Final Report

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Seafloor Survey Around the Atlantis II Seamounts Using an Autonomous Underwater Vehicle

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INTRODUCTION

An integrated ocean acoustics field experiment named New England Seamounts Acoustics (NESMA) was planned and is conducted at the time when this report is written to investigate underwater acoustic propagation, scattering and ambient sound fields in the New England Seamounts Chain (see Fig. 1), specifically at the Atlantis II Seamounts in the Gulf Stream pathway. The study area has several acoustically important environmental processes and features coupling with each other, including seamount geology and Gulf Stream dynamics. To improve the understanding of the seafloor and sub-bottom geoacoustic properties that controls the strength of acoustic signal reflections in the study area, especially the top plateau of the seamount (see the bathymetric map in Fig. 1), a comprehensive seafloor and sub-bottom survey using an autonomous underwater vehicle (AUV) equipped with a variety of acoustic and optical sensors was conducted as a joint research effort with the Woods Hole Oceanographic Institution (WHOI), Ocean Infinity (OI), and the United States Geological Survey (USGS).

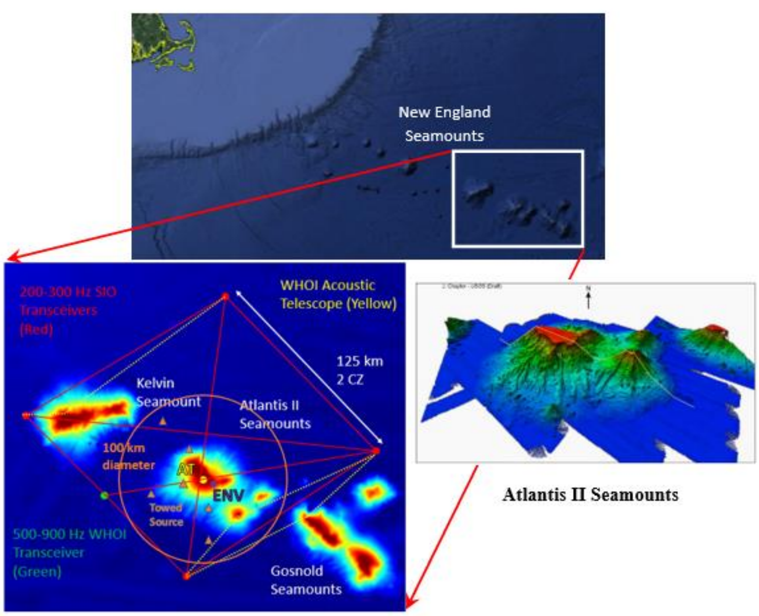

Figure 1. The NESMA experiment layout at the Atlantis II Seamounts.

Seamount acoustics research has been previously funded by the Office of Naval Research (ONR), for example, the Basin Acoustic Seamount Scattering EXperiment (BASSEX) in 2004 (Baggeroer et al., 2006; Heaney and Baggeroer, 2007). Compared to the previous work, which has established a solid foundation for the proposed 3D acoustic study, the Atlantis II Seamounts has the potential for greater environmental variabilities including seafloor bathymetry and seabed geology (Houghton et al., 1977). In addition to the proposed AUV seafloor survey, intensive data collection and modeling efforts are also conducted in the NESMA experiment to improve the understanding of the coupling and correlation among other environmental processes impacting the acoustics.

OBJECTIVES

A comprehensive seafloor and sub-bottom survey using an autonomous underwater vehicle (AUV) equipped with a variety of acoustic and optical sensors was conducted in the Atlantis II Seamounts area. The AUV sensors include a multibeam echo sounder (MBES), sidescan sonar (SSS), sub-bottom profiler (SBP) and still image camera. The primary project objective is to determine mooring anchor landing locations with high confidence of not hitting endangered cold-water corals. The survey data can also support the following scientific goals: seafloor geoacoustic property estimation from sonar signal returns and seafloor object identification from cross-platform observation.

The survey area is on the pathway of the Gulf Stream (GS), so high speed GS currents pose a great challenge to operate the AUV. Hence, another scientific and engineering objective of this project is to optimize AUV survey planning with a numerical simulator with realistic environmental conditions and incorporating existing marine geological measurements in the area. Ultimately, the AUV data collected under this project will also contribute to seafloor and sub-bottom databases, such as the Global Predictive Seabed Model (GPSM), and improve our understanding of seamount geology.

APPROACH

The Atlantis II Seamounts are right in the pathway of the Gulf Stream, of which the current can be 2.5 m/s (5 kts) or higher (Andres, 2016) at the seamount location (see Fig. 2). This imposes a challenging condition to conduct a seafloor survey using a remotely operated vehicle (ROV) tethered with a surface vessel. To overcome the challenge, a seafloor survey utilizing an AUV was proposed. To ensure the success of the seafloor survey, a numerical simulator incorporating realistic environmental information including bathymetry and water current profiles was utilized to assist the survey planning.

The primary approach in the proposed seafloor survey study is to utilize a Kongsberg HUGIN® AUV (see Fig. 3) equipped with a variety of acoustic sonars and a still image camera. The depth rating of the AUV is 6000 m, and it weighs 1850kg with batteries that provide 48-54 hours long endurance. All other technical details of AUV payloads are explained in the Mobilization and Calibration Report prepared by the Ocean Infinity and appended at the end of this report.

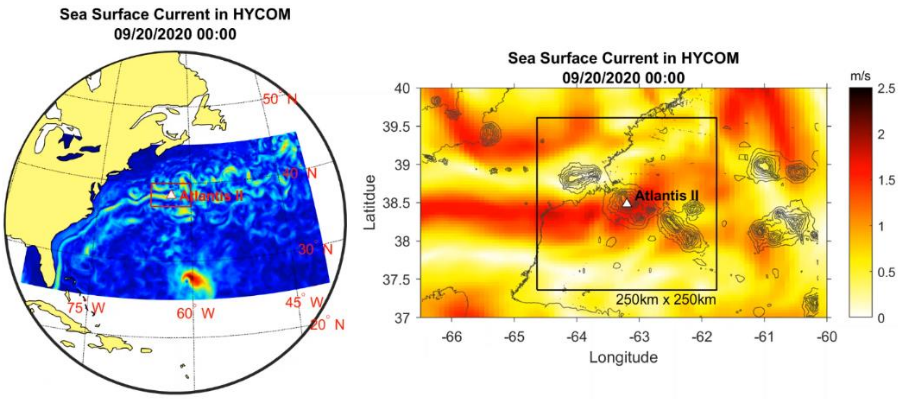

Figure 2. Meandering Gulf Stream around the Atlantis II Seamounts shown in the data-assimilated HYbrid Coordinate Ocean Model (HYCOM; NRL 2020) . The surface current speed can go up to 2.5 m/s (5 kts).

(a)

(b)

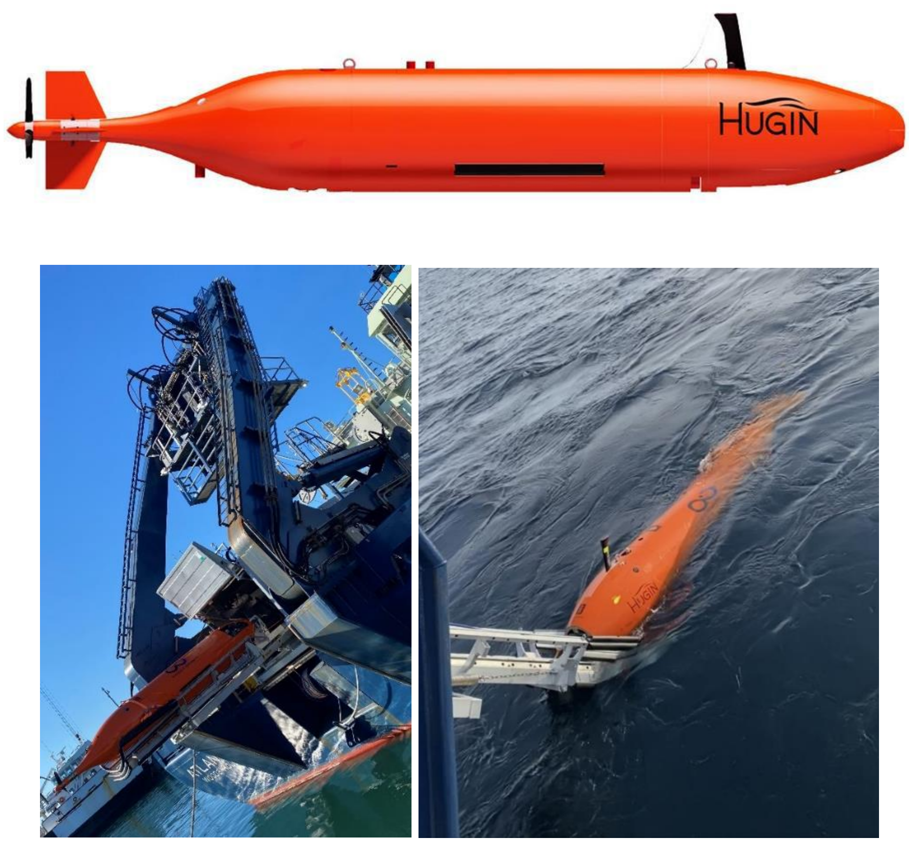

Figure 3. (a) Kongsberg HUGIN AUV, and (b) the deck-mounted launch and recovery system (LARS) The dimensions of the AUV are 6 m long and 0.75 m wide (outer diameters). The AUV was equipped with still image camera, multibeam echosounder (MBES), sidescan sonar (SSS) and subbottom profiler (SBP) for the seafloor survey. The bottom right photo was taken during the AUV was deployed for one of the survey missions on the Atlantis II AUV survey cruise.

WORK COMPLETED AND RESULTS

A successful survey cruise was conducted in July 2022, and the total survey area was ~46.3 km^2. As shown in Fig. 4, there were twelve targeted survey boxes (red boxes in the figure) with 80-100% camera photo coverage, and the entire survey area had 100% sonar coverage. Other accomplishments are detailed in the following.

1. AUV survey coverage and sensor types

The project has utilized a Kongsberg HUGIN® AUV to conduct a seafloor and subbottom survey on the top of the Atlantis II Seamount (see Fig.4). The AUV operation also utilized a Konsberg HiPAP USBL system for navigation. The survey sensors included a multibeam echosounder (MBES), sub-bottom profiler (SBP) sonar, sidescan sonar (SSS) and still image camera. Figure 5 shows examples of the images taken by these sensor instruments. A comprehensive Operations Report prepared by the Ocean Infinity is attached in this final report as an appendix.

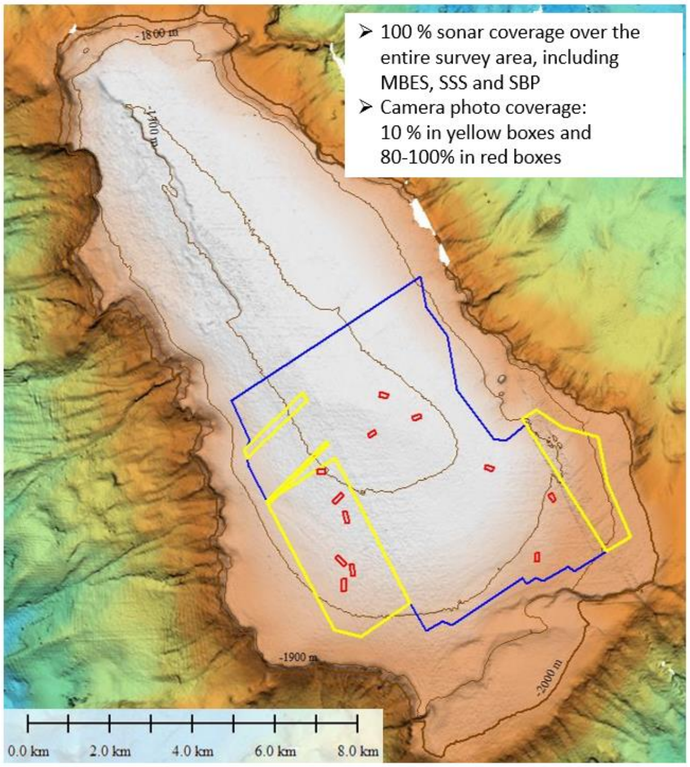

Figure 4. The AUV survey map on the top of the Atlantis II Seamount. The total survey area was ~46.3 km^2 with 100% sonar coverage. There were 1.2 M seafloor photos taken, and the photo coverage rates were 10% in the yellow boxes and 80-100% in the red boxes.

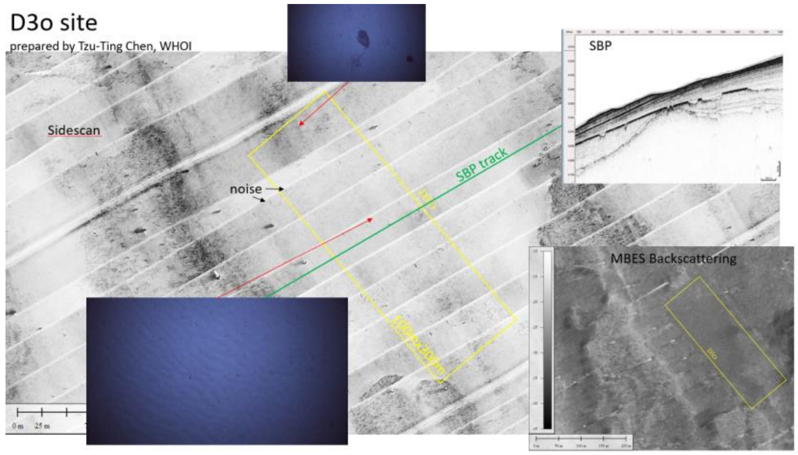

Figure 5. Examples of AUV survey data at one of the targeted survey sites (red boxes in Fig. 2). The images include multibeam echosounder (MBES) backscattering (bottom right), sidescan sonar (center), subbottom profiler (SBP) (top right), and two geo-referenced camera photos. One of the photos (the top one) shows a rock on the seafloor, and another shows sand ripples.

2. Mooring location selection

The AUV survey data has been analyzed to determine mooring locations for the New England Seamounts Acoustic Experiments. An example of such a selection process is provided in Fig. 6, where one can see that areas of large rocks/boulders (potential coral habitats) within a target survey area (~100m x 200m) are first identified. After that, we can then find a potential mooring landing area with high confidence of not hitting endangered coral.

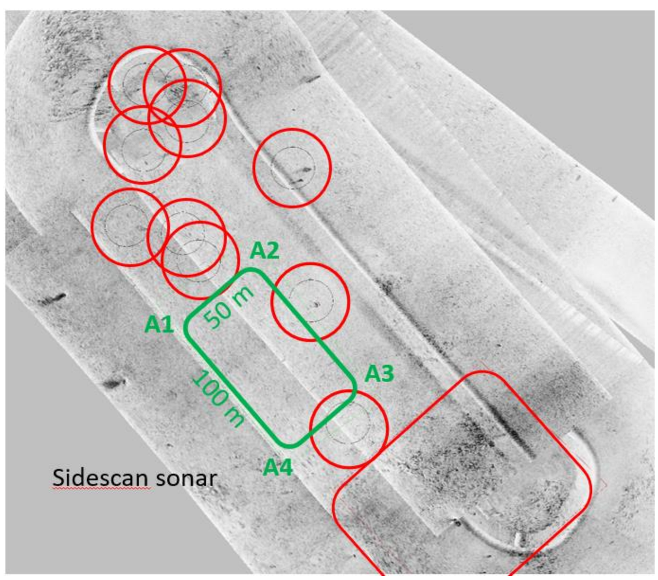

Figure 6. An example of mooring location selection. The background image was of sidescan sonar. With camera photo confirmation, the red areas contain large rocks/boulders (potential coral habitats). The green area is a potential mooring location because of no sign of corals or large rocks.

3. Other relevant data analysis

The survey data has also been analyzed for other scientific topics. As shown in Fig. 7, the high resolution (25 cm) multibeam sonar can clearly map seafloor objects, confirmed by camera photos, and enable a large area survey by providing wider survey swaps with higher AUV altitude. Figure 7 also shows an example of camera photo mosaic, which will provide ultimate evidence showing objectives on the seafloor. Two example camera photos are provided in Fig. 8, and one can clearly see a black coral on the top of a rock.

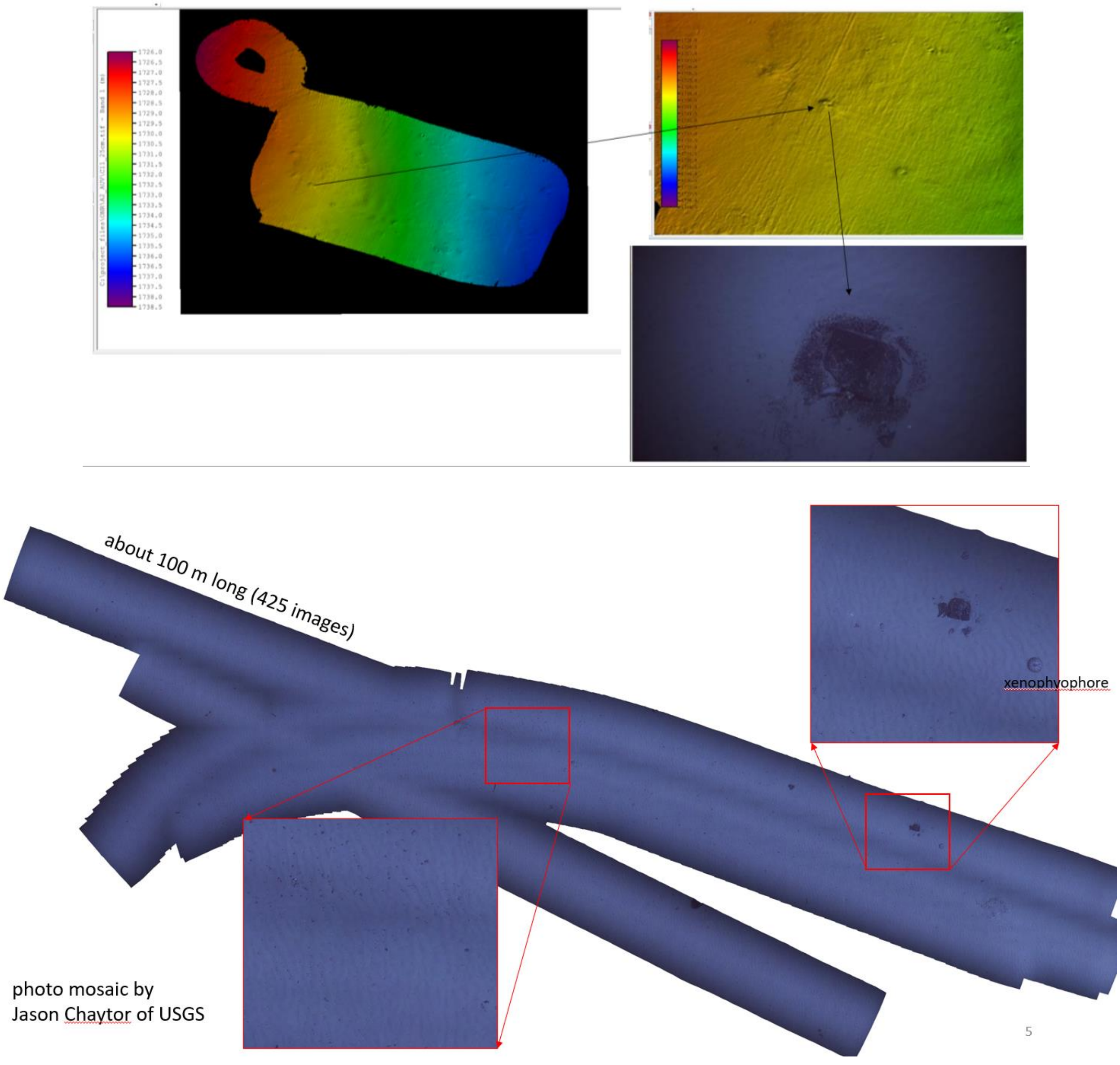

Figure 7. Examples of a multibeam survey image (top) and camera photo mosaic (bottom). The resolution of the multibeam image was 25 cm, and one can see a clear correspondence between the multibeam echosounder survey result and camera observation.

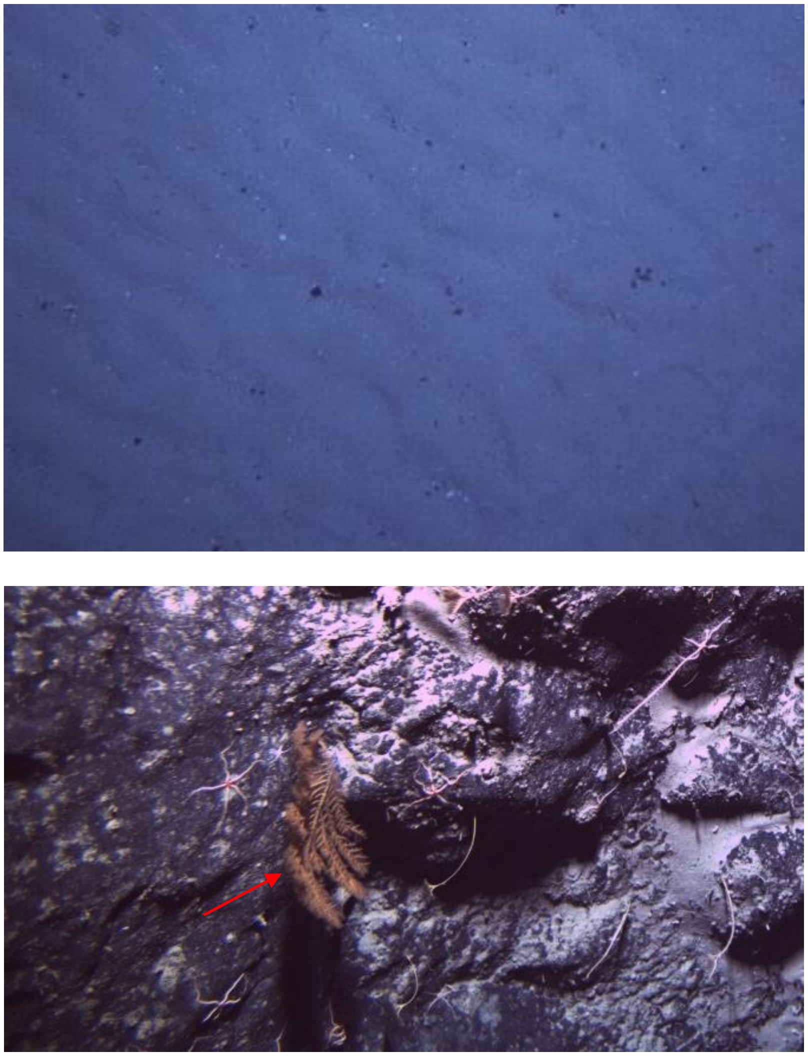

Figure 8. Examples of camera photos. The size of the images is 2.5 m $\times$ 1.5 m. One can see a black coral (indicated by the red arrow) and starfishes in the lower photo.

4. Geological and geoacoustic study

This section focuses on investigating the influence of geology on sound propagation at Atlantis II Seamounts. The aim is to analyze acoustic data in both the horizontal and vertical directions to gain a better understanding of the sound propagation characteristics and scattering phenomena associated with the seamount. Various data collection techniques, including the AUV survey metnioned above with multi-beam sonar, sub-bottom profiling, are employed to establish a geological model. The analysis will utilize ray tracing, parabolic equation approaches, and geo-acoustic analysis to enhance the geological model and improve our understanding of the seamount's evolution.

Geophysical data have been utilized to identify the top of three distinct formations (Fig. 9b) that characterize the geology of Atlantis II Seamount. These formations include a sediment layer, a limestone layer (Fig. 9c), the top located approximately 20 meters below the seafloor, and an igneous basement (Fig. 9d) situated around 40 meters below the seafloor.

The next step in this study is to evaluate the potential range of sediment characteristics for each layer by utilizing geophysical data and geo-acoustic analysis. Acoustic data collected from the large angle bottom reflection experiment conducted during the NESMA 2023 Experiments will be analyzed to verify the velocity and material characteristics of the layers. By refining the velocity and properties of the layers, this project aims to achieve a high level of accuracy in the geological information. This will greatly contribute to subsequent simulations and modeling efforts.

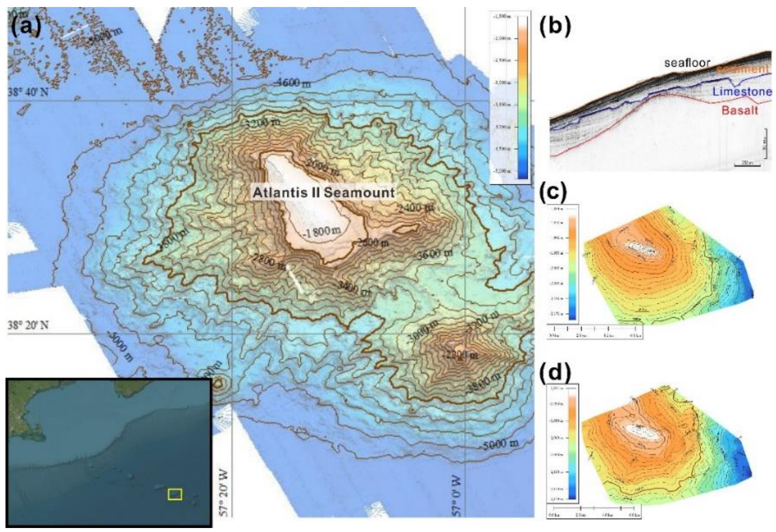

Figure 9. (a) Regional map of Atlantis II Seamount. (b) Three sub-bottom profile formations. (c) Limestone depth. (d) Igneous basement depth.

IMPACT/APPLICATIONS

The primary objective of the reported research is to study the seafloor and sub-bottom geoacoustic properties on the Atlantis II Seamounts. The potential relevance of this work to the Navy is on better understanding acoustic bottom reflection loss. Ultimately this relevance can be extended to increasing the capability of naval sonar systems and predictions in the study area and other similar seamount environments.

RELATED PROJECTS

This project is directly related to an ONR TFO DRI program named "New England Seamounts Acoustics (NESMA)" Experiments. There are more than 25 projects under this DRI, including an field work based project led by the PI in this report: "New England Seamounts Acoustics (NESMA) Physics-Based Acoustic Field Analysis with Integrated Networks," N00014-22-1-2013.

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Heaney, K.D. and Baggeroer A.B. (2007). “Measurements of 3-dimensional downslope acoustic propagation during the Basin Acoustic Seamount Scattering Experiment (BASSEX-04)” Oceans 2006 - Asia Pacific.

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Naval Research Laboratory (2020), HYCOM Consortium for Data-Assimilative Ocean Modeling. https://www7320.nrlssc.navy.mil/GLBhycomcice1-12/

HONORS

1. Keynote Speaker at the International Conference on Underwater Acoustics 2022, 20-23 June 2022, Southampton, UK (https://icua2022.org/speakers/)

PUBLICATIONS

1. Meeting abstract

2022 **Y.-T. Lin**, J. Chaytor, G. Packard, T.-T. Chen and N. Kukshtel, “Acoustic seabed characterization with autonomous underwater vehicles,” *J. Acoust. Soc. Am.*, vol. 152, A102.

SEAFLOOR SURVEY AT ATLANTIS II SEAMOUNT – WHOI CRUISE AT47REV2

Mobilization and Calibration Report

AUV Survey

US North East Coast

CLIENT
WHOI

DATE
17 August, 2022

CREATED BY
Stephanie Montrichard

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Abbreviations And Definitions

CRP ....Common Reference Point
CTD ....Conductivity, Temperature and Depth
Dim Con..Dimensional Control
DP ....Dynamic Positioning
DVL ....Doppler Velocity Log
GAPS...(Trade mark) Global Acoustic Positioning System, a USBL system
GPS ....Global Positioning System
HF ....High Frequency
IMU ....Inertial Measurement Unit
INS ....Inertial Navigation System
ITP ....Inspection and Test Plan
ITRF ....International Terrestrial Reference Frame
LF ....Low Frequency
MAC..Mobilisation and Calibration
MBES ....Multibeam Echosounder
MRU ....Motion Reference Unit
MSL ....Mean Sea Level
MV...Motor Vessel
PC ....Personal Computer
POS MV ....(Trade mark) Position and Orientation System for Marine Vessels
PPS ....Pulse Per Second
PTU ....Passive Transmitter Unit
QC..Quality Control
RMS ....Root Mean Square
SBP ....Sub-Bottom Profiler
SD ....Standard Deviation
SN ....Serial Number
SSS ....Side Scan Sonar
Stbd ....Starboard
SV ....Sound Velocity
SVP ....Sound Velocity Profile
SVS ....Sound Velocity Sensor
TX ....Transducer
USBL ....Ultra-Short Baseline
UTC...Universal Time Coordinated
UTM..Universal Transverse Mercator

1. Introduction

This document outlines the calibrations, verifications and tests performed on-board MV Deep Helder for the Woods Hole Oceanographic Institution (WHOI) Atlantis II Seamount Survey. The project-specific Inspection and Test Plan (ITP) can be found in Appendix A.

Figure 1 MV Deep Helder.

1.1 Equipment List

1.1.1 Vessel - MV Deep Helder

The equipment mobilized on the MV Deep Helder is specified in Table 1.

Table 1 MV Deep Helder equipment list.

Equipment	Model	Quantity
Primary Positioning System	Applanix POS MV 320 with FUGRO G2 corrections	1
Secondary Positioning System	Fugro Seastar with XP2 corrections	1
Heading / Motion Sensor	Applanix POS MV 320	1
Secondary Gyro and INS System	IXSEA GAPS III USBL	1
Underwater Positioning System (USBL)	HiPAP 352 MGC	1
Hull Sound Velocity Probe	Valeport miniSVS	1
Sound Velocity Profiler	Valeport SVX2	1 (1 spare)
Atmospheric pressure sensor	Vaisala PTU 303	1
Multibeam Echosounder	Kongsberg EM2040 Dual Head (EM2040D)	1
Single Beam Echo Sounder	Konsberg EA 400	1
Sub Bottom Profiler	Innomar	1

1.1.2 AUV Hugin 6000

Figure 2 Hugin AUV and recovery system (LARS).

The equipment mobilized on the Hugin 6000 AUV is specified in Table 2.

Table 2 Hugin 6000 AUV equipment list.

Equipment	Model	Quantity
GPS Receiver	Novatel OEM615-D1S-00G-0T0	1
CTD	SAIV SD208	1
Inertial Motion Unit	Honeywell HG9900 IMU	1
Compass	ULTISENSE DMC-SX-5000 2/4	1
Doppler Velocity Log	Nortek DVL500	1
Obstacle Avoidance Sonar	Imagenex Sonar and KM algorithm FLS	1
Altimeter	Kongsberg Mesotech 200/675 kHz forward and downward looking	1
USBL Transponder	HiPAP cNODE Minis 34-40V	1
Depth Sensor	DigiQuartz 8CB4000	1
Multibeam Echosounder	Kongsberg Maritime EM2040 0.7°x0.7° (at 400 kHz)	1
Side Scan Sonar	Edgetech 2205 with 75, 225 and 410 kHz (two frequencies selectable at a time)	1
Sub-bottom Profiler	EdgeTech DW-216	1
Magnetometer	Ocean Floor Geophysics SCM	1
Colour Camera	CathX M12-A1000	1
Camera Flash	Aphos S32	1

1.2 Scope of Work

The specific tasks undertaken during the mobilization and calibration periods can be summarized in the table below.

Table 3 Mobilisation and calibration periods

	Activity	Location	Completion Date
	Sensor Offsets		
1.	Confirmation of correct entry within the online survey systems	New Bedford, MA, USA	July 15, 2022
	Navigation System		
2.	Static validation	New Bedford, MA, USA	July 15, 2022
	Heading System		
3.	Heading / MRU system calibration	HIPAP is pre-calibrated by Kongsberg	N/A
	Sound Velocity probe (SVP) verification		
4.	EM2040D (hull mounted)	Alvin Canyon, USA	July 17, 2022
5.	Valeport SVX2	Alvin Canyon, USA	July 17, 2022
6.	SAIV SD208 (AUV mounted)	Alvin Canyon, USA	July 17, 2022
	Multibeam Calibration		
7.	Kongsberg Maritime EM 2040 (AUV mounted)	Alvin Canyon, USA	Aug 1, 2022
	DVL		
8.	DVL verification	Alvin Canyon, USA	Aug 1, 2022
	USBL verification		
9.	Spin test	Alvin Canyon, USA	Aug 1, 2022
	Side Scan Sonar verification		
10.	Edgetech 2205 (AUV mounted)	Blake Plateau, USA	Aug 6, 2022
	Sub Bottom verification		
11.	Edgetech DW-216 (AUV mounted)	Blake Plateau, USA	Aug 6, 2022
	CATHX Imagery		
12.	CATHX system test (AUV mounted)	Atlantis II Seamount	July 17, 2022

All tasks were completed according to the Inspection and Test Plan (ITP) included as Appendix A.

2. Test Location

A series of calibration tests were performed between the 17 July and 18 July 2022 at the Alvin Canyon offshore of Massachusetts in approximately 380m water depth. Additional post project calibrations and verifications were done on the 1st of August at the Alvin Canyon. Additional verifications were conducted on the following project at the Blake Plateau work site on the 6th August 2022 in ~800m water depth.

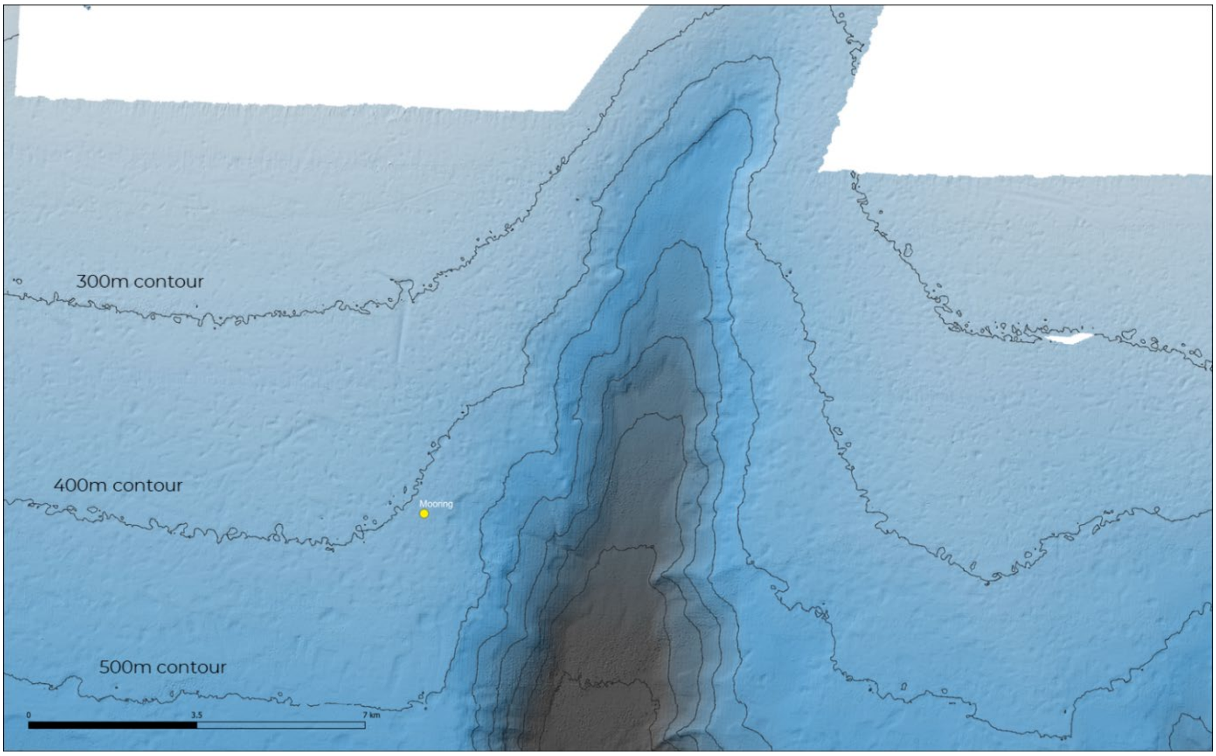

Figure 3 Alvin Canyon calibration site.

3. Datums

The geodetic datum used during the project is presented in Table 4.

Table 4 Datum parameters.

GPS POSITIONING SPHEROID PARAMETERS. (DATUM: WGS84)	
Ellipsoid	GRS80
Semi major axis	6 378 137.000 metres
Inverse Flattening:	298.257 222 101

The projection parameters used during the project are presented in Table 5.

Table 5 Projection parameters.

Projection Parameters			
Survey Area	Test Site Blake Plateau	Test Site Alvin Canyon	Project Site
Projection	UTM	UTM	UTM
Zone	17N	19N	20N
Central Meridian	81° West	69° West	63° West
Latitude of Origin	0°	0°	0°
False Northing	0 m	0 m	0 m
False Easting	500 000.00 m	500 000.00 m	500 000.00 m
Scale Factor at CM	0.9996	0.9996	0.9996
Units	Metres	Metres	Metres
EPSG Code:	32617	32619	32620

Table 6 Vertical datum.

Vertical Reference Parameters	
Vertical reference	MSL
Height model	EGM2008

4. Dimensional Control

4.1 M/V Deep Helder

Whilst the vessel was in dry dock in Amsterdam, Netherlands, in February 2017 and additionally in April 2019, a Dimensional Survey was undertaken by Oceanfix International on behalf of Ocean Infinity (Sweden). Refer to Appendix B for the full report.

The following equipment was used:

- Trimble M3 (2”) total station. S/N C600581 (February 2017)
- Trimble M3 (5”) total station. S/N CD051047 (February 2017)
- Topcon GT-1002 total station. S/N UQ001014 (April 2019)
- Various minor survey equipment: tripod, rulers, prism etc.

A vessel reference frame was established using the MRU mounting plate as the central reference point (CRP) and the ships along and across-hull axis as angular references, see below Figure 4. A number of fix points were surveyed around the vessel. Coordinates and installation angles of the following instruments were established:

- All GPS Antennae
- Sensor mounting plates including POS MV IMU
- EM2040D
- USBL Hydrophone Pole
- Number of reference points around the vessel, including all sensor deployment/tow points

The sensor offsets and rotations are applied with respect to coordinate system illustrated in Figure 4.

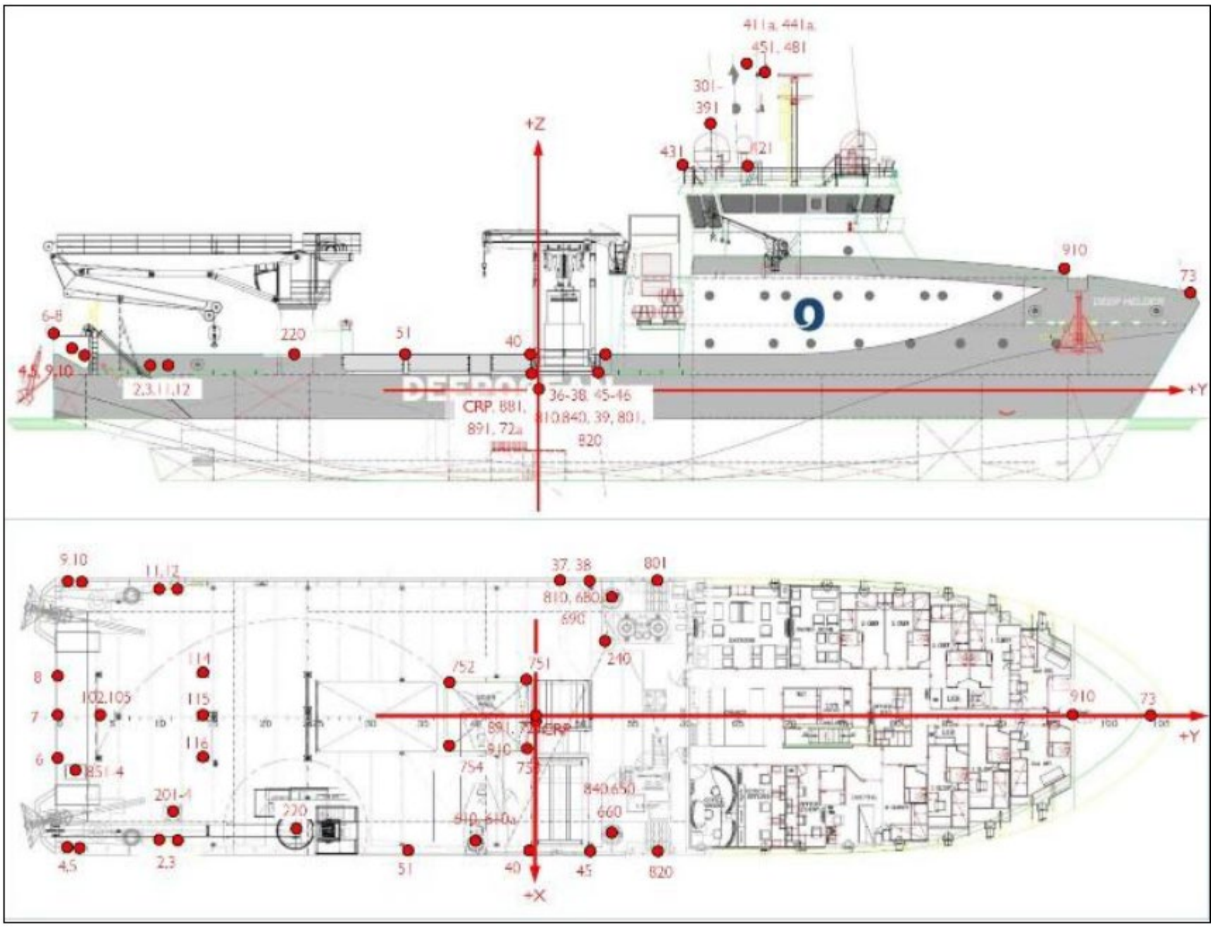

Figure 4 Vessel reference frame.

Ocean fix axis:

- X axis is positive to Starboard
- Y axis is positive to Forward
- Z axis is positive Upward

A summary of the vessel offsets is presented in Table 7.

Table 7 Vessel offset summary table.

System	Offset			Angle			Comment
	X (m)	Y (m)	Z (m)	Heading (°)	Pitch (°)	Roll (°)	
PosMV IMU	0.009	0.003	0.128	-0.01	0.08	0.32	Top of unit
PoSMV 1 Antenna	-2.392	9.630	16.356				Top of antenna
PoSMV 2 Antenna	0.415	9.618	16.361				Top of antenna
Fugro centre antenna	0.019	9.617	16.339				Phase centre
Fugro port antenna	-2.779	9.633	16.344				Phase centre
Fugro starboard antenna	0.819	9.623	16.342				Phase centre

System	Offset			Angle			Comment
	X (m)	Y (m)	Z (m)	Heading (°)	Pitch (°)	Roll (°)	
HiPAP 352 USBL Transducer Reference	-6.744	4.151	-6.460				HiPAP 352 Reference Point on Transducer when deployed.
EM2040 TX	6.734	4.264	-4.931	0.11	0.87	-0.32	After MBES mount extension by 0.8 m.
EM2040 RX Port	6.386	4.233	-4.781	359.5	0.79	36.41	After MBES mount extension by 0.8 m.
EM2040 RX Stbd	7.077	4.232	-4.781	0.72	0.71	-37.94	After MBES mount extension by 0.8 m.
Draft sensor	6.459	3.960	-4.660				Draft sensor (hull-mounted Mini SVS at EM2040TX)
Weather Station	N/A	N/A	3.300				

4.2 AUV

The Hugin 6000 AUV comes pre-installed from the manufacturer with an .ini file that lists all of offsets to each sensor from the CRP. These offsets are all fixed by the mounting plates.

Table 8 shows installation offsets to some of the key instruments.

Table 8 AUV offset summary table.

Description	X (m)	Y (m)	Z (m)	Comment
AUV Nose Cone/ CRP	0.000	0.000	0.000	
IMU	-4.579	0.004	0.053	
DVL	-4.340	0.000	0.286	
Pressure (NavP/KfSensors)	-4.304	0.320	-0.100	
Compass	-1.147	-0.269	-0.163	
Altimeter Down	-0.437	-0.080	0.276	
Altimeter Forward	-0.414	0.080	0.258	
Vehicle GPS Antenna	-1.098	-0.022	-0.754	
Forward Looking Sonar (FLS)	-0.018	0.000	0.061	
CTD	-5.254	0.000	-0.214	
EM 2040 TX - MBES	-1.086	0.000	0.414	Acoustic centre
EM 2040 RX – MBES	-1.375	0.000	0.383	Acoustic centre
Edgetech 2205 - SSS	-2.662	-0.407	0.146	Centre face
Edgetech 2205 - SSS	-2.662	0.407	0.146	Centre face
Edgetech DW-216 - SBP - TX	-3.818	0.000	0.402	Centre face
Edgetech DW-216 - SBP - RX	-3.431	0.000	0.419	Centre face

Description	X (m)	Y (m)	Z (m)	Comment
Magnetometer	-0.520	-0.285	-0.053	
Colour Camera	-4.112	0.000	0.420	

5. Navigation Systems

5.1 GNSS Static Verification

A static verification of the positioning system was performed on 15th July 2022 whilst alongside in the port of New Bedford, USA. Position data from both the Primary (POS MV 320 with FUGRO G2 corrections) and Secondary navigation system (Fugro Seastar with XP2 corrections) were logged for a period of 60 minutes. The positions from the two systems were compared in a scatter plot to identify any deviation between the two systems.

The following plot presents the correlations between the two positioning systems. Each dot represents a deviation between the two systems at a given time (delta X and delta Y). Analysis of the results illustrates a good correlation, as presented in Figure 5.

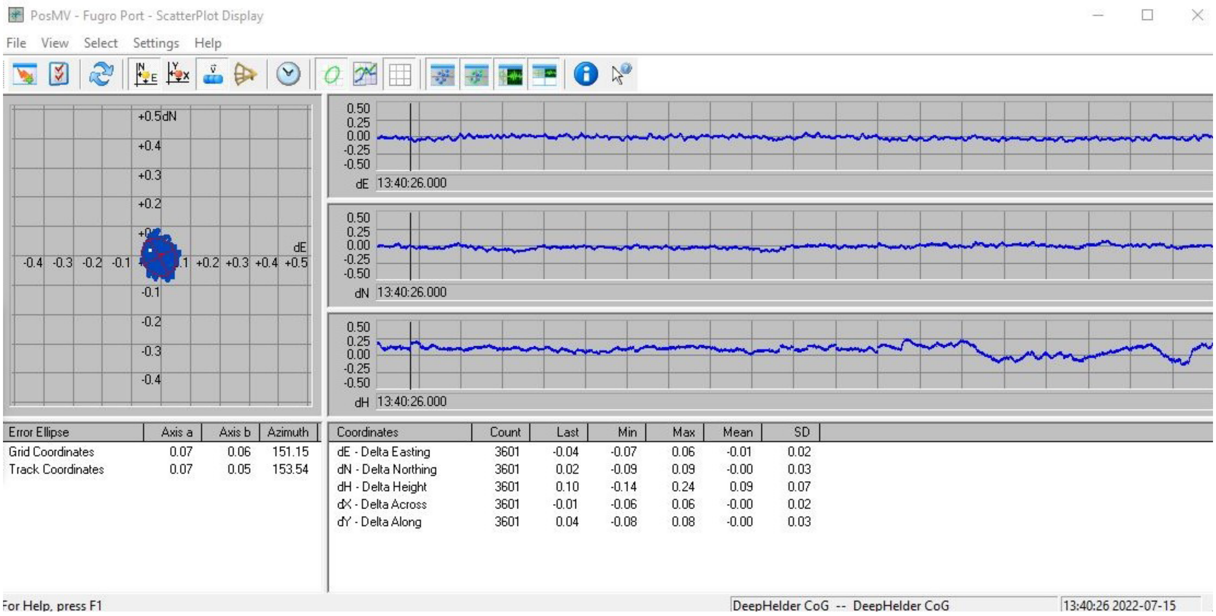

Figure 5 Vessel GNSS static verification.

Table 9 Vessel GNSS static verification summary.

Date	**2022-07-15**
Start time	12:39
End time	13:40
Observations	3601
Rejections	Zero
Mean Easting (m)	340555.112
Mean Northing (m)	4609652.482

Table 10 Vessel GNSS static verification result.

POS MV – Fugro Seastar	**SD Easting (m)**	**SD Northing (m)**	**SD Height (m)**
Static validation	0.02	0.03	0.07

The static verification showed that the two positioning systems of the vessel were matching within the required specification of a maximum of 0.3 m difference

6. Sound Velocity

Acoustic ray paths are influenced by the water temperature, salinity and density through which the rays pass and uncertainties in these qualities will lead to significant errors.

Further, the properties of the water column are largely unpredictable and vary both spatially and temporally. To ensure that the overall accuracies of the acoustic measurements are preserved, sound velocity (SV) observations must be made with sufficient frequency, spread and accuracy to preserve the required positional precision.

In order to acquire sound velocity profiles during the survey, two different systems were mobilised:

- Midas SVX2 3000 (SN: 8045)
- Midas SVX2 (SN: 8046)

A velocity profile repeatability verification between two SVX2 sensors was made offshore on the 17th of July 2022. Four casts were acquired with the SVX2 (two down and two up) in the same location using the two different sensors. Additionally, these profiles were compared against the MBES mounted MiniSVS. The test was performed in order to confirm that the variance between the sensors were within specification, which is less than 1 m/s. Results are shown in Table 11 and Figure 6 below proving good repeatability.

Table 11 Sound Velocity Profile comparison; average SV and seabed SV.

System	Average SV (m/s)	Seabed SV (m/s)
Midas SVX2 3000 (SN: 8045)	1498.982	1483.684
Midas SVX2 3000 (SN: 8046)	1498.788	1483.661

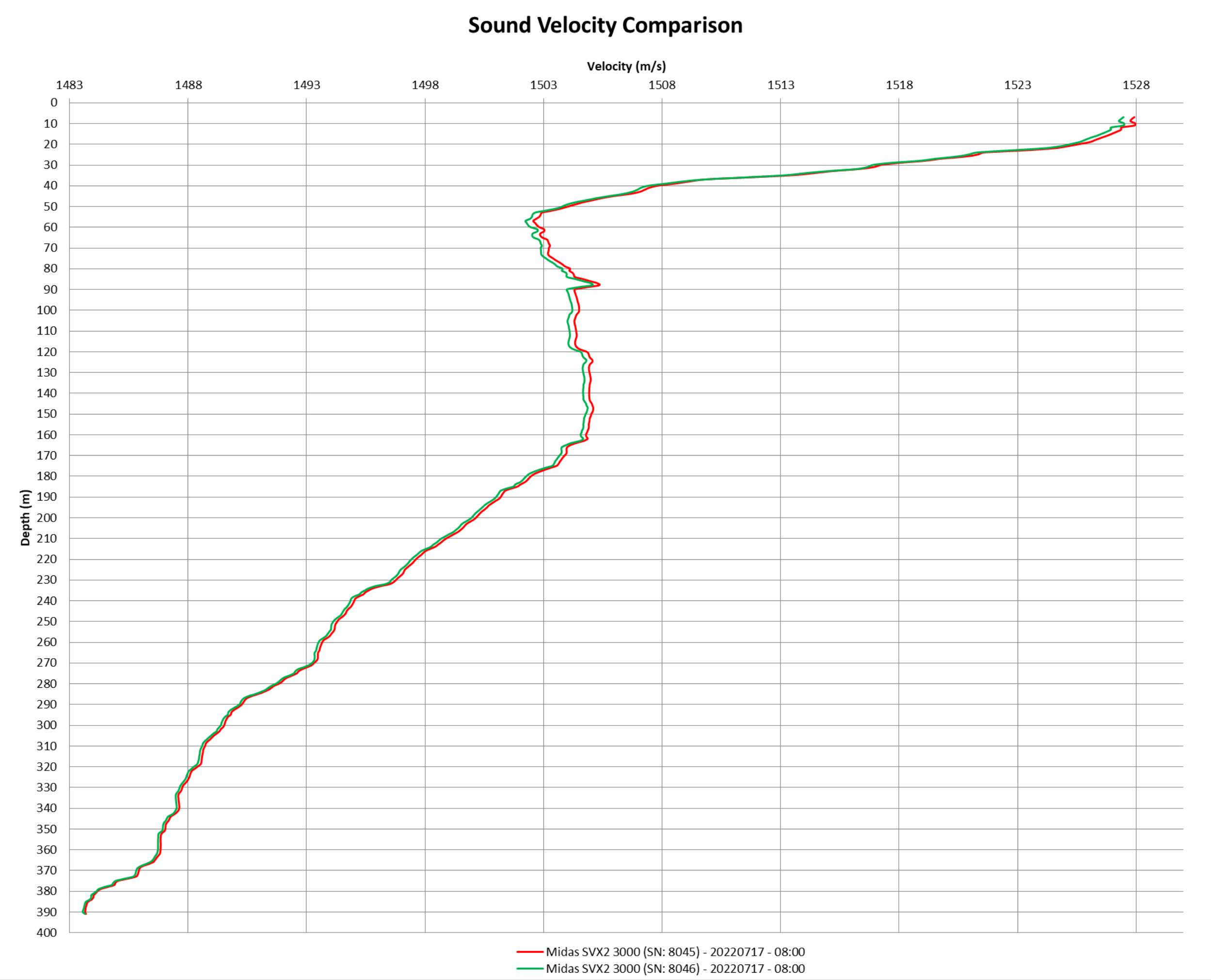

Figure 6 Sound velocity profile repeatability comparison.

For operational efficiency, the SAIV SD204 CTD sensor mounted on the AUVs will be used to acquire CTD profiles upon launch and recovery of the vehicles. As such, the SAIV sensor to be used should be subject to comparison with the CTD sensors in order to demonstrate their consistency and repeatability.

The SAIV SD204 was verified against the Valeport SVX2. The procedure for validation of SV and CT probes was to compare the cast of the SAIV SD204 CTD + against the SVX2.

The Upcast from the AUV CTD was compared with down and up from the SVX2 in the same location using the two different sensors. A comparison of these SV and CT profiles are shown in Table 12 below.

Table 12 Sound velocity profile comparison; average SV, SV at 1757 m water depth.

System	Average SV (m/s)	SV (m/s) at 1757 m water depth
Midas SVX2 3000 (SN: 8046)	1510.685	1497.80
SAIV SD204 CTD (SN: 1429)	1510.711	1496.59

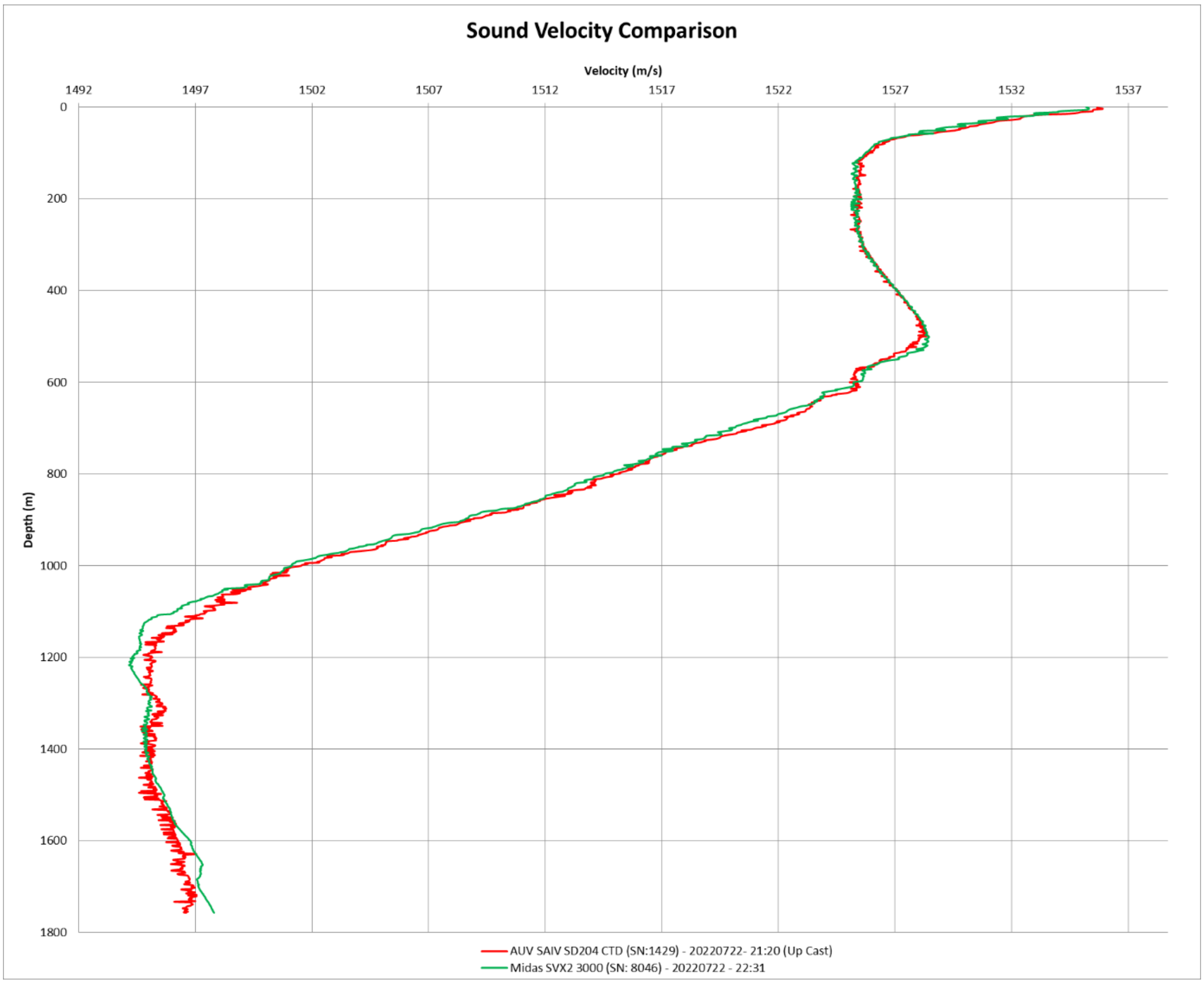

Figure 7 Sound velocity profile repeatability comparison.

7. USBL Verification

The HiPAP 352P-MGC USBL system installed on the Port moon pool pole has a built in MGC R3 IMU. A USBL calibration is not required as it is a self-calibrated system and was certified by Kongsberg.

A verification of the HiPAP was performed on 1 August 2022 in accordance with the Mobilisation and Calibration Procedure (104313-BOE-OI-MAC-PRO-DEEPHELD).

The USBL verification took place offshore at the Alvin Canyon area on 1 August 2022.

The verification process involved deploying a cNode beacon on the seabed and then performing a Spin Test as described below. The aim was to verify the offsets from the GNSS primary receiver and the USBL transducer were correct, thus verifying if the USBL system was suitable for use on the project.

7.1 Static Spin Test

A USBL transponder mounted at a fixed position on the seafloor was used, in a water depth of 387 m. Using Dynamic Positioning (DP), the vessel was positioned with the HiPAP transducer directly over the cNode beacon. The vessel performed a 360-degree spin at a rate of 12 degrees per minute.

Errors in the existing calibration parameters or sensor offsets would be expected to result in an excessive scatter of the observed transponder positions and a donut torus pattern. The result from the spin test is presented in Table 13.

The Specification states that the Route Mean Square must be < 1 % of the slant range (3.87m).

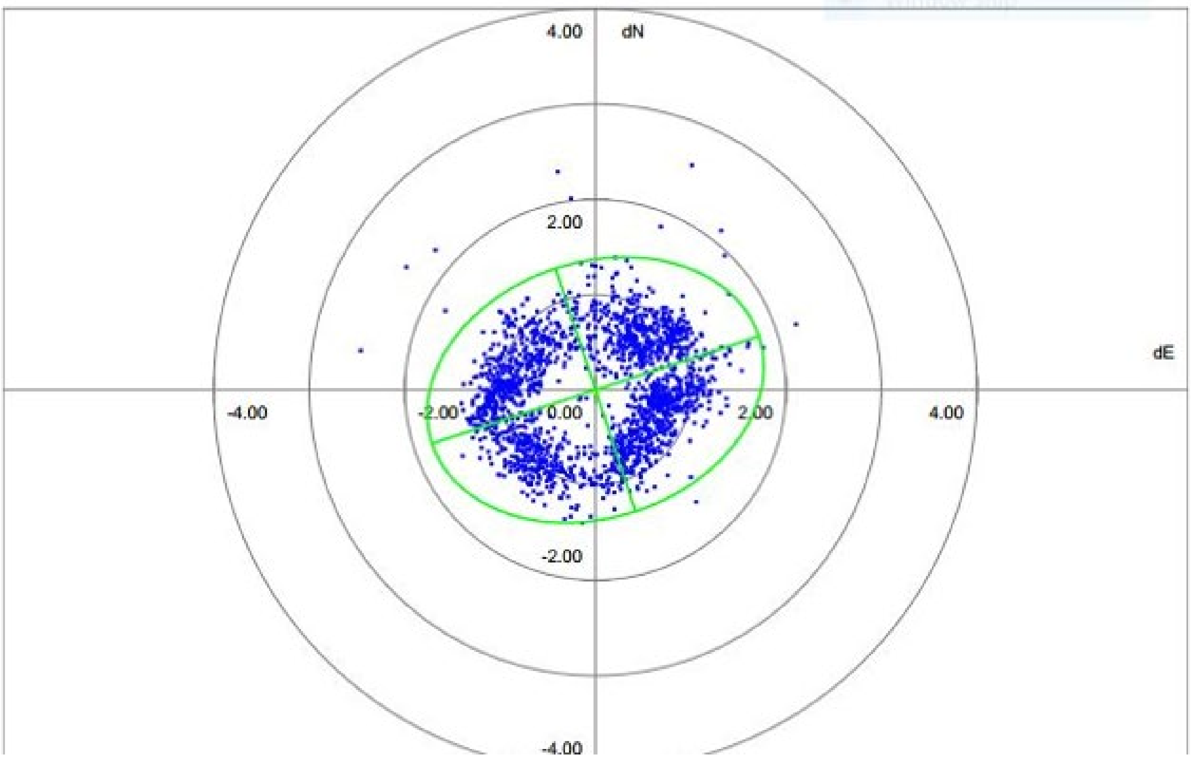

Figure 8 Static USBL spin test result.

Table 13 Static USBL spin test result.

	Easting (m)	Northing (m)	Depth (m)
Average Position	366783.68	4423232.79	-386.88
Standard Deviation 2σ	0.72	0.57	0.17

Considering 2 axis, you can get the *standard distance*

$$SD_{x,y}\sqrt{0.72^2 + 0.57^2} = \mathbf{0.92\ m}$$

Therefore, the RMS is within the Specification standards.

8. DVL Calibration & Verification

8.1 DVL Method

The mission plan for DVL verification consisted of three parallel lines in which the vehicle flew over each line at a different speed. The lines were set at 5000 m length and at a 50 m line separation. The AUV vehicle operated in supervised mode with continuous positioning updates at an altitude of approximately 40 m above the seabed. In order to reduce the influence of potential USBL positioning errors on the results of the DVL calibration, the verification was performed with low vessel thruster gain.

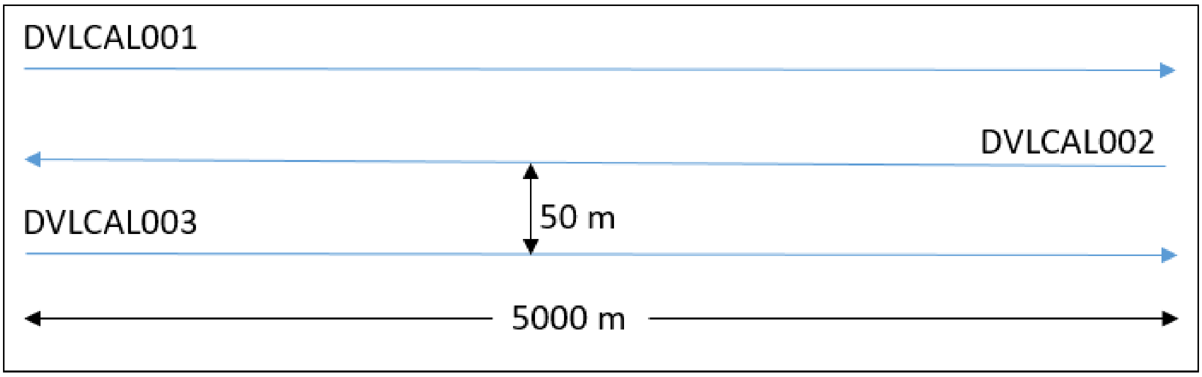

Figure 9 DVL Verification Line Pattern

8.2 DVL verification Result

Kongsberg recommends that the DVL calibration be performed at a depth range of 200-300 m when using DGPS-HiPAP positioning, the reason is that the error in positioning increases with depth, therefor the accuracy of the DVL calibration results is reduced. Since the water depth is deeper in calibration area, longer observation lines were needed to reduce the effect.

Table 14 DVL Values in AUV 12

Parameters	Previous DVL Values	Calculated DVL Values
Scale	1.00826	0.99847
Roll	-0.104°	-0.168°
Pitch	0.380°	0.356°
Yaw	0.214°	0.217°

The graphs below in Figure 10 to Figure 13 show the comparison of DVL elements with all values set to zero as red, and after the calibration with the newly obtained values as green.

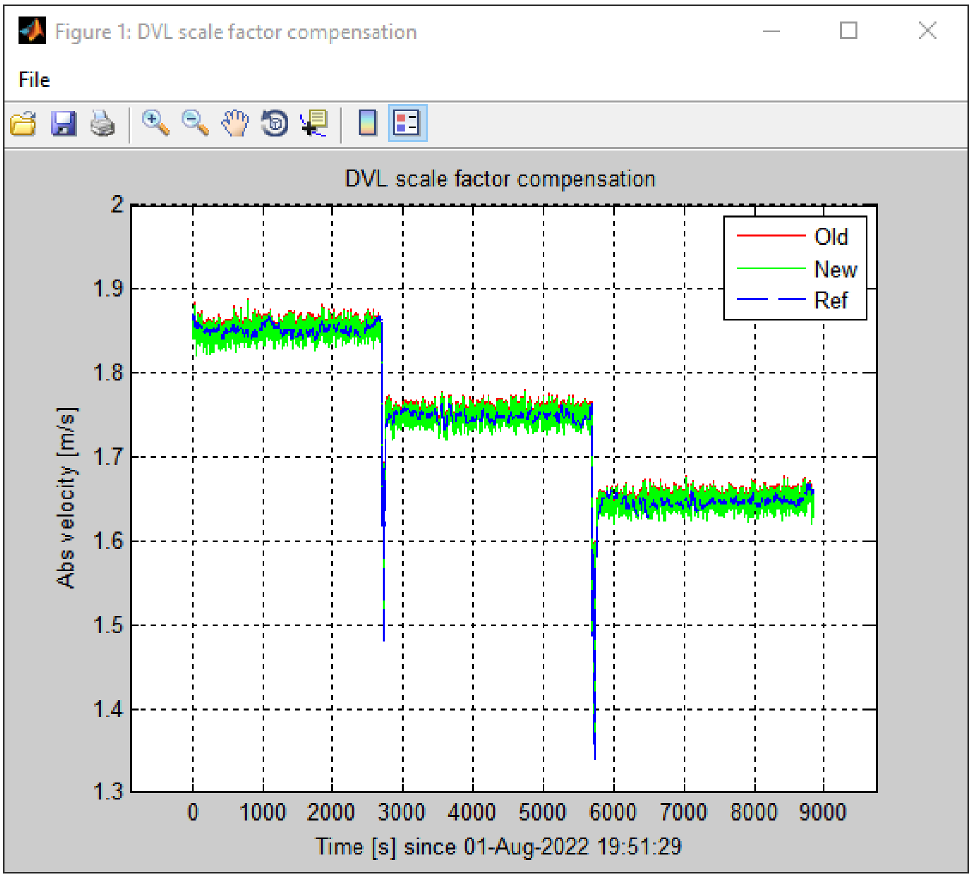

Figure 10 DVL scale factor compensation

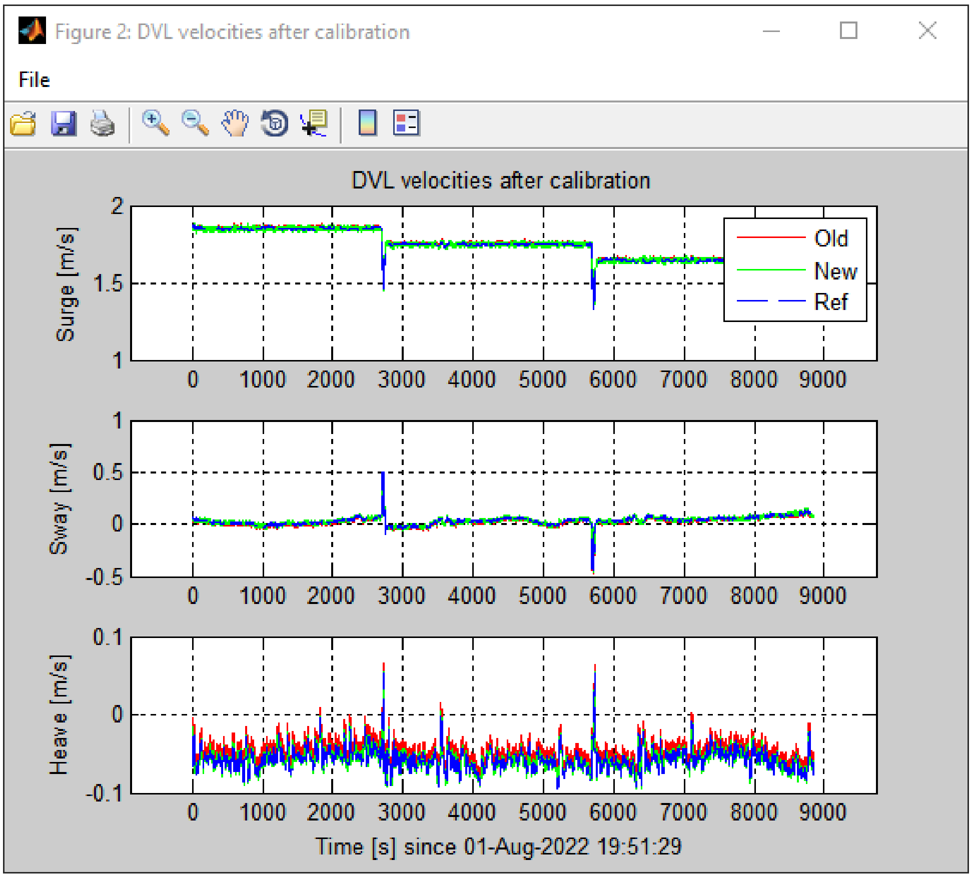

Figure 11 DVL velocities after calibration

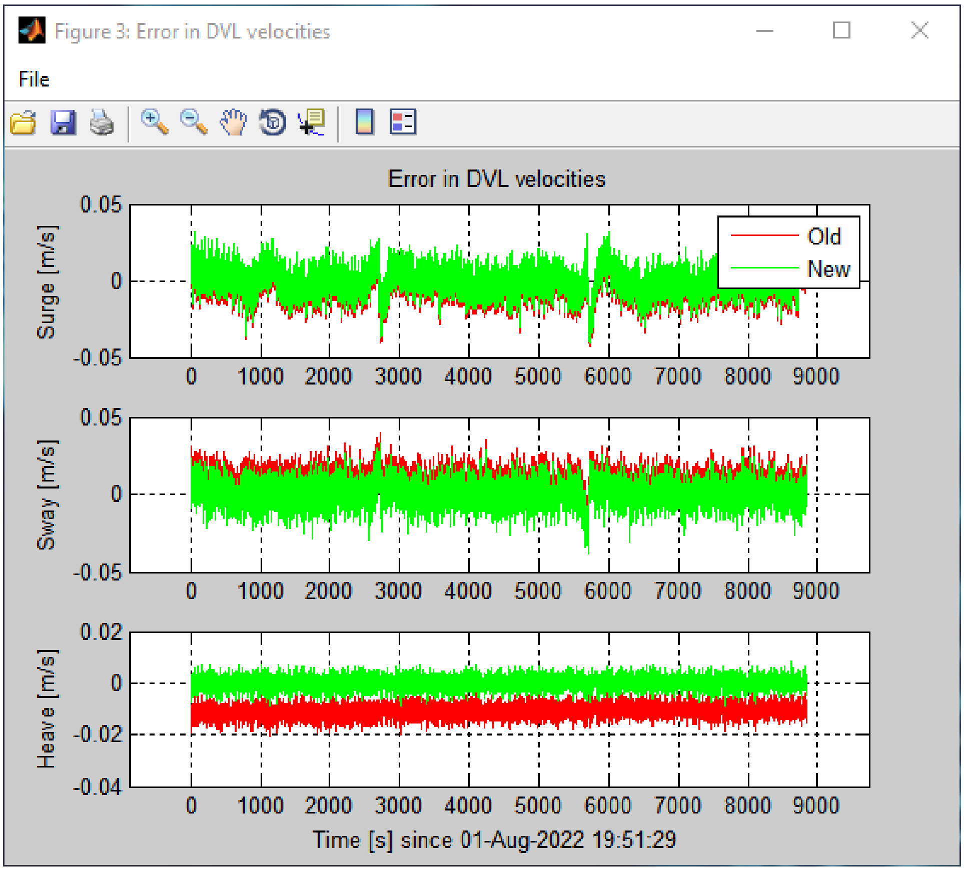

Figure 12 Error in DVL velocities

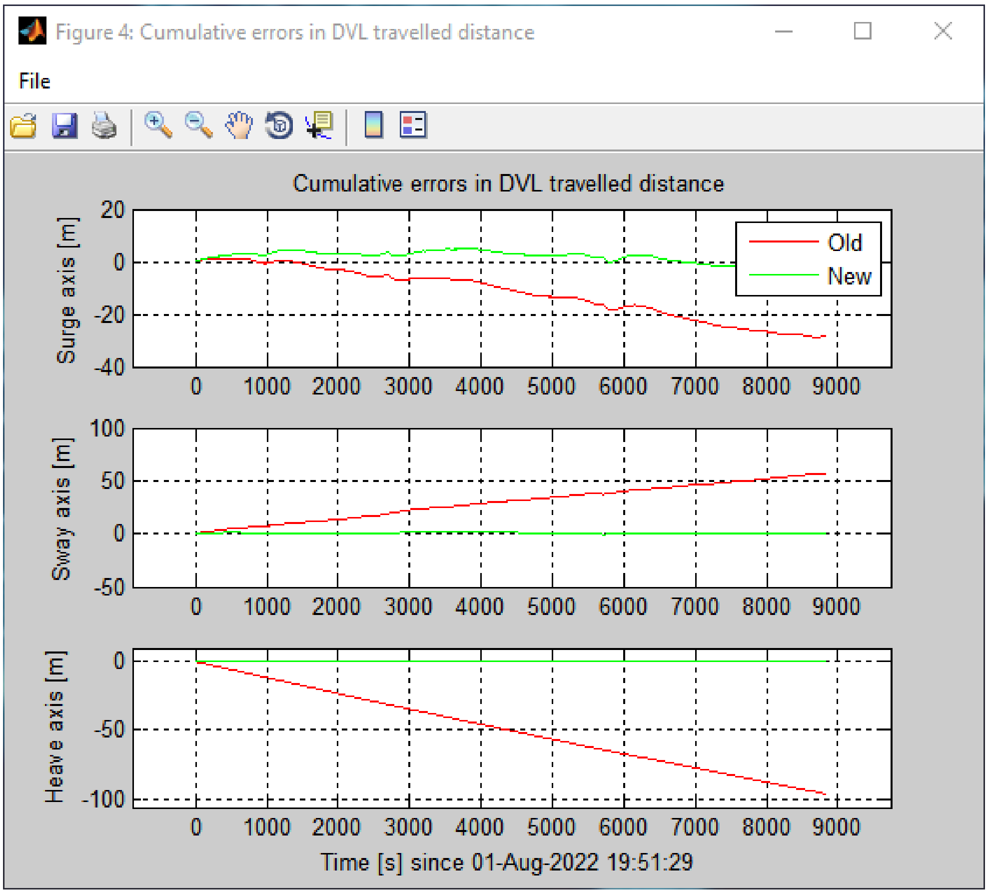

Figure 13 Cumulative errors in DVL travelled distance

9. AUV MBES Calibration

With the MBES echo sounder, motion sensor and gyro all installed on an AUV, there will always be some residual misalignment between the sensors. Any deviations in roll will translate to depth measurement errors in the outer beams, increasing with beam angle. Deviations on pitch will result in along track position errors.

To establish any latency issues between the time stamp and the acquired MBES data, a latency calibration is required. Latency errors identified by this calibration will be presented as speed-dependent position error data, and applied to the processed data accordingly.

In order to verify this, an MBES Calibration and Verification was performed over the top of a crevice at the Alvin Canyon site shown in Figure 3 at E 366503.054, N 4425982.1293.

9.1 MBES Verification Method

Prior to the calibration, the MBES positional offsets were verified to be correctly entered into the acquisition software. A sound velocity cast was also taken and again, the profile entered into the acquisition software. The calibration was then able to take place as per the mission plan.

The mission plan for the AUV MBES calibration consisted of three parallel lines. The vehicle operated in Supervised Mode with continuous positioning updates. The AUV altitude was approximately 40 m and speed 3.6 knots (survey operational speed). The additional latency line was run at a 3.0kts. The line lengths were 1000 m, and line spacing was about 50 m.

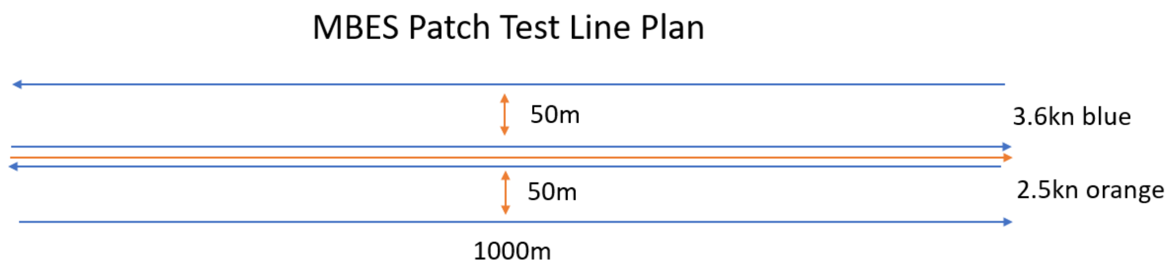

Figure 14 AUV Verification Mission – MBES Line Plan Schematic

The AUV subsea depths were determined using pressure sensors within the AUV. These pressure values were then processed along with the vehicles CTD data and surface pressure readings in NavLab using the UNESCO pressure to depth formula in order to calculate the depth of the seafloor. All depth values were reduced to Mean lower Low Water (MLLW).

The bathymetry data was then corrected with post processed navigation from NavLab and then processed in EIVA NaviModel in order to confirm if any roll, pitch and heading misalignment angles were present in the MBES system. These values could then be compensated for by adjusting the MBES setup within the Hugin Operating System (HOS).

9.2 AUV MBES Calibration Results

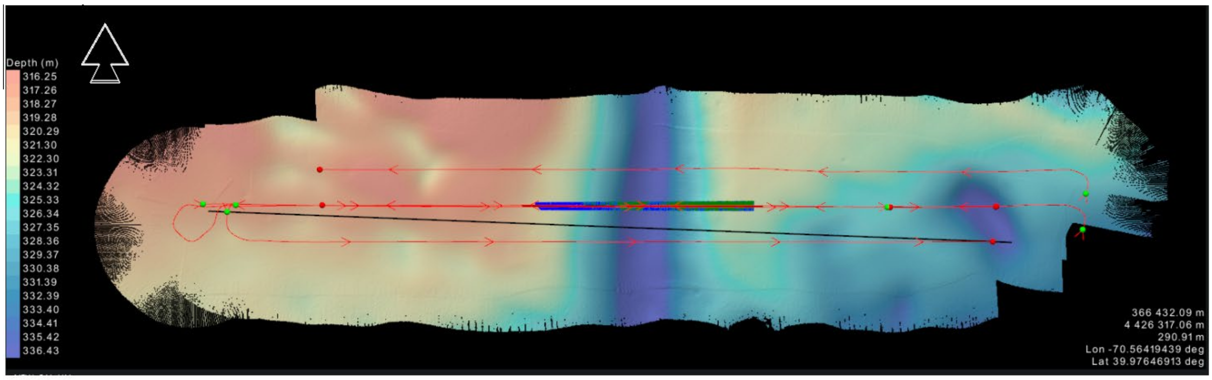

Figure 15 AUV - Bathymetric surface calibration overview

Table 15 MBES calibration results.

PARAMETERS	VALUES
Pitch	0.220°
Roll	-0.083°
Heading	0.619°
Latency	0ms

The values below in Table 16 have to be applied to all of the raw data for the project via post processing. The values embedded in the raw data files are from a previous job; as a valid Patch Test was not able to be conducted prior to the survey time frame, but immediately afterwards.

Table 16 MBES Patch Values in Raw Data

Patch Values Applied to Raw Data	Value to be Applied in Post Processing
Pitch = 0.350	Pitch = 0.220
Roll = -0.093	Roll = -0.083
Heading = 0.310	Heading = 0.619

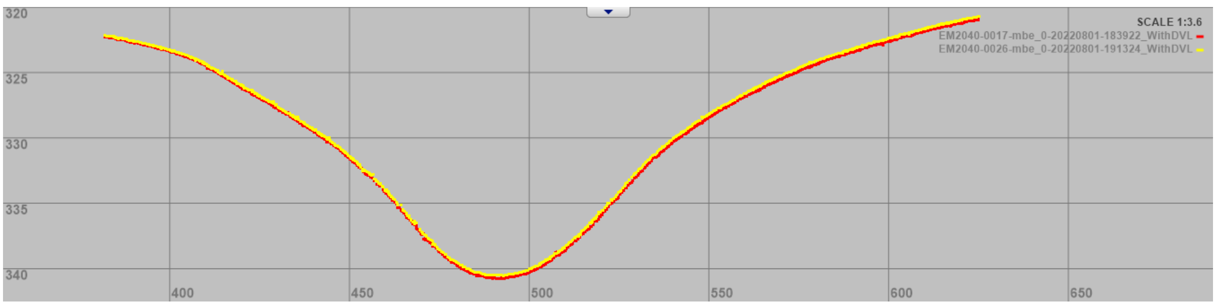

Figure 16 AUV - Pitch before calibration

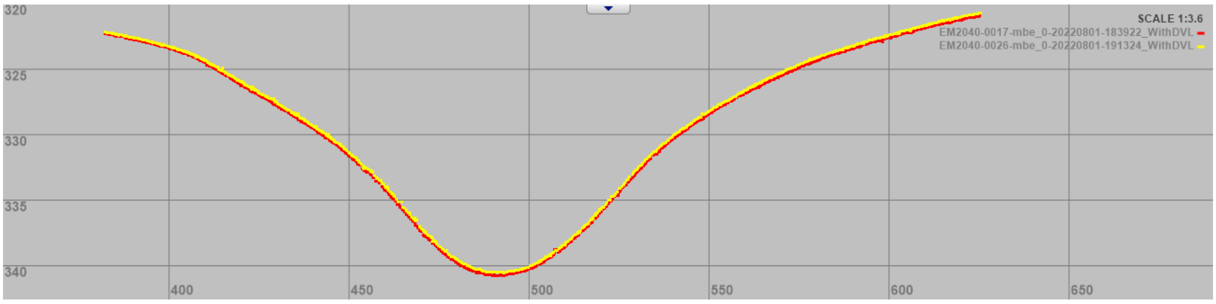

Figure 17 AUV - Pitch after calibration

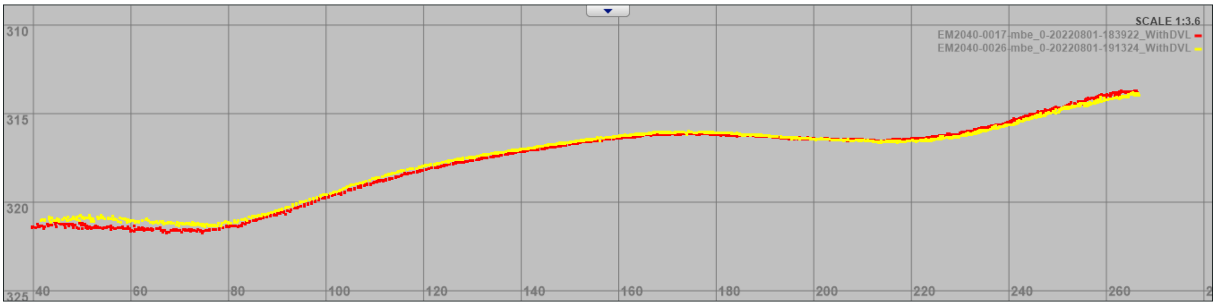

Figure 18 AUV - Roll before calibration

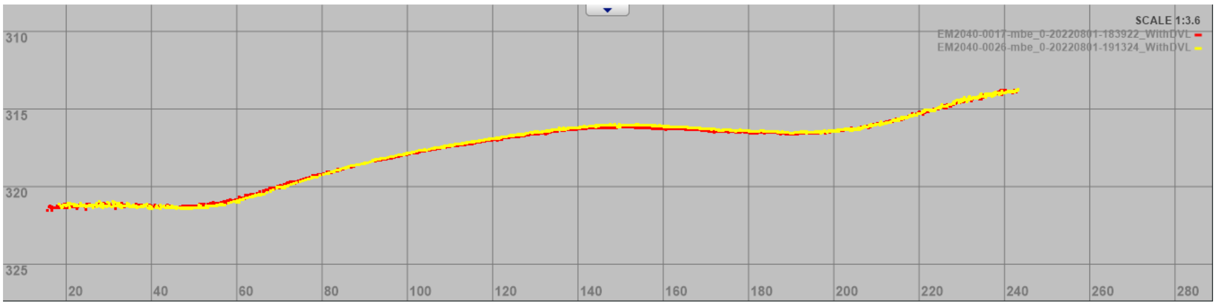

Figure 19 AUV – Roll after calibration

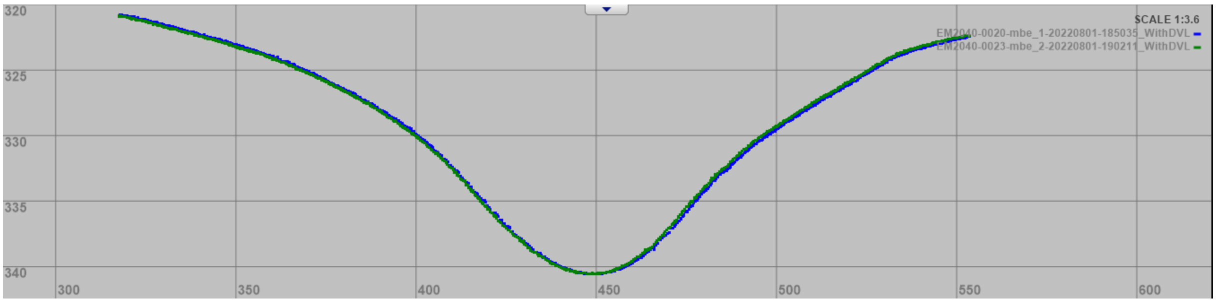

Figure 20 AUV - Heading before calibration

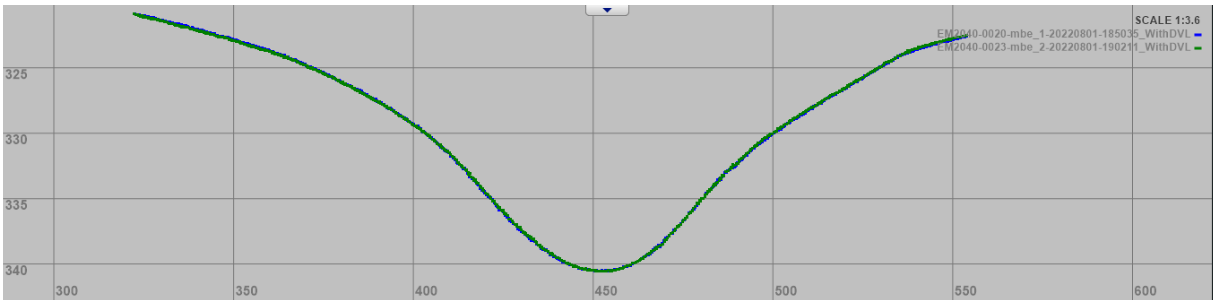

Figure 21 AUV - Heading after calibration

9.3 AUV MBES Navigation and Positioning

The following figure shows an example of the NavLab post-processed navigation track plots for a portion of the Verification and Calibration survey lines on the AUV. The colours of the measurements in Figure 22 are explained below:

- Green - Real Time track plot (monitored during the acquisition using predictive INS model based on historical positional data).
- Blue - Smooth track plot (the final result of post-processing navigation after smoothing the data with a Kalman filter).
- Grey points -HIPAP USBL Positions

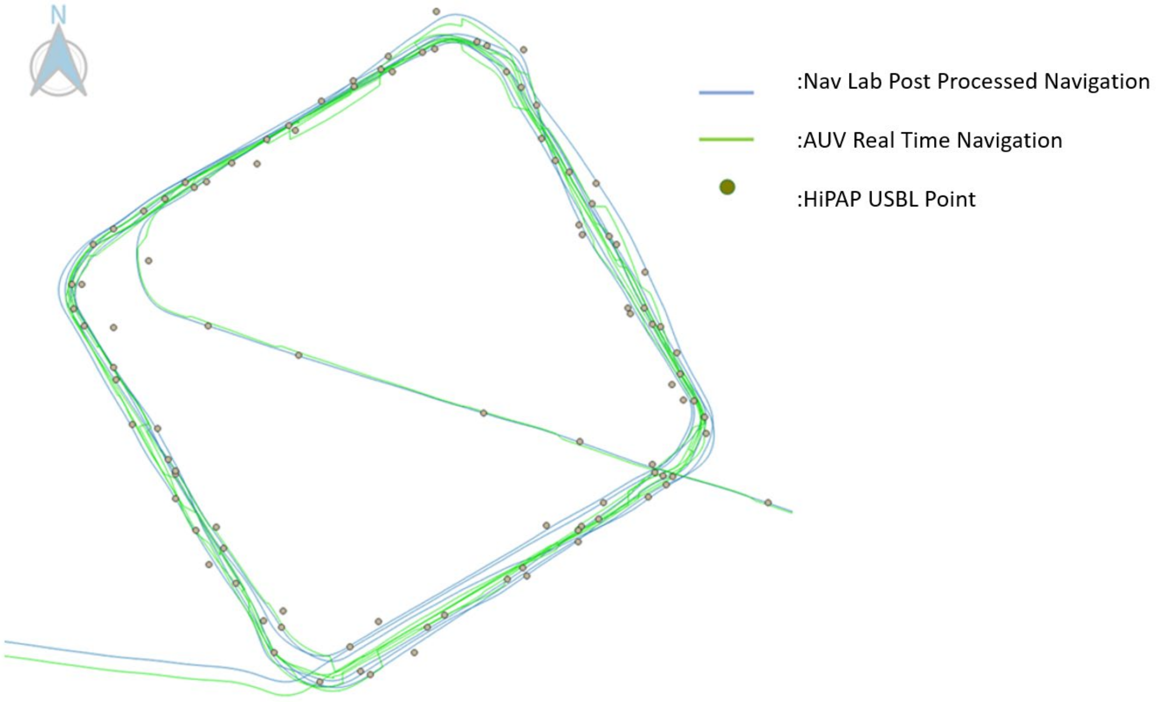

Figure 22 AUV Navigation

10. Side Scan Sonar Verification

The verification of the AUV-mounted Side Scan Sonar (SSS) was carried out as part of the offshore calibrations. The Edgetech 2205 was run in High-Definition mode with 75kHz and 225kHz frequency settings (SSL and SSH, respectively) over the Blake Plateau site.

10.1 SSS Verification Procedure

Before the SSS verification test, the setup of the SSS was checked following the Ocean Infinity startup checklist.

To verify that the positioning of the SSS data is within project specification (acceptance criteria stated in ITP, Appendix A) and that the visual data quality is met, the positions of well-defined surficial geology boundaries were compared with the same boundaries identified in MBES data. The results are presented in section 10.3 and in Figure 23.

10.2 SSS Verification Parameters

The acquisition parameters used are presented in Table 17.

Table 17 Acquisition Parameters Summary.

		Comment
Acquisition:	Geodetic (LL)	ITRF 2014/WGS 84
	Projected (XY) *(Shall be avoided)*	UTM 17N
Speed		3.6 kn
Altitude		40 m
Range	HF	200 m
	LF	200 m
Frequency	HF	225 kHz
	LF	75 kHz
Ping rate	HF	3.5 Hz
	LF	3.5 Hz

10.3 SSS Verification Results

Three lines were run inside survey area with 130 m line spacing, using 200 m as sonar range. From those three lines a mosaic was created. AUV altitude was approximately 40 m and speed was around 3.6 knots. Water depth at the location of the selected surficial geology boundary was approximately 763 m. The selected surficial geology boundaries were interpreted as a transition from homogeneous to remobilized SAND.

The positioning of the AUV SSS data was very good, both between transducers and when compared to the MBES data.

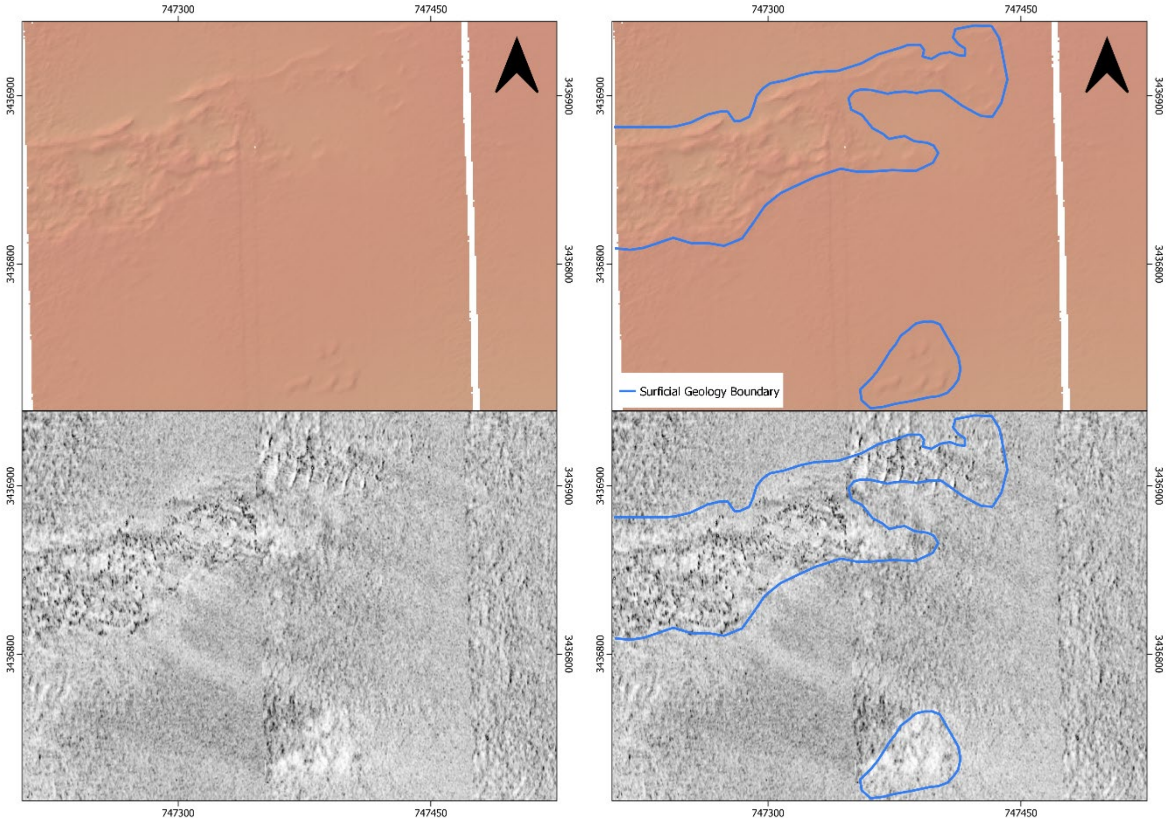

Figure 23 Verification images in MBES and SSS from AUV. Blue lines are surficial sediment boundaries.

11. AUV SBP Pulse Verification

The verification and pulse trials of the AUV-mounted Sub Bottom Profilers (SBP) were conducted using the Edgetech DW-216 Chirp SBPs on the AUV. The Pulse Trials took place in the same locations as the MBES verification.

The pulse trials were conducted in order to determine the best SBP pulse type setting to be used throughout the WHOI survey campaign and are within the specifications outlined by WHOI. It also aimed to verify the positioning of the SBP data.

11.1 SBP Pulse Trials Method

Prior to the SBP pulse trials, the payload parameters for the SBP were verified following the Ocean Infinity start-up checklist. A tap test was also performed to verify that the sensor was functional.

The SBP pulse trials were then completed by making four passes over two 500m long survey lines in the area near Alvin Canyon. The lines were run back and forth in opposing directions at a constant speed (3.6 knots), heading and altitude (stable and in agreement with planned survey altitude of 40 m), to confirm if any deviation in position existed. On each line, a master ping rate of 2 Hz was used, with a different SBP pulse setting:

- Pulse Trial 1: 1 kHz to 9 kHz and pulse length of 20ms
- Pulse Trial 2: 1 kHz to 9 kHz and pulse length of 40ms

These parameters were adjusted in the payload settings and then communicated to the AUV at the end of each line, prior to commencing the next.

After the AUV was back on deck, the SBP data was downloaded and imported into the data processing and interpretation software. The positioning of the data, as well as the data quality were then verified and the optimum pulse setting selected for use in the WHOI project, as shown in the following sections.

11.2 SBP Pulse Trials Results

The results of the four pulse trial lines are shown in the next figures. All the figures were exported from SonarWiz. The x-axis shows easting and northing and the y-axis delineates 100 ms intervals.

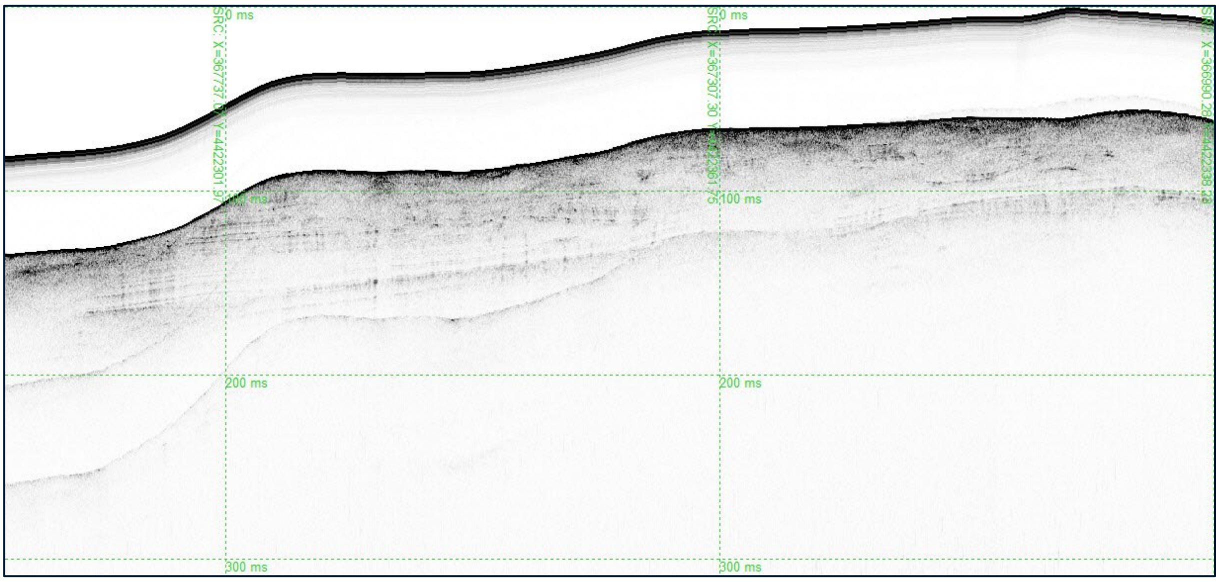

Figure 24 AUV SBP Pulse Trial 1 W-E (1 - 9kHz, 20ms)

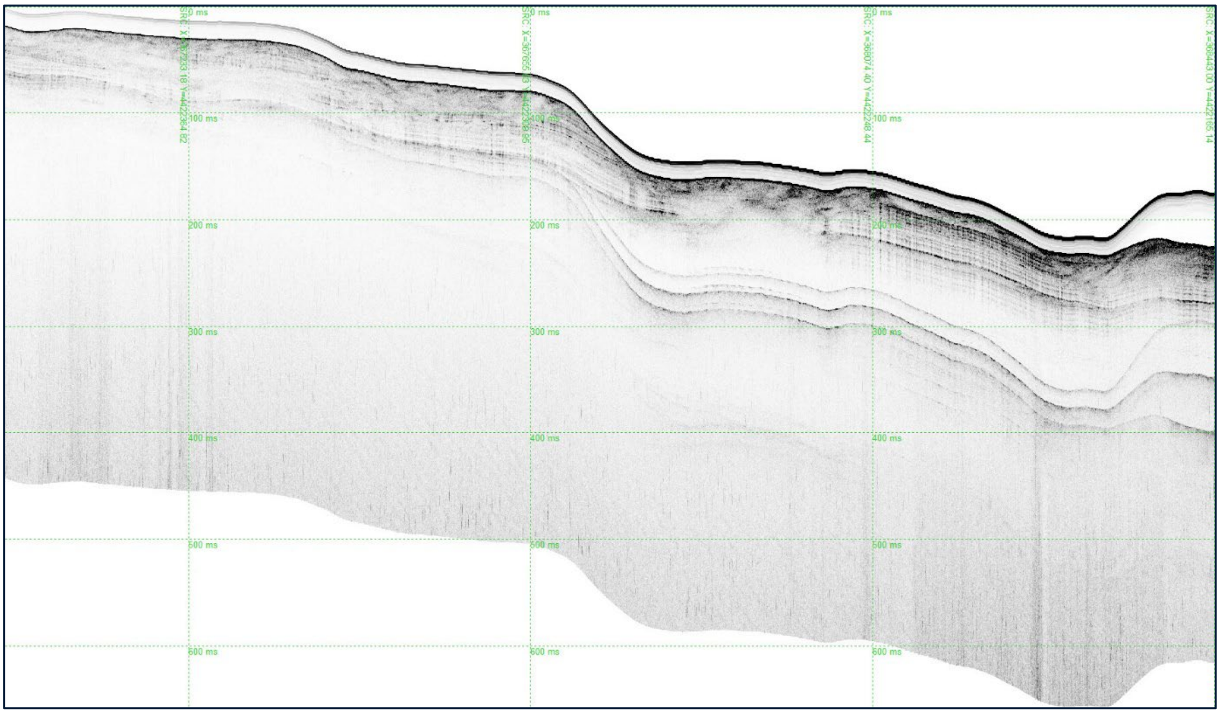

Figure 25 AUV SBP Pulse Trial 2 E-W (1 - 9kHz, 40ms)

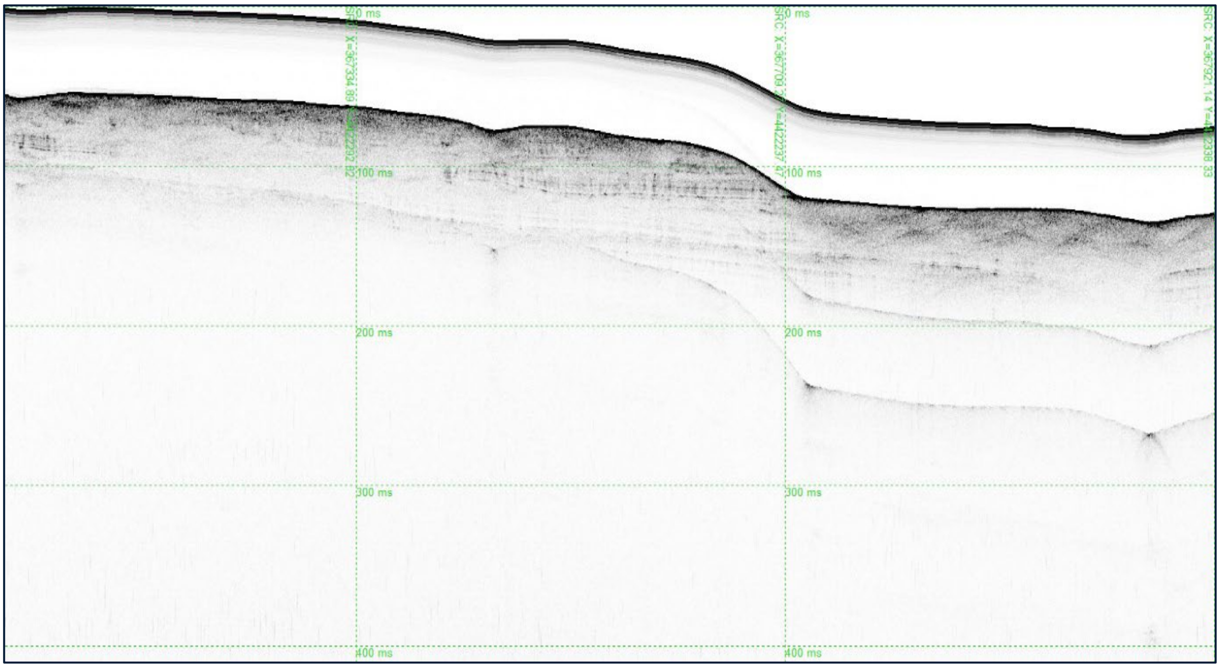

Figure 26 AUV SBP Pulse Trial 3 W-E (1 - 9kHz, 20ms)

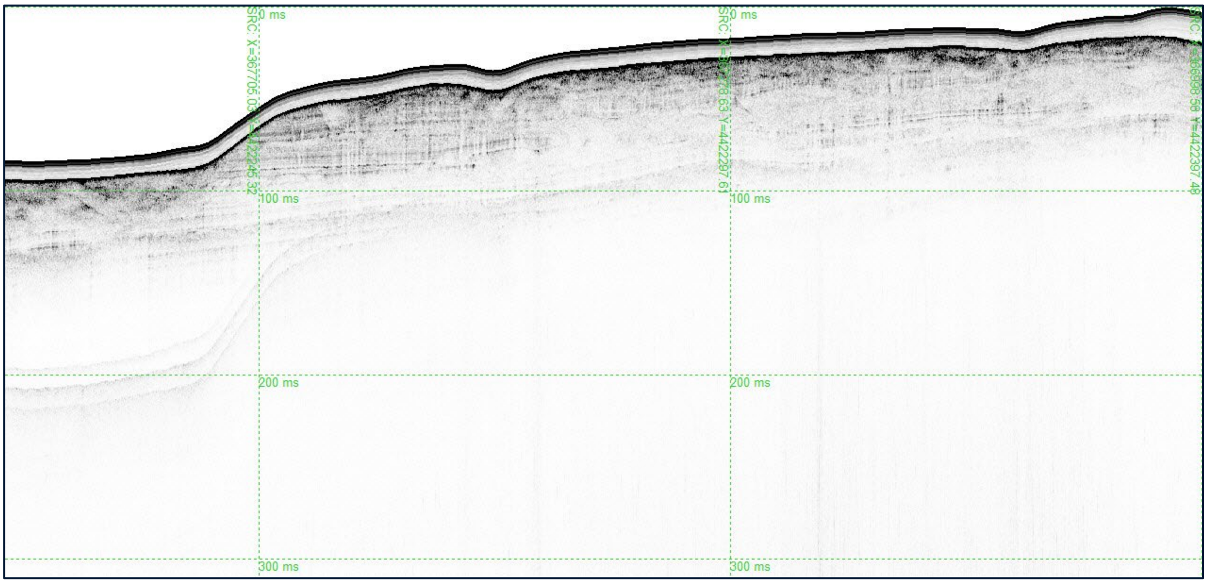

Figure 27 AUV SBP Pulse Trial 4 E-W (1 - 9kHz, 40ms)

The data shows that both settings achieved acceptable penetration and resolution. Noise in the data is a result of the Acoustic Down Link (ADL) from the HiPAP to the AUV. Because of the comparable quality of all lines, the client decided a 20 ms pulse length was fit for purpose.

11.3 SBP Positioning Verification

To verify the SBP horizontal and vertical positioning, the average MBES surface was exported from NaviModel and imported into the processing software SonarWiz. The MBES overlaid on the SBP data (red line in Figure 28) to compare the location of various seabed features. The visual comparison presents positive results with a very good horizontal correlation and an acceptable vertical match, with offsets due to the differences in the system physics that are within specs. Based on this comparison, the data and processing workflow is found fit to purpose and no further alignments are required.

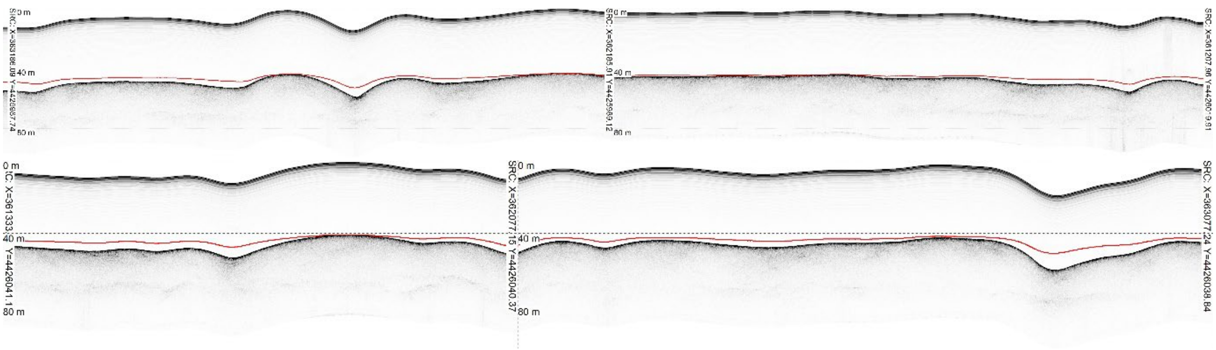

Figure 28 Example of two AUV SBP lines comparing to MBES seabed depth (red line).

11.4 SBP Verification Conclusion

All SBP verification lines showed high quality data. Comparisons were made between all four (4) pulse settings and a summary of results sent to the Client. It was agreed that the pulse type 1 settings (1-9 kHz, 20ms pulse length) were the most suitable for the survey campaign.

The performance of the resolutions and penetration will be assessed periodically throughout the survey to ensure the acquired SBP data continues to meet the client's specification

12. CathX Still Camera

12.1 Speed and Altitude Test

A test of the AUV-mounted CathX camera was carried out as part of the offshore calibrations on 17th July 2022 and 19th July 2022. A M12-A1000 CathX camera (12.5 MP) with APOS32 lighting is mounted on the AUV. The verification was carried out near Alvin Canyon at a water depth of approximately 380m and at the survey site at a water depth of 1800 m.

12.1.1 Procedure

Two test lines were run at four different altitudes and one speed as shown in Table 18. The CathX line ran at 8m altitude was conducted at the Alvin Canyon test site. A high quantity of particulates was visible in the water column causing unclear imagery. The additional test lines were conducted at the main survey site in deeper water with reduced chance of particulate in the water column.

Table 18 Environmental photography test settings.

AUV Altitude (m)	AUV Speed (kn)
8	3.6
5	3.6
4	3.6
3	3.6

12.1.2 Results

Image quality achieved was deemed suitable for purposes of the transect survey. Objects the size of 0.2 m were visible and identifiable to major faunal groups at an altitude of 5 m and a speed of 3.6 kn, which was the recommended altitude and speed for the visual survey.

Images may also be edited if deemed necessary to obtain the best white balance and contrast.

Example still images for the different settings are shown in Figure 29 to Figure 32.

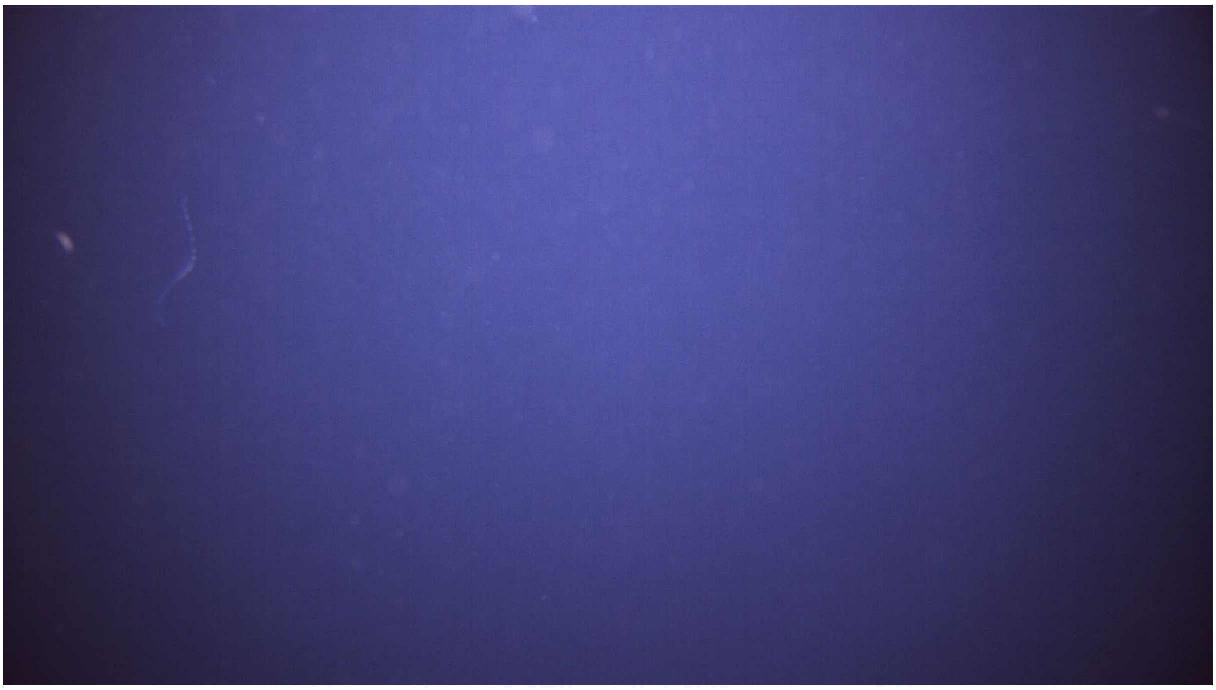

Figure 29 Still photography test – 8 m and 3.6 knots.

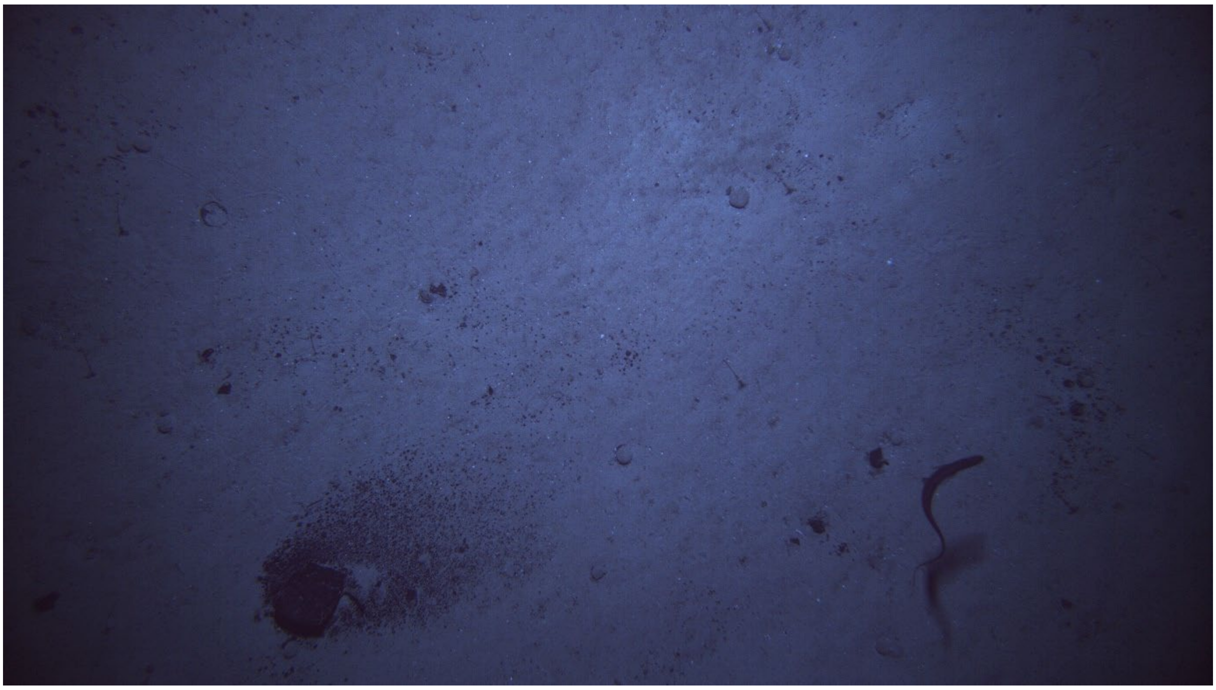

Figure 30 Still photography test - 5 m and 3.6 knots

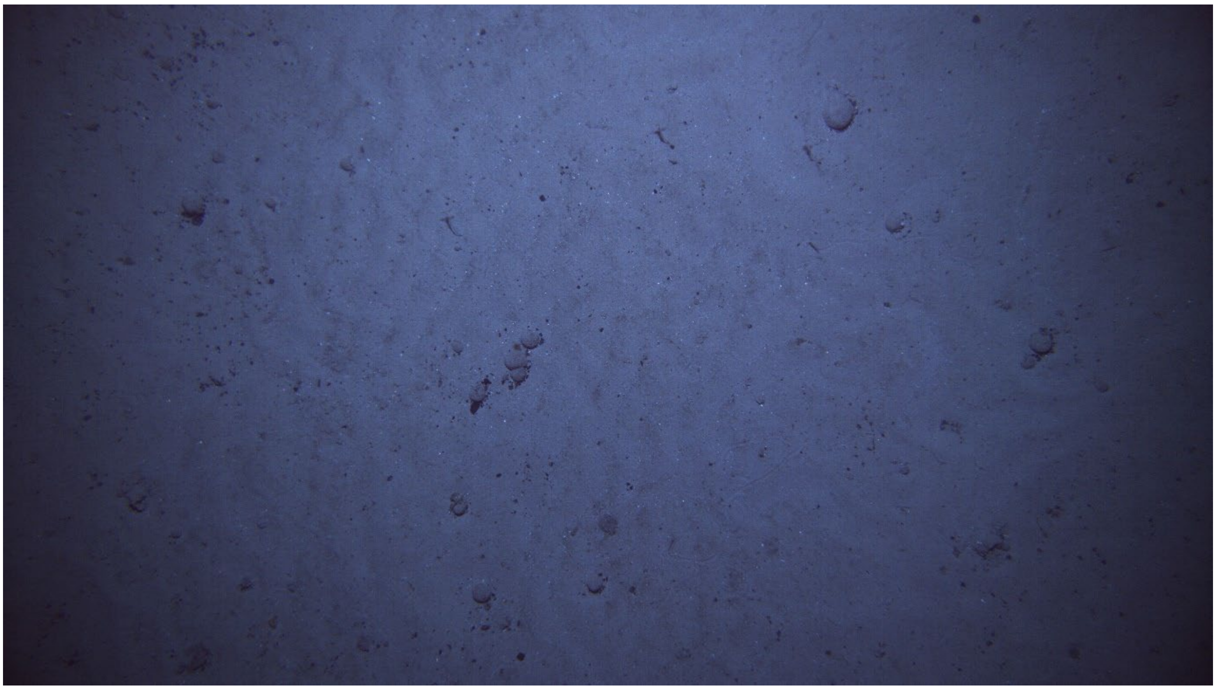

Figure 31 Still photography test - 4 m and 3.6 knots.

Figure 32 Still photography test - 3 m and 3.6 knots.

Absolute positioning was verified against MBES data (Table 19).

Table 19 CathX position comparison.

	Easting (m)	Northing (m)
Cathx image	480759.50	4258451.38
MBES data	480759.61	4258451.61
Difference	0.11	0.24

13. Mobilisation and Calibration Approval

Mobilization and verification approved on 2022-08-09

__________________________ Chad Bonin Offshore Manager	_______________________ Tsu-Ting Chen Client Representative

Appendix A Inspection and Test Plan

Appendix B Dimensional Survey Deep Helder

Operations Report

SEAFLOOR SURVEY AT ATLANTIS II SEAMOUNT – WHOI CRUISE AT47 REV2

AUV Survey

US North East Coast

CLIENT
WHOI

DATE
17 August 2022

CREATED BY
Chad Bonin

DOC NO.
104257-WHO-OI-SUR-REP-OPE

APPROVED BY
Andy Sherrell

REVISION
Issue A

OCEAN INFINITY®

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Revision	Date	Status	Check	Approval
A	2022-08-17	Issued for Client Use	Donatien Eve	Andy Sherrell
02	2022-08-09	Issue for Client Review	Donatien Eve	Andy Sherrell
01	2022-08-04	Issue for Internal Review	Donatien Eve	Andy Sherrell

Revision Log

Date	Section	Change

Document Control

Responsibility	Position	Name
Content	Offshore Manager	Chad Bonin
Content, check	Project Report Coordinator	Donatien Eve
Check	Reporting Quality Controller	Hannes Corbett / Pontus Frost
Approval	Project Manager	Andy Sherrell

Table of Contents

Appendices

Figures

Tables

Abbreviations and Definitions

CTD....................Conductivity, Temperature and Depth
DGPS....................Differential Global Positioning System
DP....................Dynamic Positioning
DPR....................Daily Progress Report
DVL....................Doppler Velocity Log
ENF....................Emergency Notification Flowchart
ESRI....................Environmental Systems Research Institute, Inc. (company that has developed the ArcGIS software)
GAPS....................Global Acoustic Positioning System
GPS....................Global Positioning System
HAZOP....................Hazard and Operability Study
HSE....................Health, Safety and Environment
HSEQ....................Health, Safety, Environment and Quality
IMU....................Inertial Measurement Unit
INS....................Inertial Navigation System
ITRF....................International Terrestrial Reference Frame
km....................kilometre
LARS....................Launch and Recovery System
m....................metre
MAC....................Mobilisation and Calibration
MAG....................Magnetometer
MBES....................Multibeam Echo Sounder
MINCS....................Improvement and Non Conformity System
OI....................Ocean Infinity Sweden AB
OI MS....................OI Management System
MRU....................Motion Reference Unit
MSL....................Mean Sea level (vertical datum)
OM....................Offshore Manager
PPS....................Pulse Per Second
QA....................Quality Assurance
QC....................Quality Control
QINSy....................Quality Integrated Navigation System
SBP....................Sub-Bottom Profiler
SD....................Standard Deviation
SSS....................Side Scan Sonar
SVP....................Sound Velocity Profile
USBL....................Ultra Short Baseline System
UTC....................Coordinated Universal Time
UTM....................Universal Transverse Mercator

1. Introduction

1.1 Project Information and Survey Area

Ocean Infinity America (OIA) has been awarded an AUV project with the Woods Hole Oceanographic Institution (WHOI) for a seafloor and sub-bottom study using an Autonomous Underwater Vehicle (AUV) in the Atlantis II Seamounts area to determine seafloor suitability to place anchors for a large subsea acoustic antenna. Working depth at site is 1700-2000m depths.

The AUV will collect SSS/MBES/MBBS/SBP for immediate initial evaluation upon recovery of the AUV, with subsequent AUV dives collecting CathX imagery to ground truth the data. The goal is to find at least six sandy areas (at least ~100m x 100m) to place anchors, transponders and environmental monitors. There also needs to be ~500-1500m of separation between individual sites.

AUV mission plans will need to be updated to account for areas the client wants to focus on within the larger area.

The following primary AUV sensors will be used: SSS, SBP, MBES/MBBS, CathX, CTD, Turbidity.

The AUV12 fly away system currently in the US will be mobilized, which includes the 20ft OPS container, 20ft Spares container, and 40ft LARS container as the primary launch and recovery platform. A rental HiPAP352MGC USBL system will also be installed in the moon pool.

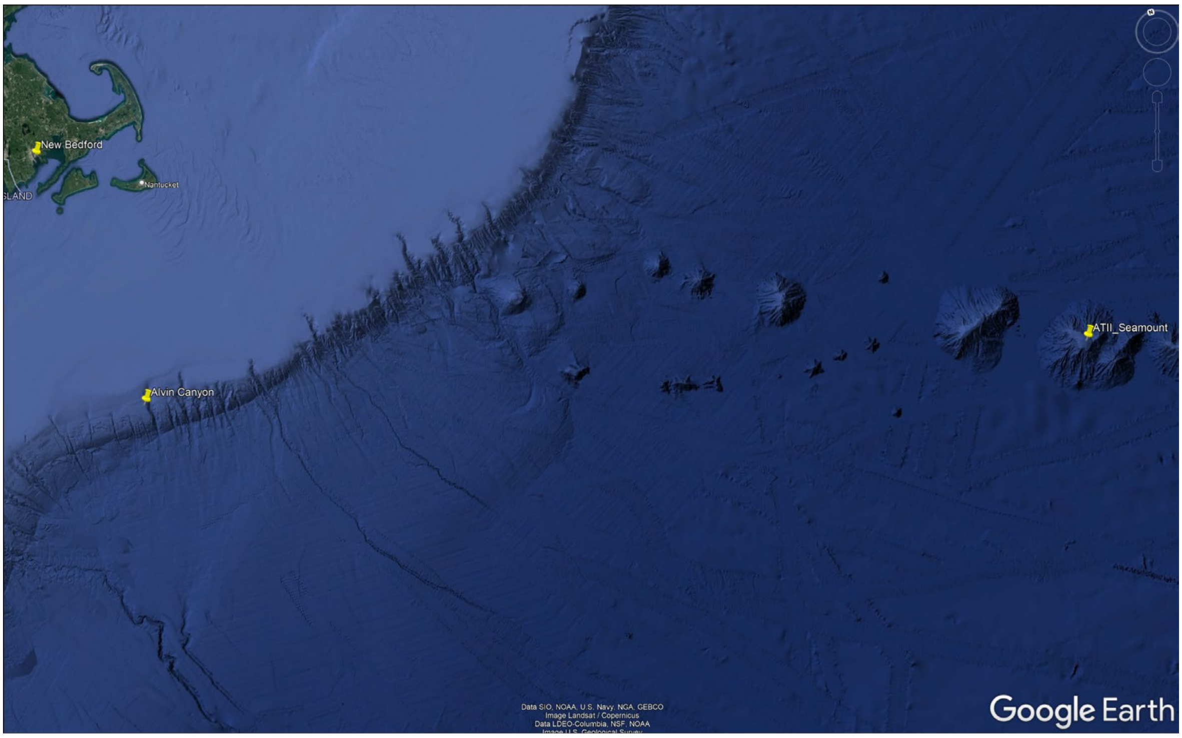

Figure 1: Project area, Alvin Canyon test site, and New Bedford mobilization location

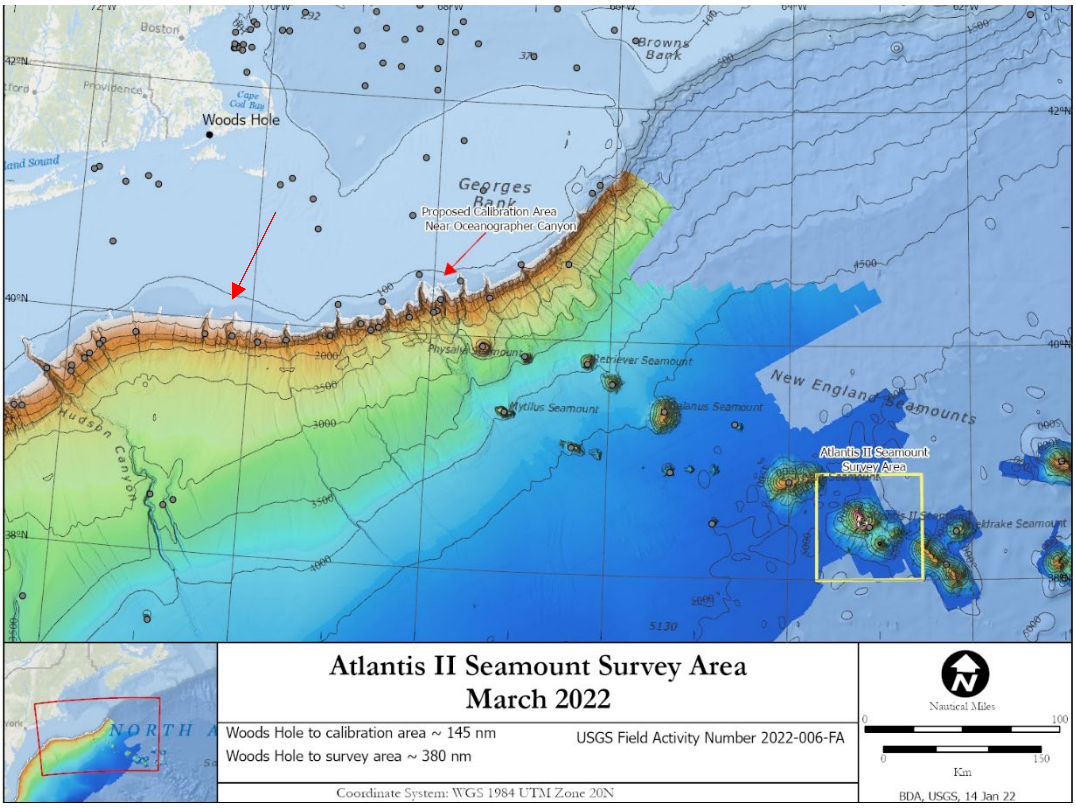

Figure 2: Project area and potential test site location.

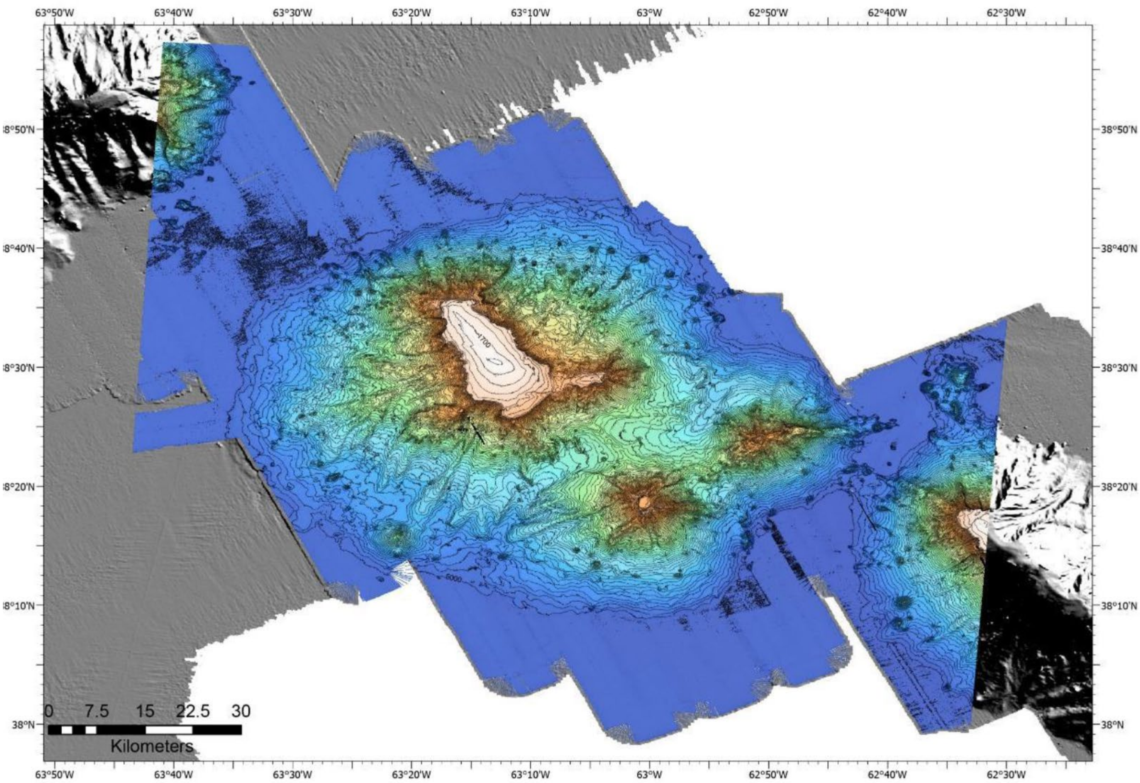

Figure 3: Bathymetric map of the Atlantis II Seamounts. (Courtesy of Jason Chaytor, USGS).

Table 1 Project Details

CLIENT:	Woods Hole Oceanographic Institute (WHOI)
PROJECT:	AT47 Atlantis II Seamount
Ocean Infinity USA (OI) Project Number:	104257
SURVEY TYPE:	AUV, Geophysical survey
AREA:	US North East Coast
SURVEY PERIOD:	17 days
SURVEY VESSELS:	Deep Helder
OI PROJECT MANAGER:	Andy Sherrell
CLIENT PROJECT MANAGER:	Derek Buffit

1.2 General Scope of Work

AUV collected SSS/MBES/MBBS/SBP for immediate initial evaluation upon recovery of the AUV, with a subsequent AUV dive collecting CathX imagery to ground truth the data. Goal was to find at least six sandy areas (~500m x 500m) to place anchors, with ~500-1500m separation between each area.

AUV mission plans were updated to account for areas client selected within larger area.

Primary AUV sensors used were as following: SSS, SBP, MB, CathX, CTD, Turbidity.

1.3 Purpose of Document

This document provides details of the operations on board the M/V Deep Helder during the Atlantis Seamount II survey between 2022-07-13 and 2022-07-31. It describes the survey tasks undertaken, provides time spent on various tasks and the order in which these were performed. The equipment used will be described together with the acquisition parameters.

The report also gives an account of the health, safety, and environment (HSE) performance for the vessel during the operational period.

The report is intended to provide technical information to complement the processing and results, which are presented in the Processing Report and Interpretative Report, see Table 2.

1.4 Report Structure

Section 2 covers the HSE aspects of the operations including a summary of reported incidents. In Section 3 the survey parameters are outlined. Section 4 show overall AUV line plan for project. Section 5 highlights deviations from the Scope of Work and summarises the survey task performed. Finally, Section 6 describes the Survey Performance in detail, including a daily narrative, description of the data acquisition, and a data quality evaluation.

1.5 Reference Documents

The documents used as references to this Operations Report are presented in Table 2.

Table 2 Reference Documents

Ref.	Document Number	Title	Author
1.	104257-WHO- OI -HSE-PRO-HAZOP	Hazard and Operability Study Incl. Operational Procedures	OI

Ref.	Document Number	Title	Author
2.	104257-WHO-OI-HSE-PRO-HSEPLAN	HSE Plan - Vessel	OI
3.	104257-WHO-OI-HSE-PRO-ENFDEEPH	Emergency Notification Flowchart - Vessel	OI
4.	104257-WHO-OI -MAC-PRO-DHELDER	Mobilisation and Calibration Procedures - Deep Helder	OI
5.	104257-WHO-OI-MAC-REP-DHELDER	Mobilisation and Calibration Report - Deep Helder	OI
6.	104257-WHO-OI-SUR-REP-OPEDHELDER	Operations Report	OI
7.	QUA-W-QUA-QASSURAN-MAN	Quality Assurance Manual	OI

2. Health, Safety, Environment and Quality

2.1 Overview

This section covers the HSE information for the following vessel during the Atlantis II Seamount – WHOI Cruise AT47 Survey:

- M/V Deep Helder: 2022-07-13 to 2022-07-31

The HSEQ summary presented takes into account the activities during these periods.

A total of 6756 man hours have been registered for the vessel during the time period stated above. No fatality, major injury or major environmental damage has occurred or been reported. A short summary of incidents and issues are presented below.

2.2 Objectives

The project specific Health Safety Environment (HSE) Objectives were:

- Zero Harm to People
- Zero Harm to the Environment
- Increase actions/decisions for reduced environmental impact
- Ensure there is emergency preparedness in case of an incident
- Fulfil all national and international requirements
- Fulfil all client and internal demands

During the time period stated above all objectives were fulfilled.

2.3 Incident, Accident & Non-Conformity Reports (MINCS)

The reporting of accidents, near misses, and non-conformities as well as suggestions for improvements are important parts of the OI HSE system. Incidents, accidents, near misses, other non-conformities and improvement suggestions are reported to the OI Improvement and Non-Conformity System (MINCS) for incident investigation, corrective actions and distribution to client.

The MINCS is web based and each of OI's personnel has access to the system and is responsible for registering incidents, accidents and other non-conformities experienced or witnessed by that person.

A total of 1 MINCS were reported during the time period stated above. All the MINCS reports are listed in Table 3 and Table 4.

Table 3 All MINCS reports registered on board the M/V Deep Helder

Mincs Number	Type of Report	Status	Date of Occurrence	Heading
3067	Non Conformity	Resolved	2022-07-15	Deep Helder- SVP Winch Failure

Table 4 All MINCS reports registered in the project, report summary

MINCS	REPORT SUMMARY
3067	Motor control contactor seized closed causing problems to overload protection circuit; 110VAC step down power board not providing adequate power. New motor control contactor installed; overload protection system replaced; changed power step down from 110VAC to 12VDS – Wired to operate/run locally.

2.4 Safety Observation Card System (SOB)

The observations reported through the SOB system are handled and coordinated locally on board the vessels/units/sites. SOB reports not possible to solve locally are raised as MINCS reports. The SOB data is also used as a statistical tool to find overall areas of improvement. A total of 0 SOB Cards were reported for the time period stated above.

SUMMARY OF SOB ANALYSIS

Observations were reported according to category representation above. A total of 0 observations were positive and the remaining areas where room for improvement where “condition of equipment and vessel” was the most common category followed by “procedure / training”.

2.5 HSE Statistics

The HSE statistics from the project period stated above are detailed in Table 5.

Table 5 HSE Statistics

HSE Items	DEEP HELDER
Man-hours	6756
Safe Job Analyses (SJA)*	0
Vessel Inductions/Familiarisations	7
Safety Observations Card (SOB)	0
Toolbox Talks**	34
Safety Drills	1
Workplace Inspections	0
Safety Walks	0
MINCS reports	1
Green Options***	0

* SJA: Prior survey start-up and at crew change with new personnel.
** Toolbox talks: Prior to specific work operation.
*** Green Options: decisions resulting in less negative environmental impact (e.g. reduced speed).

3. Survey Parameters

3.1 Project Parameters

3.1.1 Geodetic Datum and Grid Coordinate System

The geodetic datum used for SSS, SBP, and raw MBES during acquisition and processing are presented in Table 6. The projection parameters will also be used in QINSy (Table 7).

Table 6 Geodetic parameters

Horizontal Datum: WGS 84	
Datum	WGS84
Ellipsoid	GRS80
Prime Meridian	Greenwich (8901)
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.314 m
Inverse Flattening (1/f)	298.257222101
Unit	International metre

OI treat the ITRF2014 realization to be equivalent to WGS84.

(Reference https://confluence.qps.nl/qinsy/en/international-terrestrial-reference-frame-2014-itrf2014-29856813.html)

3.1.2 Projection Parameters

Table 7 Projection parameters.

Projection Parameters		
Survey Area	**Test Site**	**Project Site**
Projection	UTM	UTM
Zone	19 N	20 N
Central Meridian	69° 00’ 00’’ W	63° 00’ 00’’ W
Latitude origin	0	0
False Northing	0 m	0 m
False Easting	500 000 m	500 000 m
Central Scale Factor	0.9996	0.9996
Units	metres	metres

3.1.3 Vertical Reference Parameters

The vertical reference parameters used for processing and reporting are presented in Table 8.

Table 8 Vertical reference parameters.

Vertical Reference Parameters	
Vertical reference	MSL
Height model	EGM2008

3.1.4 Time Datum

Coordinated universal time (UTC) is used on all survey systems on board the vessel. The synchronization of the vessel's onboard system is governed by the pulse per second (PPS) issued by the primary positioning system. All displays, overlays and logbooks are annotated in UTC as well as the daily progress report (DPR) that is referred to UTC.

4. Survey Line Plan

During the AT47 cruise the Survey Lines were split into 8 missions to achieve the coverage in Block Mission 1A and 1B (figure 4 below). Mission1A in the figure below was only partially surveyed due to time constraints and 1B having priority.

Figure 5 shows all of the survey lines including CATHX lines overlaid on the MBES data.

Mission 1- Priority 1 Lines SW- NE.

Mission 2 - Priority 1 Lines SW- NE.

Mission 3 - Priority 1 Lines SW- NE.

Mission 4 - Priority 1 Lines SW- NE.

Mission 5 included Priority Lines SW-NE and 5 CathX boxes with 2m and 8m line spacing.

Mission 6 - Priority 1 Lines SW- NE.

Mission 7 - Priority 1 Lines SW- NE.

Mission 8 - 7 CathX boxes with 2m line spacing.

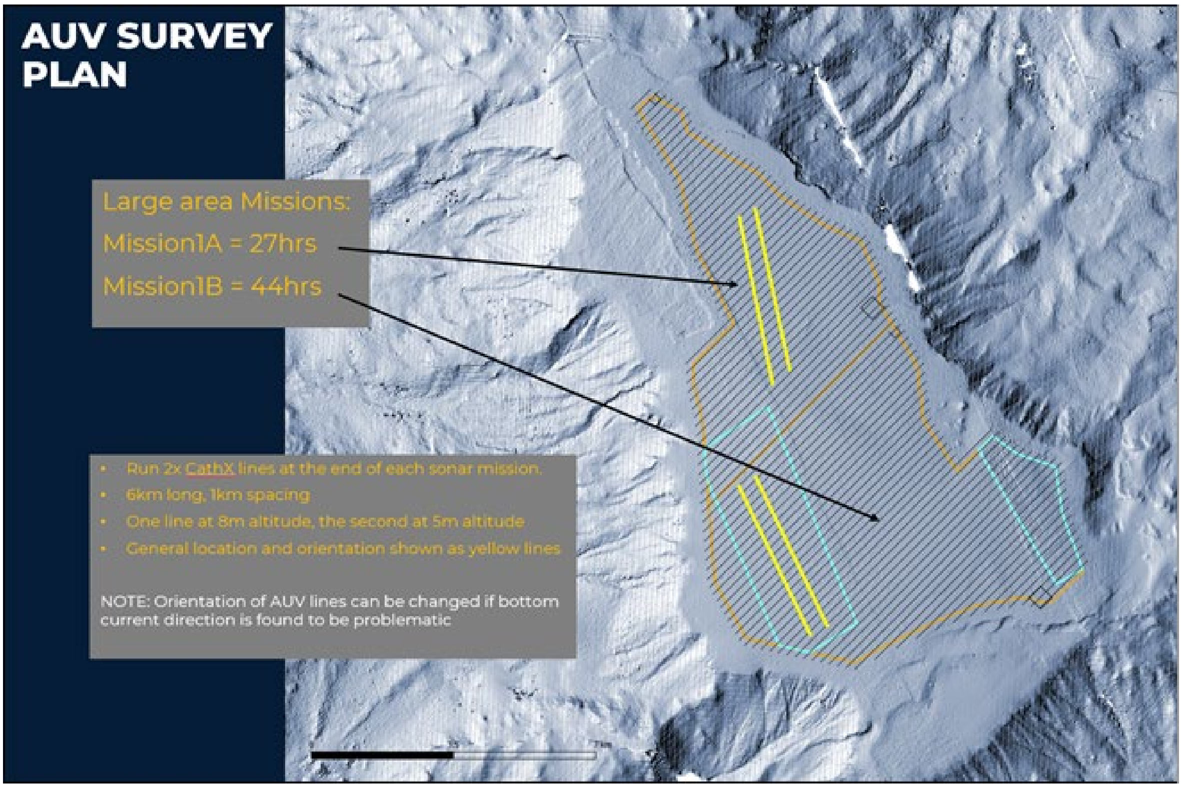

Figure 4 Survey lines

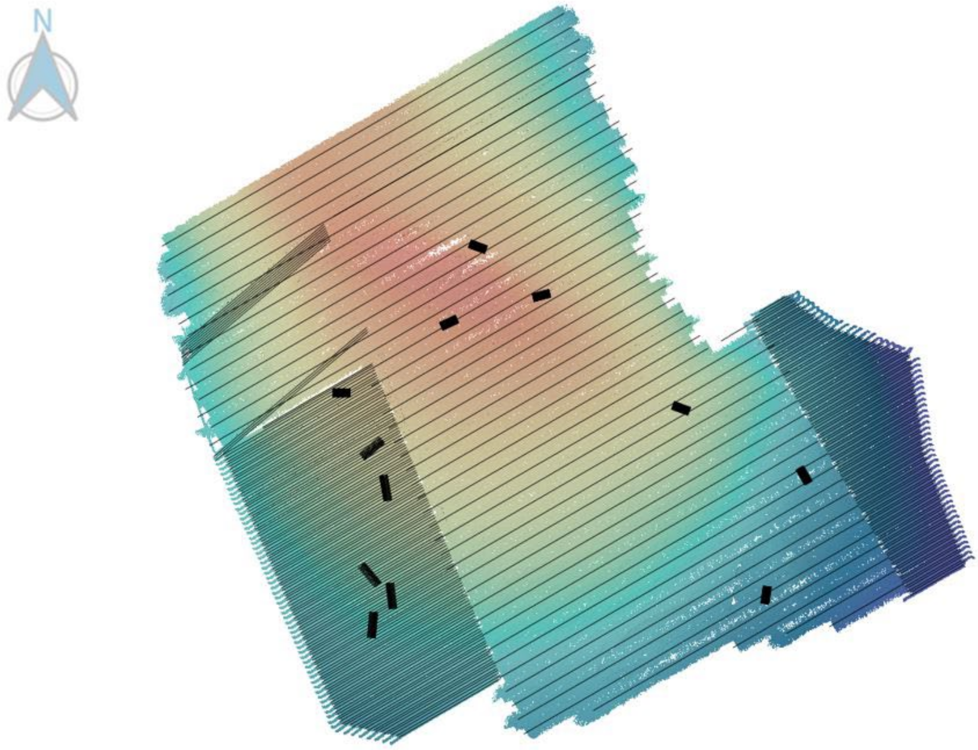

Figure 5 Survey lines collected by AUV overlaid on the MBES data from the Project

5. Operations

5.1 Deviations from the Scope of Work

The USBL verification and subsequent AUV MB patch test and DVL calibrations were postponed to post project due to rental transponder failing during descent at the test site. The subsequent DVL calibration and AUV MB patch tests were also done post project.

No deviations from the Scope of Work at the project site were undertaken.

5.2 Survey Tasks

A summary of the survey tasks performed are presented in Table 9, and the tasks are described in the following sections.

Table 9 Survey tasks

TASK	DATE	DESCRIPTION
Mobilisation and Calibration	July 13-July 16, 2022	Equip vessel with AUV
Sea trials	July 17, 2022	Calibrate and verify AUV operation
MAC Report	July 17- Aug 8, 2022	Develop report for all mobilisation and calibrations for the project
Geophysical Survey	July 19- July 29, 2022	MBES, SSS, SBP Survey, Imaging
Imagery Survey (CathX)	July 19- July 29, 2022	MBES, SSS, SBP Survey, Imaging
Demobilisation	July 31, 2022	Demob personnel

5.2.1 Mobilisation and Calibration Test

The mobilisation was conducted alongside New Bedford, Massachusetts, between July 13 to July 16, 2022, with sea trials of equipment completed at July 17, 2022. The mobilisation was successful, and the performance of the equipment was accepted on the July 16, 2022. Some further verifications were performed on the August 1-2 and August 6,2022.

The mobilisation consisted of equipping the vessel with an AUV system including a LARS container, working lab and spare equipment container. Calibrations carried out included dock side positional verifications, functionality testing of the MBES, SSS, SBP, MAG, CathX Imaging and SVP comparisons. The CathX imaging was compared against the MBES data for positional verification. The SSS and SBP sensors both conducted a positional verification and the SBP also conducted a pulse test.

Detailed methodology and calibration test (MAC) procedure are presented in the MAC procedures, 104257-WHO-OI -MAC-PRO-DHELDER. The results of the MAC tests are presented in the MAC report, 104257-WHO-OI-MAC-REP-DHELDER, Table 2.

5.2.2 Cruise Summary

The geophysical survey was conducted by the Hugin 6000 AUV on M/V Deep Helder from July 19 to July 29, 2022. Eight total missions were completed during the time frame. The initial AUV survey was a mission to collect MB/SSS/SBP/CTD data. The MBES was the primary sensor that dictated the line spacing and altitude, which was 40m altitude and 180m line spacing. July 19-23, 25-27 and 29, 2022 included the collection of MBES, SSS, SBP, and CathX imaging. July 24 included the collection of MBES, SSS, SBP, and CathX imaging and an equipment breakdown due to three broken vibration dampener mounting screws on the STBD SSS transducer and a broken front drop weight housing mounting bracket. July 28 included the collection of MBES, SSS, SBP, and CathX imaging and an equipment breakdown due of the strobe cable on the CathX system that was failing at depth. All equipment failures were logged in a respective fault report.

5.2.3 CathX imagery survey

Once sonar data was collected over the site, it was quickly assessed on board by the client's team to determine smaller focus areas to send the AUV back to collect CathX images and higher resolution sonar data when required. This was an iterative process and continued throughout the project duration. During the CathX survey, line spacing was either 2m or 5m, with a 5m altitude for the AUV to provide high quality imagery.

5.2.4 Demobilisation

The demobilisation of the AUV equipment did not occur as there was a follow-on project with BEOM. Some of the AUV, Vessel, and all of the Science Crew changed out on July 31st, 2022.

6. Survey performance

6.1 Positioning

6.1.1 Surface Positioning

The positioning was provided by an Applanix POS MV with Fugro Starfix (G2 corrections) as the primary source and Fugro Starfix (XP2 corrections) as secondary, they held a high quality throughout the project. During survey operations, both positioning systems performed very well and provided very stable positioning with a constant position difference between primary and secondary system smaller than 0.1 m. Alarms were setup comparing positions obtained from the two different positioning systems installed on board, with this alarm being triggered if difference between the two systems exceeded 0.3 m. An additional alarm was also setup to monitor the incoming position corrections to flag if the corrections were lost at any time.

6.1.2 Underwater Water Positioning

Underwater positioning on M/V Deep Helder was provided by the Kongsberg HiPAP 352MGC system. Subsea positioning was of a height standard throughout the project. A cNode beacon was installed on the AUV in order to provide a relative position of the AUV.

6.2 Data Acquisition and Quality

6.2.1 Positioning and Navigation

Surface positioning was provided by the Applanix POS MV with Starfix (G2 corrections). Subsurface positioning was provided by the HIPAP 352 system aided by MGC R3 MRU/Gyro. Both surface and subsurface positioning systems worked well during the project with positional accuracy monitored online at all times.

6.2.2 AUV Hugin 6000

Position updates were sent via telemetry between the AUV and HIPAP352 APOS software. These handshake updates were carried as the vessel followed the AUV along the mission plan in AUV Supervised mode to maintain the highest possible positional accuracy.

6.2.3 Multibeam Echo Sounder

The MBES ping rate was set to 10Hz during the survey in order to allow synchronized triggering with the Edgtech DW216 SBP and Edgetech 2205 SSS. The contribution of soundings from adjacent lines provided more than sufficient density.

Survey speed was on average 3.6 knots to maintain the required sounding density of 5 pings per m². Sounding density was checked offline in the EIVA NaviModel processing program as part of daily QA/QC checks. Here, the sounding density option of the working dynamic surface (gridded at 1 meter) was reviewed to determine adequate MBES data coverage.

MBES data quality was of a high standard for the duration of the project.

The MBES acquisition settings are presented in Table 10.

Table 10 MBES acquisition settings

SURVEY SPEED (knots)	FREQUENCY (kHz)	BEAM SPACING	DETECTION MODE	COVERAGE (m)	PING RATE (Hz)
3.6	300	High Density	Min Depth	200	10

6.2.4 Edgetech Side Scan Sonar

An EdgeTech 2205 SSS system was used during the survey operations to provide detailed acoustic imagery. The SSS data was collected with target altitudes of 40 m in general and 5-8 m on CathX lines, which is within 10 to 20 percent of the maximum range (standard criteria). The SSS data was acquired with dual frequencies: 230 kHz (High frequency) with a range of approximately 200 m at 40 m altitude or 50 m at 5-8 m altitude, and 410 kHz (Very high frequency) with a range of approximately 200 m at 40 m altitude or 50 m at 5-8 m altitude. On one dive, Low frequency data was acquired at 40 m altitude and at a frequency of 75 Hz with a range of approximately 200 m. The general settings used to collect SSS data are summarised in Table 11.

The data quality from the EdgeTech 2205 was of a high standard throughout the project.

Table 11 SSS survey settings

SURVEY SPEED (knots)	ALTITUDE (m)	PULSE TYPE FREQUENCY (kHz)	TRIGGER	TRIG ADVISOR	PULSE LENGTH (ms)	PREDICTED RANGE (m)
3.6	40	230/410	Coupled SSS Very High	1	2/1	200
3.6	5-8	230/410	Coupled SSS Very High	1	2/1	50
3.6	40	75/230	Coupled SSS High	1	3/1	200

6.2.5 Edgetech Sub-Bottom Profiler

An Edgetech DW-216 SBP system was used during the survey operations to provide seismic information. The SBP data was acquired in a frequency ranging between 1 to 9 kHz achieving penetration between 5 and 40 m. The SBP data was collected with a target altitude of 40 m or 5-8 m on CathX lines. The general settings used to collect SBP data are summarized in Table 12.

The data quality from the Edgetech DW-216 was of a high standard throughout the project.

Table 12 SBP Edgetech acquisition settings

SURVEY SPEED (knots)	ALTITUDE (m)	FREQUENCY (kHz)	TRIGGER	MASTER PING RATE (Hz)	PULSE LENGTH (ms)
3.6	40/5	1-9	Coupled SSS Very High	3.5/10	20
3.6	40	1-9	Coupled SSS High	3.5	20

6.3 Daily Narrative

A summary of the daily narrative can be found in Table 13. For full DPRs please refer to Appendix B.

Table 13 Daily narrative

DATE	NAME
July 13, 2022	Mobilisation of AUV Operations and Spares Container
July 14, 2022	Mobilisation of all containers complete. Begin Interfacing/integration.
July 15, 2022	Mobilisation continue with Interfacing/integration.
July 16, 2022	Completed Mobilisation and Transit to Calibration/Test Site
July 17, 2022	Transit to Calibration/Test Site, Calibrations including SVP, MBES patch test, CathX camera test, DVL calibration, Transit to Survey Site
July 18, 2022	Transit to Atlantis II Seamount survey site

DATE	NAME
July 19, 2022	Transit to Survey Site, SVP Cast, Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data, WOW
July 20, 2022	WOW, Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data
July 21, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data
July 22, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data
July 23, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data
July 24, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data, Equipment repair to replace vibration dampeners and mounting brackets
July 25, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data
July 26, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data
July 27, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data, WOW
July 28, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data, Equipment repair of CathX Camera
July 29, 2022	Geophysical Survey at Atlantis II Seamount survey site for MBES, SSS, SBP and CathX data, Transit to Port
July 30, 2022	Transit to Port
July 31, 2022	Transit to Port, Demobilisation

6.4 Breakdown of Hours

The breakdown of hours during the project are summarised in Table 14 and Figure 6.

Table 14 Breakdown of hours

	TIME (HH:MM)	PERCENTAGE (%)
MOBILISATION		
Transit to/from Project	66:40	14.62
Mobilisation	86:00	18.86
Calibration	17:40	3.87
Demobilisation	06:10	1.35
OPERATIONAL		
AUV Geophysical Survey/CathX Imagery	201:00	44.08
Waiting On Weather	21:00	4.61
Transit within survey operations	37:00	8.11

	TIME (HH:MM)	PERCENTAGE (%)
Additional survey on client request	00:00	0
NON-OPERATIONAL		
Standby on Client Request	00:00	0
Standby	00:00	0
Resurvey	00:00	0
Breakdown Equipment	20:30	4.50
Breakdown Vessel	00:00	0
TOTAL	456:00	100.0

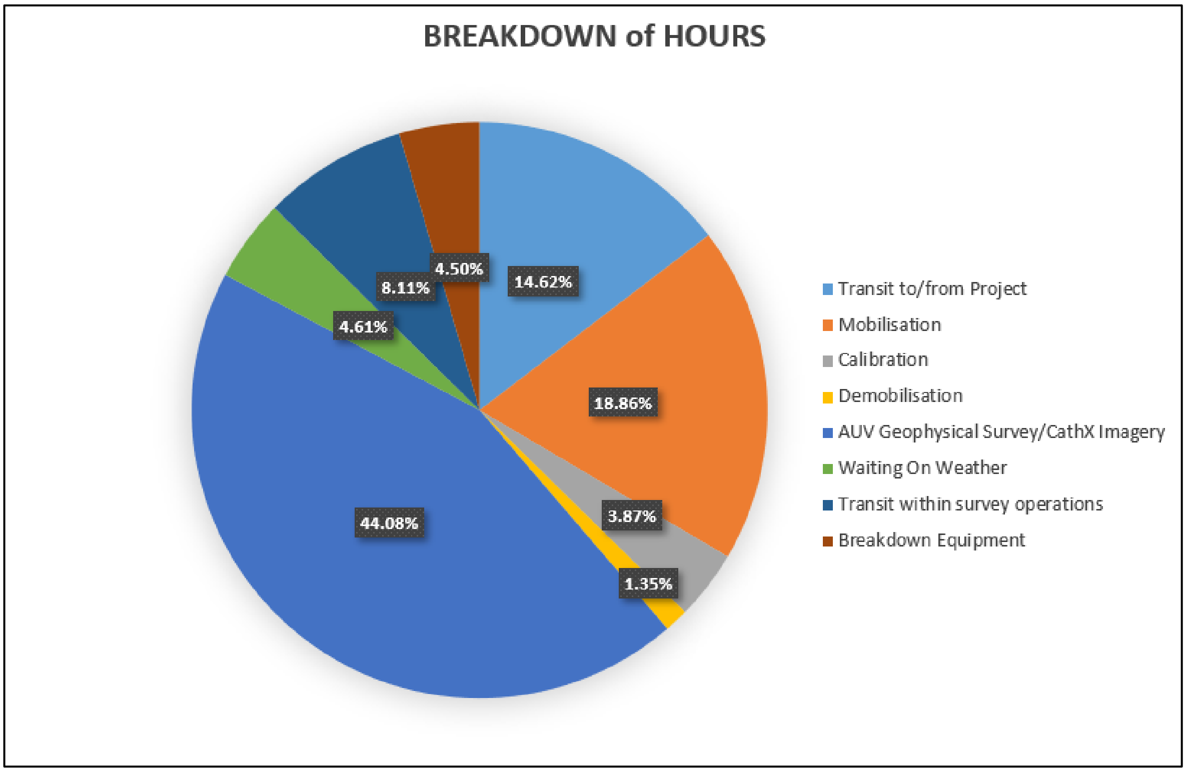

Figure 6 Breakdown of hours pie chart.

6.5 Personnel

The following AUV and survey personnel were involved in the acquisition and processing phases of the project, Table 15.

Table 15 Survey personnel on M/V Deep Helder

Name	Position	Company
Chad Bonin	Offshore Manager	Ocean Infinity
Devon James	AUV Supervisor	Ocean Infinity
James Johnekins	AUV Operator	Ocean Infinity
Austin Gray	AUV Operator	Ocean Infinity
Emma Shannon	AUV Operator / 4D Nav / Survey	Ocean Infinity

Name	Position	Company
Regis Reddinger	AUV Supervisor / 4D Nav / APOS	Ocean Infinity
Benjamin Ullom	AUV Operator	Ocean Infinity
Johan Barne	Senior Surveyor	Ocean Infinity
William de Garis	Surveyor	Ocean Infinity
Samantha Dehart	Surveyor	Ocean Infinity
Anders Sjövall	Survey Engineer	Ocean Infinity
Vinicius Rodrigues	Marine Geologist	Ocean Infinity
Rebecca Millsap	Marine Geologist	Ocean Infinity
Suhairi Suman	Data Processor	Ocean Infinity
Mark Quinn	Data Processor	Ocean Infinity

6.6 Survey Vessel

The AUV survey operation was conducted on the survey vessel M/V Deep Helder. The vessel was fully equipped for survey activities and AUV support.

The Deep Helder equipment is presented in Table 16.

For full vessel specifications, see Appendix C.

Table 16 Vessel equipment summary

Instrument	Name
Primary Positioning System	POS MV 320 with FUGRO G2 corrections
Secondary Positioning System	Fugro Seastar with XP2 corrections
Primary Gyro and INS System	Applanix POS MV 320
Secondary Gyro and INS System	iXblue GAPS III
Underwater Positioning System (USBL)	Rental: HiPAP 352 MGC
Survey Navigation System	QPS QINSy
Surface Pressure Sensor	Vaisala Pressure Sensor
Sound Velocity Sensor	Valeport Midas SVX2, deployed over the side
Hull Mounted Sound Velocity Sensor	Valeport MiniSVS
Multibeam Echo Sounder	Kongsberg EM2040D (200-400 kHz)
Single Beam Echo Sounder	Kongsberg EA 400
Parametric Sub-Bottom Profiler	Innomar Medium 100

Figure 7 M/V Deep Helder

6.7 Survey Equipment

The AUV Hugin 6000 equipment summary is presented in Table 17.

Table 17 Hugin 6000 AUV system equipment.

Instrument	Name
GPS Receiver	Novatel OEM615-D1S-00G-0T0
CTD	SAIV SD208
Inertial Motion Unit	Honeywell HG9900 IMU
Compass	ULTISENSE DMC-SX-5000 2/4
Doppler Velocity Log	Nortek DVL500
Obstacle Avoidance Sonar	Imagenex Sonar and KM algorithm FLS
Altimeter	Kongsberg Mesotech 200/675 kHz forward and downward looking
USBL Transponder	HiPAP cNODE Minis 34-40V
Depth Sensor	DigiQuartz 8CB4000
Multibeam Echosounder	Kongsberg Maritime EM2040 0.7°x0.7° (at 400 kHz)
Side Scan Sonar	Edgetech 2205 with 75, 225 and 410 kHz (two frequencies selectable at a time)
Sub-bottom Profiler	EdgeTech DW-216
Magnetometer	Ocean Floor Geophysics SCM
Colour Camera	CathX M12-A1000
Camera Flash	Aphos S32

7. Processing and Processed Data Quality

The positioning data from each AUV dive mission folder was post-processed using the NavLab software from Kongsberg. The following standard steps were used in the analysis and processing of the AUV navigation data.

- Extraction of raw sensor data. The real-time position assigned to the AUV during acquisition was the result of many different aiding sensor inputs. These included the onboard INS, DVL, and pressure sensors along with external aiding positioning input from the vessel USBL system (when in range) The raw data from the same sensors are used in post-processing of the AUV navigation and are extracted by NavLab for analysis.
- Editing/Filtering of raw sensor data. After the raw aiding sensor data was extracted, it was reviewed in a series of graph views to identify suitable filters to be used to reject noisy data. The user can perform manual rejection of noise points within each graph view.
- Updated configuration files applied by NavLab processing algorithm. Based on the observed quality of the raw aiding sensor data, the user can update a series of configuration files which define the thresholds of acceptable data. Depending on the aiding sensor, these thresholds were expressed in terms of absolute distance and angular values as well as standard deviation values.
- Run algorithm. Which performs a 2-way Kalman filtering of the modelled position (now based on filtered aiding sensor data) and a subsequent re-distribution of residuals across the entire length of the modelled dataset. The end result was a high-frequency, high-precision position of the AUV.
- QC the final modelled result. This was done by creating a series of track files that allowed the user to check the post-processed results (Figure 8). The track files were based on the following datasets:
    - Raw USBL positioning
    - Real-time AUV positioning
    - Post-Processed AUV positioning
- Comparison between track files listed above (Figure 8) were then used to identify areas which required further attention due to spurious positioning results. The user would then re-examine the raw sensor data at these locations, perform additional editing of the appropriate raw sensor data and re-run the processing algorithm.
- Export the final post-processed navigation result. The final AUV track was exported to a series of file formats which were used by standard geophysical processing software packages to inject the new navigation results.

During this project the processing of the AUV positioning data in NavLab did not deviate from the described workflow. The level of manual rejection of raw sensor points depended on the observed data quality but other universal settings such as length of moving windows to identify erroneous points were not changed at any point.

All other sensor data was quickly processed to create rapid on board QC checks using reference surfaces or georeferenced images to aid in the quality assurance of the data set and rapid assessment of the data post AUV dive.

All further and final processing of the sensor data will be done by the client as per the agreed SOW.

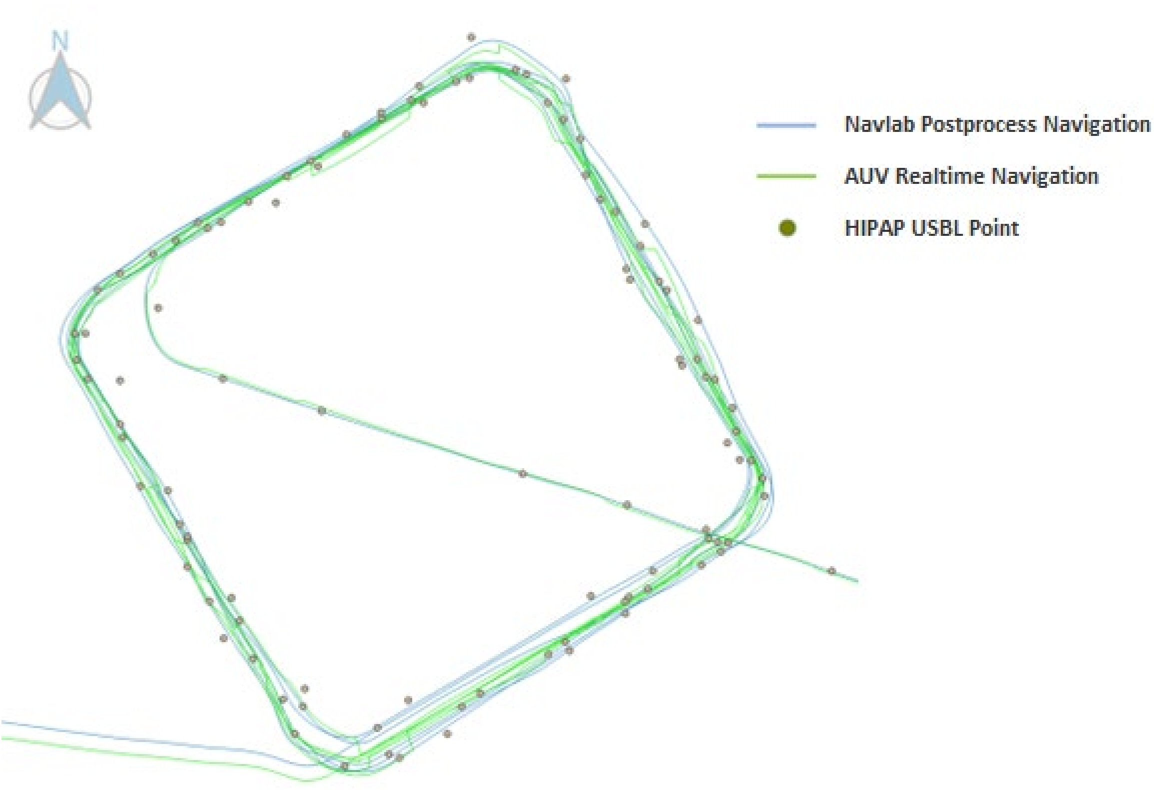

Figure 8 QC of post-processed navigation results.

Appendix A Mobilisation and Calibration Report

Appendix B Daily Progress Reports

Appendix C Vessel Specification

Appendix D Vessel Equipment Specification

Appendix E AUV Equipment Specification

REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED START DATE	3. DATES COVERED END DATE
20230630	Final Research Performance Progress Report	20220301	20221231

4. TITLE AND SUBTITLE
Seafloor Survey Around the Atlantis II Seamounts Using an Autonomous Underwater Vehicle

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER
	N00014-22-1-2165	
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**

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14. ABSTRACT
A comprehensive seafloor and sub-bottom survey using an autonomous underwater vehicle (AUV) equipped with a variety of acoustic and optical sensors was conducted in the Atlantis II Seamounts area. The AUV sensors include a multibeam echo sounder (MBES), sidescan sonar (SSS), sub-bottom profiler (SBP) and still image camera. The primary project objective is to determine mooring anchor landing locations with high confidence of not hitting endangered cold-water corals. The survey data can also support the following scientific goals: seafloor geoacoustic property estimation from sonar signal returns and seafloor object identification from cross-platform observation.

15. SUBJECT TERMS
Atlantis II Seamounts, geoacoustics, Gulf Stream, autonomous underwater vehicle

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