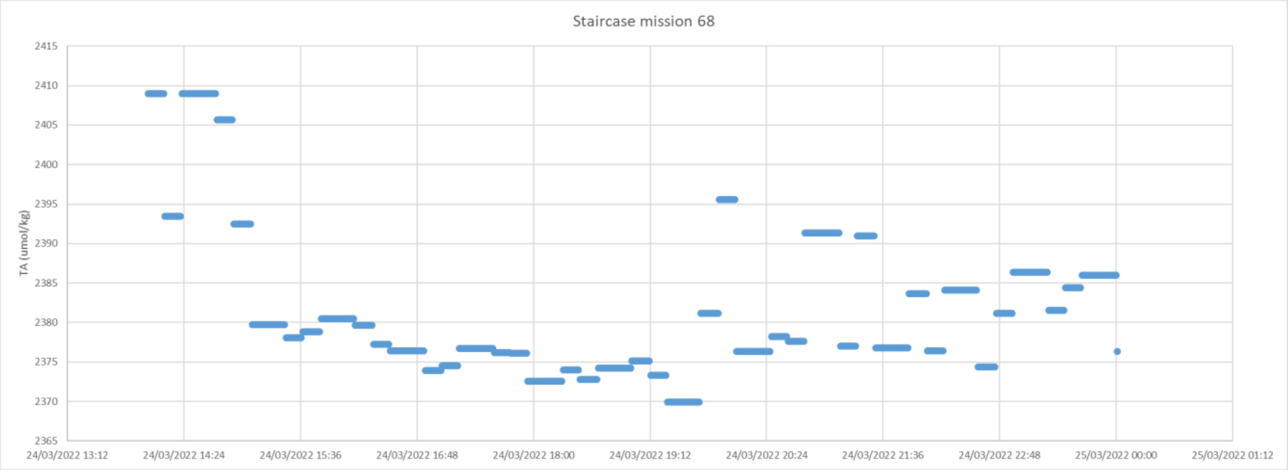

Mission 63
DO ml L-1
6.18
6.16
6.14
6.12
6.1
6.08
6.06
6.04
6.02
10:48:00 AM
12:00:00 PM
01:12:00 PM
02:24:00 PM
03:36:00 PM
04:48:00 PM
06:00:00 PM
07:12:00 PM
08:24:00 PM
09:36:00 PM

MISSION 68

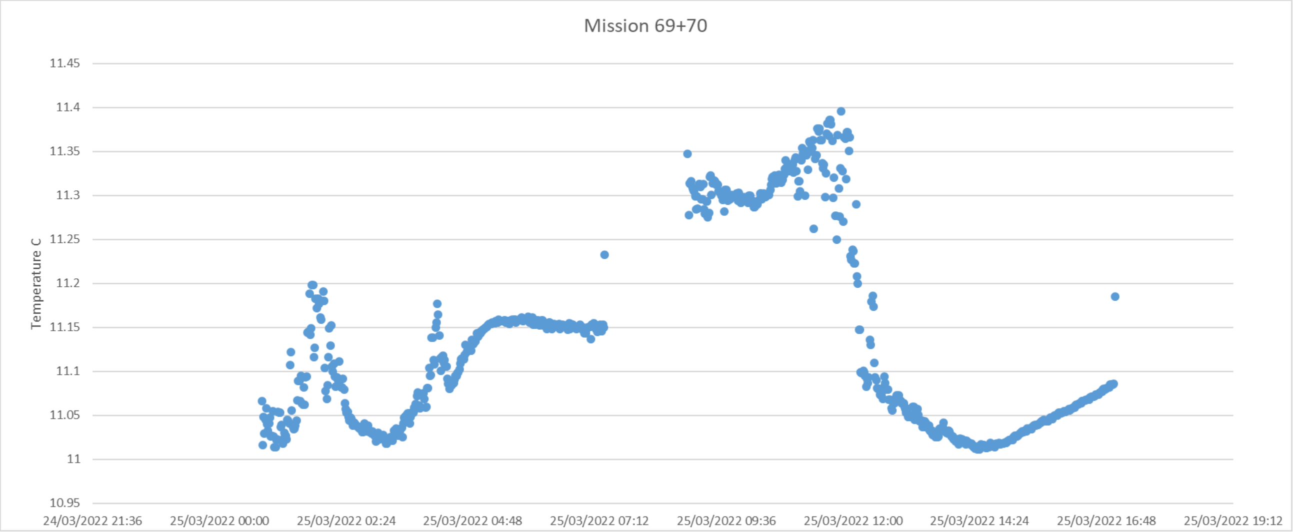

Staircase mission 68
Temperature C
11.15
11.1
11.05
11
10.95
10.9
10.85
24/03/2022 13:12
24/03/2022 14:24
24/03/2022 15:36
24/03/2022 16:48
24/03/2022 18:00
24/03/2022 19:12
24/03/2022 20:24
24/03/2022 21:36
24/03/2022 22:48
25/03/2022 00:00
25/03/2022 01:12

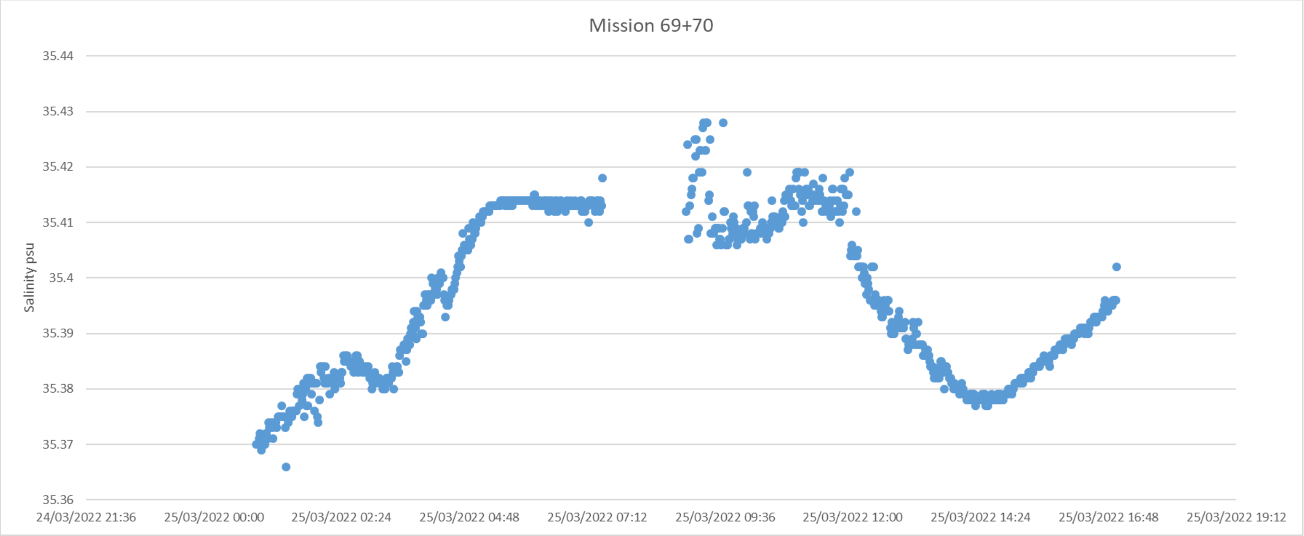

Staircase mission 68
Salinity psu
35.395
35.39
35.385
35.38
35.375
35.37
35.365
35.36
35.355
35.35
24/03/2022 13:12
24/03/2022 14:24
24/03/2022 15:36
24/03/2022 16:48
24/03/2022 18:00
24/03/2022 19:12
24/03/2022 20:24
24/03/2022 21:36
24/03/2022 22:48
25/03/2022 00:00
25/03/2022 01:12

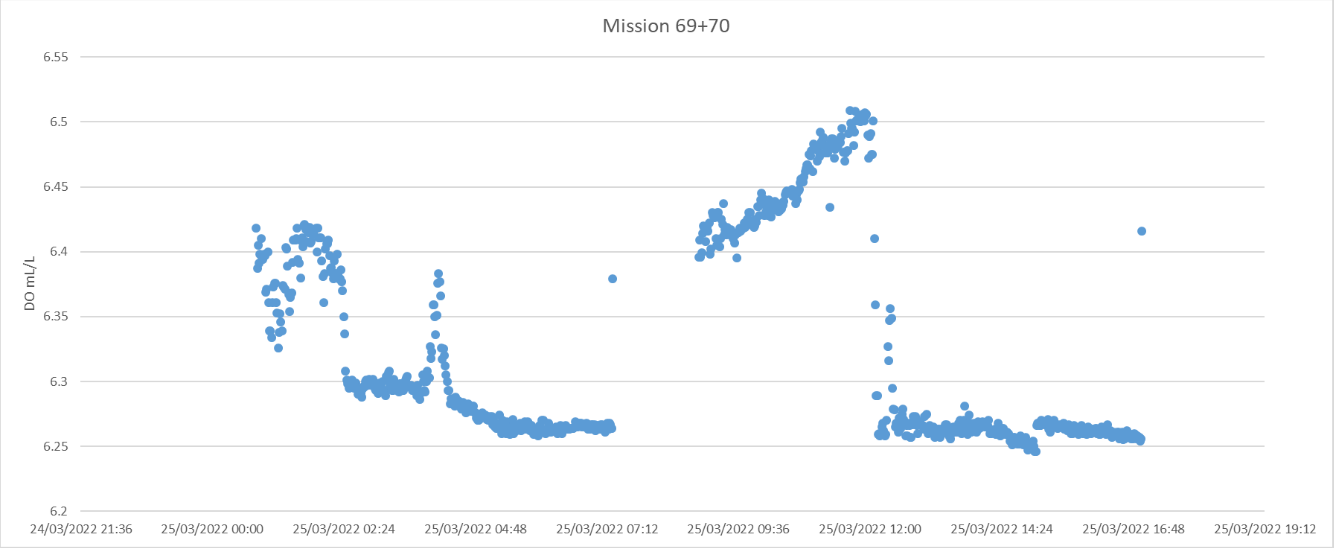

Staircase mission 68
pH
8.05
8.045
8.04
8.035
8.03
8.025
8.02
24/03/2022 13:12
24/03/2022 14:24
24/03/2022 15:36
24/03/2022 16:48
24/03/2022 18:00
24/03/2022 19:12
24/03/2022 20:24
24/03/2022 21:36
24/03/2022 22:48
25/03/2022 00:00
25/03/2022 01:12

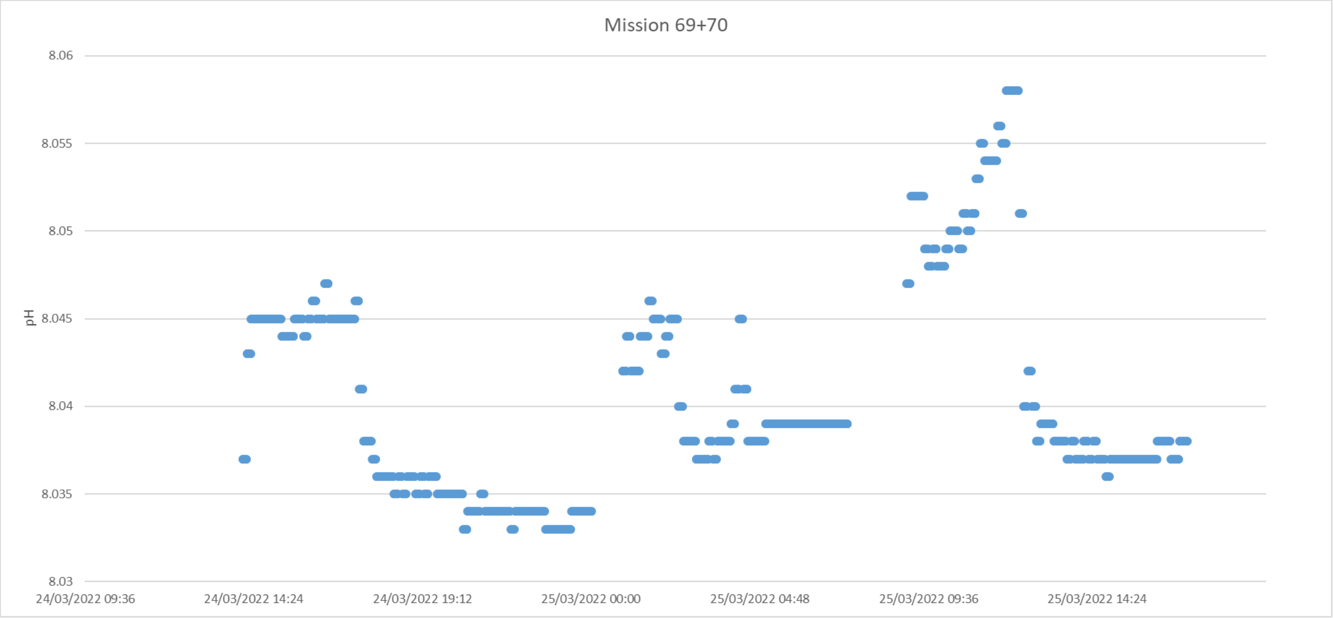

Staircase mission 68
TA (umol/kg)
2415
2410
2405
2400
2395
2390
2385
2380
2375
2370
2365
24/03/2022 13:12
24/03/2022 14:24
24/03/2022 15:36
24/03/2022 16:48
24/03/2022 18:00
24/03/2022 19:12
24/03/2022 20:24
24/03/2022 21:36
24/03/2022 22:48
25/03/2022 00:00
25/03/2022 01:12

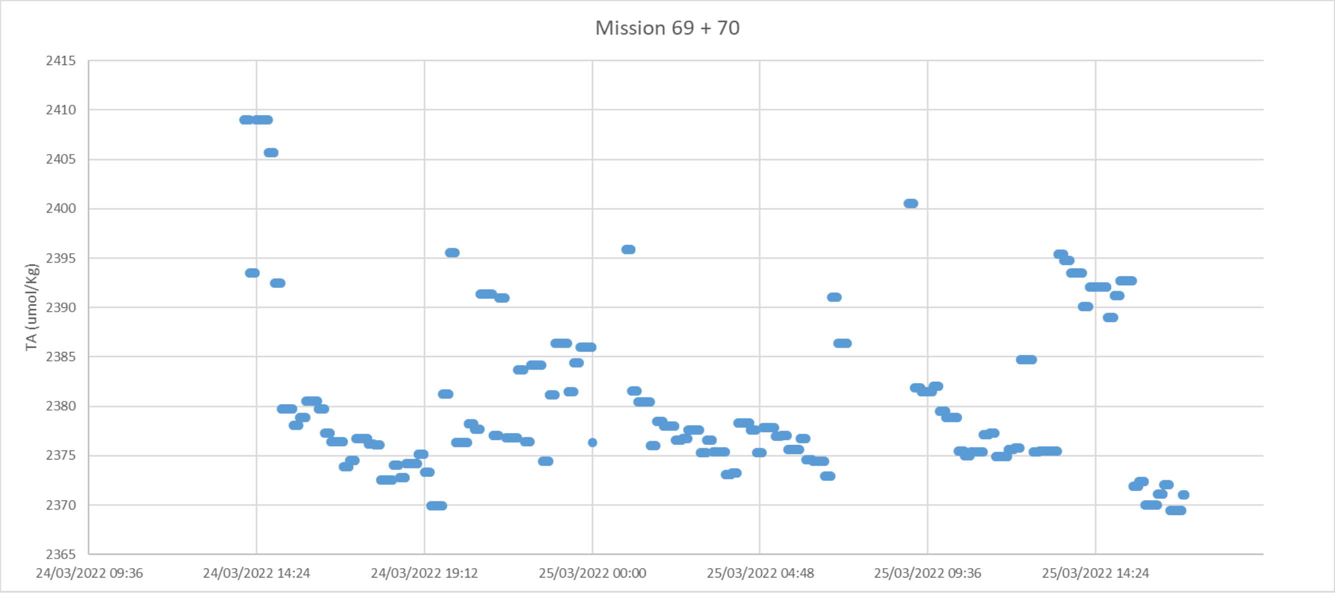
MISSION 69&70



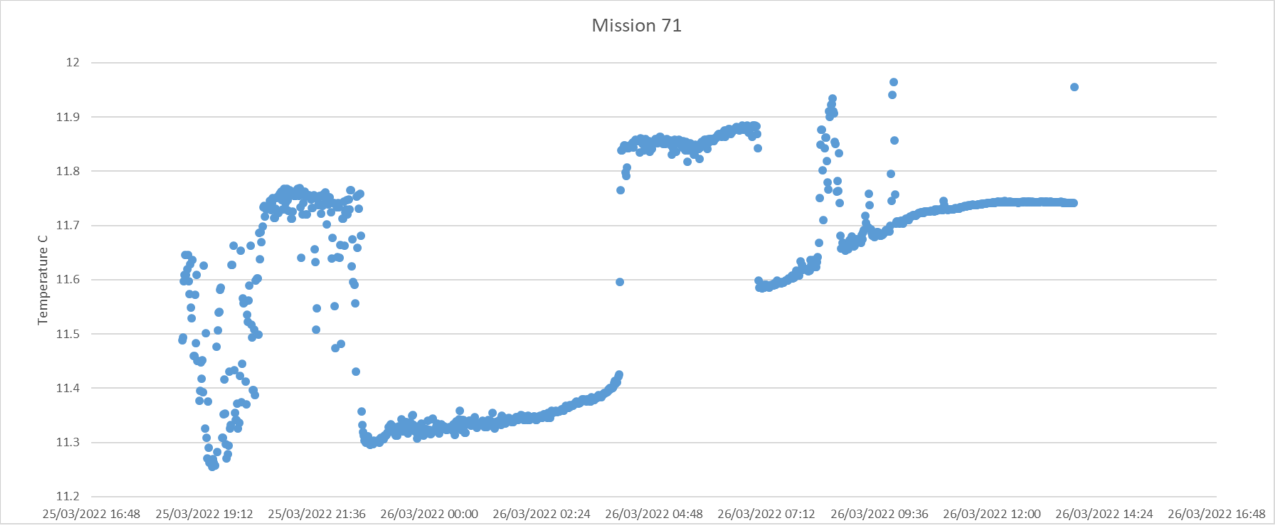


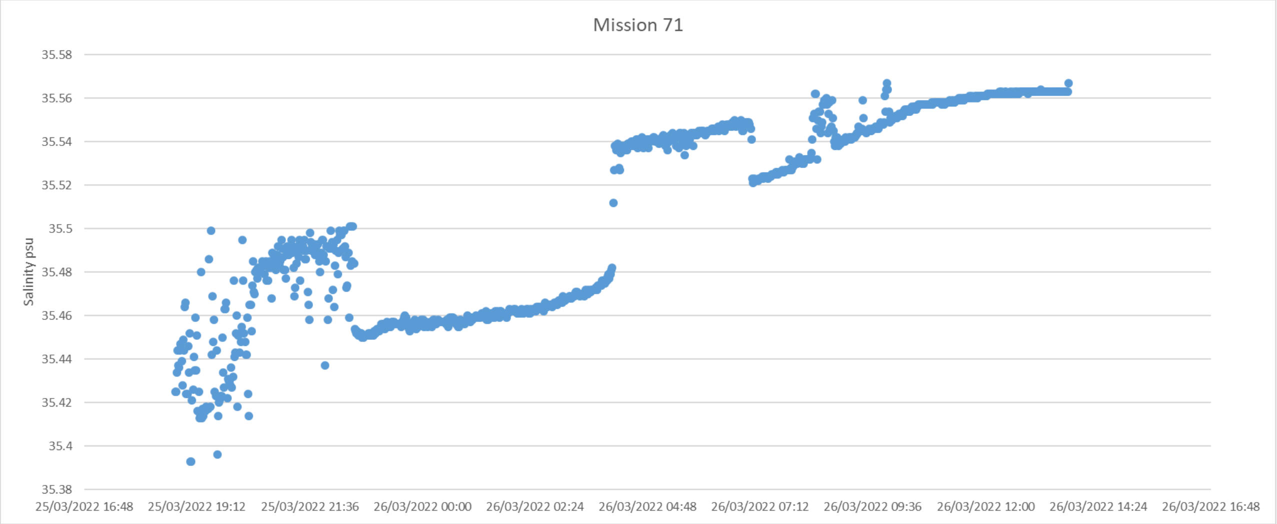


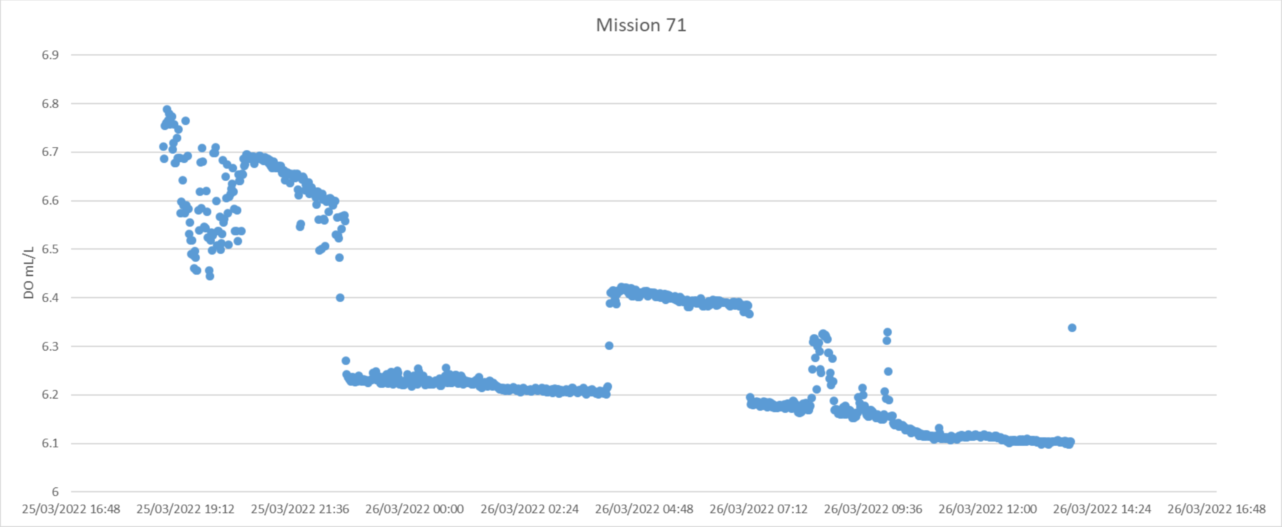

Mission 69+70
pH
8.06
8.055
8.05
8.045
8.04
8.035
8.03
24/03/2022 09:36
24/03/2022 14:24
24/03/2022 19:12
25/03/2022 00:00
25/03/2022 04:48
25/03/2022 09:36
25/03/2022 14:24

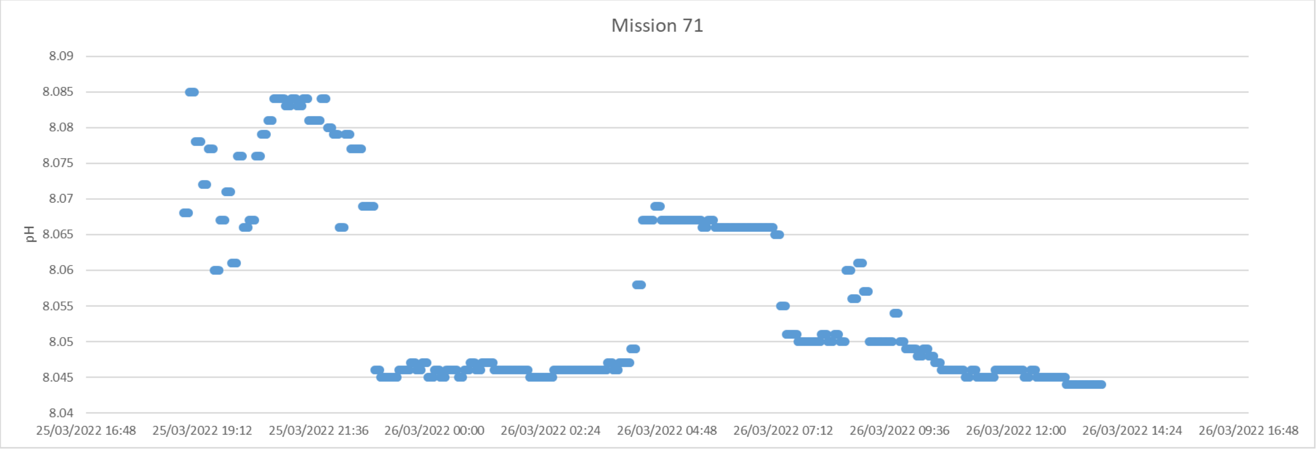

Mission 69 + 70
TA (umol/Kg)
2415
2410
2405
2400
2395
2390
2385
2380
2375
2370
2365
24/03/2022 09:36
24/03/2022 14:24
24/03/2022 19:12
25/03/2022 00:00
25/03/2022 04:48
25/03/2022 09:36
25/03/2022 14:24

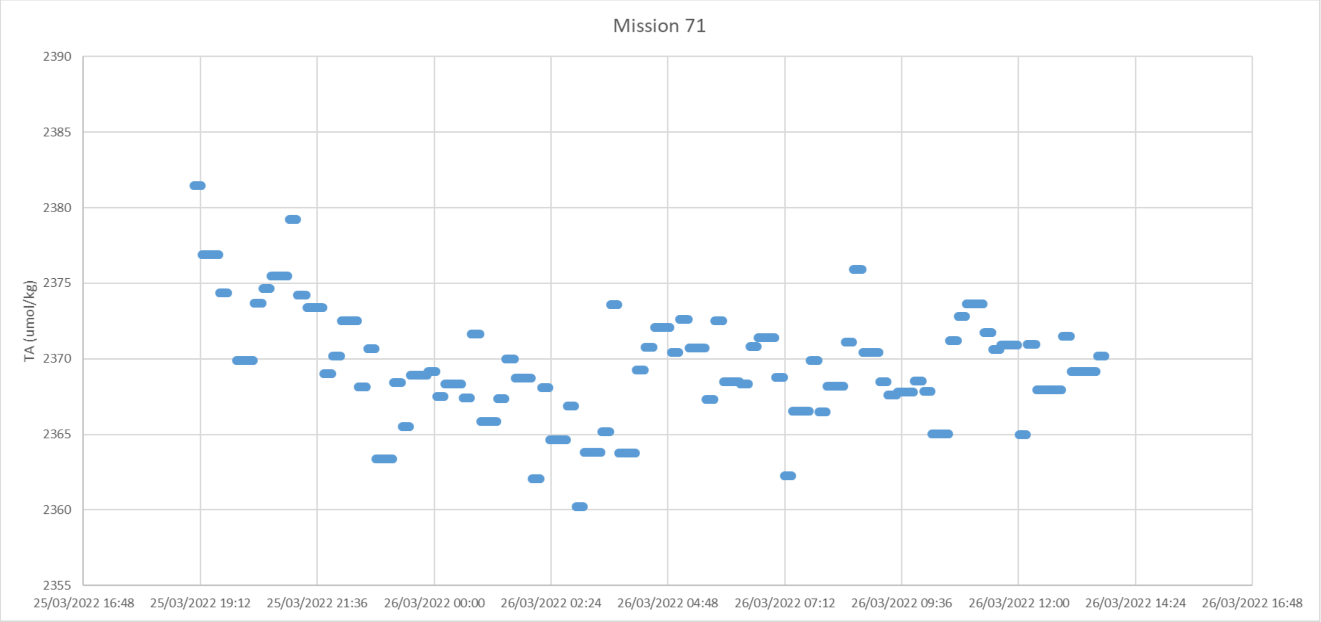
MISSION 71


Mission 71
Temperature C
12
11.9
11.8
11.7
11.6
11.5
11.4
11.3
11.2
25/03/2022 16:48
25/03/2022 19:12
25/03/2022 21:36
26/03/2022 00:00
26/03/2022 02:24
26/03/2022 04:48
26/03/2022 07:12
26/03/2022 09:36
26/03/2022 12:00
26/03/2022 14:24
26/03/2022 16:48

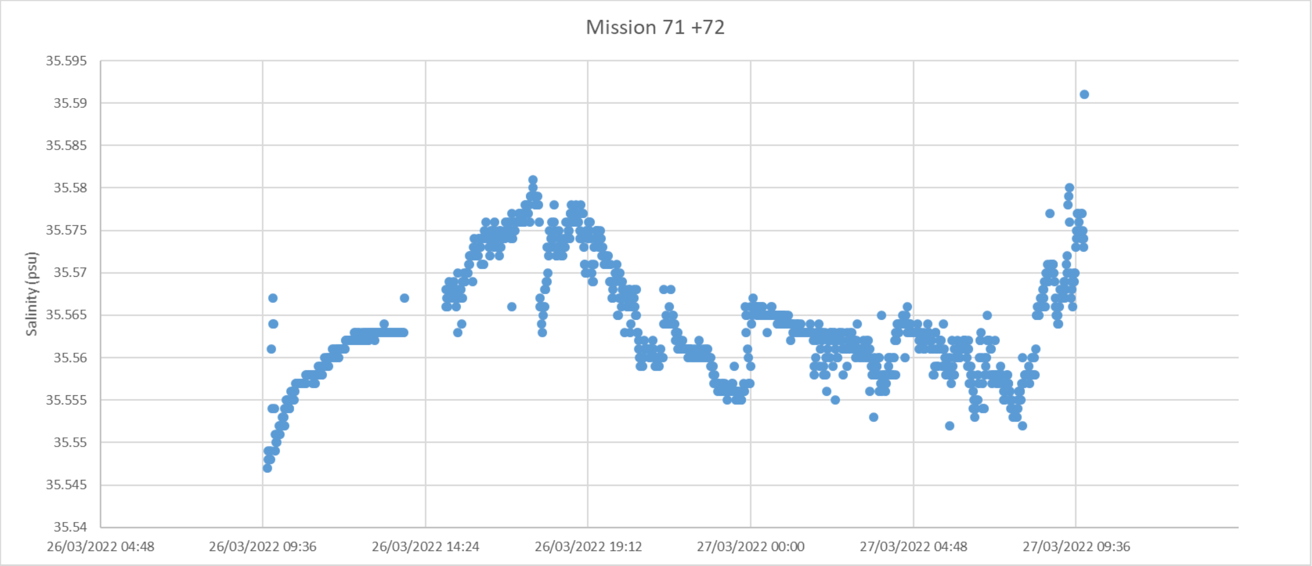

Mission 71
Salinity psu
35.58
35.56
35.54
35.52
35.5
35.48
35.46
35.44
35.42
35.4
35.38
25/03/2022 16:48
25/03/2022 19:12
25/03/2022 21:36
26/03/2022 00:00
26/03/2022 02:24
26/03/2022 04:48
26/03/2022 07:12
26/03/2022 09:36
26/03/2022 12:00
26/03/2022 14:24
26/03/2022 16:48

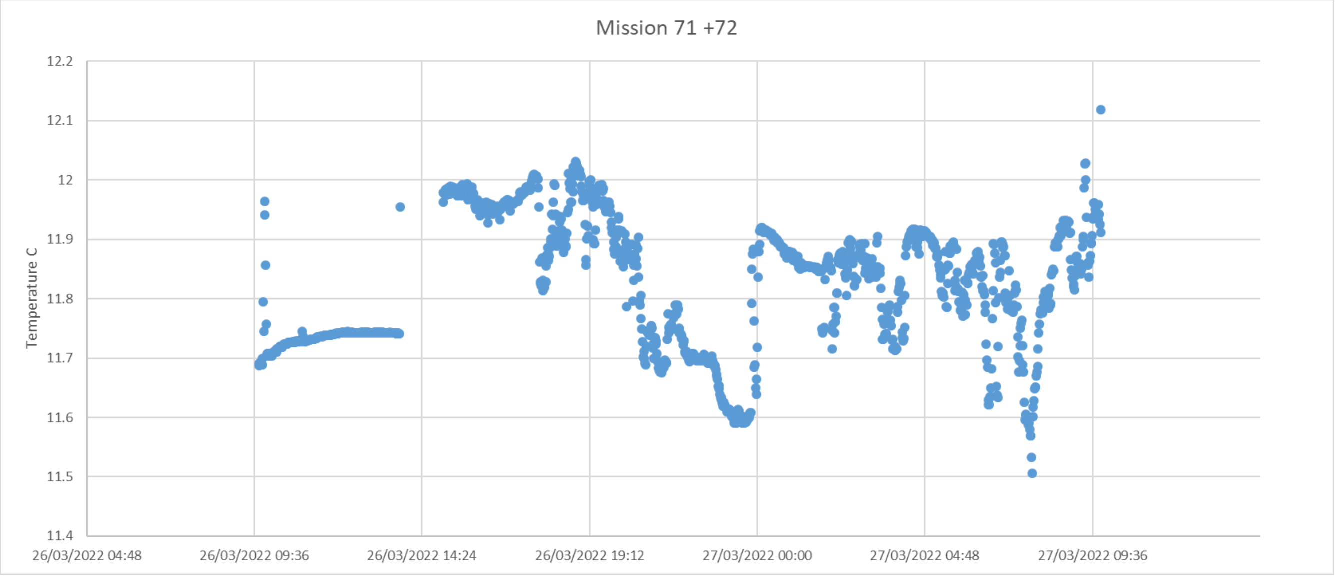

Mission 71
DO mL/L
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6
25/03/2022 16:48
25/03/2022 19:12
25/03/2022 21:36
26/03/2022 00:00
26/03/2022 02:24
26/03/2022 04:48
26/03/2022 07:12
26/03/2022 09:36
26/03/2022 12:00
26/03/2022 14:24
26/03/2022 16:48

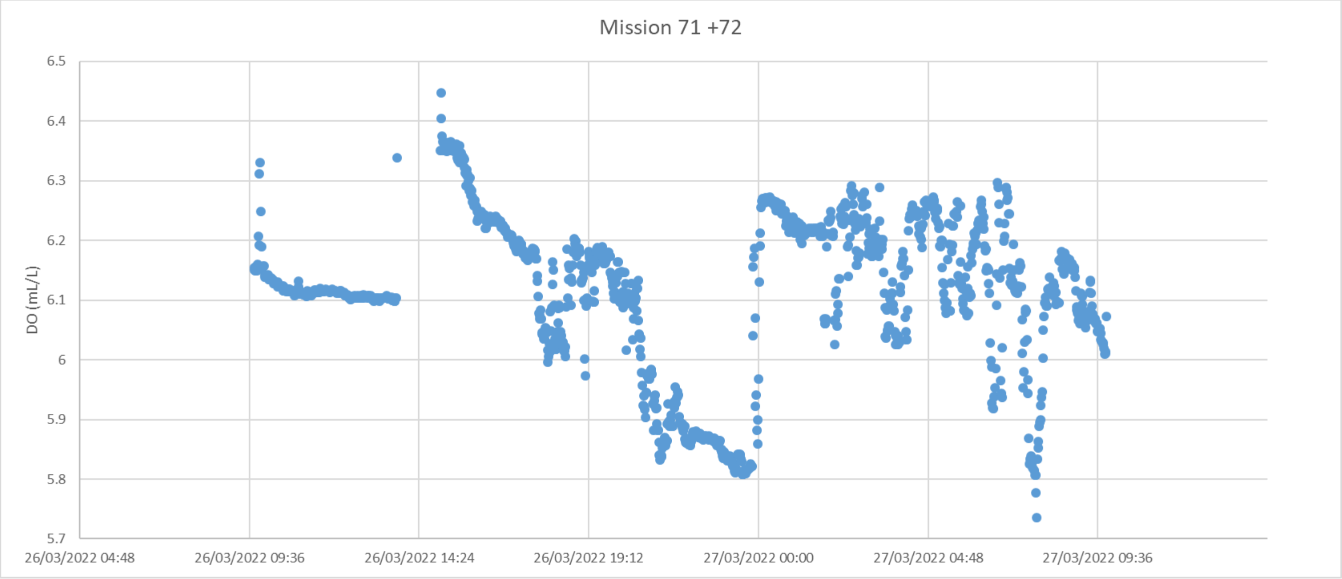


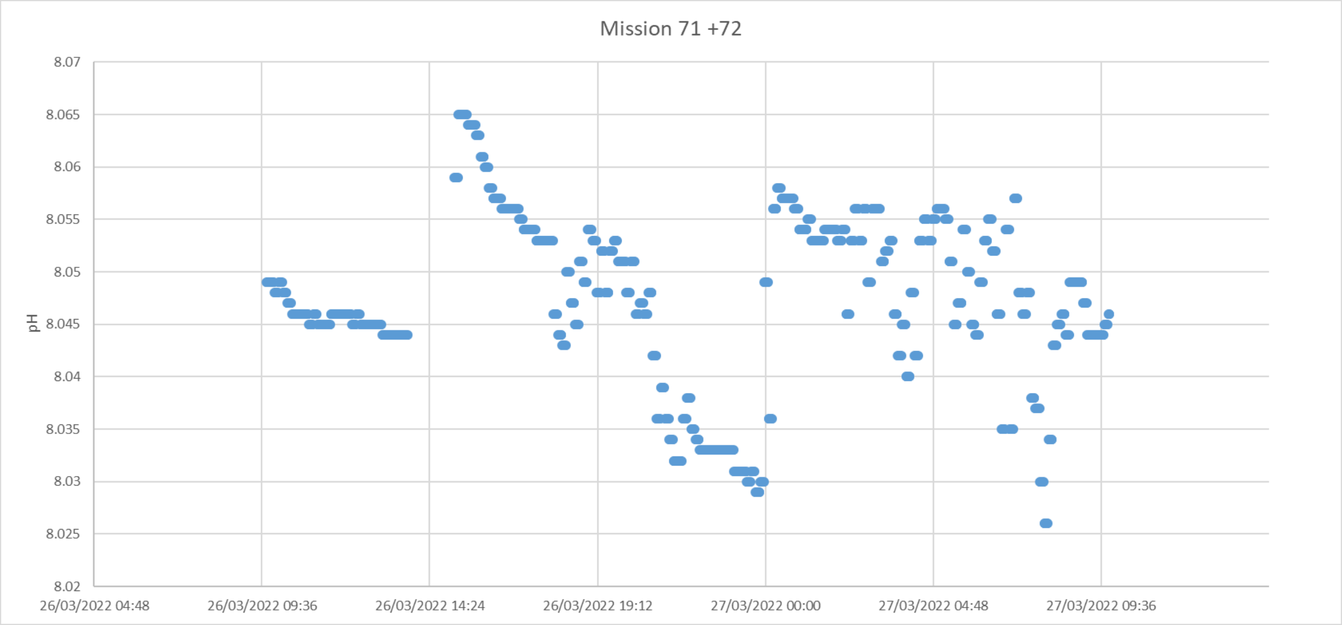


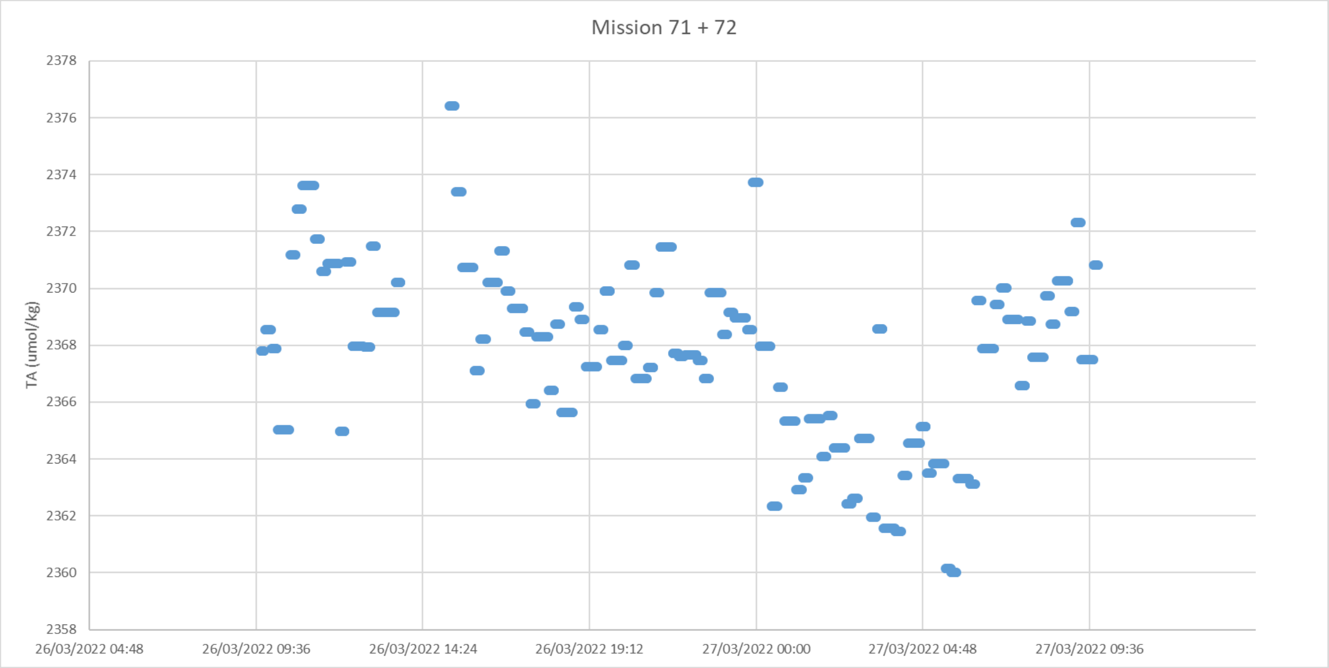
MISSION 71+72


Mission 71 +72
Salinity (psu)
35.595
35.59
35.585
35.58
35.575
35.57
35.565
35.56
35.555
35.55
35.545
35.54
26/03/2022 04:48
26/03/2022 09:36
26/03/2022 14:24
26/03/2022 19:12
27/03/2022 00:00
27/03/2022 04:48
27/03/2022 09:36


Mission 71 +72
Temperature C
12.2
12.1
12
11.9
11.8
11.7
11.6
11.5
11.4
26/03/2022 04:48
26/03/2022 09:36
26/03/2022 14:24
26/03/2022 19:12
27/03/2022 00:00
27/03/2022 04:48
27/03/2022 09:36


Mission 71 +72
DO (mL/L)
6.5
6.4
6.3
6.2
6.1
6
5.9
5.8
5.7
26/03/2022 04:48
26/03/2022 09:36
26/03/2022 14:24
26/03/2022 19:12
27/03/2022 00:00
27/03/2022 04:48
27/03/2022 09:36


Mission 71 +72
pH
8.07
8.065
8.06
8.055
8.05
8.045
8.04
8.035
8.03
8.025
8.02
26/03/2022 04:48
26/03/2022 09:36
26/03/2022 14:24
26/03/2022 19:12
27/03/2022 00:00
27/03/2022 04:48
27/03/2022 09:36


Mission 71 + 72
TA (umol/kg)
2378
2376
2374
2372
2370
2368
2366
2364
2362
2360
2358
26/03/2022 04:48
26/03/2022 09:36
26/03/2022 14:24
26/03/2022 19:12
27/03/2022 00:00
27/03/2022 04:48
27/03/2022 09:36

6.3 Underway measurements

Figure 6.5: *Underway setup used for the CarCASS sensors*

Underway measurements were collected in the underway system in the chemistry laboratory. The CarCASS sensors used for underway measurements were the NOCS pH, NOCS TA and the NOCS DIC. The sensors were connected to the ships underway system via a custom made underway device that had connecting filters fitted at the bottom and a water feed from the top to avoid problems with air bubbles entering the chemical sensors, as shown in Figure 6.5. This system worked well throughout the cruise. Samples were also collected three times a day, 6.00 am, 12.00 pm and 6.00 pm, from the same underway system. The sensors used throughout the cruise for the underway measurements are shown below in Table 5.1. TA 11 had to be swapped out on the 22.03.2022 due to a broken IE55 pin. It was replaced with TA17* that had been used on the CTD.

Sensor	ALR	CTD	Underway
NOCS LOC pH	43	49	36
NOCS LOC TA	16	17	11 & 17*
NOCS LOC DIC	05 EPU17	Not Deployed	10 EPU12

Table 6.1: *Sensors deployed for CarCASS for ALR, CTD and Underway measurements*

Underway measurements were on most of the time although were switched off due to issues with a water leak and the TA sensor failure, as shown in Table 5.2 below.

Time Started	Time Finished	Measurement Frequency & File Nos			Position	Underway Notes
		pH 36b	TA 11 & TA17	DIC 10 EPU12		
15.03.2022 16:00	16.03.2022 8:00	1 per hour NOCS0812	1 per 6 hours	1 per hour NOCS0322	WP1	Broken IE55 pin moved outside of bath
16.03.2022 9:00	17.03.2022 15:00	1 per hour NOCS0816	1 per 6 hours NOCS0735	1 per hour NOCS0327		
17.03.2022 17:00	**18.03.2022 08:00**	**Continuous NOCS0817**	**Continuous NOCS0736**	**Continuous NOCS0328**	**Transit across chlorophyll gradient**	**See plot: Figure 6.6**
18.03.2022	21.03.2022	1 per hour NOCS0818	1 per 6 hours NOCS0737	1 per hour NOCS0329 NOCS0330 NOCS0333	Transit across chlorophyll gradient	

22.03.2022 12:50	23.03.2022 8:50	1 per hour NOCS0836	1 per 6 hours NOCS0247 *	1 per hour NOCS0342		Leaking sink
24.03.2022 14:00	**28.03.2022 06:00**	**1 per hour NOCS0838**	**1 per 6 hours NOCS0253 * NOCS0255 * NOCS0256 ***	**1 per hour NOCS0346**	**Transit 1 – 10 across shelf**	**See plot: Figure 6.7**
28.03.2022	29.03.2022	1 per hour NOCS0840	1 per 6 hours NOCS0260 *	1 per hour NOCS0348	Transect 9 to 7	Repeat due to ALR CTD not turned on

Table 6.2: *NOCS Wet Chemical Sensors on the Underway*

*Swapped over to TA17

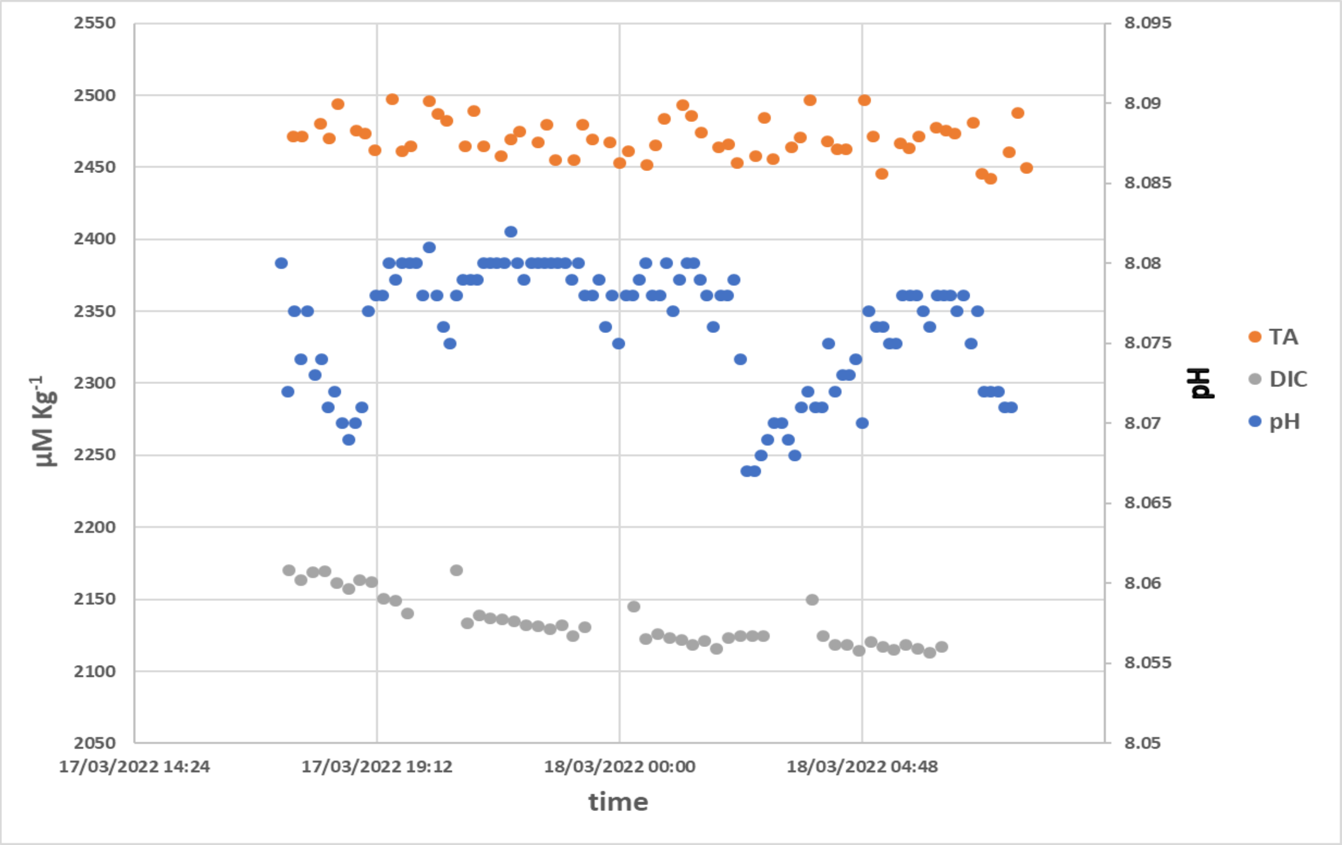


Figure 6.6: *20km transit across a chlorophyll gradient showing TA, DIC and pH changes measured from the NOC chemical sensors in the underway system.*

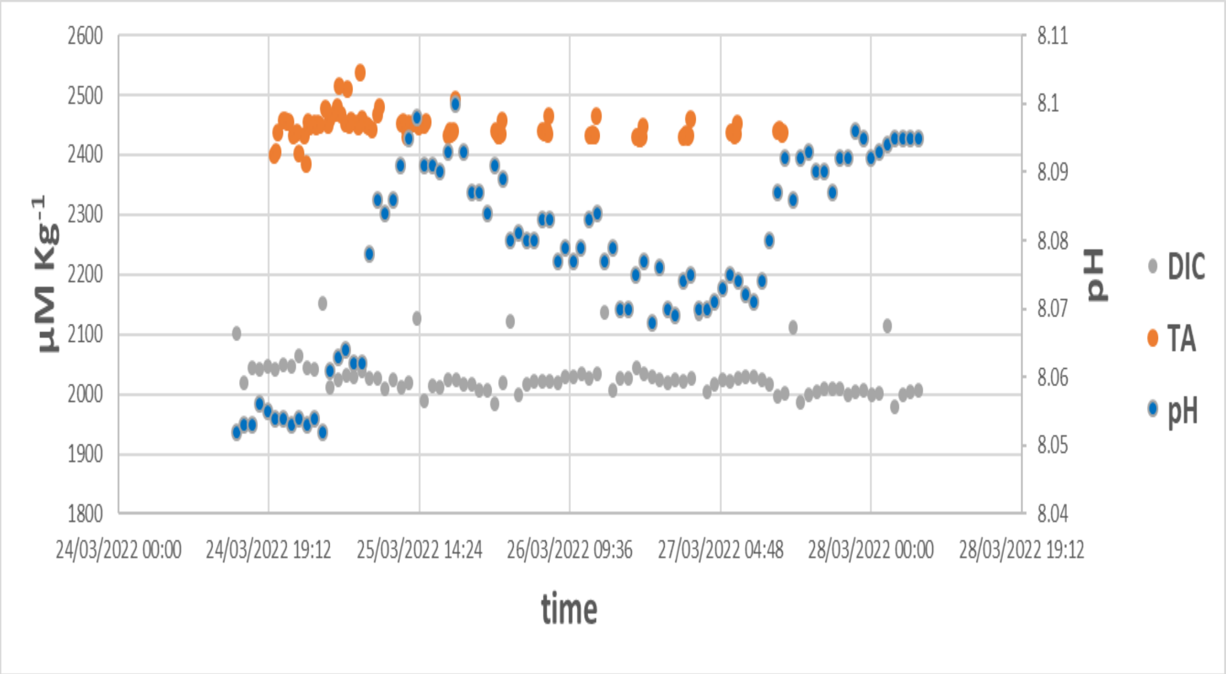


Figure 6.7: *200 km transit between T1 and T10 showing TA, DIC and pH changes measured over several days from the NOCS sensors in the underway system.*

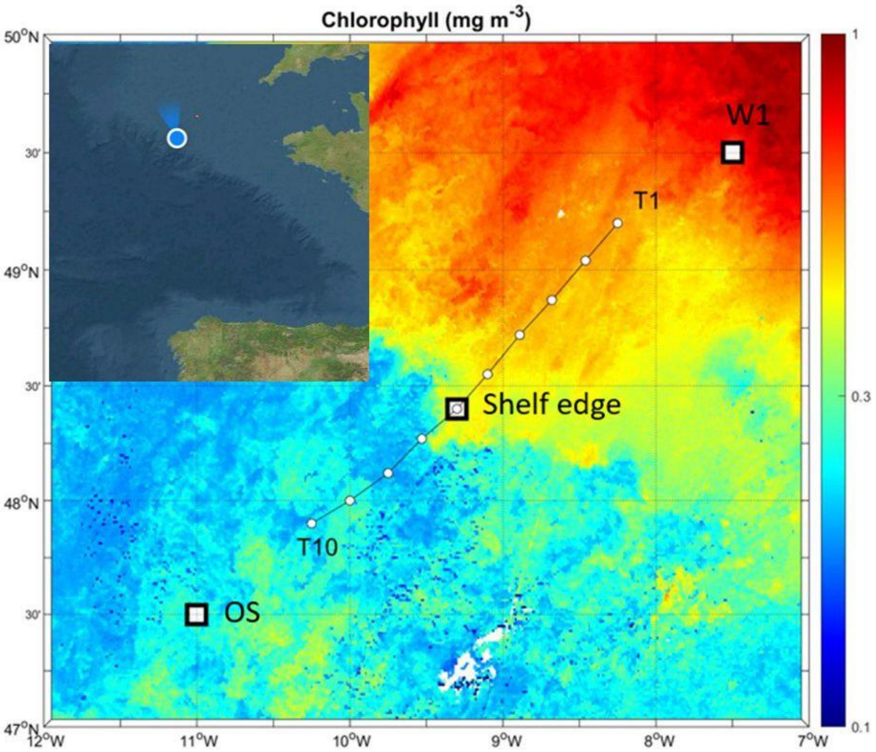


Figure 6.8: *Showing T1 to T10 transect and general position (see inset)*

A SeaFET was also deployed on the Underway in a separate system to the NOCS wet chemical sensors. Samples were taken from both underway systems every 6 hours..

Date	SeaFET	Measurement Frequency	Descrete Samples				SeaFET Notes
			00:00:00	06:00:00	12:00:00	18:00:00	
14/03/2022	N/A		N/A	N/A	N/A	N/A	
15/03/2022	721-100	1hr	N/A	N/A	U1	U2	Bucket change 14:30
16/03/2022	721-100	1hr	N/A	U3	U4	U5	No underway between 10:00 and 18:30
17/03/2022	721-100	2min	N/A	U6	U7	U8	Transit across chlorophyll gradient
18/03/2022	721-100	10min	U9	U10	U11	U12	Sampling underway from 10:10 every 10 min
19/03/2022	721-100	10 min	N/A	U13	U14	U15	Every 10 minutes
20/03/2022	721-100	10 min	N/A	U16	U17	U18	Every 10 minutes
21/03/2022	721-100	5 min	N/A	U19	U20	U21	Every 10 minutes
22/03/2022	721-100	5 min	N/A	U22 / U22d	U23& / U23d	U24 / U24d	Duplicate underways for BIOS bottles.
23/03/2022	721-100	2min	N/A	U25 / U25d	U26 / U26d	U27 / U27d	
24/03/2022	721-100	2min	N/A	U28 / U28d	U29 / U29d	U30 / U30d	
25/03/2022	721-100	2min	N/A	U31 / U31d	U32 / U32d	U33 / U33d	
26/03/2022	721-100	2min	N/A	U34 / U34d	U35 /U35d	U36 / U36d	
27/03/2022	721-100	2min	N/A	U37 / U37d	U38 / U38d	U39 / U39d	

28/03/2022	721-100	2min	N/A	U40 / U40d	U41 / U41d	U42 / U42d	
29/03/2022		2min	N/A	U43 / U43d	U44 / U44d	U45 / U45d	Last underway

Table 6.3: *NOCS Wet Chemical Sensors on the Underway*

6.4 CarCASS sensors on the CTD Rosette and CTD sampling for TA/DIC analysis

6.4.1 Objective:

Collect discrete water samples from CTD casts in effort to validate measurements made by sensors onboard the ALR surveying the corresponding regions. There will also be direct comparison between the CTD discrete water samples from each CTD cast and sensors onboard the same CTD cast. The discrete water samples will be analysed in a lab for Total Alkalinity (TA), Dissolved Inorganic Carbon (DIC), and pH upon return from DY149.

6.4.2 Sampling:

Discrete Water Samples

There was a total of 159 discrete water samples taken across 18 different CTD casts at various depths (Table 1). Water samples were collected in 250-300mL glass bottles and then injected with 250µL of Mercuric Chloride (a biocide) to preserve the carbonate state of the seawater. The bottles were sealed and securely packed away for analysis to take place in the laboratory.

Lab on Chip WETCHEM Sensor

The Ocean Technology and Engineering Group’s Total Alkalinity Lab on Chip sensor and pH Lab on Chip sensor were deployed for data collection on 2 different CTD casts (Table 6.4). During these CTD casts, there were stops made at various depths for a duration of 20 minutes each on the assent. This was done to allow the sensors to take 1-2 measurements at these depth since their measurement frequency is ~10 minutes. The delay at each depth also gives the sensor time to acclimate to the current conditions – such as temperature – that impact the measured variable.

Figure 6.9: *LOC Sensors deployed on CTD Rosette*

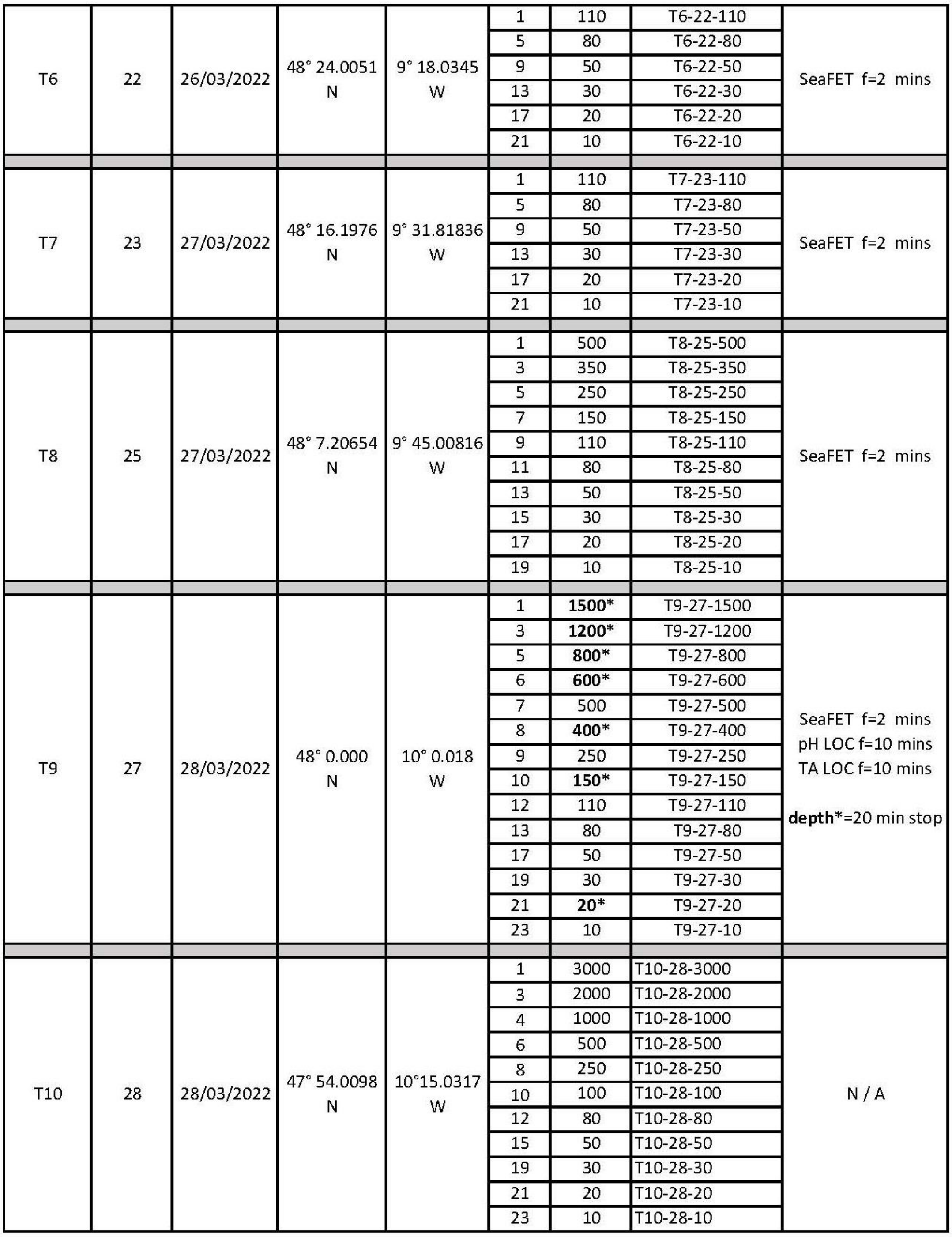
Sea-Bird SeaFET electrochemical pH Sensor

The deep SeaFET (V2 S/N 100) was clamped to the CTD frame and deployed with independent power source (12 D Cell Alkaline batteries in housing) on 16 different CTD Casts. (Table 6.4) The SeaFET measured every 2 minutes during deployments and was removed between casts to be kept submerged in seawater in the ship's lab to maintain calibration. The data collected by the SeaFET can offer another set of measurements that can be compared to by the LOC sensors and the validation water samples.

Figure 6.10: *Sea-Bird Scientific™ SeaFET V2 diagram and dimensions*

Station	CTD Cast	Date	Latitude	Longitude	Niskin	Depth m	Water Sample ID	Sensors Deployed
W1	2	16/03/2022	49° 30.547 N	7° 30.522 W	1	100	W1-2-100	SeaFET f=2 mins pH LOC f=10 mins (Test Only) TA LOC f=10 mins (Test Only)
					5	75	W1-2-75	
					9	50	W1-2-50	
					11	30	W1-2-30	
					17	10	W1-2-10	
					20	10	W1-2-0	
OS_A	5	18/03/2022	47° 30.0093 N	10° 48.0291 W	1	1000	OS_A-5-1000	N / A
					3	800	OS_A-5-800	
					5	600	OS_A-5-600	
					7	400	OS_A-5-400	
					9	250	OS_A-5-250	
					11	150	OS_A-5-150	
					13	100	OS_A-5-100	
					17	50	OS_A-5-50	
					21	20	OS_A-5-20	
					23	10	OS_A-5-10	
MID_AB	6	18/03/2022	47° 30.70 N	10° 41.00 W	1	1000	MID_AB-6-1000	N / A
					3	800	MID_AB-6-800	
					6	600	MID_AB-6-600	
					7	400	MID_AB-6-400	
					9	250	MID_AB-6-250	
					11	150	MID_AB-6-150	
					13	100	MID_AB-6-100	
					17	50	MID_AB-6-50	
					21	20	MID_AB-6-20	
					23	10	MID_AB-6-10	
OS_B	7	19/03/2022	47° 31.4119 N	10° 33.6531 W	1	1000	OS_B-7-1000	N / A
					3	800	OS_B-7-800	
					5	600	OS_B-7-600	
					7	400	OS_B-7-400	
					9	250	OS_B-7-250	
					11	150	OS_B-7-150	
					13	100	OS_B-7-100	
					17	50	OS_B-7-50	
					21	20	OS_B-7-20	
					23	10	OS_B-7-10	
OS_B	9	20/03/2022	47° 30.01 N	10° 33.006 W	1	1000	OS_B-9-1000	SeaFET f=2 mins
					3	800	OS_B-9-800	
					5	600	OS_B-9-600	
					7	400	OS_B-9-400	
					9	250	OS_B-9-250	
					11	150	OS_B-9-150	
					13	100	OS_B-9-100	
					17	50	OS_B-9-50	
					21	20	OS_B-9-20	
					23	10	OS_B-9-10	
OS_AB4	10	20/03/2022	47° 30.1347 N	10° 36.6344 W	1	1000	OS_AB4-10-1000	SeaFET f=2 mins
					2	800	OS_AB4-10-800	
					3	600	OS_AB4-10-600	
					5	400	OS_AB4-10-400	
					7	250	OS_AB4-10-250	
					9	150	OS_AB4-10-150	
					11	100	OS_AB4-10-100	
					16	50	OS_AB4-10-50	
					21	20	OS_AB4-10-20	
					23	10	OS_AB4-10-10	

OS_AB2	12	21/03/2022	47° 30.0036 N	10° 44.4011 W	1	**1000***	OS_AB2-12-1000	SeaFET f=2 mins pH LOC f=10 mins TA LOC f=10 mins **depth***=20 min stop
					2	**800***	OS_AB2-12-800	
					3	600	OS_AB2-12-600	
					5	**400***	OS_AB2-12-400	
					7	250	OS_AB2-12-250	
					9	**150***	OS_AB2-12-150	
					11	100	OS_AB2-12-100	
					16	50	OS_AB2-12-50	
					21	**20***	OS_AB2-12-20	
					23	10	OS_AB2-12-10	
OS_B	13	22/03/2022	47° 30.2658 N	10° 44.0403 W	1	1000	OS_B-13-1000	SeaFET *f*=2 mins
					2	800	OS_B-13-800	
					3	600	OS_B-13-600	
					5	400	OS_B-13-400	
					7	250	OS_B-13-250	
					9	150	OS_B-13-150	
					11	100	OS_B-13-100	
					16	50	OS_B-13-50	
					21	20	OS_B-13-20	
					23	10	OS_B-13-10	
T1	14	23/03/2022	49° 12.197 N	8° 14.218 W	1	100	T1-14-100	SeaFET f=2 mins
					5	75	T1-14-75	
					9	50	T1-14-50	
					13	30	T1-14-30	
					17	20	T1-14-20	
					21	10	T1-14-10	
T1	16	24/03/2022	49° 12.0094 N	8° 14.90734 W	1	110	T1-16-110	SeaFET f=2 mins
					5	80	T1-16-80	
					9	50	T1-16-50	
					13	30	T1-16-30	
					17	20	T1-16-20	
					21	10	T1-16-10	
T2	17	24/03/2022	49° 2.425 N	8° 27.604 W	1	110	T2-17-110	SeaFET f=2 mins
					5	80	T2-17-80	
					9	50	T2-17-50	
					13	30	T2-17-30	
					17	20	T2-17-20	
					21	10	T2-17-10	
T3	18	25/03/2022	48° 52.199 N	8° 40.818 W	1	110	T3-18-110	SeaFET f=2 mins
					5	80	T3-18-80	
					9	50	T3-18-50	
					13	30	T3-18-30	
					17	20	T3-18-20	
					21	10	T3-18-10	
T4	20	25/03/2022	48° 43.2045 N	8° 53.44428 W	1	110	T4-20-110	SeaFET f=2 mins
					5	80	T4-20-80	
					9	50	T4-20-50	
					13	30	T4-20-30	
					17	20	T4-20-20	
					21	10	T4-20-10	
T5	21	26/03/2022	48° 32.588 N	9° 5.444 W	1	110	T5-21-110	SeaFET f=2 mins
					5	80	T5-21-80	
					9	50	T5-21-50	
					13	30	T5-21-30	
					17	20	T5-21-20	
					21	10	T5-21-10	



T6	22	26/03/2022	48° 24.0051 N	9° 18.0345 W	1	110	T6-22-110	SeaFET f=2 mins
					5	80	T6-22-80	
					9	50	T6-22-50	
					13	30	T6-22-30	
					17	20	T6-22-20	
					21	10	T6-22-10	
T7	23	27/03/2022	48° 16.1976 N	9° 31.81836 W	1	110	T7-23-110	SeaFET f=2 mins
					5	80	T7-23-80	
					9	50	T7-23-50	
					13	30	T7-23-30	
					17	20	T7-23-20	
					21	10	T7-23-10	
T8	25	27/03/2022	48° 7.20654 N	9° 45.00816 W	1	500	T8-25-500	SeaFET f=2 mins
					3	350	T8-25-350	
					5	250	T8-25-250	
					7	150	T8-25-150	
					9	110	T8-25-110	
					11	80	T8-25-80	
					13	50	T8-25-50	
					15	30	T8-25-30	
					17	20	T8-25-20	
					19	10	T8-25-10	
T9	27	28/03/2022	48° 0.000 N	10° 0.018 W	1	**1500***	T9-27-1500	SeaFET f=2 mins pH LOC f=10 mins TA LOC f=10 mins **depth***=20 min stop
					3	**1200***	T9-27-1200	
					5	**800***	T9-27-800	
					6	**600***	T9-27-600	
					7	500	T9-27-500	
					8	**400***	T9-27-400	
					9	250	T9-27-250	
					10	**150***	T9-27-150	
					12	110	T9-27-110	
					13	80	T9-27-80	
					17	50	T9-27-50	
					19	30	T9-27-30	
					21	**20***	T9-27-20	
					23	10	T9-27-10	
T10	28	28/03/2022	47° 54.0098 N	10°15.0317 W	1	3000	T10-28-3000	N / A
					3	2000	T10-28-2000	
					4	1000	T10-28-1000	
					6	500	T10-28-500	
					8	250	T10-28-250	
					10	100	T10-28-100	
					12	80	T10-28-80	
					15	50	T10-28-50	
					19	30	T10-28-30	
					21	20	T10-28-20	
					23	10	T10-28-10	

Table 6.4: *CTD Cast and CarCASS Sampling*

Preliminary Analysis and Findings:

Discrete Water Samples

There are no reports yet of the discrete seawater analysis for TA, DIC, pH. These measurements will be conducted at the National Oceanography Centre by the Ocean Technology and Engineering group. The TA of the seawater samples will be determined using open cell titration. The DIC of the seawater samples will be determined using infrared detection of CO_2 purged from the acidified sample via the *Automated Infra Red Inorganic Carbon Analyzer* (AIRICA). The pH of the samples will be determined using spectrophotometry. All laboratorial analysis will be done using recorded SBE 9 corresponding CTD data to accurately determine values.

Lab on Chip WETCHEM Sensor

While reasonable TA raw data files were produced from the CTD casts by the LOC sensor, they require further analysis and refinement before confirmation of accurate data. This will be done at the National Oceanography Centre after the cruise. pH values were accurately produced and adjusted using the WETCHEM GUI and matching the measurement timestamps to those of the coinciding CTD cast to correct for temperature and salinity. The following MATLAB code was used to calculate the corrected pH, given the sensor thermistor temperatures, r adjusted values, and e values output by the GUI, and the temperature and salinity output by the SBE 9 on the CTD casts:

```
Thermistor_K = calc_ph.T_Thermistor + 273.15;
P_dBar=0;
e1 = (-0.007762)+(0.000045174*Thermistor_K)+(0.0000017*P_dBar);
e3_e2 =-0.020813+0.000260262.*Thermistor_K+0.00010436.*(calc_ph.S_psu
35)+(P_dBar.*0.0000046);

pK2e2= -246.64209+0.315971.*(calc_ph.S_psu)+0.00028855.*(calc_ph.S_psu).^2+(7229.23864-
7.098137.*(calc_ph.S_psu)-0.057034 ...
   .*(calc_ph.S_psu).^2)./Thermistor_K+(44.493382-0.052711.*(calc_ph.S_psu)).*log(Thermistor_K)-
0.0781344.*Thermistor_K...
   -(0.05645./Thermistor_K).*P_dBar;

a= (calc_ph.r_adjusted)-e1;
b=(1-(calc_ph.r_adjusted) .*e3_e2) ;

x=a./b;

pHT=pK2e2+log10(x);
delta_T_degC=(calc_ph.T_degC)-calc_ph.T_Thermistor;

In_Situ_pH = pHT-(0.01582.*delta_T_degC);
```

The depth profiles produced by the LOC pH sensor can be seen in the below figures on CTD cast 0012 and CTD cast 0027 alongside the SeaFET measurements and SBE 9 DO measurements.

Sea-Bird SeaFET electrochemical pH Sensor

The SeaFET made measurements every 2 minutes for each CTD cast. The SeaFET sensor was given deployment instructions via Sea-Bird's software platform UCI v2.0.4. The SeaFet calibration coefficients and other technical details were determined via the UCI command terminal and Tera Term. The sensor's raw data produces voltages and timestamps that then require extensive calculations paired with SBE 9's temperature, depth, and salinity. The calculations and values used to calculate the pH from the SeaFET's raw data are as follows:

$$pH_{CELL} = \frac{V_{FETREF} - k_0 - k_2 * t - f(P)}{S_{nernst}} + \log(Cl_T) + (2 * [\log(\gamma \pm HCl) T\&P]) - \log\left(1 + \frac{S_T}{K_{S,T\&P}}\right) - \log\left(\frac{1000\ (1.005 * S)}{1000}\right)$$

Where:

$$\boldsymbol{S_{nernst}} = \frac{\boldsymbol{R * T * \ln(10)}}{\boldsymbol{F}}$$

Where:

- R is the universal gas constant (8.3144621 J /(K mol))
- t is the temperature in ^{o}C
- T is the temperature in K
- S is the Salinity in psu
- P is the pressure in dbar
- p is the pressure in bar (used in formulas below)
- F is the Faraday constant (96485.365 C/mol)
- The constants k0 and k2 are the cell standard potential offset and temperature slope respectively
- f(P) is the sensor pressure response function (6th order polynomial):

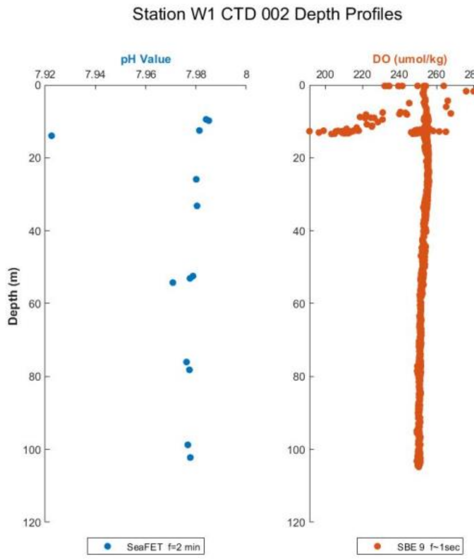
$$\boldsymbol{f(P) = f_1 P + F_2 P^2 + F_3 P^3 + F_4 P^4 + F_5 P^5 + F_6 P^6}$$

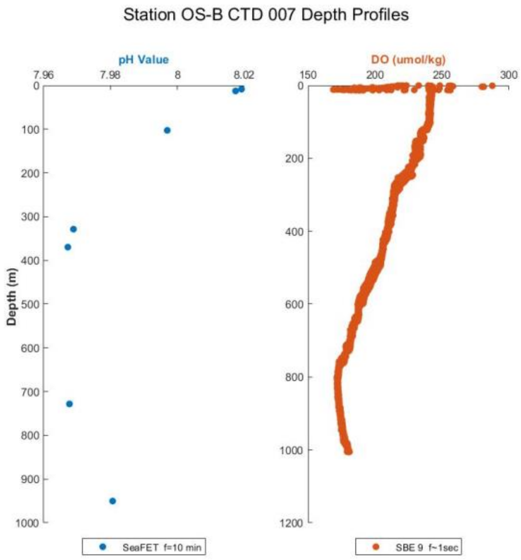
K_0, K_2, f_1, f_2, f_3, f_4, f_5, f_6 are given by SeaFET calibrations using command: GetCC.

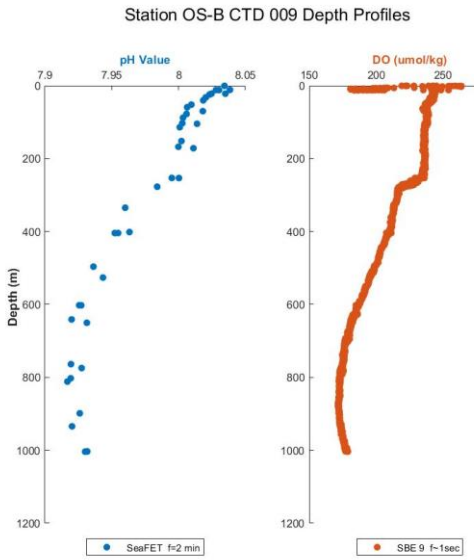
The remaining variables required to determine the pH in the above equations are as follows:

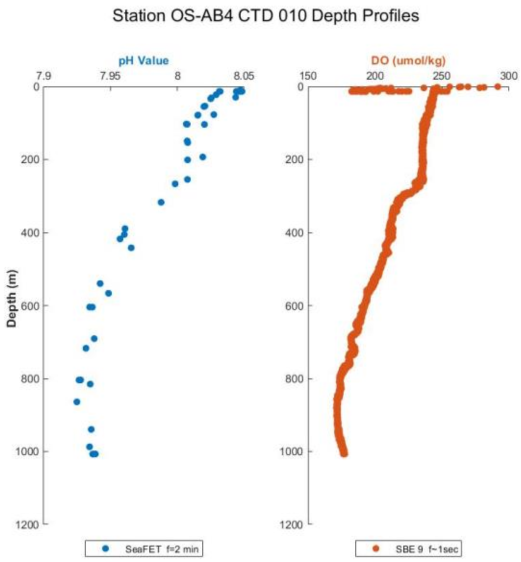
- Total chloride in seawater (Cl_T)
- Partial Molal Volume of HCl $(\overline{V}_{HCl})$
- Sample Ionic Strength (I)
- Debye-Huckel constant for activity of HCl (A_{DH})
- Logarithm of HCl activity coefficient as a function of temperature $(\log(y_{\pm HCl})_T$
- Logarithm of HCl activity coefficient as a function of temperature and pressure $(\log(y_{\pm HCl})_{T\&P})$
- Total sulfate in seawater (S_T)
- Acid dissociation constant of HSO_4^- (K_S)
- Partial Molal Volume of HSO_4^- $(\overline{V}_S)$
- Compressibility of HSO_4 $(\overline{K}_S)$
- Acid dissociation content of HSO_4^- $(K_{S,T\&P})$

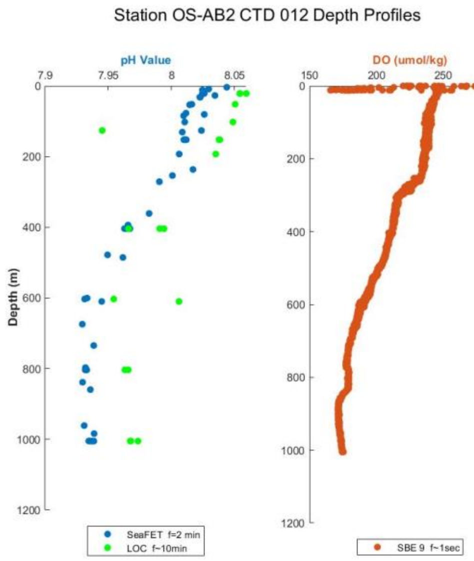
The adjusted pH values determined by the SeaFET , corresponding SBE 9 data, and calculations are plotted against depth for several CTD casts in the preliminary plots below. Please note that the points plotted also include that of what the sensors picked up on the descent to depth, which may not as accurately represent the seawater conditions as well as those measurements taken from the controlled delayed stops on the accent.

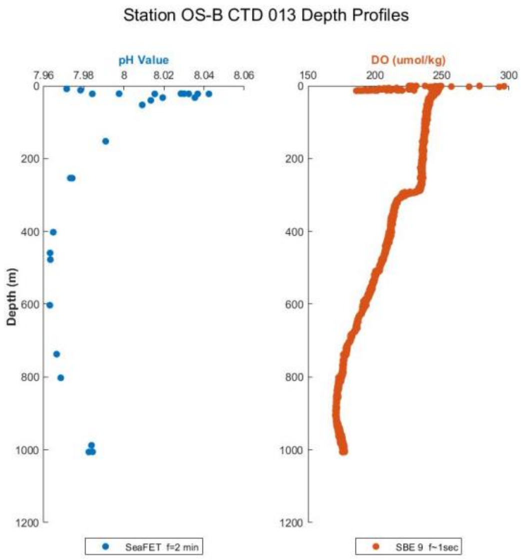

Station W1 CTD 002 Depth Profiles
pH Value
7.92
7.94
7.96
7.98
8
Depth (m)
0
20
40
60
80
100
120
SeaFET f=2 min
DO (umol/kg)
200
220
240
260
280
300
SBE 9 f~1sec

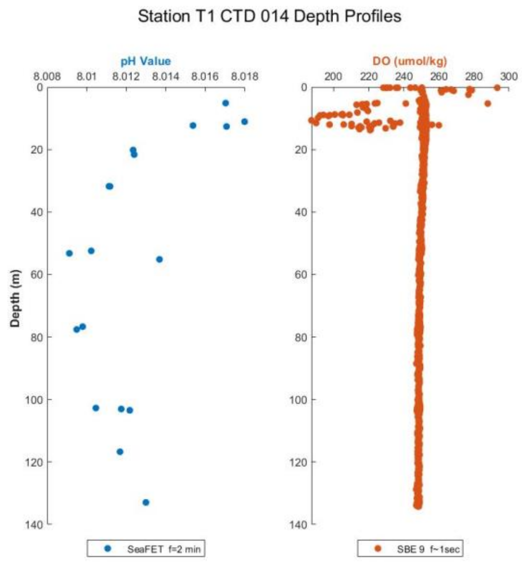

Station OS-B CTD 007 Depth Profiles
pH Value
7.96
7.98
8
8.02
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
SeaFET f=10 min
DO (umol/kg)
150
200
250
300
0
200
400
600
800
1000
1200
SBE 9 f~1sec

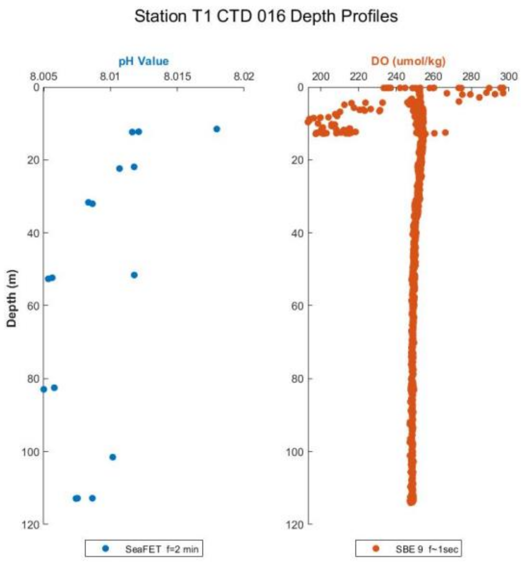

Station OS-B CTD 009 Depth Profiles
pH Value
7.9
7.95
8
8.05
Depth (m)
0
200
400
600
800
1000
1200
SeaFET f=2 min
DO (umol/kg)
150
200
250
300
SBE 9 f~1sec

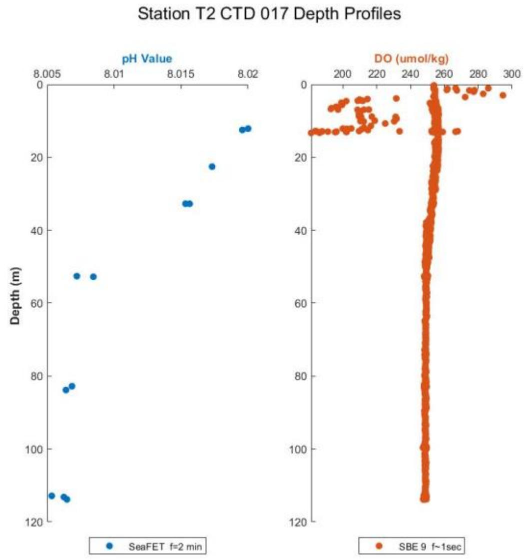

Station OS-AB4 CTD 010 Depth Profiles
pH Value
7.9
7.95
8
8.05
Depth (m)
0
200
400
600
800
1000
1200
SeaFET f=2 min
DO (umol/kg)
150
200
250
300
SBE 9 f~1sec

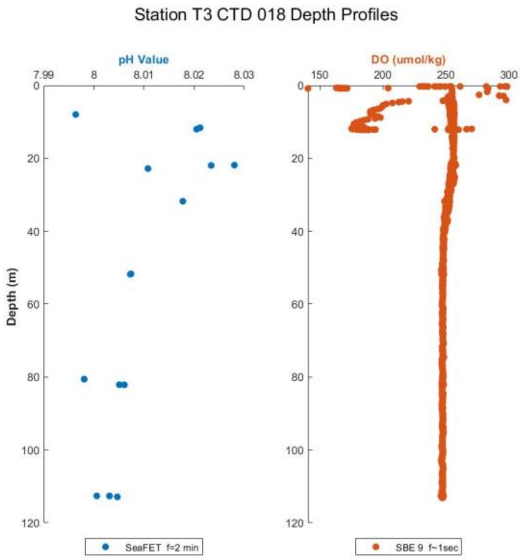

Station OS-AB2 CTD 012 Depth Profiles
pH Value
7.9
7.95
8
8.05
Depth (m)
0
200
400
600
800
1000
1200
SeaFET f=2 min
LOC f~10min
DO (umol/kg)
150
200
250
300
SBE 9 f~1sec

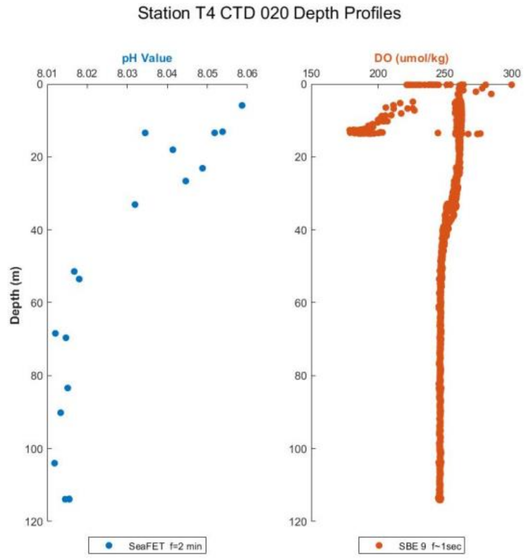

Station OS-B CTD 013 Depth Profiles
pH Value
7.96
7.98
8
8.02
8.04
8.06
Depth (m)
0
200
400
600
800
1000
1200
SeaFET f=2 min
DO (umol/kg)
150
200
250
300
SBE 9 f~1sec

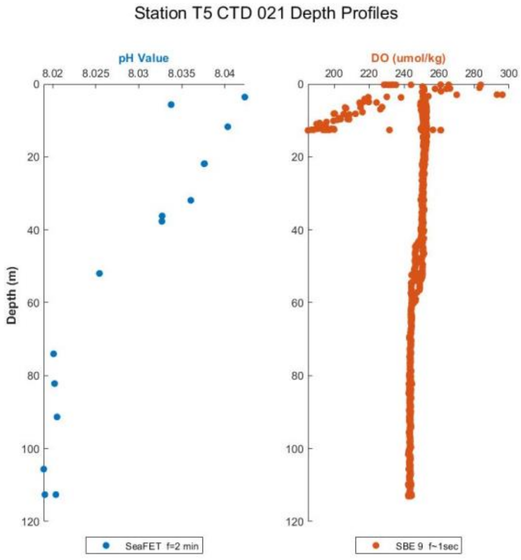

Station T1 CTD 014 Depth Profiles
pH Value
8.008
8.01
8.012
8.014
8.016
8.018
DO (umol/kg)
200
220
240
260
280
300
Depth (m)
0
20
40
60
80
100
120
140
SeaFET f=2 min
SBE 9 f~1sec

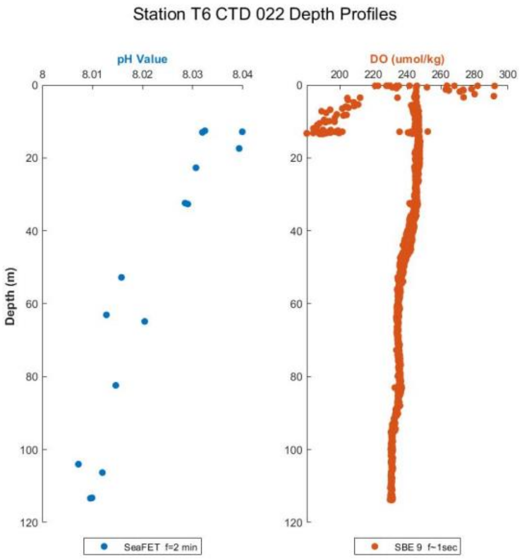

Station T1 CTD 016 Depth Profiles
pH Value
8.005
8.01
8.015
8.02
DO (umol/kg)
200
220
240
260
280
300
Depth (m)
0
20
40
60
80
100
120
SeaFET f=2 min
SBE 9 f~1sec

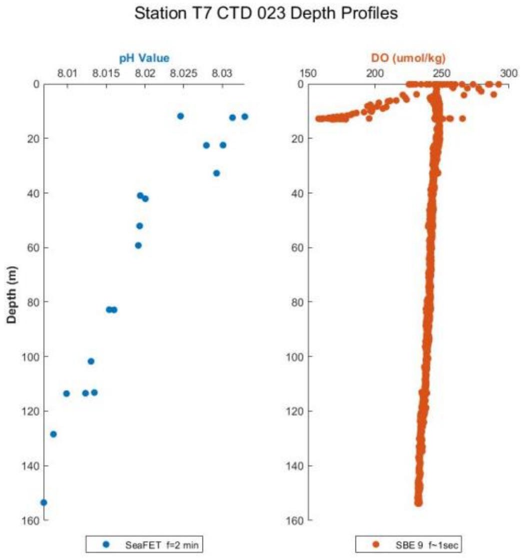

Station T2 CTD 017 Depth Profiles
pH Value
8.005
8.01
8.015
8.02
DO (umol/kg)
200
220
240
260
280
300
Depth (m)
0
20
40
60
80
100
120
SeaFET f=2 min
SBE 9 f~1sec

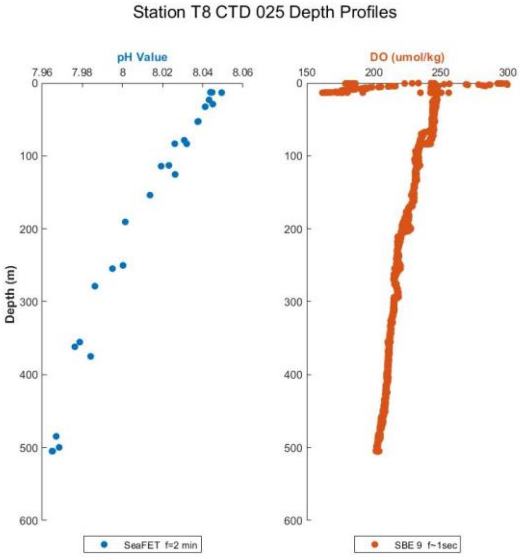

Station T3 CTD 018 Depth Profiles
pH Value
7.99
8
8.01
8.02
8.03
DO (umol/kg)
150
200
250
300
Depth (m)
0
20
40
60
80
100
120
SeaFET f=2 min
SBE 9 f~1sec

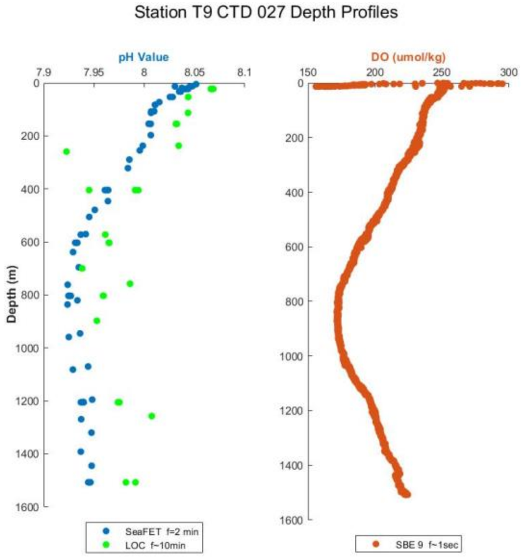

Station T4 CTD 020 Depth Profiles
pH Value
8.01
8.02
8.03
8.04
8.05
8.06
DO (umol/kg)
150
200
250
300
Depth (m)
0
20
40
60
80
100
120
SeaFET f=2 min
SBE 9 f~1sec


Station T5 CTD 021 Depth Profiles
pH Value
8.02
8.025
8.03
8.035
8.04
DO (umol/kg)
200
220
240
260
280
300
Depth (m)
0
20
40
60
80
100
120
SeaFET f=2 min
SBE 9 f~1sec


Station T6 CTD 022 Depth Profiles


Station T7 CTD 023 Depth Profiles


Station T8 CTD 025 Depth Profiles


Station T9 CTD 027 Depth Profiles

References

1 Yin, T., Papadimitriou, S., Rérolle, V. M. C., Arundell, M., Cardwell, C. L., Walk, J., Palmer, M. R., Fowell, S. E., Schaap, A., Mowlem, M. C. & Loucaides, S. A Novel Lab-on-Chip Spectrophotometric pH Sensor for Autonomous In Situ Seawater Measurements to 6000 m Depth on Stationary and Moving Observing Platforms. *Environ. Sci. Technol.*, doi:10.1021/acs.est.1c03517 (2021).

2 Culberson, C., Pytkowicz, R. M. & Hawley, J. E. Seawater alkalinity determination by pH method. *J. Mar. Res.* **28**, 15-+ (1970).

3 Sayles, F. L. & Eck, C. An autonomous instrument for time series analysis of TCO2 from oceanographic moorings. *Deep-Sea Research Part I-Oceanographic Research Papers* **56**, 1590-1603, doi:10.1016/j.dsr.2009.04.006 (2009).

4 Millero, F. J., Lee, K. & Roche, M. Distribution of alkalinity in the surface waters of the major oceans. *Mar. Chem.* **60**, 111-130 (1998).

7. CTD bottle sampling

Neil Wyatt, Mark Moore, Alan Wright, Jacob Harper (University of Southampton)

A total of 28 CTD casts were deployed during DY149. Of these, 21 were with the stainless steel CTD and 7 with the titanium framed CTD. The metadata associated with each cast can be found in the following Table 7.1.

Date	Lat °N	Lon° E	CTD #	Site	Time in water (GMT)	Time on deck (GMT)	Max depth (m)	Type	Notes
15/3/2022	49 29.980	07 29.966	1	Shakedown	1838	1913	114	Stainless	
16/3/2022	49 30.547	07 30.522	2	W1	1513	1543	100	Stainless	
16/3/2022	49 30.844	07 26.404	3	Shakedown	1844	1913	100	Titanium	Bottle soak
17/3/2022	47 30.090	10 59.990	4	OS Bottle rinse	1542	1704	1000	Stainless	Bottle rinse following battery explosion
18/3/2022	47 30.101	10 48.029	5	OS-A	0806	0925	1000	Stainless	
18/3/2022	47 31.048	10 40.556	6	OS mid A-B	1706	-	1000	Stainless	Time on deck incomplete on log sheet
19/3/2022	47 31.411	10 33.653	7	OS-B	0905	-	1000	Stainless	Time on deck incomplete on log sheet
19/3/2022	47 30.811	10 33.708	8	OS-B	1438	1555	1000	Titanium	
20/3/2022	47 30.012	10 33.006	9	OS-B	0934	1100	1000	Stainless	
20/3/2022	47 30.136	10 36.635	10	OS-AB4	1516	1649	1000	Stainless	
20/3/2022	47 30.140	10 36.630	11	OS-AB4	1726	1830	1000	Titanium	
21/3/2022	47 30.000	10 44.400	12	OS-AB2	1608	1854	1000	Stainless	
22/3/2022	47 30.265	10 33.041	13	OS-B	0705	0958	1000	Stainless	
23/3/2022	49 12.197	8 15.218	14	T1	0906	0943	130	Stainless	
23/3/2022	49 12.020	8 15.090	15	T1	1038	1105	100	Titanium	
24/3/2022	49 12.010	8 14.987	16	T1	0842	0917	110	Stainless	
24/3/2022	49 02.425	8 27.604	17	T2	1757	1828	110	Stainless	
25/3/2022	48 52.199	8 40.818	18	T3	0616	0648	110	Stainless	
25/3/2022	48 43.204	8 53.444	19	T4	1102	-	110	Titanium	Time on deck incomplete on log sheet
25/3/2022	48 43.205	8 53.444	20	T4	1210	1250	110	Stainless	
26/3/2022	48 32.588	8 5.444	21	T5	0842	0913	110	Stainless	Check Longitude
26/3/2022	48 24.005	9 16.036	22	T6	1613	1644	110	Stainless	
27/3/2022	48 16.198	9 31.818	23	T7	0701	0739	150	Stainless	
27/3/2022	48 7.206	9 45.008	24	T8	1453	1520	110	Titanium	
27/3/2022	48 7.206	9 45.008	25	T8	1535	1632	500	Stainless	
27/3/2022	48 7.206	9 45.008	26	T8	1649	1709	500	Titanium	Test cast for AMT pH sensor
28/3/2022	48 0.000	10 0.018	27	T9	0609	0956	1500	Stainless	
28/3/2022	47 54.008	10 15.030	28	T10	1138	-	3000	Stainless	Time on deck incomplete on log sheet

Table 7.1: *CTD casts*

7.1 Biological sampling from CTD

For each stainless steel CTD cast, seawater was typically collected from 6 or 7 depths from the near surface down to 150 m to filter for pigments (chlorophyll-a via fluorometric analysis, chlorophyll and accessory pigments via High-Performance-Liquid-Chromatography) and particulate absorption spectra via spectroscopy (PABS). Sampling and protocols typically followed those employed previously (see e.g. Moore et al., 2007 a & b) and are described briefly later in this section.

Date (JDay)	Site	Event	CTD cast	Niskin Bottle	Nominal Depth (m)	Variables Filtered
75	W1	003	2	21, 17, 13, 10, 8, 4	7, 10, 30, 50, 75, 100	Chl-a, HPLC, PABS
77	OS_A	005	5	24, 22, 18, 16, 14, 12	10, 20, 50, 75, 100, 150	Chl-a, HPLC, PABS
77	OSmid A+B	009	6	24, 22, 18, 16, 14, 12	10, 20, 50, 75, 100, 150	Chl-a, HPLC, PABS
78	OS_B	010	7	24, 22, 20, 16, 14, 12	10, 20, 30, 75, 100, 150	Chl-a, HPLC, PABS
79	OS_B	012	9	24, 22, 18, 16, 14, 12	10, 20, 50, 75, 100, 150	Chl-a, HPLC, PABS
79	OS_AB 4	014	10	24, 22, 18, 14, 12, 10	10, 20, 50, 75, 100, 150	Chl-a, HPLC, PABS
80	OS_AB 2	016	12	24, 22, 18, 14, 12, 10	10, 20, 50, 75, 100, 150	Chl-a, HPLC, PABS
81	OS_B	017	13	24, 22, 18, 14, 12, 10, 8	10, 20, 50, 75, 100, 150, 250	Chl-a, HPLC, PABS
82	T1	018	14	24, 20, 16, 11, 8, 4	10, 20, 30, 50, 75, 100	Chl-a, HPLC, PABS
83	T1	20	16	24, 20, 16, 12, 8, 4	10, 20, 30, 50, 80, 100	Chl-a, HPLC, PABS
83	T2	22	17	24, 20, 16, 12, 8, 4	10, 20, 30, 50, 80, 110	Chl-a, HPLC, PABS
84	T3	23	18	24, 20, 16, 12, 8, 4	10, 20, 30, 50, 80, 110	Chl-a, HPLC, PABS
84	T4	25	20	24, 20, 16, 12, 8, 4	10, 20, 30, 50, 80, 110	Chl-a, HPLC, PABS
85	T5	26	21	24, 20, 16, 12, 8, 4	10, 20, 30, 50, 80, 110	Chl-a, HPLC, PABS
85	T6	27	22	24, 20, 16, 12, 8, 4	10, 20, 30, 50, 80, 110	Chl-a, HPLC, PABS
86	T7	28	23	24, 20, 16, 12, 8, 4	10, 20, 30, 50, 80, 110	Chl-a, HPLC, PABS
86	T8	30	25	24, 18, 14, 12, 10, 8	10, 20, 50, 80, 110, 150	Chl-a, HPLC, PABS
87	T9	32	27	24, 22, 20, 18, 15, 11	10, 20, 30, 50, 80, 150	Chl-a, HPLC, PABS
87	T10	33	28	24, 22, 20, 17, 13, 11	10, 20, 30, 50, 80, 100	Chl-a, HPLC, PABS

Table 7.2: *overall list of CTD samples collected*

High Performance Liquid Chromatography (HPLC):

For phytoplankton pigment analysis (chlorophylls, carotenoids), 1000 mL of seawater was filtered onto Whatman GF/F filters for later extraction and analysis of pigments by HPLC. After filtration, HPLC filters were placed into Nalgene^{TM} Cryoware^{TM} vials, flash frozen in liquid nitrogen and stored at -80°C prior to later analyses.

Particulate Absorption (PABS):

Water samples of between 0.25 and 0.5 L were filtered through Whatman glass fibre GF/F filters using a glass manifold on the filtration rig, then placed into Nuclon^{TM} Delta Surface petri dishes, flash frozen in liquid nitrogen and stored in the -80ºC freezer. The *in vivo* light absorption spectrum of phytoplankton and non-algal particles will be measured using a UV-VIS spectrophotometer back in Oxford.

Chlorophyll-*a* analysis:

In order to provide an index of phytoplankton biomass over the spatio-temporal area covered by the vessel and the water column itself, seawater samples for the determination of chlorophyll-*a* concentrations were collected and processed from CTD and underway samples. Briefly, 100 mL of seawater was filtered onto Whatman glass fibre GF/F filters and the filters extracted in 6 mL of 90 % acetone over 24 hours at 4°C in a fridge in the dark. Measurements of chlorophyll-*a* were subsequently made on board using a Turner Designs Trilogy fluorometer set up with a non-acidification kit (after Welschmeyer, 1994). The fluorometer was calibration against a pure chlorophyll-*a* extract in November 2021. A Turner solid standard (Part No. 8000-952) was used at the start and end of each set of readings as well as an 90% acetone blank sample to monitor for instrument drift. Both of these readings are subsequently used in the calculations to determine chlorophyll-*a* concentrations (see Equation 1).

Chlorophyll-*a* concentrations in mg m^{-3} (µg L^{-1}) were calculated as:

$$Chl\ a = Dilution * \ (R)adj * \ (F - blank) * \ (\frac{v}{V}) \qquad \text{Equation (1)}$$

Dilution = 1 (unless required for an over-range sample)

(R) adj = response factor adjusted for the shift in the solid standard

F = sample fluorescence

blank = acetone blank reading

v = acetone extracted volume (6 mL)

V = filtered sample volume in mL

References:

Welschmeyer 1994 Limnology and Oceanography 39 1985–1992

Moore et al., 2007a Deep-Sea Research II 54 (2007) 2066–2084

Moore et al., 2007b Deep-Sea Research II 54 (2007) 2045–2065

7.2 Trace metal CTD sampling

Neil Wyatt, Mark Moore (University of Southampton)

Overview:

Marine primary production drives carbon fixation in the ocean and is the base of the marine food web. It is therefore an important component of the Earth system (Falkowski and Raven, 2007). Trace metals, such as iron, are required for numerous vital cellular processes (e.g. photosynthesis, respiration, nitrogen fixation), and are therefore essential for the growth of marine microbes (Twining and Baines, 2013, Tortell et al., 1996). Understanding the distribution of trace metals in the ocean is vital in understanding carbon cycling and how this may change under future climate scenarios.

To study trace metal cycling in the DY149 study area, seawater was collected for trace metal and phytoplankton cell analyses to quantify metal distribution and phytoplankton cellular stoichiometry, respectively. Water column samples were collected using OTE-Niskin bottles (10 L OTE bottles with external springs for trace metal sampling, mounted onto a titanium frame with Kevlar conducting wire). All sample processing was conducted in a trace metal clean laboratory using clean handling techniques.

A total of 7 CTD deployments were carried out with the titanium frame. The first deployment was intended to soak the bottles overnight to ensure that they were 'trace metal clean' for future deployments. The seventh and final Ti-CTD cast of DY149 was used to conduct testing of a pH sensor and had no OTE-Niskin bottles attached. This left 5 Ti-CTD casts for trace metals sampling during DY149. On these 5 Ti-CTD casts, unfiltered seawater samples were collected for the analysis of total dissolvable trace metals (TdTM) whilst samples for the determination of dissolved trace metals (dTM) were filtered through a 0.2 µm cartridge filter (Sartorius). A total of 34 TdTM and 42 dTM samples were collected during DY111. Samples were acidified on-board to 0.024 M using ultra-pure HCl (UpA, Romil) and will be later analysed at National Oceanographic Centre, Southampton. In addition, two salt samples from the 5 casts were also collected for salinity sensor calibration.

Phytoplankton cells were collected by filtering 1 L of seawater through acid-washed 5 µm polycarbonate filters (Nuclepore, Whatman) using a purpose built trace metal clean Teflon filtration rig. Phytoplankton collected on the filter were gently flushed into acid-washed Sterilin vials with 0.2 µm filtered seawater and made up to 30 mL resulted in a phytoplankton concentration 33 times the original value. The concentrated phytoplankton samples were fixed by addition of trace metal clean 10% glutaraldehyde (Twining et al., 2011) to a final concentration of 0.4%, left in the fridge overnight to allow cross-linking of cell structures and then stored at -80° C until analysis. In total, 22 phytoplankton cell samples were collected. Corresponding measurements were collected for phytoplankton photophysiology from all Ti-CTD casts, except CTD-015, by collecting 50 mL of unfiltered seawater from each OTE bottle into dark HDPE bottles. These samples were kept in continuously flowing underway seawater until analysis by single turnover active chlorophyll fluorescence, typically within 30 min of collection.

Date	Station	CTD	dTM	TdTM	Phytoplankton	Fv/Fm	Salt
19/3/2022	OS-B	08	12	12	5	5	2
20/3/2022	OS-AB4	11	12	4	5	5	2
23/3/2022	T1	15	6	6	4	-	2
25/3/2022	T4	19	6	6	4	4	2
27/3/2022	T8	24	6	6	4	4	2

Table 7.3: Trace metal sampling summary.

References:

Twining et al. (2011). Deep sea Research II, 58, 325-341.

8. Satellite Data Provision:

Jacob Harper (University of Southampton)

Processed week-day satellite coverage for ocean colour and sea surface temperature in the area between 2º to 14º W and 46º to 52º N was provided for the duration of the cruise by the NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS). A table of the satellites used is provided below (Table 8.1).

Satellite	Instrument	Output
Sentinel-3A	Ocean and Land Colour Instrument (OLCI)	Chlorophyll (mg m^{-3})
Sentinel-3B		
Sentinel-3A	Sea and Land Surface Temperature Radiometer (SLSTR)	Sea Surface Temperature (SST ºC)
Sentinel-3B		
NOAA-20	Visible Infrared Imaging Radiometer Suite (VIIRS)	Chlorophyll (mg m^{-3})
Suomi NPP		
Multi-scale Ultra-high Resolution (MUR) SST Analysis		Sea Surface Temperature (SST ºC)

Table 8.1: *Satellite products used*

The Near Real Time (NRT) data included a 1-day composite of the previous day as well as a 7-day composite, both at 1km resolution. 1-day images showed high detail of fronts and eddies but were often limited in their coverage by cloud cover while 7-day images provided a less detailed or sometimes blurred picture for the entire area. The MUR data is a multisensor product which includes microwave imaging and provides data regardless of cloud conditions. However, these images were available one day later than the other data.

Satellite Data Usage:

The satellite data for ocean colour and SST was plotted each day it was available with examples found in Figures 8.1 and 8.2. The chlorophyll images allowed comparison to the underway transmission and fluorescence data as well as the 6-hourly chlorophyll-a sampling. Locations of high chlorophyll provided by the satellite images were used to plan transects for the Autosub Long Range (ALR) and for ship sampling, targeting gradients in the phytoplankton biomass.

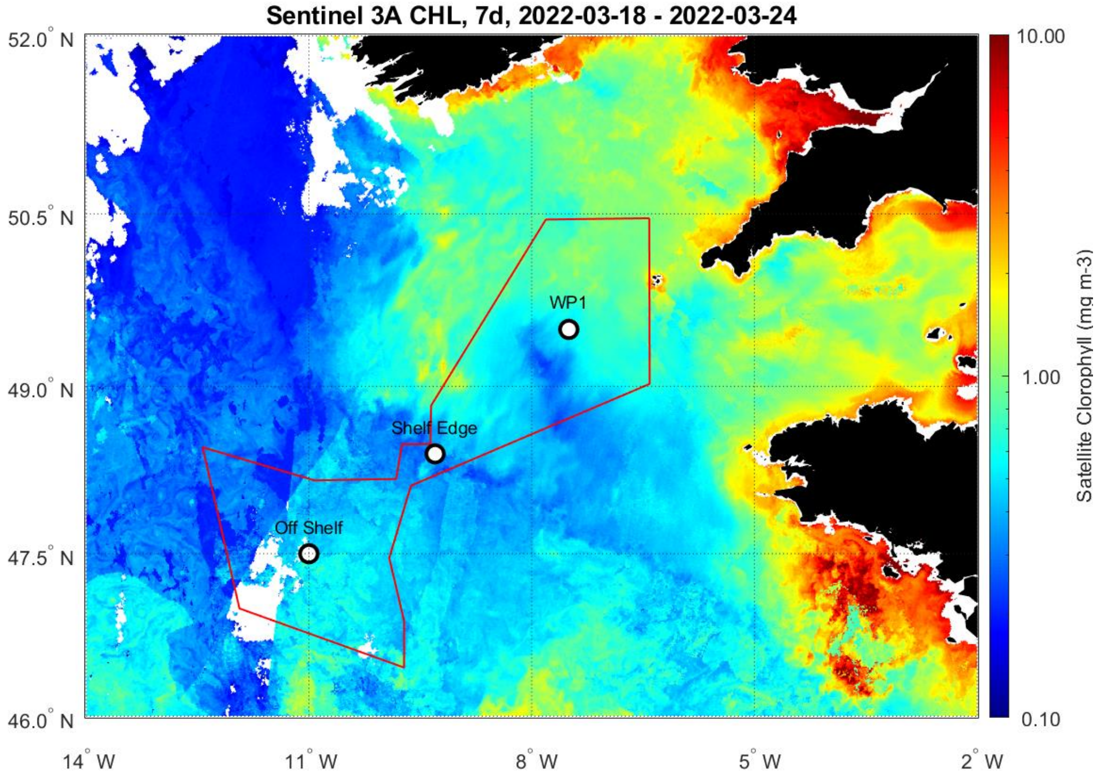


Figure 8.1: *7-day composite satellite derived chlorophyll for the period of the 18th to the 24th of March 2020. The Cruise boundary is shown in red while the three main stations are indicated with white markers. This image was provided by NEODAAS from the Sentinel-3A satellite Ocean and Land Colour Instrument.*

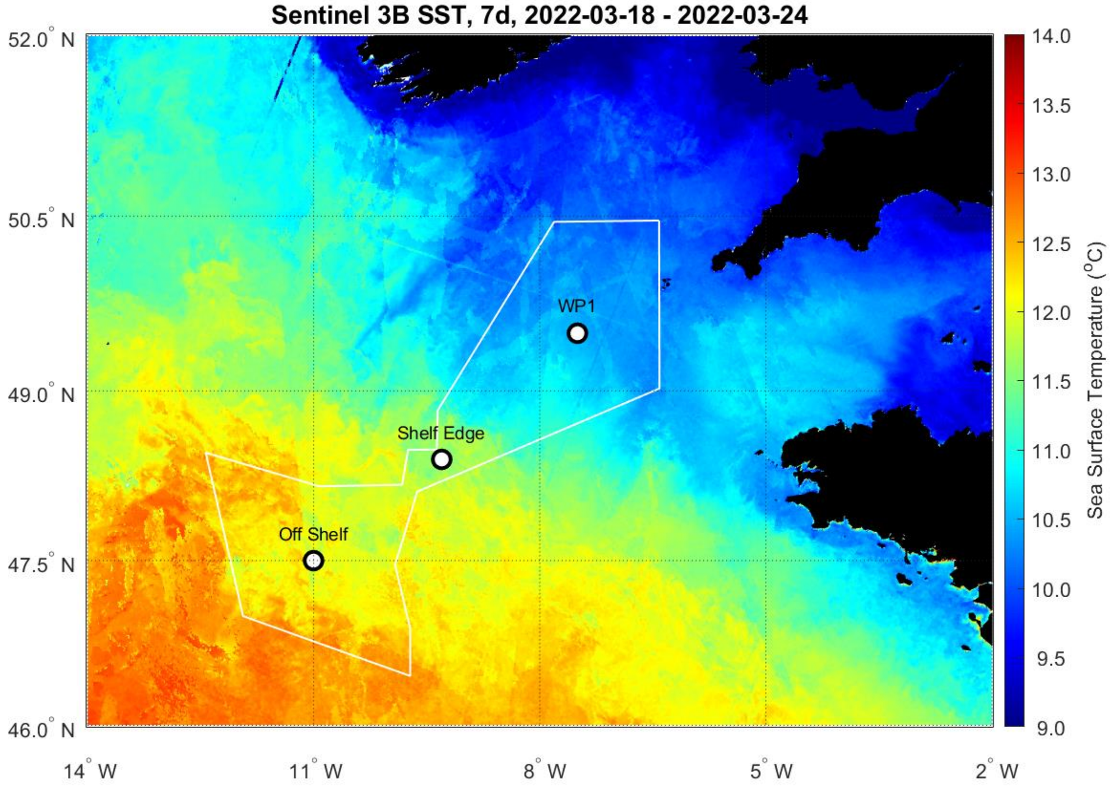


Figure 8.2: *7-day composite satellite derived sea surface temperature for the period of the 18th to the 24th of March 2020. The Cruise boundary is shown in white while the three main stations are indicated with white markers. This image was provided by NEODAAS from the Sea and Land Surface Temperature Radiometer.*

9. NMFSS Ship Systems Computing and Underway Instruments

Nick Harker (NOC)

9.1 Overview

Ship Scientific Systems (SSS) is responsible for operating and managing the Ship's scientific information technology infrastructure, data acquisition, compilation and delivery, and the suite of ship-fitted instruments and sensors in support of the Marine Facilities Programme (MFP)

All times in this report are in UTC.

9.2 Scientific computer systems

Underway data acquisition

The data acquisition systems used on this cruise are detailed in the table below. The data and data description documents are filed per system in the *Data* and *Documentation* directories respectively within Ship Systems folder on the cruise data disk.

Data acquisition system	*Usage*	*Data products*	*Directory system name*
Ifremer TechSAS	Continuous	NetCDF ASCII pseudo-NMEA	/TechSAS/
NMF RVDAS	Continuous	ASCII Raw NMEA	/RVDAS/
Kongsberg SIS (EM122)	Discrete	Kongsberg .all	/Acoustics/EM-122/
Kongsberg SIS (EM710)	Discrete	Kongsberg .all	/Acoustics/EM-710/
Kongsberg SBP	Unused	None	/Acoustics/SBP-120/
Kongsberg EA640	Continuous	None, redirected to Techsas/RVDAS RAM	/Acoustics/EA-640/
Kongsberg EK80	Unused		/Acoustics/EK-60/
UHDAS (ADCPs)	Continuous	ASCII raw, RBIN, GBIN, CODAS files	/Acoustics/ADCP/
VMDAS (ADCPs)	Unused		/Acoustics/ADCP/
Sonardyne Ranger2	Discrete	redirected to Techsas/RVDAS RAM	/Acoustics/USBL/

Table 9.4: *Data acquisition systems used on this cruise.*

Data description documents per system:
/Ship_Systems/Documentation/[System]/Data_Description

Data directories per system:
/Ship_Systems/Data/[System]/

Significant acquisition events and gaps

No significant gaps in continuous ocean monitoring data (underway and ADCP), multibeam used discontinuously, dependant on weather.

9.3 Instrumentation

9.3.1 Position, attitude and time

System	**Navigation (Position, attitude, time)**		
Statement of Capability	*/Ship_Systems/Documentation/GPS_and_Attitude*		
Data product(s)	NetCDF: */Ship_Systems/Data/TechSAS/NetCDF/* Pseudo-NMEA: */Ship_Systems/Data/TechSAS/NMEA/* Raw NMEA: */Ship_Systems/Data/RVDAS/NMEA/*		
Data description	*/Ship_Systems/Documentation/TechSAS* */Ship_Systems/Documentation/RVDAS*		
Other documentation	*/Ship_Systems/Documentation/GPS_and_Attitude*		
Component	*Purpose*	*Outputs*	*Headline Specifications*
Applanix PosMV	Primary GPS and attitude.	Serial NMEA to acquisition systems, multibeam and ADCP.	Positional accuracy within 2 m.
Kongsberg Seapath 330	Secondary GPS and attitude.	Serial and UDP NMEA to acquisition systems and multibeam	Positional accuracy within 1 m.
Oceaneering CNav 3050	Correction service for primary and secondary GPS and dynamic positioning.	To primary and secondary GPS	Positional accuracy within 0.15 m.

Fugro Seastar / MarineStar	Correction service for primary and secondary GPS and dynamic positioning.	To primary and secondary GPS	Positional accuracy within 0.15 m.
Meinberg NTP Clock	Provide network time	NTP protocol over the local network.	

9.3.2 Ocean and atmosphere monitoring systems: SURFMET

System	**SURFMET (Surface water and atmospheric monitoring)**	
Statement of Capability	*/Ship_Systems/Documentation/Surfmet*	
Data product(s)	NetCDF: */Ship_Systems/Data/TechSAS/NetCDF/* Pseudo-NMEA: */Ship_Systems/Data/TechSAS/NMEA/* Raw NMEA: */Ship_Systems/Data/RVDAS/NMEA/* Underway records & Autosal: */Ship_Systems/Data/Autosal*	
Data description	*/Ship_Systems/Documentation/TechSAS* */Ship_Systems/Documentation/RVDAS*	
Underway events and other documentation	*/Ship_Systems/Documentation/Surfmet*	
Calibration info	See Ship Fitted Sensor sheet for calibration info for each sensor.	
Component	*Purpose*	*Outputs*
Inlet temperature probe (SBE38)	Measure temperature of water at hull inlet	UDP NMEA to SBE45
Drop keel temperature probe (SBE38)	Measure temperature of water in drop keel space	UDP NMEA to Surfmet VM
Thermosalinograph (SBE45)	Measure temp, sal and conductivity at sampling board	Serial to Interface Box
Interface Box (SBE 90402)	Signals management	Serial to Moxa
Transmissometer (CST)	Measure of transmittance	Voltage output to Surfmet VM
Fluorometer (WS3S)	Measure of fluorescence	Voltage output to Surfmet VM
Air temperature and humidity probe (HMP155)	Temperature and humidity at met platform	Analogue to NUDAM
Ambient light sensors (PAR, TIR)	Ambient light at met platform	Analogue to NUDAM
Barometer (PTB210)	Atmospheric pressure at met platform	Analogue to NUDAM
Anemometer (Windsonic)	Wind speed and direction at met platform	Serial to Moxa

The NMF Surfmet system was run throughout the cruise, except times for cleaning, entering and leaving port, and whilst alongside. Please see the separate information sheet for details of the sensors used and whether their recorded data have calibrations applied or not.

9.3.3 Hydroacoustic systems

System	**Acoustics**
Statement of Capability	*/Ship_Systems/Documentation/Acoustics*
Data product(s)	Raw: */Ship_Systems/Data/Acoustics* NetCDF (EA640, EM122cb): */Ship_Systems/Data/TechSAS* NMEA (EA640, EM122cb): */Ship_Systems/Data/RVDAS* Sound Velocity Profiles used: */Ship_Systems/Data/Acoustics/Sound_Velocity*
Data description	*/Ship_Systems/Documentation/Acoustics*
Other documentation	*/Ship_Systems/Documentation/Acoustics*

Component	*Purpose*	*Outputs*	*Operation*
10/12 kHz Single beam (Kongsberg EA-640)	Primary depth sounder	NMEA over serial, raw files	Discrete Free running
12 kHz Multibeam (Kongsberg EM-122)	Full-ocean-depth multibeam swath.	Binary swath, centre-beam NMEA, *.all files, optional water column data	Discrete Free running
70 kHz Multibeam (Kongsberg EM-710)	Coastal/shallow multibeam swath.	Binary swath, centre-beam NMEA, *.all files.	Free running
Sub-bottom Profiler (Kongsberg SBP-120)	Multi-frequency echogram to provide along-track sub-bottom imagery.	BMP, raw files, optional water column data.	Unused
Drop keel sound velocity sensor	Provide sound velocity at transducer depth	Value over serial to Kongsberg SIS.	Continuous
Sound velocity profilers (Valeport Midas, Lockheed XBT)	Direct measurement of sound velocity in water column.	ASCII pressure vs sound velocity files. Manually loaded into Kongsberg SIS or Sonardyne Ranger2.	Unused
75 kHz ADCP (Teledyne OS75)	Along-track ocean current profiler	(via UHDAS)	Continuous Free running
150 kHz ADCP (Teledyne OS150)	Along-track ocean current profiler	(via UHDAS)	Continuous Free running
USBL (Sonardyne Ranger2)	Underwater positioning system to track deployed packages or vehicles.	NMEA over serial	Discrete

9.3.4 Marine Mammal Protection

/Ship_Systems/Documentation/Acoustics/MMOs

System	*Actions taken to protect mammals, in compliance with NERC and JNCC protocols*
12 kHz Multibeam (Kongsberg EM-122)	60-minute bridge observation. Marine mammal protection ramped start initiated at 45 minutes into observation if no mammals sighted. Clock restarted if mammals sighted.
Sub-bottom Profiler (Kongsberg SBP-120)	System not used.

MMO surveys were performed before use and restart of EM122 if it had been off for more than 10 minutes.

9.3.5 ADCPs

Path of ADCP data on the cruise datastore:
/Ship_Systems/Data/Acoustics/ADCP

Attribute	*Value*
Acquisition software	UHDAS
Frequencies used	75 kHz, 150 kHz
Running mode	Free-running (untriggered)
Configuration details	os150: Narrow band 40 bins, length 8m, 4m blanking, os75: narrow band, 60bins, length 16m, 8m blanking. Performance from beam 1 is currently degraded so running a 3 beam solution. Bottom tracking was used leaving port in Southampton to allow calibration data to be collected.

9.3.6 Other Systems

Cable Logging and Monitoring

Winch activity (except Trace Metal Free winch) is monitored and logged using the CLAM system.

10. Sensors and Moorings

Paul Henderson

10.1 CTD Cast Summary

Total number of casts: 29

Stainless steel frame casts: 22

Titanium frame casts: 7

Deepest casts:

Stainless steel frame – 3000m (Cast 028)

Titanium frame – 1000m (Cast 011)

CTD Technicians: Paul Henderson / Jade Garner

*Cast 029 (2500m) to fix scrolling error – no data or bottles

10.2 Stainless Steel CTD

CTD Wire

CDT Wire 2 was used for all casts. The mechanical and electrical termination was the same as used in DY149. Resistance and insulation of the cable were checked periodically. The torque setting on the fasteners of the mechanical termination was checked throughout and no slippage was noted. The termination is to be removed at the end of the DY149 to allow for a sample of the cable to be sent for destructive testing. The was an error with the scrolling on cast 028 (3000m). An extra cast, 029 (2500m), was carried out to correct this – no data was collected from this cast

CTD Wire 2 before cast 001 readings:

Resistance 75.1 Ohms	Insulation >550 MOhms @500 VDC

CTD Wire 2 readings after cast 029:

Resistance 75.9 Ohms	Insulation >550 MOhms @500 VDC

S&M sensor set-up

CTD frame was set-up post DY146 with primary conductivity and temperature sensors on the 9plus and secondary conductivity and temperature sensors on the vane. Other sensors on the frame were dissolved oxygen, altimeter, fluorometer, transmissometer, backscatter and 2 x PAR. Full sensor information can be found on the Sensor Information Sheet – Appendix 1. All sensors functioned well without any problems. No sensors were swapped out during the cruise. PAR sensors were removed for casts deeper than 500m.

Water Samplers

OTE 20L Water Samplers were use on the SS frame and performed well through out the cruise with only one bottle not firing (Bottle 12 Cast 014). Bottles 03 and 08 where removed from the frame after cast 005 and replaced with spares. Bottle 03 had a broken tap and bottle 08 was scorched. There was no time on the cruise to repair bottles 03 and 08 so they will be sent ashore after DY149. A number of the water samplers' taps had their o-rings replaced over the cruise.

10.2.1 User supplied equipment

Wet chemistry

Wet chemistry sensors (nitrate, phosphate, silicate, pH, DIC and TA) developed by OTE for the Autonuts and CarCASS projects were deployed on the stainless steel frame in place of bottles on many casts.

Initially these sensors were powered by individual battery packs. The battery packs were withdrawn after cast 002. To continue this work, it was calculated that two sensors could be power by the spare 9plus analog port (JT4) when PAR was not required. A cable was made up to supply 14.5VDC to a hub developed by OTE which transferred power to the wet chemistry sensors.

Typical current draw on 9plus analogue ports:

Dissolved Oxygen	4 mA
Altimeter	60 mA
Transmissometer	35 mA (50 mA Max)
BBRTD	50 mA
Fluorometer	250 mA (400 mA Max)
Wet Chemistry 1	200 mA
Wet Chemistry 2	200 mA
Total	799 mA (964 mA) [out of an available 1000 mA]

Hub and cables for wet chemistry sensors

Wet chemistry sensors prior to deployment

SeaFET

SBE SeaFET v2 was deployed on most CTD casts for CarCASS. This was positioned horizontally in clamps between the 9plus and transmissometer/fluorometer. The clamps were made during the cruise by OEG. The sensors had to be removed from the frame to keep the sensor in good condition between casts.

SeaFET on CTD frame

ANB pH

ANB pH sensor was attached, with jubilee clips horizontally to the CTD frame between the 9plus and transmissometer/fluorometer opposite the SeaFET. This was to compare pH data with the SeaFET and wet chemistry pH for CarCASS. The sensor was powered by a Xeros beacon battery pack after its initial battery pack was deemed unsafe.

ANB pH sensor on CTD frame

Sound velocity

A recently calibrated Valeport MIDAS SVP (sound velocity probe) was carried on the CTD for SSS. The data from this was compared to a CTD calculated sound velocity profile. Probe was attached to outside of frame with steel cable and jubilee clips.

USBL Beacons

Two USBL beacons were tested on the CTD frame: QsY2 for SSS and ALR2211 for MARS ALR. Both beacons worked well and depths read within 1m of the CTD depths and each other most of the time. Beacons were attached to outside of frame with jubilee clips.

Battery Incident

A battery pack (XPRIZE Battery Housing) suffered a catastrophic failure following deployment on cast 002. The incident happened around seven hours after the CTD was recovered to deck (~23:00 16/03/2022). It was reported after the event that a member of the science party noticed signs of water ingress on the battery pack. It is likely that salt water reacted with the lithium batteries producing gas which led to an explosion. No one was injured in the incident. There was superficial damage to the frame and water sampler 08. All similar battery packs were withdrawn for the remainder of the cruise. The CTD returned to action the following day after it was cleaned up and all sensors and cables were inspected for damage. A health and safety investigation is being carried out.

Pictures show the damaged nitrate sensor after the incident along with damage to CTD frame and water sampler

10.3 Trace Metal Free CTD

CTD Cable and Winch

The 21mm Lebus MFCTD Contingency Winch was set up on the hanger top and maintained by OEG. There were no mechanical issues with the winch over the course of the cruise. The cable was terminated twice as there were a number of modulo errors on cast 003 and a poor insulation value. The cable performed well on all subsequent casts after the second termination. A Yalegrip was used as a backup to the mechanical termination.

21mm Lebus MFCTD Cable after first termination:

Resistance 149.7 Ohms Insulation >220 MOhms @250 VDC / ~400 MOhms @500 VDC

21mm Lebus MFCTD Cable after cast 003:

Resistance 150.1 Ohms Insulation ~28 MOhms @ 50VDC

21mm Lebus MFCTD Cable after second termination:

Resistance 149.2 Ohms Insulation >220 MOhms @500 VDC / ~400 MOhms @500 VDC

21mm Lebus MFCTD Cable after cast 026:

Resistance 149.5 Ohms Insulation >220 MOhms @500 VDC / ~400 MOhms @500 VDC

Titanium frame ready for deployment with Yalegrip as backup

S&M sensor set-up

The Titanium CTD frame was set up with same configuration as the stainless steel frame. Primary conductivity and temperature sensors on the 9plus and secondary conductivity and temperature sensors on the vane. Other sensors on the frame were dissolved oxygen, altimeter, fluorometer, transmissometer, backscatter and 2 x PAR. Full sensor information can be found on the Sensor Information Sheet – Appendix 2. All sensors functioned well without any problems. No sensors were swapped out during the cruise. PAR sensors were removed for cast deeper than 500m. A pH Sensor was trialled on cast 026

Water Samplers

10L Trace Metal Free Water Samplers 01 – 12 were used on the titanium frame. Water samplers 13 and 14 were cleaned to be used as spares. All bottles fired successfully on all cast. Bottles were stored and sampled in the clean laboratory by the science party.

AMT pH Sensor

AMT pH-combined sensor S/N 346 was trialled on cast 026 on the titanium frame. On previous cruises the pH sensors were reading 5V (maxed out) when deployed on the stainless steel frame. On this cast the sensor read between 2.6 and 2.85V (pH 8.0 – 8.4). The sensor was not calibrated before the cast so a manufacturers calibration from February 2022 was used. The data was spikey with step changes.

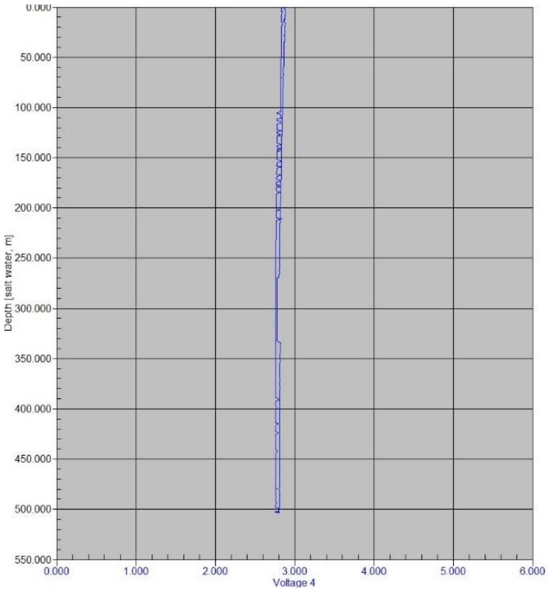


Figure 10.1: *Raw voltage from pH sensor*

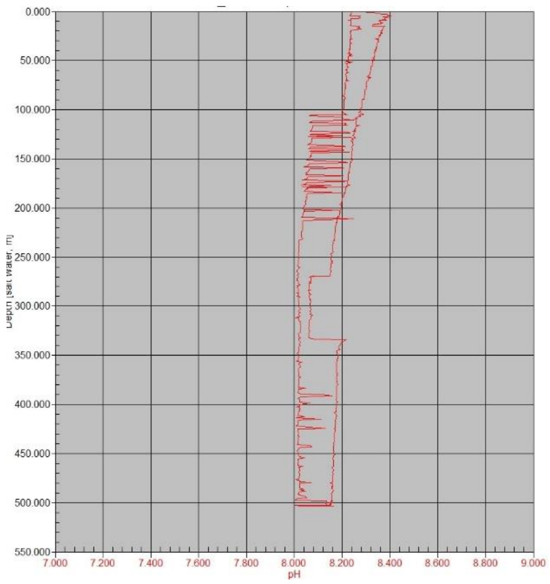


Figure 10.2: *uncalibrated pH from sensor*

10.4 SBE Data Processing

Basic post-processing of the CTD cast data was carried out following guidelines established with BODC (ref. Moncoiffe 7th July 2010). Additionally, CTD2MET processing was carried out for each cast as well as processing to obtain sound velocity profiles for the acoustic systems.

The data was processed using SBE Data Processing, V7.26.7. The following modules were used to process the data:

- Data Conversion
- Bottle Summery
- Align CTD
- CellTM
- Derive
- Bin Average
- Strip

Configuration reports can be found in Appendix 3 (stainless steel) and Appendix 4 (Titanium)

10.5 Autosal

A Guildline Autosal 8400B salinometer, S/N: 71185, was used for salinity measurements. The salinometer was sited in the Salinometer lab. Bath temperature was set at 21°C, the ambient temperature being approximately 18.5-19.0°C. The salinometer was standardised before the first set of samples, and checked with an additional standard analysed prior to setting the RS. Once standardised the Autosal was not adjusted for the duration of sampling.

A standard was analysed after each crate of samples to monitor & record drift. Standards were recorded in the spreadsheet as ‘0’ and had a standard salinity value of 34.994 from batch P165. Standard deviation was set to 0.0002.

A program written in Labview called “Autosal” was used to record data for salinity values. Salinity samples were taken and analysed from most casts and the results tabulated in spreadsheets SALFORM_SS.xlsx.

10.6 CTD UPS

The UPS for the CTD slave computer (SBE CTD Topside Rack 1B) was replaced, following issues with the previous UPS on DY146, with Eaton 9130 S/N GJ513A0441.

10.7 FASTOcean Fluorometer

CTG FASTOcean PTX Fast Repetition Rate Fluorimeter FRRF3 S/N 16-0485-001 was brought for benchtop use by the science party with S/N 19-0424-001 as back-up. Neither instruments were utilised on the cruise.

Appendix 10.1

SENSOR INFORMATION SHEET – Stainless Steel Frame

SHIP: RRS DISCOVERY	CRUISE: DY149

FORWARDING INSTRUCTIONS / ADDITIONAL INFORMATION:

Main Stainless Steel 24-way CTD frame on DY149

Checked By: Paul Henderson/Jade Garner	DATE: 29-March-2022

Instrument / Sensor	Manufacturer/ Model	Serial Number	Channel	Casts Used
Primary CTD deck unit	SBE 11plus	11P-24680-0588	n/a	All casts
CTD Underwater Unit	SBE 9plus	09P-24680-0637	n/a	All stainless casts
Titanium EM CTD Swivel	Machinery Development Services/V2_2	1267-2	n/a	All casts
Stainless steel 24-way frame	NOCS	SBE CTD6	n/a	All stainless casts
Primary Temperature Sensor	SBE 3P	03P-4593	F0	All stainless casts
Primary Conductivity Sensor	SBE 4C	04C-2571	F1	All stainless casts
Digiquartz Pressure sensor	Paroscientific	79501	F2	All stainless casts
Secondary Temperature Sensor	SBE 3P	03P-4712	F3	All stainless casts
Secondary Conductivity Sensor	SBE 4C	04C-3272	F4	All stainless casts
Primary Pump	SBE 5T	05T-3085	n/a	All stainless casts
Secondary Pump	SBE 5T	05T-3607	n/a	All stainless casts
24-way Carousel	SBE 32	32-31240-0423	n/a	All stainless casts
Primary Dissolved Oxygen Sensor	SBE 43	43-3836	V0	All stainless casts
Free	NA	NA	V1	NA
Fluorometer	CTG Aquatracka MKIII	088244	V2	All stainless casts
Altimeter	Teledyne Benthos PSA-916T	59494	V3	All stainless casts
PAR Upward-looking DWIRR	CTG 2pi PAR	PAR02	V4	All stainless casts <500m
PAR Upward-looking UWIRR	CTG 2pi PAR	PAR04	V5	All stainless casts <500m
Transmissometer	WETLabs CStar	CST-1719TR	V6	All stainless casts

Light Scattering Sensor	WETLabs BBRTD	BBRTD-1055	V7	All stainless casts
20L Water Samplers	OTE	Set D	n/a	All stainless casts

Appendix 10.2

SENSOR INFORMATION SHEET – Titanium Frame

SHIP: RRS DISCOVERY	CRUISE: DY149

FORWARDING INSTRUCTIONS / ADDITIONAL INFORMATION:

Main Titanium/Metal Free 24-way CTD frame on DY149

Checked By: Paul Henderson/Jade Garner	DATE: 29-March-2022

Instrument / Sensor	Manufacturer/ Model	Serial Number	Channel	Casts Used
Primary CTD deck unit	SBE 11plus	11P-24680-0588	n/a	All casts
CTD Underwater Unit	SBE 9plus	09P34173-0758	n/a	All metal free casts
Titanium 24-way frame	NOCS	CTD TITA 1	n/a	All metal free casts
Primary Temperature Sensor	SBE 3P	03P-5494	F0	All metal free casts
Primary Conductivity Sensor	SBE 4C	04C-3768	F1	All metal free casts
Digiquartz Pressure sensor	Paroscientific	90074	F2	All metal free casts
Secondary Temperature Sensor	SBE 3P	03P-5495	F3	All metal free casts
Secondary Conductivity Sensor	SBE 4C	04C-3529	F4	All metal free casts
Primary Pump	SBE 5T	05T-6320	n/a	All metal free casts
Secondary Pump	SBE 5T	05T-6916	n/a	All metal free casts
24-way Carousel	SBE 32	32-60380-0805	n/a	All metal free casts
Dissolved Oxygen Sensor	SBE 43	43-2831	V0	All metal free casts
Free	NA	NA	V1	NA
Fluorometer	CTG Aquatracka MKIII	88-2050-095	V2	All metal free casts

Altimeter	Teledyne Benthos PSA-916T	62679	V3	All metal free casts
PAR Upward-looking DWIRR	CTG 2pi PAR	PAR05	V4	All metal free casts <500m
PAR Downward-looking UWIRR	CTG 2pi PAR	PAR09	V5	All metal free casts <500m
Transmissometer	WETLabs CStat	CST-1837TR	V6	All metal free casts
Light Scattering Sensor	WETLabs BBRTD	BBRTD-758R	V7	All metal free casts
10L TMF Water Samplers	OTE	NA	n/a	All metal free casts
pH-combined sensor	AMT	346	V4	Cast 026 only

Appendix 10.3

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Date: 03/30/2022

Instrument configuration file: C:\Users\sandm\Documents\Cruises\DY149\Data\Seasave Setup
Files\DY149_SS_0637_nmea_PAR.xmlcon

Configuration report for SBE 911plus/917plus CTD
------------------------------------------------

Frequency channels suppressed : 0
Voltage words suppressed      : 0
Computer interface            : RS-232C
Deck unit                     : SBE11plus Firmware Version >= 5.0
Scans to average              : 1
NMEA position data added      : Yes
NMEA depth data added         : No
NMEA time added               : Yes
NMEA device connected to      : PC
Surface PAR voltage added     : No
Scan time added               : Yes

1) Frequency 0, Temperature
   Serial number : 03P-4593
   Calibrated on : 12-May-2021
   G            : 4.35399637e-003
   H            : 6.44584672e-004
   I            : 2.17867036e-005
   J            : 1.76162691e-006
   F0           : 1000.000
```

Slope : 1.00000000
Offset : 0.0000

2) Frequency 1, Conductivity
Serial number : 04C-2571
Calibrated on : 22-Apr-2021
G : -9.94000277e+000
H : 1.54257691e+000
I : -2.28658601e-004
J : 1.28188621e-004
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

3) Frequency 2, Pressure, Digiquartz with TC
Serial number : 79501
Calibrated on : 24-Jan-2020
C1 : -6.052595e+004
C2 : -1.619787e+000
C3 : 1.743190e-002
D1 : 2.819600e-002
D2 : 0.000000e+000
T1 : 3.011561e+001
T2 : -5.788717e-004
T3 : 3.417040e-006
T4 : 4.126500e-009
T5 : 0.000000e+000
Slope : 0.99977900
Offset : -1.24262
AD590M : 1.293660e-002
AD590B : -9.522570e+000

4) Frequency 3, Temperature, 2
Serial number : 03P-4712
Calibrated on : 07-May-2021
G : 4.40432474e-003
H : 6.33750828e-004
I : 1.93980572e-005
J : 1.21554176e-006
F0 : 1000.000
Slope : 1.00000000
Offset : 0.0000

5) Frequency 4, Conductivity, 2

Serial number : 04C-3272
Calibrated on : 13-Apr-2021
G : -9.77399824e+000
H : 1.27209077e+000
I : 1.87324341e-004
J : 4.72878715e-005
CTcor : 3.2500e-006
CPcor : -9.57000000e-008
Slope : 1.00000000
Offset : 0.00000

6) A/D voltage 0, Oxygen, SBE 43
Serial number : 43-3836
Calibrated on : 30-Mar-2021
Equation : Sea-Bird
Soc : 4.18500e-001
Offset : -5.04000e-001
A : -4.90320e-003
B : 2.06780e-004
C : -2.90040e-006
E : 3.60000e-002
Tau20 : 1.09000e+000
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

7) A/D voltage 1, Free

8) A/D voltage 2, Fluorometer, Chelsea Aqua 3
Serial number : 088244
Calibrated on : 07 August 2020
VB : 0.176199
V1 : 2.032520
Vacetone : 0.245650
Scale factor : 1.000000
Slope : 1.000000
Offset : 0.000000

9) A/D voltage 3, Altimeter
Serial number : PSA-916T 59494
Calibrated on :
Scale factor : 15.000
Offset : 0.000

10) A/D voltage 4, PAR/Irradiance, Biospherical/Licor
Serial number : 02
Calibrated on : 27-Jun-2019
M : 0.45712800
B : 1.08610800
Calibration constant : 100000000000.00000000
Conversion units : Watts/m^2
Multiplier : 0.99890000
Offset : 0.00000000

11) A/D voltage 5, PAR/Irradiance, Biospherical/Licor, 2
Serial number : 04
Calibrated on : 03-Sep-2020
M : 0.51512300
B : 1.00565600
Calibration constant : 100000000000.00000000
Conversion units : Watts/m^2
Multiplier : 0.99830000
Offset : 0.00000000

12) A/D voltage 6, Transmissometer, WET Labs C-Star
Serial number : CST-1719TR
Calibrated on : 15th March 2022
M : 21.1708
B : -0.0783
Path length : 0.250

13) A/D voltage 7, OBS, WET Labs, ECO-BB
Serial number : 1055
Calibrated on : 15/07/2019
ScaleFactor : 0.003639
Dark output : 0.043000
Scan length : 45

Appendix 10.4

```
Date: 03/30/2022

Instrument configuration file: C:\Users\sandm\Documents\Cruises\DY149\Data\Seasave Setup
Files\DY149_TITA_0758_nmea_PAR.xmlcon

Configuration report for SBE 911plus/917plus CTD
------------------------------------------------

Frequency channels suppressed : 0
Voltage words suppressed      : 0
Computer interface            : RS-232C
Deck unit                     : SBE11plus Firmware Version >= 5.0
Scans to average              : 1
NMEA position data added      : Yes
NMEA depth data added         : No
NMEA time added               : Yes
NMEA device connected to      : PC
Surface PAR voltage added     : No
Scan time added               : Yes

1) Frequency 0, Temperature
   Serial number : 03P-5494
   Calibrated on : 02-Sep-2021
   G             : 4.32435107e-003
   H             : 6.26313513e-004
   I             : 1.96660867e-005
   J             : 1.53497610e-006
   F0            : 1000.000
   Slope         : 1.00000000
   Offset        : 0.0000

2) Frequency 1, Conductivity
   Serial number : 04C-3768
   Calibrated on : 05-Aug-2021
   G             : -1.02212028e+001
   H             : 1.49576033e+000
   I             : -4.78100129e-004
   J             : 1.28114112e-004
   CTcor         : 3.2500e-006
   CPcor         : -9.57000000e-008
   Slope         : 1.00000000
   Offset        : 0.00000
```

```
3) Frequency 2, Pressure, Digiquartz with TC
   Serial number : 90074
   Calibrated on : 19-Jul-2019
   C1          : -6.571123e+004
   C2          : 2.050504e-001
   C3          : 1.612220e-002
   D1          : 2.883800e-002
   D2          : 0.000000e+000
   T1          : 2.986693e+001
   T2          : -2.678465e-004
   T3          : 3.986390e-006
   T4          : 7.472100e-010
   T5          : 0.000000e+000
   Slope       : 0.99996000
   Offset      : 0.31620
   AD590M      : 1.283700e-002
   AD590B      : -8.642460e+000

4) Frequency 3, Temperature, 2
   Serial number : 03P-5495
   Calibrated on : 06-Aug-2021
   G           : 4.38200585e-003
   H           : 6.30639783e-004
   I           : 2.00705241e-005
   J           : 1.54050436e-006
   F0          : 1000.000
   Slope       : 1.00000000
   Offset      : 0.0000

5) Frequency 4, Conductivity, 2
   Serial number : 04C-3529
   Calibrated on : 05-Aug-2021
   G           : -9.91577107e+000
   H           : 1.56877523e+000
   I           : -1.81949655e-003
   J           : 2.35222769e-004
   CTcor       : 3.2500e-006
   CPcor       : -9.57000000e-008
   Slope       : 1.00000000
   Offset      : 0.00000

6) A/D voltage 0, Oxygen, SBE 43
   Serial number : 43-2831
   Calibrated on : 07-Jul-2021
```

Equation : Sea-Bird
Soc : 4.72500e-001
Offset : -4.79400e-001
A : -4.81820e-003
B : 1.90360e-004
C : -2.22120e-006
E : 3.60000e-002
Tau20 : 9.80000e-001
D1 : 1.92634e-004
D2 : -4.64803e-002
H1 : -3.30000e-002
H2 : 5.00000e+003
H3 : 1.45000e+003

7) A/D voltage 1, Free

8) A/D voltage 2, Fluorometer, Chelsea Aqua 3
Serial number : 088-095
Calibrated on : 12 November 2020
VB : 0.514614
V1 : 1.947820
Vacetone : 0.611730
Scale factor : 1.000000
Slope : 1.000000
Offset : 0.000000

9) A/D voltage 3, Altimeter
Serial number : PSA-916T 62679
Calibrated on :
Scale factor : 15.000
Offset : 0.000

10) A/D voltage 4, PAR/Irradiance, Biospherical/Licor
Serial number : 05
Calibrated on : 02-Oct-2019
M : 0.47253300
B : 1.11774500
Calibration constant : 100000000000.00000000
Conversion units : Watts/m^2
Multiplier : 0.99890000
Offset : 0.00000000

11) A/D voltage 5, PAR/Irradiance, Biospherical/Licor, 2
Serial number : 09
Calibrated on : 03-Sep-2020

M : 0.52185900
B : 1.00704200
Calibration constant : 100000000000.00000000
Conversion units : Watts/m^2
Multiplier : 0.99880000
Offset : 0.00000000

12) A/D voltage 6, Transmissometer, WET Labs C-Star
Serial number : CST-1837TR
Calibrated on : 15 March 2022
M : 21.5315
B : -0.1572
Path length : 0.250

13) A/D voltage 7, OBS, WET Labs, ECO-BB
Serial number : 758R
Calibrated on : 30/08/2019
ScaleFactor : 0.004284
Dark output : 0.054400
Scan length : 45