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KAIMEI+ “Cruise Report”
KM24-10C

Verification Test for Long-Distance Measurement Technology Using Reflected Laser and Doppler Detection Technology (Final Evaluation Test #1)

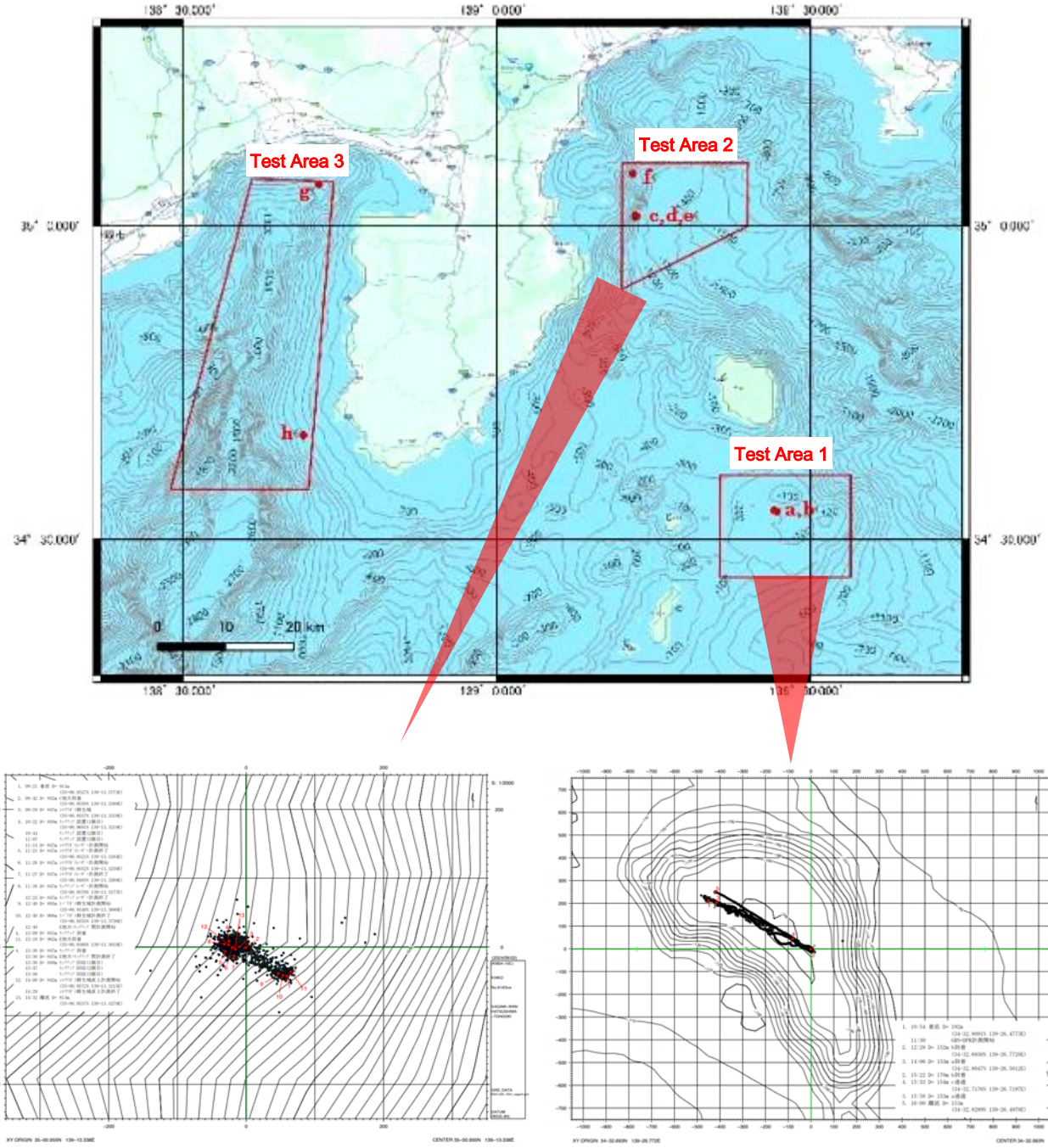
Omuro Sea Hole | Off East of Hatsuhima

Sep.16,2024 - Sep.23,2024

Japan Agency for Marine-Earth Science and Technology
(JAMSTEC)

1. Cruise Information

- Cruise ID : KM24-10C
- Name of vessel : R/V KAIMEI
- Title of cruise : Verification test for long-distance measurement technology using reflected laser and Doppler detection technology (Final evaluation test #1)
- Chief Scientist [Affiliation] : Shojiro Ishibashi [JAMSTEC]
- Cruise period : 16/09/2024 – 23/09/2024
- Ports of departure / call / arrival : Yokosuka/JAMSTEC – Yokosuka/JAMSTEC
- Research area : Omuro Sea Hole | Off East of Hatsuhima
- Research map :



2. Research Proposal and Science Party

● Title of proposal

Verification test for long-distance measurement technology using reflected laser and Doppler detection technology (Final evaluation test #1)

● Representative of Science Party [Affiliation]

- Japan Agency for Marine-earth Science and TeChnology (JAMSTEC)
- Mitsubishi Electric Defense and Space technologies corporation (MEDS)
- Technical Manager, Tamagawa Electronics Co., Ltd. (TME)
- Hamamatsu Photonics K.K.(HPK)
- Nippon Marine Enterprises Co., Ltd (NME)

● Science Party (List) [Affiliation, assignment etc.]

- Shojiro Ishibashi	Senior Researcher, Technology Development Department, JAMSTEC
- Masako Takayanagi	Research Assistant, Technology Development Department, JAMSTEC
- Takamitsu Okada	Engineering Researcher, MEDS Co., Ltd.
- Daisuke Tetsuta	Engineering Researcher, MEDS Co., Ltd.
- Keisaku Takada	Engineering Researcher, MEDS Co., Ltd.
- Takashi Saito	Engineering Researcher, TME Co., Ltd.
- Yutaka Hasegawa	Engineering Researcher, HPK
- Morifumi Takaesu	Observation Technician, NME Co., Ltd.

● Operation team of the “KAIKO Mk-IV”

-Operation Manager	KIDO TEPPEI
-2nd ROV Operator	IHARA SHOTA
-2nd ROV Operator	TAYAMA YUDAI
-2nd ROV Operator	SAKAKIBARA YUDAI
-2nd ROV Operator	OKITA YUKI
-2nd ROV Operator	ASANO WATARU
-3rd ROV Operator	NAKANISHI YOTARO

● Captain and crew of the R/V KAIMEI (List) [Affiliation, assignment etc.]

-Captain	KIMURA NAOTO
-Chief Officer	MURAMATSU TAKESHI
-2nd Officer	IIDA YASUTO
-3rd Officer	SARASHINA HIROKI
-Jr.3rd Officer	TSURUMAKI AOI
-Chief Engineer	FUNAE KOJI
-1st Engineer	MORI TAKAHIRO
-2nd Engineer	ONO KAZUKI
-3rd Engineer	SATO DAITO
-Chief Electronic Operator	NASU TOKINORI
-2nd Electronic Operator	MAEDA KOHEI
-3rd Electronic Operator	OKADA FUMINE
-Boat Swain	OHATA MASANORI
-Able Seaman	HIRAI SAIKAN
-Able Seaman	MIYASHITA TAKUYA
-Able Seaman	NASU KENTA
-Able Seaman	MIURA TAKUMI
-Sailor	NAKAYAMA SHOTARO

-Sailor	YOKOYAMA TAISUKE
-No.1 Oiler	FUJIWARA MASAYUKI
-Oiler	KOZAKI MAKOTO
-Oiler	WATANABE SEIYA
-Assistant Oiler	MIZUNO RIKU
-Assistant Oiler	KUBO KIYOYUKI
-Chief Steward	CHIKUBA YUKIHIDE
-Steward	NOJIRI TAKEHIRO
-Steward	SONODA KAZUMA
-Steward	KATO TAKU

3. Research/Development Activities

● Purpose, background

In this research, by understanding the underwater propagation characteristics of reflected laser, we aim to realize comprehensive underwater seabed sensing. Aiming to establish the underwater vehicle technology that actively incorporates underwater optics technologies, we focused on the characteristics of reflected laser (scattered light) in the seawater and worked on

(1) To obtain time-information from reflected laser,
(2) To detecting reflectance from reflected laser,
(3) To extracting Doppler components from reflected laser.

On this cruise, the "Green-laser Demonstrator" incorporating a laser source device in the green wavelength range and the "UV-laser Demonstrator" incorporating a laser source device in the UV wavelength range were installed at the rear of the ROV “KAIKO”, and "Estimation of physical properties using seabed laser reflection and performance evaluation test #1" was conducted. In addition, a "Laser-Doppler Demonstrator" incorporating a green wavelength laser source device was installed at the front of the “KAIKO”, and "Performance evaluation test #1 of the Laser-Doppler Demonstrator" was conducted.

● Activities (observation, sampling, development)

<Estimation of Physical Properties using Seabed Laser Reflection and Performance Evaluation Test #1>

In this test, the “Green-laser Demonstrator" and ``UV-laser Demonstrator" installed onboard ROV “Kaiko” were used to measure the laser reflectance of several seabed-mockups placed on the seabed. This provided the basic data needed for an algorithm to classify estimate physical properties of seabed sediments.

Based on the specifications and performance of both demonstrators, the minimum measurement altitude was set at approximately 2m and the maximum measurement altitude was set at approximately 15m. Fig. 1 shows an overview of this test. The “Green-Laser Demonstrator" and “UV-Laser Demonstrator" were installed on the KAIKO at the same time, and were attached to the main frame on both sides of the KAIKO’s rear part. Both the power supply system and signal system were controlled arbitrarily from the support ship (KAIMEI) by using the payload I/F of KAIKO.

In this test, an underwater mock-up storage case was installed inside KAIKO’s sample basket. The seabed-mockup storage case (hereinafter referred to as the “storage-case”) is a metal case that stores a mockup that simulates the seabed (seabed-mockup). The storage-case was stored in a storage rack frame (hereinafter referred to as the “rack-frame”) installed inside KAIKO’s sample basket. The rack-frame is able to store 3-5 storage-cases (maximum 6 containers). Fig. 2, Fig. 3 and Fig. 4 shows an overview of the seabed-mockup, the storage-case and the rack-frame, respectively. Fig.5 shows the appearance of KAIKO, which is equipped with both demonstrators.

In this test, KAIKO first landed on the seabed at an arbitrary location, took out the storage-case from the rack-frame, and installed it on the seabed. At this time, the storage-cases were placed at intervals of approximately 3-5 meters. After setting up multiple storage cases on the seabed, KAIKO took off from the bottom and began to measure them by irradiating laser beams at each storage-case from an arbitrary

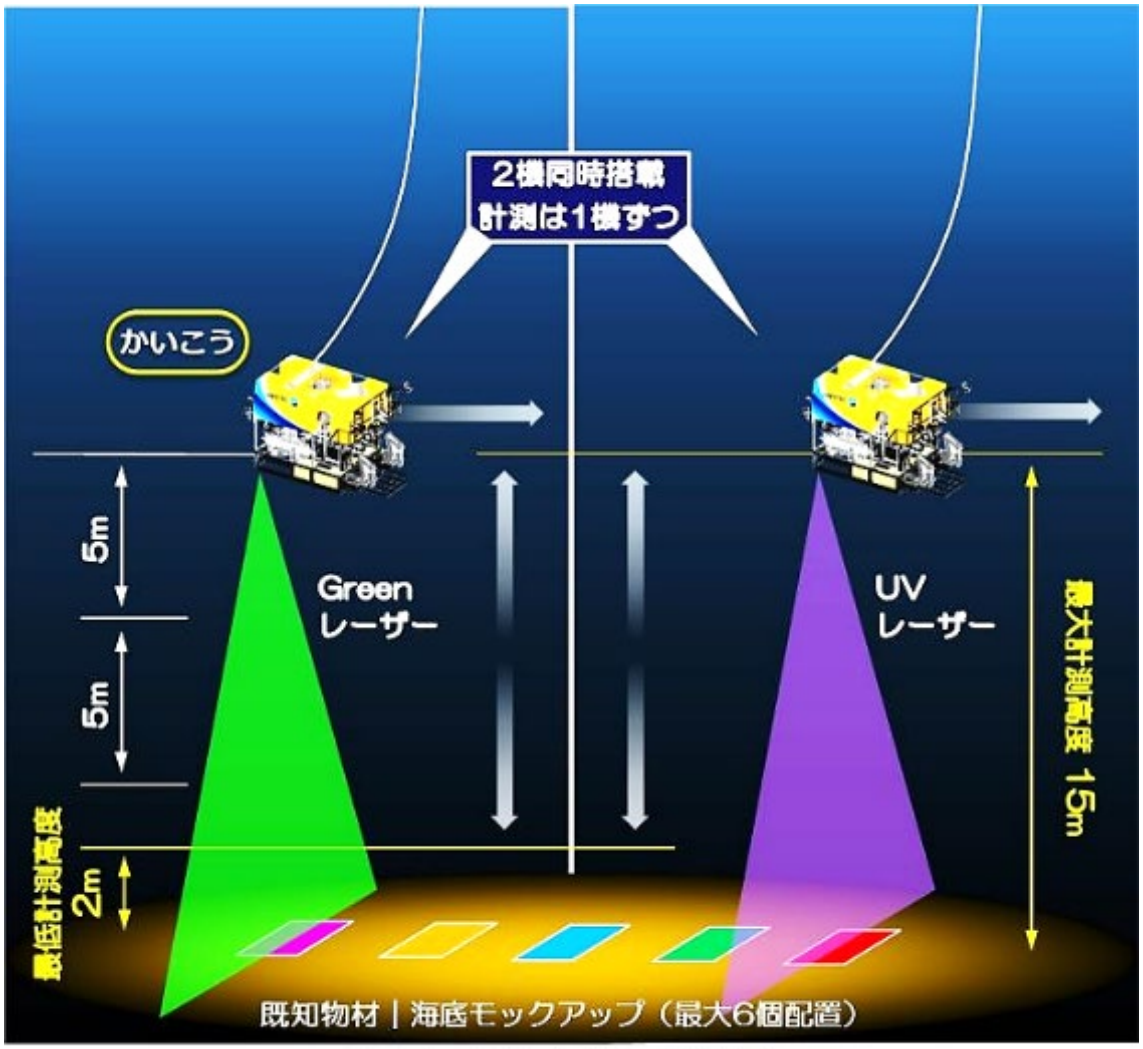
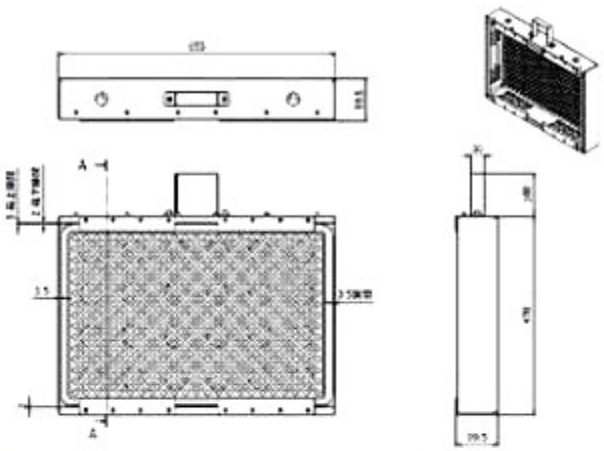


Fig. 1　Overview of the “Estimation of Physical Properties using Seabed Laser Reflection and Performance Evaluation Test #1”.

Size	645x420x95mm
Weight (air)	20-40kg
Working Depth	1,000m

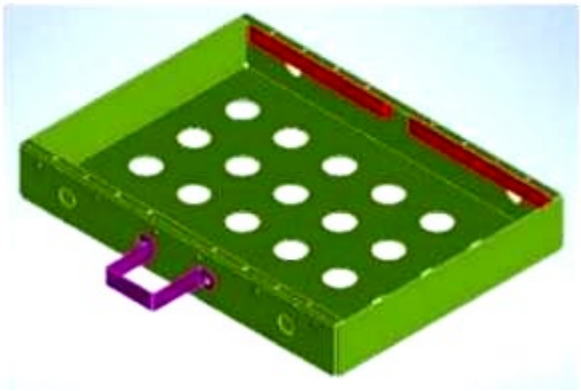
Fig. 2　Seabed-mockups stored into storage cases.

altitude. Since the measurement ranges of the Green-laser Demonstrator and the UV-laser Demonstrator are different, the target altitude was adjusted each time on site and measurements were carried out. At the



Size	655x570x100mm
Weight (air)	< 15kg
Working Depth	1,000m

Fig. 3　Storage-cases.



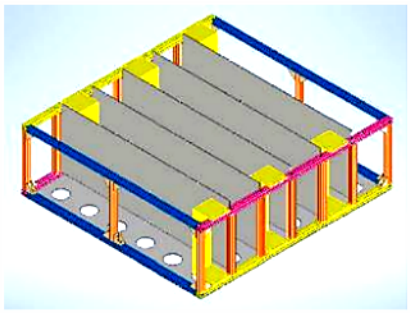
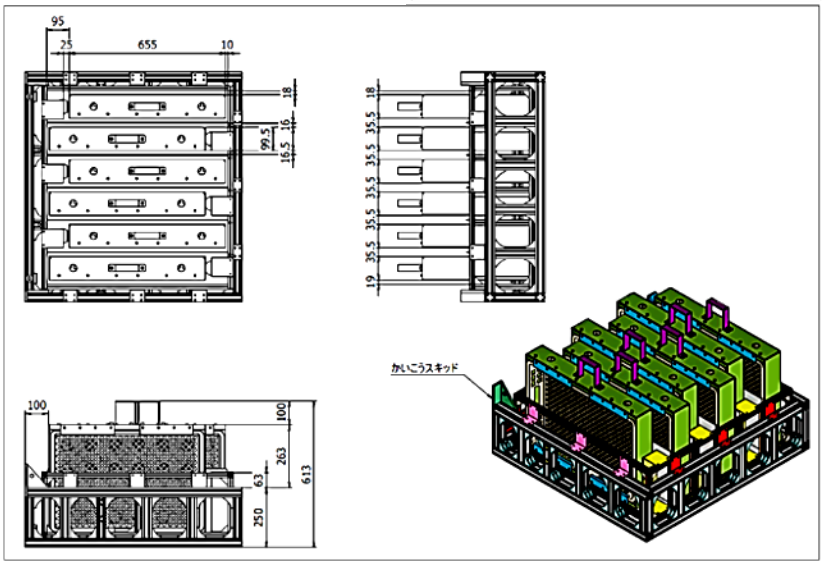


Fig. 4　Rack-frame.

Size	790x750x350mm
Weight (air)	< 50kg
Working Depth	1,000m



same time, KAIKO maintained a desired altitude as much as possible while navigating at a low and constant speed of less than 1 knot.

In this test, while KAIKO dived and cruised, we conducted the technology verification to generate long-distance ranging and high-resolution images using the "Green Laser Demonstrator". As the result of this test, the Green-laser Demonstrator confirmed a horizontal visualization resolution of over 8,000 pixels.

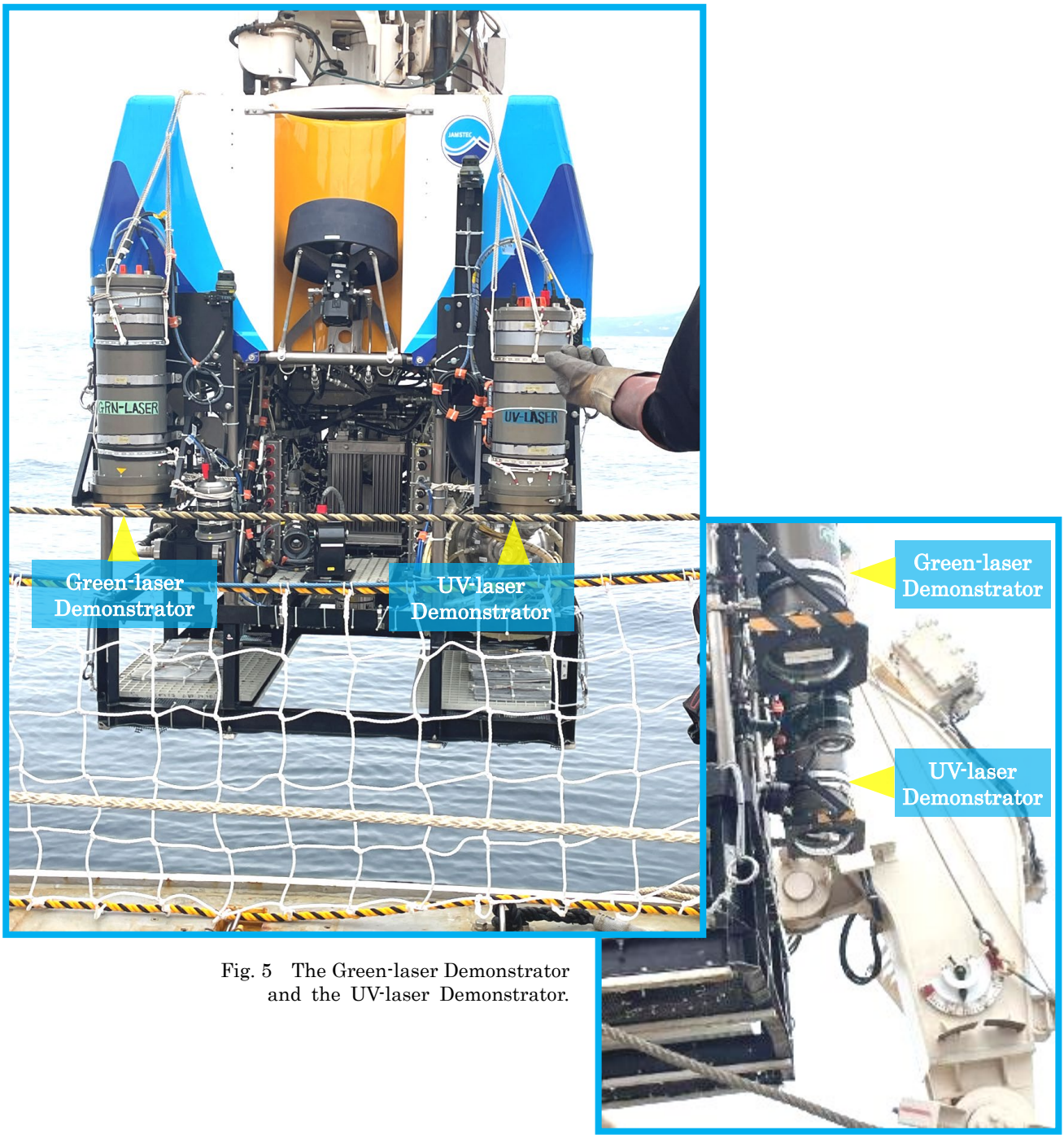


Fig. 5 The Green-laser Demonstrator and the UV-laser Demonstrator.

This means to achieve one of the final goals of this research. In addition, at that time, the Green-laser Demonstrator confirmed the longest measurement distance (maximum laser distance measurement) of 67m (round-trip propagation distance: 134m). This also means to achieve one of the final goals of this research.

<Performance Evaluation Test of the Laser-Doppler Demonstrator #1>

This test will evaluate the basic performance of the combined navigation technology with an inertial navigation system (INS) that detects the speed of a moving object by extracting the Doppler shift of reflected laser in an underwater environment. From the results of this test, improvements and refinements to the Laser-Doppler Demonstrator will be extracted and prepared for the next cruise (Dec. 2024 | KM24-14C). Fig. 6 shows an overview of this test. The premise for realizing this technology is to "detect the

Doppler shift of laser reflected by suspended matter in the seawater." In other words, it means detecting "velocity relative to suspended matter ≒ velocity relative to water." The relative velocity of the moving object (underwater vehicle) is defined by assuming that the suspended matter in the seawater is an instantaneous stationary target, with respect to the relative velocity in the short time it takes for the laser emitted from the underwater vehicle to be reflected by the suspended matter and received. The relative velocity detected in this way is input as an observation term for the INS's combined navigation calculation processing (Kalman filter with 13DOF) to evaluate the effect of improving navigation performance. Therefore, the direction of the laser is the direction of movement of the underwater vehicle, and the target is several meters ahead of the underwater vehicle (estimated: minimum 2m, maximum 5m), and the measurement target is the suspended matter in the seawater that exists in the test area. In this test, the ideal condition is for the underwater vehicle (ROV "KAIKO") to travel at as slow and constant a speed as possible, and the results of this test (the accuracy of the detected speed value) are determined by the operation that does not make large attitude changes (roll and pitch changes) and suppresses vertical component movement as much as possible. In addition, it is extremely important to maintain the heading (heading direction) at that time. Therefore, we believe that the use of KAIKO, which is equipped with an inertial navigation system incorporating a high-performance optical gyro and has an autonomous navigation function based on this, is optimal and essential for this test. We aim to create the (ideal) situation by self-propulsion that combines heading maintenance, depth maintenance, and speed maintenance, rather than self-propulsion by WL or WP navigation.

The ideal sea area for this test is one where there is a lot of suspended matter in the sea and where sunlight does not reach. Therefore, the basic depth is 300m or more in a sea area with sufficient water depth, and in addition, considering a sufficient distance (altitude) where there is no influence of seabed deposits (such as the blowing up of sediments), we specified navigation at a constant depth with an altitude of 200m or

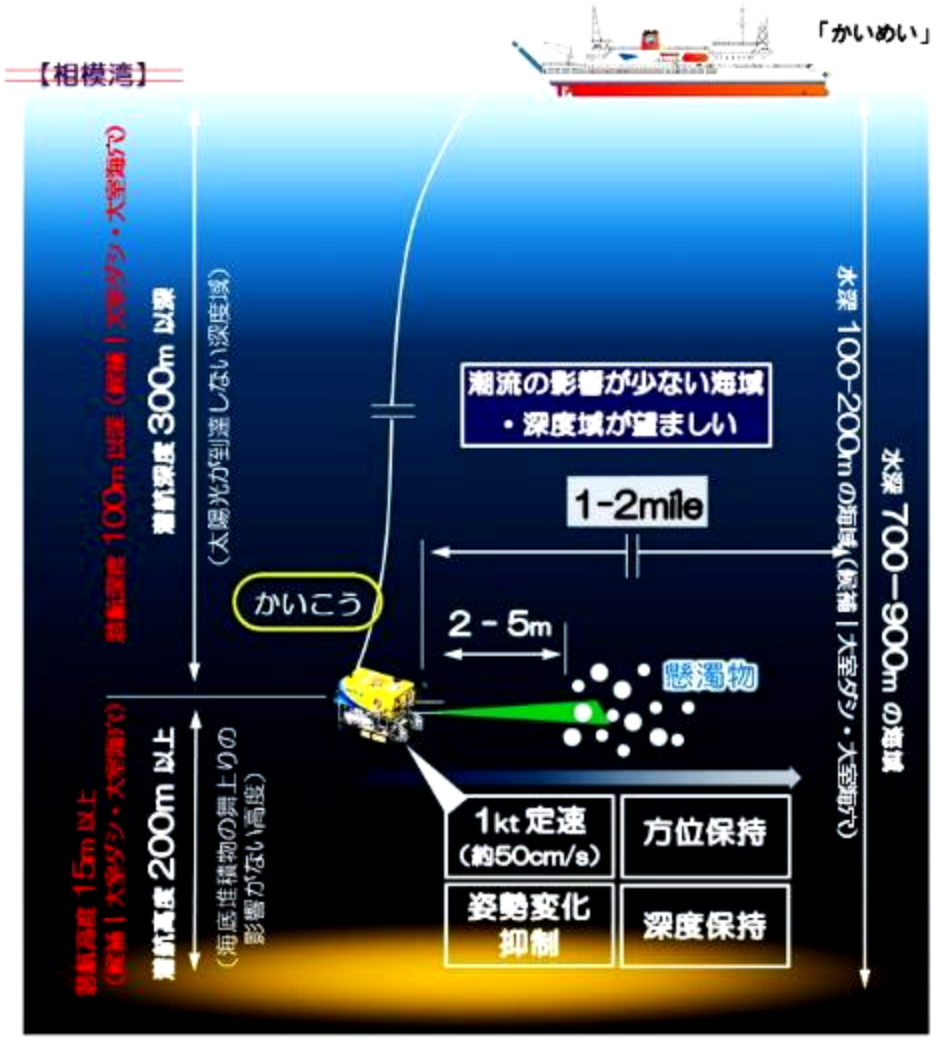


Fig. 6
Overview of the
“Performance Evaluation
Test of the Laser-Doppler
Demonstrator #1”.

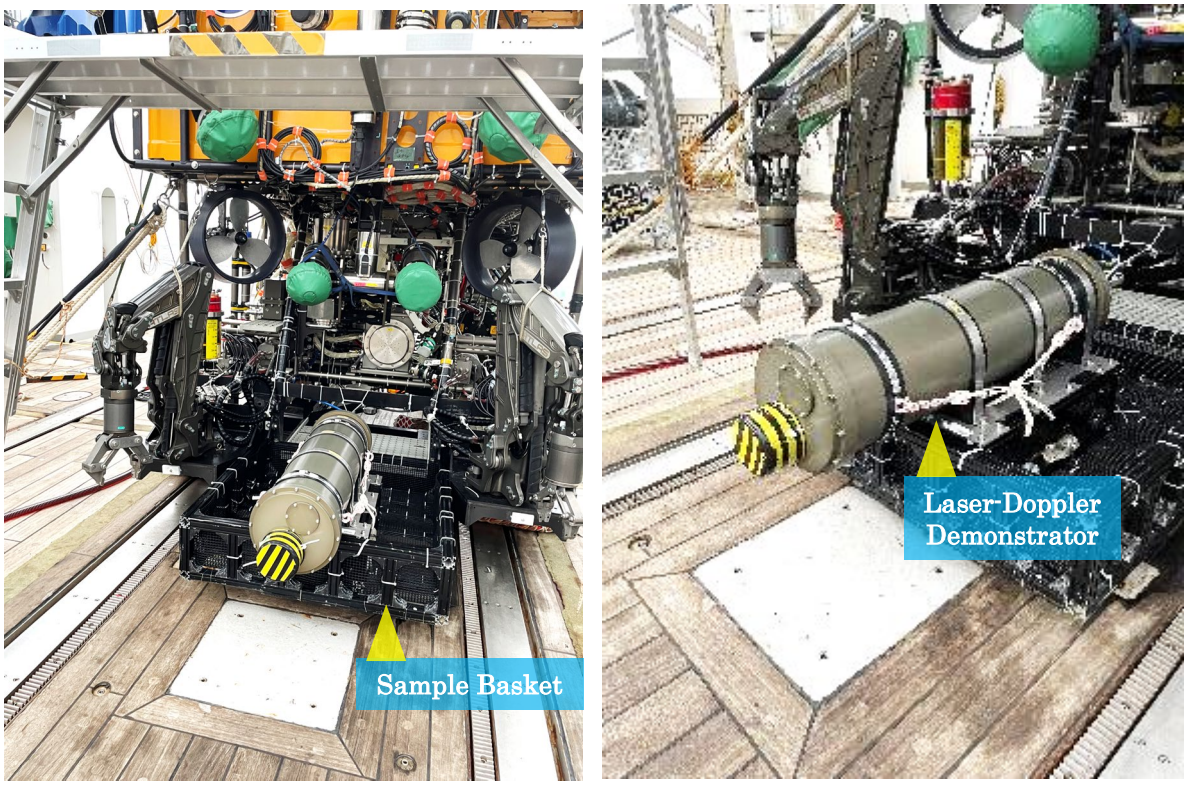


Fig. 7　The Laser-Doppler Demonstrator

more in the test area2. Also, this test was conducted in the test area1. At that time, KAIKO cruised keeping the altitude over 15m and at over 100m as the depth. In the test environment and conditions, we navigated at a low speed less than 0.5knot and at a constant depth (e.g. speed control + depth control), and conducted tests of 1 mile or more (about 1 hour) in one direction multiple times as much as possible (continuously if possible). This ensured the accuracy of the test results by considering the characteristics that depend on the Schuler period (about 90 minutes) required for the evaluation of the accuracy of inertial navigation calculations. It was desirable to define the navigation using the autonomous navigation function of the KAIKO, and the navigation speed, navigation distance, target depth, target direction, etc. were appropriately adjusted with the relevant parties on-site, taking into account the weather, sea conditions, and environment on the day of the dive, as well as the results of each dive.

In this test, the Laser-Doppler Demonstrator was installed on a dedicated auxiliary stand inside the sample basket always kept on the KAIKO. The Laser-Doppler Demonstrator was installed facing the bow of the KAIKO (≒ direction of travel), and the laser was also emitted in the same direction. Therefore, the speed detected by the Laser-Doppler Demonstrator (speed relative to suspended matter) was almost the speed in the bow direction of the KAIKO, which was strictly different from the speed in the direction of travel. Fig. 7 shows an image of the Laser-Doppler Demonstrator installed on the KAIKO.

● Results

<DIVE #911>

Date　: 09/17/2024

Sea area　: Omuro-dashi / Omuro-sea hole (Test Area1)

Payload　: Green-Laser Demonstrator / Laser-Doppler Demonstrator

Sampling　: no

Log　:

1.	10:54	D= 192m	Landing (34-32.8091N 139-26.4773E)
	11:30	GRN+DPR	Test Start
2.	12:28	D= 152m	Point ‘b’ Arrival (34-32.6930N 139-26.7720E)

3.	14:06	D= 153m	Point ‘a’ Arrival (34-32.8047N 139-26.5012E)
4.	15:22	D= 170m	Point ‘b’ Arrival
	15:33	D= 154m	Point ‘c’ Go Through (34-32.7176N 139-26.7197E)
5.	15:58	D= 153m	Point ‘a’ Go Through
6.	16:00	D= 153m	Test Finish ---> Rise-Up start (34-32.8289N 139-26.4978E)
7.	16:14		Rise-Up

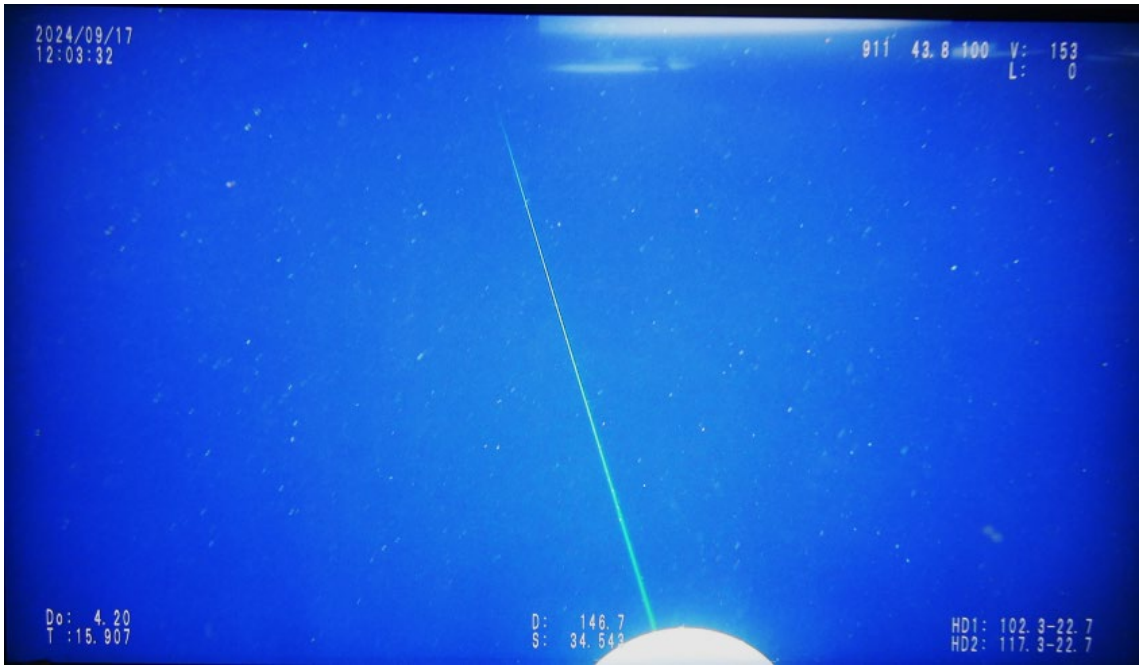


Fig. 8 A scene of DIVE #911 (Laser-Doppler Demonstrator)

<DIVE #912>

Date : 09/18/2024
Sea area : Omuro-dashi / Omuro-sea hole (Test Area1)
Payload : Green-Laser Demonstrator / Laser-Doppler Demonstrator
Sampling : no
Log :

1.	09:12	D= 155m	Landing (34-32.8025N 139-26.4953E)
2.	09:32	D= 151m	Remark Point (d) (34-32.7711N 139-26.5590E)
3.	10:15	D= 142m	Point ‘b’ Arrival (34-32.6935N 139-26.7725E)
4.	10:31	D= 148m	Remark Point (e) (34-32.7051N 139-26.7546E)
5.	11:20	D= 160m	Point ‘b’ Arrival
6.	11:45	D= 160m	Remark Point (f) -> 2D measurement (34-32.7427N 139-26.6375E)
7.	12:56	D= 159m	Remark Point (d)
8.	13:06	D= 160m	Remark Point (f) (34-32.7195N 139-26.7261E)

9.	13:43	D= 191m	Point ‘b’ Arrival
	14:19	D= 191m	Remark Point (d)
10.	14:41	D= 190m	Remark Point (g) (34-32.8313N 139-26.7133E)
11.	15:24	D= 190m	Explore Chimneys (34-32.6994N 139-26.7746E)
12.	15:46	D= 193m	Test Finish ---> Rise-Up start (34-32.7134N 139-26.7756E

Fig. 9 A scene of DIVE #912 (scanning Image measured by Green-Laser Demonstrator in a real time)

<DIVE #913>

Date : 09/20/2024
Sea area : Off East of Hatsushima / Sagami Bay (Test Area2)
Payload : Green-Laser Demonstrator / Laser-Doppler Demonstrator
Sampling : no
Log :

1.	09:11	D= 846m	Landing (35-00.9600N 139-13.3346E)
	10:47	D= 813m	Test Start (Laser-Doppler)
2.	12:01	D= 809m	Test Finish (Lalser-Doppler) (35-01.5700N 139-13.6700E)
3.	12:15	D= 873m	Test Start (GRN-Laser) (35-01.5848N 139-13.6802E)
2.	12:27	D= 846m	Test Finish (GRN-Laser)
	12:28	D= 842m	Test Start (Laser-Doppler)
4.	14:09	D= 846m	Test Finish (Laser-Doppler) (35-00.9784N 139-13.3589E)
	14:10	D= 845m	Rise-Up Start

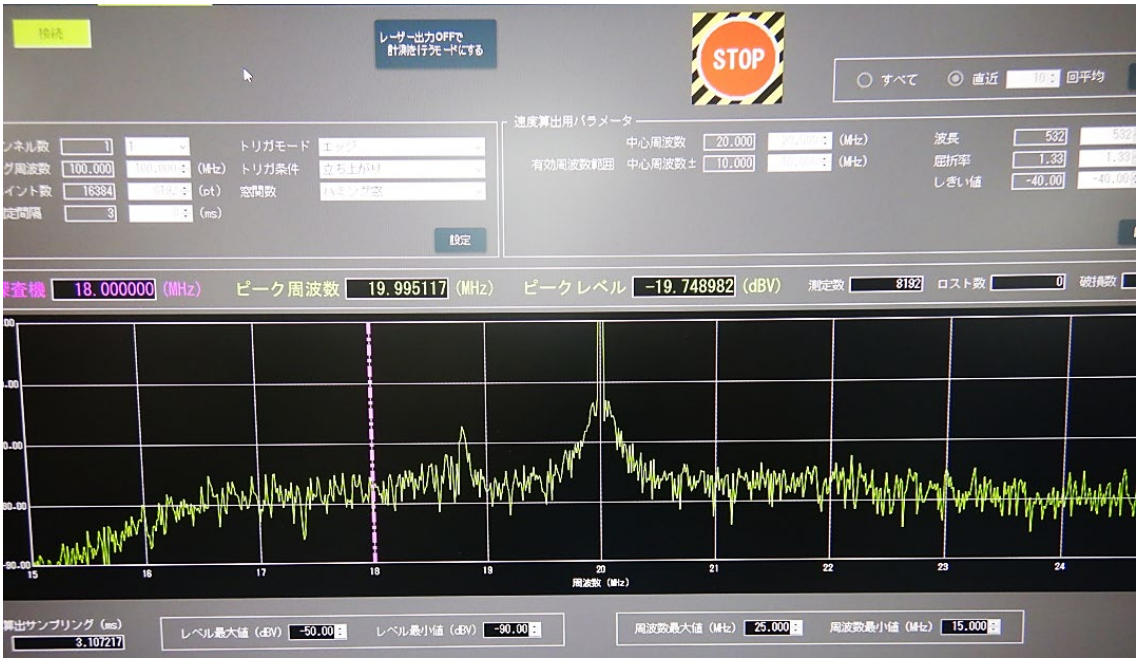


Fig. 10　A scene of DIVE #913 (FFT signals measured by Laser-Doppler Demonstrator)

<DIVE #914>

Date : 09/22/2024
Sea area : Off East of Hatsushima / Sagami Bay (Test Area2)
Payload : Green-Laser Demonstrator / UV-Laser Demonstrator
Sampling : no
Log :

1.	09:21	D= 911m	Landing (35-00.9327N 139-13.3773E)
2.	09:42	D= 852m	Point 'C' Arrival (35-00.9550N 139-13.3380E)
3.	09:59	D= 847m	Check the Seabed Benthos (35-00.9557N 139-13.3318E)
4.	10:22	D= 850m	Set the mock-up #1 (35-00.9601N 139-13.3219E)
	10:44		Set the mock-up #2
	11:07		Set the mock-up #3
	11:14	D= 847m	Start Test (scan the seabed benthos)
5.	11:21	D= 847m	Finish Test (35-00.9521N 139-13.3184E)
6.	11:26	D= 847m	Start Test (scan the seabed benthos) (35-00.9552N 139-13.3250E)
7.	11:27	D= 847m	Finish Test (35-00.9485N 139-13.3269E)
8.	11:38	D= 847m	Start Test (scan the mockups) (35-00.9578N 139-13.3177E)
	12:23	D= 847m	Finish Test
9.	12:40	D= 893m	Start Test (scan the seabed benthos) (35-00.9348N 139-13.3690E)
10.	12:48	D= 900m	Finish test (35-00.9333N 139-13.3736E)
	12:49		Start Test (between point'E' and mockups)
11.	13:09	D= 851m	Point 'mockup area' Arrival

12.	13:18	D= 902m	Point ‘E’ Arrival (35-00.9360N 139-13.3810E)
13.	13:30	D= 847m	Point ‘mockup area’ Arrival
	13:30	D= 847m	Finish Test
	13:38	D= 850m	Recovery the mockup #1
	13:47		Recovery the mockup #2
	13:56		Recovery the mockup #3
14.	14:00	D= 842m	Start Test (scan the seabed benthos) (35-00.9572N 139-13.3215E)
	14:29		Finish Test
15.	14:32	D= 813m	Start Rise-Up (35-00.9537N 139-13.3279E)

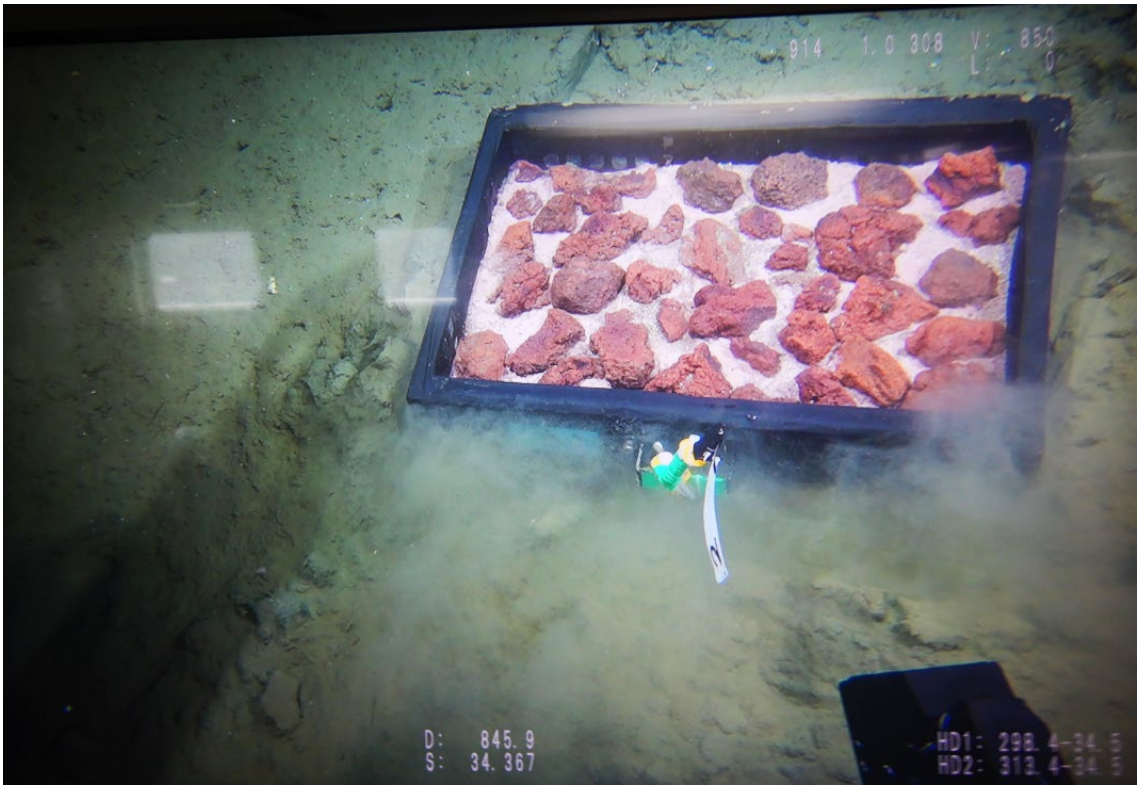


Fig. 11 A scene of DIVE #914 (Setting the seabed mockup on the seabed using KAIKO’s manipulator)

○ 4. Cruise Log

Date	Local Time	Note	Noon Position Weather/Wind/Sea Condition
16-Sep-2024	11:30	Scientists party onboard R/V KAIMEI	JAMSTEC
	12:00-12:50	Scientists meeting	35-19.1N,139-39.0E
	13:00	Let go all shore line & left YOKOSUKA port	Weather: -
	14:00-14:40	Onboard lecture for safety and onboard life	Wind direction/force: -
	17:25	Arrived at research area(Oomurodashi)	Wave scale: -
	17:26	Released XBT	Swell scale: -

	18:00-19:20	Scientists meeting	Visibility(miles): -
17-Sep-2024	9:05	Hoisted down "KAIKO Mk-IV"	Oomurodashi
	9:30	Lounched "KAIKO Mk-IV" #911	34-32.7N,139-26.6E
	10:54	"KAIKO Mk-IV" landed on the sea bottom (D=192m)	Weather: bc
	16:00	"KAIKO Mk-IV" left the sea bottom (D=153m)	Wind direction/force: SE/2
	16:28	Hoisted up "KAIKO MK-IV"	Wave scale: 2
	16:35	Recovered "KAIKO Mk-IV"& finished the operation	Swell scale: 1
	18:10-19:35	Scientists meeting	Visibility(miles): 8
18-Sep-2024	8:26	Hoisted down "KAIKO Mk-IV"	Oomurodashi
	8:45	Lounched "KAIKO Mk-IV" #912	34-32.8N,139-26.6E
	9:12	"KAIKO Mk-IV" landed on the sea bottom (D=193m)	Weather: bc
	15:46	"KAIKO Mk-IV" left the sea bottom (D=155m)	Wind direction/force: SW/5
	16:10	Hoisted up "KAIKO MK-IV"	Wave scale: 3
	16:17	Recovered "KAIKO Mk-IV"& finished the operation	Swell scale: 1
	18:00-18:10	Scientists meeting	Visibility(miles): 8
19-Sep-2024		Maintenance day for "KAIKO Mk-IV"	Off Ito
	18:40-19:20	Scientists meeting	35-01.3N,139-07.2E
			Weather: c
			Wind direction/force: SE/2
			Wave scale: 1
			Swell scale: 0
			Visibility(miles): 8
20-Sep-2024	6:15	Released XBT	East of off Hatsushima
	8:18	Hoisted down "KAIKO Mk-IV"	35-01.5N,139-13.7E
	8:33	Lounched "KAIKO Mk-IV" #913	Weather: c
	9:11	"KAIKO Mk-IV" landed on the sea bottom (D=873m)	Wind direction/force: WNW/2
	14:10	"KAIKO Mk-IV" left the sea bottom (D=846m)	Wave scale: 2
	14:52	Hoisted up "KAIKO MK-IV"	Swell scale: 1
	14:58	Recovered "KAIKO Mk-IV"& finished the operation	Visibility(miles): 8
	18:00-18:50	Scientists meeting	
21-Sep-2024		Maintenance day for "KAIKO Mk-IV"	Off Ito
	18:00-19:30	Scientists meeting	35-00.7N,139-07.9E
			Weather: c
			Wind direction/force: West/7
			Wave scale: 4
			Swell scale: 1
			Visibility(miles): 8

22-Sep-2024	8:20	Hoisted down "KAIKO Mk-IV"	East of off Hatsushima
	8:33	Lounched "KAIKO Mk-IV" #914	35-00.9N,139-13.3E
	9:21	"KAIKO Mk-IV" landed on the sea bottom (D=911m)	Weather: c
	14:32	"KAIKO Mk-IV" left the sea bottom (D=813m)	Wind direction/force: SW/6
	15:22	Hoisted up "KAIKO MK-IV"	Wave scale: 4
	15:31	Recovered "KAIKO Mk-IV"& finished the operation	Swell scale: 3
	18:00-19:40	Scientists meeting	Visibility(miles): 6
23-Sep-2024	9:00	Arrived at YOKOSUKA, then completed voyage KM24-10C	

● 5. Notice on Using

This cruise report is a preliminary documentation as of the end of cruise.
This report is not necessarily corrected even if there is any inaccurate description (i.e. taxonomic classifications). This report is subject to be revised without notice. Some data on this report may be raw or unprocessed. If you are going to use or refer the data on this report, it is recommended to ask the Chief Scientist for latest status.
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