

JAMSTEC

2013 Annual Report



Japan Agency for Marine-Earth Science and Technology

JAMSTEC

2013 Annual Report

Fiscal Year 2013 Overview of the Japan Agency for Marine-Earth Science and Technology



An around-the-world voyage project of *SHINKAI 6500* "QUELLE2013" was carried out.



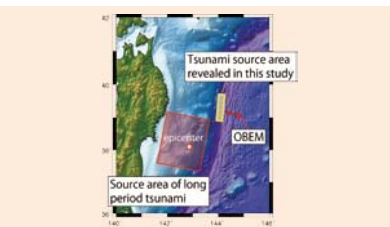
JAMSTEC successfully developed a process for making nanoemulsions for a short period of time. This work was inspired by hot fluid spewing from deep-sea hydrothermal vents.



The world's first live broadcasting from *SHINKAI 6500* at a 5,000-m depth in the Caribbean Sea was watched by approx. 300,000 viewers.



The construction of the research vessel *SHINSEI MARU* has been completed. This vessel will serve for the "Tohoku Ecosystem-Associated Marine Sciences (TEAMS)" program.



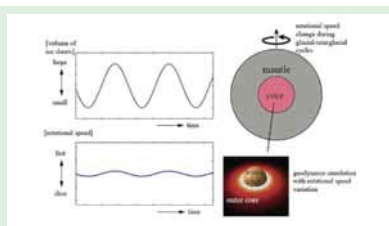
JAMSTEC and its partners successfully identified the source location of the massive tsunami generated following the Tohoku Region Pacific Coast Earthquake.



The deep-sea boom arrived. JAMSTEC, the National Museum of Nature and Science, and other partners held a special exhibition titled "Shinkai (The Deep)."



JAMSTEC and its partners succeeded in generating electricity using a fuel cell installed in an artificial hydrothermal vent.



JAMSTEC successfully revealed the effect of rotational speed change on the Earth's magnetic field.



Depth: (a) 1,979 m and (b) 1,830 m

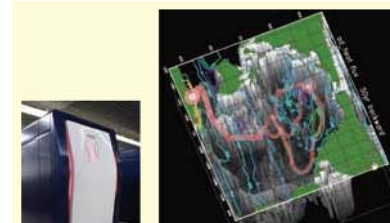
JAMSTEC collected the world's first samples of primary magma at an underwater volcano.



Causal mechanisms of the large slip during the Tohoku Region Pacific Coast Earthquake were revealed.



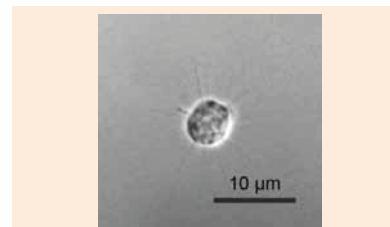
A new ocean-bottom tsunami monitoring methodology with Vector TsunamiMeter was tried out.



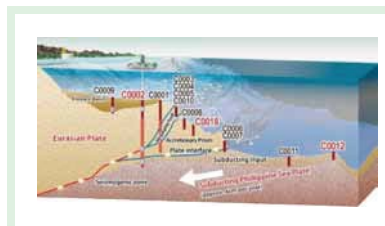
JAMSTEC has discovered warming of the deep Pacific Ocean and its mechanisms, leading to a great contribution to the IPCC Fifth Assessment Report.



The naming and unveiling ceremony was held for the new underwater vehicle *KAIKO Mk-IV*.



Lateral transfer of eukaryotic ribosomal RNA genes was observed for the first time in the world.



The world record of scientific drilling depth was updated during the drilling operation at the Nankai Trough (3,058.5 m below seafloor)



Field experiments of a free-fall deep-sea exploration system Edokko No. 1 was successfully conducted. JAMSTEC has supported the project as a part of its partnership program for practical use.

Preface

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has just completed its second mid-term plan for the five years from FY2009 to FY2013. During this period, we have achieved various results in marine science technology and other relevant fields.

In the field of global environmental change, our research results based on the observation results obtained by our vessels, including the research vessel MIRAI, under an international project were cited in the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC).

Moreover, in the field of biology science, JAMSTEC participated in the Tohoku Ecosystem-Associated Marine Sciences (TEAMS) and conducted an investigation on the changes in the marine ecosystem in the coast area caused by the Tohoku Region Pacific Coast Earthquake and subsequent tsunami to evaluate their impact. Through this investigation, we attempted to reveal the current status of the biological resources and environment of the offshore bottom fishery as well as the mechanisms of the changes. Moreover, we discovered a breakthrough new enzyme from *Hirondellea gigas* living in the Mariana Trench, which could open up the gate for the utilization of biomass.

In relation to the Great East Japan Earthquake in March 2011, we have conducted investigations on various ships and promoted inspection of the field under the Japan Trench Fast Drilling Project (JFAST). As a part of this project, we collected geological samples from the plate boundary fault that is believed to have caused the giant earthquake and tsunami and conducted long-term temperature measurement in the drilled hole, among other surveys. As a result of such surveys, we found that the friction coefficient at the shallow portion of the plate boundary fault was extremely low at the time of the earthquake and it was in a slippery state.

In the field of technology development, JAMSTEC has started the development and operation of the unmanned explorer *KAIKO MK-IV* and autonomous underwater vehicles *YUMEIRUKA*, *OTOHIME* and *JINBEI*, bringing together all of the element technologies that we have cultivated to date. Moreover, we have just started the construction of a wide-area seabed research vessel, which is expected to contribute to wide-area scientific research on marine resources, etc. in the future.

JAMSTEC starts its third mid-term plan from FY2014. In order to promote the third mid-term plan, JAMSTEC has reorganized the conventional system into one that allows more cross-sectional and strategic research and development. With a view to contributing to solutions to the important issues presented in the government's ocean policies, under our new regime, we will put priority on the following research and development activities.

- (1) Research and development of submarine resources
- (2) Research and development on marine and global environmental change
- (3) Research and development on seismogenic zones

- (4) Research and development on marine biosciences and engineering
- (5) Promotion of comprehensive ocean drilling science
- (6) Research and development on advanced synthetic information science
- (7) Construction of a research and development base for opening up ocean frontiers

Utilizing the scientific knowledge to be gained from addressing these issues, JAMSTEC will pursue comprehensive understanding of the ocean, earth and life systems, while also meeting national and social needs flexibly and intensively.

We at JAMSTEC are determined to fulfill our duties by working as a team in response to the demands of citizens and society. 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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3. Supporting Member System (JAMSTEC Partners)

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

(1) Outline of Activities

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is a general research institute for ocean science and technology in Japan that contributes to resolving various problems crucial to the survival of humanity based on results obtained by fundamental ocean researches and technological development, and elucidating the global system centered on the ocean.

Fiscal year 2013 was the last fiscal year of the second mid-term objective period which started in April 2009 and was the year that consolidated the research and technological development implemented in that period.

The JAMSTEC has conducted the research and study of the Tohoku Region Pacific Coast Earthquake since shortly after the occurrence of the earthquake. In FY2013, we succeeded in retrieving the long-term borehole thermometer installed in the borehole of the deep sea drilling vessel *CHIKYU* during the borehole investigation for the Tohoku Region Pacific Coast Earthquake carried out in FY2012 and directly observed the residual frictional heat generated by the fault movement for the first time in the world. Using the heat data, the geological samples collected by *CHIKYU*, on-site borehole measured data, etc., the JAMSTEC scientifically proved the generating mechanism of the Tohoku Region Pacific Coast Earthquake, which led to significantly advancing the elucidation of the generating mechanism of subduction zone great earthquakes and tsunamis. Three papers regarding the results of these researches were simultaneously published in *Science*, an American scientific journal.

Furthermore, the JAMSTEC is working on the “Tohoku Marine Science Center Project” which is a project subsidized by the Ministry of Education, Culture, Sports, Science and Technology jointly with the Tohoku University and the University of Tokyo, aimed at the restoration of the marine ecosystem that was drastically changed by the earthquake and subsequent tsunamis and reviving the fishing industry. In June 2013, the Tohoku Marine Ecosystem Research Vessel *SHINSEI-MARU* was delivered to the JAMSTEC and research and study in the coast of Tohoku region and its adjacent seas were started.

With regard to research on global environmental changes, the JAMSTEC is making various observations of the atmosphere, ocean and land using the Ocean and Earth Research Vessel *MIRAI*, observation buoys, land radars, etc. In September 2013, the Working Group I Report (Physical Science Basis) and Assessment, Fifth Assessment Report for the Intergovernmental Panel on Climate Change (IPCC) was published. The JAMSTEC has substantially provided its scientific knowledge and information to the Report and Assessment and has contributed to elucidating the global environmental changes as seen by the fact that 121 scientific papers published in the past regarding climate change observations and predictions written mainly by the researchers were quoted in the Report and Assessment.

In researches of the extreme environment biosphere, the JAMSTEC undertook a voyage around the world called *QUELLE* 2013 for approximately one year using the manned research submersible *SHINKAI 6500* and succeeded in obtaining a great number of valuable samples and data from the Indian Ocean, the Brazilian offshore, the Caribbean Sea, and the South Pacific

Ocean, aiming at identifying the biosphere in the extreme environment including high-temperature hot water, spring water, and hadal zone. In addition, in collaboration with Webmedia, we provided live Internet coverage of submersible exploration in the Caribbean Sea 5,000 meters deep, which was viewed by approximately 300 thousand people.

As for PR activities, we have called attention of the people to our research results by such activities as holding a special exhibition “*Shinkai*” jointly with the National Museum of Nature and Science, which attracted more than 590 thousand visitors and created a boom in the deep sea.

As a result of the Cabinet decision made on December 24, 2013 regarding “the basic policy on the reform of independent administrative agencies, and other matters,” it was decided that the JAMSTEC will become a R&D legal entity and that responsibility for the “Dense Oceanfloor Network system for Earthquakes and Tsunamis (DONET)” will be transferred to the National Research Institute for Earth Science and Disaster Prevention. We intend to conduct future operations accordingly.

(2) Changes in the Budget and Number of Staff

The graph below shows the changes in JAMSTEC’s budget and staffing since it became an independent administrative agency. The FY2013 budget was tight due to the policy of achieving financial soundness based on the situation in which the national expenditure continues to greatly exceed tax revenues. However, supplementary budget was allocated for the construction fees etc. of a wide-area seabed research vessel following the FY2012 budget.

Although the number of staff is on the increase in recent years due to the increase of fixed-term staff as a result of increasing the competitive funds, the JAMSTEC made efforts to maintain an appropriate pay standard and control personnel expenses by taking such measures that adhere to the purpose of the temporary special measures on payroll of government officials (effective for two years from April 1, 2012).



(3) Offices and Institutes

As of March 31, 2012, we have the following offices and institutes:

Name	Location
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

(4) Organization Chart

[Board members]President
Asahiko TairaExecutive Director
Yoshihisa Shirayama**[Research Sector]****Research Institute for Global Change (RIGC)**

- Ocean Climate Change Research Program
- Tropical Climate Variability Research Program
- Northern Hemisphere Cryosphere Program
- Environmental Biogeochemical Cycle Research Program
- Global Change Projection Research Program
- Climate Variation Predictability and Applicability Research Program
- Advanced Atmosphere-Ocean-Land Modeling Program
- Project Team for Risk Information on Climate Change

Research Director, Research Institute for Global Change (RIGC)
Masao Fukasawa**Earthquake and Tsunami Research Project for Disaster Prevention**Project Leader, Earthquake and Tsunami Research Project for Disaster Prevention
Yoshiyuki Kaneda**Submarine Resources Research Project**Project Leader, Submarine Resources Research Project
Eiichi Kikawa**Institute For Research on Earth Evolution (IFREE)**

- Plate Dynamics Research Program
- Solid Earth Dynamics Research Program
- Deep Earth Dynamics Research Program
- Geochemical Evolution Research Program

Research Director, Institute For Research on Earth Evolution (IFREE)
Mithuhiro Toriumi**Institute of BioSciences (BioGeos)**

- Marine Biology Research Program
- Extremebiosphere Research Program
- Earth and Life History Research Program

Research Director, Institute of BioSciences (BioGeos)
Hiroshi Kitazato**Application Laboratory (APL)**Integrated and Intellectual Information Science and Technology Program
— Society-Oriented Prediction Engineering Science Program
— Deep Sea Engineering Science Program
Head of Application Laboratory (APL)
Toshio Yamagata**[Development and Promotion Sector]****Marine Technology and Engineering Center (MARITEC)**

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

Director-General, Marine Technology and Engineering Center (MARITEC)
Yoshio Isozaki**Earth Simulator Center (ESC)**

- Information Systems Department
- Advanced Simulation and Technology Development Program
- Simulation Application Research and Development Program

Director-General, Earth Simulator Center (ESC)
Kunihiro Watanabe**Data Research Center for Marine-Earth Sciences (DrC)**

- Data Management and Engineering Department (DMED)
- Global Oceanographic Data Center (GODAC)
- Earth Science Information Database Construction Team

Director-General, Data Research Center for Marine-Earth Sciences (DrC)
Shiro ImaiExecutive Director
Hitoshi HottaExecutive Director
Hisashi DobashiAuditor
Yasushi TayaAuditor
Hiroyuki Nakahara**Laboratory for Earth Systems Science**

- Precambrian Ecosystem Laboratory Unit
- Space and Earth System Modeling Laboratory Unit

Unit Leader, Precambrian Ecosystem Laboratory Unit
Ken TakaiUnit Leader, Space and Earth System Modeling Laboratory Unit
Kanya Kusano**Mutsu Institute for Oceanography (MIO)**

- Research Group
- Research Promotion Group
- General Affairs Division, MIO

Director, Mutsu Institute for Oceanography (MIO)
Shuichi Watanabe**Kochi Institute for Core Sample Research (KOCHI)**

- Research Group
- Science Services Group
- General Affairs Division, KOCHI

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

- Project Team for Analyses of Changes in East Japan Marine Ecosystems

Research Support Department

- Research Support Division I
- Research Support Division II

[Management Sector]**Planning Department**

- Planning Division
- Strategic Planning Office
- Corporate Integration Office

General Affairs Department

- General Affairs Division
- Facility Management Division
- YES General Affairs Division
- Tokyo Office
- Legal Affairs Division

Human Resources Department

- Human Resources Division I
- Human Resources Division II
- Employee Relations Division
- Employee Support Division

Finance and Contracts Department

- Finance and Accounting Division
- Finance Division
- Contracts Division I
- Contracts Division II

Safety and Environment Management Office**Audit Office****Center for Deep Earth Exploration (CDEX)**

- Planning and Coordination Office, CDEX
- Operations Department
- International Cooperation Project Promotion Group
- HSE Group

Director-General, Center for Deep Earth Exploration (CDEX)
Wataru Azuma**Advanced Research and Technology Promotion Department**

- Business-Academia Collaboration Division
- External Funding Division
- International Affairs Division
- Library Division

Public Relations Department

- Public Relations Division
- Press Division

(5) Research Facilities

Vessels

CHIKYU

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

NATSUSHIMA

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

KAIYO

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

YOKOSUKA

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

KAIREI

Deep sea research vessel
Length: 106.0 m
Gross tonnage: 4,517 tons
Complement: 60 persons
Commissioned: 1997

MIRAI

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

HAKUHO MARU

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

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: 4.3 tons

KAIKO

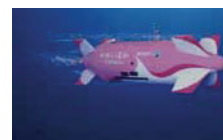
Remotely operated vehicle
Depth capability: (Launcher) 11,000 m
(Vehicle (Mk-IV)) 7,000 m
Length/dry weight: (Launcher)
5.2 m/5.8 tons
(Vehicle (Mk-IV)) 3.0 m/3.9 tons

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: 1280
Number of nodes: 160
Peak quality: 131 teraflops
Main memory capacity: 20 terabytes

Training pool**Hyperbaric chamber****Ultrasonic tank****Core Repository**

(6) International Cooperation

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

To contribute to the elucidation of these issues and promote ocean observation and research further effectively and efficiently, the JAMSTEC is promoting international joint projects as well as establishing and maintaining cooperative relationships with international organizations such as the United Nations organizations and other overseas research institutions.

1) Contributions to Multilateral Framework for International Collaboration

The JAMSTEC sends experts to related international meetings of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) to support IOC-related activities as well as identifies the international trends necessary for smooth implementation of ocean observation and research under the enforcement of the United Nations Convention on the Law of the Sea. The “Japan Group of Experts to Advance IOC Programs” which was established within the JAMSTEC since January 2008 to strengthen the Japanese promotion system for relevant IOC projects and meetings, has been exchanging views and reviewing international research projects. In FY2013, subgroups of experts for three fields out of the subgroups established under the Japan Group of Experts to Advance IOC Programs exchanged their views at several meetings, and in June 2013, the Japan Group of Experts to Advance IOC Programs held its 6th meeting. Based on the results of views exchanged in each subgroup meetings, future perspectives on IOC-related activities were discussed. Furthermore, in January 2013, the JAMSTEC sent a staff member from the International Affairs Division to the headquarters of IOC (Paris, France) for two years in order to contribute to Japan’s contribution to the IOC as well as contribute to the development of international marine researches.

In addition, the JAMSTEC sends researchers and contribute to research activities, as needed, to other international oceanographic organizations, including the South Pacific Applied GeoScience Commission (SOPAC), an influential organization in the South Pacific region, which is one of JAMSTEC’s main observation and research areas.

2) Joint International Projects

The JAMSTEC participates in the following joint international projects and is contributing to their activities:

- The Array for Real-Time Geostrophic Oceanography (ARGO)
- Climate Variability and Predictability (CLIVAR)
- Global Earth Observation System of Systems (GEOSS)
- Global Ocean Observing System (GOOS)
- International Continental Scientific Drilling Program (ICDP)
- International Seismological Centre (ISC)
- International Margins Program (InterMARGINS)
- An initiative for international cooperation in ridge-crest studies (InterRIDGE)

- Integrated Ocean Discovery Program (IODP)
- Ocean Biogeographic Information System (OBIS)
- North Pacific Marine Science Organization (PICES)

3) Cooperation under Intergovernmental Cooperation Agreements

The JAMSTEC conducts cooperative researches based on intergovernmental cooperation agreements Japan has concluded with such countries as the United States, the United Kingdom, Italy, India, Australia, Canada, South Korea, China, Germany, New Zealand, Brazil, France, Russia, and the EU.

The main intergovernmental cooperation meetings and workshops held in FY2013 are as follows:

- June 2013 The 8th Meeting of the Japan-France Joint Committee on Science and Technology
- June 2013 The 2nd Japan-EU Joint Committee on Science and Technology
- July 2013 Japan-Australia Marine Science Workshop
- September 2013 The 11th Japan-Russia Joint Committee on Science and Technology
- September 2013 The 2nd Japan-New Zealand Joint Committee on Science and Technology

4) Cooperation with Foreign Institutions

The JAMSTEC has concluded memorandums of understanding (MOUs) for comprehensive cooperation on researches respectively with relevant institutions in the United States, the United Kingdom, Indonesia, Australia, Canada, South Korea, Germany, New Zealand, and France. In FY2013, the JAMSTEC held a periodic meeting organized under the MOU with the Korea Institute of Ocean Science and Technology (KIOST) in August 2013 and with the National Oceanic and Atmospheric Administration in the United States in February 2014. We also concluded new MOUs with the European Consortium for Ocean Research Drilling (ECORD) and the Australian and New Zealand International Ocean Discovery Program (IODP) Consortium (ANZIC) in FY2013.



MOU Signing Ceremony with the ECORD

In addition to MOUs for comprehensive cooperation on researches with relevant institutions in various countries, the JAMSTEC has signed agreements for conducting joint researches with the relevant institutions in 24 countries. In FY2013, we renewed the agreement for conducting joint researches with the Agency for Assessment and Application of Technology (BPPT) in Indonesia and signed new agreements with the National Institute

of Water and Atmospheric Research (NIWA) of New Zealand and the Moscow State University (MSU).

Furthermore, based on the agreement for research cooperation with the International Arctic Research Center, University of Alaska (IARC), the JAMSTEC is conducting joint researches with the University. We are also conducting joint researches with the International Pacific Research Center, University of Hawaii (IPRC), based on the agreement for research cooperation. In order to further promote cooperation in joint researches with these two institutions, we concluded MOUs for comprehensive cooperation on researches as well as signed new agreements for conducting joint researches with them.

The JAMSTEC also participates in the Partnership for Observation of the Global Oceans (POGO) which is a forum for major oceanographic institutions around the world. Our executive staff attended the 15th POGO Annual Meeting held in Hobart, Australia from January 22-24, 2014. The staff participated in discussions on oceanographic observation with oceanographic institutions around the world and developed further cooperation with them.

5) Other International Cooperation

In FY2013, the JAMSTEC carried out a research voyage around the world to explore the limit of life, called QUELLE 2013 using the manned research submersible *SHINKAI 6500*. At the anchorage sites of the voyage in South Africa, Brazil, Tonga, and New Zealand, the *SHINKAI 6500* and its supporting mother ship *YOKOSUKA* was opened especially for the government officials and persons involved in science and technology, persons from the local Japanese Embassy, and local Japanese citizens in the country and introduced JAMSTEC's activities and Japan's oceanographic researches. In particular, in Brazil, we were able to create a foundation for us to conduct future R&D activities and in Tonga, we received a visit from the royal family.

The JAMSTEC also received visits from foreign governmental research institutes including the Helmholtz Association of German Research Centres, the Alfred Wegener Institute for Polar and Marine Research, National Applied Research Laboratories (NARLabs) of Taiwan, and the National Oceanography Centre Southampton (NOCS) of the United Kingdom. The visitors inspected our facilities and exchanged opinions with us.

Furthermore, we held the Japan-Australia Marine Forum "Coral Reefs and Environmental Changes" jointly with the Australian Institute of Marine Science in July 2013. Researchers from Japan and Australia explained in plain words the research conducted on environmental changes and its future prospects to the general public. We also proactively introduced our R&D operations through graphic panel exhibitions, lectures, and explanations at such events as the *Intergovernmental Group on Earth Observations* (GEO) 10th Plenary and Ministerial Summit (January 2014, Geneva, Switzerland) and Annual Meeting of the American Association for the Advancement of Science (February 2014, Chicago, United States).



Opening of the *YOKOSUKA* and *SHINKAI 6500* especially for high school students in South Africa during QUELLE 2013



YOKOSUKA at anchor in Port of Santos, Brazil during QUELLE 2013



Opening of the *YOKOSUKA* and *SHINKAI 6500* especially for government officials and the press in New Zealand during QUELLE 2013



Panel Discussion during the Japan-Australia Marine Forum "Coral Reefs and Environmental Changes"

2. Departmental Overviews and Notable Achievements

Research Institute for Global Change (RIGC)

Overview

The earth we inhabit consists of various natural habitats in the oceans, atmosphere, and on land, and all of the ecosystems nurtured on the earth interact with one another to shape the global environment. The earth has a history of approximately 4.6 Gyr, and her environment has been of tremendous benefit, protecting and fostering man's existence and civilization for the last few millennia. However, in recent years, drastic environmental changes (e.g. global warming) have occurred as a result of human activity. It is a challenge for the natural science to understand these changes, to investigate what causes them, and to contribute to the sustainable development of society through predictions of future changes of the global environment including not only long-term climate changes but also extreme weathers of shorter time periods, such as heat waves, cold waves, and heavy rains.

RIGC aims to observe the atmosphere, oceans, and land, with associated ecosystems using variety of techniques to detect global changes comprehensively. And, based on these observational results, models are developed to integrate knowledge toward a better understanding and prediction of future environmental changes. RIGC defines our mission as: "Carrying out global environment variation research so that JAMSTEC will play a foundational role as the world's center of excellence (COE) in natural sciences, seeking to be recognized as an organization that can respond to the social and economic needs of Japan as well as of the world," based on our vision of "making use of the knowledge we accumulate through natural sciences for the establishment of a sustainable, more productive society in which humans and the global environment coexist harmoniously." In particular, one can easily recall our response to the accidental discharge of radioactive materials from the Fukushima Daiichi nuclear plant following the Tohoku Region Pacific Coast Earthquake of March 11, 2011, when we monitored the ocean and used the results to predict the diffusion of radioactive materials in the ocean, providing the information to the public. RIGC/JAMSTEC now plays an indispensable role in ocean observation and prediction concerning climate change; this is reflected in the fact that as many as 121 papers with the first authors of RIGC scientists were cited in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and also in the fact that a large number of papers referred to observation data provided by RIGC/JAMSTEC and/or results of the MIROC prediction model. Now, a new Japanese national program, "Program for Risk Information on Climate Change" started including RIGC. It is our pleasure to be participated in such program as this one to demonstrate the performance of RIGC/JAMSTEC.

Ocean State Estimation by Synthesis of a Variety of Ocean Observations

It is well-known that changes in the subsurface ocean play a critical role in climate change with the time scales of inter-annual to multi decades. Designed basin-scale ocean

observation has been carried out since the second half of the 20th century under international collaborative programs in order to promote climate change research. On the one hand, research vessels have been measuring water temperature and salinity as well as other dissolved substances by sampling ocean water at particular locations. On the other hand, since the beginning of the 21st century, continuous and large-scale ocean monitoring has been carried out by free-drifting profiling floats over the global oceans. The former method enables us to capture subtle changes of the ocean to depths close to the sea floor, but the monitoring is limited to where the observation vessels go. The latter method enables us to monitor changes over a large area, but the precision and the depth to which the monitoring can be carried out are not as good as those of research vessels. Further, since the 1990s, satellite data has been available to estimate sea-surface temperatures and sea-surface heights with relatively high resolution. Within this background, available ocean observation data (which is the only tool to reveal changes in the real ocean environment) is growing characteristically superior, depending on each data-gathering method.

In order to extract integrated climate-change information from these diverse data and obtain new findings with a level of uncertainty as small as possible, sophisticated analysis, which effectively utilizes the superiority of each type of data, is required. To this end, studies on "integrated ocean observation" have become quite common. On the basis of statistics, we can implement data-assimilation systems, which integrate multiple types of observations objectively, in order to produce better state estimation.

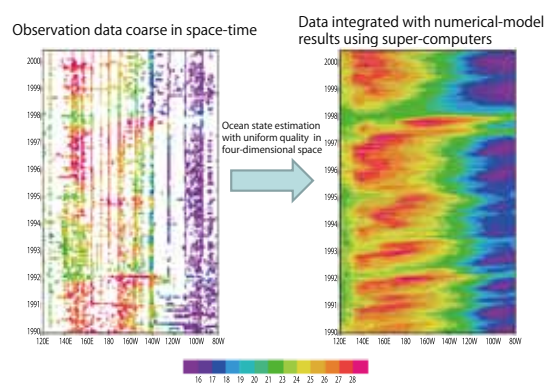


Figure 1. shows water temperature along the Equator in the Pacific Ocean at a depth of 100m, from 1990 to 2000. The graph on the left shows the observation data mainly collected using mooring buoys and free-drifting profiling floats while the graph on the right shows results of ocean state estimation. The blank spaces (unobserved points) on the left have been filled in using dynamics of an ocean general-circulation model. The unit used is degrees Celsius.

In particular, with the advancement of computational power in recent years, it is now possible to integrate not only the observation data but also other information concerning the

ocean circulation obtained by numerical models in order to better estimate the ocean state with chronologically and spatially uniform quality for the past few decades (Fig. 1).

JAMSTEC applies a data-assimilation method called the four-dimensional variational method, which is suitable for dynamical analysis, to generate an improved ocean state estimation over the last 53 years (1957 to 2009), which could contribute to various studies on climate change (ESTOC: Estimated State of global Ocean for Climate research). Here, we also attempted to integrate data concerning dissolved inorganic carbon (DIC), whose change has been a focus of attention in recent global warming studies (<http://www.godac.jamstec.go.jp/estoc/j/>). Here is an example of a research result using ESTOC. It is known that changes in ocean temperatures affect the sea surface height because of expansion or compression caused by changes in heat. Figure 2 shows the changes in sea surface height caused by the changes in the water-temperature (thermal steric height) field given by ESTOC. Images such as this one, displaying time-space continuous changes in the ocean environment including the subsurface, are difficult to assess with high quality using only the ocean observations obtained by vessels and floats/buoys and remote-sensing products. Our ocean state estimation is, therefore, a valuable tool for climate change research.

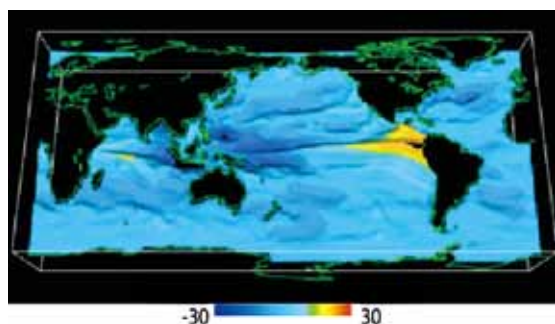


Figure 2. Changes in sea surface height caused by ocean temperature changes, down to depth of 800m, estimated from ESTOC. Snap shot as of December, 1997. One can see the sea surface height increasing by about 30cm off the coast of Peru due to large-scale El Nino. (unit: cm)

We will not only continue to study climate change using ESTOC but also carry out research on data-assimilation methods so that one can more efficiently use data obtained by advanced ocean observations, which are evolving in multiple ways.

To better understand the Indian Ocean dipole

The Indian Ocean Dipole (IOD) is a coupled ocean-atmosphere phenomenon in the tropical Indian Ocean, which typically exhibits a sea surface temperature (SST) variation of 1-2°C over the western and eastern Indian Ocean (Fig. 3). It is reported that it influences not only the local but also the global climate through the change of atmospheric circulation.

A positive or cold IOD is characterized by a cold (warm) SST anomaly in the southeastern (central-western) tropical Indian Ocean (Fig. 3a), while the opposite phase is called a negative or warm IOD (Fig. 3b).

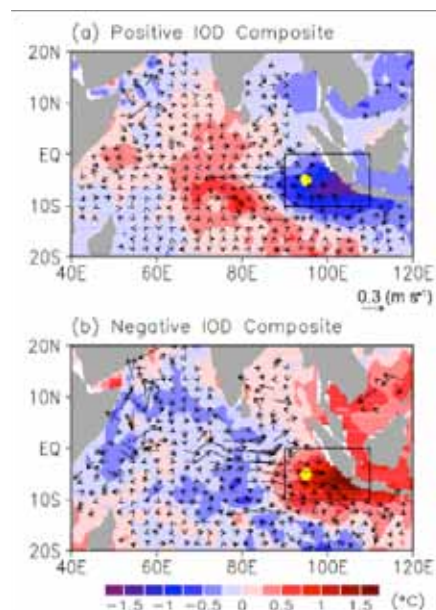


Figure 3. SST and ocean surface current for the case of (a) positive IOD (composite of 6 events of 2003, 2006, 2007, 2008, 2011 and 2012), and (b) negative IOD (composite of 2005 and 2010 events). The yellow circle indicates the location of a TRITON buoy used in this study

In this study, we used daily-average data from a moored TRITON buoy deployed at 5°S, 95°E, and examined the mixed layer temperature (MLT) balance in the southeastern tropical Indian Ocean for eight events observed during 2002–2012 to clarify the processes that produced the anomalous SST conditions (six cold and two warm events). Heat balance analyses revealed that during the development phase of cold/warm events, oceanic horizontal heat advections mainly produced the anomalous MLT (left panels of Fig. 4). In contrast, air-sea heat fluxes had a primary role in suppressing MLT anomalies during the decaying phase. Anomalous heat gain due to enhanced shortwave radiation and reduced latent heat loss caused the decay of cold events (Fig. 4, upper right), while air-sea flux tended to cool the positive MLT anomalies due to reduced shortwave radiation under cloudy conditions (Fig. 4, lower right). These results suggest that IOD evolves with different feedback processes during the developing and decaying phases.

As noted earlier, the IOD has an impact on the regional and global weather/climate. For example, recent analyses using radars deployed in Sumatra Island, Indonesia, as well as satellite data showed that the transition period from the dry season to wet season occurs one month ahead/behind during the warm/cold phase of IOD. Such information is useful for agriculture in Indonesia.

While the features and impacts of IOD have been documented well as mentioned above, its initiation mechanism has not been revealed, although there are various hypotheses including the role of the Madden-Julian Oscillation. This fact indicates the necessity of a full understanding based on the comprehensive observation from the Indian Ocean through the Indonesian Maritime Continent from the viewpoint of ocean-atmosphere-land interaction processes.

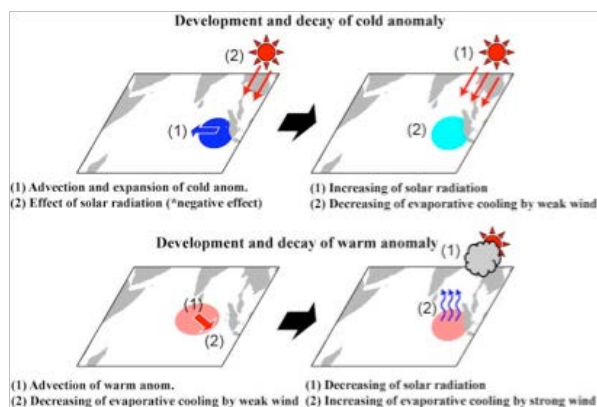


Figure 4. Schematic diagram of key processes during the developing (left) and decaying (right) phases of positive (upper) and negative (lower) IOD.

(1) Heat flux through the Barrow Canyon into the Arctic Basin

Pacific-origin water from the Bering Strait influences the Arctic basin in a number of important ways. The cold winter water ventilates the interior halocline and provides nutrients that spur primary production. The summer water is a predominant source of heat and freshwater. Barrow Canyon, in the northeast Chukchi Sea, is a major conduit for Pacific water to enter the interior Arctic basin. We have conducted year-round mooring measurements in the mouth of Barrow Canyon since 2000. High-resolution hydrographic and velocity data along the mooring array were also obtained in summer and early fall by R/V *Mirai*. Assemblies of annual mooring data and high-resolution data collected by ship along the mooring array enabled quantitative estimations of volume, freshwater, and heat fluxes in Barrow Canyon. The annual mean volume transport through Barrow Canyon was 0.48 Sv, approximately 55% of the annual mean Pacific water transport through Bering Strait. The year-to-year variation in heat flux (relative to the freezing point) was substantial, ranging from 0.93 TW (2006) to 3.07 TW (2012). In particular, during the recent enhanced sea-ice melt in the Arctic basin (2007, 2010, and 2012), the heat flux was large, at 3.0 TW or more. Heat fluxes observed in these years are sufficient to melt 1m-thick ice over an area of 360,000 km², which is nearly equal to the total land area of Japan. We plan to study how such oceanic heat affects the environment of the Arctic Ocean (Fig. 5).

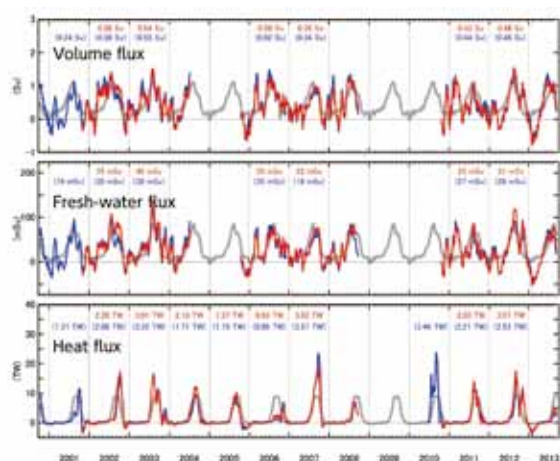


Figure 5. Changes in volume, fresh-water, and heat fluxes entering the Arctic basin through Barrow Canyon (from Sept. 2000, to Sept. 2013). The gray line indicates the mean value; the red and blue lines indicate values obtained by three mooring sites and by one mooring site, respectively, in Barrow Canyon. Updated version of Itoh, et. al. (2013).

(2) Changes in Water Circulation around the Arctic Land Region and Future Changes

Due to recent warming trends, elements of the water-circulation mechanism (snow, rain, reservoir, evapotranspiration, discharge) show more drastic changes, with water circulation more powerful as the period of change gets shorter. The Siberian rivers flowing into the Arctic Ocean are showing a long-term notable increase in the flow volume while the precipitation rise in Eastern Siberia is increasing the humidity. These are resulting in thicker active layers, withering of forests, and other large-scale changes. They are also believed to have powerful impact on river flows as well as water and heat circulations between the atmosphere and land. For these reasons, we studied the effects, both of the past and the future, of the river discharge of the land-surface process in the Lena River region using a land-surface model and now discuss the results.

Figure 6 shows annual changes in precipitation, river discharge, and evapotranspiration. This figure indicates that the increased precipitation is the main cause for the rise in the river discharge and that to a certain degree it also contributes to increased evapotranspiration.

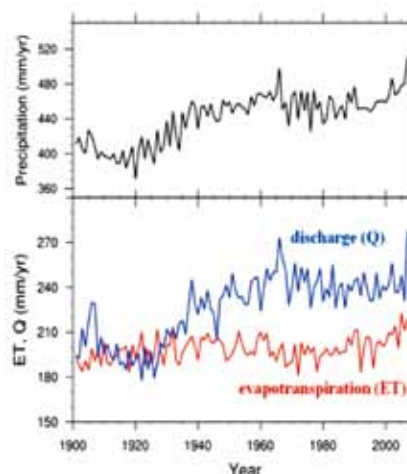


Figure 6. Precipitation (black), river discharge (blue), and evapotranspiration (red) in the Lena River region for 1900 to 2010, obtained by computation using the land-surface model

In order to find out future changes, we carried out a warming experiment based on the warming scenario A1B and obtained long-term deviations of the river discharge and evapotranspiration with respect to the current numbers (Fig. 7). The results show that the future rise in precipitation will have little effect on the river discharge but will have significant impact on the rise in evapotranspiration. In other words, while the recent rise in precipitation has been causing a notable increase in river discharge, the long-term increase in precipitation, predicted to occur due to warming, will instead bring about a significant rise in evapotranspiration accompanied by vegetation changes and thus may not result in a drastic rise in river discharge.

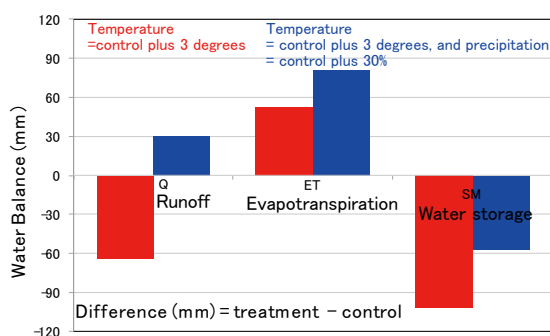


Figure 7. Deviations from current values in water balance in the Lena River region, obtained by a warming experiment based on the warming scenario A1B (Red indicates temperature = Ctrl + 3°C ; blue indicates the same but in addition, the precipitation is Ctrl + 30%).

(3) Improving Forecast Precision by Adding Observation Points

It is becoming widely known that the reduction of sea ice in the Arctic Ocean has a wide variety of social impacts. In particular, it is necessary to correctly grasp the atmospheric current around the Arctic Ocean in order to understand extreme climate phenomena in the mid-latitude regions and to navigate through the Arctic Ocean (forecasting sea ice and weather). While there is not much aerological observation data over the Arctic Ocean, observation data collected by the *Mirai* and other vessels can help us correctly re-create and predict the positions and intensity of arctic low-pressure systems as well as the temperature distribution, as demonstrated by the data-assimilating system ALERA2 of the Japan Agency for Marine-Earth Science and Technology (Fig. 8). The 2013 and 2014 arctic navigation trips by the *Mirai* will experimentally enhance the radiosonde observation network of the Arctic Circle under international collaboration and carry out a data-assimilating experiment in order to find out over how large of an area in the Arctic Circle the weather forecast can be improved.

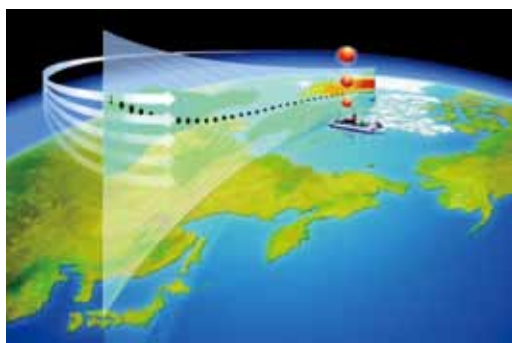


Figure 8. Concept figure of the 2010 *Mirai* arctic navigation trip. The radiosonde observation over the Arctic Ocean makes corrections such that the temperatures of the convection zone in the Arctic Circle are lowered while those of the lower stratosphere are increased. Observations extend partly to the air temperature and windy spots in the mid-latitude regions.

Exploring origins of PM2.5 particles over East Asia

PM2.5, made up of fine airborne particles with diameters less than 2.5 μm , strongly affects the Earth's climate by reflecting or absorbing solar radiation and by acting as cloud/ice nuclei, as well as adversely impacting human health. Also, iron- and nitrogen-containing particles, including naturally blown soil dust and those emitted from industrial human activity, could be deposited on the ocean surface after being transported and then affect the marine ecosystem as a nutrient. Despite the significance of PM2.5, information on the origins, composition, and recent changes in the mass concentrations of PM2.5 is limited, and thus elucidation of its behavior in the atmosphere remains a challenge. In January 2013, public awareness was sharply raised because media reported serious pollution in Beijing, where hourly PM2.5 mass concentrations reached 900 $\mu\text{g}/\text{m}^3$, and suggested possible transport to Japan. The Environmental Biogeochemical Cycles Research Program (EBCRP) has been conducting studies on the origins of PM2.5 particles for years and has provided relevant information to meet social needs.

1. Explore current status and origins of PM2.5 pollution in East Asia

We have been conducting continuous observations of the PM2.5 mass concentrations at Fukue Island, Nagasaki Prefecture, located in the “entrance” region of the transboundary air pollution from the Asian continent. From the observational results for four years, seasonality with low concentrations in summer and high concentrations in the other seasons was identified, suggesting the importance of wintertime monsoons in increasing the concentrations. Events with high PM2.5 concentrations were recorded within the air masses originating from the continent and were generally associated with high concentrations of black carbon (soot), a tracer of human activity. These facts were regarded as evidence of the transboundary transport of air pollution. A regional-scale chemical transport model based on WRF-CMAQ was used to simulate PM2.5 over East Asia. It successfully reproduced the observed temporal variation patterns in PM2.5 at Fukue Island. One drawback was that the model tended to underestimate the PM2.5 concentration levels; from detailed comparison of composition levels, we found that the model successfully reproduced the mass concentration levels of water-soluble species (e.g., sulfate), while it considerably underestimated those of organics by a factor of about 5 (Fig. 9). In the future, we must further explore the origins of organic aerosols to improve our predictive capability.

Paying adequate attention to this limitation, we further used the model system to evaluate the geographical distribution and to study possible origins of PM2.5. The model was able to reproduce the observed west-to-east decreasing gradient in the PM2.5 mass concentrations over Japan (Fig. 10), as found when our data at Fukue were combined with the data from the monitoring network over Japan developed by the Ministry of the Environment. We conducted sensitivity-model runs in which emission rates of PM2.5 precursors from each of the China, Korean Peninsula, and Japan regions were decreased by 20%, respectively. Based on the response of the PM2.5 concentration over Japan to these emission perturbations, we determined the contributions of each

source region to the PM_{2.5} concentrations over Japan. As a result, we found that the contribution from China exceeded 50% in western Japan (from Kyushu to Kinki), while the contribution from Japan itself was larger in the Kanto area. Such source apportionment provides critical information to understand the causal relationship in the geochemical cycles and to establish adequate countermeasures.

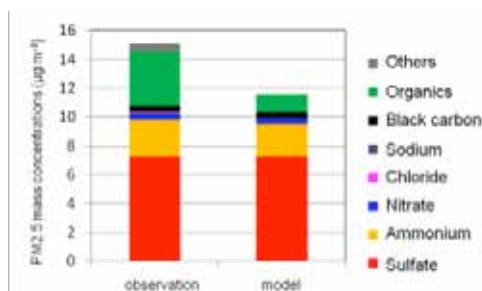


Figure 9. Average PM_{2.5} composition observed (left) and modeled (right) for Fukue Island in spring 2009.

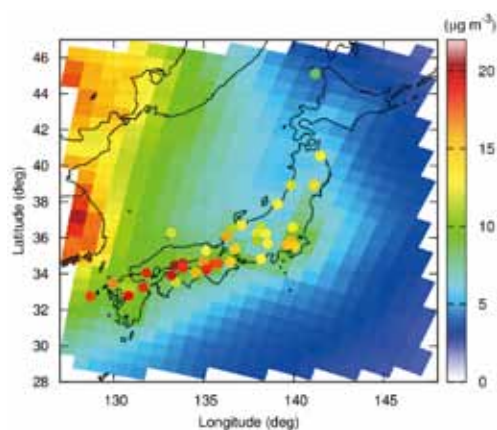


Figure 10. West-to-east decreasing gradient in the PM_{2.5} mass concentrations over Japan annually averaged for 2010. Observations: dots, model simulations: contours.

2. Development of a fluorescence-based instrument to classify organic aerosols

To better characterize the origins of atmospheric organic aerosols, a new, fluorescence-based instrument was developed (Fig. 11). In the instrument, particles entering the chamber were individually irradiated by a pulsed UV laser beam and the wavelength of the emitted fluorescence was used to classify the organics into several categories. The basic performance of the instrument was demonstrated, partly aided by parallel observations of tracers characterizing sources (combustion, soil, etc.) We plan to continue evaluation of the instrument and then obtain ambient data, to better characterize each of the classified organics in order to improve our understanding and model performance.

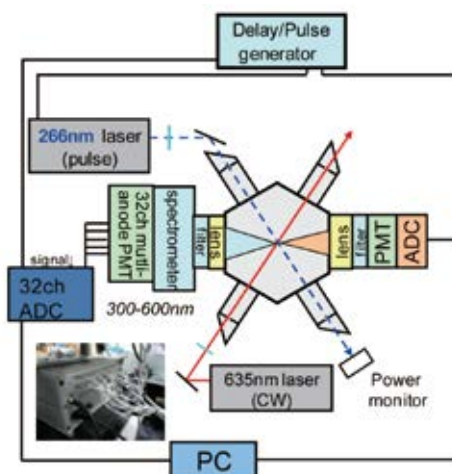


Figure 11. Schematic diagram of a laser-induced fluorescence instrument to classify organic aerosol particles.

Mechanism of the 100,000-year glacial-interglacial cycles

There have been climate changes with approximately 100,000-year periodicity known as 'glacial-interglacial cycles' over the past million years. They are characterized by growth and reduction of large continental ice sheets whose volume corresponds to 130m in terms of changes in the global sea level, accompanied by climate changes of global-scale. The essential factor for these large climate changes is considered to be variation of summer insolation at high northern latitudes (known as the Milankovitch theory). Using paleoclimate data, statistical analyses have demonstrated that the glacial cycles are closely linked to the periodicities of the factors to determine the summer insolation, such as eccentricity, obliquity and precession cycles. However, dominant periodicities in the summer insolation are 20,000 and 40,000 years, while the 100,000-year periodicity corresponding to the glacial cycles is insignificant, and the physical mechanisms for the cycles have been unclear.

In this study, numerical simulation using comprehensive climate and ice-sheet models succeeds in reproducing the previous ice sheet variations of 100,000-year cycles, as well as the volume and geological distribution of northern hemisphere ice sheets during their growth phases (Abe-Ouchi et al 2013). It is shown, for the first time in the world, that such alternation of glacial and interglacial climates over 100,000 years is caused by insolation and internal feedback between the climate, the ice sheets, and the lithosphere-asthenosphere system. In particular, geological patterning of and the climate over the North America Continent are shown to be the key factor in climate change, where the ice sheet can be very sensitive to small insolation change. It is also shown that the variation of atmospheric content of carbon dioxide is not determinative in the evolution of the 100,000-year glacial cycles, but helps to amplify the response of climate systems to changes in insolation.

Moreover, multiple steady states of ice sheets under a summer insolation, which generate hysteresis structures, are shown. It is shown that the difference in the shape and position of the hysteresis loops between the ice sheets over North America and those over Eurasia plays a key part in determining the periodicities of glacial cycles. The North American ice sheet,

in contrast to the Eurasian ice sheet, grows through several precession cycles (20,000-year periodicity) after its inception, while its amplitudes decrease towards an eccentricity minimum (100,000-year periodicity). The more an ice sheet grows towards lower latitudes, the smaller the insolation required to make the ice sheet retreat. After a large ice sheet is established, a moderate increase in insolation due to changes in the eccentricity can be sufficient to trigger reduction of the ice sheet toward an almost complete retreat within several thousand years. It is shown that such a rapid retreat is mainly controlled by interaction among climate, ice sheet, and lithosphere-asthenosphere systems. Increased ice-sheet loading causes lowering of the bedrock. Because of the delay in the isostatic response, lowered bedrock is maintained during the melting of the ice-sheet, which leads to rapid retreat of a large ice sheet.

Changes in climate and/or ice sheets over the polar region are not only an indicator of recent global warming, but also have an aspect of directly influencing the global sea level. This study is significant in order to validate the reliability of the numerical model of ice-sheets and the climate to compute the response of ice-sheets to global warming. Also it is expected that the understanding of past climate changes will advance following this study.

This study was mentioned in a press release by JAMSTEC and presented in 'Nature' journal. It is also introduced by 'News and View' in the same volume and by 'Science' journal (Fig. 12).

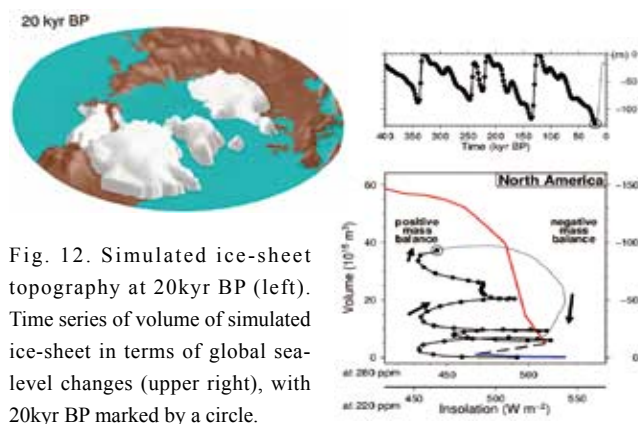


Fig. 12. Simulated ice-sheet topography at 20kyr BP (left). Time series of volume of simulated ice-sheet in terms of global sea-level changes (upper right), with 20kyr BP marked by a circle.

Diagram of ice-sheet volume as a function of input insolation (lower right). The horizontal axes are summer insolation when CO₂ content is 280ppm and 220ppm, respectively. The red and blue lines show steady-state ice sheet volume under constant insolation, in multiple steady states. The black line shows time evolution of ice-sheet volume during the last 120kyr, where black dots denote every 2kyr and the circle indicates 20kyr BP. Ice sheets grow according to the changes in the insolation while approaching the red curve. Growth reaches a peak at 20kyr, followed by a rapid decrease toward the blue curve.

Subtropical dipoles and the Southern Hemisphere climate

The subtropical dipole is an interannual climate phenomenon over the mid-latitude ocean basin in the Southern Hemisphere, which accompanies in its positive phase a warmer-than-normal sea surface temperature (SST) in the southwestern part of each

basin and a colder-than-normal SST in the northeastern part (Fig. 13.). The subtropical dipole develops typically during the austral summer (December–February) and causes a rainfall increase in southern Africa, southeastern Brazil, and New Zealand. Since the rainfall variations are sometimes linked to socio-economically important applications, such as natural disaster prevention, major crop yield, and water resources management, a detailed understanding of generation mechanisms of the subtropical dipole and improvement of the ability to predict them is essential.

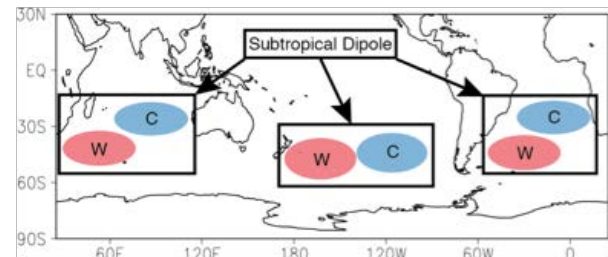


Figure 13. Climate phenomena in the mid-latitude Southern Hemisphere, called a “subtropical dipole.” Red (Blue) indicates an SST that is warmer (colder) than normal.

The generation mechanism of the subtropical dipole has been identified in our previous studies (Fig. 14). During October–December when the subtropical dipole starts to develop, the subtropical high anomalously strengthens in its southern part. Over the northeastern part of the subtropical high, an anomalously dry southeasterly wind from the high latitude enhances evaporation. This results in a colder-than-normal SST, causing the surface water to mix with water underneath and deepen the surface mixed-layer. Although the solar radiation acts to warm the mixed-layer, its contribution is smaller compared to the normal situation due to the thicker-than-normal mixed-layer depth. This leads to development of the northeastern pole with a colder-than-normal mixed-layer temperature. The mechanism for the southwestern pole development is found to be a mirror image to that for the northeastern pole. Associated with the subtropical dipole is an increase in moisture transport from the ocean to surrounding land and hence the increased rainfall over some of the rim countries.

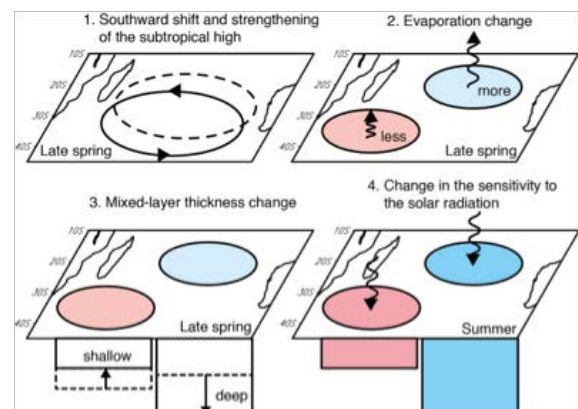


Figure 14. Generation mechanism of the subtropical dipole (southern Indian Ocean case).

What is responsible for the variation in the subtropical high during the development of the subtropical dipole? Previous

studies suggest that El Niño-Southern Oscillation (ENSO) in the tropics and the climate phenomenon in the higher latitudes of the Southern Hemisphere, called the Antarctic Oscillation (AAO), may contribute to the interannual variation in the subtropical high. However, the detailed mechanism of the variation remains unclear. We have conducted, therefore, a series of experiments by using a coupled general circulation model (SINTEX-F2) that is executed on the Earth Simulator. In the experiment, where the interannual variation in each tropical basin is suppressed, the subtropical dipole occurs in association with the strengthening of the subtropical high in its southern part. The occurrence frequency and amplitude of the subtropical dipole do not significantly change compared to the case with the interannual variations. In addition, the variation in the subtropical high is found to be strongly related to the AAO (Fig. 15). These results imply that even in the absence of tropical climate phenomena such as ENSO, the AAO induces the variation in the subtropical high and leads to the subtropical dipole.

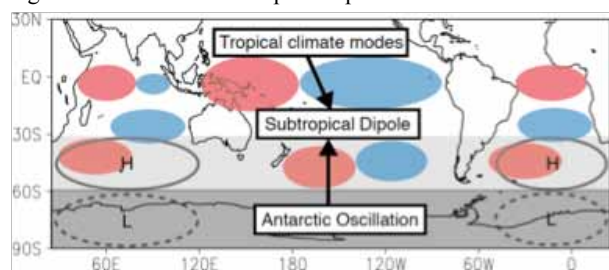


Figure 15. Climate phenomena that lead to the subtropical dipole: ENSO, Indian Ocean Dipole, and Atlantic Niño in the tropics and the AAO in the higher latitudes of Southern Hemisphere are shown, respectively.

A detailed understanding of the generation mechanisms of the subtropical dipole contributes to a better ability to predict the phenomenon. Results obtained in this study suggest that accurate representations of climate phenomena in the higher latitudes of the Southern Hemisphere, as well as in the tropics, need to be included in prediction models. Since the higher latitude climate phenomena are in turn influenced by other processes such as sea-ice distribution and the ozone amount over Antarctica, it is also important to incorporate these elements appropriately in a climate model. Efforts to provide reliable prediction information to international communities by developing such a climate model are in full progress.

Studies on Prediction of Typhoon Formation Using the K-computer

While typhoons provide the water resource, they often cause massive disasters by winds and rain. For those living in Southeast Asian countries, it is crucial to predict not only the path and intensity of each typhoon but its formation (birth) with high precision, being near the ocean regions where typhoons are formed.

A typhoon is a collection of clouds extending thousands of kilometers, and its formation and growth processes involve multiple phenomena of various scales, from tropical waves spanning tens of thousands of kilometers to individual cumulonimbus clouds only a few kilometers in size. Therefore,

in order to predict typhoon formation, we need a numerical model that can comprehensively re-create these phenomena. Since the beginning of the last decade, our research team has been developing NICAM, a global atmospheric numerical model with a super-high resolution, capable of resolving individual cumulonimbus clouds and re-creating waves spanning tens of thousands of kilometers.

In 2004, we saw an atmospheric fluctuation in the tropical northwestern Pacific region, referred to as an “intra-seasonal fluctuation.” this resulted in the formation of five and eight typhoons in June and in August, respectively, the two months with significant convection activity in the sea east of the Philippines (the averages for the two months are 1.7 and 5.9, respectively); on the other hand, in July and September, with little convection activity, only two and three typhoons were formed, respectively (the averages are 3.6 and 4.8, respectively). An intra-seasonal fluctuation is, therefore, closely connected to the formation of typhoons. Studies already completed have shown that NICAM is capable of re-creating, with high precision, the intra-seasonal fluctuation and the resulting typhoon formation, but we had not known exactly how far in the future and with what accuracy the prediction is possible because we needed a computer faster than the earth simulator.

K-computer created in Kobe in September, 2012, has the computational power about 100 times that of the Earth Simulator. Our research team took on this problem by carrying out a 30-day simulation on the K-computer beginning on each of the days in August 2004.

Figure 16 shows the prediction of the convection activity east of the Philippines on each simulation during August. NICAM was generally able to predict the northbound progress of the active convection in August and the weakening of the convection activity in September.

We then studied the forecast precision of typhoon formation. Out of the four typhoons formed in the first half of August, Typhoons #11 and #14 were difficult to predict, even right before their formation. These typhoons were formed north of 26 degrees latitude north, did not grow significantly, and lasted briefly. On the other hand, Typhoons #12 and #13 were clearly predicted. It was also discovered that Typhoons #15 through #18, formed in the latter half of August, were clearly predicted about two weeks prior but not sooner.

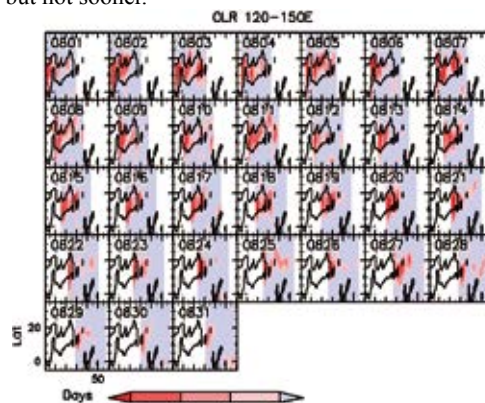


Figure 16. Convection activity east of the Philippines. The horizontal axis indicates the number of days since August 1, and the vertical axis the latitude. The red color shows the regions where active convection was simulated, and the regions surrounded by black curves showed active convection. Four-digit numbers represent MM/DD when the simulation began.

Why was it difficult to predict them more than two weeks in advance? Figure 17 shows how simulations that began on seven separate days were able to predict the spread of the west wind in the region where Typhoon #18 was formed. Spread of the west wind on the south side of the region where Typhoon #18 was formed was predicted in all of the simulations that had begun one week prior and in half of those that had begun two weeks prior. However, none of the simulations predicted it three weeks prior. We thus discovered that prediction of spread of the west wind played an important role in the prediction of typhoon formation.

Simulations also showed some errors where typhoons were erroneously formed (shown in red in Figure 17). In order to improve the forecast precision, it is necessary to properly understand what takes place in the tropical oceans and to use that knowledge to make the model better.

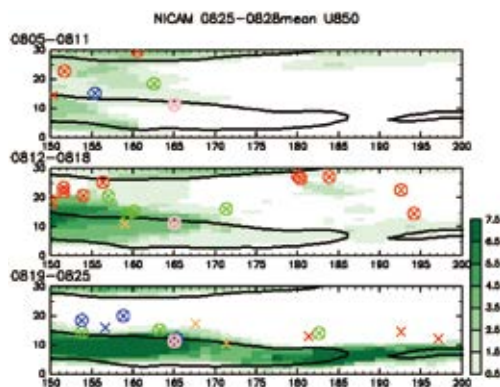


Figure 17. Seven simulations of typhoon formation, three weeks prior (top), two weeks prior (middle), and one week prior (bottom). The beginning date is indicated on the top left corner of each graph. These graphs show how many simulations correctly predicted the west-wind region at approximately 1500m altitude immediately before the formation of Typhoon 18. Black curves show the area where the west wind was actually observed. The pink spot around 11 degrees north and 165 degrees east marks the position of Typhoon 18 on August 28. The blue, orange, and green spots mark the location of the typhoon predicted by NICAM. The red spots show where the typhoon position was erroneously predicted.

Advanced near-term climate prediction using the ensemble data assimilation system

In near-term climate prediction, we require high skills in hindcasting the internal variations in the climate system as well as global warming, by employing initialization of the atmosphere-ocean coupled states. So far, to perform many sets of ensembles of decadal hindcast experiments, we have assimilated only the oceanic variables to the climate model as initialization. When verifying our skills in Pacific decadal hindcasts, for example, we surely validate the ability to predict the surface air temperature (SAT) of some areas (e.g., around Japan) over a few years (Fig. 18). On the other hand, we usually suffer from low accuracy in the indices of the Pacific decadal variability (e.g., the Pacific Decadal Oscillation and the North Pacific Gyre Oscillation) primarily due to large errors of SAT and sea surface temperature (SST) over the mid- and high latitudes of the North Pacific (Fig. 18). Error sensitivity analyses reveal that these hindcasted SST errors are closely related to the initial errors of the Aleutian Low and the delayed responses of the extratropical ocean. Therefore, a more

realistic initial condition of the atmosphere has the potential to improve our hindcast skills.

We have recently developed a new system for coupled atmosphere-ocean data assimilation. In order to assimilate both the atmosphere and ocean observations more properly in the climate model, we have implemented a sophisticated calculation using the so-called Ensemble Kalman Filter (EnKF) method. We have verified the effectiveness of our advanced assimilation system, by performing two sets of ensemble data assimilation experiments during the 2004–2010 period. Even though using only the surface pressure (Ps) and SST observations as input data, the model reproduces well the global atmosphere circulation in the troposphere and the ocean mixed-layer temperature. In particular, the sea level pressure (SLP) errors in assimilating both the atmosphere and ocean observations (Fig. 19b) are quite smaller than in assimilating only the ocean observation as in our conventional experiments (Fig. 19a). Since the atmospheric assimilation provides us with realistic initial conditions capable of improving the skill in seasonal-to-decadal climate predictions, we will apply this system to the initialization for near-term climate prediction. Toward compiling reanalysis datasets, in addition, we will also perform the 100-year-long assimilation experiments by addressing some issues, such as model bias and tuning the parameters in assimilation.

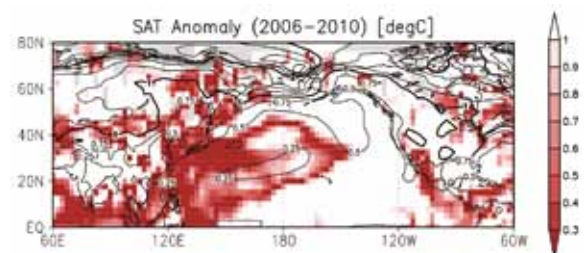


Fig. 18. Hindcasted SAT anomalies (contour) and normalized root-mean-squared errors (shade) averaged over the 2006–2010 period. Plotted values are the results of 6-member ensembles of the initialized hindcast experiments starting on January 1st, 2006.

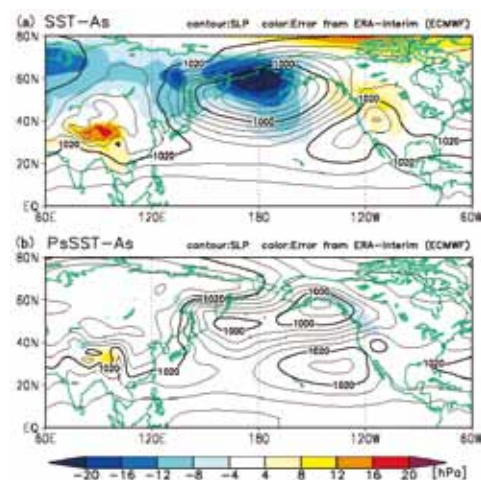


Fig. 19. Monthly means of SLP (contour) and their errors (shade) on January 2006 (i.e., the first month of the hindcast experiment shown in Fig. 18). Plotted values are the 30-member ensemble means of the data assimilation experiments by using (a) SST only and (b) both Ps and SST, respectively.

Institute for Research on Earth Evolution (IFREE)

Overview

The Institute for Research on Earth Evolution has been investigating the details of dynamics involving the entire earth interior, from the crust to the core, to learn about massive earthquakes and volcanic eruptions on the earth's crust as well as to obtain quantitative modeling of the concentration processes of useful elements in the crust. For these purposes, the Institute has set up basic research projects as well as applied research systems that combine projects. To carry out these studies, the Institute has four research programs: Oceanic Plate Dynamics Program, Solid Earth Dynamic Processes Program, Deep Earth Dynamics Program, and Earth Interior Materials Circulation Program. These programs have also been leading International Ocean Drilling Program (IODP) in collaboration with the Kochi Institute for Core Sample Research (under IFREE) and two other research institutes, using the JAMSTEC's own research vessel, the deep-sea scientific drilling vessel *Chikyu*, and the U.S. scientific drilling vessel *JOIDES Resolution*.

In 2013, we clarified the relaxation processes continuing since the 2011 Great East Japan Earthquake, to understand the physical meanings of the large seismic displacement reaching down to the trench axis, together with the physical process of plate boundary earthquakes, of seismic activities before and after the earthquake, and of seismic structure change within the island arc crust over the oceanic plate as well as the change of submarine topography. We also succeeded in the borehole drilling reaching the active giant thrust boundary of the Pacific Plate and recovered the continuous sets of cores across the plate-boundary faults, identifying the peculiar structures and properties of the faults materials. We also traced the development of accretion structures using the distinct-element method in large scales and discovered that the boundary front shows a very large fluctuation in particle movements before drastic breakout by boundary thrust. Along with these computer experiments, 3-dimensional analog experiments are now displaying nonlinear dynamics of sediment accretion.

Nonlinear behaviors of plate dynamics are shown as unstable plates (seen by stagnant slabs) falling onto the deep mantle. We also built a dense observation network in the western Pacific region to study the subduction process of the Pacific plate; based on the fact that it stagnates at a depth of about 600 km, forming a large-scale folding pattern, we have verified the accumulation of the slab by its folding within the lower mantle, at depths exceeding 1500 km. It is suggested that slab movement in deep parts of the earth significantly contributes to the dynamics of subduction on the surface level.

Global geochemistry is also playing a critical role in our understanding of water and gas circulation in plate border regions. In the process of formation of island-arc crust, the enrichment process of useful elements forming economic ore resources involves more than just the circulation enrichment of only the crust interior, a factor traditionally considered; it has become clear that, in addition, the process involves contribution from subducting sediments enriched in useful elements by means of fluid migration in the mantle beneath the island arcs.

Further, systematic analyses and studies of heavy isotopes in the sediments on the sea floor have allowed us to identify an enormous meteorite impact that did not accompany massive extinction of life about 220 million years ago.

Oceanic Plate Dynamics

Evolution of the Oceanic Plate Structure Immediately Before Subduction

The islands of Japan are arc-shaped islands formed by the subduction of oceanic plates, where seismic and igneous activities occur frequently, including trench-type massive earthquakes such as the 2011 Tohoku Region Pacific Coast Earthquake. Since these activities result from mutual actions of the Japanese islands (on the top) and the oceanic plate (on the bottom), one cannot understand the mechanism of these activities without first understanding the subduction of the oceanic plate. In particular, water transported by the ocean plate as hydrous minerals is thought to be crucial. It is water that defines igneous and volcanic activities in a subduction zone, sometimes contributing to earthquakes by dehydration reaction and friction coefficients on a plate boundary; it is water that has impact on the mantle convection by affecting mantle properties. From regional to global scales, water is closely linked to the dynamics of the earth's interior.

However, it is not known where or how the oceanic plates take in this water or how much water the plates transport to the subduction zone. Conventionally, it has been believed that hydration of the ocean crust by hydrothermal circulation in the mid-ocean ridge is the most important factor in the process by which the oceanic plates take in the water. However, more advanced structure research and rock experiments in recent years have suggested the possibility that the water penetrates to the oceanic plates through faults that accompany plate bending in the outer-rise sea regions where the oceanic plates bend right before their subduction from the trench. Because the mantle can contain larger amounts of water than the crust through serpentinization, if the water has indeed penetrated to the mantle, it is possible that the amount of water supplied to the subduction zone is much more than conventionally imagined.

For these reasons, for the last ten years, many structure research studies have been carried out in subduction zones all over the world in order to learn about the structural evolution of oceanic plates caused by the growth of plate-bent faults. It has been discovered that, as bent faults grow, the P-wave velocity (V_p) inside the oceanic plate goes down. Such a decrease in V_p suggests the possibility of (1) higher porosity due to the growth of a fault or a crack or (2) water penetration; however, one cannot determine which one is occurring by V_p alone. In order to distinguish the two possibilities and to see if water is penetrating inside the oceanic plate, it is essential to measure the Poisson ratio or the V_p/V_s ratio, quantities sensitive to the existence of water.

We undertook a large-scale structure exploration in the Pacific Ocean plate immediately before the subduction into the Kuril Trench, using a sea-floor seismograph device equipped

with an air gun and a three-component seismometer (vertical motion, two horizontal components) to find not only V_p but also V_s (Figure 1).

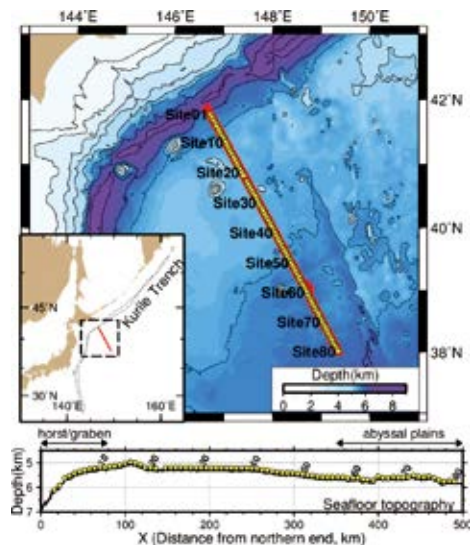


Figure 1. Structure exploration by a sea-floor seismograph device equipped with an air gun off the Kuril Trench. The top figure shows the region investigated; the bottom one shows the sea floor topography along the line indicated. Note that the left (north) side has more grown (horst/graben) bent fault.

Since an air gun only emits the sound (P) wave in the water, we do have the challenge of using a converted wave from the P wave to the S wave to understand the S-wave structure under the floor. However, our three-component seismometer records a converted wave clearly, and on the data thus obtained, we applied a structure modeling method (developed anew for this project) which uses converted waves. Using this method, we were able to, for the first time in the world, confirm that the V_p/V_s ratio inside the oceanic plate increases as the bent fault grows (Figure 2).

The rise in the V_p/V_s ratio is consistent with the increase in the amount of water inside the ocean plate, a strong indication that water is penetrating into the ocean plate as the bent fault grows. In other words, this result once again demonstrates how crucial it is to understand property changes in the oceanic plate structure immediately before the subduction if one is to understand earthquakes and volcanic activities that occur in subduction zones.

With that said, however, quantitative discussion on the amount of water that actually penetrated is a future challenge. The growth level of a bent fault varies significantly from location to location, and we do not yet know how much that variation affects the amount of water penetration from location to location. In the future, to understand uneven properties of earthquakes and volcanic activities in subduction zones, we need to continue our research in the amount of water taken in by oceanic plates as the faults grow.

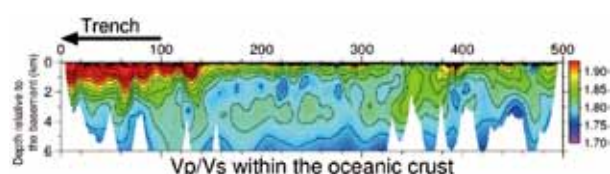


Figure 2.

The V_p/V_s ratio structured along the exploration line. The vertical axis indicates relative depth from the top of the ocean crust. For the first time ever, it was shown that as one gets closer to the trench axis, the V_p/V_s ratio increases from shallow areas (Fujie et al., 2013).

Solid-Earth Dynamic Process Research Program

Last year, we carried out the Japan Trench Fast Drilling Project (JFAST) and obtained borehole logging data and drilling samples. We analyzed them and determined the structure and composition of the plate-boundary fault that slid during the 2011 Tohoku Region Pacific Coast Earthquake (Figure 3: Chester et al., 2013). We also performed a dynamic experiment on the fault sample and determined that the shearing force of the plate-boundary fault is small (Ujii et al., 2013). Further, collecting thermometers placed in drilling holes, we estimated that the friction coefficient was extremely small during the earthquake (Fulton et al., 2013). In the southern sea drilling, on the other hand, detailed analysis of the sediment sample obtained on the Philippine Sea Plate revealed the material-supply process and its change over time from the islands of Japan, East Asia, and the Izu-Ogasawara arc into the Philippine Sea Plate for the last 15 million years, something that no one had known before (Pickering et al., 2013).

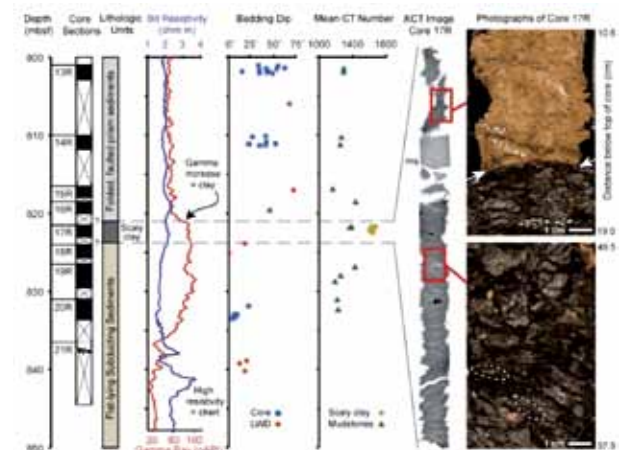


Figure 3. Borehole logging data, core analysis data, and core images collected near the plate boundary fault

We also examined via numerical computations the effects of the thermal conductivity of core materials, a concept made precise by recent high-temperature, high-pressure physics, on the heat chemical evolution of the core and the mantle. It turns out that the thermal conductivity of the core does not impact the thermal evolution of the mantle or the core but rather impacts the magnetic-field evolution and the density structure of the core (Figure 4). Additionally, we have developed a new method of coupling Stokes flows with the distinct-element method, enabling numerical model computations of the correlation between the magma (highly viscous fluid motion) and the crystals (Figure 5). Furthermore, our numerical simulation research using a high-precision shock-wave capturing code and a radiation-magnetic fluid dynamics code has demonstrated that (1) an amplified magnetic field inside the wave front causes

non-linear stabilization of the Kelvin-Helmholtz instability and (2) the saturation value of the magnetic turbulence initiated by the magneto-rotational instability increases by the convection motion (initiated by turbulence dissipation). We also formulated a phase-reduction method for vibration convection, leading to an analysis and optimization of common-noise synchronization of the vibration convection. We also formulated a phase-reduction method for vibration convection with space-translation degree of freedom.

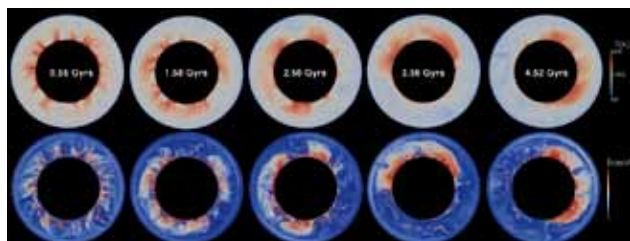


Figure 4. Progress over time of temperature (top) and composite structure (bottom) obtained by computations of heat-chemical evolution of core-mantle coupled systems

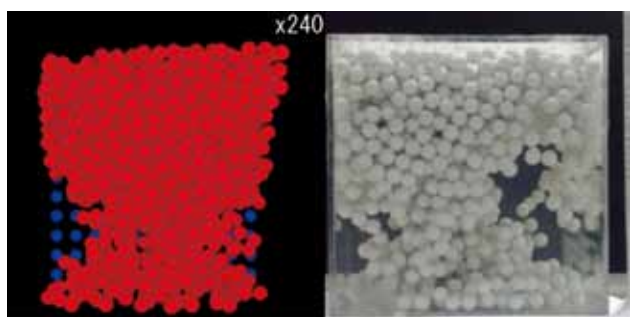


Figure 5. Motion of particles in high viscosity (right) compared with computations by the Stokes-DEM method

In this program, we also took active part in outreach activities for solid-earth science. Here is an example. Among earth science fields, compared to atmospheric and oceanic physics and volcano fields, seismology is a field where phenomena are difficult to see, and there has been very little available in terms of materials for dynamic experiments involving fault destruction and wave propagation. We have developed an indoor seismic exploration experience apparatus using agar (gelatin-like food), for which the seismic wave velocity is low and where seismic waves are visible. Using such an apparatus, one can not only see wave propagation but also observe and analyze wave forms just as in a normal seismic wave exploration. We actually took this device, carried out a seismic exploration lesson to high school students, and studied the effects (Figure 6). We were also highly praised for actual demonstrations open to general public and for symposia held concerning seismology education. Through this apparatus, with which one can experience wave propagation first-hand and intuitively, it is expected that the society in general will gain a good understanding on what type of research is involved in seismic exploration.



Figure 6. High-school lesson using an indoor seismic exploration experience apparatus. On the left, students are observing wave propagation by hitting agar. On the right, students are analyzing wave forms with advice from a researcher.

Deep-Earth Activity Research Program

A combination of ocean-floor geophysics observation, geochemistry research, and convection simulation of the mantle and the core is being used to study the nature and causes of deep-earth activities and to assess their impact on the earth's surface environment.

Change in the Geomagnetic Field Due to Change in the Earth's Rotational Speed

The geomagnetic field is formed and maintained by a dynamo action at the core of the earth's interior. This magnetic field prevents cosmic rays such as galactic cosmic rays and solar winds from directly pouring to the earth's surface and prevents dissipation of the atmosphere due to the rays. Therefore, it plays an essential role in protecting the environment on the earth's surface where living organisms can survive.

The geomagnetic field is not steady; its intensity is known to vary significantly over various time scales. To understand the cause of this variation is considered to be an important element in understanding the future of the change in the magnetic field and of our habitable environment.

One recent point of interest concerning the change in the magnetic field is changes over time scales varying from 10,000 to a hundred thousand years. Over such periods, the magnetic field has fluctuated drastically, up to tens of percentage points, resembling the climate change wherein glacial periods and interglacial periods alternate (Milankovitch cycle). But not much is known concerning the origin of change in the geomagnetic field or its relationship with climate change.

We focused on the fact that the climate change in which glacial and interglacial periods alternate causes the continental ice sheets in high-latitude regions to expand and contract repeatedly, causing the moment of inertia of the entire globe to change, which in turn causes the earth's rotational speed to fluctuate.

Such a change is thought to affect the geomagnetic field by impacting the convection inside the outer core. Based on this hypothesis, for the first time in the world, we carried out an analysis of the effects that a change in the earth's rotational speed has on the geomagnetic field using numerical simulations by the Earth Simulator at Jamstec.

Consequently, we discovered that the convection motion of liquid metals inside the earth's outer core changed as a result

of the change in the earth's rotational speed, quantitatively proving that this causes the change in the geomagnetic field. The change in the rotational speed (2%) caused a much bigger change in the geomagnetic field (about 20 to 30%) (Fig. 7), and we also discovered that there is a time lag between the changes in the rotational speed and the change in the magnetic field. We also found out that the change in the rotational speed caused a significant change, approximately 10%, in the amount of heat flux from the core to the mantle.

Not only are these results useful in understanding the mechanism of the change in the geomagnetic field, but they are also expected to be a powerful step in finding the relationship between climate change and the change in the geomagnetic field, which has not been fully understood. (These results were published in *Physical Review Letters* in 2013).

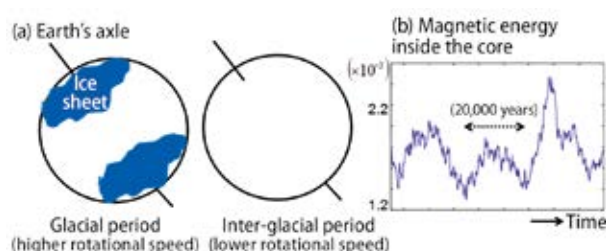


Figure 7.

(a) Between glacial and inter-glacial periods, variation in the ice sheets changes the earth's moment of inertia and the rotational speed.

(b) Simulation results show that the rotational speed change with a 20,000-year cycle (one of Milankovitch cycles) results in 20 to 30% change in the geomagnetic field while the rotational speed changed only by 2%.

Giant Meteorite Impact in the Triassic and Oceanic Anoxic Events in the Late Jurassic, Discovered by Osmium Isotope

The Triassic Period refers to the time period from about 237 million to 200 million years ago, known as the time period with repeated events of mass extinction. One of the extinction events speculated in the past is the possibility of a meteorite impact, but there had not been any clear proof of such. In 2012, for the first time in the world, a proof of a meteorite that fell in the later Triassic was discovered in a claystone between rocks called "cherts" exposed along the Kiso River in Sakahogi, Gifu (Onoue et al, 2012, PNAS). However, it was not known whether this meteorite caused a significant change in the earth's environment.

A research group consisting of Kyushu University, Kumamoto University (national university corporations), and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC, an independent administrative corporation) carried out an osmium isotope analysis (osmium is an element in the platinum group) on the rock samples collected in Sakahogi in Gifu as well as in the city of Tsukumi in Oita (Fig. 8).

As a result, we have discovered solid evidence that a massive meteorite with diameter between 3.3 and 7.8 km collided with the earth approximately 215 million years ago.

Another similar example of a result obtained by osmium isotope analysis is the determination of when the Besshi-type deposit was formed. Besshi-type mines, named after the

Besshi Mine in the prefecture of Ehime, are thought to have been formed by hydrothermal activity of submarine volcanos along mid-oceanic ridges in the Pacific Ocean. When they were formed, however, had been unknown. Using the rhenium-osmium isotope dating method, we determined that they were formed in the late Jurassic, approximately 150 million years ago. Extremely powerful volcanic and hydrothermal activities of the central ridge created large-scale submarine hydrothermal sulfide deposits while the carbon dioxide spouting out of the volcanos increased the carbon-dioxide concentration in the atmosphere. This eliminated ice sheets from the Polar Regions, suspending the general oceanic circulation and causing the oceans to be anoxic globally. Consequently, these events led to a series of geological phenomena, resulting in the preservation of submarine hydrothermal sulfide deposits. This was a revolutionary research result that revealed the close link between the formation of the earth's resources and environmental changes in paleoceanography.

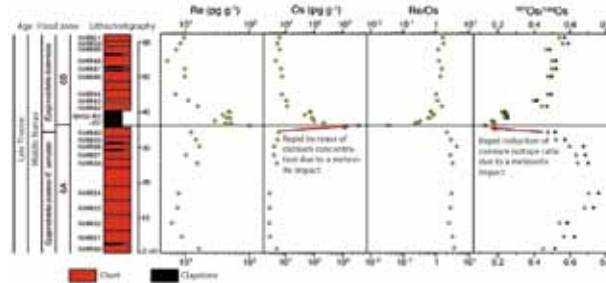


Figure 8. Vertical changes in osmium concentration and osmium isotope ratio. In claystones, we found a high osmium concentration and a low osmium isotope ratio, both of which are characteristics of a meteorite. The sample was collected in Sakahogi, Gifu.

Formation and destruction of oceanic plates

The formation and destruction of oceanic plates are fundamental key issues in earth science for understanding plate tectonics and material circulation in the earth's interior. IFREE worked on these topics and revealed important insights. An ocean drilling project on an oceanic plate in the Hess Deep using R/V *Joides Resolution* (US) recovered "layered gabbro" rocks for the first time, from the lower half of the oceanic plate (Fig.9, photo). This gabbro forms primary to evolved (crystallized) basalt magma originating in the mantle (Fig.9, upper right panel). Such diverse magma can form an average mid-ocean ridge basalt composition (Fig. 9, lower right panel).

The Pacific oceanic plate sinks deep into the earth along the Japan Trench and stagnates up to 700km beneath China and Korea (Fig.9, left). Young basalt volcanoes are distributed above the stagnant slab. From these, we found chemical components derived from the oceanic basalt and sediment in the deep stagnant slab. This suggests that destruction of the stagnant slab is underway and released water and melt induces basalt volcanism (Fig. 9, left).

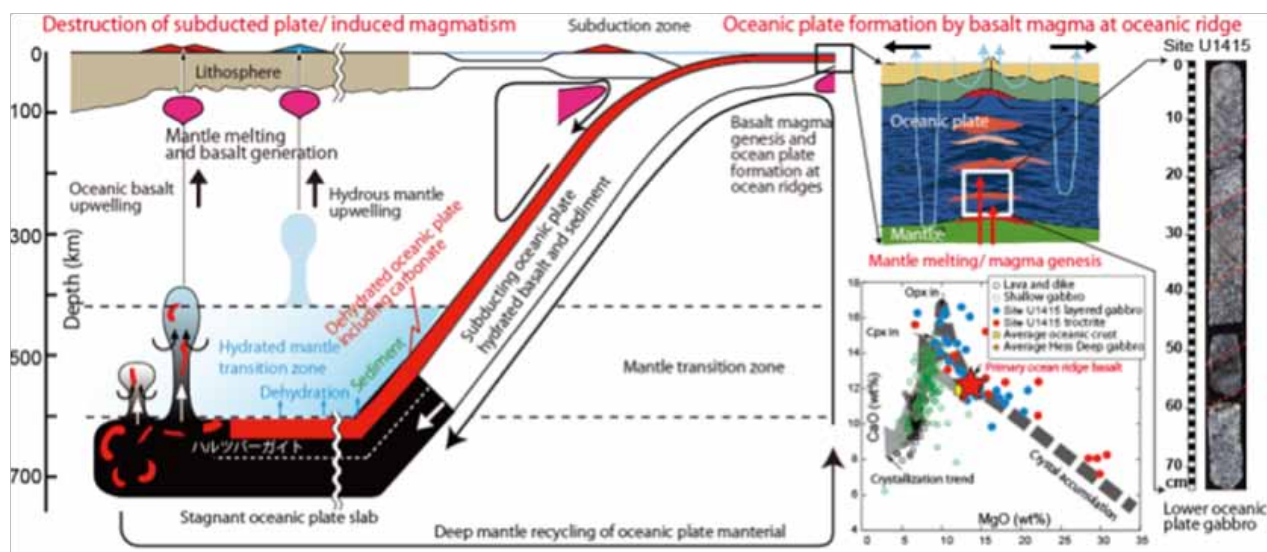


Figure 9. Formation of an oceanic plate on a mid-ocean ridge (right), and basalt magma genesis induced by the destruction of a subducted stagnant slab (left). Figures simplified from Gillis et al. (2014) *Nature* and Sakuyama et al. (2014) *Chemical Geology*.

Primary Magma in Subduction Zones

In order to learn about the formation of the continental crust and the origin of volcanos, it has been considered essential to understand the origin and properties of magma. However, since magma compositions change by the time magma appears on the earth's surface, the formation process and compositions of magma remained unknown for primary magma (magma just formed).

Pagan is an active volcanic island, the largest in the Mariana Islands, with an altitude of 570m. A majority of the volcano proper is under the ocean, with foothills extending down to a depth of 3000m. In 2010, we used the unmanned exploration vessel *The Hyper Dolphin*, owned by JAMSTEC, and carried out an underwater study on the sea floor (approximately 1800 to 2200m) around Pagan Island. There we collected fresh pillow lava (Fig. 10) on a sea floor incline (at a depth of approximately 2000m). An analysis of this lava showed that it consists of undifferentiated magma, the type whose composition is very close to that of primary magma. This allowed us to speculate the composition of primary magma by results of an indoor experiment. For the first time in the world, we carried out systematic collection and analysis of lava consisting of undifferentiated magma at a volcano in a subduction zone.

As the result of our systematic primary-magma analysis, a new hypothesis entitled "Mission Immiscible" was proposed concerning the origin of magma in subduction zones (Tamura et al., 2014). This hypothesis suggests the following: the original composition of slab components derived from a subducted plate has carbonate melt and silicate melt, which are mutually immiscible (unmixed as fluid), and these independently melt the mantle, creating distinct primary magma.



Figure 10. Primary magma collected on the sea floor by Pagan Island in the Mariana Arc

Institute of Biogeosciences (BioGeos)

Overview

The focus of the Institute of Biogeosciences (BioGeos) is the investigation of life, and the ecological and metabolic functions of the organisms in the oceanic biosphere. In particular, we investigate extreme environments for organisms, such as deep-sea hydrothermal vents, cold seeps, and anaerobic and subsurface environments beneath the seafloor. We also strive to provide knowledge beneficial to the development of society and the economy by investigating potential applications and roles of biotic communities adapted to oceans and extreme environments. Furthermore, by understanding the relationship between the oceanic biosphere and the atmosphere/oceans/solid earth, we aim to assess the effects of future global environmental changes on the biosphere.

Seventy or more researchers at BioGeos, belonging to the Marine Biodiversity Research Program, the Extremobiosphere Research Program, and the Earth and Life History Research Program, have conducted studies on the following themes:

- 1) Elucidation of the origin and evolutionary mechanism of life (understanding of biodiversity)
 - *From the origin of life to early evolution (limit of life)
 - *The evolution of Eukaryotes (understanding the origin of eukaryotes through endosymbiosis)
 - *From single cellular to multicellular organisms (cell differentiation, information transfer, etc.)
- 2) Elucidation of the structure and functions of the global biosphere
 - *The biogeochemical cycle and its change during the Earth's history
 - *Monitoring of the marine environment (ocean acidification, biodiversity fluctuation)
 - *The adaptive ecology of organisms in extreme environments (such as those with: high temperature and pressure, low temperature, CH_4 , H_2S , anoxia, etc. → special metabolic system, endosymbiosis)
- 3) Research into the application of functional molecules such as bio-materials and enzymes, and microorganisms
 - *Carbon dioxide fixation using bioreactor and carbon dioxide capture and storage (CCS)
 - *Energy development using organisms and enzymes (for instance $\text{CH}_4 \rightarrow \text{C}_3\text{H}_8$)
 - *Development of reagents and materials using beneficial enzymes and membrane materials

However, various technologies need to be developed in order to conduct these studies. BioGeos is developing new methods for: performing biological and chemical analysis, culturing organisms in extreme environments, and *in situ* biological environment monitoring. By using these research technologies and the JAMSTEC facilities, we have produced leading global research findings through our participation with international research programs such as the Integrated Ocean Drilling Program (IODP), InterRidge, and the Census of Marine Life (CoML).

The Great East Japan Earthquake, which occurred on March 11, 2011, and the nuclear power plant accidents that followed, caused significant damage to the marine ecosystems in northeastern Japan. After the disastrous Earthquake and Tsunami, BioGeos was among the first to begin research focusing on offshore areas, in order to continuously investigate the effect of the earthquakes and tsunamis on the marine ecosystems, as well as to investigate the potential recovery of such ecosystems.

BioGeos is conducting studies targeting oceanic areas from the continental shelf to the upper continental shelf off the Sanriku coast, mainly via the Tohoku Ecosystem-Associated Marine Sciences (TEAMS), which was launched in FY2011. We have created a detailed submarine topographic map of the offshore area of Sanriku and have shown that a large amount of debris was distributed from the continental shelf to the upper continental slope. The distributional areas differ from the northern Sanriku offshore area to the southern Sanriku offshore area. Moreover, it has been made clear that the rubble has decomposed, rather than remaining as foreign objects for submarine areas, and some of them are even serving as a fish bank. Considering that such information will benefit fisheries, we continue to communicate and share this information with the authorities concerned.

In 2013, we had a round-the-world voyage titled “QUELLE 2013” on the submersible research vehicle *SHINKAI 6500* and the support ship *YOKOSUKA*, and conducted an intensive investigation on extreme environments that are seen mainly in the deep waters of the Southern Ocean. In this research voyage, we tried to explore the origin of life and the mechanism of evolution by understanding how the biotic communities in the deep sea adapt to an extreme environment as well as their energy use. We conducted our investigation in the Atlantic Ocean off Brazil, the Cayman Rise in the Caribbean Sea, and the Tonga-Kermadec Trench and discovered new life forms that have adapted to various habitats. Furthermore, we also revealed geological phenomena that contribute to the formation of the habitats for these life forms. Some of those results have been covered by the media, which, we believe, helped to draw public attention to JAMSTEC. In terms of outreach activities, we conducted seminars at open houses for citizens and researchers, Japanese schools, and local junior high and high schools as the ships called at Cape Town (South Africa), Rio de Janeiro and Santos (Brazil), Nuku'alofa (Tonga), and Auckland (New Zealand), presenting the outstanding level of JAMSTEC's research and technology development.

Marine Biodiversity Research Program

In the Marine Biodiversity Research Program, we study marine biodiversity, especially that of the deep sea. We also study related subjects, such as interactions among various marine organisms (prey-predator interactions, symbiosis, etc.), the roles of marine organisms in marine ecosystems, factors affecting the distribution of marine organisms, and evolutionary mechanisms underlying marine biodiversity. In addition, we are searching for useful enzymes and natural products in diverse marine

organisms. Using the information we have obtained about marine organisms and their distributions, we are collaborating with the Data Research Center for Marine-Earth Sciences (DrC) and the Global Oceanographic Data Center (GODAC) of JAMSTEC to create a database called BISMAL (Biological Information System for MARine Life: <http://www.godac.jamstec.go.jp/bismal/j/>).

This database is the Japanese Node of the international database, Ocean Biogeographic Information System (OBIS: <http://www.iobis.org/ja>). We are also developing tools for analyzing biodiversity in BISMAL in the hope that this database will be useful for biological scientists throughout the world.

In addition, in FY2013, we also participated in the Tohoku Ecosystem-Associated Marine Sciences (TEAMS) and QUELLE 2013.

Discovery of a surrogate for sterol in anaerobic eukaryotes

It is known the eukaryotes generally have sterols that are a kind of triterpenoid in the cellular membranes. Although sterols play a role as potent stabilizers, they are also associated with maintaining the fluidity of eukaryotic cell membranes and phagocytic activity. The phagocytosis of eukaryotes is thought to play an important role in the acquisition of mitochondria during the course of evolution. Sterols are synthesized from squalene via complicated biochemical reactions in which molecular oxygen is required. Therefore, sterol synthesis occurs only under aerobic conditions. We then questioned how the anaerobic eukaryotes maintain their cell membrane flexibility and the phagocytic activity. In marine anoxic environments, not only bacteria and archaea but also various eukaryotic microbes are found. These anaerobic eukaryotic microbes do not likely synthesize sterols *de novo* in the oxygen-poor environments. In addition, they cannot obtain sterols from their food, eubacteria and archaea, because these prokaryotes generally lack sterols. However, most anaerobic eukaryotic microbes live in anoxic environments by phagocytizing eubacteria and archaea. Recently, we showed that some anaerobic eukaryotic microbes possess the gene that synthesizes tetrahymanol, a triterpenoid that does not require molecular oxygen for its synthesis (Fig.1), and that tetrahymanol has the possibility of functioning as an alternative to sterols. Many other anaerobic eukaryotic microbes, however, were shown to lack sterols and tetrahymanol. It is an enigma: what takes the place of sterol to maintain high membrane fluidity and phagocytic activity in such anaerobic eukaryotes? In the coming years, we will study the mechanism underlying the maintenance of cell membrane fluidity in the triterpenoid-lacking anaerobic eukaryotes, and discuss the origin of eukaryotic organisms.

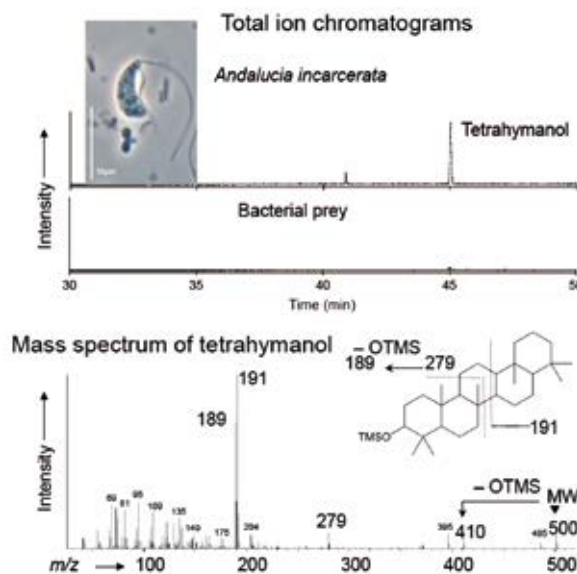


Figure 1. Gas chromatography/mass spectrometry (GC/MS) of lipid extracts from an anaerobic eukaryotic microbe, *Andaluia incarcerata*. Tetrahymanol was detected in the lipid extracts from *A. incarcerata*, but not sterols. Tetrahymanol was not detected from the prey bacteria in the same medium.

The mucus glycoprotein secreted from the gill tissues of *Calymene* clam

Calymene clams live in deep-sea hydrothermal vents and seep areas in symbiosis with sulfur-oxidizing bacteria in their gills. To understand the interaction between host and symbiotic bacteria, we constructed a library of monoclonal antibodies (mAb) against the gill tissue of *Calymene okutanii*. We screened for gill-specific mAbs by immunostaining, and obtained a mAb that bound to the bacteriocyte that is the gill epithelial cell containing symbiotic bacteria, its surface, and interfilamental space of the gill tissue, but not to the frontal zone, where no symbiotic bacterium is found (Fig. 2). To identify the molecule that the mAb recognized, we performed enzyme treatment, a comparison with lectin binding, cross reactivity to mucous polysaccharide, and analysis of monosaccharide composition by HPLC, and showed the possibility that the molecule recognized by mAb, is a glycoprotein secreted from gill tissues. Western blot analysis using this mAb showed that this glycoprotein was detected only in the gill tissue but not in other tissues (mantle, foot and ovary). In general, mucus is thought to be important in mucosal immunity for protection of the animal from infections by pathogenic microorganisms and viruses. This glycoprotein contained in the mucus may play important roles in the protection of bacteriocyte and maintenance of the symbiosis.

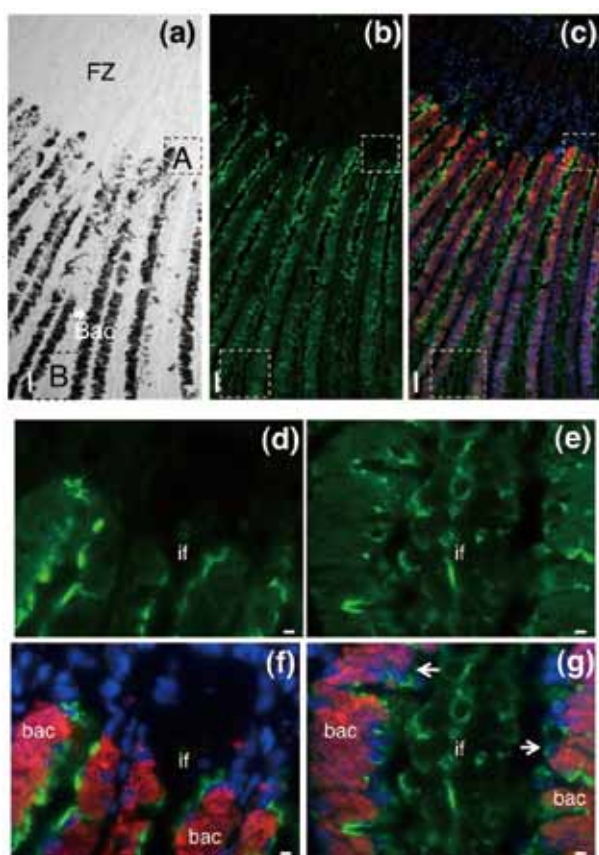


Figure 2. Immunostaining of the glycoprotein expressed in gills of *Calyptogena okutanii*. (a) Bright field; (b-g) fluorescence immunostaining of the gill filaments using the monoclonal antibody; (a-c) low magnification micrographs showing the gill filaments; (d-g) higher magnification micrographs showing the frontal (d, f) and middle (e, g) regions of the gill filaments. Green fluorescence: glycoprotein stained with the fluorescence labeled monoclonal antibody; red: symbiotic bacterium stained with a polyclonal antibody against bacterial chaperonin (GroEL); blue: DNA stained with DAPI. Scale bar (a)-(c): 50µm; (d)-(g): 5µm. The arrow shows bacteriocyte; FZ: frontal zone; bac: bacteriocyte; if: interfilamental space.

In situ experiment for understanding of early process in ecological succession of whale fall

When whales, the largest animals in the Earth's history, die, most of them sink to the deep-sea floor and form unique biological assemblages, which are called "whale-fall ecosystems." A whale carcass is the largest organic parcel falling on the nutrition-poor deep-sea floor, and is thought to be equivalent to 2,000 years of background organic carbon flux. Although such impact of the whale carcass is significantly large on the deep-sea floor ecosystems, little research has been performed because of the limited opportunities and/or difficulty of the sample (whale carcass) availability.

To observe the initial successional phase of the whale-fall ecosystems, we conducted a large-scale whale-fall experiment in Sagami Bay in collaboration with NHK and US Discovery Channel. For the experiment, we used a dead juvenile sperm whale that had washed ashore after dying in Chita peninsula, Aichi Prefecture, in April 2008 and been stored frozen. It had a

total length of about 5 meters and body weight of about 1.2 tons.

In June 2012, after 3 hours of whale deployment we started direct observation using human-occupied submersibles and an ROV, and conducted long-term observations using sea-floor-based time-lapse video/still cameras, which were continued for about two and a half months until August 2012. It was revealed that the whale carcass's soft tissues, such as muscle and fat, were consumed in an extremely short period: more than 50 % of the soft tissues were consumed in two weeks. The carcass was skeletonized after two months. The major consumers of the soft tissues were bluntnose sixgill sharks (*Hexanchus griseus*) (Fig. 3), snubnosed eels (*Simenchelys parasitica*), Japanese spider crabs (*Macrocheira kaempferi*), and giant isopods (*Bathynomus doederleinii*) but there were only a few hagfish, known as a dominant consumer of whale carcasses off California. After only two months, *Osedax* polychaetes, which live only on/in the bones of vertebrates, appeared.

This experiment clearly showed that the deep-sea ecosystem dynamically reacts and changes rapidly when a huge organic parcel is supplied on the seafloor. The various processes formerly believed to occur during the whale carcass decomposition are not common in other whale falls. Considering that tens of thousands of large whales sink to deep-sea, and that more marine mammals and large fishes are living in the ocean, such a massive organic carbon flux may play a role of a super highway of mass transport from the surface to the deep in the world's oceans.



Figure 3. Bluntnose sixgill shark (*Hexanchus griseus*) on a whale carcass installed in Sagami bay

Cultivation of *Calyptogena* clams in a hydrogen sulfide supplying aquarium

To study the mechanism of symbiosis in *Calyptogena* clams, it is extremely important to conduct experiments and observations using live specimens under cultivation in the laboratory. To establish the long-term cultivation of *Calyptogena* clams, we designed and made a new aquarium with a hydrogen sulfide supplying device. Then, we performed an inorganic carbon isotope uptake experiment, and confirmed that $^{13}\text{C-CO}_2$ is incorporated into the clam and fixed as an organic carbon by the symbiotic bacteria. We made two conditions, with or without hydrogen sulfide (control experiment), and kept the clams for a week (Fig.4). Stable carbon isotope analyses of the gill which harbors the symbiotic bacteria and of the asymbiotic organ, foot, showed that the ^{13}C -fixed organic carbon was detected in one of each of the clams cultivated with and without hydrogen sulfide. Higher ^{13}C -organic carbon content was detected in the specimen

cultivated with than that without hydrogen sulfide. This result clearly indicates that the abilities to fix inorganic carbon and to synthesize organic matter by the symbiotic bacteria were kept in the *Calymene* clam after cultivation for more than 10 days in the laboratory aquarium. The present experiment shows, (1) we can probably establish a cultivation method for the deep-sea *Calymene* clam, which has been believed to be extremely difficult to be kept alive in the laboratory, (2) the stable carbon isotope labeling/analysis provides a powerful tool to study ecology/physiology/biochemistry of *Calymene* clams, which has been believed to be unsuitable for laboratory experiments. In future, using this laboratory experimental system, we will get deeper insight in the ecology/physiology/biochemistry of the deep-sea symbiotic bivalves.



Figure 4. *Calymene* clams in the hydrogen sulfide supplying aquarium. The clams are in a healthy looking condition on coral sands and showing their siphons. Hydrogen sulfide was supplied through a tube buried in the sediment (coral sands), both oxidative (in sea-water) and reductive (in the sediment) environments were achieved in the small aquarium.

Thermostability mechanism of thermostable agarase

Upon exploring the useful enzymes from deep-sea bacterium, we found thermostable agarase-producing bacteria from a seabed mud sample taken at a depth of 2,406m located in Suruga Bay. This enzyme has already been commercialized as a gene analysis enzyme, and applied for human genome analysis. This year, we report the mechanism of thermostability of this enzyme.

First, we established a method of mass producing this enzyme using genetic engineering techniques. Then we examined the crystallization conditions of this enzyme for X-ray crystallography. By the crystallography of the obtained high-quality enzyme crystal (Fig. 5A), we constructed 3-dimensional structural models of the enzyme based on their diffraction pattern (Fig. 5B). By comparison with the 3 dimensional structure of a non-thermostable agarase, it was suggested that the compactness of the molecular structure is important for the high thermostability (Fig. 5C). Compared to non-thermostable agarase, the thermostable agarase has fewer loops, which are composed of random coils, at least at three sites, and has more proline residues on the surface of the enzymatic molecule (Fig. 5D). The present results provide us with important information about the high thermostability of enzymes, which we hope to apply to the development of industrial enzymes.

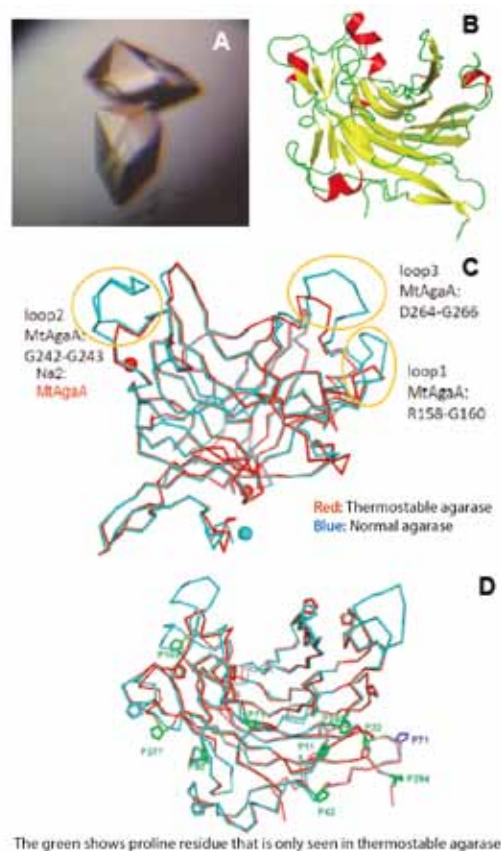


Figure 5. Crystals of the thermostable agarase (A), three-dimensional structure obtained from crystallographic analysis (B), comparison of the three-dimensional structure with that of a normal agarase (C), rich proline seems to form a hard structure (D).

Extremobiosphere Research Program

(1) Deep-sea and crustal biosphere research

In the Extremobiosphere research program, we planned and executed a voyage that led to a world extreme environment biosphere quest, QUELLE 2013, using *SHINKAI 6500* and *YOKOSUKA*. In the Indian Ocean, we revisited the Dodo and Solitaire hydrothermal fields in the Central Indian Ridge Rodriguez segment. Then, regarding the white scaly-foot gastropod and *Alviniconcha* snails, we carried out next-generation research on the symbiotic system and ecophysiology of a hydrothermal chemosynthetic community, such as the measurement of various environmental conditions, precious sampling by in situ fixation, and measurement of metabolic activity by shipboard experiments simulating the field environment. Unfortunately, we were hardly able to survey the Kairei and Edmond hydrothermal vent fields at all. However, making use of a slim opportunity, we found a new hydrothermal field, Yokoniwa field, which is the sixth hydrothermal vent field in the Indian Ocean. Then, in the Caribbean Sea, we carried out a survey of the hydrothermal activity area in Mid-Cayman Rise, located on the ultra-slow-spreading ridge and spouting the world's deepest hot liquid. In this research, we became the first in the world, to conduct a live broadcast of science research using a manned submarine (on Niconico Douga). About 350,000 people watched the live broadcast in Japan, and a total of 500,000 people watched the programs associated with this survey. This shows that the science research itself can be good scientific outreach which collects general public interest (Fig. 6).



Figure 6. The chimney with clumps of *Rimicaris hybisae* at the world's deepest Beebe hydrothermal vent field in the Cayman Rise, Caribbean Ocean. 350,000 people watched the live broadcast.

On the other hand, the survey of the hydrothermal activity area in Mid-Cayman Rise revealed the diversity of hydrothermal fluid chemistry in ultra-slow spreading. Results suggesting new knowledge about the driving principle of Hyper-SLiME type microbial ecosystems were also obtained. Then, we surveyed the low-temperature serpentinized hydrothermal fluid field (the Sinkai field) in the Mariana forearc area. In the field, serpentinite fluid is seeping, accompanied with a carbonate chimney at a depth of 5,600m. Thus, it was clarified that the Mariana trench-forearc-island arc-back arc system is an active geological field that causes extremely dynamic hydrothermal circulation, from the biological-microbiological standpoint. Moreover, we performed

research on biodiversity on the seamount in the South Pacific Ocean and microbial activity in an abyssal plain. Using these series of observational data and samples from the survey voyage, we will proceed with more detail research about diversity and function of unknown microbial ecosystems in the deep-sea and under sea floor. (Fig. 7).

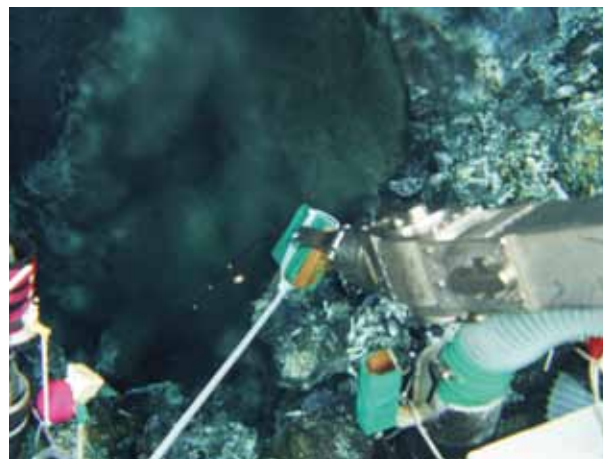


Figure 7. Hydrothermal vent of the Von Damm vent field, discharging high temperature hot liquid from just above the ocean core complex in the Caribbean Mid-Cayman Rise

(2) Deep-sea chemosymbiosis system Research

We succeeded in the genome sequencing of symbiotic bacteria in the digestive tissue of scaly-foot gastropods (black scaly foot). The sides of the gastropods' feet are covered by iron sulfide and they live in the central Indian Ocean Ridge, Kairei field.

It was revealed that this symbiotic bacteria is a gammaproteobacterium, with 2.6Mb of genome, and its genome reduction has hardly been affected. This symbiotic system has been acquired relatively recently. The genome sequence showed the possibility that they have a chemoautotrophic life by sulfur oxidation and possibly using hydrogen in addition to sulfur compounds. However, the shipboard breeding experiments revealed that they are using hydrogen sulfide as a primary energy source (Fig. 8).

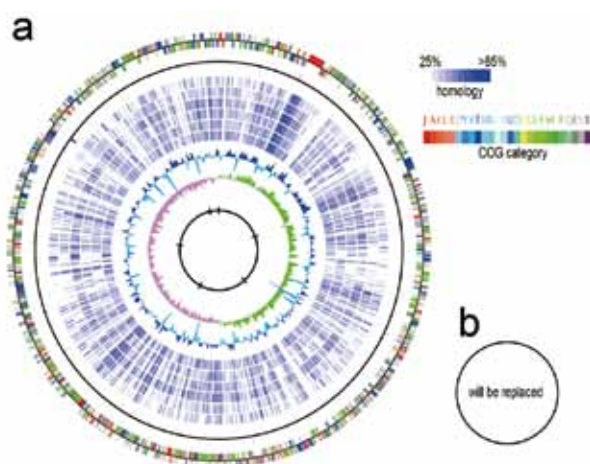


Figure 8. The genomic structure of symbiotic bacterium in the digestive tissue of scaly-foot gastropods, whose feet are covered by iron sulfide and who live in the central Indian Ocean Ridge, Kairei field.

Moreover, it was also found that the bacteria have received severe selective pressure from scaly-foot gastropods and the symbiotic system had extremely poor genetic diversity. This study is the world's first genomic analysis of snail symbiotic bacteria. In the future, we can expect that this research will become a milestone study about the symbiotic evolution between snails and symbiotic bacteria, which possess a unique symbiotic system (Fig. 9).

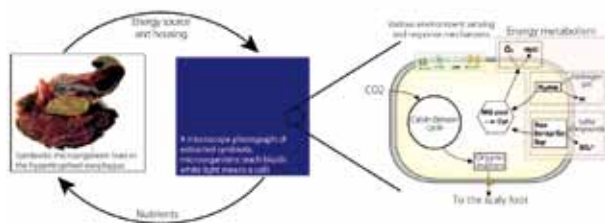


Figure 9. The symbiotic relationship between scaly-foot and symbiotic bacteria in the digestive tissue of scaly-foot gastropods, whose feet are covered by iron sulfide and who live in the central Indian Ocean Ridge, Kairei field.

In addition, we were able to achieve breakthrough results about the symbiotic system of hydrothermal vent galatheid crabs (*Shinkaia crosnieri*), which is a chemosynthetic life form living dominantly in the Okinawa Trough hydrothermal fields. In the past, it was believed that epibiotic bacteria live in the bristles of hydrothermal vent galatheid crabs and that the crabs live by eating the bacteria. However, although it had been suggested that the sulfur-oxidizing and methane-oxidizing proteobacteria are epibiotic bacteria, the evidence that shows it directly was not obtained. First, we demonstrated that the epibiotic bacteria are doing the sulfur-oxidizing metabolism by direct activity measurement. In addition, we succeeded in an activity measurement under field pressure using a newly developed high-pressure breeding instrument, and revealed for the first time that there is no change in the activity of the epibiotic bacteria under atmospheric pressure or high pressure conditions. Moreover, we proved that the most dominant epsilon-proteobacteria is an

entity of sulfur-oxidizing bacteria by measuring the activity of symbiotic bacteria using Nano SIMS and specifying the cells of the symbiotic bacteria. Then, we carried out the same experiment for methane-oxidizing symbiotic bacteria and demonstrated that methane-oxidization is performed by a methanotroph of gamma proteobacteria, and that their activity is not affected by the pressure. We also performed the meta-transcriptomic analysis based on RNA by the newly developed in situ fixation method, and found that the method is extremely effective because nearly 90% of mRNAs are degraded during collection of the organism samples from deep-sea. In the future, in addition to developing the innovative functional-analysis-methodology, by way of experiments using the breeding instrument in a simulation of the field environmental condition, meta-transcriptomic analysis by field fixation, and the field activity measurement, we hope to reveal the unknown physiology and ecology of the chemosynthetic life and symbiotic bacteria in the deep-sea (Fig. 10).

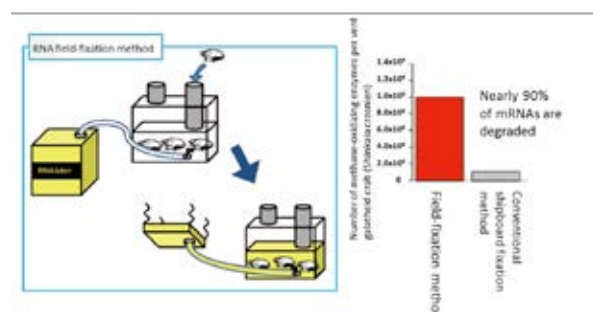


Figure 10. Development of the field-activity-maintenance-sampling system and result from meta-transcriptomic analysis for the external symbiotic bacteria of hydrothermal vent galatheid crabs. It was shown that the field fixation method is extremely effective.

(3) Development of the deep-sea and crustal biosphere research tools

We performed a series of study for artificial hydrothermal vents created by the deep-sea drilling vessel CHIKYU in IODP Okinawa hydrothermal drilling cruise, and the development of the deep-sea and crustal biosphere research tools. One tool developed was an ultra-pure crustal fluid collection tool "Kandata system," utilized for the borehole. We successfully collected subseafloor crustal fluid in Mariana forearc serpentite seamount and determined the chemical characteristics of pure serpentinization fluid, as well as researched the presence of subseafloor microbial community. In addition, we succeeded in the world's first deep-sea hydrothermal electricity generation utilizing artificial hydrothermal vents, which was a breakthrough that expands widely the possibilities of combined power generation utilizing future artificial hydrothermal vents. Furthermore, over the two years of research and observation about the hydrothermal fluid discharge pattern, the hydrothermal chemistry and the peripheral faunal communities, in the Iheya north field, which are changed by IODP Okinawa hydrothermal drilling, were carried out. We revealed the changes in time series of hydrothermal chemical derived from the subseafloor hydrothermal pool, the colonizing pattern of chemosynthetic biological communities that emigrated

to the new environment, and the changes in biomass, the first time in the world. The study that reveals the response of the deep-sea ecosystem for artificial environmental change is an important approach in the future deep subseafloor biosphere research, and we were able to widely publish this effectiveness. As another approach, we are steadily promoting the development of the various field-environmental sensors and new analysis tools that clarify the diversity, function, physiology and ecology in detail of the unknown subseafloor biosphere.

Earth and Life History Research Program

Discovering the link between the changes of the Southern Ocean and climate change in the northern hemisphere

The International Ocean Discovery Program (IODP) collected sediments that cover the past 2,000 years in the Southern Ocean off Adélie Land with high precision (Site U1357B). Using this sediment sample, many researchers from around the world are working together to reveal the changes that have happened to the Southern Ocean. In this context, we have studied the surface water environment at this site, particularly in terms of the historical changes of the hydrologic characteristics. The nitrogen stable isotope ratio of chlorophyll a and its derivatives, which were put into practical use under this research program, provides us with precious information concerning the past nitrogen cycle in the Southern Ocean. The results revealed not only that the nitrogen stable isotope ratio has been dramatically changing over the past 2,000 years, but also that such change has been occurring in line with the climate changes in the northern hemisphere, especially Europe, such as the Little Ice Age, Medieval Warm Period, and Dark Age (Fig. 11). During warm periods in the northern hemisphere, more nitrate is consumed by phytoplankton in the surface water, and the opposite has happened in the cold periods. Although a detailed mechanism to link these phenomena still remains a mystery at this time, these results clearly show that there is some kind of teleconnection between the climates of different areas on the Earth.

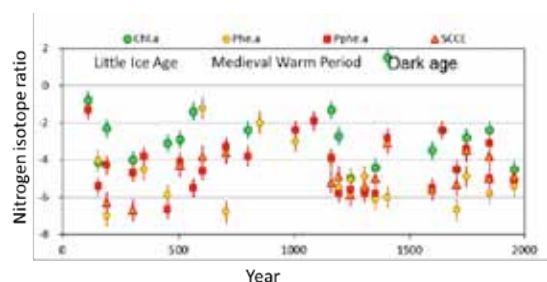


Figure 11. Records of nitrogen stable isotope ratio of chlorophyll compounds contained in the sediments collected in the Southern Ocean (off Adélie Land). Chl a: chlorophyll a; Phe a: Pheophytin a; Pphe a: Pyropheophytin a; SCE: Steryl chlorin ester.

Discovery of environmental disturbance in the Japan Trench four months after the earthquake

Four months after the Tohoku Region Pacific Coast Earthquake in 2011, we shot high vision movies of underwater

and submarine situations, using a free-fall camera system, and collected samples of the sediment core at the axis of the Japan Trench, which is 110 km away from the epicenter (Investigation Point 1), and at 4.9km east from there in the Pacific Ocean (Investigation Point 2). As a result of analyzing the recorded movie, we found that there was a very cloudy layer from 30m to 50m above the sea bottom at both investigation points. Little benthic habitats were found to be living on the seabed of the trench. The results of an observation and analysis of the sediments revealed that the sediment (Investigation point 1) from the surface to a depth of 31cm in the trench axis were comprised of sediments from the slope which were re-accumulated by at least three turbulent mud flows. This finding was also supported by an analysis of natural and artificial gamma ray emitting nuclides. In addition, cesium-134 from the Fukushima Daiichi nuclear disaster was also detected in the sediments of the surface layer (0–1 cm depth) collected in the Pacific Ocean (Investigation Point 2) (Fig. 12). The case of the detection of such short lived nuclide in the hadal sea floor would be an absorption in marine snow caused by a subsequent phytoplankton blooming observed from late March to early April by remote sensing. Also, a survey in June discovered a mass of marine snow, which is considered to have been produced and sunk during said period, at a point 5,800m below the sea surface near the survey point. On the other hand, the dilution effect by turbulent mud flow is considered to be a reason for the non-detection of cesium-134 at the trench axis (Investigation Point 1). In other words, it is suggested that the slope of the Japan Trench was gravitationally unstable due to frequent aftershocks, which makes it easier to form a turbulent mud flow.

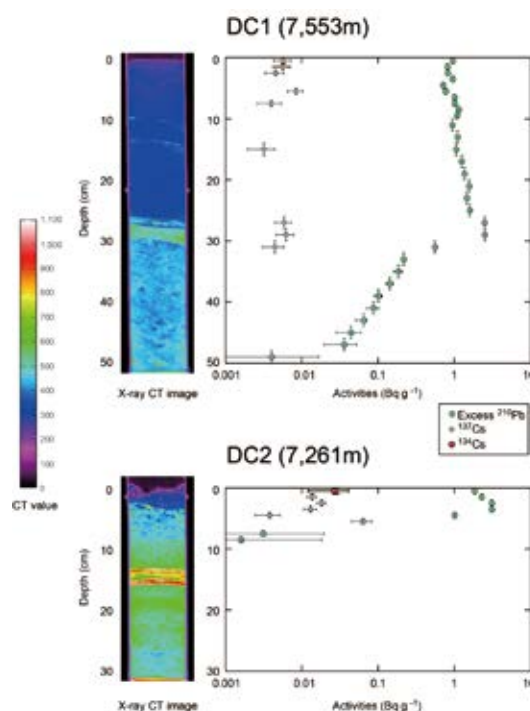


Figure 12. X-ray CT images of the sediment core collected from the Japan Trench (above) and the Pacific Ocean (below), and the profiles of Excess 210 Pb, 137Cs, and 134 Cs

Revealing the food chain structure of marine organisms in reef areas

The marine ecology is comprised of complicated predator-prey relationships between various biotic communities. Utilizing the trophic level estimation method using the amino acid nitrogen isotope ratio, which was developed under this program, the predator-prey relationships in the ecological system can be accurately investigated. As an example of the application of this method, we present the trophic levels of various marine organisms living in a reef area (Fig. 13). Seaweed, which is luxuriant in reef areas, supports the bottom of the ecosystem (primary producer). Above it are primary predators, such as abalone, turban shells, and sea urchins. The next level is omnivorous crustaceans, including crabs, which are topped by various kinds of fish as second and third predators. Finally, morays are at the top of the reef ecosystem. By using the amino

acid nitrogen isotope ratio, the trophic levels of individual organisms can be identified at a precision of ± 0.2 , which enables the visualization of an ecosystem.

This method can be described as a breakthrough, considering that the precision of the conventional methods using skeletal structures, stomach contents, and all nitrogen isotope ratios, ranged between ± 1 and 2. Our research is not only capable of estimating precise trophic levels, but it can also determine the relationships, as well as their evolution, between symbiotic organisms and host organisms and the ecosystem's response to environmental changes. We can conclude that an increase or decrease of a part of the organisms can change the whole balance of the system.

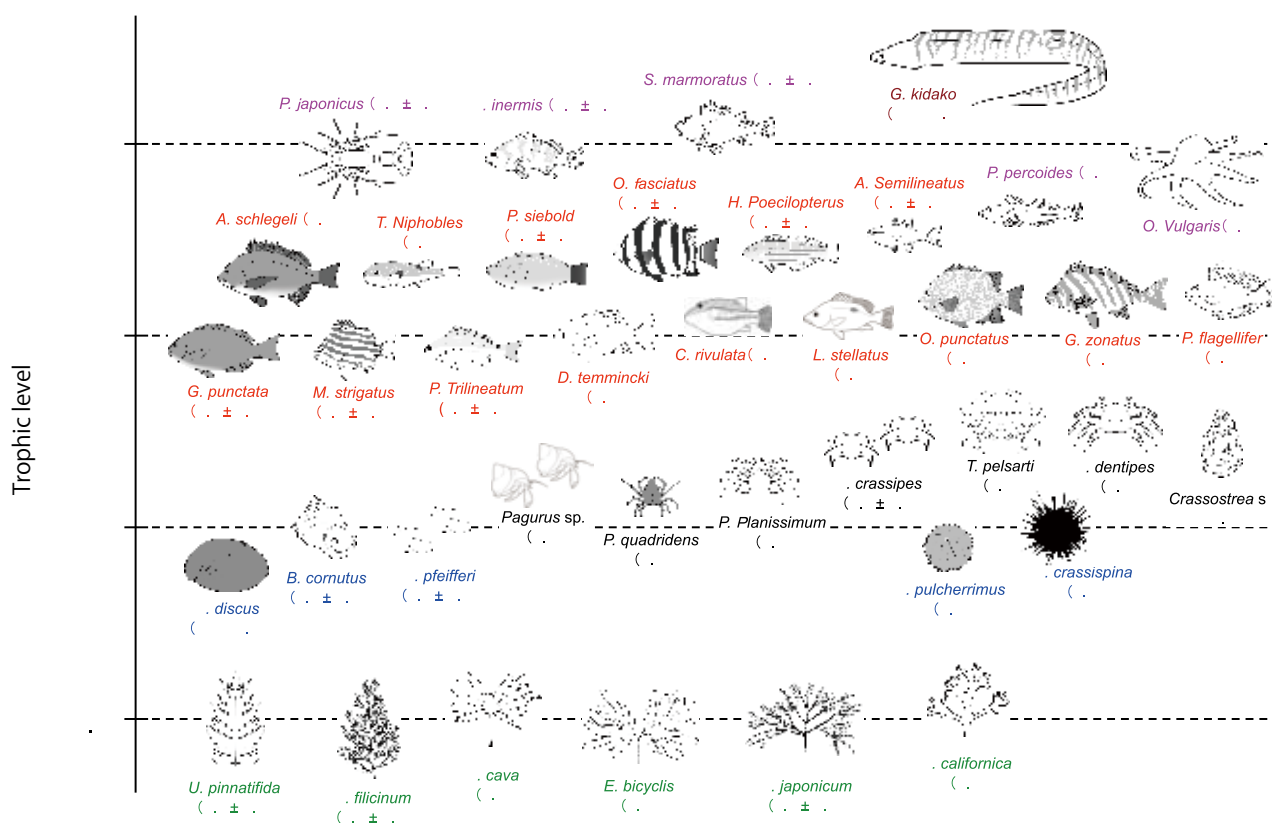


Figure 13. Trophic levels of various marine organisms in a reef area

Earthquake and Tsunami Research Project for Disaster Prevention

Overview

The Earthquake and Tsunami Research Project for Disaster Prevention has been conducting surveys, research, and technological development with the aim of reducing the damage caused by earthquakes and tsunamis.

The Great East Japan Earthquake in 2011 was responsible for the greatest tsunami damage documented in the modern history of Japan.

Surrounded by four tectonic plates, Japan is one of the most earthquake-prone countries in the world; consequently, large-scale earthquakes and tsunamis have hit the nation repeatedly, causing considerable damage each time.

Seismological research in Japan is among the best in the world; however, following the Great East Japan Earthquake, it has been hotly debated whether research on subduction-zone earthquakes had been sufficient and whether the research findings have been used appropriately in outreach activities aiming to prevent and mitigate disasters and in anti-disaster and evacuation measures. Based on lessons learned from the Great East Japan Earthquake, it is an urgent challenge to review research topics related to subduction-zone earthquakes and to disclose and apply information on the results of seismological research so that we can prepare ourselves for the Nankai Trough Massive Earthquake and an earthquake directly under the Tokyo Metropolitan Area, both of which are feared to occur in the future.

Several research projects are currently being undertaken as part of the Earthquake and Tsunami Research Project for Disaster Prevention, and this year's findings are described below.

Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET)

For the second phase of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET2), this year we finalized the route for laying submarine cables and the spots for setting observatories, based on the preliminary survey results of the planned ocean region undertaken last year, and we began the construction work.

At the locations of the landing stations, we built pipelines from land to shallow sea by the horizontal directional drilling method to bring the submarine cables up to land. We have also completed the development and manufacturing of equipments that will be under the water, such as observation sensors. We then began the construction of observatories and related equipments including submarine cables on the sea floor. By March, 2014, the backbone cable on the north side had been laid, and three science nodes (extensible branching units) had been connected to the backbone cable (Fig. 1).

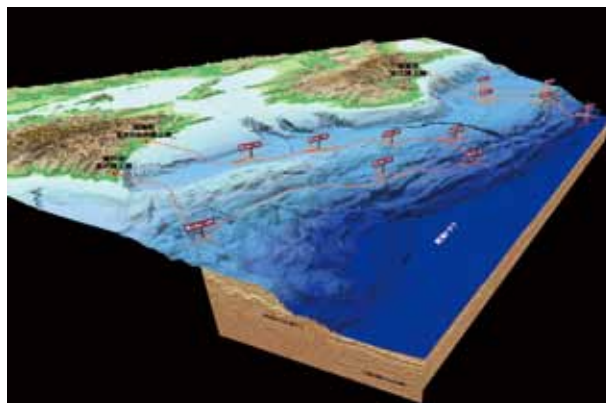


Figure 1. Schematic diagram of DONET

Compared with the first phase of DONET set up in Kumano-nada (DONET1), DONET2 is able to carry out observation over a larger area. For the construction of its observatories, it is necessary to lay extension cables by ROV. Because the task of laying extension cables by ROV requires delicate operation for extended periods of time, automation of laying work was necessary. Among the various steps required to lay extension cables, the most important one is to control the amount of cable slack. Last year, we developed a device that controls the cable slack automatically, and this year, after having confirmed its effectiveness by testing it in the actual sea, we have adopted it for the construction of DONET2.

Since DONET1 was fully implemented in operation, we have been using DONET data to determine the hypocenters of microearthquakes that occur in this region. This year, microearthquakes have been less frequent than last year; in fact, we have observed a shift of the crust in a more limited region. We continue to monitor crust activities near Kumano-nada using DONET data.

Since the Great East Japan Earthquake, we have also been doing research in real-time tsunami prediction. Focusing on the tsunami amplification, we developed a real-time tsunami prediction system that displays the tsunami size (height) and flooded area in the coastal region based on the water pressure observed by DONET.

In an attempt to make these results useful to the society, we signed two joint-research agreements in 2013. One is the "Agreement concerning the Use and Applications of Observation Data Obtained by DONET," signed in September with the prefecture of Wakayama. The other is the "Agreement concerning the Applications of Observation Data Obtained by DONET," signed in October with Chubu Electric Power Co., Ltd and Owase city. The former one, with the prefecture of Wakayama, is the first agreement signed with a municipal organization.

These agreements were signed as a pilot project, exploring the possibility of equipping the society with the observation information obtained by DONET. It is our hope that these agreements will help expand the use and applications of observation information obtained by DONET in the future.

Research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai trough region

Based on the knowledge collected by the “Evaluation and disaster prevention research for the coming Tokai, Tonankai, and Nankai earthquakes,” completed in 2012, we began the “Research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai trough region” in August, 2013.

This project involves joint research in sciences, engineering, and sociology to prepare ourselves for a Nankai Trough Large-Area Earthquake, feared to occur in the future. This research is commissioned by universities, research organizations, and the Ministry of Education, Culture, Sports, Science and Technology. We discuss prediction of and measures to take in every type of disaster caused by earthquakes and tsunami, as well as realistic ways to recover and rebuild after the disaster, and we do so jointly with the administration (federal and local government bodies), universities, research organizations, and companies that provide crucial lifelines, through community research meetings, seeking to equip the society and the public.

In this “Research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai trough region,” we aggressively address research activities in the field of disaster prevention. Based on the lessons we learned from the Great East Japan Earthquake, we are also involved in forecasting micro- and macro-scale disasters and in building disaster-preventing platforms as well as educating the public concerning disaster prevention. Additionally, we have added regional research meetings where we hear challenges from municipal government bodies and businesses that provide lifelines; in order to reflect the most recent feedback and results in disaster-prevention and disaster-reduction measures, we have begun these meetings in the Tokai, Kansai, Shikoku, and Kyushu regions. At the same time, we have held a kick-off symposium, which engages residents in education activities concerning disaster-prevention and disaster-reduction, and a “disaster-reduction café” at each of the four above-mentioned regions (Fig. 2).

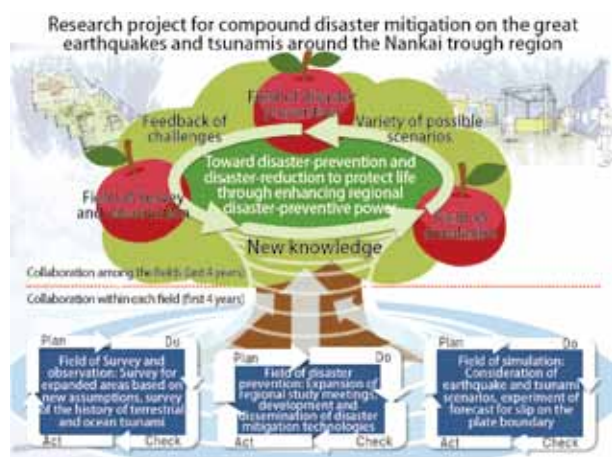


Figure 2. Conceptual diagram of the Research project for compound disaster mitigation on the great earthquakes and tsunamis around the Nankai trough region.

This year, JAMSTEC carried out a reflection-method earthquake survey using the PMCS (portable multi-channel seismic reflection survey) system installed on the ocean-research vessel *the Kaiyo*, as well as a multi-beam submarine topography survey, off the coast of Kochi. We also carried out a reflection-method earthquake survey using the MCS system installed on the deep-sea research vessel *the Kaiei*, as well as a marine refraction survey using an ocean-bottom seismograph (OBS), from the Kii Peninsula along the southern Ryukyu arc. We also did a geological survey using *the Kaiyo* and a multi-beam submarine topography study at the same location. As for earthquake observation on land, we did an earthquake survey and monitored seismic activities in the Miyako-Yaeyama Islands and collected data in an attempt to gather new information concerning the Nansei Islands, where little research has been done thus far (Fig. 3).

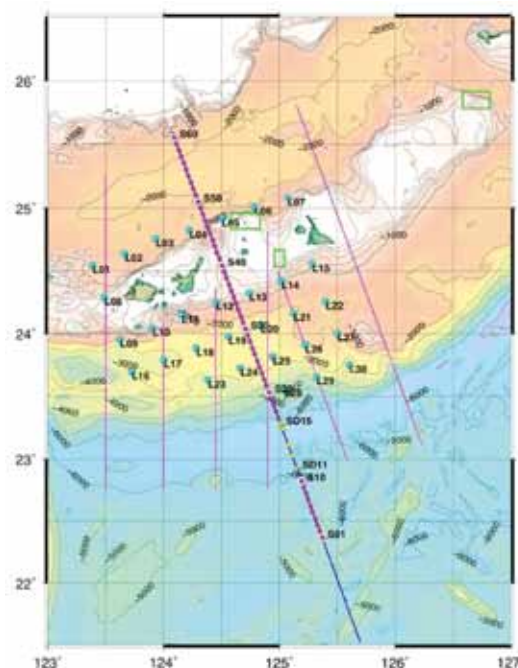


Figure 3. Sea-region survey map of the Nansei Islands

Fault Information Comprehensive Assessment Project in Sea Regions

This began as a new project in August, 2013, as the “Fault Information Comprehensive Assessment Project in Sea Regions.”

Whereas hazard assessment such as long-term assessment of faults has been undertaken in an organized and efficient manner for land regions, fault information is lacking and hazard assessment remains insufficient for sea regions. Thus, through this project, we collect reflection survey data and the velocity structure, apply latest data-processing technology, and read/investigate faults from the reflection profile in sea regions surrounding Japan. The fault information thus obtained is organized using consistent standards so that basic resources can be provided for tsunami hazard assessment.

This year we collected data in the Sea of Japan from related organizations and implemented an analysis system to analyze the reflection data thus obtained (Fig. 4).

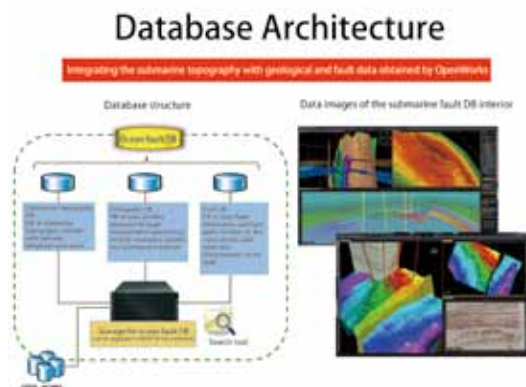


Figure 4. Image diagram of the database for the Fault Information Comprehensive Assessment Project in Sea Regions

Earthquake and Tsunami Study Project in the Sea of Japan

Based on the body of knowledge accumulated by the “Focused Study and Observation Research in Deformation-Concentrated Zones,” completed in 2012, we began a new project, “Earthquake and Tsunami Study Project in the Sea of Japan,” in August, 2013.

In this project, we first began an investigative observation Niigata and off the coast of Niigata and Nishi Tsugaru as the “Focused Study and Observation Research in Deformation-Concentrated Zones,” building a model of earthquake-source faults. However, for other regions, observation data had been insufficient to establish a model of earthquake-source faults or a tsunami-source model. This lack of information concerning earthquake- and tsunami-related disasters along the Sea of Japan has been a point of concern for municipal government bodies, business owners, and residents as they consider disaster-preventive measures. To alleviate this problem, we plan to collect observation data in the region spanning from the Sea of Japan to the coastal areas and the land region and build a tsunami-source model in the Sea of Japan as well as a model of earthquake-source faults in the coastal areas and the land region (Fig. 5).

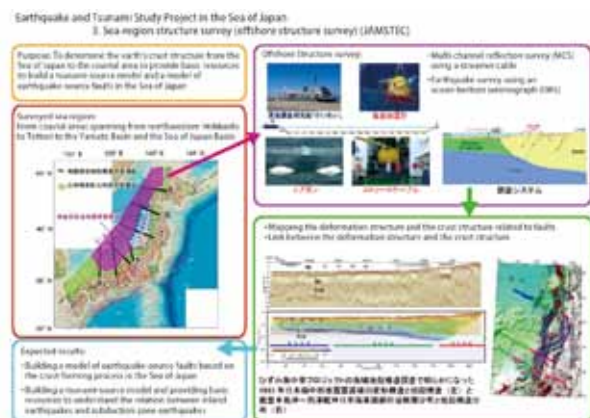


Figure 5. Diagrams showing the Earthquake and Tsunami Study Project in the Sea of Japan

Research for Precision Improvement in Earthquake and Tsunami Prediction Using the K computer

In the “HPCI Strategic Program,” a project supported by the Ministry of Education since 2011, we have been carrying out research in improving the precision of earthquake prediction, improving the precision of tsunami prediction, and simulation concerning natural disasters such as urban earthquakes.

The goal of this project is to anticipate a complex disaster caused by a subduction-zone earthquake and tsunami, such as a massive earthquake in the Nankai Trough, and develop a simulation system that will aid countermeasures to prevent and reduce disasters. In the future, the role of simulation will be essential in countermeasures to prevent and reduce disasters as it will contribute, for instance, to help develop advance strategies such as securing emergency escape routes through detailed disaster prediction based on multiple scenarios (Fig. 6).

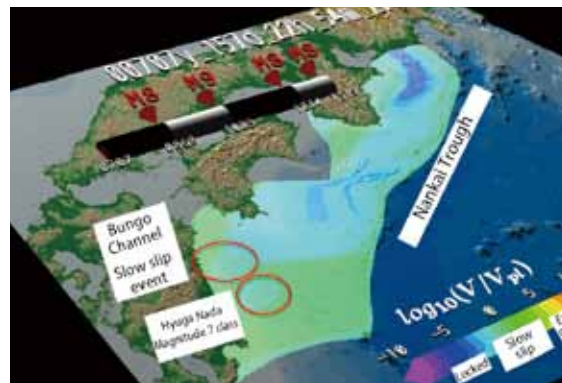


Figure 6. Simulation Diagram

This year, JAMSTEC has completed fine-tuning of several large-scale simulation programs in responding to the public's expectations concerning challenges of earthquakes and tsunami. We then installed the programs on the K computer and implemented detailed, accurate computations on seismic-wave propagation, ground vibration, tsunami propagation, and runoff.

We have also held several meetings for reporting our research results, such as the third HPCI Strategic Program Area 3 Symposium “Geoscience for Prevention and Reduction of Disasters Using a Supercomputer” and the fourth HPCI Strategic Program Area 3 Earthquake/Tsunami Simulation Workshop in an attempt to return our research results back to the society.

We will continue our efforts to integrate a variety of simulation research and development, including earthquake occurrence cycles, earthquake motions, tsunami flooding, quake-resistance of buildings, and evacuation activities, and to build an integrated simulation system that can assess complex disasters.

Disaster Reduction in Earthquakes and Tsunami in the Marmara Strait and Disaster-Prevention Education in Turkey

In June, 2012, within the framework of the “Science and Technology Research Partnership for Sustainable Development” (SATREPS), which is a joint contract venture between the Japan International Cooperation Agency and the Japan Science and Technology Agency, a joint research and technology collaboration project was adopted with the Republic of Turkey.

This project began its full operation this year.

The North Anatolia Fault, which traverses through Northern Turkey from east to west, is one of the most watched faults in the world due to its recent activity. Based on the recent history of great earthquakes here, it appears that the fault is being destroyed from east to west; however, ever since the Izmit Earthquake of 1999, which caused enormous damages, the Sea of Marmara, situated to the west, has not seen any major earthquakes. Referred to as a “blank region of earthquakes,” this region is considered extremely risky for future earthquakes (Fig. 7).



Figure 7. Map and earthquake history of the North Anatolia Fault (the blank region of earthquake is seen near the Sea of Marmara)

This region contains the metropolis of Istanbul, where 18% of Turkey's total population lives, and it is said a massive earthquake would result in 30,000 to 40,000 human casualties. Meanwhile, Turkey still has many challenges in terms of disaster prevention and disaster reduction, such as buildings not in compliance with earthquake-resistance standards. It is urgent to raise the people's awareness and to promote strategic measures.

In this project, many universities and research institutions of Japan and Turkey will work together to undertake earthquake monitoring, simulation, and risk assessment in regions surrounding the Sea of Marmara, including sea-floor observation. We will then hold discussions concerning disaster-prevention education and transmission of information based on such scientific knowledge, contributing to heightened disaster-prevention awareness of the Turkish people and to the promotion of disaster-prevention and disaster-reduction measures. This year we held a workshop in Turkey and had a research discussion with over 50 people participating from the two countries. We also carried out a sea-location test for our sea-floor observation equipment in the Sea of Marmara, conducted microseismicity observation on land, trained Turkish researchers in Japan, made improvements in simulation codes, and collected basic data. We also delivered seven ocean-bottom seismographs to Turkey and have begun technology transfer, such as showing how to handle and assemble them.

Long-Term Borehole Observation Technology Development

In February 2013, a long-term borehole observatory installed by the deep-sea scientific drilling vessel Chikyu was connected to DONET1. The observation area is one of the regions where an eastern Nankai earthquake is feared to originate. It is confirmed that the data collected by the monitoring device (deformation, temperature, pressure, seismic waves, etc.) is received in real time.

This is the first time in the world that real-time data is collected by connecting a submarine-cable monitoring network with a monitoring device inside a drilling hole under the sea floor. This enables us to carry out research on the correlation between

changes under the sea floor, such as deformation, temperature, and pressure due to minute earthquakes and crust shifts, and the occurrence of massive earthquakes. It is our hope that this will allow us to gain an understanding of earthquake-triggering mechanisms. Tiny earthquake motions and crust shifts are hard to detect by monitoring systems set up on land, but such data can now be obtained in real time. We hope to use this data for future measures to prevent and reduce disasters.

We plan to carefully validate the quality of data obtained by this long-term borehole monitoring device and to coordinate data distribution to related organizations monitoring earthquakes in the same region, where an eastern Nankai earthquake is feared to originate. We also plan to set up additional long-term borehole monitoring devices at different locations in the region and connect them to DONET1 as well (Fig. 8).

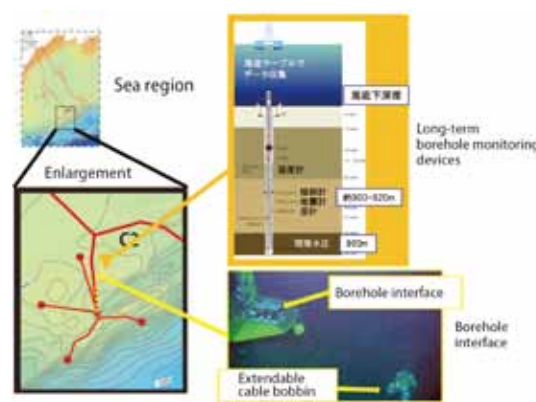


Figure 8. Long-term borehole monitoring device

Real-Time Deep Sea Floor Monitoring System

The real-time deep sea floor monitoring system has been providing hydraulic pressure data to the Meteorological Agency since 2012. This system seeks to develop technology to study the behaviors of marine organisms at fixed observation points real-time, validate it, and apply it to an actual system. In order to obtain basic data necessary for the development of technology that will remotely identify animals by their clicking sounds, we are also involved in gathering data related to the howling of animals and marine biological reactions from among the sound data accumulated for the last 18 plus years, as well as earthquake data, tsunami (water pressure) data, and data on the deep-sea environment (Fig. 9).

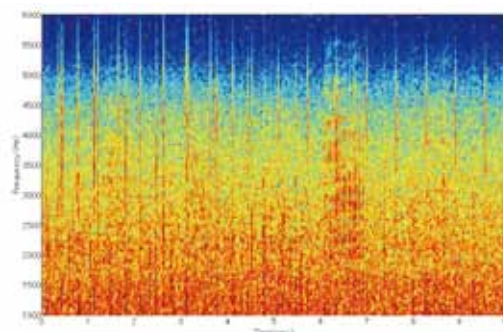


Figure 9. Spectrogram of the howling of sperm whales detected from the sound-monitoring data

Submarine Resources Research Project

Overview

Under the Submarine Resources Research Project, JAMSTEC is carrying out cutting-edge studies on submarine resources through its five research groups, taking advantage of the rich expertise and technology on marine research JAMSTEC itself has developed.

During the program's third year, 2013, the Submarine Resources Research Project made sixteen research voyages (including related voyages). This year, we also gained new knowledge and collected large amounts of data and samples through its research voyages. In addition, we are actively involved in geochemical research to understand the mechanism whereby submarine resources are generated, accumulating valuable data.

Below, we present the main results of each research group.

Earth Biotechnology Research Group

The Earth Biotechnology Research Group is carrying out fundamental and applied engineering research for the understanding of submarine volcanos and hydrocarbon resource environment in seas around Japan, for applications of the prominent carbon convertibility of the natural energies and microorganisms, and for the construction of a permanent carbon-circulation system.

In 2013, the group used a multiple-type high-pressure reactor called the "Geo-Bio Reactor System," able to re-create the underground temperature and pressure conditions, to do a research study on the "Mutual Interplays among Carbon Dioxide, Fluids, Minerals, and Life," simulating underground separation of carbon dioxide into a coal-bearing formation (layers where coal and sandstones are found together) (Fig. 1).

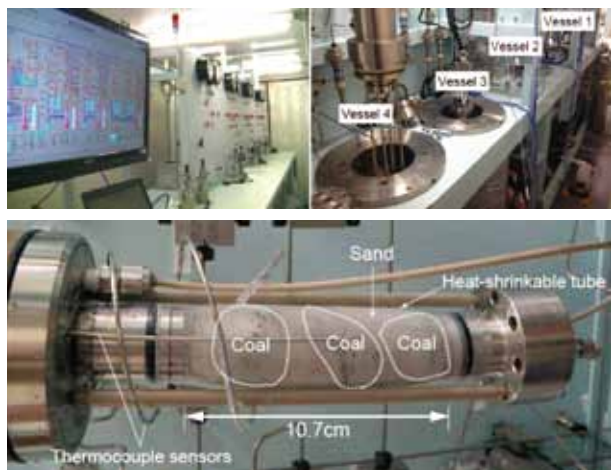


Figure 1. A column filled with coal and sandstones is set in the Geo-Bio Reactor.

First, a pressure and breakage test on brown coal against supercritical carbon dioxide, using a powdered brown coal sample (Loy Yang brown coal, Australia) collected by open-pit mining and a permeability test of a coal-bearing formation sample collected on the 337th research voyage of the International Ocean Discovery Program (IODP) using the deep-sea drilling

vessel *Chikyu* off Hachinohe, Aomori, have shown various facts. For instance, coal in a coal-bearing formation environment has extremely low water permeability and, therefore, when pressured by carbon dioxide, serves not as a storage layer but rather as a sealing layer. Further, its porosity is high, possibly making it a suitable reservoir environment for pouring in carbon dioxide.

The team also filled a thermal contraction column anaerobically with a submarine coal sample collected off Kushiro (sub-bituminous coal collected in the spring at a coal-bearing formation in the Urahoro group, provided by Kushoro Coal Mine Co., Ltd.) and powered sandstones and then added an artificial anaerobically sterilized culture medium containing supercritical carbon dioxide at 0.002 mL/min under a temperature of 40°C, a pore water pressure of 40 MPa, and a confining stress of 41 MPa. We then turned on the Geo-Bio Reactor for 56 days to perform monitoring observation from geochemical, mineralogical, and microbiological standpoints.

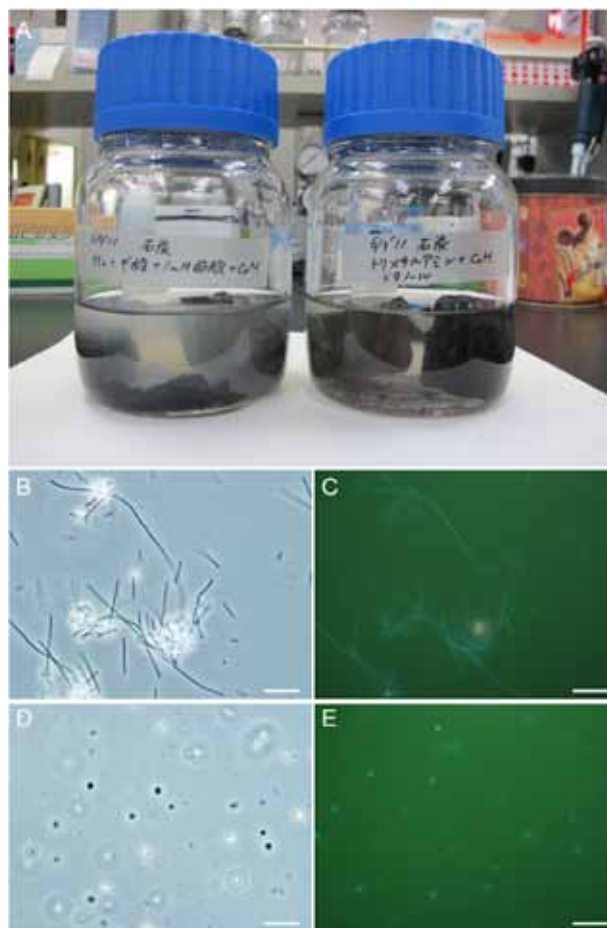


Figure 2. Methanogen grown from a submarine coal layer provided by Kushiro Coal Mine Co. Part A shows that the originally transparent culture has become clouded when coal is added and microorganisms grew. Parts B and D show photos taken by optical microscope of methanogen grown from the coal layer. Parts C and E show photos taken by fluorescence microscope of methanogen excited by ultraviolet radiation. The scale is 10 micro meters long.

The results suggest that even with the addition of supercritical carbon dioxide, microorganism groups within a core sediment do not get completely exterminated. In particular, some microorganisms with the sporulation ability, such as those in the Firmicutes and Actinobacteria groups, can survive or maintain/continue their metabolism activity. In addition, it was shown that, through the action of bacteria that form homozygous acetic acid (belonging to the *Sporomusa* group), acetic acid was formed with the added carbon dioxide. Furthermore, the results suggest that, due to the adhesion of carbon dioxide onto the coal as well as physical reactions such as a natural adhesion gas (coalbed methane) that accompanies the adhesion and the liquation of the pore water, microorganisms within a coal layer can be dispersed into the pore water of the sandstones. Also, by batch cultivation with sub-bituminous coal as the inoculum, growth of methanogen in the *Methanobacterium* and *Methanosarcina* groups was confirmed (Fig. 2). On the other hand, no methanogen growth was confirmed in the CO₂-addition experiment with the Geo-Bio Reactor set to the temperature and pressure conditions of the actual site.

These results suggest that under the conditions of the actual environment, the effects of a biological carbon-conversion system (Bio-CCS) can change carbon dioxide into an organic material such as acetic acid. These results are from a joint research study with the Civil Engineering Research Laboratory of the Central Research Institute of Electric Power Industry.

Between July 20 and July 26, 2013, the Earth Biotechnology Research Group carried out a research voyage NT 13-15 to study the exposure conditions of methane hydrate in Koshiumi Hill on the Sea of Japan using the marine research vessel *Natsushima* and the ROV *Hyper Dolphin*."

During this voyage, the Earth Biotechnology Research Group installed on the *Hyper Dolphin* a "heat sonde" to infuse carbon dioxide into deep seas, developed jointly with the civil engineering research Laboratory of the Central Research Institute of Electric Power Industry and Shin Corporation and carried out a location experiment of directly infusing liquid carbon dioxide into a methane hydrate mass and the surface-layer sediment exposed near the top of the Joetsu Sea Hill. This heat sonde uses the electrical power of the *Hyper Dolphin* and a hydraulic pump, designed for the purpose of press-infusing liquid carbon dioxide and/or water, independently or mixed, into a stratum layer under the deep submarine conditions of low temperature and high pressure. When the carbon-dioxide infusing experiment was actually conducted on the deep sea-floor using this machine, it was verified that, in the flow route of the sonde tip and the exit, carbon-dioxide hydrate was formed much more rapidly than previously believed. Therefore, we now know that, in order to press-infuse a sufficient amount of carbon dioxide, we need to improve the equipment further and reconsider necessary conditions. Meanwhile, the group has succeeded in using this heat sonde to partially melt the methane hydrate on location to produce methane (Fig. 3).

In addition, during this voyage, a pressure-preserving core reactor system developed by the Earth Biotechnology Research Group was used to collect methane hydrate samples with white biofilm-type material still attached while maintaining the actual-

location pressure. Under joint work with California Institute of Technology of the United States, the group took these pressure-preserved samples and continuously added methane and nitrogen, both labeled with stable isotopes under ¹³C and ¹⁵N, under the actual-location pressure, in order to carry out research on biological carbon and nitrogen conversion using an ultra-high sensitivity NanoSIMS (secondary ion mass spectrometer) located at the Kochi Institute for Core Sample Research.

Further, also during this voyage, a long-term temperature logger was set up as part of a joint research project with the National Institute of Advanced Industrial Science and Technology in order to obtain information on the bottom-layer water temperature change in this sea region.

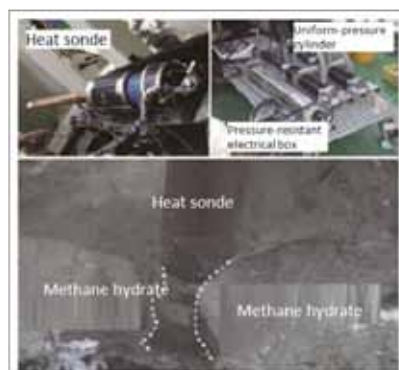


Figure 3. A heat sonde for infusing carbon dioxide is used to melt methane hydrate exposed on the sea floor.

Submarine Hydrothermal System Research Group

The drilling expedition of the D/V *Chikyu* in September, 2010, under the auspices of IODP, suggested the existence of an unexplored world-class hydrothermal deposit in the Middle Okinawa Trough. This group then carries out next-generation explorations combining multiple-research platforms and geo-biological hydrothermal sensing aiming at the following: 1) to search for a gigantic submarine hydrothermal deposit in the vicinity of Okinawa, 2) to understand how the submarine hydrothermal circulation system drives the submarine ecosystem, and 3) to create an infrastructure to develop submarine resources that may be hidden in Japanese territory.

Following 2012, in which the group had discovered some indication that unexplored active hydrothermal sites could exist in the Iheya Small Ridge, in 2013 the group carried out a next-generation exploration combining multiple-research platform and geo-biological hydrothermal sensing. Using the multi-narrow-beam echo sounder set up on the R/V *Natsushima*, we surveyed the Iheya North Knoll thoroughly and recognized signs of two unknown hydrothermal sites in addition to the well-known Iheya north active hydrothermal site found in 1995. Soon after that, AUV *Urashima* was used to conduct a detailed acoustic and geochemical survey in the area coupled with a further survey outside the Iheya-North Knoll in the Mid-Okinawa Trough. Finally, for each location of possible new hydrothermal activity, the group used the ROV *Hyper Dolphin* to survey the sea floor and locate two new active hydrothermal sites (January, 2014). Through similar explorations, the group is very much expected

Resources Geochemical Research Group

Much of the methane gas generated on earth is created by microorganisms. However, very little is known concerning at what depths below the sea floor or the ground, or how rapidly, methane is generated. This research group seeks to find answers to these questions by developing a new chemical approach.

This method involves quantifying the coenzyme referred to as “F430,” which catalyzes the final step in a line of biochemical reactions that generates methane in cells of microorganisms called methanogen. By quantifying F430, one can estimate the inherent capacity for methane generation. The concentration of F430 contained in a sediment core sample obtained by drilling the sea floor indicates its inherent capacity for generating the methane gas; its ratios to carbon and nitrogen isotopes should also give us some information on the contribution of methanogen, such as what carbon and nitrogen sources are used by this microorganism that produces methane. However, extraction, separation, and quantification of F430 from sea-floor sediments have never been done, nor its analysis method established. Our research group has been working hard to develop a method for analyzing F430 from its beginning. As a result, the group has succeeded in establishing a way to use high-speed liquid chromatography, mass spectrometer, and mass spectrometer (LC/MS/MS) to analyze F430 contained in sea-floor sediments to the extremely small amount of 0.1 femtomole (1×10^{-16} mole).

This new method was then applied to the sediment sample (12–208 m) drilled out off the coast of the Shimokita Peninsula. It was discovered that this sediment sample contained between 0.02 and 1.2 picomoles (0.02 to 1.2×10^{-12} mole) per gram of F430. In particular, there was a big peak around the depth of 70 m, where there is a high capacity of methane generation (Fig. 8).

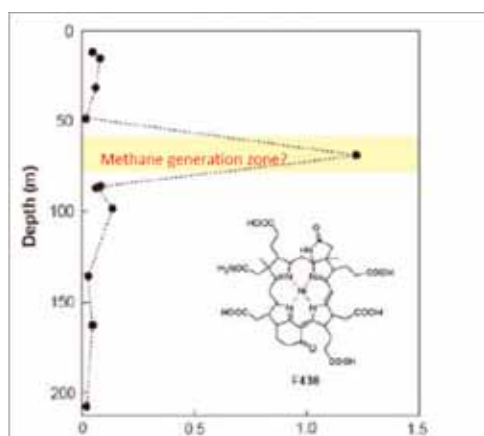


Figure 8. F430 concentration in the sediment sample collected off the Shimokita Peninsula

At this point we do not yet know why the capacity for methane generation is high at this depth. Perhaps the concentrations of basic substances that produce methane, such as hydrogen, acetic acid, and methanol, are high there. When there is sufficient provision of the basic substances, along with optimum conditions for methanogen, the methane generation rate can be estimated at a maximum of 26 moles per day per gram of sediment in this stratum.

Resources Origins Research Group

This research group seeks to find the ultimate origins for various resources (with a focus on submarine mineral resources) by addressing questions of time-space scale, such as when, during what era, these resources were created on earth and what type of chemical reactions produced them. These will then lead to development in multiple areas of possibilities hidden within submarine resources, including an understanding of environmental changes that contribute to resource generation, development of decoding those changes, and development of methods to collect useful elements artificially.

A particularly significant accomplishment this year was the discovery of mud that contains high concentrations of rare earth elements using the deep-sea research ship *Kairei* in January. It had already been known through research by Prof. Yasuhiro Kato (Univ. of Tokyo), et. al. that a large region of the Pacific Ocean contains sediments rich in rare earth elements. In our research, we anticipated that such sediments rich in rare earth elements exist in the vicinity of the Minami Torishima Island. We collected sediment core samples from the depths of 5600 m to 5800 m in the area, analyzed them chemically, and carried out a vertical distribution analysis of concentrations of rare earth elements near the sea-floor stratum. We collected the sediments by inserting a pipe equipped with a weight called a piston corer into the sea floor. The results showed that at one location to the south of the Minami Torishima Island, there was a sediment containing an extremely high concentration of rare earth elements (hereafter referred to as “rare earth mud”), with concentration beyond 6,500 ppm (0.65%) at maximum around 3 m below the sea floor. This is 3 to 10 times the concentration at formerly known rare earth sites. In addition there was another location where rare earth mud was found in shallow levels, within 10 m of the sea floor (Fig. 9).

In this research study, the group also learned that depth and thickness information on rare earth mud can be efficiently obtained by sub-bottom profiler (SBP), a sonar submarine-stratum profiling device). SBP images of the sea region in question allow one to distinguish between bedrock charts and the mud above them (probably rare earth mud) by shade. Rare earth mud does not show stripes, which are characteristic of mud, while the surface-layer mud above it shows stripes in contrast. It is believed that these characteristics and patterns could be used to verify the depth where rare earth mud is found, as well as its thickness, but the depth information on rare earth mud was verified by comparing SBP data with the actual core analysis values.

These research results are expected to contribute to scientific discoveries necessary for research and development in origins studies in the future, including the quantity and distribution of rare earth resources near the Minami Torishima Island.

In addition to the above results, the group is involved in projects to understand the rare-metal concentration mechanism into the manganese crust using synchrotron radiation and to determine its growth speed. The group is also doing a variety of resources origins studies with key terms such as “micro and macro” and “natural and experimental.” These include an artificial composition experiment of black ore deposit by

high-temperature, high-pressure hydrothermal experiment and a study in the element-leaching process of the deposit's base rock.

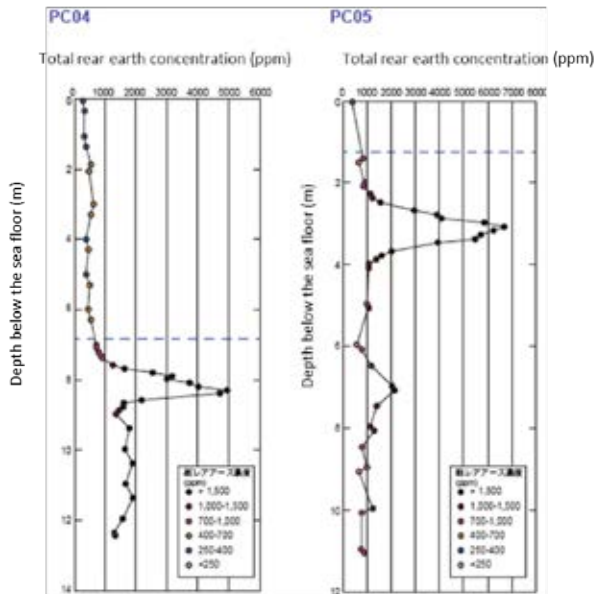


Figure 9. Total concentration changes in rear earth elements in the sediment core collected near the Minami Torishima Island

Environmental Effects Assessment Research Group

This group carries out research studies using active hydrothermal regions affected by scientific drilling as a resources-development model. In particular, the group has the following emphases: (1) biological distribution using image data; (2) biological group composition using genetic data; and (3) assessment methods based on the restoring force of the ecosystem.

In the megabenthos distribution analysis using image data, the group determined the number of individual megabenthos groups using image data provided by SeaXerocks, a 3-D image mapping system developed by the Institute of Industrial Science at the University of Tokyo, as well as high-definition video images, and studied its relationship with environmental factors (Fig. 10).

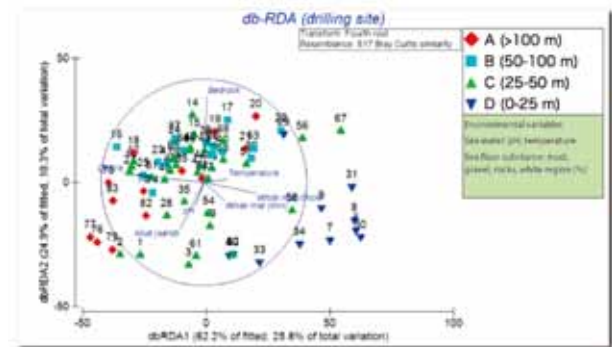


Figure 10. Inhabitation characteristics estimated by organism distribution and multi-variant analysis of environmental factors

When the group collected the thermometers set up prior to the drilling and analyzed them, it was learned that the hydrothermal activity began in the white region 11 months after the drilling (Fig. 11).

In the diversity analysis of organismic groups via genes, the group extracts DNA from sediment samples in hydrothermal regions, reads the diversity data of the megabenthos group, and study the diversity; this is work in progress.

The group also participated in an international workshop (Deep Ocean Stewardship Initiative, DOSI), contributing to the writing of a proposal for deep-sea environmental impact assessment.

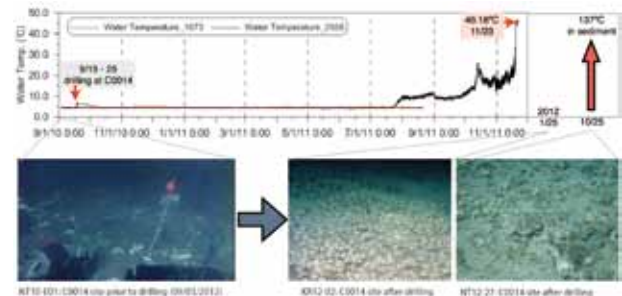


Figure 11. Temperature change in the sediment surface and phase change of megabenthos

Laboratory for Earth Systems Science: Precambrian Ecosystem Laboratory Unit

Overview

Understanding how the earth evolved into a unique planet teeming with life is one of the most significant intellectual aspirations of humans. Such knowledge would potentially enable the discovery of other life-forms within our universe, possibly even within our own solar system, as well as the conditions that enable the existence of such life forms. The Precambrian Ecosystem Laboratory currently consists of three fulltime researchers, eight part-time researchers, and one visiting research student. We believe that an interactive system developed between the planet Earth and life at the moment of our planet's birth and over the course of the initial evolutionary processes that followed, and that this system played a primary role in co-evolution. The mantle, the ocean, the continents, the atmosphere, and all the organisms that inhabit them, have all developed, functioned, and evolved as a unified interactive system. It appears that the major mechanisms of this earth-life interactive system were established more than six hundred million years ago, and geologically, this is called the Precambrian age. With the ultimate goal of elucidating the primary evolution of primitive, earth-life interactive systems (the Precambrian explosion), the Precambrian Ecosystem Laboratory attempts to understand the entire history of the Precambrian time—from the birth of the first sustainable life system, to the evolution and propagation of life-forms in the global marine environment (process of photosynthesis development and diversification of energy metabolisms). This is accomplished by conducting reproductive experiments in laboratories and by restoring the Precambrian time (using geological records on the present Earth, the functions and genomic information preserved in the present microorganisms, and the material cycle and ecological functions that occur in similar environments of the Earth).

(1) New developments in full-decoding research into changes in global CO₂ concentration within the Archean era and reproductive experiment

The most important factors that control the carbon cycle on our present-day Earth are the release of CO₂ into the sea by submarine volcanic activities and the deposition of carbonate rocks in the shallow waters of the continental-shelf. However, in the Archean era, the Earth had few continents, and the carbonate rocks in the continental shelves that are seen at present, had not yet been formed. Therefore, it is believed that CO₂ was constantly released to the atmosphere and the ocean via submarine volcanic activities. Based on theoretical research and various geological records, it has also been suggested that, following the formation of the Earth, CO₂ in the atmosphere and the ocean gradually decreased. However, at present, we have no knowledge of the relationship between the mechanism and timing of the reduction, and dramatic geological events remain unknown. The Precambrian Ecosystem Laboratory aims to understand changes in CO₂ concentration and fluxes in the atmosphere, the ocean, and the crust during the Archean era, as this is considered to have served as the largest environmental factor involved in causing the Precambrian explosion. (Fig. 1)

In FY 2011/2012, we determined the carbon flux between the atmosphere, the ocean, and the crust, from 3.2 billion years

ago, based on the mass balance and isotope ratio analysis of the carbonate rocks formed during the hydrothermal alteration process of the oceanic crust in the early Archean era (3.2 billion years ago). It was revealed that, at that time the CO₂ flux from the ocean to the oceanic crust was 100 times greater than at present. This indicates that the concentration of atmospheric CO₂ was also at least 100 times higher. In FY 2012/2013, we conducted a mass balance and isotope ratio analysis of the carbonate rocks formed during the hydrothermal alteration process of the oceanic crust (2.6 billion years ago), during the time when formation of the large continents began. Prior to these experiments, the Precambrian Ecosystem Laboratory had hypothesized that the time when carbonate rocks were increasingly deposited in the shallow waters of the continental shelf, coincided with the sudden decline in atmospheric CO₂. These experiments confirmed that our hypothesis was correct, and we have now obtained evidence that the amount of CO₂ that existed in the atmosphere and the oceans 3.2 billion years ago was reduced to one-tenth of the level 600 million years later (i.e., 2.6 billion years ago).

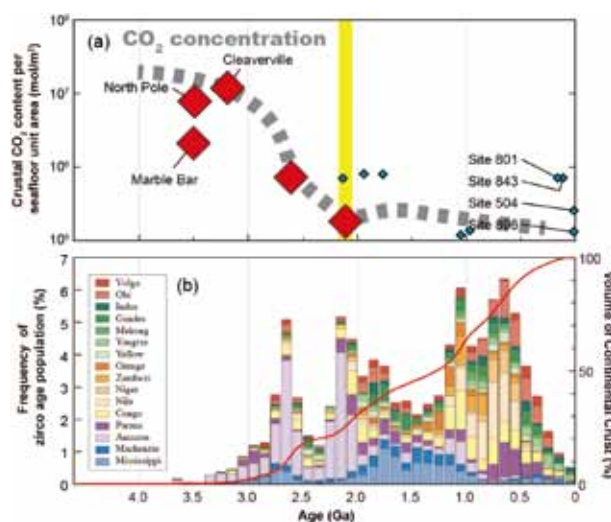


Figure 1. (a) Changes in levels of CO₂ concentration; and (b) continental growth curve throughout the Earth's history. Red symbols indicate the levels of CO₂ concentration determined by the Precambrian Ecosystem Laboratory.

However, when CO₂ concentrations in the atmosphere and the ocean are lower, it becomes more difficult to use the CO₂ history reproduction method, which uses hydrothermally altered carbonates in the oceanic crust, and which is the best used in our laboratory. This is because hydrothermally altered minerals convert into sulfates and not carbonates. Therefore, we have been developing a CO₂ history reproduction method that uses fluid inclusions preserved in hydrothermal deposits within the oceanic crust, and have already used this method in FY2012/2013 to analyze fluid inclusions from the hydrothermally altered oceanic crust, which were formed 2.2 billion years ago at the time of what is known as the "snowball earth."

There are several theories as to how the "snowball earth" was formed, and no study has directly quantified the levels of CO₂ in the atmosphere and the ocean during this time in the Earth's history. We directly measured the CO₂ concentration and isotope ratio of ancient hot water and CO₂ that was trapped in minerals

2.2 billion years ago. All of the previous studies on hydrothermal fluids have indicated that the CO_2 concentration of hydrothermal fluid always exceeds the dissolved CO_2 concentration of seawater. We found that the lowest CO_2 concentration in hydrothermal fluids 2.2 billion years ago was 7 mM. This value indicates that the concentration of CO_2 dissolved in the ocean 2.2 billion years ago was 7 mM or lower, which is at most only 2–3 times as high as the current level. In other words, the CO_2 concentration at that time was only two to three times as high as it is now. For the first time, these results support the hypothesis that the “snowball earth” was caused by a decrease in atmospheric CO_2 , 2.2 billion years ago. (Fig. 2)

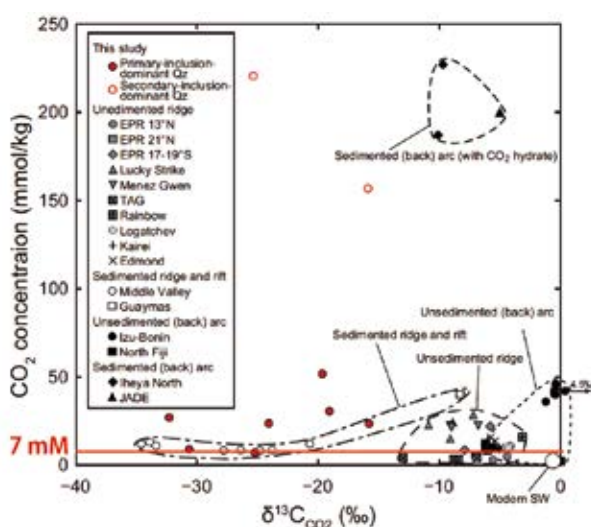


Figure 2. CO_2 concentration in fluid inclusions preserved in hydrothermal sediment within the oceanic crust were formed 2.2 billion years ago (red circles)

Atmosphere and ocean from the Hadean eon to early Archean eon contained approximately 500 to 1000 times as much CO_2 as the current amount. Such high concentration of CO_2 is believed to cause a completely different hydrothermal circulation in the oceanic crust from the present Earth. One of such hypotheses was the one publicized as a research by the Precambrian Ecosystem Laboratory Unit in 2010, which suggested that the hydrothermal fluid from the Hadean eon to early Archean eon was highly alkaline white smoker. The reason for this hypothesis is because the discharging fluid becomes alkaline as CO_2 is removed due to hydrothermal alteration of the oceanic crust (basaltic rocks and komatiite) when the CO_2 concentration in the ocean is high. Although this process was estimated by thermodynamic calculation, no experimental verification had been conducted. In this context, the Precambrian Ecosystem Laboratory Unit conducted a hydrothermal alteration experiment of sea water containing basaltic rocks and high amount of CO_2 , using its high temperature/high pressure hydrothermal reaction experimental device. (Fig. 3) As a result, we found that, in hydrothermal reactions at 250°C , all of 400mM dissolved CO_2 is trapped as altered carbonate minerals within approximately 100 days and generated hydrothermal fluid becomes alkali. Furthermore, in hydrothermal reactions at 350°C , three-fourths

of CO_2 become altered carbonate minerals after a day from the start of the reactions. These results are important because of the following two reasons. The first reason is that these results experimentally proved the hypothesis that the hydrothermal fluid from the Hadean eon to early Archean eon was highly alkaline white smoker. The other reason is that they revealed that CO_2 would be fixed to the oceanic crust as hydrothermally altered carbonate minerals if water containing a high concentration of CO_2 were introduced to the present hydrothermal circulation in the oceanic crust. Technologies to encapsulate CO_2 contained in the atmosphere and ocean to the crust are called CCS (Carbon Capture and Storage), which is recently studied and developed as an extremely important technology for greenhouse gas reduction. We believe this research achieved breakthrough results from the viewpoint that it experimentally proved the possibility of “subseafloor hydrothermal CCS” that can fix CO_2 in the crust if only we could collect and dissolve emitted CO_2 in water and introduce it to the hydrothermal circulation in the oceanic crust.

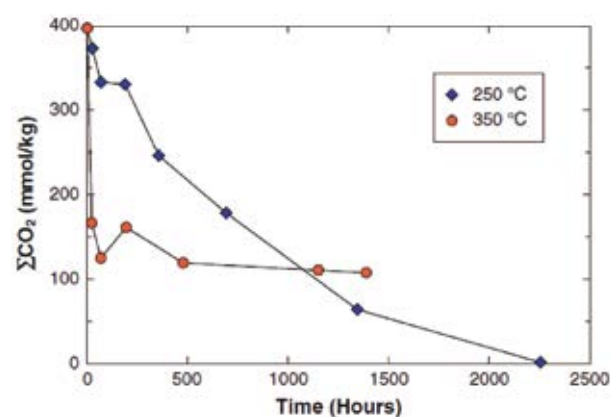


Figure 3. Change in the concentration of dissolved inorganic carbon in hydrothermal reaction experiment using seawater with high CO_2 concentration and basaltic rocks of the oceanic crust

(2) Innovative technologies for investigating earth-life history and the Precambrian explosion: Multiphase isotope ratio systematics research

To decode the detailed processes ranging from the birth of life to the occurrence of large multicellular organisms in the Cambrian explosion (which are more likely to be recorded as fossils), it is extremely important to use geological records as well as information on the mass balance and isotope ratio of materials known as chemical fossils. However, the isotope ratio fractionation and equilibrium in chemical reactions and biological/metabolic processes are based on extremely fragile experimental data and theories, and they still remain largely classified as empirical chemical indicators. In addition, one isotope ratio of a single element provides only a low resolution, and the decoding of chemical, biological, and metabolic processes requires multiphase isotope ratio analysis that combines multiple elements and isotope ratios. The Precambrian Ecosystem Laboratory is advancing research vigorously into a Precambrian explosion navigation system, known as “multiphase isotope ratio systematics research.” This

is based on high-accuracy maps and GPS, and combines isotope ratio fractionation and equilibrium indicators from within the diverse chemical, biological, and metabolic processes that use the mass balance of many elements and multiple isotope ratios.

To investigate the global nitrogen cycle, our research previously focused on the mass balance and nitrogen isotope ratio of nitrogen gas and organic nitrogen. For nitrogen isotope ratio indicators preserved in geological records, the contribution of a nitrogen fixation metabolism that directly connects nitrogen gas and organic nitrogen is important. However, because research has previously only been conducted on the nitrogen fixation metabolism of photosynthetic microorganisms, discussions have been limited to an association with the dynamics and evolution of these microorganisms. In FY2012/2013, our laboratory has conducted polyphasic isotope ratio systematics research on the nitrogen fixation metabolism of thermophilic hydrogenotrophic methanogens, (the most important primary producer in the Precambrian explosion). For the first time, we show that nitrogen fixation by thermophilic hydrogenotrophic methanogens had characteristics that induced an isotope ratio fractionation different from that of photosynthetic microorganisms. The results were then applied to the interpretation of nitrogen isotope ratio indicators left in geological records; and it was found that traces of a nitrogen fixation metabolism were preserved in chemical fossils from 3.5 billion years ago. It was therefore concluded, that since the birth of life on the earth, nitrogen fixation has been used for nitrogen utilization to support biological activities.

Significant results have also been obtained from polyphasic isotope ratio systematics research on methane, the most important chemical indicator in the co-evolution history of earth-life. The carbon isotope ratio and hydrogen isotope ratio of methane are commonly used singly or jointly as indicators for understanding the origin, generation, accumulation, transportation, and consumption of methane. However, details of isotope ratio fractionation and equilibrium in these processes remain unknown. In FY2012/2013, for the first time, we experimentally confirmed the phenomenon known as hydrogen fixation in methane. This is a process whereby hydrogen, a constituent molecule of methane, is directly absorbed into methane during methane generation by thermophilic methanogens. This finding refutes one of the common premises of isotope systematics of H_2O - H_2 - CH_4 . Our analysis of the carbon isotope ratio and hydrogen isotope ratio of methane therefore indicates that there is a need to revise the rule that estimates the origin, generation, accumulation, transportation, and consumption of methane. Our findings also clearly indicate a direct relationship between the isotope ratios of H_2 and CH_4 , providing a clue to revealing the association between the origin and sources of hydrogen, (the most important energy source during the Precambrian explosion), and of methanogens (the most important primary producer).

In FY2012/2013, we developed a rapid, high-accuracy method for analyzing the chlorine isotope ratio, in collaboration with the Subsurface Geobiology and Advanced Research Project, and with the financial support of the JAMSTEC budding research award. It is now expected that the multiphase isotope ratio analysis of the carbon isotope ratio and chlorine isotope ratio of chloromethane will reveal the origin and supply of chloromethane. However, we also had an alternative goal when developing this method. This method allowed us to perform microanalysis of the chlorine isotope ratio, which provides a clue to revealing the evolution of the oceans on the earth. It is expected that, by analyzing the chlorine isotope ratio of hot water and seawater fossils found in a very small number of geological records, the method will provide a definitive answer to the decoding of its evolution. Additionally, by analyzing the samples from returning space probes, such as Haybusa-2, and of meteorites, this method could serve as a tool for decoding the creation process and evolution history of the oceans on other planets.

Laboratory for Earth Systems Science: Space and Earth System Modeling Laboratory Unit

Overview

The environment and life on the earth are continuously impacted by the earth's interior and space, ever changing and evolving, and the surface environment also influences the earth's interior. In particular, in order to understand the mechanism of long-term variability of global environment and predict it, one needs to elucidate the processes which govern the evolution of the space and earth system.

This laboratory unit aims at determining the mechanism to predict the evolution of the earth environment by quantitatively studying the complex interactions between the different layers including the earth's surface, its interior and space, via state-of-the-art numerical simulation, super-high pressure experiments, and observational studies.

Thermal conductivity modeling for the core, considering electric resistance saturation

The heat conductivity of the earth's core is a critical physical property that can restrict the heat flow of the core-mantle boundary and the cooling speed of the core. Until recently, a relatively small value of 30 W/m/K, estimated by Stacey, et. al., was frequently used. This time, however, we looked at a phenomenon referred to as the "saturation of electric resistance," an idea well-known in metallography, and carried out a modeling experiment assuming its effect. The results confirmed what had been shown in the previous work concerning the electric resistance of the Fe-Si alloy (Gomi, et. al., 2013, PEPI). Because the heat conductivity of a metal is inversely proportional to its electric resistance, the heat conductivity becomes multiple times as much as its conventional value when considering the effect of resistance saturation. Our estimates are also consistent with recent results of theoretical computations. Such high heat conductivity of the core suggests many new facts in earth history, such as the heat flow at the core-mantle boundary being at least 10TW and the inner core having been born less than 1 billion years ago.

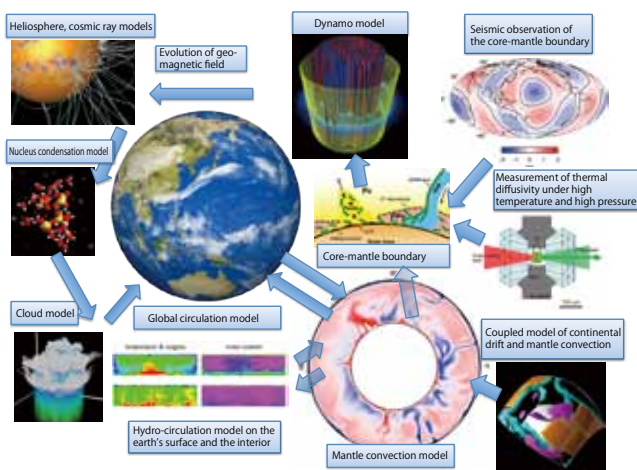


Figure 1. Research topics studied at Space and Earth System Modeling Laboratory Unit.

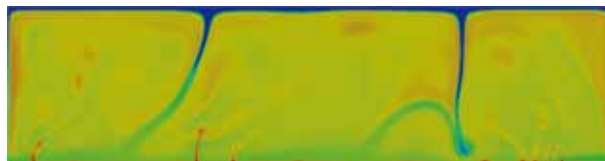


Figure 2. Potential temperature distribution obtained by the mantle convection simulation of a super earth (red indicates high values; blue, low values). While the Rayleigh number is about 1000 times that of the earth's mantle, the hot flow rising from the core-mantle boundary (bottom side of the figure) loses its momentum below the middle layer, unable to reach the planet's surface.

Mantle Convection of Extrasolar Planet Super Earth

An earth-like giant planet in the extrasolar system, with a mass up to ten times the earth's mass, is called a super earth. We have investigated the mantle convection of super earths with approximately 10 times the mass of the earth through numerical simulation using the Earth Simulator. We discovered that, due to high compressibility and changes in the adiabatic temperature of the mantle of a super earth, the rising stream within the mantle weakens drastically, unable to reach the surface. We also learned that the thermal transportation efficiency of the mantle convection is very small, about a quarter of the value predicted by the earth's model (Fig. 2).

These results suggest that on super earths the force that drives the cooling convection of the core is weakened, preventing the magnetic field of the planet from being very strong, and that volcanos due to hot spots are not formed. We hope that further comparisons with the earth's model will lead to a deeper understanding of not only the super earths but also the habitability of our own planet. These results were published in the December, 2013, issue of the *Astrophysical Journal Letters*.

Reversal of Flow Field Reproduced by Numerical Simulation

In order to understand the earth's outer core, it is crucial first to understand the behavior of the convection of liquid metals when magnetic field exists. For convection of liquid metals under the influence of horizontal magnetic field, it had been shown by a laboratory experiment that the flow direction of the convection rolls is reversed in irregular time intervals. We succeeded in reproducing this phenomenon through numerical simulation and were able to study the detailed process of this reversal.

In Figure 3, a horizontal magnetic field is imposed, and convective rolls along the magnetic field spontaneously form. For most of the duration, there are five rolls; however, intermittently the structure changes to four rolls as shown in the figure when the roll axes bend and each roll axis joins up with the one right next to it. After this, in the process of returning to its five-roll structure, the flow direction gets reversed. This can be understood as repetition of "skewed-varicose instability" with respect to the roll structure, a property universally seen in a convection pattern when there is a factor that constrains the flow direction, such as the effects of the magnetic field or rotation.

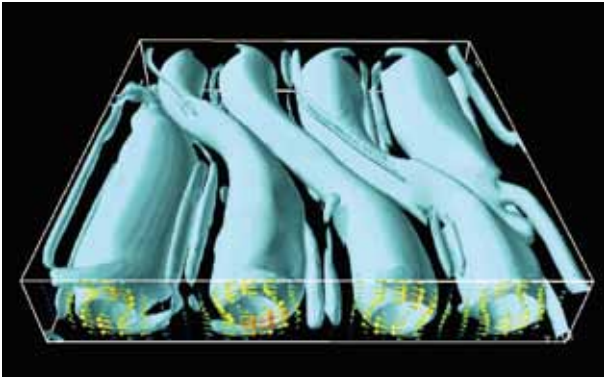


Figure 3. Convective rolls in magneto-convection simulation

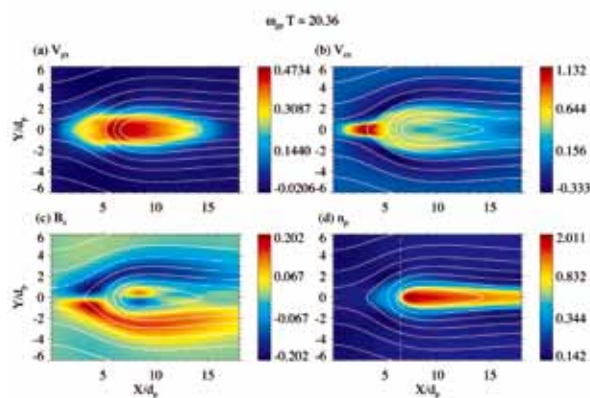


Figure 4. Results of high-precision kinetic simulation of magnetic reconnection. (a) Velocity of ions in the x-direction (b) Velocity of electrons in the x-direction (c) Intensity of the magnetic field in the direction perpendicular to the surface (d) Ion density. The lines represent the magnetic field lines.

High-Precision Simulation of Magnetic Reconnection

Solar flare is one of the biggest explosive phenomena in the solar system in which the magnetic energy accumulated on the surface of the sun and in the solar corona abruptly explodes in release, causing massive impacts not only on the earth's environment but also on the infrastructures of our society such as satellite and telecommunications systems. This energy release is believed to be caused by topological change in magnetic lines, referred to as magnetic reconnection. Magnetic reconnection is known to occur not only on the sun but also in various plasmas; it is believed to be closely linked with energy releases in the magnetosphere, related to aurora explosions on earth as well. However, its detailed dynamics and structure are not yet fully understood.

For electro-magnetic fluid dynamics models and plasma kinetics models, we implemented simulation with a high level of precision not achieved before in order to explore what causes fast magnetic reconnection in high-temperature plasmas. We discovered that when high-temperature plasmas have sufficiently high magnetic Reynolds numbers, magnetic reconnections can rapidly proceed locally due to strong non-linear effects. This is in stark contrast with the conventional belief that small-scale reconnections occur and spread out globally in high-temperature plasmas; it was a new discovery for plasmas on the sun and the earth. In addition, we developed a new computational algorithm that enables us to carry out kinetic simulation with a high level of precision hereto unknown, allowing us to compute, with high precision, the magnetic reconnection accompanying non-thermal particle acceleration as seen in Figure 4.

Restoration of Paleo Geo-Magnetic Fields by Micro-Sample Measurements

Information on earth's magnetic fields in the past are useful in constraining the cooling model of the earth's interior and in estimating the magnetosphere change, but there are hardly any rocks that preserve magnetic records from before 2.5 billion years ago. Through microscopic observation and magnetic measurement of 3.4-billion-year-old granites, we discovered that there are special nano-scale magnetites within feldspar minerals with extremely stable magnetic records preserved within. Since granites today cover more than half of all the rocks from 2.5 billion years ago, it is now expected that restoration of the geo-magnetic fields is possible by selectively measuring micro-samples of minerals like these.

Application Laboratory (APL)

Organization and Future Vision

Based on knowledge gained from fundamental research in marine and earth sciences accumulated by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the Application Laboratory aims for realizing scientific innovation through mutual enlightenment between research and social needs, thereby contributing towards the creation of a sustainable society. The laboratory was established in 2009 as a virtual organization, and in 2012, it became an entity with regular working budgets to fund three substantial programs: the Integrated and Intellectual Information Science and Technology Program; the Society-Oriented Prediction Engineering Science Program; and the Deep Sea Engineering Science Program.

The Application Laboratory is a new and developing organization. However, we believe that its role is becoming increasingly important. The Great East Japan Earthquake and the country's response to this event have made Japan painfully aware of the need for co-development of marine and earth sciences with the needs of the society. We believe that future predictions of natural phenomena should be at a level applicable for society needs, and in any development that uses marine and earth resources, sustainable maintenance of the global environment, including the biosphere, should be considered carefully, and it must contribute to better living of the human society. Future Earth, a large-scale joint initiative of the International Council for Science (ICSU), the International Social Science Council (ISSC), and other international organizations aiming to create a new interdisciplinary field that strives to realize better coexistence of humans and the planet by halting the deterioration of the global environment, is about to begin. The Application Laboratory was established ahead of such world trends. The activities of the three programs implemented in 2013 are described below:

The Integrated and Intellectual Information Science and Technology Program

This program aims to develop methods by which information based on marine earth simulation and observation can be provided in a usable and understandable way to meet social demand. This will be made possible through collaboration with users of the simulation results. Building a prototype information system enabling information transmission and knowledge sharing to be integrated is also one of our objectives. The group also promotes introduction of software EXTRAWING (developed for new display formats and information transmission of numerical data) to more researchers, extension of software capabilities, and research and development of new visualization technologies.

EXTRAWING, visualizing simulation data and observation data in three dimensions, has already established a way by which the data can be displayed in a realistic way on a virtual globe. Using this software, users can put different types of data or multiple data on top of one another, go into the interior of a phenomenon taking place from top, bottom, right, and left, and can see the simulation results freely from any viewpoint in three dimensions. Figure 1 shows the simulation results displayed on EXTRAWING when the user views the Minato Mirai 21

(MM21) district in Yokohama using the Multi-Scale Simulator for the Geoenvironment (or MSSG, pronounced “message”) with a horizontal resolution of 5 meters. MM21 is a district where the city of Yokohama is promoting future planning, aiming to build a low-energy, idealistic urban society. Our group is involved in a joint research project with the city of Yokohama and Yokohama National University, discussing this urban planning and policies to maximize the effects of such planning. We are proposing new ideas toward simulation that responds to the needs of society as well as the analysis and implementation for quantitative assessment of the effects of realizable policies.

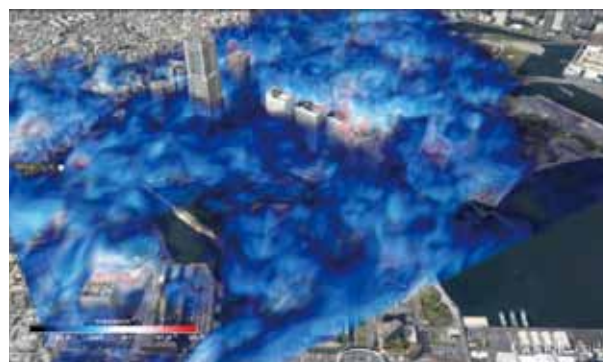


Figure 1. Example of applying simulation obtained by MSSG in the future urban planning of MM21

Society-Oriented Prediction Engineering Science Program

The predictability of subtropical dipoles in the southern Indian and Atlantic Oceans and the new face of climate variation (the Ningaloo Niño/Niña) are investigated using the SINTEX-F1 coupled model results. Several innovative research results are also reported this year.

1. First Discovery of Predictability of the Subtropical Dipole Modes

Despite the known difficulty in predicting subtropical climate variations, skillful seasonal predictions of the south Atlantic Subtropical Dipole (SASD) and the Indian Ocean Subtropical Dipole (IOSD) are demonstrated using the SINTEX-F1 seasonal prediction system^{*1} (Yuan et al. 2014a, Climate Dynamics). The accuracy of prediction of the southern African summer precipitation is also found to be high in the SINTEX-F1 model (Yuan et al. 2014b, Climate Dynamics) owing to the model's good performance in predicting SASD, IOSD and ENSO. The precipitation anomalies over southern Africa (16°–33°E, 22°–35°S) in December–February are highly predictable from the October 1st initialization. This study presents promising results for seasonal prediction of precipitation anomalies in the extra-tropics, where seasonal prediction has been considered a difficult task.

^{*1}: SINTEX-F1 seasonal prediction system: A global-scale real-time ensemble seasonal prediction system developed by JAMSTEC to predict seasonal climate anomalies, built on the basis of SINTEX-F1. Each month, the results of real-time

seasonal predictions are updated on the JAMSTEC website.

URL: <http://www.jamstec.go.jp/frcgc/research/d1/iod/e/seasonal/outlook.html>

2. First Discovery of Predictability of the Ningaloo Niño/Niña

Unprecedented oceanic warming was observed off the West Coast of Australia in the austral summer of 2010/11. In February–March 2011 the sea surface temperature (SST) anomalies reached about 3°C, which is more than four times the standard deviation of the interannual variation in the most recent 30 years. This event seriously damaged marine ecosystems and agriculture and was recently named “Ningaloo Niño,” after a similar equatorial event, El Niño, in the Pacific, by Drs. Ming Feng (CSIRO), Swadhin Behera (APL/JAMSTEC), and Toshio Yamagata (APL/JAMSTEC).

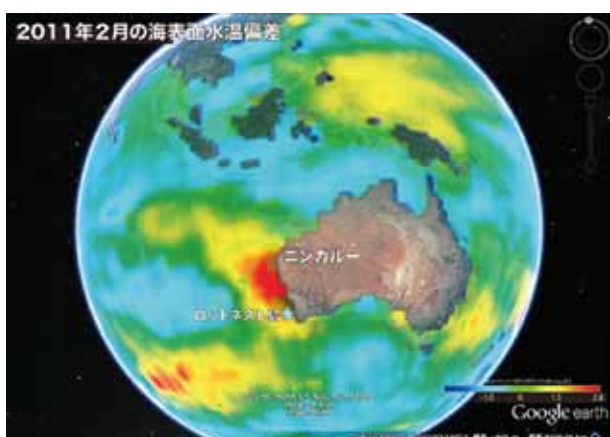


Figure 2. SST anomaly (°C) for February 2011 based on the climatology of 1983–2006 by using OISSTv2 observation data of the National Oceanic and Atmospheric Administration (NOAA). VDVGE software developed at the JAMSTEC Earth Simulator Center was used to draw the diagram. Seawater temperature is abnormally warm near the West Coast of Australia, off Ningaloo.

Dr. Takeshi Doi (APL/JAMSTEC) explored the seasonal predictability of the Ningaloo Niño/Niña using the “SINTEX-F1 seasonal prediction system”^{*1} and found that the SINTEX-F1 seasonal prediction system can predict the occurrence of the Ningaloo Niño/Niña event six months in advance (Doi et al. 2013, Scientific Reports). In particular, the extremely strong Ningaloo Niño event of 2011 was predicted 9 months in advance. Until now, seasonal prediction research has focused on tropical climate variations, such as the El Niño, on the scale of several thousand kilometers. The present results open a new door to predictions of regional climate variations on a scale as small as a few hundred kilometers and far away from the tropics. Spurred by this success, we will continue to improve the accuracy of prediction of the Ningaloo Niño/Niña for societal and economic applications.

3. First Discovery of a Link between Antarctic Ozone Depletion and Summer Warming over Southern Africa

A joint research team of our program and the Bindura University of Science of Zimbabwe discovered that the increase in the summer temperature over Southern Africa is linked to the loss of ozone over Antarctica and the associated intensification of

the Angola low-pressure system over southern Africa (Manatsa et al. 2013, Nature Geoscience).

4. Prediction of Seasonal Climate-induced Variations in Global Food Production

A joint research team of our program and National Institute for Agro-Environmental Sciences has reported a global assessment of the reliability of crop failure hindcast for major crops at two lead times derived by linking ensemble seasonal climatic prediction with statistical crop models (Iizumi et al. 2013, Nature Climate Change).

5. JAMSTEC Symposium on the New Faces of Climate Variability; Yokohama, Japan, October 30–31, 2013

The 2-day symposium on the new faces of climate variability, sponsored by JAMSTEC, discussed successes and challenges in predicting climate modes, such as the ENSO, the ENSO Modoki, the Ningaloo Niño/Niña, the North Atlantic Oscillation, and the decadal climate variations (Doi 2014, EOS). In addition to the participants from Japan, many international participants attended the symposium from the United States, the United Kingdom, France, Spain, Italy, Australia, Korea, India, Zimbabwe, and Mozambique.

The Deep Sea Engineering Science Program

This program is promoting the activities of the “Study Group on Deep-Sea Sub-Surface Layers,” holding three workshops this year (Photo 1).



Photo 1. Third workshop of the “Study Group on Deep-Sea Sub-Surface Layers” (at Nasu Plateau)

The purpose of this study group is to build knowledge and technology on deep-sea sub-surface layers necessary for active uses of the deep-sea surface in the near future, including sea-floor resources and substance storage, with a view to the future 20 years from now. To this end, the group consists of internal and external researchers in the industry, government, and academic institutions in addition to graduate students (who will play a major role 20 years from the present) accompanied by their own professors from the beginning, promoting advanced education. With the generosity of the Institute of Technology members of Penta-Ocean Construction Co., Ltd., the third workshop was held as a multiple-day retreat at the Retreat Center of Penta-Ocean Construction Co., Ltd. and of the Institute of Technology in Nasu Shiohara, allowing the members to be involved in active discussions and visits to experiment facilities until late night hours. The workshop also invited Mr. Suzuki of the

Japan Oil, Gas and Metals National Corporation (JOGMEC, an independent administrative corporation), who spoke on most recent on-location topics concerning the development of methane hydrate.



Figure 3. Cross section of one ballistic-orbit unit (periodic boundary)

Under this program we also began five new joint research projects with external research organizations and the industry this year. Additionally, the highly sophisticated computation technology based on a particle model developed thus far at the Deep Sea Engineering Science Program is being used for a fee by many in the industry this year, resulting in a total intellectual property revenue of over 6 million yen; the accumulated intellectual property revenue through this software and algorithms has now exceeded 100 million yen. This number is ahead of the recent trend in the reform of independent administrative corporations: that “the Japan Agency for Marine-Earth Science and Technology shall obtain its non-tax operational funds through its own efforts.” It proves that the Application Laboratory is more than fulfilling its role. Some of these joint projects are described below.

Together with the Railway Technical Research Institute, an incorporated foundation, we are involved in “research to increase the scale and precision of ballast aggregate analysis.” Under this project we have developed a pre-processor that faithfully models all ballasts and crossties using the actual orbital cross-section scale in order to perform simulation using QDEM (quadrature demodulator) as the ballasts and crossties distort and sink dynamically (Figure 3).

In the actual computations, one crosstie and approximately 50,000 pieces of gravel are defined as one unit, assigned to one GPU, and as many GPUs as necessary for simulation are linked in parallel. In order to significantly reduce the computation time, the pre-processor then considers the boundary in the orbital direction of one unit as a periodic boundary, allowing for automatic formation of irregularly shaped ballasts and consolidated computations of the oscillation (Figure 4).

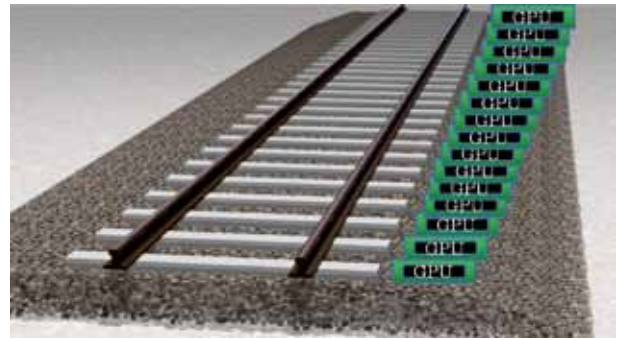


Figure 4. Ballast oscillation simulation with multiple GPUs in parallel

Mutsu Institute for Oceanography (MIO)

Overview

Mutsu Institute for Oceanography (MIO) was established as the Mutsu Office managing the home port of the research vessel *MIRAI*, which is one of the largest oceanographic research vessels in the world and rebuilt from the former nuclear powered test ship Mutsu. MIO was reorganized as a research institute conducting study on the bio-geochemical cycle in the northern Pacific Ocean after the research facilities had all been put into place.

The most important role of MIO is to support all activities of *MIRAI*, e.g. coordination of its arrival and departure, maintenance of large equipment for oceanographic observation research, and support for analyzing the samples collected by *MIRAI*. In order to conduct these activities, MIO is equipped with a research and administration office, observation equipment and machinery maintenance shop, and sample analysis facility building. Various facilities and equipment for maintenance of the oceanographic surface buoy system, “TRITON buoys,” and others are prepared in the observation equipment and machinery maintenance shop. The sample analysis facility building has a clean laboratory, sea water pre-process laboratory, chemical experiment laboratory, and other rooms. ICP-MS, isotope MS, HPLC, and some chemical analytical instruments are set up in those laboratories.

The main research of MIO, the North Pacific time-series observation research, aims at investigating marine environment changes and biogeochemical cycle studies. In other words, its purpose is to identify how changes in environmental loads stemming from today's human activities can be observed by accumulating data over a long time. In this research, our focus is to clarify internal change of dissolved carbon dioxide in seawater and to estimate the vertical flux of carbon through bio-geochemical processes. MIO has also started observational research in the eastern Tsugaru Strait because the environment in the coastal area might be affected by the increasing carbon dioxide concentration. In order to conduct these research activities, we have established collaborative agreements with the graduate school of Fisheries Sciences at Hokkaido University and the Aomori Prefectural Industrial Technology Research Center.

As to the promotion of marine science, MIO send out general marine science information and the research results obtained by JAMSTEC to people in the Shimokita area. These activities are supported by the local government agencies, schools, and local FM radio stations.

Accomplishments in 2013

North Pacific Time-series Observation Research

We participated in the MR13-04 cruise and collected time-series data, and recovered and deployed sediment traps. We compiled the data collected at time-series observation stations K2 (47°N, 160°E, bottom depth 5200m) and S1 (30°N, 145°E, 5900m), and analyzed the data with regard to the acidification in the northwestern Pacific Ocean region. The mixing ratio of carbon dioxide by volume in dry air ($x\text{CO}_2$) in the surface water in winter at S1 has increased along with the same ratio of that in the atmosphere. This change is similar to the trend that has been observed in the subtropical regions of the western North Pacific

Ocean. At K2 station in the western subarctic region, the oceanic $x\text{CO}_2$ increase in winter was slower than that in the atmosphere. (Fig. 1). pH values at both K2 and S1 have been decreasing over the years, with the pH rate at K2 being slower than that at S1.

Temporal changes in the $x\text{CO}_2$ and pH in the surface layer affect CaCO_3 saturation state. The saturation depth of calcite at K2 shoals at a rate of 3 m/yr, slower than that at S1.

The above research findings were obtained through joint efforts with the Environmental Biogeochemical Cycle Research Program of the JAMSTEC team.

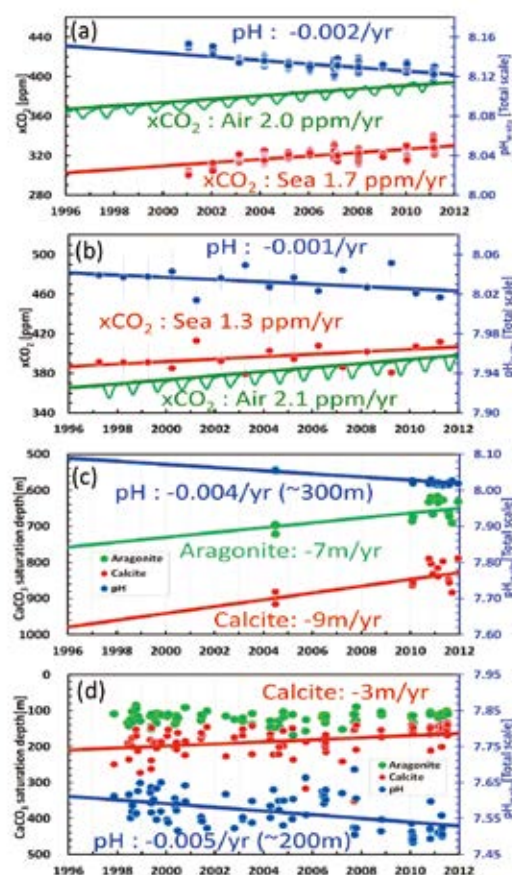


Figure 1: Temporal changes of carbonate system at time-series stations K2 and S1 in the western subarctic and subtropical region of the North Pacific Ocean. [Data obtained by R/V *MIRAI* (Wakita, et. al., 2013), the Japan Meteorological agency and SOCAT version.2 (Bakker et al. 2014)]

- (a): The mixing ratio of carbon dioxide by volume in dry air ($x\text{CO}_2$) in the surface layer in winter (red), $x\text{CO}_2$ in the atmosphere in winter (green), pH in winter (blue) at S1
- (b): $x\text{CO}_2$ in the surface layer in winter (red), $x\text{CO}_2$ in the atmosphere (green), pH in winter (blue) at K2
- (c): The CaCO_3 saturation depth for aragonite (green), calcite (red), pH at a depth of ~300 m (blue) at S1.
- (d): The CaCO_3 saturation depth for aragonite (green), calcite (red), pH at a depth of ~200 m (blue) at K2.

Feasibility studies in the Tsugaru Strait

MIO has been conducting studies around the eastern Tsugaru Strait. First is a public event of marine organism observation at the north coast of Shimokita Peninsula. The purposes of this activity are to increase public awareness of marine science and to detect changes in the coastal environment. Second is oceanographic observation research by a training ship of Hokkaido University around the eastern part of the Tsugaru Strait in collaboration with the graduate school of Fisheries Sciences, Hokkaido University. The oceanographic data has been accumulated since 2009. On a recent cruise, we introduced an additional instrument, “fast repetition rate fluorometer” (FRRF), to measure in-situ activity of chlorophyll in the surface layer, which is an indicator for primary productivity. The changes in the temperature and salinity distributions (Fig. 2) would be mainly due to seasonal variation

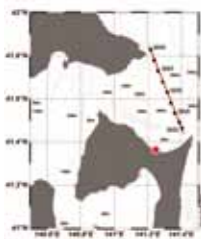
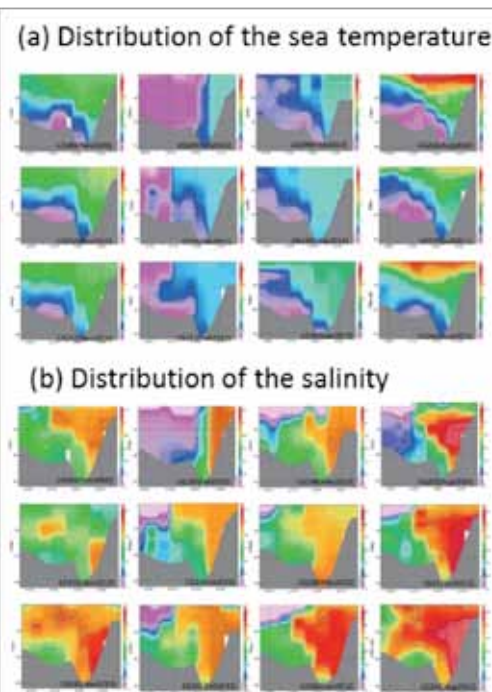


Figure 2: Meridian sections of (a) temperature and (b) salinity at the eastern end of the Tsugaru Strait and the observation line (the bottom panel). From top left to right, 2009 (Nov.), 2010 (Feb., May, August, Nov.), 2011 (Feb., May, July, Nov.), 2012 (Feb., June, Aug.)

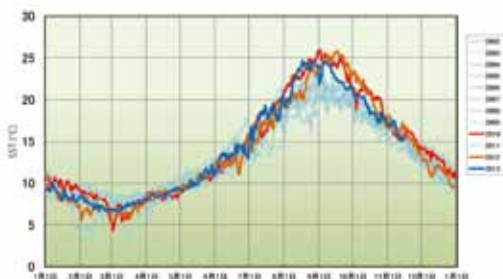


Figure 3: Seasonal and interannual variation of sea surface temperature (SST) at outside of the Sekinehama port.

and more frequent phenomena (e.g. tide cycles), but could also be influenced by global climate change. Third is sea surface temperature monitoring outside Sekinehama port since 2002 (Fig. 3). We plan to continue these activities in order to accumulate data so that we can analyze global climate changes and the effects on the regional sea around the Tohoku region, Japan.

Other Research Activities

1) Research on how eelgrass responds to environmental changes

An experimental device which can control carbon dioxide partial pressures and temperature simultaneously was developed. This device made it possible for us to elucidate how living organisms distributed in the coastal areas respond to environmental changes. We have conducted an incubation experiment targeting the cosmopolitan eelgrass, *Zostera marina*, which is widely seen in the northern hemisphere as well as the endemic species, *Z. caespitosa*, which is present only around the Sea of Japan area. The latter showed less resistance to temperature rises compared to the former.

2) High Frequency Observation of Carbon Dioxide Partial Pressure in the Antarctic Ocean

This observation was started in 2011 and was supported with a Scientific Research Grant of the Japan Society for the Promotion of Science. We produced a number of drifting in-site pCO₂ measurement buoys developed by MIO and released those buoys in the Antarctic Ocean with the support of the National Institute of Polar Research and icebreaker SHIRASE in December 2013. Those buoys have flowed along the course indicated in Figure 4 and have consistently obtained the surface temperature and carbon dioxide partial pressure. The drifting area is wider than what we initially expected. Those buoys might be affected with the wind because they are not equipped with drogues.

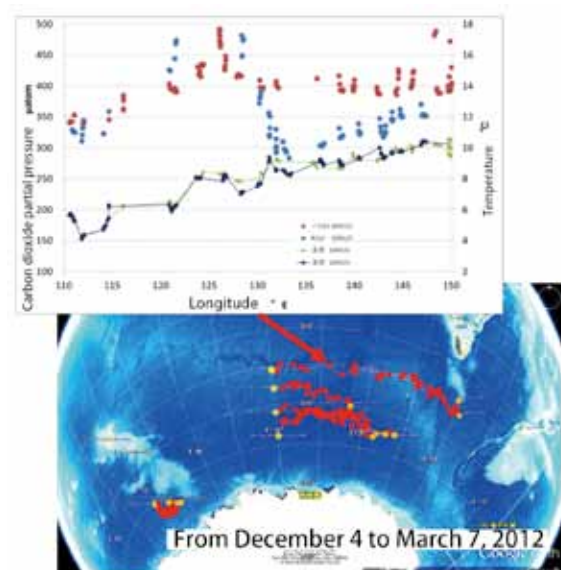


Figure 4: Drifting paths and data of carbon dioxide partial pressures and water temperatures obtained from the two buoys (no quality control).

Kochi Institute for Core Sample Research (KOCHI)

Overview

Center for Research, Analysis, and the Curation of Core Samples

The Kochi Institute for Core Sample Research (KOCHI) serves the world's scientific community as a center for core-based research, and houses unique facilities used to contribute to a broad range of scientific ocean-drilling research. Our institute is not only responsible for the storage and curation of core samples that have ever been drilled from the world's oceans, but also for conducting multidisciplinary research on the physical properties, isotopic geochemistry, deep sub-seafloor biosphere using such samples. Another unique feature of the Institute is that it takes charge of some of the costs involved in running the laboratory's facilities (many of which, such as the mass spectrometer, non-destructive core loggers and microbiological instruments, are the properties of Kochi University). Sharing these instruments with our partner, the Center for Advanced Marine Core Research of Kochi University (CMCR), enables a mutually cost-effective research environment.

We store approximately 100-km-long core samples taken from around Japan and in the Indian Ocean, and we have developed some innovative curatorial techniques (Photo 1). "Deep Biosphere Samples (DeepBIOS)" are the core samples stored at temperatures below -80°C for the special use of microbial research. The "Virtual Core Library" is designed to provide quick access to X-ray CT images of core samples. We believe that such efforts will lead the broader scientific community to benefit from a more intensive use of core samples (e.g., in environmental, natural resource, or disaster studies). Furthermore, we opened an exhibition booth at the Fall Meeting of AGU (American Geophysical Union) held in the U.S. from December 9 to 13, 2013, with a view to promote the use of core samples overseas.

With the supplementary budget for fiscal 2012, we implemented waterproofing measures to protect our precious excavated core samples stored at KOCHI from possible tsunamis caused by earthquakes in the Nankai area (Photo 2).



Photo 1. Core samples collected during the IODP Expedition 346 "Onset and evolution of millennial-scale variability of Asian monsoon and its possible relation with Himalaya and Tibetan Plateau uplift" (October 16). Core samples from 10,816 sections filled up the storage at KOCHI.



Photo 2. Packing work (left) and a packed core sample (right)

The Integrated Ocean Drilling Program, which was led by Japan and the U.S., using the drilling research vessels *CHIKYU* (Japan), *JOIDES Resolution* (U.S.), and a mission-specific platform (Europe), completed its scheduled period of 10 years, and was renewed to the International Ocean Discovery Program (IODP) on October 1, 2013. In line with this reorganization, we signed a new trustee contract on core samples from IODP, etc., which are stored at KOCHI, with Ocean Leadership, INC. (U.S.) and decided to continue curatorial services for IODP.

To spread knowledge of marine science and technology to a wider audience, we held an open-house on November 3, and this event attracted 1,204 visitors (Photo 3). Moreover, we have offered opportunities for people in regional areas to raise their interest in science, through having seminars for general audience (Kochi Core Center lectures), cooperation in exhibitions at the events and seminars based on requests from regions, and outreach classes at schools. We especially encourage young scientists to lead future drilling projects through involvement from partner graduate schools and core analysis schools.

From November 6 to 17, we held a special exhibition titled "Exploring the Mysteries of the Universe and Earth: Asteroidal sample return mission *HAYABUSA* × drilling research vessel *CHIKYU*" (visited by 1,604 people) at the Kochi Liberty and People's Rights Museum in Kochi City.

In addition, we participated as lecturers in the Kochi CST (Core Science Teacher) Training Center Program, which is jointly carried out by Kochi University and Kochi Prefecture Education Committee. We opened a course on November 9 with six participants, and provided lectures and practical exercises on the theme "geology of Shikoku area and ocean core science" at KOCHI.



Photo 3. Open house at Kochi Core Center.

Major Results in FY2015

1. Research results from IODP Expedition 343 “Japan Trench Fast Drilling Project (JFAST)”

In this expedition, drilling achievement by CHIKYU has greatly contributed to understanding of the mechanism of the huge slip of 50m in the shallow portion of the fault in the Tohoku Region Pacific Coast Earthquake, which triggered a giant tsunami, and to understanding of whether it is a common phenomenon in subduction zones.

The shallow portion of the fault was considered to resist earthquake slips that are transferred from the deeper seismogenic zone, since the “velocity strengthening” (a mechanism whereby fault zone strength increases for a high-speed, coseismic slip) works in this portion. In other words, earthquakes are generated in the deep part of faults, which has a velocity weakening nature (fault zone strength decreases for a high-speed slip), and are transmitted to the shallow part, but a slippage in a shallow part would be comparatively small (e.g. Sumatra earthquake (2004), Nankai earthquake (1946), etc.)

However, core samples and measured data collected by JFAST through its unique methods, such as friction experiments and measurement of temperature inside excavation holes, revealed that fault slips are happening in a part of a very thin, smectite-rich layer, and that the friction coefficients (a good proxy for the fault strength) of the materials of the slipping faults are low. These findings have brought about a new hypothesis that the large slip in the shallow part near the trench was attributed to a mechanism whereby the friction coefficient was reduced at a coseismic, high-speed slip velocity even in the shallow part, which challenges the conventional ideas about such mechanism.

However, it was also pointed out that the case of the Tohoku Region Pacific Coast Earthquake does not necessarily explain all giant tsunami mechanisms.

(1) A Mechanism for the giant slip during the Tohoku Region Pacific Coast Earthquake was revealed by hydrologic analysis on drilled fault samples

We conducted a laboratory hydrologic experiment which simulates the in situ condition by applying raised pressure on a drilled core sample and evaluated its fluid transport characteristics. As a result, we found that the water permeability is very low (i.e. fluid or water is less transmittable) around the plate boundary fault that slipped in the Tohoku Region Pacific Coast Earthquake (Left, Fig. 1). Furthermore, we also found that this low permeability owes to an extremely high smectite content (a kind of clay mineral). In addition, the results of simulation on fluid flow and pressure increasing behavior in the fault zone revealed that the slip friction force was significantly reduced (reduction of the fault's friction resistance, i.e. easier to slip) as the pressure of the fluid is raised from friction heating that accompanies earthquake fault slips, and this leads to a large slip in the shallow portion of a plate boundary fault (Right, Fig.1).

These research results have shown that fluids have a strong relationship with the slipping mechanism of the shallow part in the case of a giant earthquake. We expect these results to help the clarification of the mechanisms for giant earthquakes and tsunamis in subduction zones, including possible Nankai earthquakes.

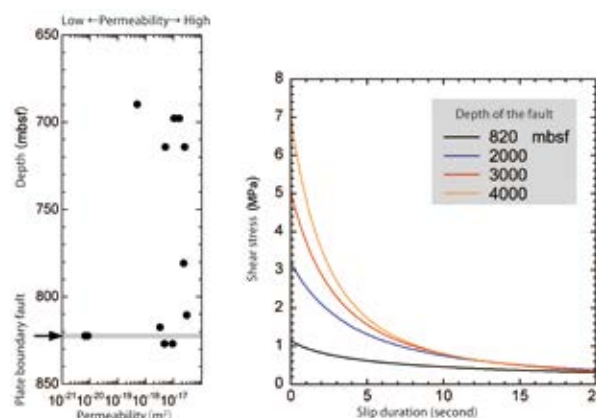


Figure 1. (Left) Depth profiles of permeability from 680m to 830mbsf (meters below sea floor) at Site C0019 of IODP Expedition 343. Fluids flow more easily when permeability is higher. The plate boundary fault exists around 820mbsf.

(Right) Change in share stress of the fault (equivalent to fault's friction resistance) in case of a fault slip. Lines in different colors indicate the changes in different depth of the plate boundary fault. The slip resistance becomes low due to the raised fluid pressure, whose effect is more significant as it gets deeper.

(2) Stress state near the earthquake source fault of the Tohoku Region Pacific Coast Earthquake

In research conducted last fiscal year, we analyzed the breakouts of the drilled borehole wall and measured the stress state (how the forces are applied) near the earthquake source fault of the Tohoku Region Pacific Coast Earthquake. As a result, we found that the horizontal stress that caused a fault slip in the giant earthquake was almost completely released near the fault after the earthquake, and that the stress state has become a normal faulting regime. Meanwhile, as a result of estimating the stress state before the earthquake based on an analysis on the bedding and minor fault structure and referring to previous research results, it was revealed that the stress state was a reverse faulting regime, which has a strong horizontal stress that causes the reverse fault slips. These results show that the significant release of stress and energy from the shallow portion of the plate boundary fault near the Japan Trench during the Tohoku Region Pacific Coast Earthquake lead to the massive fault slip and tsunami.

This fiscal year, the expedition 343 scientists including the KOCHI members monitored the temperature inside the drilled borehole C0019D and successfully detected the residual heat from the friction heat produced during the Tohoku Region Pacific Coast Earthquake. Thanks to this achievement, we could identify the depth where the fault ruptured during the earthquake and revealed that the dynamic friction force that worked on the fault plane during the earthquake was very small. These results were published by Science, the world's leading scientific magazine, as was last year's coverage of the research results concerning stress state. The small dynamic friction force conforms to the research results from last year that the stress was almost completely released as well as with the above-mentioned results that have suggested the reduction of slip friction resistance due to the low permeability.

(3) Fluid flow near the fault zone of the Tohoku Region Pacific Coast Earthquake revealed by geochemical analyses on interstitial water of the drilled core samples

We analyzed the interstitial water squeezed from the drilled core samples and revealed the depth profiles of dissolved chemical components. We found that water (fluid) that is poor in chlorine ions and enriched in sulfate ions is supplied from the Pacific plate that lay under the plate-boundary fault, and mixed with two other distinct end-component fluids to produce the observed interstitial water. However, the composition of the interstitial water continuously changes across the plate-boundary fault, and does not show any abrupt change near the fault (Fig.2). This suggests that there is no significant active fluid flow along the plate-boundary fault. These results are consistent with experiment results that suggest the low permeability of the fault materials as well as with the results from the bore-hole temperature monitoring described above.

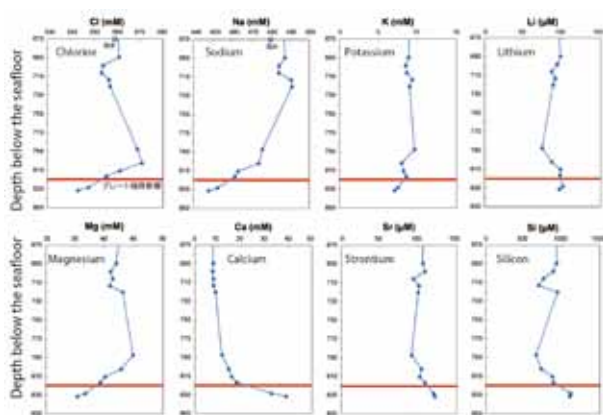


Figure 2. Vertical profiles of dissolved chemical components in the interstitial water of the core samples. The chemical composition of the interstitial water shows a continuous change and has neither a minimum nor maximum around the plate-boundary fault.

2. Participation in IODP Expedition 348: The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Stage 3

In order to reveal the mechanism of trench-type earthquakes, IODP Expedition 348 was conducted in the Kumano Basin, offshore of the Kii Peninsula from September 2013 to January 2014, to reach the asperity zone of the fault that caused a magnitude-8 class earthquake.

This expedition was to deepen IODP Riser Hole C0002, which had already been drilled in the 2012 Expedition to 3,000m below the surface of the seabed, to 3,600m, towards the giant splay fault at 5,000m deep. The purposes were the logging inside the drilled hole, collection of core samples, and installation of casing pipes to protect the wall of the drilled hole (Fig.3). From KOCHI, Takehiro Hirose, chief researcher of the Fault Mechanics Research Group, was onboard this expedition as a Co-Chief Scientist.

Although the drilling carried out in this expedition did not reach the giant splay fault, we expect that the results will contribute to the verification of a hypothesis that the nature of asperity in a giant seismogenic zone is decided not only by the

physical property of the fault materials but also by the physical property of the whole deposition layer on the upper part of the fault.

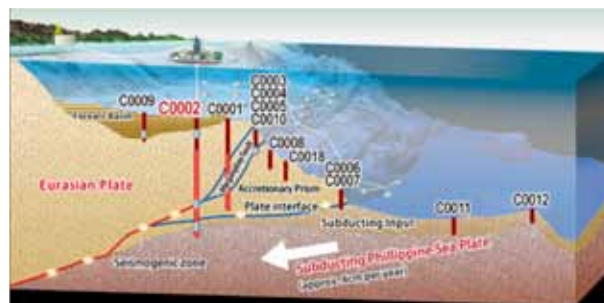


Figure 3. Drilling sites (prepared based on the figure by Moor and others (2007, SCIENCE))

3. Participation in IODP Expedition 347: Paleoenvironmental evolution of the Baltic Sea Basin through the last glacial cycle

IODP expedition 347 was carried out from September 2 to November 1, 2013, using a special drillship *GREATSHIP MANISHA* provided by ECORD. Subseafloor sediment samples were successfully collected from 7 sites during this expedition (Photo 4). The purposes of this expedition were to understand the paleoenvironmental change in the Baltic Sea, as well as the characteristics of the transition from the glacial to interglacial period and the mechanisms of the ending of the glacial period. By collecting and analyzing core samples, we were able to reveal the paleoenvironment of the Baltic Sea in the latest glacial period, which was 130,000 years ago. Another goal of this expedition was to understand how the extreme climate change during the last glacial period influences the deep biosphere underneath the Baltic Sea.



Photo 4. (Left, above) Baltic Sea, where the drilling was carried out; (Left, bottom) *GREATSHIP MANISHA*; (Right) Collected core sample (onboard *GREATSHIP MANISHA*)

Nan Xiao, a member of geomicrobiology group of KOCHI, was onboard this expedition as a microbiologist. She performed the sampling process for the post cruise microbiological research and also carried out a survey on microbial biomass in the Baltic Sea sediment by using flow cytometry technology.

A common and conventional method for a survey on microbial biomass of the submarine biosphere was used to count the fluorescent-stained microbes underneath a microscope. However, this method can only analyze a limited number of samples since it requires complicated sample treatments and high-level techniques and experiences in microscopic observation. During this expedition, we processed cell count of microorganisms by using both the flow cytometer and conventional microscopic method and found that these two methods produced identical results. This result proved that the flow cytometer method is a powerful tool for the biomass survey from the sediment samples and could provide reliable results on a drilling platform. For post cruise research, KOCHI will do the research focus on the cultivation of eukaryotic microorganisms that experienced glacial and interglacial cycle, as well as the survey on their functional genes.

4. Research on deep Earth biosphere under IODP Expedition 337: Deep Coalbed Biosphere off Shimokita

IODP Expedition 337 titled “Deep Coalbed Biosphere off Shimokita,” was carried out at 80km off the coast of Hachinohe City, Aomori Prefecture, from July to September of 2012. This expedition successfully drilled to 2,466m below sea floor by using riser-drilling vessel “*CHIKYU*,” which hold the world record for deepest drilling in the history of scientific ocean drilling. The core samples collected from this expedition provide chances to scientifically understand the environmental constitution of hydrocarbon resources originated in the deep coalbed, which expanded from southern Hokkaido to the Pacific Ocean off the Tohoku Area. Furthermore the core samples from this expedition can be used to understand the relationship between the carbon cycling and the life activities, including the biomass, diversity and metabolic activities of the microorganisms in the sediment. Geomicrobiology Group, Kochi, the lead of this investigation, is developing the most-advanced methods to evaluate the life signals of the microorganisms living in the geologically extreme environment. To accomplish this goal, preventing and evaluating external contamination, using accurate and supersensitive analysis that combines isotopic geochemistry and molecular biological techniques are required. For the widespread utilizations of the core samples collected from this expedition, joint research with domestic and overseas research institutes including National Institute of Advanced Industrial Science and Technology, Kyoto University, University of Bremen (Germany) and California Institute of Technology were collaborated. Furthermore, the Geomicrobiology Group has concluded joint research agreements with Center for Advanced Marine Core Research, Kochi University, and J. Craig Venter Institute (U.S.). These ongoing joint research projects are investigating the co-evolutionary process of the geological environment with the deep biosphere, including the studies on genetic diversities and metabolic functions of the microbial community.

5. Establishment of an accurate method for the determination of ^{236}U using inductively coupled plasma mass spectrometry (ICP-MS)

To verify whether global warming is caused by anthropogenic CO_2 emissions or is a part of the cyclic climate change system of the Earth, we need to understand the range and the rate of temperature changes in the past. The oxygen isotope ratio ($^{18}\text{O}/^{16}\text{O}$) of marine calcium carbonates (skeletons of coral, foraminifera, etc.) records the temperature of the time when they were formed, according to which, glacial periods and interglacial periods have been alternately repeated on the Earth. The age of the formation of marine calcium carbonates can be determined by measuring the trace amount of a uranium isotope (^{234}U) that decays to a thorium isotope (^{230}Th) contained in the sample.

The Isotope Geochemistry Group collaborated with Agilent Technologies and IFREMER (institute Français de Recherche pour l'exploitation de la mer) concerning age determination techniques for marine calcium carbonates from coral, etc., using the ^{234}U - ^{230}Th dating method. Wide kinetic energy distribution of produced ions was efficiently suppressed by using a new-generation ICP-MS instrument Agilent 8800 (Fig.4) that has a serially-arranged quadrupole electric field. This enabled the removal of the influence of the strong beam of ^{238}U , which is the most abundant uranium isotope in the natural environment, on signals of ^{236}U , which is necessary for ^{234}U - ^{230}Th age determination. In addition, we also succeeded in significantly reducing the influence of uranium hydride ions, which has been a major problem in conventional ICP-MS, by detecting uranium oxide ions (UO^+) obtained by the reaction of uranium and oxygen molecules (Fig.5). By this means, we achieved an accurate quantitation technique for ^{236}U that is far more prompt and easier compared to other types of mass spectrometry, opening new horizons for ^{234}U - ^{230}Th age determination using this technique.

We expect that this technique will contribute to detailed analysis on paleoclimate changes in the warming period from the past glacial period to the interglacial period using samples from various latitudes and sea areas. The Group intends to further enhance the sensitivity and accuracy using the MS instrument for smaller samples.

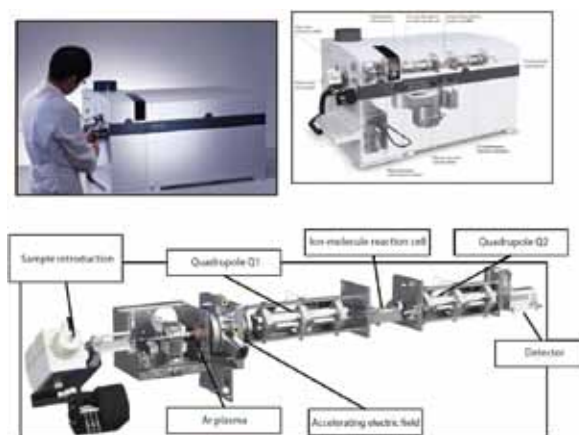


Figure 4. Appearance of Agilent 8800 and enlarged image and description of individual parts of the MS device (cited from Agilent's website)

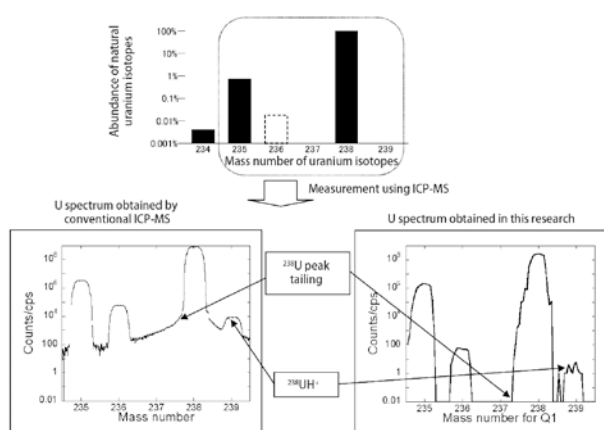


Figure 5. Abundance of natural uranium isotopes, and comparison between the mass spectra obtained through Agilent 8800 and conventional ICP-MS

6. Improvement of the research environment at KOCHI

(1) Enhancement of analysis capability for geological characteristics of core samples

Plate subduction zones (around a trench, etc.) are one of the areas where most active crustal movements are happening and are studied by geological researchers from all around the world. The recent research development has suggested the importance of the water's behavior inside the fault. In response to this, KOCHI has installed facilities that enable detailed analysis on the internal structure of the materials, such as the fault microstructure analysis system, KO consolidation experiment device, fault zone permeance and diffusion measuring system, and hydrothermal experiment device. We expect that this will help us to identify the behavior of crust movement more accurately, and make a significant contribution to seismic fault research.

(2) Microanalysis instruments and techniques for extremely small samples or regions

In order to conduct elemental and/or isotope analysis in a variety of samples, (micro) organisms, minerals, organic matters, and water, we have introduced state-of-the-art analytical instruments, including IMS-1280HR (large geometry type secondary ion mass spectrometry: SIMS), FIB (focused ion beam), TEM (transmission electron microscope), and iMScope imaging mass spectrometry. Combined with a current facility

of NanoSIMS (ultrahigh spatial resolution SIMS) and SEM that were introduced under the Advanced Research Infrastructure Program in 2011, KOCHI has gained a top-class high sensitivity and accurate microanalysis capability. We now enable research excellence by providing microanalysis facilities and expertise to researchers.

We are going to develop a micro-analysis system consisting of SIMS, TEM and FIB (Fig. 6). The system can be applied to the precious samples, such as drilled Core obtained by the D/V CHIKYU. The KOCHI complements JAMSTEC's existing experimental facilities, and is fostering new growth in interdisciplinary research among geochemistry, seismology, planetary science, biology and life science.

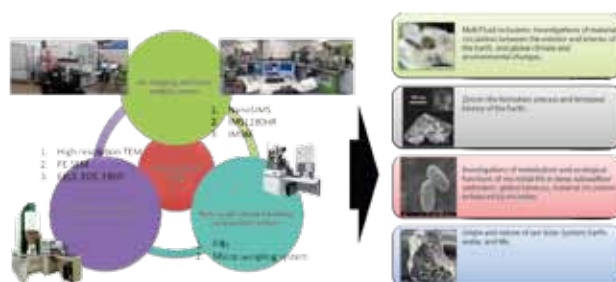


Figure 6. Overview of the Advanced Microanalysis Laboratory in KOCHI.

Marine Technology and Engineering Center (MARITEC)

Overview

The Marine Technology and Engineering Center (MARITEC) has three primary functions. First, we develop advanced technology for ocean surveying and observation. Second, we support ocean research efforts through the operation, management and improvement of research vessels, underwater vehicles, and observation equipment, as well as activities related to vessel construction. Thirdly, we offer technical and skills training.

Fiscal year 2013 saw completion of the *R/V Shinsei Maru*, a vessel with many advanced features that will be used mainly for marine ecosystem research and surveys in the Tohoku region. This is the first vessel constructed for ocean surveys and research since the *R/V Kairei*, which was completed in 1997. Further, a contract for the construction of a larger research vessel capable of surveying wide areas of seafloor was signed. This multi-function vessel will have equipment for sampling seafloor resources as well as a system for surveying the crustal structure below the seafloor. Work on the vessel has begun and completion is expected toward the end of fiscal 2015.

A new remotely operated vehicle (ROV) for use in surveying seafloor resources was completed in fiscal 2012 and we held a naming ceremony in December of that year. Three field tests with the new ROV were carried out in fiscal 2013, confirming that it performs superbly. A number of field tests also took place of three autonomous underwater vehicles (AUVs) as the first step to putting them into practical use.

We have also carried out basic research and development work as well as field tests related to other cutting edge technology with the aim of developing various new systems.

Fiscal year 2013 was also a successful year for research vehicle operations and deep-sea investigations. The *R/V Yokosuka* completed the QUELLE 2013 round-the-world voyage over a period of 10 months between early January and the end of November. She is the mother ship for the Shinkai 6500, a manned research submersible. This long voyage yielded valuable research results in various different sea areas.

In April, the *Kairei*, a deep sea research vessel, and the *ROV Kaiko 7000II* managed to recover a temperature monitoring system being used to investigate the Tohoku Region Pacific Coast Earthquake. The 820 meter long device had earlier been installed below the seafloor at a depth of about 7,000 meters in the Japan Trench by the *D/V Chikyu* deep-sea drilling vessel. Also, the *Urashima* deep-sea cruising AUV and the *ROV Hyper Dolphin* undertook voyages to survey seafloor resources.

More detailed reports follow below.

Technology Development

MARITEC continues to push the frontiers of AUV and ROV technology, aiming to bring the most advanced technology into practical use. Our next-generation advanced deep water AUVs and ROVs equipped with the latest technology allow high precision geoscientific surveys and seafloor resource explorations to be carried out over a wider area than previously possible. At the same time, we are also pursuing research and development

of advanced marine technologies for the future.

Looking at our most advanced deep water ROV technology, we conducted the first field tests of the latest ultra deep-water ROV, which was completed in fiscal 2012 and is designed to conduct seafloor resource surveys.

Operating at a depth of about 5,450 meters, we tested its maneuverability and performance while also verifying the capabilities of its high output manipulator. Motion control is one of the crucial characteristics of this ROV, so we implemented specific tests to verify auto depth control, auto direction control, auto trim and auto roll control, as well as the ability to maintain a stationary position, in semi-automated cruising. In other tests, we checked the auto cruise function, which enables the ROV to automatically cruise along a pre-programmed survey line, and the ability to drop emergency ballast, confirming that these functions work reliably.



Figure 1. *Kaiko Mk-IV*: Heavy ROV for seafloor resource exploration

During the upcoming fiscal year, we plan to build up experience by conducting tests at a depth of 7,000 meters to validate the performance of the ROV and to train operators. This is the maximum operating depth of the ROV.

Particular strengths of this ROV are the following:

- **Heavy duty capabilities.** The ROV is equipped with powerful hydraulic thrusters with a total propulsive force of about 600kg and a high output manipulator with a gripping force of up to 250kg.
- **Sophisticated research functions.** The ROV is equipped with video and image-capture systems including a high-resolution HDTV camera, a wide-angle fish-eye lens TV camera and a high-resolution still camera.
- **Improved positional accuracy.** The ROV is equipped with a high-precision inertial navigation system developed by MARITEC.
- **Improved automatic maneuvering and working.** The auto control mode includes depth maintenance, direction maintenance, trim maintenance, fixed position maintenance and auto cruising.
- **Interchangeable payloads.** The ROV is equipped with communication and control ports as well as a hydraulic connector, so various research and observation equipment

can be fitted to suit particular needs.

Following a public naming competition, the name *Kaiko Mk-IV* was given to this ROV (Fig. 1 to 3). We also refer to the overall system, including the older launcher that continues in deployment, as *Kaiko*.



Figure 2. *Kaiko Mk-IV* field test



Figure 3. Testing the high power manipulator

Three new AUVs designed for the exploration of seafloor resources and geoscientific research have each been undergoing repeated testing in preparation for entering service. Following experimental observations of methane hydrate deposits in the Japan Sea during August 2012, the *Jinbei* cruising AUV has been undergoing various sea trials based on expected operations in the field. The other cruising AUV, *Yumeiruka*, is equipped with cutting edge instruments including an interferometric sonar and a synthetic aperture sonar. Because its front and rear X-rudders have the capability to achieve high maneuverability, we improved its control performance by adjusting coefficients of the control system. AUV *Yumeiruka*, then, successfully achieved constant-pitch-control during autonomous depth-change operation in a sea trial. (Figure 4).

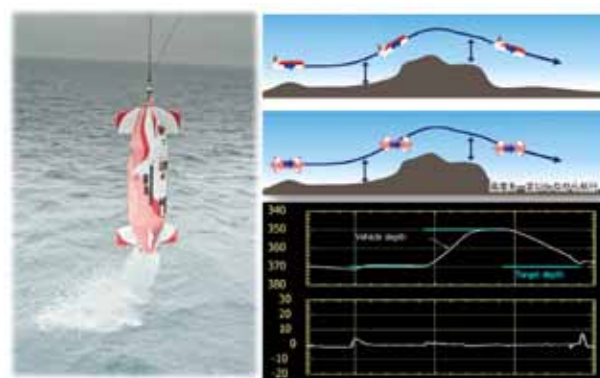


Figure 4. A recovery scene of AUV *Yumeiruka* (left); control concept with or without constant pitch control (upper right); and depth and pitch data measured (lower right)

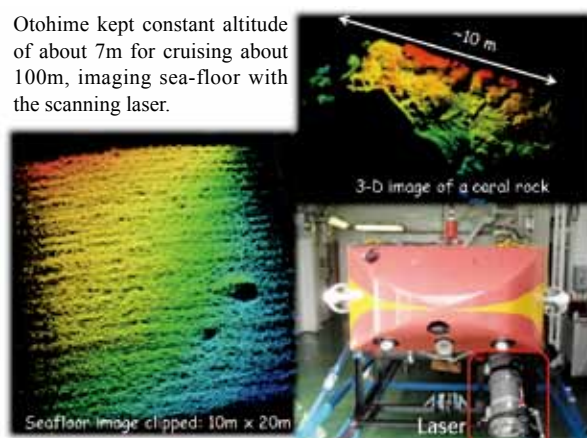


Figure 5. A snap shot of the working AUV, *Otohime* and scanning laser. A seafloor image obtained with scanning laser (left); and 3-D image of coral reef (upper right)

The *Otohime*, a working type AUV, successfully completed a seafloor visualization with a 3-D scanning laser in January 2013 (Fig. 5). In October, real-time tele-operation test including manipulation control were completed successfully using the geostationary communication satellite Kizuna (Wideband Internet Demonstration Satellite).

We have also been developing a design for an underwater observation float with “virtual mooring” as a replacement for conventional buoys. In fiscal 2013, a newly developed small buoyancy engine was fitted to the float. Field tests verified the float’s basic performance.

Furthermore, a tsunami monitoring buoy is under development in which JAMSTEC’s own acoustic communication technology and mooring observation buoy technology for strong current areas is deployed. In January, the second sea trial was carried out in the Kii Peninsula. This buoy incorporates a crustal movement monitoring system based on technology developed by JAXA and Tohoku University. The new system is expected to play an important role in a future disaster prevention system.

Research Vessel Construction

The Tohoku Region Pacific Coast Earthquake caused extreme damage to the marine ecosystem. With the aim of restoring fisheries in the area, the research vessel *Shinsei Maru* was constructed to carry out research into affected marine ecosystems. Following a launch ceremony on February 15, 2013, outfitting, yard tests and then sea trials were completed before the ship was delivered to JAMSTEC on June 30 (Fig. 6). From July until September, the research equipment on board was put through sea trials; then, for October and November, training cruises were held. The vessel left on its first research cruise on December 8.

To carry out wide-ranging research on marine ecosystems, the vessel has been equipped with survey systems that include a scientific fish-finder, multi-beam echo sounders, an acoustic positioning system, water sampler with CTD (conductivity, temperature, and depth), a gravimeter, a 3-D magnetometer, and meteorological instruments. It also carries as a number of cranes and winches. For the convenience of researchers on board, the vessel has a satellite communications system, which makes contact with the shore possible at all times, and ship-wide wireless LAN access. To improve operability and ensure optimum conditions for use of the survey systems, the vessel has azimuth thrusters and a dynamic positioning system. In October, this leading edge research vessel was opened to the public at Otsuchi Port in Iwate, where it is registered, and at Harumi wharf, Tokyo.



Figure 6. Vessel for marine ecosystem research in Tohoku region: R/V *Shinsei Maru*

We have also signed a construction contract for a new research vessel capable of wide-area seafloor surveys on September 27, 2013. The vessel will be used for scientific surveys of wide areas of seafloor around Japan. These surveys will include wide-area 3-D seismic survey, seafloor sampling using a seafloor drilling system, and detailed seafloor investigations using ROVs, AUVs and sonars fitted the vessel. Through these surveys the studies of the ocean floor earthquake's mechanism and seafloor resources will be promoted. The new vessel will be delivered the end of fiscal 2015 (Fig. 7).



Figure 7. Image of new research vessel for wide-area seafloor research

Operation of Research Vessels and Deep-Sea Survey Systems

JAMSTEC operates and manages the academic research vessels R/V *Hakuho Maru* and R/V *Tansei Maru* according to a plan developed by the Steering Committee for Joint Usage Research Vessel Operations (secretariat: Atmosphere and Ocean Research Institute of the University of Tokyo).

Other research vessels and deep-sea research facilities are operated and managed according to publicly solicited research proposals selected by the Ocean Research Promotion Committee (secretariat: JAMSTEC, which mostly consists of external members) and voyage plans developed by JAMSTEC.

The operation of these vessels and research facilities requires coordination not only with researchers who spend time aboard and/or who are part of the research programs, but also with fisheries related to the research and relevant Japanese and overseas authorities who must give permission for research activities within their exclusive economic zones. For this fiscal year, we have leased a wharf neighboring our own at JAMSTEC's Yokosuka Headquarters while construction goes on to deepen our wharf.

Notable activities by our research vessels in fiscal year 2013 are outlined below.

The results of research by R/V *Natsushima* and the ROV *Hyper-Dolphin* were published. In surveys around Pagan Island, one of the Mariana island chain, in July 2010, pillow lava was recovered from the seafloor. This proved to be the first ever sample of primary lava formed in the upper mantle in the subduction zone.

The R/V *Kaiyo* continued, from the previous fiscal year, preliminary research related to the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET-2) in the hypocenter region of the potential Nankai earthquake. The AUVs *Jinbei*, *Yumeiruka*, and *Otohome* also underwent testing to prepare them for actual deployment. In November, a test of Edokko No.1 was carried out; this is a shuttle vehicle with the ability to dive to 8,000 meters in depth and was manufactured by a Small and Medium-size Business alliance in Tokyo with the aim of developing a new market. The test took place off the Boso Peninsula at a depth of 7,800 meters and the craft successfully captured 3D video footage of the seafloor (Fig. 8).



Figure 8. Deployment of *Edokko No.1* and still from video

The mother ship *R/V Yokosuka* and manned submersible *Shinkai 6500* were in operation as a part of QUELLE 2013 in the Indian Ocean, the Atlantic Ocean off the coast of Brazil, the mid Cayman Rise in Caribbean Sea, waters around the Mariana Islands, and the Tonga Deep in southern Pacific Ocean. Far from the coast of Brazil, we discovered granite that originated on land. While at the mid Cayman Rise, we used the Internet to broadcast footage to the general public in real time from an operating manned submersible. More than 350,000 people followed the live stream (Fig. 9). We achieved this by linking *Shinkai 6500*, operating at about 5,000 meters below the surface, with the *R/V Yokosuka* mother ship using a fine optical fiber cable for two-way communications. During the live stream, the optical fiber failed, but it was still a great achievement to broadcast from such a great depth for a long period. It was only possible with expert manual control of *Shinkai 6500*'s movements.



Figure 9. Live broadcast from *Shinkai 6500*

The *R/V Kairei* deployed the *ROV Kaiko 7000II* in April to successfully recover a long-term temperature monitoring system that had been installed in a bore hole nine months previously. The 820 meter monitoring system was withdrawn from a bore hole originally drilled by the deep sea scientific drilling vessel *D/V Chikyu* at a depth of 6,897 meters in the Japan Trench. This is where the seafloor experienced the most radical topographical change during the Tohoku Region Pacific Coast Earthquake (Fig. 10). The recovery would not have been possible without expert handling on the part of the mother vessel and the *ROV*. Our research refutes the previously established hypothesis that seismic shifts do not occur at the upper levels of a plate boundary. Rather, we proved conclusively on the basis of geological materials collected by the *D/V Chikyu* and others that, in the Tohoku Region Pacific Coast Earthquake, the upper region of the plate boundary zone experienced seismic slippage near the

axis of the Japan Trench. These results were published in *Science* magazine in the US.

The *R/V Kairei* was also involved in earthquake research using a multichannel seismic (MCS) survey system off the Sanriku coast of Japan and in the East China Sea off the Ryukyu archipelago. Other research investigated the distribution of rare earth sediment, which contains high concentrations of rare earths, which was discovered around Minami-Torishima Island in 2012, as well as the promising manganese nodules on the seafloor. The total distance covered by the *R/V Kairei* for research in this fiscal year reached 3,516km.

During the year, field trials of the *ROV Kaiko Mk-IV* unmanned were also carried out.

Temperature monitoring system recovery

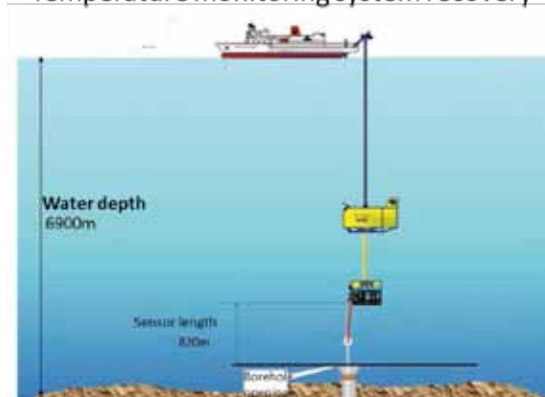


Figure 10. *Kaiko 7000II* recovering temperature monitoring system from bore hole

The oceanographic research vessel *R/V Mirai* continued the previous fiscal year's work in the Arctic Ocean. Activities included wide-area observations, ocean surface observations using moored buoys, as well as stationary point observations, which were implemented for the first time. The vessel was also deployed for research into the distribution of ocean floor hydrothermal deposits in the Okinawa Trough and rare earth sediment around Minami-Torishima Island.

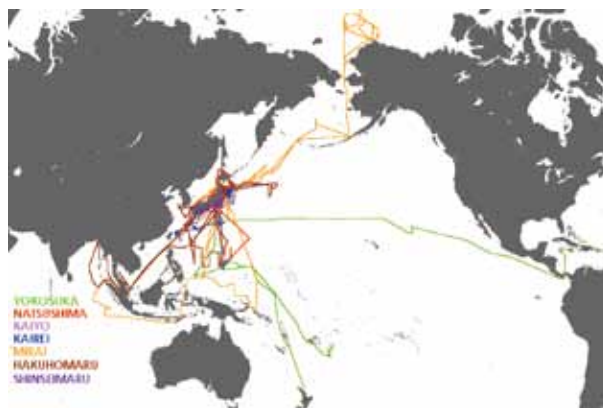


Figure 11. Voyages by our research vessels in fiscal year 2013

The *R/V Hakuho Maru* was in operation for 248 days during the year. The *R/V Shinsei Maru* for 161 days. The *R/V Natsushima*

for 268 days; the *R/V Kaiyo* for 246 days; the *R/V Yokosuka* for 279 days; the *R/V Kairei* for 244 days; and the *R/V Mirai* for 260 days (Fig. 11).

Looking at our observation devices, aside from the seismometers routinely used for refraction seismic surveying, we deployed ultra-deep seafloor seismometers for gathering data in extremely deep water at 11 locations, including one at a depth of 7,400 meters off the Sanriku coast in the Japan Trench. They were all recovered later.

A portable reflective multichannel seismic (MCS) survey system, which was introduced last fiscal year, was deployed on the *R/V Kairei* and the *R/V Kaiyo*. The system was used for research covering a total distance of 2,222km.

In order to elucidate the mechanism by which the climate change phenomenon causes wide-ranging abnormal weather in the equatorial region, we have set up a system of moored ocean observation buoys to monitor atmospheric and oceanic conditions. There are 12 TRITON buoys operating in the western Pacific Ocean and three small, lightweight m-TRITON buoys in the Indian Ocean. All data gathered via these buoys has been made public. In the western Pacific Ocean, we have temporarily shut down two of the buoys in preparation for imminent replacement by a new means of observation.

To maintain this buoy network into the future, it is important to expand international joint operations. To achieve this, we have been tackling the transfer of the m-TRITON buoy technology to Indonesia by the end of fiscal 2013; we have just handed over the second buoy.

Outreach and Publishing of Research Results

Our many research vessels and deep sea research systems yield many research findings, and these are made public through open days and research presentations. Not only the *R/V Shinsei Maru*, which has already been mentioned, but also other vessels held open days for the general public as follows: the *R/V Kaiyo* at the “open facilities day” at the JAMSTEC Yokosuka Headquarters in May; the *R/V Natsushima* at Ocean Festa Oga in Akita in July; and the *R/V Mirai* at the “open facilities day” at the Mutsu Institute for Oceanography. The *R/V Yokosuka* held special open days for royalty and various government officials while on the QUELLE 2013 round-the-world cruise: in Rio de Janeiro and Santos, Brazil, in May; in Nuku’alofa, Tonga, in October; and in Oakland, New Zealand in November.

In February 2014, we held Blue Earth 2014, a presentation of research results on a research vessel. We also held our 2nd Technology Presentation in September to introduce the activities of MARITEC to the general public.

Technical Training Sessions

MARITEC operated 13 training sessions for external technicians using JAMSTEC facilities and a total of 321 people participated. These sessions included diving skills training and workshops for diving administrators to hone their dive management skills. We also held ocean skills classes to give our newly hired personnel technical and skills training.

Earth Simulator Center (ESC)

Earth Simulator

The Earth Simulator was rated first place in the Top 500 Supercomputer Rankings for two-and-a-half years after the start of its operation in 2002, and it has significantly contributed to development in earth sciences technology and related fields.

In March 2009, the Earth Simulator was updated to the new system. Owing to its theoretical peak performance of 131 TFLOPS (1 TeraFLOP is one trillion floating operations per second) and highly effective performance, it has been used extensively in research and development centering on the field of marine earth sciences technology, including climate change and global warming, in which a wide variety of physical phenomena are intertwined with a high degree of complexity. Moreover it is also used for industrial use much.

The Earth Simulator exceeded the performance measurement result in the HPC Challenge Award 2012, as it recorded 11.88 TFLOPS in the benchmark Global FFT (total performance of fast Fourier transform) category and gained the third position in the world after Riken's K computer and the IBM Power 775 system. Although the theoretical peak performance of the K computer used for measurement is 81 times as fast as the Earth Simulator, the effective performance is only 17.3 times as fast using Global FFT as a measure of effectiveness.

Additionally, the Earth Simulator has 4.7 times as much effective efficiency as the K computer.



Figure 1. Earth simulator

Multiscale Simulation & Modeling Research Group

Complex interactions among the ecosystem—comprising the atmosphere, ocean, land, sea ice and the biosphere—and human activities remain unclear with regard to weather and climate on the Earth. Considering that these phenomena inherently involve multiple spatial and time scales, the Multiscale Simulation & Modeling Research Group has been working on the research and development of the Multi-Scale Simulator for the Geoenvironment (MSSG), which aims at seamless simulations of such multi-scale weather and climate phenomena. As seamless prediction simulations require large-scale and high-performance supercomputers, MSSG has been designed so that its performance

on the Earth Simulator, in particular, is maximized. The MSSG on the Earth Simulator has shown its promising capability of performing the largest-scale calculations of various phenomena.

In this fiscal year, to predict the future urban heat environment by using the MSSG and to make the best use of the results in adaptation plans, we have developed a new heat radiative transfer model for quantitative assessment of the effect of street trees on the urban heat environment. The preliminary calculation targeted a green tract of land in Tokyo around noon in summer. It successfully showed that taller trees result in larger radiative heat fluxes, which are determined by the balance between absorption at the crown and energy used for transpiration. This result signifies that tall trees suppress temperature rises more effectively than short vegetation such as bushes and lawns (Fig. 2).

The above result would be a good step for our future research. The advanced heat radiative simulation with MSSG can be applied to an assessment in urban heat environment for the future. We have already performed the MSSG simulations for the Tokyo urban area for the past and today and compared the results (Fig. 3). This kind of comparison would be useful for proposing optimal schemes for future cities.

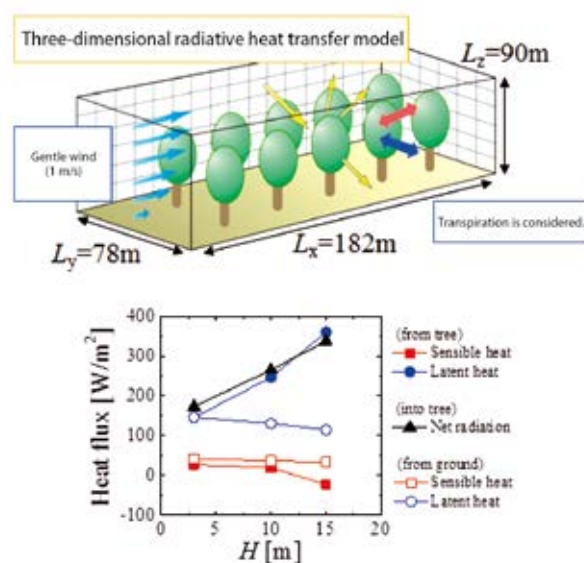


Figure 2. Overview of the model representing the characteristics of trees (top)

Heat fluxes calculated by the ultrahigh-resolution radiation simulation with a horizontal resolution of 1 m (bottom)

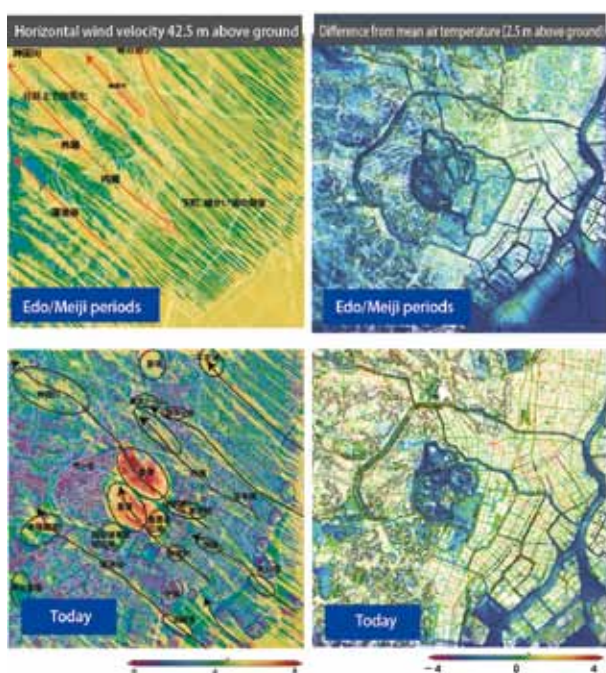


Figure 3. Summertime flow streams and temperature variation distribution obtained from MSSG with a horizontal resolution of 5 m. Flow on the left, and temperature distribution on the right. Top) Detailed land use and buildings today and during the Edo/Meiji periods are considered in the simulation, with the results of simulation of the summertime wind and air temperature distributions compared.

Advanced Visualization and Perception Research Group

Scientific visualization technology that expresses simulation data graphically is essential for instant understanding of the simulation results and more accurate data analysis. It is also indispensable for transmitting the results both inside and outside the institute. Aiming for rapid visualization of the enormous amount of simulation data from the Earth Simulator and efficient extraction of most useful information, we have been investigating various advanced visualization techniques, such as virtual reality (VR) visualization using the CAVE system known as BRAVE, visual data mining, and techniques for transmitting visualized results so that the results can contribute to society.

As a study on visualization using VR techniques, we are researching a user interface for selecting the necessary operations to be reapplied from the operation history of visualization software. Figure 4 illustrates the selection of a specific visualization operation from the operation history displayed on a smartphone by using a Web application that we developed. This will allow the user to select the visualization results of his or her interest, such as interesting three-dimensional structures, out of all visualization results drawn by interactive operations of a VR system, and will improve the efficiency of VR visualization.



Figure 4. Operation of the visualization software for a VR system on a smartphone

Next, visual data mining for assisting analysis of simulation results will be explained. We are investigating techniques for extracting the characteristics and causes of natural phenomena, such as oceanic currents and eddies, via the application of multivariate and cluster analyses, feature extraction from a variable space, information mapping onto a real space and mutual linking between variables and real space information. Figure 5 illustrates one example of the application of visual data mining to the results of an ocean general circulation model. The explicit extraction of current structures, such as those of the Japan Current, was achieved by extracting the seven-point sets of largest flow velocity from a scattergraph that consisted of two variables of temperature and velocity (the small square area in the lower right of Fig. 5) and color-coding and projecting the point sets onto a real space. This technique can also be used to investigate how characteristic structures, such as eddies, observed in the real space are distributed in a space that consists of two variables.

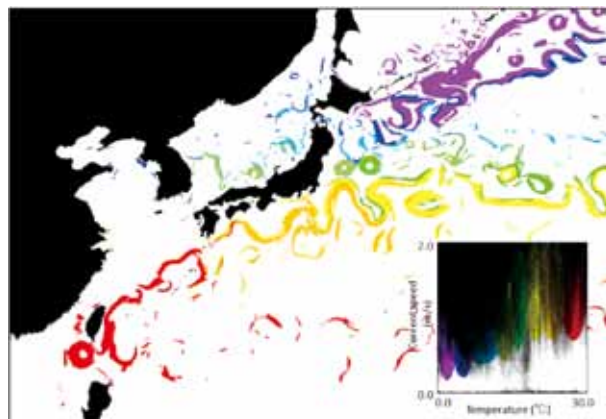


Figure 5. An example of applying visual data mining to an ocean general circulation model

We also promote EXTRAWING, a project involving novel representations of simulation results and effective transmission of those results to the general public. In this project, our original visualization technique that represents simulation results on Google Earth is deployed in the development of various methods for representing, presenting and transmitting information, such as in the development of visualization programs, information transmission via a Web application, analysis and comparison of data sets, and the development of a three-dimensional observation method using VR equipment such as BRAVE. Figure 6 illustrates a presentation method with which visualized results from several

different simulation models can be compared effectively, three-dimensionally, and under the same conditions. This is achieved by linking two or more Google Earth files and sharing spatial information (viewpoint position, scaling, mouse operation, etc.) among the files.



Figure 6. A presentation method of visualization results from several different simulation models

Geophysical Fluid Simulation Research Group (GFSG)

To further understand climate variations and their predictability, we are conducting simulation studies using ocean, atmosphere, and coupled atmosphere–ocean models. We will introduce an example using a high-resolution ocean model reproducing ocean circulation in a wide scale range from fine to large scales. The ocean model at a high resolution of $1/30$ degree (about 3km) of the North Pacific can demonstrate submesoscales (from several km to several tens of km), such as eddies and filament structures (Fig. 7). The submesoscale variations play an important role in vertical mixing in the upper layer ocean, and then have a great influence on tracer fields including biological materials. Our simulation shows that submesoscale activities in the Kuroshio Extension region vary seasonally: strong in winter and weak in summer (Fig. 8). In spring, the mixed layer becomes shallow rapidly, and vertical motions also weaken suddenly. In contrast, submesoscale activities gradually decay from spring to summer. Seasonal variations of activities in a scale larger than mesoscale are not apparent. These results in our simulation should be validated by future high-resolution satellite and in-situ observations.

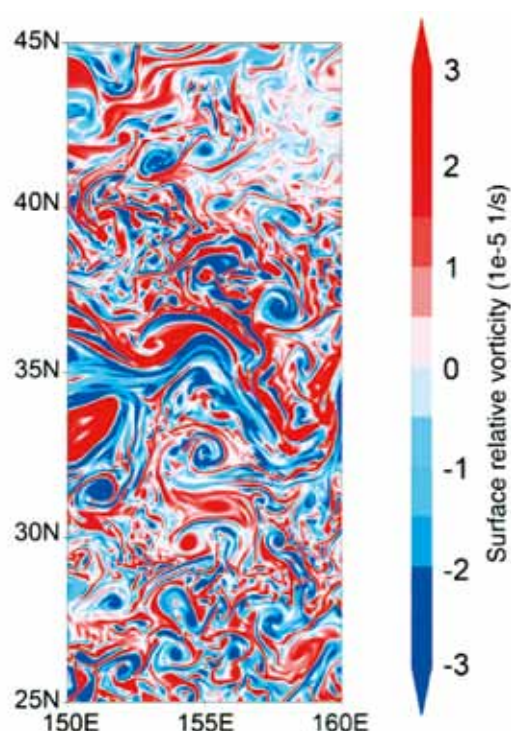


Figure 7. Surface relative vorticity (10^{-5} , $1/s$) in the Kuroshio Extension region of 150-160E and 25-45N on March 15, 2001.

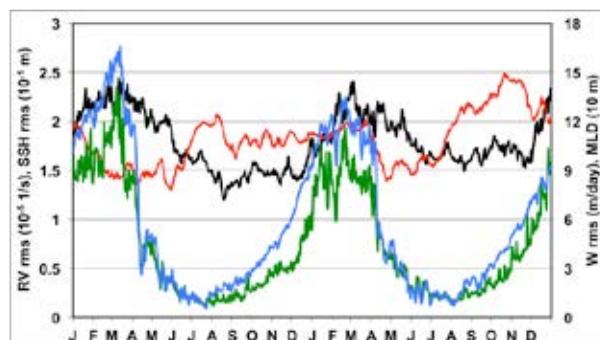


Figure 8. Time series of submesoscale activities from 2001 to 2002 in the box region (150-160E and 25-45N). (RV rms, black curve) Rms relative vorticity corresponding to submesoscale activities, (SSH rms, red curve) rms of sea surface height corresponding to large scale activities, (W rms, blue curve) rms of vertical motions, and (MLD, green curve) mixed layer depth.

Observing System Research and Ensemble Data Assimilation Development

We develop ensemble-based analysis systems of atmospheric, cryospheric, and greenhouse gas data and conduct observing system research in order to evaluate observations and to study predictability. This is a crosscutting team among the Earth Simulator Center and several programs of the Research Institute for Global Change, conducted in cooperation with researcher at Doshisha University.

Adding and removing observation to and from our own analysis system reveals the value and effect of the observation in terms of changes in the analysis and forecast which use the analysis as the initial condition. Such a study is called ‘observing system experiment.’

In early August 2012, a cyclone generated over north Siberia moved to the Arctic Ocean and then rapidly developed (Fig. 9). The surface central pressure of the cyclone reached 966 hPa, which is the low-pressure record for Arctic cyclones generated in summer since satellite observations began in 1979. Before the generation of this ‘great’ Arctic cyclone, the R/V *Polarstern* (meaning ‘pole star’), a German icebreaker from the Alfred Wegener Institute for Polar and Marine Research (AWI), conducted radiosonde observation over the Greenland and Norwegian Seas. Therefore, we investigated the effects of these radiosonde data taken by the R/V *Polarstern* on the predictability of the great Arctic cyclone, in cooperation with researchers at AWI.

Firstly we made an ensemble analysis without assimilating the observational data taken by the R/V *Polarstern* (OSE), besides the reference ensemble analysis assimilating all the available observational data (CTL). Then two sets of ensemble forecasts of the great Arctic cyclone were carried out using these ensemble analyses as their initial conditions from 00UTC on August 3, 2012, just before the rapid development of the cyclone. In the case forecasted from the CTL analysis (red lines in Fig. 10) the development and movement of the cyclone is reproduced fairly well, but is not in the case forecasted from the OSE analysis (blue lines in Fig. 10). These results suggest that the better reproduction of the large-scale atmospheric field in the ensemble analysis by assimilating the radiosonde data is essential to the better forecast of the great Arctic cyclone, because the R/V *Polarstern* did not directly observe the cyclone.



Figure 9. A satellite image of the ‘great’ Arctic cyclone of 2012 (from NASA).

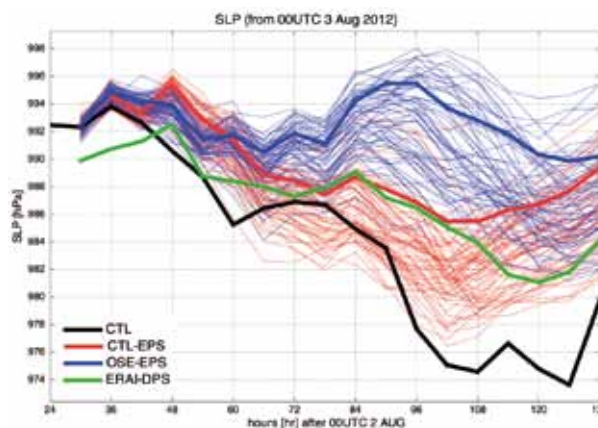


Figure 10. Time evolution of the minimum sea-level pressure [hPa] of the great Arctic cyclone in the ensemble forecasts from the CTL (red) and OSE (blue) analyses of 00UTC on August 3, 2012. The thick (thin) lines show the value in the ensemble mean (each ensemble member). The black (green) line shows the value in the ALERA2 analysis (the deterministic forecast from the ERA-Interim). After Yamazaki et al. (JGR-Atmospheres, 2015).

Simulation Technology Application Research Group (STAR)

To promote the use of the Earth Simulator in research, development, design, and manufacture in industries, we are implementing the Program for Strategic Industrial Use of the Earth Simulator with the support of the Open Advanced Research Facilities Initiative of the Ministry of Education, Culture, Sports, Science and Technology. In fiscal 2013, we selected ten research projects and provided them with technical supports; eight of these projects were in the category “Technical development for reducing environmental loads,” and two were in the category of “Technical development for realizing a safe and secure society.”

As an example, we will briefly describe a research project entitled “Development of heat-resistant β -fructofuranosidase” by the Carbohydrate Research Laboratory of ENSUIKO Sugar Refining Co., Ltd. (see excerpts from the use report of the Earth Simulator Industrial Use Symposium 2013).

β -fructofuranosidase from *Anthrobacter* sp. K-1 catalyzes the synthesis of functional oligolactose, which is a special health food that stimulates mineral absorption. Today the sugar is industrially manufactured by batch production from lactose and sucrose using the enzyme.

In order to cope with recent demands to reduce carbon dioxide emissions and wastes and improve energy utilization efficiency, the sugar production process should be streamlined into continuous production using a bioreactor system in which a heat-resistant enzyme is fixed.

The research team has succeeded in sharply increasing the heat resistance of the enzyme by inducing random mutations and acquiring 24Y447P, which has 5 amino acid substitutions in the wild-type peptide. Because the heat resistance needs to be further improved for industrial production, a study was carried out that involved unveiling the heat resisting mechanisms of the acquired mutants, predicting new amino acid substitutions that would increase the heat resistance, and verifying the resistance by actually preparing the mutants.

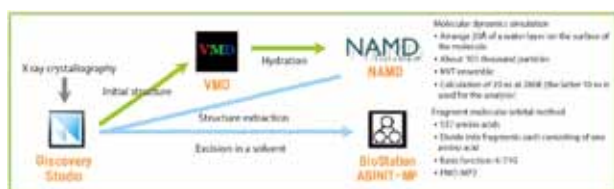


Figure 11. Simulation method

As shown in Fig. 11, we repeated series of simulation and mutant construction by using 24Y447P as the base, and obtained mutant 29-3, which has improved heat resistance (Fig. 12). Mutant 29-3 has two amino acids substituted at D260P and K247D from the peptide sequence of 24Y447P, and the substitution at K247D especially improved heat resistance conspicuously, increasing the life at 62°C by 1.5 fold. The ability to synthesize oligosaccharide (LS) was slightly higher than that of the wild-type (Fig. 13).



Figure 12. Structure of mutant 29-3

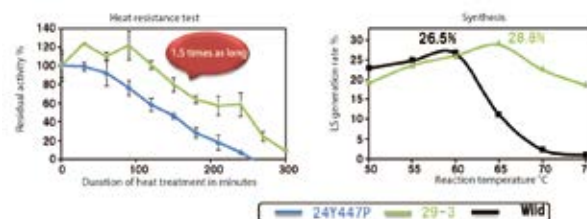


Figure 13. Experimental results

The successful development of the heat-resistant mutant 29-3 of β -fructofuranosidase, which is an enzyme to be used for the synthesis of functional oligosaccharide, was a result of simulation designing. At first, we estimated that chances for improving 24Y447P, which was a highly heat-resistant mutant created from the wild-type by random mutation, were low, but our success in further improving the heat resistance in such a short time shows that simulation designing of heat-resistant enzymes is effective.

Fee-based Earth Simulator utilization program

As a rule, the use of the Earth Simulator requires the publication of user information and a summary of research projects. We, however, offer a program for fee-based use of the Earth Simulator under which the user retains the exclusive ownership of the simulation results. Under the program, our professional staff provides technical assistance such as programming and tuning as required by the user. A first-time user may carry out a trial (initial evaluation) free of charge to gain confidence.

During fiscal 2013, we participated in Japan's largest specialty fair for manufacturers, the Design Engineering & Manufacturing Solutions Expo (held inside Manufacturing World 2013 Japan; Total attendance: 76,701 [sponsor announcement]).

We presented exhibits introducing this fee-based simulator use program and examples of use by several businesses, and received inquiries from several businesses.

Development of Advanced Prediction Researches for Natural Disaster Prevention and Reduction

Japan has been attacked almost every year by typhoons, local heavy rainfall, earthquakes, tsunamis, etc., and has suffered severe damage. In particular, on March 11, 2011, Japan was attacked by a huge earthquake whose epicenter was located off the Pacific coast of the Tohoku region, and a subsequent huge tsunami. Around the Tohoku Area, the number of victims amounted to almost 20,000, and the loss of property was devastating and catastrophic. Such large-scale natural disasters have huge impacts on society and economic activities, and therefore, prompt and efficient measures are required immediately to reduce and prevent such disasters. Because field experiments cannot be made, in order to evaluate the influence of natural hazards which cause these large-scale natural disasters, and verify measures for disaster prevention and reduction, such measures should be examined by large scale simulations using supercomputers. We have actually carried out large-scale simulations by using “Earth Simulator.” Also, since fiscal year of 2011, we have embarked on “Strategic Programs for Innovative Research; Advanced Prediction Research for Natural Disaster Prevention and Reduction (Field 3)” (led by the chief officer, Shiro Imawaki, Director General, Data Research Center for Marine-Earth Sciences, JAMSTEC). Under this program, we have been implementing highly-accurate, large-scale simulations concerning these natural hazards jointly with a number of universities and laboratories across Japan by linking the “K Computer” and “Earth Simulator” with the aim of predicting the intensity and number of typhoons, hurricanes and cyclones globally under global warming conditions, demonstrating the feasibility of numerical prediction of local heavy rainfall, providing a basis for next-generation earthquake hazard maps, improving the accuracy of tsunami warnings, and reducing damage due to natural hazards through natural disaster simulation for entire urban areas.

In order to advance these studies, we established a JAMSTEC Kobe Satellite by leasing a laboratory on the premises of the RIKEN Advanced Institute for Computational Science (Kobe), where the “K Computer” is located, and another laboratory in the building of the Foundation for Computational Sciences. In that process, we will pursue the most efficient synergistic effect of using two supercomputers, the “K Computer” and “Earth Simulator” and try to educate young scientists who would be the next generation. Also, in fiscal year of 2011, we joined the HPCI (High Performance Computing Infrastructure) Consortium, which is engaged in improving the computational system for the purpose of rationalizing computer resources nationwide, and presents the collective views of the computational science community. We will make every effort to disseminate collective views as a representative of the user community involved in the efficient future utilization of computer resources and computational geoscience

Data Research Center for Marine-Earth Sciences (DrC)

Overview

The Data Research Center for Marine-Earth Sciences (DrC) manages and releases observational data and sample information obtained by the research activities of JAMSTEC. In addition, functions of the DrC also involve conducting the development and operation of information systems necessary to enable our objectives, and integrating various data to create new value-added products in response to the needs of education, research, and society.

The Data Management and Engineering Department (DMED) of DrC at the Yokohama Institute for Earth Science receives and stores these data and sample information, as well as controlling the data quality. In 2013, DrC renewed the "Deep Sea Floor Rock Sample Database (GANSEKI)," and it provides two types of information services, the "BISMaL-Mapper" as a visualization and analysis support system for researchers by using data in the "Biological Information System for Marine Life (BISMaL)," and the "GODAC Data Site -NUUNKUI-" as a portal site for data and sample information systems in DrC. In addition, DrC develops a real-time seismic waveform viewing system using data from the "Dense Oceanfloor Network system for Earthquakes and Tsunamis (DONET)," and provides products of reanalysis obtained by the atmosphere-ocean coupled data assimilation method and the velocity field obtained by prediction of seasonal/annual variability for simulation of the drifting debris originating from the Great East Japan Earthquake and tsunami in the Pacific Ocean. In addition, DrC participates in the "Tohoku Ecosystem-associated, Marine Sciences (TEAMS)," manages and releases these observational data and research information, and develops various information systems for Science communities and Society of Tohoku region.

The Global Oceanographic Data Center (GODAC) in Nago City, Okinawa, which is the DrC's central base for the dissemination of information, carries out activities aimed at making observational data and deep sea images of the DrC available to the general public, and also produces awareness-raising events in this region. In addition, GODAC develops a system of cooperation with educational institutions and museums in the northern Okinawa region. Moreover, GODAC has begun to open the science educational events and to develop educational contents for marine science and technology, in collaboration with them.

1. Management and Dissemination of Marine-Earth Observation Data and Samples

a) Data Search Services

DrC provides two types of data search services, the "JAMSTEC Data Search Portal" and the "JAMSTEC Data Catalog." Users are able to search for observation data by selecting their area of interest on a map with the "Data Search Portal" and are also able to search for datasets or databases by selecting keywords in the classification tree with the "Data

Catalog." In 2013, it became possible to download data files from the "Data Catalog" and researchers are able to publicize data sets without developing their own data site.

At present, the "Data Search Portal" contains approximately 44,000 entries of data or samples, and the "Data Catalog" contains 40 database entries. DrC has provided metadata in "Data Catalog" for the "Global Change Master Directory" operated by NASA and updated them this year.

DrC also renewed the "Earth Environment Portal" in GODAC and opened it as an infrastructure system for data dissemination in DrC featuring the single sign-on function.

b) Dissemination of the data and sample information from Research Cruises

The database "Data Research System for Whole Cruise Information in JAMSTEC (DARWIN)" contains about 5,500 data entries from 944 research cruises or 2,376 dives. In 2013 new functions for the data visualization and extraction have been developed.

Document data such as cruise reports that can be shown in DARWIN is managed by the "Document Catalog." At present "Document Catalog" opens about 2,586 documents, which are comprised of scientific papers or reports (for example, such as research results from JAMSTEC), as well as documents relating to public relations.

DrC disseminated information and analysis data of sediment core sample through "Core Data Site," but it was operated as a group of html files. The new database has been developed since 2012 and opened as "Core Electronic Database of Ocean Floor (COEDO)" (Fig. 1). With COEDO's development all the data dissemination sites in DrC were transferred to the database. COEDO opens 846 core information items, 2,260 analysis data, and 6,455 sections of samples.



Figure 1. Top page of Core sample database "COEDO" and data page
URL: <http://www.godac.jamstec.go.jp/coedo/e/>

DrC has also opened the new version of the "Deep Sea Floor Rock Sample Database (GANSEKI)" and it was designed

to extend the dissemination of data types, to improve its user interface, and to cooperate with the database providing cruise information. Using the new GANSEKI, users can search for samples by area on a map and other metadata simultaneously, and by the range of chemical analysis data.

GANSEKI continues to provide its metadata for the international geochemical data portal “EarthChem,” which has been collaborating with GANSEKI since 2009. DrC provided rock samples for research, education, and the purpose of improving public relations. The number of registered metadata has now increased to 23,314, the number of samples to 11,912 and the number of geochemical analysis data to 18,403. In 2013 DrC made presentations in JpGU, AGU and other scientific meetings to announce the new features of GANSEKI and to promote the re-use of samples in our archive.

Biological sample curators visited researchers in institutes other than JAMSTEC and extracted the issues on cooperation with researchers and curators. DrC continuously arranged the information on type specimen in JAMSTEC and will open it in the next year. DrC has opened information of over 30,000 biological samples including samples collected by the “Marine Biodiversity Research Program” in the Institute of Biogeosciences, JAMSTEC, since the 1980’s through the “Marine Biological Sample Database.” Most of the data is shared with the Biological Information System for Marine Life (BISMaL, see below) and contributes to the Ocean Biogeographic Information System (OBIS), the international biogeographical database.

These sample databases use cruise/dive information and observation information as common metadata, which is managed in the integrated metadata management system. In 2013 DrC expanded the relation between sample databases and the metadata management system to unify the metadata between those databases and to make their management efficient.

c) Dissemination of images

By 2012 DrC finished digitizing the video tapes of main cameras or negatives of still cameras of all the dives by the JAMSTEC’s deep sea submersibles stored in the DrC archive. In 2013 DrC continued to digitize the remaining video tapes of sub-cameras.

Responding to the fact that recording media of all of the video cameras of JAMSTEC’s submersibles changed to hard disk drives, DrC has standardized the procedures to archive video files in LTO5, which is the current-generation data archive tape. DrC stored the digitized video images and disseminated resized video files in GODAC, bringing the total volume of data in the archive to 177 TB. DrC also continued to reconstruct the work flow of image file processing and to develop efficient management systems.

By using the “JAMSTEC E-Library of Deep sea Images (J-EDI),” DrC opened videos and images from about 2,000 deep sea dives in 2013. The annotation to main video cameras of deep sea dives has been completed this year.

The new features of J-EDI, which enables logged in users to download images or make their own libraries, were made

available. Many images were provided for the “Deep Sea” exhibition held in the “National Museum of Nature and Science.” A special gallery for “Deep Sea” exhibition, gathering the images provided for the exhibition, as well as a gallery for popular images or frequently searched keywords, was opened. (Fig. 2).

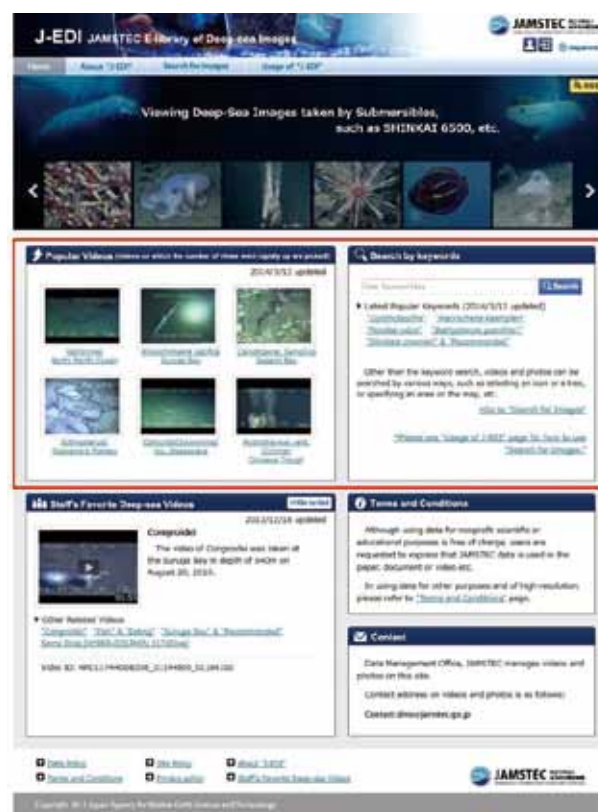


Figure 2. Gallery for popular videos and frequently searched keywords
URL: <http://www.godac.jamstec.go.jp/j-edi/e/>

d) Dissemination of information on biodiversity

The Biological Information System for Marine Life (BISMaL), an integrated database for biodiversity and the distribution of marine life, disseminates biological information from JAMSTEC and works as the base system for the Japan regional OBIS node (J-RON). The OBIS (Ocean Biogeographic Information System) is an international database containing information on the biodiversity and biogeography of marine life. DrC developed, and now operates the BISMaL under collaboration with the Institute of Biogeosciences, JAMSTEC.

In 2013, DrC registered 2,000 taxon names, bringing the total number of such names to about 19,000. The number of publicly opened occurrence data of marine organisms, including the plankton dataset (about 290,000 records) of Japan Oceanographic Data Center imported through J-RON, was extended to about 340,000 records.

DrC improved the BISMaL system and also opened the “Visualization and Analysis Support System for Marine Life Distribution,” which enables users to analyze and visualize data from BISMaL on a map (Fig. 3).

J-RON is expected to attend the “International Oceanographic Data and Information Exchange (IODE)” as an “IODE Associated Data Unit (ADU)” and JAMSTEC are making arrangements among related administrations or institutes. Some new datasets from domestic organizations are reported to J-RON.



Figure 3. Sample image of BISMAL Mapper for Marine Species Distribution

URL: <http://www.godac.jamstec.go.jp/mapper/e/>

e) Analysis of access to the data dissemination sites

DrC analyzed the access to the data dissemination sites continuously. This year's feature was that access to the J-EDI and the BISMAL surged during the summer vacation due to the influence of the “Deep Sea” exhibition.

DrC analyzed and divided access of research/education users from others, and classified the access sources of research/education into six categories; “higher education,” “research/development organizations,” “government,” “museums,” “local governments,” and “primary/middle education.” The access from these six sources is considered to be relatively high among research or education purposes.

Of the access to image databases, 90 percent was access from others (via internet service providers or private companies), and the access from “primary/middle education” in the six categories above was the highest among the remaining 10 percent. On the other hand, half of the access to the observation databases was from research/education users and access from “research/development organizations” and “higher education” was high.

These results will be utilized to enhance the contents of databases and to design improved user interfaces in order to fit the target users of the relevant site.

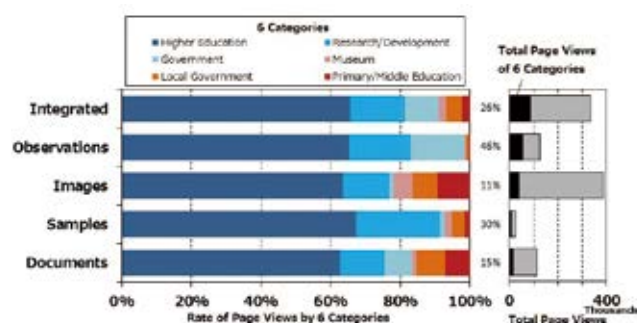


Figure 4. Six categories of research/education users and their ratios in terms of page views.

2. Providing new data to meet the needs of society

1) Data Integration and value-added products

We developed an atmosphere-ocean-ecosystem coupled four-dimensional variational data assimilation system, capable of performing dynamic analyses. This system is used for the improvement of predictions on a seasonal to inter-annual time scale, and an optimal design of observation system. The downscaling system is also developed for delivering detailed ocean circulation fields.

a. Prediction of seasonal to inter-annual variation

It is considered that 4D-VAR data assimilation products, in which high frequency components are removed, are effective to predict seasonal to inter-annual variation as initial conditions. In this fiscal year, we developed the 4D-VAR system to couple with the marine ecosystem model in collaboration with the Strategic Ocean Monitoring Research Team, RIGC. Using this system, we conducted the forecast experiment of biogeochemical fields such as nutrients and phytoplankton for seasonal to inter-annual time scale.

Figure 5 shows the results of the 3-year prediction of phytoplankton from January 2011 using the assimilation result for October–December 2010. The prediction results represented well not only for spring bloom but for autumn bloom, and inter-annual variations are realistic. The inter-annual variations of spring bloom are associated with those of winter mixed-layer depth, and it is suggested that the strength of the spring bloom is controlled by the entrainment of nutrients from the subsurface layer.

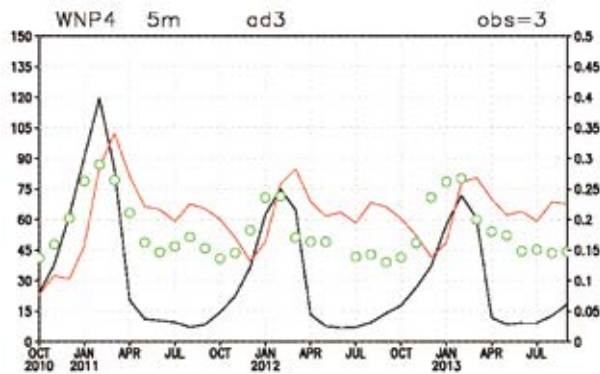


Figure 5. Prediction result for Phytoplankton (redline: right axis) in the subtropical region of the northwestern Pacific (130-170E, 20-20N) and satellite observation data (green dots: right axis). Mixed layer depth is also shown (black line: left axis)

“Estimated State of Global Ocean for Climate Research (ESTOC)” is developed for visualizing and providing the long-term ocean integrated data set.

This dataset is derived from the 4D-VAR data assimilation system to reproduce 50-year ocean variability, in collaboration with Strategic Ocean Monitoring Research Team, RIGC. In this website, users can produce various images, such as horizontal maps, vertical profiles, and time series for ocean state variables, and can download the whole dataset.



Figure 6. Screen shot of ESTOC

URL: <http://www.godac.jamstec.go.jp/ESTOC>

b. Application for fisheries study

As part of a project commissioned by MEXT in fiscal 2010, we have been developing a system by which to locate fishing grounds and predict variability in the stock of neon flying squid, with cooperation from various universities, research institutions, and the Hachinohe Fishery Cooperative.

This year, we are continuing to develop a system for estimating potential fishing areas using a Habitat Suitability Index model with the products of eddy-resolving data assimilation and a prediction system for medium range variability in the stock of fishery resources. In addition, we have improved the distribution system of the environmental information and developed an

interactive system to receive reports on catches from the fishing vessels.

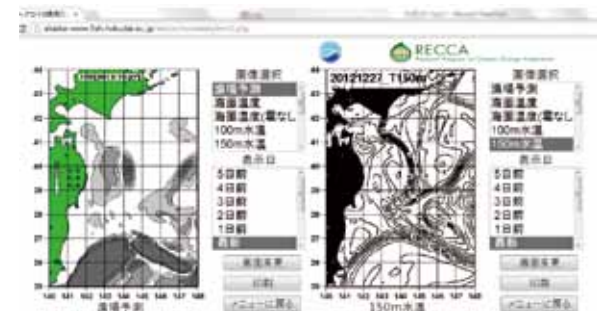


Figure 7. Website for providing fishery information. Potential fishing area (left), temperature at 150m depth (right)

Using the interactive system, we can analyze the real-time information to develop the estimation model and distribution system.

Another application for fisheries, high-resolution data assimilation products are used for the estimation of potential fishing areas of Japanese Flying Squid in Tsugaru strait, and modeling the growth of Japanese scallops in Funka bay in collaboration with Hokkaido University.

c. Transport simulation of marine materials

In cooperation with the relevant agencies and institutions, we continued to carry out a study to estimate and predict the distribution of vast amounts of driftage which were washed away by the tsunami following Tohoku Region Pacific Coast Earthquake. With respect to the prediction of the marine driftage, JAMSTEC and other research institutions are carrying out a study commissioned by the Ministry of the Environment. We are tracing the driftage using the product of a reanalysis obtained by the atmosphere-ocean coupled data assimilation system and the velocity field obtained by a prediction of seasonal/annual changes. This year, the ensemble simulations are carried out to evaluate the uncertainty of the prediction.

The simulation studies of the distribution of radioactive substances are also carried out with Japan Atomic Energy Agency.

d. Data Integration and Analysis System (DIAS)

Commissioned by MEXT in 2006, and in collaboration with various stakeholders, we have been carrying out a project for development of the Data Integration and Analysis System (DIAS). This system will be used to integrate diverse observation data and their assimilation and prediction products with socioeconomic data so as to create new scientific knowledge and public benefits, such as adaptation to climate change, resource management, and disaster prevention.

The second phase of the “Global Environmental Information Integration Program” began in 2011, led by University of Tokyo, in conjunction with JAXA, National Institute of Environmental

Studies. We have been developing a prototype of the system by which to provide products of the atmosphere–ocean coupled assimilation system to various users. At the same time, we have started discussions on how to operate the system, which is expected to be in practical operation in fiscal 2016.

2) Development of an earthquake research information database

The installation of all 20 observation stations of the ocean bottom earthquake and tsunami observation network was completed during fiscal 2011. The Yokohama Institute of JAMSTEC now receives the data collected by these observation points in real time, and stores them as a database using an international standard format, called SEED. The Institute for Research on Earth Evolution (IFREE) is accumulating crustal structure data collected through observations of the sea area off the coast of the Kii Peninsula and the island of Shikoku by ocean-bottom seismographs and multi-channel seismological surveys. In order to continue detailed monitoring of the sea area in which a massive earthquake is predicted to occur, and to study the mechanisms which generate massive earthquakes, we established a dedicated team in December 2011 for the purpose of developing an earthquake research information database through the integration of discrete databases. We have developed a data viewing system for real-time strong-motion seismograph and pressure-gage data through the Internet due to the ability of the ocean bottom pressure gage to detect the arrival of tsunami waves generated by 2011 Tohoku earthquake much earlier than the tsunami hit the coast. We have already started to open this real-time viewing system to the local governments close to the ocean bottom observation network as a trial, so that they may use these data for prompt evacuation in times of tsunami hazard.

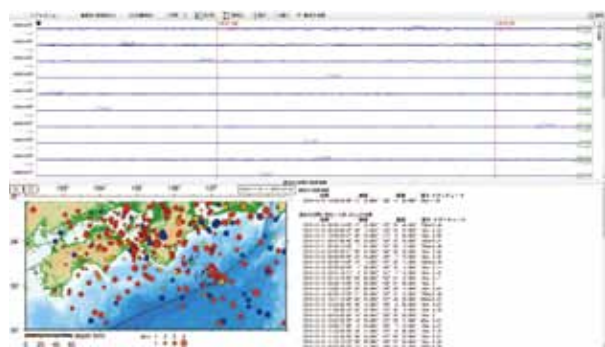


Figure 8. Prototype of real-time seismograph viewing system

3) Contribution to the Tohoku Ecosystem-Associated Marine Sciences Project

The Tohoku Ecosystem-Associated Marine Sciences (TEAMS) is a research project with the aim of restoring marine ecosystems and fisheries damaged off the Pacific coast by the 2011 Great East Japan Earthquake and Tsunami. Led by JAMSTEC, Tohoku University, and the Atmosphere and Ocean Research Institute (AORI) of the University of Tokyo, TEAMS has been bringing together researchers from the field of marine science to investigate areas around the Tohoku coastal region and the off-Sanriku region, since 2011. In this research program, DrC carries out activities with the aim of managing research data obtained from various observations, and of releasing these data and related information.

In the 2013 fiscal year, we have begun to accumulate and manage observational data and those metadata obtained by this project, according to TEAMS data policy.

The investigation plans and reports were collected under the data policy, and have been publicized via the TEAMS official site (URL: <http://www.i-teams.jp>), in August 2013. In addition, we opened the TEAMS official website in English, in February 2014.

We developed the Data catalog system disseminating data sets from TEAMS investigations. Using this system, we opened a data service site, named "Research Information and data Access Site of TEAMS (RIAS)" in March 2013 (Fig. 9). Furthermore, we have been engaged in systems development to share a variety of information among TEAMS colleagues. In addition, we began to develop the platform for the reporting system for observations on organisms obtained from the investigation in TEAMS.



3. Activities to Promote Marine Science to the Public

1) GODAC's Promotion Efforts

The Global Oceanographic Data Center (GODAC, located in Nago City, Okinawa) works to improve public understanding of JAMSTEC's work through various activities and events. Through its efforts, GODAC aims to enhance knowledge of marine science and technology as well as improving public accessibility to the work of JAMSTEC. GODAC makes facilities and equipment such as lecture rooms and video systems available to the general public, with activities that in fiscal 2013 included the following: four GODAC Seminars to introduce JAMSTEC's latest research (for a total of 48 seminars to date); four sessions of a Marine Classroom for children aimed at furthering the understanding of ocean science (for a total of 24 sessions to date); and a GODAC open house (on November 23, 2013, attracting 1,218 visitors) (Figures 10 and 11).

At the end of December 2013, the total number of visitors to GODAC since it opened its doors had reached 147,722.

2) Encouraging More Collaboration with Local Organizations

GODAC is enthusiastically involved with local organizations. We take in students for on-the-job training and internships. And we participate in various local events, such as the Nago City Environmental Fair and the Nago Summer Festival, for which we provide exhibits and assistance.

In fiscal year 2013, we inaugurated the "All Yanbaru Manabinomachi (learning town) Project" based on collaboration with local organizations (such as education/research institutes) that began in the previous fiscal year. (Yanbaru refers to the northern Okinawa area.) Our various activities as part of this project contribute to the local community and assist the development of human resources. One important role is participation in Nago City's Education Day Symposium.

This year, our collaborations have been with the Nago City administration, Okinawa National College of Technology, University of the Ryukyus, Meio University, Nago Museum, and Okinawa Churashima Foundation. We are working to develop the project further with creation of an information network connecting these organizations, aiming to improve utilization of marine technology and help develop human resources.



Figure 10. Scene from a GODAC Seminar



Figure 11. GODAC open house event

Center for Deep Earth Exploration (CDEX)

Outline

The Center for Deep Earth Exploration (CDEX) efficiently and safely operates the deep sea drilling vessel *CHIKYU* (Fig. 1) under an international framework, as the comprehensive promotion institution of the International Ocean Discovery Program (IODP) that assumes the operation of *CHIKYU*, the main scientific drilling vessel of the IODP. The Integrated Ocean Drilling Program started in 2003 and was completed in September 2013. It was changed to the new International Ocean Discovery Program (IODP) in October 2013.

The IODP is an international program for scientific ocean drilling led by Japan and the United States for the objective of elucidating global environmental changes, the solid earth cycles and geodynamics, and the deep biosphere. For the new program, 26 countries including Japan, the United States, and Europe reached an agreement to continue ocean drilling research based on internationally-discussed science programs. Furthermore, along with the change of the program, the operation of the program is no longer under the management by the Central Management Office, which was maintained with expenses shared among countries, and the IODP instead introduced a system in which each promotion institution in Japan, the United States, and Europe operates its vessels in cooperation.

The objectives of the CDEX are to comprehensively manage the sailing, drilling, science services, and technology development conducted by *CHIKYU*, and achieve the scientific objectives of the IODP by efficiently and safely operating *CHIKYU*.



Figure 1. Deep Sea Drilling Vessel *CHIKYU*

Nankai Trough Seismogenic Zone Experiment

The aim of this project is to drill the plate boundary fault and the megasplay fault that are recognized as the sources of great earthquakes and tsunamis in the Nankai Trough region, and to collect geological samples, as well as measure physical properties (logging) and observe crustal movements (monitoring) at drill holes, for the purpose of elucidating the generating mechanism of earthquakes and tsunamis. During IODP Expedition 348 conducted in 2012, riser drilling was performed in order to drill from directly under the casing pipe (C0002 borehole, seabed depth of approximately 860 meters, underwater depth of 1,939

meters) installed in the drill hole drilled by IODP Expedition 326 in 2010 to deeper parts (Fig. 2). During IODP Expedition 338 in 2012, drilling was conducted at the same location, but due to the damage to machinery and tools incurred by sudden change of hydrographic condition, the operations were suspended at a seabed depth of approximately 2,000 meters to protect the drill hole.

In FY2013, logging while drilling and collecting geological samples to a seabed depth of 3,058.5 meters through riser drilling was performed in the drill hole (C0002 borehole) where the IODP Expedition suspended operations in the previous fiscal year. A casing pipe for protecting the drill hole wall was also installed. (Fig. 3) The drilling operation was a process for the ultra-deep drilling to be performed 1,939 meters below sea level to the seismogenic zone assumed to exist at 5,000 meters below seabed.



Figure 2. Preparations for Riser Drilling

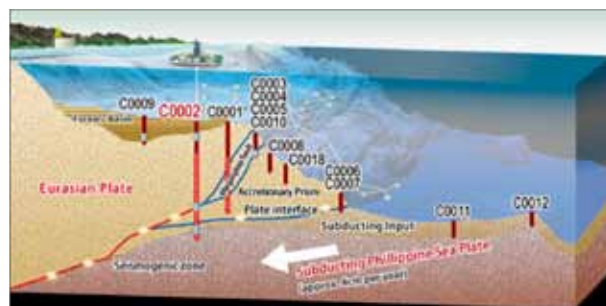


Figure 3. Schematic Diagram of the geological structure of the Nankai Trough Seismogenic Zone Site

Retrieval of the Long-term Borehole Temperature Observatory Sensors Installed in the Hypocentral Area of the Tohoku Region Pacific Coast Earthquake

On the night of April 26, 2013, the unmanned research submersible *KAIKO 7000II* retrieved the long-term borehole thermometer installed in the waters in the vicinity of the Japan Trench axis, approximately 220 kilometers off the Oshika Peninsula, Miyagi Prefecture (at latitude 37°56'N and longitude 143°55'E), during IODP Expedition 343 Japan Trench Fast

Drilling Project (JFAST) II using the deep sea drilling vessel *CHIKYU* implemented in July 2012. (Fig. 4)



Figure 4. Retrieval of observational equipment using *KAIKO 7000II*

The overall length of the long-term borehole temperature sensor is approximately 820 meters. It consists of 55 high precision thermometers that were mainly placed in the plate boundary fault and its vicinity. (Fig. 5)

When data was collected from the retrieved long-term borehole temperature sensor, it was found that the thermometer recorded temperature changes for a period of nine months at the plate boundary fault and strata in the area where a large slip occurred.



Figure 5. Retrieved observational equipment placed on deck

Elucidation of the Generating Mechanism of Great Earthquakes/Tsunamis that Occurred During the Tohoku Region Pacific Coast Earthquake

Based on data such as geological samples, data measured in boreholes, and data collected with the long-term borehole temperature sensor by the Japan Trench Fast Drilling Project, it scientifically proved that at the time of the Tohoku Region Pacific Coast Earthquake, seismic slips occurred at the shallow plate boundary fault in the vicinity of the Japan Trench axis, which

led to an extremely important conclusion that caused scientists to fundamentally reconsider the common belief that “seismic slips do not occur at shallow plate boundary faults.”

In 2013, an American scientific journal, *Science*, published four papers on the results of research. Other papers will be published in scientific journals in the future.

The main paper can be summarized with the following four points.

- (1) Despite the previous belief that energy generated by large earthquakes does not accumulate in faults near a trench axis and that, as such, seismic slips would not occur there, the strata of the tip of the hypocentral area of the Tohoku Region Pacific Coast Earthquake (in the vicinity of the Japan Trench axis) proved that energy does accumulate in such faults and seismic slips may occur there.
- (2) The thickness of the plate boundary fault that caused the Great East Japan Earthquake was less than 5 meters, which is extremely thinner than the fault zone perceived in the past (Fig. 6).



Figure 6. Plate boundary fault that was collected

- (3) Through laboratory experiments conducted on geological samples of faults, it was proved that the likelihood of a slip occurring is increased due to the facts that fault materials consist of weak clay and that frictional heating during earthquakes causes the dilation of fluids in cracks of fault materials. The previously unknown mechanism of fault slips during earthquakes was elucidated.
- (4) From the actual results obtained from a number of thermometers to measure temperatures installed in the seafloor drill holes, a temperature anomaly of 0.31 degrees (Celsius) higher than the surrounding temperature in the plate boundary fault, a phenomenon that confirmed abovementioned (3), was found. This led us to verify that the coefficient of the fault during the earthquake was extremely low (Fig. 7).

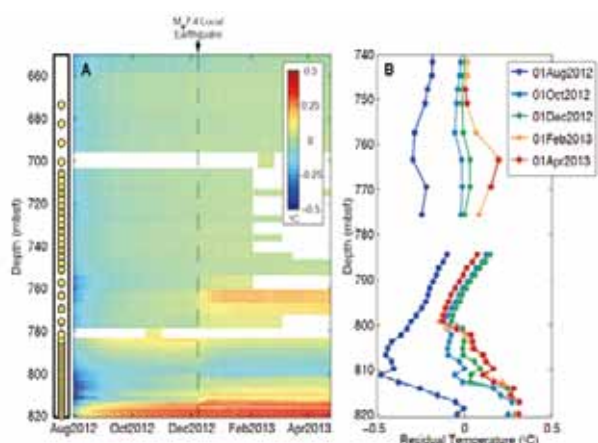


Figure 7. A. Chronological data of temperature measurements at depths beyond 650 meters, showing the average values of daily measured temperature excluding effects of the geothermal gradient. B. This graph shows the temperature distribution in the depth direction for each 2 month period. (Source: Fulton et al., 2013)

The fact that during earthquakes, seismic slips occur and devastating tsunamis are caused in areas in the vicinity of a trench axis, which was inconceivable in the past, was confirmed through scientific verifications by the results of the researches.

These results indicate that research studies on the earthquake/tsunami from a new perspective are promising and furthermore, that modeling and numerical simulation are required not only for the Tohoku Region but also the Nankai Trough, the Ryukyu Arc, the Izu-Ogasawara Arc, and the eastern margin of the Japan Sea. For tsunamis, it is necessary to review the methods used to estimate the magnitude of great earthquakes/tsunamis in order to envision the largest scale tsunami that may be generated based on scientific grounds, by taking account of the propagation of destruction of strata/faults to the area near the trench axis.

The knowledge and information acquired from these results also indicate that the great earthquakes/tsunamis in the Pacific Rim cannot be fully explained by a single mechanism and that further research studies are necessary in order to understand the distinguishing features in each ocean area.

We intend to further pursue detailed analysis of the core samples, data on fault materials, logging data, etc., and using the new knowledge acquired, scientifically contribute to disaster prevention and reduction throughout the whole world.

The CHIKYU+10 International Workshop

At the start of the IODP, and as a new program, the CHIKYU+10 International Workshop was held in Tokyo from April 21–23, 2013. It was sponsored by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and mainly organized by the Center for Deep Earth Exploration (CDEX), for the purpose of discussing the important scientific topics that should be challenged by the deep sea drilling vessel *CHIKYU* in the future. A total of 397 people (261 from Japan and 136 from abroad) from 21 countries participated. The Workshop brought

together international expertise that led to lively discussions (Fig. 8).

The main scientific topics were “Active Faults,” “Earth’s Mantle,” “Deep Life,” “Continent Formation,” and “Sediment Secrets.” Researchers brought along information on the potential investigation points that are most suitable for conducting research on these topics and technical experts of *CHIKYU* provided information on the equipment and technology necessary for achieving the issues introduced by the researchers, resulting in sharing of their information.

The fact that such a large scale international conference was held indicates that scientific drilling researchers in the world are greatly interested in *CHIKYU*.



Figure 8. Participants of the CHIKYU+10 International Workshop

Holding of the CHIKYU IODP Board (CIB) Meeting

At the start of the IODP, and as a new program, the *CHIKYU* IODP Board (CIB) was established as the President’s external advisory committee for operating the deep sea drilling vessel *CHIKYU*. The 1st meeting was held from July 23–25, 2013, organized by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and run by the Center for Deep Earth Exploration (CDEX).

At the CIB Meeting, discussions on supporting (i) the long-term plan for scientific expeditions by *CHIKYU*, (ii) plans for data management, core curation, publication, outreach activities, capacity building, etc. under the framework of the IODP, and (iii) holding of workshops for writing proposals and the necessity of setting up special teams for executing the plans, were held.

For the issues identified by the CIB, coordination with various related parties will be made and the results of the coordination will be reflected in the plans. Furthermore, the CIB Meetings will be held at regular intervals. Through the meetings, the related institutions in Japan and the relevant countries will maintain a cooperative relationship directed at achieving the same goal.

Education and Outreach Activities

For the purpose of providing the public with a broad understanding of the scientific drilling and research conducted by the deep sea drilling vessel *CHIKYU*, CDEX creates information contents that convey its research activities, including the video website, “*CHIKYU* TV,” and PR magazine, “*CHIKYU* Hakken,” and provides them via the Internet. CDEX also proactively cooperates by accepting interviews from the media such as television and by providing film and video to magazines and other media.

For education, CDEX introduces the site of advanced research based on a fundamental understanding of earth/life science at schools, science museums, etc. throughout Japan, and conducts field excursions, practical works and lectures. (Fig. 9)



Figure 9. IODP outreach program, “Sand for Students”

Furthermore, CDEX sets up exhibition booths at academic conferences held in Japan and abroad to introduce *CHIKYU* and disseminate its research results.

In FY2013, we conducted workshops in various places, including the disaster areas to report our research results, to coincide with the public announcement of the results of IODP Expedition 343, the Japan Trench Fast Drilling Project (JFAST) implemented in 2012.

In addition, for the purpose of broadly disseminating the Deep Sea Scientific Drilling Project that *CHIKYU* will work on for the next 10 years under the new IODP Science Plan to the people and give them an opportunity to think about the Plan, CDEX held a special talk titled “Declaration of Adventure! Heading inside the Earth and to Space with *HAYABUSA* and *CHIKYU*” in Tokyo on April 14, 2013 (Fig. 10). The event was webcasted live.

CDEX is planning to hold a symposium to summarize the results of the Integrated Ocean Drilling Program that was implemented for 10 years from 2003 to 2013 and completed in 2013.



Figure 10. Special Talk Event, “Declaration of Adventure! Heading inside the Earth and to Space with *HAYABUSA* and *CHIKYU*”

Project Team for analyses of Changes in East Japan Marine Ecosystems (Tohoku Ecosystem-Associated Marine Sciences (TEAMS) Project)

Overview

Tohoku Ecosystem-Associated Marine Sciences (TEAMS) is a joint marine ecosystem exploration and research project that is guided by Ministry of Education, Culture, Sports, Science and Technology (MEXT). It was launched in January 2012 (fiscal year 2011) to contribute to the restoration of fisheries and other marine industries affected by the Great East Japan Earthquake of March 11, 2011.

The project aims to gain a firm understanding of the impact of this giant magnitude 9.0 earthquake and subsequent massive tsunami on the marine ecosystem and to elucidate the mechanism of change as well as to provide support for the science-based restoration of fisheries. The main participants, JAMSTEC, Tohoku University, and the University of Tokyo, are working closely together and cooperating on activities such as exploration and research. The project will continue for a period of 10 years.

The work of TEAMS is divided into four units of activity with a total of 16 research themes. Units 1 to 3 promote exploration and research, while unit 4 develops methods for disseminating research data with the aim of restoring local marine industries in the disaster-stricken region. JAMSTEC is particularly involved in unit 3, mostly carrying out offshore surveys and research using various resources such as research vessels and a new small ROV named Crambon. In unit 4, we are working to elucidate current underwater activity and what will happen in the future using our technological expertise and the knowledge we have accumulated. All TEAMS results will be made public.

Details of some of our work with TEAMS and its outcomes are given below.

Unit 3: Understanding the Offshore Seafloor Ecosystem

Theme 1: Mapping of Debris in Fisheries and Elucidation of Decomposition Process

Using our ROVs *Crambon* and *Hyper-Dolphin*, we have been doing underwater research to elucidate how tsunami and earthquake debris are distributed over offshore fisheries and what impact it has had on the ocean ecosystem. Our findings are that, in seafloor valleys at a depth of 400 to 500 meters, there is still a significant amount of scattered debris. High concentrations of various species were observed around the waste material; that is, the debris has become something of a gathering-place for fish (Fig. 1). An analysis of data from offshore fisheries cleaning operations using dragnets, as provided by Miyagi Prefecture, has shown that there is less debris further from the shore, with the distribution pattern differing according to the type of debris. The amount of debris collected has fallen to about half of that just after the earthquake.



Figure 1. Various debris in a seafloor valley off Kamaishi at a depth of about 550 meters. A number of marine species are using the debris.

Theme 2: Clarifying the Distribution and Behavior of Resource Species and Analysis of Population Structures

We are developing a bio-tracking system to acquire a clear understanding of the distribution and behavior of resource species. An experiment to test the functionality of the new system was carried out in October 2013 off Toni, at a depth of 430 meters. We collected 10 snow crabs from the area and fitted their shells with small acoustic pingers before releasing them back into the ocean. Using three acoustic base stations capable of picking up pinger signals, we succeeded in obtaining tracking data (Fig. 2). In fiscal 2014 and beyond, we plan to expand the functionality of this system and aim to track about 30 individuals.

We have also studied the genetic diversity of the walleye pollack (*Theragra chalcogramma*) population spawned since the earthquake. This fish is an important marine resource. No change in diversity has been detected, so we suspect that the walleye pollack population of the area was not affected by the earthquake.

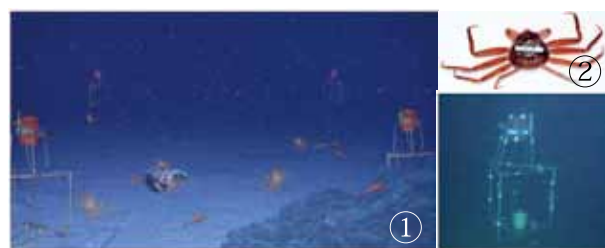


Figure 2.

1. Bio Tracking System
2. Snow crab fitted with small pinger
3. Acoustic base station listening for pinger signals

Theme 3: Long-term Monitoring of Environment for Marine Resource Organisms (Fisheries)

Between August 2012 and October 2013, we monitored a lander system that had been installed on the seafloor at a depth of 998 meters off Otsuchi, Iwate prefecture. The lander measured various physical and chemical characteristics, such as current speed and direction, water temperature, salt content, turbidity and the concentration of dissolved oxygen, on an hourly basis. Photos and high-resolution video of the seafloor were also obtained (Figures 3-1, 3-2), with one still photo captured each day and three minutes of video each week. From this data, we determined that current strength and direction change frequently, while water temperature, salinity and dissolved oxygen concentrations vary little.

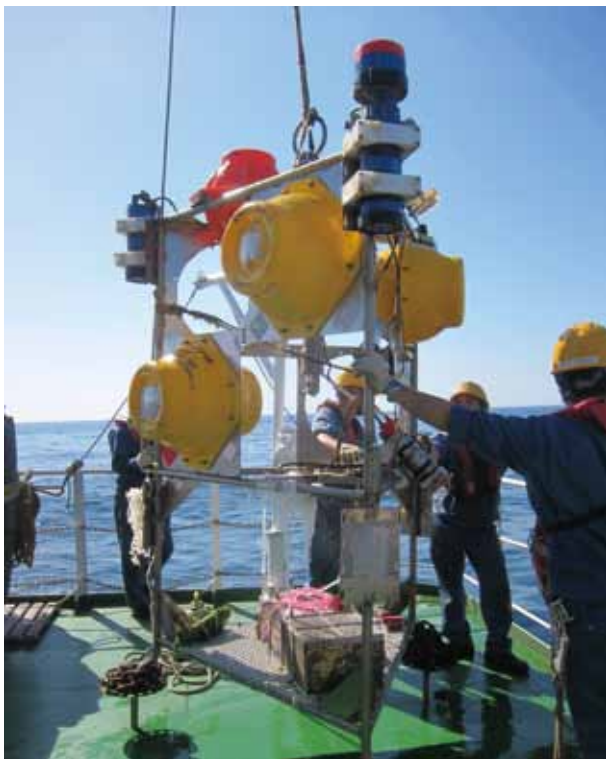


Figure 3-1. Lander system recovered after 14 months of long-term observations



Figure 3-2. Still picture obtained by the lander system, showing brittle stars (Ophiurida) and a scorpionfish (*Scorpaenopsis macrochir*)

Theme 4: Trophic Level and Chemical Accumulation

We are monitoring the composition and concentration of PCBs (polychlorinated biphenyls) in the bodies of various ocean fish. The PCB concentration in all the fish we have analyzed so far, of 32 different species, has been far less than the standard set by the Ministry of Environment, and concentrations are at the same general level as before the earthquake and tsunami. We also tested the nitrogen isotope ratio in the amino acids of these fish, from which we can estimate their trophic level (or position in the food chain). Thus we determined the PCB concentration and accumulation rate as well as the trophic level of each species. Among the 32 species collected off Tohoku, the lucifer shark (*Etmopterus lucifer*) was found to have the highest trophic level, with a score of 4.6 (Fig. 4).

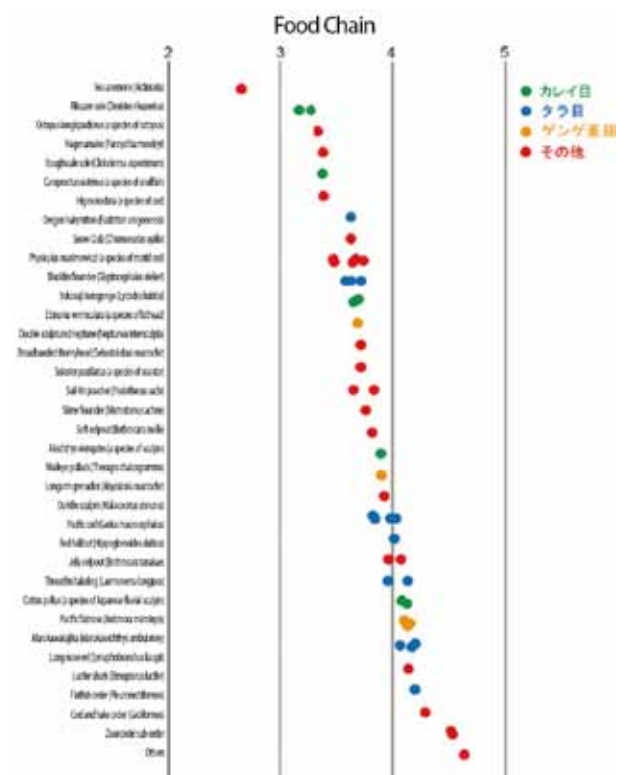


Figure 4. Trophic level of tested fish based on nitrogen isotope ratio in amino acids

Theme 5: Ecosystem Habitat Mapping

We aim to create a habitat map of organisms with which to study the impact of the earthquake and tsunami on the ocean ecosystem. Based on the ocean-floor topography and information on the distribution of species and debris obtained during research voyages, together with existing research data, we are beginning to analyze the changes that resulted from the earthquake. Research so far shows that, on the badly damaged southern Sanriku coast, a number of organisms living in the sand and some eelgrass (*Zostera marina*) varieties were hard hit by the tsunami; it also appears that different approaches to sea area management have resulted in different progress with their recovery (Fig. 5). We are continuing to collect more data and conduct further analysis, especially to evaluate the deeper ocean floor.

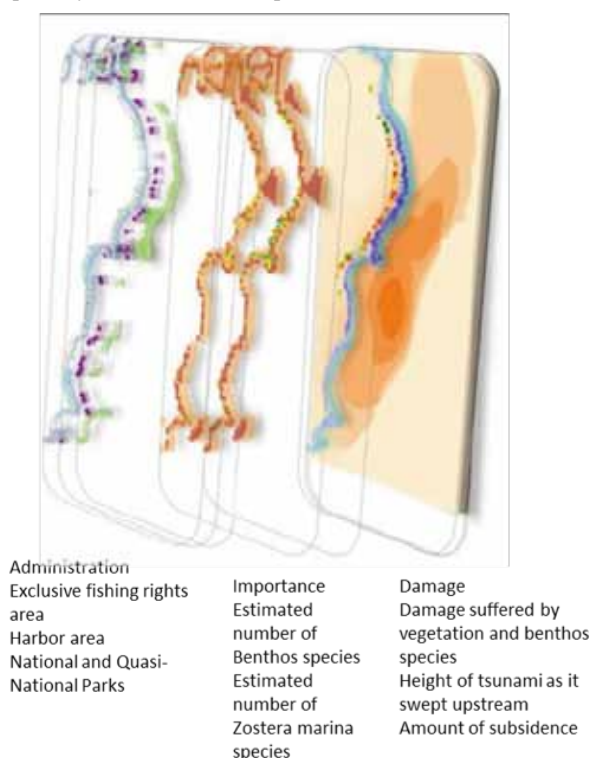


Figure 5. Example of habitat mapping

Unit 4: Improvement and Operation of Data Management and Publication Functions

The purposes of this project are to work cooperatively with researchers who might find TEAMS data useful, to meet certain needs of the earthquake-affected area, and to disseminate information that assists in the recovery of marine industries affected by the earthquake. With these purposes in mind, we are developing methods of sharing our data and ensuring the immediate release of information. Our ultimate aim is to develop a Tohoku coast and ocean database that brings together data from different research institutions.

The main mode of dissemination for information gathered through TEAMS research activities is the project website. In 2013, we implemented a new policy for the systematic management and dissemination of information. This includes information about the observation plans and reports, the data and related information collected, and the results of the research. In developing this policy, we held a number of meetings with other participating research institutions to discuss how to handle collected data for optimum dissemination.

Survey plans, research reports, and other information were initially made accessible to the public in August 2013 on the TEAMS official website (<http://i-teams.jp/>), with new information is being added all the time. Further, we developed the data catalog system disseminating data sets from TEAMS investigations. Using this system, we opened a data service site, named "Research Information and data Access Site of TEAMS (RIAS)" in March 2013 (Fig. 6).

Research and other initiatives that JAMSTEC undertakes in relation to this project are also made public on our own website (<http://www.jamstec.go.jp/team/>). Here, we publish research plans, event information, results of surveys and research, and information on marine organisms and the environment. We encourage you to visit our site.

JAMSTEC's third mid-term plan, which begins in fiscal year 2014, nominates the Eastern Japan Marine Ecosystem Dynamics Project Team as responsible for promoting TEAMS marine ecosystem research program. One aim for future research is to elucidate the specific marine ecosystem that results from an active plate subduction zone, where marine ecosystems fluctuate dynamically.

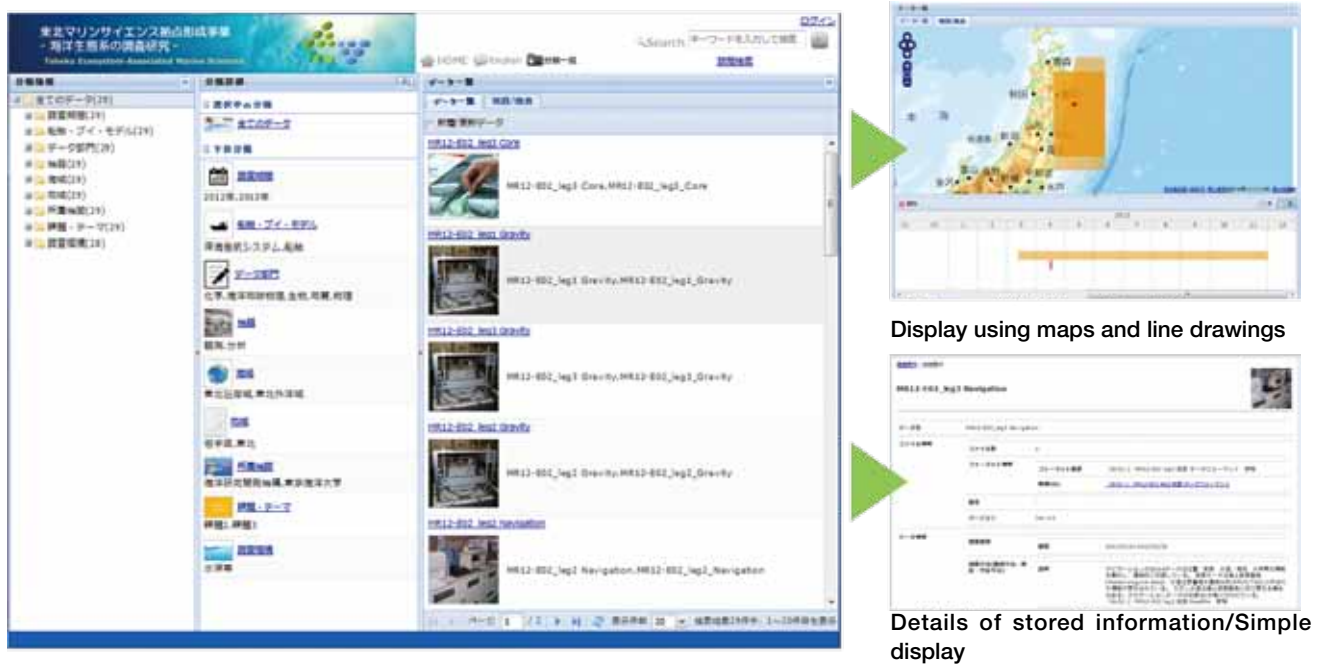


Figure 6. TEAMS data site "Research Information and data Access Site of TEAMS (RIAS)" (URL: <http://www.i-teams.jp/rias/e/>)

3. 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.

This year, 2011, marked the 40th anniversary of the foundation of the supporting member system. Aiming at an open and international Center of Excellence for marine research and development, we aim to continue progressing together with members of the system (referred to as "JAMSTEC Partners") through the furthering of research goals and the commercialization of research results.

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. (Donations to the supporting member system are subject to 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 and intellectual properties
- Technical support through the dispatch of technical advisors and lecturers to in-house training for members

These benefits can always be used if you join JAMSTEC Partners.

For inquiries about the system, please contact us:

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A seminar for JAMSTEC Partners



The science café [MARE Café]



Facility Tour for JAMSTEC Partners



CHIKYU tour



Trial cruise and excursion on KAIREI



SHINSEI MARU special tour for JAMSTEC Partners





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