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R/V Kaiyo cruise report

KY10-04

6 - 9th March, 2010

Teishi Knoll, Sagami Bay

Underwater Technology Research Centre
Institute of Industrial Science
The University of Tokyo

Contents

Cruise summary

Cruise number:

KY10-04

Title:

Development of a survey strategy to perform detailed observations of large area seafloor deposits using a 'Bottom Skimmer' mobile sensing platform

Survey site:

Teishi Knoll

Cruise period:

March 6, 2010 (Yokosuka, Japan) to March 9, 2010 (Yokosuka, Japan)

Overview of observation:

Detailed survey of seafloor mineral deposits, such as cobalt rich ferro-manganese crusts, is at present, greatly limited by the resolution of the acoustic instruments used. More detailed observations require the development of new survey techniques and as such, our group is currently developing a survey system that uses a mobile sensing platform, or 'Bottom Skimmer', to perform high-resolution visual, acoustic and chemical analysis of the seafloor from low altitudes. This research is being carried out under the title 'Development of a method to perform high resolution measurements of cobalt-rich ferro-manganese crust thickness', under the 'Program for the development of fundamental tools for the utilization of marine resources' of the Japanese Ministry of Education.

In order to make high-resolution measurements, it is necessary for the bottom skimmer to land, and provide a stable platform at a fixed distance from the seafloor in order to take its readings. In order to achieve this, it is first necessary to detect and automatically identify suitable landing sites to provide stable footing for the bottom skimmer. Our group has developed a system to accurately measure seafloor bathymetry based on light sectioning using a sheet laser. Using this system it is possible to profile the seafloor with centimeter order resolution, and through two-dimensional frequency analysis of this information, it is possible to identify flat areas on which the system can land. During the cruise, several of the sensors being developed for this project, including the laser profiling system and an underwater microscope, were mounted on the AUV/ROV ‘Tuna-Sand’ as a test platform. The system was deployed and performed low altitude, close range measurements of the seafloor, to verify the performance of the proposed system and also identify key issues for future developments.

In total, the system was deployed 5 times inside the crater of the Teishi knoll, with two dives on the 6th, one dive on the 7th and a further two dives on the 8th March. Each dive lasted between 1 to 3 hours. The sensor parameters were calibrated during dive TS#32. During dive TS#33 the system was deployed in a relatively flat area towards the centre of the crater and the laser profiling and microscopic imaging systems were tested. After the first 2 dives, seafloor bathymetry of the survey area was taken using the multi-beam sonar of the R/V Kaiyo. In dive TS#34, the south-east cliff of the crater was surveyed. Profiles were taken of the steep slopes and rocky outcrops in this region and microscopic images were taken of the seafloor. During dives TS#35 and TS#36, Tuna-Sand performed terrain navigation using seafloor bathymetry data obtained during the cruise, to survey a specific area of seafloor that was identified prior to the dive. During the dives the laser profiling system was used to automatically identify and guide the vehicle to landing sites in real-time.

The proposed sensor systems deployed operated as planned during the cruise, and the results obtained will be fed back into the design of the bottom skimmer system that is currently under development. Furthermore, the tests performed during this cruise verified the functionality and performance of several of the systems that will be deployed during the cruise to Takuyo Seamount No. 5, scheduled for June 2010.

1. Purpose of Cruise

The purpose of this cruise was to test a strategy to perform multi-resolution observations of the seafloor using a hovering type autonomous underwater vehicle (AUV). Of particular importance was the implementation of a newly developed AUV landing algorithm and microscopic imagery of the seafloor to measure sand grain size. The main goal was to gain engineering in-sight into the instrumentation and methods used and feedback this information into our future surveys.

The multi-resolution survey strategy is proposed to help overcome the engineering paradox of surveying a wide area of seafloor, whilst maintaining high resolution. The strategy involves superimposing high-resolution visual observations of the seafloor, including microscopic imagery of the seafloor, obtained at discrete intervals within a wide area acoustic map of the region obtained during a single AUV dive. It is hoped that this kind of survey technique will allow for a better overview and understanding of the surveyed region. The different resolutions of observation for this cruise are summarized in figure 1 and in table 1.

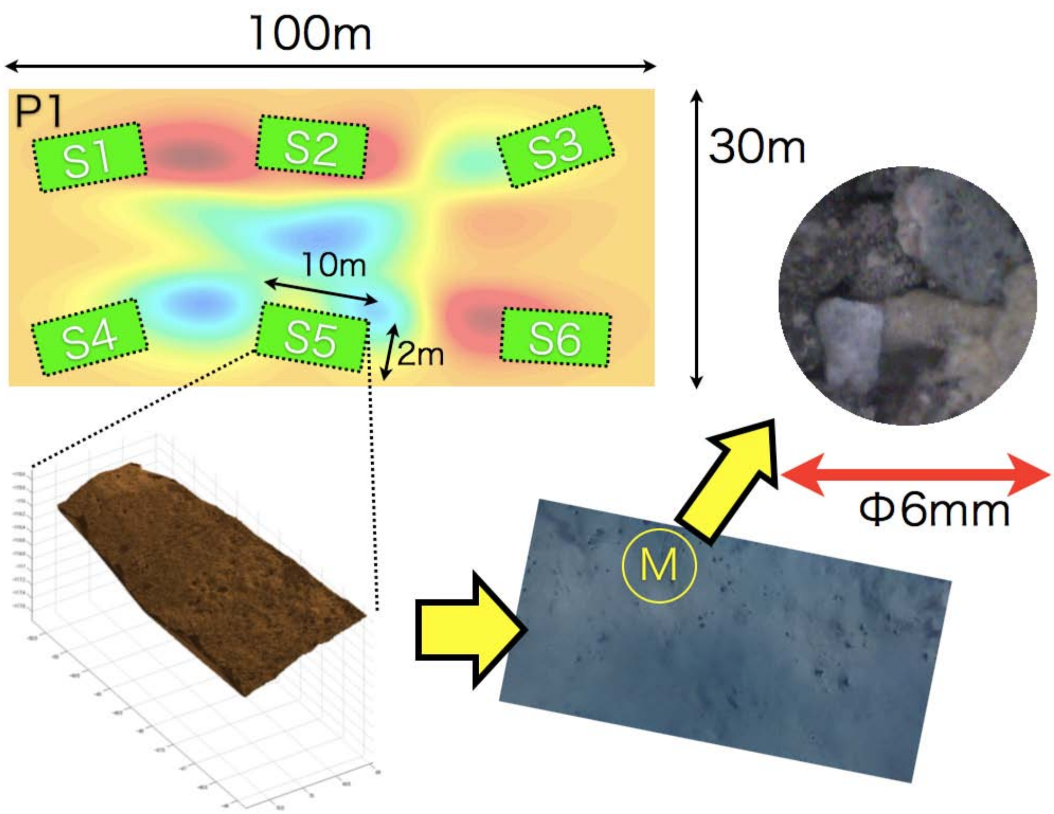

Fig. 1 Multi-resolution survey strategy

Method	Altitude	Area	Resolution	Type
Acoustic profile	15m	100 x 30m	~20cm	Bathymetry
Laser profile	2m	10 x 2m	~10mm	Bathymetry
Camera	2m	10 x 2m	~0.5mm/pixel	Image mosaic
Microscope	0m (landed)	6 x 4 mm	~10μm/pixel	Image

Table 1 Details of different resolution observations made during the cruise

In each case, the strategy maintains generality and different instruments can be used to obtain different types of data. The obstacle avoidance and landing algorithms applied would allow an AUV to perform these types of observation.

2. Cruise Log

2-1 Survey Area and time schedule

A total of 5 dives, TS#32-#36 were performed over 3 days as shown in figure 2 and table 2. The bathymetry data in figure was obtained using the R/V Kaiyo’s multi-beam sonar. The point 34°59'40"N 139°07'45"E (WGS84) was set as the origin.

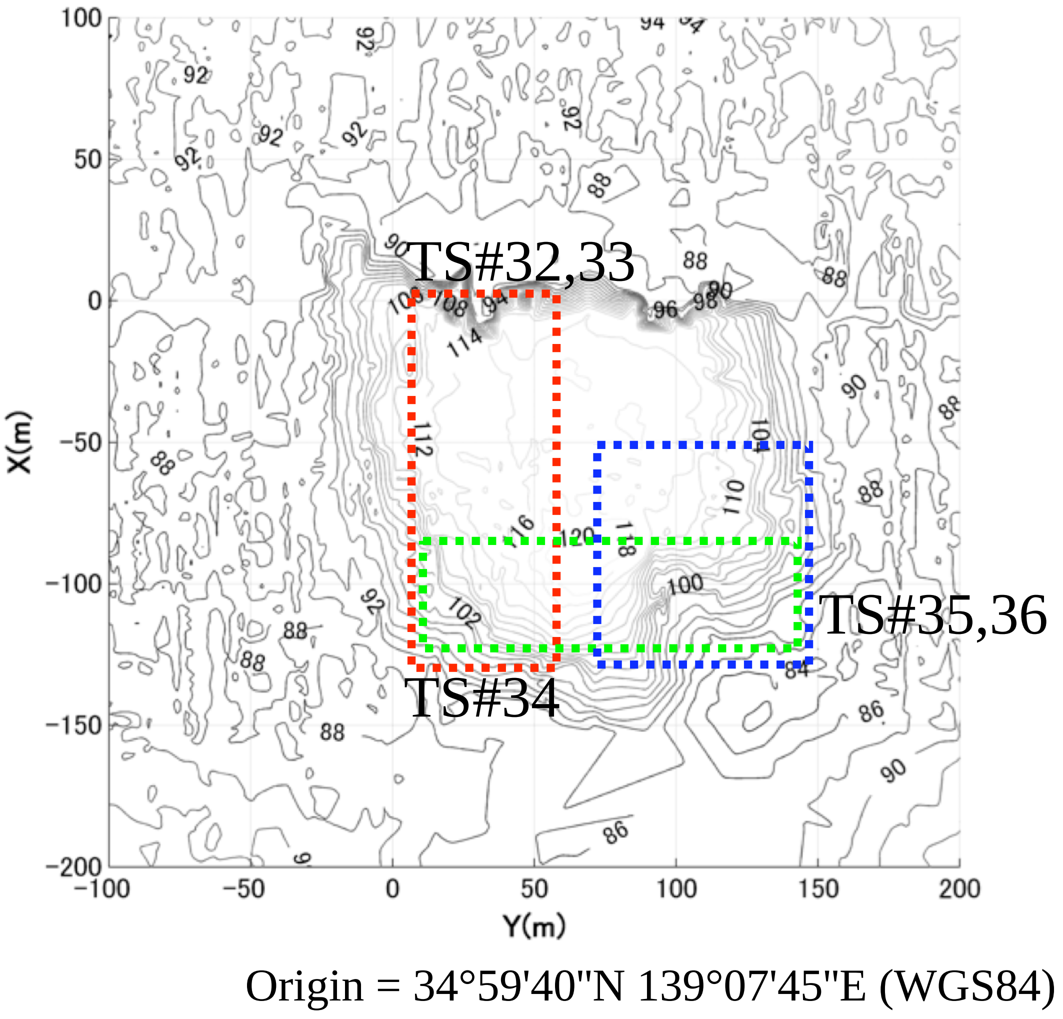

Fig. 2 Survey area

Date	Time	Description	Area	Remarks
5th March 2010	13:00	Load equipment	Yokosuka	
6th March 2010	7:00	Research party board		
	8:00	Depart		
	11:53	Arrive at survey area	34°59'40"N 139°07'45"E	
	13:21	Deploy vehicle		TS#32
	13:53	End mission		
	15:59	Deploy vehicle		TS#33
	17:30	End mission		
7th March 2010	8:22	Deploy vehicle		TS#34
	9:43	End mission		
	Afternoon			Bad weather
8th March 2010	8:45	Deploy vehicle		TS#35
	10:30	End mission		
	13:49	Deploy vehicle		TS#36
	14:53	End mission		
9th March 2010	7:00	Arrive at Yokosuka	Yokosuka	
	8:00	Unload equipment		
		Research party disembark		

Table 2 Schedule

2-2 Research party

Name	Nationality	Affiliation	Position
Tamaki Ura *	Japan	IIS, The University of Tokyo	Professor
Takashi Sakamaki	Japan	IIS, The University of Tokyo	Technician
Blair Thornton	United Kingdom	IIS, The University of Tokyo	Research Associate
Takeshi Nakatani	Japan	IIS, The University of Tokyo	Project Researcher
Adrian Bodenmann	Swiss	IIS, The University of Tokyo	Project Researcher
Mehul Naresh Sangekar	India	IIS, The University of Tokyo	Post-graduate Student
Misumi Aoki	Japan	Nippon Marine Enterprises, Ltd.	Marine Technician

Table 3 Research party (* principle investigator)

3. Platforms and Instruments

3-1 Tuna-Sand

The AUV Tuna-Sand was used as the test vehicle for the experiments conducted. Figure 3 and table 4 show the general arrangement of the vehicle and its specification respectively. During this cruise the vehicle was tethered and operated in ROV mode for all operations. In ROV mode a fibre optic cable is used to send navigational commands to the vehicle and monitor its sensor readings. Figure 4 shows the instruments used on this cruise mounted on-board Tuna-Sand.

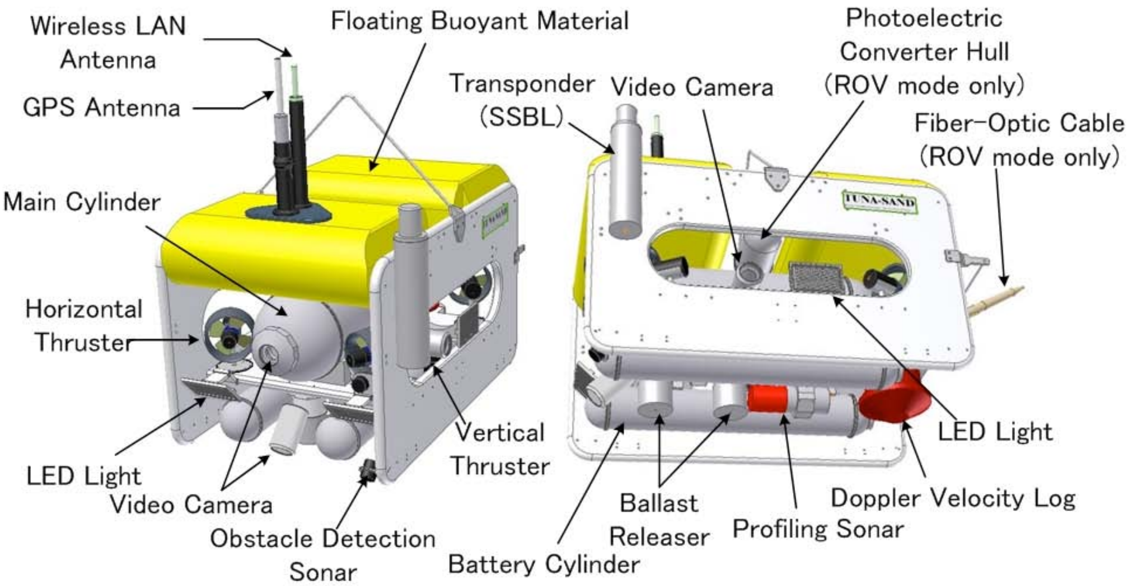

Fig. 3 General arrangement of Tuna-Sand

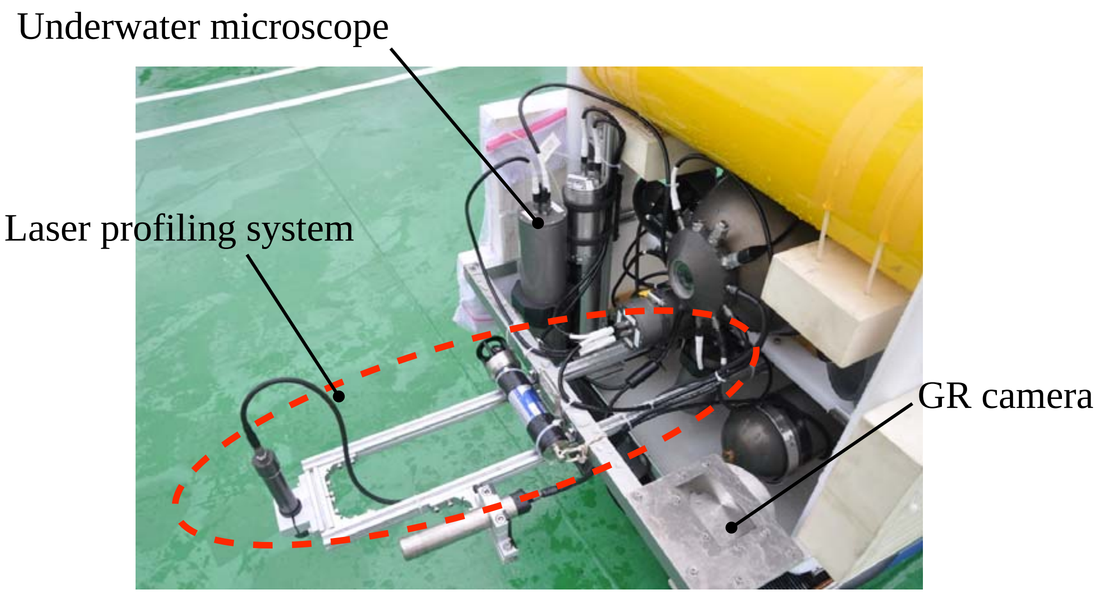

Fig. 4 Instruments mounted on Tuna-Sand during this cruise

Vehicle	
Size	1.1m(L)×0.7m(H)×0.7m(W)
Mass	280 kg
Max.speed	1.7 knot
Max.depth	1,500 m
Duration	5 hours
Actuators	Thrusters 220W × 4, 100W × 2
Power	NiMH Battery 50.4V 9Ah × 4
Communication	Wireless LAN, Fiber-Optic Comm.(ROV mode only)
CPU (Main)	NS Geode GX1-300MHz
CPU (Comm. with sensors)	NS Geode GX1-300MHz
OS	VxWorks
Sensors	
Inertial Navigation System	iXSea PHINS (FOG)
GPS	NovAtel OEM4-G2L
Doppler Velocity Log	RDI Navigator 600kHz
Depth	Mensor Series 6000
Obstacle Avoidance	Echo sounder ×3
SSBL	System Giken
Payload	
Camera	Hitachi KP-D20B(CCD) ×2
Lighting	LED light board × 2
Bathymetry	Imagenex 881a Profiler 675 kHz
Sheet laser	Global Laser GreenLyte-MV-Excel× 2

Table 4 Specification of Tuna-Sand

3-2 Laser profiler

A system based on light sectioning, was implemented and tested to map the seafloor with high resolution. The profiling system consists of a sheet laser and a camera assembly. Underwater housings were made for these devices and pressure tested to depth of about 3000m. Position information from vehicle's sensors is also necessary for the system to generate bathymetry. The data from Doppler Velocity Log (DVL) and depth sensor is used by the vehicle's inertial navigational sensor (INS) to provide the vehicles roll, pitch, yaw and x, y, z positions.

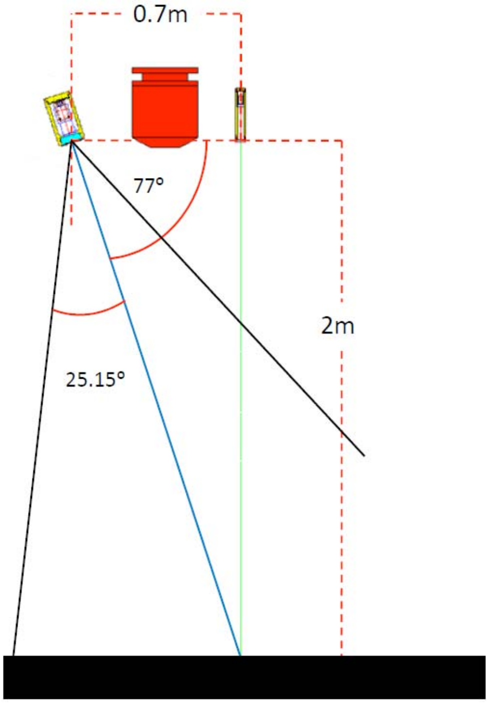

Fig. 5 Laser profiling system

The laser and camera was separated with a baseline of 0.7m. The camera was mounted at an angle of 77° with respect to horizontal, as shown in figure 5. The camera used had a horizontal opening angle of 61° and vertical opening angle of 50.3° in water, with a pixel resolution of 640x480. By knowing the rotational and translational offset, we can convert the pixel data into 3D coordinates by triangulation.

During operation a green laser line is projected onto the surface of the seafloor. This projection is captured by the camera, and the laser line extracted from the image by identifying green pixels. By doing this we can identify the laser even if the vehicles lights are switched on and water is not clear, as shown in figure 6. Using the position information of the vehicle, the pixel data of the laser profile can be converted into 3D bathymetry coordinates by simple geometric transformations.

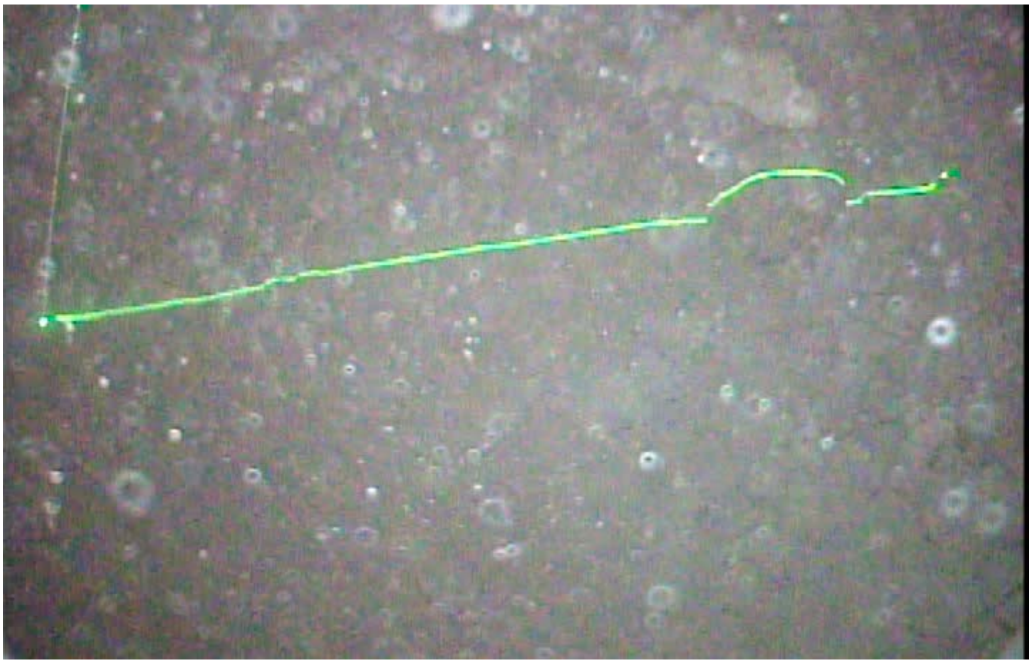

Fig. 6 Example of laser profiling during this cruise with lights on in turbid water

The laser profiling system provides sufficient resolution for the landing algorithm to work in real time. The profiling system ideally operates at an altitude of 2m off the seafloor, with a vehicle surge velocity of 0.1m/s to provide sufficient vertical and horizontal resolution. Under these conditions the system has a swath of 2.5m, a vertical resolution of 6 to 10mm, a horizontal resolution of 4 to 6mm across the section, and a resolution of 6 to 10mm along the path taken by the vehicle.

3-3 Camera

A high resolution camera was used to take images of the seafloor. Images were taken at every eight seconds during scanning operations. By using position information from the vehicle the images were stitched together to generate a photo mosaic. Underwater housing was made for this camera and mounted on the vehicle. Specifications of the camera used are given in table 5.

Camera model	Ricoh GR digital
Sensor	1/1.8” CCD
Image size	3264×2448 pixels
Focal length	5.9 mm
Field angle (in water)	48.0 deg×37.0 deg

Table 5 Specifications of camera used for mosaicing

3-4 Underwater microscope

To study the seafloor at even higher resolution, a microscope system was developed and implemented. Microscopic images of the sea floor can be useful for sand grain structure or microbial analysis. The microscope used was a DZ4 microscope from Union Optics with a magnification of 1.25~15x. An underwater housing was designed for the microscope and depth rated to 3000m. The focusing distance of the microscope underwater was 60mm.

Fig. 7 Underwater microscope and linear stage

In order to raise and lower the microscope for focusing onto the subject under observation, a linear stage was developed. The linear stage is oil filled, with a stepper motor used for actuation. The system is depth rated to 3000m, with stroke of 60mm. The system is shown in figure 7.

During operation the microscope is lowered by the linear stage and images are taken at each step. By focusing onto different vertical planes, the 3D profile of the seafloor can be generated. The objects are illuminated by white LED lights. Figure 8 shows microscopic image of a rock sample.

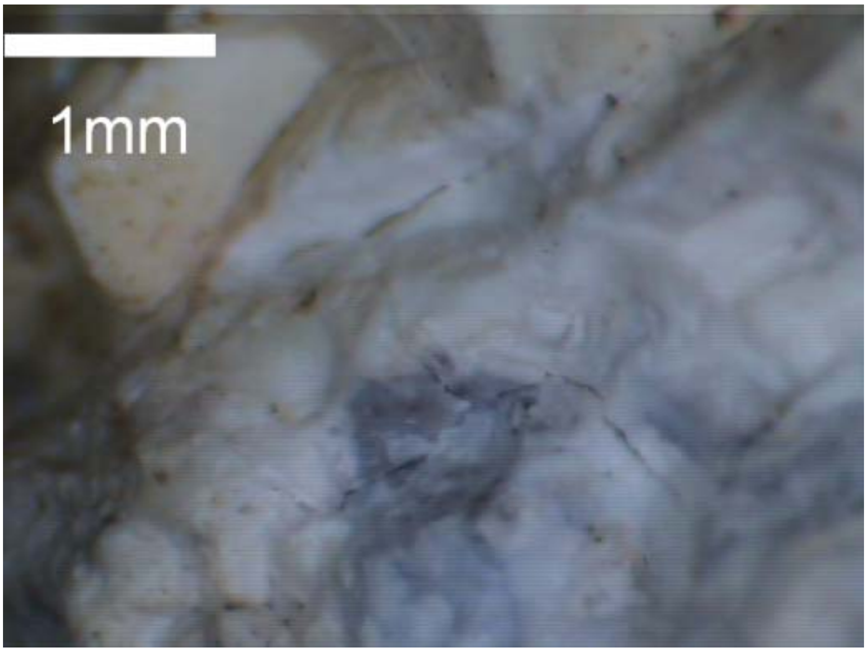

Fig. 8 Image of rock sample obtained using microscope

4. Methods

4-1 Acoustic bathymetry

Acoustic bathymetry was obtained using an Imaginex 881a profiler 675kHz. A wide area of the seafloor (100 x 30m) was scanned from an altitude of 15m while the vehicle cruised at a speed of 0.2~0.3m/s. Figure 9 shows an example of the bathymetry of the seafloor created using this method, obtained during TS#34.

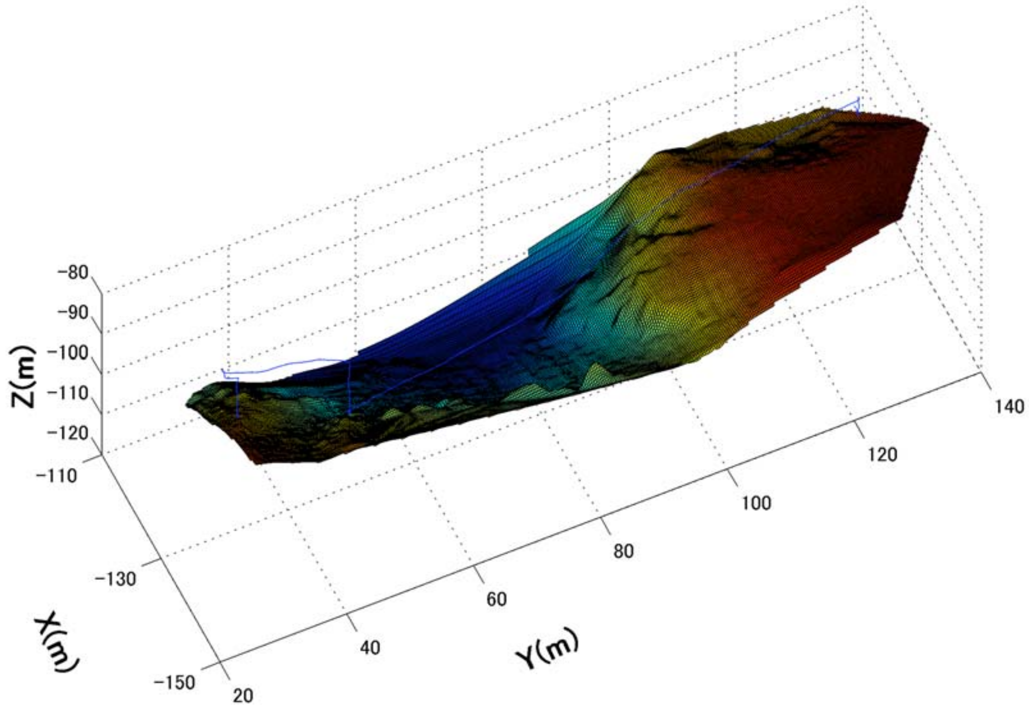

Fig. 9 Acoustic bathymetry of the seafloor obtained during TS#34, ~20cm resolution

4-2 Laser bathymetry

The laser profiling technique was used to generate high resolution centimeter order bathymetry data of the seafloor. Scanning was performed from an altitude of 2m with a vehicle speed of 0.1m/s at intermittent locations along the dive routes. A suitable patch of seafloor was profiled in the direction of travel of the vehicle and the pixels from the laser profile were converted to 3D bathymetry coordinates using position information from the sensor data available. The bathymetry was generated in real-time for the landing algorithm to generate a landing site.

Figure 10 shows bathymetry generated during dive TS#35. Various features of the terrain can be clearly observed, that would not be visible in an acoustic image. The generated bathymetry was used by the landing algorithm to find out a suitable landing site for the AUV.

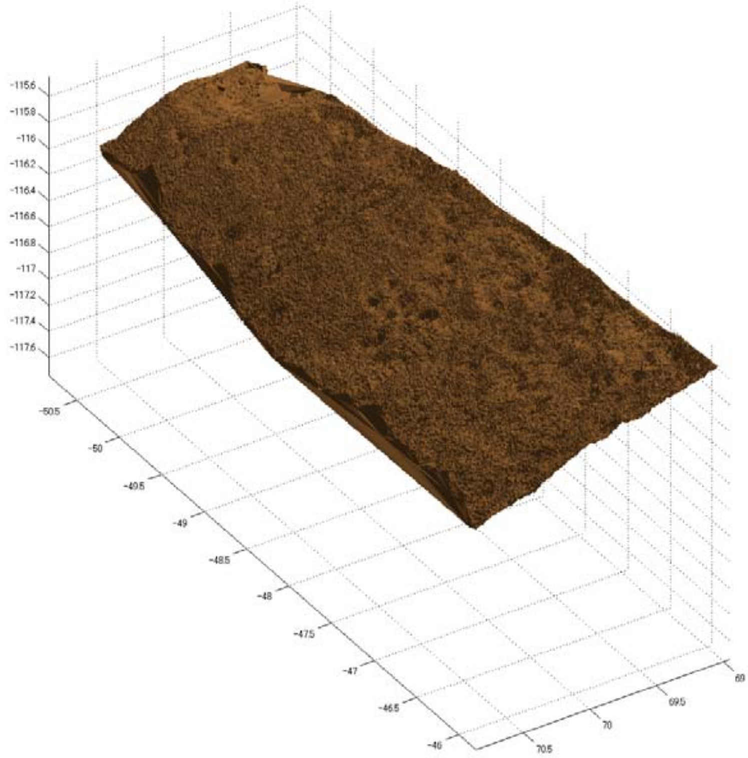

Fig. 10 Laser profiling bathymetry of the seafloor obtained during TS#35, resolution ~10mm

4-3 Landing algorithm

A landing algorithm was developed to find suitable landing sites for an AUV. During this cruise, the landing algorithm was applied in real-time to identify landing sites and the vehicle was landed manually based on this information. This algorithm uses bathymetry data generated from the laser profiling technique to find a flat area of land. After a 10x2m patch of seafloor bathymetry has been generated after profiling, spectral analysis is carried out. Different surfaces, depending on their shape and size, exhibit different frequency components that can be used to distinguish between them. A 2D Fourier transforms converts the bathymetry into frequency components, which can be used to separate different types of surfaces. An inverse 2D Fourier transform can then be performed and a threshold applied to identify areas smooth enough for the vehicle to land. Once the obstacles large enough to cause trouble for the AUV to land have been found, a continuous patch of land suitable for landing needs to be identified. For this, simple image processing operators are used to find flat regions large enough for a structuring element to fit completely within its boundary. The structuring element chosen here corresponds to the size of the robot that needs to land in the area. Figure 11 shows the landing algorithm being applied on data obtained during TS#34.

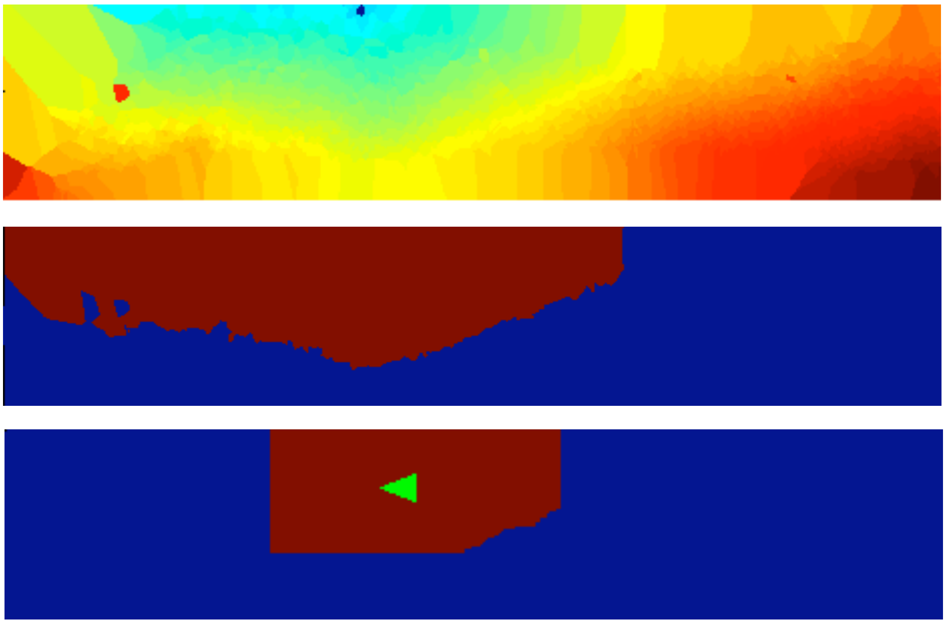

Fig. 11 Landing algorithm being applied to a 10x2m patch of land scanned during TS#34

4-4 Seafloor imagery

The GR camera setup was used to take high resolution images of the seafloor at intermittent locations. By knowing the position information of the locations where the images were taken, they can be stitched together to generate a photo mosaic. Photo mosaics were generated at the areas where laser scanning was performed, from an altitude of 2m with a vehicle speed of 0.1m/s. Figure 12 shows a photo mosaic of a data of approximate area 10x10m taken during the dive TS#35. The seafloor observed was flat and sandy which can be clearly seen from the photo mosaic.

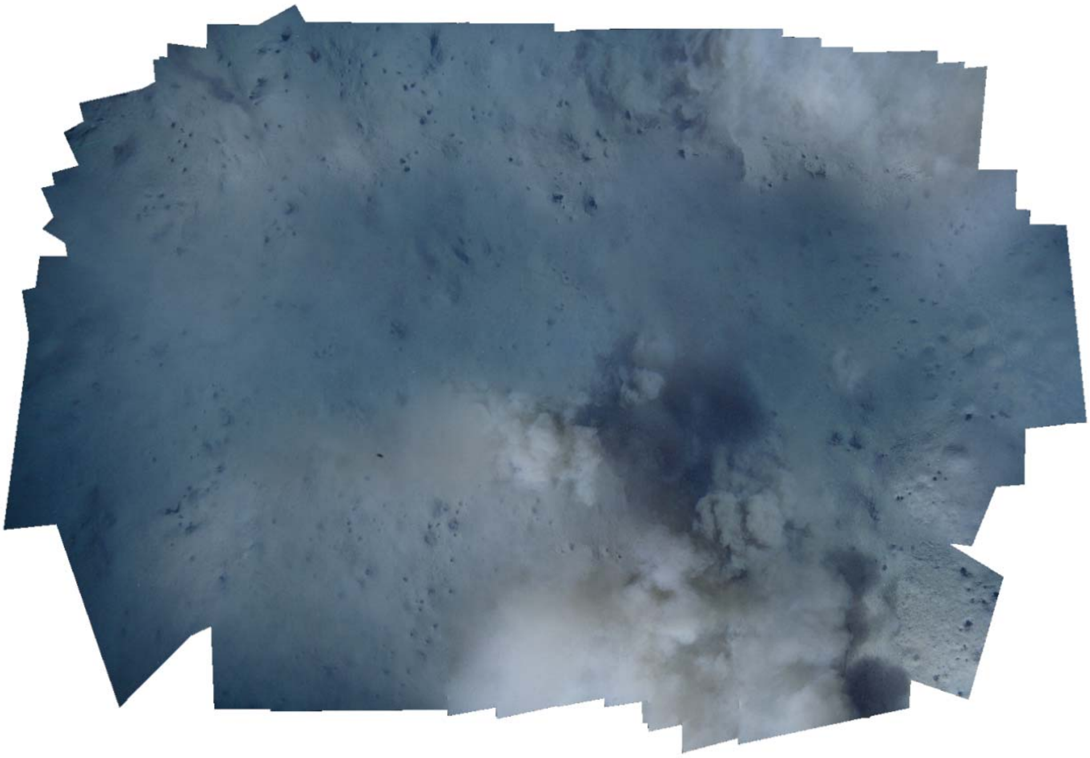

Fig. 12 Photo mosaic of 10x10m patch of seafloor taken during TS#35

4-5 3D pixel mapping

By combining laser profiled bathymetry data with the colour information of each pixel for which profile data was obtained based on the AUV's position and orientation data. The algorithm developed maps pixels of the seafloor photos to the bathymetry's 3D points and hence generates a list of points with their *x*, *y* and *z* coordinates as well as their RGB colour values. Plotting these points yields a 3D model of the scanned sea floor patch, as shown in figure 13.

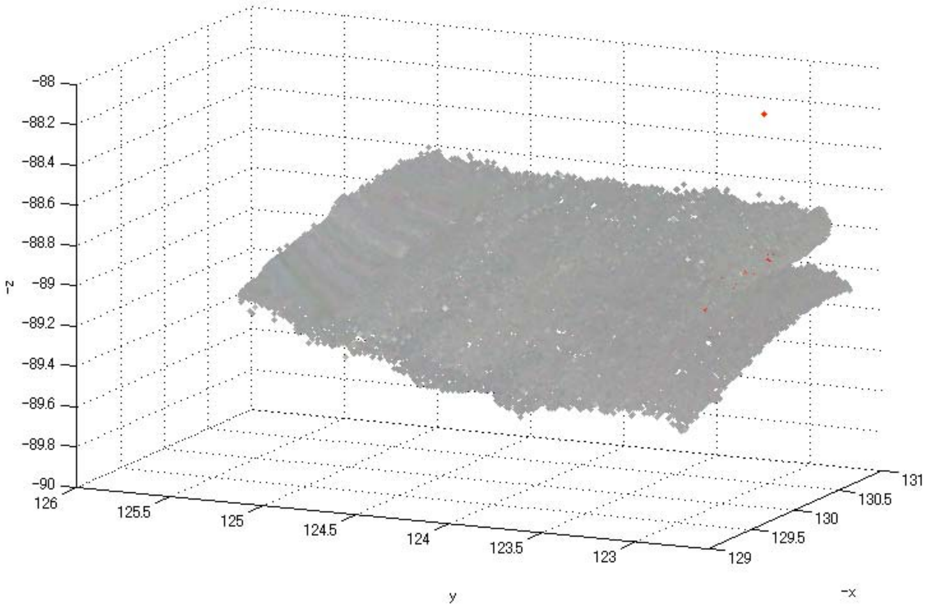

Fig. 13 3D pixel map created during TS#34

4-6 Microscope images

1. The microscope setup developed was used to take magnified images of the seafloor. Once the vehicle had landed, the microscope was lowered by the linear actuator to focus onto the surface of the seafloor.

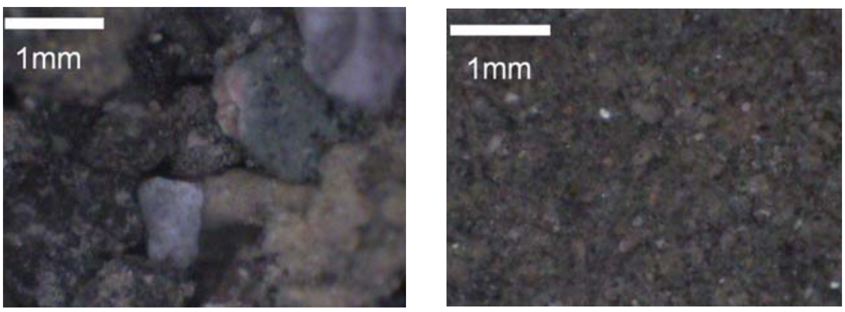

Fig. 14 Microscopic images of the seafloor obtained during TS#34 and TS#35

5. Dive Logs
5-1 TS#32

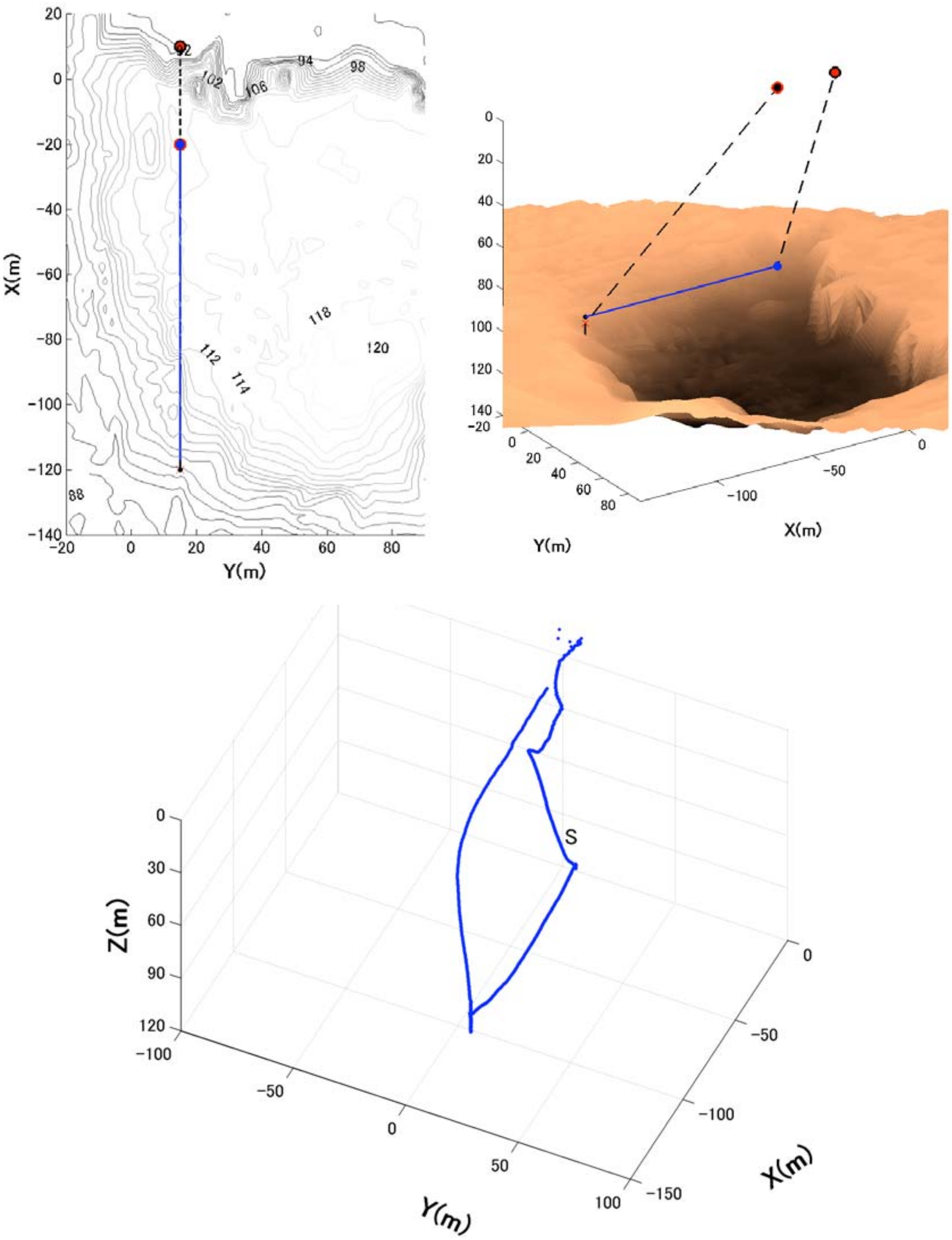

Fig. 15 Vehicle trajectory

Dive Summary

13:21 Vehicle deployed

13:30 Waypoint 1 reached and ballast 1 released

13:42 Waypoint 2 reached at 15m altitude

13:53 Cannot dive due to excess buoyancy, end mission.

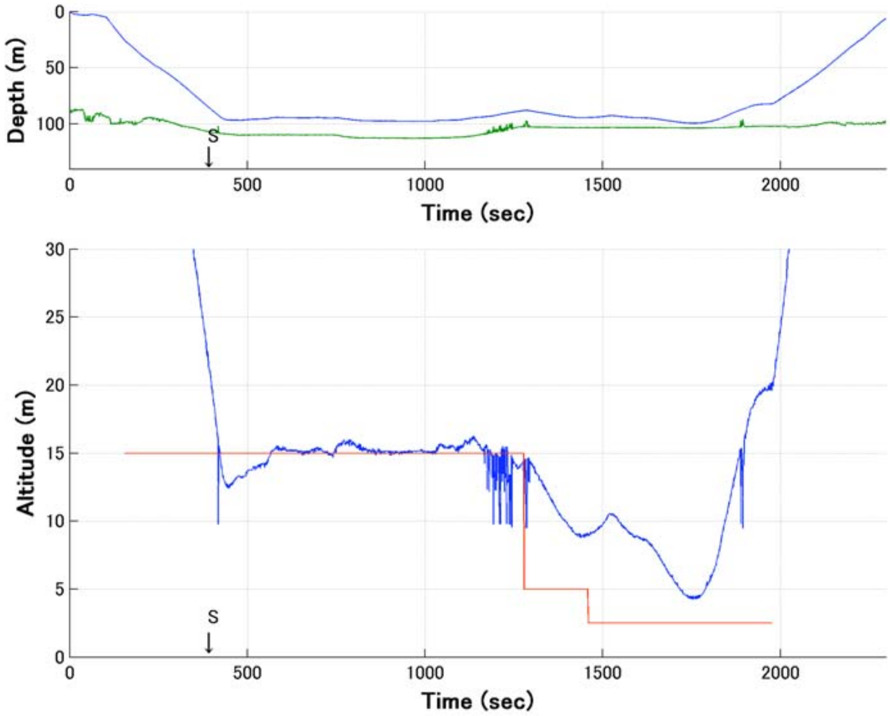

Fig. 16 Vehicle depth and altitude

5-2 TS#33

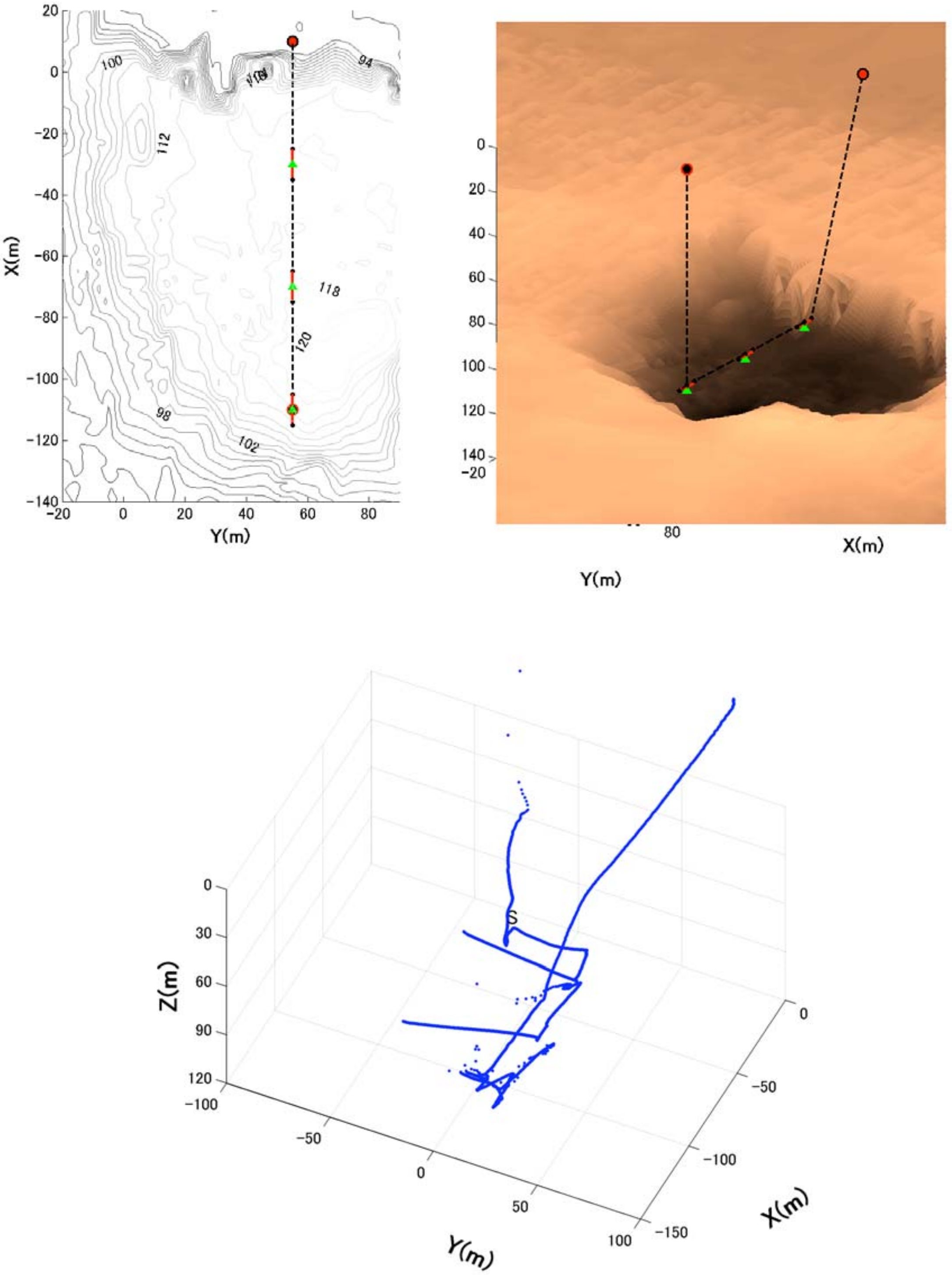

Fig. 17 Vehicle trajectory

Dive Summary

15:59 Vehicle deployed

16:10 Waypoint 1 reached

16:21 Landing, microscopic images of the seafloor taken

16:27 Continue laser scanning

16:39 Landing

17:02 Landing, microscope scan of the seafloor was taken

17:08 Microscope scan of the seafloor was taken

17:11 Release ballast 1

17:18 Landing, microscopic images of the seafloor were taken

17:23 Laser profiling at altitude 1.8m and scanning at 0.1m/s

17:31 Low batteries detected, release ballast 2, end mission.

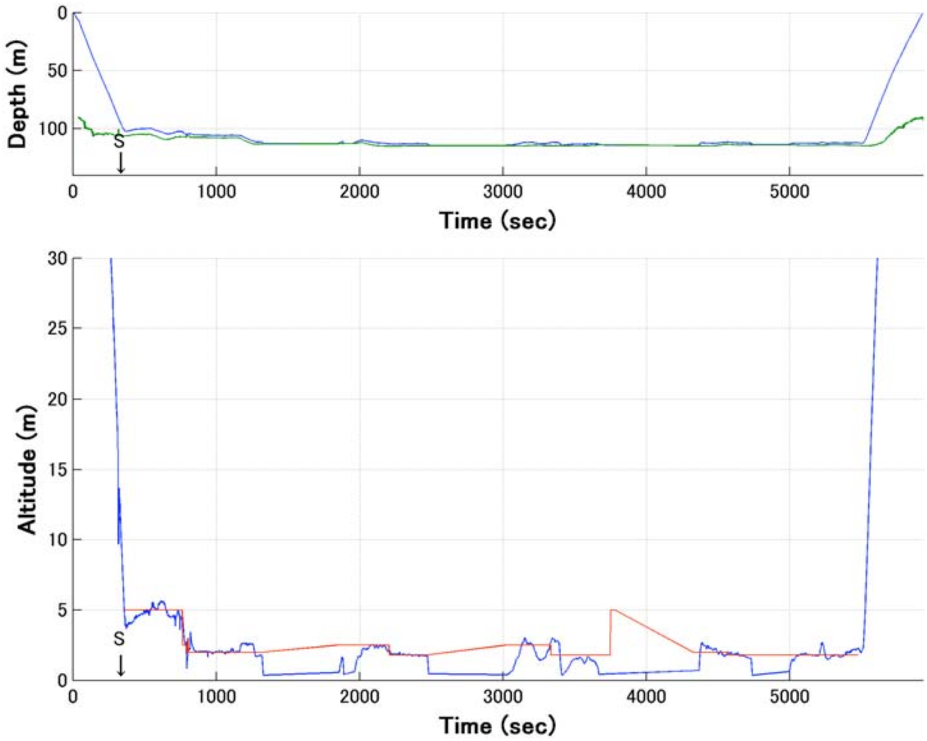

Fig. 18 Vehicle depth and altitude

5-3 TS#34

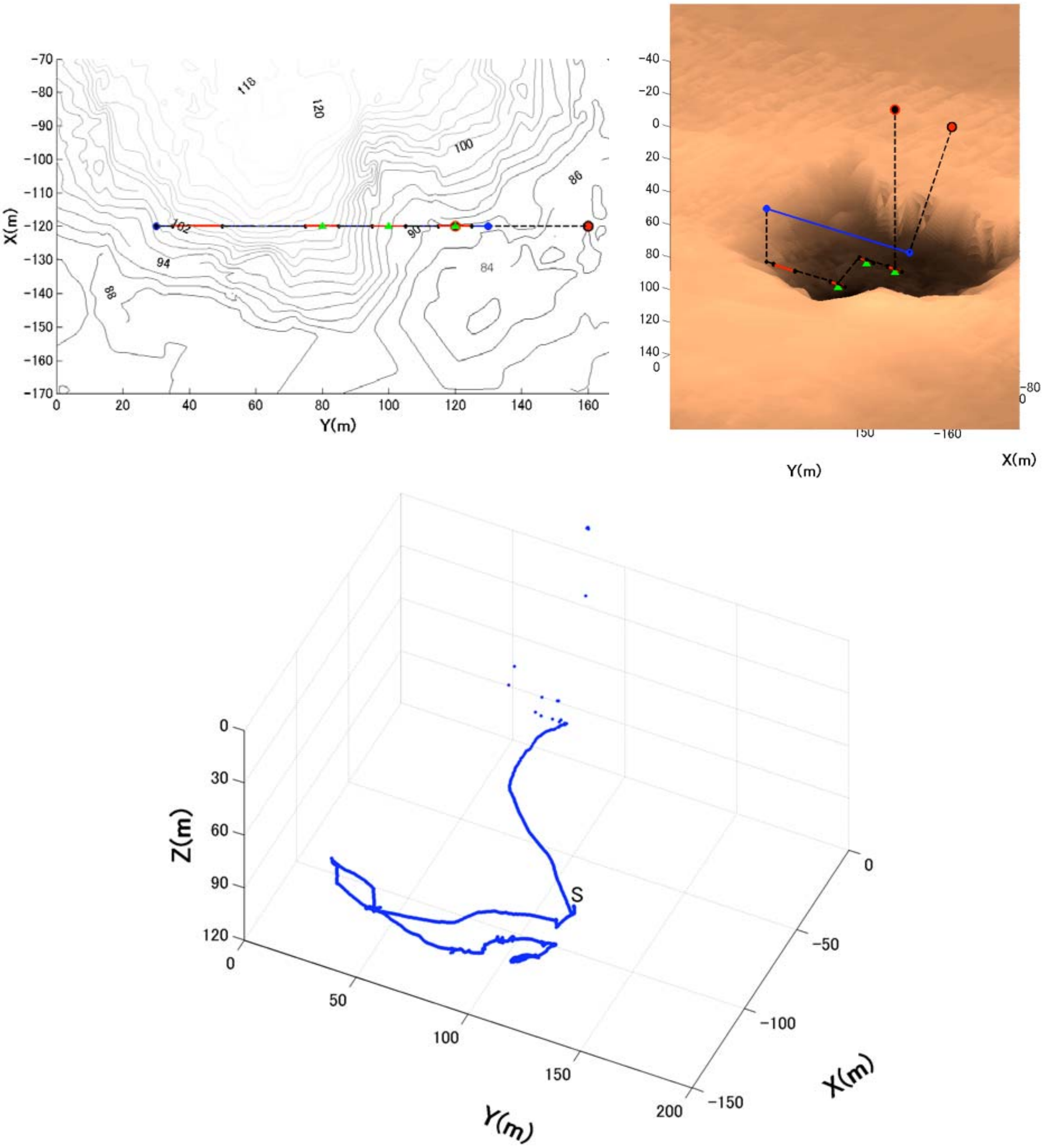

Fig. 19 Vehicle trajectory

Dive Summary

8:21 Vehicle deployed

8:29 Waypoint 1 reached

8:40 LED switched on, water turbid

8;42 Terrain very dangerous for navigation

8:57 Area too bumpy to land

9:05 Landing, microscopic images were taken

9:13 Emergency stop due to obstacle

9:19 Landing

9:37 Landing, microscopic images were taken

9:43 Low battery, both ballasts released, end mission.

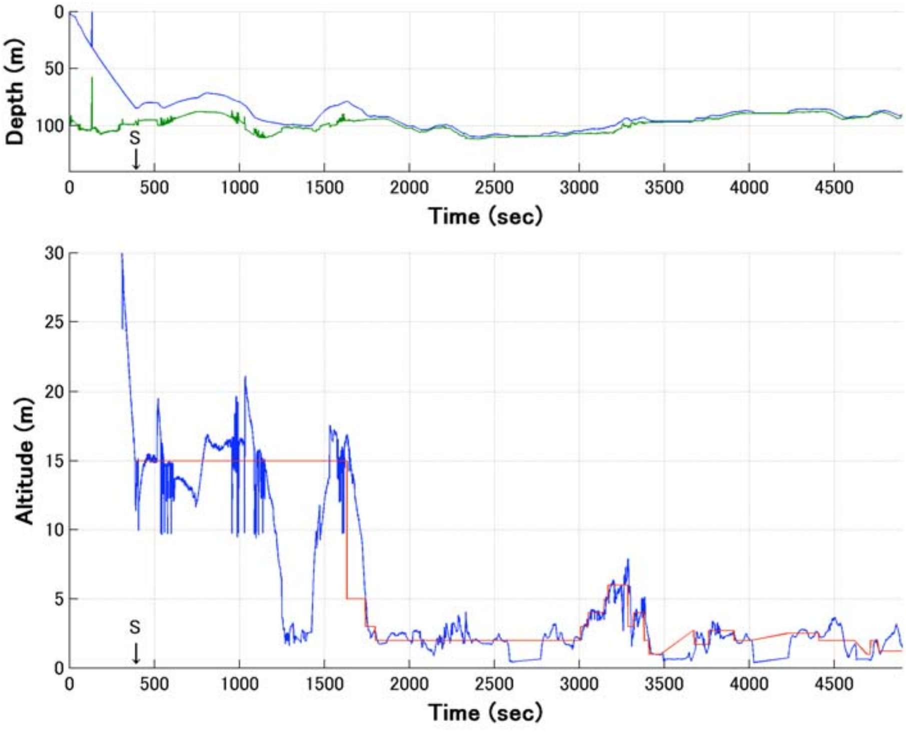

Fig. 20 Vehicle depth and altitude

5-4 TS#35

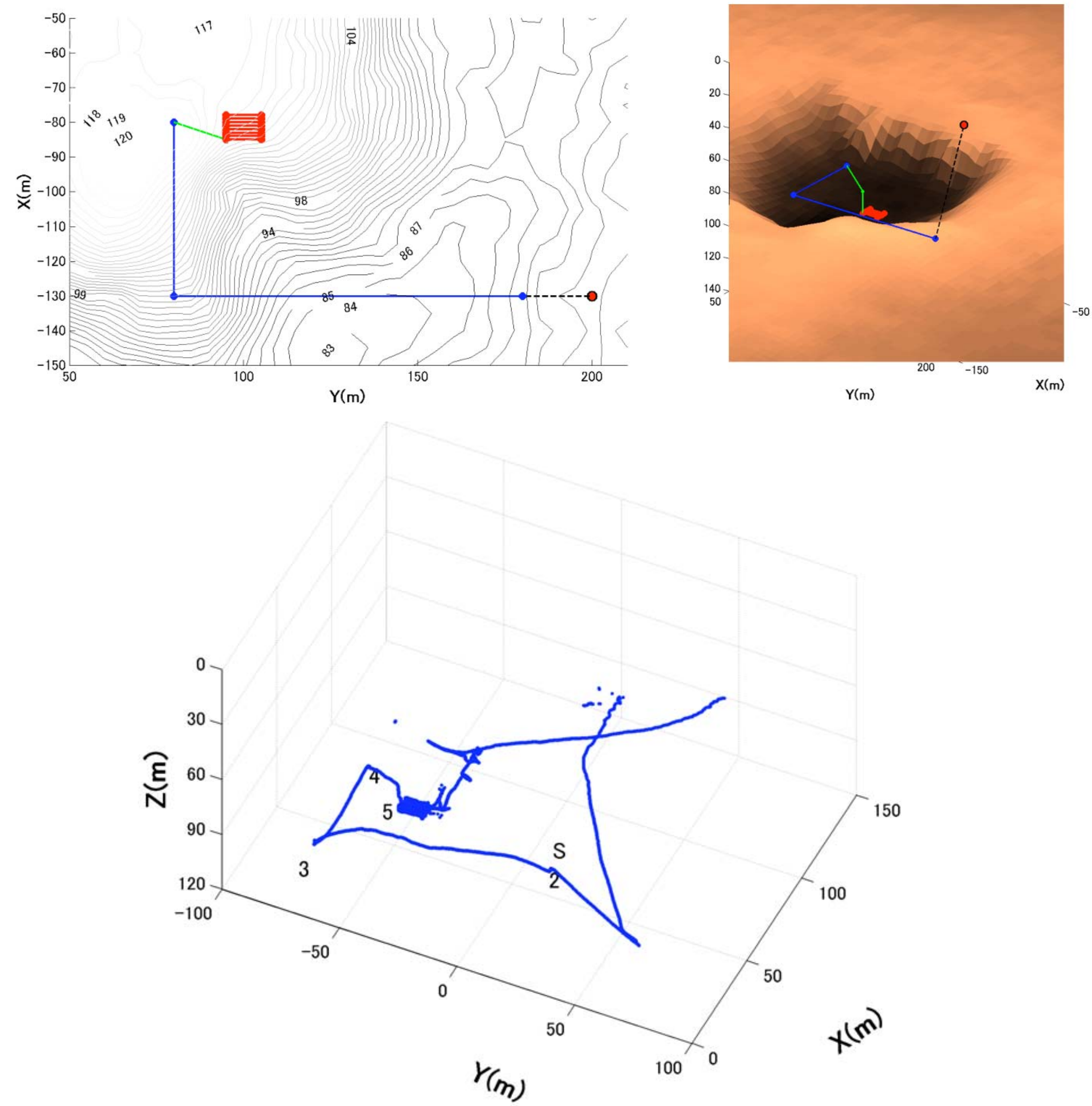

Fig. 21 Vehicle trajectory

Dive Summary

8:45 Vehicle deployed

8:58 Waypoint 1 reached

8:59 Terrain navigation started

9:13 Terrain navigation completed

9:14 Laser profiling equipment switched on

9:40 Landing, microscope images were taken

9:49 Landing, microscope images were taken

9:57 Landing, microscope images were taken

10:04 Landing

10:29 Low battery voltage, release ballast, end mission.

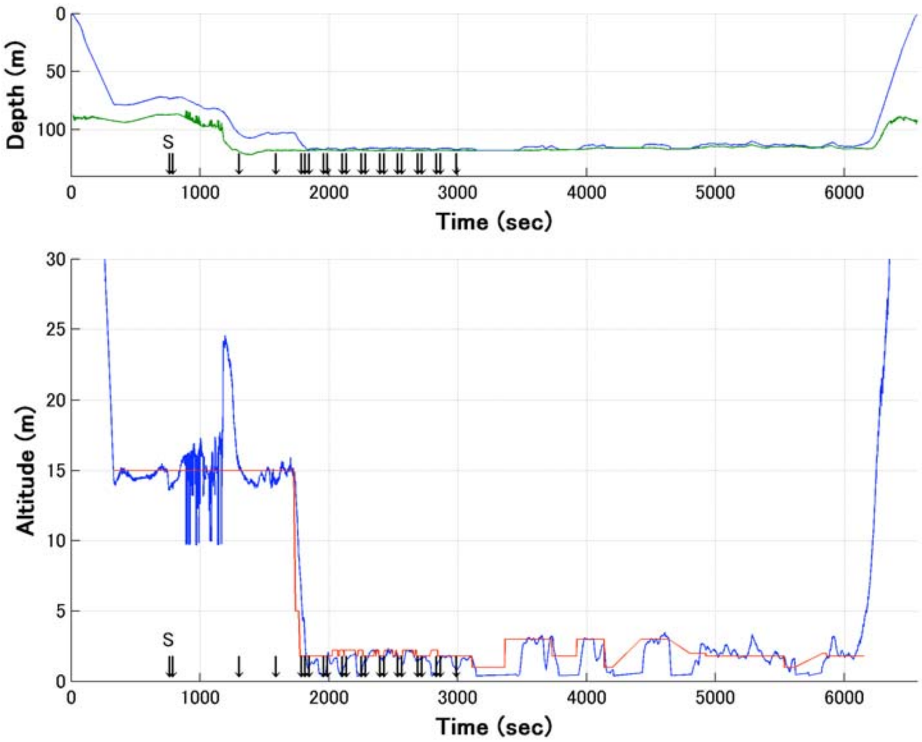

Fig. 22 Vehicle depth and altitude

5-5 TS#36

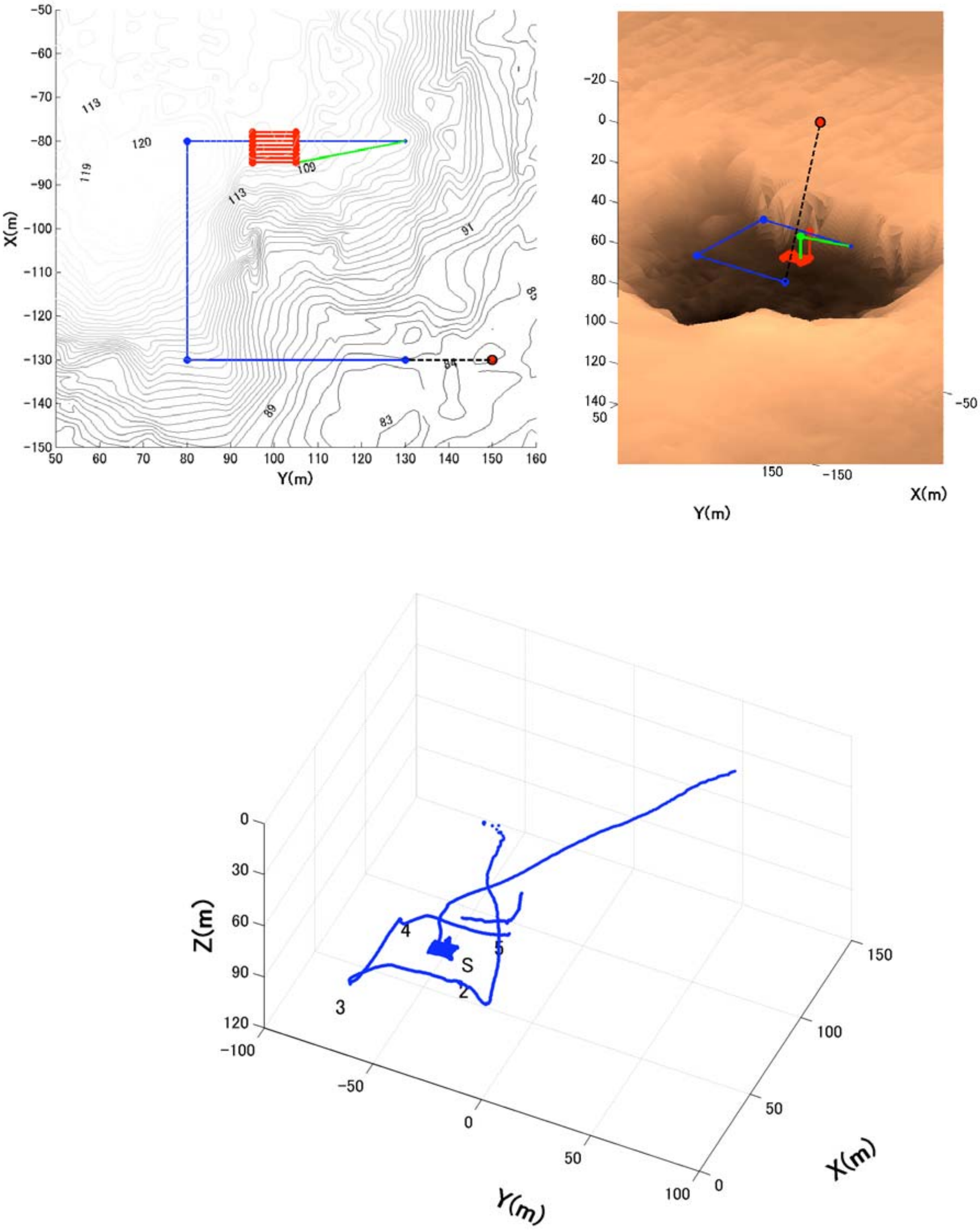

Fig. 23 Vehicle trajectory

Dive summary

13:49 Vehicle deployed

13:56 Waypoint 1 reached

13:59 Terrain navigation started

14:16 Terrain navigation completed

14:21 Laser scanning started

14:53 Low battery voltage, ballast release, end mission.

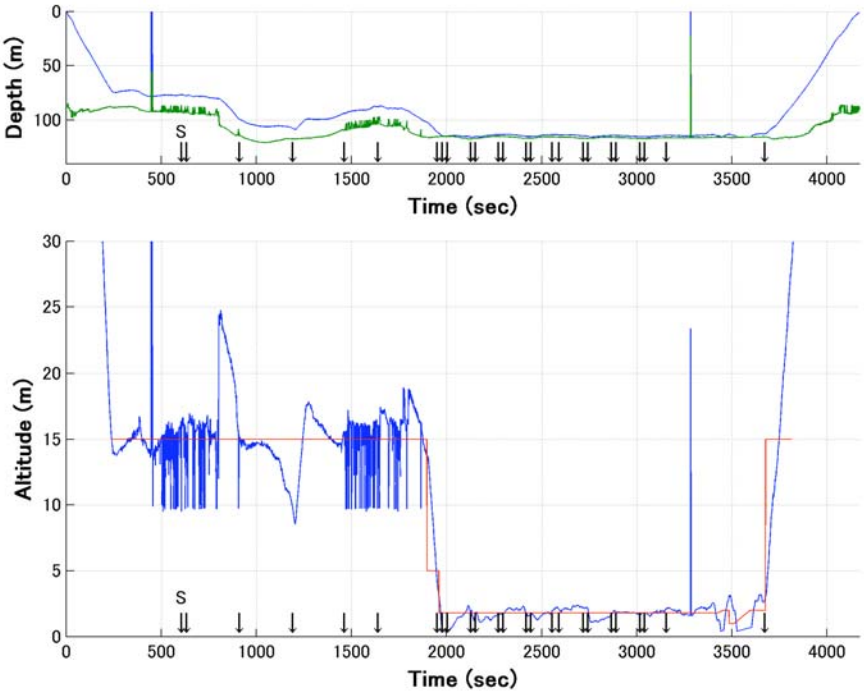

Fig. 24 Vehicle depth and altitude

6. Future Plans

This survey provided valuable engineering in-sight into the instrumentation and methods necessary for a landing AUV. The data obtained during this cruise will be used to optimize the landing and pixel mapping algorithms. It is also intended that the data will form a basis to extend the landing algorithm to perform autonomous classification. The survey techniques and instruments will be refined and it is planned that they will be applied with additional payloads during the NT10-11 cruise to survey manganese crusts which is planned for later this year. Finally, it is intended that the landing algorithm will be applied to generate landing commands for a landing AUV currently under development at the University of Tokyo.

Impressions of my first cruise

The KY10-04 was the first cruise I attended as a researcher and it was definitely a very interesting and enriching experience. In terms of research I was glad that we were able to carry out our experiments without having any major problems and obtained valuable data. I was surprised at how much preparation, technical equipment and human workforce was needed to deploy the underwater robot. The fact that everything went well, shows that the crew was well prepared and has a lot of expertise. However, the atmosphere wasn’t so lively, and sometimes I felt that people were not so dynamic. Already when we arrived at the port I was surprised at the size of the ship and number of crew. Everybody was friendly, the food was tasty, the cabin big enough and well equipped, which all contributed to make this cruise a pleasant one.

Adrian Bodenmann

Acknowledgements

KY10-04 marked the end of Captain Sadao Ishida’s long career as captain. It was our great pleasure to mark this with the successful deployment of our vehicle and sensing systems, to which we owe a great debt to Captain Ishida’s experience and fine judgment. We, the research party deeply appreciate and are indebted to the hard work and efforts of Captain Ishida, the crew of the R/V Kaiyo, Mr. Nariyuki Nakai and the members of JAMSTEC.

Fig. 25 Photo taken together with crew members

Additional note

During the cruise, we heard news of the sad loss of the AUV ‘ABE’ developed by Dr. Dana Yoerger of the Woods Hole Oceanographic Institution, at the Chili triple junction. Failure of a glass sphere used in the vehicle’s pressure vessel is thought to be the most likely cause of the accident. It is particularly sad to hear of this loss, since ABE was one of the bravest and most advanced AUVs in the world. During its many years of operation, ABE greatly contributed to the recognition of AUVs as a practical tool for ocean research, and its numerous discoveries have contributed greatly to our understanding of the ocean. It is hoped that the spirit of the late ABE will live on through the hard work and dedication of the AUV research community, and will continue to drive the development of AUV technology.