JAMSTEC
2010 Annual Report

Japan Agency for Marine-Earth Science and Technology

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Preface

JAMSTEC started its second midterm plan two years ago. In its second year, fiscal 2010, we achieved all items in the annual plan and some items yielded excellent results beyond the plan. Among them, for the operation of research vessels, we secured high operating rates with planned maintenance, efficient operation, and appropriate safety measures. We believe this contributed to promoting research activities in the oceans.

JAMSTEC has been advancing its undertakings generally well even in the recent austere fiscal environment. In particular, for fiscal 2010, toward realization of "the strategy for the world's environment and energy power through green innovation," which is cited in the government's New Growth Strategy, we made aggressive proposals on research and technology development for utilization of seabed resources in the seas around Japan and for adaptation measures for climate change and climate fluctuations. As a result, we obtained a budget for "Submarine Resources Research" along with government-subsidized projects and competitive funds. This year, we found strong direction in the activities of JAMSTEC.

The year 2010 was also the International Year of Biodiversity, as set out by the United Nations. We participated in the 10th Conference of the Parties (COP10) to the Convention on Biological Diversity, which was held in Nagoya, Japan, and introduced our ongoing research in biodiversity, such as research on deep sea ecosphere and surveys of the land ecosystem via satellite.

Furthermore, the deep sea drilling vessel *Chikyu* operated actively, starting with Nankai Trough drilling in July, then Okinawa Trough drilling, and later Nankai Trough drilling again. We also installed the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET). Including other undertakings, JAMSTEC as a whole generally functioned well this year.

In such overall conditions, the Great East Japan Earthquake occurred on March 11, and JAMSTEC suffered damage to the *Chikyu*, which was in the region at the Port of Hachinohe. Facing this unprecedented situation, JAMSTEC, as the country's representative oceanographic research agency, shall utilize its research abilities, facilities, and equipment to the maximum, aggressively carrying out cooperation on emergency surveys requested by the government and other work. The entire staff shall make efforts as a single body to meet the needs of society.

JAMSTEC's predecessor, the Japan Marine Science and Technology Center, started in 1971. Its 40th anniversary is in October this year. We shall convert our 40 years of experience into the power to move forward, making reexaminations of phenomena that have become common sense and advancing our research, while renewing our awe of the earth and having the viewpoint more than ever of ascertaining its entirety with a system-earth scientific approach.

Finally, JAMSTEC shall continue to advance research and development that contributes to measures against natural disasters, and further shall make efforts on yielding results that contribute to society. We would like to ask for your continued support and cooperation toward the future.

Yasuhiro Kato
President
Japan Agency for Marine-Earth Science and Technology

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President

Executive Director

Auditor

[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

Institute for Research on Earth Evolution (IFREE)

- Basic Research Program
- Advanced Research Program

Research Director, Institute for Research on Earth Evolution (IFREE)
YOSHIO FUKAO

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

Earthquake and Tsunami Research Project for Disaster Prevention

Project Leader, Earthquake and Tsunami Research Project for Disaster Prevention
YOSHIYUKI KANEDA

Global Warming Research Project for IPCC-AR5

Project Leader, Global Warming Research Project for IPCC-AR5
TATSUSHI TOKIOKA

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
YOZO HAMANO

Application Laboratory

- Climate Variations Research Laboratory Unit

Head of Application Laboratory
TOSHIO YAMAGATA

Mutsu Institute for Oceanography (MIO)

- Research Group
- Research Promotion Group
- General Affairs Division

Director, Mutsu Institute for Oceanography (MIO)
SHUICHI WATANABE

Kochi Institute for Core Sample Research (KOCHI)

- Research Group
- Science Services Group
- General Affairs Division

Director, Kochi Institute for Core Sample Research (KOCHI)
WATARU AZUMA

Research Support Department

- Research Support Division I
- Research Support Division II

[Development and Promotion Sector]

Marine Technology and Engineering Center (MARITEC)

- Advanced Marine Technology Research Program
- Department of Applied Ocean Engineering
- Research Vessel Management and Operations 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)
KUNIHIKO 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)
TOSHIYUKI AWAJI

Center for Deep Earth Exploration (CDEX)

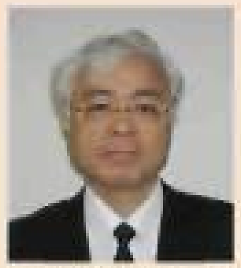
- Planning and Coordination Department
- Operations Department
- Engineering Department
- IODP Department
- HSE Group

Director-General, Center for Deep Earth Exploration (CDEX)
WATARU AZUMA

Observing System Research and Technological Development Laboratory

- Southern Ocean Buoy Laboratory Unit
- Autonomous Profiling Shuttle Development Laboratory Unit

Unit Leader, Southern Ocean Buoy Laboratory Unit
YASUTAKA AMITANI



Unit Leader, Autonomous Profiling Shuttle Development Laboratory Unit
MASAMI MATSUURA

Advanced Research and Technology Promotion Department

- Research Advancement Division
- International Affairs Division
- Public Relations Division
- Library Division

[Management Sector]

- **Planning Department**
  - Planning Division
  - Technology Planning Office
  - Press Office
- **Administration Department**
  - Administration Division
  - Personnel 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**

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

(1) Outline of Activities

An Incorporated Administrative Agency, the Japan Agency for Marine-Earth Science and Technology (hereinafter referred to as 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 by applying obtained results to securing the global environment, preventing disasters, and securing resources as well as by tackling fundamental ocean research and technological development and elucidating the global system centering on the ocean.

JAMSTEC entered its second midterm objective period in April 2009. In its second year, fiscal 2010, we achieved all items in the annual plan. Some items yielded excellent results beyond the plan.

The deep-sea drilling vessel *Chikyu* operated actively, starting with Nankai Trough drilling in July, then Okinawa Trough drilling, and later Nankai Trough drilling again. Including installation of DONET and other undertakings, JAMSTEC as a whole generally functioned well this year.

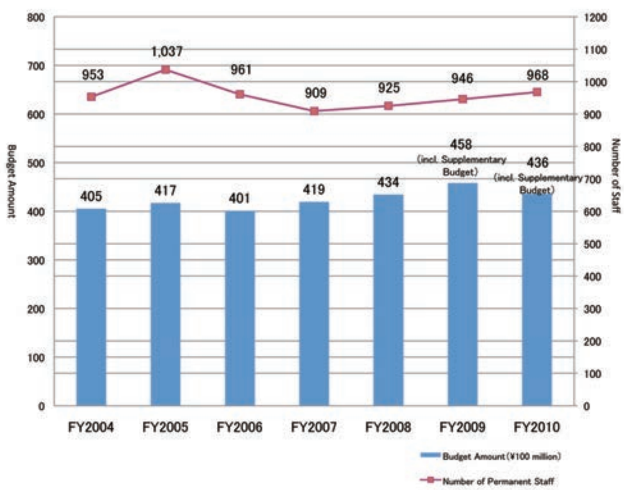
In such overall conditions, the Great East Japan Earthquake occurred on March 11, and JAMSTEC suffered damage to the *Chikyu*, which was in the region at the Port of Hachinohe. Facing this unprecedented situation, JAMSTEC, as the country's representative oceanographic research agency, shall utilize its research abilities, facilities, and equipment to the maximum, aggressively carrying out cooperation on emergency surveys requested by the government and other work. The entire staff shall make efforts as a single body to meet the needs of society.

(2) Change in the Budget and the Number of Staff

The graph below shows the change in the budget and staffing of JAMSTEC since it became an independent administrative agency in 2004. The 2010 budget was very tight. The change of government in August 2009 caused a review of the budget request policy, and the Government Revitalization Unit carried out project-sorting and radical review of existing projects. The JAMSTEC budget reflected their results. Even in these conditions, we shall challenge themes regarding the environment and energy while centering on research and development in the ocean, opening up new frontiers and aiming to "coexist with the earth" as well.

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, personnel expenses, which were subject to reduction under the Act Concerning Promotion of Administrative Reform to Realize a Simple and Efficient Government (Act no. 47 of 2006), were reduced by more than 5% by fiscal 2010 compared with fiscal 2005. Also, based on the 2006 Basic Policies for Economic and Fiscal Policy Management and Structural Reform (Decision of the Cabinet of July 7, 2006), we shall continue our effort to reduce personnel expenses until fiscal 2011.

Change in the Budget and the Number of Staff



(3) Offices and Institutes

As of March 31, 2010, we have the following offices and institutes.

Taking into account the points advised by the Government Revitalization Unit, we moved the Tokyo Office in March 2011 to a building jointly occupied by the Japan Atomic Energy Agency and the Institute of Physical and Chemical Research. Furthermore, we closed our Washington, D.C., office at the end of March 2011.

Name	Location
Yokosuka Headquarters	Yokosuka City, Kanagawa Prefecture
Yokohama Institute for Earth Science	Yokohama City, Kanagawa Prefecture
Mutsu Institute for Oceanography	Mutsu City, Aomori Prefecture
Kochi Institute for Core Sample Research	Nankoku City, Kochi Prefecture
Tokyo Office	Minato Ward, Tokyo
Global Oceanographic Data Center	Nago City, Okinawa Prefecture

(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: 67.3m
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

Subbmersibles 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

Hyperbaric chamber

Ultrasonic tank

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 that include United Nations organizations and overseas research institutions.

(a) 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 observations 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 2010 three Subgroups of Experts, established under the Japan Group of Experts to Advance IOC Programs, exchanged their views at meetings. In May 2010 the Japan Group of Experts to Advance IOC Programs held its third meeting, and based on the views expressed in each Subgroup of Experts, discussed future perspectives of IOC-related activities.

JAMSTEC is a member of the South Pacific Applied Geoscience Commission (SOPAC), an influential commission in the South Pacific region, one of JAMSTEC's major observation and research areas. On request, JAMSTEC sends researchers to other international oceanographic organizations to contribute to their research activities.

(b) International Joint Projects

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

- The Array for Real-time Geostrophic Oceanography (ARGO)
- Climate Variability and Predictability (CLIVAR)
- Global Earth Observation System of Systems (GEOSS)
- Global Ocean Observing System (GOOS)
- International Continental Scientific Drilling Program (ICDP)
- International Margins Program (InterMARGINS)
- International cooperation in ridge-crest studies (InterRidge)
- Integrated Ocean Drilling Program (IODP)
- Ocean Biogeographic Information System (OBIS)
- North Pacific Marine Science Organization (PICES)

(c) 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, the EU, and Japan. The intergovernmental cooperative meetings held in fiscal 2010 were:

- the 22nd meeting of the Japan-U.S. Liaison Group on the Geosciences and Environment, June 2010
- the first meeting of Japan–New Zealand Joint Committee on Cooperation in Science and Technology, October 2010
- the third meeting of the Brazil-Japan Joint Committee on Science and Technology, December 2010

(d) Cooperation with Foreign Institutions

Under the memoranda and agreements signed with the institutions concerned in the United States, the United Kingdom, India, Indonesia, Australia, Canada, South Korea, Germany, and France, JAMSTEC provides interorganizational research cooperation. JAMSTEC is also a member of the Partnership for Observation of the Global Oceans (POGO), a forum of major oceanographic research institutions around the world. An executive director of JAMSTEC attended the 12th annual meeting, POGO-12, held in Korea January 24–26, 2011.

(e) Other International Collaborations

Visitors from overseas governments and research institutions came to see JAMSTEC facilities and exchange views. Those visitors included the Vice President of the Vietnam Academy of Science and Technology (VAST), the Assistant Administrator of the U.S. National Oceanic and Atmospheric Administration (NOAA), the President of the Korea Ocean Research and Development Institute (KORDI), the Executive Secretary of the Agency for the Assessment and Application of Technology (BPPT) of Indonesia, the Executive Secretary of the Intergovernmental Oceanographic Commission (IOC) of UNESCO, and others.

As part of its international activities, JAMSTEC participated in exhibitions at the seventh plenary session of the Group on Earth Observations (GEO); the 2010 GEO Beijing Ministerial Summit in November 2010 in Beijing, China; and the 2011 annual meeting of the American Association for the Advancement of Science (AAAS) in February 2011 in Washington, D.C.

2. Departmental Overviews and Notable Achievements

Research Institute for Global Change (RIGC)

Overview

On Earth where we live, the global environment is shaped by the interaction of natural environments, such as the atmosphere, oceans and land, and the ecosystems nurtured within these environments. While Earth is 4.6 billion years old, its environment has protected and nurtured the rise of humankind and its civilizations over the last several thousand years while giving us diverse benefits. Human activities in recent years, however, have brought precipitous changes to Earth's environment, including global warming. It is an urgent and significant challenge for human society to understand the state of these changes (including the changes which are inherent in nature), identify their causes, and predict future changes in Earth's climate and environment.

The Research Institute for Global Change uses a wide variety of techniques to observe and study the atmosphere, oceans, land, and ecosystems to determine the actual nature of their changes. Based on the findings, we uncover the mechanisms underlying these changes, develop models that integrate various types of knowledge, and predict climate change in the near future as well as future environmental changes. We do so because we uphold the vision of using the knowledge we accumulate through our scientific activities to help build a sustainable and productive society in which humankind and Earth's environment exist in harmony. This is the foundation of our mission to provide scientific information to society, and to carry out integrated studies of environmental changes by combining observations and predictions with the aim of enabling JAMSTEC to respond to the economic and social needs of Japan as well as the world as a whole.

It is very difficult to elucidate the mechanisms of all global changes and predict them accurately. We will, however, be greatly gratified if you understand that all of the research projects and the relentless efforts of the researchers at RIGC will carry us one step closer to bringing our vision to reality, and we are making steady progress in achieving it.

New Findings on Anthropogenic CO_2 Storage in the Ocean Interior

Background

CO_2 is emitted into the atmosphere by human activities, but not all of it stays in the atmosphere. About 50% of emissions are estimated to remain in the atmosphere, and the remainder is estimated to be absorbed by the ocean and the terrestrial biosphere in similar amounts. This implies that both the ocean and the terrestrial biosphere act to suppress increases of the CO_2 concentration in the atmosphere. The global average atmospheric CO_2 concentration in 2009 was 387 ppm. Without absorption by the two reservoirs, however, the CO_2concentration would reach a much higher level. Therefore, an important issue for predictions of future CO_2 concentration in the atmosphere and of global warming is to estimate how much CO_2 emitted into the atmosphere is absorbed by the ocean.

Outline of Research Methods

To tackle the issue outlined above, RIGC has performed highly accurate measurements of CO_2 concentrations in the ocean in the form of dissolved inorganic carbon and related properties such as salinity, dissolved oxygen, and nutrients using the RV *Mirai*. From 2003 to 2004, we conducted observations in the South Pacific, the South Atlantic, and the South Indian Ocean during an around-the-world southern hemisphere cruise called BEAGLE 2003. After 2005, we conducted the observations mostly in the Pacific (Fig. 1). Using the data obtained by our observations and those obtained in the 1990s, we computed anthropogenic CO_2 and estimated rates of anthropogenic CO_2 storage.

Results and Discussion

Anthropogenic CO_2 stored in the ocean interior in the period from the Industrial Revolution through the mid-1990s has been estimated to be 6–7 g/m^2/yr in terms of carbon. However, from data analyses, we found that the values obtained in subtropical regions of the South Indian Ocean and the South Pacific were about 12 g/m^2/yr, twice as high as the previous estimate value (Fig. 2). In contrast, the rate of anthropogenic CO_2 storage in the North Pacific was close to the previous estimate value. Accordingly, anthropogenic CO_2 is now being stored in the South Indian Ocean and the South Pacific at a rate twice as high as the average rate after the Industrial Revolution. Furthermore, it was also found that the higher rate in the South Indian Ocean was attained recently (1995–2003/2004), which was clarified by comparing the recent rate with the rate in the period 1978–1995 (Fig. 3).

The above results indicate that anthropogenic CO_2 is not absorbed at a constant rate in all the oceans. Instead, the rates show large temporal and basin-to-basin variations. This implies that estimation of absorption of anthropogenic CO_2 by the ocean, which is indispensible for predictions of global warming, should be revised for individual oceans at an interval of about a decade at least.

The facts that rates of anthropogenic CO_2 storage in the South Indian Ocean and in the South Pacific are twice that of other oceans, and that the rate in the South Indian Ocean has doubled in the most recent decade, are not considered in authoritative reports such as those of the IPCC. We judge that the role of the oceans in absorbing anthropogenic CO_2 in the atmosphere has to be evaluated based on more extensive observations.

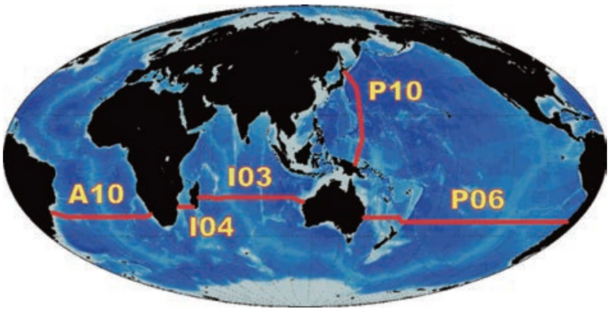


Figure 1. Observation lines along which hydrographic observations were made. Symbols P, A, and I indicate the Pacific, Atlantic and India, respectively.

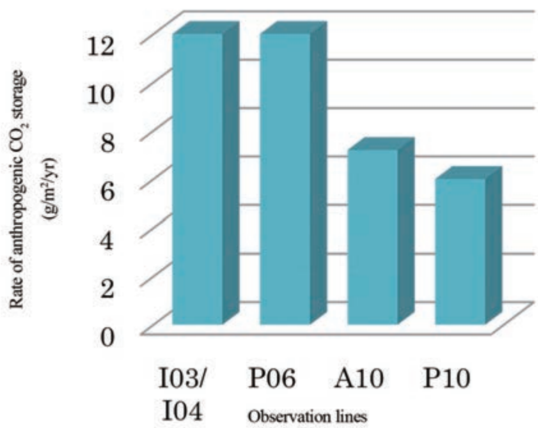


Figure 2. Rates of anthropogenic CO_2 storage in the South Indian Ocean (I03/I04), South Pacific (P06), South Atlantic (A10), and North Pacific (P10). The rates in the South Indian Ocean and in the South Pacific are higher than those in other oceans.

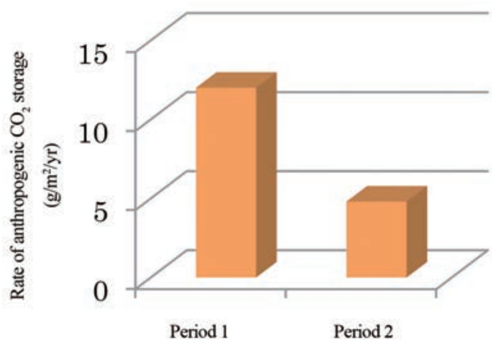


Figure 3. Difference in the rate of anthropogenic CO_2 storage in the South Indian Ocean by time period. Period 1 is 1995–2003 and Period 2 is 1978–1995.

A Key Component of the MJO Initiation Process Proposed

The Madden-Julian oscillation or MJO is known as the dominant intraseasonal (30–60 days) variability in the tropics. The MJO is an eastward-propagating (~5 m/s) disturbance with strong atmospheric convection that usually occurs over the central and eastern Indian Ocean. Influences of the MJO spread over the world through interactions with monsoons, El Niño, and in other ways. Explaining the initiation process of MJO convection has been a major concern of MJO studies since its discovery in the early 1970s.

While insufficient in situ data in the Indian Ocean make it difficult to reveal these processes, there had been no intensive observation focusing on MJO convection onset. Hence, to address the atmospheric and oceanic conditions when convection in the MJO is initiated, the field experiment MISMO (*Mirai* Indian Ocean Cruise for the Study of MJO Convection Onset) took place from late October to early December 2006. The location and period were determined based on statistical analyses.

Based on satellite-derived cloud data analyses, it was confirmed that the MISMO observation network could capture the onset of large-scale cloud systems associated with the MJO in mid-November. By analyzing GPS-derived water vapor data, a gradual moistening with a prominent 3–4-day cycle associated with a meridional wind component was found (Fig. 1), and it results in an increase of 8–10 mm from early to mid-November. Then, by analyzing the satellite and reanalysis data, it was shown that the structure was consistent with mixed Rossby-gravity waves, suggesting a tight relationship between the development of convection and equatorially trapped large-scale waves (Fig. 2). Recent numerical studies also support the idea that this meridional advection of water vapor might play a key role for moistening processes.

To further advance our knowledge on the initiation process of MJO convection as well as to improve the skill of numerical simulation and prediction, a new international field experiment called CINDY 2011 (Cooperative Indian Ocean Experiment on Intraseasonal Variability in the Year 2011) is going to take place in the central Indian Ocean from October 2011 through January 2012. More than 300 researchers from 13 countries and territories are expected to join this campaign. During the campaign, we will form a quadrilateral atmospheric sounding array with islands and ships, since the results described above suggest the importance of measuring meridional moisture advection for precise budget analyses.

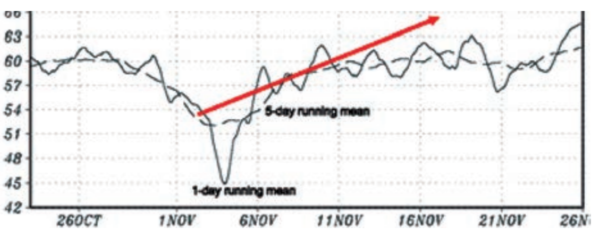


Figure 1. Time-series of GPS-derived water vapor obtained onboard the RV *Mirai* at 0°, 80°E from October 24 to November 26, 2006. Solid (dashed) line indicates 1-day (5-day) running mean values.

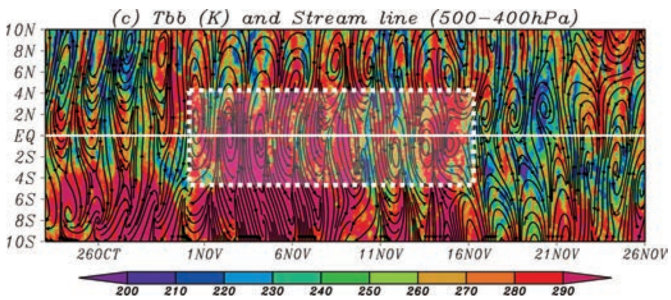


Figure 2. Time-latitude cross-section of the 3–4-day period component of equivalent blackbody temperature (shading) and stream lines (contour) in the 500–400 hPa level at 80°E. A reanalysis data set known as Japan Meteorological Agency Climate Data Assimilation System (JCDAS) was used to calculate stream lines. White solid line indicates the equator. White dashed line indicates the period when the vortex centers are located over the equatorial region.

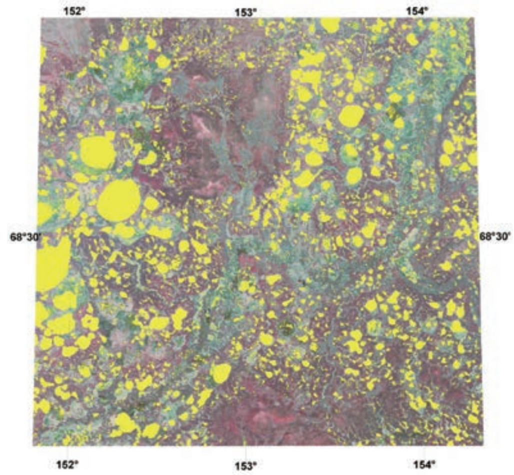
Dramatic changes in the polar region and their impact

Introduction

Changes in the atmosphere, oceans, and land conditions in cold climate regions have corresponded with the global warming trend, and given rise to fluctuations in sea ice cover, thawing of permafrost, and other phenomena. However, the actual state of many of these changes is hardly known, and there are issues with reproducing the past conditions and predicting future conditions. It is therefore important that we carry out observations at key sites in order to identify actual conditions, understand the processes of change, and assess how these changes affect the middle latitude regions as well as Earth as a whole.

Decreasing sea ice cover in the Arctic Ocean

During our voyage to the Arctic (MR10-05) in 2010, we carried out automatic observations of the ocean, sea ice, and weather conditions in the ice-covered areas and observations of ocean–atmosphere interactions on the Atlantic side of the Arctic (Barents Sea). In 2011, we gained knowledge of the warming of the undersurface of sea ice in the ice-covered sea. Itoh et al. (2011) clarified the contributions from solar radiation, which warms oceans by penetrating through sea ice during a melting period, according to the observed conditions of sea ice (i.e. ice thickness and proportion of melt ponds). Generally, short-wave radiation, which is the source of heat for the Arctic Ocean in summer, enters primarily through the surface of open water and warms the sea and precipitates the melting of the sides and bottom of sea ice. This is because the most of the short wave radiation is reflected off the surface of sea ice. However, an analysis of the 2006 and 2007 observation data indicated that nearly 50% of the heat penetrated through thin first-year ice in an advanced stage of melting and contributed to increasing the temperature of the surface layer of the ocean. This process is believed to be a factor in the recently accelerating loss of sea ice.



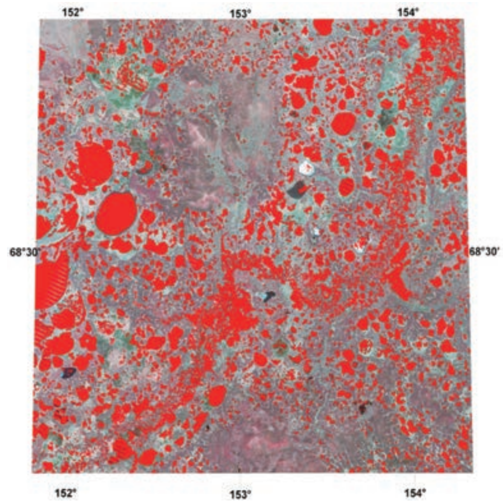


Figure 1. Changes in water areas in an approximately 50×50 km area of the Alazeya River basin (Top: 1975; Bottom: 2008) Yellow and red areas indicate water cover.

Changing glaciers and lakes due to global warming

We examined the distribution and recent fluctuations glaciers and lakes, which act as terrestrial reservoirs. First, we developed an inventory of undescribed Mongolian glaciers for 2000 (MGI2000) from satellite images. This inventory confirmed that there were 580 glaciers with a total area of 424 km^2, and that the surface area had decreased by 19% over 50 years. Secondly, we investigated the distribution of lakes and their changes in northeastern Siberia, and found that the area of water near Yakutsk expanded by around 5% between 2000 and 2007 when wetness increased. The increase in the number of small areas of water (0.1 km^2) appears to indicate an increase in thermokarst development. The changes were more pronounced in northern Siberia on the shore of the Arctic Ocean (Fig. 1) and the Alazeya River basin, with water covered areas increasing by 10% between 1975 and 2001 and 20% between 2001 and 2008. In the northern Eurasia region, we observed receding glaciers and expanding lakes, indicating dynamic changes taking place in water retention on land in the cold climate region. This is likely to be due to the effect of warming.

Changing water cycle

We discovered that the recent rises in the temperature and wetness of the permafrost and resulting changes in the topography of these regions in eastern Siberia not only corresponded to a decreasing sea ice cover in the Arctic Ocean but were also connected to increased outflow from the rivers, increased snow accumulation in winter as well as increased precipitation in summer and autumn. These are likely to be related to the formation of a dipole in the general circulation in the Arctic. The water cycle is a system formed by a chain of precipitation — retention — evaporation/outflow. Any abnormality in this system indicates a change in the terrestrial water cycle due to the deterioration of the permafrost environment and topographical changes induced by it (i.e. the development of frost zones and lakes that cause an increase in stored volume) as well as changes in vegetation (i.e. changes in volume of evapotranspiration).

Decreasing sea ice affects climate in Japan

During 2011, we studied the effects of the decreasing sea ice cover on East Asia through teleconnection. In spite of the fact that the winter of 2009/2010 was warmer than average, Japan was hit by waves of cold snaps (Fig. 2). They appeared to correspond to the Arctic oscillation but this does not explain the phenomenon well. With respect to the cold snap on December 18, an abnormal peak that formed over the Barents Sea accumulated cold air over western Siberia. As a result of this barometric anomaly moving westward and forming a blocking high and a wave pattern downstream, advection of cold air masses toward East Asia and Japan occurred. This pattern was observed repeatedly, clearly indicating the strong possibility that a phenomenon which originated in the Barents Sea would affect winter weather in Japan.

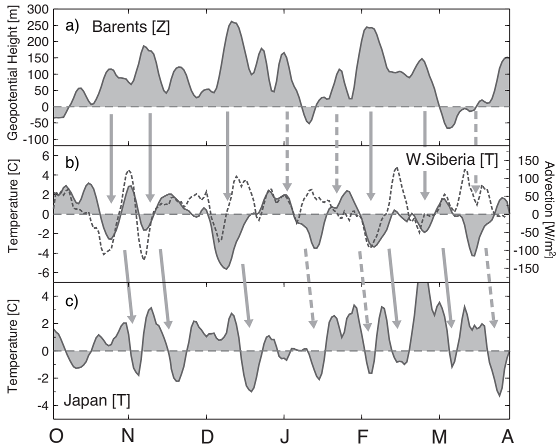


Figure 2. (a) Variations in geopotential height at 500 hPa near the Barents Sea (0°E–100°E, 70°N–90°N); (b) Temperatures and thermal advection (dotted line) at 850 hPa over Siberia (40°E–100°E, 45°N–65°N); and (c) Ground surface temperatures measured at 58 observation points in Japan. The letters on the horizontal axis indicate the first day of each month. (Hori et al., 2011)

Discovery of a new deep-layer circulation

Ocean circulation has the function of globally redistributing heat which Earth receives from the Sun. Because of this, the climate on Earth is neither too hot nor too cold. In addition to the surface currents, such as the Kuroshio Current, oceans also ventilate in deep layer in the form of slow currents flowing at depths of several thousand meters. The present deep water was formed when high-salinity seawater cooled in the area off Greenland in the North Atlantic. The cooling made the water heavy and it downwelled to a depth where it has ventilated around the world as deep currents. It takes in the order of 1000 years for the deep current to reach the North Pacific. Past studies have found that the formation of deep water was interrupted as a result of an inflow of a large volume of freshwater to the high-latitude region of the North Atlantic during the cold period that occurred 17000 years ago. Effects of the change on the circulation in other oceans have yet to be understood. In order to understand the behavior of a deep-layer circulation in the Pacific Ocean during this period, we analyzed marine sediment data for the Pacific Ocean and the results of a paleoclimate model simulation.

Proxy indices recorded in the marine sediment are used to find out the state of the historic deep-layer circulation. By using the radio carbon age of foraminifera, calcium carbonate-shelled zooplankton, embedded in the sediment on an equi-time slice collected from the North Pacific (Fig. 1), we established the ventilation age in the intermediate and deep layers of the Pacific Ocean. Carbon-14 (^{14}C) is a nuclide generated in the atmosphere by cosmic rays. It dissolves into the ocean surface in the form of carbon dioxide. Planktic foraminifera living in the ocean surface and benthic foraminifera living at the bottom of the ocean take in ^{14}C from seawater when they form their calcium carbonate tests. As a result, the difference between the ^{14}C ages of the planktic and benthic foraminifera tells the ventilation age of the intermediate-deep and deep-layer at the time. If the difference is small, it indicates the prompt transport of ^{14}C to the deep layer; if large, a stagnated circulation.

The radiocarbon ages of foraminifera recorded in the marine sediments in northwestern North Pacific indicate that the ventilation age 17000 years ago (Fig. 2: Heinrich Event 1) was 800 to 900 years younger than the ventilation age at present (about 1800 years). It means that the ventilation was very active in the intermediate-deep layers of the western North Pacific. Furthermore, using a paleoclimate model (LOVECLIM), in an experiment in which freshwater was supplied to the North Atlantic, we uncovered a propagation mechanism in which (1) the formation of deep water and the Atlantic meridional overturning circulation weakened due to a decrease in the density of the surface water (Fig. 3①); (2) the ocean surface current flowing north also weakened, and cooling started from the high latitude region in the North Atlantic; (3) the cooling spread to middle to low latitudes, and the trade winds became stronger at the same time; (4) the Inter Tropical Convergence Zone near the equator shifted southward and caused the transport of water vapor from the North Atlantic to the Pacific Ocean to decline (Fig. 3②); and (5) as the Bering Strait closed at that time, the seawater in the high latitude area of the North Pacific increased in salinity with no freshwater supply from the Arctic Ocean which started the formation of deep water (Fig. 3③). The results of the modeling supported to the results of the sediment analysis, and we established that there was a deep oceanic convection in the subarctic pacific down to a depth of 2500 m. The findings of this study indicate that the formation of deep water in the ocean is dependent on

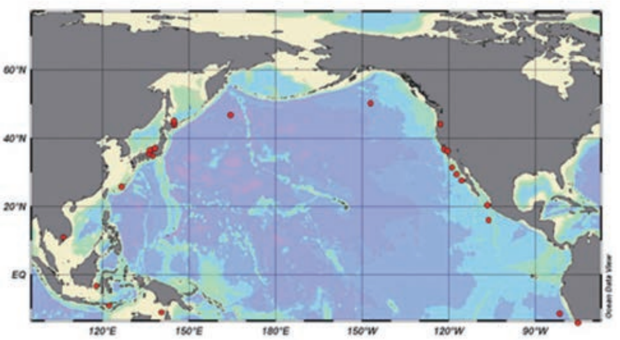


Figure 1. Marine sediment collection sites (red dots)

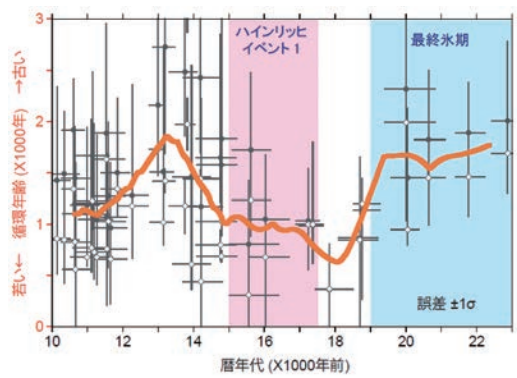


Figure 2. Ventilation age changes estimated from the difference between carbon-14 age of planktic and benthic foraminifera in marine sediments collected in the northwestern North Pacific and part of the eastern Pacific Ocean (from depths of 900–2800 m)

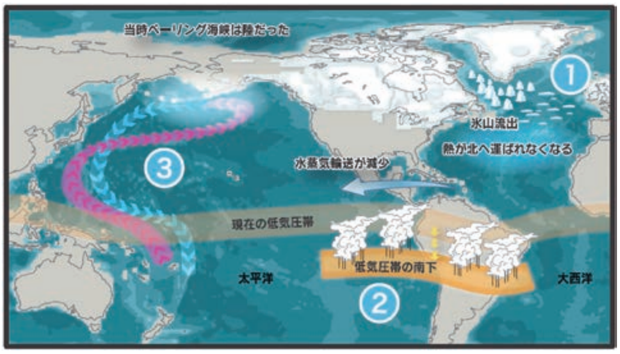


Figure 3. Scheme of mechanism for the formation of deep water in the North Pacific 17000 years ago

a delicate balance between heat and salinity, and a slight shift of the balance due to the inflow of freshwater and other causes such as closed Bering Strait will change the circulation pattern of deep water and have a significant effect on the global climate (Okazaki et al., 2010; Science, 329, pp. 200–204).

We are presently carrying out a study to reconstruct the changes in biogeochemical cycle during the deglaciation, and are beginning to find out that the plaleo productivity of primary Producer was also changing. We plan to carry out detailed analyses in order to explain the mechanism that linked ocean circulation and biogeochemical cycle.

The Quasi-biennial Oscillation in a Double-CO_2 Climate

Heavy precipitation occurs in the equatorial troposphere (from the surface to ~17 km altitude) due to active cumulus convections. A large-scale zonal-mean zonal wind oscillation called the quasi-biennial oscillation (QBO) exists in the equatorial stratosphere (~17 km to ~50 km altitude). The QBO is driven by atmospheric waves generated by cumulus convections. There is evidence that the tropical QBO has significant remote dynamical effects from the south pole to the north pole and from the surface to the mesosphere (~50 km to ~85 km altitude). For example, the QBO affects the circulation in the extratropical stratosphere and in the extratropical lower atmosphere even down to the surface. In the tropical stratosphere itself the QBO is strong enough that it may have a significant role in determining the mean chemical composition (e.g., ozone, methane, water vapor) and hence mean climate. Therefore, the QBO is an important phenomenon for climate change. There is no evidence that any of the models employed in the IPCC AR4 model intercomparison simulated the QBO. The QBO is very difficult to simulate in the climate model. This is the first study to investigate how the QBO changes in a double-CO2 climate using a climate model that simulates the QBO by model-resolved waves only.

Fig. 1 shows a time–height cross-section of the monthly-mean zonal-mean zonal wind over the equator in the present and future climates. Westerly (red) and easterly (blue) winds alternate with a period of about two years with descending phases. Thus the QBO oscillation is well simulated by the model. In the future climate, the QBO period becomes longer and QBO amplitude weaker than in the present climate. The downward penetration of the QBO into the lowermost stratosphere is also curtailed in the future climate. Fig. 2 shows latitude–height cross-sections of climatological annual mean zonal mean temperature and zonal wind in the present and future climates. The black and red contours correspond to present and future climates, respectively. The tropopause shifts slightly higher in the future climate. A warming in the troposphere and cooling in the stratosphere are evident. The upper parts of the subtropical jets strengthen. The upward displacement of a zero wind line is obvious in the extra-tropics. These temperature and zonal wind changes result in a significant increase of the mean upwelling in the equatorial stratosphere. The effect of this enhanced mean circulation overwhelms counteracting influences from strengthened wave fluxes in the warmer climate, which makes the future QBO changes seen in Fig. 1b.

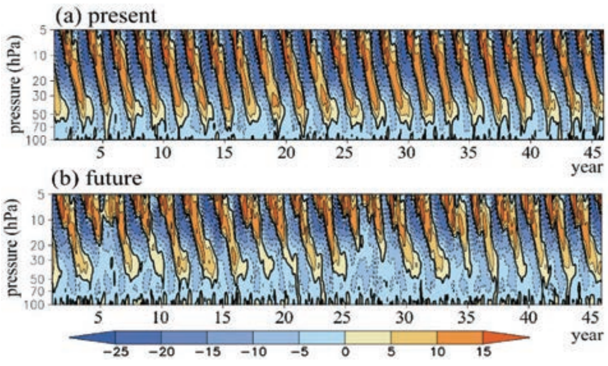


Figure 1. Time-height cross sections of zonal mean zonal wind at the equator in (a) present and (b) double-CO_2 climates. The contour intervals are 5 ms^{-1}. Red and blue colors correspond to westerly and easterly winds, respectively.

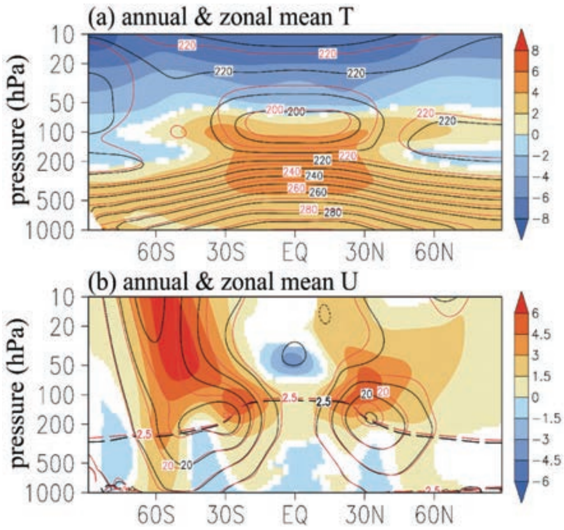


Figure 2. Climatological annual and zonal mean (a) temperature and (b) zonal wind. Black and red lines correspond to the present and future climates, respectively. The tropopause is illustrated by the dashed line in (b). Differences with statistic significance ≥ 95% are colored. Contour intervals are (a) 10 K and (b) 10 ms^{-1}. Color intervals are (a) 2 K and (b) 1.5 ms^{-1}.

Tidally-generated Nonhydrostatic Wave Trains in the Indonesian Seas

Background

Tidal mixing in the ocean can be attributed to a series of nonhydrostatic processes, such as Kelvin-Helmholtz instability, hydraulic jump–like overturning, internal swash or surf action on a sloping bottom, and the shoaling of internal solitary-like gravity waves (ISWs). Recent oceanographic studies have paid considerable attention to tidal mixing in the Indonesian Seas, as this process changes the vertical structure of the Indonesian Throughflow (ITF) and thereby affects heat transport between the Pacific and Indian Oceans, which is an important component of global thermohaline circulation.

Lombok Strait (LS) is one of the major passages for the ITF and is known to have a tall, sharply defined sill that induces strong tidal flows of ±3.5 m/s. Fig. 1a depicts an ERS-1 Synthetic Aperture Radar (SAR) image over the LS region that shows two sets of wave arcs (A and B) in the Java Sea and one wave arc (C) in the Indian Ocean, all of which are generated at the sill by the M2 tide. The leading wave arc is followed by a train of waves 2–7 km in length, which are the surface expressions of ISWs. Wave trains of this type represent some of the largest nonhydrostatic phenomena in the ocean and may contribute to enhanced vertical mixing through wave breaking.

Numerical Simulation

Using a two-dimensional nonhydrostatic numerical model that takes into account the variable width of the strait region, two experiments have been performed, one without and one with an idealized ITF component in the upper layer flowing southward toward the Indian Ocean. These correspond to conditions in boreal winter and summer, respectively. Both experiments show trains of ISWs. Overall, ISWs are more numerous on the north side of the sill, where the narrower channel in effect amplifies the disturbances. In both experiments about 3.9 GW of energy is injected into barotropic and baroclinic tidal currents, of which about 2.6 GW is radiated away by internal gravity waves. The ITF regulates the way that the radiated energy is partitioned between the two sides of the sill. Without the ITF (boreal winter), the northward radiated energy flux is greater in magnitude than that radiated to the south. However, when the ITF is present (boreal summer), the northward radiated energy flux is smaller in magnitude than that radiated to the south. From this result, it is expected that vertical mixing is enhanced on the Java Sea side in boreal winter, and enhanced on the Indian Ocean in boreal summer.

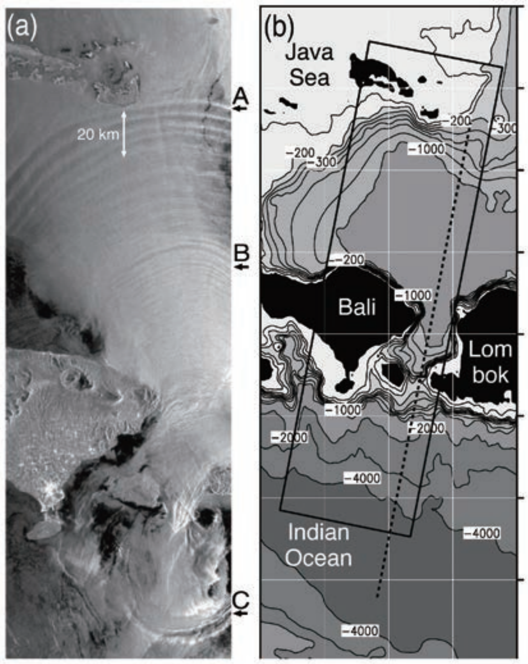


Figure 1. (a) ERS-1 SAR image over Lombok Strait acquired at 0232 UTC on April 23, 1996. (b) Bottom topography (m), with the solid box representing the region covered by figure 1a and the dashed line representing the main axis of the strait along which the numerical model is configured.

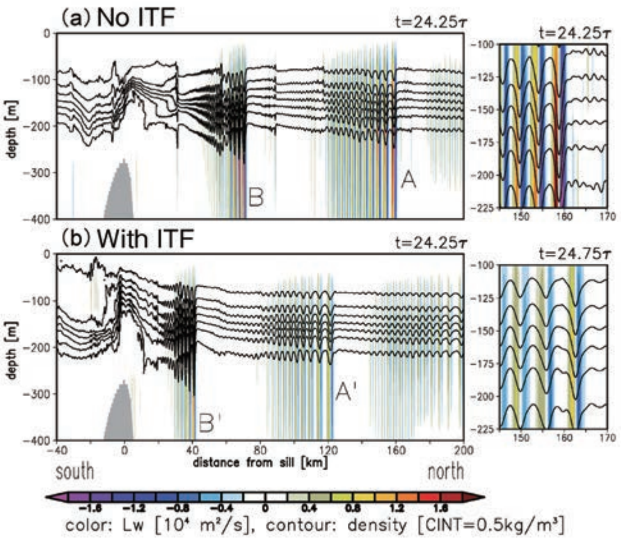


Figure 2. Left: Modeled snapshots of the horizontal gradient of upward flow speed (colors) developing to the north of the sill, for situations when the ITF is (a) absent ("no ITF") and (b) present ("with ITF"). The isopycnal contours are shown in black (contour interval = 0.5 kg m^{-3}). The topographic sill is shown as a gray hump. The letters A, A' and B, B' signify the relative locations of the leading edges of corresponding wave packets. Right: Close-up views of the waves A and A' when they pass through regions that are equidistant from the sill.

Progress in joint research of tropical field observation and global cloud-resolving modeling

Tropical atmosphere–ocean variabilities play an important role in global change and, at the same time, are closely related with human activities today. JAMSTEC has been carrying out intensive observations of the tropics using the oceanographic research vessel *Mirai* to study the intra-seasonal variations and cloud disturbances that spawn typhoons (the Tropical Climate Variability Research Program). We also ran a global cloud-resolving model (NICAM), which was developed by the next-generation modeling research program and University of Tokyo, on "Earth Simulator" to carry out a large-scale numerical simulation to explain the mechanisms that govern atmosphere–ocean variabilities in the tropics. We are able to explain the phenomenon from a new perspective by integrating in-situ observation data and the global cloud-resolving simulation data which can cover the entire tropics at a high spatiotemporal resolution. This may lead to improvement of accuracy of a numerical model. Accordingly, we have strengthen the linkage between observation and modeling in 2010. The following are some of the notable outcomes of this close association.

One notable outcome is the progress made in the research project on Typhoon TY0806 (Fengshen), of which we successfully observed the genesis process during the intensive observation period of PALAU2008. The genesis processes of typhoon in the equatorial region are highly complex and are influenced by large-scale disturbances, such as the monsoon circulation, intra-seasonal variabilities, and equatorial waves. The global cloud-resolving simulation is an innovative and useful technique for us to understand such multi-scale processes. During this fiscal year, we carried out a numerical simulation of Typhoon Fengshen using the NICAM with the highest resolution (3.5-km mesh). The numerical calculations successfully reproduced the large-scale distribution of clouds and precipitation (Fig. 1a, b) and the wind fields associated with summer monsoons and intra-seasonal variabilities in the western Pacific region (not shown). This allows us to investigate genesis and development processes of typhoon under realistic conditions. In the early developing stage of Typhoon Fengshen, the asymmetric distribution of clouds was pronounced in both the observation and numerical calculation (Fig. 1c, d). Afterwards, an axisymmetric structure was established through several key processes. While the spatiotemporal range of *in situ* observational data is limited (Fig. 1c), we can estimate the whole picture of the phenomena that occurred at the observation sites by analysing simulation data. Based on the analysis, we have found that tropical wave disturbances played important roles in the cyclogenesis.

Typhoon Fengshen is also known by poor performance of track forecasts by operational models (Fig.2a). We performed sensitivity calculations with a 14-km mesh (to save calculation costs to invesigate decisive factors for the typhoon's track) (Fig. 2b), and we found that the calculations with smaller tracking errors (red lines etc. in Fig. 2b) tended to better reproduce the cloud and precipitation distribution in the typhoon. It is also noteworthy that the simulation with a high resolution (3.5-km mesh) better reproduced cloud and precipitation distribution and the typhoon track (Fig. 1c, d; Fig. 2b). This fact suggests the protential of high resolution forecasts in reducing.

In our new effort to strengthen the links between observation and modeling, we also started providing logistical support by numerical weather forecasts for the observation sites. We built a real-time forecast calculation system using NICAM in the 2010 fiscal year and achieved a thrice-weekly operation during the PALAU2010 observation. Considering the importance of speed in fieldsupport, we adopted regionally stretched grid system to NICAM. A dedicated PC cluster was installed for forecasting. The advantage of the numerical forecast using NICAM is that it can simultaneously and seamlessly calculate large-scale disturbance and individual meteorological events that occur in the vicinity of the observation area. While our forecast system need improvement in many aspects, the opetation of the system confirmed that it can predict general tendency of atmosphrenic analysing simulation fields. The forecasts were also used in the scheduling of aircraft observations. We plan to improve our forecast system and use it in an international observation project CINDY2011, which is conducted in the 2011 fiscal year.

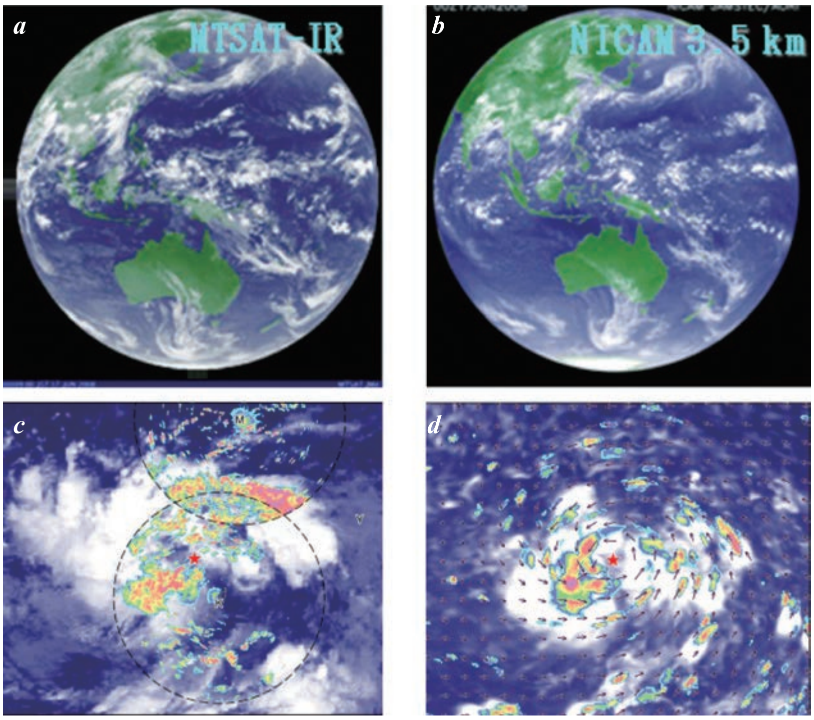


Figure 1. Global distribution of outward long-wave radiation 2 days before the genesis of Typhoon Fengshen (2008/6/17 00UTC). (a) Satellite infrared image (MTSAT-IR); (b) Simulated image; (c) Zoom-up of (a). Colors indicate the distribution of precipitation observed by radar (in circles); (d) Zoom-up of (b). Colors indicate surface precipitation.

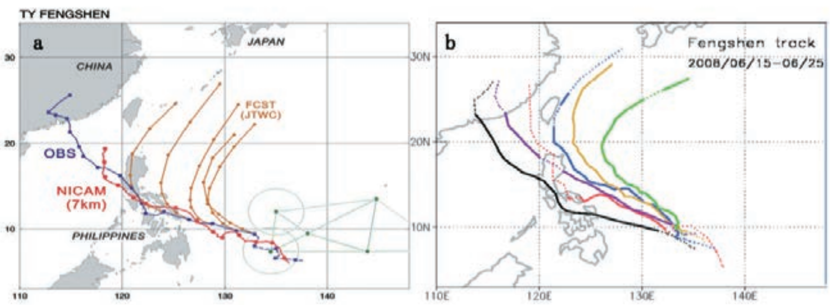


Figure 2. Tracks of Typhoon Fengshen
(a) Observation (black) and forecasts by Joint Typoon Warning Center (JTWC), and by. 7-km mesh NICAM with stretched grid system(red); (b) On observation (black), global 3.5-km mesh NICAM simulation (purple), and global 14-km mesh NICAM simulations (red, blue, yellow, and green). The PALAU2008 observation array is also drawn in (a).

Institute for Research on Earth Evolution (IFREE)

Overview

One of the objectives of the core research programs of the Institute for Research on Earth Evolution (IFREE) is to solve the mystery of the Earth. In order to do so, we use various techniques, such as geophysical observations and geological surveys of the ocean, chemical analysis of rock samples, high-temperature and high-pressure experiments, numerical simulations, and laboratory experiments to investigate the changes and processes of Earth's evolution occurring on the vast time scales of the entire Earth system encompassing interplanetary space, the atmosphere, the oceans, and the crust, mantle and the core of the Earth (Fig. 1). These fundamental studies help us understand the interior activities of the Earth which generate seismic and volcanic events that have a considerable impact on human activities as well as the basic principles underlying the environmental changes occurring on the outer surface of the Earth.

Another objective of the IFREE is to gain a comprehensive understanding of the evolution of the Earth through cross-disciplinary research projects. For this objective we have developmental research programs, and we lead the world in our integrated exploratory studies that combine and expand upon the outcomes of the fundamental studies. Our research covers the following subjects: "shallow layer dynamics" to understand the structures and deformation of the area between the sea floor and the oceanic lithosphere through observations and simulations; "deep earth dynamics" to study the structures and dynamic behaviors of the deep earth, as well as interactions of the deep and surface layers of the Earth from a materials science perspective, through sea floor observations; "material circulation" to gain petrographic and geochemical understandings of the circulation and evolution of materials in the interior of the Earth; "Earth in a multilayered relationship" to gain an integrated understanding through the hierarchical combination of the microscale phenomena in the geosphere and macroscale phenomena, such as the formation of large-scale structures; "evaluation of massive seismic events" to identify the structures of subduction zones from the ocean and land observation data and to simulate massive seismic events; the "Seafloor Network Task Force" which constructs and displays in visual form an integrated database of the geophysical/chemical data of the Earth's oceans; and the "IODP Task Force" which proposes seafloor drilling plans and carries out preliminary studies using Japan's ocean drilling vessel *Chikyu* under IODP (the Integrated Ocean Drilling Program). In addition, the IFREE is carrying out research projects for a cross-disciplinary study of subsea floor structures and seismic/volcanic activities in the Japan Trench, northeastern Japan, and the Sea of Japan, as well as exploratory studies to uncover the relationships between the activities in the Earth's interior and its surface biosphere.

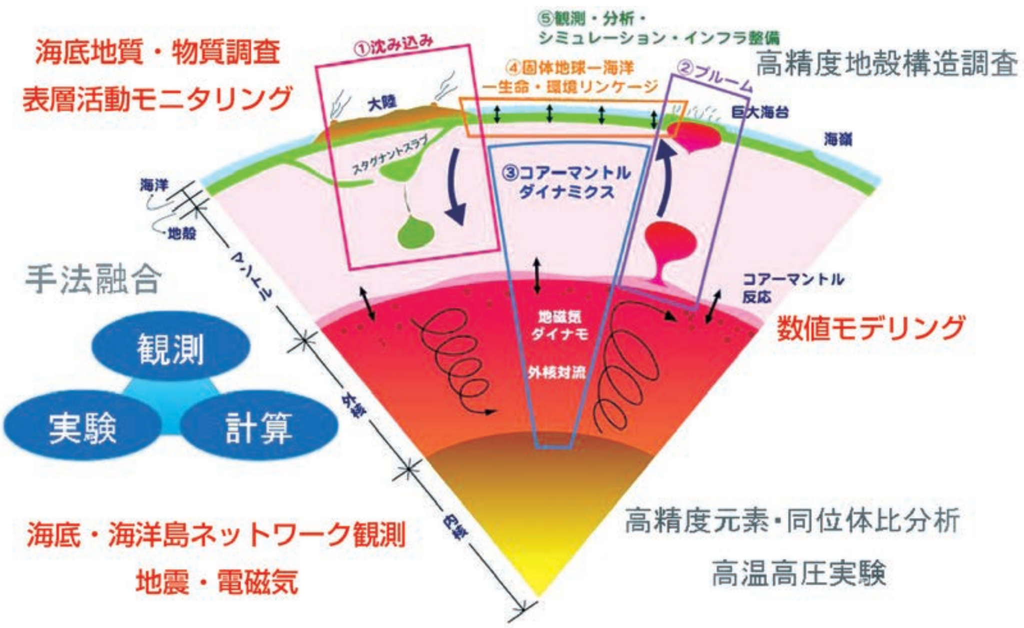


Figure 1. Conceptual diagram of the research fields and techniques of the IFREE.

Subduction of plates and stagnant slabs

The mantle of the Earth is made of solid rock. On a geological time scale, however, the mantle behaves like a slowly moving fluid. This movement is the plate motion which we see on the surface of the Earth. It generates earthquakes and volcanic activities, and on a much longer time scale, creates island arcs, such as the Japanese archipelago, and great mountain ranges, such as the Himalayas. It is the force that moves continents. Because of this, understanding the movements of the mantle is very important for studying the evolution of the Earth and for identifying an environment suitable for the survival of humankind. At the IFREE, we are carrying out comprehensive studies of the mantle through seismological and geomagnetic observations, chemical analyses, high-pressure rock experiments, fluid experiments, and numerical simulations. The following paragraphs introduce some of the outcomes of our study: the structure of the mantle represented by seismic wave analysis (tomography), and the movement of the mantle calculated by a numeric simulation that incorporates a variety of effects to reproduce the observed mantle structure.

We are building a tomographic model of the mantle using seismic wave data collected from around the world. The installation of seismographs in the areas of the Pacific Ocean where few observation points existed has made it possible for us to view the structure of the mantle at a high resolution. The results of our modeling work are published on the JAMSTEC website (www.jamstec.go.jp/pacific21/ja/) to allow quick comparisons with the results produced by other groups.

Seismic wave tomography visualizes structures (slabs), which are believed to be extensions of plates subducted from the surface, reaching deep into the transition zone of the mantle and remaining there in many parts of the Earth. These so-called stagnant slabs are present in complex forms over a wide area beneath the western Pacific Ocean including the Japanese archipelago (Figs. 2 and 3).

Important factors for the subducted slabs to become stagnant are thought to be the phase transition of the minerals that make up the mantle at a depth of 660 km, a rapid increase in the viscosity of the lower mantle, the temperature dependency of this viscosity, the rheology of the plate, and the receding sea trenches. Yet there has been no spherical shell model of the mantle which can address these factors together. Using "Earth Simulator", we incorporated the effects of these factors into a 3-dimensional spherical shell model (Fig. 4). For the phase transition corresponding to the depth of 660 km, which is based on the values of the latest data, the viscosity of the lower mantle was set 40 to 400 times that of the upper mantle. The near-surface mantle was set to become a solid plate due

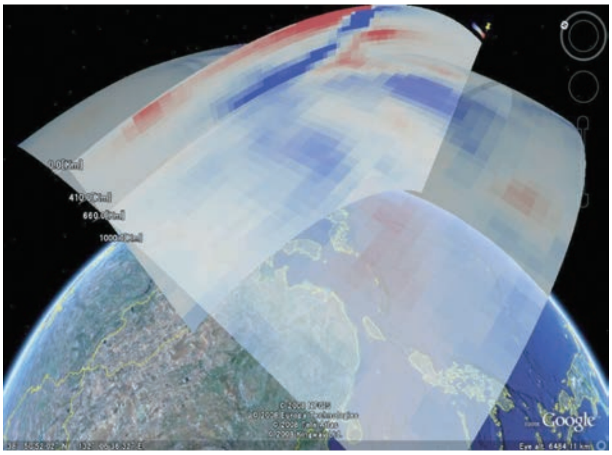


Figure 2. Display of seismic wave tomography by Google Earth. A combination of horizontal cross-section at 660 km below the western Pacific Ocean and vertical cross-section traversing from the Japanese archipelago to the Asian Continent. Colors indicate the deviation of the velocity of seismic waves from the standard value (blue: high velocity; red: low velocity). The blue parts are slabs. (Source: www.jamstec.go.jp/pacific21/ja/)

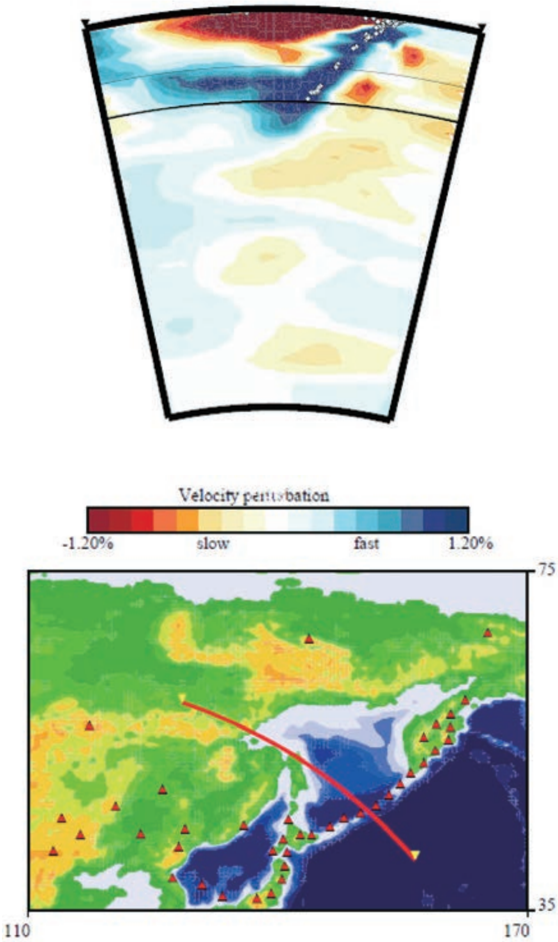


Figure 3. Seismic wave tomography covering the area from the Kuril Islands to the Asian Continent (vertical cross-section of the area corresponding to the red line in the map below). The Pacific Plate can be seen to have subducted from the trench and is now lying.

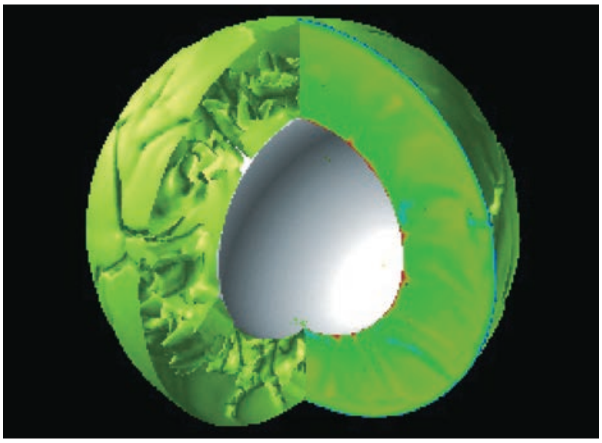


Figure 4. Simulation of convection of the mantle in a spherical shell. Display shows the temperature field and isothermal plane. A complex structure is seen in which descending flows from the surface reach deep or stall in the process.

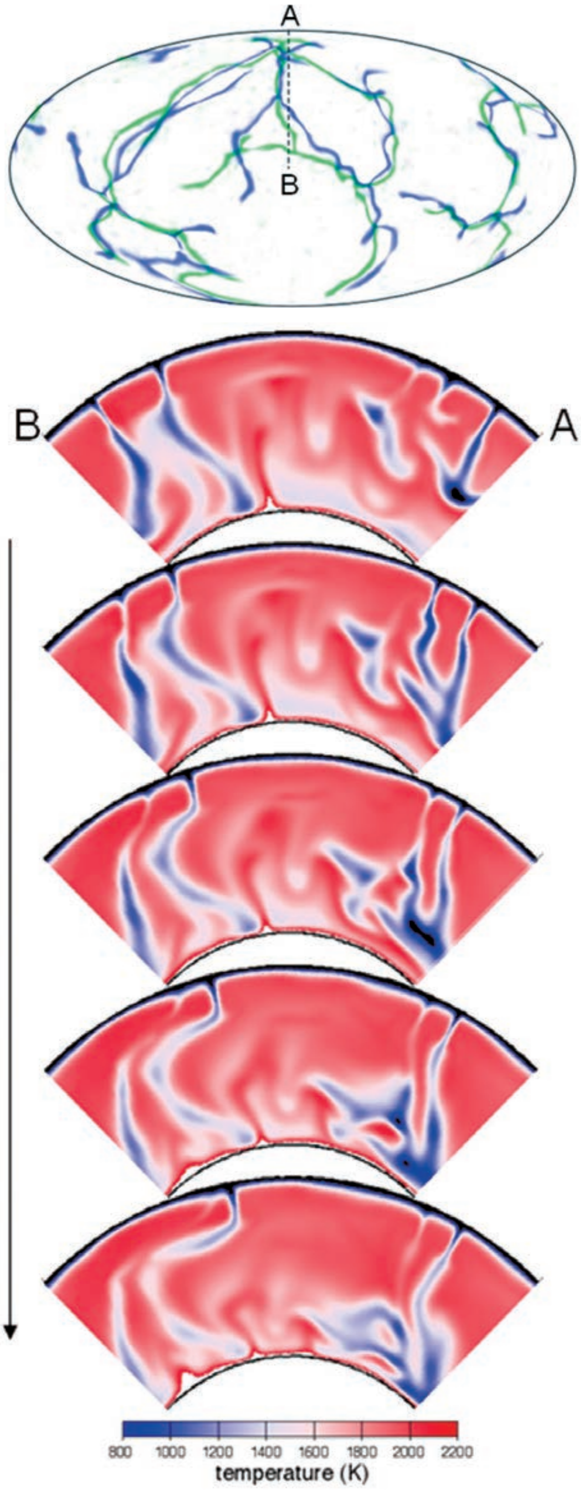


Figure 5. Changes in the flow field over 200 million years according to the simulated mantle convection. Top: Shifting of the subduction locations at the surface (green: the original position; blue: after 200 million years); Bottom: Vertical cross-section of the A–B line in the above diagram. Time elapses downwards; the colors indicate temperature fields. The images show how the structure lying near the transition zone of the mantle is formed with a rightward shift of the descending flow on the left side at the surface.

to the dependency of the viscosity on temperature, and the phenomenon of yielding near the ground's surface was also incorporated to account for rheological factors. The calculations successfully reproduced the process of the natural formation of localized linear subduction zones at the surface, as plate tectonics had assumed, and also reproduced large-scale plates, as seen on the real Earth, and their downward movement from the boundary.

The co-dependency between a stagnant slab lying in the transition zone and another slab penetrating the lower mantle, as seen in the seismic wave tomography, is naturally reproduced in this simulation. By tracking development over time we found out the process by which stagnant structures are formed by the shifting of the subduction point at the surface (Fig. 5). The key to the formation of a stagnant structure is that the flow of the upper and lower mantles can become uncoupled as a result of a decrease in buoyancy due to the phase transition at the depth of 660 km, and the difference in the viscosities creates a significant difference between the flow speeds of the upper and lower parts of the mantle. In other words, the lying slab structure is formed because the pattern of the upper mantle changes quickly while the slab stagnating due to the phase transition at the depth of 660 km is slow to change its position due to the slow moving lower mantle. This is how the shifting of the subduction point, or a phenomenon equivalent to the receding of a sea trench, occurs near the surface in the areas where the slabs stagnate.

Calculations covering several billion years revealed that the subducted slabs repeatedly stagnated and collapsed due to the effect of both the phase transition of the minerals in the transition zone of the mantle and the rapid increase in the mantle's viscosity. Such intermittence is believed to cause the relocation of plates, large-scale igneous activities, and variations in the strengths of geomagnetic fields, and has significant effects on the environment.

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The origin of the continental crust and the IODP (Integrated Ocean Drilling Program)

Asteroid Itokawa, on which Japan's spacecraft Hayabusa landed, is believed to hold records of the nascent planets of our solar system; for this reason, humans have thought of collecting samples directly from it. At the same time, the planets, which were born 4.6 billion years ago, experienced different evolutionary processes in reaching their present forms. The third planet of the solar system on which we live has gone through a unique evolutionary process not experienced by any other planets to become the planet Earth teeming with life. One special feature unique to the Earth is the continental crust, which has puzzled geoscientists for many years. At the IFREE, we are trying to discover the origin of the continental crust by collecting samples directly from beneath the sea floor through ocean deep drilling expeditions under the IODP (Fig. 6). In short, we are on a mission to unravel a mystery in the evolution of the Earth.

The continental crust is typically composed of andesite. Andesite is a type of lava containing about 60% silicon dioxide (SiO_2), which erupts in the form of magma along the subduction zone of a plate. Seismic waves travel through the middle crust of an oceanic island arc at the same velocity as through andesite, indicating that the continental crust was formed as magma in the subduction zone and accumulated in the middle crust. This explanation, however, does not come close to solving the mystery of the origin of the continental crust. In the first place, the formation of the continental crust begins with a part of the mantle (the upper mantle), which is the largest component of the Earth, (partially) melting to create magma. The present-day crust is a stratified structure consisting of the upper, middle, and lower crust. This structure is not possible unless the early crust differentiated for some reason. How then did the oceanic crust evolve into the island arc crust containing the middle crust which is composed of andesite

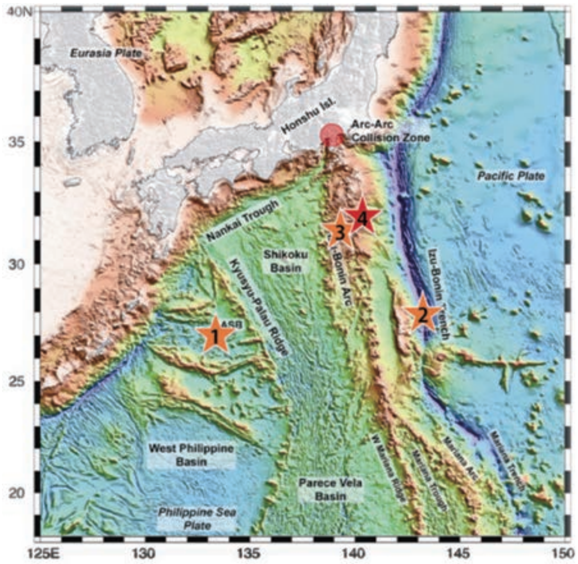


Figure 6. Four drilling sites for the seafloor deep drilling program (Project IBM) planned by the IFREE under the IODP. Numbers 1 to 4 correspond to IBM1, IBM2, IBM3, and IBM4, respectively.

(Fig. 7)? Is this middle crust the same as the continental crust? Project IBM was designed to explain these questions. If we were to analyze the most important middle crust, there is no other means but to collect samples directly from the crust by drilling into the sea floor.

Seafloor drilling is a massive project in which we cannot fail; therefore, we use every means available to us to construct and propose the latest and the most probable hypothesis before resorting to seafloor drilling. As a preliminary survey, we carried out an investigation of seismic waves using marine research vessels to understand the crustal structures, and we conducted a geological survey of the sea floor and collected samples by dredging and by using a manned submersible (*Shinkai 6500*) and an unmanned submersible (*ROV Hyperdolphin*). In the following sections, we present some of the new findings of the latest preliminary survey which are helping Project IBM evolve into a well-refined project.

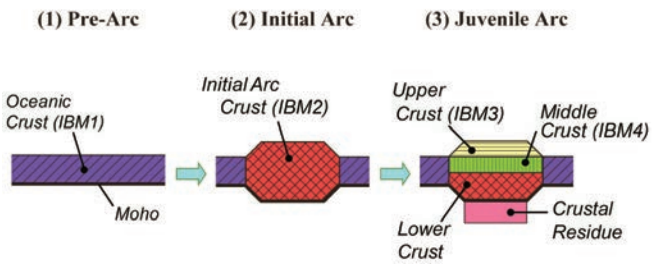


Figure 7. Four Project IBM drilling points (IBM1, IBM2, IBM3, and IBM4), corresponding to four stages of evolution, from the genesis of the subduction zone to the formation of the middle crust. The mission is to find out the origin of the continental crust born out of the ocean by drilling through the sea floor to collect samples of the oceanic crust prior to the start of subduction (IBM1), the first crust (IBM2), the differentiated upper crust (IBM3), and the middle crust (IBM4), and synthesizing the results.

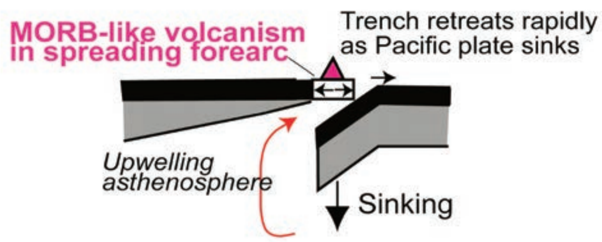


Figure 8. The asthenosphere rises at the start of the subduction, causing an expansion of the sea floor in the fore-arc area where magma similar to the submarine ridge basalt erupts.

How did subduction begin?

Finding the origin of subduction is one of the scientific targets drawing a large amount of attention today. How did subduction between different plates begin? What did the earliest igneous activity look like?

A survey by dredging and by the manned submersible (*Shinkai 6500*) unearthed igneous rocks from an era dating back to a period between the beginning of the subduction and 50 Ma in the land side of the trench of the Izu-Bonin-Mariana Arc. This magma was named FAB (Fore-Arc Basalt). The model presented in Fig. 8 was produced by an analysis of FAB. The forearc area became a tension field in the beginning stages of the subduction. The entire fore-arc area became an expanded boundary temporarily, and similar magma (FAB) erupted from the submarine ridge at the center. Later, andesite with a high magnesium content called boninite erupted only for a period of 48 to 45 Ma. After that, the process moved on to so-called igneous activity to form an island arc. Was the earliest magma, however, really FAB? What existed beneath FAB? Did the transformation from FAB to boninite, and from boninite to island arc magma, occur suddenly or gradually? There remain many fundamental questions which surveys using dredging and submersibles cannot answer. The drilling of IBM2 is an attempt to find answers to these questions and describe the timeline and the origin of the igneous activities at the beginning of the subduction.

How did the middle crust evolve?

We plan to drill IBM4 (Fig. 6) using the deep sea drilling vessel *Chikyu* to collect samples of the middle crust in order to understand the evolution of the island arc crust and the origin of the continental crust. If it is accomplished, it will be the first such successful mission in human history. Is IBM4, however, the most suitable drilling point for the purpose? The answer is clearly illustrated by Fig. 9 and 10. Fig. 9 represents the relationship between the crustal structure of the Izu-Bonin Arc and the quaternary basalt volcanoes. Three very interesting facts can be seen in this figure: (1) The middle crust protrudes into the shallow layer beneath the basalt volcanoes; (2) the middle crust beneath the basalt volcanoes is thick, that is, the basalt volcanoes are developing the middle crust; and (3) the average speed of the crust movement beneath the basalt volcanoes is slow, that is, it is close to becoming a continental crust. Therefore, drilling right through a basalt volcano down to the middle crust is the best scenario for us to understand the relationship between volcanoes and the middle crust. Is IBM4 suitable for that scenario? An ODP drilling survey 20 years ago identified IBM4 to possibly be an island arc volcano which was formed during a period in the Eocene–Oligocene epoch.

This is clearly supported by the crustal structure indicated by the preliminary survey (Fig. 10). The protrusion of the middle crust into the shallow layer indicates that it developed during island arc volcanic activities. There is no subduction zone other than the Izu-Bonin Arc that so clearly confirms the relationship between volcanoes and the crustal structure. Japan can achieve the drilling of the middle crust for the first time in human history by leading the world on the successful drilling of IBM4. The IFREE is making steady progress toward that goal.

Completion of the continental crust

The island arc crust illustrated in Fig. 9 is not continental crust at this point. In order for the island arc crust to evolve into continental crust, mafic lower crust must be removed from the island arc crust. New findings indicate that this last stage of the creation of the continental crust is occurring in the collision zones of island arcs. In the Izu-Bonin-Mariana Arc, it is the collision zone situated at the northernmost part between the Izu Arc and the Honshu Arc (Fig. 11).

The middle crust which was formed in the Izu Arc is found exposed in the collision zone. It is, however, the middle crust which has lost its original date information after a partial melting. Some was separated from the melt, and some had its crystals aggregated or deformed, and it rose and settled in the collision zone. It can be said to be the middle crust which has been overcooked to the point that no original information remains in it. At the same time, the lower crust is sinking into the mantle of the Honshu Arc together with the lithospheric mantle (Fig. 11). The upper and middle crusts which were formed in the island arc are likely to have accumulated in the collision zone and developed into the continental crust.

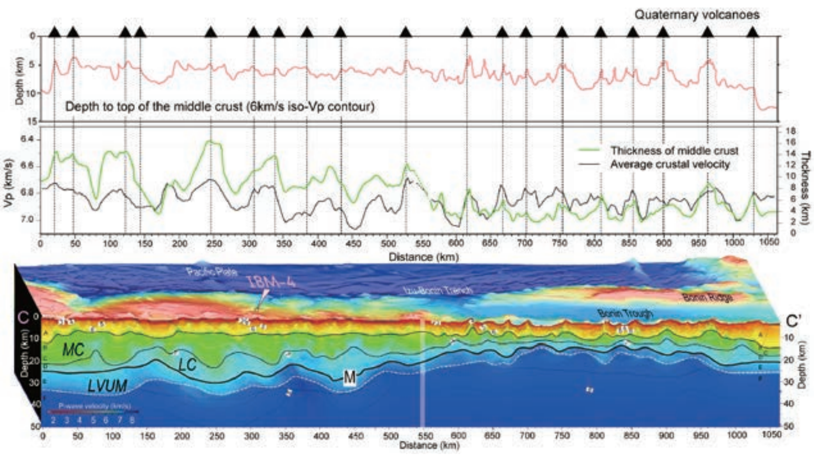


Figure 9. Relationship between the crustal structure and quaternary volcanoes (▲) in the Izu-Bonin Arc. MC, LC, and LVUM represent the middle crust, the lower crust, and the low-velocity upper mantle, respectively. Beneath the volcanoes, the middle crust has bulged into the shallow layer and thickened, and the speed of the movement of the crust as a whole has slowed.

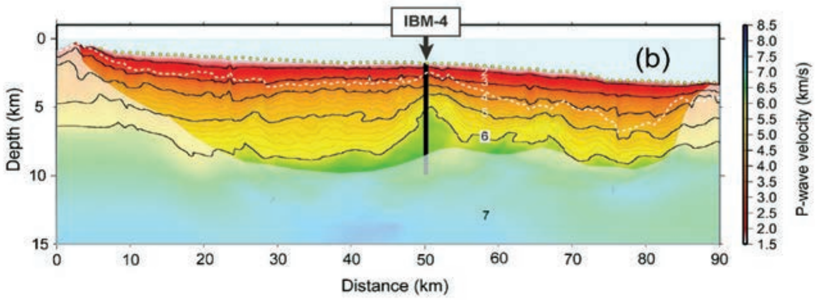


Figure 10. Crustal structure of the east–west profile line transecting IBM4. IBM4 is an island arc volcano of the Eocene-Oligocene Epoch under which the middle crust is seen protruding into the shallow layer, indicating that it is the most suitable drilling point to uncover the relationship between island arc volcanoes and the middle crust.

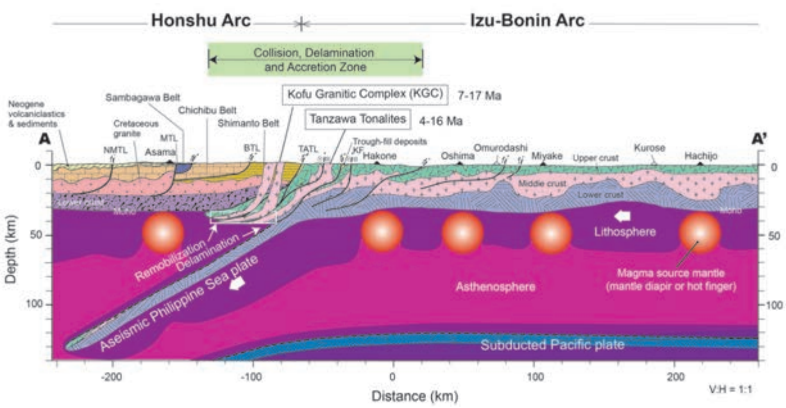


Figure 11. Delamination and completion of the formation of the continental crust in the collision zone between the Izu Arc and the Honshu Arc.

Institute of Biogeosciences (BioGeos)

Overview

At the Institute of Biogeosciences (BioGeos), we carry out researches on biodirersity of organisms that are flourishing in the marine biosphere and their ecological features and metabolic functions. In particular, we focus our research efforts on environments which are extreme for the organisms, such as deep sea, hydrothermal vent systems, cold seepage systems, anaerobic environments, and deep in the crust of the Earth beneath sea floor. We also work to make clear the roles and potential usefulness as bio-resources of the groups of organisms adapted to the oceanic/extreme environments, and provide this knowledge and information to help social and economic development of the human society. In addition, we aim to help evaluate how the Earth's environmental changes in future would affect the marine biosphere by understanding the mutual relationships among the atmosphere, the oceans, and the solid Earth.

More than 60 researchers are engaged in research activities in the following specific areas under three research programs (Marine Biodiversity Research, Extremobiosphere Research, and Earth and Life History Research):

1) Studies of the origin of life and the mechanisms of its evolution (an understanding of biodiversity):
  - The genesis of life to early ecosystem evolution (limits of life);
  - Evolution of eukaryotes (understanding of the birth of the eukaryotes by intracellular symbiosis);
  - From monocellular to multicellular organisms (e.g. cell division and transmission of information mechanisms)

2) Studies of the structures and functions of the Earth's biosphere, particularly in the ocean:
  - Biogeochemical cycles and their history;
  - Monitoring of the marine environment (e.g. the acidification of oceans and changes in biodiversity);
  - Adaptive ecology of the organisms in extreme environments (e.g. unique metabolic systems and intra-cell symbiosis in environments under high temperature/ high pressure or low temperature, with CH4, H2S, or anaerobic conditions)

3) Applied research on functional molecules, such as biological materials and enzymes, and microorganisms:
  - Carbon dioxide capture and storage (CSS) by bioreactors;
  - Development of energy sources using organisms and enzymes (e.g. CH_4 to C_3H_8);
  - Development of reagents and materials using useful enzymes and membrane substances

In order to carry out these studies to their fullest extent, we must develop a wide variety of technologies both in the ocean and in laboratory. At our Institution, we have developed a wide array of new techniques for bio/chemical analysis, cultivation of organisms living in extreme environments, and *in situ* monitoring of the organic environments. The Institute of Biogeosciences produces international level results by using these research techniques as well as the facilities of JAMSTEC, and participating in international research programs, such as the IODP, InterRidge, and CoML.

Marine Biodiversity Research Program

This research program is composed of six research teams. We are studying marine biodiversity, distribution of marine organisms, their ecological roles, their interactions with each other, and their interaction with marine environments. These studies will lead us to understand the effects of environmental changes on marine biodiversity, distribution of marine organisms, and the effects of marine organisms on their environments. Another aim of our research is to find useful marine resources and to develop new technologies to use them in the future. For that purpose, we are searching for unique and interesting enzymes and natural products that may be useful for human society. We are also developing technologies to produce large quantities of high-quality enzymes and natural products.

The six research team and their activities are as follows.

The activities of the Deep-sea Ecosphere Research Team focus on the study marine biodiversity and factors determining the distribution of marine organisms. The ecological roles of benthic and planktonic organisms are also studied.

Dense animal communities have been found at hydrothermal vents and seep areas. Animals in these communities are known to be symbiotic with chemoautotrophic and methane oxidizing bacteria, which produce organic carbons to support the animal communities. The Chemo-ecosystem Evolution Research Team is trying to prove a hypothesis that this chemo-ecosystem developed in shallow waters and then moved to deeper waters via sunken large animal carcasses or large pieces of wood, which produce reduced sulfur compounds such as hydrogen sulfide as well as methane.

The Symbiosis and Evolution Research Team is studying molecular biological mechanisms underlying the symbiosis between the animals of dense deep-sea communities and their symbiotic sulfur oxidizing and methane oxidizing microorganisms. Genomic changes in the symbionts and hosts associated with the symbiosis are also interesting subjects for this research team.

The deep sea is a harsh environment—dark, low temperature, and very high pressure. The Extremobioshphere Cell Biology Research Team is studying adaptation mechanisms to this extreme environment by focusing attention on cellular components, especially membranes. Techniques to control cellular attachment to substratum with electronics are being developed. Biological decomposition of biodegradable plastics in deep-sea environments is also a research target of this team.

The Marine Bioresource Exploration Research Team is searching for useful natural products and enzymes in deep-sea organisms. Biotechnological techniques are also being developed.

The United Biogeoresource Exploration Team is attempting to develop cultivation techniques of deep-sea organisms for scientific research. It is very difficult to cultivate deep-sea animals in the laboratory. The environments where they live are very different from shallow water. Many of them live in the transition zone between oxic and anoxic reducing environments. For instance, deep-sea *Calyptogena* clams insert a foot into sediments where oxygen is depleted but respire oxygen in seawater through their gills. Because many researchers from different research teams have similar problems in cultivating deep-sea animals and microorganisms, they have formed a united research team to develop new technology to conquer the problems in cultivating deep-sea creatures.

Topics in 2010

The year 2010 was the International Year of Biodiversity. In October, the 10th conference of the parties (COP10) of the Convention on Biological Diversity (CBD) was held in Nagoya, Japan. This was also the final year of the Census of Marine Life (CoML), an international project of the last decade. The achievements of CoML have been published as a list of marine organisms with their distribution data in a huge biological database called the Ocean Biogenographic Information System (OBIS). Many scientists at JAMSTEC contributed to CoML in various academic fields, including biodiversity in the seas surrounding Japan, Continental Margin Ecosystems (CoMargE), Chemosynthetic Ecosystem Science (ChEss), the Global Census of Marine Life on Seamounts (CenSeam), and the Census of Marine Zooplankton (CMarZ).

In one of these contributions, we collaborated with 50 Japanese and foreign marine biologists and ecologists to evaluate the biodiversity of marine organisms in the seas around Japan for the first time in the history of Japanese biology. In total, 33,629 species of marine organisms have been described in the seas around Japan. So far, approximately 250,000 species, from microorganisms to large organisms that include plants and animals, have been described from the world's oceans. Marine biodiversity near Japan is very high, at 13.5% of the world total marine species diversity (Fig. 1). To understand the biodiversity around Japan, we are studying mechanisms that generate biodiversity, such as biological interactions that include symbiosis, mechanisms supporting biodiversity such as food web structures, life histories and factors determining the distribution of marine organisms, and biodiversity in unexplored biospheres such as those in deep-sea environments.

We are searching for potentially useful natural products and enzymes in deep-sea environments. In 2010 we studied diversity of deep-sea fungi and found that there are many undescribed new species of fungi in the deep sea. From one of them, we found a new surfactant, indicating that they may be a new source for useful or practical materials. We also developed a new host-vector system producing some interesting deep-sea enzymes.

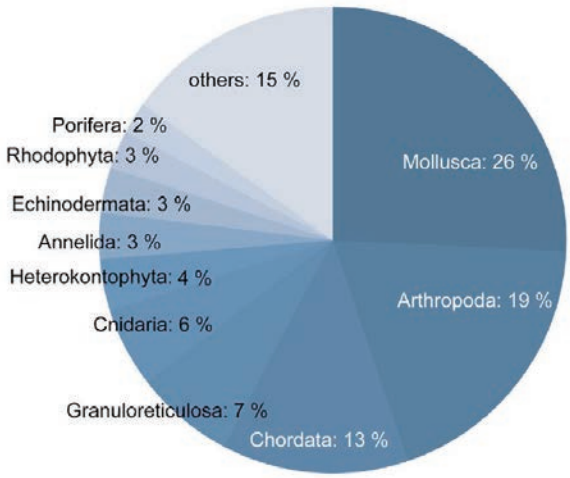


Figure 1. Marine biodiversity around Japan. Diversity in phyla are shown. The top 10 phyla contain approximately 85% of the recorded species.

Extremobiosphere Research Program

(1) Voyage to Okinawa for deep hot biosphere drilling, and the discovery of a massive hydrothermally-altered zone and a hot water lake under the sea floor

The hydrothermal activity in the Okinawa Trough exists under one of the world's most unusual geological conditions and has many unusual chemical properties. To gain an understanding of the ecosystem of the microorganisms living immediately below the Okinawa Trough hydrothermal activity area, we sailed on the deep sea drilling vessel *Chikyu* and carried out drilling from September 1 to October 4, 2010. This expedition was the first step in a large research project aiming to uncover the full picture of the subseafloor hydrothermal circulation system, and to decipher the volume, scale, diversity, functionality, and roles of the ecosystem of the microorganisms presumably living "very actively" in its circulating environment beneath the sea floor. The historical background and the progress of this research program have been published in detail on our website (www.jamstec.go.jp/biogeos/j/xbr/sugar/OkinawaDrilling/OkinawaDrilling.html). JAMSTEC also provides videos of the drilling expedition and research reports on our website (www.jamstec.go.jp/okinawa2010/j/).

The drilling expedition onboard *D/V Chikyu* and an analysis of the samples collected during the voyage have discovered: (1) the presence of an unexpectedly large hydrothermally-altered zone and a subseafloor hot water pool (hot water lake) under the sea floor of the Iheya-North hydrothermal field of the Okinawa Trough; (2) the stratified structure of hot water which is phase-separated by boiling in the subseafloor hot water pool; and (3) the presence of a massive deposit of "kuroko" (black ore) in the process of its formation beneath the sea floor (Figs. 1 and 2). The expedition also successfully created the world's first large-scale manmade hydrothermal vents by installing metal pipes and caps on the boreholes. Signs of the activities of thermophilic methanogens, methanotrophs, and sulfate-reducers are presently emerging in the upper region of the subseafloor hydrothermal pool. In addition, we are studying the physical and chemical properties of the subseafloor hot water by using these manmade hydrothermal vents. We are expecting to make a good progress in our research program.

(2) Whole-genome analysis and understanding of the functions of unidentified and difficult-to-cultivate archaeum and bacterium found living in the subterrestrial hydrothermal environment

Hot springs seep out into the mine roadway 300 m underground in a mine in Kagoshima Prefecture. Mat-like communities of microorganisms proliferate along the flows of hot spring water. Unlike the subaerial hot springs, no light shines into the underground tunnel, making it an ideal target for a study of the ecosystem of microorganisms in the dark. After nearly 10 years of research efforts, we had yet to successfully cultivate the two archaeal and bacterial species which constitute the microbial ecosystem, making it impossible for us to understand what functions they had and what role they played in the environment in which they were found. In order to discover the characteristics and the functions of these microorganisms that have steadfastly fought off all known cultivation methods, we tried a metagenomic analysis of their functions as a last resort under this program.

As a result, we successfully decoded nearly the whole genomes of the archaeum and bacterium in question, and estimated their functions and ecological roles. The archaeum, which was named *Candidus Caldiarchaeum subterraneum,* had a genome 1.7 Mbp long (Fig. 3). An estimation based on the genes found in the genome suggested that this archaeum may be using hydrogen or carbon monoxide as its energy source to grow autotrophically through the carbon dioxide fixation path that is unique to the archaea, which consists of decarboxylation/4-hydroxybutyric acid cycle, through aerobic or nitrate respiration. It also had a eukaryotic ubiquitin system, indicating that it was a new type of archaeum which is phylogenetically and functionally different from the archaea known to this date. The bacterium, on the other hand, which had been an unidentified bacterium known as OP1 but was named *Candidus Acetothermus autotrophicum,* had a genome more than 2 Mbp long (Fig. 4). This bacterium was recognized as a member of the oldest of all the known bacterial species. Its genome, however, was found to have a metabolism called the acetate-generating reductive acetyl-CoA cycle. An acetogens that could generate acetate from hydrogen and carbon dioxide had been thought to be one of the ancient life forms together with methanogens. However, it was considered a "pipedream" hypothesis because no known thermophilic bacteria on an ancient phylogenetic lineage, such as methanogens, had ever been found to have this type of metabolism. The result was the world's first discovery of a potential thermophilic acetogen of bacterium, on a deep branch of phylogenetic tree like the hyperthermophilic methanogens. It has given us a great clue to the understanding of the energy metabolism of the most ancient life forms that was born in Earth.

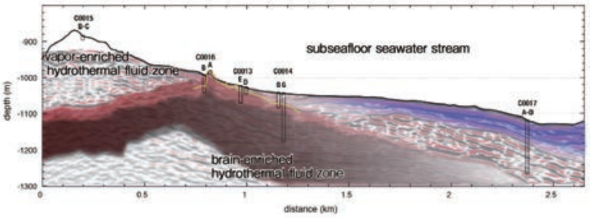


Figure 1. Schematic diagram of a massive hydrothermal pool (hot water lake) stretching under the sea floor in the Iheya-North hydrothermal field of the Okinawa Trough and its structure stratified by density, discovered by the drilling expedition (IODP Expedition 331) onboard the deep-sea drilling vessel *Chikyu*.

Figure 2. Photograph of the world's first "kuroko" (black ore) sample collected from the subseafloor. The sample was collected from ~10 m under the sea floor through the C0016B borehole shown in Fig. 1 by the drilling expedition (IODP Expedition 331) onboard the deep-sea drilling vessel *Chikyu*.

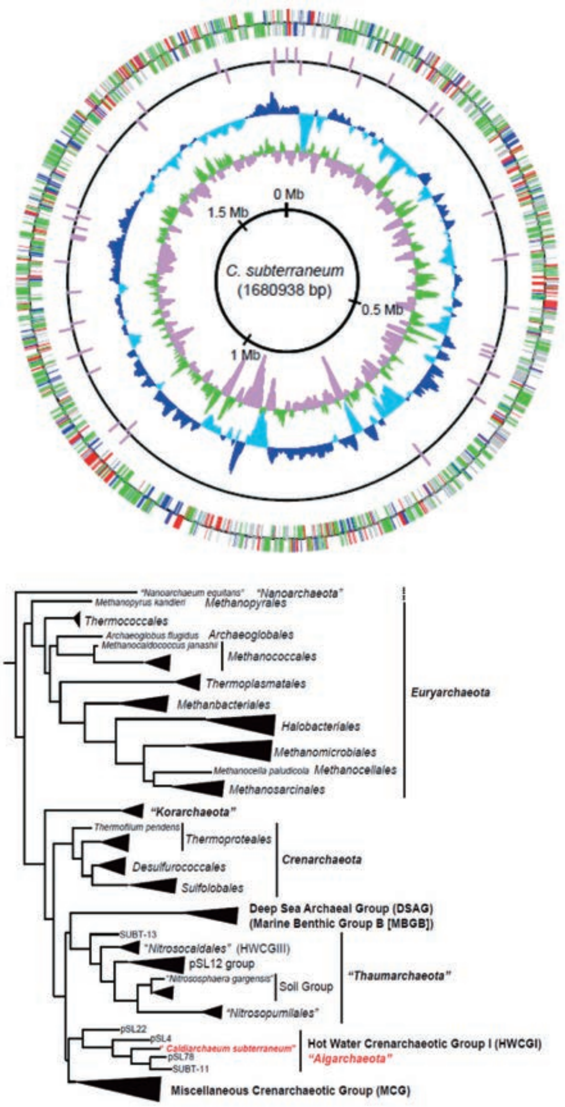


Figure 3. Genomic structure of *Candidus Caldiarchaeum subterraneum*, an archaeum which has never been cultivated and with unknown characteristics, as revealed by metagenomic analysis (top) and its phylogenetic position (bottom). We proposed that the archaeum should represent the fourth kingdom of the archaea.

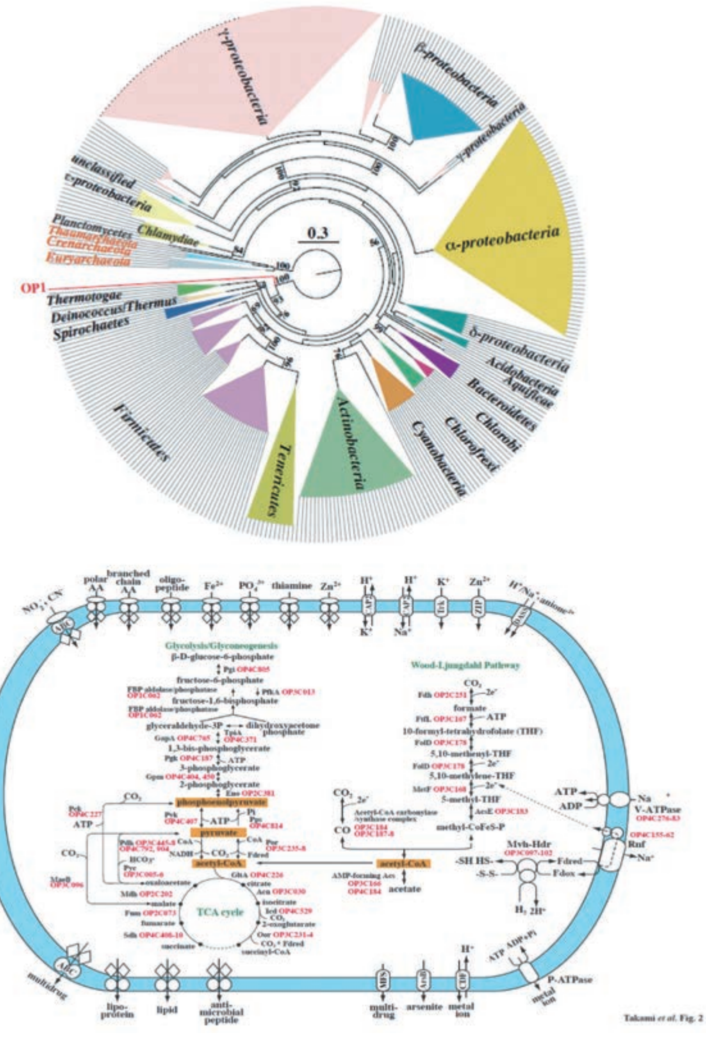


Figure 4. The phylogenetic position of *Candidus Acetothermus autotrophicum*, a bacterium which has never been cultivated and with unknown characteristics, as revealed by metagenomic analysis (top) and its estimated metabolic pathways (bottom). It is believed to be an acetogenic bacterium having a reductive acetyl-CoA cycle. It is the first bacterial example to support a hypothesis that the ancestors of the archaea and the bacteria were methanogens and acetogens, respectively, which were born in a small hole in a deep-sea hydrothermal chimney-like structure.

Earth and Life History Research Program

Eco-friendly life of microorganisms at the deep-sea floor

Under this program, we are carrying out studies to find out what is happening in the ocean today, and apply our findings to reconstructing the historical environments of the Earth. We concentrate our efforts in the reconstruction of the Earth with weight on biological research activities in an area bordering conventional geoscience and biology. In this report, we explain one of our important achievements during the fiscal year: how we discovered a new metabolic process of the deep-sea archaea.

The bottom of the deep sea is teeming with diverse microorganisms which play important roles in the carbon cycle on the surface environment of the Earth. The microorganisms called archaea, in particular, have recently been found to be distributed in large numbers in oceans and marine sediments. The marine archaea, however, have been difficult to isolate and cultivate. Even basic information, such as their activities in seawater and marine sediment and their life patterns, is not well known.

We used the unmanned submersible *Hyperdolphin* to conduct an incubation experiment with ^{13}C-labeled glucose at the bottom of Sagami Bay (1453 m deep; see Fig. 1) in order to track the activities of the archaea. We focused our efforts or isolating ether lipids, which are synthesized only by archaea, from the sediment and measuring the concentrations of ^{13}C in it to note the ^{13}C derived from the glucose sprinkled on the sea floor.

A large amount of ^{13}C in the ether lipids was found in glycerol but virtually none in isoprenoids. This finding indicates that glucose was used by the archaea to synthesize glycerol but not isoprenoids. In other words, isoprenoids were not newly synthesized but were likely to be have been "recycled" from isoprenoids synthesized by ancestors of the archaea and left in the sediments after their death. The archaea were taking the old isoprenoids into their cells and using them to build their own cell membranes in order to carry on an eco-friendly living on the energy-depleted sea floor.

Our study uncovered for the first time that the membranes of the archaea had a process which could take in large molecules with a mass number larger than 500 Da, such as isoprenoids (Fig. 2). Our findings also suggest that the activities of the archaea in the ocean have been vastly underestimated by past studies. Our study has shown that the archaea potentially have a much larger role in the carbon cycle in the ocean than previously believed.

When combined with the activities of protozoans, such as foraminifera, which are being studied under the same program, our findings will help us gain an accurate understanding of the cycles of the bioelements, such as carbon and nitrogen, on the sea floor.

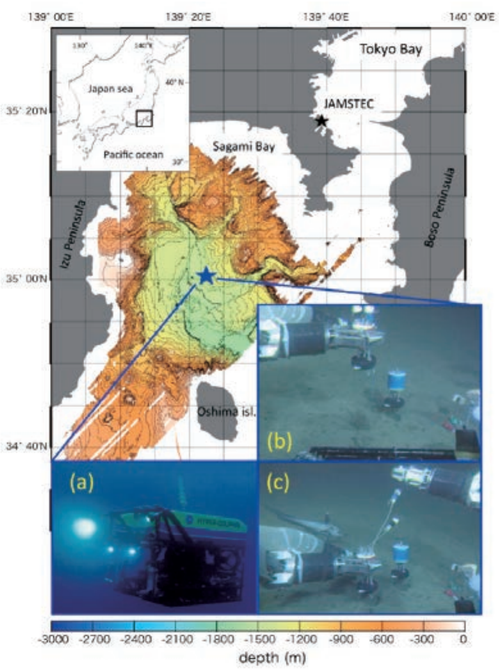


Figure 1. Unmanned submersible *Hyperdolphin* conducting an incubation experiment of the bottom of Sagami Bay.

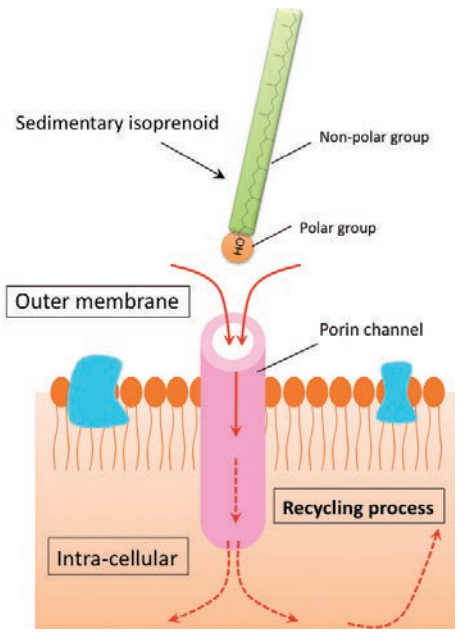


Figure 2. Hypothetical process of the intake of extracellular isoprenoids through a channel in the cell membrane. Isoprenoid molecules are taken into the cells through a passage in the membrane by adsorbing to hydrophilic protein in the porin channel, and are then re-used in the cell to make the organic compounds required for biological activities.

Earthquake and Tsunami Research Project for Disaster Prevention

The Ministry of Education, Culture, Sports, Science, and Technology (MEXT) announced that the probability within 30 years of a massive earthquake measuring Magnitude 8 is 87% in the Tokai seismic area, 60–70% in the Tonankai seismic area, and 50–60% in the Nankai seismic area. MEXT also estimated that if earthquakes occur together in these areas, damage will be about 81 trillion yen, which is close to Japan's annual national budget. How to prepare for trench-type massive earthquakes is one of the most important issues for Japan.

To address this problem, and at the request of the Japanese government, the Earthquake and Tsunami Research Project for Disaster Prevention is developing a system for early detection of earthquakes and tsunamis and for more advanced earthquake prediction using real-time observation data, elucidation of detailed crust structures of hypocenter regions, computer simulation research on earthquake occurrence, and other measures. The following sections outline these research and development projects.

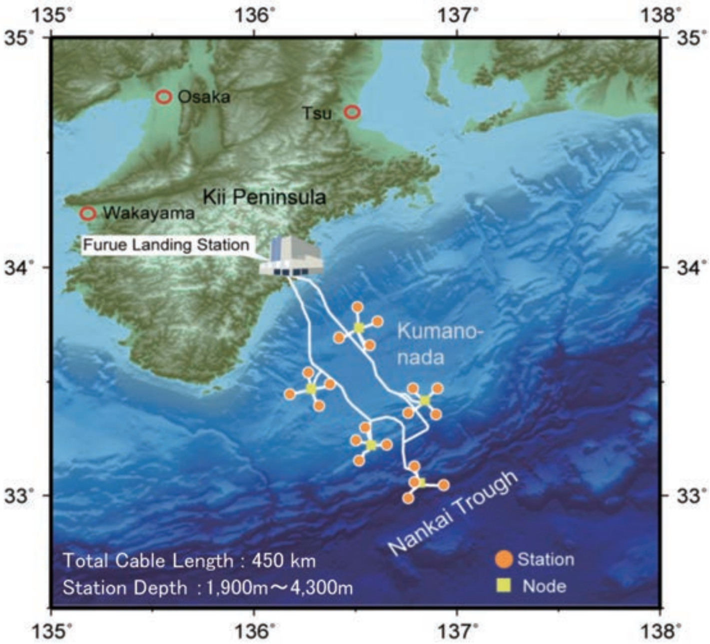


Figure 1. Deployment diagram of the Dense Ocean-floor Network System for Earthquakes and Tsunamis (DONET).

Dense Ocean-floor Network System for Earthquakes and Tsunamis (DONET)

Since fiscal 2006, we have been carrying out a project entrusted by MEXT to construct an earthquake and tsunami observation and monitoring system to be used for disaster prevention and mitigation. We have installed and networked high-precision earthquake and tsunami sensors at 20 sites on the floor of the Sea of Kumano off the Kii Peninsula, which is the theorized hypocenter of a future Tonankai earthquake. We have already started observations (Figs. 1 and 2).

Data from each sensor is sent in real time from the land station in Furue-cho, Owase City, Mie Prefecture via dedicated lines to JAMSTEC, the National Research Institute for Earth Science and Disaster Prevention, and the Japan Meteorological Agency. It is expected to contribute to raising the precision and speed of earthquake early warning and tsunami warning as well as advancing earthquake prediction models.

In 2010, as the project's second stage, we started construction of DONET2, a new dense ocean-floor network for the Nankai earthquake hypocenter area. DONET2 is planned to install and network about 30 units of observation equipment southwest of the Kii Peninsula. At the same time, we are advancing the system, for example by exchanging its cables for those that carry higher voltages.

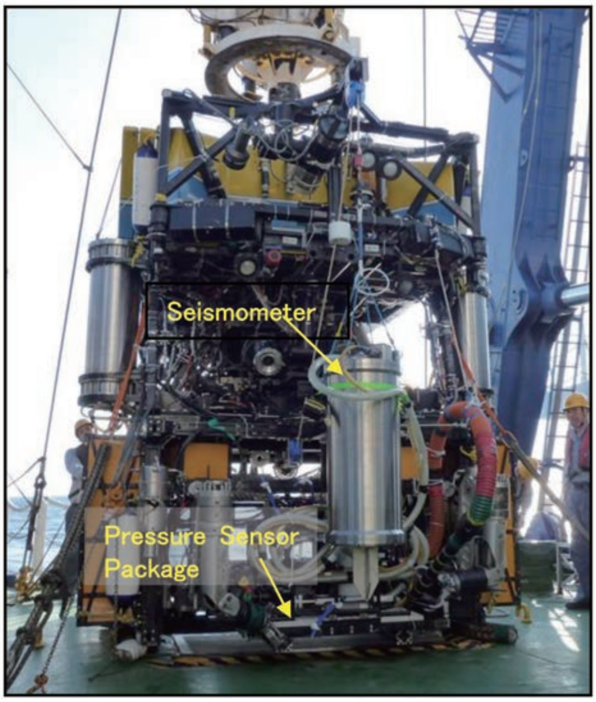


Figure 2. The *Hyper-Dolphin*, an unmanned operated vehicle modified to install observation equipment on the seafloor.

Evolution Research of the Seismic Linkage around the Nankai Trough

In fiscal 2008, commissioned by MEXT, a research project aiming to assess the possibility of a linked occurrence of Tokai, Tonankai, and Nankai earthquakes was started under the cooperation of JAMSTEC, Tohoku University, the University of Tokyo, Kyoto University, Nagoya University, Kochi University, the National Research Institute for Earth Science and Disaster Prevention, and other bodies.

This project is largely divided into three research groups: the first is doing observational research, mainly investigating crust structure; the second is doing simulation research to find out how linked and unlinked earthquakes cause destruction by constructing models of earthquake occurrence cycles; and the third is doing disaster prevention and mitigation research to formulate a personal-damage reduction strategy, based on high-precision prediction of strong ground motion and tsunamis caused by massive earthquakes.

In observational research this year, we carried out investigation and observation to understand the structure and seismic activities of the Philippine Sea Plate, which is subducting at the western side of the Nankai Trough region, including the Sea of Hyuga. Analysis revealed that the Philippine Sea Plate changes in structure from the ocean crust off Shikoku through a transition zone to the thick crust of the Kyushu-Palau Ridge, and that the structure boundary between the transition zone and the Kyushu-Palau Ridge corresponds to the western edge of the region destroyed by the 1968 Hyuga-nada Earthquake (Figs. 3 and 4).

In simulation research, we developed a new model that approximates the subducting plate boundary with a curved surface close to the actual shape of the fault, and compared it with the conventional model, which approximates the plate boundary with a flat surface fault, to find out what difference this may cause (Fig. 5). We also made models of “slow earthquakes,” in which long-period seismic waves surpass others compared with ordinary earthquakes, and of massive earthquakes, to examine the temporal and spatial changes in slip speed at the plate boundary.

In disaster prevention and mitigation research, we have been organizing local study meetings with the participation of the national and local disaster prevention officials, and lifeline providers in regions at Kochi, Osaka, Nagoya, Mie, and other places where damage is expected, and we conducted activities to apply research results to realistic disaster prevention and mitigation plans.

Intensive Investigation, Observation, and Research on the Crustal Strain Concentration Zone

On the Japan Sea side and the inland area of northeastern Japan, there is a region called a crustal strain concentration zone, where the 2004 Niigata Chuetsu Earthquake occurred and other earthquakes have frequently struck and caused extensive damage. In 2008, a project was started to clarify the overall picture of the crustal strain concentration zone.

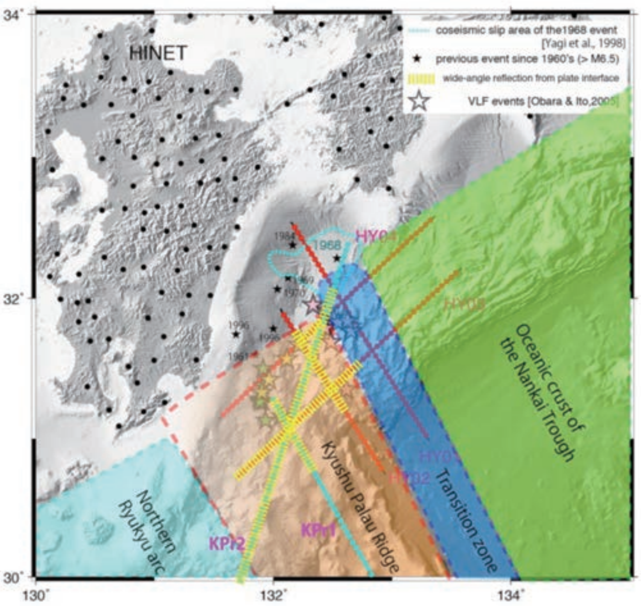


Figure 3. The structure of the Philippine Sea Plate changes to the Kyushu-Palau Ridge.

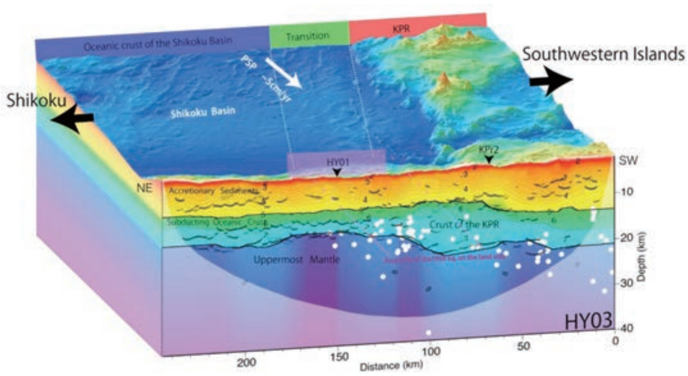


Figure 4. Interpretation of the sea-bottom section with a measuring line from the Nankai Trough to the Kyushu-Palau Ridge.

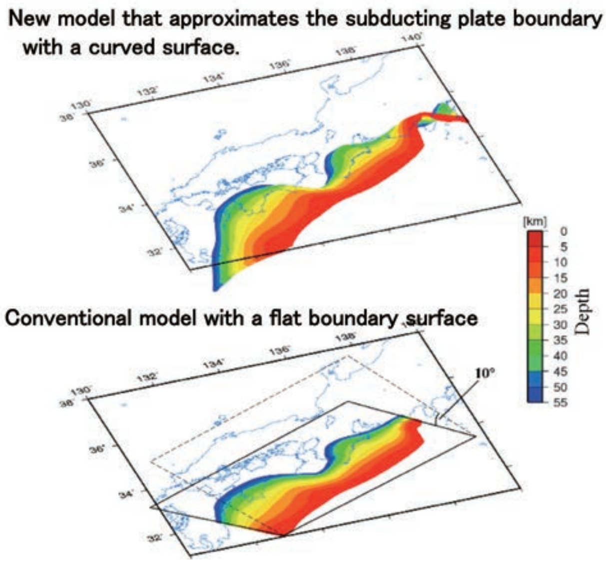


Figure 5. Fault models of the subducting Philippine Sea Plate.

Through exploration of the structures from the seabed off the Noto Peninsula to that off Sado Island, which we carried out in the last fiscal year, we confirmed that the crust became thinner with the past expansion of the Japan Sea, and we also identified anticlinal structures made by subsequent compression deformations. From the exploration we carried out in this fiscal year, it was revealed that there is a strong compression deformation around the hypocenter region of the 2004 Niigata Chuetsu Earthquake (Fig. 6). Now we will expand the area of our investigation to the hypocenter region of the Japan-Sea Earthquake and seek structural features that define the mechanism of past huge earthquakes.

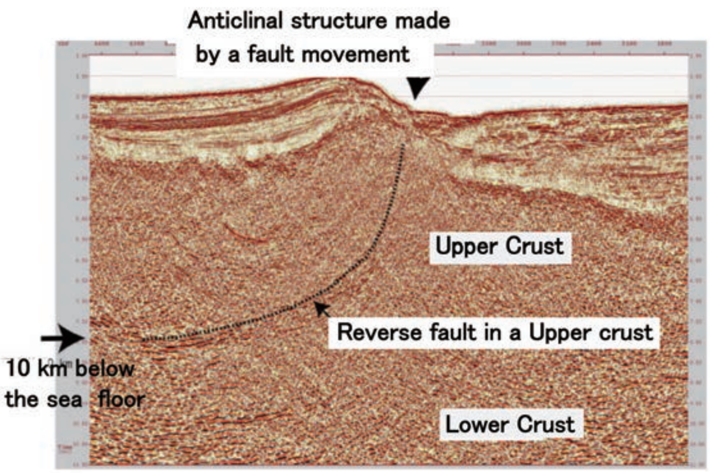


Figure 6. Reflection record section (the vertical axis is travel time in seconds), showing the reverse fault (dotted line and arrows) developing southeast of the Noto Peninsula. The base layer and the sedimentary layer show an uplifted structure, which is considered to be made by fault movement. The fault's bottom is located on the boundary between the upper crust and the lower crust.

Development of Long-term Borehole Measurement Technology

We installed and secured seismometers, clinometers, strain gauges, thermometers, and other sensors in a drilling hole (at Site C0002, water depth 1,938 m, about 750–940 m below the seafloor) drilled by the deep-sea drilling vessel *Chikyu* during the IODP NanTroSEIZE cruise of November–December 2010 (Fig. 7). We started developing these sensors in fiscal 2009. These sensors can realize stable observation for a long period of time even in the severe environment of pressure over 1,200 times as high as on the ground and at a temperature of 170–180°C. At present, observation data are temporarily stored in data-recording devices on the seafloor and collected by an ROV. However, these sensors will be connected to the DONET network, enabling comprehensive real-time observation and monitoring on and under the seafloor of the hypocenter region of Tonankai earthquakes. It is expected to contribute to early detection of earthquakes and tsunamis, more advanced prediction of earthquake occurrence, and disaster prevention and mitigation.

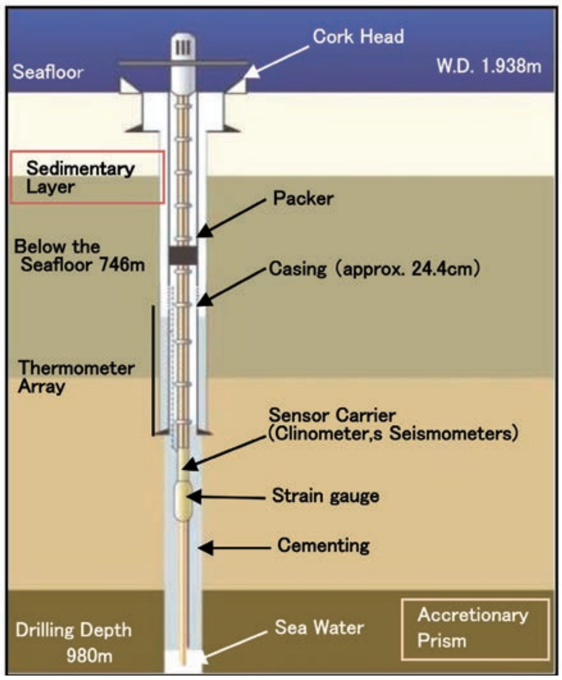


Figure 7. Cross-section of Site C0002, where long-term borehole monitoring system are installed.

Global Warming Research Project for IPCC-AR5

Overview

The Global Warming Research Project for IPCC-AR5 is carrying out research for the “Innovative Program of Climate Change Projection for the 21st Century” commissioned by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and part of the “Integrated Research on Climate Change Scenarios to Increase Public Awearness and Contribute to the Policy Process ” commissioned by the Ministry of the Environment. The purposes of the Project are to contribute to the coming IPCC’s Fifth Assessment Report (AR5) as well as to provide scientific support to government policies relating to climate change through the development of an advanced global warming projection model, a reduction of uncertainties in the projection, and assessments of the effects of natural disasters. During the 2010 fiscal year, we have accomplished the following:

Development of an Integrated Earth System Model and scenario experiments with the use of it

For the 5th Assessment Report of the IPCC , we carried out experiments on a global warming projection based on the protocol provided by the Coupled Model Intercomparison Project Phase 5 (CMIP5) by using an integrated earth system model we’ve developed. The results showed that temperatures in 2100 would rise in a range of 2° to 7°C (compared to the average in the 1980–1999 period) under the specified scenarios. The sea ice in the Arctic Ocean is predicted to disappear during the summer of 2030. This is earlier than the timing predicted by the models used by other research institutions around the world. It is not, however, unrealistic when the observed trends in sea ice loss are considered. The results of our analysis also suggested that the behavior of the terrestrial carbon cycle would be affected by the changes in future land use scenarios. We obtained also that the period of the quasi-biennial oscillation (QBO) observed in the equatorial lower stratosphere will become slightly longer.

Completion of the Near-term Climate Change Prediction Experiment

Using a coupled atmosphere–ocean model of relatively high resolution (atmosphere: 60 km; ocean: 20–30 km), we carried out a near-term climate change prediction experiments on “Earth Simulator”, and finally completed the calculation which took nearly 2 years. Compared to the previous experiments with a model of a medium resolution (atmosphere: 300 km; ocean: 100 km), we confirmed that the high resolution model gives a satisfactory reproduction of regional atmospheric and oceanic climates. Because of its high resolution, the reproducibility of extreme weather events, such as typhoons and severe rainfall events, was also high. Regarding the

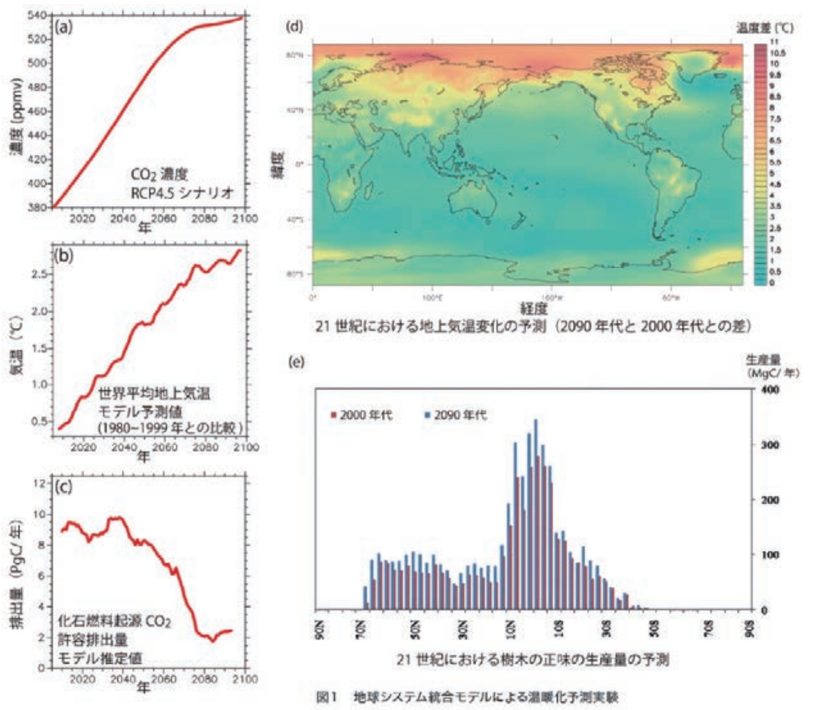


Figure 1. Examples of the results of the Global Warming Projection Experiment using a coupled global system model

projection skills for the targeted Pacific Decadal Oscillation (PDO), it was estimated to be about the same in both cases, however, more detailed analyses are currently ongoing.

Developments in the study on evaluation of uncertainties

We proposed a new approach to interprete the results of an ensemble experiment to evaluate uncertainties in climate models. The results of an analysis of the climate model ensemble based on the proposed approach indicated that the existing ensemble has reproduced the uncertainties in the climate system satisfactorily. In order to confirm the universality of this finding, we evaluated a model ensemble of the last glacial maximum simulation using seawater temperature data and obtained similar results. We also developed an efficient calculation technique using a simplified earth system model to estimate the extent to which the uncertainties in the climate system will be due to the uncertainties in the terrestrial carbon cycle process. We have completed adjustments of the model to reproduce variances in the existing models, and are working on a large-scale ensemble.

Progress in the study of trends in typhoons and other extreme events under the global warming

1) Using a 20 km-resolution global atmospheric model of the Meteorological Research Institute of the Japan Meteorological Agency (AGCM20km), we investigated how the activities of typhoons in the northwestern Pacific Ocean would change under the SRES-A1B scenario. The results showed (a) a noticeable decrease in the number of typhoons generated and the frequency of their presence (–23%); (b) an eastward shifting of their northward tracks ; and (c) a noticeable decrease in the number of typhoons approaching Southeast Asia (–44%). These changes are due more to changes in originating locations than changes in the large-scale circulation system, and are strongly influenced by the sea-surface temperature distribution changes .

2) We carried out an experiment using a cloud-resolving global atmospheric model (NICAM) with 7.5 km resolution and confirmed what has been suggested in the IPCC 4th assessment report, that is, while tropical cyclones would decrease in number globally under a certain warming scenario (e.g. the doubled atmospheric carbon dioxide concentration), the number of intensive tropical cyclones increases. The results of the experiment also indicated that the cloud top height tends to be higher for more intensive tropical cyclones and such trend becomes more noticeable under global warming. Unlike the conventional climate models, NICAM can directly calculate the lifecycle of a cumulonimbus cloud systems and hence, a new progress in the study of future tropical cyclones can be expected.

3) We compared the characteristics of the AGCM20km with those of a nonhydrostatic regional model of the Meteorological Research Institute of the Japan Meteorological Agency (NHM5km) for extreme rainfall events near Japan. Comparisons of maximum daily precipitation, number of precipitation days , and daily precipitation intensity index between the two models, showed that the biases in NHM5km were about one-third of those in AGCM 20km, suggesting that downscaling by NHM5km is effective in improving the quantitative projections of extreme rainfall events due to climate changes.

Studies to improve a global warming projection model

1) We are developing a global nested ocean model with the aim of improving the accuracy of global warming projections by specifically increasing the accuracy of sea surface temperature around Japan and its vicinity. In order to improve the accuracy of this model , we introduced a tripolar coordinate system in a global model and confirmed improvements in reproducing climate. We also developed a coupler for the coupling of this global nested ocean model with an atmosphere model.

2) For the purpose of understanding the process of changes in terrestrial ecosystems due to climate changes and the effects of the ecosystem changes on climate as well as increasing the accuracy of the model, we carried out experiments to reproduce past ecosystem and climate and to study the interaction of future global warming and ecosystems with the use of an integrated earth system model. The results indicated that the warming during the current century would be most pronounced in the Arctic high latitude region, and trees would begin to grow in the tundra in northern Siberia. This has the possibility of causing changes in the surface albedo and thus further feedback on climate. Accordingly, we are trying to improve the current terrestrial ecosystem model to address all aspects of terrestrial ecosystems, including adaptation to climate change by plants and the decomposition of organic matter by microorganisms in the soil.

Laboratory for Earth Systems Science - Precambrian Ecosystem Laboratory Unit

Overview

The true law which made it possible for the Earth to become a rare "planet full of life" is the subject of greatest common intellectual curiosity for all humankind. It gives us the most important clue for finding out the possibility and conditions needed for life to exist elsewhere in space, including our own solar system. At the Precambrian Ecosystem Laboratory, we believe the true law to be the fact that a set of systems encompassing the "mantle, ocean, continents, atmosphere, and life" had already been established in the earliest stages of the evolution of Earth and Life, that is, an interactive system of "Earth and Life", and continued to function and evolve over time. Almost all of the mechanisms of the "Earth–Life" interactive system are believed to have been in place long in the Precambrian age more than 600 million years ago. The evolution of these mechanisms was the true reason why Earth could become a rare "planet full of life", which led to the so-called "Precambrian Explosion", the biggest event in the history of the evolution of the Earth and life. At the Precambrian Ecosystem Laboratory, we are trying to unravel the mystery of the Precambrian age—the process of evolution of the first persistent life system from its birth to its propagation in the planet-wide ocean environment (the acquisition of a photosynthesis system and the diversification of energy metabolism)—by reconstructing a full story from the geological records remaining on today's Earth, from the functions and genomic information recorded in today's microorganisms, and from material circulation and ecosystem functions that occur in similar environments on the modern Earth, and we are carrying out reproductive experiments in the laboratory. Our ultimate goal is to explain the early evolution of the primitive Earth Life system (the Precambrian Explosion).

At present, four dedicated full-time researchers, six researchers from other institutes, and one guest research student work at the Precambrian Ecosystem Laboratory.

Overview of the 2010 achievements

The major outcomes of the projects in the 2010 fiscal year were: (1) the proposal of the "highly alkaline, hot hydrothermal vent" hypothesis that the deep-sea hydrothermal that supported the early evolution of life in the Hadean–Early Archean eon was strongly alkaline; (2) the discovery of the third and fourth deep sea hydrothermal fields and the white scaly-foot gastropod in the Indian Ocean; and (3) the proposal of the "MMR" hypothesis which explains the sites and mechanisms of the generation of methane in the Okinawa Trough hydrothermal circulation system which was the destination for the Okinawa hydrothermal drilling expedition.

The outcomes of research efforts in various scientific fields in the 20th century indicated that the deep-sea hydrothermal environment was the likely site of the birth and early evolution of life in the Earth. Since the first deep-sea hydrothermal activity was discovered in the East Pacific Ocean Rise in 1979, it had been thought that, like the present day black smokers, the deep-sea vent was an acidic hot water rich in iron-sulfides throughout the history of the Earth. The reaction between rock and sea water which generates hydrothermal fluid, however, is dependent on the composition of seawater. If the composition back then on early Earth was different from that of seawater today, then the composition of the hydrothermal fluid at that time must have been different as well. As the seawater in the Hadean–Archean eon (4 to 2.5 billion years ago) is believed to have been weakly acidic and contained a very high concentration of CO_2, we carried out a thermodynamic calculation and theoretically reproduced the deep-sea hydrothermal fluid in the Hadean–Archean eon based on the chemical composition of altered igneous rocks on the sea floor of that period.

The results revealed that the pH value of the hydrothermal fluid rose as more carbon dioxide dissolved into seawater, and the pH value of the hot hydrothermal water in the Hadean–Archean eon was higher than pH 9 (Fig. 1). The results also indicated that the concentration of metals, such as iron, was low in hydrothermal fluid but silica was abundant. This finding indicates that in that period the hydrothermal fluid did not spout from the sea floor from black smokers rich in iron sulfide which we see today but white smokers (Fig. 2).

The outcome of our study has not only disproved the present perception of the deep-sea hydrothermal activities and their chemical properties but has also provided a clue to solving the most perplexing problem in the history of the Earth. Iron-oxides ore is an essential resource which supports the "iron society" of humankind. The iron-oxides ore in the photograph (Fig. 3) was mined from the stratum called the banded iron formation. A great scale of iron-oxides accumulated to form the banded iron formation only in the early Earth; it is no longer formed on today's Earth. Earth was very reductive until 2.5 billion years ago when the concentration of oxygen in seawater began to rise due to oxygenic photosynthesis by cyanobacteria. The banded iron formation was believed to have been formed by the precipitation of iron which had been dissolved in seawater. On the other hand, the banded iron formation has existed on a relatively small scale for more than 3.8 billion years. This fact has caused considerable argument about the most perplexing problem in the history of the Earth: Did oxygen already exist on Earth 3.8 billion years ago? If, however, the hydrothermal fluid in the early Earth was alkaline, then the banded iron formation would have developed because iron dissolved in seawater near the hydrothermal vent would be easily oxidized not by oxygen but by changes in pH. Our model indicates that the development of the banded iron formation was possible without the presence of oxygen in the ocean 3.8 billion years ago. It also explains the geological records that indicate the existence of other reductive environments very well. Our model solves the question as to the development of the banded iron formation more than 2.5 billion years ago.

Since the discovery of the first hydrothermal activity in the deep sea in 1979, more than 300 deep sea hydrothermal waters have been discovered at the sea floor around the world. Yet only two hydrothermal fields have been found in the Indian Ocean since the first sign of hydrothermal activity was reported in 1988. The Precambrian Ecosystem Laboratory led an expedition to the Rodriguez segment of the Central Indian Mid-ocean ridge where signs of hydrothermal activity were reported by *R/V Hakuho Maru* of the Ocean Research Institute of the University of Tokyo in 2006. There we carried out an investigation of the Great Dodo Lava Plain in the north and the Roger Plateau in the south over the period from September to October, 2009, using a deep-tow camera and the submersible *Shinkai 6500*. Not only did we discover two new hydrothermal vents (Fig. 4) and uncover the diversity of the hydrothermal activities in the Indian Ocean but we also made an important discovery of the "white scaly foot" which is a rare deep-sea organism that synthesizes chemicals (Fig. 5). These discoveries were published on our official website together with a detailed article and a video footage showing the moment of discovery of a hydrothermal vent, and attracted considerable public attention (www.jamstec.go.jp/less/precam/j/achievements.html#01).

The most important point of the drilling research project using the deep-sea drilling vessel *Chikyu*, which has been included in the achievements of the Extremobiosphere Research Program of the Institute of Biogeosciences, was to gather data to support the development of a model of the subseafloor hydrothermal circulation system in the Okinawa Trough. This hydrothermal circulation system exists under some of the world's most unusual geological conditions and has unusual chemical properties. Understanding the subseafloor hydrothermal circulation system in the Iheya North hydrothermal system has been a subject challenging not only the Extremobiosphere Research Program but joint research efforts of the researchers of the Institute for Research on Earth Evolution of JAMSTEC and many universities. The final conclusive work, however, was a detailed analysis of the chemical composition of the hydrothermal fluid and isotopic chemical properties, and a carbon mass balance calculation which integrated these analytical data. The results indicated that the source of hydrothermal fluid in the Iheya North hydrothermal field was interstitial water in the sediment filling the Okinawa Trough far away from the Iheya North Knoll, and methane generated by microorganisms in the sediment was the ultimate origin of the high concentrations of methane contained in the hydrothermal fluid. We proposed this as the "methane generation by microorganisms in the source area of hydrothermal fluid" hypothesis (the MMR hypothesis), and the drilling research in the Iheya North hydrothermal field onboard *D/V Chikyu* was carried out for the purpose of testing this hypothetical model.

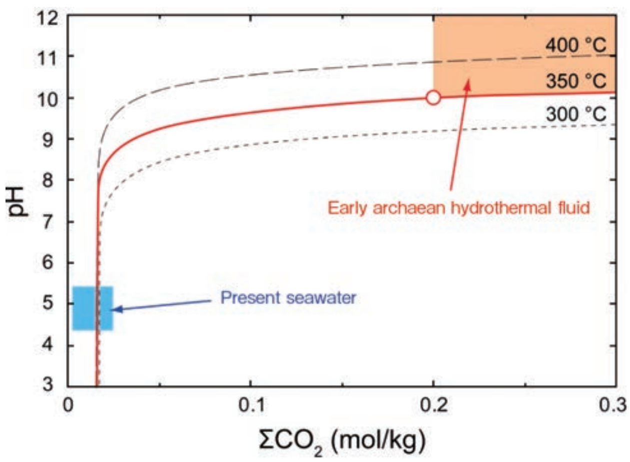


Figure 1. Relationship between the CO_2 concentration and pH in hydrothermal fluid.
The value of pH rises as the concentration of total CO_2 in hydrothermal fluid increases. The blue area represents the hydrothermal fluid spouting from the mid-ocean ridge today, while the orange area represents the fluid in the early Archean eon determined by calculations carried out in this study.

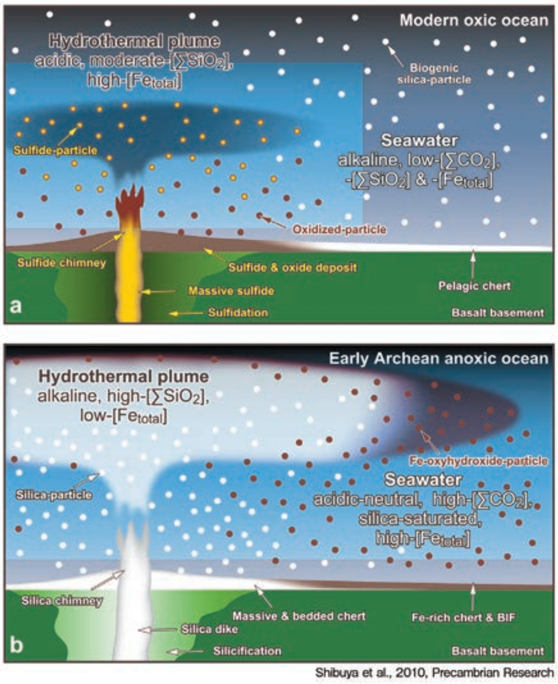
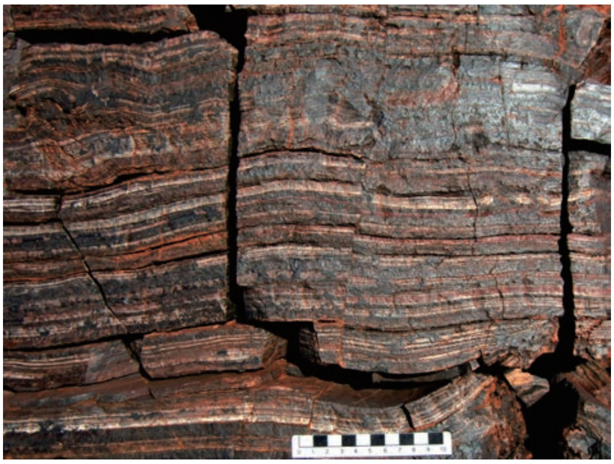


Figure 2. Schematic diagram comparing the present-day and early Archean hydrothermal fields

(a) Present-day hydrothermal field. Black, acidic hot water spouts from a chimney of sulfides (mainly iron sulfide), with sulfides, or oxides of these sulfides oxidized by seawater, accumulating around the vent. Away from the hydrothermal vent, silica particles originating from organisms (radiolarians and diatoms) precipitate slowly. (b) Early Archean hydrothermal field. White, alkaline hot water spouts from a chimney of silica. In the hydrothermal fluid–seawater mixing zone, iron ions in the seawater are oxidized by alkaline hydrothermal fluid. White silica precipitated directly from the hydrothermal fluid accumulates near the vent, and iron-oxides accumulate away from the vent.

Figure 3. Banded iron formation formed 3.2 billion years ago. The banded iron formation consists mainly of alternating white layers (silica) and reddish black layers (iron oxide).



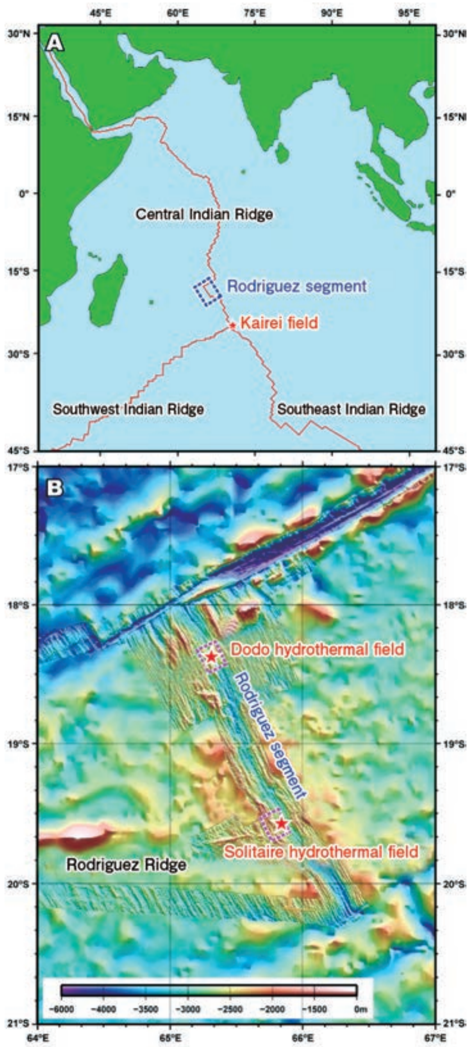


Figure 4. Location of the Dodo and Solitaire hydrothermal fields discovered in the Indian Ocean.

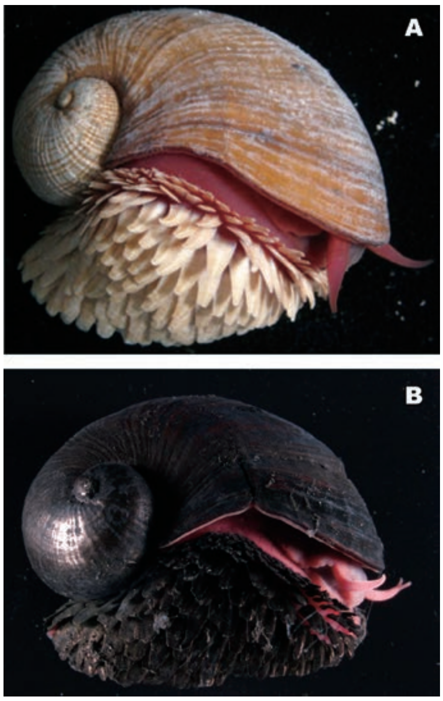


Figure 5. “White scaly-foot” newly discovered in the Solitaire hydrothermal field (A). It has while scales and shell in contrast to the only previously known “original scaly-foot” (B) in the ocean ridge hydrothermal fields.

Laboratory for Earth Systems Science - Space and Earth System Modeling Research Laboratory Unit

Overview

The environment and life on the surface of the Earth are always undergoing changes and evolution under the continuous influence of the Earth's interior and the universe. At the same time, the results of those changes and evolution have a significant impact on the changes in the Earth's interior. The objectives of the Space and Earth System Modeling Research Laboratory are to explore the future of the Earth by identifying and quantifying the intricate and multi-sphere interactions which include the universe, the surface of the Earth, and the Earth's interior. Through leading-edge numerical simulations, ultrahigh pressure experiments, and observational studies we aim to understand the activity of the present Earth and the mechanisms of large-scale global environmental changes in the history of the Earth.

Overview of the 2010 achievements

We are making progress in task-oriented research projects relating to coupled modeling of the universe and the surface of Earth, the surface of the Earth and the interior of the mantle, and the mantle and the core of the Earth, as illustrated in the figure below. One of the major achievements during the 2010 fiscal year was the successful reproduction by "Earth Simulator" of the complex process of the formation and development of clouds and precipitation by developing a "Super-Droplet Method (SDM)", a new calculation technique capable for accurately simulating cloud droplets and raindrops for the universe–Earth's surface coupled model, and linking it to an atmospheric circulation model. With respect to the coupled model of the Earth's surface and interior, we carried out a simulation of mantle convection involving igneous activities to investigate how changes in the internal heat source during the Earth's evolution would change the amount of water taken into the mantle. We learned from the simulation that the water which seeped into the lithosphere was released into the atmosphere by frequent eruptions of superheated materials which triggered large-scale volcanic activities and very little entered the mantle on the early Earth, while in the present mantle, the constant subduction of plates caused the sinking slabs to transport a large amount of water deep into the mantle. With respect to the mantle–core coupling, we measured the thermal diffusivity of $MgSiO_3$, a major mineral present in the lower mantle, in the perovskite phase under 300 000–1 100 000 atm to determine the rate of heat flow from the core to the mantle, and succeeded for the first time in the world by adapting a measurement technique called the thermo-reflectance method. The results of the measurements indicated that the heat conductivity of the lowermost part of the mantle was 50% larger than the previous estimates, suggesting the higher heat flux through the core-mantle boundary.

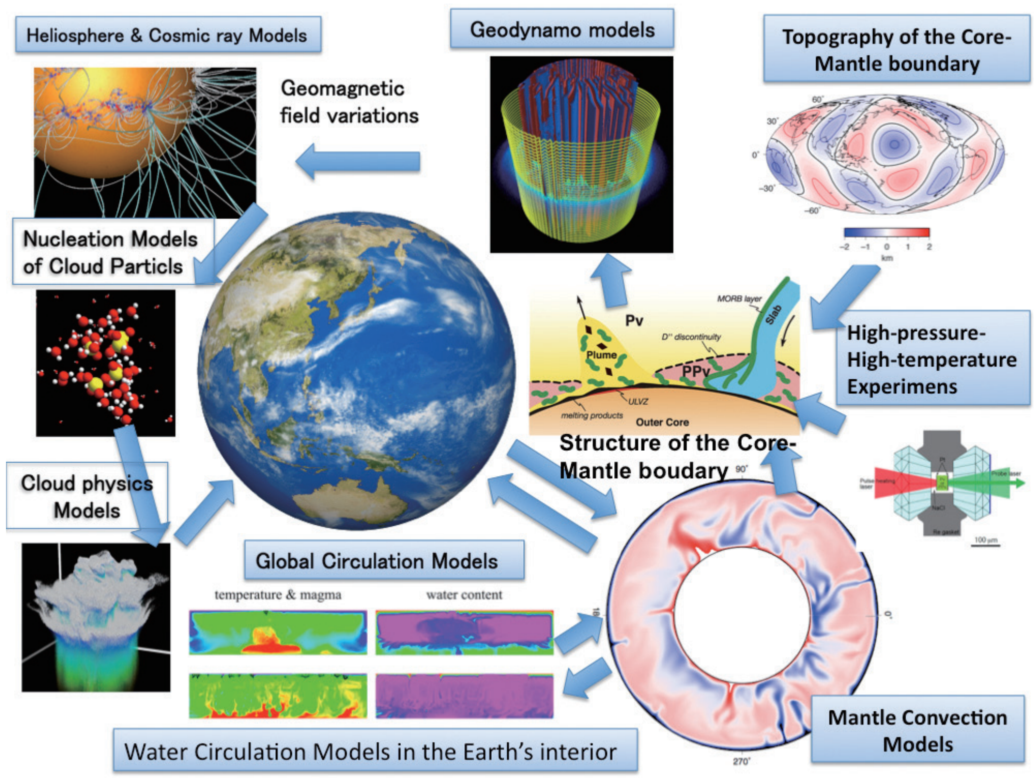


Figure 1. Correlation diagram of the research tasks undertaken by this laboratory in developing a correlational model of the universe, the Earth's surface, and the Earth's interior.

Application Laboratory (APL)

Outline

The Application Lab has the purpose of connecting research results directly to social contributions and realizing innovation by mutual enlightenment and sustained cooperation between research and society. At present, we aim to apply results from basic research in atmosphere-ocean science to society and deploy them widely to be used in society. These goals include: (1) prediction of climate change, changes in the ocean, and other changes, and provision and verification of related applied information as well as contribution to construction of the observation-prediction-verification system; (2) prediction of weather in the tropics and in the East Asia region using a global cloud-resolving atomospheric model, and provision and verification of related applied information; and (3) prediction of atmospheric chemistry changes using a tropospheric ozone diffusion model and provision and verification of related applied information.

The Application Lab is deploying joint research not only in Japan but also internationally by introducing competitive funds, and the lab is expanding its fields of activity. Below is a description of the results of a JST-JICA Science and Technology Research Partnership for Sustainable Development research project called “Prediction of Climate Variations and its Application in the Southern African Region,” which started in fiscal 2010, and an explanation of success in La Niña prediction.

The third meeting of the World Climate Conference, held in Geneva in August 2009, adopted a resolution statement to concretely apply climate change prediction to real society, which is known to have determined the formulation of the IPCC Report in the past. This is a very important theme that attracts worldwide attention. The worldwide deployment of this “climate service” is in line with the purpose of the Application Lab. The Application Lab so far has been leading the world in research on prediction of the Indian Ocean Dipole Mode and El Niño. We have started research and development to apply the results of this research to administrative and industrial activities such as agriculture and water management, not only in Japan but also in developing countries whose environment is fragile in the face of climate change (Fig. 1).

The JST-JICA Science and Technology Research Partnership for Sustainable Development project aims to “promote international joint research that is based on needs of developing countries, deals with global problems, and has a concept of future social implementation, in cooperation with Official Development Assistance (ODA), and acquire new knowledge leading to solving global problems and improving the levels of both science and technology” (excerpt from www.jst.go.jp/global). In this project, we promote research and development of prediction models for characteristic climate change in South Africa, research and development of community-based weather and climate change prediction models for Western Cape Province and Limpopo Province, and research and development of state-of-the-art models using Earth Simulator in cooperation with local researchers. In addition, with local agricultural experimental stations as well as the University of Pretoria and the University of Cape Town, we will distribute our predictions on local climate change to local residents and people concerned with agriculture. In addition to academic joint research, we are also holding lectures for students and mutual exchange of researchers, and supporting development of human resources. In fiscal 2010 we held the opening reception and symposium for joint research in South Africa in August, a symposium and workshop in Japan in December, and deployed aggressive research activities (Fig. 2). In March, we sent lecturers to the University of Pretoria and the University of Cape Town and held a lecture series. The Application Lab’s activities were also introduced at COP16, the United Nations Climate Change Conference held in Mexico in November 2010.

Through continuation of the predictability experiment by SINTEX-F models, which has been leading the world in prediction of climate change modes in the tropics, we correctly predicted that a state of El Niño would quickly change to a state of La Niña in the Pacific Ocean in the middle of 2010. The heat-storage effect of the Indian Ocean during the state of El Niño, and the state of grown La Niña, are considered to be the important factors that caused fierce heat in 2010. SINTEX-F models accurately predicted the development of La Niña (Fig. 3) and its effects, such as flooding in Brazil and Australia. This is epoch-making. We will continue to aggressively distribute information on these results domestically and outside Japan.

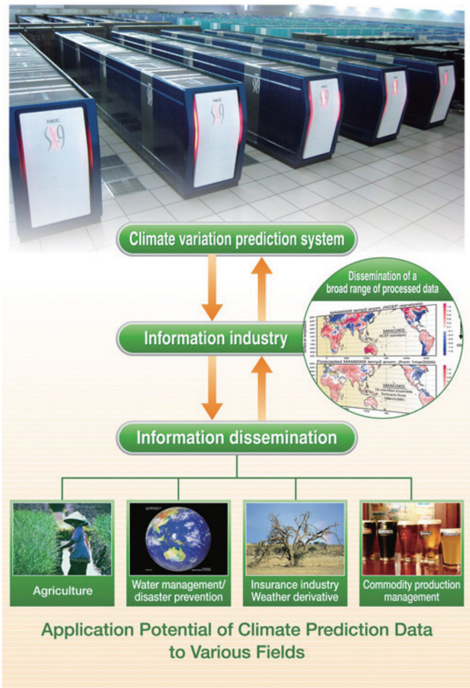


Figure 1. Applicability of climate prediction data to various fields.

Figure 2. Deployment of the JST-JICA Science and Technology Research Partnership for Sustainable Development project.

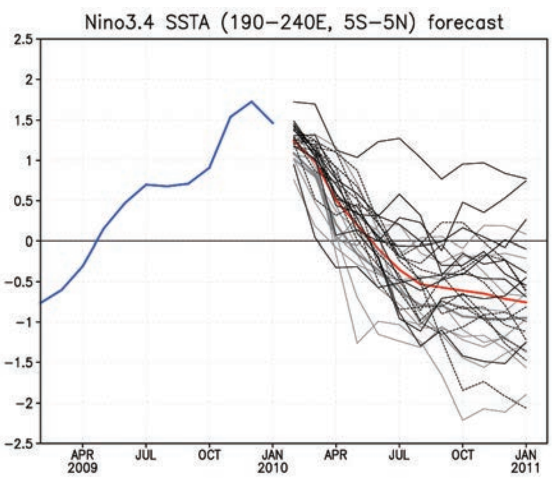


Figure 3. Success of La Niña prediction by SINTEX-F.
Prediction results of sea-surface temperature deviation in the Nino 3.4 region (5°S–5°N; 120°W–170°W) as of January 2010 (ensemble prediction February 2010–January 2011; red line indicates the mean value of prediction results).

Mutsu Institute for Oceanography (MIO)

Outline

The Mutsu Institute for Oceanography (MIO) started in October 1995 as the Mutsu Office of the Japan Marine Science and Technology Center, which was the predecessor of JAMSTEC. Later, in October 2000, the Mutsu Office became MIO. This year is the institute's tenth. MIO started as the home port and observation support base of the oceanographic research vessel *Mirai*, which was converted from the nuclear-powered experimental ship *Mutsu*. After improving its facilities and equipment, MIO's role became that of a research institute to understand global environment changes of the past and to clarify bio-geochemical cycle as a basis for the global environment changes of recent years.

Even after transitioning from an office to a research institute, the most important role of MIO is to support various kinds of research carried out by the *Mirai*. We conduct maintenance on large observation devices such as the TRITON buoys used by the *Mirai*. And as the home port of the *Mirai*, we handle the various kinds of coordination necessary for port entry and departure, provide a variety of support for on-board researchers, and more.

Research at MIO has changed somewhat with the times. We are continuing to work on the North Pacific Time-series Observation Research, which has been the core of research on global bio-geochemical change, with the *Mirai* used as the platform. In the North Pacific Time-series Observation Research, we have been conducting observations one or more times each year to accumulate data with the purpose of clarifying the change in carbon dioxide absorption and interannual changes in vertically transported chemicals in the subarctic zone of the North Pacific Ocean. We are also trying to find new methods for effectively carrying out time-series observation research. Until March 2010, we had been developing an ocean-drifting carbon dioxide sensor for the earth observation technology research project commissioned by MEXT.

It has become known that the increase of carbon dioxide in the atmosphere has an impact not only on environmental change in open sea areas but also on environmental change in coastal areas, and it greatly affects marine biological resources. The Tsugaru Strait is one of venerable area in the climate change. Taking advantage of its location near the Tsugaru Strait, and in cooperation with concerned people engaging in fisheries around MIO as well as the Faculty of Fisheries Sciences of Hokkaido University, we at MIO are preparing for advancing time-series observation research on a coastal area.

We are also conducting activities to disseminate and utilize research results from activities of the *Mirai* and other vessels along with recent developments in oceanographic research, in cooperation with relevant organizations in the Mutsu-Shimokita area and the rest of Aomori Prefecture. Specifically in 2010, we held the MIO 10th Anniversary Commemorative Ceremony and many other events, including opening the *Mirai* and MIO's facilities to the public and holding symposia, and we were visited by many people (Fig. 1).

Figure 1. A scene from the MIO 10th Anniversary Commemorative Ceremony, November 21, 2010.

Achievements in Fiscal 2010

North Pacific Time-series Observation Research

The final goal of the North Pacific Time-series Observation Research project is to understand through observation the material cycle in the subarctic zone of the western North Pacific Ocean and to clarify changes in the bio-geochemical cycle and/or environment corresponding to global warming. For this, we need to acquire continuous data and publish it. In Japan, other than the Meteorological Agency and the Meteorological Research Institute, no one has much long-term observation data on the ocean, particularly regarding chemical substances, and there is not enough data to understand the bio-geochemical cycle and its changes. Continuous data from the subarctic zone of the North Pacific also becomes important when considering future marine biological resources.

Since 1999 MIO has been collecting data on carbon dioxide in the ocean at a time-series observing station in the subarctic zone of the western North Pacific Ocean (Station K2, 47°N, 160°E). We organized and released the data from the Carbon Dioxide Information Analysis Center (CDIAC) and JAMSTEC. In fiscal 2010 we reviewed the observation data, added corrections and new data, and released it again. In addition, we organized and evaluated observation data obtained since 1992 from observing station KNOT (44°N, 155°E), where intensive observation was conducted in the late 1990s as a time-series observing station in Japan. We released this data to be used for assessing change in the environment near the surface layer (CDIAC, http://cdiac.ornl.gov/oceans/Moorings/KNOT.html). In the North Pacific Time-series Observation Research project, we also obtained data relating to bio-geochamical cycle, such as data on chemical components of particle collected by the sediment traps and primary production. We are ready to release this data in succession.

Evaluation of observation data clearly showed that the amount of carbon dioxide transported from the ocean to the atmosphere in winter is decreasing in the subarctic zone of the western North Pacific. As shown in Fig. 2, the partial pressure of carbon dioxide in the surface layer of the subarctic western North Pacific is different from that of the subtropical zone, where it fluctuates under the large influence of surface water temperature, such as at the time-series observing station BATS off Bermuda in the North Atlantic Ocean. In winter, because of vertical mixing, the partial pressure of carbon dioxide is higher in the ocean than in the atmosphere, and carbon dioxide is transported from the ocean to the atmosphere. In summer, growing phytoplankton fix carbon dioxide, which lowers the partial pressure of carbon dioxide, and carbon dioxide is transported from the atmosphere to the ocean. However, gas exchange between ocean and atmosphere is more effectively according the stormy weather. Then, carbon dioxide transport in winter is more important for an annual total gas transport. Therefore, it is important to estimate the winter status from observation data and consider its interannual change.

From observation data in different seasons, we estimated the partial pressure of carbon dioxide in the mixed layer in winter. Fig. 3 shows its interannual change. Compared with the yearly increasing rate in the atmosphere, that of carbon dioxide partial pressure in the mixed layer is small. This shows that the carbon dioxide that is released from ocean to atmosphere is decreasing. This is consistent with the fact that the amount remaining in the ocean is increasing. It is expected that this trend will continue until around 2017, and subarctic western North Pacific will absorb carbon dioxide from the atmosphere throughout the year, similar to the middle-latitude Pacific Ocean. The decreasing pH trend of the surface-layer water—ocean acidification—is smaller than that at the time-series observing stations BATS off Bermuda and ALHA off Hawaii. It is supposed that the influence of acidification is not larger than in other sea areas at present.

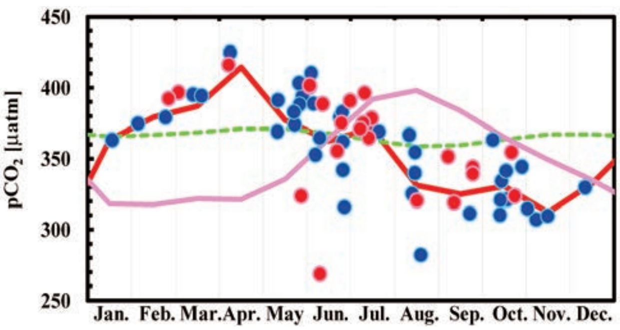


Figure 2. Seasonal change in the carbon dioxide partial pressure in surface-layer water of the subarctic western North Pacific.
Red dot: carbon dioxide partial pressure observed at station K2.
Blue dot: carbon dioxide partial pressure at station KNOT.
Red solid line: mean value of carbon dioxide partial pressures at stations K2 and KNOT.
Pink solid line: mean value of carbon dioxide partial pressures at the BATS.
Green broken line: seasonal change of the carbon dioxide partial pressure in the atmosphere. (Takahashi 2009)

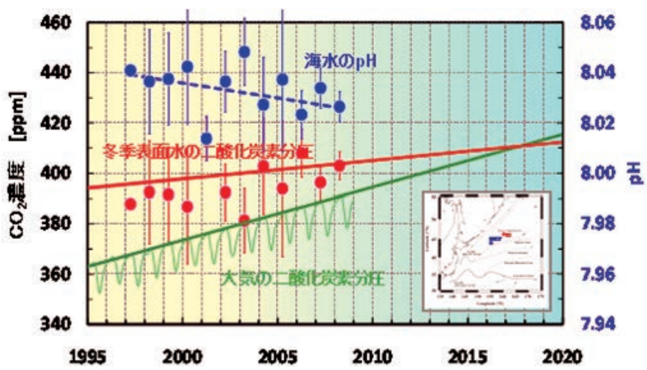


Figure 3. Interannual change in the carbon dioxide partial pressure in surface-layer water of the subarctic western North Pacific.
Red dot: change in the carbon dioxide partial pressure in the winter mixed layer, estimated from stations K2 and KNOT.
Blue dot: change in the pH in the winter mixed layer, estimated from stations K2 and KNOT.
Green line: change in the carbon dioxide partial pressure in the atmosphere observed at Ryori.

Technology Development at MIO

We developed a carbon dioxide sensor as a research theme of the earth observation technology research project commissioned by MEXT that finished at the end of March 2010. The sensor finally satisfies the following specifications and is durable enough for observations (Fig. 4).

Specifications of the CO_2 sensor developed

- Size: 340 × 450 mm
- Weight: about 15 kg
- Precision: <2 μatm
- Sensitivity: <1 μatm
- Service life: about 1 year
- Observation frequency: 3-day interval, 4 times measurements during 1 day
- Other: able to use solar cells

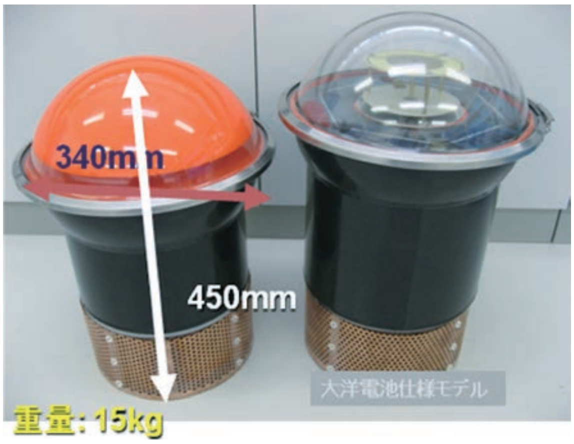


Figure 4. Appearance of the drifting carbon dioxide sensors developed at MIO.
Left: ordinary use type; Right: solar cell–equipped type.

Tsugaru Strait Coastal Area Observation Research

For new development of time-series observation research and wider application of results from research on environmental change, MIO is planning observation research on environmental changes in coastal areas and is preparing implementation in cooperation with the Faculty of Fisheries Sciences of Hokkaido University and other organizations.

Warming and ocean acidification due to increased carbon dioxide have significantly greater impact on coastal areas than on the open sea, and both are thought to have large impacts on useful ocean biological resources related to fisheries and other activities. The Tsugaru Strait side of the Shimokita Peninsula, where MIO is located, is mostly occupied with warm Tsugaru Current water, but it also receives influence from the Oyashio Current. Thus our guess is that this sea area is highly vulnerable to environmental changes (Fig. 5).

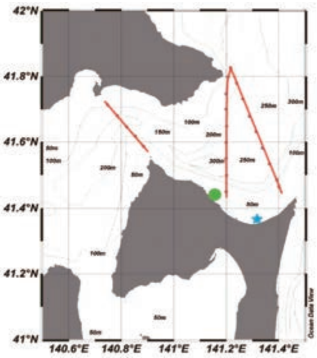


Figure 5. Map of the MIO area and observing stations.
Blue star: MIO and Sekinehama Port.
Green dot: site of a nature observation event (Chijirihama, Mutsu City).
Red line: ocean observation line conducted in cooperation with the Faculty of Fisheries Sciences of Hokkaido University.

MIO has been measuring water temperatures at Sekinehama Port since 2002 in cooperation with the Aomori Prefectural Fisheries Research Center (now the Fisheries Research Institute of the local independent administrative agency Aomori Prefectural Industrial Technology Research Center). Also, in cooperation with nearby fishing cooperative associations, MIO is measuring the vertical distribution of water temperatures at places where the water depth is about 20 m. Fig. 6 shows the seasonal change in surface water temperature in Sekinehama Port. It was about 6°C in February and 22°C in August and September, showing seasonal changes. In 2010, from winter to spring, the temperature tended to be lower than in an ordinary year. In September, however, it was 26°C, several degrees higher than in an ordinary year. High seawater temperatures were also observed in Sekinehama in almost the same period as the period that brought widespread damage to the fisheries in Mutsu Bay.

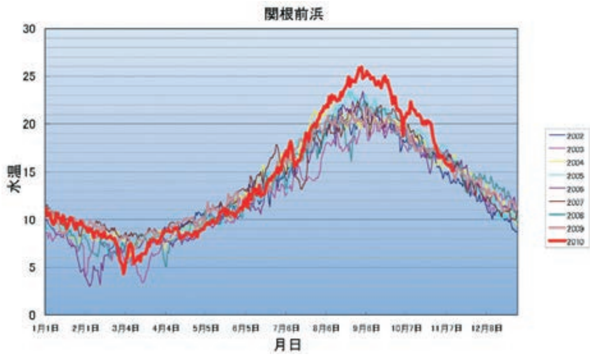


Figure 6. Seasonal change in surface water temperature in Sekinehama Port, Mutsu City.
August–October 2010 (red line), water temperatures were higher than in an ordinary year. They agree with the high temperatures observed in Mutsu Bay.

To see the interannual change in water temperature, we obtained the deviation from the monthly average (Fig. 7). Although some of the most recent eight years had remarkably low temperatures, the general trend is that low temperatures appear less frequently year by year since observations began; the temperature is getting higher. This trend may be related to global warming.

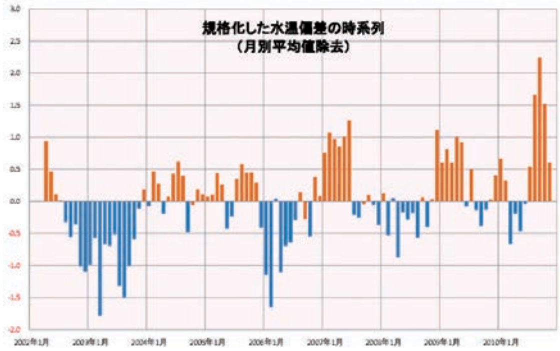


Figure 7. Time-series of seawater temperature deviation, standardized by subtracting monthly average.

In November 2009 we began cross-sectional observation of the eastern Tsugaru strait using the *Ushio-maru*, the training ship of the Faculty of Fisheries Sciences of Hokkaido University. These observations are for obtaining the basic hydrographic condition before carrying out long term observation on the coast of Tsugaru Strait. In Tsugaru Strait, not much observation has been done so far, possibly because it is difficult to do.

Fig. 8 shows cross-sectional distributions of salinity and temperature at the eastern Tsugaru strait. In November, salinity is generally high, and Tsugaru Warm Current water occupies the bay. In February, salinity slightly decreases, and temperature also drops, with the influence of the cold Coastal Oyashio Current water. In May, its influence is remarkable, and in July, the Tsugaru Warm Current water is observed in south area.

To assess the environment of the eastern mouth of Tsugaru Strait, observe the change in distribution of seashore organisms, and reveal its relationship with environmental change, we started a citizen-participant survey of seashore organism distribution at Chijirihama, Mutsu City, in September 2010 (Fig. 9). We plan to continue the organism distribution survey along with environmental measuring of Tsugaru Strait.

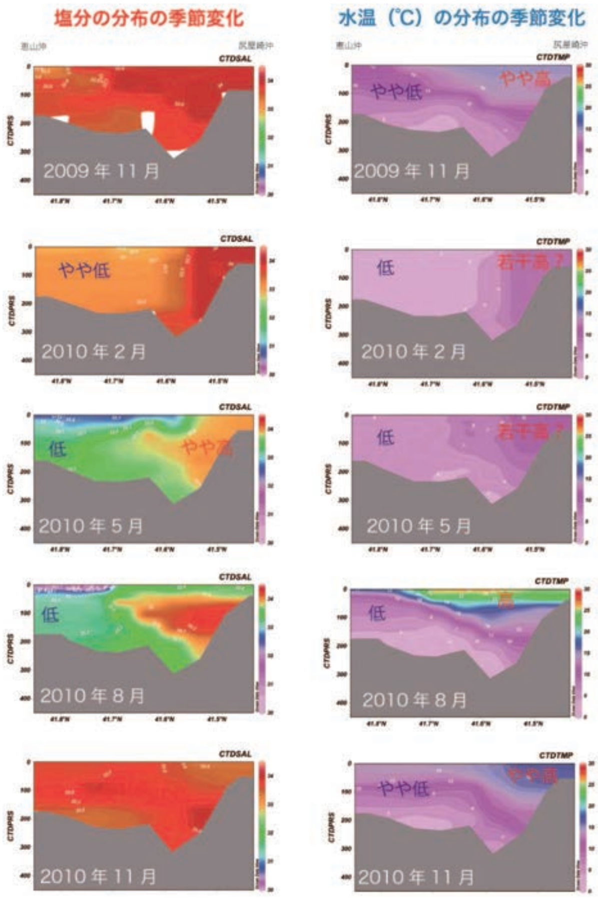


Figure 8. Cross-sectional distribution of salinity (left row) and temperature (right row) observed in the eastern Tsugaru strait. From top, cross-sectional distributions in November 2009, February, May, August, and November 2010.

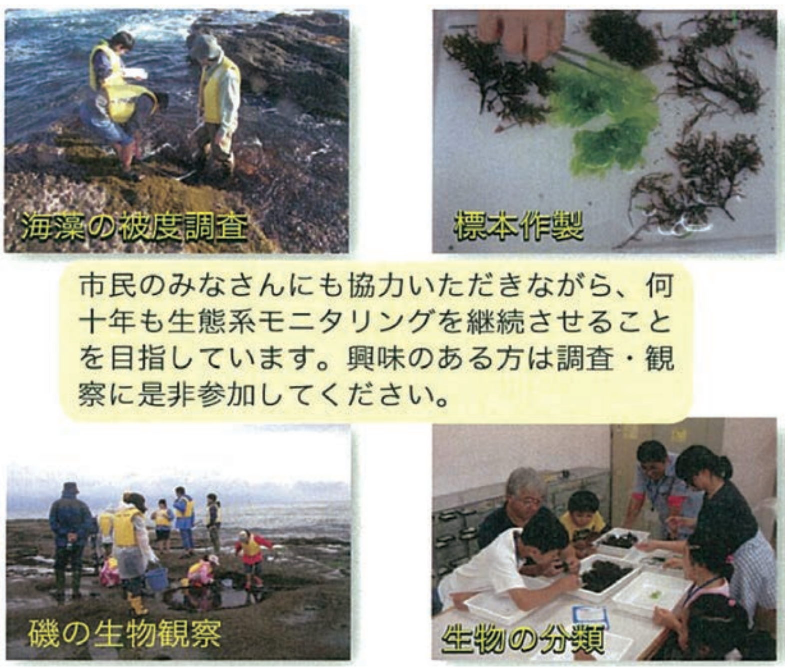


Figure 9. Scenes from the citizen-participant seashore observation event at Chijirihama, Mutsu City; from a poster of the MIO 10th Anniversary Open House.

Kochi Institute for Core Sample Research (KOCHI)

Overview

World class center for studies of core samples

The Kochi Institute for Core Sample Research is the fifth research center of JAMSTEC. KOCHI provides core curation services as one of the world's three core repositories under the Integrated Ocean Drilling Program (IODP), and plays a pivotal role as a center for scientific drilling through the processes of analysis, study, and safekeeping of the core samples. In addition, we present the outcomes of our research efforts to local citizens by holding open house events at our facility and visiting elementary schools to give lectures which provide opportunities to raise interest in science.

Physical Property Research Group

Aiming at understanding the mechanisms that trigger the Nankai–To-Nankai earthquakes

We measure the frictional property and hydraulic characteristics of the fault zone that controls seismogenic faulting and the rock in the surrounding area (Fig. 1) using the core samples collected under the IODP Nankai Drilling Project. We are also working on the development of devices for the measurement of various petrophysical properties in the deep subterranean environment which affect seismic behavior.

We have been participating in *D/V Chikyu* Voyage 319 under the IODP Nankai Drilling Project since the previous fiscal year, and we are trying to determine the stress conditions within the strata by using borehole experiments and core samples to their full extent. This year, our post-cruise study successfully explained how the stress conditions change according to changes in the strata (Fig. 2).

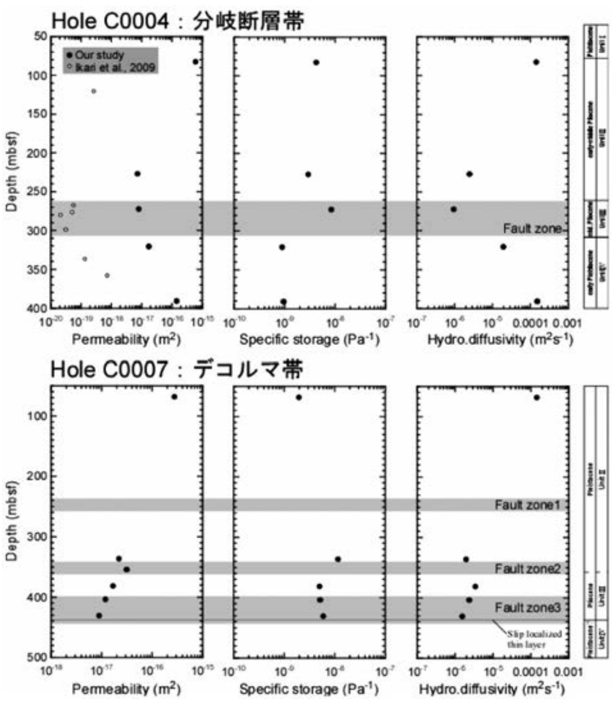


Figure 1. Hydraulic structure of the shallow part of the Nankai Trough estimated by using the Nankai drilling core samples. The samples revealed that the water permeability of the fault zone was low in both the branch fault zone and decollement zone. In the branch fault zone, it was lower than in the surrounding rock. In the decollement zone, the permeability decreased as the depth increased. This permeability structure of the fault zone suggests that high pore water pressure is maintained near the fault zone.

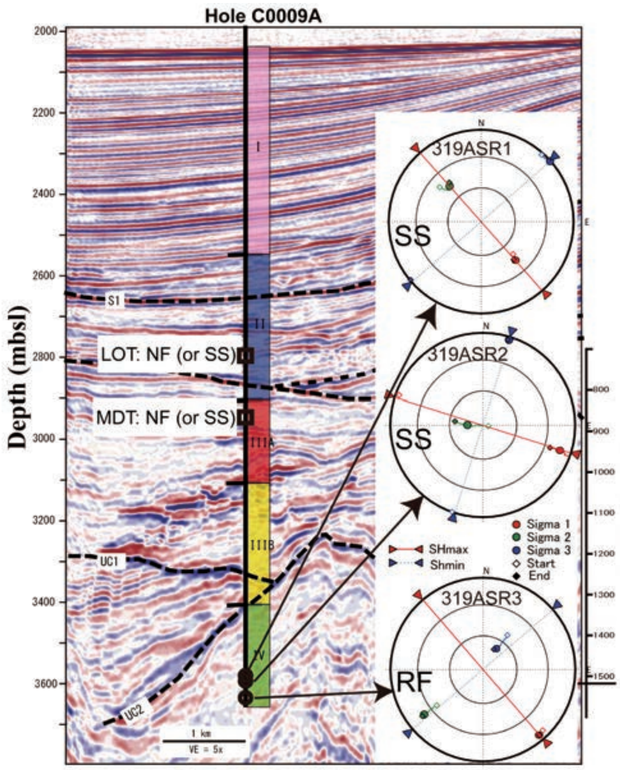


Figure 2. Measurement of anelastic strain recovery (ASR) using the core samples collected by the drilling of Site C0009 located immediately above the massive earthquake zone in the Nankai Trough indicated that the stress conditions were different in the cover sediment and the accretionary prism (Fig. 2; Lin et al., 2010, AGU).

Geochemical Research Group

Using magnesium isotopes to study the mechanism by which marine organisms generate their carbonate skeletons

Carbonate used in the formation of the skeletons of marine organisms often indicates the biological effects of magnesium isotopes which are lighter than seawater. In the case of deep-sea coral and large foraminifera which form their skeletons using high magnesium calcite, a high-precision isotopic analysis has suggested a strong possibility that they build their carbonate skeletons by a method similar to inorganic precipitation (Fig. 3).

Detection of high temperature water–rock interaction in a seismic fault

Hot water (fluid) facilitates fault slip during an earthquake, and is believed to be a factor in the generation of tsunami. We are developing a technique which evaluates whether a high-temperature fluid was generated in seismic faults during their past active periods based on changes in chemical composition of fault rock. Our analysis is beginning to confirm the history of the generation of high-temperature fluid in faults within the accretionary prism of propagating fault slips in massive seismic events (Fig. 4).

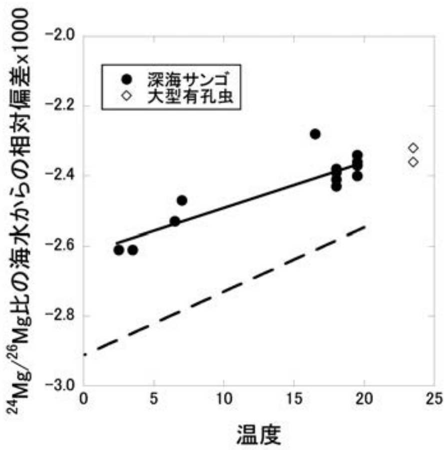


Figure 3. Relationship between magnesium isotopic ratio in deep-sea coral and large foraminifera and growth temperature (solid line). Regardless of their species or growth rates, the temperature dependency pattern resembles the inorganic precipitation of high magnesium calcite (dotted line).

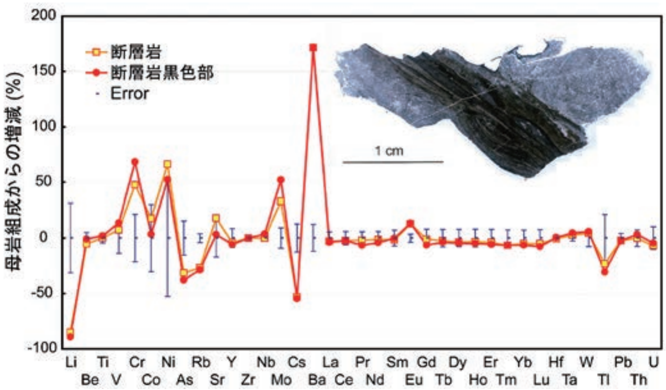


Figure 4. Microscope image and the results of analysis of fault rock in the Emi accretionary prism in Boso Peninsula. Decreases in lithium (Li) and cesium (Cs) indicate the generation of hot water at temperatures of 350°C or higher during the earthquake. A similar event may occur in the current Nankai accretionary prism.

Geomicrobiology Group

IODP Expeditions – Is there life at the “end of the world”?

The Geomicrobiology Group is carrying out an investigation of the subseafloor biosphere in the center of the South Pacific Gyre which is the farthest point from any land on the Earth and where the seawater has the highest transparency in the world. How does the biosphere look beneath the floor of the ocean where the basic photosynthetic production in the surface seawater is the lowest on Earth? In order to answer this question, we are carrying out studies on the existence and evolution of life at the “end of the world”. We are studying the functions of unknown life forms and their role in the environment of the Earth by using the most advanced research techniques, such as the measurement of microbial volume in the core samples by using our proprietary life form detection and quantification system, understanding of life functions by a supersensitive high-precision analytical technique which integrates isotopic geochemistry and molecular biology, and single-cell biology which makes genomic and isotopic study of a single cell possible.

IODP Exp. 337: Drilling survey of the biosphere of the deep coal bed off Shimokita Peninsula — Understanding of hydrocarbon cycle and biological activities supported by subseafloor coal bed and a practical study of geobiology

Organic matter buried beneath the sea floor is believed to be decomposed by the heat and pressure of the ground and play a considerable role in the production of energy sources, such as petroleum and natural gas. The researchers in the Geomicrobiology Group carry out leading-edge studies of the subseafloor biosphere to understand the relationship between the 50 million-year-old deep lignite layer and natural gas and methane hydrate in the surface layer as well as subseafloor microbiological actions relating to the decomposition of organic matter. These studies include drilling the sea floor about 80 km off the coast of Shimokita Peninsula more than 2200 m deep, a world record in scientific ocean drilling, by *D/V Chikyu*. These studies form part of the "Promotion of the state-of-the-art study of Life and Earth Sciences with Facilities of the Subseafloor Simulation Laboratory and *Chikyu*" supported by the funding program for leading-edge research and development of the Japan Society for the Promotion of Science (JSPS) for fiscal years 2010–2011. We also carry out reaction experiments for the "CO_2–minerals–life" interactions under conditions that represent the actual subseafloor environment for a geobiotechnological study of energy-recycling/carbon sequestration in the strata by subseafloor microorganisms and the carbon cycle (Bio-CCS Plan).

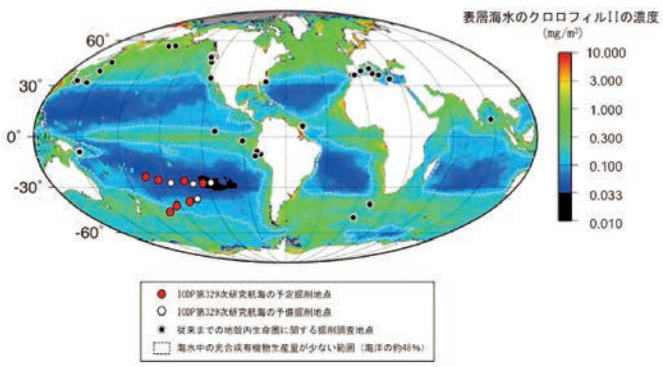


Figure 5. Drilling sites in the South Pacific Gyre planned for IODP Expedition No. 329, and the past drilling sites in the continental coast for crustal biosphere research.

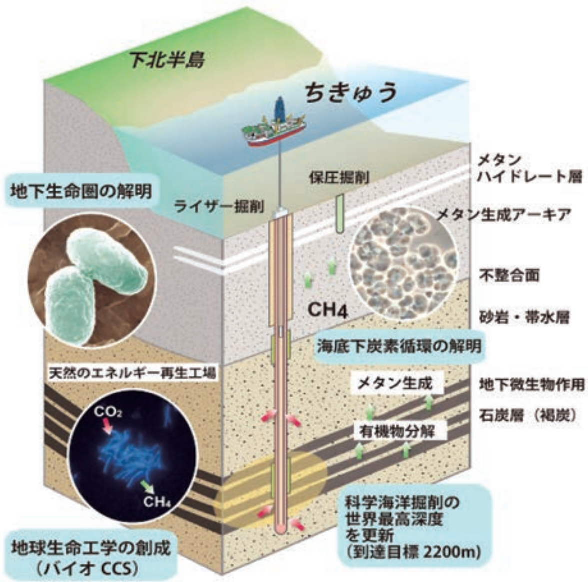


Figure 6. Outline of the IODP drilling survey of the biosphere in the coal bed off Shimokita Peninsula under the JSPS funding program for leading-edge research and development

Science Services Group

The Science Services Group provides services to KOCHI and other research organizations inside and outside Japan in three areas.

Research support and technological development

We provide support services to meet the needs of researchers at KOCHI as well as other research organizations inside and outside Japan. Our support services range from a series of processes from pre-treatment and preparation of specimens through to measurement and data analysis in fields including physics, chemistry and microbiology.

We assist the Physical Property Research Group by carrying out experiments on fast fracture slips and measurements of physical properties, such as thermal conductivity and porosity; the Geochemical Research Group through the standardization of established techniques for the measurement of boron isotopes in carbonates and the development of new measurement methods; and the Geomicrobiology Group through the development of techniques for cell count of microorganisms in subseafloor sediment with enhanced accuracy and sensitivity and the alkaline solution-extraction of DNA from subseafloor microorganisms. The results of these activities are published through scientific societies.

Our outreach program provides lecturers to seminars of the science group of the Kochi Prefectural High School Education Association. We also developed a route map through Aki, Kisei and Naka-Tosa to assist field studies. Our staff act as lecturers at the Core Analysis School which we host every year.

JAMSTEC core curation

The core samples of JAMSTEC are a collection mainly of piston cores from the Pacific Ocean including the sea near Japan. This is the largest seafloor core sample collection after the IODP collection in Japan and is available for use by researchers and educators. The JAMSTEC Core Curation Team is currently carrying out an analysis and examination of data so as to make microfossil dating information of the core samples available online to users of the samples.

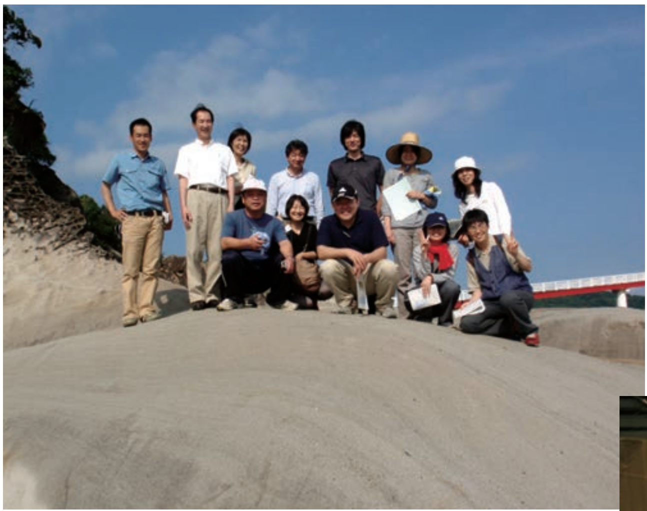


Figure 7. An excursion with the science group of the Kochi Prefectural High School Education Association

IODP core curation

From the core samples collected by the Bering Sea Drilling project in December 2009, we gathered a total of 53 000 samples, the largest landed samples from a single voyage, and delivered them to researchers in nine countries. We also created the Virtual Core Library to make the X-ray CT scan image files taken onboard *D/V Chikyu* accessible via our website (www.kochi-core.jp/VCL/). In addition, for the rapidly advancing field of subseafloor biosphere research, we started the storage and control of samples collected onboard (routine microbiological samples [RMS]) and maintain them under very low temperatures (–80°C and –160°C) and in an environment protected from external contamination.

Figure 8. The core samples of JAMSTEC which had been stored at its Yokosuka Headquarters and Mutsu Laboratory are consolidated at the Kochi Core Center where they are prepared to be made available for use by scientists and educators.

Figure 9. RMS being lowered into the special freezer tank (set to –160°C) for storage.

Marine Technology and Engineering Center (MARITEC)

Summary

MARITEC conducts research and development in advanced technology relating to the ocean; support for research, such as the operation, administration, and functional improvement of research ships, marine observation systems, and facilities; and activities for training experts.

Topics of Fiscal 2010 Outcomes

Advanced Marine Technology

The elemental technology has been researched and developed for the Next-generation Autonomous Underwater Vehicle (Fig. 1), which can cruise autonomously for a long time over a long distance. It will be utilized for resource exploration, such as investigating hydrothermal deposits with resource mapping equipment. In fiscal 2010, using the marine robot *MR-X1* as a test vehicle in the sea, tests were conducted of a lithium-ion battery as a power source with a capacity 1.7 times that of a conventional product; an inertial navigation system half the size of a conventional product; a space-distributed CPU system that actualizes increased system performance by reducing CPU load; and a high-performance imaging system that actualizes measurement with 3-D stereo views. The effectiveness of these systems was confirmed by these tests.

A long-range transmission test of a communication system was successfully conducted in the sea over a horizontal distance of 1,000 m using Time Reversal Acoustic Communication. Short-range transmission tests, with a horizontal distance of 800 m at a speed of 80 kbps and 600 m at 120 kbps, were also conducted successfully. By applying the developed underlying technologies, MARITEC aims to build the Next-generation Autonomous Underwater Vehicle.

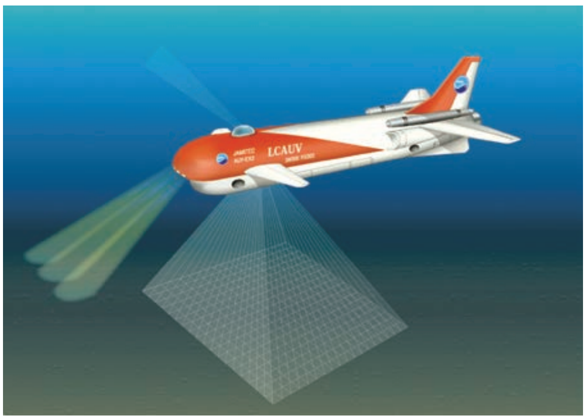


Figure 1. The Next-generation Autonomous Underwater Vehicle

The elemental technology for the High-performance Remotely Operated Vehicle (Fig. 2), which can do high-precision heavy work such as seabed investigation at great water depths of 7,000 m or more, has been researched and developed. In fiscal 2010, tests were conducted in the sea of high-strength lightweight cable to connect the vehicle to its support vessel; a rotary joint for fiber-optic communication that will be used to rotate the cable drum in the water; and a flipper-thruster crawler system for propulsion. The effectiveness of these systems was confirmed by these tests. A new mechanical hand was designed as a work manipulator, and a prototype model of an all-around image system for imaging technology was built. By applying these developed underlying technologies, MARITEC now aims to build the High-performance Remotely Operated Vehicle.

Figure 2. High-performance Remotely Operated Vehicle

Advanced fundamental technology necessary for marine observation and next-generation investigation has been researched and developed. A transmission test was conducted in the sea to send HDTV images taken by the *MR-X1* in the deep sea to JAXA’s Tsukuba Space Center via the Kizuna satellite in real time (Fig. 3). New structural materials utilizing carbon fiber–metal composites or ceramics for observation equipment to be used under or over 7,000 m depth and in cool-temperature circumstances have been designed. A system to conduct measurements and independent on-the-spot decision-making has also been developed.

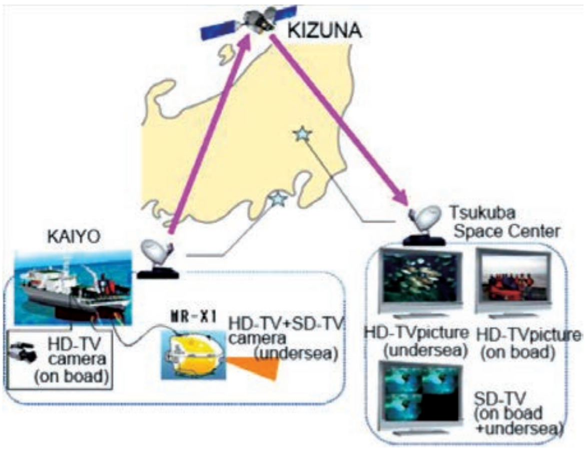


Figure 3. Transmitting HDTV test pictures via satellite.

Cooperation in Operating Ships for Academic Research

The research vessels *Hakuho-Maru* and *Tansei-Maru*, which were transferred from the Atmosphere and Ocean Research Institute of the University of Tokyo in 2004, have been operated and managed on the base plans made by the Cooperative Research Vessels Steering Committee.

In 2010 the *Hakuho-Maru* was at sea for 299 days, including cruises in the Indian Ocean and through the Antarctic Ocean to the Timor Sea. The *Tansei-Maru* carried out 286 days of cruises. MARITEC has also supported observations on these research vessels by placing marine technicians aboard.

Providing Research Vessels and the Deep-sea Investigation System

The research vessels *Natsushima, Kaiyo, Yokosuka, Kairei*, and *Mirai* have been operated and managed based on the plans for research and development to be carried out by JAMSTEC as well as the plans for research topics collected from the public by the Ocean Research Promotion Committee of External Experts. For operations, MARITEC has carried out the necessary coordination with people involved in fisheries, and has also coordinated to acquire permission to do research within other countries' exclusive economic zones. Also, commissioned cruises with external funding have been conducted, and open-house events and educational-experience cruises for outreach were provided. Further, as part of urgent investigations into the 2011 Great East Japan Earthquake off the Pacific coast, MARITEC set up seismographs in the hypocenter area, and conducted monitoring in the Soma offshore region.

Achievement report meetings are also held every year. In March of fiscal 2010, the Blue Earth '11 event and a symposium were held celebrating 20 years of the *Shinkai 6500's* commission.

In fiscal 2010, the *Natsushima* carried out 274 days of cruises, the *Kaiyo* 244 days, the *Yokosuka* 277 days, the *Kairei* 284 days, and the *Mirai* 296 days, including cruises to the Antarctic Ocean (Fig. 4).

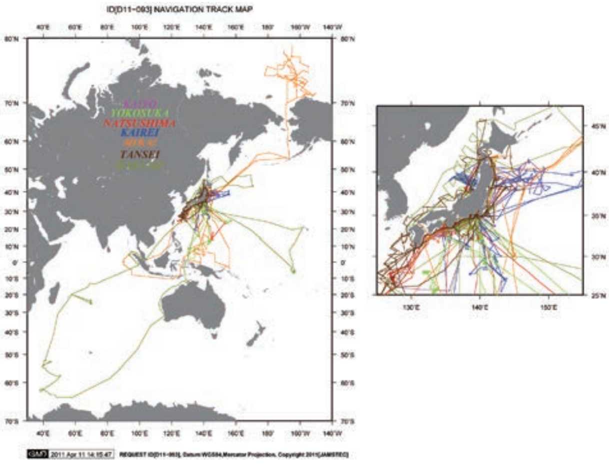


Figure 4. Cruise tracks in fiscal 2010.

Manned research submersibles and unmanned vehicles have been operated and undergone functional improvements (Fig. 5). In fiscal 2010, the manned research submersible *Shinkai 6500* and the remotely operated vehicles *Hyper-Dolphin* and *Kaiko 7000-II* were operated based on plans for research topics collected from the public. The *Hyper-Dolphin* did wiring work for Do-Net at Kumano-Nada off the Kii Peninsula. Improvements were made to the *Shinkai 6500*, such as exchanging propulsion-system equipment and equipment in the pressure-resistant shell.

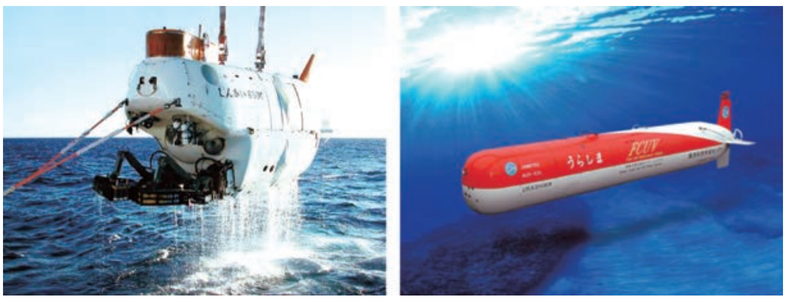


Figure 5. Left: the *Shinkai 6500*; right: the *Urashima*.

The international surface buoy array, which monitors conditions in the atmosphere and the ocean, has been deployed to understand the mechanisms of El Niño–La Niña and dipole phenomena that cause abnormal weather. Fifteen TRITON buoys have been deployed in the Pacific Ocean, and three m-TRITON buoys—a small, light type of TRITON buoy—have been deployed in the Indian Ocean (Fig. 6). Data from these buoys have been published on the Internet.

A buoy system for the Southern Ocean near Antarctica has also been developed, and test mooring offshore at Muroto-Misaki in Hokkaido was conducted until February 2011.

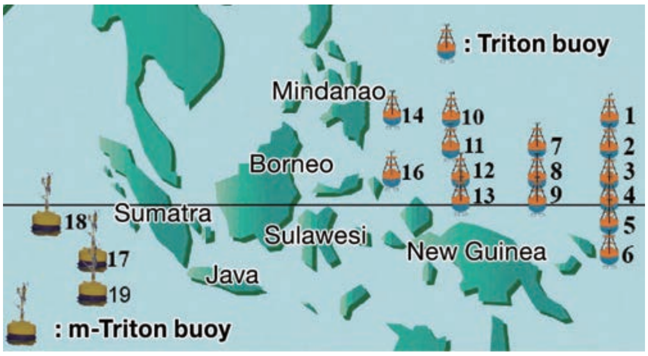


Figure 6. Deployment of m-TRITON and TRITON buoys.

Improvement of training and Qualifications of researchers and technicians

Training was carried out for divers doing external dives and water-escape by helicopter for people who will be on board the deep-sea drilling vessel *Chikyu*, as well as technical training for support technicians at Kaiyogi-jyuku and sea safety training for on-board researchers (Fig. 7).


Figure 7. Upper left: divers training; upper right: water-escape by helicopter training; lower left: Kaiyogi-jyuku; lower right: sea safety training.

Earth Simulator Center (ESC)

The Earth Simulator

The Earth Simulator was rated in first place in the Top 500 Supercomputer Rankings for two and a half years from the start of its operation in 2002, and it has significantly contributed to development in earth science and technology and related fields. In March 2009 the Earth Simulator was updated to a new system. Due to its theoretical peak performance of 131 TFLOPS (1 teraFLOP is one million million floating operations per second) and highly effective performance, it has been used extensively in research and development as well as industrial applications centering on the field of marine-earth science and technology, including climate change and global warming, in which a wide variety of physical phenomena are intertwined with a high degree of complexity. By improving the program run environment, the Earth Simulator exceeded last year's performance measurement result in the HPC Challenge Award, recorded 11.88 TFLOPS on the benchmark Global FFT (total performance of fast Fourier transform) category, and gained first position in the world. This result exceeded the performance of 10.70 TFLOPS of the Oak Ridge National Laboratory's Jaguar, which has 17.8 times higher theoretical peak performance. The Earth Simulator was also awarded the third prize, as it was last year, in the EP STREAM (Triad) per system category, a measure of memory access speed at multiple loads.

Figure 1. Earth Simulator.

Multiscale Simulation and Modeling Research

Global weather and climate systems consist of the atmosphere, the oceans, land, sea ice, and the ecosystem along with chemical substances emitted by human activities and their complex interactions. The Multiscale Modeling Research Group is working on developing a model to view such complex mechanisms composed of various space-time scales phenomena, which will enable us to predict seamlessly a wide range of phenomena from the weather to climate variability. This model is the Multiscale Simulator for the Geoenvironment (MSSG, pronounced "message"). In order to clarify how climate variability such as El Niño affects the Japan region or urban regions within Japan, we need to simulate globally and on the city scale at the same time. To do this, we need to advance the model, and concurrently research and develop new algorithms and parallel computation techniques to make the most of the Earth Simulator. MSSG is a nonstatic coupled atmosphere, ocean, land, and sea ice model that can resolve cloud activity. It is being further developed toward higher precision for the purpose of directly contributing to society by predicting very detailed weather with its downscaling techniques and applying the predictions to adjustment steps for warming.

Figure 2. Three-dimensional temperature distribution in a simulation by MSSG with a 5-m horizontal resolution of the conditions of the atmosphere on the periphery of Yuraku-cho, Tokyo, at 15:00 on August 5, 2005. It is expected to be applied for elucidation of the mechanism of the heat-island phenomena, proposals on adaptive measures for cooling urban areas, and quantitative evaluation of effects.

Figure 3. Elucidation and modeling of the production process of clouds is one of the themes of MSSG's model development, because it affects rainfall prediction. In MSSG, individual droplets making up the cloud and their phase changes are modeled, in which collisions of droplets are taken into consideration. This figure is a snapshot results of clouds and rainbow reproduced by simulation using MSSG.

Advanced Visualization and Perception Research

Scientific visualization that represents simulation data graphically is an essential means to understand a simulation visually. Visualization techniques are required to make progress to keep pace with simulation techniques, like two wheels working together. The Advanced Visualization and Perception Research Group is working on research into advanced visualization techniques, including large-scale parallel visualization, virtual-reality visualization (Fig. 4), visualization representation techniques, and smart visualization (Fig. 5) in order to quickly visualize enormous amount of data obtained by large-scale simulations using the Earth Simulator as well as to efficiently extract useful information from them.

Figure 4. Three-dimensional visualization in a geodynamo simulation by the BRAVE virtual-reality visualization system. Faster processing for realizing real-time isosurface reconstruction was accomplished by combining with a general-purpose graphics processing unit (GPGPU).

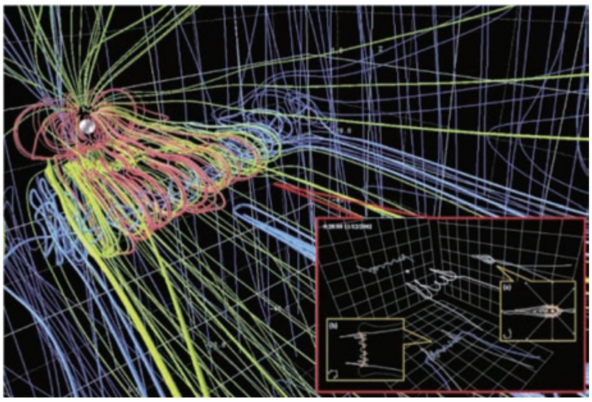


Figure 5. A visualization result of magnetic field lines calculated by the global magnetspheric magnetohydrodynamic (MHD) simulation. Distinctive magnetic field lines which affect the magnetospheric dynamics are automatically extracted and classified according to their three-dimensional topologies, by a visual data mining technique which is a typical technique of smart visualization.

Geophysical Fluid Simulation Research

The Geophysical Fluid Simulation Research Group is working on simulation research for a deeper understanding of climate change and its predictability by using ocean models, atmosphere models, and coupled atmosphere-ocean models. Here we introduce one result of the simulation by a super-high-resolution ocean model, which we use for research on the oceanic microstructures on the scale of a few kilometers observed in the surface layer of the ocean. Recent satellite observations provided high-resolution data on ocean surface temperatures and colors, which revealed even smaller eddies and filaments of only a few kilometers in size in mesoscale eddies (about 100 km). These oceanic microstructures involve active vertical movement, so they are suspected to have large influences on ocean surface-layer currents, such as the Kuroshio Current, and on the primary production of the oceanic ecosystem, such as phytoplankton. Thus we are trying to conduct a simulation of the North Pacific Ocean that can reproduce the submesoscale phenomena on the scale of a few kilometers in size by using a super-high-resolution ocean general circulation model (OFES). In simulation with 3-km horizontal resolution, we can now represent submesoscale eddies and filaments along the Kuroshio Current and the warm Tsushima Current (Fig. 6). This result is being analyzed energetically in collaboration with JAMSTEC's Research Institute for Global Change, the International Pacific Research Center (IPRC), and the French Research Institute for Exploitation of the Sea (IFREMER).

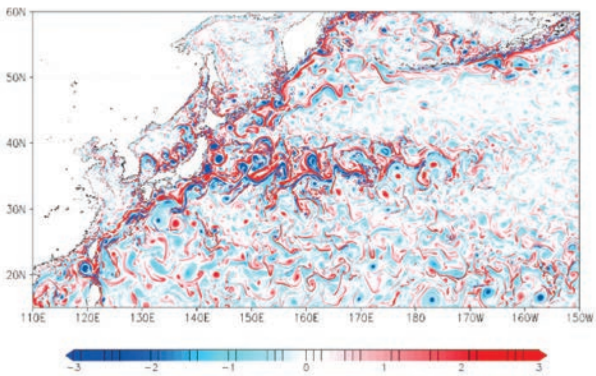


Figure 6. Submesoscale phenomena reproduced in a super-high-resolution North Pacific simulation (surface relative vorticity ($\times 10^{-5}$ s^{-1}): quantities to show rotational direction and strength).

Observing System Research and Ensemble Data Assimilation Development

The team is developing the world's most advanced ensemble analysis system that fuses observation and simulation. This system is being used for optimization of observing systems and predictability studies. The team comprises researchers at ESC as well as those from several programs at the Research Institute for Global Change. The research is ongoing in collaboration with researchers from the University of Maryland and Doshisha University. Errors obtained from the ensemble analysis system vary daily, depending not only on observation density but also on atmospheric flow. Such error information could not be obtained by existing methods of analysis, and it can be used for designing observation systems because it shows where to observe in order to achieve effective observation. In fiscal 2010, in order to evaluate observation done by JAMSTEC, we started ALERA2, a global ensemble atmosphere analysis starting from January 2008. From ALERA2 computations, Fig. 7 shows, as an example, the low pressure system that brought strong wind and heavy snowfall on February 23–24, 2008. Our analysis also reproduced the strong winds observed that exceeded 20 m/s (arrows). Errors in 10-m-level winds are great around the center of the low pressure system (colors). In this region, sea surface temperatures vary significantly from north to south along the Oyashio Current, which suggests active interactions between the atmosphere and the ocean. We will carry out intensive observations aiming to elucidate atmosphere-ocean interaction and verify the effectiveness of the observations.

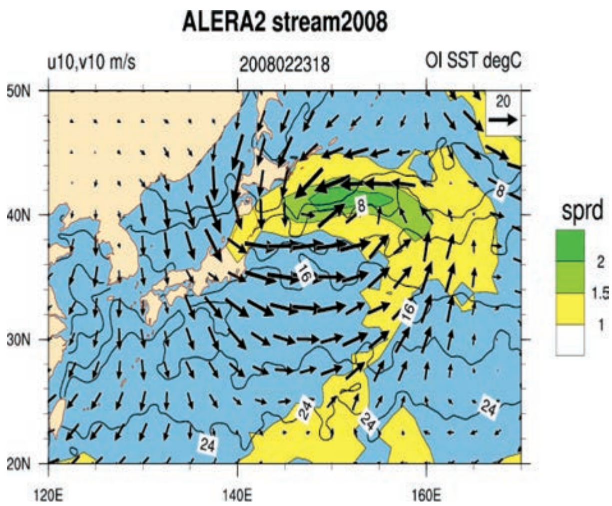


Figure 7. Wind velocity at 10 m above ground (m/s, arrow), its error (m/s, color) and the sea surface temperature (°C, contour) at 18:00 UTC on February 23, 2008 (3:00 Japan time on February 24).

Simulation Technology Application Research

We are conducting research to promote application of the Earth Simulator to research and development as well as design and production in industry, funded by MEXT under the Program for Promoting by Sharing Advanced Research Facilities. In fiscal 2010 we selected 13 projects—including those involving fluid dynamics, nanomaterials, reduction of environmental loads, biology, and disaster prevention—and provided technical support for them.

An example is the "Development of a Fast, High-precision Numerical Analysis Technique for Rotating Machines by a 3-D Finite Element Method" by Toyo Electric Manufacturing Co. Rotating machines (motors) are said to account for more than 50% of the nation's electric power consumption. Improving the efficiency of rotating machines is an important and inevitable theme among environmental issues. On this theme, the company, in cooperation with Gifu University and JAMSTEC, succeeded in parallelizing magnetic-field analysis programs using a 3-D finite element method and implementing fast, large-scale analysis of the magnetic field.

Fig. 8 shows an analysis model of an interior permanent magnet (IPM) motor (from *The Earth Simulator Industrial Use Symposium 2010 Presentation Materials*). IPM motors have permanent magnets embedded in their rotors. By controlling the current phase, they can run with large torque and at a wide range of speed. They are efficient energy-saving motors, and their use has been rapidly spreading in recent years to electric vehicles, hybrid vehicles, high-performance air conditioners, large industrial motors, motors for electric trains, and other uses. One of the important technological problems with motors is how to control torque-lowering when the rotor becomes eccentric. In the past, computing with a 1/48-region model without eccentricity was the limit. Now, as we have succeeded in parallelizing and speeding-up using a domain decomposition method on the Earth Simulator, we can compute the problem with inclined eccentricity in a 1/1-region model (full model) within a few days. This is great progress toward applications for design and development of efficient rotors.

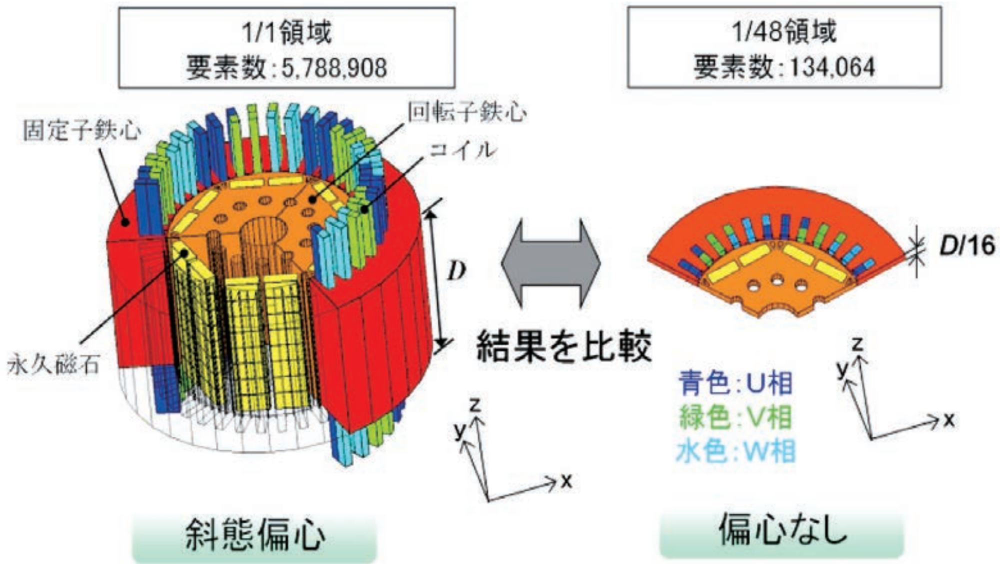


Figure 8. An analysis model of an IPM motor.

Collaborative Research with Companies from a New Point of View

The ESC, in collaboration with JAMSTEC's IFREE, has been conducting joint research with DNP Fine Chemicals Co. (formerly The Inctec Inc.) for a technique to reproduce on a computer the complex movement of ink, and has in the last fiscal year developed prototype ink simulation software. This prototype enables us to simulate ink's complex behavior, which was difficult to deal with using conventional numerical hydrodynamic techniques. Now, to elucidate practical parameters, we are verifying the result with experiments. Hopefully it will be used to improve quality control in printing, such as prevention of ink peeling during high-speed printing, and will also have a wide variety of other applications, such as simulation of the earth's crust and mantle, which flow and crack together.

Earth Simulator Confidential Use

In principle, information on Earth Simulator users and outlines of their research are disclosed to the public. However, we have established a confidential fee-based use system in which such information is not open to the public. In this system, we support users in program development and technicalities such as tuning. We also provide a free advance evaluation system (trial use) before drawing up onerous contracts so that users can try simulations using the Earth Simulator. In fiscal 2010, several companies used this fee-based system to commercialize analysis service.

Data Research Center for Marine-Earth Sciences (DrC)

Outline

The Data Research Center for Marine-Earth Sciences was established in April 2009 with the goal of managing and releasing data and sample information obtained by JAMSTEC, preparing functions necessary for them, and developing and providing data with new added value produced by integrating various data along with practically useful products in response to needs in research, education, and socioeconomy (see Fig. 1). The Data Management and Engineering Department at the Yokohama Institute for Earth Science receives, stores, and does quality control of data and sample information and also prepares products with added value, while the Global Oceanographic Data Center (GODAC), at Nago City in Okinawa Prefecture, releases various data and video information to the public and also conducts activities to increase understanding.

Figure 1. DrC Organization Chart.

Data Management and Engineering Department
Data Management Group

Management and Release of Oceanographic Data

The Data Management Group, in cooperation with relevant departments, collects and stores various observation data obtained by JAMSTEC research vessels, and also conducts quality control, data release, and data provision. For other observation data, the group handles metadata management and release.

Relevant regulations, including "Basic Policies on the Handling of Data and Samples (Data Policy)," provide that scientists who obtain data shall submit them, after post processing such as data correction, within the Publication Moratorium Period. For cruises in fiscal 2008 to which the rule above was applied, the Publication Moratorium Period ended in fiscal 2010. The Data Management Group requested submission of posttreated data, and started accepting data and metadata. These data were released via each cruise's data publication Web page.

For those surveys and observations that JAMSTEC carried out by means other than cruises, the researchers who actually carried out the work are supposed to store and release the data. However, metadata are uniformly stored and released by the Data Management Group. In fiscal 2010, for land area surveys and observations, the group decided which items of metadata were to be collected and how to release them to the public, and then started collecting metadata. Collected metadata are registered in the Data Search Portal, classified into land weather observations, land vegetation observations, and other categories, and are made available to the public.

Since the cruises of fiscal 2010, the basic observation instruments installed on each vessel have been operated continuously for as long as possible. The data that was collected received basic quality control as routine observation data, and publication was started on each cruise's data publication Web page.

For data obtained by ships, in fiscal 2010 the group started consideration of how to publicize data from Doppler radar systems and magnetometers. The group also started publication of past cruise reports on its Web site.

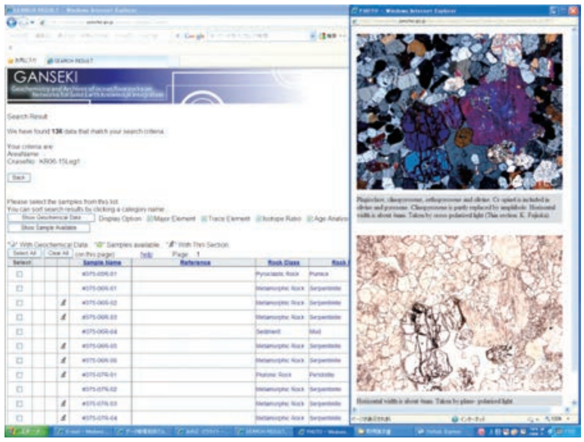


Figure 2. Rock sample database and slice photos.

Figure 3. JAMSTEC Core Data Site.

For samples collected, the group began publishing photos of rock slices on the GANSEKI database, which provides rock acquisition information and analysis data to the public (Fig. 2), and continued providing metadata to international portal sites. For core samples, the group released information on past in-house cruises and high-resolution sample photos (Fig. 3). For biological samples, the group ran a marine biological sample database and began providing sample occurrence information to BISMaL.

Until fiscal 2009, GODAC had been digitalizing (encoding) video images taken by submersibles. In fiscal 2010, the Yokohama Institute, which manages the master tapes, took on this work, aiming to reduce transport risk and increase work efficiency.

Data Integration and Analyses Group

Development of Marine Data Management and Provision Systems

We are undertaking system development and function enhancement for managing, providing, and publicizing various observation data obtained by JAMSTEC research vessels. In fiscal 2010 we developed a system to uniformly manage metadata of cruises, dives, and the like that are common to each data publication system. We also classified each data site and data set into fields and constructed a catalog system to make them searchable.

Construction of the Biological Information System for Marine Life

In collaboration with GODAC and the Marine Biodiversity Research Program of the Institute of Biogeosciences, we are developing an integrated data-provision site for handling diversity and distribution information on marine biology, called the Biological Information System for Marine Life or BISMaL (Fig. 4). In fiscal 2010 we constructed a function for online data cooperation with the Ocean Biogeographic Information System (OBIS) in an international joint project called Census of Marine Life (CoML). We also expanded data management functions.

Furthermore, we reconstructed the Video Information database linked with BISMaL, and strengthened functions of the Marine Biological Sample database.

Figure 4. BISMaL pages.

Creation of Data with Added Value and Practically Useful Data

We are now developing products with added value using an integrated database in which different kinds of global observation data and simulation models are linked. At present, we have developed integrated products for viewing the ocean, atmosphere, chemicals, and conditions of the ecosystem on a global scale with applications for monitoring warming and management of living aquatic resources, and we have constructed a combined database for submarine observation network data and land global observation data.

Data Integration and Analysis System

From fiscal 2006 to 2010, we have been operating contract services for MEXT's Data Integration and Analysis System in collaboration with the University of Tokyo, the Japan Aerospace Exploration Agency (JAXA), and other organizations. In the most recent fiscal year, reflecting surveys of users, we enhanced the visualization function and the download function for ocean reanalysis data, the land surface process data set of the Eurasian cryosphere, the data set on typhoon courses of the first half of the 20th century, among others, and we renovated the Web site as MAPS (My Atlas and Plot Service) in November 2010 (Fig. 5). Moreover, we jointly developed a document metadata construction tool so that metadata are easily registered using this tool on the Data Integration and Information Fusion Core System introduced by the University of Tokyo. We registered data sets and metadata, and the data sets have been open to the public since October 2010. Furthermore, we launched FIntAn (Fruit of Integration and Analysis) in February 2011 as an information site to introduce the findings gained from data provided in MAPS to more people in ways they can understand easily, as well as to promote use of the data (Fig. 6).

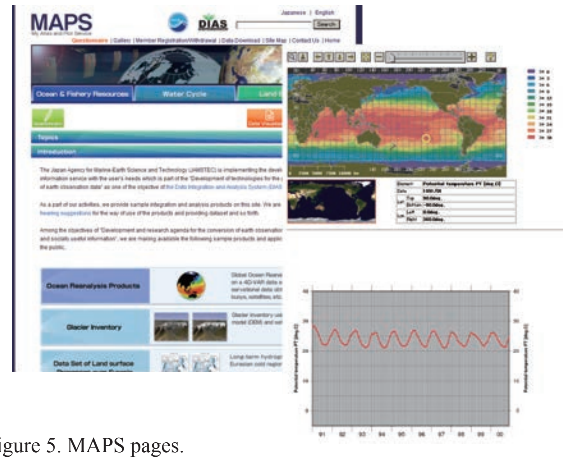


Figure 5. MAPS pages.

Figure 6. FIntAn pages.

Specifically, as part of the preparation of climate change data, we have developed coupled reanalysis data obtained from observation data from 1980 to the present and numerical models. Also, while bearing in mind applications for management of living aquatic resources, we have conducted prediction experiments for El Niño, Indian monsoons, and other phenomena, trying to improve their precision (Fig. 7).

Renovation and Practical Use of Techniques to Predict Changes in Fishery Resources and Ocean Conditions Accompanying Climate Change

Since fiscal 2010, as a project commissioned by MEXT, we have been downscaling and developing the atmosphere-ocean-ecosystem assimilation system that will be needed for formulation of adaptive plans for changes in fishery resources and ocean conditions accompanying climate change. We will use the system to develop techniques to find fishing places for flying squid and to estimate changes in fishery resources.

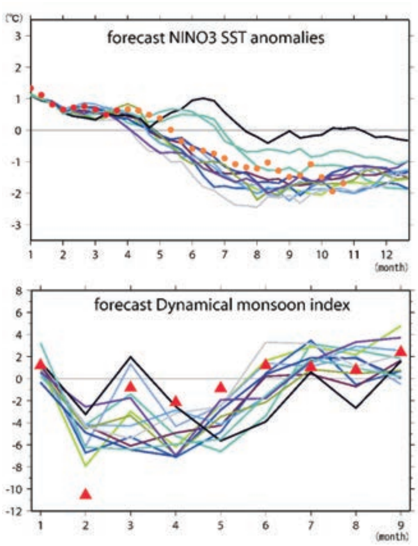


Figure 7. 2010 prediction results, with 4D-Var coupled atmosphere-ocean reanalysis as initial values. Monthly time-series of (top) the El Niño Index (sea surface water temperature deviation in the Nino 3 region) and (bottom) the Dynamical Indian Monsoon Index. Broken lines show results of respective ensemble experiments; circles and triangles show observed values.

Global Oceanographic Data Center (GODAC)

About the Global Oceanographic Data Center

The Global Oceanographic Data Center (GODAC) is a base for information of the Data Research Center. It is located in Toyohara, Nago City, Okinawa Prefecture.

GODAC's facilities were built by Nago City to attract information-related companies to the northern districts of Okinawa and to create employment opportunities and promote multimedia human resources development. GODAC has been operated by JAMSTEC since 2001 and marked the ninth anniversary of its establishment on November 24, 2010.

GODAC digitalizes, sorts, stores (in digital archives), and provides valuable deep-sea images as well as other materials via Web sites. Moreover, GODAC opens its facilities and equipment to the public free of charge and holds various events in order to increase understanding of marine science and technology.

Figure 8. Exterior view of GODAC.

Digital Archives and Data Release

GODAC is digitalizing valuable deep-sea images taken by submersibles such as the *Shinkai 6500* and remotely operated vehicles owned by JAMSTEC. The data are widely available to the public with an index of relevant information and video explanations through the Deep-sea Video database. GODAC also digitalizes and releases periodicals published by JAMSTEC such as *Blue Earth*, and cruise reports and track charts of the submersibles.

In fiscal 2010, GODAC started adding indices to still-image data in addition to video data, and inputted explanations of photographed species and geographical features for about 8,000 frames. Since the former large-capacity storage device for video data could not receive support from the manufacturer after the end of fiscal 2010, it was replaced with a new system, and the video data was transferred.

GODAC has been registering biological classification information with BISMaL, the Biological Information System for Marine Life, which launched in 2009. GODAC also started providing metadata to OBIS, an international database that releases biological and geographical information to the public.

GODAC also improved the function of the rock-sample database and core data site.

Increasing Understanding of Marine Science and Technology in Okinawa Prefecture and Public Relations Activities to Contribute to the Community

GODAC has opened its facilities and equipment to the general public along with its lecture rooms and video system, holding 37 seminars since its opening in order to increase understanding of marine science and technology. The number of visitors since the facility opened on November 24, 2001, reached 100,000 in August 2010 (Fig. 9), and 110,048 as of the end of March 2011.

As activities related to the sea for the general public, GODAC held marine classes, including beachcombing, training for observing the ocean, and observing plankton, a total of 14 times (Fig. 10)—four times in fiscal 2010—along with marine handicraft classes during summer and spring vacations. GODAC also provided trial experience operating GODAC's underwater video-camera robot, the *Nirai Kanai* 150, and other events (Fig. 11).

By the end of March 2010, GODAC had also released 829 photographs and videos of everyday forms of coral reefs in the Okinawa sea area, taken by the underwater video-camera robot, on the Coral Reef Network Web system (http://coral.godac.jp), which not only aids researchers but also helps young people and the general public understand coral reefs. It also released a new Web site, Sango Kids, to introduce coral reefs to children, and Investigation and Research at Sekisei Lagoon, a site for JAMSTEC research results.

In fiscal 2010, GODAC accepted 14 members from seven entities for work-experience study and internship, and participated in or cooperated with various events such as the 2010 Nationwide Whale Forum in Nago, the Whale Festival held in Nago, and the Nago Cherry Blossom Festival to promote understanding of marine science and technology.

Figure 9. 100,000th visitor: children from Nago City Agarie Ward After-school Child Care Center.

Figure 10. Marine class, held in December 2010.

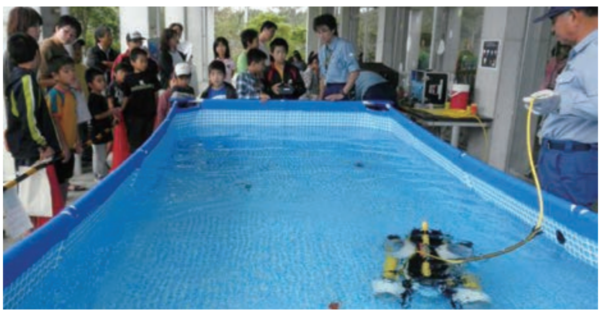


Figure 11. Trial operation experience at an open house.

Center for Deep Earth Exploration (CDEX)

Overview

The Center for Deep Earth Exploration (CDEX) operates the Deep Sea Drilling Vessel *Chikyu* safely and efficiently as a major agency operating under the framework of the Integrated Ocean Drilling Program (IODP), an international project led by Japan and the United States of America. We also provide scientific support services through maintaining a database of research data gathered from the expeditions by D/V *Chikyu*, and through appropriate control and provision of data and samples to create a research environment in which both onboard and IODP-related researchers can use for their maximum benefit for researches. In order to achieve the IODP goals, we work hard on the development and accumulation of technologies for deep-sea riser drilling, which is regarded as the next-generation ocean exploration technology.

1. Nankai Trough Seismogenic Zone Experiment

The massive earthquake zone in the Kumano-nada off the Kii Peninsula is one of the most active seismogenic zones in the world; it generates strong earthquakes and is expected be the hypocenter of massive quakes in Japan, such as the Tou-Nankai earthquakes. This project aims to carry out drilling within this zone to gain a better understanding of seismogenic conditions, as well as the processes of seismogenic and tsunamigenic activities in the faults at the plate boundary in order to collect geological samples and take various borehole measurements. The project consists of four stages. Stage 1 was completed in the period from September 21, 2007 to February 5, 2008. In 2010, we made three drilling cruises (IODP Exps. 326, 332, and 333) covering stages 2 and 3 of the project.

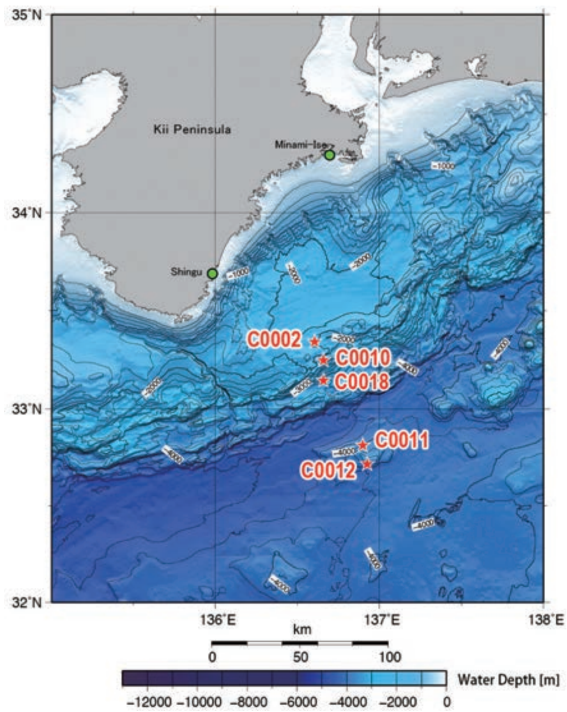


Figure 1. Seafloor map for the Nankai Trough Seismogenic Zone Drilling Plan

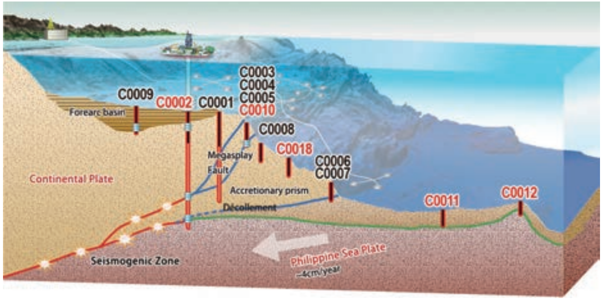


Figure 2. Outline diagram of the Nankai Trough Seismogenic Zone Drilling Plan

Achievements of Expedition No. 326

During this expedition, Hole C0002F had been drilled to 872.5 meters below 1,939m of the seafloor and the hole was lined with successfully cemented 20 inch casing. Now we confirm that Hole C0002F is ready for deep riser drilling (6,000-7,000m below seafloor) the are ningsurface -to collect core samples of the seismogenic zone between the Philippine Sea and Eurasian plates in the Nankai accretionary margin and carry out *in situ* long-term borehole monitoring in the near future.

Achievements of Expedition No. 332

We successfully installed a long-term observatory system in a borehole. This observation device was developed for the Marine-Earth Observation System, which is designated as one of the critical national technologies. The achievements of the expedition include the following:

(1) Installation of Long-Term Borehole Monitoring System (LTBMS)

The main goal of Expedition 332 was to drill and case a borehole at Site C0002 (1937.5 m water depth) and install an integrated Long-Term Borehole Monitoring System (LTBMS) that combines thermal, hydrologic, and geodynamic sensors to monitor pore fluid pressure, temperature, strain, tilt, and seismicity. The LTBMS was installed and fixed at a depth of 750-940m in the borehole.

The LTBMS is cemented in consolidated strata in the borehole, which provides a high degree of sensitivity and accuracy for observation and monitoring of precise changes in the seismic fault and the crust around it.

(2) Installation of a temporary borehole observatory in the shallowest part of the megasplay fault

At the Site C0010 (2523.7m water depth), we successfully recovered a simple pore pressure and temperature monitoring system (SmartPlug) which had been installed during Expedition 319 in 2009 in the shallowest part of the megasplay fault. The SmartPlug yielded pore water pressure and temperature data in the borehole for 15 months since its installation. The data record the signals of earthquakes and tsunamis that occurred in the circum-Pacific region and crustal deformation that resulted by them.

We also succeeded replacement the SmartPlug with a GeniusPlug temporary observatory. In essence, the observatory is similar to the SmartPlug except that the instrument is ~30 cm longer. This extension includes the added OsmoSampler for fluid storage over time as well as the osmotically driven microbiology chambers of the flow-through osmotic colonization system (FLOCS) unit and also means that final placement needs to be much closer to the active fault zone than the SmartPlug. This observatory will be used until a long-term borehole monitoring system is installed during the next expedition to this site.

We plan to install another long-term borehole observatory in the shallowest part of the megasplay fault (Site C0010) to monitor the fault at the site.

We also plan to implement real-time observation and monitoring in the hypocentral region for the Tou-Nankai earthquakes through a comprehensive seafloor and subseafloor observation network. For this purpose, a long-term borehole monitoring system will be connected to the DONET, a submarine cabled earthquake and tsunami observatory network installed in the Kumano-nada off the Kii Peninsula.

Figure 3. Installation of a long-term borehole monitoring system

Achievements of the Expedition 333

Expedition 333 conducted drilling and coring of previously unsampled intervals of sediment and basalt at IODP Sites C0011 and C0012 in the Shikoku Basin, together with downhole measurements of temperature, and drilling and coring at a site near the updip terminus of the megasplay fault.

The most important accomplishments of the expedition 333 at the sites C0011 and C0012 were determination of heat flow, coring through a transition in physical properties within the upper part of the Shikoku hemipelagite, repeated coring and sampling of fluid above the sediment/basement interface for shore-based geochemical studies, and coring into the basalt to 100 m below the sediment/basalt interface.

At the Site C0018, a nearly complete slope basin stratigraphic succession comprising six mass transport deposits that record ~1 m.y. submarine landsliding history near the shallow megasplay fault zone area are also successfully drilled and sampled.

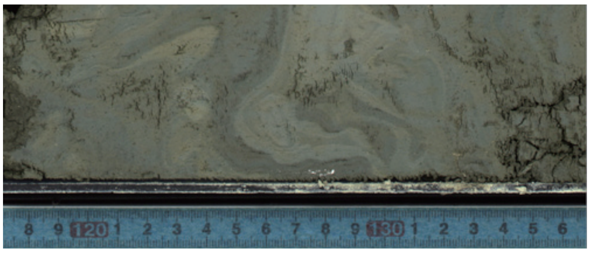


Figure 4. Deformed structure inside submarine landslide mass (at 139 m below the seafloor, 3084 m deep)

2. Okinawa DEEP HOT BIOSPHERE - 1

Achievements of Expedition 331

We drilled 5 sites in the Iheya North active hydrothermal field at Okinawa Trough in order to investigate metabolically diverse subseafloor microbial ecosystems and their physical and chemical settings for the first time in the world.

(1) Discovery of subseafloor hydrothermal structure and hydrothermal alteration zone

The temperature readings from the bottom of the borehole were higher than those expected at C0013 (about 100 m east to the center of a high-temperature hydrothermal fluid plume), and C0014 (350 m further east of C0013). There, the Expedition recovered cores of volcanic sediment containing hydrothermally-altered sulfate minerals. Horizontal flows of hot fluids were also found at several depths. This indicates that in the eastern Iheya North hydrothermal field, there are several layers of caprock, where high-temperature vent fluids are trapped but can migrate laterally. Such interaction of hydrothermal waters and seawater passing through the layers causes hydrothermal alteration of rock (hydrothermal alteration zone).

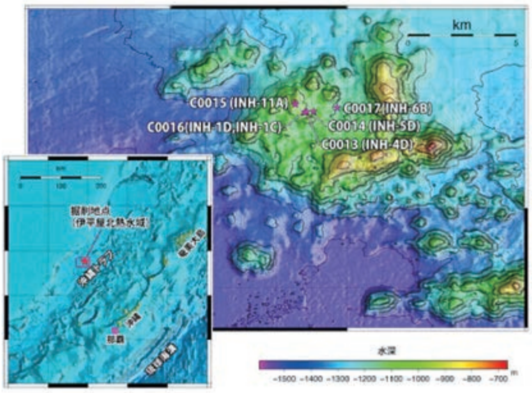


Figure 5. DEEP HOT BIOSPHERE study area and drill sites

(2) Discovery of a subseafloor hydrothermal fluid reservoir

The chemical composition of pore water contained in the cores revealed the presence of lighter vapor-rich water in the upper portion of the hydrothermal fluid reservoir; heavier high-salinity water accumulated at the bottom.

It is theorized that a hot fluid with high salinity sinks to the bottom of the hydrothermal fluid reservoir. The drilling into the hydrothermal mounds in Expedition 331 brought back the first direct evidence for this theory. The huge and deep expanse of the hydrothermal fluid reservoir in Iheya has also overturned the concept that the extent of fluid circulation and its flux volume are relatively small at plate convergence boundaries, such as the Okinawa Trough.

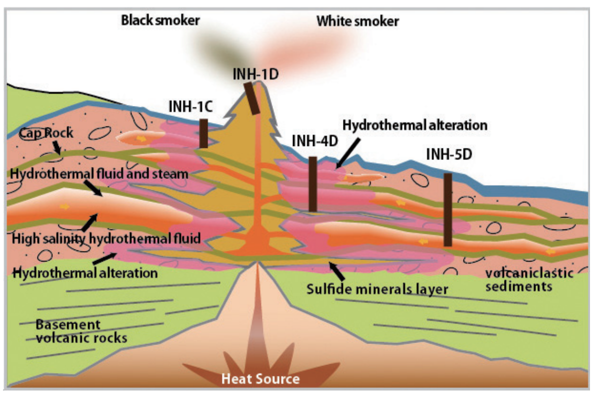


Figure 6. Subseafloor image of the eastern side of Iheya North hydrothermal system

(3) Distribution and mineralogy of hydrothermal sulfide minerals: clues to uncover the hydrothermal ore genesis

The recovered cores contained a wide range of minerals composed of hydrothermally synthesized metal sulfides, providing clues to the chemical and depositional environment. It is commonly known that hydrothermal mounds (e.g. Site C0016) consist mainly of sulfide minerals. The Iheya hydrothermal system is not an exception; especially at C0013 and C0014, veins of sulfide minerogenic layers are extending through the bottom portion of the thick hydrothermal alteration zone. The finding has scientific significance as it may reveal the processes of the generation of hydrothermal deposits.

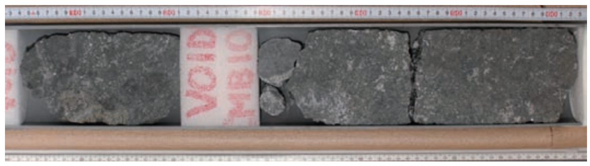


Figure 7. Collected core sample rich in metal ores

(4) Establishingment an artificial hydrothermal vent

After the completion of coring, we built an artificial hydrothermal vent on the wellhead of the borehole by using an Remotely Operated Vehicle (ROV). We plan to study the process of the development of the microorganism community through the observation of this artificial hydrothermal vent over the next several years,.

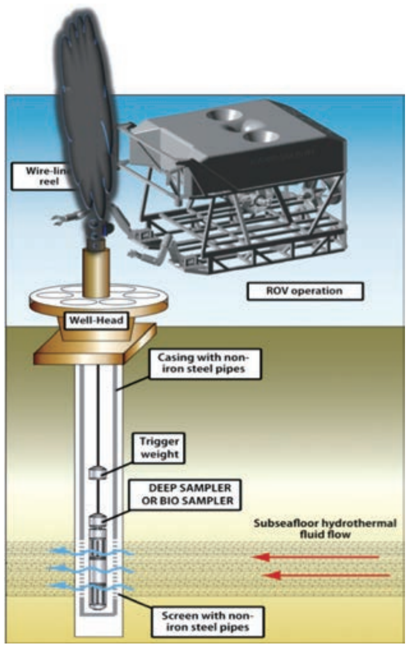


Figure 8. Conceptual diagram of the artificial hydrothermal vent

Observing System Research and Technological Development Laboratory

Outline

The Observation System Research and Technology Development Laboratory was established in fiscal 2009 with the aim of developing technology that opens up new fields related to observation systems. It consists of the Southern Ocean Surface Buoy Lab Unit and the Autonomous Profiling Shuttle Development Lab Unit within the laboratory, and it is conducting the following research and development projects.

Southern Ocean Buoy Laboratory Unit

At the Southern Ocean Surface Buoy Lab Unit, we are developing ocean observation buoys of a great-depth surface-mooring type (Fig. 1), which can be operated in the Southern Ocean in tough and icy conditions.

The ocean observation buoy is moored by connecting the buoyancy body on the ocean surface to the anchor at the bottom of the ocean with a wire and fiber cable. To make the buoyancy body small, the mooring line is about 1.4 times as long as the water depth, which allows play in the line. To measure the weather and oceanic conditions where it is installed, the part of the buoy above the surface has weather sensors that include a wind speed and direction meter, a hygrothermometer, a barometer, a rain gauge, and a shortwave radiometer; and the wire line under the water has underwater sensors that include current meters, water temperature meters, salinometers, and depthmeters. Conventional ocean observation buoys have been installed in the equatorial regions of the Indian Ocean and the Pacific Ocean, helping with predictions of El Niño and other phenomena.

Based on the technology fostered so far, we are now developing a new buoy for moor in the Southern Ocean by adding new measures for strong winds and high waves and the low-temperature environment. By installing this ocean observation buoy off Antarctic Adélie Coast (60°S, 140°E) in the Southern Ocean, we aim to contribute to research on oceanic general circulation and climate change.

In fiscal 2010, to assess behavior of the entire mooring system in strong winds and high waves, we developed motion simulation software that is dynamic and can take into consideration the influence of high waves. Also, to assess the low-temperature environment and to plan measures for it, we used a large-experiment building to carry out icing tests on weather sensors (Fig. 2), and considered how to prevent icing. To confirm and verify these results, we made a test buoy for an actual sea and carried out a test mooring at a site 50 kilometers west of Cape Erimo, Hokkaido, from the end of November to February 2011 (Fig. 3). Now we are analyzing the data obtained. From now on, based on these results, we will begin designing a prototype Southern Ocean buoy and deploy it in fiscal 2011off the Adélie Coast in the Southern Ocean.

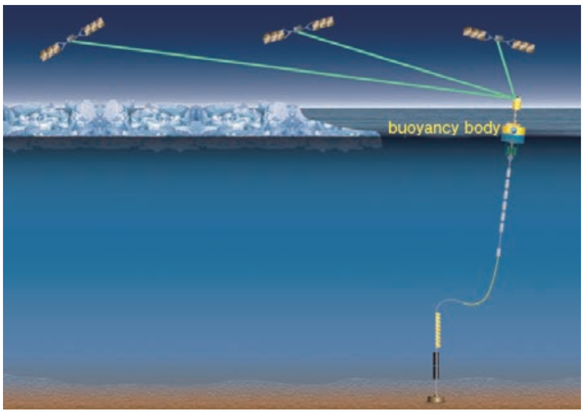


Figure 1. Image of the Southern Ocean observation buoy.

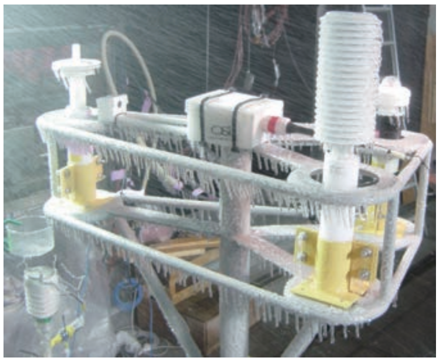


Figure 2. Icing test of weather sensors.

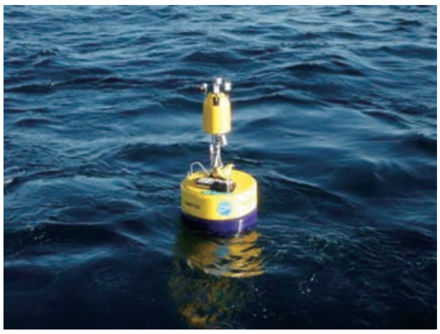


Figure 3. Test in an actual sea area, off Cape Erimo.

Autonomous Profiling Shuttle Development Laboratory Unit

At the Autonomous Profiling Shuttle Development Laboratory Unit, we are doing research and development on (1) a shuttle-type robotic vehicle that autonomously carries out oceanographic observation between the sea bottom and the sea surface within a fixed area over a long period of time, and (2) a float, called Deep NINJA, that observes the deep sea at a depth of up to 4,000 m.

The Autonomous Profiling Shuttle controls its buoyancy by changing the volume of the vehicle itself using a buoyancy engine. It glides through the sea, going back and forth between the surface and the seafloor while measuring water temperature, seawater density, and so on. Fig. 4 depicts its operation. When floating on the surface, it measures its position using GPS and transmits observation data to land via satellite. When diving, it shifts batteries and other components in the pressure vessel to change its center of gravity to control its attitude and direction of movement, corrects its position against any ocean current or tidal current, and stays within a certain area for a long period of time. In the sea, it sleeps for a certain length of time to save on battery consumption and thereby realizes long-term observation. We aim to deploy these vehicles at key observation points, such as around the Arctic Ocean, the Antarctic Ocean, and the equatorial region, to construct an efficient oceanographic observation network.

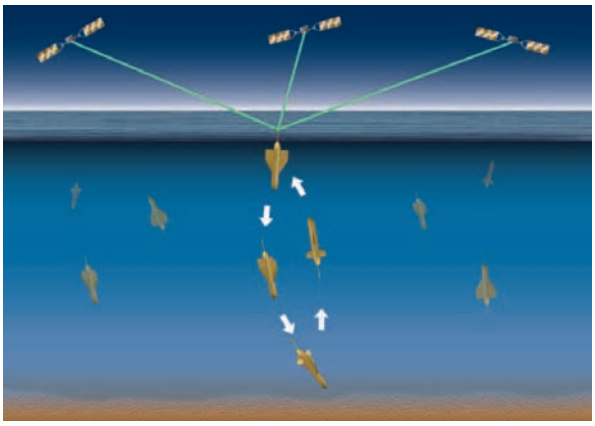


Figure 4. The Autonomous Profiling Shuttle.

In fiscal 2010 we carried out basic design of the shape, weight, buoyancy, power consumption, methods of motion control, and so on and started design and trial manufacture of a prototype. To glide through seawater, the vehicle needs to have low fluid resistance as well as stability of attitude and direction-control ability. To realize a vehicle with such hydrodynamic characteristics, we carried out hydrodynamic tests using the model shown in Fig. 5.

In contrast, profiling floats are suitable for observation in a wide marine area. They can continue ocean observation for several years after being thrown into the sea. Therefore, at present, a system of about 3,000 profiling floats has been completed, and it can observe water temperatures and salinity in the oceans of the world almost in real time. For technical reasons, however, the present profiling floats are limited to observation at water depths of up to 2,000 m. Meanwhile, recent research has been revealing that changes in the ocean deeper than 2,000 m have considerable influence on the global environment. Thus an idea was presented internationally: Let's expand this observation network of profiling floats into the deep sea to monitor changes in the deep layers of the oceans. The necessary profiling floats for the deep seas are being developed in a few countries.

Since profiling floats have many functions in common with the shuttle-type robotic vehicle, we can use the technologies we have fostered in developing the shuttle. In October of this fiscal year, we started joint development with Tsurumi-Seiki Co. of a profiling float for the deep sea, the Deep NINJA (Fig. 6), which can conduct observations in water depths up to 4,000 m.

We aim to put this deep-sea profiling float to practical use by the end of fiscal 2012 and to complete a system to distribute around Japan and abroad. In this fiscal year, we started developing a buoyancy engine capable of 4,000 m depth, a lightweight pressure vessel, and control programs. After obtaining basic data through indoor experiments, we plan to do comprehensive tests in an actual sea area in fiscal 2011.

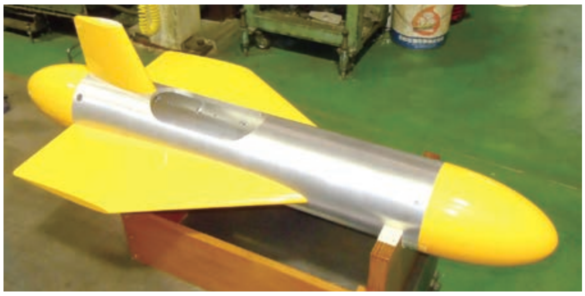


Figure 5. Model of the shuttle-type robotic vehicle.

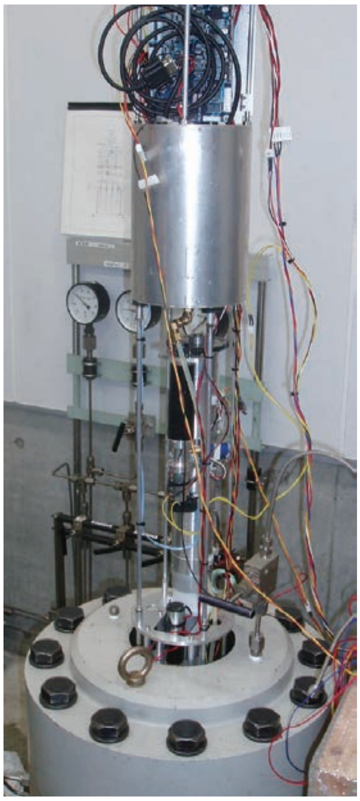


Figure 6. Deep NINJA prototype being tested (photo provided by Tsurumi-Seiki Co. Ltd.).

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