

JAMSTEC

2014 Annual Report



Japan Agency for Marine-Earth Science and Technology

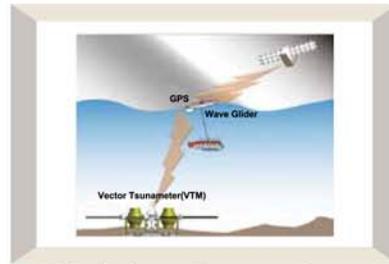
JAMSTEC

2014 Annual Report

Fiscal Year 2014 Overview of the Japan Agency for Marine-Earth Science and Technology



The third medium-term plan was launched.

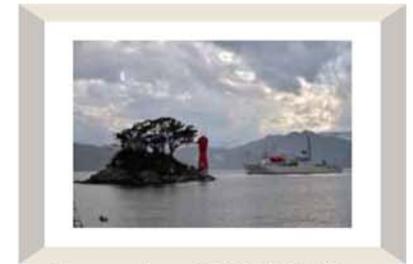


The effectiveness of a new ocean bottom Tsunami Meter (VTM) was demonstrated, and its real-time trial observation was successfully completed.



New international partnerships have been developed.

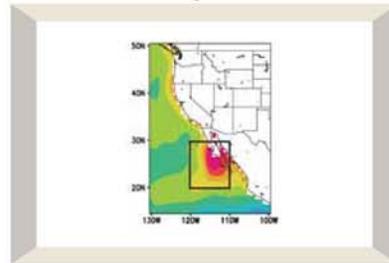
Photo: PORTAL DO MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO



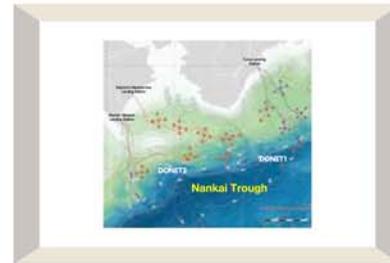
The research vessel *SHINSEI MARU* was open to the public at the Otsuchi Port.



Construction and extension of the quay and the ROV maintenance shop were completed at the Yokosuka Headquarters.



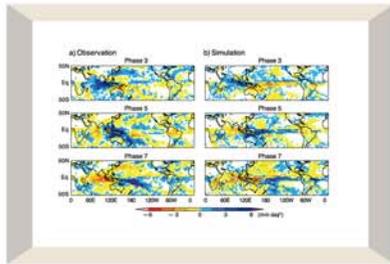
The "California Niño/Niña" phenomenon was discovered for the first time.



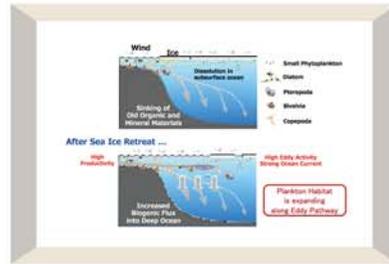
DONET observation data began to be shared with local authorities and a power company.



Shinkai crosnieri obtains nutrition from epibiotic bacteria found on setae.



The month-long predictability of the tropical Madden-Julian Oscillation (MJO) was demonstrated.



The research found that eddies played a role in creating better plankton habitats in the Arctic Ocean.



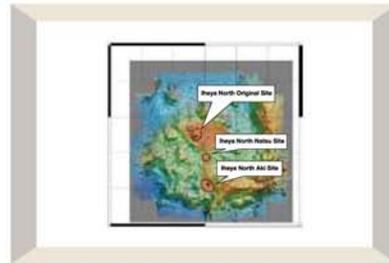
A new core storage was completed at the Kochi Institute for Core Sample Research.



The process of continental drift was successfully reproduced using supercomputer facilities, and its driving force was revealed.



"Next-generation technology for ocean resources exploration" – one of the measures for the Cross-ministerial Strategic Innovation Promotion Program (SIP) was launched.



A large hydrothermal fluid reservoir across the Iheya North Knoll was discovered in Okinawa Trough.



Identified Hadal/Trench biosphere.



Earth Simulator was replaced with a new system.

Preface

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is implementing its third mid-term plan from FY2014. To facilitate the execution of this plan, JAMSTEC underwent organizational reform allowing cross-sectional and strategic research and development (R&D). In order for us, under the new organization, to contribute to resolving important issues specified in the national government's ocean policies, we consider the following R&D activities particularly vital.

- (1) R&D of submarine resources
- (2) R&D on marine and global environmental change
- (3) R&D on seismogenic zones
- (4) R&D on marine biosciences and engineering
- (5) Promotion of comprehensive ocean drilling science
- (6) R&D on advanced synthetic information science
- (7) Construction of a research and development base for opening up ocean frontiers

Based on the scientific knowledge gained from these activities, we aim to understand the ocean, Earth and life systems as a whole, and take quick and focused actions to deal with national and social needs.

In FY2014, too, we made significant accomplishments in various fields. In the study based on the observation of seismic sea waves, we conducted large-scale structural surveys of crust and upper mantle off the southeast coast of Hokkaido using an underground structure survey system and ocean-bottom seismographs. As a result, we made new discoveries concerning driving forces of plate motion. We have also started providing observational information from the Dense Ocean-floor Network System for Earthquakes and Tsunamis (DONET) to municipalities and private firms.

In view of changes in the global environment, we discovered that plankton habitats in the Arctic Ocean showed improvements due to the effect of oceanic eddies. Specifically, as the amount of sea ice in the Arctic Ocean decreased in conjunction with global warming, strengthened oceanic eddies moved a large amount of nutrient-rich seawater originating from a continental shelf into the Arctic Ocean.

The research vessel *Shinsei Maru* entered Otsuchi Port, where it is registered, for the first time. We held a commemorative lecture and opened the vessel to the public. At the event, we set up a booth to introduce the Tohoku Ecosystem-Associated Marine Sciences (TEAMS) project and our other activities. Many local residents

visited our booth. The valuable footage showing the deep-sea floor landscape off the Sanriku coast and deep-sea organisms received particularly great responses.

In relation to the Cross-ministerial Strategic Innovation Promotion Program (SIP), we conducted scientific drilling studies on the Iheya Ridge in the Okinawa region as a part of "scientific research on the origin of marine resources" under the framework of the JAMSTEC-led initiative called "next-generation technology for ocean resources exploration." In this study, we discovered vast hydrothermal reservoirs.

On April 1, 2015, the corporate status of JAMSTEC changed from an independent administrative institution to a national R&D agency. In addition to promoting world-class research and technological development to facilitate integrated understanding of the ocean, Earth and life, we will also support future advancement of Japan, a major maritime country, by creating marine-based values through engagement in such activities as the utilization of marine resources, the development of marine life engineering, and the upgrading of marine and earth information.

We would deeply appreciate your continued support, understanding and encouragement.



Asahiko Taira

President

Japan Agency for Marine-Earth Science and Technology

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1. Overview of the Japan Agency for Marine-Earth Science and Technology

(1) Overview

The vital role of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is to create scientific knowledge of global environmental changes, particularly the marine environment, that affect human society in a variety of ways. To fulfill this role, JAMSTEC considers the ocean, Earth and life as integrated components of a single system and identifies patterns of various processes viewed at different temporal and spatial scales. By doing so, we aim to understand the ocean, Earth and life systems as a whole and promote R&D that contribute to solving issues of humankind and to the sustainable growth and prosperity of Japan.

JAMSTEC carries out its activities according to the approved mid-term plan, which was formulated to meet the medium-term objectives set by the Minister of Education, Culture, Sports, Science and Technology. The implementation of the third mid-term plan started in FY2014. To carry out goal-oriented R&D projects in line with national and social needs in a cross-sectional manner, we consider the following R&D activities particularly vital.

- (1) R&D of submarine resources
- (2) R&D on marine and global environmental change
- (3) R&D on seismogenic zones
- (4) R&D on marine biosciences and engineering
- (5) Promotion of comprehensive ocean drilling science
- (6) R&D on advanced synthetic information science
- (7) Construction of a research and development base for opening up ocean frontiers

1) Research Sector

In order to promote interdisciplinary research, we reorganized our research system into a problem-solving-oriented strategic R&D area (five R&D centers, an application laboratory, and two project teams) and a basic research area in which advanced research is conducted to address the fundamentals of issues (11 research areas).

a. Strategic R&D area

The relevant personnel will quickly and intensively work on vital issues as goal-oriented projects and international scientific projects. To this end, we have set up R&D centers, an application laboratory, and project teams to form a problem-solving-oriented R&D organization.

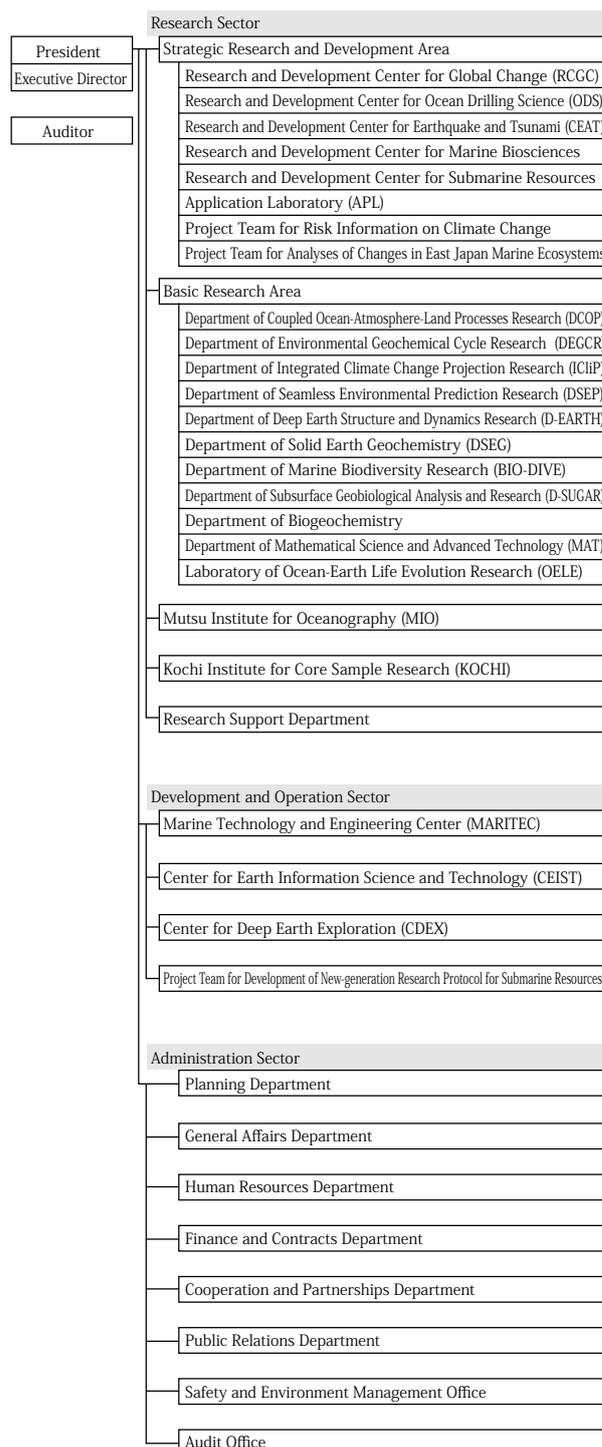
b. Basic research area

The relevant personnel will carry out advanced research contributing to the pioneering of new scientific knowledge related to the core of the issues about goal-oriented and innovative projects. To achieve this, we have set up “research areas” to form a horizontal organization aiming at common scientific goals.

2) Development and Operation Sector

In order to collectively implement both the development and operation of information infrastructure, we have established a new Center for Earth Information Science and Technology (CEIST) by integrating the development and operation functions of the former Earth Simulator Center and the role of managing and publishing data and samples played by the former Data Research Center for Marine-Earth Sciences.

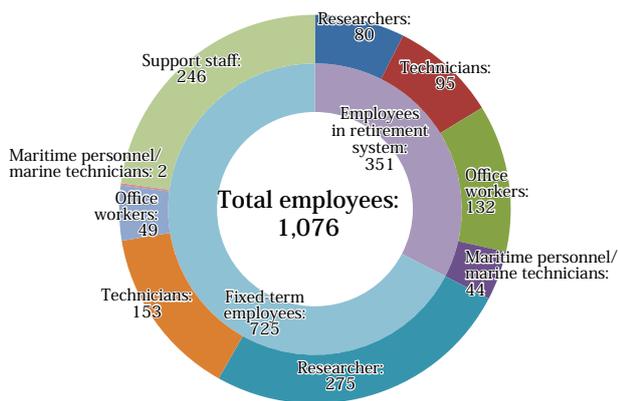
Organization chart after structural reform



(2) Personnel

Although the number of JAMSTEC employees has been generally increasing, owing to the increase of fixed-term staff members resulting from the acquisition of competitive funding, we made efforts to maintain an appropriate number of employees and limit personnel expenses in response to the recommendation of the National Personnel Authority regarding salary standards and the review request from the central government about the company housing system.

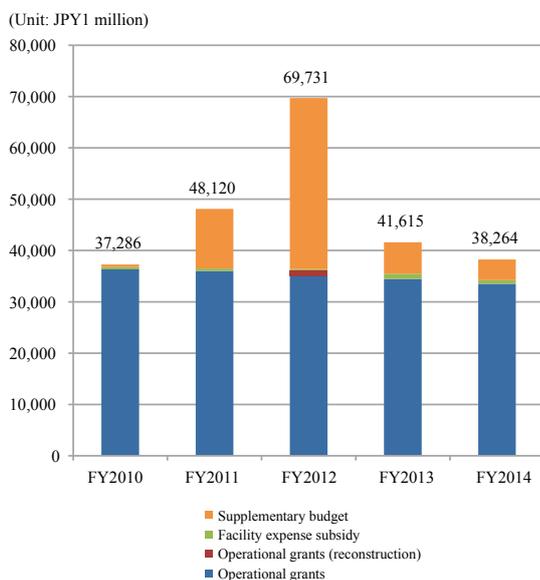
Personnel distribution (as of March 31, 2015)



(3) Budget

The following bar chart illustrates the budget trend of JAMSTEC over 5 years. While the amounts of subsidies JAMSTEC receives to cover facility maintenance and shipbuilding expenses vary from year to year, the amounts of operational grants are decreasing every year. Thus, JAMSTEC needs to increase operational efficiencies and acquire research funding from more diverse external sources.

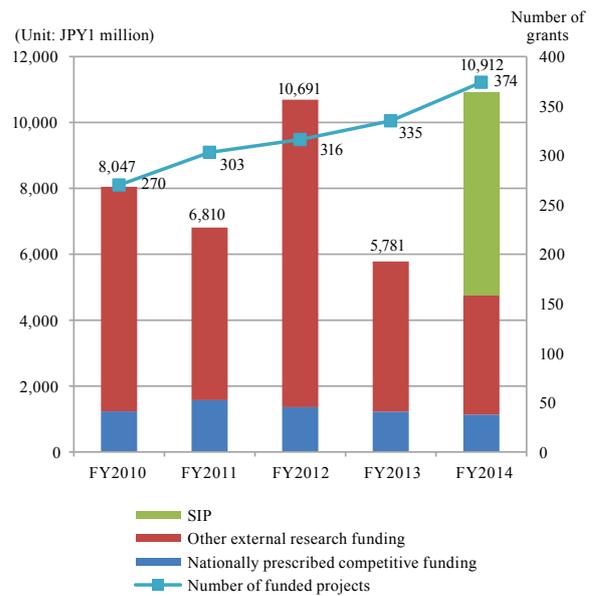
Change in budget of JAMSTEC



(4) External research funding

In regard to the acquisition of external research funding, while the amount per project is decreasing, the number of funded projects is increasing. In FY2014, JAMSTEC received funding to carry out a project called “next-generation technology for ocean resources exploration” under the Cross-ministerial Strategic Innovation Promotion Program (SIP).

Change in the number of external research grants acquired by JAMSTEC (as of March 31, 2015)



(5) Offices and Institutes

As of March 31, 2015, we have the following offices and institutes:

- Yokosuka Headquarters (Yokosuka City, Kanagawa Prefecture)
- Yokohama Institute for Earth Sciences (Yokohama City, Kanagawa Prefecture)
- Mutsu Institute for Oceanography (Mutsu City, Aomori Prefecture)
- Kochi Institute for Core Sample Research (Nankoku City, Kochi Prefecture)
- Tokyo Office (Chiyoda Ward, Tokyo)
- Global Oceanographic Data Center (Nago City, Okinawa Prefecture)

(6) Organization Chart

[Board members]



President
Asahiko Taira



Executive Director
Yoshihisa Shirayama



Executive Director
Hitoshi Hotta



Executive Director
Hisashi Dobashi



Auditor
Yasushi Taya



Auditor
Yuko Maeda

[Research Sector]

Strategic Research and Development Area

- Research and Development Center for Global Change (RCGC)
- Research and Development Center for Ocean Drilling Science (ODS)
- Research and Development Center for Earthquake and Tsunami (CEAT)
- Research and Development Center for Marine Biosciences
- Research and Development Center for Submarine Resources
- Application Laboratory (APL)
- Project Team for Risk Information on Climate Change
- Project Team for Analyses of Changes in East Japan Marine Ecosystems



Associate Executive Director
Wataru Azuma

Basic Research Area

- Department of Coupled Ocean-Atmosphere-Land Processes Research (DCOP)
- Department of Environmental Geochemical Cycle Research (DEGCR)
- Department of Integrated Climate Change Projection Research (ICIP)
- Department of Seamless Environmental Prediction Research (DSEP)
- Department of Deep Earth Structure and Dynamics Research (D-EARTH)
- Department of Solid Earth Geochemistry (DSEG)
- Department of Marine Biodiversity Research (BIO-DIVE)
- Department of Subsurface Geobiology Analysis and Research (D-SUGAR)
- Department of Biogeochemistry
- Department of Mathematical Science and Advanced Technology (MAT)
- Laboratory of Ocean-Earth Life Evolution Research (OELE)



Associate Executive Director
Masao Fukasawa

- Mutsu Institute for Oceanography (MIO)
- Kochi Institute for Core Sample Research (KOCHI)
- Research Support Department



Director, Mutsu Institute for Oceanography (MIO)
Shuichi Watanabe



Director, Kochi Institute for Core Sample Research (KOCHI)
Masataka Kinoshita

[Development and Operation Sector]

Marine Technology and Engineering Center (MARITEC)

- Planning and Coordination Office
- Marine Technology Development Department
- Research Fleet Department
- Research Vessel Construction Office



Director-General,
Marine Technology and Engineering Center (MARITEC)
Yoshio Isozaki

Center for Earth Information Science and Technology (CEIST)

- Planning and Coordination Office
- Advanced Earth Information Research Department
- Geoinformatics Research Department
- Information Systems Department
- Data Management and Engineering Department
- Global Oceanographic Data Center (GODAC)



Director-General,
Center for Earth Information Science and Technology (CEIST)
Keiko Takahashi

Center for Deep Earth Exploration (CDEX)

- Planning and Coordination Office
- Operations Department
- Technology Department
- Science Services Department
- Health, Safety and Environment (HSE) Group



Director-General,
Center for Deep Earth Exploration (CDEX)
Hitoshi Hotta

Project Team for Development of New-generation Research Protocol for Submarine Resources

[Administration Sector]

- Planning Department
- General Affairs Department
- Human Resources Department
- Finance and Contracts Department
- Cooperation and Partnerships Department
- Public Relations Department
- Safety and Environment Management Office
- Audit Office

(7) Research Facilities

Vessels

CHIKYU



Deep-Sea Drilling Vessel
 Length: 210 m
 Beam: 38.0 m
 Height from hull: 130 m
 Gross tonnage: 56,752 tons
 Complement: 200 persons
 Maximum drilling depth: 2,500 m
 Length of drill strings: 10,000 m
 Commissioned: 2005

YOKOSUKA



Support Vessel
 Length: 105.2 m
 Gross tonnage: 4,439 tons
 Complement: 60 persons
 Commissioned: 1990

NATSUSHIMA



Research Vessel
 Length: 67.3m
 Gross tonnage: 1,739 tons
 Complement: 55 persons
 Commissioned: 1981

KAIREI



Deep Sea Research Vessel
 Length: 106.0 m
 Gross tonnage: 4,517 tons
 Complement: 60 persons
 Commissioned: 1997

HAKUHO MARU



Research Vessel
 Length: 100.0 m
 Gross tonnage: 3,991 tons
 Complement: 89 persons
 Commissioned: 1989

KAIYO



Research Vessel
 Length: 61.5 m
 Gross tonnage: 3,350 tons
 Complement: 60 persons
 Commissioned: 1985

MIRAI



Oceanographic Research Vessel
 Length: 128.5 m
 Gross tonnage: 8,706 tons
 Complement: 80 persons
 Commissioned: 1997

SHINSEI MARU



Research Vessel
 Length: 66.0 m
 Gross tonnage: 1,629 tons
 Complement: 41 persons
 Commissioned: 2013

Submersible and Underwater Vehicles

SHINKAI 6500



Manned Research Submersible
 Depth capability: 6,500 m
 Complement: 3 persons
 Length: 9.5 m
 Dry weight: 26.7 tons

URASHIMA



Deep-Sea Cruising AUV
 Depth capability: 3,500 m
 Length: 10.0 m
 Dry weight: 7.0 tons

HYPER DOLPHIN



3,000 m class ROV
 Depth capability: 3,000 m
 Length: 3.0 m
 Dry weight: 3.8 tons

KAIKO



Remotely Operated Vehicle
 Depth capability:
 (Launcher) 11,000 m
 (Vehicle (Mk-IV)) 7,000 m
 Length/dry weight:
 (Launcher) 5.2 m/5.8 tons
 (Vehicle (Mk-IV)) 3.0 m/6.0 tons

JINBEI



Autonomous Underwater Vehicle
 Depth capability: 3,000 m
 Length: 4.0 m
 Dry weight: 1.7 tons

OTOHIME



Autonomous Underwater Vehicle
 Depth capability: 3,000 m
 Length: 2.5 m
 Dry weight: 0.85 tons

YUMEIRUKA



Autonomous Underwater Vehicle
 Depth capability: 3,000 m
 Length: 5.0 m
 Dry weight: 2.7 tons

ABISMO



Remotely Operated Vehicle
 Depth capability: 11,000 m
 Length/dry weight: (Launcher) 2.7 m/3.0 tons
 (Vehicle) 1.3 m/0.35 tons

Other Facilities



Earth Simulator

Number of processors: 5,120
 Peak performance: 1.31 petaFLOPS
 Memory bandwidth: 1.31 petabytes/sec
 Memory capacity: 320 terabytes



Core Repository

(8) International Cooperation

Ocean observation and research on a global scale is required to address the issues of global-scale environmental variations that include climate change.

JAMSTEC promotes international joint projects and maintains and builds good cooperative relationships with United Nations bodies and other international organizations, as well as overseas research institutes, with the aim of contributing to efforts to unravel such issues and promoting more effective and efficient ocean observation and research.

1) Contribution to Multilateral International Cooperation

JAMSTEC sends experts to various international meetings of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) to support IOC-related activities, and studies international requirements necessary for the smooth implementation of ocean observation and research under enforcement of the United Nations Convention on the Law of the Sea (UNCLOS). The Japan Group of Experts to Advance IOC Programs, which was established within JAMSTEC in January 2008 to reinforce the Japanese system for promoting relevant IOC projects and meetings, has been exchanging views and reviewing international research projects. Two Subgroups of Experts established under the Japan Group of Experts to Advance IOC Programs exchanged their views in FY2014. The Japan Group of Experts to Advance IOC Programs held its seventh meeting in June 2014 and discussed future perspectives of IOC-related activities based on the views expressed at each Subgroup of Experts. Since January 2013, JAMSTEC has seconded a staff member to the IOC Headquarters in Paris, France, to contribute to the international development of ocean research and to assist Japan in making contributions to IOC. JAMSTEC has extended this staff member's period of secondment until January 2017.

JAMSTEC's efforts for earth observation and data dissemination greatly contribute to the development of the Global Earth Observation System of Systems (GEOSS), which the Group on Earth Observations (GEO), an intergovernmental body comprised of more than 90 countries including Japan, contributes to decision-making for global issues. At the seventh GEOSS Asia-Pacific Symposium held in Tokyo in May 2014, JAMSTEC organized the Working Group "Ocean Observation and Society" as a co-chair from Japanese organizations and led discussions for formulating a framework for promoting coastal meta-data sharing with ocean and climate monitoring organizations in the Asian-Pacific regions. JAMSTEC also dispatches researchers and other staff members to participate in the meetings of other international organizations and projects relating to oceans as needed, thereby contributing to their research activities.

2) International Joint Projects

JAMSTEC participates in the following joint international projects and contributes to project activities.

- ARGO (The Array for Real-Time Geostrophic Oceanography)
- CLIVAR (Climate Variability and Predictability)
- GOOS (Global Ocean Observing System)
- GCOS (Global Climate Observing System)

- GO-SHIP (Global Ocean Ship-Based Hydrographic Investigations Program)
- ICDP (International Continental Scientific Drilling Program)
- ISC (International Seismological Centre)
- InterMARGINS (International Margins Program)
- InterRIDGE (International Cooperation in Ridge-Crest Studies)
- IODP (International Ocean Discovery Program)
- IOCCP (International Ocean Carbon Coordination Project)
- OBIS (Ocean Biogeographic Information System)
- PICES (North Pacific Marine Science Organization)

3) Cooperation Based on Bilateral Cooperation Agreements

JAMSTEC undertakes research cooperation on the basis of bilateral cooperation agreements that Japan has concluded with countries and regions including the United States, the United Kingdom, Italy, India, Australia, Canada, the Republic of Korea, China, Germany, Norway, New Zealand, Brazil, France, Russia, and the EU.

The following list shows the major bilateral cooperation meetings and workshops held in FY2014.

- September 2014 The 1st Germany-Japan Marine-Earth Science Workshop
- October 2014 The 8th Japan-India Joint Committee on Science and Technology Cooperation
- October 2014 Japan-Russia Workshop on Arctic Research
- November 2014 The 9th Japan-UK Joint Committee on Cooperation in Science and Technology
- November 2014 UK-Japan Workshop on Autonomous Investigations of the Arctic's Response to Changing Climate
- February 2015 The 5th Japan-Norway Joint Committee on Cooperation in Science and Technology
- March 2015 Japan-US Arctic Strategy and Policy Workshop

4) Cooperation with Relevant Overseas Organizations

In August 2014, JAMSTEC and the Ministry of Science, Technology and Innovation (MCTI) of Brazil concluded a Declaration of Intent concerning cooperation in the field of marine-earth science; JAMSTEC also concluded a Letter of Intent facilitating the launch of mutual cooperation in ocean and earth science and technology with several research institutes affiliated to the Ministry of Earth Sciences (MoES) of India.

In addition, JAMSTEC has concluded memoranda of understanding (MOUs) on comprehensive inter-institutional research cooperation with organizations in the United States, the United Kingdom, India, Indonesia, Vietnam, Australia, Canada, the Republic of Korea, Germany, New Zealand, Brazil, and France. In FY2014, JAMSTEC held regular meetings based on MOUs with the French Research Institute for Exploitation of the Sea (IFREMER; in June) and with the Agency for the Assessment and Application of Technology of the Republic of Indonesia



Memorandum presentation ceremony in the presence of the leaders of Japan and Brazil

(From left: JAMSTEC President Taira, Prime Minister Abe, Minister Diniz)

Photograph Source: PORTAL DO MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVANOV (URL: http://www.mct.gov.br/index.php/content/view/355827/Ministro_assina_atos_de_cooperacao_em_ciencia_e_tecnologia_com_Japao.html)

(BPPT; in October). Moreover, JAMSTEC concluded new MOUs with four institutes and a consortium, namely Geoscience Australia (GA), the National Institute of Oceanography (NIO) of India, the Marine Natural Resources–Environment Survey Center (MGMC), the Vietnam Institute of Geosciences and Mineral Resources (VIGMR), and the Australian and New Zealand IODP Consortium (ANZIC). The MOU concluded with ANZIC concerns participation in a research program using the deep sea scientific drilling vessel (D/V) *Chikyu* over the subsequent ten years.

JAMSTEC has Letters of Intent, MOUs, and agreements for research cooperation with 66 organizations and 2 consortiums in 22 countries. In FY2014, JAMSTEC renewed its joint research agreements with institutions including the Agency for the Assessment and Application of Technology of the Republic of Indonesia (BPPT), the Alfred Wegener Institute for Polar and Marine Research (AWI) in Germany, and the National Institute of Geological Sciences of the University of the Philippines (NIGS/UP), as well as concluding a new joint research agreement with such organizations as the Philippine Atmospheric, Geophysical and Astronomical Services Administration of the Department of Science and Technology of the Philippines.

As the sole Japanese organization participating in the Partnership for Observation of the Global Oceans (POGO), a forum for major oceanographic institutions around the world, JAMSTEC promotes closer partnerships with other oceanographic institutions worldwide. In January 2015, JAMSTEC participated in the 16th Annual Meeting of POGO in Tenerife, Spain and exchanged information with other institutions concerning such topics as ocean observation.

5) Other International Collaborations

Since April 2014, visitors from overseas governments, research institutes, and embassies came to see JAMSTEC and exchanged views. Such organizations and programs include Fisheries and

Oceans Canada (DFO); the Australian Embassy, Tokyo; the Joint Session of the Ocean Development Sub-Committee France-Japan Science and Technology Cooperation Agreement; the Research Council of Norway; the Delegation of the European Union to Japan; the Japan Science and Technology Diplomatic Circle (S&TDC); the Australian Academy of Technological Sciences and Engineering; the Embassy of Brazil in Tokyo; a preparatory meeting for the Japan-Russia Arctic Research Mini-Workshop; GNS Science, New Zealand; a Youth Ambassador Program of Indonesia; the Atlantic Canada Opportunities Agency; the Department of Mineral Resources (DMR) of the Ministry of Natural Resources and Environment of Thailand; the Scripps Institution of Oceanography (SIO), the United States; the Registrar of the International Tribunal for the Law of the Sea (ITLOS); the French Association of Scientific Journalists in the Informative Press (AJSPI); the Norwegian University of Science and Technology (NTNU); the Australian Minister for Industry, Innovation and Science; participants in the UK-Japan Workshop on Autonomous Investigations of the Arctic's Response to Changing Climate; the Ministry of Science, Technology and Innovation (MCTI) of Brazil; the Ministry of Natural Resources and Environment (MONRE) of Vietnam; the Korea Institute of Geoscience and Mineral Resources (KIGAM); the European Commission (EC) Directorate-General for Research and Innovation; various government ministries of Thailand; Centre for Monitoring and Early Warning of Natural Disaster (CEMADEN), Brazil; the National Oceanic and Atmospheric Administration (NOAA) of the United States; the Embassy of France in Tokyo; and the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand.

JAMSTEC presented its research and development activities at the poster exhibitions of the seventh GEOSS Asia-Pacific Symposium (May 2014; Tokyo) and the 11th Plenary Session of the Group on Earth Observations (GEO-XI; November 2014; Geneva, Switzerland).



The delegation of Indonesian high school students on the Youth Ambassador Program visiting the Yokohama Institute for Earth Sciences.

2. Outlines of Topics and Notable Achievements in FY2014

(1) Research and development of submarine resources

Overview

Under this theme, we aim to quantitatively determine various elements, isotopes and chemical species related to the formation of submarine resources, and to comprehensively understand the formation factors of submarine resources, perceiving them as a part of a larger material cycle of the Earth. Our research has the following four focuses: clarification of the generation mechanism of submarine hydrothermal deposits and establishment of survey methods based on such study; clarification of the generation mechanism of cobalt-rich crust and rare earth mud and establishment of methods for discovering high-quality mineral deposits based on such study; clarification of the generation mechanism of submarine hydrocarbon resources and research on continuous carbon and energy cycles; and establishment of environmental impact assessment methods.

Below, we present the major results achieved in FY2014.

1. Hints to new exploration protocol through investigation of ore-genesis mechanism of submarine hydrothermal ore deposits

1.1. High-speed and less-biased uniform acoustic exploration method for hydrothermal activity

A series of expeditions using R/Vs coupled with AUV and ROV were conducted in order to locate unknown hydrothermal activity in the mid-Okinawa Trough. According to our proposing protocol, an acoustic survey by hull-mounted MBES of research vessels is now utilized by other institutions. In the expeditions, five candidate hydrothermal discharging sites were newly located (stars in Fig. 1). A detailed report of the fundamental structure and/or spatial distribution of the microbial ecosystem in the exploration was partly released to press.

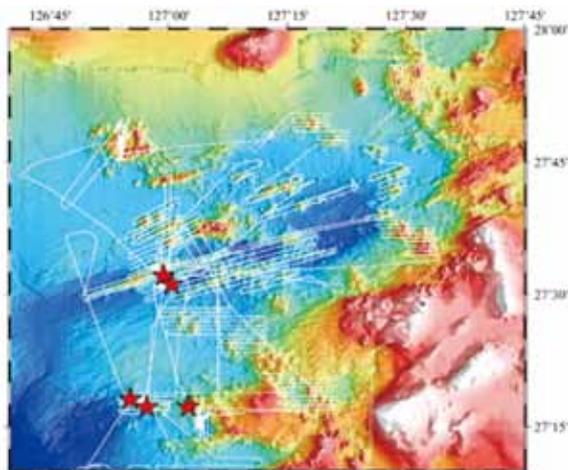


Figure 1. The ship tracks of R/V Yokosuka at the YK14-17 Cruise and potential hydrothermal sites newly identified (☆)

1.2. Output measurement of hydrothermal fuel cell at an artificial vent

During the NT15-02 Cruise, an *in-situ* experiment on a deep-sea hydrothermal fuel cell was conducted for 12 days (Fig. 2). The output voltage of the cell was ca. 0.35 V at the beginning, then it suddenly dropped to approx. 0.2 V. Four days after, output went gradually up to approx. 0.6 V and stabilized, which is consistent with the maximum value according to theoretical expectations. It suggests that almost ideal power generation was achieved.

Further investigations on retrieved electrodes could reveal the reason why the output voltage of the cell increased four days after the start of the experiment. Such increase may be caused by a decrease in some energy-loss either by 1) growth of the sulfide minerals on the anode (hydrothermal fluid-side) promoting H_2S oxidation and/or 2) growth of microbial colonies on the cathode (seawater-side) promoting oxygen reduction.

In the latter half of the 12-day *in-situ* experiment of the fuel cell, very effective power generation was observed, which enables us to proceed to further steps: 1) using larger electrodes and 2) a much longer experiment of a few months to a few years.

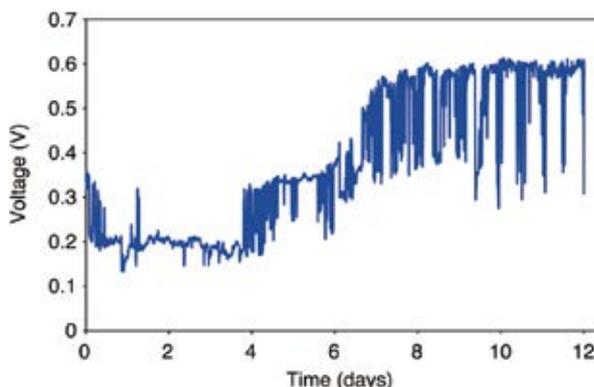


Figure 2. Temporal change of output of deep-sea hydrothermal fuel cell

1.3. Re-Os dating on the Hitachi-mine

The oldest radiometric age of an ore-body in Japan was obtained from the Hitachi-mine, categorized into the Hitachi-subtype VMS deposit. Such a type of mine is regarded to be formed by seafloor hydrothermal activity on an arc or back-arc setting. The value of the age was 533 Ma determined by the Re-Os isochron method. (Sep 3, 2014, released to press). This result was reported as peer-reviewed research papers.

1.4. Investigations for subseafloor microbial community beneath hydrothermal vent

We investigated the impacts of lithologic structure and geothermal gradient on subseafloor microbial communities at a marginal site of the Iheya North hydrothermal field in the Mid-Okinawa Trough (Integrated Ocean Drilling Program Expedition 331). The results indicate that the subseafloor microbial community compositions and functions at the marginal site

of the hydrothermal field were highly affected by the complex fluid flow structure, such as recharging seawater and underlying hydrothermal fluids, coupled with the lithologic transition of sediments. In addition, we studied the effect of anthropogenic disturbance by scientific drilling operations (IODP Expedition 331) on the seabed landscape and megafaunal habitation for over 3 years. Although the effects of the drilling operation on the seabed landscape and megafaunal composition were probably confined to an area of maximally 30 m from the drill holes, the newly established hydrothermal vent ecosystem lasted at least 2 years and may still be persisting, and the ecosystem in the area has been affected by the drilling operation for long-term. These investigations were reported as peer-reviewed research papers.

2) Investigation into the formation of cobalt-rich crust and rare earth mud, and the development of a method contributing to the discovery of high-quality mineral deposits based on the investigation

(1) Crust dating through osmium (Os) isotope stratigraphy

We measured Os in crust samples collected from the 5th Takuyo Seamount, the Micronesia M-10 Seamount, the Shatsky Rise, the Ontong Java Plateau, the area off the coast of Brazil and other locations. As a result, we found that the rate of crustal growth was constant during the period from 15 million years ago to the present time in such locations in the northwest Pacific Ocean as the 5th Takuyo Seamount and Ryusei Seamount irrespective of water depth and sea area (Fig. 3). In contrast, on the Micronesia M-10 Seamount, the rate of crustal growth varied with time from 1 to 4 mm. In addition, our data indicated that on the 5th Takuyo Seamount, there was a no-growth period of 15 million years, several tens of millions of years ago, while on the Micronesia M-10 Seamount, crustal growth was relatively constant, even though both of these seamounts are located in the western Pacific Ocean. Furthermore, we took crust samples in the area off the coast of Brazil using the manned research submersible *Shinkai 6500* to determine chirality composition and Os isotope composition. Based on this study, we concluded that the crustal growth probably occurred in both upward and downward directions at the same time.

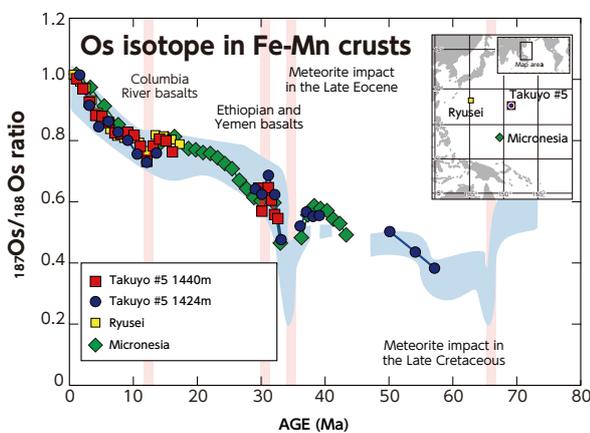


Figure 3. Dating of a manganese crust based on the ratio of different osmium isotopes

(2) Dating of rare earth mud based on Os isotope stratigraphy

During the KR13-02 cruise by the deep-sea research vessel *Kairei*, we surveyed rare-earth-rich mud, and during the MR14-E02 cruise by the research vessel *Mirai*, we took core samples of rare earth mud. These surveys and the analysis of core samples indicated that the area of rare-earth-rich mud may be stretching westward in the study range. In addition, based on measurement of the Os isotope ratio in deep-sea sediments, we found that the dates of both PC04 and PC05 rare-earth-rich mud samples collected during the KR13-02 cruise by *Kairei* matched with the date of the meteorite impact in the Late Eocene (Fig. 4).

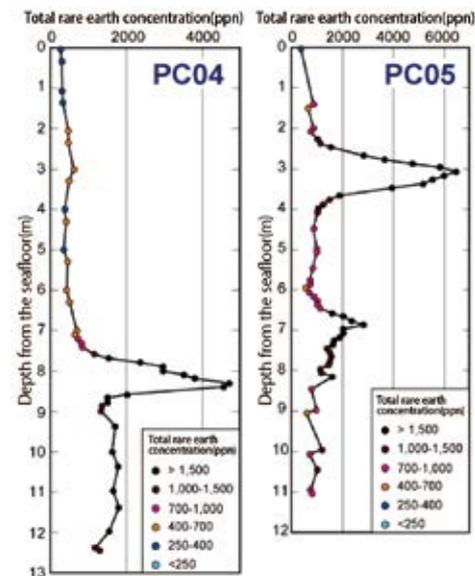


Figure 4. Depth profiles of core samples containing very high concentrations of rare earth

3) Investigation into the formation of submarine hydrocarbon resources and research on continuous carbon and energy cycles

(1) Research on hydrological and carbon cycles in Kumano Basin mud volcanoes in the Nankai Trough

In general, fluids that have been exposed to high temperatures, such as hot spring water, are known to have light lithium (Li) isotope compositions (low $^7\text{Li}/^6\text{Li}$ ratio). In contrast, groundwater in areas absent of seawater and heat sources is known to have heavy Li isotope compositions (high $^7\text{Li}/^6\text{Li}$ ratio). Moreover, based on the difference in Li isotope ratio between fluids (liquid phase) and rocks/mud (solid phase), it is feasible to estimate the temperature of the locations where elution of Li occurs due to reacting liquid and solid phases. Taking advantage of these relationships, studies were conducted on core samples taken from the summit of the Kumano mud volcano No.5 in the Nankai Trough using *Chikyu* in 2012. Based on the Li isotope ratio ($^7\text{Li}/^6\text{Li}$ ratio) of pore fluids in the core samples, we determined the origin of the fluids contributing to the formation of the mud volcano and temperature history of the fluids. The results of the isotope ratio analysis indicated that the studied fluids contain a large amount of Li with light Li isotope compositions (low $^7\text{Li}/^6\text{Li}$ ratio) and that some portion of the fluids in the mud volcano was once hot, ranging between

210 and 310°C, and existed at great depths.

These results suggested that the fluids present in mud volcanoes across the Nankai Trough may have not only resulted from dehydration of clay minerals (smectite-illite transformation) occurring at a depth of 5 km or less from the seafloor (60 to 150°C) but also from further depths of 20 km or more, which are about the depths at which epicentral areas of major earthquakes exist (Nishio et al., EPSL, 2015) (Fig. 5). These results also indicate that generation and movement of fluids at great depths below the seafloor are more complex than has been thought and are occurring at a large spatial scale. From the viewpoint that fluids originated from great depths at which epicentral areas of major earthquakes exist, there may be “natural pipelines” connecting great depths below the seafloor and marine surface sediment.

In future studies, we might be able to understand the relationship between factors relating to the formation of mud volcanoes and geological changes, chemical characteristics of materials transported from great depths, and element cycle processes by conducting detailed studies on topographic data and samples collected from scientific drilling and deep-sea surveys.

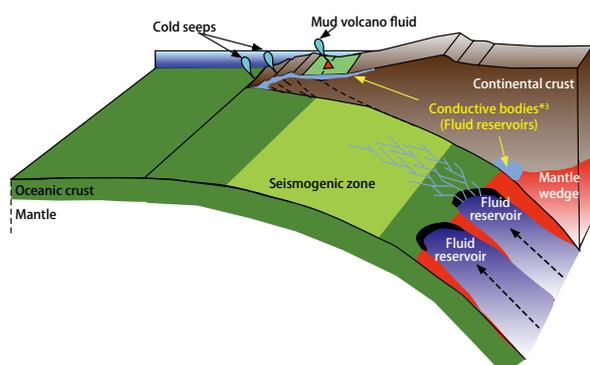


Figure 5. Diagram showing the routes through which fluids rise from great depths (at a temperature of about 300°C or higher) and reach Kumano mud volcanoes in the Nankai Trough

In addition, a research group led by Ijiri of the Geobio-Engineering and Technology Group, Research and Development Center for Submarine Resources, has been accumulating biogeochemical and microbiological research data obtained from core samples taken at depths of about 20 km or less from the seafloor in the drilling operation conducted from the summit of the Kumano mud volcano No.5 in the Nankai Trough. It is particularly noteworthy that we have obtained biogeochemical data indicating the effect of homoacetic acid produced by the activities of microorganisms (acetic acid production by microorganisms through CO₂ reduction) in the surface sediments of the mud volcano, and biogeochemical data indicating the formation of thermophilic methane in the deep part of the mud volcano. Also, in the joint research with Massachusetts Institute of Technology, we are estimating the temperature at which methane was produced in the mud volcano by assessing gas samples collected from the inner part of the mud volcano using a hybrid PCS system.

(2) Research on hydrological and carbon cycles in mud volcanoes off the coast of Tanegashima Island

There are many mud volcano-like mounds formed in groups

in areas relatively close to Tanegashima Island. So far, Japan National Oil Corporation and others have conducted piston coring, reported unusually low salt concentrations, indicating the presence of methane hydrates, and reported certain carbon isotope compositions, indicating the presence of methane resulting from thermal decomposition in the deep part of the mounds. However, still unknown are the distribution and activities of mud volcanoes, the spatial extent of existing methane, the mode of methane production on the transects across the land and plate boundaries, and detailed distribution of methane in terms of chemical and hydrocarbon compositions. Vast sea areas with potential scientific values and resources still remain unexplored.

The Research and Development Center for Submarine Resources started a project from FY2012 to understand detailed topography and distribution of mud volcanoes. For this purpose, we selected active mud volcanoes as targets for detailed studies and conducted wide-area mapping using data from a multibeam echo sounder mounted on the bottom of the vessel *Urashima*.

As a result, we found many mud volcanoes off the coast of Tanegashima Island, and identified clear evidence indicating an ejection of muddy fluid on the submarine acoustic image. The muddy fluid ran down the slopes of the mountain from its summit crater, forming a submarine valley and then an alluvial fan at the end. We also found that on large mud volcanoes, with their widths being about 2,000 m or greater, muddy fluid tends to flow on their north-side slopes. Furthermore, we confirmed that all of the mud volcanoes in which we conducted subsurface structural surveys had unclear reflective surfaces in their lower parts, indicating that these volcanoes likely consist of sediments with high gas content.

(3) Research on deep coalbed biosphere and carbon cycle off the coast of Shimokita Peninsula

In 2012, we conducted drilling surveys at Site C0020, about 80 km off the coast of Hachinohe, Aomori Prefecture, using the riser-drilling system of *Chikyū*. This project was supported by the Integrated Ocean Drilling Program (IODP) and the Leading-edge Research Infrastructure Program. In these surveys, we intermittently collected core samples at depths up to 2,466 m below the seafloor, which broke the world record for the deepest scientific drilling, and made progress in international joint research focusing on the physical limits of the anaerobic biosphere in the continental coastal area rich in organic matter.

The samples collected in this study represent wetlands and marshes that once existed in coastal areas of the northern Japan during the Paleogene period, more than about 20 million years ago, which have been buried under the seafloor. Based on the biogeochemical and microbiological data we have collected so far, we are unveiling biological and non-biological processes in which buried organic matter matures into coalbeds and then turns to unconventional hydrocarbon resources such as natural gas and methane hydrates over geological time.

The genetic analysis of environmental genome DNA, which was directly extracted from the sediment core samples taken in these drilling surveys, suggested the existence of microbial communities at extremely low density—an indicator of the near physical limits of the biosphere. In FY2014, we worked jointly with the J. Craig Venter Institute of the U.S. in a comprehensive analysis of base sequences derived from exotic microorganisms

that may exist in fluid mud, air and water from core samples and in reagents. By doing so, we extracted and evaluated life signals unique to the environment associated with great depths below the seafloor. Moreover, we succeeded in enrichment culturing of methane-producing anaerobic microbial communities isolated from core samples taken at a depth of about 2 km from the seafloor (Fig. 6).

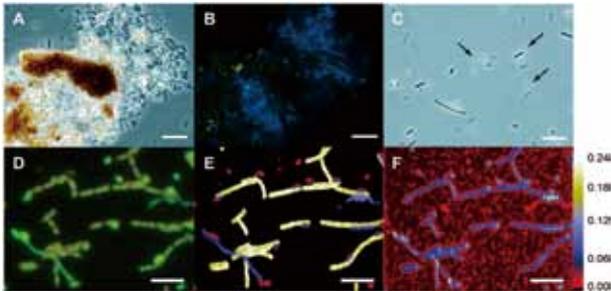


Figure 6. Microbial communities found at the world's greatest depth below the seafloor. They were isolated from core samples collected in the coalbeds at a depth of about 2 km from the seafloor and were cultured using a downflow hanging sponge reactor. Culturing was conducted at about 40°C, which is close to the temperature of their native habitat, in anaerobic or oxygen-free conditions. We observed the growth of microbial communities, which produce methane using carbon substrates (A–C).

(A) Optical micrograph of microbial cells attached to a coalbed. (B) Fluorescence micrograph showing autofluorescence (blue) of coenzyme F420, a substance unique to methane bacteria, as it was excited by ultraviolet irradiation. Growth of methane-producing bacteria, a close relative of Genus *Methanobacterium*, has been confirmed based on genetic analysis. (C) Optical micrograph showing spore-like cells (arrows). We added ^{13}C labeled with stable carbon isotope (^{13}C) to the culture solution, and conducted elemental composition image analysis of cells using a nano secondary ion mass spectrometer (NanoSIMS) 50L (D–F). (D) Fluorescence micrograph of cells stained with a fluorescent dye (SYBR Green I), which binds specifically to cellular DNA. NanoSIMS image analysis indicating (E) $^{13}\text{C}/^{12}\text{C}$ ratio and (F) elemental composition of ^{12}C (viewing the same subject as (D)). Change of color gradient from red to yellow indicates an increase in $^{13}\text{C}/^{12}\text{C}$ ratio. The white scale bars are 10 μm long (1/100 of 1 mm).

(4) Research on coenzyme F430 of methane bacteria in methanogenic sediments

Coenzyme F430 is an essential enzyme in the metabolic pathway of methanogenesis in methane bacteria. If the content of F430 in sediments can be quantified, it may be possible to determine the depth distribution of methane-producing potential under the seafloor and methane-producing conditions such as temperature and pressure of methanogenic sediments. In this study, we successfully developed a methodology to extract, separate and quantify an extremely small amount of F430 in sediments. When we applied the technique to sediment core samples collected off the coast of Shimokita Peninsula, we found that sediment layers at depths of 60 to 70 m from the seafloor had F430 concentrations nearly one order of magnitude higher than were in the sediment layers at any other depths.

4) Development of environmental impact assessment methods

(1) Surveys and observations

High-resolution survey and observation technologies are means to provide basic information needed for research on marine ecosystem changes. These technologies are also essential to study processes and mechanism of changes that occur in relation to environmental change, using accumulated time-series data.

Among research projects conducted during FY2014, the observational study on hydrothermal communities is particularly significant as a rare observational case in hydrothermal ecology. We observed the communities from the initial formation to transition stages in relation to environmental change caused by the IODP scientific drilling in 2010 (Fig. 7). This study is noteworthy because we developed a method to quantify habitat distribution of hydrothermal communities using accumulated camera images taken from underwater vehicles for long-term observational studies (Nakajima et al. 2014), and because we successfully retrieved habitat distribution data and information on the changing seafloor environment from image records, which had been unused for a long time. As we established the ecosystem baseline based on samples and environmental data collected during previous survey cruises, we were able to clearly verify change and fluctuation of seafloor biota at the drilling sites (Nakajima et al. 2015, in press).

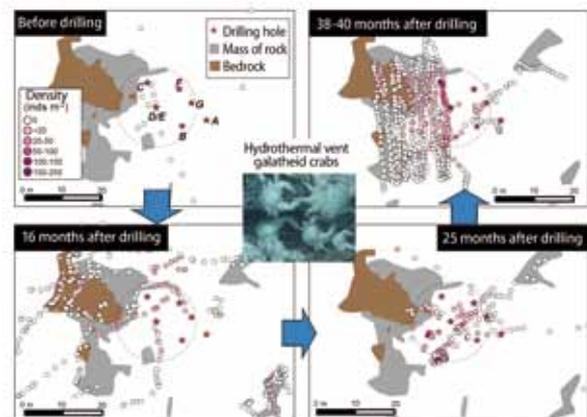


Figure 7. Change in the distribution of hydrothermal vent galatheid crabs (*Shinkaiia crosnieri*)

We established a method to efficiently detect hydrothermal activities based on echo sounder data collected by vessels and AUVs, and discovered new hydrothermally active areas in the Mid-Okinawa Trough. These results are valuable in terms of their contribution to determining the extent of hydrothermal ecosystems in the sea area and analyzing their impact. This survey method can be used not only as a procedure to detect hydrothermal mineral deposits, but also as a procedure to determine the range of hydrothermally active areas and the distribution of biological communities—essential information for the formulation of strategies regarding environmental impact assessment and the conservation of hydrothermal communities.

As for the development of observational equipment using advanced technology, we are aiming to collect high-resolution data in the deep-sea environment. In this project, we are focusing on collecting image data containing a large amount of information, and collecting environmental data using on-site sensors.

Regarding the development of an observation system using an ultra-high-definition video camera (8K camera), we designed a pressure resistant container to be installed on an underwater vehicle, and created a substrate for converting optical wavelengths using an optical multiplex transmission system. In addition, we checked the effectiveness of the size measurement method, which functions within images taken by a stereo camera.

Furthermore, we designed, created and tested an on-site observation system. We made the basic design for the ecosystem monitoring system that is to be connected to submarine cables, improved specifications of the transportable seafloor observation platform so that it is applicable in the hydrothermal environment, and established a methane measurement method by on-site measurement sensors in the deep-sea environment.

(2) Data analysis

We are conducting a R&D project, focusing on the analysis of image information to determine the distribution and quantity of organisms, the analysis of environmental metagenomes to survey communities consisting of meiofauna (small benthic invertebrates) and microorganisms, and mathematical analysis to evaluate the current state of ecosystems and predict their future changes.

In the development of a video data analysis system, we developed a method to analyze several video camera images while displaying them on a single console screen (Umetsu 2014) (Fig. 8). We also developed the R program, which enables us to separately retrieve environmental data collected in each underwater mission and rearrange the data in chronological order. Using these tools, we are reanalyzing video images of past underwater surveys to determine habitat distribution of zooplankton.

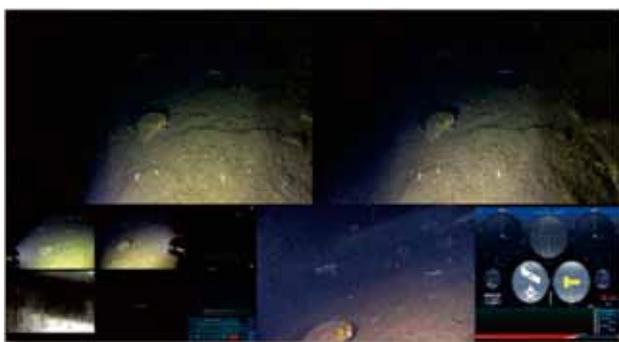


Figure 8. A system capable of displaying multiple images taken by underwater vehicles

By analyzing the genetic lineage of meiobenthos communities using an environmental metagenomic method, we were able to clearly identify community composition formed in each habitat. These results strongly indicate that the application of environmental metagenomic analysis is useful in the monitoring of biological communities.

To enhance the system for analyzing environmental metagenomes, we improved functions of the system for identifying functional groups of microbial communities based on gene sequence data (Metabolic and Physiological Potential Evaluator or MAPLE) by fixing bugs. In addition, we reduced the time it takes for analysis and improved analytical functions by introducing a high-speed server and enhancing the drawing function of the system for evaluating metabolic functions. By introducing a next-generation sequencer (MiSeq), we also developed a system for

analyzing environmental metagenomes, capable of performing a series of steps: sample processing, reading of genetic data, and data analysis. We plan to efficiently transfer the technology for analyzing environmental metagenomes to the private sector by validating all of the steps of the technology starting from the sample processing step, and by applying the technology in actual environmental impact assessments.

No clear standards have yet been set for environmental assessments conducted in outer seas and deep seas, and impact assessments performed in resource development are still in the trial stage. In this project, we conducted analysis on the preservation of chemosynthetic communities in the sea areas around Japan, referring to Ecologically or Biologically Significant Areas (EBSA), which had been proposed as a standard for determining the importance of sea areas under the framework of the Convention on Biological Diversity. We published a scientific paper on this study (Nakajima 2014) and verified the analytical method (Yamakita 2015). While we need to conduct reanalysis due to insufficient deep-sea environmental data currently available, our current results will contribute to practical use and standardization of environmental impact assessment methods in the deep sea as we implemented the EBSA method, which has been used as an international standard (Fig. 9).

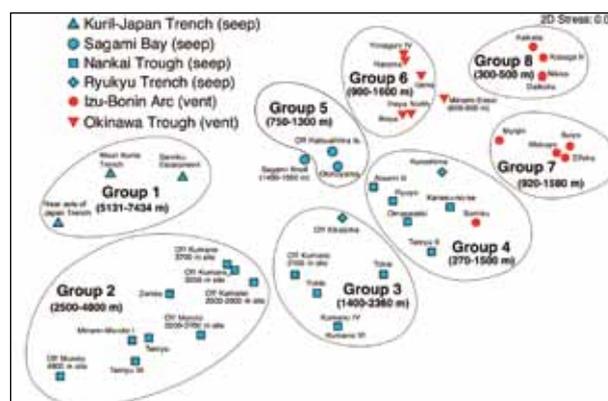


Figure 9. Composition of deep-sea chemosynthetic communities in the sea areas around Japan and analysis results based on the EBSA criteria.

(3) Practical use and standardization

In this R&D project, our goals are to develop a practical system for evaluating the state of marine environments and transfer the technology to the private sector, and to propose the system as an international standard to be adopted by the environmental impact assessment guidelines for submarine resource development. To achieve these goals, we need private companies' opinions and cooperation. As such, in FY2014, we studied the current situation of private companies by reviewing interviews with them conducted by a private survey company, and discussed conditions and issues of gaining their cooperation.

To standardize criteria and methods of environmental assessment, it is essential to validate their technical soundness from an international viewpoint. So, in collaboration with the French Research Institute for Exploitation of the Sea (IFREMER), with which we were considering conducting joint research on environmental impact assessment, we are working to hold an international workshop at the end of June 2015, and created a prospectus and a program for the event.

(2) Research and development on marine and global environmental change

Overview

In this project, to help solve global-scale environmental problems—a pressing issue of humankind, we will accurately understand the real situation of changes occurring in oceans, the atmosphere and lands, comprehensively understand global change, and perform reliable predictions.

We intend to comprehensively understand global change by collecting, accumulating and analyzing new observational data related to changes and fluctuations occurring in climate, geochemical cycles and marine ecosystems, and to evaluate the impact of these changes on meteorological phenomena in Japan. We also aim to increase the international presence of JAMSTEC and Japan by providing scientific knowledge useful in international efforts led by the Intergovernmental Panel on Climate Change (IPCC) and other parties.

Summary of main accomplishments

A: Detection of long-term changes in the general circulation of the ocean by use of ship-based repeat hydrographic observations

To understand the large-scale circulation of the ocean, its transport of heat and materials, and changes in that circulation during recent decades, the Global Ocean Ship-based Hydrographic Investigations Program (GOSHIP) has been carrying out high quality, land-to-land, and full-ocean, water-column, ship-based hydrographic observations (Fig. 1). Since 1999, the Japan Agency for Marine-Earth Science and Technology has conducted repeat hydrographic observations with the R/V *Mirai* along more than 10 international observation lines and has made public the high-quality data obtained from those surveys. A comparison of these high-quality data with historical data has allowed us to estimate the large-scale transport of heat and materials and long-term changes thereof.

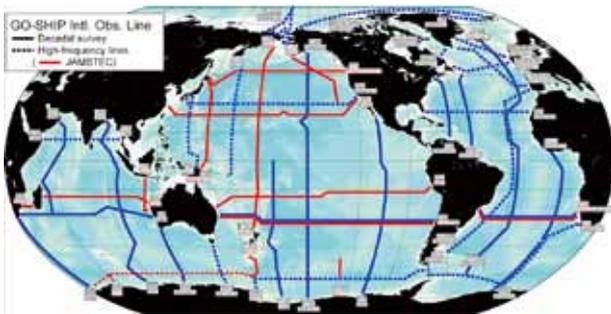


Figure 1. International repeat hydrographic observation lines.

We discovered large-scale warming of bottom water for the first time in the world along the WHP P01 line at 47°N of the North Pacific Ocean by comparing the historical hydrographic data obtained in 1985 with the repeat hydrographic data obtained in 1999. Since 1999, similar bottom-water warming has been observed throughout the world’s oceans and has been summarized in the Intergovernmental Panel on Climate Change Fifth Assessment Report. Previous studies based on numerical model analyses have suggested that the bottom water of the Pacific warms when bottom water formation off the Adelle Coast of Antarctica decreases because

such changes are quickly manifested in the North Pacific by changes in the pressure fields caused by the propagation of Kelvin and Rossby waves. Although it might be difficult for only two surveys in a decade to reveal a decrease in the volume transport of bottom water, data from multiple surveys in recent decades have been gathered, and those data are therefore expected to reveal long-term changes in the large-scale circulation of the ocean.

Subsequent to the discovery of large-scale warming of bottom water, the P01 line was designated to be one of the high-frequency, sustained, repeat-observation lines used to monitor climate change and global warming. The R/V *Mirai* carried out repeat hydrographic observations along the P01 line in 2007 and 2014 (Fig. 2). Four sets of high-quality hydrographic section data along the P01 line were therefore gathered during the last 30 years. The R/V *Mirai* obtained data in 2007 and 2014 that ensured a higher level of comparability than conventional data, and those data made it possible to detect small changes in water properties in the deep ocean. In addition, in 2014 water sampling was carried out not only for physical/chemical properties of seawater but also for flow cytometric analysis of microbial populations (red dots in Fig. 3) and for microbial diversity by genetic analysis (black dots in Fig. 3). On-board experiments to study the microbial nitrogen cycle were also carried out. Analyses of microbial communities are expected to be novel tools for studying the general circulation of the ocean because the distribution of microbial communities is thought to be related to the distribution of water masses.

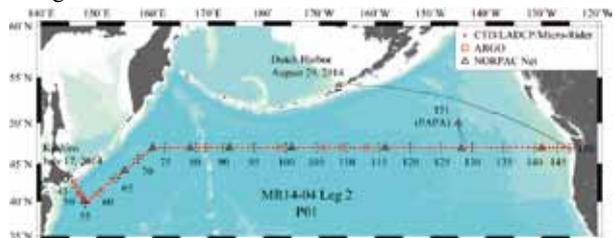


Figure 2. Station locations of the 2014 P01 repeat hydrographic observations by the R/V *Mirai*. Selected station numbers are shown with cross marks.

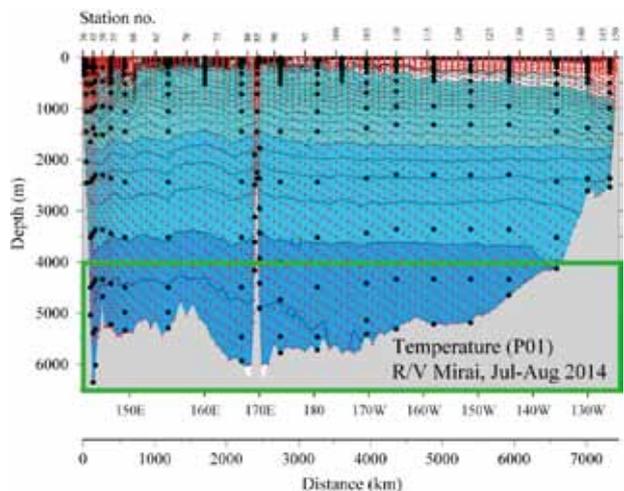


Figure 3. Temperature cross section of the 2014 P01 repeat observations by the R/V *Mirai*. Red and black dots indicate water sampling depths for analyses of the physical/chemical properties of seawater and microbial communities, respectively.

Long-term changes in the properties of bottom water (average depths greater than 4,000 m) in the northern part of the North Pacific Ocean were examined by using the data obtained along the P01 line (Fig. 4). The temperature of the bottom water has continued to warm at a rate of 1.4 mK per decade, similar to the rates reported in previous studies. No significant change in salinity could be detected. During the same time interval, we found that dissolved oxygen concentrations decreased linearly with time at a rate of 1.0 $\mu\text{mol/kg}$ per decade. By combining the P01 data with the data obtained along the WHP P02 (30°N) and P03 (25°N) lines, we elucidated the long-term trends of increasing bottom water temperatures and decreasing dissolved oxygen concentrations in the North Pacific Ocean.

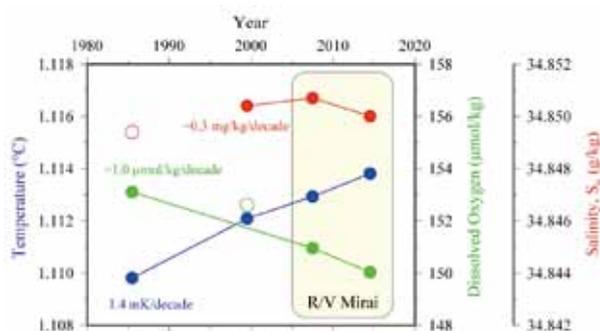


Figure 4. Long-term changes in temperature, salinity, and dissolved oxygen concentrations on the P01 line averaged at depths greater than 4,000 m. Data indicated by open circles were not used for the estimation of long-term trends because the quality of the data was suspect.

If all the bottom water warming resulted from isotherm heaving (deepening) in response to propagating oceanic waves, changes of salinity and dissolved oxygen resulting from the isotherm heaving can be estimated to be -0.2 mg/kg and $-0.5 \mu\text{mol/kg}$ per decade, respectively, based on the meridional gradients of bottom-water temperature, salinity, and dissolved oxygen. Although such a decrease in salinity is below the limit of detection using the present methodology, the associated decrease of dissolved oxygen can explain about half of the observed decrease in dissolved oxygen. Because the rate of oxygen uptake of the bottom water can be estimated from the relationship between radiocarbon and dissolved oxygen in the bottom water to be $1.2 \mu\text{mol/kg}$ per decade, the other half of the observed decrease in dissolved oxygen can be explained by additional remineralization associated with an increase of bottom water residence time. In fact, the net northward volume transport at depths greater than 4,000 m across sections P02 and P03 in the North Pacific, estimated from geostrophic velocities calculated assuming a level of no motion at 4,000 m, decreased linearly at a rate of 0.4 Sv (1 Sv is $10^6 \text{ m}^3/\text{s}$) per decade from 1985 to 2013. The long-term trends of warming, decreases of dissolved oxygen, and decreases of the northward volume transport of bottom water in the North Pacific Ocean are all attributable to a reduction in the magnitude of the Antarctic overturning circulation due to global warming.

B: Enhanced role of eddies in the Arctic marine biological pump

Evaluating the responses of biogeochemical cycles to decreasing sea ice is important to predict long-term trends in fishery resources. Improved summer light conditions have been reported to enhance planktonic photosynthesis in the Eurasian pelagic area of the Arctic Ocean. Furthermore, the accumulation of nutrient-poor freshwater suppressed the primary production of phytoplankton in the central Canada Basin during the 2000s. The biological pump of particulate organic carbon (POC), which is one of the sequestration mechanisms of atmospheric CO_2 to deep sea, has been reported to be ineffective in the cryopelagic Canadian Arctic deep basins. Whereas the primary productivity of phytoplankton could be modest even under sea ice cover, the low abundance of ballast particles such as shell-bearing micro-planktons might have prevented biological materials from sinking toward deep layers. On the other hand, the relative contribution of the lateral transport of shelf-origin materials to basin interiors remains uncertain. The western Canada Basin and the Chukchi Borderland, which have experienced a remarkable reduction of sea ice and substantial biological shifts during the early 21st century, are located downstream of Pacific-origin water that obtains heat, nutrients, and organic material over the shallower Chukchi shelf. Further investigations of the physical and biogeochemical properties along the Pacific water pathway will provide valuable information regarding communication between the Bering Sea and the central Arctic. In this study, we detected a significant amount of sinking biogenic materials with fresh zooplanktons using measurements from sediment traps deployed in the Northwind Abyssal Plain (NAP; Fig.5) since autumn 2010. We then addressed background mechanisms and possible future conditions of the biological pump from the viewpoint of shelf water transport using an eddy-resolving (5-km grid size) framework in a pan-Arctic sea ice-ocean model.

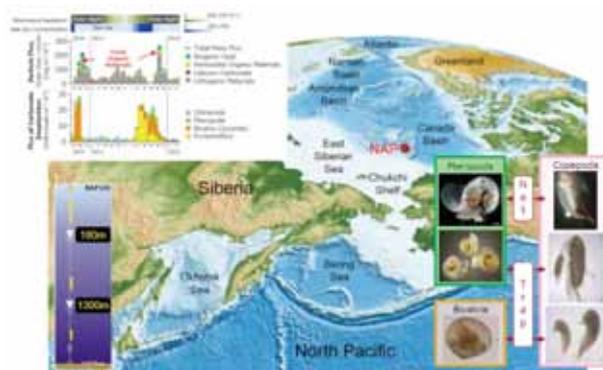


Figure 5. Topographic map of the Arctic-subarctic regions and trapped particles at Station NAP shown by a red dot.

A seasonal experiment using the pan-Arctic sea ice-ocean model demonstrated that the flux of particulate organic nitrogen (PON) at Station NAP reached summer and early winter peaks at 180 m (Fig. 6). We proposed that mesoscale eddies originating in the vicinity of the Beaufort shelf break played an important role in biological pumping in the western Arctic basin. Our model reproduced both cold and warm shelf-break eddies. A cold eddy

migrated westward along the pathway of basin-wide Beaufort Gyre circulation and passed Station NAP in November. This eddy, generated in June, carried near-freezing shelf water and retained its cold core at least until December. Due to a phytoplankton bloom and zooplankton grazing, the PON concentration within the cold eddy increased from June to August in most of the water column, and the high values were kept until the eddy passed Station NAP in November. Because the PON concentration within the cold eddy was higher than that in the surrounding basin water, the second peak of PON flux occurred in early winter at Station NAP. Warm eddies generated after the sea ice retreat in late summer had a greater contribution to PON flux compared with cold eddies produced under sea ice in early summer. A higher PON flux was localized in part of the southern Canada Basin, where baroclinic eddies traced the anti-cyclonic Beaufort Gyre. The higher water temperatures in the ocean surface layer of warm eddies kept their pathways away from the sea ice cover; thus, both the warmer conditions and the greater light intensity favored phytoplankton photosynthesis and subsequent zooplankton grazing. In the Mackenzie shelf region, it has been reported that the resuspension of shelf bottom sediments and cross-shelf transport of POC were induced by buoyancy-driven convection following winter sea ice formation and by baroclinic eddies. In contrast, our results showed that high plankton activity was accompanied by the development and migration of summer eddies in the downstream region of the Pacific water pathway.

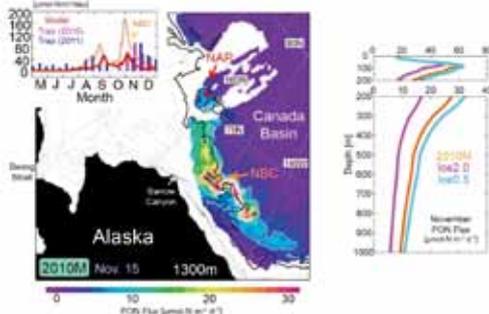


Figure.6 Spatial distribution, NAP time series, and vertical profiles of the simulated PON flux.

The eddy-induced early-winter biological pump would be enhanced by sea ice retreat. To address the impact of sea ice reduction on the early winter PON flux, we performed two additional experiments in which the sea ice thickness given as the initial condition on March 1 was multiplied by 2.0 or 0.5 in the entire model domain (named the Ice 2.0 case and Ice 0.5 case, respectively). The average summer sea ice extent during the 1990s was similar to the Ice 2.0 case, and the 2012 sea ice margin was located farther north than that seen in the Ice 0.5 case. The modeling results indicate that the magnitude of the biological pump might have doubled over the last two decades in the southwestern Canada Basin (Fig. 6). This trend arose because the eddy-driven transport of shelf-origin nutrients and biological materials toward the Canada Basin was promoted (Fig. 7). The factor for this difference could be attributed to changes in shelf bloom and eddy activity. The improved light conditions owing to sea ice reduction increased phytoplankton biomass in early summer. The earlier

shelf bloom hastened nutrient depletion and rapidly reduced the PON content per eddy from summer to autumn. On the other hand, the removal of sea ice drag increased the Barrow Canyon outflow and eddy kinetic energy. Additionally, the enhanced eddy generation and development promoted greater PON export to the deep basin under conditions of less sea ice. We can indicate that eddy-induced lateral nutrient supplies to the euphotic zone have favored the increasing phytoplankton growth in the Canada Basin, whereas the deepening nutricline in part caused by sea ice reduction may suppress primary productivity. Thus, the environmental transition for lower trophic ecosystems in the marginal Beaufort Gyre, including the NAP area, differs from the situation in the central gyre. Now, we need to consider how far the area of high biological activity will spread in the near future and how ocean dynamics will contribute to the pan-Arctic marine ecosystem. Because mesoscale eddies have been detected in multiple shelf-basin boundary regions of the Arctic Ocean, the ecological function of laterally transported organic materials is likely to gain more importance as a food source for plankton and higher-trophic organisms in the basin interior.

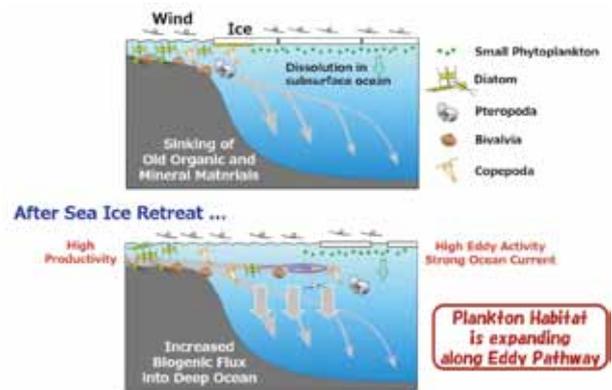


Figure.7 Schematic diagram of sea ice impact on plankton habitats and particle sinking.

C: Satellite-based observations may be underestimating tropospheric NO₂ vertical column density

We compiled ground observation network data having been collected in Japan, China, South Korea and Russia since 2007 using Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS). Then, we systematically validated data of nitrogen dioxide (NO₂), an atmospheric pollutant, collected using an OMI (Ozone Monitoring Instrument) satellite sensor (Fig. 8) for the first time in the world, and found that 30 to 50% of satellite observations were underestimations. We found that the underestimations may be related to the “shielding effect” caused by aerosols such as PM2.5, fine atmospheric particles, which obscure detection of NO₂ near the Earth’s surface by scattering sunlight, which serves as probe light (light needed for the sensor to detect targets) for satellite observation.

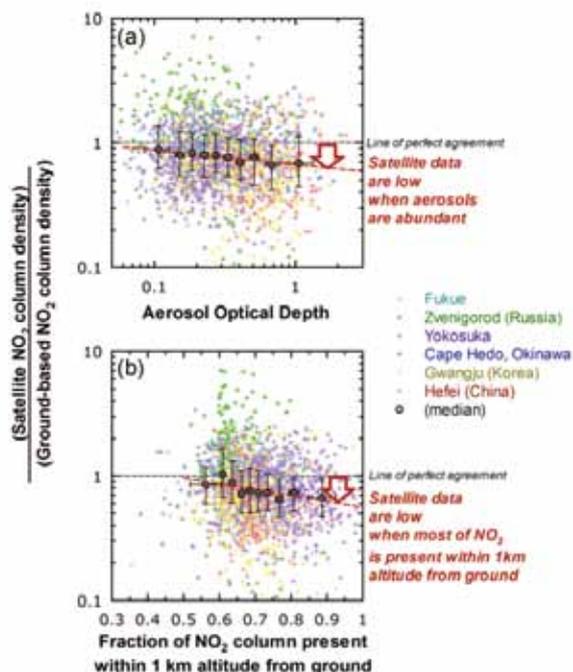


Figure 8. It was found that OMI satellite data have low biases compared to those from ground observations (shown by the red arrows) when aerosol optical depth is larger (figure a) and when NO₂ is abundantly present near the Earth’s surface (figure b).

Economic growth in Asia is impacting global climate through the emission of PM_{2.5} aerosols and increased release of gaseous pollutants such as ozone. Satellite observations have been playing a crucial role in monitoring global changes. However, this technology is prone to inaccuracy in quantifying absorption of a very small amount of sunlight (1% or less) by NO₂ and is susceptible to the effect of NO₂ and clouds present in the stratosphere. Thus, there were some opinions that accuracy of satellite observations should be verified. The advantage of satellite observations over ground observations is that the former allows more accurate determination of “tropospheric NO₂ vertical column density” using a large amount of information including accurate assessment of the impact of aerosols and the altitude distribution of NO₂. Verification demonstrated that NO₂ values measured from the ground are greater than those measured from the satellite (1) when the amount of aerosols coexisting with NO₂ (optical depth) in the atmosphere is large and (2) when NO₂ is most abundant at altitudes up to 1 km.

These results suggest that the amount of NO₂ production estimated based on satellite data needs to be corrected upwardly, and that the impact of human activities on global climate may be greater than generally believed. In addition, we were able to demonstrate for the first time using ground measurements that it is important to appropriately take into account light scattering effects of aerosol particles such as PM_{2.5} in order to increase the accuracy of NO₂ measurements based on satellite observations.

D: Understanding of marine nitrogen cycle in the western North Pacific based on stable isotope analysis and modeling

In this study, we aimed to increase the certainty of the marine nitrogen cycle model by taking into account concentration and flux of nitrogen as well as ratios of different nitrogen isotopes, and to identify a marine nitrogen cycle mechanism using the model. In FY2014, we participated in the MR14-04 cruise during which we took water samples for measuring ratios of nitrate and chlorophyll isotopes around two fixed observation sites (K2 in a subtropical zone and S1 in a subarctic zone) in the western North Pacific. We are currently analyzing these samples. In addition, we collected water samples for measuring ratios of nitrate isotopes at the S1 site during the KY14-09 cruise and at the K2 site during the KH-14-02 cruise. We completed taking measurements in these samples. In FY2014, we newly added nitrous oxide (N₂O) into the marine nitrogen cycle–nitrogen isotope model, which was previously built using observational data including nitrogen isotope ratios (Fig.9), and ran the updated model using the data collected at the K2 and S1 sites. The model generally well simulated observed seasonal changes of chlorophyll and nitrate concentrations and nitrogen isotope ratios (Fig. 10). We were also able to simulate seasonal changes of N₂O concentration and isotopic molecular species for the most part (figure not shown). The model estimated that N₂O is released at the K2 and S1 sites at the rates of 32.3 mg N/m²/yr and 2.7 mg N/m²/yr, respectively. Model sensitivity experiments suggested that nitrification is mainly involved in N₂O production at the K2 site while at the S1 site, nitrification as well as denitrification by nitrifying bacteria are involved in N₂O production. Furthermore, the model also indicated that the involvement of ammonia-oxidizing bacteria and ammonia-oxidizing archaeobacteria contributed to about 50% of N₂O production at both sites. These results were consistent with the results of culture experiments conducted in FY2013 in which the rate of N₂O production was estimated using an archaeobacterial inhibitor and a 15N tracer.

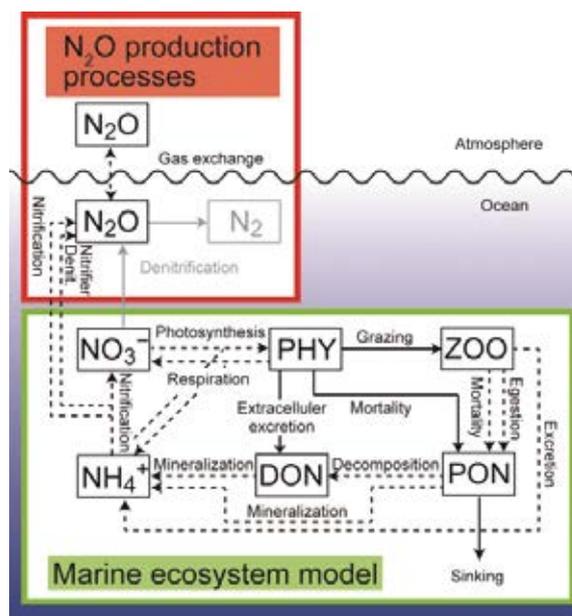


Figure 9. A schematic representation of the marine ecosystem isotopomer model which consists of a marine ecosystem model based on Yoshikawa *et al.* [2005] and the N₂O production processes with nitrogen isotopomers.

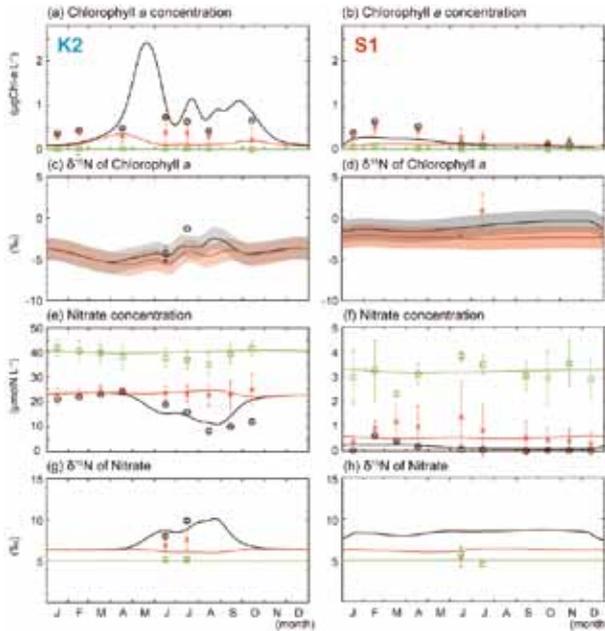


Figure 10. Simulated (lines) and observed (symbols) seasonal variations in K2 (a, c, e, g) and S1 (b, d, f, h). The black, red, and green lines indicate the simulated results in the upper, middle, and lower layers, respectively. The vertical bars for symbols represent the standard deviations in each box.

E: Interannual variations of stratospheric water vapor: precise picture and mechanism

Stratospheric water vapor contributes to global radiative forcing and plays a vital role in climate change. For example, some studies suggest that there is a correlation between change in the amount of stratospheric water vapor and change in the temperature of Earth’s surface. In the stratosphere, large-scale atmospheric circulation called the Brewer-Dobson circulation (BDC) is at work in which air rises in the equatorial stratosphere, spreads into both the Northern and Southern Hemispheres, and descends in the high latitudes. Water vapor is distributed widely through the BDC (Fig. 11(a)). Water vapor enters the stratosphere from the troposphere through the tropical tropopause, which can be viewed as a starting point of the BDC. The amount of water vapor moving into the stratosphere is determined

by saturated water vapor pressure as a function of tropical tropopause temperature. Thus, change in tropical tropopause temperature is closely associated with change in the condition of stratospheric water vapor. A decade ago, there was no observation equipment available capable of performing accurate long-term measurements of stratospheric water vapor, and therefore many aspects of change in stratospheric water vapor had remained unknown. The Aura MLS satellite launched in June 2004 enabled the measurement of stratospheric water vapor with greater accuracy than ever before. Organically combining the latest satellite observation technology, climate model experiments and the Coupled Model Intercomparison Project Phase 5 (CMIP5), we attempted to reveal the precise picture and mechanism of interannual variations of stratospheric water vapor.

Based on a spectral analysis of observational data, we found that equatorial quasi-biennial oscillation (QBO) was the predominant interannual variation variable of stratospheric water vapor. For this reason, we conducted a composite analysis with respect to the phase of the equatorial QBO. Figure 11(b) shows a time–altitude cross section of the variable representing interannual variations of stratospheric water vapor. In the equatorial stratosphere, we discovered anomalies in water vapor transmitting downwardly with time. Meanwhile, in the upper troposphere and lower stratosphere over the equatorial region, upward transmission, depicted as a boomerang-like structure, is the predominant interannual variation variable.

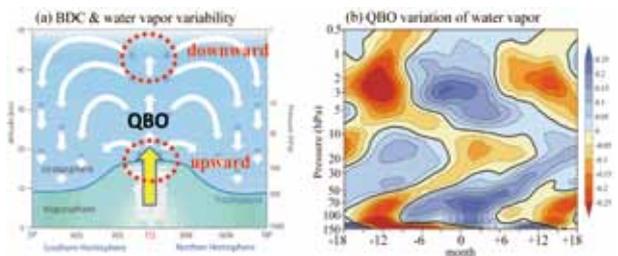


Figure 11. (a) Schematic illustration of the BDC (vector). Dot circles depict dominated areas of downward and upward propagation of H₂O anomalies. (b) composite of the QBO in interannual variation of 12°S–12°N average H₂O where month 0 corresponds to the westerly-to-easterly transition of the zonal wind at 30 hPa.

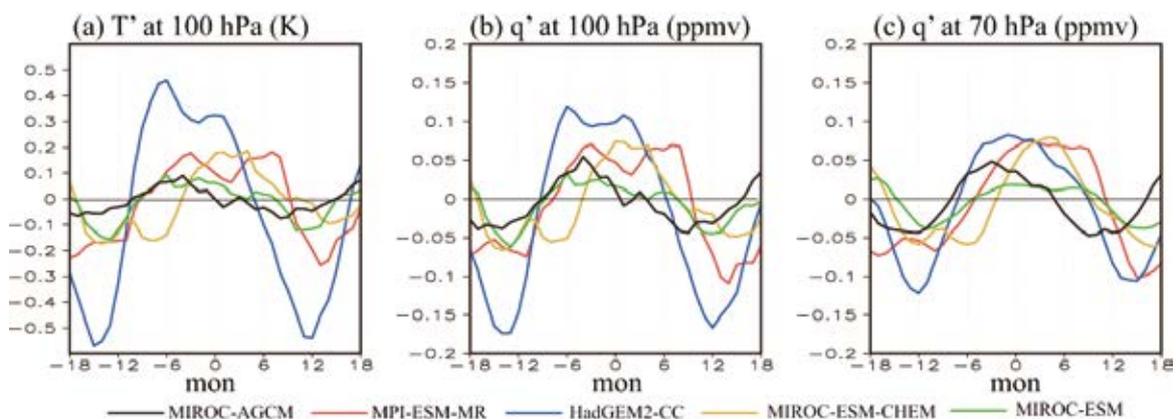


Figure 12. Time variation of the QBO composite (a) temperature and (b,c) H₂O mixing ratio at (a,b) 100 hPa and (c) 70 hPa in GCMs that could simulate the QBO.

Next, we attempted to identify the mechanism driving the phenomena described above by conducting climate model experiments using the MIROC-AGCM as well as using the world's climate models employed in the CMIP5.

Only models that adequately integrated the physical process of stratospheric water vapor production (methane oxidation) successfully simulated observed upper stratospheric water vapor variations. We also found that downward transmission signals in the upper stratosphere can be explained by taking account of a secondary vertical circulation driven by QBO and the effect of methane oxidation producing water vapor in the upper stratosphere. On the other hand, upward transmission signals in the lower stratosphere are generated by QBO having descended to the tropopause and caused temperature anomalies there. In other words, we revealed that when the temperature of the tropopause abnormally increases (decreases) in relation to the amplitude of QBO, greater (less) amounts of water vapor are transported into the stratosphere, and thus interannual variations of water vapor in the lower stratosphere are highly correlated with the amplitude of QBO around the tropopause. Figure 12 shows time variation of the QBO composite temperature at 100 hPa, and water vapor at 100 hPa and 70 hPa in each of the CMIP5 model simulations and in our T106 MIROC-AGCM control simulation. It is clear that models with larger QBO temperature variability at 100 hPa have larger QBO water vapor concentration variability at 100 hPa, and there seems to be little phase lag between the QBO temperature variations and the water vapor variations. This is consistent with the notion that simple cold trapping determines the water vapor mixing ratios at 100 hPa. Figure 2c shows the same composites for the QBO but for water vapor at 70 hPa.

This study has been published in the *Journal of the Atmospheric Sciences* issued by the American Meteorological Society.

F: MJO initiation during the CINDY2011 period

The Madden-Julian Oscillation is a dominant variability in the tropics, which is characterized by a large envelope of clouds [$O(10,000 \text{ km})$] and the period of 30–60 days. Because of its large spatial and temporal scale, the MJO has broad impacts on the world's weather and climate, such as the meteorological disaster over Asia (e.g., typhoons, heavy rain). Better understanding and higher forecast skill of the MJO are important to extended-range forecasts and climate projection. Especially, the initiation process of the MJO over the Indian Ocean had been the most difficult aspect lacking *in situ* observations. In order to tackle this

problem, international observation project Cooperative Indian Ocean experiment on intraseasonal variability in the Year 2011 (CINDY2011) was conducted during boreal fall to winter in 2011. The data obtained from observations and from the near real-time forecasts using Nonhydrostatic Icosahedral Atmospheric Model (NICAM) are available for research use (http://www.jamstec.go.jp/iorgc/cindy/index_j.html).

A key process of the initiation of the MJO is moisture accumulation, which has been keenly investigated by recent studies using field data and model outputs. We have analyzed objective analyses, satellite and field observation data, and NICAM outputs to understand the moistening process in the two MJO events that occurred during the CINDY2011 observation period (October–November 2011). Here we mainly report findings using the objective analysis. In order to understand scale interactions, all the variables were decomposed into three components by frequency band; high-frequency (<20 days), MJO (20–80 days), and basic state (>80 days). Then, moisture tendency associated with the MJO were diagnosed to estimate the contribution from each component. The results show that in both MJO events, the easterly anomaly of the MJO band (20–80 days) was accelerated by 8–10 days prior to the MJO convective initiation, which enhanced the transport of rich moisture over the Maritime Continent toward the equatorial Indian Ocean domain (box in Fig. 13), leading to middle tropospheric moistening there. The transport of the MJO-band moisture variability by the basic-state wind also made conditions favorable to convective initiation in the middle troposphere.

Further analysis of the easterly acceleration suggested possible contributions from mid-latitude disturbances (e.g., Rossby wave activity) in both MJO events. As to the high-frequency components, positive effects on moistening were found. Moreover, triggering the role of high-frequency convective disturbance was suggested in the October MJO event. Based on the wavelet spectral analysis, this high-frequency disturbance was identified as a convectively-coupled equatorial Kelvin wave. Additional analysis using the NICAM forecast data confirms that this wave disturbance induced deep tropospheric latent heat release. These results suggest a potential source of predictability of MJO convective initiation in the mid-latitude variabilities and high-frequency disturbances. Progress in this research topic is expected by the development of our “seamless environmental prediction model” that can simulate local weather and global climate variability in a unified framework.

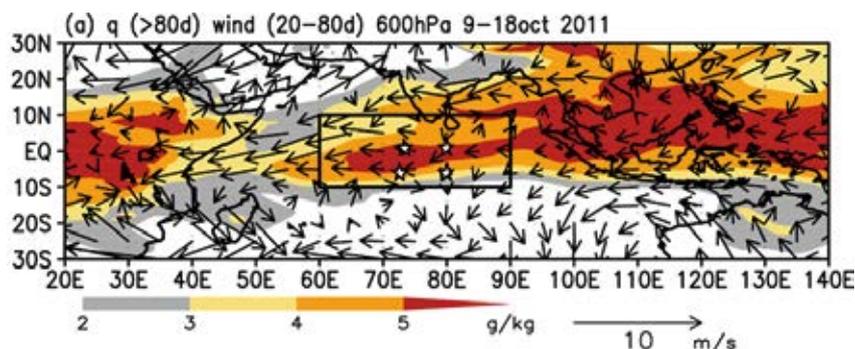


Figure 13. Horizontal distribution of the MJO-band (20–80 days) moisture (color) and basic (>80 days) wind (vector) at 600 hPa prior to the convective initiation of the October MJO event (averages in 9–18 October 2011). The box indicates the domain of the budget analysis and stars indicate the locations of the intensive observation site.

(3) Research and development on seismogenic zones

Overview

In this project, we aim to understand the precise picture of earthquake and tsunami generation using the latest marine observation technologies and applying advanced simulation/monitoring research, and to deliver a variety of observational data and research results to the public for the purpose of mitigating the risk of earthquake and tsunami disasters. In addition, we will accumulate scientific knowledge regarding the impact of earthquakes/tsunamis on marine ecosystems and their recovery from these disasters, thereby contributing to the recovery of disaster affected areas.

- **Research for understanding precise conditions of seismogenic zones along plate boundaries**

To contribute to better understanding of earthquakes and tsunamis occurring in seismogenic zones, we perform sophisticated surveys/observations/research concerning crustal structures, crustal activities, seismogenic history and other aspects. We also carry out analytical research contributing to more accurate prediction of earthquake occurrence, ocean-bottom motions and tsunamis using data obtained from earthquake and tsunami observation systems in sea areas such as the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) and taking advantage of the framework which allows us to exchange data with relevant research institutes. Moreover, we simulate various phenomena occurring in seismogenic zones and integrate the results of simulations with data obtained from marine scientific drilling. Through this approach, we will accumulate new scientific knowledge contributing to understanding the precise conditions of seismogenic zones where a major earthquake is expected to occur.

Simulation of a repeating earthquake triggered by the Great East Japan Earthquake — Demonstrating important analytical approach for earthquake predictions —

A repeating earthquake, which occurs off the coast of Kamaishi (Fig. 1) at nearly constant intervals and magnitudes, has been known globally as an example of a characteristic earthquake. Most characteristic earthquakes occur at long intervals and cause great damage, but the repeating earthquake off the coast of Kamaishi occurs at short intervals with distinctive small magnitudes. As such, models of earthquakes off the coast of Kamaishi are relatively easy to validate. In addition, because high-precision observational data has enabled detection of weak seismic signals in recent years, these earthquakes have been a very valuable target for studying the mechanisms of earthquakes occurring in plate boundary areas.

However, when the magnitude-9 Great East Japan Earthquake struck in 2011, regular intervals and magnitudes of the repeating earthquake off the coast of Kamaishi greatly deviated (Fig. 1). This research team assumed that the deviation was caused by a “postseismic slip” (slow fault slip that continues after the earthquake) triggered by the great earthquake, which propagated toward the area off the coast of Kamaishi. Thus, the research team hypothesized that the massive postseismic slip

prompted by the great earthquake reached the area off the coast of Kamaishi and led to deviation of the conventional cycle of the repeating earthquake there.

Given that large-scale computation is required to numerically simulate seismic cycles with greatly varying magnitudes, we used the JAMSTEC supercomputer system, Earth Simulator, to validate the simulations. As a result, we successfully simulated the major deviation from the regularity of small earthquakes, which occurred after a postseismic slip passed through the area off the coast of Kamaishi (Fig. 2).

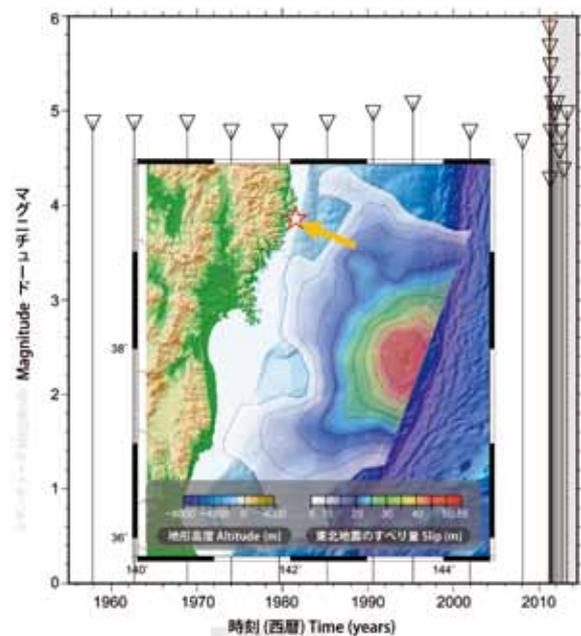


Figure 1. Hypocenter (☆) and activity history of a repeating earthquake off the coast of Kamaishi. Borders between white and gray background colors represent the time at which the Great East Japan Earthquake occurred, and the arrow in the map indicates the direction of postseismic slip propagation estimated in this study.

According to a simulation-based scenario, during the time periods in which small earthquakes inherently occur, only around the center of an unstable frictional zone (an area with a skating-rink-like property—as slip velocity increases, frictional resistance decreases, but once the motion stops, the motionless state persists as if being frozen) may slip fast enough to trigger earthquakes while in the surrounding area (a stable frictional zone—a viscous area in which as slip velocity increases, frictional resistance also increases), slow slip events occur repeatedly. After a large earthquake strikes, a massive postseismic slip passes through the unstable frictional zone, which triggers a rapid seismic slip over the zone, inducing an earthquake with greater magnitude than usual. During this sequence of events, the massive postseismic slip propagates focal areas of small earthquakes one after another, which causes the slip propagation to accelerate in the surrounding area. Then, the front of the massive slip approaches a small postseismic slip in the vicinity triggered by a small earthquake before the massive slip occurred. Because the front of the small slip ceases to propagate shortly, shear stress (a force tending to cause deformation of a material by slippage along a plane parallel

to the imposed stress) increases on the slip front in the focal area of small earthquakes.

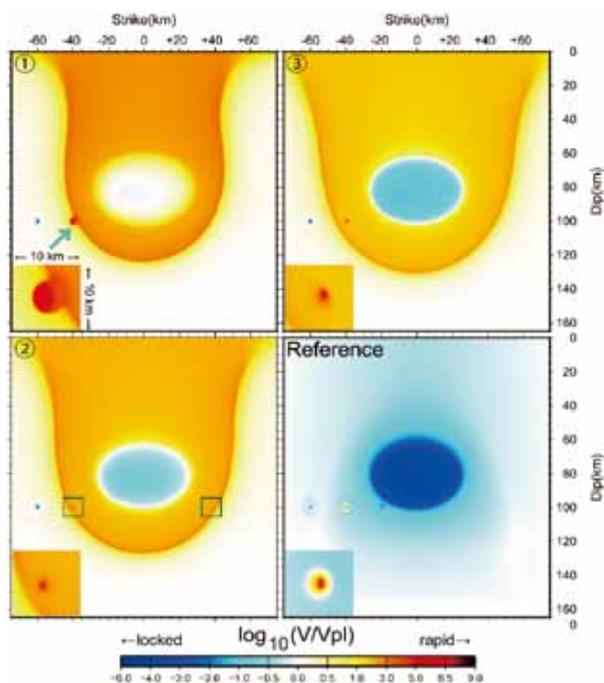


Figure 2. Snapshot of slip velocity distribution at subduction plate boundaries based on numerical simulations. Warm colors (yellowish to reddish) indicate rapid slip while cold colors (bluish) represent no slip. A small diagram in the lower left corner of each diagram shows an enlarged image of a focal area of small earthquakes.

This sort of spatial distortion of focal areas also has been observed off the coast of Kamaishi. Based on the results of the simulations explained above, postseismic slip triggered by the Great East Japan Earthquake appeared to propagate toward the west-northwest from an east-southeast position off the coast of Kamaishi (indicated by an arrow in Fig. 1).

In summary, 1) to understand the mechanism of repeating earthquake occurrence, it is important, besides gaining insightful new knowledge, to determine the conditions contributing to the deviation of small earthquake characteristics in terms of frictional properties and frictional constitutive law, by identifying probable conditions using numerical simulations (and by conducting rock-laboratory experiments as an independent method). 2) We were able to demonstrate the validity of the new analysis method for estimating the postseismic slip propagation direction using numerical simulations as an independent way of a geodetical approach.

These results are applicable not only to the specific case taking place off the coast of Kamaishi but also to other cases of repeating earthquakes. They also may be applicable to studies on the Nankai Trough. In particular, they can be useful in specifying conditions, such as frictional properties and frictional constitutive law, for modeling great subduction zone earthquakes around Japan. Such study is currently in progress in conjunction with the “research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai Trough region” led by the Ministry of Education, Culture, Sports, Science and Technology.

In addition, we are studying the method to detect subtle crustal movements relating to small repeating earthquakes occurring around subduction zones, which are difficult to measure from the land, using the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET).

Trial observations successfully conducted using the real-time ocean bottom tsunami monitoring system equipped with a vector tsunameter

The Great East Japan Earthquake generated the largest tsunamis since the 1896 Sanriku earthquake, causing devastating damage to the coastal areas of the Tohoku region. To reduce the risk of future tsunami disasters, it is a pressing issue to develop the capability to promptly and accurately estimate sizes and times of tsunamis arriving to Japanese coasts. To meet this goal, we developed a vector tsunameter (VTM) (Fig. 3).

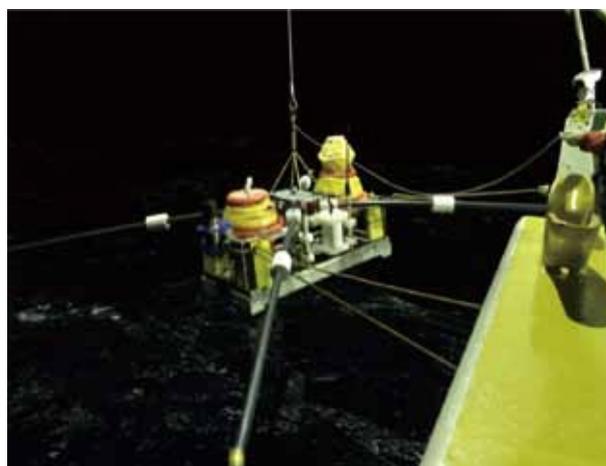


Figure 3. Deploying a vector tsunameter (VTM) in the sea

A VTM is a combination of a deep-sea differential pressure gauge (DPG), which detects pressure changes associated with ocean-bottom motions, crustal movements and changes in water level caused by tsunamis, and an ocean bottom electro-magnetometer (OBEM), which detects changes in electromagnetic fields induced by seawater flow resulting from tsunami propagations. The device is capable of separate measurements of water-level changes and seawater flow associated with tsunami propagations, velocity/direction of tsunami propagations, and crustal movements associated with earthquakes. These measurements have enabled detailed understanding of tsunami generation processes at epicenters and tsunami propagations through complex topography. So, the VTM may contribute to an increase in reliability of tsunami forecasts in coastal areas.

Using measurements of electromagnetic field changes on the seafloor, we successfully identified the source of short-period tsunamis, which may have contributed to the amplification of tsunamis generated by the Great East Japan Earthquake (See the October 8, 2013, press release titled “Tsunami source of the 2011 Tohoku earthquake detected by an ocean-bottom magnetometer”). Moreover, we successfully observed the propagation process of tsunamis generated by the 2010 Chile earthquake using an array of OBEMs (See the January 8, 2014, press release titled “A new ocean bottom

tsunameter based on the ocean dynamo effect”). These results demonstrated that VTMs to be deployed on the seafloor for tsunami observations are capable of accurately detecting signs of tsunami generations and propagations.

We obtained the abovementioned results by retrieving ocean bottom tsunameters several months after those tsunamis occurred and by analyzing the collected data. To make VTMs contribute to accurate tsunami predictions in coastal areas and to reducing risks of future tsunami disasters, it is necessary to develop a continuous tsunami monitoring system capable of sending VTM observation data to the ground in real time.



Figure 4. Wave Glider ready for deployment

To achieve this, we have been developing a real-time monitoring system equipped with a VTM. In this system, data collected on the seafloor by a VTM is transmitted to a Wave Glider, an autonomous ocean-going platform (Fig. 4), floating on the sea surface directly above the VTM, using a sound transmitter. Then, the data is transmitted from a Wave Glider to the ground via satellite communications. A Wave Glider is suited for long-term observations as it is capable of continuous travelling on the sea without fuel by using waves as a source of propulsive force. This system enables real-time transmission of a variety of sea-bottom data (magnetic field, electric field, tilt, water pressure, etc.) collected by a VTM to the ground.

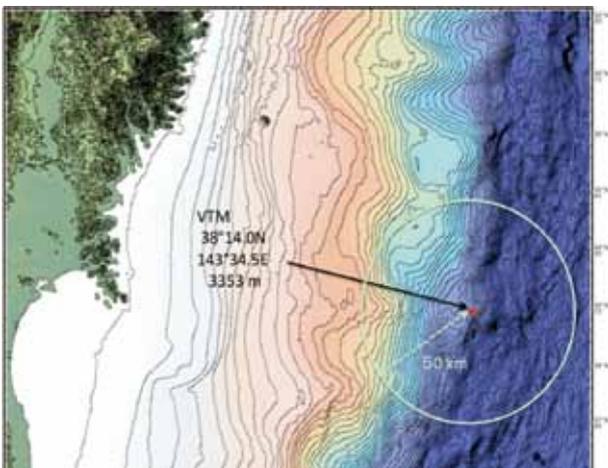


Figure 5. Observation site where the real-time ocean bottom tsunami monitoring system equipped with a VTM is in place

This system was deployed in the sea area about 200 km away from the coast of Sendai (about 3,400 m deep, Fig. 5) on March 13, 2014, using the research vessel *Shinsei Maru*, and it was confirmed that the system transmitted reliable data in real time from a VTM set on the seafloor to the ground during its operation for several months. We were able to deploy the system very quickly as it took us only about four hours. The quick deployment of the system ready for data transmission to the ground demonstrated the system’s high mobility.

During the system’s operation period, an earthquake hit Chile on April 2 (Japan time). The system successfully collected detailed data related to tsunami propagation processes (direction to tsunami wave source, velocity, wave heights, etc.), which reached the Pacific coasts of Japan, and transmitted the data in real time early morning on April 3. As a result, the system was found useful (Fig. 6).

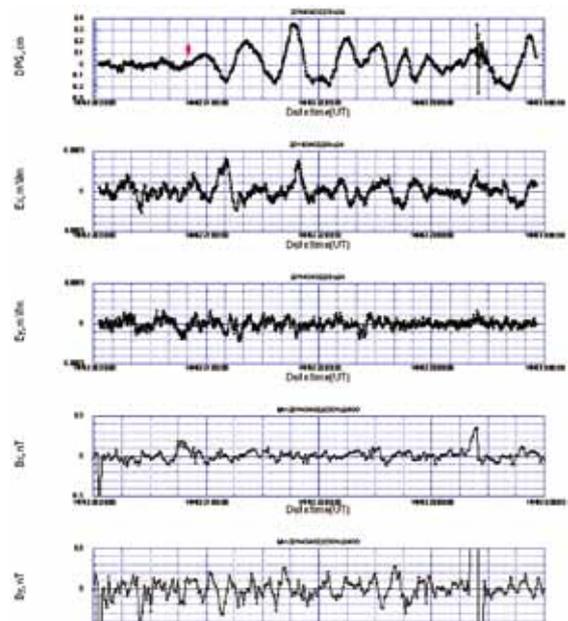


Figure 6. Tsunami records related to the 2014 northern Chile earthquake

In FY2014, we developed a highly accurate real-time ocean bottom tsunami monitoring system equipped with a VTM, and conducted trial observations using the system. Based on the operational data obtained using the system, we will carry out research and development toward practical use of this system.

Microearthquakes occurring in Nankai Trough cause excitation of Earth's free oscillations —New incessant excitation sources discovered—

The Earth consists of the atmosphere, oceans and solid earth made of rocks. The Earth is known to undergo oscillations in various locations resulting from interactions among these three components. The most well-known example is that when an earthquake occurs, seismic waves generated by the earthquake propagate across the globe, oscillating not only the solid earth but also the atmosphere and oceans. The more intense the earthquake is, the longer the global oscillations due to seismic waves last. However, earthquake-excited oscillations are recognizable only immediately after the occurrence of earthquakes.

On the other hand, even when no earthquake is occurring, the solid earth is known to oscillate under the influence of atmospheric and oceanic waves. This phenomenon is called “Earth's free oscillations” and “microseisms” (Fig. 7). The dominant time periods (dominant frequencies) of Earth's free oscillations and microseisms are about several hundred seconds and 5–15 seconds, respectively. The longer the oscillation period is, the deeper into the Earth the oscillation energy travels. This principle enables studying internal structures of Earth and other planets through analyzing these types of oscillations. Conversely, the use of shorter-period oscillations allows more detailed investigations of internal structures to a shallower depth in Earth/other planets. However, in previous studies, constant oscillations with shorter periods than microseisms had not been found. Also, because seismic waves are sporadic and irregular in occurrence, they had not been considered as excitation sources for such persistent oscillations.

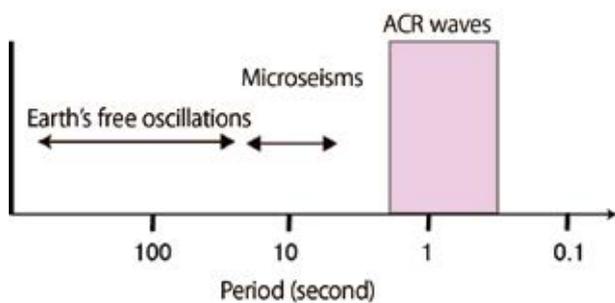


Figure 7. Predominant periods of Earth's free oscillations, microseisms and acoustic-coupled Rayleigh (ACR) waves

This research group searched for the existence of persistent oscillations by applying seismic interferometry to hydrophone data collected at about 150 sea-bottom observational points around the Nankai Trough from September through December, 2011. This is one of a few subduction zone observational networks available in the world with very densely arranged observational points, and this was the world's first study to search for the existence of persistent oscillations by applying seismic interferometry to noise data collected around trenches and troughs.

In this study, we found that ACR waves, whose periods of 0.5 to 1.4 seconds are shorter than the periods of conventionally known microseisms, are propagating constantly (Fig. 7). During the three-month period of hydrophone deployment, we observed ACR waves everyday by analyzing daily wave propagation data. In addition, we performed theoretical calculations to determine depths at which ACR wave energies occur, and found that they occur both in oceans and solid earth below the seafloor. These results suggest that ACR waves are phenomena unique to the oceanic environment and cause oscillations in oceans and solid earth below the seafloor.

We also studied the direction of ACR wave propagations and found the following: on the east side of the Nankai Trough, waves propagate both northwardly and southwardly from around the trough axis; on the northwest side of the trough, waves propagate in the north and south directions; and on the southwest side of the trough, waves propagate only southwardly. Furthermore, by comparing these wave propagation directions with the distribution of epicenters associated with earthquakes having occurred in this area, we found that ACR waves have been released from sources of many earthquakes (Fig. 8). These results indicate that earthquakes generate ACR waves. Because ACR waves do not weaken easily and they propagate slowly, they constantly exist in areas where microearthquakes occur frequently.

Based on all of these results, we concluded that frequent microearthquakes in subduction zones make ACR waves excited, and propagations of excited waves cause constant oscillations of oceans and the earth under the seafloor (Fig. 9). In previous studies, only fluids were thought to be capable of generating persistent oscillations, but in this study, we found that earthquakes may also generate them.

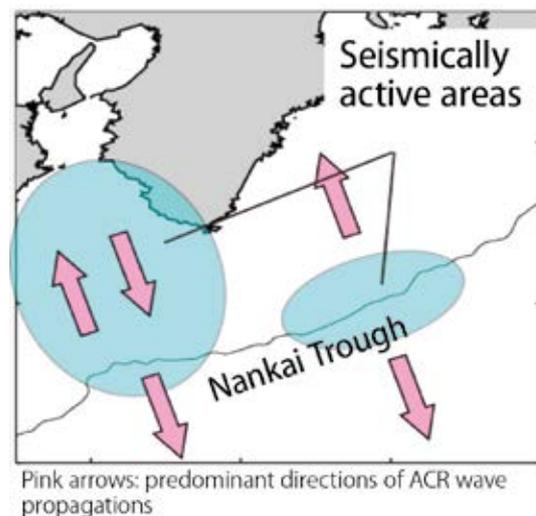


Figure 8. Acoustic-coupled Rayleigh (ACR) waves released from seismically active areas

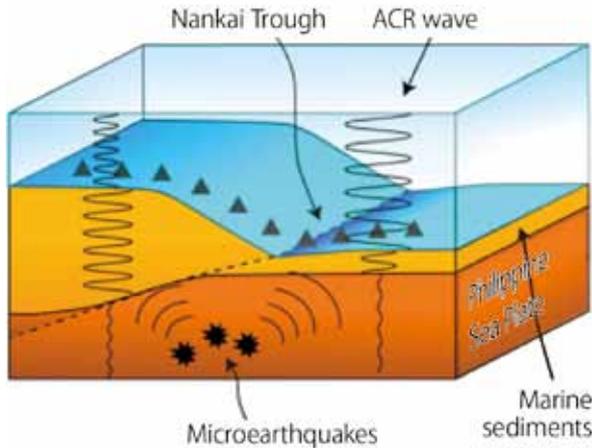


Figure 9. Constant excitation of ACR waves by microearthquakes

The velocity of ACR waves observed in this study changes greatly depending on the seismic wave velocity structure at shallow depths beneath the seafloor. As such, shallow structure under the sea bottom can be identified through detailed examination of ACR wave velocities. A simple approach of deploying observational devices on the sea bottom will enable surveys of Earth’s internal structure and enhance seafloor observations in terms of efficiency and cost saving.

Also, as ACR waves can be observed using DONET, it may be feasible to detect the movement of fluids existing beneath the seafloor by monitoring the velocity of ACR wave propagations in real time. This approach may facilitate the understanding of subduction zone dynamics.

• **Comprehensive evaluation of disaster potential of earthquakes and tsunamis**

In light of the lessons learned from the Great East Japan Earthquake, we are studying realistic earthquake and tsunami simulations. We evaluate earthquake/tsunami damages in sea areas surrounding the Japanese archipelago including the Nankai Trough, the Nansei islands region and the Japan Trench. Also, to apply research results to disaster prevention and mitigation measures, we are preparing to perform various simulations and developing information infrastructure for the purpose of alleviating damages caused by earthquakes/tsunamis that might occur in the Sea of Japan and sea areas around the Nankai Trough. Using these means, we will evaluate disaster potentials attributed to oceanic crustal movements and changes in the sea bottom.

Implementation of real-time tsunami prediction system

At the Research and Development Center for Earthquake and Tsunami (CEAT), in order to make the information output from the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) useful for local communities to formulate disaster prevention and mitigation measures, we are conducting joint research with Wakayama Prefecture and Chubu Electric Power Company in Owase City, aiming to develop a real-time tsunami prediction system. DONET is a system to observe various sea-bottom activities using several types of sensors including strong-motion seismometers, broadband seismometers, water pressure gauges, fine differential pressure

gauges, hydrophones and precision thermometers. DONET also sends out collected data in real time using submarine cables. To make DONET endure continuous use for dozens of years to come, we set marine cables with loops in places to allow extension as needed, and connected observation sensors to the nodes (which are hub devices allowing connection between the backbone cable system and sub-sea instruments) using a remotely operated vehicle (ROV). These arrangements allow us to spread out observation points as needed and make maintenance of the system convenient. The whole of DONET consists of DONET1 deployed in the Kumano Sea and DONET2 deployed in the sea area south of Kii Channel. At present, DONET1 has 20 observation points in operation. Two and 29 new observation points are being added to DONET1 and DONET2, respectively (Fig. 10). After the addition is completed, DONET will be able to monitor earthquakes and tsunamis in real time in the area ranging from the Kumano Sea to off the coast of Cape Muroto.

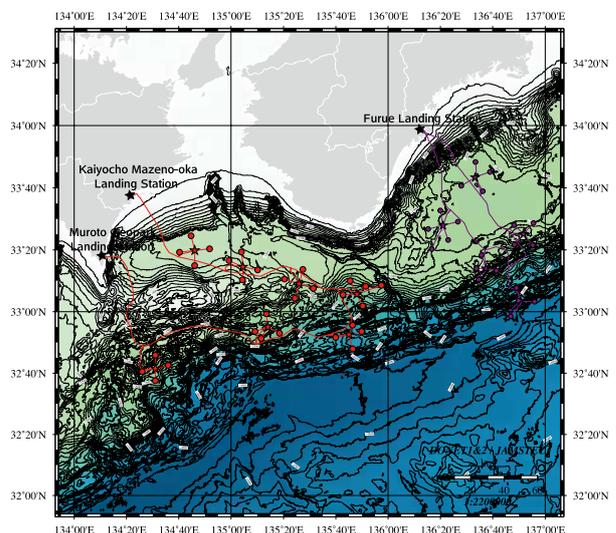


Figure 10. DONET observation points. Purple dots represent DONET1 observation points in operation, and red dots denote DONET2 observation points to be added.

When the Great East Japan Earthquake struck on March 11, 2011, DONET detected tsunamis caused by the earthquake about 15 minutes sooner than was detected in Owase Bay. As illustrated by this example, an advantage of DONET is its capability to quickly detect seismic activities and tsunamis triggered by subduction-zone earthquakes. The velocity of tsunami waves is determined in relation to water depth, and after tsunami propagations reach shallow sea areas, the height of the tsunami waves gradually increases. The amplification of tsunami waves is attributed to such factors as the topography of tsunami propagation pathways and the shape of coastlines. Taking these factors into account, amplification of tsunami waves can be assessed by simulations even before tsunamis actually occur. At CEAT, we focused on this simulation approach and assessed the tsunami amplification factor in advance. Then, we developed a system for displaying tsunami wave height, tsunami arrival time and an inundation map of an area concerned in real time based on

tsunami wave height measured by DONET water pressure gauges (Takahashi et al. 2015). As DONET2 is under development, data collected at 20 observation points in DONET1 are currently used to operate this system. To complete this system, we need to develop a means to transmit data collected by DONET to a server in real time, predetermine target points to which real-time tsunami prediction is tuned, and prepare a tsunami database by conducting tsunami simulations while taking into account the positions of DONET observation points and target points. We explain in more detail below.

As the system receives data from DONET every second, it selects a proper fault model, associated waveform and inundation map from the tsunami database which was built in advance, and displays them. We will transmit a total of nine components of data: three components of strong-motion seismometer data (200 Hz), three components of broadband seismometer data (200 Hz) and three components of water pressure gauge data (10 Hz). We have decided to use several different pathways to send the DONET data to facilitate the implementation of disaster prevention and mitigation measures. Data is transmitted from the Furue Landing Station to Owase City using a terrestrial circuit and Owase City's disaster prevention network (radio link), and to Chubu Electric Power Company and JAMSTEC Yokohama Institute for Earth Sciences using a terrestrial circuit via Owase City and a satellite circuit. We confirmed that all of these pathways are adequate for the purpose of transmitting DONET data in real time. In addition, data is sent from the Furue Landing Station to Wakayama Prefecture using a terrestrial circuit.

Regarding tsunami simulations, we assumed more than 1,500 different earthquake source models to represent the area ranging from off the coast of Boso Peninsula to Hyuga-nada, and carried out six hours' worth of tsunami waveform simulations taking into account 51 DONET observation points and all target points. Currently, 20 DONET observation points are operational, but we count 51 points in our simulation work in anticipation of upcoming DONET upgrading. Ratios of maximum tsunami wave heights between DONET observation points (expressed as an average absolute value among 20 observation points) and target points had considerable variability, but they were positively correlated overall (Baba et al. 2013). When a tsunami is automatically detected at DONET observation points (Takahashi et al. 2014), the system selects appropriate models from the tsunami database based on the amplitudes of the tsunami waves estimated using DONET water pressure data, and displays the tsunami wave height, tsunami arrival time and an inundation map. As the amplitudes of the tsunami waves sent from DONET water pressure gauges increase, predictions will be updated (Fig. 11). This system estimates the direction to an epicenter based on seismometer data and narrows down options of earthquake source models to be selected. This is how the system enhances its prediction accuracy. However, since the system is linked only to DONET1 deployed in the Kumano Sea for now, it is still not applicable to earthquakes occurring in the Nankai Trough area. We are planning to upgrade the system by linking it to DONET2 observation points and make it applicable to Nankai earthquakes. We are also considering extracting inundation height information for each target point from the tsunami database. We will decide how to display these types of information as we discuss this matter with users.

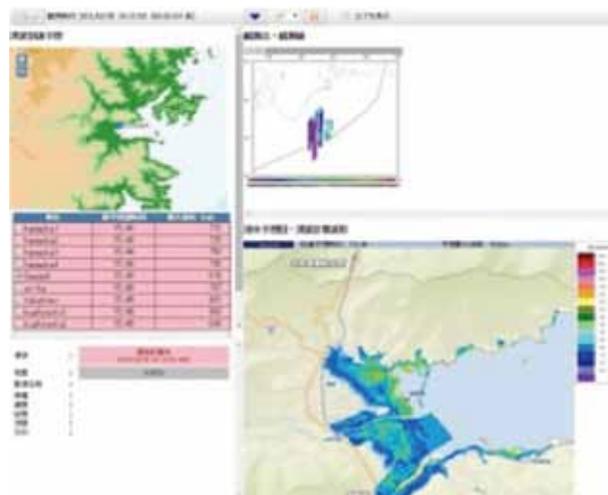


Figure 11. Example of real-time tsunami prediction for Owase Bay. A list of information such as tsunami arrival time and tsunami wave height is displayed on the left. The real-time DONET water pressure gauge reading is shown on the upper right. An inundation map is displayed on the lower right.

The merit of this system is that tsunami prediction can be made for areas smaller than municipalities. The height of tsunami waves varies greatly depending on the orientation of bays in the coastal area and the seafloor topography. In the process of tsunami simulations, we use fine-grained topographic data with 5–10 m resolutions. This method allows us to take account of fine structures such as breakwaters. To take into consideration even finer structures such as windbreaks and trees planted for preventing erosion, we can integrate land use type information, in terms of friction coefficients of water and ground, into tsunami simulations. However, we are not taking that approach for now. We are currently not using such detailed information due to different views existing among users on tsunami simulations.

Users should be aware of the fact that real-time predictions of course have a margin of error and there may be missing data from time to time. Accordingly, to inform users of any errors that might occur in simulation models, we display the best model and several other models selected based on DONET water pressure data. Also, while we use several different pathways to send data, there still is a chance to encounter missing data. Therefore, we have decided to display DONET waveform data in real time among other kinds of information mentioned above while using this system. Wakayama Prefecture has obtained Kushimoto Town's permission to use this system for predicting tsunami arrival time and tsunami wave height for the town as a part of the prefecture's meteorological service. Furthermore, to increase the use of DONET data, we are planning to integrate DONET2 observation points into the system, and thereby enhance real-time prediction of tsunamis occurring in the Nankai Trough area.

- **Research on damage to ecosystems caused by earthquakes and tsunamis and research on recovery efforts**

The earthquakes and tsunamis that struck on March 11, 2011, dramatically disrupted marine ecosystems in the Tohoku coastal and offshore areas. We have been conducting surveys

and research for 10 years to understand the precise conditions of the disrupted seafloor environment and marine ecosystems in these areas. In this project, we aim to monitor the recovery of ecosystems disrupted by the massive earthquake in collaboration with the people in the disaster-affected areas of Tohoku, provide scientific information obtained from the aforementioned study mainly to the communities in the disaster-affected areas, and contribute to the recovery of fisheries industries.

The research system we are using in this project is groundbreaking, so we hope to popularize it in a way so that it will become a model methodology for monitoring disruption and recovery of marine ecosystems, which are expected to occur in the future around the world including Japan. Here, we present some of our activities.

Analysis of seafloor ecosystem changes and environmental impact assessment

To determine the impact of debris on ecosystems in the Tohoku offshore areas, we first needed to acquire seafloor topography information. So, we continued our effort in creating seafloor topography maps using a vessel. As a result, we completed mapping more than 70% of fishery operation areas, at depths of 1,000 m or less, off the coasts of Miyagi and Iwate Prefectures (Fig. 12).

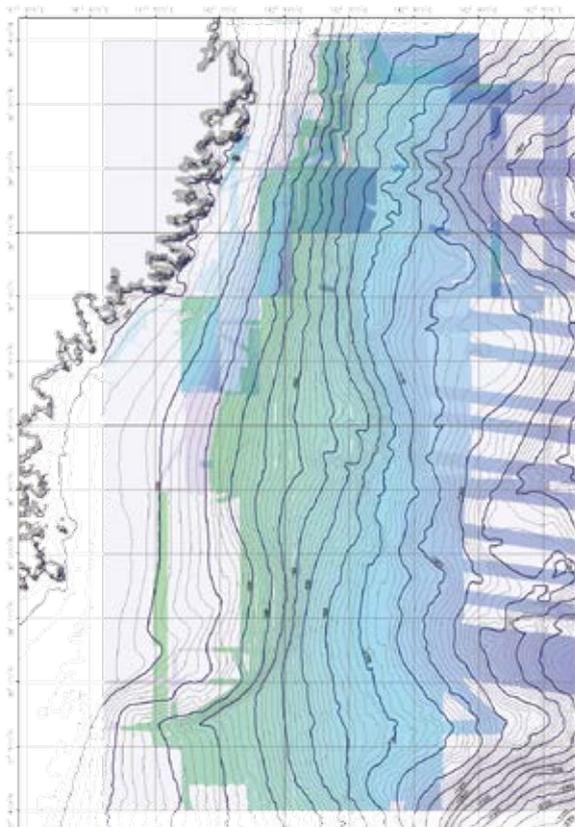


Figure 12. Seafloor topography map of a Tohoku offshore area

In debris surveys, we selected unique points by conducting acoustic probing. Then, we carried out visual observations using a remotely operated vehicle (ROV). During that process, we discovered a large structure appearing to be an about 70-m-long

vessel at a depth of 115 m around the boundary between Miyagi and Iwate Prefectures (Fig. 13). The large object discovered by acoustic probing was in fact identified as a vessel based on visual observations using an ROV. We also found that the vessel probably sank before the Great East Japan Earthquake as indicated by its structure. We notified the findings to Iwate and Miyagi Prefectures and the Miyagi Coast Guard Office in Shiogama.

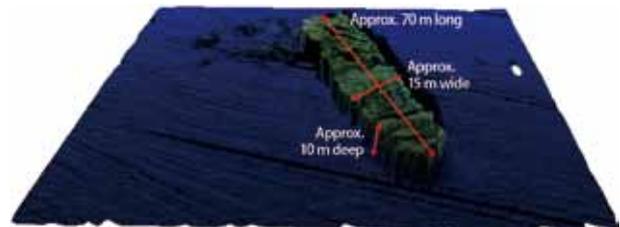


Figure 13. Acoustic image of a sunken vessel

Monitoring of marine environmental changes

We have been evaluating changes in the marine environment and marine life off the Sanriku coast from the viewpoint of material cycles. This effort includes oceanic observations to evaluate recovery processes after the earthquake disaster, long-term continuous observations around the bottom boundary layer, observation of surface layer sediments, measuring nitrogen isotopes of amino acids in organisms, and measuring harmful materials.

[Oceanic observations]

Figure 14 shows the results of oceanic observations conducted off the coast of Otsuchi in March 2015. At depths of 50 m or less, sea water appeared to be an Oyashio Current water mass (including the coastal Oyashio Current), which is cold with low salinity ($\leq 3.5^{\circ}\text{C}$ and $\leq 33 \text{‰}$), while at depths of around 150 m, sea water appeared to be a water mass of the altered Tsugaru Warm Current ($\geq 5.5^{\circ}\text{C}$ and $\geq 33.5 \text{‰}$).

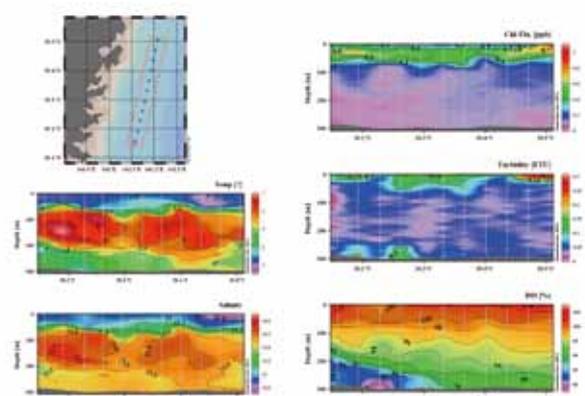


Figure 14. Results of oceanic observations carried out off the coast of Otsuchi using the chartered vessel *Kaiyo Maru No.8* in March 2015
 Upper left: map showing observation points. Middle left: water temperature ($^{\circ}\text{C}$).
 Lower left: salinity. Upper right: chlorophyll (ppb).
 Middle right: turbidity (FTU). Lower right: dissolved oxygen (%).

We compared the data collected during the KS-14-3 cruise by *Shinsei Maru* in March 2014 with the data collected along the observation line between Shiriya Saki and Esan Misaki at the eastern entrance of the Tsugaru Strait. From February to March 2014, the coastal Oyashio Current, which was unusually cold with low salinity compared to normal years, approached the Shimokita Peninsula, causing severe damage to fisheries. In normal years, warm water derived from the Tsushima Warm Current travels across the Tsugaru Strait from the Sea of Japan into the Pacific Ocean. However, we presume that the 2014 phenomenon occurred because the subsurface water of the Sea of Japan (having water characteristics similar to those unique to the Sea of Japan) passed through the affected area. The same subsurface water also has been detected along the observation line lying near the Aomori–Iwate border during the KS-14-3 cruise by *Shinsei Maru* in March 2014. The subsurface water was not detected along the observation line lying off the coast of Otsuchi.

[Seafloor observatories (landers)]

To understand changes occurring in the sea bottom, we have set lander systems off the coast of Otsuchi. We analyzed the data collected by the lander systems set at depths of 300 and 998 m off the coast of Otsuchi in FY2013 and obtained the following results.

(1) Lander set at a depth of 300 m

- At a depth of 300 m, water basically flows from north-northeast to south-southwest at rates of 0–30 cm/sec, though temporal direction reversal sometimes occurs, and there are 12- and 24-hour cyclic patterns (Fig. 15). These patterns may be related to tidal fluctuation.

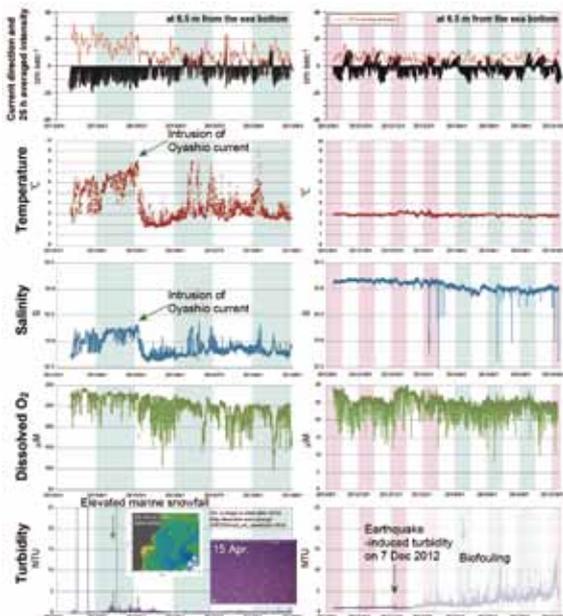


Figure 15. Current direction, flow rate, water temperature, salinity and turbidity measured by the landers. Graphs on the left show measurements taken at a depth of 300 m off the coast of Otsuchi (Mar. 12–Sep. 2, 2013) while graphs on the right represent measurements at a depth of 998 m (Aug. 14, 2012–Oct. 14, 2013).

- Water temperature and salinity decreased rapidly in early May 2013, from 8°C and 33.3 ‰ to 2°C and 32.8 ‰ (Fig. 15). The change presumably occurred as a coastal Oyashio Current/Oyashio Current water mass—or what is called by local fishermen “cold water”—traveled through the observation point.
- In addition, turbidity change was generally associated with phytoplankton bloom at the sea surface. We think that the effect of settling particles on water turbidity is significant in locations where the seafloor is shallow (Fig. 15).

(2) Lander set at a depth of 998 m

- Water mass flowing from north-northeast to south-southwest is the predominant component, which travels at rates of 0–15 cm/sec and has 12- and 24-hour cyclic patterns. These patterns, similar to those observed at a depth of 300 m, may be related to tidal fluctuation (Fig. 15).
- We observed turbid sea water on December 7, 2012, which was presumably caused by an earthquake (M = 7.3) with an epicenter off the coast of Miyagi Prefecture. Based on images taken, we confirmed that benthic organisms were covered with mud on December 7, but were not on the following day (Fig. 16). This observation may indicate that water immediately above the seafloor can be easily disturbed but returns to its normal state quickly.



Figure 16. Turbidity change caused by an earthquake on December 7, 2012, which was recorded by a lander set at a depth of 998 m off the coast of Otsuchi.

Top graph: Change in sea water turbidity. Photographs: Change in the visual appearance of the seafloor from December 6th (top), to 7th (middle) and to 8th (bottom)

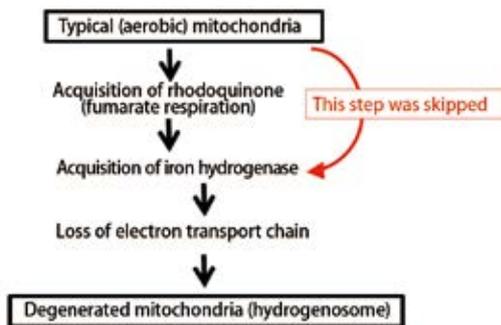


Figure 2. Evolutionary processes in which mitochondria adapt to an anaerobic environment. Mitochondria of *Cantina marsupialis* have skipped the first evolutionary step.

To understand organelle symbiosis within eukaryotic cells, we analyzed the mechanism by which *Bathymodiolus* acquires the chemosynthetic capability of its symbiotic bacteria. *Bathymodiolus septemdiarium* inhabits hydrothermal areas with lower hydrogen concentrations. We found that a single-ribotype symbiont population in an individual of the host is composed of several subpopulations that either possess or lack the gene clusters encoding hydrogenase or nitrate reductase (Fig. 3). Depending on habitat conditions, *B. septemdiarium* incorporates these several types of symbiotic bacteria with or without genes that enable them to utilize hydrogen or nitrate for the energy metabolism. This finding suggested that genome heterogeneity of *B. septemdiarium* symbiont may enable differential utilization of diverse substrates and confer metabolic flexibility.

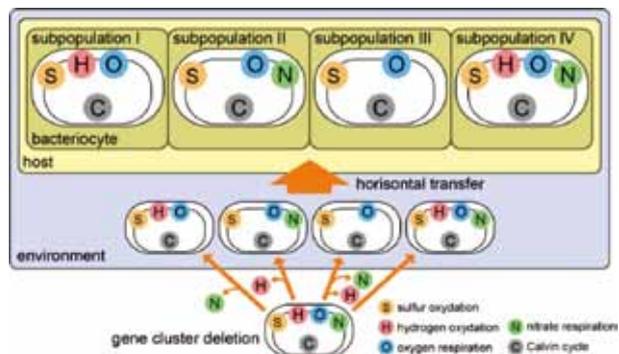


Figure 3. Genomic variants of the symbiont corresponding to subpopulations I–IV (or more) exist in the environment and are acquired from the environment in a host individual. The proportions of the different symbiont subpopulations in a host appeared to vary with the environment or with the host’s development.

In addition, we analyzed diet diversity of the stomach contents of juvenile chum salmon collected in the Sanriku coastal area (in a separate project) based on the mitochondrial DNA (COI region), and frequently recovered a gene sequence originated from an unknown eukaryote, which may belong to a novel phylum. As a next step, we will work on its morphological identity and taxonomy.

• Analyzing the basic structure of deep-sea ecosystems
C: Identification of top predators in deep waters

To identify higher-order consumers in deep-sea ecosystems, we acquired a total of 230 specimens of 37 species primarily from Suruga Bay as bycatch (database registered). Then, we sorted out higher-order consumer candidates from the specimens. We analyzed stable isotope ratios of total organic nitrogen and carbon for 40 candidate samples in 20 species, and the results suggested that higher-order consumers include *Centroscymnus owstonii* (roughskin dogfish) and *Centrophorus squamosus* (leafscale gulper shark). In addition, we analyzed stable isotope ratios of amino acid nitrogen for eight species and found that trophic levels of *C. owstonii* and *Pseudotriakis microdon* (false catshark) ranged from 4.4 to 4.5. These values are similar to those of top predators existing in shallow sea areas. To collect many tissue specimens from species of top predator candidates in a non-lethal manner, we are developing an *in-situ* biopsy system (IBIS) and have come up with the concept for the design (Fig. 4). Main system components include a video camera, LED lights, a biopsy device, a trigger generation device and an ultrasonic current meter. In FY2014, we studied the shape of the biopsy needle and tested needles used to pierce target organisms. Then, we made general decisions on the shape of the biopsy needle and the method of retrieving biopsy samples.

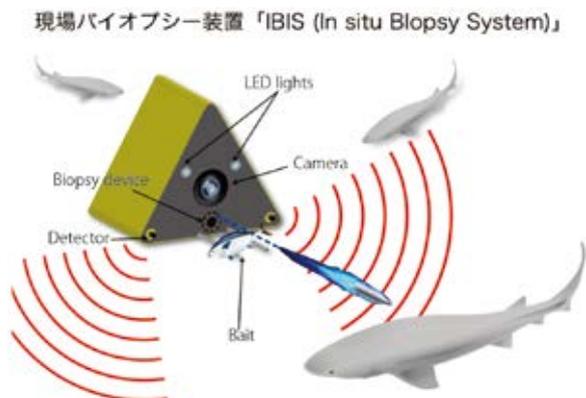


Figure 4. Concept of an in-situ biopsy system (IBIS)

D: Mathematical modeling of ecosystems

We are aiming to formulate a system stability evaluation theory as it applies to multilayer networks. Organisms feed in their habitats and migrate between habitats. When the mode of inter-habitat migration varies among organisms, the overall dynamics can be represented by a mathematical model called a reaction-diffusion system in conjunction with a multilayer network. The conventional stability evaluation methods (e.g., linear stability analysis) that are highly compatible with a reaction-diffusion system are not applicable to the abovementioned ecosystem. In this project, we developed a method to approximately evaluate the stability of the ecosystem and checked the usability of the method through numerical experiments (Fig. 5, manuscript submitted).

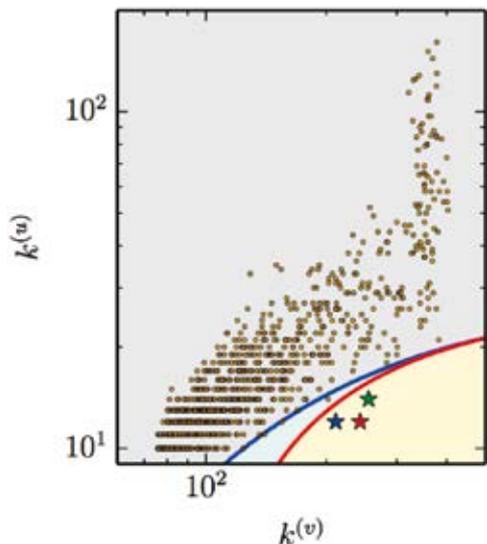


Figure 5. The red curve represents the border between stable and unstable regions in the parameter space suggested by an approximation theory. Dots and stars denote parameters confirmed to be stable and unstable, respectively, through numerical experiments.

We are also studying self-organizing advection on the network. It is known that material transport driven by advection in a continuous medium may destabilize the system. However, we were not able to verify that the advection induced destabilization in a medium with a general structure (network system). In this project, we formulated a theory that explains the destabilization and validated the theory through numerical experimentations (Fig. 6, manuscript in preparation).

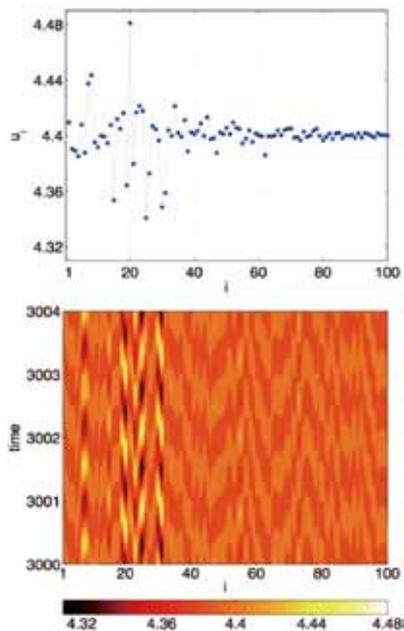


Figure 6. Example of self-organizing pattern caused by advection-induced destabilization. The horizontal axis represents network node numbers in the order of high to low advection strength.

E: Identification of biochemical processes that actually operate in the ocean

We developed a micrometabolomic method, which uses isotopic labeling and the new software MassWorks for gas chromatography/mass spectrometry (GC/MS). The amounts of samples required in this method are three or more orders of magnitude less than the amounts required for conventional methods using nuclear magnetic resonance (NMR), and thus the new method is applicable to metabolic analysis of micro samples such as microorganisms. Figure 7 illustrates a study on carbon fixation pathways in *Thermosulfidibacter takaii* cultured on a substrate of ¹³C-labeled acetic acid. Besides this example, the following two studies had been completed using the new method. In the study in which we cultured benthic foraminifers in situ using ¹⁵N-labeled acetic acid, we found that foraminifers contribute to controlling nitrogen cycles around the seafloor as they have a symbiotic relationship with denitrifying bacteria. In another study, we collected archaeobacterial mats from methane seeps in the Black Sea, separated the different layers, and analyzed each layer for the ratio of carbon isotopes in amino acids. As a result, we discovered that these archaeobacteria synthesize amino acids and lipids intracellularly using biochemical pathways totally new to science. We are currently preparing to publish these studies.

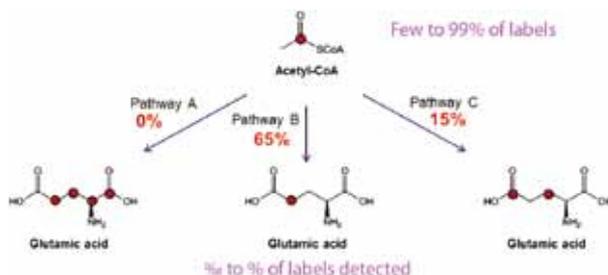


Figure 7. Carbon fixation pathways in *Thermosulfidibacter takaii* cultured on a substrate of ¹³C-labeled acetic acid

- Accumulating scientific knowledge on microbial ecosystem structures, symbiotic interactions among environment, microorganisms and macroorganisms, and evolutionary processes through exploration of extreme biospheres

A: Discovery of hadal/trench biosphere in the Mariana Trench

In the Challenger Deep of the Mariana Trench, the deepest ocean on Earth, we discovered microbial ecosystems in a hadal (depths of 6,000 m or more) water mass (an oceanic water body with relatively homogeneous temperature and salinity across it), which was clearly different from abyssal microbial ecosystems, demonstrating the existence of a unique hadal/trench biosphere. In this study, there was no apparent distinction observed between the hadal zone in the trench and the overlying abyssal zone (4,000–6,000 m deep) in terms of physical and geochemical factors such as water density, temperature, salinity and nutrient concentrations as well as abundance of microbial cells and viruses. Despite that, hadal microbial communities were distinct from those in the bathyal and abyssal zones (1000-6000m) in the

dominance of heterotrophic lineages (Fig. 8).

These results indicated that the microbial ecosystems had developed in hadal trench waters, relying on organic matters unique to the hadal environment, and provided totally new insight into marine microbial ecosystems. We also confirmed increased organic matter decomposition flux in the trench in terms of change in the composition of nitrifiers communities (Fig. 9).

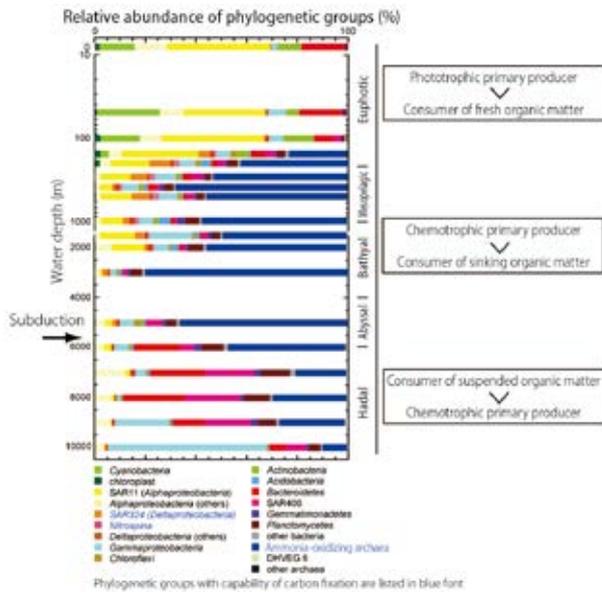


Figure 8. Microbial community structure in Challenger Deep of the Mariana Trench indicated by SSU rRNA gene tag analysis. At depths of mesopelagic through abyssal zones, phylogenetic groups with capability of carbon fixation (major lineages are listed in blue font), such as ammonia-oxidizing archaea, are dominant, while at depths of hadal zone phylogenetic groups of heterotrophs especially *Gammaproteobacteria*, *Bacteroidetes* and SAR406 are dominant.

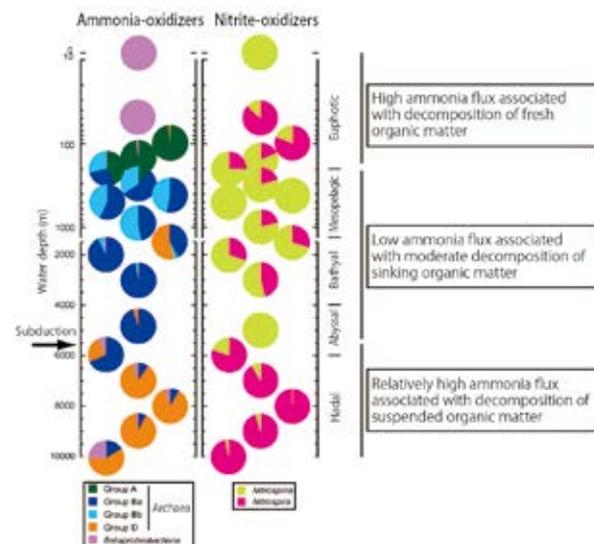


Figure 9. Change in the composition of nitrifiers communities (ammonia-oxidizing archaea and bacteria, and nitrite-oxidizing bacteria) in the Challenger Deep of the Mariana Trench. We conducted gene-level quantitative analysis on ammonia-

oxidizers (subgroups of ammonia-oxidizing archaea and the ammonia-oxidizing members of Betaproteobacteria) and nitrite-oxidizing bacteria (genera of *Nitrospina* and *Nitrospira*) detected in this sea area. The figure shows a relative abundance of phylogenetic groups at each water depth. In addition, we ranked these groups based on their preference to flux (availability) of electron donors (ammonia and nitrite). In the order of high to low fluxes, their orders are: Betaproteobacteria > Group D > Group A > Group B among ammonia-oxidizers, and *Nitrospira* > *Nitrospina* in nitrite-oxidizing bacteria.

B: World's first scientific demonstration of nutritional relationship between *Shinkaia crosnieri* and epibiotic chemosynthetic bacteria

While many deep-sea vent invertebrates associated with epibiotic chemosynthetic bacteria have been discovered around the world, the role of epibiotic bacteria, including the provision of nutrients to their host animals, had not yet been confirmed. In FY2014, we conducted studies on *Shinkaia crosnieri* (Goemon-Koshiori-Ebi in Japanese) densely inhabiting around deep-sea hydrothermal vents in the Okinawa Trough, and analyzed the role of its epibionts and the mechanism of nutrient transport to the host (*S. crosnieri*) through experiments, in which the habitat of *S. crosnieri* was recreated, and long-term rearing. Consequently, we successfully obtained direct evidence that *S. crosnieri* acquires nutrition by feeding on chemosynthetic bacteria attached to its body hair (setae).

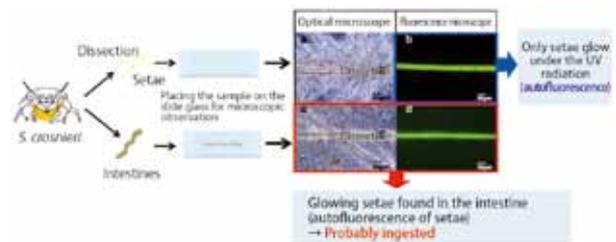


Figure 10. (a) Optical micrograph and (b) fluorescence micrograph of setae collected from the body surface of *Shinkaia crosnieri*. (c) Optical micrograph and (d) fluorescence micrograph of setae collected from intestines of *S. crosnieri*.

- Promoting better understanding of physical and chemical processes under extreme environments and demonstrating potential utility of unique biological functions through applied research

C: Identification of metabolic functions unique to (micro) organisms inhabiting extreme environments and of biological systems toward the application of biomimetics

Using micrometabolome technologies, we analyzed metabolic functions of *Thermosulfidibacter*, a thermophilic hydrogen-oxidizing bacterium which is very difficult to culture, and discovered the existence of a novel, reversible TCA cycle in the bacterium.

In addition, we started a new research project on biomimetics based on biological systems found in marine/

deep-sea organisms. In FY2014, we held a series of discussions with researchers in the Department of Mathematical Science and Advanced Technology, and decided to view the water flow systems (or internal water passages) of sponges (animals of the phylum Porifera) as an autonomous water transport network. Then, we started R&D activities aiming to identify the structure and functions of water flow systems in sponges in collaboration with other departments. From the viewpoint of biomimetics, we are interested in the following two aspects:

- 1) functions of sponges' water flow systems as related to their topological characteristics, and
- 2) mechanism to generate water flow through flagellar movements.

In FY2014, we freeze-dried sponges and took three-dimensional images of them using X-ray micro-computed tomography (Fig. 11). After statistically analyzing image information, we found that sponges' water passage networks have a power-law distribution, rather than the expected fractal distribution.

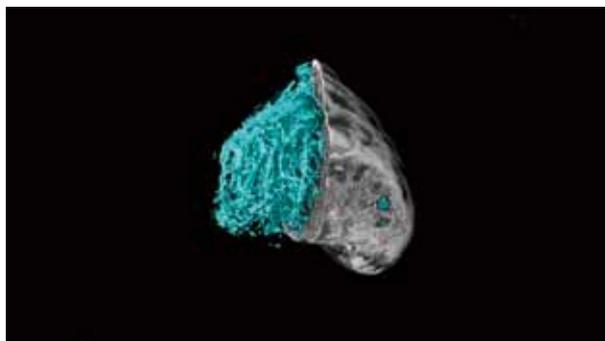


Figure 11. X-ray micro-computed tomographic image of a sponge's water flow network

In addition, we succeeded in measuring the velocity of water flowing in living sponges using magnetic resonance imaging (MRI). We also made progress in the development of a model experimental system using freshwater sponges toward visualization and quantification of flagellar movements within a choanocyte chamber. Foraminifers form a lime shell using calcium ions available in sea water. However, it is still unknown whether they actually absorb external calcium during^(a) the calcification process or they use internally stored calcium during that process. That is because it has been impossible to observe the movement of extracellular calcium with sufficient accuracy. Accordingly, we attempted to verify calcification dynamics indirectly by analyzing pH, a factor we think is important in regulation of calcification, rather than directly measuring calcium. We graphically expressed pH measurements associated with calcification and compared a spatial distribution of pH data with a proton reaction-diffusion model. As a result, we were able to confirm that the amount of protons flowing out of a foraminifer was in the same order of magnitude as the amount of lime needed for the calcification process. This result provides strong collateral evidence that foraminifers passively take in calcium from the environment using proton-calcium exchangers.

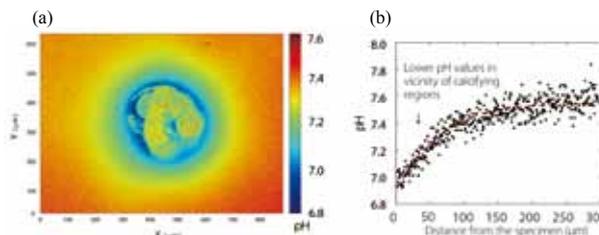


Figure 12. Analysis of pH dynamics in foraminifers. (a) Color gradient image representing pH associated with a calcification process in foraminifers. Darker shades indicate lower pH. (b) Theoretical analysis of spatial distribution of pH. Dots are experimental values and dotted line is a theoretical curve.

D: Creation of soft materials through the recreation of extreme environments and technology to search for organisms using soft materials

Until FY2013, we conducted R&D regarding “monodisperse nanodroplet generation in quenched hydrothermal solution (MAGIQ)” using unusual characteristics of high-temperature/high-pressure water associated with hydrothermal vents based on a new principle fundamentally different from the conventional one. In the conventional “top-down” emulsion process, external energies are applied to break down large oil droplets into fine ones whereas in the “bottom-up” MAGIQ emulsification, fine oil droplets are produced using a phase separation method. In FY2014, we continued R&D activities to clarify the difference between the two methods, and found that in MAGIQ, there was a good correlation between the sizes of oil droplets produced and the HLB (hydrophilic-lipophilic balance) of emulsifiers. In addition, to promote the use and popularization of this technology in the industrial sector, we are developing a prototype product of MAGIQ jointly with a private company. We are also conducting research on radical polymerization in which extremely high heat is briefly applied under high pressure. After confirming that intended reactions actually take place in the radical polymerization process, we applied for a patent. Furthermore, we developed a new polymerization device to facilitate our R&D activities. Then, we found that our polymerization method has a high potential as we were able to achieve polymerization conversion rates of 90% or higher and a narrow molecular weight distribution ($M_w/M_n \leq 1.5$) in one minute of reaction time under favorable reaction conditions.

In ultrasensitive enzymatic reaction assays using a nanofiber substrate, we developed an experimental system to identify reaction mechanisms using mathematical models, and carried out technological studies toward establishing gel surface fabrication technology to be used for the development of biomaterials.

- **Conducting research on a new source of oxygen produced by deep-sea/marine organisms and on functions of and technology to produce physiologically active substances**

E: Search for new drug-leading compounds and industrial enzymes using microorganisms originating from deep-sea/crustal samples

As many antibiotics and secondary metabolites of industrial importance have been discovered from actinomycetes, these microbes are considered to be very beneficial. We used samples taken from crusts as a source of microorganisms, and successfully isolated and cultured many new actinomycetes using an innovative culture method. One of the isolated species was found to produce a high-potency activator of anti-MRSA (Methicillin-resistant *Staphylococcus aureus*) (MRSA is a bacterium resistant to several antibiotics, posing major medical issues). In the future, we will conduct joint research with the National Institute of Infectious Diseases to pursue medical application of the newly discovered substance.

After cellulose, lignin is the second most abundant organic compound on Earth in terms of biomass. A number of countries have begun research on effective utilization of lignin because it may potentially substitute for 95% of petroleum-based chemical products due to its structural characteristics and because it has high expectations to serve as a raw material for so-called biorefineries. We discovered that a particular species of deep-sea microorganism is capable of selectively extracting phenolic monomers (compounds with a phenylpropane backbone) out of lignin (patent pending). After presenting the new technology at the meeting hosted by the Japan Science and Technology Agency, we received inquiries regarding the technology from 18 private companies.

In addition, we crystallized thermostable β -agarase (reagent enzyme commercialized by Nippon Gene Co., Ltd.) derived from deep-sea microorganisms, analyzed its three-dimensional structure using X-rays, identified its heat resistance mechanism, and published the study.

F: Efforts toward the development of deep-sea biological resources through open innovation

We have made advancement in the development of deep-sea biological resources in collaboration with industries by providing technological assistance and isolates of deep-sea microorganisms. In FY2014, we began developing a new framework allowing us to provide deep-sea samples such as sediments to external parties so that the development of deep-sea biological resources will be further accelerated through open innovation. A department in charge of industry-academia collaboration is currently formulating a system for this initiative, and the system is expected to be completed by FY2015. We are planning to start providing samples to external parties on a trial basis after the completion.

(5) Promotion of comprehensive ocean drilling science

Overview

There are five subtopics in this project. First, (a) develop technologies necessary for this project and carry out drilling research using them to address the following four main aspects: (b) formation and subduction of plates, (c) deep biospheres, (d) sediment records and (e) mantle.

Regarding the development of technologies, we developed fundamental technologies related to drilling of super hard rock formations, drilling in high temperature areas and ultra-deep drilling; developed methods for conducting high-precision and high-resolution analysis on drilling samples; and developed technologies to integrate different types of data representing a wide range of spatial scales from millimeters to kilometers. We are on schedule in terms of progress made and results produced.

As for the drilling research concerning the formation and subduction of plates, we conducted a six-month-long drilling cruise in the Ogasawara sea area after more than 10 years of planning, and obtained valuable samples and data. In addition, we proposed a new hypothesis regarding how the continentals were formed. Also, we submitted a new drilling research proposal—aiming to unveil the history of earthquakes having occurred off the Sanriku coast in the Tohoku region—to the International Ocean Discovery Program (IODP). Moreover, we developed a new analysis method that combined trace element/isotope analyses and equilibrium model calculations, to assess temperature conditions of frictional heat generated by seismic slip that occurred in the Nankai Trough subduction zone.

With respect to the drilling research concerning deep biospheres, we conducted interdisciplinary research to elucidate relationships between life activities under the seafloor and water/carbon/energy cycles, making full use of various fundamental technologies for deep-sea surveys and advanced analyses including the deep-sea drilling vessel *Chikyu*. Then, we published a paper demonstrating the existence of ultralow-temperature biospheres in oxygen-filled sediments lying immediately above the oceanic crust (i.e., basaltic basement). These biospheres occur in about 40% of the seafloor worldwide. In addition, we internationally presented our scientific achievements made in the past 10 years in connection with the IODP through different means including publishing a book that compiled these achievements. We also submitted a new drilling research proposal which received the highest compliments.

Regarding the drilling research concerning sediment records, we led the formulation of three new drilling research proposals. We are also making good progress in studies toward reconstructing paleoenvironments and understanding deep earth dynamics using drilling samples, and in the development of new research methods.

In regard to the drilling research concerning mantle, to understand the relationship between mantle convection and plate motion, we made advancement in the study on deep earth structures from the viewpoints of both materials science and geophysics, and interpreted the data using numerical simulations. Consequently, we found that mantle convection associated with cold plume formation under continents is consistent with the current arrangement of continents and the

density anomaly determined by tomography. Hence, we are ahead of schedule in terms of progress and accomplishments made.

(a) Investigation into dynamics of crustal activities and material cycles using drilling samples and drilling holes

This subtopic has three main objectives. Summaries of these objectives and the current status of progress are described below.

(1) Development of methods for high-precision and high-resolution analyses on samples and data representing varying scales

We developed a high-precision and a high-resolution isotope analysis method for analyzing material cycles and elementary processes associated with earthquake faults, global changes and magma using drilling samples. By developing this method, we established basic technology for high-precision rapid analysis of boron isotopes and high-precision analysis of local lead isotopes, which are useful in research on ocean acidification and fluid–rock interactions, using a multiple collector inductively coupled plasma mass spectrometer (MC-ICP-MS) and other devices. We also formulated new indicators of ocean general circulations based on high-precision copper isotope analyses (Fig. 1). In the development of the latter method, we created isotope imaging technology using a newly acquired nano secondary ion mass spectrometer (NanoSIMS) with the vision of developing an advanced microscopic regions analytical system which seamlessly covers spatial range as small as submicron. These achievements exceeded targets set in the study plans.

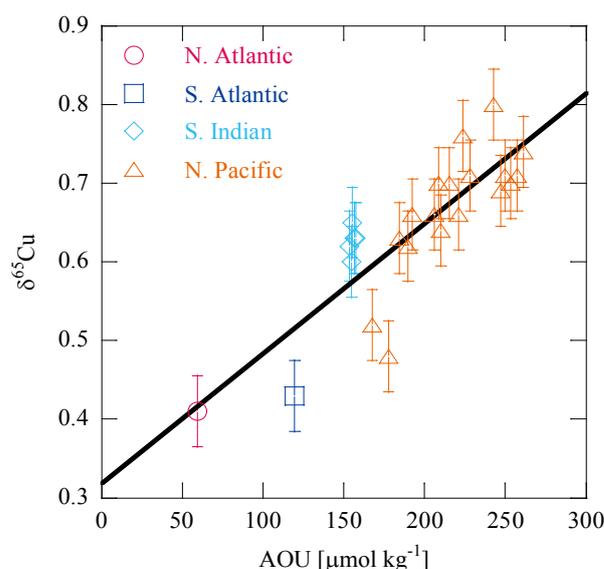


Figure 1. High-precision isotope analysis using a small amount of copper

(2) Development of fundamental technologies enabling the creation of drilling, measurement and deep-sea drilling technologies

To ensure *Chikyu's* safe and efficient scientific drilling operations, we developed technologies related to drilling operations, devices and systems, and gathered knowledge contributing to efficient maintenance and management of the whole system including the body of the vessel. Specifically, we enhanced the durability of the high-functionality, mud-water-driven core barrel (a part of a turbine driven coring system (TDCS)) to be used for drilling of super hard rock formations and drilling in high temperature areas, and evaluated its performance. As a result, TDCS is now ready for tests in offshore operations. In addition, we collected strength data for aluminum drill pipes to be used for ultra-deep drilling and created design tools. We also built a prototype of a lightweight riser tube using a new material to be used for ultra-deep drilling, and evaluated its performance in small-scale tests. Furthermore, we prepared equipment to be used for the development of a system for long-term borehole monitoring to be set in the Nankai Trough, and tested it on land. These technologies were developed as planned.

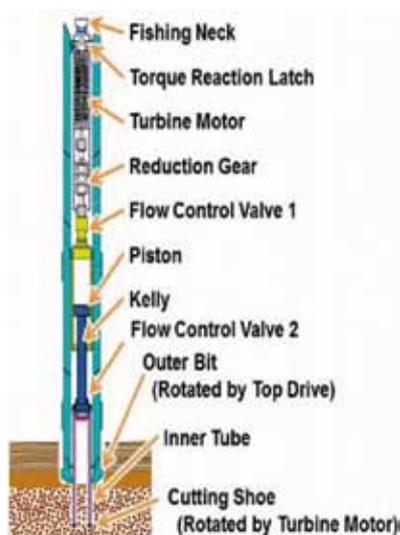


Figure 2. Schematic of a turbine driven coring system (TDCS)

(3) Development of technology to integrate different types of data for understanding of sub-seafloor structure and characteristics at multiple levels

We studied data processing methods enabling the scientific use of drilling information, studied advanced use of drilled cuttings and mud logging, and developed equipment related to these activities. Specifically, we developed methods to analyze and utilize mechanical specific energy data obtained from drilling to optimize real-time monitoring of drilling performance using *Chikyu*. We also submitted a proposal to IODP, aiming to conduct in-situ experiments to understand the physical properties of formations using real-time drilling data. In addition, we are making progress with data processing/analysis methods to comprehensively integrate and interpret

data on drill cuttings/core samples, logging and seismic waves, ranging from millimeters to kilometers in spatial scale. Then, we will apply these methods to analyze drilling data collected during the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) (Fig. 3).

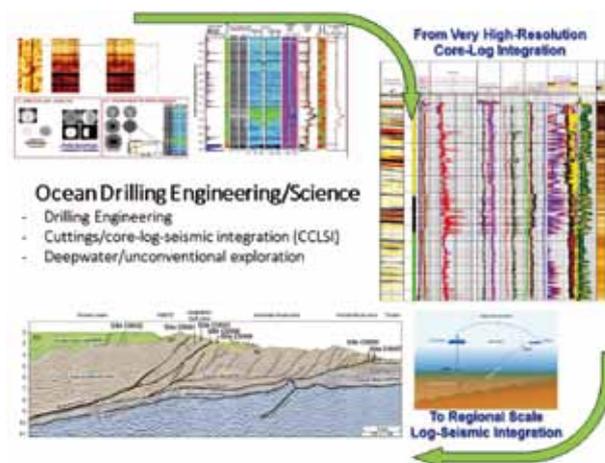


Figure 3. Conceptual diagram illustrating cuttings/core-log-seismic integration (CCLSI)

Moreover, we carried out various tests and technological feasibility research to realize deep sea/ultra-deep drilling (e.g., drilling in the IBM arc and mantle drilling) in collaboration with industries. These R&D activities were completed as planned.

The R&D for this subtopic was implemented in coordination among JAMSTEC departments (Research and Development Center for Ocean Drilling Science, Center for Deep Earth Exploration, and Kochi Institute for Core Sample Research) and in collaboration with drilling-related industries (Mitsubishi Heavy Industries, Schlumberger, Total S.A. and Shell, etc.), domestic industries (Mitsubishi Rayon, Mitsubishi Heavy Industries and NLC) and other research institutes (University of Tokyo, Kyoto University, Kochi University and AIST, etc.).

As stated above, the implementation of the mid-term plan and the plans for FY2014 is mostly on schedule, and we carried out a part of FY2015 activities ahead of schedule.

Our research results had a global impact on the R&D related to high-precision analyses. However, the underlying purpose of subtopics (b) through (e) is to develop fundamental technologies that promote research activities. As such, our intention is not necessarily to produce high-impact results by ourselves.

We publicized our results via press releases posted on the JAMSTEC website and through other means. The world-class deep-sea riser drilling technology installed on *Chikyu* has been recognized as essential technology to Japan, and contributed to the realization of deep sea/ultra-deep drilling, which is expected to increase in the form of joint projects with industries and other research institutes. We also contributed to fostering skilled employees in JAMSTEC and other organizations by offering courses to teach how to use fundamental technologies (Core School, etc.).

(b) Investigation into formation and change processes of oceanic/continental plates and magma

The summary and the current status of progress of this subtopic are described below.

(1) Comprehensive understanding of island-arc evolution and the origin of continental crust

We carried out three IODP drilling cruises (Exp. 350, 351 and 352) in the Izu-Bonin-Mariana (IBM) arc for a total duration of six months using *JOIDES Resolution* (JR), and completed most core sampling and logging scheduled (Fig. 4). We spent more than 10 years planning and formulating a study proposal before implementing this drilling project. We hope that this project will make a great impact globally.

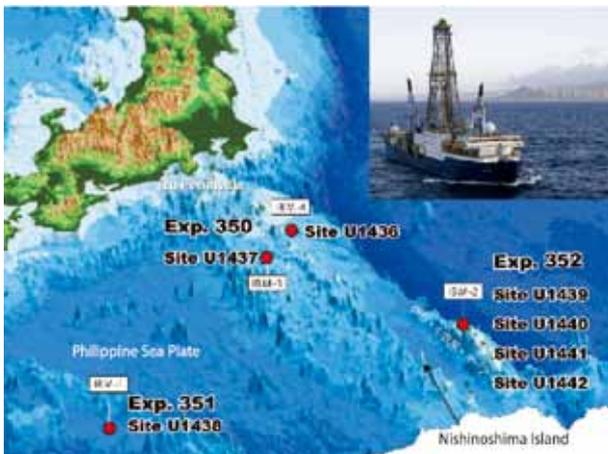


Figure 4. Sites at which drilling took place during the 350th, 351st and 352nd IODP cruises

Furthermore, we put forward a novel hypothesis regarding continental formation processes, and implemented the “Tairiku Project” around Nishinoshima Island in order to test the hypothesis. As a part of this project, we created an unmanned research vehicle jointly with the Marine Technology and Engineering Center and Tokyo University of Marine Science and Technology to collect lava samples on erupting Nishinoshima Island.

(2) Identification of plate structure and changes in crustal and mantle structures

To study the deformation structure on the edge of the Japan Trench axis, we mapped the shallowest part in the focal area of the Great East Japan Earthquake and the focal area of the 1933 Sanriku earthquake. This deformation structure is related to the thickness of sedimentary layers on the Pacific Plate, distribution/relative elevation of bent faults, and the development of a fault zone. Based on these accomplishments, we submitted a new JTRACK proposal aiming to identify characteristics of substances present in young faults, to reveal the history of earthquakes through drilling along the trench axis, and to determine the extent of faults across a wide area.

We successfully developed a system enabling measuring

physical properties of riser drill cutting samples, such as stress-strain curves, strength and elastic modulus which are essential in rheological analysis. Moreover, we succeeded in measuring elastic wave velocity by developing and using an elastic wave velocity measurement system integrated with high-frequency piezoelectric elements and high-voltage pulsars (Figs. 5 and 6).

It has been confirmed that frictional heat was generated when seismic slip occurred in slip zones of mega splay faults, which were discovered during the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE). However, opinions had been divided regarding the temperature conditions of frictional heat. Consequently, we developed a new analysis method which combined trace element/isotope analyses, equilibrium model calculations, and reaction kinetics calculations. The analysis indicated that fluid–rock interactions took place at 250°C or lower in the faults when the earthquake occurred.

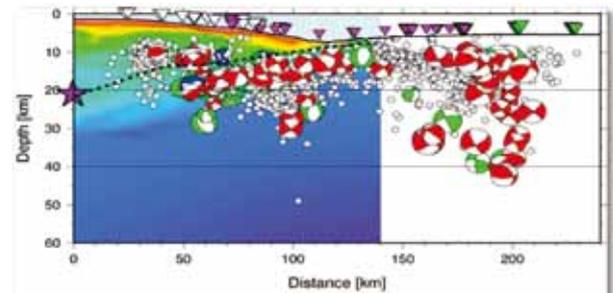


Figure 5. Velocity structure and hypocenter distribution mechanism around the Japan Trench

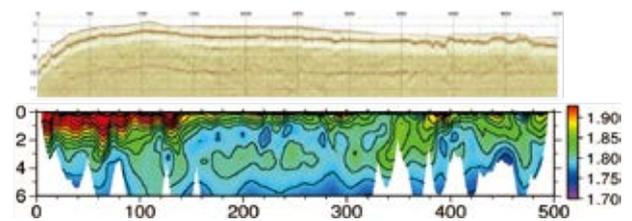


Figure 6. Multi-channel seismic (MCS) cross section of the Japan Trench as viewed from the seaward side and changes in crustal and mantle structures (V_p/V_s)

(c) Studies on relationships between life activities under the seafloor and water/carbon/energy cycles

To understand relationships between life activities under the seafloor, which are referred to as Earth’s last biosphere frontier, and water/carbon/energy cycles, we actively promoted ocean drilling science in the international framework using the deep-sea drilling vessel *Chikyu*, and carried out interdisciplinary research making full use of various JAMSTEC-owned fundamental technologies for deep-sea surveys and advanced analyses in a synergic manner.

To implement this subtopic, we developed a method to sensitively and accurately evaluate life signals in geological samples taken from sediments and rocks using new analysis technologies, and successfully developed technologies enabling ultra-sensitive, high-precision cell counting,

selective cell sorting/analysis, and quantitative evaluation of the F430 biomarker serving as a methane production indicator. These capabilities allow us to evaluate the physical limits of biospheres. By applying these advanced analysis technologies to core samples taken in IODP and other projects, the following kinds of studies can be carried out: determining the relationship between advection of deep-seated fluids resulting from plate activities and life activities; identifying the physical limits of biospheres existing below the seafloor; determining relationships between sub-seafloor biospheres and physicochemical/thermodynamic environmental factors that regulate ecosystem functions in terms of carbon cycle; exploring the precise picture of global-scale sub-seafloor biospheres existing in continental coastal areas, oceanic sediments and oceanic crusts; and determining the role of these biospheres in element cycles. These studies may address several propositions of great scientific significance. Consequently, scientists developed a novel academic theory leading to major advancement of scientific understanding and a paradigm shift (Fig. 7). Furthermore, studies in which the oceanic crust environment in early Earth was experimentally recreated produced important scientific knowledge related to principles/phenomena involved in the transition from abiotic molecular evolution to biotic evolution, and related to global carbon cycle flux in the atmosphere and oceans in primitive Earth.

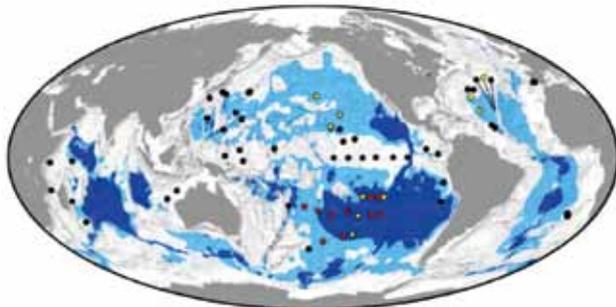


Figure 7. Dark blue: areas where oxygen has highly likely penetrated down to the basaltic basement. Light blue: areas where oxygen has likely penetrated down to the basaltic basement. Dots: drilling survey sites.

We organically integrated a wide range of data collected in the abovementioned R&D activities and came up with a theory. While we are still preparing a manuscript about the theory for publication, a part of the study has already been accepted and published in major scientific journals including *Nature Geoscience* in FY2014. The article has been highly received worldwide. In addition, in efforts to contribute widely to society through research, we released explanatory articles on and summaries (in Japanese) of the studies under this subtopic to the general public through press releases, lectures to the public and outreach activities. We also compiled our scientific achievements made in the past 10 years in connection with the IODP program into an over-800-page review book and it was published by Elsevier B.V.

Furthermore, to promote scientific ocean drilling using *Chikyu*, JAMSTEC researchers engaging in these studies played a vital role in formulating proposals for several IODP drilling projects such as “Constraining the temperature limit of the microbial deep biosphere in the Nankai Trough subseafloor (Fig. 8),” which received highest praises from the IODP Science Evaluation Panel (SEP) and external parties, “Deep biosphere secrets of the Mediterranean salt giant (DREAM),” and “Lord Howe Rise project.”

We steadily implemented the plans for FY2014 and made scientifically significant accomplishments. We also formulated a new academic theory and made discoveries using advanced analysis technologies we developed and based on implicit data. These achievements may lead to outstanding results in these R&D activities.

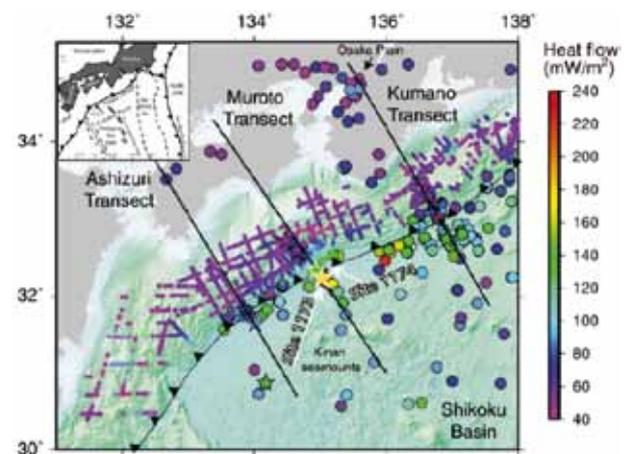


Figure 8. Proposed drilling sites (marked with stars) for the drilling surveys to identify the physical limits of the biosphere off the coast of Cape Muroto

(d) Investigation into historical events on Earth using sediment records

(1) Formulation of drilling research proposals and preparations therefor

We submitted a preliminary proposal for the drilling project to be conducted in the Mediterranean Sea. Subsequently, the SEP granted us to draw up a full proposal. In addition, we held a workshop for Japanese and European researchers to discuss the formulation of proposals for studies on halite sediments and microorganisms.

Regarding the drilling study in the Bright Basin, South Australia, concerning an ocean anoxic event in the Cretaceous, we wrote and submitted a preliminary proposal, revised the proposal based on comments received from the SEP, and resubmitted it.

We also submitted a preliminary proposal for the Lord Howe Rise project, after attending the workshop in April 2015 and discussing the scientific significance of this project. Through these activities, we implemented proposal formulation as initially planned.

(2) Studies toward reconstructing paleoenvironments and understanding deep earth dynamics using drilling samples

Regarding the studies of drilling samples, we wrote papers for publication on studies conducted at the exit of the Mediterranean Sea and in the Antarctic Ocean, and released the studies to the press. Also, we were nearly on schedule in conducting comprehensive chemical composition analysis of marine sediments in the Pacific Ocean, preparing for drilling surveys in Lake Suigetsu, and studying deep earth dynamics that affect long-term climate changes.

(3) Development of research methodologies

We were on schedule in developing new methodologies for the measurement of trace gases and isotopes by mid-infrared lasers (Fig. 9) and for high-precision analysis of heavy isotopes.

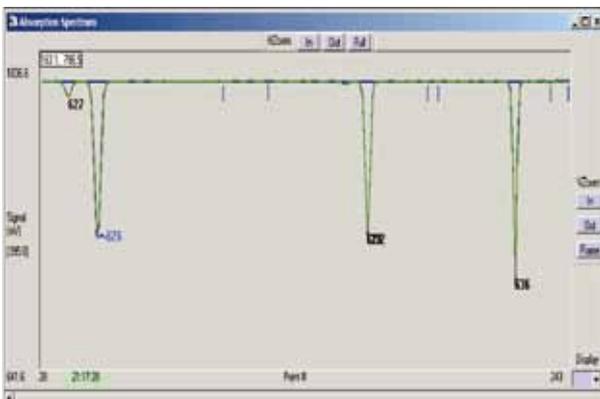


Figure 9. Mid-infrared spectra of carbon dioxide gas

(e) Investigation into unexplored deep Earth dynamics using drilling science

We made progress in the study of deep Earth structure in terms of both materials science and geophysics, and conducted simulations to understand how that structure interacts with mantle convection/plate motion. Specifically, we (1) mapped the mantle composition structure in detail in the Eastern and Western Hemispheres based on erupted basalts, (2) performed seismic wave/electromagnetic imaging of the mantle, especially of that in the plume upwelling areas in the South Pacific Ocean, (3) conducted numerical simulations of mantle convection including continental drift and water transport, (4) performed experiments under high pressure to study physical properties at great depths and carried out basic research to understand physical properties, and (5) prepared for and conducted ocean and land surveys related to oceanic plate structures (e.g., water content and its distribution). As a result, we made the following four major accomplishments.

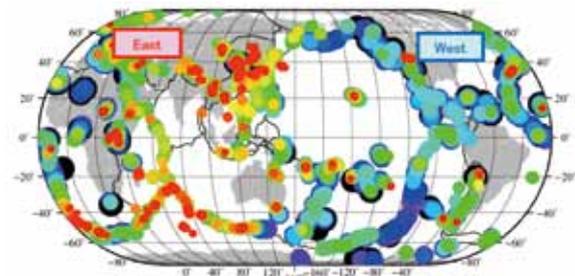


Figure 10. Chemical composition of mantle

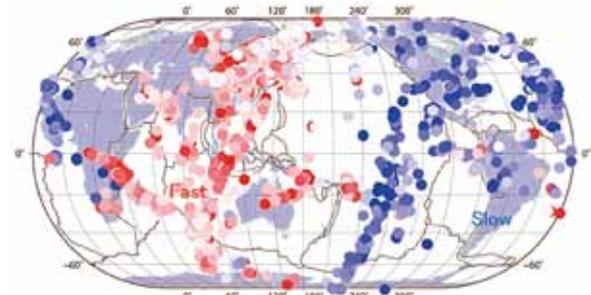


Figure 11. Seismic wave velocity in the inner core

(A) We found that mantle in the Eastern Hemisphere (whose border runs closely to the international date line) is rich in hydrophilic components that had been delivered by focused subduction towards the supercontinents which existed broadly in the Eastern Hemisphere between 250 and 900 million years ago. Furthermore, we discovered that this hemispherical geometry is very similar to the seismic wave velocity structure in the inner core. Based on these observations, we propose that the supercontinents control the spatial pattern of mantle convection which may directly affect the Earth’s core, and termed the model “top-down hemispherical dynamics” (Figs. 10 and 11). This achievement exceeded expectations with respect to the plans for FY2014.

(B) For the first time in the world, we successfully detected a large and vertically-extending low electrical resistivity structure, which is thought to be associated with a plume, in the area with concentrated hotspots in the South Pacific Ocean (Fig. 12). Because this structure is connected to a large area of the lower mantle where seismic waves are propagated slowly, we presume that the upwelling mantle originating from the greatest depth branches at a depth of about 1,000 km and provides heat and materials to the hotspots.

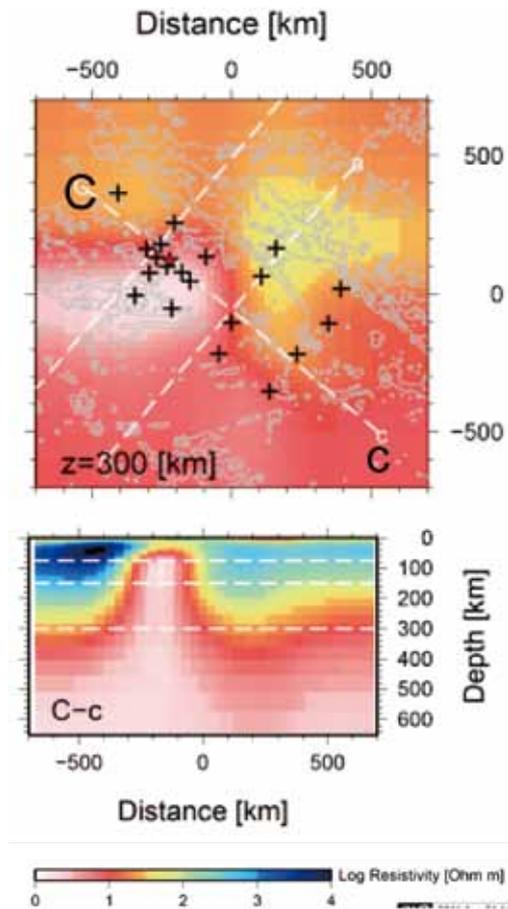


Figure 12. Electrical resistivity distribution of hotspots in the Tahiti area resulting from electromagnetic tomography. Top: horizontal section view at a depth of 300 km. Bottom: vertical section view along the C-c line shown in the top diagram.

(C) We simulated the relationship between continental drift/plate motion and mantle convection, focusing primarily on reproducing fast movement of the Indian subcontinent. As a result, we found that mantle convection associated with cold plume formation under continents is consistent with the current arrangement of continents and the density anomaly determined by tomography. In addition, we developed the first simulation model capable of taking into account the assumption that water brought into magma via subducted slab reduces the density and viscosity of the magma. The simulation suggested that water may have played a vital role in the formation of stagnant slab, expansion of back-arc basins, and even 4.5 billion years of Earth's heat budget. This project is also advancing ahead of schedule.

(D) We developed an experiment system capable of recreating high temperature/pressure conditions corresponding to those of mantle, and measured physical and optical properties of diamond under high pressure. We presented results on new pressure indicators that we formulated through experiments conducted under high pressure and results contributing to the analysis of natural specimens.

(6) Research and development on advanced synthetic information science

Overview

In R&D on advanced synthetic information science, we are utilizing the knowledge we have obtained from an interdisciplinary perspective, making full use of the Earth Simulator. In addition, we will continue to expand and develop knowledge and promote the application of advanced synthetic information science in marine and earth sciences to find sound actions and solutions for the betterment of the future.

We are also conducting R&D to develop technology for creating value-added information usable by society, and building global environmental information infrastructure to pass on information to society in an extensive, easy-to-understand and effective manner. To achieve these, we are working on the following three specific projects:

- (a) R&D of advanced process models
- (b) Establishment of large-scale simulation technology for creating advanced information
- (c) R&D for integrating and synthesizing data/information and dissemination of information to society

The research implementation system for this project is operating on the premise to work in cross-organizational coordination, and the system has been contributing to producing results in advanced process research, large-scale simulations and creating value-added information. Also, regarding coordination with non-JAMSTEC organizations, the research implementation system has been used for exchanging information and conducting joint model development with universities and research institutes in Japan and overseas. We are also considering applying research products in society in coordination with the industrial sector including autonomous bodies and people involved in fisheries industries.

(a) R&D of advanced process models

Advanced process models are used to accurately predict various phenomena at different scales. Through a mathematical science-based interdisciplinary approach, we are developing advanced mathematical and physical models and simulation methods while considering individual problems as one integrated problem. In addition, we are conducting R&D to improve the reliability of the developed model by carrying out numerical experiments using the model and by evaluating the repeatability of each process through demonstrative tests.

During FY2014, we developed a phase synchronization model simulating oscillatory convection of geophysical fluids as an advanced process model, introduced two phase parameters—space and time—for the modeling of progressive oscillatory waves such as Rossby waves, and theoretically demonstrated that these parameters can be described by ordinary differential equations. The theory we built, which leads to understanding of phase synchronization phenomena occurring in geophysical fluids, received great responses from relevant academic societies.

In addition, to address the effect of city-block-sized

green spaces, which may serve as potential urban oases, on the thermal environment, we developed an advanced tree model (ultra-high-resolution simulation of urban thermal environment) taking into account turbulence and three-dimensional radiation. Then, we successfully reproduced the mechanism of courtyard trees lowering ambient temperature by analyzing the thermal environment surrounding Marunouchi Park Building (Fig. 1). The high-resolution simulation model capable of replicating meteorological phenomena in urban areas may contribute to the evaluation of tree effects in urban areas and the understanding of the mechanism behind the occurrence of severe rainfall, which are of great social interest. As such, we issued a press release on this subject.

Furthermore, with the aim of creating a world-level simulation in terms of detailed processes, we developed an aerosol two-dimensional bin module for formation and aging simulation (ATRAS) and validated the model using observational data collected in the eastern Asia region. As a result, we are now able to evaluate the effect of aerosols on solar radiation more adequately taking into account particle size and the state of aerosol mixture (Fig. 2).

We developed these creative new models, we are making steady progress in R&D for achieving high accuracy, and we demonstrated oscillation characteristics of geophysical fluids. In addition, to comply with the Science Council of Japan's recommendations, we submitted our data for urban thermal and wind simulations as scientific evidence.

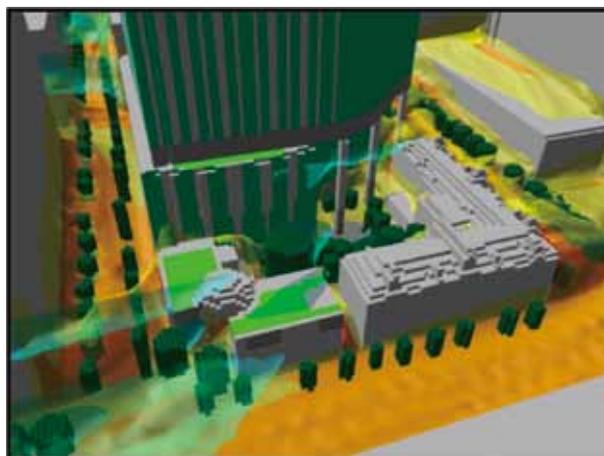


Figure 1. Outcome of simulating the three-dimensional distribution of ambient temperature. The effects of radiative cooling and transpiration are contributing to lowering air temperature.

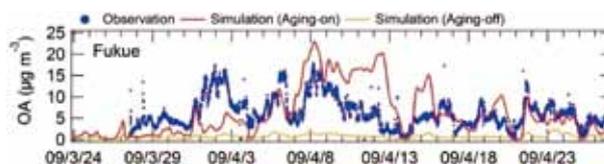


Figure 2. Concentrations of organic aerosols on Fukuejima Island. Observed high aerosol concentrations were more accurately simulated when the state of aerosol mixture was adequately taken into account.

(b) Development of large-scale simulation technology for creating advanced information

We are developing large-scale simulation technology for creating advanced information with the purposes of producing integrated knowledge and information related to marine and earth sciences. Our goal is to develop technologies for large-scale numerical simulation as well as integrated data processing and analysis using observational data, which can provide useful information to society.

As a step toward developing a large-scale simulation for passing on useful information to society, in FY2014, we analyzed data from ensemble experiments using a high-resolution nonhydrostatic icosahedral atmospheric model (NICAM), and demonstrated that the simulation might be capable of one-month forecasting of Madden-Julian oscillation events and two-week forecasting of typhoon formations (Fig. 3). These research results were reported in a number of newspapers and web media as valuable accomplishments for society.

As for the development of global chemical transport models taking into account atmospheric water-soluble organic nitrogen and iron emitted through combustion processes, we

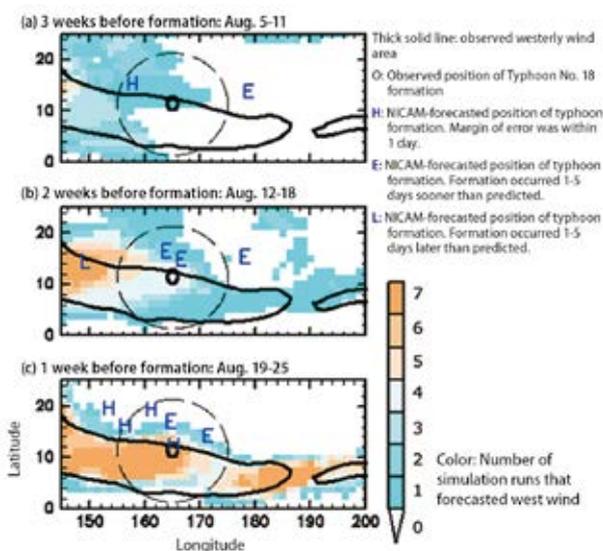


Figure 3. Results of seven forecast experiments focusing on Typhoon No. 18 of 2004. About 3 weeks (top), 2 weeks (middle), and 1 week (bottom) before typhoon formation were set as starting points.

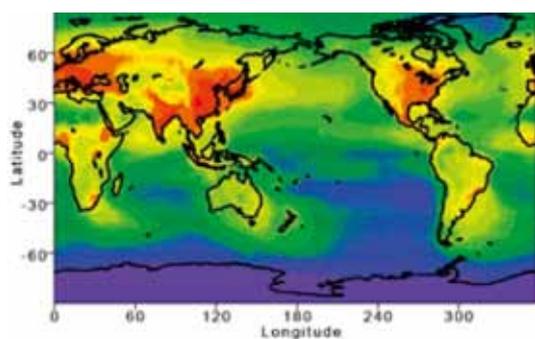


Figure 4. Increased amount of water-soluble organic nitrogen supply due to its input from atmosphere (A total of 3.5 Tg N yr⁻¹ increase compared to pre-industrial revolution era).

developed a global aerosol-chemical transport model taking into account organic nitrogen, and evaluated the flux of organic nitrogen entering oceans. Through these activities, we found that atmospheric pollutants in East Asia may be an important source of water-soluble organic nitrogen entering oceans from the atmosphere (Fig. 4).

In addition, with regard to the development of SAR satellite data simulators, we succeeded in quantitative evaluation of spectral shapes in a high-frequency range, which had been impossible, by adding a new energy source term into a numerical ocean wave model. After this breakthrough, we were able to develop a prototype numerical model simulating SAR satellite data and validate the large-scale simulation (Fig. 5).

We actively presented these scientifically significant results in the forms of publications (31 research papers), most of which appeared in international journals, and presentations at scientific meetings (72 presentations). As an example, one study dealt with release of dinitrogen monoxide (N₂O), a major long-lived greenhouse gas. The results of this study, in combination with highly-accurate observations, will contribute to the understanding of N₂O dynamics and thus IPCC activities. It is also hoped that the results will lead to narrowing the uncertainties in future climate change projection, and evaluating the impact of human activities on biogeochemical cycles on the Earth's surface.

We have begun providing climate experiment data, including those by NICAM, to domestic and international research communities such as the Program for Risk Information on Climate Change, thereby contributing to creating information on global warming. Also, regarding the development of the software Volume Data Visualizer for Google Earth (VDVGE), its use at universities and research institutes is expanding since its release. In the aspect of projection and risk assessment of climate change, we are making efforts in public relation activities by, e.g., holding a symposium for the general public in September and hosting an international workshop for experts in November. Also we are contributing to society through research by providing information on disaster forecast and prevention (based on a regional coupled ocean-atmosphere model) in an understandable manner for the public using three-dimensional visual contents.

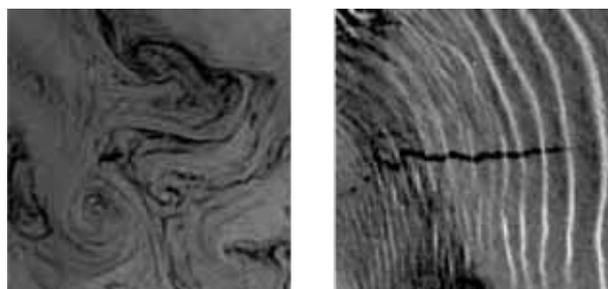


Figure 5. An example of SAR satellite imagery showing modulation of sea ripples (ERS-1 SAR ESA©). We determined the energy spectrum of ripples with wavelengths less than 50 cm, which had been unknown to exist, through observation and simulations.

(c) R&D for integrating and synthesizing data/information and dissemination of information to society

In this project, in order to create scientifically beneficial integrated information and value-added information usable by society, we are aiming to conduct R&D of technology needed for practical products such as data assimilation and visualization methods. We are also conducting fundamental study on concrete methods to pass on integrated and synthesized data such as observation, simulations and forecasts as well as value-added information to society in an extensive, easy-to-understand and effective manner.

In FY2014, as a part of R&D efforts to achieve data assimilation through integration of observational data and simulations, we considered atmospheric chemical reactions and developed an extended global data assimilation system for atmospheric tracer components, capable of simultaneously assimilating data of several different atmospheric pollutants (Fig.6). We also made progress in data integration and synthesis as we successfully forecasted the El Nino Modoki phenomenon using a coupled ocean-atmosphere prediction system.

With respect to the use of integrated and synthesized data, we produced value-added information related to fishery resources focusing on *Ommastrephes bartramii* (neon flying squid) by using high-resolution data. We also built a system to deliver information on predicted fishing grounds (Fig. 7) and identified the mechanism of neon flying squid resource fluctuation. By actually delivering fishing ground information to people involved in fisheries industries using this system, we paved the way for contributing to the field of fisheries.

Moreover, in order to transmit information on the atmospheric forecast, we developed a method to realistically visualize detailed three-dimensional large-scale data. This method enabled us to represent clouds realistically by combining two physical quantities, which are the downward shortwave radiation and the cloud content, computed in weather simulations (Fig. 8). Consequently, we succeeded in representing the three-dimensional structure of clouds more clearly in Google Earth and in observing it while operating interactively (patent pending).

Regarding the efforts to contribute to society through research, results produced by the Research Program on Climate Change Adaptation (RECCA) have been incorporated into climatic warming countermeasures formulated in Aomori, Toyama and Nagano Prefectures. In addition, concerning the system to deliver information on predicted fishing grounds for neon flying squid, we added extra values to simulation research, and included marine information service, which takes care of all processes up to information delivery, into the system, making it a package. Furthermore, we are steadily distributing our research accomplishments externally by posting experimental forecasts of real-time ocean-atmosphere variability on the website and by making press releases on research accomplishments open to the general public.

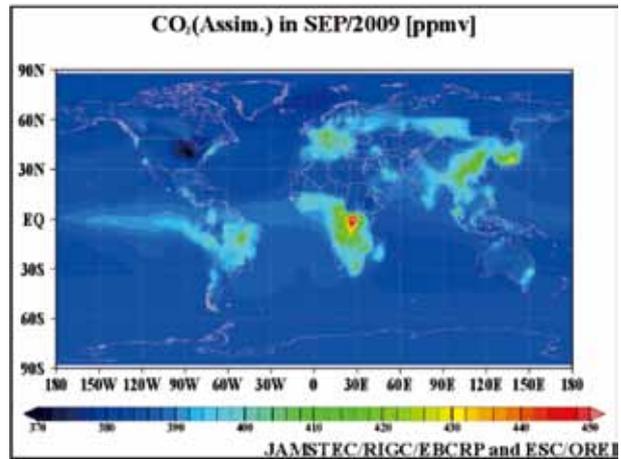


Figure 6. Global chemical weather forecast system compatible with assimilated greenhouse gas datasets and radioactive materials

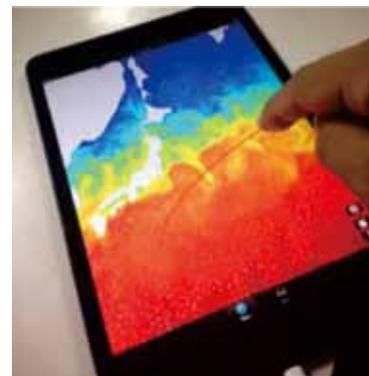


Figure 7. Development of an application enabling users to intuitively control the display while viewing oceanographic information



Figure 8. Display of realistic clouds. Left: only cloud water content data was used; right: downward shortwave radiation data was added.

(7) Construction of a research and development base for opening up ocean frontiers

Overview

In ocean R&D, developing more advanced ships, ocean observation networks, and observation equipment for obtaining various data is essential to developing a comprehensive understanding of the vast ocean space and is an extremely important part of advancing Japan's marine science and technology. Accordingly, as well as developing cutting-edge key technology that will enable humankind to take on the challenge of opening up unexplored frontiers and cultivating new fields, JAMSTEC is undertaking proactive, cross-cutting efforts to build a research base to open up ocean frontiers by making full use of these technologies, so that we can promote R&D of submarine resources, marine and global environmental change, seismogenic zones, and marine biosciences and engineering.

Specifically, deep sea investigation systems, such as manned submersibles and remotely operated vehicles are essential key technologies for conducting R&D, so as well as making these more advanced and developing the necessary elemental technologies, JAMSTEC has set a five-year medium-term goal of establishing operation technologies for each system, with the aim of promoting more effective observation and surveys (Fig. 1).

In FY2014, the first year of this medium-term plan, JAMSTEC divided this topic into three subtopics – (a), (b), and (c) – according to their objective, and put together a roadmap for each one, having clarified the requisite actions and outcomes. Based on the new framework, JAMSTEC's technology development departments began working closely together on these technology R&D projects.

In the case of (a) Research and Development on Ocean Technology, development of the individual elemental technologies is underway and the construction of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) is also proceeding smoothly. Regarding

(b) Development of highly accurate and highly efficient Observation Systems, technology development aimed at creating more advanced AUVs and ROVs is progressing and we are endeavoring to make a contribution to society by feeding back the fruits of our research through the commercialization of inertial navigation systems and items made using JAMSTEC-developed fabrication techniques that have won awards from external organizations. In the area of (c) More Advanced, Higher Efficiency Operation Technology, we are testing the systems that have been developed, in order to develop practical applications for them, conducting numerical analysis in conjunction with this process. We are progressively applying the technologies developed to front-line research.

The following provides a detailed explanation of our achievements in regard to each subtopic.

(a) Research and Development on Ocean Technology

This subtopic focuses on R&D of advanced technology to facilitate the construction of high-precision, efficient observation and survey systems, such as advanced elemental technologies for acoustic/compensatory communication systems, measurement/sensing, positioning, detection/identification, monitoring, sample recovery, and analysis; energy systems required for long-term operation of exploration and observation systems; and technologies associated with the installation of observation sensors and platforms for conducting surveys and observation of the deep ocean floor.

JAMSTEC carried out the following activities in FY2014.

In the area of developing systems for environmental measurement in deep-sea environments, reducing environments, and experimental tanks, as well as developing various sensors, we have made a prototype reusable deep-sea LED light that consumes little power and is suitable for long-term use on

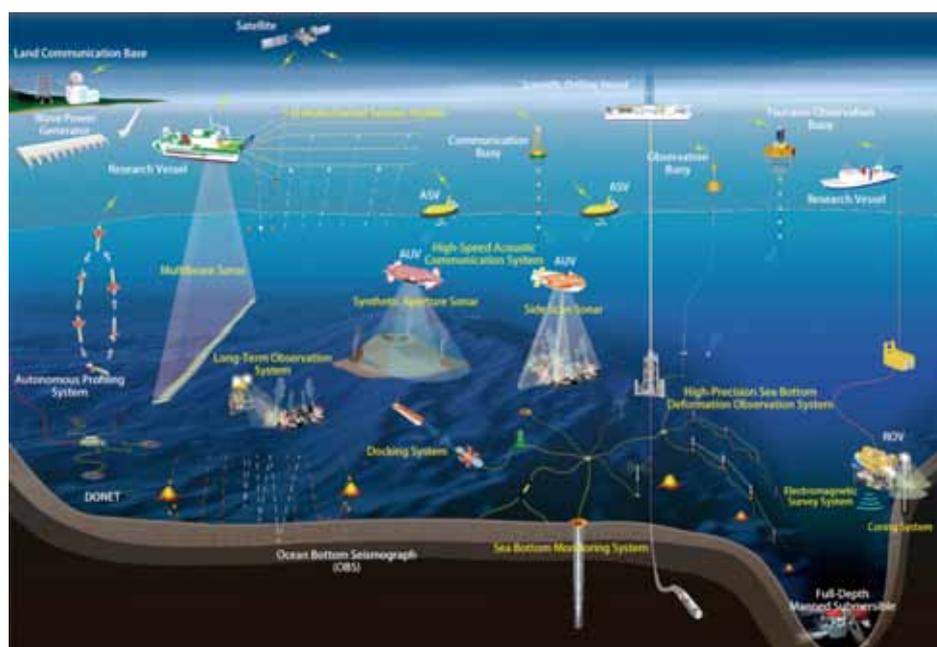


Figure 1. Illustration of an exploration system

the deep ocean floor, more than 10,000 m below sea level. Our objective in doing so is to develop a small lander to carry out surveys and observation. We have introduced a methane concentration sensor to facilitate comprehensive in site measurement in marine and submarine environments.

Regarding the development of chemosynthetic culture systems that reconstruct environments of the hydrothermal vent and methane seepage, with the aim of maintaining biological test samples, we succeeded in culturing *Calyptogen* clams for 129 days by applying a laboratory culturing technique involving the addition of hydrogen sulfide. We identified that the pressure of culture conditions should be considered in future study to rearing chemosynthetic organisms for longer periods.

In the area of developing in-situ biopsy systems for the non-lethal collection of biogenic samples from large organisms, we have begun selecting needle tip shapes and designing tissue samplers. As part of our development of bio-tracking systems for tracking the behavior of marine organisms, we have created a prototype pinger.

Regarding R&D of technology that uses acoustic and electromagnetic waves, such as ISSBL, underwater laser, and new means of communication, we have examined analytical programs for use in acoustic source tracking technology and have begun preparing test instruments.

In our efforts to develop advanced field measurement technologies, such as imaging devices, flow analyzers, and automatic CO₂ measuring apparatus, we have made progress with the development of a hybrid pH-CO₂ sensor (Fig. 2) that we anticipate will become standardized, and have successfully used it to obtain data in actual ocean environments. Moreover, regarding the development of marine species recognition techniques using image processing, we have begun developing benthic organism habitat mapping techniques, and have carried out preparations for system design and manufacture. We have also investigated basic technologies for enabling ROV to navigate the seafloor by means of positioning data from video camera images and identified future research topics by analyzing sample images.

In regard to marine and deep-sea energy technology R&D, we have conducted model experiments using a compact wave power generation system fitted to a buoy, and have gained an understanding of basic attributes, such as wave height in an air chamber. With regard to elemental technologies for next-generation platforms, we obtained basic data concerning the



Figure 2. Hybrid CO₂ sensor (outlined in red) fitted to the *Kaiko 7000 II*

attributes of the unit using a model based on the *Otohome* AUV and measured marine test data from the actual vehicle. Moreover, as part of our development of pressure-resistant ceramic containers, we confirmed the volume independence of the compressive strength and began analyzing nonlinear FEM. This research was conducted in partnership with private-sector research institutes, among others.

Regarding the development of technology for increasing the reliability of marine systems, we conducted interviews regarding real-life examples, with a view to formulating quality control standards, and also standardized CAD for electrical and mechanical design.

DONET is an observation platform on the deep ocean-floor, and advanced technologies have been developed to facilitate the installation of DONET, such as an automated cable-laying system for installation of a thin optical-fiber submarine cable and an efficient method for installation of a caisson that is used for housing a seismometer. A hydraulic hammer has also been developed to allow the installation of a caisson under the firm ocean-floor.

Regarding data transmission systems that can function at high temperatures, we developed a testing environment for optical transmission modules, with a view to developing borehole telemetry. We have made progress with preparations for the installation of two observation points, into which we plan to install borehole observation systems for high-temperature tests, and also carried out sensor stability tests and component assembly tests at Kamioka Mine. In addition, we made progress in developing technology for improving the accuracy of the water pressure gauges installed on the seafloor and in boreholes, achieving a confirmed accuracy improvement from the equivalent of a depth of 10 cm, as had been the case hitherto, to the equivalent of a depth of 1.3 cm.

(b) Development of Highly Accurate and Highly Efficient Observation Systems

This subtopic focuses on the development of underwater and seafloor exploration systems for the efficient, effective exploration and use of unknown territories, as well as related subsystems and observation systems for high-precision long-term observation of three-dimensional spaces covering an extensive area. JAMSTEC is also making progress with the development of profiling floats and other new observation infrastructure, sensors, and measuring instruments. Once the development of each item has been completed, we will move it into the operational phase, to accelerate its commercialization.

JAMSTEC carried out the following activities in FY2014.

We developed a 2kW HEML fuel cell and made preparations for underwater tests, with the aim of developing and conducting deep-sea trials of a prototype deep-sea fuel cell that can serve as a deep-sea power source, which will make long-term underwater measurement possible.

In the area of sensors fitted to AUVs, we are developing an underwater 3D laser scanning device and have ourselves the elemental technology development target of achieving visual recognition of an object 20m ahead to a resolution of 2 cm or less. We conducted marine tests of a prototype model, which we used for imaging of a coral reef at Ishigaki Island, and confirmed that it was able to acquire images. In addition, we have developed

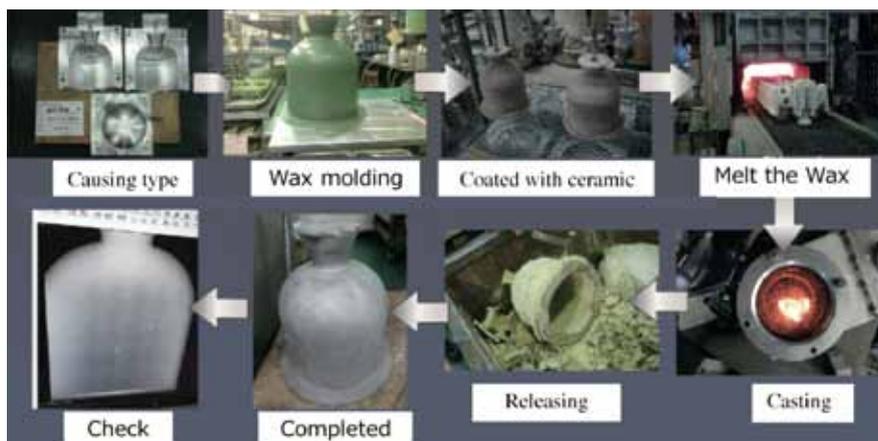


Figure 3. The titanium container manufacturing process



A prototype titanium container

long-distance acoustic communications technology and increased the precision of compact deep-sea inertial navigation systems for high-precision observation of 3D spaces, as well as moving forward with the development of various sensors.

In our efforts to develop underwater gliders for long-term observation of fixed areas, we have conducted marine tests and checked the performance of directional controls. Regarding the development of compact multipurpose floats, we evaluated compact buoyancy engines and conducted pressure resistance tests of each element in each part to check the performance of the basic elements. In partnership with a private-sector company, we have developed a titanium alloy pressure-resistant container using a lost-wax precision casting technique (Fig. 3) that facilitates the low-cost manufacture of these titanium containers. For this achievement, we received the Incentive Award at the 30th Sokeizai Industry Technology Awards.

As part of our efforts to improve the performance of mooring systems for areas with strong tidal currents, we developed a prototype for a new wire rope containing communication lines, to improve underwater communications performance and reduce resistance due to tidal currents.

In seeking to develop more advanced ROV elemental technologies, with a view to developing next-generation power transmission cables, we carried out various trials to evaluate the properties of long cables, including thermal behavior and voltage drop, and built and evaluated a model for the thermal behavior of cables. Moreover, in the area of multi-coring systems fitted to ROVs, we carried out onshore test drilling to obtain data, and then considered which conditions would be most suitable for drilling by an ROV. Furthermore, regarding propulsion systems and around view monitor systems, we produced a compact onshore test device and carried out onshore tests, as well as identifying improvements to be made in the future.

With regard to the development of ultra high-strength buoyancy materials, we tested the pressure resistance of samples and verified their practicality.

In the area of the development of ultra high-precision continuous measurement network systems using underwater lasers, we presented an overview of our test data from the previous fiscal year at an international academic conference and examined systems with a view to their application in such areas as the measurement of seafloor strength.

Regarding the development of technology for continuous monitoring of the seafloor using optical fiber cables and the construction of a fluctuation model based on this data, we produced and installed a measuring system for continuous monitoring of fluctuations in the surface of the seafloor and succeeded in the real-time measurement of fluctuations in the surface of the seafloor during storms causing rough seas.

(c) More Advanced, Higher Efficiency Operation Technology

This subtopic focuses on the development of more advanced functions of AUV and ROV and simultaneous operation technology of multiple vehicles to promote more efficient and effective observation, exploration, and surveys. The development of operation technology for the efficient construction of a seafloor cable network and the maintenance of it are due to begin operating in FY2015 and we are building basic technologies for the efficient operation of integrated survey and observation systems that incorporate them.

JAMSTEC carried out the following activities in FY2014.

Regarding the development of AUVs, we conducted marine tests and performance checks of the *Yumeiruka* and *Otohime* vehicles and undertook initiatives aimed at the improvement and commercialization of operation technologies. Moreover, with a view to the simultaneous operation of multiple vehicles, we manufactured a prototype marine repeater and conducted tests at sea. We conducted three marine tests using *Jinbei*, and carried out tests and drills aimed at introducing a portable landing, lifting, and recovery system that will enable *Jinbei* to operate from vessels other than those belonging to JAMSTEC.

Regarding the development of more advanced and efficient operation technology for the ROV *Kaiko Mk-IV* (Figure 4), following on from FY2013, we conducted post-construction tests to confirm performance. Specifically, we checked the functioning of each part of the unit at a depth of 1,000 m and verified the soundness of its systems following improvements to the unit, such as the hydraulic fluid cooler for instruments manufactured for the first time this fiscal year. Moreover, in seafloor navigation tests, we tested the performance of the automatic navigation control, which is one of this ROV's key features (auto altitude function, auto depth function, auto heading hold function,

dynamic positioning function, auto-cruise function) and verified that its automated motion controls operated with the requisite level of accuracy when operating in “figure of eight” mode and auto-cruise mode.



Figure 4. *Kaiko Mk-IV*

In light of the excellent results of these performance tests, the *Kaiko Mk-IV* had its first outing for actual research purposes on a voyage using the *Kaiko* System in the latter half of this fiscal year. Firstly, in a survey of the origins of the ferromanganese crusts from the 5th Takuyo Seamount, we mounted a hydraulic rotary cutter on the manipulator and succeeded in cutting ferromanganese crust samples from the seamount in question at a depth in excess of 4,000 m, which was the first time that this unit had operated at such a depth. In addition, the powerful hydraulic manipulator (maximum load of 250 kg when lifting at full reach) with which it is fitted made it easy to lift up the ferromanganese crust samples and deposit them in the sample basket (Fig. 5). Moreover, on two other voyages, we made preparations for its actual operation, installing a station for observing the electromagnetic field on the seafloor, as well as recovering data from A-CORK (Advanced Circulation Observation Retrofit Kit, a device for long-term hydraulic modeling of boreholes), setting the seafloor pressure gauge, and testing a simple pore water pressure probe. We plan to phase *Kaiko Mk-IV* into full operation, starting with the FY2015 public invitation program.

While continuing to operate marine observation buoys, we reviewed the maintenance of the buoys and their sensors, and began establishing a water temperature traceability system. Moreover, we are making progress with the efficient operation of alternative means of marine observation, including deliberations concerning the introduction of the Wave Glider.



Figure 5. *Kaiko Mk-IV*
Collecting ferromanganese crust samples

With regard to very long drills, in order to improve the safety and efficiency of deep ocean drilling by the D/V *Chikyu*, we developed a 3D SPH simulation code for fluid mixtures of cuttings and slurry, with a view to understanding the phenomenon of dynamic instability caused by very long drills when they rotate. As a result, we succeeded in numerically replicating the circulation of these mixtures inside riser pipes. Moreover, we were awarded Third Prize in the Japan Society for Computational Engineering and Science Graphics Awards for our large-scale simulation of the settlement behavior of railway ballast in which we replicated this behavior by simulating a real-life situation.

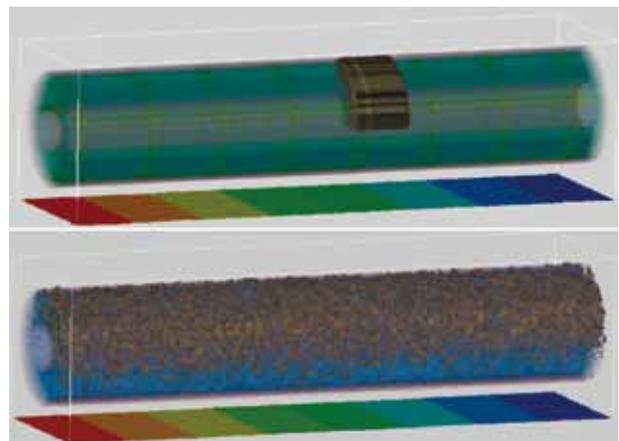


Figure 6. Simulation of the circulation of the mixture of slurry and cuttings inside a riser pipe
(Top) Initial configuration
(Bottom) Steady state
The mock slurry is dispersed and circulates inside the pipe

3. Operation of research and development infrastructure and promotion of the International Ocean Discovery Program (IODP)

(1) Operation of research vessels and deep-sea survey systems

Overview

We planned and implemented the operation of research vessels (except for *Chikyu*) owned by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) based on the publicly solicited research projects adopted by the Ocean Research Promotion Committee consisting mostly of external members, JAMSTEC's own research projects, and the research projects adopted by the Steering Committee for Joint Usage Research Vessel Operations (secretariat: Atmosphere and Ocean Research Institute of the University of Tokyo).

During FY2014, the number of days spent by seven vessels for research missions in Japan and overseas totaled 1,770 days. This translates to an average of 253 days of research expeditions per vessel (Fig. 1).

To set up a domestic research cruise, we gained a general consensus from the fishery office of each prefecture. Meanwhile, for the overseas survey, we obtained permission to conduct our survey from the competent authority of the appropriate coastal states. In addition, when the structural surveys were conducted using sonar that generates oscillations, we deployed a marine mammal observer on the bridge and implemented a soft start (a procedure in which the oscillation frequency is gradually increased from the lowest to the maximum levels) in accordance with the "guidelines for minimizing the impact on marine mammals from seismic surveys," drawn up in FY2013.

Special notes for each research vessel active in FY2014 are given below.

The research vessel *Hakuho Maru* engaged in long-term navigation from the beginning of December to the end of February, travelling from the western Pacific Ocean to the Antarctic Ocean. During this mission, the research team studied water samples taken from a large-scale deep circulation system driven by Antarctic bottom water, and identified three-dimensional distributions of trace elements and isotopes.

In September, the research vessel *Shinsei Maru* returned to its home port, Otsuchi Port, for the first time after the outbreak of the Great East Japan Earthquake. The vessel was opened to the public. University researchers took part in this event as guest lecturers, and their presentations were greatly appreciated by the local residents.

In May, the research vessel *Natsushima* traveled for a survey mission to study the spawning ecology of eels near the West Mariana Ridge. The research team attempted to film the spawning behavior of eels using a deep-sea camera system *Edokko-1* (Fig. 2) and other devices. Unfortunately, filming was unsuccessful. In June and July, a research team sailed a survey mission to identify the mechanism behind changes in the marine ecosystem off the Sanriku coast. The team succeeded in the observation of the present debris situation in detail using a *HYPER-DOLPHIN* and the behavioral studies of *Chionoecetes*, *Sebastes* and other animals using a bio-tracking system.



Figure 2. *Edokko-1*

Research vessel *Kaiyo* was used throughout the year for the construction of the Dense Ocean-floor Network System for Earthquakes and Tsunamis (DONET-II). In addition, the autonomous underwater vehicles (AUVs) *Yumeiruka* and *Jinbei* were tested, and an autonomous surface vehicle (ASV, Fig. 3), which is playing a vital role in the development of a system enabling simultaneous operation of multiple AUVs, underwent sea trials for the first time in February.



Figure 3. An autonomous surface vehicle (ASV)

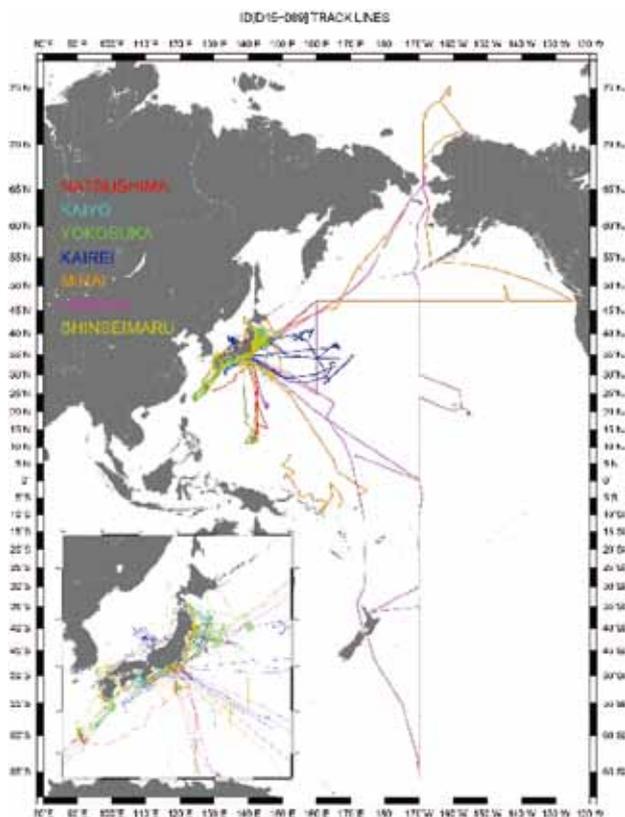


Figure 1. Sailing records of research vessels during FY2014

The support vessel *Yokosuka* was employed throughout the year to support underwater surveys conducted by *Shinkai 6500* and *Urashima*. *Urashima* was also used for resource survey missions, which yielded great results.

In July, the deep-sea research vessel *Kairei* was used to perform a seismic survey in the Sea of Japan. In collaboration with the Earthquake Research Institute of the University of Tokyo, which was carrying out integrated seismic surveys in an adjacent area, we conducted studies to obtain images of integrated crustal structures.

Since its operation began in 1998, the research vessel *Mirai*, equipped with a Doppler radar for rainfall observation, had been conducting observation in various environments ranging from polar to tropical regions. However, due to progressing deterioration of its equipment, the vessel was upgraded in FY2014. The radar was replaced with latest-model radar equipped with a solid-state transmitter and employing a dual polarization system (Fig. 4). These improvements enabled more accurate observation of precipitation intensity.



Figure 4. A Doppler radar dome

Furthermore, when the upgrading took place, the position of the radar dome was elevated by 3 m, which reduced the range of electromagnetic interference called shadow, thereby increasing the observable areas (Fig. 5).

Mirai continuously conducts observation in various regions including north polar and tropical regions. As a vessel equipped with a dual polarization radar, *Mirai* succeeded for

the first time in the world in fixed-point observation of arctic low-pressure systems in the Arctic Ocean and the observation of the change from a typhoon to an extratropical cyclone in the North Pacific Ocean. In the western Pacific Ocean, we retrieved 11 TRITON buoys in operation and set up eight new TRITON buoys. In the Indian Ocean, three small lightweight m-TRITON buoys were replaced, allowing continuous operations. We are publicizing the data collected from these buoys. During the maintenance trip in the western Pacific Ocean, we did not replace buoys at three observation points, and temporarily suspended observations at these points. We are planning to replace these buoys with different observation means in the near future.

The operation of the deep-sea exploration system started in early April when *Shinkai 6500* was used to carry out underwater operation. Then, *Shinkai 6500* was utilized for surveys in the Japan Trench and the Northwest Pacific Ocean from April 10 to 24, and for underwater surveys in the Mariana Trench in July. After 25 years in service, *Shinkai 6500* is still in good condition and continues to make significant contributions in deep-sea research.

The AUV *Urashima* was used for the testing of a small-sized gravimeter and a synthetic aperture interferometry sonar (red circle in Fig. 6), which were developed as fundamental tools. In addition, *Urashima* made enormous contributions in producing significant results in publicly solicited research projects.



Figure 6. Installation of a synthetic aperture interferometry sonar on *Urashima*

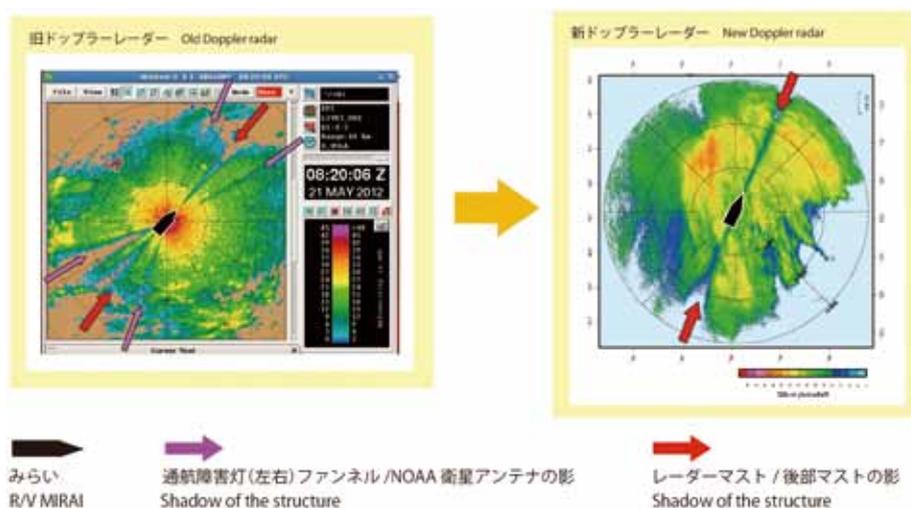


Figure 5. Comparison of shadow reduction between old and new Doppler radars.

The test operation of the unmanned explorer *Kaiko Mk-IV* (Fig. 7) has begun with the purpose of allowing operators to master maneuvering of the equipment. We are planning to use it for survey missions after making improvements so that it can be operated at a depth of 11,000 m.

Because *Kaiyo* and *Natsushima*, which had been serving as main hosts of *HYPER-DOLPHIN*, will be decommissioned in FY2015, we are planning to use *Shinsei Maru* as a new host of *HYPER-DOLPHIN* by creating a new control panel to be installed in the vessel.



Figure 7. *Kaiko Mk-IV*

We updated the existing 6,000-m-class tow body by adding a camera system to it, and tested the updated tow body for practical use (Fig. 8). We are planning to use it for survey missions after making further improvements.



Figure 8. A 6,000-m-class tow body

Research Vessel Construction

A new research vessel is under construction (Fig. 9). The purpose of the vessel is to promote scientific research in a wide area, including scientific surveys of marine resources in waters around Japan. The vessel will feature a crustal structure survey using a three-dimensional seismic imaging system, sediment/core sampling using drilling equipment installed on the

seabed, simultaneous use of multiple autonomous underwater vehicles, and a detailed survey using acoustic devices.



Figure 9. A new research vessel for wide-area seafloor research

Principal particulars of the vessel are as follows.

Length × breadth × designed load draft: approx. 100 m × 19.0 m × 6.0 m
International gross tonnage: approx. 5,800 t
Accommodation: 65 persons (27 crew members, 38 researchers)
Main equipment:
2-D and 3-D seismic survey system
40 m piston coring system
Boring Machine System
Power Grab
CTD and water sampling system (Maximum operation depth: 10,000m)

As a continuing project from FY2013, in FY2014, we conducted detailed designing of the research vessel. Specifically, we checked the performance of the vessel hull by tank tests using a model, and carried out discussion using a one-tenth scale model of the rear part of the work deck and a three-dimensional computer aided model of the laboratory in the vessel. We began constructing blocks in October and started placing them on the building berth in January (Fig. 10).

The construction of the vessel is expected to be completed at the end of FY2015.



Figure 10. A new research vessel is under construction (March 2015)

Twenty fifth anniversary of the completion of the manned research submersible *Shinkai 6500*

FY2014 marked the 25th anniversary of the completion of *Shinkai 6500*. As a commemorative event, “Nico Nico Cho Party III” was held at Makuhari Messe in April. At the event, we exhibited the real *Shinkai 6500*, which attracted many visitors (Fig. 11). It took us about one full hour to transport the submersible from the Port of Chiba to the event hall in the late evening. Video of the transport was broadcasted live.



Figure 11. *Shinkai 6500* displayed at the “Nico Nico Cho Party III” event

In addition, at JAMSTEC 2015 held in March, we gave a lecture about the contributions made by *Shinkai 6500* during the 25 years of service and future expectations for the submersible.

Given that the research project titled “The development of a full-depth manned research submersible” was nominated by the Science Council of Japan as a master plan of large-scale research in February 2014, we believe that manned research submersibles have been proven useful in academic research.

To develop a next-generation manned research submersible as a successor to the 25-year-old *Shinkai 6500*, in FY2014, we conducted basic studies on pressure hulls and other aspects of submersibles. We also gained information about the application of CFRP materials from material manufacturers, and exchanged opinions with researchers at the University of Tokyo regarding the creation of buoyancy materials using a 3D printer. Furthermore, we drew up and externally announced a plan for the development of the full-depth manned research submersible *Shinkai 12000* (Fig. 12).



Figure 12. Conceptual image of *Shinkai 12000*

Hosting of diving training and its termination

During FY2014, we held diving management courses at JAMSTEC facilities 14 times for external technicians interested in working as diving technique trainers or managers. A total of 326 people took the courses.

These JAMSTEC-hosted courses made great contributions to industries, governments and academia as they were attended by many people in these sectors between FY1987 and FY2014. No accident occurred during these training sessions and a total of 6,949 people took the courses. Because of the recent change in the corporate status of JAMSTEC to a national R&D agency, hosting of diving technique training no longer fits our services. For this reason, we closed the courses at the end of FY2014.



Figure 13. Participants of the report meeting held after the conclusion of the diving training program

(2) Operation of Earth Simulator

Overview

After the first-generation Earth Simulator completed its service as a flagship machine, the second-generation Earth Simulator (ES2) (Table 1) had been used since its introduction in March 2009 for various research projects, mainly in the fields of marine and earth sciences dealing with climate change and fluctuation including global warming, a major issue addressed in the IPCC fifth assessment report. The operation of ES2 ended at the end of February 2015 and test operation of the new Earth Simulator started from March. When the operation of ES2 was concluded, there were 426 registered ES2 users. During FY2014, ES2 used more than 90% of its computer resources to execute simulations and its nodes were idle only for 3.7% of the time period including scheduled maintenance. Accordingly, ES2 operated stably and continuously throughout its running period (Fig. 1).

Computation node	
Number of CPUs	8
Number of cores (per CPU)	1
GFLOPS (per CPU)	102.4 GFLOPS
Memory capacity	128 GB
Memory bandwidth	2,048 GB/s
System	
Total number of processor nodes	160
Total number of CPUs	1,280
Total peak performance	131 TFLOPS
Total memory capacity	20 TB
Total memory bandwidth	328 TB/s

Table 1. Specifications of ES2

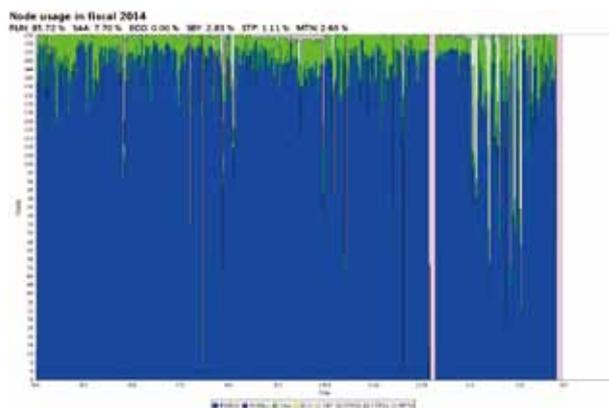


Figure 1. ES2 node usage in FY2014

Procurement and introduction of the new Earth Simulator

To introduce a new supercomputer as a successor to ES2, we continued deliberation taking into account the outcome of consultations with external experts regarding conditions required to continue surveys, which started in 2012, to identify technology trends and users' resource needs and to maintain and strengthen international competitiveness academically and technologically. In addition, we systematically carried out fair and transparent procurement in compliance with international

procurement guidelines. After a decision was made on the model of the new Earth Simulator through the bidding process, we immediately worked on a system design and the transfer of users' programs, then conducted an availability test on the system and validation of the system's total performance, and started preliminary operation on 50% of the system in March 2014 as scheduled.

In this procurement process, we kept in mind the top-priority goal of "maximizing research and development achievements" using the new Earth Simulator, and created the optimum computer system environment. We evaluated computational performance, primarily focusing on effective performance requirements to minimize the turnaround time of six major application programs JAMSTEC selected, and decided to introduce an NEC SX-ACE supercomputer through a competitive bidding process (Fig. 2). The new Earth Simulator is among the world's largest distributed-memory type parallel vector computers. It is equipped with a total of 5,120 computation nodes, with each node having a 4-core CPU and 64 GB memory (Table 2).

As a result of this procurement, we were able to acquire a system with effective performance more than 10 times greater than the requested computational performance level (8 times greater performance level than that of ES2) at about a 34% lower price than we initially estimated based on various studies we conducted. In addition, the introduction of a water cooling system reduced power consumption of the simulator system to a level equal to one-third or less of the power consumption by ES2. Also, comparing system performance with the major meteorological organizations in Europe and the United States, the new simulator has sustained international competitiveness in terms of computational performance (Fig. 3).

According to an evaluation of national research and development agencies conducted in FY2014 (by the Minister of Education, Culture, Sports, Science and Technology), JAMSTEC received an A grade for its sound, transparent and effective acquisition of the new simulator system through the procurement process mentioned above and due to high expectations for JAMSTEC to make outstanding achievements in the future in line with the goal of "maximizing research and development achievements."



Figure 2. New Earth Simulator after completing installation

Computation node	
Number of CPUs	1
Number of cores (per CPU)	4
GFLOPS (per CPU)	64 GFLOPS
Memory capacity	64 GB
Memory bandwidth	256 GB/s
System	
Total number of processor nodes	5,120
Total number of CPUs	5,120
Total number of cores	20,480
Total peak performance	1.3 PFLOPS
Total memory capacity	320 TB
Total memory bandwidth	1.3 PB/s

Table 2. Specifications of the new Earth Simulator

Total HPCG performance (TFLOPS)

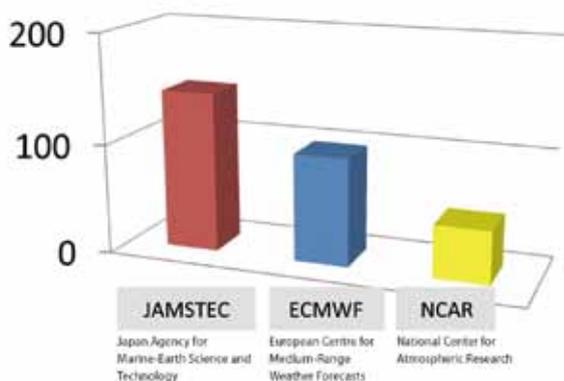


Figure 3. Comparison of computational performance (HPCG performance of three systems)

Technical support

To promote efficient use of computer resources including Earth Simulator, and to encourage users to produce results quickly, the Center for Earth Information Science and Technology (CEIST) is providing users with a variety of technical support in aspects of both computational techniques and operation. In FY2014, we prepared for the operation of the new Earth Simulator, further enhanced ES2 user support, and prepared the environment for the use of a large-scale shared memory system (UV 2000 model, Silicon Graphics International Corp.), which is viewed as Earth Simulator’s pre/post processing system.

We have formulated manuals and technical references for various purposes and made the latest information accessible to users by setting up a webpage for users as a unified information source (<https://www.jamstec.go.jp/es3support/>).

In addition, to offer users technical support for programing and other aspects, we are providing services to address various technical issues through the establishment of a help desk to which users can direct their inquiries in person or by email or other means. Specifically, we offer consultation regarding how to use the computer and programming, make technical staff available

for program optimization, and provide operational support to meet users’ needs.

We are developing a technical support system (Fig. 4) enabling the operational support unit and technical support unit of the system vendor to work in coordination, and enabling the Computational Technology Group and the System Engineering and Operations Group of the Information Systems Department, CEIST, to play a central role. We provide high-quality technical support to meet the needs of users by developing a system that enables coordination between CEIST technical support staff, who thoroughly understand the needs of researcher users and thus are capable of serving as consultants knowledgeable on research, and the system vendor who has in-depth knowledge of hardware and software.



Figure 4. Technical support system for supercomputer users

During FY2014, the help desk received a total of 160 inquiries. Of these, 66 inquiries were regarding how to use the supercomputer, 13 regarding remote access, 13 regarding programming, and 68 regarding other matters. It was notable that many questions were asked about data backup for ES2 and about the new Earth Simulator during FY2014. We were able to give our initial responses to the questions within 24 hours on average, and we are continuing to enhance this support by responding to users’ inquiries even more quickly.

In terms of technical support, we proposed the effective use of a job scheduling system, provided support for compiling and debugging programs, and ported 11 free and commercial software applications into the new system and checked their operations as requested by users. The contents of these types of support are accessible through our website, exhibitions and oral presentations. The information is intended to help users expand the range of their system utilization and improve their skills to use the Earth simulator.

Industrial use of Earth Simulator

To popularize Earth Simulator utilization, we promoted the use of the simulator by industries through two types of services: “fee-based confidential-type usage of Earth Simulator” and “fee-based open-type usage of Earth Simulator” under the Program for Strategic Industrial Use of Earth Simulator, a subsidized project run by the Ministry of Education, Culture, Sports, Science and Technology.

The fee-based confidential-type usage of Earth Simulator has been implemented since FY2007. To make the service easy to use for industries and other users, we have been continuously accepting applications and providing technical advice and support related to porting and optimization of programs. In addition, as a part of our efforts to promote fee-based usage of Earth Simulator, we started offering fee-based confidential-type usage of the large-scale shared memory system (UV 2000 model, Silicon Graphics International Corp., Fig. 5), which is viewed as Earth Simulator’s pre/post processing system.

Theoretical performance: 49.152 TFLOPS
 Total number of processors (cores): 256 CPU sockets (2,560 cores)
 [Intel Xeon E5-4650v2 (2.4 GHz, 10 cores)]
 Total memory: 32 TB
 OS: SUSE Linux Enterprise Server 11 SP3

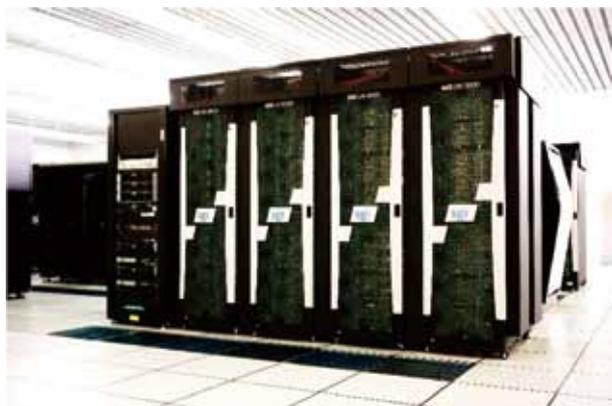


Figure 5. Large-scale shared memory system (SGI UV 2000)

In addition, we ported applications commonly used by industries—OpenFOAM (computational fluid dynamics software), Elmer FEM (multiphysical simulation software using the finite element method), and Amber and Gromacs (molecular dynamics software)—into the UV 2000 system and checked their operations. We also evaluated parallel performance of each software using large data and confirmed good performance. We summarized these results in a document to promote the fee-based confidential-type usage of Earth Simulator.

Regarding the fee-based open-type usage of Earth Simulator under the Program for Strategic Industrial Use of Earth Simulator, we have been offering this service since FY2009 using the funding provided for implementing the Project for Creation of Research Platforms and Sharing of Advanced Research Infrastructure. In this system, users can

use the simulator for free for up to two years or the first two uses as they are considered as trial uses. During FY2014, 8 of 12 uses were counted as trial uses. We operated the large-scale shared memory system, which was introduced for this service, and made it available for shared use by simulator users. We held an “Earth Simulator Symposium for Industrial Use 2014” on October 23, 2014. To demonstrate the effectiveness and convenience of newly activated SGI UV 2000 at the symposium, we made a new attempt in which we invited software vendors who handle major software applications used in industrial use of supercomputers. At the same time, we noted that these applications had been installed on the SGI UV 2000. The symposium was a great success with 130 attendees, owing partly to the participation of the software vendors who attracted the attention of many attendees. After the symposium, inquiries about available software applications are increasing, and simulator users are showing greater interest in them.

To upgrade simulation technology, we have been conducting “collaborative research on the sophistication of the computational simulation software toward constructing a platform for leading industrial research and development,” with the Institute of Industrial Science, University of Tokyo, since FY2008. In FY2014, we created faster simulation software needed in material and bio fields, promoting increased use of Earth Simulator by industries.

In these projects, we contributed toward the development and expansion of numerical simulation technology for industries by providing technological support to 12 organizations using Earth Simulator, and contributed to society by issuing reports of results produced using the simulator, holding symposiums, disseminating information from our website, and presenting some examples of industrial use of the supercomputer to the public. The AdvanceSoft Corporation researchers worked on a project in which they installed five software applications on the SGI UV 2000 system and evaluated the system usage. This project promoted the launch of the “supercomputing service”—fee-based utilization of the system.

(3) Management and dissemination of marine-earth science data and samples

Overview

The Data Management and Engineering Department of CEIST receives, collects and archives various data/samples collected by JAMSTEC through its research activities related to marine and earth surveys and observations, controls data quality, and develops and operates data publication systems. By FY2014, we released to the public about 46,500 sets of metadata for observational data/samples and 49 sets of metadata for databases and data sites.

Based on the Basic Policies on the Handling of Data and Samples by JAMSTEC, enacted in FY2007, we are managing and archiving data and samples obtained using JAMSTEC vessels and research submersibles/autonomous underwater vehicles carried by JAMSTEC vessels, and developing and operating observational data publication systems. In FY2014, we are continuing to register and disclose more data, and completed digitizing standard definition videos taken using major research submersibles.

New initiatives

We also opened to the public the JAMSTEC deep-sea Data-Image Virtual Exploration System (JDIVES), which displays underwater survey routes three-dimensionally, and added graph displays to the Data Research System for Whole Cruise Information (DARWIN), which releases data obtained during cruises. In addition, we developed MIO Ocean Radar Data Site for the Eastern Tsugaru Strait (MORSETS) to realize semi-real-time distribution of sea surface current direction and velocity data collected in the eastern Tsugaru Strait using a marine shortwave radar deployed by the Mutsu Institute for Oceanography.

Supporting reconstruction after the earthquake disaster

To understand changes in marine ecosystems in Tohoku coastal areas since the magnitude 9.0, 2011 Tohoku-oki Earthquake struck and to contribute to restoration of the fisheries industry, we joined the Tohoku Ecosystem-Associated Marine Sciences (TEAMS)—a program launched in February 2012 for surveys and research on marine ecosystems—and are developing a data management framework for disseminating and providing research results and information obtained in this program and building data sharing/publication systems. In FY2014, we are continuing to collect, archive and disseminate data (research plans/reports, observational data/metadata, and research summaries) according to the TEAMS data policy, and started operating a website for TEAMS members to enable information sharing among parties involved in TEAMS. In addition, we started test operation of TEAMS Biological Observation Record Archive System (BORAS) to facilitate buildup and sharing of biological information.

Release of earthquake information

JAMSTEC's Yokohama Institute for Earth Sciences receives observational data in real time from the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET), whose 20 operational points in the Kumano Sea have been in operation since FY2011. To conduct detailed monitoring of seismic activities in this area where a major earthquake is predicted to strike, and to study the mechanism of major earthquakes, we are developing JAMSTEC-Ocean Seismological Database-Integrated by Network Data (JOIN), while the Data Research and Development Group has been operating and managing a database since April 2014. In FY2014, we began demonstration operation of the Real-time Earthquake Information System (REIS), which releases data collected by ocean-bottom seismographs in real time, and started test operation of the DONET Event Data Download System, which enables provision of seismic event data to researchers.

Publication of biodiversity information

We comprehensively distribute JAMSTEC biological information using the Biological Information System for Marine Life (BISMaL), which handles information on diversity and distribution of marine organisms, collect information on diversity of marine organisms around Japan, and widely publicize it after systematically organizing it. Since 2010, JAMSTEC has been serving as a Japanese node in the Ocean Biogeographic Information System (OBIS), and providing BISMaL data to OBIS. In light of the fact that OBIS was placed under the umbrella of the International Oceanographic Data and Information Exchange (IODE), a program managed by the Intergovernmental Oceanographic Commission of UNESCO (UNESCO/IOC), in January 2015, JAMSTEC was recognized as an IODE Associate Data Unit (ADU).



Release of data to the public through the JAMSTEC deep-sea Data-Image Virtual Exploration System (JDIVES)

(4) Operation of *Chikyu* and promotion of IODP

Overview

The Center for Deep Earth Exploration (CDEX) takes charge of the operation of the deep sea drilling vessel *Chikyu* (Fig. 1), a unique drilling platform for the International Ocean Discovery Program (IODP) with 26 member countries including Japan, the United States and the Europe. As a major organization implementing the IODP, CDEX comprehensively manages operation, drilling, scientific services and technological development using *Chikyu* under the international framework. *Chikyu* is the only scientific drilling vessel in the world to be equipped with a riser drilling system. With *Chikyu*, we are aiming to tackle scientific propositions that are of interest to all of humankind, such as the understanding of mechanisms behind major earthquakes, tsunamis and global-scale environmental changes, as well as the exploration of the deep subsurface biosphere and the environment that produces submarine resources. We will address these issues by conducting drilling surveys at great depths, which could not have been accomplished by conventional scientific drilling vessels and research vessels.



Figure 1. Deep sea drilling vessel *Chikyu*.

Conclusion of a memorandum with the IODP participating countries

In April 2014, JAMSTEC signed a memorandum with the Australia-New Zealand IODP Consortium (ANZIC)—a group relating to offshore drilling for research purposes consisting of 25 research organizations and universities in Australia and New Zealand—under the IODP framework. This memorandum includes statements—such as that researchers in Australia and New Zealand are permitted to board *Chikyu* to take part in IODP research missions—that will promote collaborative relations between Japan and Australia/New Zealand.

Regarding the joint use of *Chikyu* and the U.S. scientific drilling vessel JOIDES Resolution (JR), a bilateral agreement was made in writing at the beginning of the IODP implementation in October 2013.

With these collaborative structures in place, we will continue to work on IODP scientific projects using *Chikyu*.

Compulsory provision of *Chikyu* for the Cross-ministerial Strategic Innovation Promotion Program (SIP)

In July 2014, we provided *Chikyu* to conduct “Scientific research on formation processes of ocean resources,” as a part of the SIP-supported project, “Next-generation technology for ocean resources exploration.”

We conducted simultaneous drilling and logging around the area where hydrothermal reservoirs were discovered beneath the seafloor in FY2010, through scientific drilling surveys conducted during the IODP Expedition 331, “Deep Hot Biosphere”. Based on this investigation, we recognized the distribution of hydrothermal reservoirs beneath the Iheya North Knoll and collected physical property data on the strata in the Okinawa Trough.

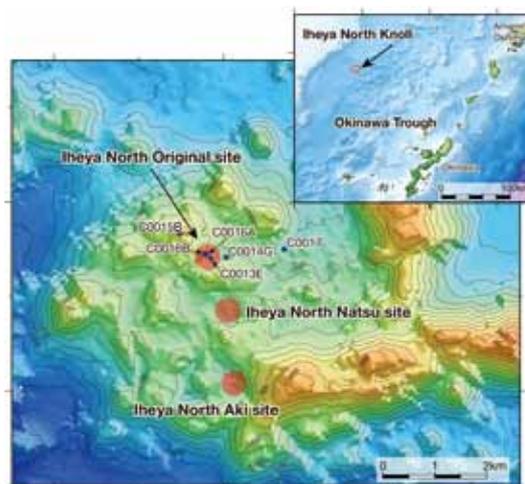


Figure 2. Drilling sites at the Iheya North Knoll of the Okinawa Trough.

Display presentation at scientific meetings

To disseminate the latest information on the current situations to the scientific community among the participating countries, we set up booths for display presentations at the international geoscience meetings hosted by the Japan Geoscience Union (JpGU), the Asia Oceania Geosciences Society (AOGS) and the American Geophysical Union (AGU) respectively. Also, in collaboration with the U.S. and European organizers, we planned and held an IODP town hall meeting during the AGU conference, the largest meeting for IODP members.



Figure 3. A scene from the IODP town hall meeting held during the AGU conference in 2014.

Toward FY2015

July 2015 will mark the 10th anniversary of *Chikyu* in service. We are planning to hold various commemorative events.

As periodical inspection and repair of the 10-year-old *Chikyu* is set to be conducted, we are currently preparing for replacement of various kinds of equipment and rearrangement of research compartments.

Public relations activities

In terms of public relations activities, JAMSTEC and the National Museum of Nature and Science co-hosted a symposium, “Accomplishments of the Integrated Ocean Drilling Program (IODP) over the past 10 years.” In addition, we held lectures and external classes 25 times, cooperated with interviews by domestic and overseas media 22 times, and provided video and images for publications by domestic and overseas media 63 times.

We also renewed the CDEX/JAMSTEC website. Specifically, we rearranged the conventional website, which contained contents for the general public and for IODP members in a mixed manner, into three websites: the *Chikyu* website (www.jamstec.go.jp/chikyu), the Center for Deep Earth Exploration (CDEX) website (www.jamstec.go.jp/cdex), and the International Ocean Discovery Program (IODP) website (www.jamstec.go.jp/iodp).



Figure 4. The new *Chikyu* website.

4. Supporting member system (JAMSTEC Partners)

Aiming at a central institution for research and development in the field of ocean science and technology, the Japan Marine Science and Technology Center, the predecessor of JAMSTEC, was established in October, 1971 as an authorized corporation based on the Japan Marine Science and Technology Center Act, at the proposition of the Japan Business Federation, with close cooperation and support of industry, government, and academia. Along with the establishment of the center, a supporting member system was started to widely seek understanding and support in research and development activities. The purpose of this system was to advance the development of Japan's ocean science and technology together through donations from many industries and organizations. Since the start of the system, we have been able to build and upgrade facilities and equipment necessary for the promotion of comprehensive research and the development of ocean science and technology.

Since the reorganization into the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in April 2004, under the continued understanding and support from many industries and organizations through the system, we have continued promoting research on the prediction of global environment variations and on elucidation of the origin of life and the development of fundamental technologies supporting the leading-edge research by exploring the Earth as a system. With an ambition to make JAMSTEC into an international center of excellence for ocean research and development, we hope to make social contributions for a better tomorrow, by such means as putting the research results into commercial use, under the cooperation of the members of JAMSTEC Partners.

(Supporting members donating to JAMSTEC are eligible to receive a tax benefit under Article 37 of the Corporation Tax Act.)

- Membership Privileges

JAMSTEC Partners offers various membership privileges to use our research and development results.

- **Information sharing on the research and development results** through various seminars, science café, technology exchange meeting, etc.
- **Business support** for the members, such as support for technology development using JAMSTEC's equipment and facilities including research vessels, Remotely Operated Vehicle, etc.
- **Preferential treatment** concerning the use of JAMSTEC's facilities, etc.
- **Technical support** through the dispatch of technical advisors and lecturers to in-house training for members

These benefits can be used if you join JAMSTEC Partners.

For inquiries about the system, please contact us:

Administration Department, Tokyo Office, JAMSTEC

Address: Fukokuseimei Bld. 23F, 2-2-2 Uchisaiwaicho, Chiyoda-ku, Tokyo 100-0011 Japan

Phone: +81-3-5157-3900

FAX: +81-3-5157-3903

E-MAIL: sanjokai@jamstec.go.jp

A seminar for JAMSTEC Partners



The science café [MARE Café]



Facility Tour for JAMSTEC Partners <Kochi> - 1



Facility Tour for JAMSTEC Partners <Kochi> - 2



Trial cruise and excursion on *KAIREI*



Technology exchange meeting



