

JAMSTEC

2012 Annual Report



Japan Agency for Marine-Earth Science and Technology

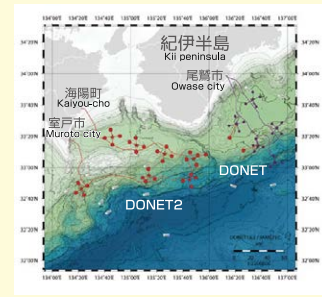
JAMSTEC

2012 Annual Report

Fiscal Year 2012 Overview of the Japan Agency for Marine-Earth Science and Technology



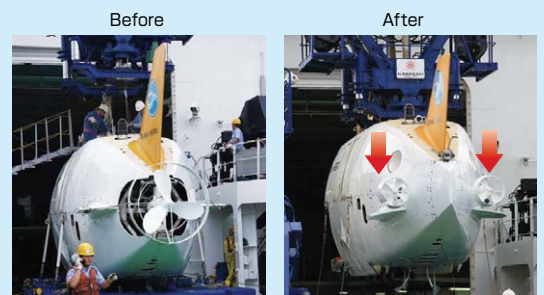
The Presidency was assumed by Asahiko Taira.



The Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) has been advanced in view of Nankai earthquakes.



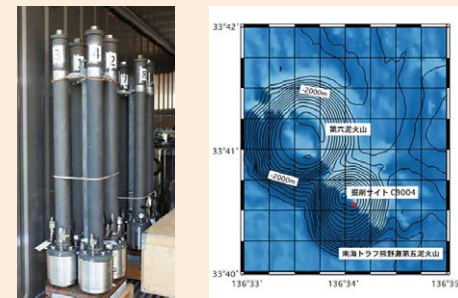
JAMSTEC succeeded in the creation of artificial hydrothermal vents and the collection of minerals.



The deep submergence vehicle SHINKAI 6500 was upgraded.



The deep submergence vehicle SHINKAI 2000 was transported for a long-term exhibition in Enoshima Aquarium.



JAMSTEC succeeded in the development of the "hybrid-pressure coring system" for the deep sea drilling vessel CHIKYU. Pressurized core samples were collected from submarine mud volcanoes located in Kumano-nada of the Nankai Trough.



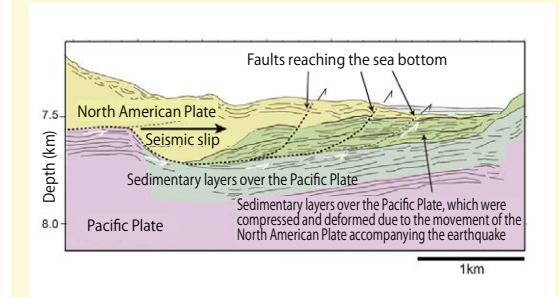
The 10th anniversary of the foundation of the Yokohama Institute for Earth Sciences. The 10th anniversary of the development of the Earth Simulator.



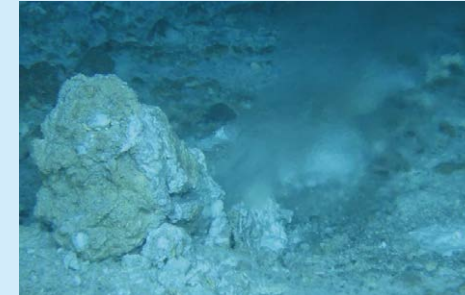
JAMSTEC participated in the Tohoku Ecosystem-Associated Marine Science Project. The website specializing in the study and survey of the marine ecosystem in Tohoku waters was launched.



Novel useful yeast was discovered from amphipods, *Hironellea gigas*, living in the Mariana Trench - the deepest spot in the ocean.



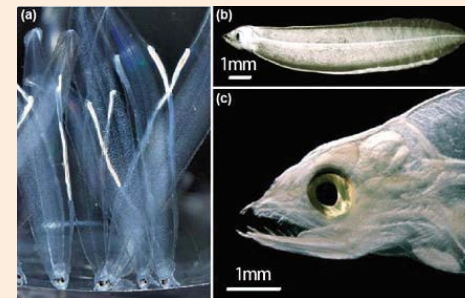
Faults of the 2011 Great East Japan Earthquake which extended to the trench axis were identified on the sea floor off the Pacific coast of Tohoku.



The Omurodashi located southeast of Izu-Oshima was recognized as an active submarine volcano.



JAMSTEC succeeded in collecting core samples from the world-record depth of scientific drilling off the coast of Hachinohe, Aomori Prefecture.



JAMSTEC and The University of Tokyo succeeded in revealing the feeding habits of eel larvae.



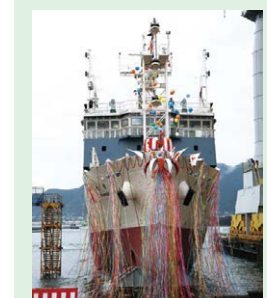
SHINKAI 6500 embarked on the voyage around the world called QUELLE 2013.



JAMSTEC started long-term observation of the Antarctic bottom water by using deep-sea profiling floats for the first time in the world.



TANSEI MARU retired.



SHINSEI MARU was launched.

Preface

In this fiscal year, JAMSTEC will complete the fourth year of the second mid-term plan, and is getting ready for embarking on the final phase of the plan.

During the fiscal year, we obtained findings concerning the mechanism whereby mountainous clouds progress eastward. This influences global climate change, and we conducted our observations as part of international projects. In the field of biological science, we successfully discovered highly reactive novel yeast from super abyssal gammaridea discovered in the deepest spot of the Mariana Trench. In the field of technological development, we developed 3 new unmanned autonomous probe vehicles with an aim to ensure that surveys of ocean resources and ocean environments are carried out efficiently and accurately.

With regard to the Tohoku Region Pacific Coast Earthquake, which occurred in March 2011, we as a research institute significantly contributed to the unraveling of scientific mysteries by conducting surveys on crustal structures through the use of the “KAIREI,” making submersible explorations in the focal region through the use of the “SHINKAI 6500,” etc. Moreover, during this fiscal year, we implemented the “Japan Trench Fast Drilling Project (JFAST)” by “CHIKYU” with the aim of collecting geological samples from the plate border fault which is assumed to have caused the massive earthquake and tsunami waves, and measure the long-term borehole temperature.

In February, the new “SHINSEI MARU” was launched while the “TANSEI MARU” was retired after 31 years of service. With her home port at Otsuchi-cho, Iwate Prefecture, the “SHINSEI MARU” will principally engage in surveying the marine ecosystem off the Coast of Tohoku, Japan. We strongly hope that the findings of our survey efforts will contribute to the restoration of Tohoku.

JAMSTEC is getting ready to start drawing up a specific plan for the next mid-term plan phase starting from fiscal 2014. By studying the trend in social conditions in Japan and progress in research and development in the field of ocean, earth and life for the past 5 years, we set up the objectives which we should achieve in 15 years, considered how to achieve them, and eventually established our “long-term vision.”

Against this backdrop, we held the first meeting of the JAMSTEC Advisory Board (JAB) this March by inviting the representatives of domestic and overseas ocean research institutions as well as experts in order to obtain advice and recommendations from international perspectives with regard to the direction we should take and the roles we should play.

One of our most important issues we have to tackle during

this fiscal year is to draw up a constructive road map toward achieving our objectives based on the advice we were given in the meeting. For this purpose, we are planning to restructure our organization. By breaking down the work and projects into patterns according to their characteristics, we are going to build the optimum governance for each pattern. As for the research organization, we are planning to revise its present system which is somewhat inflexible and segmentalized as well as our mission implementation system which is rather unfocused.

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 tackling fundamental ocean research and technological development, and elucidating the global system centered on the ocean.

Fiscal Year 2012 is the fourth year of the second mid-term objective period which started in April 2009, and we made further efforts in the development of our projects with a view to achieving the mid-term objectives. In response to the recent increasing trend toward revising the conventional policies after the Great East Japan Earthquake and returning research results to society, we clearly specified what we should head for by drawing up JAMSTEC Vision—An Integrated Understanding of the Ocean, Earth, and Life as a 15-year plan. Moreover, we organized, for the first time, an Advisory Board which comprises the representative of domestic and overseas ocean research institutions as well as experts, and received advice and suggestions from an international perspective with regard to our projects.

Research and study in connection with the Tohoku Region Pacific Earthquake was started immediately after the event, and in FY 2012, we successfully identified the earthquake fault by meticulously analyzing data on the subsurface structure of the focal region, and collected geological samples from the plate border fault by using the deep sea drilling vessel *CHIKYU*.

Regarding the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) was successfully connected to a long-term borehole observation device installed in a borehole made by *CHIKYU*. This enabled data under the seabed is obtained on a real-time basis for the first time in the world. Also, for the project to drill the Deep Coalbed Biosphere off-Shimokita, we successfully collected core samples, obtained physical property data, and achieved the deepest oceanographic drilling in the world.

Near the deep seabed, unknown creatures are living. A novel enzyme, which is expected to lead to the use of natural biomass such as wood, was discovered from the amphipod (*Hirondellea gigas*) living in the Mariana Trench, the deepest spot in the ocean. Also, a voyage around the world called *Quelle 2013* by the Manned research submersible *SHINKAI 6500* was started in January 2013 to reveal the ecological system of the extreme environment. For FY 2013, a number of research activities are planned in the Atlantic Ocean, Caribbean Sea and South Pacific Ocean, and their achievements are anticipated.

Recently, it was found that a huge amount of mineral resources are stored in the seabed of the 6th-largest territorial sea in the world and exclusive economic zone of Japan. We launched the Submarine Resources Research Project in 2011 to promote research and development activities, and in FY 2012,

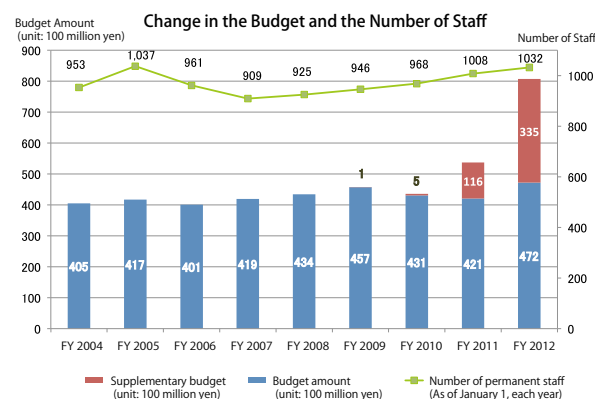
we revealed that deep sea mud including highly-concentrated rare-earth minerals was present in the seabed around Minami-Tori-shima or Marcus Island.

To achieve these scientific results, we are operating eight research vessels. In January 2013, the Research vessel *Tansei-maru* was retired. In return, the *SHINSEI MARU* was launched in February 2013. After the handover in FY 2013, she is expected to embark on research activities focusing on off the Coast of Tohoku, Japan.

(2) Change in the Budget and Number of Staff

The graph below shows the change in JAMSTEC's budget and staffing since it became an independent administrative agency. The FY 2012 budget was still very tight because of the occurrence of the Great East Japan Earthquake. However, a supplementary budget was allocated to restoration expenses for the Japan Trench Fast Drilling Project (JFAST). Also, along with the change of the governing party in November 2012, a hefty supplementary budget was compiled, and the budgets for the construction of a wide-area seabed research vessel, etc. were allocated.

The number of staff has tended to increase in recent years because of increases in competitive funds, which increased the number of staff under a system of restricted terms of office. However, continuous efforts have been made to maintain an appropriate level of wages and control the manpower cost by taking measures such as those similar to the special measures concerning remuneration for national public officers (effective for two years from April 1, 2012).



(3) Offices and Institutes

As of March 31, 2012, we have the following offices and institutes. In August 2012, the Yokohama Institute commemorated its 10th anniversary.

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 City, Tokyo
Global Oceanographic Data Center	Nago City, Okinawa Prefecture

(4) Organization Chart

■ President ■ Executive Director ■ Auditor



President
ASAHIKO TAIRA



Executive Director
YOSHIIISA SHIRAYAMA



Executive Director
HITOSHI HOTTA

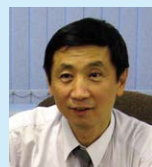
[Research Sector]

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



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

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)
MITSUHIRO TORIUMI

Institute of Biogeosciences (BioGeos)

- Marine Biodiversity Research Program
- Extremobiosphere Research Program
- Earth and Life History Research Program



Research Director, Institute of
Biogeosciences (BioGeos)
HIROSHI KITAZATO

Submarine Resources Research Project



Project Leader, Submarine Resources
Research Project
EIICHI KIKAWA

[Development and Promotion Sector]

Marine Technology and
Engineering Center (MARITEC)

- Planning and Coordination Group
- 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)
KUNIHICO WATANABE

Data Research Center for
Marine-Earth Sciences (DrC)

- Data Management and
Engineering Department (DMED)
- Global Oceanographic Data
Center (GODAC)



Director-General, Data Research Center
for Marine-Earth Sciences (DrC)
SHIRO IMAWAKI



Executive Director
HISASHI DOBASHI



Auditor
YASUSHI TAYA



Auditor
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 TAKAI



Unit Leader, Space and Earth System
Modeling Laboratory Unit
KANYA KUSANO

Application Laboratory

- Integrated and Intellectual Information Science and Technology Program
- Society-Oriented Prediction Engineering Science Program
- Deep Sea Engineering Science Program



Head of Application Laboratory
TOSHIO YAMAGATA

Mutsu Institute for
Oceanography (MIO)

- North Pacific Time-series
Research Group
- Research Promotion Group
- General Affairs Division, MIO



Director, Mutsu Institute for
Oceanography (MIO)
SHUICHI WATANABE

Kochi Institute for
Core Sample Research (KOCHI)

- Physical Property Research Group
- Geochemical Research Group
- Geomicrobiology Group
- Science Services Group
- General Affairs Division, KOCHI



Director, Kochi Institute for Core Sample
Research (KOCHI)
MASATAKA KINOSHITA

Research Support Department

- Research Support Division I
- Research Support Division II

[Management Sector]

Planning Department

- Planning Division
- Strategic Planning Office
- Press Office

Administration Department

- Administration Division
- Human Resources Division
- Employee Relations Division
- Facility Management Division
- Employee Support Division
- YES General Affairs Division
- Tokyo Office
- Legal Affairs Office

Finance and Contracts
Department

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

Safety and Environment
Management Office

Audit Office

(5) Research Facilities

Vessels

CHIKYU

Deep-sea drilling vessel
 Length: 210 m
 Beam: 38 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

MIRAI

Research vessel
 Length: 128.5 m
 Gross tonnage: 8,687 tons
 Complement: 80 persons
 Commissioned: 1997

KAIREI

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

YOKOSUKA

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

HAKUHO MARU

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

KAIYO

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

NATSUSHIMA

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

TANSEI MARU

Research vessel
 Length: 51.0 m
 Gross tonnage: 610 tons
 Complement: 38 persons
 Commissioned: 1982

(※ The retired in January 2013)

Submersibles and ROVs

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 autonomous underwater vehicle
 Depth capability: 3,500 m
 Cruising distance: 300 km
 Length: 10 m
 Dry weight: 10 tons

HYPER DOLPHIN

3,000 m Class Remotely operated vehicle
 Depth capability: 3,000 m
 Length: 3.0 m
 Dry weight: 3.8 tons

KAIKO 7000 II

7,000 m Class Remotely operated vehicle
 Depth capability: (launcher) 11,000 m
 (vehicle) 7,000 m
 Length / dry weight: (launcher) 5.2 m/5.8 tons
 (vehicle) 3.0 m/3.9 tons

DEEP TOW

Deep ocean floor survey system
 Depth capability: 4,000 m
 – 6,000 m
 Length: approx. 3.5 m
 Dry weight: approx. 1.0 ton

Other Facilities

Earth Simulator

Number of processors: 1280
 Number of nodes: 160
 Peak quality: 131 teraflops
 Main memory capacity: 20 terabytes
 User disk capacity: 1.5 petabytes

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

(6) International Collaboration

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

To elucidate these issues and promote ocean observation and research more effectively and efficiently, JAMSTEC is promoting international joint projects and also striving to establish and maintain cooperative relationships with international organizations such as United Nations organizations and overseas research institutions.

1) Contributions to Multilateral Framework for International Collaboration

JAMSTEC sends experts to various task forces of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) to support IOC-related activities, and studies the international requirements necessary for smooth implementation of ocean observation and research under 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 JAMSTEC in January 2008 to strengthen the Japanese promotion system for relevant IOC projects and meetings, has been exchanging views and reviewing international research projects. In FY 2012, two Subgroups of Experts established under the Japan Group of Experts to Advance IOC Programs exchanged their views at several meetings, and in June 2012, the Japan Group of Experts to Advance IOC Programs held its fifth meeting. Based on the views expressed in each subgroup of experts, future perspectives of IOC-related activities were discussed. Also, in January 2013, JAMSTEC sent a staff member from the International Affairs Division to the headquarters of IOC (Paris, France) for two years.

In addition, JAMSTEC sends researchers, as needed, to other international oceanographic organizations, including the South Pacific Applied Geoscience Commission (SOPAC), an influential commission in the South Pacific region, one of JAMSTEC's major observation and research areas, to contribute to their research activities.

2) Joint International Projects

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

- The Array for Real-Time Geostrophic Oceanography (ARGO)
- The Climate Variability and Predictability Programme (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 Drilling Program (IODP)
- Ocean Biogeographic Information System (OBIS)
- North Pacific Marine Science Organization (PICES)

3) Cooperation under the Intergovernmental Cooperative Agreement

JAMSTEC conducts cooperative research based on an intergovernmental cooperative agreement among the United States, the United Kingdom, Italy, India, Australia, Canada, South Korea, China, Germany, France, Russia, EU, etc., and Japan.

The major intergovernmental cooperative meetings held in fiscal 2012 were:

- The 14th meeting of the Japan-Australia Joint Committee on Science and Technology, August 2012
- The 12th meeting of the Japan-Canada Joint Committee on Science and Technology, January 2013
- The 21st meeting of the Japan-Germany Joint Committee on Science and Technology, March 2013

4) Cooperation with Foreign Institutions

JAMSTEC has concluded comprehensive memoranda of understanding for research cooperation with the institutions concerned in the United States, the United Kingdom, India, Indonesia, Australia, Canada, South Korea, Germany and France. In FY 2012, JAMSTEC held an annual meeting under the memorandum of understanding with the Korea Ocean Research and Development Institute (KORDI)* in June, and with the Office of Oceanic and Atmospheric Research of the National Oceanic and Atmospheric Administration (NOAA/OAR) in November. JAMSTEC also concluded a new memorandum of understanding with Natural Resources Canada (NRCan) and with the National Institute of Water and Atmospheric Research (NIWA) of New Zealand, and renewed those with the Office of Oceanic and Atmospheric Research of the National Oceanic and Atmospheric Administration (NOAA/OAR) and the French Research Institute for Exploitation of the Sea (IFREMER).

JAMSTEC also participates in the Partnership for Observation of the Global Oceans (POGO), a forum of major oceanographic research institutions around the world. The executive director of JAMSTEC who is in charge of research, attended the 14th annual meeting POGO-14 held in Cape Town, South Africa, from 22 to 24 January, 2013.

Moreover, JAMSTEC is involved in two joint studies based on collaborative agreement, one with the International Arctic Research Center (IARC), University of Alaska and the other with the International Pacific Research Center (IPRC), Hawaii University.

* Korea Ocean Research and Development Institute (KORDI): was restructured and reestablished as the Korea Institute of Ocean Science and Technology (KIOST) in July 2012.

5) Other International Collaborations

Visitors from international governmental research institutes including NRCan, KIOST, the Commonwealth Scientific and Industrial Research Organization (CSIRO) and IFREMER, came to see JAMSTEC facilities and exchange their views.

Furthermore, JAMSTEC actively presented our research and development projects using exhibit panels and descriptions in the United Nations Conference on Sustainable Development (Rio +20) held in Rio de Janeiro, Brazil, in June 2012, the 9th plenary session of the Group on Earth Observations (GEO) held in Foz do Iguaçu, Brazil, in November 2012, the annual meeting of the American Association for the Advancement of Science (AAAS) held in Boston, United States, in February 2013, the 6th GEOSS Asia-Pacific Symposium held in Ahmedabad, India, in February 2013.

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 and atmosphere and on land, and all of the ecosystems nurtured on the earth interact to shape the global environment. The earth has a history of approximately 4.6 Gyr, and its environment has been of tremendous benefit to all life for only a portion of that time. In particular, the earth has protected and fostered human existence and civilization for many thousands of years. However, in recent years, drastic environmental changes (including global warming) have occurred as a result of human activity. It is a challenge for all natural sciences to understand these changes, investigate their causes, and contribute to the permanent development of society through predictions of future changes of the global environment. Such changes include inherent variations of nature and other events that may be more relevant to us owing to their timescales: heat waves, cold waves, and heavy rains.

RIGC aims to monitor the atmosphere, oceans, and land, along with the associated ecosystems, using a wide variety of techniques to define prevailing conditions, understand the mechanisms of change, and develop forecasting models that combine new findings with existing expertise to better predict future changes. This is summed up by the mission of RIGC: “implementing global environment variation research so that JAMSTEC will not only have a foundation as the world’s center of excellence (COE) in natural sciences but also be recognized as an organization that responds to the social needs of Japan and the world,” with a vision that involves “making use of the knowledge we have accumulated using natural sciences for the establishment of a sustainable, more productive society in which humans and the global environment coexist harmoniously.” Our response to the release of radioactive materials from the Fukushima Daiichi nuclear plant following The Tohoku Region Pacific Coast Earthquake included ocean monitoring and provision of monitoring information to the public; in particular, this involved forecasting the spread of radioactive materials in the ocean. This response was highly acclaimed by the international community at the Group on Earth Observations (GEO) meetings and other events, and JAMSTEC currently plays an essential role in oceanic observation and the prediction of climate variations; this is reflected in the number of JAMSTEC-affiliated studies to be published in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), which is currently being compiled. Moreover, the governmental program entitled “Program for Generation of Climate Change Risk” has been launched, and RIGC has been entrusted with the main part of this project. We are delighted to have the opportunity to demonstrate that all RIGC projects and researchers are dedicated to realizing the vision and mission described above and are happy

to confirm that our vision and mission are coming to fruition.

CO₂ accumulated in the Pacific Ocean during the past decade

Concentrations of CO₂ in the atmosphere have increased owing to the release of anthropogenic CO₂ by human activities such as fossil fuel consumption and deforestation. Many previous studies and reports, such as the 4th IPCC Report, have demonstrated that this CO₂ increase is a primary cause of global warming. It has also been reported that the ocean absorbs about 30% of all anthropogenic CO₂ released into the atmosphere, thus playing a role in the mitigation of warming by decreasing the amount of atmospheric CO₂ remaining.

The future role of the ocean in warming has been brought into question by several recent scientific findings. Increases in water temperature due to warming have been shown to lower the seawater solubility of CO₂. Marine organisms are known to decrease CO₂ concentrations at the sea surface through photosynthesis, enhancing CO₂ uptake by the oceans. However, marine organisms are predicted to be influenced by global warming; therefore, it is possible that biological activity could be affected by warming. Consequently, it is important to clarify, based on observations, how much CO₂ is actually absorbed and accumulated in the ocean.

To address this, we attempted to quantify the amount of anthropogenic CO₂ that accumulated in the interior of the Pacific Ocean over the previous decade (i.e., from the 1990s through the 2000s) using CO₂ data and related data obtained by JAMSTEC and other institutions.

Figure 1 illustrates the distribution of anthropogenic CO₂

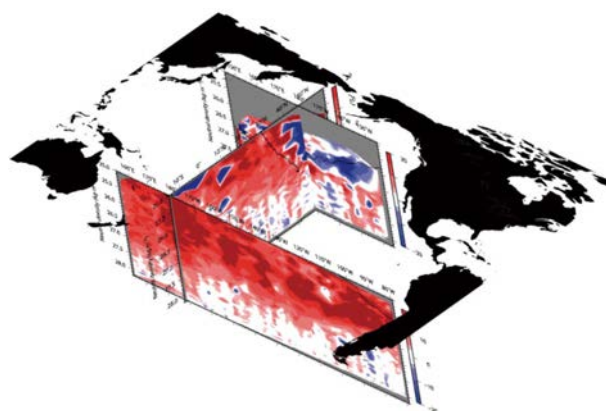


Figure 1. Distribution of increases in anthropogenic CO₂ along observation lines. The section extending eastward from near Japan shows the distribution along the observation line at 47°N, whereas the section extending eastward from Australia shows that along the observation line at 17°S. The north–south section illustrates the distribution along the observation line at 179°E. Red and blue indicate increases and decreases, respectively. Units are $\mu\text{mol kg}^{-1}$.

increases over the study period. The data were obtained by the R/V *Mirai* of JAMSTEC. This figure demonstrates that anthropogenic CO₂ accumulation was considerable, particularly in the subtropical regions of the South Pacific. Conversely, little accumulation of anthropogenic CO₂ was found in the subarctic region of the North Pacific; in fact, CO₂ may even have decreased in this region during the study period. Such an apparent decrease could be related to the scarcity of data in the region, or to the existence of ocean fronts, which represent the boundaries of water masses. However, it is possible that some environmental changes occurred to induce actual decreases of anthropogenic CO₂ accumulation, particularly because biological activity is predominant in the region and because concentrations of both oxygen and nutrients (which are indicative of environmental change) exhibit bi-decadal variations. Accordingly, the subarctic region in particular should be the subject of continuous observations.

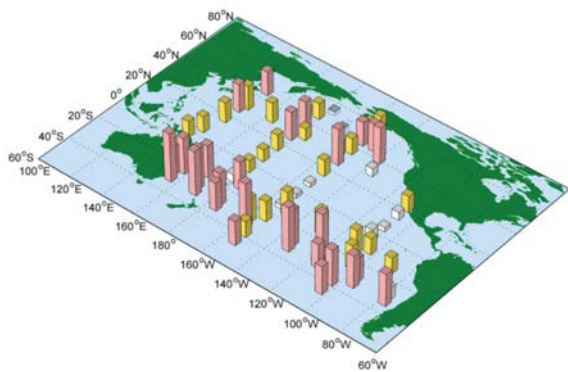


Figure 2. Distribution of anthropogenic CO₂ accumulation per unit area per year (mol m⁻² year⁻¹). Pink and yellow indicate accumulation of > 0.7 and 0.5–0.7, respectively. White indicates accumulation of < 0.5.

We attempted to quantify the amount of anthropogenic CO₂ that accumulated during a decade for the entire Pacific Ocean. High-quality dissolved inorganic carbon data, measured at least twice a decade, are necessary for this calculation. However, such data are sparse because they are found only along the observation lines of the World Ocean Circulation Experiment (WOCE) program, which was conducted primarily in the 1990s. Therefore, we used data from along WOCE lines and calculated averages at intervals of 20° and 10° for longitude and latitude, respectively; the WOCE lines are mostly oriented parallel to lines of longitude and latitude.

Horizontal distributions of anthropogenic CO₂ accumulation per unit area per year are shown in Figure 2. As seen in Figure 1, the largest accumulations were found in the subtropical regions of the North (>0.5 mol m⁻² year⁻¹) and South Pacific (>0.7 mol m⁻² year⁻¹). The smallest accumulations were found in the equatorial region and the subarctic region of the North Pacific. This pattern mirrors that of anthropogenic CO₂ accumulation during the period

from the Industrial Revolution to the 1990s, suggesting that the ocean's capacity for absorbing anthropogenic CO₂ has remained unchanged, at least for the Pacific Ocean as a whole, over recent decades.

Calculation of anthropogenic CO₂ accumulation for the whole Pacific Ocean from the 1990s to the 2000s (Fig. 2) produced a value of 8.5 PgC (= 8.5 × 10¹⁵g, expressed in terms of carbon). This is almost equivalent to the value of 8.0 PgC estimated by a model calculation.

Although it has been confirmed that ocean's capacity for absorbing anthropogenic CO₂ has remained unchanged for the whole Pacific, the accumulation of CO₂ has exhibited regional variations. In particular, a large accumulation was obvious in the subtropical region of the South Pacific. The fact that the ocean absorbs anthropogenic CO₂ from the atmosphere is helpful for the mitigation of global warming. However, this absorption affects the marine environment because seawater (which is weakly alkaline) is neutralized by the absorbed CO₂ (which is a weak acid). This phenomenon is known as ocean acidification. Furthermore, this process is accompanied by decreases in the saturation state of calcium carbonate (CaCO₃), which is a component of the shell and skeletons of marine organisms; accordingly, ocean acidification is one of the processes currently being investigated intensively.

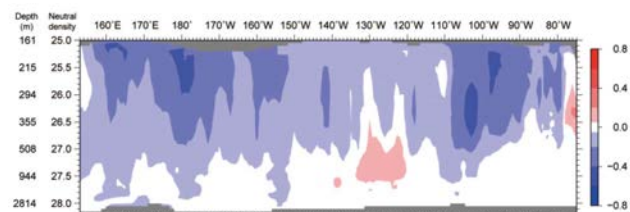


Figure 3. Changes in saturation state of CaCO₃ along the observation line at 17°S. This figure illustrates the saturation state of aragonite, which is a mineral form of CaCO₃. Blue and red indicate decreases and increases, respectively.

Figure 3 illustrates changes in the saturation state of CaCO₃ from the sea surface to about 1500 m depth along the observation line along 17°S. The distribution of saturation state shows a decreasing trend that exhibits a good relationship with increases in anthropogenic CO₂; therefore, it is inferred that the saturation state can be attributed to accumulation of anthropogenic CO₂.

It has become evident that the CaCO₃ saturation state decreases in accordance with large increases of anthropogenic CO₂ in the subtropical region of the South Pacific. Because seawater in the region originates from the Southern Ocean, it is probable that the marine environment around the Antarctic continent has undergone recent changes. Thus, we intend to conduct extensive investigations in the Southern Ocean.

Effects of Asian winter monsoon on precipitation on the Maritime Continent

The Asian winter monsoon is characterized by its strong seasonal winds, which are induced by the development of the Siberian high and the accompanying outflow of cold air. This outflow of cold air reaches not only the areas surrounding Japan, but also the subtropical and tropical zones; in fact, the cold northerly wind (northerly surge) often crosses the equator to the Southern Hemisphere, greatly influencing the climate of the mid-latitude and tropical regions. To determine the effect of these northerly surges, which induce heavy rains in Southeast Asia, RIGC has conducted meteorological observation for the region and has investigated the effects of cross-equatorial northerly surges on precipitation variations in Southeast Asia using various datasets, including satellite observation data and objective re-analysis atmospheric circulation data.

An ocean wind distribution chart derived from satellite observations demonstrates that the northerly surges that accompany the Asian winter monsoon often cross the equator to reach Java in the Southern Hemisphere (Fig. 4). Although cross-equatorial northerly surges occur every year, strong cross-equatorial northerly surges that persist for longer than a week (e.g., the surge that caused heavy rainfall in the Indonesian capital, Jakarta, in February 2007) typically occur only once every few years. We statistically investigated the relationship between the occurrence of cross-equatorial northerly surges and the distribution of precipitation in the tropical region of Southeast Asia and showed that the cross-equatorial northerly surges cause a significant increase in precipitation in the region, particularly in northern Java and the Java Sea (Fig. 5). Furthermore, the interannual variations of precipitation in northern Java during periods of cross-equatorial northerly surge were found to be consistent with the interannual variation of precipitation for the entire rainy reason (December to March), indicating that this cross-equatorial northerly surge is one of the major factors controlling precipitation variations in the rainy season.

The heavy rain in Jakarta in 2007 submerged much of its urban area, killing more than 100 people and displacing 300,000 people. During this period, heavy rains tended to occur at night and in the early morning on consecutive days. During the rainy season in the southern mountainous region of Java, strong thunderstorms caused by convection clouds often occur from afternoon to evening (Fig. 6a). Then, at night, as the thunderstorms dissipate, air cooled by precipitation flows down the mountain slope to the Java Sea as land breeze (Fig. 6b). From night to early morning, this land breeze and a cross-equatorial northerly surge collide with each other, forming a convergence region at the coast of Jakarta and causing heavy rains at night and in the early morning (Fig. 6c).

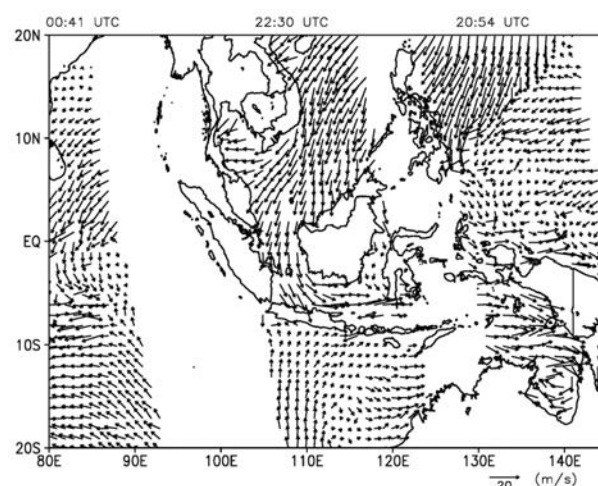


Figure 4. Distribution of ocean surface winds observed by the QuickSCAT satellite on February 1, 2007

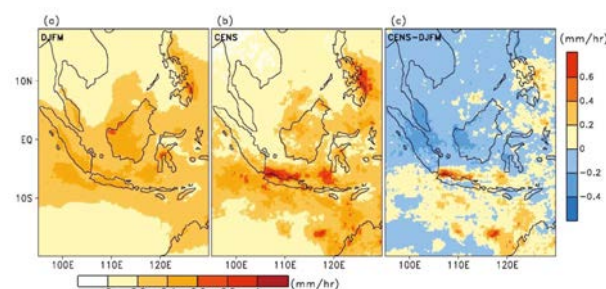


Figure 5. Distribution of precipitation on the Maritime Continent: (a) climatic data (rainy season: December to March), (b) periods of cross-equatorial northerly surges, (c) difference between (a) and (b).

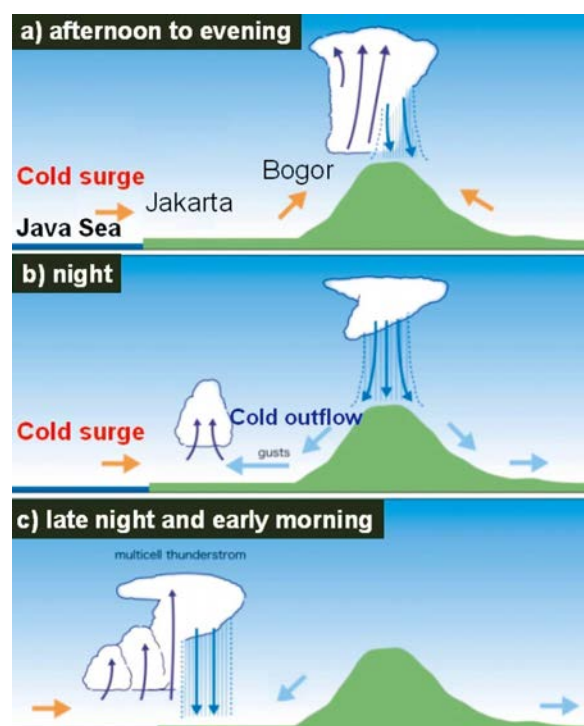


Figure 6. A conceptual diagram of the mechanism underlying heavy rain in Jakarta induced by the cross-equatorial northerly surge

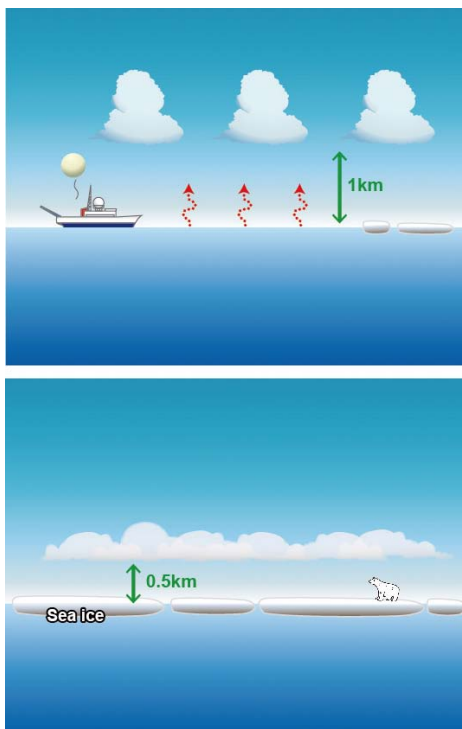
Effects of a sudden decrease of sea ice area in the Arctic Ocean

The atmosphere, oceans, and land areas of cold regions have changed with global warming, which has caused decreases in sea ice area and the melting of frozen soil. However, the mechanisms underlying many such phenomena remain poorly understood, and the reproduction of past events and prediction of future events have yet to be perfected. Therefore, it is important to elucidate the processes underlying these variations in natural systems by conducting observations at key sites; then, the effects of these mechanisms can be assessed for not only the circum-Arctic and mid-latitude regions but also the entire earth.

It is well known that the area of sea ice in the Arctic Ocean started decreasing noticeably since the late 1990s, reaching its lowest extent in history during the late summer of 2012. We obtained two new findings regarding the effects of these changes on the atmosphere and climate of surrounding continental areas.

(1) Sea ice retreat reduces Arctic low-level clouds

Field observation data collected by the research vessel *Mirai* demonstrate that low-level clouds (i.e., those with a cloud base below 500 m) occurring from summer to autumn over the Arctic Ocean have decreased by 30% owing to sea ice retreat (Sato et al. 2012, GRL). Although low-level clouds (including fog) occur readily in sea ice regions, the results of this study show that the supply of heat and water vapor from the sea surface increases as sea ice retreats. This allows stratocumulus and other convective clouds with a relatively high cloud base to develop more readily (Fig.7). Because conventional satellite monitoring cannot be used to observe cloud base height over the Arctic Ocean, changes in this structure have been investigated using numerical modeling.



This study is the first to verify changes in the vertical cloud structure accompanying sea ice retreat on the basis of field observation data.

- (2) Effects on climatic changes on the circum-Arctic continental regions. It is known that the decrease in sea ice area in the Arctic Ocean has had widespread effects on, for example, the transport of winter cold air masses to East Asia. We investigated the relationship between the decrease in sea ice area and climatic changes in the circum-Arctic continental regions. For the period between 1976 and 2006, we performed a regression analysis on the sea ice area (September) and the average temperature and average snow depth in the following winter (December to February; in Figure 8, positive and negative values indicate increases and decreases, respectively, in temperature and snow depth). The relationship between decreases in sea ice area and temperature (Fig. 8b) was expressed by positive values for North America and negative values for Siberia, particularly for eastern Siberia, revealing a considerable difference between the continents. Conversely, snow depth (Fig. 8c) was expressed by negative regression coefficients, indicating that snow depth has decreased with sea ice area overall. In particular, the regions exhibiting significant increases in regression coefficients were found to be concentrated in northeastern Siberia. We suggest that increasing precipitation in fall has acted in conjunction with decreasing temperatures to help increase snow depth.

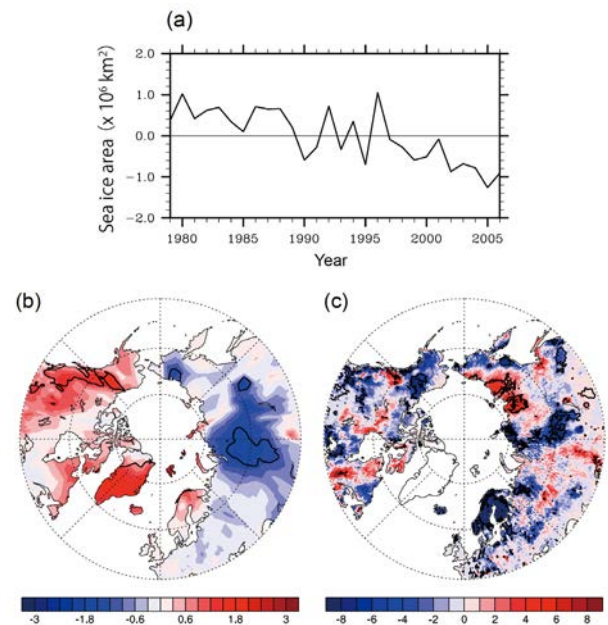


Figure 8. (a) Temporal changes in sea ice area in the Arctic Ocean in September. (b) and (c) Regression coefficients for yearly sea ice area and winter temperature and snow depth in December–February (positive values indicate increases in temperature and snowfall accompanying decreases in sea ice area). Black lines surround areas in which significant differences were found.

Figure 7. Difference in cloud structure over the ocean without (top) and with (bottom) sea ice. Heat supply from the sea surface increases with retreat of sea ice, allowing cloud with a high cloud base to become prominent.

Observational study of the biogeochemical cycle in the western North Pacific

Recently, the possibility that change in the ocean and terrestrial environments as a result of intensified socioeconomic activity could induce changes in ecosystems and their related biogeochemical cycles has been of great concern globally. In order to clarify the response of the marine ecosystem and related biogeochemical cycles to climatic and oceanographic change, the Environmental Biogeochemical Cycles Research Program (EBCRP) has been conducting observational studies using research vessels, mooring systems, and satellites at time series stations located in the subarctic (station K2) and subtropical (station S1) gyres; these stations are subjected to different oceanographic characteristics and external forces, including seasonal wind, mesoscale eddies, and eolian input. Based on time series observations since 2010, the following results have been verified in relation to primary productivity, eolian supply of lithogenic materials, and ecosystem change.

1. Limiting factors of primary productivity

Both stations exhibit seasonal variability in primary productivity (PP). At station K2 in the subarctic gyre, PP reaches its annual maximum during June and July and its minimum during January and March. Conversely, at station S1 in the subtropical gyre, PP reaches its annual maximum in February and its minimum in autumn. Annual average values of PP at K2 and S1 were estimated to be about $290 \text{ mg-C m}^{-2} \text{ day}^{-1}$ and about $270 \text{ mg-C m}^{-2} \text{ day}^{-1}$, respectively. According to statistical analysis, PP is limited by light (PAR) and nutrients at K2 and S1, respectively (Fig. 9); this might be indicative of the fact that PP at “nutrient-rich” K2 increases when the stratification is intensified by global/oceanic warming and when light conditions are more favorable for phytoplankton (usually in winter). However, the supply of Fe (which is likely a limiting factor of PP at K2) from the subsurface might decrease and act as a negative feedback on PP.

It is of particular note that PP at S1 was found to be comparable to that at K2, likely because nutrient supplies were often low or exhausted in the upper layer at S1. Vertical supply from the subsurface and horizontal supply from the subarctic gyre are two of the possible mechanisms for supplying nutrients to the upper ocean. Satellite data analysis indicates that the concentration of

chlorophyll increases with decreasing sea surface temperature (SST) (Fig. 10). Furthermore, multiple Argo float observations conducted near S1 by the Ocean Climate Change Research Program (OCCRP) revealed that the passage of mesoscale eddies increases oxygen content in the subsurface layer through increases in phytoplankton. This increase was found to be closely synchronized with increases in the flux of biogenic material, which were observed by a time series sediment trap at S1. Thus, it is suspected that mesoscale eddies act as a mechanism to supply nutrients to the upper layer at S1, partly supporting PP.

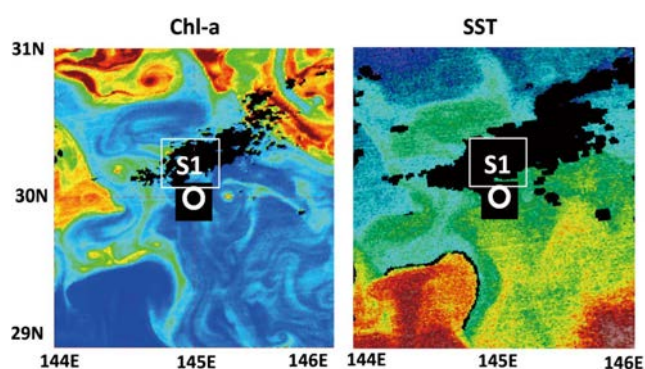


Figure 10. Horizontal distribution of (a) the concentration of chlorophyll-a and (b) SST around station S1 (observed by satellite on April 11, 2011, at a spatial resolution of 1 km)

2. Nutrient supply of terrestrial origin

Nutrients of terrestrial origin, such as nitrate, phosphate, and iron (Fe), can also be supplied to the marine surface layer via the atmosphere. During our cruises, we collected atmospheric aerosol particles for preliminary analysis of trace metals, with particular focus on Fe. Mass concentrations of Fe in late spring and summer were found to be $0\text{--}43 \text{ ng m}^{-3}$ and $0\text{--}74 \text{ ng m}^{-3}$ for fine ($<2.5 \mu\text{m}$) and coarse ($>2.5 \mu\text{m}$) particles, respectively, suggesting that the contribution of fine particles (which are emitted primarily as a result of industrial human activity) is non-negligible compared to that of coarse particles, which consist primarily of natural mineral dust. The observed Fe/Al ratios of aerosol particles at the K2 site deviated considerably from those measured for Asian dust (Kosa) particles, suggesting the presence of particles from other sources. Moreover, analysis of the V/Al ratio, a sensitive tracer of heavy oil combustion, indicated that anthropogenic influence is widespread over the open Pacific Ocean.

3. Ocean acidification and biological response in the subarctic circulation

Understanding of ocean acidification has emerged as a key priority for ocean environmental science. Our observations demonstrate that ocean acidification is occurring in the western North Pacific as a result of reduction in pH in the vicinity of observational station K2 (in the subarctic area); these pH changes are related to rising atmospheric carbon dioxide (CO_2) and

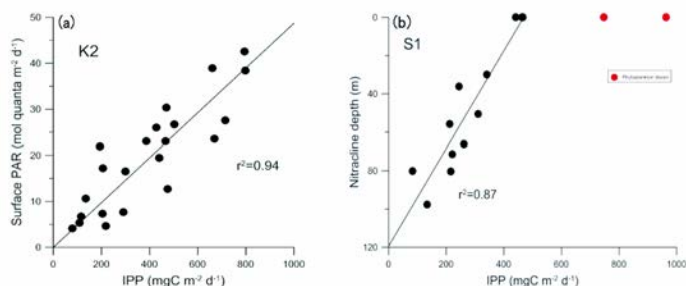


Figure 9. (a) Relationship between primary productivity (IPP) at K2 and (b) relationship between IPP and nutrients (nitracline depth)

consequent increases in oceanic $p\text{CO}_2$. To elucidate the effects of ocean acidification on shell-bearing marine plankton, we are developing a method to measure the shell density of carbonate-shelled zooplankton (planktic foraminifers) using a microfocus X-ray computing tomography (MXCT) technique (Fig. 11). The quantitative results for the planktic foraminifer *Globigerina bulloides*, a common species in the North Pacific, demonstrated remarkable decreases in shell density in winter seasons (January to March), suggesting density losses of approximately 60% (compared to unaffected shells in other seasons) at station K2. Furthermore, the carbonate saturation state (Ω) of the surface water was found to decrease and the saturation horizon became shallower in the winter season as a result of strong vertical mixing accompanied by upwelling of intermediate water containing abundant CO_2 . Shell degradation seems to be closely related to such oceanic physicochemical changes throughout the year. Our results suggest that the following would occur if ocean acidification became more advanced: 1) amplification of the existing remarkable seasonality of ocean acidification in the western North Pacific; 2) degradation of the carbonate shells of plankton in the water column; 3) possible damage to particular calcareous species; and 4) extensive damage to the marine ecosystem.

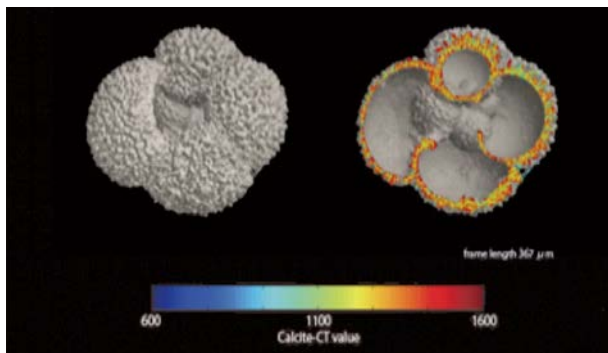


Figure 11. Computed tomography images indicating shell density of planktic foraminifera *G. bulloides* recovered from station K2. Left: surface texture of the shell. Right: cross-sectional image of the shell. Colors with gradation indicate differences in shell density: warm and cold colors indicate higher and lower densities, respectively. Carbonate shell degradation progresses in a mosaic pattern and is not homogeneous.

Uncertainty in allowable carbon emissions for the RCP4.5 concentration scenario

Consideration of uncertainty is essential in interpreting future climate projections. Here, using an ensemble of simulations with an intermediate-complexity climate model in a probabilistic framework, we estimate future ranges of temperature change and carbon dioxide (CO_2) emissions for the Representative Concentration Pathways (RCP) 4.5 concentration pathway (Fig. 12). RCP4.5 assumes the second lowest CO_2 concentration level in 2100 from the four scenarios developed for the Fifth Assessment Report of the IPCC.

Treatment of uncertainty

Uncertainty is first estimated by allowing modeled equilibrium

climate sensitivity, aerosol forcing, and intrinsic physical and biogeochemical processes to vary within widely accepted ranges. Results are then further constrained by comparison with contemporary measurements of air temperature and seawater temperature, historical estimates of carbon emissions, and vegetation-related data.

Uncertainty in temperature rise and allowable carbon emissions

Despite these additional constraints, the resulting range of temperatures for RCP4.5 remains large: by the year 2300, global warming (with respect to preindustrial levels) is estimated to be 1.5–3.9 and 1.8–4.0 K (5–95th percentiles) for the unconstrained and constrained analyses, respectively. Allowable CO_2 emissions at peak emission are projected to be 6.7–13.3 and 9.0–12.8 PgC yr^{-1} , respectively (for the same percentiles).

Very low net carbon emissions are required after the year 2100, and direct sequestration of carbon dioxide may be necessary to offset the minimum emissions required for society to function.

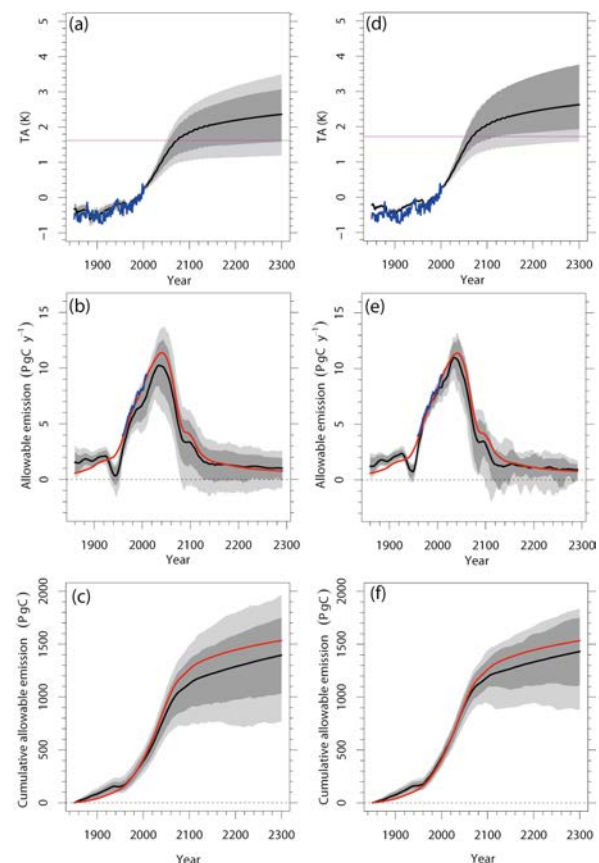


Figure 12. Time series of (a) global mean surface air temperature, (b) allowable annual emissions, and (c) cumulative allowable emissions, for the period 1850–2300 for RCP4.5. The black curve indicates the ensemble mean; the dark and light grey shadings correspond to the 68% (16–84th percentile) and 90% (5–95th percentile) ranges, respectively. The blue curve represents the HadCRUT3 data in (a) and the historical estimates of emissions (from CO2now.org) in (b). The red curves in panels (b) and (c) represent the RCP emissions scenario. In panel (a), anomalies are from 1880–1999 averages; the horizontal magenta line represents an increase of 2 K from the preindustrial level (here, the average for 1850–1869). (d)–(f) are the same as (a)–(c), but for our constrained set of simulations using the eight observed datasets.

Where does the emitted carbon go?

For many sets of parameters, the land will become a net carbon source within the 21st century, although the ocean will remain a carbon sink. The uncertainty in cumulative allowable emissions is very large, even with additional constraints, and the temperature rise for a given amount of emissions is difficult to predict.

For land carbon storage, which strongly influences allowable emissions, major reductions are seen in the northern high latitudes and the Amazon basin, even after atmospheric CO₂ is stabilized, while for ocean carbon uptake, the tropical ocean regions exhibit negative uptake and relatively large uncertainty.

Parameters causing uncertainty

The parameter with the most significant effect on allowable emissions is climate sensitivity, followed by some of the physical parameters for the oceans (e.g., vertical diffusivity). Some carbon cycle-related parameters (e.g., maximum photosynthetic rate and the temperature dependency of plant respiration) also have significant effects.

Rainband along the Kuroshio Current in the East China Sea

The importance of warm sea surface temperatures (SSTs) in organizing cloud and precipitation bands along the mid-latitude western boundary currents has been suggested in several previous studies. However, a fundamental question that remains to be solved is whether the mid-latitude ocean can influence the free atmosphere beyond the marine boundary layer. Our study in FY2012 revealed convincing evidence for an organized narrow convective rainband along the Kuroshio in the East China Sea.

The radar image illustrated in Figure 13a (taken at 0000 UTC or 0900 Japanese Standard Time on May 20, 2010) indicates a well-organized rainband in the East China Sea to the west of the Okinawa Islands. This rainband was collocated with a belt of SST maxima along the Kuroshio (Fig. 13b, red arrow), suggesting that the high SST may be the prime factor promoting the organization of the rainband. After emerging around 0600 UTC on May 19, this particular rainband persisted for more than 20 h. Notably, the rainband formed well south of the Baiu/Meiyu front, which appears as a quasi-stationary seasonal frontal system in a weather chart (Fig. 13b).

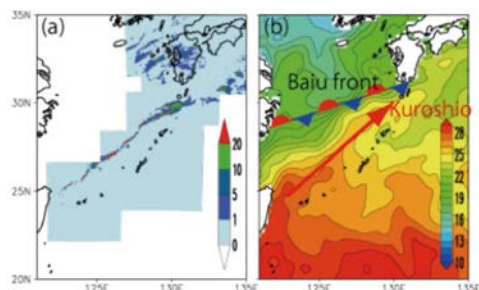


Figure 13. (a) Precipitation (mm h⁻¹) observed with the Japan Meteorological Agency radar network and (b) satellite-observed sea surface temperature (°C) at 0900 JST, May 20, 2010. The locations of the Baiu front and the Kuroshio are schematically superposed.

To test the hypothesis that the warm SSTs help organize and maintain the convective precipitation of the rainband, a pair of hindcast experiments were conducted using a regional atmospheric model; the control experiment (CNTL) used the original high-

resolution SSTs as a boundary condition and another case (SMTH) used an SST field that had been artificially smoothed in space (see Fig. 14b). As shown in Figure 14a, the CNTL run was generally successful in reproducing the narrow rainband structure in the East China Sea, especially between 24°N and 28°N. The simulated rainband occurs over the band of SST maxima along the Kuroshio Current, to the south of the stationary Baiu front. Conversely, this particular rainband cannot be seen in the SMTH case (Fig. 14b), in which the SST field has been smoothed. Most of the precipitation differences between the two cases can be accounted for by convective rainfall associated with the warm Kuroshio Current.

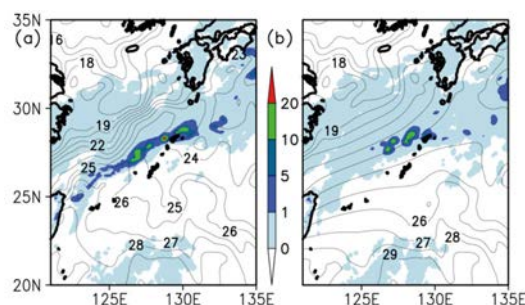


Figure 14. Horizontal distribution of SST (°C, contours) and precipitation (mm h⁻¹, shade) from (a) CNTL run and (b) SMTH run

The mechanism responsible for this peculiar rainband is illustrated schematically in Figure 15. In a typical Baiu front structure without the Kuroshio, cold dry air from the continent to the north (blue arrow) and warm humid air from the ocean to the south (dashed red arrow) converge at the front, causing a cloud band along the front. However, with the real Kuroshio Current, the SST maximum is sufficiently warm to destabilize the warm humid air from the south. Consequently, deep convection accompanied by rain is triggered over the Kuroshio, forming the rainband observed in the radar image.

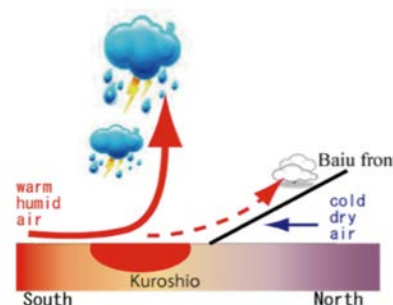


Figure 15. Schematic of the mechanisms of rainband formation

The above results clearly suggest that the SST frontal structure is a key parameter for climate prediction and disaster prevention in the mid-latitude regions. To enhance our understanding in this field, we have recently started to investigate similar influences of the warm SST on the formation of heavy rainfall events over Japan, such as that in northern Kyushu in July 2012.

Moderation of Urban Heat Island Effects for Adaptation to Global Climate Change

Future climate change under global warming is projected using coupled general circulation models (CGCMs). Currently, the

improvement of accuracy and evaluation of uncertainty in future climate projection can be considered primary research topics and are being investigated actively worldwide. Recently, interest in strategies for adaptation to future climate change has increased globally for both local and national governments. To determine adaptation plans at the local level, spatially detailed climate projections with horizontal resolutions of several kilometers are required. However, as the spatial resolution of CGCM (about 100–250 km) is insufficient for such adaptation studies, our group is applying a downscaling method to climate projection. This method allows calculation of high-resolution climate projections over limited areas, such as Japan, using a regional climate model.

Over the last century, the observed surface air temperature in major cities has increased more than the global mean surface air temperature ($+0.74^{\circ}\text{C}$). This is because the surface air temperature in urban areas is affected by the urban heat island phenomenon and global warming, associated with increases in the concentration of anthropogenic greenhouse gases. Accordingly, urban areas are more likely to experience extreme high-temperature events in future.

Historical maximum temperatures were recorded at many observation points in Japan during summer in 2010. The Tokyo meteorological station also observed its highest monthly mean surface air temperature on record, 29.6°C , in August 2010. The red bars in Figure 16 represent a histogram of hourly surface air temperature observed in Tokyo during that month. The white bars indicate the projected occurrence frequency of hourly surface air temperature for one year in August in the 2070s, as obtained by downscaling. The histogram for the 2070s is similar to that for 2010, suggesting that the 2010 hottest summer will become the norm in the 2070s.

Many methods have been proposed for mitigation of the urban heat island effect, including changing urban form, greening of parking lots and building walls, increasing roof albedo, and changing pavement materials. This study focuses on the urban form aspect and investigates the moderating effects of changes in urban form on heat island effects in the hot summer of 2010 using a regional climate model.

In addition to the current urban scenario, this study assumes two other urban scenarios: the dispersed city and compact city scenarios were introduced by Yamagata et al. (2011) using a land use equilibrium model and are based entirely on urban economic theory. The land use model considers three types of agents: households, developers, and absentee landlords. The distribution of residential buildings varies depending on the demand for land and housing under given conditions, whereas the distributions of offices and commercial buildings are fixed to those in the current urban scenario. The dispersed city scenario assumes an automobile-dependent society, and the urban areas in this scenario expand throughout the Tokyo metropolitan area (TMA) (Fig. 17a). Conversely, the compact city scenario assumes that automobile use is prohibited, such that urban areas become concentrated along train lines (Fig. 17b).

Changes in nighttime surface air temperature due to modification of urban form are illustrated in Figures 17c and 17d. In the dispersed city scenario, surface air temperature increases throughout most of the TMA, except in the central part. Warming of more than 0.6°C is simulated in Chiba and Ibaraki prefectures owing to expansion of the urban area. In the compact city scenario, the surface air temperature reduces by about 0.1°C over a large area of the TMA, excluding the central part, where temperature

increases by about 0.1°C owing to the concentration of population.

Changes in nighttime surface air temperature weighted by population distribution are illustrated in Figures 17e and 17f. The compact city scenario offers the potential to reduce the area-averaged heat island intensity. However, nighttime temperature increases in the central part of the TMA, suggesting that the thermal environment is poorer in the city center (where population density is high) in the compact city scenario. That is, the concentration of urban areas does not always represent the optimum approach for improving the poor thermal conditions that result from heat island phenomena and global warming. However, this could be compensated for by other strategies, such as the greening of urban areas. The moderation of urban heat islands could become an effective strategy for adaptation to global warming in urban areas. Therefore, urban planning that includes the mitigation of urban heat islands will be important for future local climate.

Yamagata, Y., H. Seya, and K. Nakamichi, 2011: Scenario analysis of the future urban land use in the Tokyo Metropolitan Area. *Journal of Society of Environmental Science*, 24(3), 169–179 (in Japanese).

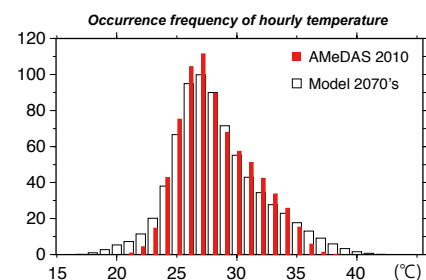


Figure 16. Occurrence frequency of hourly surface air temperature for one year at the Tokyo meteorological station. Red bars illustrate the observations in August 2010; white bars indicate the projected future climate in August in the 2070s.

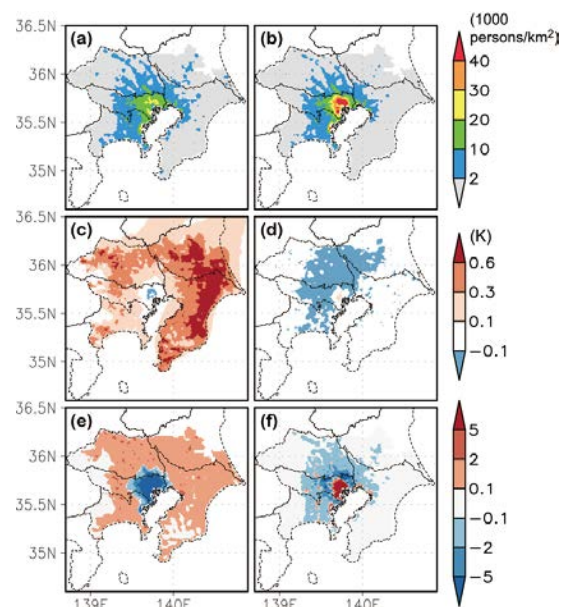


Figure 17. (a–b) Distribution of population per square kilometer. (c–d) Differences in nighttime surface air temperature in August 2010 from the current urban scenario. (e–f) Differences in nighttime surface air temperature weighted by population density from the current urban scenario. Left and right panels illustrate the dispersed and compact city scenarios, respectively.

Institute for Research on Earth Evolution (IFREE)

Overview

The 2011 Tohoku Earthquake caused plate deformation beneath the Japanese archipelago and the surrounding areas. This was triggered by one of the diverse stress-relaxation processes that occurred at the plate boundary zones, and it left a significant mark on the dynamic processes of the Pacific Plate and the crust and wedge mantle of the Japanese archipelago that sits thereon.

IFREE has been investigating the mechanism of these stress-relaxation processes, and has installed and collected a large number of ocean-bottom seismographs as well as conducted subsurface structure surveys using a multichannel seismic survey system (MCS). It is also evident that east-west tensile stretching, caused by normal faulting in various directions, predominates in the upper crust of the Japanese archipelago, and that earthquakes are caused by a normal-fault complex in the region where the Pacific Plate, which is located outside the axis of the Japan Trench, extends in an east-west direction. These earthquakes are thought to be derived from a bending deformation caused by the subduction of the plate in the outer rise region of the trench. Now, for the first time, the movement of an earthquake cluster, which follows the extension of a crack from shallower to deeper areas, has been confirmed, and after an outer-rise earthquake of magnitude 7.4 (December, 7, 2012), the authorities were able to warn of the possible occurrence of large-scale earthquakes during the stress-relaxation process. Furthermore, a survey on the detailed structure of the Japan Trench axis performed using a precision MCS that has recently entered the practical stage showed that the boundary fault reaching the trench axis greatly deforms the stratified deposits at this axis.

Through international joint research projects using global networks, as well as closely connected local agile observation networks for the detailed exploration of priority areas, global seismology has determined the detailed structure of a stagnant slab in the western Pacific region. As a result, it has been revealed that the subducting Pacific plate is proceeding, while forming a stable boundary with the surrounding viscous layers in the mantle transition zone, thereby giving the surrounding mantle an unstable structure, associated with heat and stress. Furthermore, an ocean bottom magnetometer has recently been developed and put into practical use, allowing direct measurement of displacement vectors of water in a deep sea. The device enables high-dimensional tsunami observation, and is expected to significantly contribute to the clarification of the physical process of tsunamis and the reduction of associated disasters.

After the 2011 Tohoku Earthquake, JAMSTEC successfully conducted a direct drilling survey into faults, using the deep sea drilling vessel *CHIKYU*, and thereby making a significant contribution to the history of scientific research. During the survey, a rock-like material, previously unknown to humankind, was collected from the decollement near the seismic plane, and a significant accumulation of hydrogen gas in the upper column was observed. The results of this survey will be published in

the future in the findings of Integrated Ocean Drilling Program (IODP) international joint research. A discrete element method (DEM) calculation experiment, (which, in a sophisticated manner, incorporates actual-scale gravity and the movement speed associated with the formation process of the adduct occurring in the plate boundary region), confirmed a gradually developing high-porosity zone, across which the stress changes noticeably. These results were consistent with those observed for the adduct along the Nankai Trough. In addition, the Dense Oceanfloor Network system for Earthquakes and Tsunamis (DONET), which has recently entered the practical stage, discovered a region of long-period earthquake clusters and medium anisotropy inside the adduct.

Project IBM (Izu-Bonin-Mariana), an IODP international joint study aimed at deepening the understanding of continental crust formation, is now in full operation. At the Project IBM international conference in Hawaii, along with revelations of other findings, intensive discussions took place regarding the discovery that the relationship between the crust thickness and magma at the Izu-Bonin-Mariana Arc depends on the formation rate of its middle crust. This discovery has generated impetus for deep sea drilling studies, which are now planned for next year and into the future.

Effects of the 2011 Tohoku Earthquake on the stress field in the Pacific Plate

Following the 2011 Tohoku Earthquake, which occurred on March 11, 2011 (magnitude 9.0), seismic activity has been activated over a wide area along the Japan Trench. After the mainshock, many earthquakes with a normal faulting mechanism occurred in the Pacific Plate (located on the eastern side of the Japan Trench—on the ocean-side slope of the trench), including one of magnitude 7.5 occurring approximately 40 minutes after the mainshock. Since such earthquakes have relatively shallow hypocenters, there is a concern that if a large-scale quake occurs it could cause a large tsunami. In support of such a concern is the example of the 1933 Showa-Sanriku Earthquake (magnitude 8.1), a major intraplate, normal faulting, quake that occurred off the Sanriku Coast and caused devastating tsunami-related damage. It occurred within the Pacific Plate, and was located to the eastern side of the hypocenter of another major tsunami earthquake, the 1896 Meiji-Sanriku Earthquake (magnitude 8.2).

The ocean-side slope of the Japan Trench, which is located on the eastern side of the hypocenter of the 2011 Tohoku Earthquake, lies a considerable distance from Japan (approximately 250 km); therefore, it is difficult to accurately determine the hypocenter distribution of earthquakes that occur in the region using land observation. To accurately determine the location and mechanism of the hypocenter of an earthquake that occurs inside the Pacific Plate, in this study 20 pop-up ocean bottom seismograph units were installed on the Pacific Plate on the eastern side (ocean-side) of the trench at water depths of 5000 m and 6000 m. They were

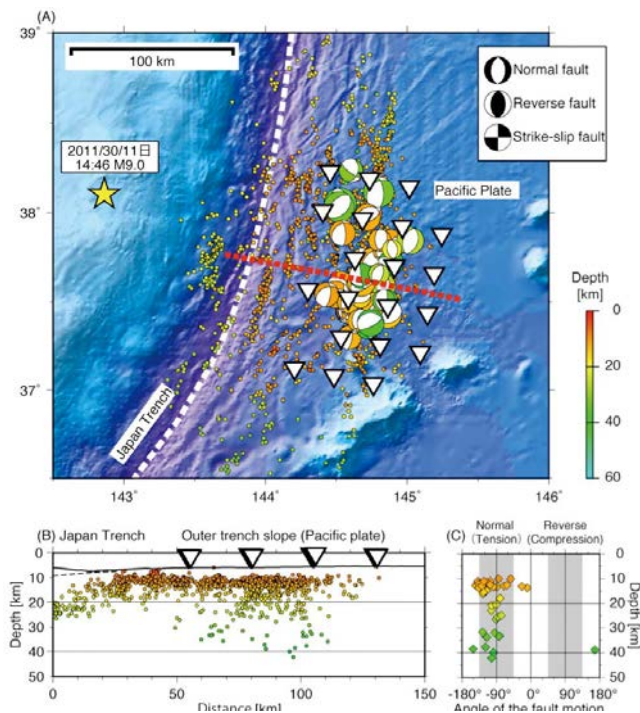


Figure 1. Observed results.

(A): Hypocenter distribution and focal mechanisms obtained from OBS observations. (B): Cross section along the red dashed line in (A). The earthquakes occurred in the Pacific plate at depths shallower than about 40 km. (C): Depth versus angle of the fault motion with respect to the strike. The earthquakes had normal-faulting focal mechanisms (angle near -90°) at all depths.

installed in late April 2011 from the deep sea research vessel *KAIREI*, during a survey of the crustal structure and ocean-floor topography in the hypocenter region of the 2011 Tohoku Earthquake, and the seismographs were collected by early July 2011 from the support vessel *YOKOSUKA*. The seismic wave data recorded by the seismographs were used to analyze the location and mechanism of hypocenters of earthquakes.

Based on the data collected during the two-month observation period, approximately 1700 hypocenters were determined and earthquake focal mechanisms were determined for 50 earthquakes (Fig. 1). It was shown that the earthquakes that occurred inside the Pacific Plate were distributed at depths of up to 40 km and that such earthquakes had a normal faulting earthquake focal mechanism despite their depths.

An analysis of the stress field inside the Pacific Plate located on the ocean-side slope of the Japan Trench reveals that owing to the folding of the plate as a result of the subduction at the trench, extension occurs in the shallower part and compression occurs in the deeper part (Fig. 2, upper left). An ocean bottom seismic observation conducted by Tohoku University in combination

with other organizations (Hino et al., 2009) in the same area as the present study but prior to the 2011 Tohoku Earthquake showed that while normal faulting-type earthquakes tend to be located at depths of up to 20 km, reverse faulting-types tend to be concentrated at depths of around 40 km, indicating the presence of a stress field, which is considered to result from the folding of the plate.

However, the earthquake focal mechanism determined in our study indicates that the extensional field is predominant at depths of up to 40 km (Fig. 2, lower right). A comparison of the differences in the observed stress field inside the Pacific Plate before and after the earthquake, indicates that the area inside the plate at a depth of around 40 km has possibly transformed from a compression to a extension as a result of the 2011 Tohoku Earthquake. Such changes in the stress field are believed to be associated with the active normal faulting seismic activities inside the plate after the main earthquake.

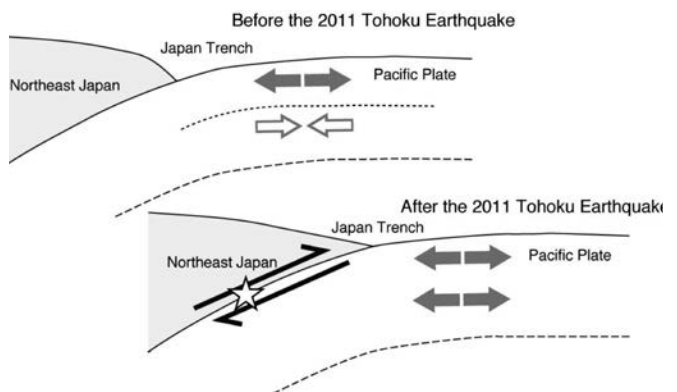


Figure 2. Comparison of the stress regime in the Pacific plate before and after the 2011 Tohoku Earthquake.

Before the 2011 earthquake, stresses in the Pacific plate were tensional in the upper layers of the oceanic lithosphere and compressional beneath. On the other hand, the tensional stresses extend to depths of about 40 km after the 2011 earthquake.

Solid Earth Dynamics Research Program

We participated with the drilling voyage for research into the Great East Japan Earthquake (IODP Expedition 343: JFAST) and revealed the potential existence of fault zones several meters thick at depths of 720 m and 820 m (the latter representing the plate boundary). We also collected layers from the trench bed using piston coring. Through this analysis, we can deny, based on the undisturbed magnetic fabric, the previously held belief that the raising of the trench bed after the earthquake was due to a submarine landslide, and discovered that the surface layer on the land-side slope of the trench was significantly disturbed.

During the research drilling voyage to the Costa Rica earthquake zone (IODP Expedition 344: CRISP-2), we conducted wireline logging. Using electrical resistance imaging, we determined that the horizontal maximum stress moved in an east-west direction (perpendicular to the current crust movement direction) as well as successfully reproducing past stress history.

Based on the examination of cores obtained in the drilling voyage to the Costa Rica subduction zone (IODP Expedition 334), we obtained information on stress transition that corresponds to the seismic cycle typically observed for erosion-type subduction zones.

We have also analyzed the magnetic fabric of the submarine landslide layer on the land-side slope of the Nankai Trough (drilled in 2011), and attempted to reproduce the sliding history of the layer. Based on numerical calculations, our modeling studies on the faulting movement suggests that in faults where earthquakes frequently occur, increased friction at a slow sliding speed (a few centimeters/year) makes it impossible for earthquakes to occur. However, when combined with significant weakening of faults at a fast sliding speed (around 1 m/s), propagated destruction may cause a large-scale seismic sliding. Furthermore, it has become evident that such areas exhibit diverse behavior (anchoring, creeping, etc.) between earthquakes. These findings have been submitted to and accepted by the journal *Nature*.

Using numerical experiments on the long-term development process of an accretionary prism, we have also discovered a new mechanism for the formation of multiple decollments, and have shown that the spatiotemporal variation of the stress field consistent with the mechanism, occurs inside the accretionary prism.

In our solid earth numerical simulation, which was a mantle convection simulation in which mineral physics parameters obtained by thermodynamic equilibrium calculation were directly incorporated, we have so far proposed that a new interpretation is necessary to determine the cause of the abnormal seismic velocities observed for the lowermost mantle, which has so far only been analyzed using seismic wave analysis and mineral physics.

By using a simulation code for core formation caused by planetary collision, we assessed the inhomogeneity of the melting and differentiation process, which we believe exists in deeper parts of the earth. By incorporating the effects of the temperature field in the simulation code for core formation,

we have also successfully determined the initial conditions for thermal convection in the earth's interior. In addition to this, we have developed for ES2 the multiphase flow code for Stokes flow (highly viscous flow) and particles, with the aim of reproducing the effects of deep magma chambers.

In our study on the 3D nonlinear development of the Kelvin-Helmholtz instability, using the simulation code for 3D magnetic fluid, we showed that even a small in-plane magnetic field is amplified by the growth of instability, which then inhibits nonlinear development. We also investigated the nonlinear saturation level of magnetorotational instability using the same code, and showed that when the pressure of the magnetic field exceeds gas pressure, owing to the growth of instability, slow-mode dissipation inhibits the nonlinear saturation level of magnetic stress.

Development of the Vector Tsunameter

The tsunami triggered by the 2011 Tohoku Earthquake caused enormous damage to Japan. To mitigate future tsunami-related disasters, it is critical to develop a new tsunami monitoring system that can predict the scale and arrival time of a tsunami reaching the Japanese coast at an early stage. Contributing to this purpose, IFREE has developed and manufactured a new seafloor tsunami observation device, known as the Vector Tsunameter (VTM). It combines a deep sea differential pressure gauge (DPG), which detects earthquake motion and water-level changes caused by crustal movement and a tsunami as the pressure changes, with an ocean-bottom electro-magnetometer (OBEM), which detects electromagnetic field changes induced by a seawater flow caused by the propagation of tsunami. The VTM can therefore separately observe water-level changes, seawater flow, and the propagation speed and direction of a tsunami, as well as the crustal movement caused by an earthquake. This enables a detailed understanding of the source processes of tsunami generation and propagation through complex topography. It is therefore expected that the VTM will improve the reliability of tsunami predictions in coastal areas. The first VTM was completed in November 2012 and was installed at the seafloor of the Shikoku Basin (25°45.94' N, 137° 0.48' E, depth = 4898 m) during the KR12-18 research cruise of R/V *KAIREI*.

Stagnant slab and volcanism in Northeast China

Northeast China is an area known for active volcanic activities, such as the Changbai volcanic complex on the border between China and North Korea, and the Wudalianchi volcano near the border of China and Russia. These intraplate volcanoes are far from the subduction zone beneath Japan and are difficult to explain in terms of plate tectonics. Previous tomography models show that the Pacific slab subducted from the Japan Trench is stagnant at a depth of 600 km and extends horizontally to China. Based on these results, previous studies proposed that the volcanism in Northeast China is associated with the stagnant slab below. A joint project was launched by Japan, China, and the USA to address the causes of the intraplate volcanism, and a multi-national collaborative seismic experiment deployed more



Figure 3. (Top) Deployment of the Vector Tsunami Meter (VTM) from *KAIKEI*. (Bottom) VTM on the seafloor photographed by *KAIKO 7000II*

than 120 broadband seismometers across Northeast China from September 2009 to August 2011. The maximum spacing of the instruments in the experiment was less than 100 km with an aperture of roughly 1000 km (Fig. 4). Combining the data from the dense seismic experiment with global data, we constructed a new P-wave tomography model of the mantle. We successfully obtained higher resolution images than previous studies by taking finite frequency effects on travel times as a function of frequency into account. The new model shows there is no stagnant slab beneath Songliao Basin where previous tomography images showed an extended stagnant slab. The absence of the slab appears as a hole within stagnant slabs to the north and south at 600 km depth. Figure 5 (A) and (B) depict the cross-sections along the lines (A) and (B) shown in Figure 4. The Pacific slab subducted from Japan Trench is observed as fast anomalies indicated in blue. While a stagnant slab can be clearly seen in the cross-section passing through the southern edge of the Songliao Basin (Fig. 5B), such a stagnant slab cannot be observed in the cross-section passing through the center of the basin (Fig. 5A). The volcanoes in Northeast China are located around the Songliao basin. It is therefore considered that the volcanism in Northeast China is caused by the hole of the stagnant slab rather than the stagnant slab.

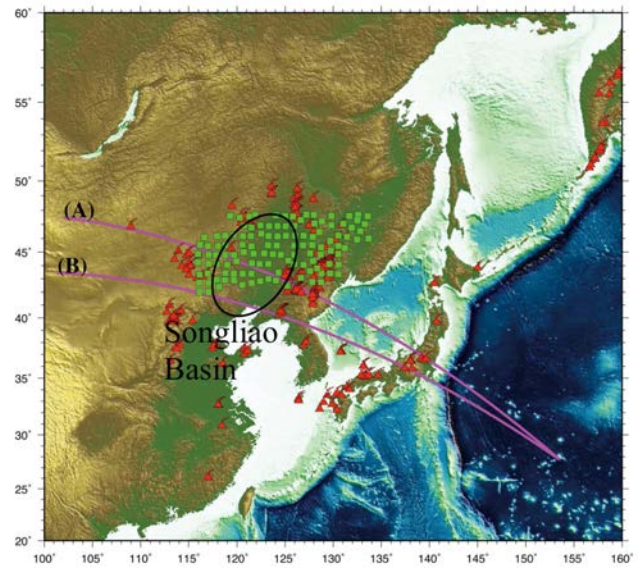


Figure 4. High bandwidth seismographic observation sites (green squares) and volcanoes that erupted in the Quaternary and the Neocene (red symbols) in northern East China

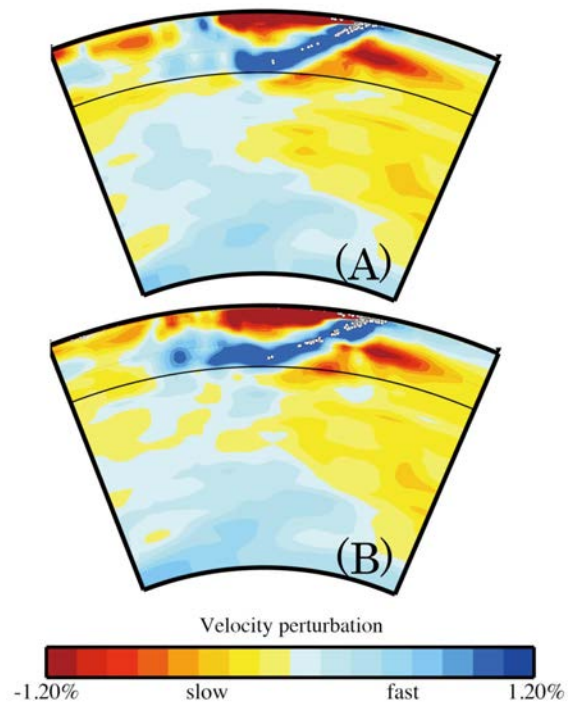


Figure 5. Cross sections along the lines A and B in Fig. 4 (P-wave velocity structure)

Clue to understanding crustal growth process

One of the central issues in earth and planetary sciences is to gain understanding of the origin of the continental crust, which is a unique feature of the earth and is not seen elsewhere in the solar system, and the growth processes involved from oceanic to continental crust. It is the belief of IFREE, that the oceans play an important role in the formation of the continental crust. However, to fully understand the mechanism involved, it is necessary to drill within the seafloor. In relation to this, IFREE has delivered four drilling plan proposals to IODP and has already conducted preliminary surveys. Specifically, led by Japanese researchers, scientists from many countries (including the USA), will drill four sites in the Izu-Bonin arc to deepen our understanding of the growth of the island-arc crust and identify the origin of the continental crust (Fig. 6). IBM-1 drilling will target the coastal crust that existed prior to the start of subduction. IBM-2 will drill the incipient island-arc crust at a site immediately after the point when subduction began, and from which magma is completely different from that of that presently erupted. IBM-3 will drill the back-arc side, which is far away from the trench, in order to identify the changes of the crust along an east-west direction. Using the deep-sea drilling vessel *CHIKYU*, IBM-4 will dig to a depth of 5.5 km below the seafloor, into the middle crust where the continental crust is formed. Humankind has not yet reached the middle crust, which is being formed within the island arc, but our vessel *CHIKYU* is capable of drilling to a deep area within it. The importance of these drilling proposals has been highly acclaimed internationally, and as a result of such support, it has been decided that the drilling vessel *JOIDES Resolution* will conduct IBM-1, IBM-2 and IBM-3 for a period of over six months in 2014. It should also be noted that the importance of IBM-4 was further highlighted at an international conference in September 2012 (<http://www.jamstec.go.jp/ud2012/>). Preparations are steadily progressing for this momentous step for humankind.

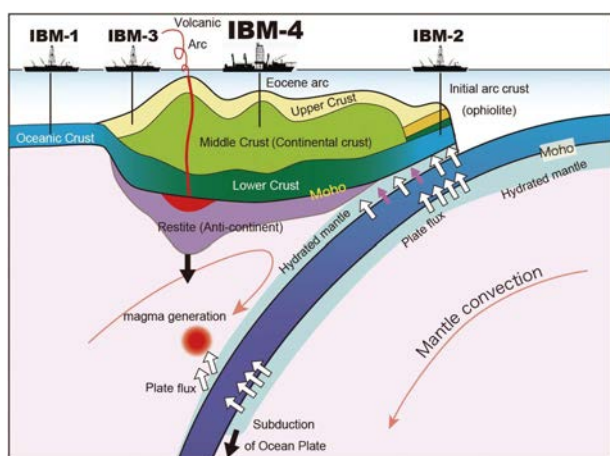


Figure 6. Drilling proposal submitted by IFREE. IBM-1, IBM-2, and IBM-3 will be conducted by American drilling vessel *JOIDES Resolution*. IBM-4 will be humankind's first attempt to drill to a depth of 5.5 km below the seafloor (using the drilling vessel *CHIKYU*).

This research into crustal formation requires a detailed knowledge on the processes through which magma, supplied

by the mantle, thickens the crust. IFREE investigated the origins of tholeiitic and calc-alkaline basaltic magmas typically found in island-arc volcanoes, and showed that the magma that rises from the mantle is calc-alkaline. Investigations also showed that rocks containing amphibole, which form the lower crust, are melted by magmatic heat from the mantle, forming tholeiitic basaltic magma.

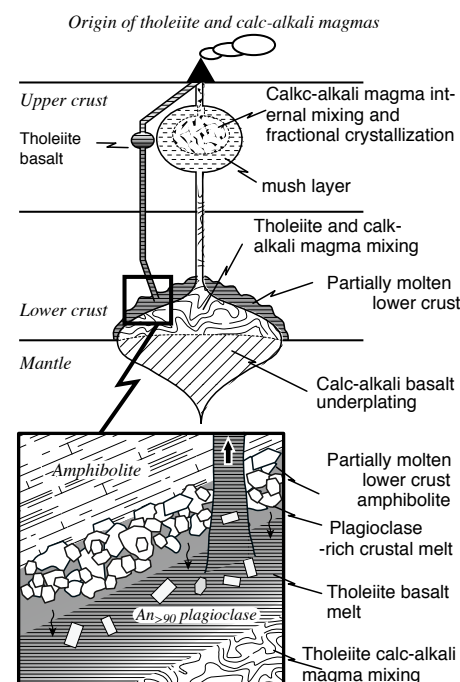


Figure 7. Process by which calc-alkali magma derived from the mantle melts the lower crust to produce tholeiite magma (Takahashi et al., 2012).

Furthermore, IFREE has vigorously investigated topics such as the depth at which a magma chamber is formed inside the crust, based on the analysis of volatile components contained in magma (Fig. 8). It is of interest that through these studies it is indicated that andesite magma is accumulated in the boundary between the upper crust and the middle crust, but that basaltic magma is accumulated in the boundary between the middle crust and the lower crust; each forming a magma chamber. It is hoped that the relationship between these magma distributions and the formation of the middle crust will be elucidated.

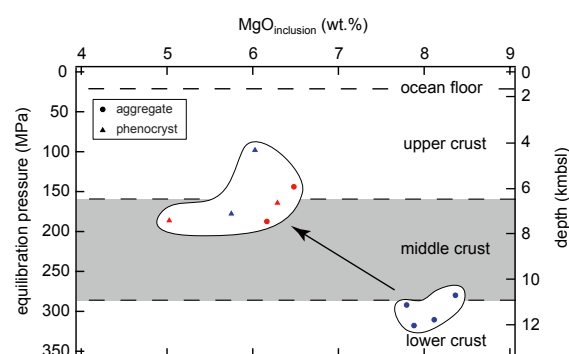


Figure 8. Determination of the depths of magma chambers based on volatile components

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 the deep-sea hydrothermal vents, cold seeps, and anaerobic and subsurface environments beneath seafloor. We also strive to provide knowledge beneficial to the development of the society and the economy by investigating the 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, conduct studies on the following themes:

1) Elucidation of the origin and evolutionary mechanism of life (understanding of biodiversity)

- *From the origin of life to the early evolution (limit of life)
- *The evolution of Eukaryotes (understanding the origin of eukaryotes through endosymbiosis)
- *From single cellular to multicellular organisms (cell differentiation, signal transduction, etc.)

2) Elucidation of the structure and functions of the global biosphere

- *The biogeochemical cycle and its change during the Earth history
- *Monitoring of the marine environment (ocean acidification, diversity variation)
- *The adaptive ecology of organisms in extreme environments (such as those with: high temperature and pressure, low temperature, CH₄, H₂S, anoxic, 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 CH₄ → C₃H₈)
- *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 of 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 Tohoku Region Pacific Coast Earthquake, which occurred on March 11, 2011, and the nuclear accidents that followed, caused significant damage to the marine ecosystems in north eastern Japan. After the disaster, 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 last year. 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. Considering that such information will benefit fisheries, we continue to communicate and share this information with the authorities concerned.

During 2013, BioGeos will conduct an around-the-world research voyage, and extreme environments distributed in the deep sea, mainly in the Southern Ocean, will be studied intensively using the support ship *YOKOSUKA* and the submersible research vehicle *SHINKAI 6500*. In particular, we are surveying the mid-ocean ridge of the Indian Ocean, the South Atlantic off the coast of Brazil, the Cayman Rise in the Caribbean Sea, and the Tonga-Kermadec Trenches. This voyage has been nicknamed QUELLE 2013. QUELLE is an acronym for Quest for the Limit of Life; in German, the word “quelle” means “origin” or “source.” We find this name symbolic, as our aim is to study biotic communities adapted to deep-sea extreme environments and to understand their adaptive ecologies and energy utilization, in order to elucidate the origin of life and evolutionary mechanisms.

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.

Discovery of a unique chemosynthetic animal community

In dark deep-sea environments, chemosynthetic animal communities play an important role as producers of organic carbon in deep-sea ecosystems. Chemosynthetic animal communities have been found in methane rich or sulfide rich environments near hydrothermal vents and seeps. *Calyptogenia* clams are known to form such chemosynthetic animal communities. In collaboration with the Hydrographic and Oceanographic Department of Japan, Shizuoka University, the University of Iowa, Fukada Geological Institute, the University of Texas at Dallas, the University of Hawaii at Manoa, and the University of Rhode Island, we found a new type of *Calyptogenia* clam community that is composed of a new *Calyptogenia* species. This community was found at the Shinkai Seep Field (SSF: depth was 5620 m) on the slope of the Challenger deep in the Mariana Trench, where hydrogen sulfide is produced by serpentinization of peridotite (Figs. 1 and 2). This discovery indicates that chemosynthetic communities form in geological settings wherein the mantle substance reacts with seep-water. Because this environment is thought to be similar to the ancestral environment where the earliest life appeared on the earth, this location may serve as an excellent model for the study of the origin of life on earth.

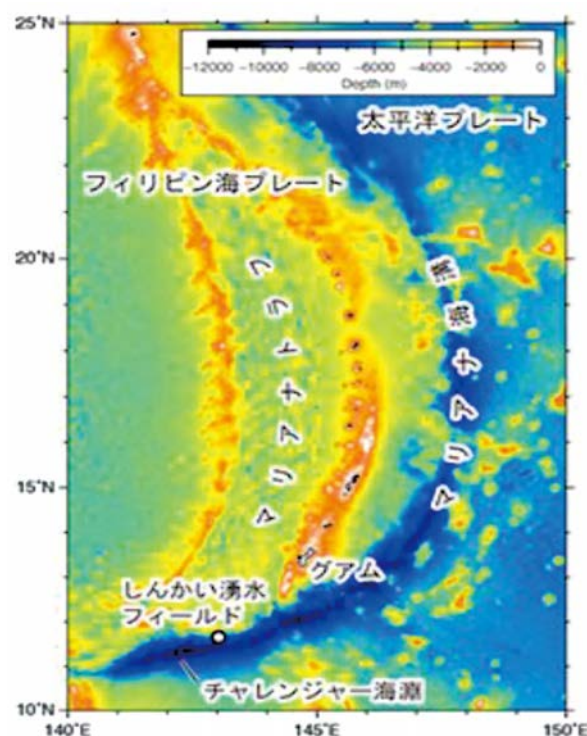


Figure 1. A community of a possible new *Calyptogenia* species found at Shinkai Seep Field in the Mariana Trench.



Figure 2. A colony of a possible new species of *Calyptogenia* clam found at the Shinkai Seep Field

Cultivation of *Osedax japonicus* and its complete life cycle

In 2004, *Osedax* was first reported as a new genus of Annelida after it was found on a sunken whale carcass. Since then, many species of this genus have been found in whalebone animal communities. These are closely related to Siboglinid polychaete tubeworms and have no digestive tract, mouth, or anus. These tubeworms drill a hole into whalebones and harbor heterotrophic symbiotic bacteria in a root-like structure, which is inserted into the hole in the whalebone. We were the first in the world to successfully grow *O. japonicus* from fertilized eggs to reproductive adults, a complete life cycle, in the laboratory. In addition, we isolated and cultured 2 bacterial strains from sediments sampled near whalebones. The bacterial strains were molecularly phylogenetically identical to the symbionts of *O. japonicus*. When they were added to the developing larvae of *O. japonicus*, they infected the larvae and newly established a symbiotic relationship with the host (Fig. 3). This indicates that the symbiotic system of *O. japonicus* and the symbiotic bacteria we isolated will provide a good experimental model system for the study of symbiosis.

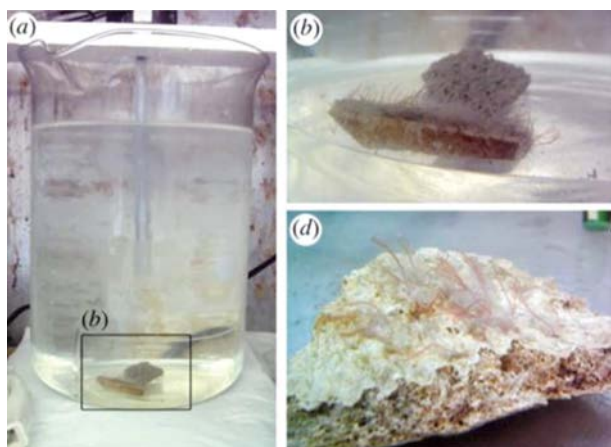


Figure 3. *Osedax japonicus* cultured in the laboratory.

Inorganic carbon transport mechanism in the *Calyptogena* clam-symbiont system

In *Calyptogena* clams, which are chemosymbiotic animals, thioautotrophic symbiotic bacteria intracellularly symbiose in the host gill epithelial cells. The symbiont oxidizes hydrogen sulfide, fixes inorganic carbon, and produces organic compounds. The host animal obtains these organic compounds and uses them as nutrients. While animals generally use nutrient organic compounds and discharge inorganic carbon, these symbiotic host animals take up inorganic carbon and supply it to the symbiont for thioautotrophic metabolism. Comparative biochemical studies of the gill tissues of *Calyptogena* clams, some related symbiotic mussels, and an asymbiotic mussel showed that *Calyptogena* clams express large amounts of carbonic anhydrase in their gill epithelial cells. This enzyme probably plays an important role in the transport of inorganic carbon to the symbiont in their gill tissues (Fig. 4).

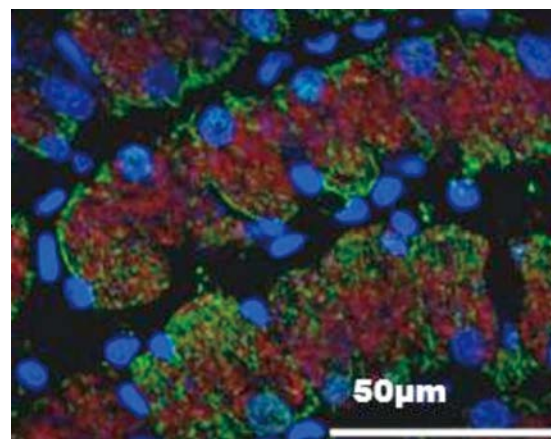


Figure 4. Localization of carbonic anhydrase in the gill epithelial cells of *Calyptogena okutanii*. Blue, nuclei of clam cells; Red, thioautotrophic symbiotic bacteria; Green, carbonic anhydrase of *C. okutanii*.

Development of a microscopic observation chamber for determining the effect of high pressure on animal behavior

A microscopic chamber for observing animal behavior under high pressure is under development. The animal in the chamber is observed through a small Pyrex glass window while pressurized seawater is supplied to the chamber by a high-pressure pump. We have used this chamber to observe *Artemia franciscana*. Under 200 atm, the animals moved actively, but at 600 atm, the animals ceased their motions and sank to the bottom of the chamber. When the pressure was decreased to 1 atm, the animals resumed their normal active motions. We plan to use this chamber to observe the behavior of various animals, including deep-sea animals, and comparatively study the effects of pressure on their behavior (Fig. 5).

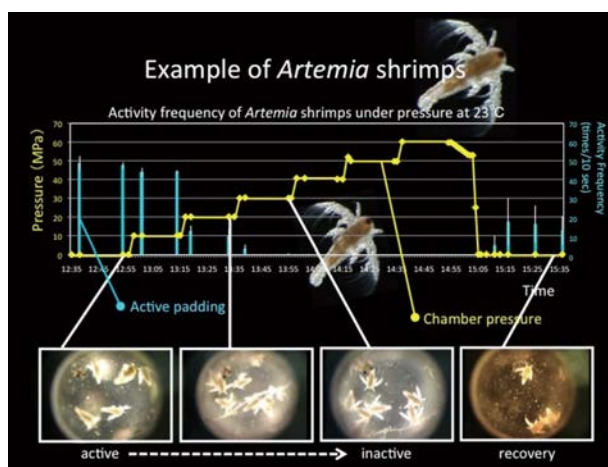


Figure 5. Effect of high pressure on the motile behavior of *Artemia salina*. Ordinate, Pressure in Mpa; Abscissa, time of day during the experiment. The pressure at a depth of 2000 m is 20 Mpa. Blue lines indicate motile activities (paddling) of *A. salina*.

Searching for useful enzymes in deep-sea microbes

Seaweeds contain unique carbohydrates. Some red algae belonging to the order Gigartinales contain carrageenan. This carbohydrate is often added to various foods and drinks as a gum in order to increase viscosity. Carrageenan is a polymer with units of sulfated galactose and anhydrogalactose. Three types of carrageenan, each with different sulfate contents, are known: kappa, iota, and lambda. We searched for specific hydrolyzing enzymes for these 3 types of carrageenan and found them in deep-sea bacteria. The lambda carrageenase, which specifically hydrolyzes the lambda-type carrageenan, was the very first hydrolyzing enzyme of this compound reported in the world. A new EC number, EC 3.2.1.162, was assigned to it by the Enzyme Commission of the International Union of Biochemistry and Molecular Biology. Because the substrate specificities of the enzymes that we discovered were high enough to permit identification of the 3 types of carrageenan, we developed a new method of identifying them in foods and beverages (Fig. 6). This method is simple and accurate, and several food companies have expressed interest in using it.

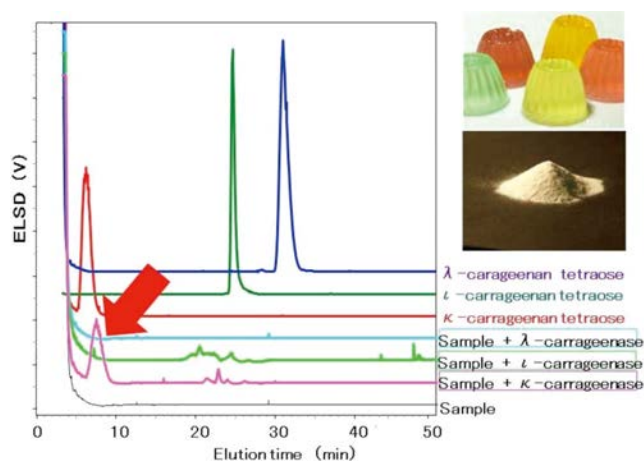


Figure 6. Upper right. Some foods containing carrageenan. Result of carrageenan type analysis of a food item indicating that the food contains kappa-carrageenan (Left).

Extremobiosphere Research Program

(1) Diversity within the hadal trench biosphere

The extremobiosphere research program, which investigates dark ecosystems in order to understand the cycles of energy, materials, genetic factors, and functional factors in such ecosystems, focused on environments such as deep-sea hydrothermal areas and cold spring areas. However, in 2012, the program began to research the hadal trench biosphere in the subduction zone of the western Pacific.

Based on the results of a structural and functional analysis of microbial populations found in marine sediment in the Bonin Trench at a depth of 10,000 m, we have revealed the existence of an active microbial ecosystem within the hadal sediments. This ecosystem has a metabolic network in which the activity

of unique heterotrophic organisms is interweaved with processes such as decomposition of organic matter generated by surface photosynthetic production, reproduction by ammonia oxidation through which ammonia mineralized by metabolism of organic matter is recycled, and nitrate reduction and anaerobic ammonia oxidization resulting from reproduction.

In the Mariana Trench, which is a hadal trench situated in a subduction zone in the western Pacific, we conducted a structural and functional analysis on the microbial populations found in a range of habitats, such as the water mass and the sediments. It is predicted that unique heterotrophic microbial populations, associated with the breakdown of organic matter produced by present and past surface photosynthesis, develop in the hadal water mass, but not in the sediment, as in the Bonin Trench. Within the sediment, however, a microbial ecosystem predominates in which ammonia-oxidizing microbial populations depend on ammonium supplied by the water mass. As the reasons for the state and drive principles for the Bonin and Mariana Trenches are different, it is suggested that this relates to physical and chemical factors, such as the difference in surface productivity and the formation of a closed environment by an ocean current in the trench.

(2) Research on genetic factors within the dark ecosystem

We analyzed genetic factors in the sediment environment in the Bonin and Mariana Trenches, and in the fore-arc basin off the Shimokita Coast, with a particular focus on the metagenome analysis of viruses. Few studies have been conducted on the diversity and dynamics of viruses found in a hadal marine sediment. It was shown that in all sediment environments, viruses that predominate have single-stranded DNA as a genetic factor. A structural analysis of the viruses showed that specific taxa predominate in hadal marine sediments. It has since been revealed that many of the viruses are Lysogenic viruses.

Another project was to quantify the virus biomass in core samples collected during seafloor drilling surveys. In particular, we used core samples from depths of up to a few hundred meters below the seafloor in areas such as the fore-arc basin off the Shimokita Coast, the Cascadia Basin, and the continental slope in the Gulf of Mexico. We investigated the relationship between microbial biomass and virus biomass, as well as their association with sedimentary characteristics. The results reveal that microbial production and activity in the sub-seafloor environment are not necessarily correlated with the virus biomass. This is consistent with the findings of our metagenome analysis, which show that a limited number of infectious viruses inhabit marine sediments, and that temperate viruses predominate. It was also shown that the physical diagenesis (compression) of sediment had an even stronger influence on the maintenance (preservation) of virus biomass than the microbial population production.

We also successfully isolated temperate viruses from chemically synthesized microorganisms, which are important genetic factors in dark ecosystems, and we determined

their genomic sequences. We lysogenized the prophage of Epsilonproteobacteria, an important primary producer in deep-sea hydrothermal environments, and determined the genome sequence of the virus, thereby obtaining important findings concerning the transfer of genetic factors between the host and the virus. Epsilon proteobacteria in many deep-sea hydrothermal environments contains a prophage that infected the ancestral form of the bacteria prior to its evolution and radiation, indicating the possibility that the prophage played an important role in the evolution and adaptive radiation of Epsilon proteobacteria. Following the quantification of virus biomass in the deep-sea hydrothermal environment in 2011, we made considerable advances in research into genetic factors within the dark ecosystem during 2012.

(3) Discovery of new cellulase from well shrimps in the Mariana Trench

To comprehensively understand the ecosystem in the hadal trench biosphere, the Extremobiosphere Research Program has conducted a metagenome analysis of the sediment collected from the Mariana Trench. In addition, to investigate the ecology of the amphipod, *Hirondellea gigas*, a creature at the top of the food chain in the oligotrophic hadal trench biosphere, we analyzed its gastrointestinal enzymes. At least four polysaccharide-degrading enzymes were confirmed, among which we discovered a cellulase that was completely different from known cellulases. This cellulase directly converted crystalline cellulose to glucose and cellobiose at a ratio of 2:1, and at present, this is the only known enzyme that can directly produce glucose from cellulose. Based on these results, it is strongly suggested that *H. gigas* ingests wood chips and other materials found within deep-sea sediment. These findings were released to the media in August, along with publication of this research, and they generated excitement within Japan and overseas. We have now begun genetic cloning to mass-produce this enzyme.

(4) Creation of new soft matter materials using research from the deep-sea extreme environments

A deep-sea hydrothermal activity zone could be partially supercritical above the liquid-vapor critical point (374 °C and 218 atm for pure water). It is known that, under such high-temperature and high-pressure extreme environments, water behaves in a totally different manner than normal (e.g., it mixes freely with oil). Using the characteristics of water under such an extreme state, the Extremobiosphere Research Program has developed an emulsion method based on a principle fundamentally different from that of traditional methods. This method allows for the preparation, in less than 10 seconds, of a highly transparent nano-emulsion in which ultrafine oil droplets (diameter smaller than 100 nm) are dispersed in water. This method can be used to manufacture products that require emulsions such as food, cosmetics, and medicines. The advancement of future joint research towards such applications is eagerly expected.

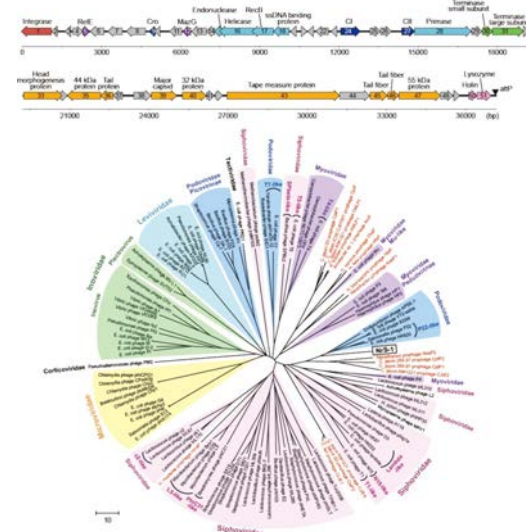


Figure 7. Genome gene structure and virus taxonomy of the lysogenic phage NrS01 isolated from Epsilonproteobacteria (*Nitratiraptor* sp.), the genomic sequence of which has been determined

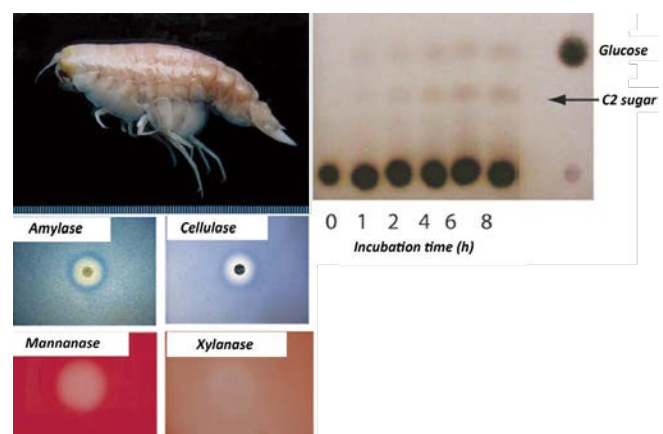


Figure 8. *Hirondellea gigas* collected from the Mariana Trench; four types of polysaccharide-degrading enzymes; and reaction products of the new cellulase. Thin-layer chromatography shows that glucose and cellobiose are the only degradation products of cellulose.

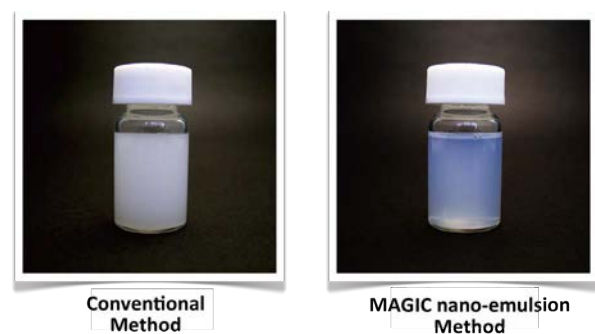


Figure 9. Highly transparent emulsion (nano-emulsion) created in a supercritical fluid

Earth and Life History Research Program

Understanding the feeding habits of eel larvae

The diets of various organisms in the wild can be determined using our diet analysis method that employs the nitrogen isotope ratio of amino acids. Using this method, the diet of the eel larva *leptocephalous* was estimated in collaboration with Professor Katsumi Tsukamoto of the University of Tokyo.

Recently, eel harvest has decreased significantly, and the development of full-cycle culture technologies has been called for. However, to realize full-cycle culture, it is necessary to ascertain what leptocephali eat in the wild. Several theories have so far been proposed, and have long been discussed. These include the marine snow theory, the larvacean “house” theory, and the gelatinous zooplankton theory. BioGeos analyzed leptocephali collected at the Mariana Trench as well as cultured specimens to determine their trophic levels. We obtained a result of 2.4, which is close to the trophic level of zooplankton that exclusively feeds on phytoplankton (Fig. 10). We consider, therefore, that this result refutes the larvacean “house” theory, (which requires a trophic level of 3 or higher), and supports the marine snow theory, thereby resolving this long-standing discussion.

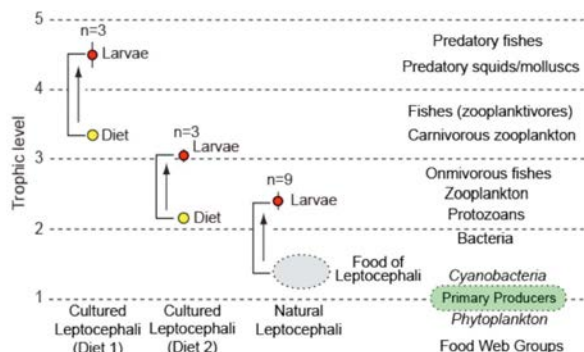


Figure 10. Estimated trophic levels of leptocephali cultured and collected from the Mariana Trench

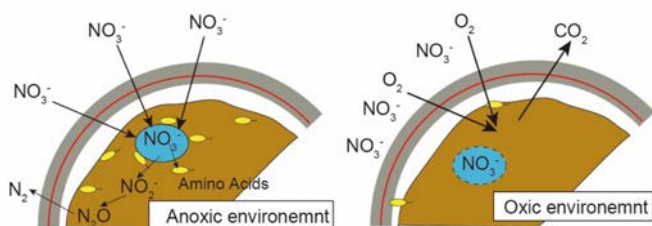


Figure 11. Schematic figure of benthic foraminiferal utilization of nitrate. Under anoxic conditions, nitrate was utilized from foraminiferal nitrate pools and remained nitrate become enriched in ^{15}N .

Adaptation of shallow-water benthic foraminifera to anoxic environments

Sediment-water interface plays important roles in the marine nitrogen cycle since various nitrogen processes take place across the oxic part in the overlying water to anoxic part in the deeper part of sediments. Some benthic foraminiferal species have been reported to respire nitrate under dysoxic conditions. However, little is known about their ecological/physiological adaptations to such dysoxic environments. We incubated a shallow water benthic foraminifera, *Ammonia beccarii*, under oxic and anoxic conditions to compare their nitrate utilizations using stable isotope labeling techniques. The measured nitrogen isotopic ratios indicated that enhanced utilization of nitrate under anoxic conditions. This may be facilitated by prokaryote in the foraminiferal cells. The difference between $\delta^{15}\text{N}$ of foraminiferal bulk cell including prokaryotes and calcareous test organic matter which solely originated from foraminifera, may become useful proxy to infer foraminiferal adaptation to anoxic environments.

Food chain in the marine ecosystem

The marine ecosystem consists of various biotic communities and exists based on complicated predator-prey interactions among organisms. This knowledge is extremely important in identifying the response patterns of organisms to environmental changes. Using our trophic level estimation method, which is based on an analysis of amino acid nitrogen isotope ratios, we conducted research with the aim of understanding the structure and roles of the marine ecosystem, as well as the adaptation patterns of constituent marine organisms to the environment through evolution and symbiosis. Through this study, we have shown that this trophic level estimation method can be applied to photosynthesis-based ecosystems as well as to chemosynthesis-based ecosystems, and therefore, to the broader marine ecosystem (Fig. 12).

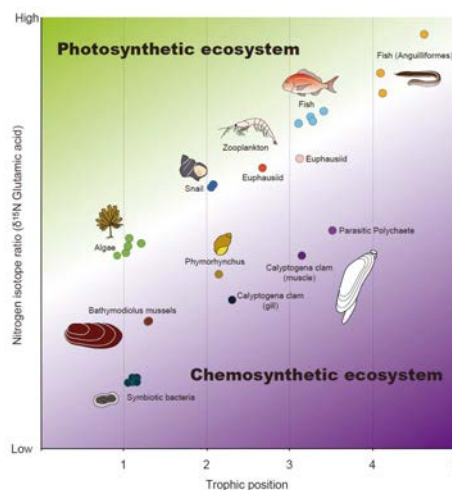


Figure 12. The nitrogen isotope ratios of glutamic acid and phenylalanine were determined for marine organisms collected in the Sagami Bay. Trophic levels were then calculated to clearly distinguish between photosynthesis-based and chemosynthesis-based ecosystems.

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 2011 Tohoku Earthquake 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. Japan is currently the global leader in seismological research; however, following the 2011 Tohoku Earthquake, it has been hotly debated whether previous research on subduction zone earthquakes has been sufficient and whether the research findings have been used appropriately in outreach activities (which aim to prevent and mitigate disasters) and anti-disaster and evacuation measures. Based on lessons learned from the 2011 Tohoku Earthquake, an urgent review of research topics related to subduction zone earthquakes is required; additionally, better information transmission and use of the findings of seismological research should be ensured to help prepare for Nankai Trough megathrust earthquakes and near-field earthquakes in the Tokyo metropolitan area, the recurrence of which has been projected.

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)

This year, we conducted preliminary research to investigate the second phase of DONET (DONET2). Specifically, we conducted oceanfloor bathymetric surveys using an echo sounder, surveys of the route along which submarine cables will be installed using Deep tow (a deep ocean floor survey system), and piston core surveys at sites where observation will be undertaken in the target area (area surrounded by blue broken line in Fig.

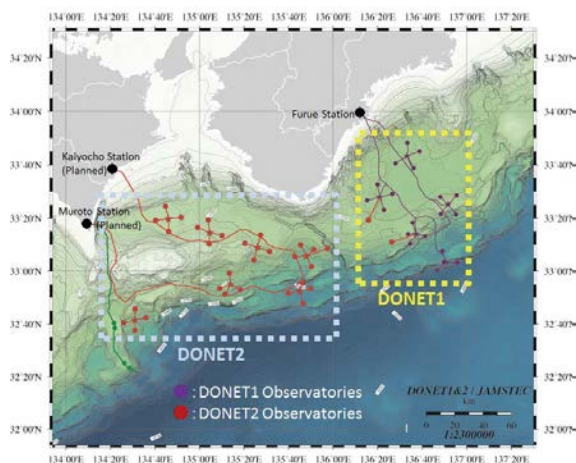


Figure 1. Target areas of DONET (currently under operation) and DONET2

1). Based on these surveys, we determined the optimum cable installation route and the locations of the observation stations. We also developed and manufactured submarine devices such as observation sensors.

For the planned land station sites, we are currently establishing a pipeline from land to the shallow sea using the horizontal directional drilling (HDD) method to enable landing of submarine cables.

Compared with DONET, which was established off the coast of Kumanonada, DONET2 will contain a larger number of observation stations; therefore, it will require more efficient submarine operation using remotely operated vehicles (ROVs). Dense deployment of observation stations is one of the characteristics of DONET and requires installation of extension cables using an ROV. Because installation of such extension cables requires long hours of delicate installation control, techniques that increase the efficiency of this installation through the use of automated ROVs are expected.

This year, we have developed a device that automatically adjusts the laying of the tension cable, the most important part of the cable installation operation, and have confirmed its effectiveness in an experiment conducted in the project area. This device measures the ground speed of the ROV using the Doppler velocity log (DVL) and controls the laying of the extension cable attached to the rear side of ROV based on this speed (Photo 1).

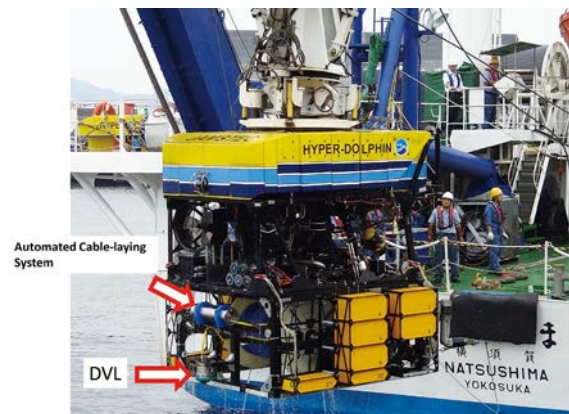


Photo 1. Automated cable-laying System

The DONET observation stations currently under operation clearly detected the seismic waves and tsunamis caused by the M7.7 earthquake that occurred on Oct 27, 2012, near the Queen Charlotte Islands in Canada.

The seismic waves were observed just past noon on October 28 (Japan time), and the first tsunami wave was observed before 22:00 on the same day (Japan time) (Fig. 2). According to hydraulic meter data, a tsunami with a wave height of 7 mm was observed at one of the observation stations (KME20; 1977 m depth). Subsequently, many more tsunami waves were observed.

The tsunami period of approximately 3 minutes were observed.

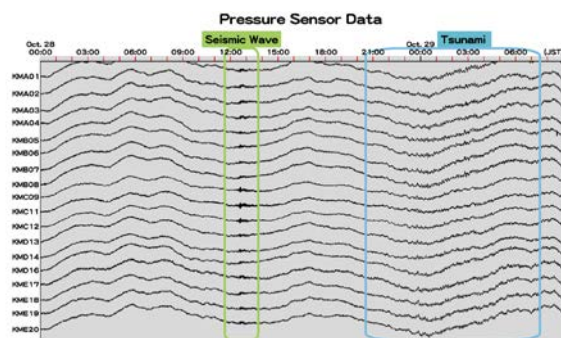


Figure 2. Pressure sensor data (sea tide was eliminated)

Research assessing the interrelation between Nankai megathrust earthquakes

Some of the megathrust earthquakes that have occurred repeatedly in the Nankai Trough occurred interrelated with the Tokai, Tonankai, and Nankai earthquakes; moreover, it has been suggested that such interrelated earthquakes may continue to occur in future. Since 2008, entrusted by the Ministry of Education, Culture, Sports, Science and Technology and in collaboration with other universities and research institutes, we have been investigating how these earthquakes can occur interrelated and grow to such enormous scales.

To investigate the shape of the subducting Philippine Sea plate and the detailed structure of the areas near the plate border, JAMSTEC has been conducted structural exploration, observed seismic activity, and implemented reflection surveys using an ocean bottom seismograph, traversing the trough from west to east. We performed structural exploration and observation of seismic activity in the Tokai offshore area this year.

Based on analysis of the observational data collected to date, we have been able to estimate the deep structure of the land-ocean border area using a plate geometry model for the Hyuganada area combined with data collected at land observation stations. Figure 3 illustrates the survey lines.

Based on the results of the structural analysis, we have grasped the shape of the Philippine Sea plate between Hyuganada and off the coast of Shikoku in detail; we have also identified structural changes occurring inside the overriding plate and are gradually beginning to understand their association with the focal regions of mega-earthquakes (Fig. 4).

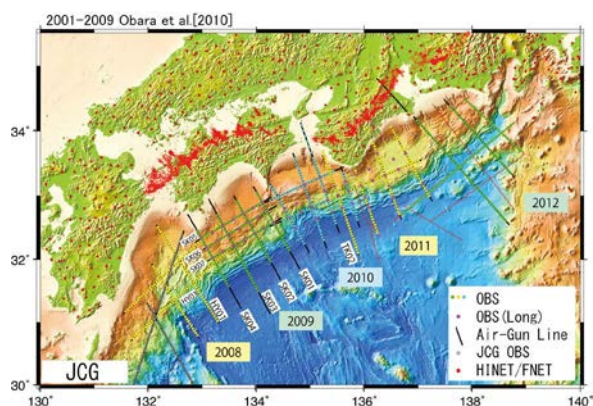


Figure 3. Survey lines

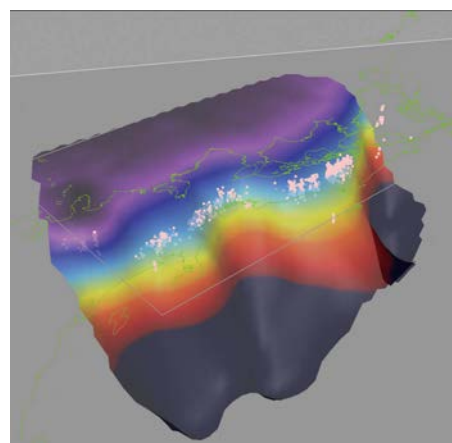


Figure 4. Plate geometry model incorporating structural information for the region between Hyuganada and off the coast of Shikoku

However, analysis of the structure of the generation areas of deep low-frequency earthquakes has also been required for many areas. Notably, we analyzed subsets of the structural exploration data obtained for the areas surrounding the Kii Channel; based on the results, we confirmed the presence of a reflector that was significantly more intense than normal mid-crustal reflectors in the gap area of deep low-frequency seismic activities inside the overriding plate. This finding may indicate sudden changes in the boundary between the focal regions of the Nankai and Tonankai earthquakes.

As part of this research, we have hosted regional workshops attended by representatives from universities, research institutes, national and local governments, and lifeline utilities companies in Kochi, Osaka, Nagoya, Kishu, Kyushu, and other locations. Such workshops help apply our research findings to the planning of regional disaster prevention/mitigation measures.

Intensive survey and observation research in the strain concentration area

Large-scale earthquakes have occurred frequently in the Japan Sea off the coast of Tohoku (e.g., the Niigataken Chuetsu-oki Earthquake 2007 Chuetsu earthquake), and a strain concentration area is known to exist in the area.

Since 2009, entrusted by the Ministry of Education, Culture, Sports, Science and Technology, JAMSTEC has been conducted reflection surveys and research in this strain concentration area using an ocean bottom seismometer to reveal an overview of the active structure of the region, including the active faults and folds. We aim to advance the prediction of earthquake scales and improve the evaluation of the timing of earthquake occurrence and strong motion by establishing a source fault model based on the observational data.

This year, targeting the waters stretching from the eastern edge of the Sea of Japan, the area south of the Oga Peninsula to the area west of Aomori Prefecture, we conducted reflection surveys (multichannel seismic (MCS) surveys) and refraction/wide-angle reflection surveys (ocean-bottom seismic (OBS) surveys) using a multichannel streamer and ocean bottom seismometers, respectively (Fig. 5). In particular, we focused on

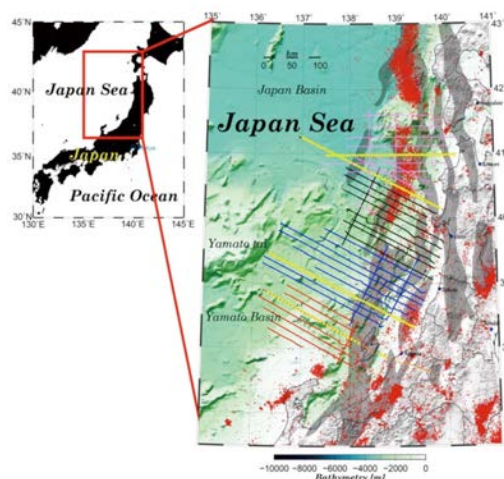


Figure 5. Survey line map for 2009–2012

the focal region as the center of the 1983 Sea of Japan earthquake.

It was shown that the crustal structure and the deformation zone differed between the northern side (off the coast of Akita Prefecture to off the coast of Nishitsugaru) and southern side (off the coast of Sado Island to off the coast of Yamagata Prefecture) of the line at 39°30'N. On the southern side, there are many active structures that suggest inversion of the structures that developed when the Sea of Japan was formed, most of which exist within the continental crust structure; such structures include the mostly westerly inclined reverse fault in the Sado Ridge and the structures of the sedimentary basin around the Mogami Trough and the continental shelf. The northern side also exhibits many inverted deformation structures around the continental shelf and in the Nishitsugaru Ocean Basin, where continental crust was formed; however, in areas west of the focal region of the 1983 Middle-Sea of Japan earthquake, deformation structures corresponding to the crustal boundary can be recognized.

Research on highly accurate earthquake and tsunami prediction by the K computer.

As part of the High-Performance Computing Infrastructure (HPCI) Program of the Ministry of Education, Culture, Sports, Science and Technology, which has been in operation since

2011, we have conducted research to investigate highly accurate earthquake and tsunami prediction and simulation of natural disasters (e.g., earthquakes) in urban areas.

The K computer began its full-scale operations at the end of September 2012. With our simulation models nearing the end of their tuning stages, we hope to see results once the models have been incorporated into the K computer and allowed to run sophisticated calculations.

Development of a long-term borehole observation technology

This technology is used to collect a wide range of data from below the ocean floor over a long period of time by loading a sensor package containing equipment such as a seismometer, an inclinometer, a strain meter, and a thermometer into a borehole (water depth 1938 m; depth below seafloor about 750–940 m). The borehole was drilled by the deep sea drilling vessel *CHIKYU*

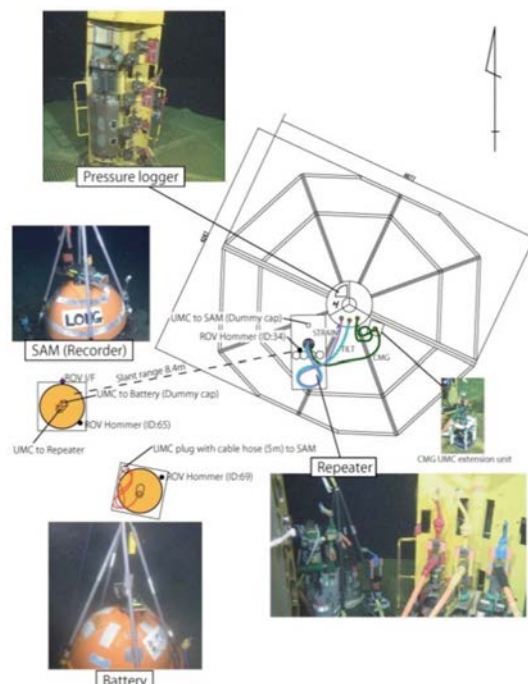


Figure 6. Long-term borehole observation C2 station

in 2010 during the IODP expedition to the Nankai Trough earthquake zone (Fig. 6).

The long-term borehole observatory was connected to DONET1 in this January during the research cruise. This means real-time observation and monitoring of the ocean floor and borehole below the surface become possible, then the improvement of earthquake occurrence scenario is expectable.

Real-time deep sea observation system

We started providing hydraulic tsunami meter data collected by the real-time deep sea observation system to the Meteorological Agency on March 9, 2012. A tsunami triggered by an earthquake that occurred on March 14 in the same year off the coast of Sanriku was observed by the Kushiro-Tokachi Observation System. The tsunami was 10 cm high at the Shoya area of Erimo Town and the Kiritappu area of Hamanaka Town. The Kushiro-Tokachi Observation System detected the tsunami 20 min earlier than the tidal observatories located along the Hokkaido coast (Fig. 7).

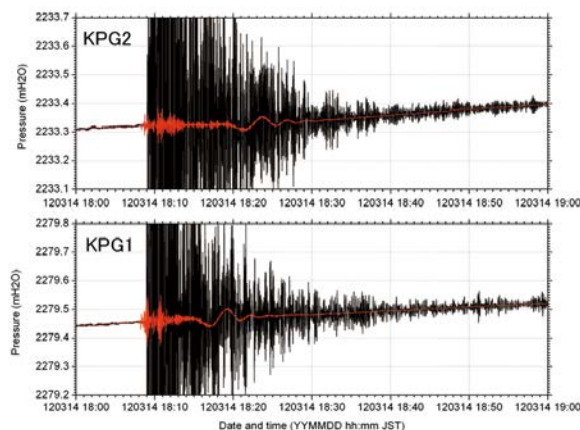


Figure 7. Tsunami observed by the tsunami meter at the Kushiro-Tokachi Observation System

Submarine Resources Research Project

Overview

The Environmental Impact Assessment Research Group was established on April 1, 2012 within the Submarine Resource Research Project (SRRP) to study the ecosystem assessment in case of resource exploitation. The research group consists of the experts from various fields such as biology, microbiology, ecology, and engineering, to investigate how to assess the impact on marine ecosystem and to determine the transition of environmental conditions.

During 2012, second fiscal year, researchers of SRRP joined a total of 21 cruises. SRRP played a principle role for 8 of them. A lot of new knowledge on submarine resources has been accumulated with these research cruises. The deep-sea expedition using an autonomous underwater vehicle (AUV), “*URASHIMA*”, achieved several prominent results, e.g. discovery of the novel hydrothermal area in the Iheya Small Ridge of Okinawa Trough, and the high-resolution topographical image of a mud volcano off the Tanegashima Island, southern Kyushu. The reports of the achievements of each research group for the 2012 fiscal year are presented in the following sections:

Geobio-Engineering and Technology Group

The Geobio-Engineering and Technology Group conducts basic and applied engineering research to help create a sustainable carbon cycle system, using the hydrocarbon resource environments in the waters close to Japan as a test field.

Between June 23 and 28, 2012, JAMSTEC conducted drilling at the Kumano mud volcano no. 5 using a hydraulic piston coring system (HPCS) and a newly developed hybrid pressure coring system (Hybrid-PCS) on the deep sea drilling vessel *CHIKYU*. Mud volcano samples were collected from the summit to a depth of 200 m; high-pressure core samples containing methane hydrates were also collected (Fig. 1; press release on July 8, 2012). Based on the measurement of in situ temperature taken inside the mud volcano, the lower limit of the stability zone of methane hydrates inside the conduit was estimated to be around 590 m from the summit. Using core samples collected during this drilling expedition, detailed studies of the geochemistry, microbiology, and sedimentology of the mud volcano were conducted.

Furthermore, between October 5 and 15, 2012, we conducted a seafloor topographic survey on a mud volcano off Tanegashima Island and captured detailed seafloor images using the side-scan sonar of the autonomous underwater vehicle (AUV) *URASHIMA*. We plan to continue investigating mud volcanoes off Tanegashima Island in 2013.

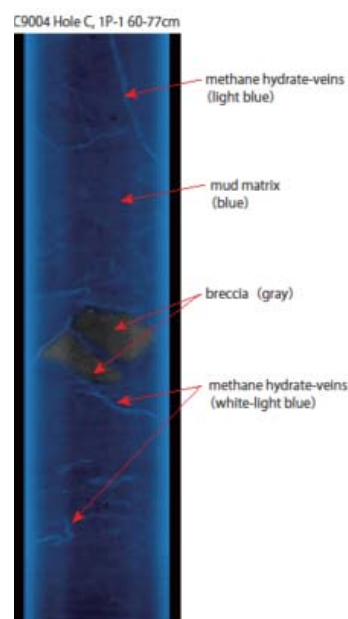


Figure 1. X-ray CT scanning image of a core sample inside an aluminum pressure vessel (200 atm)

Between July 26 and September 26, 2012, we conducted the Integrated Ocean Drilling Program (IODP) Expedition 337, entitled “Deep Coalbed Biosphere off Shimokita” on the deep sea drilling vessel *CHIKYU*. We successfully drilled 2466 m below the seafloor, which represents the deepest drilling ever achieved in scientific offshore drilling; we collected core samples from the coal formation, analyzed the isotopic composition of natural gas components continuously, and conducted detailed borehole logging (see press releases from July 12 and September 6, 10, and 27, 2012). Using the core samples and analytical data collected during the expedition, we intend to investigate a biogeochemical hydrocarbon system originating from the coal bed, the possibility of carbon dioxide sequestration (carbon capture and storage (CCS)) into a very deep coal formation, and the recycling of carbon dioxide (Bio-CCS).

Furthermore, using a new multiple high-pressure reactor known as the geo-bioreactor system, which can reproduce below-seabed temperature and pressure conditions, we have initiated research of interactions between carbon dioxide, minerals, and organisms to simulate CCS in a coal formation that consists of the coal bed and sandstone. Specifically, we are currently undertaking observation of the microstructure of sediment using the microfocus X-ray CT scan system and an electron microscope (Fig. 2), measurement of the penetration rate of liquid and supercritical carbon dioxide fluid, and a wide range of reproductive experiments and applied engineering research (particularly that investigating the development of technologies promoting carbon conversion using microorganisms). We are also preparing to investigate CCS environment dynamics using natural deep sea basal sediments and methane hydrates-exposed environments.

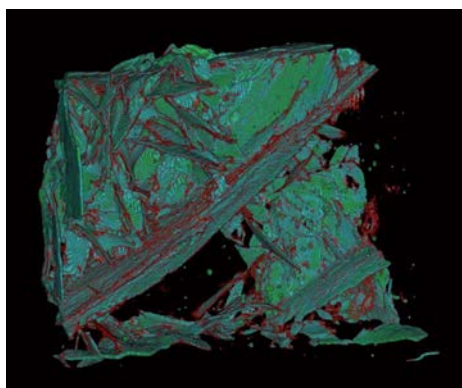


Figure 2. Microfocus X-ray CT scanning image showing the cleat structure and the distribution of iron in coal (Eocene Urahoro Group)

Submarine Hydrothermal System Research Group

The research expedition conducted by the deep-sea drilling vessel *Chikyu* in September 2010, under the framework of the Integrated Ocean Drilling Program (IODP), suggested the possible existence of the world's largest hydrothermal deposit in the deep-sea hydrothermal area of the Okinawa Trough. Our group aims to explore similar seafloor hydrothermal mega-deposits in the Okinawa Trough, based on a newly developed exploration approach combining multiple research platforms with geobiological hydrothermal plume sensing, in order to understand the relationships between hydrothermal circulation system and subseafloor ecosystems and to contribute to future mining of deep-sea hydrothermal deposits in Japan.

In 2012, as the first step of the exploration, we conducted an integrated survey in the Okinawa Trough, which combines hydroacoustic sensing and chemical sensor surveys with AUV *Urashima* and single-channel seismic (SCS) survey using R/V *Yokosuka*. This survey identified possible new hydrothermally active areas existing at the Iheya Ridge. In addition, the new data about shallow crustal structure of the area provided by the survey helped to estimate hydrothermal fluids pathways. We also tested detailed acoustic survey from a surface ship using a multi-narrow beam system to detect hydrothermal plumes. This year, we conducted the multi-narrow beam acoustic survey using R/V *Natsushima* at the Iheya North hydrothermal field and successfully captured hydrothermal plume signals that are difficult to detect chemically. This confirms that the acoustic survey from a surface ship can be a useful and efficient tool for extensive survey of deep-sea hydrothermal deposit.

We have also published the discovery of the Urashima Hydrothermal Field in the southern Marianna Basin, based on an integrated geophysical survey (acoustic and geomagnetic surveys) using AUV *Urashima*. The successful result of this survey served as a trigger to develop our new integrated hydrothermal plume survey method that combines multiple survey platforms with geobiological sensing. Using the method,

we will conduct further hydrothermal survey at the Rodriguez Triple Junction in the Indian Ocean, in early 2013.

To date, the hydrothermal fluid chemistry and diversity of microbial ecosystems in the deep-sea hydrothermal areas of the Okinawa Trough have been well studied. In contrast, there are essentially no investigations regarding mineralogical and geochemical variations of the hydrothermal sulfide deposits (including chimney structures) and their relation to geological settings of the Okinawa Trough. We are currently accumulating the data for elemental compositions and isotopic ratios of the world's best sulfide ore sample set that we collected from various hydrothermal areas in Okinawa Trough. Our initial results revealed that the composition of metal sulfides varies widely, even within the the Okinawa Trough (Fig. 3). For example, Yonaguni Knoll IV samples were found to be rich in gold, Hatoma Knoll samples were very rich in silver and antimony, and Iheya North samples contained a wide variety of rare metals. These results are quite important not only to estimating the resource potential of deep-sea hydrothermal deposits in Japan, but also to understanding ore genesis and geological background of the deposits. In future, our data will be published as an open database of basic information that will be beneficial for both academic and industrial communities.

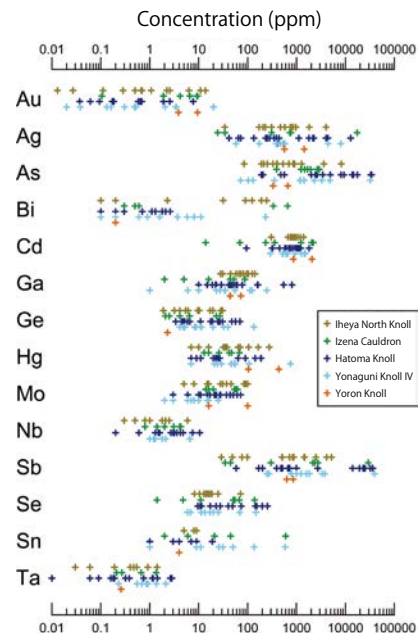


Figure 3. Concentrations of Au, Ag, and other metal elements in the chimney samples collected from various hydrothermal areas of the Okinawa Trough. Although average concentrations of the elements in the Iheya North samples are lower than those in the Yonaguni Knoll IV and Hatoma Knoll samples, some Iheya North samples exhibit high elemental concentrations that can be comparable to the other areas.

Resource Geochemistry Group

A major portion of methane on Earth is known to be produced by microorganisms. However, we do not know what depth and how fast the methane is produced by them. We study these topics by developing a novel chemical tool, namely, analysis of Factor 430 (F430) catalyzing a biochemical step forming methane. The concentration of F430 in the sediment core could suggest in situ methane production potential, whereas carbon and nitrogen isotopic compositions of F430 suggest metabolic processes of methanogens.

However, extraction, separation, and quantification of F430 in the sediment have not been conducted before. Therefore, we need to establish an analytical method of sedimentary F430 from scratch. In FY2012, we have succeeded to optimize the methodology by maximizing and stabilizing the yield of F430, and increasing the speed of analysis (Fig. 4). So far, we have realized that the F430 can be stabilized by reducing the pH of the solution lower than 1 in cold, dark storage. Moreover, we become aware of the fact that methylesterification of F430 further stabilizes the molecule during the analysis. Current analytical detection of F430 is 10 pmol, but we can reduce it to 1 pmol by applying a new sensitive photodiode array detector in our HPLC system. In the same time, we are producing a F430 standard which is requisite to precise quantification. We detected F430 from marine sediment collected off Shimokita by D/V *Chikyu* (106 m depth) and terrestrial soil samples.



Figure 4. Extracts containing F430

Ore Genesis Research Group

This research group, which targets various resources but focuses particularly on seabed mineral resources, aims to reveal the origins of resources on various spatiotemporal scales. That is, the group aims to clarify where and when in the earth's history these resources were generated and to understand the chemical processes that led to better understanding of their genesis. Such knowledge will allow successful exploitation of potential seabed resources in several ways, e.g., by improving understanding of the environmental variations associated with resource generation, by helping develop methods for the investigation of these

variations, and by designing new methods for the collection of useful elements.

This year, using the Takuyo Daigo Seamount as a model site, we conducted an extensive investigation of ferromanganese crusts that were collected systematically by the ROV Hyper-Dolphin 3K (Fig. 5).



Figure 5. Cross section of a ferromanganese crust collected at the Takuyo Daigo Seamount

Several implications have been obtained to explain the mechanisms underlying the formation of such ferromanganese crusts, including the presence/absence of a growth hiatus and the involvement of an oxygen minimum. However, no conclusive evidence has been obtained to date, owing primarily to the lack of effective dating methods. Therefore, we attempted to determine the growth chronology of the ferromanganese crusts using variations in the osmium isotopic ratio of seawater. We succeeded in determining the generation chronology of the crusts by analyzing the osmium isotopic ratio along the growth directions of crust samples collected at various water depths and comparing the results with the secular variation curve for the osmium isotopic ratio of seawater. It was shown that the growth rates have remained constant regardless of water depth from 15 Ma to the present day. In future, we intend to use this method to analyze samples collected in various sea areas.

We have also conducted research investigating element enrichment processes at the molecular level using radiation facilities such as SPring-8. Ferromanganese crusts are also known as cobalt-rich manganese crusts; specifically, they are enriched in tellurium, a rare metal. We determined that this specific enrichment is caused by the coprecipitation of tellurium with ferric hydroxide, which can be attributed to the shape of tellurium molecules. We also analyzed elements such as selenium (a homologous element), molybdenum, tungsten, arsenic, and antimony, and demonstrated that differences in the enrichment rate of oxoanions can be explained systematically by differences of absorption structure.

Furthermore, we are focusing on the high metal absorption capacity of ferromanganese oxides in an attempt to develop methods for collecting rare metals using a bioreactor. We are

investigating the optimal conditions for culturing iron- and manganese-oxidizing bacteria to develop efficient methods for the synthesis of ferromanganese oxides with higher absorption capacity. Ultimately, in future, we aim to develop a highly efficient method for collection of rare metals by simultaneously analyzing the enrichment rates and chemical states of such metals.

In addition to the topics discussed above, we intend to investigate the mechanisms of rare earth enrichment to form rare earth mud using photon radiation and will also embark on research voyages to sample the rare earth mud distributed in waters close to Japan. Moreover, using micro, macro, natural and experiment as keywords, we intend to conduct various studies investigating the origins of resources. For example, we are planning an artificial synthesis experiment for black ore deposits using a high-temperature high-pressure hydrothermal experiment and a study investigating the leaching of elements from the wall rocks of deposits.

Environmental Impact Assessment Research Group

The environmental impact assessment group conducts the study of impact assessment after the drilling expedition on hydrothermal vent area as a primary target. The case studies for environmental disturbance on the marine ecosystem will continue to collect the data to understand their capacity for and the resilience from impacts.

In situ observation for seafloor habitats using high-

definition video images by the downward camera to analysis seafloor classification and distribution of megabenthos (Fig 6), and metagenetics by environmental DNA for microbial biodiversity, are examined (Fig 7). These technical studies on assessment of marine biological diversity and monitoring of marine environments will be carried to propose the EIA method optimized to seabed resource development.

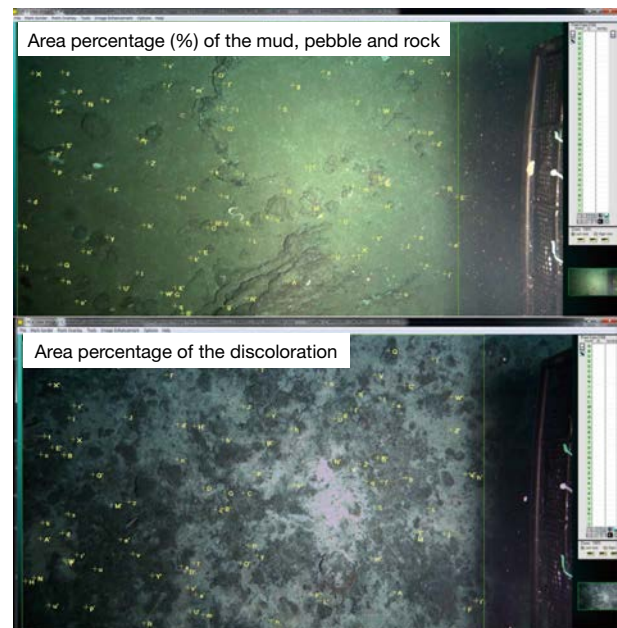


Figure 6. Habitat map based on the video picture analyse

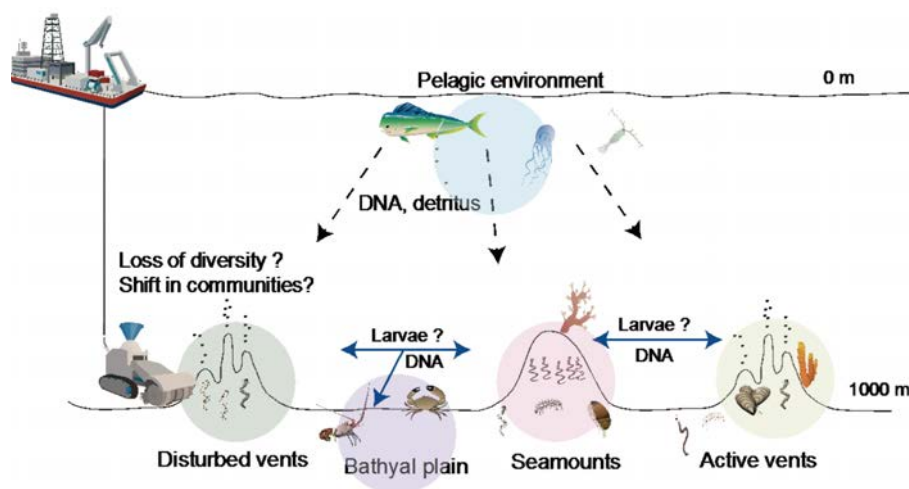


Figure 7. Image of the research in the hydrothermal region

Laboratory for Earth Systems Science: Precambrian Ecosystem Laboratory Unit

Research outline

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

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 fully 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.

In 2011, we determined the carbon flux between the

atmosphere, the ocean, and the crust, from 3.2 billion years ago, based on the stoichiometry and isotope ratio analysis of the fossils (within 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 2012, we conducted a stoichiometry and isotope ratio analysis of fossils (within 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).

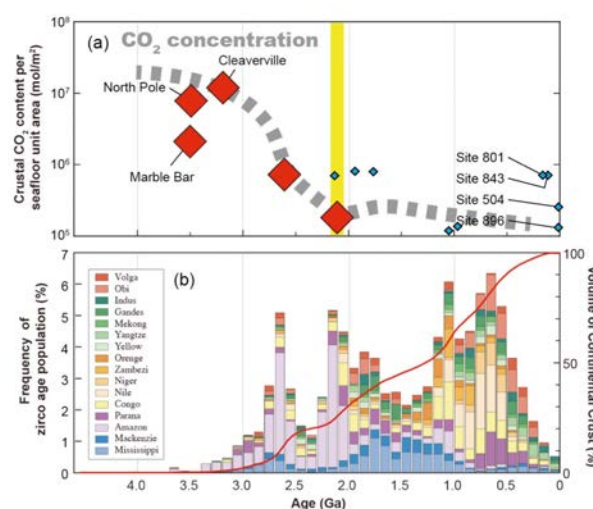


Figure 1. (a) Changes in levels of CO₂ concentration; and (b) continental growth curve throughout the Earth's history. Red symbols indicate the levels of CO₂ concentration determined by the Precambrian Ecosystem Laboratory.

However, when CO₂ concentrations in the atmosphere and the ocean are lower, it becomes more difficult to use the earth-life 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 an earth-life history reproduction method that uses fluid inclusions preserved in hydrothermal sediment within the oceanic crust, and have already used this method to analyze fossils 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 that was trapped in minerals 2.2 billion years ago. All of the previous studies on deep-sea hot water have indicated that the CO₂ concentration of seafloor hot water always exceeds the dissolved CO₂ concentration of seawater. We found that the lowest CO₂ concentration in hot water 2.2 billion years ago was 7 mM. This value indicates that the concentration of CO₂ dissolved in the ocean 2.2 billion years ago was 7 mM or lower, which is only 2.3 times as high as the current level. In other words, the CO₂ concentration at that time was only two to three times as high as it is now. For the first time in history, these results support the hypothesis that the "snowball earth" was caused by a decrease in atmospheric CO₂, 2.2 billion years ago.

(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 Precambrian explosion (which are more likely to be recorded as fossils), it is extremely important to use geological records as well as information on the stoichiometry 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 stoichiometry of many elements and multiple isotope ratios.

To investigate the global nitrogen cycle, our research previously focused on the stoichiometry 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. Our laboratory has conducted multiphase isotope ratio systematics research on the nitrogen fixation metabolism of thermophilic hydrogen-oxidizing methane bacteria, (the most important primary producer in the Precambrian explosion). For the first time in human history, we show that nitrogen fixation by thermophilic hydrogen-oxidizing methane bacteria 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.

Major advancement has also been made within multiphase isotope ratio systematics research into nitrogen catabolism, a field where research had been making little progress. Through systematic research on the stoichiometry and isotope ratio fractionation and equilibrium of nitrogen compounds in a complex nitrogen catabolism network of ammonia oxidation, nitrite oxidation, anaerobic ammonia oxidation, and denitrification, we showed that the reaction rate and flux can be quantified for an individual metabolism.

Significant results have also been obtained from multiphase 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 2012, for the first time in history, 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 methane bacteria. This finding refutes one of the common premises of isotope systematics of H₂O-H₂-CH₄. Our analysis of the carbon isotope ratio and hydrogen isotope ratio of methane therefore indicates that there is a need to revise the equation that estimates the origin, generation, accumulation, transportation, and consumption of methane. Our findings also clearly indicate a direct relationship between the isotope ratios of H₂ and CH₄, 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 methane bacteria, (the most important primary producer).

In 2012, 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 surface of our planet is host to a variety of life forms and chemical and biological environments that are constantly changing and evolving, while simultaneously being influenced by both the earth's interior and the outer space. Such changes have an enormous influence on the processes occurring within the Earth's interior. To understand the mechanisms involved in long-term and large-scale environmental variations within the global environment, and to enable their prediction, it is necessary to understand the concept that the Earth and space form an integrated system.

Our laboratory aims to predict the Earth's environmental future. This will be achieved by quantifying the interactions among multiple layers, (including those of the outer space and the Earth's surface and interior), with the use of state-of-the-art numerical simulations and ultrahigh pressure experiments and observations. In doing so, we hope to elucidate the planet's current activities, and the mechanisms involved in large-scale global environmental variations throughout the Earth's history (Fig. 1).

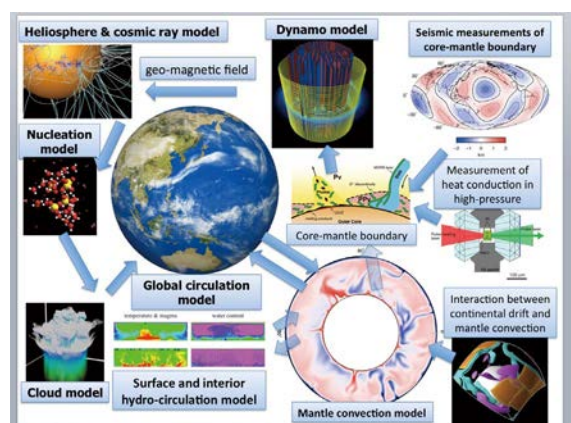


Figure 1. Research topics at the Space and Earth System Modeling Laboratory Unit

Relationship between the solar activity and climate change in glacial periods

It is known that dynamic climatic variations on a scale of 1000–2000 years occurred during glacial periods. However, the causes for these variations remain unknown and intensely discussed. By reproducing the glacial climate on a specific time scale, we showed that climate changes during glacial periods were caused by the 1000-year and 2000-year cycles of solar activities (Obrochta et al. 2012), and that the effects of these solar activities become more marked during glacial periods. Because they represent a clue to elucidating the scale and mechanism of the effect of solar activities, these findings have attracted international attention.

Elucidation of S-wave velocity structure in the lowermost mantle beneath the western Pacific, using ScS-S travel time analysis

A Large Low Shear Velocity Province (LLSVP) exists in the lowermost mantle beneath the Pacific Ocean. The S-wave

velocity structure at the western edge of the LLSVP (beneath New Guinea) was determined based on the difference in the traveltime of ScS-waves and S-waves, which traverse approximately in north-south and east-west directions. It was shown that a high velocity region exists adjacent to the low-velocity region (Idehara et al. 2012). This is an exciting new discovery, which indicates the possibility that subducted slab material has moved very close to the LLSVP.

Simulation of mantle structure evolution on terrestrial planets

We developed a terrestrial planet evolution model that considers magma generation and redistribution of subsequent radiogenic heat sources, thereby realizing the simulation of a 5-billion year structural development history. This model also considers the circulation of water between the surface layer and the mantle. According to the simulation, most of the mantle of Mars would have lost water over a period of 2 billion years because of a lack of plate subduction (Ogawa & Yanagisawa 2012). However, igneous activities would have continued for over 4 billion years due to the small amounts of residual water. This is consistent with the data collected by Mars probes, indicating that, until recently, volcanic activities existed on Mars.

Measurement of thermal conductivity of MgO under ultrahigh pressure, and the heat flow at the core-mantle boundary

The study of thermal conductivity at the core-mantle boundary is extremely important in gaining an understanding of the rate of core cooling. Through the recently discovered post-perovskite phase transition, we were able to gradually reveal the temperature structure in the lowermost mantle. Heat flow is obtained as the product of the temperature gradient and the thermal conductivity; therefore, when thermal conductivity is determined for a field it is possible to estimate the heat flow from the core. We had already experimentally determined the thermal conductivity for the main mineral in perovskite phase and the post-perovskite phase of the lower mantle. And we have now successfully measured the thermal conductivity for MgO, the second most prevalent mineral in the earth's mantle.

We determined the thermal conductivity of MgO samples in a diamond cell (up to 1.3 million atm.) It was shown that MgO has a thermal conductivity of approximately 20 W/m/K at the bottom of the mantle. Therefore, considering that the lowermost mantle consists of the perovskite phase and MgO, the heat flow from the core to the mantle is estimated to be about 10 terawatts. This value is higher than previous estimates and indicates a fast cooling rate at the core, along with a young inner core age. In addition, it is indicated that this value is consistent with the heat flow at the core-mantle boundary estimated by our thermal conductivity measurements of core material based on high pressure experiments.

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 to contribute to the realization of scientific innovation by participating in research that combines both scientific 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 budgets allocated to three 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 society. We believe that future predictions of natural phenomena should be at a level available 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 first. 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 transdisciplinary as well as interdisciplinary field that strives to realize the coexistence of humans and the planet by halting the deterioration of the global environment, is about to begin, and the Application Laboratory was established ahead of such world trends. The activities of the three programs initiated in 2012 are described below:

The Integrated and Intellectual Information Science and Technology Program

This program aims to explore the communication of science not only among the scientists but also between professional scientists and non-experts. The communication topics depend strongly on the demands from both scientific and public societies in the field of geological phenomena like atmospheric winds and ocean currents. We show our activities replying with the analyzed results from numerical simulation and observations using information technology.

Here we report our activities in 2012, especially in

- a new Visual Data Mining (VDM) methods,
- a new visualization technology,
- an automatic forecasting system and
- activity with local governments.

It is important to extract physical features from the data of oceanic simulations and observations for not only researchers to analyze them but also the public to understand the results. We are developing VDM which is one of the effective techniques to realize it. Figure 1 shows an example of the application of VDM

which applies multivariate analysis to extractions of the structure of ocean currents such as the Kuroshio Current. This study has received high acclaim and received the Best Poster Award at SC12, the international conference for high performance computing, Networking, Storage and Analysis, held in the USA in November 2012.

We promote “EXTRAWING”, a research and development project to represent geo-scientific data effectively by visualization techniques and convey the results to public. In this project, a novel method to reproduce a volume dataset as a geometric model and visualize it on a terrestrial globe of computer graphics was developed. It enables us to enter ourselves into the dataset, view it three-dimensionally from various angles and superpose multiple datasets on each other, as shown in Figure 2. A web application program was also developed for all to observe the results easily via the Internet. To discuss application of the developed tool to ocean and earth observations, we frequently hold cross-disciplinary workshops assembling researchers in various fields and officers of public relations.

The climate and/or weather prediction is one of the big demands from public. Now we have a plan to open a web page in which the results from real time or semi-real time numerical simulations about daily weather prediction are graphically presented with some interpretive articles. The page is daily updated automatically. This system will be in operation by the end of 2013. The automatic update web pages about the “Atmospheric dispersion” and “Marine dispersion” around Japan area have already been in operation and in great demand from public.

In July, we form a new research group named “Research Group for the Future City Design Corresponding to Global Environment Problems” with local governments, companies, and university. One of the most important key words is “redesigned city”. City Yokohama, as a model area and local government, contributes to provide a local detailed data to us, and then we reply the numerical results about geo-environment. With this collaboration and deep communication, the grope indicates some guiding principles for our sustainable human environments from mountain to coast through country-side and urban area.

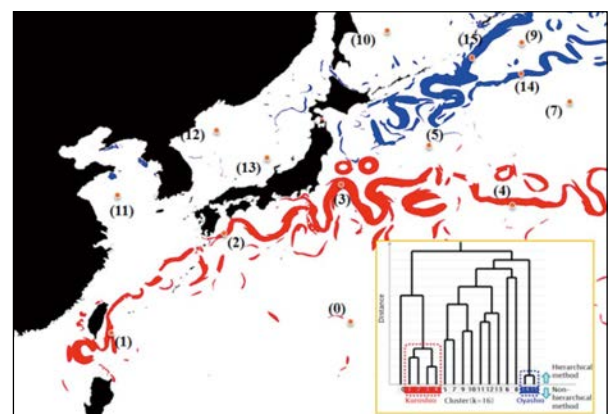


Figure 1. Extraction of ocean currents using a visual data mining method

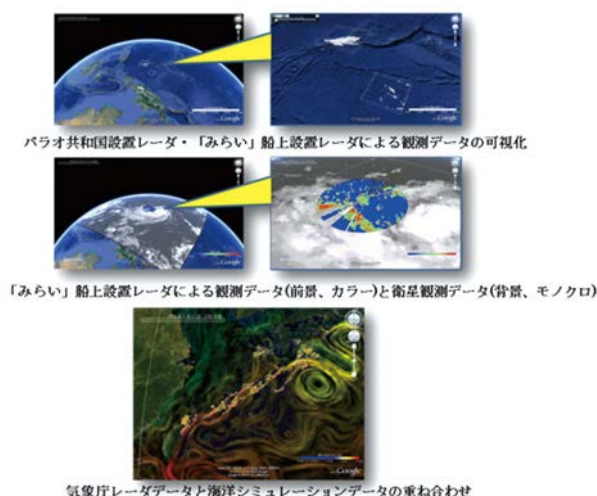


Figure 2. An example of a three-dimensional visualization by EXTRAWING

The Society-Oriented Prediction Engineering Science Program

This program aims to realize a kind of social innovation by activating the interaction between dissemination of prediction information on the occurrence of ocean-atmosphere phenomena, such as climate variations causing abnormal weather, and surveillance of social needs of the information. Currently, our activities include:— 1) the prediction of climate variations and oceanic variations, dissemination of applied information and its validation; 2) the prediction of weather in the Tropics and East Asia using the global cloud resolution Model, dissemination of applied information; and its validation; 3) the prediction of atmospheric chemistry variations using the tropospheric ozone dispersion model (and other means), dissemination of applied information and its validation. As regards to 1), we have promoted the Science and Technology Research Partnership for Sustainable Development (SATREPS) project “Prediction of Climate Variations and its Application in the Southern African Region (Fig. 3)” by drawing on our experience of leading the world in basic prediction research on the Indian Ocean Dipole Mode and El Nino, and with the support of the Japan International Cooperation Agency (JICA) and the Japan Science and Technology Agency (JST).

This project aims to establish an early warning system that delivers prediction information to local residents and farmers through research and development on seasonal prediction. Using an atmosphere-ocean coupled general circulation model (performed with the Earth Simulator), and by combining an improvement in the model’s ability to predict weather events with research and development, we are enabling the accurate prediction of local extreme weather events in the southern African region. Through this internationally collaborative research project, the Application Laboratory has now expanded its field to southern Africa, and has successfully established a cooperative relationship with developing countries. Key research outcomes of this project in 2012 are as follows:

An El Nino-like climate variation, known as El Nino Modoki, which we discovered in the tropical Pacific, has been frequently observed in recent years, attracting international attention. While El Nino typically causes drought in southern Africa, we have

found that El Nino Modoki causes heavy rain (Ratnam et al. 2012a). It is becoming widely accepted that the occurrence of El Nino Modoki has become more frequent because of the warming of the oceans, and this finding is important in understanding the effects of climate change on climate variations. We also identified the Subtropical Dipole Mode, which is observed as the surface temperature variation in the southern Indian Ocean, and have shown that this phenomenon is closely associated with climate variations in southern Africa. Furthermore, in an experiment that used the atmosphere-ocean coupled general circulation model, we have shown that the subtropical dipole mode in southern Indian Ocean was caused by the Antarctic Circumpolar Wave and El Nino (Morioka et al. 2012). However, most atmosphere-ocean coupled general circulation models used to project climate change cannot accurately reproduce a mean field and, as a notable example, problems associated with reproducing the Seychelles Dome, a huge upwelling area in the southwestern Indian Ocean, have been reported (Nagura et al. 2012). Therefore, improving the models for more reliable climate research is an important issue. For the local climate in southern Africa, we have successfully predicted the climate of southern African regions six month in advance, by downscaling the prediction results of the coupled model SINTEX-F using a regional coupled model (Ratnam et al. 2012b). We have also analyzed in detail Tropical Temperate Troughs (TTTS), which provide a substantial portion of summer rainfall over southern Africa, and introduced new TTT indicators, thereby revealing their developmental processes and, for the first time, the interaction between TTTs and climate variation modes such as El Nino (Ratna et al. 2012a). Using a regional climate model developed by the Application Laboratory, we have also conducted research on the formation mechanism of TTTs (Ratna et al. 2002b).

Another of our significant achievements is that the results obtained by our numerical models are now being used in southern Africa: the prediction results of SINTEX-F have been incorporated in a multi-model ensemble forecasting system developed by researchers in southern Africa. The regional atmosphere-ocean coupled general circulation model we developed has also been used in a computer supplied to the University of Pretoria in South Africa, and is being used for numerical predictions and heat wave research. It is expected that prediction results of the numerical prediction systems will be widely distributed to local residents and farmers through collaboration with local agricultural research stations, the meteorological agency and universities.

In addition to joint academic research, we support exchanges among researchers and human-resource development (Fig. 4). In 2012, we hosted one workshop and two symposiums jointly with the University of Tokyo and South Africa’s Council for Scientific and Industrial Research, where researchers from Japan and South Africa presented research findings and participated in active discussion. In addition, Japanese researchers gave intensive lectures to students at five South African universities over a period of four weeks. South African researchers then stayed at the JAMSTEC and Tokyo University for one week, exchanging information with Japanese researchers through workshops. Building on these results, we hope to expand our field to other southern African regions, as well as to other parts of the world, engaging in research and development that contributes to the improvement of human lives.

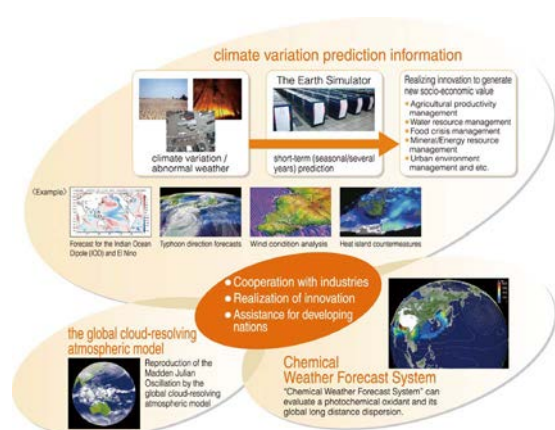


Figure 3. Possibilities for the application of climate forecasting data to various fields



Figure 4. JICA-JST Science and Technology Research Partnership for Sustainable Development (SATREPS)

The Deep Sea Engineering Science Program

The Deep Sea Engineering Science Program, which began in 2012, aims to provide scientific predictions that support an assessment of the effects of human activities, such as seabed resource extraction on the marine environment, and the assessment of post-development rehabilitation. Specifically, we will conduct ground stability assessments in the oceans, a necessary pre-development procedure, and develop basic technologies, such as those for construction and long-term continuous surveying. By integrating JAMSTEC accumulated knowledge in oceanography, marine ecology, geology, and study of mineral deposits, we will promote these predictions and technological developments to society as being “neo-engineering.” In addition to this applied research that aims to contribute to the society, we will actively promote mutual research cooperation within JAMSTEC.

One of the basic technologies used for deep-sea applications, is that of seabed operations from the sea surface. In this program we started research on the whirling of the drill pipe (described below) during the deep-sea drilling by deep-sea drilling vessel *CHIKYU* jointly with the Technology Development Group of the CDEX. In the program, we are responsible for the theoretical aspects of the problem, and this year we have analyzed the non-equilibrium dynamics of the torsion of the elastic rod. Generally, when shearing stress is externally applied to both ends of an elastic rod, twisting strain becomes uniformly accumulated inside the rod, and if the strain has exceeded a threshold, bending deformation occurs. When shearing stress is further applied under non-equilibrium state, twisting strain may become non-uniform inside the rod. In this case, the orbital motion of the bent

elastic rod, called whirling, occurs. We showed that this period of revolution was determined by the non-uniform parameters of twisting strain, bend elastic constant, twist elastic constant and tension and also theoretically showed that the dynamics of whirling could be described by the universal vibration equation; the Stuart-Landau equation.

The Deep Sea Engineering Science Program has also been making efforts to apply advanced computing technologies, based on particle models, to a wide range of industries. More specifically, in addition to research and development, the program financially contributes to the JAMSTEC by obtaining intellectual property income through commercialization of practical software. In 2012, the program obtained an intellectual property income of eight million yen, through paid external use of the additional software “Tsukumo elastic element method program GPU version” (Allemande GPUver.), which is based on research into propagation analysis of impact loads occurring in ballast (Hidem, 2012).

In the latter half of 2012, we began the “simulation research of the filtration process during nanoparticle generation process,” jointly with industry and Doshisha University. This uses large-scale high-speed simulation analysis technology that links solid particles and fluid; this technology was developed by the Applications Laboratory and has attracted the attention of the nanotechnology industry. Through this research, the microscopic behavior and interparticle interaction force of particles that are difficult to observe in experiments, can be understood, and by investigating their effects on filtration rate we can identify new methods for rational filtration. Figure 5 shows the differences in streamline and sedimentation rate distribution for the dispersal and aggregating systems. Figure 6 shows temporal changes in the filtration rate. From these Figures it can be understood that the aggregating characteristics of particles have significant effects on the filtration rate.

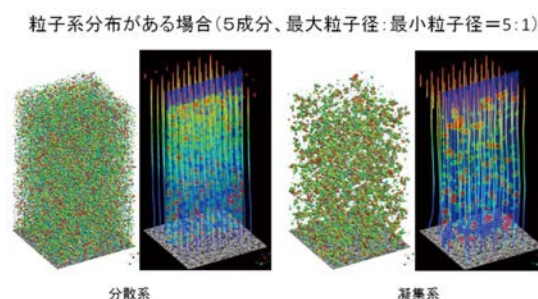


Figure 5. Distribution of sedimentation rate and porosity with particle size distribution

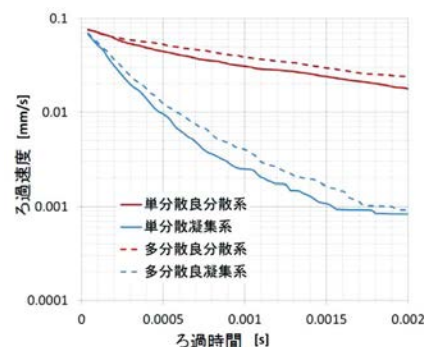


Figure 6. Temporal changes in sedimentation rate

Mutsu Institute for Oceanography (MIO)

Overview

Since its establishment in October 2000, the Mutsu Institute for Oceanography (MIO) has been the home port of the research vessel *MIRAI*, one of the largest oceanographic research vessels in the world. MIO is carrying out operations in support of the research activities of the *MIRAI* as well as research focusing on the biogeochemical cycle in the North Pacific.

MIO's support operations include various coordination activities related to the arrival and departure of *MIRAI*. Big oceanographic surface buoy system, 'TRITON buoy', is maintained at the equipment dock in MIO, where sensors and bodies are checked and adjusted. Water samples collected by *MIRAI* are processed and analyzed in the chemical laboratories. Preparation for the sampling in each cruise is also made in the laboratories. Various facilities, such as ICP-MS, high-pressure water tank, equipment of radiocarbon measurement and so on, are now used by JAMSTEC members in other campuses, too.

MIO's North Pacific time-series observation research aims to understand how the climate change in the North Pacific occurs from the viewpoint of biogeochemical cycle. In other words, it aims to identify how changes in environmental loads caused by human activity appear in the North Pacific. On this research, we have accumulated knowledge of the trend of the carbon dioxide concentration in seawater and the vertical transport of carbon through the biological pump. Since 2009 we began observations at the eastern Tsugaru Straits region where the Tsugaru Warm Current flows eastward into the Pacific. The study on the coastal environmental changes should deepen our understanding in the western North Pacific. This coastal research was carried out under the collaborations with the Graduate School of Fisheries Sciences at Hokkaido University and the Aomori Prefectural Industrial Technology Research Center.

Outreach activity is also promoted. We provide general marine science information and new knowledge of JAMSTEC to the public, around Mutsu city. The activities were carried out in collaboration with local government and schools. We continued to transmit marine scientific information via a local FM station. We also organized symposiums and opened our facilities to the public.

North Pacific Time-Series Observation Research

We made time-series observation both of the settling particles and water properties during the *MIRAI* expedition MR12-02.

Particle samples of the sediment traps at depths of 500 m and 4810 m are collected at the K2 station in subarctic region on 47°N/160°E, and the S1 station in the subtropical region on 30°N/145°E. Cs-137 and Cs-134 were detected in the samples from March 25, 2011, and April 6, 2011, respectively. These radioactive cesium detected was likely that released by the Fukushima Daiichi nuclear power plant accident by the result that Cs-134/Cs-137 ratios were close to 1.0. The data should be helpful to understand the formation and the transport of those particles in the open ocean.

The acidification in the subarctic gyre in the North Pacific

was analyzed by using the time-series data observed in last fifteen years. It was confirmed that the carbon dioxide partial pressure in winter that was estimated in the ocean surface mixed layer and the total alkalinity (TA) are increasing (Fig. 1). Such the increase in TA should make compensation for the increase in carbon dioxide partial pressure. Correlation analyses suggest that the increase of TA is related to the change of the wintertime mixed layer thickness that can be attributed to the deepening of the pycnocline. It is typically caused by increases in sea level; such increases are assumed to be caused by weakening of wintertime winds from the Eurasian continent. Based on these results, prediction of the carbon dioxide balance in the subarctic region in the North Pacific should be made in the next work.

These results discussed above are made in collaboration with the Environmental Biogeochemical Cycle Research Program of JAMSTEC.

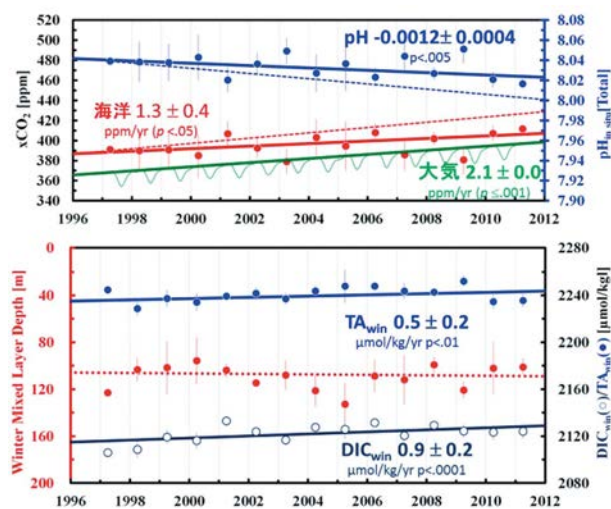


Figure 1. Annual changes in carbon dioxide partial pressure, pH (top figure), dissolved inorganic carbon, total alkalinity, and wintertime mixed layer depth (bottom figure) estimated from the data obtained at the time-series observation stations in the subarctic gyre in the North Pacific. pH was calculated based on dissolved inorganic carbon and total alkalinity; wintertime mixed layer depth was estimated based on the depth of the temperature minimum layer. Top: red indicates carbon dioxide partial pressures in the marine surface layer; green indicates reported carbon dioxide partial pressures in the atmosphere measured in Ryori (Iwate Prefecture); blue represents pH. The broken lines indicate predicted values assuming its link with the atmospheric values. Bottom: dark blue represents dissolved inorganic carbon, blue represents total alkalinity, red indicates mixed layer depth.

Coastal Marine Research at the Tsugaru Straits

Climate change is likely to be significantly affecting the organisms living in the shore area and be causing changes in their ecosystems. Marine organisms in the waters surrounding the Shimokita Peninsula are observed both at the seaside and at the sea of the Tsugaru Strait. The marine observations were made by using the training vessel 'Ushio-Maru' under the collaboration with the Hokkaido University.

Hydrographic observations in four cruises were carried out in 2011; February 23–24, May 15, July 27–28, and November

18. The distributions of temperature and salt are shown in Figure 2. Water mass of the Tsugaru Warm current, that is characterized by high temperature and high salinity, distributes in the southern part of the straits (i.e., on the right-hand side in each cross section). The Coastal Oyashio, characterized by low temperature and low salinity, flows in the northern part of the strait. The seasonal movement of the Coastal Oyashio water mass appears near the coast of Oshima Peninsula of Hokkaido. Water mass of low temperature and low salinity persists on the sea floor at the water depth of 200 meters in the northern side of the strait.

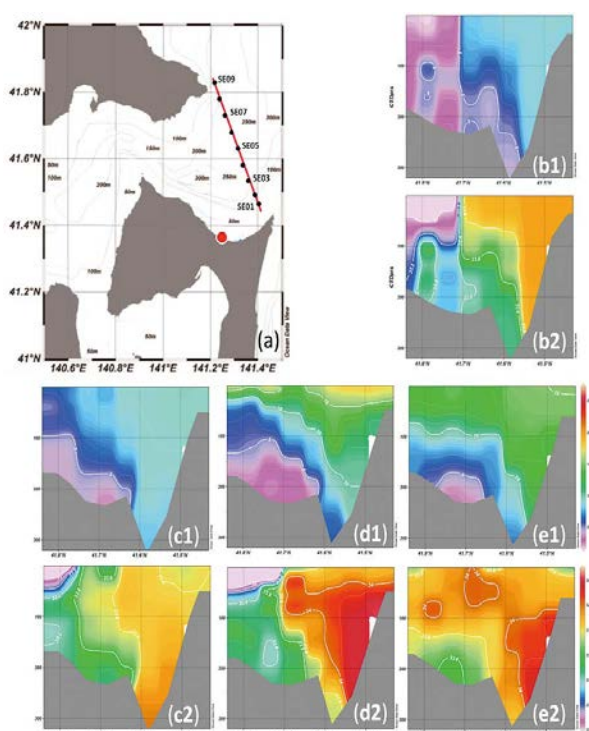


Figure 2. Cross sections of the eastern Tsugaru Straits showing the distribution of temperature and salinity (2011 data). (a) Survey line. (b1)–(e1) Temperature distribution in February, May, July, and November. (b2)–(e2) Salinity distribution in February, May, July, and November.

Microscopic examination of phytoplankton is made by using the samples collected in four cruises in 2011 (Fig. 3). Phytoplankton was most abundant in the samples collected at the SE09 station near the Hokkaido coast in the Oyashio area in late February. It was also relatively abundant in the samples collected there in May. Most of the phytoplankton was diatoms, which is consistent with the plankton composition in the Oyashio Current. On the other hand, phytoplankton was much less abundant at the SE03 station near the Honshu coast in the Tsugaru Warm Current area. Abundances were higher in May than at any other observation time, and diatoms were dominant at all times.

Other research activities

We began the research on the carbon dioxide distribution in the Antarctic Ocean using our developing new equipment, CO₂ sensor, which measures carbon dioxide partial pressure automatically on the drifting surface buoy. It was originally



Figure 3. (a) The abundance of phytoplankton for each observation period at the two observation stations in the eastern Tsugaru Straits (SE03 and SE09), with species compositions at (b) SE03 and (c) SE09.

developed under the Japan Earth Observation System Promotion Program (JEPP) of Ministry of Education, Culture, Sports, Science and Technology. In December 2012, with the support of the National Institute of Polar Research and the icebreaker *SHIRASE*, 11 units of a drifting automated pCO₂ measurement system were released at the four points in the Antarctic Circumpolar Current area shown in Figure 4. Temperature, salinity, and carbon dioxide partial pressure would be measured for a year. It is an unprecedentedly high frequency. Thus this project is likely to make us possible to estimate the amount of carbon dioxide flux between the atmosphere and the oceans in the Antarctic Ocean where there had been made poor observations of the carbon dioxide partial pressure. This project has been conducted with the support of a Scientific Research Grant of the Japan Society for the Promotion of Science.

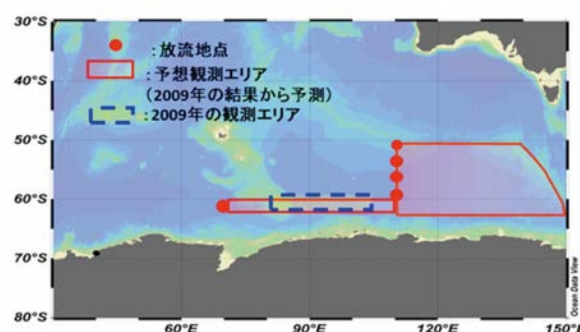


Figure 4. Release points of the drifting automated pCO₂ measurement system and predicted observation area. 11 units were released at four points.

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 every core sample that has ever been drilled from the world's oceans, but also for conducting multidisciplinary researches on the physical properties, isotopic geochemistry and the deep sub-seafloor biosphere using such samples. Another unique feature of the Institute is that it takes charge 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 mutual, cost-effective research environment.

We store ~94-km-long core samples obtained from around Japan and in the Indian Ocean, and we have developed some innovative curatorial techniques. The "Deep Biosphere Samples (DeepBIOS)" are stored at temperatures below -80 °C for use in microbial research, and the "Virtual Core Library" is designed to provide quick access to X-ray CT images of core samples. We believe that such efforts will attract the broader scientific community to benefit from a more intensive use of core samples (e.g., in environmental, natural resources, or disaster studies).



Photo 1. IODP Expedition 343 "Japan Trench Fast Drilling Project (JFAST)" core samples received on July 27, 2012. On Oct. 5, cores from IODP Exp. 337 "Deep Coalbed Biosphere off Shimokita" were also received.



Photo 2. Freezer tanks (left) and frozen samples for deep biosphere research (DeepBIOS; right).

To spread knowledge of marine science and technology to a wider audience, we held an open-house on Nov. 3, and this event attracted about 1,287 visitors. In addition to organizing this event, we have also contributed to outreach events and lectures and have conducted classes in schools. We emphatically encourage young scientists to lead future drilling projects with involvement from partner graduate schools and core analysis schools. On July 15, we held an "open ship" onboard the JAMSTEC research vessel *NATSUSHIMA* and the Remotely-Operated Vehicle *HYPER-DOLPHIN* at the Cape-Muroto fishing port; attracting 1,178 visitors. Prior to this event, we delivered a series of lectures on how great earthquakes occur at trenches, which attracted 108 visitors. On March 9, 2013, we conducted our first public lecture event to 218 visitors in Kochi-City, jointly hosted with CMCR Kochi University, with the title "Exploring great earthquakes with *CHIKYU*": – Nankai and 3.11 Tohoku events."



Photo 3. A tour of the core storage during the open house at Kochi Core Center.



Photo 4. Open ship event onboard the Research Vessel *NATSUSHIMA* at Cape-Muroto fishing port.

Leading the drilling expeditions onboard the D/V *CHIKYU* and *JOIDES Resolution*

1) IODP Expedition 343 “Japan Trench Fast Drilling Project (JFAST)”

The 2011 Tohoku-oki earthquake (Mw 9.0) produced a maximum coseismic slip exceeding 50 m along the plate boundary near the Japan Trench. It is believed that this event could have produced a large temperature increase due to frictional heating along the fault, and could have resulted in a complete stress reduction in the region.

To test this hypothesis, the IODP Expedition 343 “JFAST” was carried out using D/V *CHIKYU* to investigate the shallowest portion of the 3.11 Tohoku-oki earthquake fault zone at a water depth of 6890 m. Three scientists from KOCHI were onboard, and they successfully obtained core samples from possible fault zones at depths of between 648 m and 845 m below sea floor, as well as acquiring images of the continuous log throughout the hole.

The in situ stress state of the frontal prism was determined from borehole data (approximately one year after the earthquake), and this state was compared with the inferred pre-earthquake stress state. On the basis of the horizontal stress orientations and magnitudes estimated from borehole breakouts identified from logging-while-drilling (LWD) data, and the increase in coseismic displacement during propagation of the rupture to the trench axis, we concluded that there was a decrease in the magnitude of horizontal compressional stress during the earthquake. The stress change suggests an active slip of the frontal plate-interface, and this is consistent with coseismic fault weakening and a nearly total stress drop.

We also conducted high-velocity frictional experiments on cored fault materials, in order to clarify which features of velocity-weakening were involved during high-speed slip. From these experiments it is clear that thermal pressurization, (caused by the slip-induced frictional heating), was a factor that caused velocity-weakening. We are now investigating how the permeability of the fault and the surrounding host rock changed with the slip, in order to assess its effect on generating overpressure or slip behavior. Trace element and isotope analyses on pore fluids squeezed from core samples were also performed, to detect whether the fluid movement and temperature increased along the fault.

The information we gain from investigations into the Tohoku earthquake is also expected to improve our understanding of the Nankai earthquake.

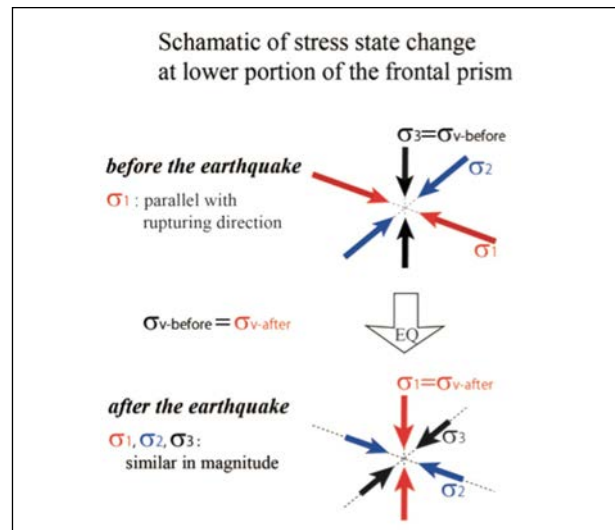


Figure 1. Schematic diagram of stress change due to the 2011 Tohoku earthquake just above the fault zone near the trench (Lin et al., 2013).

2) JAMSTEC *CHIKYU* Expedition 906: The deep submarine mud-volcano in the Nankai Trough

Deep-sea mud-volcanoes are globally distributed along the plate convergent continental margins. Mud volcanism supplies deep-sourced fluids and hydrocarbons through a diapir flow, which often supports chemosynthetic life on the seafloor. Microorganisms in the hydrocarbon-seep sediment of mud-volcanoes play important ecological roles in the biogeochemical carbon cycle, such as in the anaerobic oxidation of methane. However, the nature of deep sub-seafloor microbial communities and their ecological roles within mud-volcanoes, remains largely unknown.

During the JAMSTEC Expedition 906 (July 2012), cores were cut at depths of 200 m below the summit of the Kumano forearc basin. The primary scientific objectives were as follows: 1) to characterize the in situ geochemical and geophysical characteristics of solid, gas and fluid components in the deep mud-volcano subsurface; 2) to explore the deep sub-seafloor biosphere within the mud-volcano and evaluate the population, diversity and metabolic activity of the microbial community and its physiological state and energetic habitability; 3) to evaluate the impact of sub-seafloor microbial activities within the biogeochemical cycles of the plate accretionary wedge; and 4) to understand the nature and amount of methane hydrates and characterize the formation mechanism of the hydrocarbon reservoir in the mud-volcano diapir.

During Expedition 906, we also tested a newly developed Hybrid-Pressure Coring System (Hybrid-PCS; Photo 5), and successfully retrieved methane hydrate-bearing sediment from the mud-volcano under an in situ pressure condition (~20 MPa; Fig. 2). The Geomicrobiology Group, and other collaborative institutions, is currently conducting biogeochemical and microbiological investigations on these cored materials.

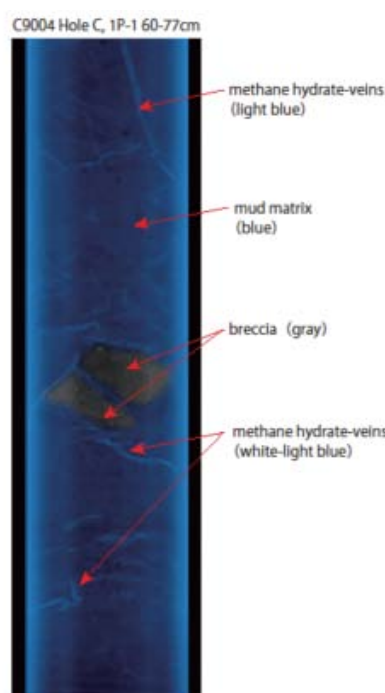


Figure 2. X-ray CT scan image of a methane hydrate-bearing core obtained from the Kumano mud-volcano, using Hybrid-PCS and PCAT (Pressure Core Analysis and Transfer system, GeoTeck, UK) during the JAMSTEC Expedition 906.



Photo 5. The pressure-tight vessel holding hydrate-bearing core samples at KCC.

3) IODP Expedition 337: The deep coalbed biosphere off Shimokita

The IODP Expedition 337 was the first expedition involving sub-seafloor microbiology that uses riser-drilling technology from the drilling research vessel *CHIKYU* (Co-chief scientist: Fumio Inagaki). The drillsite, C0020, is located in a forearc basin, which was formed by the subduction of the Pacific Plate off the Shimokita Peninsula, at a water depth of 1,180 m. Our primary objectives were to study the relationship between the deep microbial biosphere and the sub-seafloor coalbed, and to explore the limits of life in horizons deeper than ever probed by scientific ocean drilling.

We penetrated a 2466 m-deep sedimentary sequence containing a series of coal layers, at a depth of around 2 km

below the seafloor. Hole C0020A is now the deepest hole ever drilled in the history of scientific ocean drilling. Riser drilling at Site C0020 provided an unprecedented record of dynamically changing depositional environments in the former forearc basin off the Shimokita Peninsula, that occurred during the late Oligocene and Miocene epochs. This record is comprised of a rich diversity of lithological facies, reflecting environments ranging from warm-temperate coastal back-swamps to a cool water continental shelf.

For the first time in scientific ocean drilling we conducted a downhole fluid analysis and sampling investigation. Logging operations yielded data of unprecedented quality, providing a comprehensive view of sediment properties and water mobility at Site C0020. We also conducted a gas analysis using a newly installed mud gas-monitoring laboratory. Gas chemistry and isotopic compositions now provide the first indication of the existence of a sub-seafloor biosphere in deep horizons associated with the coalbed.

Using the cored materials, investigations are currently being conducted, (within the Geomicrobiology Group and other collaborative institutions), involving molecular experiments, (such as DNA extraction), gene quantification using digital PCR technique, and an analysis of microbial diversity and community structure. We have also established an Implementation Agreement between JAMSTEC and the J. Craig Venter Institute (JCVI), for research into the metagenomics and single cell genomics of the deep sub-seafloor biosphere.

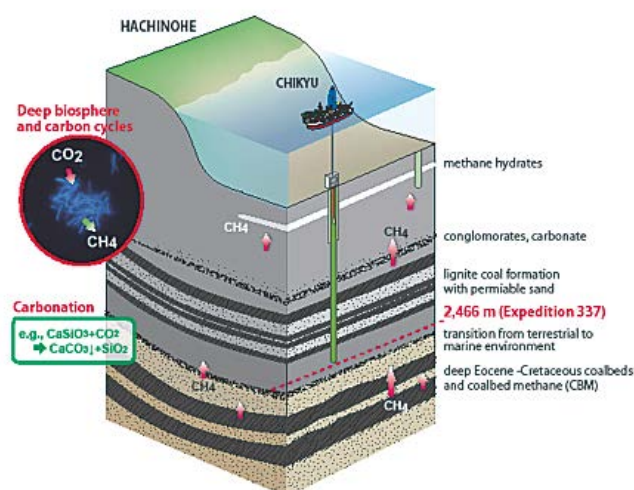


Figure 3. Overview of the deep coalbed biosphere off Shimokita, and proposed future missions involving scientific ocean drilling using D/V *CHIKYU*.

			
Depositional environment	mud stone with clam fossils and barrows (deep-sea)	lignite coal (shallow marine: e.g., tidal flat, lagoon?)	sand stone with siderite and coal (shallow marine)
Sediment depth (mbsf)	1,747-1,756.5	1,919-1,928.5	1,973-1,981.5

Figure 4. Core photographs representing shallow marine to coastal environments (IODP Exp. 337).

4) IODP Expedition 344: Costa Rica Seismogenesis Project

The Cocos Plate is subducting beneath the Caribbean plate along the Middle America Trench off the coast of Costa Rica. In order to elucidate the processes that control nucleation and seismic rupture of large earthquakes at erosional subduction zones, IODP Expedition 344, “Costa Rica Seismogenesis Project, Program A, Stage 2 (CRISP-A2)” was carried out between October 23 and December 11 2012. A scientist from KCC participated in this expedition, which was conducted onboard the *JOIDES Resolution*. Although it was not possible to reach the décollement because of the highly fractured formation, the seismogenic zone survey of an erosional margin should provide an essential insight into mechanisms involved in great earthquakes.

Pursuit of systematic approach on Earth, Planetary and Life sciences

The New Science Plan, developed for the next stage of ocean scientific drilling to take place between 2013 and 2023, asserts that all parts of the Earth system are linked through a flow of mass, energy, and life, and that their interactions have affected the development and evolution of our planet; ultimately determining its habitability through time. The report also explains that scientific ocean drilling permits researchers to access records of millions of years of the Earth’s climatic, biological, chemical and geological history, as well as making it possible to obtain in situ collections of sub-seafloor fluids, microbes, and geophysical/geochemical data.

Through multidisciplinary collaboration between our three research groups (Physical Properties, Geochemistry and Geomicrobiology), we are continuing to pursue Earth, Planetary and Life system sciences by analyzing core samples drilled with D/V *CHIKYU* using our state-of-the-art facilities and techniques.

The spatial distribution and chemical/physical features of carbon and water are essential factors for a systematic understanding of the origin and co-evolutionary process of life, the oceans and the Earth, plate tectonics and fault activities, as well as global environmental changes.

In order to extract, analyze and assess information from core samples as precisely as possible, we have been enhancing our analytical capabilities in areas such as the precise analysis of trace elements and isotopes by ultra-high resolution mass spectrometric analyses (e.g., NanoSIMS, IMS1280), ultra-high precision microbial cell detection, enumeration and sorting from core samples, high-throughput single-cell analytical technologies, laboratory experimental system simulating sub-seafloor conditions, and geophysical and geochemical analyses through core-friction experiments. Such assets enable us to conduct our cutting-edge research into Earth, Planetary and Life system sciences.



Photo 6. Set up for ultra-high resolution mass spectrometry (e.g., NanoSIMS, IMS1280)

Marine Technology and Engineering Center (MARITEC)

Overview

The Marine Technology and Engineering Center (MARITEC) has three primary functions: developing core marine technologies; supporting research activities through the operation, management, and upgrading of research vessels and observation devices; and education and technical training for engineers.

Development of advanced marine technologies

Using the technology of the next-generation cruising underwater vehicles and the technology of the components and materials for the advanced deep water remotely operated vehicles (ROVs) developed by MARITEC, we are constructing and putting into practical use autonomous underwater vehicles (AUVs) and ROVs, both of which allow extensive and accurate geoscientific surveys and exploration of seafloor resources. We are also conducting research and development of advanced marine technologies for the future.

Assembly of the AUVs was completed in late FY2011, each with unique functions; high resolution observation and high maneuverability that are useful for exploration. These vehicles are utilized the next-generation underwater vehicle technologies that we have developed as elemental technologies. The AUVs are equipped with the hybrid pH-CO₂ sensor which can simultaneously and accurately measure the pH and carbon dioxide (CO₂) concentration of seawater; the synthetic aperture sonar having a resolution that is several dozens of times higher than conventional sonars, a high-definition stereoscopic camera, a small and accurate inertial navigation system, and underwater high-energy-density lithium-ion batteries. In 2013, we carried out sea trials, incorporating a practice operation and some observations, toward practical operation in the near future.



Figure 1. YUMEIRUKA (cruising AUV for exploration of seafloor resources), JINBEI (cruising AUV for earth science research), and OTOHIME (working AUV)

By FY2011, we had developed several technologies of the components and materials for the advanced deep water ROVs, including high-strength buoyant materials, high-strength lightweight composite cables which integrates power lines and optical fibers that can connect a mother ship to a ROV, a high-capacity optical transmission system, an optical rotary joint that can be used in cable drums in deep water, and an all-around view camera system. Adopting these advanced technologies, we started to manufacture the heavy work-type ROV required for exploration of seafloor mineral resources in FY2011; this ROV must be able to conduct sampling of seafloor mineral resources and, depending on the target of exploration, carry and operate various observation and exploration devices as payloads in deep water. We completed

the manufacturing and assembly of New ROV in late March 2013. Field tests will be conducted in FY2013 to validate the performance and to conduct shakedown of this new ROV.

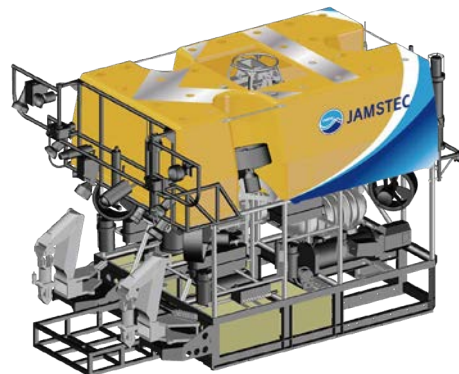


Figure 2. New heavy work-type of ROV for exploration of seafloor mineral resources

In conjunction with Nippon Marine Enterprises, we developed the self-floating ocean bottom seismograph (OBS), which represents the next generation of seismographs. In particular, the OBS represents a reduction in weight and size compared to conventional products; it also adopts noncontact electric power transmission technology and wireless technology, which reduce the time and effort required for maintenance and data loading significantly. Therefore, the OBS offers a dramatic improvement in operational efficiency. In addition to improvements in the quality of observational data, the OBS allows large-scale observations at higher densities, and has already been used to meet sophisticated research needs.



Figure 3. Left: newly developed next-generation OBS, right: conventional OBS

Furthermore, we have put into use the hadal ocean bottom seismograph (OBS), which incorporates a ceramic pressure resistant container that can withstand depths of up to 11000 m. This was developed jointly with Kyosera Corporation and has already started to contribute to the structural survey of the axis of the Japan trench (at water depths of 7000 m or more in the focal region of the Tohoku Region Pacific Coast Earthquake) and to other seismic exploration.

Research vessel operations for academic research

JAMSTEC operates and manages research vessels R/V HAKUHO MARU and R/V TANSEI MARU according to the plan developed by the Steering Committee for the Cooperative

Research Vessel Operations (secretariat: Atmosphere and Ocean Research Institute of the University of Tokyo). Total navigation days in the FY2012 were 265 days for R/V *HAKUHO MARU* and 266 days for R/V *TANSEI MARU* respectively (i.e., 531 days in total).

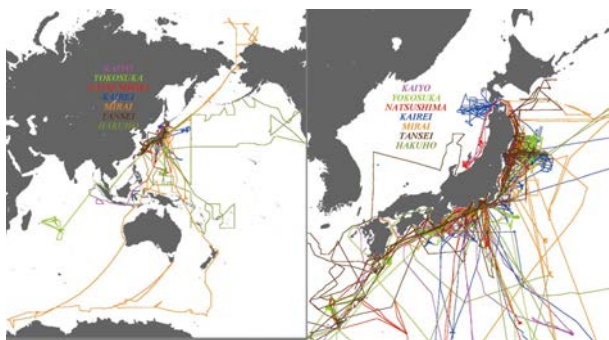


Figure 4. Tracks of 7 research vessels in 2012

Supplying voyages of research vessels and deep sea research facilities for the in-house and the public research

We also operate and manage 5 research vessels (except R/V *HAKUHO MARU* and R/V *TANSEI MARU*) and deep sea research facilities according to the annual navigation plan developed by the in-house research subjects selected by a screening committee of JAMSTEC and the publicly solicited proposed research subjects selected by the Ocean Research Promotion Committee(secretariat: JAMSTEC, which consists of external experts and others). In addition, we carry out the necessary coordination with the fisheries for the research subjects, as well as with relevant authorities inside and outside Japan to obtain permission necessary to carry out research voyage within the exclusive economic zones of other countries.

The topics of each vessel's research voyages in FY2012, R/V *NATSUSHIMA* and the remotely operated vehicle ROV HYPER-DOLPHIN conducted a study of submarine volcanic activity at Omurodashi (located on near Izu-Oshima Island) between July and August, and discovered that Omurodashi is the active submarine volcano.

R/V *KAIYO* deployed JAMSTEC m-TRITON buoy in the eastern Indian Ocean in June. Furthermore, following the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET), which began real-time observing in FY2011 in the hypocenter region of the Eastern Nankai earthquake, and conducted preliminary surveys to establish a similar system in the hypocenter region of the Nankai earthquake. The first sea trial of the new autonomous underwater vehicles (AUV *YUMEIRUKA*, *JINBEI*, and *OTOHIME*) were also carried out by R/V *KAIYO*.

This year, the manned research submersible DSV *SHINKAI 6500* and the support ship R/V *YOKOSUKA* again conducted a seafloor study near the hypocenter region of the Tohoku Region Pacific Coast Earthquake. The published study in this year reported that the enzyme extracted from the Kaiko-osoko shrimp (Crustacea Hirondelella Gigas) can contribute considerably to the production of bioethanol. Used specimens of the shrimp were collected in July 2009 from the seafloor of the Challenger Deep in the Mariana Trench (i.e., at a depth of

10,897 m) using an 11,000m class free-fall sediment sampler during a research expedition by R/V *YOKOSUKA*.



Figure 5. Kaiko-osoko shrimp collected

R/V *YOKOSUKA* and DSV *SHINKAI 6500*, sailed at Yokosuka in the first of January 2013 for a round the world voyage referred to as "QUELLE 2013". Their first destination for research dives was the Indian Ocean. The deep sea research vessel R/V *KAIKEI* conducted seismic studies off the Sanriku area and in the Nankai Trough; such studies have been of increasing public interest since the occurrence of the Tohoku Region Pacific Coast Earthquake.

The oceanographic research vessel R/V *MIRAI* voyaged to the Antarctic Ocean for the first time, reaching latitudes higher than 60°S between December and February to conduct observations. During the Antarctic voyage, R/V *MIRAI* retrieved the metrological and oceanographic observation buoy of Australia's Bureau of Meteorology, which had been drifting for two months owing to break of its mooring lines, and called at port of Hobart in Tasmania to return the buoy with receiving most welcome.

Our research vessels have been opened to the general public as follows: R/V *HAKUHO MARU* at Shimonoseki in April, R/V *NATSUSHIMA* and R/V *KAIYO* at the open facilities day of JAMSTEC Yokosuka Headquarters in May, R/V *YOKOSUKA* at the 2012 Expo Yeosu (South Korea) in June, R/V *NATSUSHIMA* at Muroto in July, and R/V *KAIKEI* at Onomichi in July, at Sendai in August, and at Shingu in November.



Figure 6. *SHINKAI 6500* after the major modification

5 research vessels (except R/V *HAKUHO MARU* and R/V *TANSEI MARU*) achieved operational 1420 days in total in FY2012, for R/V *NATSUSHIMA*, R/V *KAIYO*, R/V *YOKOSUKA*, R/V *KAIKEI*, and R/V *MIRAI* with 274, 265, 280, 301, and 300 days respectively. DSV *SHINKAI 6500*, the deep sea cruising vehicle AUV *URASHIMA*, and ROV HYPER-DOLPHIN and ROV *KAIKO 7000II* have been used by researchers of JAMSTEC and the researchers which proposed

selected publicly solicited research subjects by the committee. The first major modification of DSV *SHINKAI 6500* from completing in 1989 has been finished, and it has been used in the forefront of worldwide deep sea research without a break. The pressure container of AUV *URASHIMA* has been subdivided in time for the retrofitting of the control CPU. Furthermore, the underwater gravity meter currently being developed by the Earthquake Research Institute of the University of Tokyo was mounted in AUV *URASHIMA* and used in successful, this represented the first example worldwide of a gravity meter being used in an unmanned mission to collect data near the seafloor.

We operate oceanic observation buoy systems to monitor the El Niño and La Niña phenomena in the western pacific region and to monitor the Indian Ocean Dipole mode phenomena in

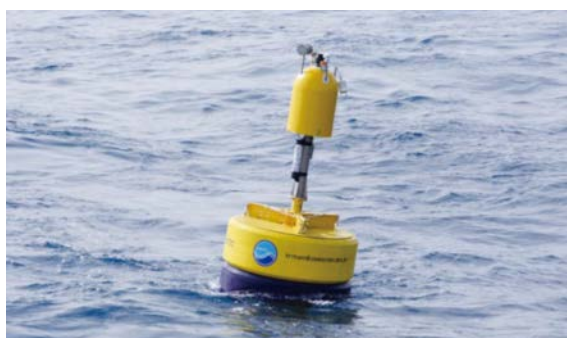


Figure 7. Buoy deployed in the Southern Ocean (near 60°S 140°E)



Figure 8. Tsunami monitoring buoy

the eastern Indian Ocean.

We deployed 15 TRITON buoys in the western Pacific region one buoy went adrift and four m-TRITON buoys in the eastern Indian Ocean (one buoy went missing); the data collected by these buoys have been made public. To maintain the ocean observation buoy array, we have been transferring m-TRITON buoy technology to Indonesia to expand the common international operation of the buoys. This transfer is scheduled to be completed during 2013. Our new southern ocean observation buoy system have deployed in January 2012 off the coast of Adelie Land in the Southern Ocean (near 60°S, 140°E) by T/S *UMITAKA-MARU*, a training ship of the Tokyo University of Marine Science and Technology. The buoy system succeeded in the long time mooring for about one year period. This was the world's first successful observation in a high-latitude area of the Antarctic Ocean using the moored surface ocean observation buoy. This technology is expected to become a key tool in climate variability research.

We developed and produced a tsunami monitoring buoy

using our original underwater acoustic communication technology and mooring observation buoy technology for strong current areas. The new buoy deployed the buoy experimentally off the Kii Peninsula in December. This buoy incorporates a GPS acoustic system that uses technology developed by JAXA and Tohoku University. The new system is thought to represent a disaster prevention system of the future.

Furthermore, with the aim of restoring fishery damaged by the Tohoku Region Pacific Coast Earthquake, we are currently constructing a marine ecosystem research vessel that will be used to investigate the effects of the Tohoku earthquake on the marine ecosystem. The research vessel R/V *SHINSEI MARU* will be completed in late June 2013. We have also released a call for proposals for a seafloor research vessel that can study wide areas, which we aim to construct by late 2015.



Figure 9. New vessel for marine ecosystem research in Tohoku region R/V *SHINSEI MARU*

The research findings obtained using these research vessels and deep sea research systems have been made public through open days for the general public and presentation of research findings (e.g., Blue Earth 2013 in February 2013). Moreover, to help the general public understand the activities of MARITEC, we held our first technical reporting meeting in September.

Training of researchers and technicians and improvement of their capacity

MARITEC provided training sessions for technicians outside the institution using the JAMSTEC facilities. These sessions included diving skills training and workshops aimed at diving administrators for honing diving operation management skills (Fig. 10). We also held Kaiyo Gijuku classes to provide technical and skills training to our newly hired personnel.



Figure 10. Diving skills training

Earth Simulator Center (ESC)

Overview

The Earth Simulator was ranked first in the top 500 supercomputers for the two and a half years after it commenced operating (in 2002) and has made significant contributions to developments in earth science technology and related fields.

The Earth Simulator was updated to a new system in March 2009. 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 and for industrial applications involving marine earth science technology (including climate change and global warming) in which a wide variety of physical phenomena are intertwined with a high degree of complexity.

The Earth Simulator exceeded the performance measurement result in the HPC Challenge Award 2012, when it recorded 11.88 TFLOPS in the benchmark global FFT (total performance of fast fourier transform) category; consequently, the Earth Simulator was ranked third globally, after the K computer (RIKEN) and the IBM Power 775 system. Although the theoretical peak performance of the K computer used for measurement is 81 times that of the Earth Simulator, its effective performance is only 17.3 times greater, assuming global FFT as a measure of effectiveness. Additionally, the efficiency of the Earth Simulator is 4.7 times that of the K computer.



Figure 1. Earth simulator

Multiscale Simulation & Modeling Research Group

Weather and climate result from complex interactions between the atmosphere, ocean, sea ice, land, and ecosystems. On top of that, human activities can affect these natural phenomena through release of chemical substances, for example. Since the both climate and weather system involves interaction of phenomena at various spatial and temporal scales, MSSG group has been working on research and development of a numerical simulation model, the Multi- Scale Simulator for the Geo-Environment (MSSG). This model is aimed toward seamless simulations of multi-scale phenomena ranging from weather to climate variation. We expect the model to capture how global warming affects climate variations, such as El Niño and the Indian Ocean Dipole, and how these climate variations influence

severe phenomena such as typhoons, heavy rain events, and urban environments.

By using MSSG, we conducted detailed simulations for predicting the characteristics of an urban environment in response to global warming. The model results demonstrate that for urban areas, the temperature within the atmospheric boundary layer is strongly enhanced by roads, buildings, and land use type; such factors can increase temperature by 0.4–3°C in addition to that caused by global warming. Such temperature increase is greater than that expected from a 30% increase in artificial heat emissions (compared to the current level). These results are submitted to the Tokyo Metropolitan Government for use in future anti-global warming measures (Fig. 2). We have also conducted detailed simulations of material dispersion in the ocean. The model results demonstrate the importance of high-resolution ocean models that explicitly solve vertical mixing and adsorption/desorption processes (Fig. 3).

We intend to investigate how seasonal variations and natural disasters on the local scale are connected in the future using MSSG. We also plan to propose concrete and adaptive measures to mitigate such disasters.

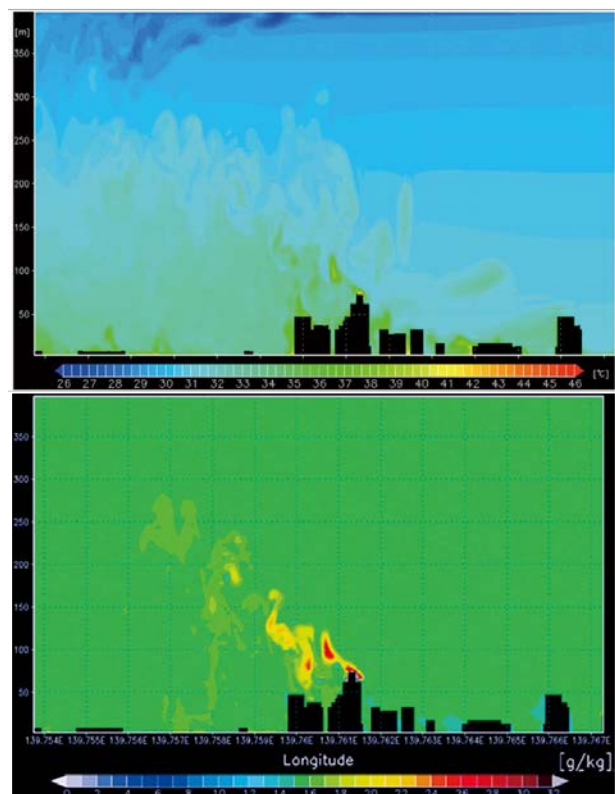


Figure 2. Model results from a hyper-resolution simulation with a horizontal resolution of 5 m in which artificial heat emissions are increased by 30%. Vertical temperature distribution (top) and specific humidity distribution (bottom).

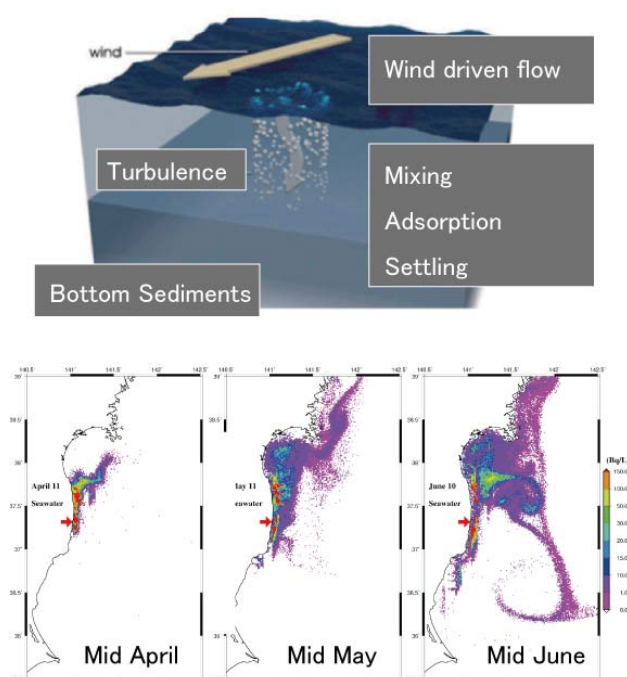


Figure 3. A schematic of how materials disperse in the ocean (top). By incorporating a particle-tracking model that is capable of tracing the movement of materials through seawater, particles, and bottom sediments, we have shown that oceanic dispersion of materials can be successfully simulated (bottom).

Advanced Visualization and Perception Research Group

Scientific visualization technologies that express simulation data graphically are essential for instant understanding of simulation results, which in turn will allow for more accurate data analysis. They are also essential for the transmission of simulation results both internally and externally. 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, all of which can contribute to society. Such techniques will allow rapid visualization of the enormous amount of data obtained from the Earth Simulator and extraction of the most useful information.

For VR techniques, we are researching a user interface that reapplies only the necessary operations from the operation history of visualization software. Figure 4 illustrates the selection of specific visualization operations from the operation history displayed on a smartphone, using a Web application we developed. This will allow selection of only the visualization results that possess an interesting three-dimensional structure, which can be selected from all visualization results displayed by interactive operations on a VR device. This technique will make VR visualization more efficient than ever.

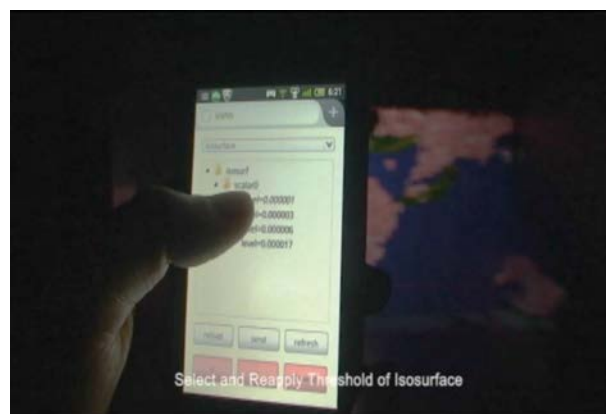


Figure 4. Operation of visualization software for a VR system on a smartphone

Figure 5 illustrates one example of the application of visual data mining to the results of an ocean general circulation model. In this example, a structure exhibiting characteristics that are different to those of the surrounding regions is calculated as a density in a variable space using a multivariate analysis technique. By projecting the data density in a multidimensional variable space consisting of several variables (e.g., temperature, density, and salinity) onto a real space, a characteristic region can be extracted by considering multiple physical quantities simultaneously, whereas this cannot be achieved using only one variable. It is clear from the figure that features such as the Gulf Stream, equatorial currents, California Current, current fronts, and vortexes are highlighted as characteristic regions. This technique allows intuitive recognition of remarkable regions in which a particular phenomenon is occurring, and its application to heuristic visualization and analysis is expected.

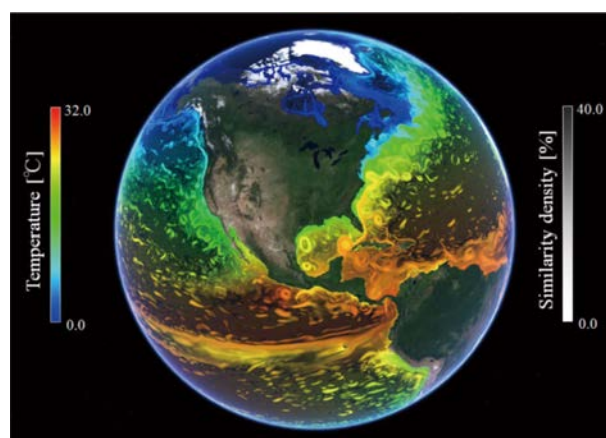


Figure 5. An example of applying visual data mining to an ocean general circulation model

We also promote EXploring and TRAvelling the World INSide Geoscientific data (EXTRAWING), a project involving novel representations of simulation results and effective transmission of those results to the general public. For example, a Web application program developed as part of the project is illustrated in Figure 6. This is an open program that can be used on the

Internet and allows anyone to display simulation results easily from both outside and inside. Furthermore, we are developing various methods to represent and transmit information, including three-dimensional representation methods for simulation results, visualization programs for EXTRAWING content, and three-dimensional observation methods for EXTRAWING content using VR equipment such as BRAVE.



Figure 6. EXTRAWING Web application
<http://www.jamstec.go.jp/esc/extrawing/>

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 introduce an example using a coupled atmosphere–ocean model focusing on air–sea interaction in the Hawaiian Lee Countercurrent (HLCC). The HLCC is an easterly current that extends several thousand kilometers westward from the Hawaiian Islands beyond the international data line. Recent satellite observations confirmed that high sea surface temperature (SST) band is distributed along the HLCC, toward which the surface winds converge to form clouds. Moreover, our global coupled atmosphere–ocean model CFES reproduced the HLCC and accompanying high SST band and surface wind convergence (Fig. 7). We conducted ensemble experiments of the standard CFES experiment and a sensitivity experiment, in which the SST used for the calculation of sea surface flux were smoothed, and compared with the ensemble averages to investigate air–sea interaction through high SST band. The results demonstrate that the ocean responds to wind curl along the wind convergence band, and then the HLCC accelerates and decelerates in the southern and northern parts of the current, respectively. The acceleration in the south is more prominent than the deceleration in the north, indicating that the dynamic feedback to the ocean following the atmospheric response caused by the high SST band accelerates and maintains the HLCC. Furthermore, the current velocity changes induced by the dynamic feedback transfer heat, influencing water temperature near the HLCC. The sensitivity

experiment method using coupled atmosphere–ocean model in this study may be used to elucidate the mechanisms in the air–sea interactions caused by the SST front in other areas.

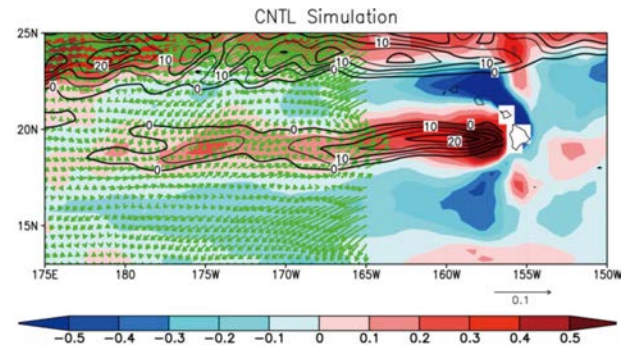


Figure 7. The Hawaiian Lee Countercurrent accompanying high SST band and surface wind convergence in the medium-resolution global coupled atmosphere–ocean model CFES. Surface eastward current speed (contour, cm s^{-1}), SST (color, $^{\circ}\text{C}$) and wind stress vectors (10^{-1} N m^{-2}). Meridional high-pass filter is applied to SST and wind stress.

Observing System Research and Ensemble Data Assimilation Development Research Team (OREDA)

We are developing ensemble-based systems for the analysis of atmospheric, cryospheric, and greenhouse gas data and conducting observing system research to evaluate observations and investigate predictability. This is a crosscutting team that includes members of the Earth Simulator Center and several programs of the Research Institute for Global Change, and research is being conducted in cooperation with researchers at the University of Maryland and Doshisha University.

Adding and removing observations to and from our analysis system can reveal the value of each observation, which is reflected in the analysis and its ensemble spread (the latter of which is regarded as the analysis error). Studies of this form are known as observing system experiments.

During the 2010 Arctic expedition of R/V *Mirai*, JAMSTEC scientists successfully obtained direct and detailed observations relating to the genesis and development of an Arctic cyclone. The observational data collected by *Mirai* were distributed to various numerical weather forecasting centers globally and were particularly valuable owing to the lack of operational radiosonde stations over the Arctic Ocean.

An observing system experiment using our ensemble-based analysis system shows that a tropopause fold is reproduced more realistically and analyzed air temperature at the 300-hPa level increases by more than 5 K as a result of the assimilation of radiosonde observations collected by *Mirai* (Fig. 8). Furthermore, the effects of data assimilation extend to around 60°N and the analyzed westerly winds associated with the polar front jet strengthen in the middle and upper troposphere. We will continue to study the effects of such intensified observations over the Arctic Ocean on the reproducibility of atmospheric conditions in the mid-latitudes, including Japan.

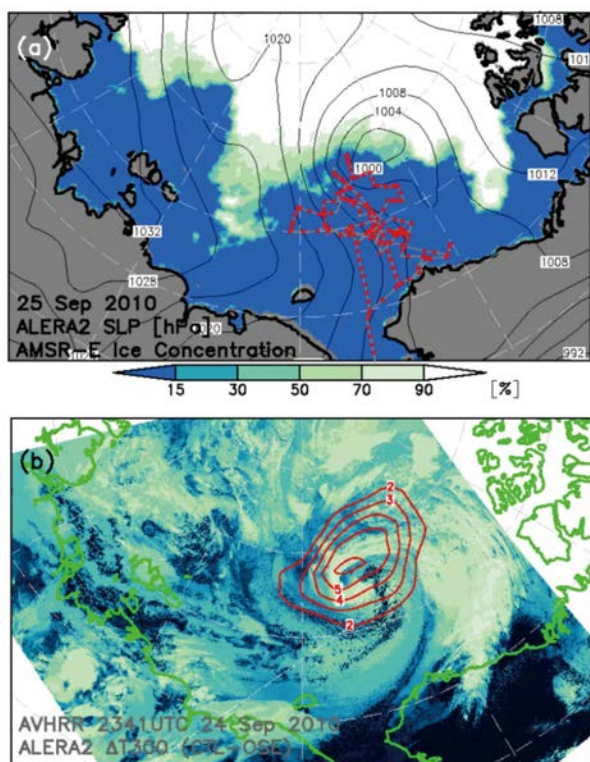


Figure 8. (a) The sea level pressure pattern (contours) for the Arctic cyclone encountered by R/V *Mirai* on September 25, 2010, and the sites of radiosonde observations (red dots) conducted by *Mirai* during the Arctic Ocean cruise. Color shows sea ice distribution. (b) Difference in analyzed air temperature at the 300-hPa level (red contours) between the cases with and without assimilation of observational data collected by *Mirai*. The background is a satellite image of the area. From Inoue et al. (2013).

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 2012, we selected 13 research projects and provided them with technical support; nine of these projects were in the category “Technical development for reducing environmental loads” and four were in the category “Technical development for realizing safe and secure society.”

As an example, we will touch upon the Kawasaki Heavy Industries project entitled “The development of technologies of high-efficiency electrical machines using large-scale numerical analysis” (see excerpts from the use report of the Earth Simulator Industrial Use Symposium 2012). In terms of energy savings, it is very important to make electrical equipment such as motors, transformers, and reactors more efficient. Electromagnetic simulation is essential in the design and development of high-efficiency electrical equipment and it is no exaggeration to state that improvement of related simulation technology will be the key to such development. In this project, the Earth Simulator was used to perform a large-scale magnetic field analysis for electrical equipment using the three-dimensional finite element method, in order to elucidate detailed electromagnetic phenomena that

occur in electrical equipment. This had previously been difficult to achieve, but will help develop technology that will improve the efficiency of electrical equipment. In particular, a reactor analysis was conducted to determine the detailed distributions of current density and magnetic flux density for segmented coil wires, and the hurdles that must be overcome to realize high efficiency were clarified.

Figures 9 and 10 illustrate an analysis model and the eddy current loss density distribution of coils, respectively. Different coil segmentation patterns were analyzed; the results showed that the interlinkage flux density and the eddy current loss increased as wire thickness increased. Moreover, it is clear that such loss can be greatly reduced by increasing the number of partitions.

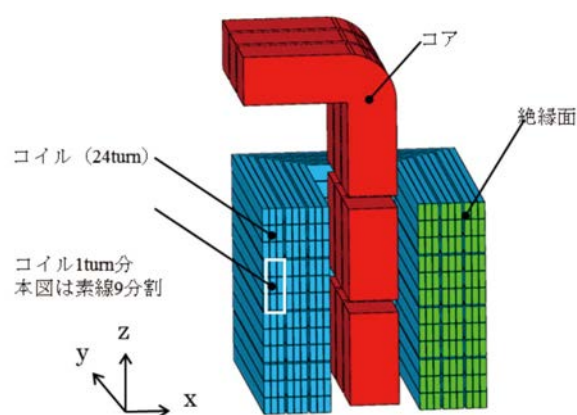


Figure 9. Analysis model

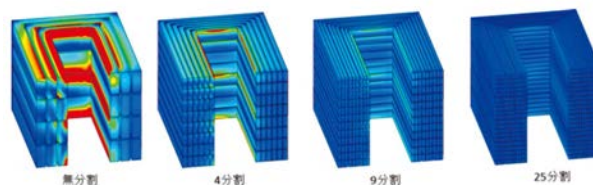


Figure 10. Eddy current loss distribution in a coil (60 Hz)

The large-scale numerical analysis quantitatively determined magnetic phenomena such as the magnetic flux density vector distribution in a reactor coil, the eddy current density vector distribution, and the eddy current loss density distribution. By advancing research further, we believe that it will become easier to design higher efficiency electric equipment, which will contribute to saving energy and reducing resource use by simplifying cooling.

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 the 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 provide 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 2012, we participated in Japan's largest specialty fair for manufacturers, the Design Engineering & Manufacturing Solutions Expo (held inside Manufacturing World 2012 Japan; Total attendance: 75,015 [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.

Establishment of Promotional Framework for Computer Science and Technology

Japan has been attacked almost every year by typhoons, local heavy rainfalls, earthquakes, tsunamis, etc., and has suffered severe damage. Especially, on 11 March 2011, Japan was attacked by a huge earthquake whose epicenter was located off the Pacific coast of Tohoku Area, 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. These 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 use of an "Earth Simulator". Also, since fiscal 2011, we have embarked on a "Strategic Programs for Innovative Research; Advanced Prediction Researches 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 rainfalls, 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 this fiscal year, we joined the HPCI (High Performance Computing Infrastructure) Consortium which is engaged in improvement of 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. 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 at the Yokohama Institute for Earth Science receives and stores these data and samples, as well as controlling the quality.

DrC provides the oceanic current reanalysis data for simulation of the drifting debris originating from the Great East Japan Earthquake and Tsunami in the Pacific Ocean, and has opened the official website for Tohoku Ecosystem-Associated, Marine Sciences (TEAMS). In addition to this, to aid in the disaster recovery from 2011 The Great East Japan Earthquake as well as disaster mitigation for future events, we are developing a new seismic wave data viewing system.

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

1. Management and Dissemination of Marine-Earth Observation Data

1) Data Search Services

The DrC provides two types of data search services, the "JAMSTEC Data Search Portal" and the "JAMSTEC Data Catalog." Users are able to search for observational data by selecting the area of interest on a map within the "Data Search Portal" and are also able to search for datasets or databases by selecting keywords in the classification tree within the "Data Catalog." In 2012, in accordance with a request from the Ministry of Education, Culture, Sports, Science and Technology, DrC provided the metadata of JAMSTEC's observation projects which are registered in the "Earth Observation Implementation Plan of Japan in 2011" for the "Search and Discovery System for DIAS Datasets." These metadata can also be extracted from the "Data Catalog."

At present, the "Data Search Portal" contains approximately 40,000 entries of data or samples, and the "Data Catalog" contains 35 database entries.

2) Dissemination of the data and sample information

In 2011, DrC developed a new database, the "Data Research System for Whole Cruise Information in JAMSTEC (DARWIN)". This contains data and sample information disseminated from the "JAMSTEC Data Site for Research Cruises". In 2012, DrC

transferred the data from the old site to DARWIN and opened it to the public (Fig. 1). There are approximately 5,500 disseminated data available, and about 600 cruises.

DARWIN provides complete search and discovery methods, and helps users to find data with the minimum amount of effort, also enabling the download of more than one data file at any one time. At the same time, DARWIN has made the registration and dissemination of data more efficient by an improvement of its management functions.

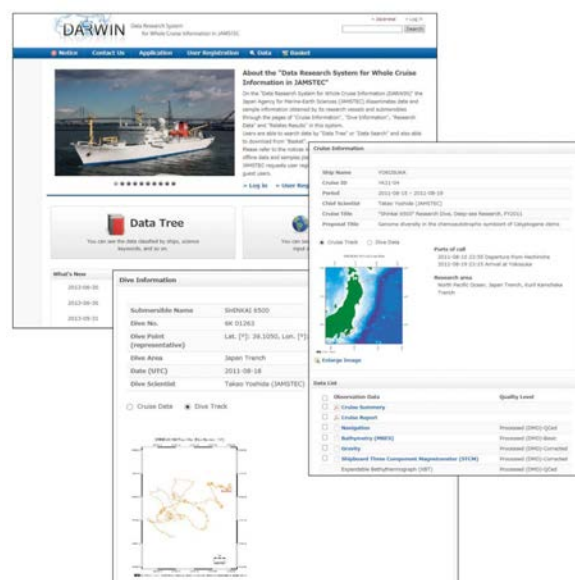


Figure 1. Screen shots of the "Data Research System for the Whole Cruise Information in JAMSTEC"

Document data such as cruise reports that can be shown in DARWIN are managed by the "Document Catalog." At present this can open about 2,500 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 has also developed and transferred to a new version of the "Deep Sea Floor Rock Sample Database (GANSEKI)" in order to extend disseminating data types, improve its user interface, and cooperate with the database providing cruise information. GANSEKI continues to provide its metadata for the international geochemical data portal "EarthChem," which has been collaborating with GANSEKI since 2009. DrC also provides rock samples for research and education and for the purpose of improving public relations. The number of registered metadata has now increased to 22,702, the number of samples to 11,114 and the number of geochemical analysis data to 17,981.

To extend the types of disseminating data available, DrC has also begun to provide the viewing of document information and X-ray CT scanogram images in the "Core Data Site," a data dissemination site for core samples, which are samples of ocean bottom sediments in the column. The number of data of samples provided has now increased to 813, the number of opened

samples to 4,433, and the number of core samples provided to 24.

In 2012, DrC presented activities on rock samples and core sample management at scientific meetings and symposiums, to promote the use of such samples.

The “Marine Biological Sample Database” is a comprehensive database containing information of the biological samples acquired on JAMSTEC’s research cruises. This database has been in operation since 2009. DrC has now extended its retrieval functions, and has added an information page for a sample request. Furthermore, DrC has contacted scientists who preserve samples, in order to provide an update on the current status of such samples. In addition to sample information gained from recent JAMSTEC cruises, the DrC has registered information relating to 12,000 samples collected by the “Marine Biodiversity Research Program” in the Institute of Biogeosciences, JAMSTEC, and the number of opened records has now increased to 26,000. Most of these data are shared with the Biological Information System for Marine Life (BISMaL, see below) and contribute to the Ocean Biogeographic Information System (OBIS), the international biogeographical database.



Figure 2. A screen shot of the top page of the “Marine Biological Sample Database” and photos of deep-sea biological samples.

3) Dissemination of images

DrC continues to digitize deep-sea still photos and video tapes obtained from research dives by JAMSTEC’s deep-sea submersibles. In 2012, the digitization of negatives and video tapes of at least one camera for every dive was completed. Responding to the recent trend of shifting video recording media to hard disk drives from video tapes, DrC has created a standard procedure for archiving video files in LTO5, which is the latest generation data archive tape. DrC has also started to reconstruct the workflow, and to develop an information system for the management and dissemination processes of images. By using the “JAMSTEC E-Library of Deep sea Images” (J-EDI), which was opened in November 2011, DrC considerably optimized the video streaming format and improved the efficiency in annotation. As a result of such improvements made during 2012, DrC added indexes to about 2,700 dives of deep sea videos and still images. A gallery page of deep sea videos that interested annotation staff was also opened (Fig.3).

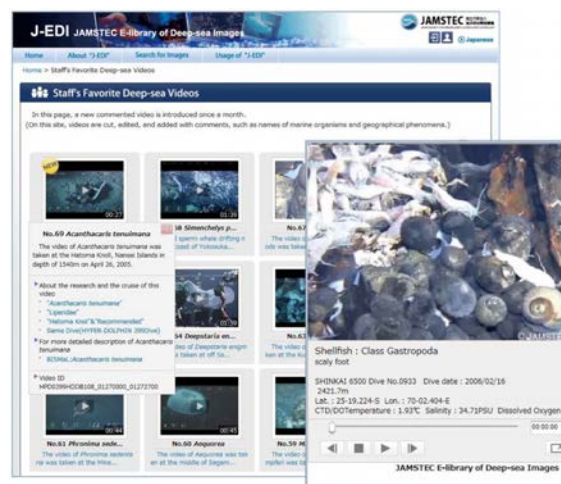


Figure 3. Staff members' favorite gallery - screen shots of deep sea videos

4) 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 2012, as a preparation for the acceptance of marine life occurrence data through J-RON, DrC extended the scope of the database from Animalia to all creatures including Archaea and Bacteria; DrC registered 5,500 taxon names, including those of macroalgae and phytoplankton to the database and then made them available. DrC improved the BISMaL system by adding the search and display window for occurrence data. DrC (Fig.4) also developed, evaluated and improved the “Visualization

and Analysis Support System for Marine Life Distribution” to promote the use of data in BISMAL, which will be opened for public use within the next year.

As part of the operation of J-RON, the Steering Committee of J-RON was established and the web site of J-RON was opened. Datasets from outside JAMSTEC were accepted, and the datasets from the project related to the “Environment Research and Technology Development Fund” of the Ministry of the Environment (comprised of 14 datasets and about 11,000 records) were registered. Their publication is now scheduled after termination of the project. The DrC performs quality control and standardizes the procedures relating to the registration and dissemination of these data.

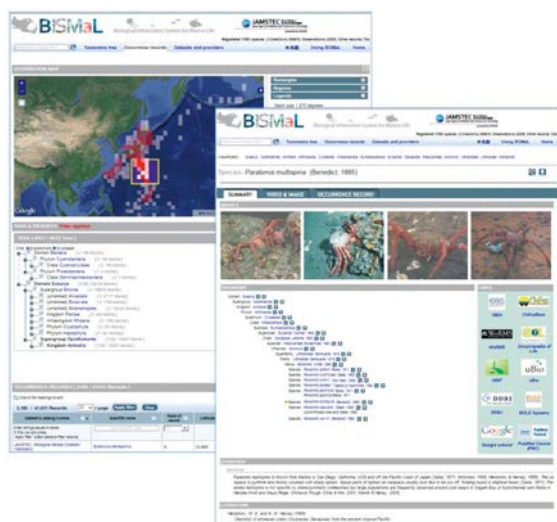


Figure 4. Images of the next version of BISMAL (under development). (Upper left: search and display window for occurrence data, lower right: classification tree window)

5) Analysis of Access on the Data Dissemination Sites

Recently, user-needs of socioeconomic sector have been increasing. Therefore, in order to understand the requirements of the users of our data dissemination sites, and to extract useful information to refine the data sites, we continue to collect and analyze the data about access to our data sites. By 2011, DrC had established a process of gathering access logs from various data sites, automatically analyzing them daily, and evaluating them monthly. By 2012, DrC had made the process routinely available and had summarized the number of visits (Fig. 5) and page views. Using the results of these analyses, it became possible to understand the periodic tendency of user access, and the results of improvements of the data sites. Classifying the origins of access into the categories (as nations or businesses) and extracting the top ranking categories have enabled us to attempt to specify the major users of each data site. The increase in the number of visits and page views of data sites reflects the interest in our sites that opened last year, and reveals that some research institutes are frequently downloading observation data.

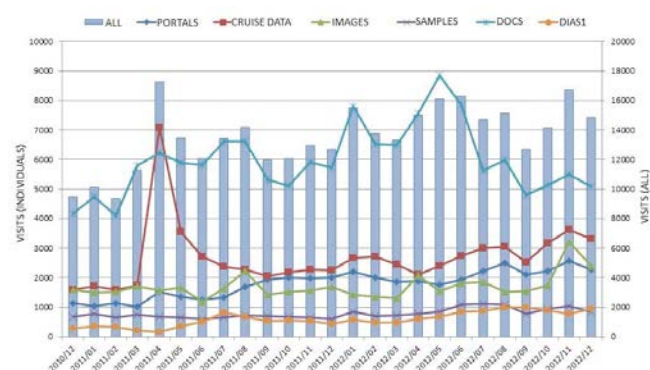


Figure 5. Changes in the number of visits to all DrC's data sites, and those to individual data sites

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 (4D-VAR) system, capable of performing dynamic analyses. This system is used for the improvement of predictions on a seasonal to inter-annual time scale, the inverse analysis of physical processes, and an optimal design of the observation system. The downscaling system has also been developed to deliver 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 in the prediction of seasonal to inter-annual variation as an initial condition. In this fiscal year, we developed the 4D-VAR system, which assimilates Argo float data gained in collaboration with the Strategic Ocean Monitoring Research Team, RIGC. By using this system, we are working towards the development of higher quality products which assimilate Argo data, and a scientific evaluation of the impact.

Figure 6 shows the root-mean-square difference of prediction results and observation data, for temperature at a depth of 195 m in two scenarios with and without the Argo float data. It is clearly shown that the differences are effectively reduced, not only in the assimilation period (Jan–Mar 2010), but also for the one-year prediction period.

Figure 7 shows the difference between cases with and without Argo data for surface winds in April 2011. The impact of Argo data assimilation is reflected in the atmospheric circulation through the air-sea interaction processes. We are continuing to analyze the mechanism whereby the Argo data assimilation improves the process.

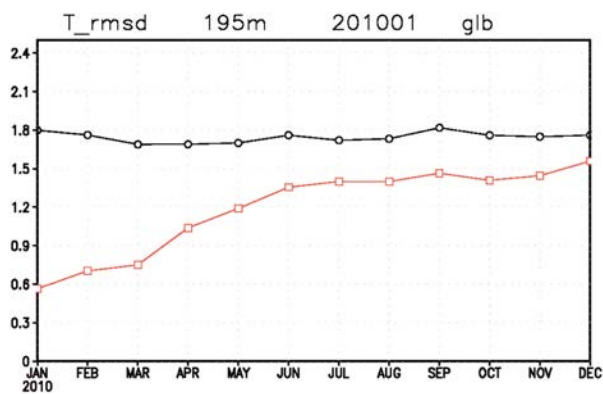


Figure 6. Time series of the root-mean square difference between the observation and model results for temperature at a depth of 195 m. Red line shows the case with Argo data assimilation, and black line shows the case without Argo data assimilation

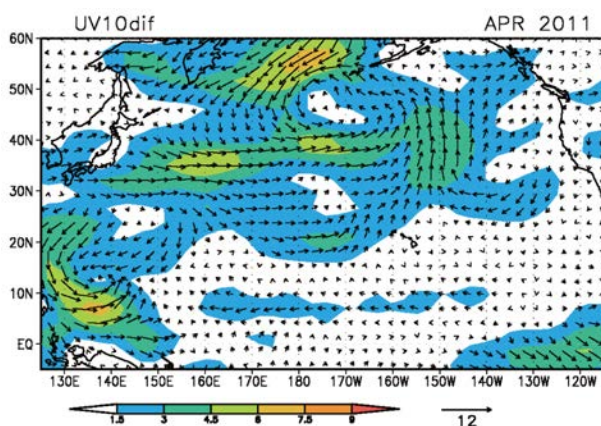


Figure 7. Difference between cases with and without Argo data assimilation for the sea-surface wind over the North Pacific in April 2011

b) Prediction of variability in fishery resources

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

This year, we continued to develop an estimation system of potential fishing areas, using a Habitat Suitability Index model, together with the products of eddy-resolving data assimilation and a prediction system of the medium range variability in stocks of fishery resources. In addition, we have tested a way of distributing information relating to environmental conditions to fishing vessels. Figure 8 shows the web site from which each fishing vessel can access daily information through Inmarsat satellite communication. Figure 9 shows the temperature distribution at a depth of 300 m, as provided by our system. We can confirm that our information system is extremely useful for operational fishing.



Figure 8. Web site pictured providing environmental conditions.

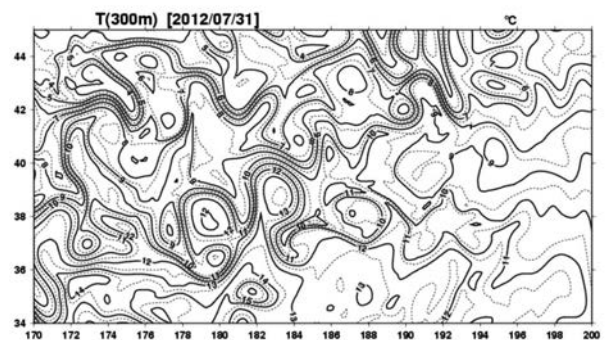


Figure 9. Distribution of temperature at a depth of 300 m in the central North Pacific

c) Data Integration and Analysis System (DIAS)

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

The second phase of DIAS, the “Global Environmental Information Integration Program” began last year, and was led by the University of Tokyo, under the collaboration with JAMSTEC, JAXA, National Institute for Environmental Studies, etc. We have been developing a prototype of the system to provide products of the atmosphere–ocean coupled assimilation system to various users. At the same time, we have started discussions on how to impart our methods of system operation, which is expected to be in practical operation in 2016.

2) Earthquake, reconstruction and disaster prevention

a) Great East Japan Earthquake and reconstruction efforts

In cooperation with relevant agencies and institutions, we continue to carry out a study which estimates and predicts the distribution of the vast amount of debris washed away by the tsunami following the earthquake, and the radioactive substances which leaked as a result of the nuclear accident.

As the floating debris and radioactive substances are expected to spread over the North Pacific over a period of several years, we are tracing them using a reanalysis product obtained by the atmosphere–ocean coupled data assimilation system, and a velocity field obtained from a prediction of seasonal/annual changes. With respect to the prediction of the drifting tsunami debris, JAMSTEC and other research institutions are carrying out a study commissioned by the Ministry of the Environment. The simulation study of the distribution of radioactive substances is carried out in collaboration with the Japan Atomic Energy Agency.

b) 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 The 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 between the off-Tohoku coast 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 the publication of this information and data. We opened the TEAMS official website in July 2012 (Fig. 10), and designed the data policy for the TEAMS project. We have also begun the construction of a data management system which collects meta-information of investigation plans, and tackles the preparation of data

acceptance, in order to establish data management organization. Furthermore, we are engaged in a platform development for the system infrastructure which will act as a base for handling access and authentication for publication of TEAMS data, and a data catalog system which will help users to find data through TEAMS data sites and databases.

3) Development of earthquake research information database

Installation of all 20 observation stations in the ocean bottom earthquake and tsunami observation network was completed during 2011. The Yokohama Institute of JAMSTEC now receives this data, which are collected at these observation points in real time. JAMSTEC then stores them as a database using an international standard format, called SEED. The Institute for Research on Earth Evolution (IFREEE), JAMSTEC is accumulating crustal structure data collected through observations of the sea area off the coast of Kii Peninsula and the Shikoku Island, using ocean-bottom seismographs and multi-channel seismological surveys. In order to continue a 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. Over the next two years, we plan to develop a system which combines these databases, so as to make them available to users.

Ocean bottom pressure gauges were able to detect the arrival of the tsunami waves generated by the 2011 The Great East Japan Earthquake, a long time before the tsunami actually hit the coast. Therefore, within the next two years, we plan to develop a data viewing system through the internet for real-time strong-motion seismograph and pressure gage data. There have been requests from local governments in areas close to the ocean bottom observation network, for use of such data so as to ensure the prompt evacuation from a tsunami hazard. We are therefore planning to develop this data viewing system to satisfy these requirements.



Figure 10. TEAMS official website (<http://www.i-teams.jp>)

3. Public understanding of marine science and technologies

1) Public understanding of marine science and technologies in GODAC

GODAC is making its facilities and equipment available to the general public, along with its lecture rooms and video system, by holding various events. The events include three GODAC Seminars (a total of 43 seminars to date), four sessions of a Marine Classroom (a total of 22 sessions to date), and a GODAC open house (on November 23, 2012, attracting

970 visitors). We are implementing the public's understanding of marine science and technologies, along with public awareness activities, using these various approaches.

At the end of December 2012, the number of visitors had reached 135,632 since GODAC opened its doors.



Figure 11. GODAC open house event

2) Promotion of collaboration between related organizations in north Okinawa

We accept students for on-the-job training and internship. Furthermore, we participate in various local events, such as the Nago City Environmental Fair, and the Nago Summer Festival, by providing exhibits and assistance.

From 2012, we have provided the ability to form advanced links and cooperation between the regional contributors in organizations in north Okinawa, such as Nago City; Okinawa National College of Technology; Sesoko Station of the Tropical Biosphere Research Center, University of the Ryukyus; Meio University; Nago Museum; and Okinawa Churashima Foundation. We are also moving to advance the establishment of information networks for the utilization of marine science and technology information, and of human resource development through human resource and technology exchanges with these organizations.



Figure 12. Official gathering of organizations in north Okinawa

Center for Deep Earth Exploration (CDEX)

Overview

The role of the Center for Deep Earth Exploration (CDEX) is to implement the Integrated Ocean Drilling Program (IODP), and to manage the Deep Sea Scientific Drilling Vessel *CHIKYU* (Fig.1) in a safe and efficient manner. CDEX also provides scientific and technical services for scientists on board the vessel, as well as managing databases used for the expeditions. In addition, CDEX is developing the world's deepest Riser Drilling system; to be used in future scientific drilling programs.



Figure 1. Deep Sea Scientific Drilling Vessel *CHIKYU*

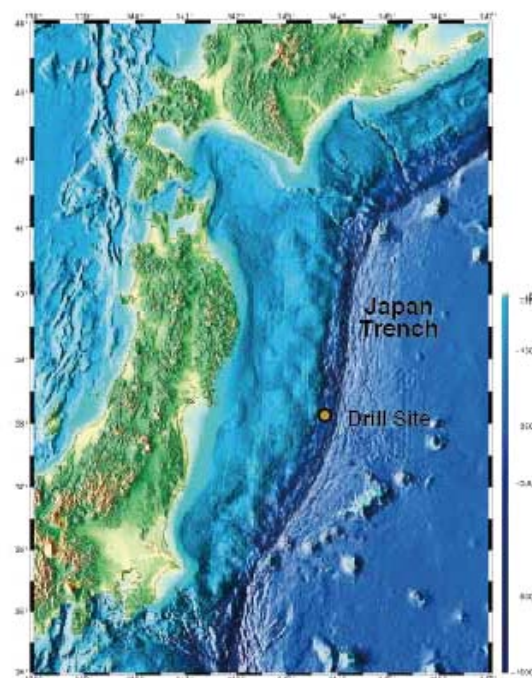


Figure 2. Drill site JFAST

Japan Trench Fast Drilling Project (JFAST I & II)

The Integrated Ocean Drilling Program Expedition 343 “Japan Trench Fast Drilling Project (JFAST)” was conducted from 1 April to 24 May 2012. The selected drill site was offshore-Ojika Peninsula in Miyagi Prefecture (Fig.2); an area where a large displacement of the seafloor occurred during the earthquake, as inferred from previous research (Fig.3). The scientific objective of this expedition was to reveal the frictional properties of the plate boundary fault that caused the Tohoku Earthquake and its associated tsunami.

In this location we conducted logging-while-drilling (LWD) to the depth of the plate boundary, (850.5 m below the seafloor), to obtain physical properties of the formations. CDEX also recovered core samples at depths of 648 m to 844.5 m across the fault zone.

Following this expedition, repairs to *CHIKYU*'s azimuth thrusters and its annual inspection were completed, and we conducted an expedition to install the observatory assembly in July 2012 (Fig.4). This was the world's first attempt to measure temperatures at the plate boundary of a fault soon after an ocean trench earthquake.

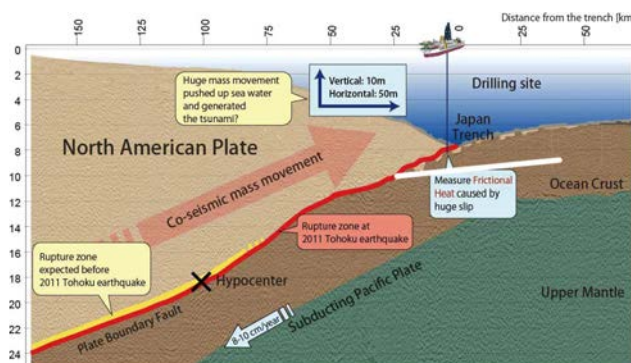


Figure 3. Schematic diagram of crustal structure at drill sites

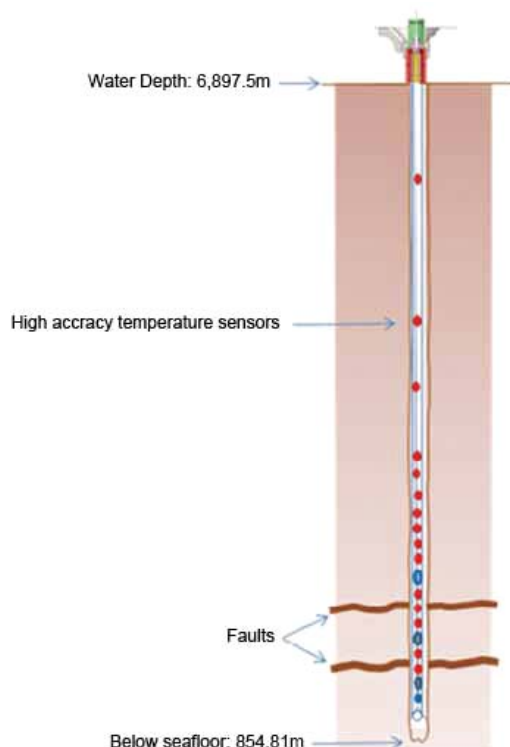


Figure 4. Miniature temperature logger (MTL) Measurement System for the JFAST operation

Deep Coalbed Biosphere off-Shimokita

The IODP Expedition 337 "Deep Coalbed Biosphere off-Shimokita" was conducted from 26 July to 27 September 2012, in the northwestern Pacific Ocean, 80 km offshore from Hachinohe (Fig. 5). The aim of this expedition was to clarify the deep underground biological activity believed to play an important role in the carbon cycling below the sea floor. The *CHIKYU*'s riser drilling system was used to reconnect and extend the bore hole which was drilled to 650 m below the sea floor (Fig. 6) during the shakedown cruise in 2006. This expedition extended the borehole to 2,200 m below the sea floor, and collected core samples and fluids, (groundwater, etc. in strata), along with LWD (logging-while-drilling) activity to collect physical property data on the strata.

In this expedition, *CHIKYU* set a world new record by drilling down to a depth of 2,466 m below the seafloor, which superseded the record held by *JOIDES Resolution* in the history of scientific ocean drilling, (which had reached a depth of 2,111 m into the seafloor at Costa Rica Rift).

Researchers are carrying out cutting-edge research, and merging the disciplines of earth and life sciences to assess the activity of underground microorganisms involved in producing methane hydrates and natural gas originating in coal beds under the deep sea floor. This includes analyzing microbial DNA and microbial culture experiments to investigate their metabolic function and evolutionary processes.

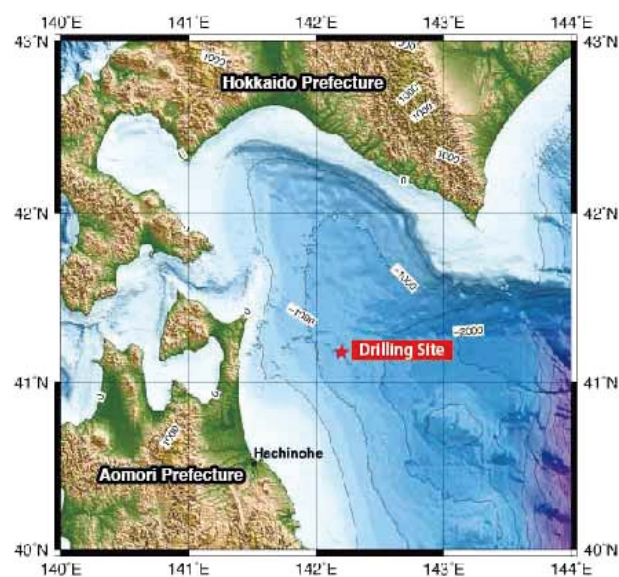


Figure 5. Study area

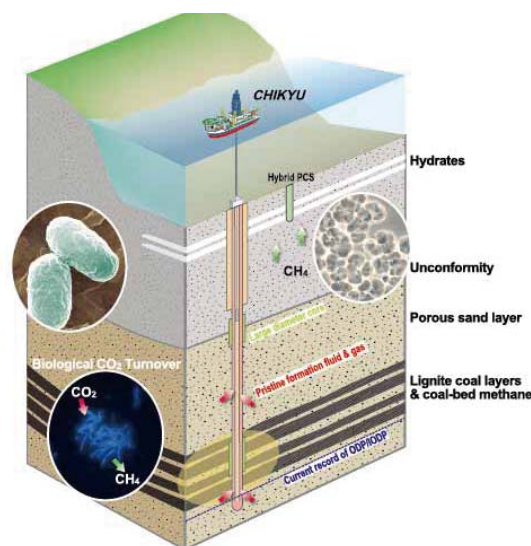


Figure 6. An image of the sub-seafloor structure of the drilling site off-Shimokita

			
Property	Geological formation formed in deep sea (Sediments including fossils of shells)	Coal bed (A part of Lignite layer 7m thick)	Geological formation formed in coastal and land (Sand layers including thinned coal bed and calcareous beds)
Collected depth below seafloor (m)	1,747-1,756.5	1,919-1,928.5	1,973-1,981.5

Figure 7. Collected cores from the sub-seafloor during Expedition 337

Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE)

The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) is a drilling project designed to investigate the role of megasplay faults in influencing plate boundary slip and subsequent tsunami generation. The mechanisms of earthquake and tsunami generation along the Nankai Trough, and the mechanisms controlling the aseismic–seismic transition along the fault system, are assessed by drilling boreholes to collect geological samples and conduct in situ measurements of the geological properties, along with monitoring crustal deformation (Fig. 8).

Expedition 338 was conducted from October 1, 2012 to January 13, 2013. Also in 2012, the expedition plans for NanTroSEIZE included drilling with a riser system to 872.5 m below the seafloor, at a water depth of 1,939 m, (at IODP Site C0002, which is located 80 km off the Kii Peninsula). Although drilling progressed to 2000 m below the seafloor, plans for 2012 were revised, as sudden changes in sea conditions resulted in damage to parts of the drilling equipment. The drilling will now be resumed in 2013. Drilling is scheduled for 2014 at other locations, (as part of the Nankai Experiment), and will include the collection of geological samples and well logging.

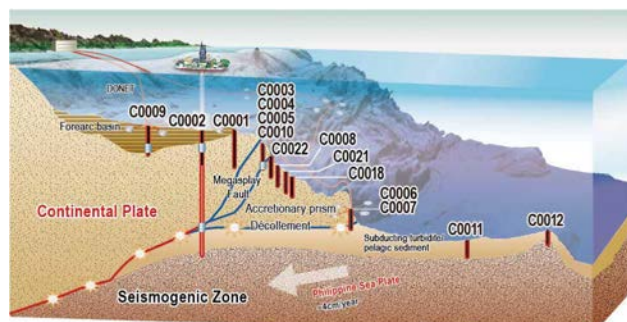


Figure 8. Schematic diagram of sub-seafloor geological structure at NanTroSEIZE site

Development of Technology

CDEX developed the Hybrid Pressure Core Sampler (Fig. 9), which is able to collect samples which retain their high underground pressure. This core sampler was installed successfully during a test operation which took place from June 26 to June 28, 2012.

A common coring system brings a gush of soft sediments and lost of sediment structure and chemical components because of lost of gasses dissolved in groundwater in the deeper part of sub-seafloor. This causes problems that we have very little concrete knowledge about. The significance of our new system is that it can retrieve deep sea sediments preserved in their original form. This system may contribute greatly to leading-edge research in the fields of geoscience and bioscience.

The test operation at the Kumano mud-volcano #5, retrieved cores from the top of the mud volcano to a depth of 60 m in the

sub-seafloor, (at a water depth of 1,900 m), whilst retaining the high pressure in the sampler. By examining the sample with X-rays (without opening the sampler), it was revealed that there was no drop in pressure, and that the sediment structure retained its original form with a solid methane hydrate.

This operation was the world's first, and the samples collected can be utilized for geochemical and microbiological researches, and kept at the Kochi Institute for Core Sample Research at JAMSTEC.

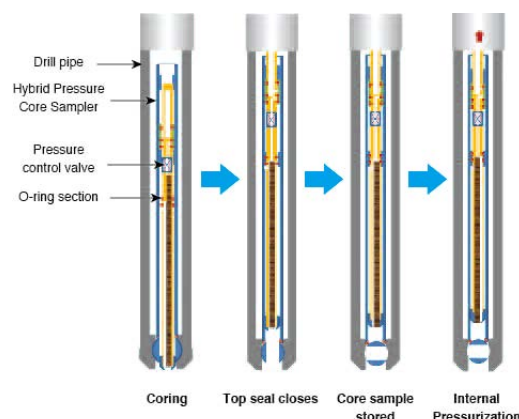


Figure 9. Mechanical explanation of the Hybrid Pressure Core Sampler

A new mud gas analysis laboratory was built on board the *CHIKYU* for use in the next research expedition (Fig.10). The laboratory allows the constant monitoring of mud returned by drilling, thereby enabling the analysis of natural gases and the supersensitive analysis of geochemical data to extract chemical compositions and methane carbon isotopes.

It is a facility for the collection of data that stands up to intense scientific scrutiny, and *CHIKYU* is the world's only drilling vessel carrying this level of analytical equipment.

The mud gas monitoring system was used in IODP Expeditions 337 and 338, and contributed to obtaining valuable data which provided information on the cycle of materials within the deep biosphere.



Figure 10. Mud gas monitoring system in container laboratory

Outreach

CDEX promotes scientific achievements and IODP activities for the general public, which this has involved the creation of a special web site showing *CHIKYU* IODP expeditions, a web movie program "*CHIKYUTV*" and a web magazine "*CHIKYU Hakken*" (Fig.11).



Figure 11. "*CHIKYU TV*" featuring the IODP Expedition 343, Japan Trench Fast Drilling Project (JFAST) (www.jamstec.go.jp/chikyutv/).

CDEX also work towards improving informative scientific literature, for the education of students and the general public. In addition, a plastic model of *CHIKYU* has now been launched by a toymaker, under the supervision of JAMSTEC (Fig.12).



Figure 12. Plastic model of *CHIKYU* (1/700) developed by a toymaker under JAMSTEC's supervision

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 obtained great support and 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.

On April 1, 2004, the Japan Marine Science and Technology Center made a new start as the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). 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.

Under continuing strict financial conditions in Japan, JAMSTEC has also made the maximum effort to reduce expenditures and improve the efficiency of projects. We very much appreciate your continued understanding and support of JAMSTEC. (Membership fees [donations] are eligible for tax deductions [Applicable law: Corporate Tax Law, Article 37].)

• **Privileged JAMSTEC Partners can:**

- Publications are distributed to members
- Allowed use of books and other information materials
- Invitations to lectures etc.
- Preferential treatment at classes, seminars
- Experts dispatched upon request to give technical guidance
- Instructors dispatched upon request to in-company seminars
- Preferential use of jointly operated testing and research facilities
- Special rights to use intellectual property
- Special opportunities to commission testing or research
- Other preferential treatment

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A seminar for JAMSTEC Partners



The science cafe



Test dive tour and boarding the research vessel *KAIREI*



JAMSTEC tour





Japan Agency for Marine-Earth Science and Technology

Research Advancement Division

Advanced Research and Technology Promotion Department

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