

An aerial view of the deck of a research vessel. The deck is painted green and has white railings. Several crew members wearing blue overalls and yellow hard hats are visible. There are various pieces of equipment, including large black spools and white cylindrical containers. The vessel is on a vast blue ocean under a bright blue sky with scattered white clouds. A single bird is flying in the upper right corner of the sky.

# JAMSTEC

## 2009 Annual Report



Japan Agency for Marine-Earth Science and Technology

# **JAMSTEC**

## **2009 Annual Report**

## Preface

JAMSTEC has started its second midterm plan in April 2009. In the first midterm plan, from fiscal 2004 to fiscal 2008, viewing the Earth as a system centering on the ocean with motto “know the Earth through the ocean,” we have urged research and development to elucidate changes in the global environment and to understand marine life. Moreover, in these five years, in addition to these activities, which may be called ordinary research and development, JAMSTEC has been committed to undertakings that directly contributed to society, such as an emergency survey after the Off-Sumatra Earthquake and surveys toward settlement of the continental shelf.

In the second midterm plan, following from “know the Earth,” we are stepping further into a viewpoint of “live close together with the Earth” in order to contribute to humanity’s sustained development and to move forward to resolve various problems deeply related to the ocean. More concretely, as responsibilities that JAMSTEC ought to take, we have spelled out the following: “To urge research on changes in the global environment concerning the ocean, trench-type massive earthquakes, ocean-originating natural disasters such as tsunamis, and biogeosciences, and to provide findings and information that serve to ensure security and safety and to develop society”; as well as “to urge development of fundamental technology to promote innovative research on the ocean and to contribute to invigoration of domestic industry and life through its use.” We shall make progress on prediction and elucidation of phenomena in global changes, such as massive natural disasters, global warming, and so on that are considered urgent matters for human beings in the 21st century.

In fiscal 2009, as the first year of its second midterm plan, we have restructured the organization by taking advantage of organizational management experience obtained during the first midterm plan. From the three newly formed institutes that stem from this restructuring, namely the Research Institute for Global Change (RIGC), the Institute for Research on Earth Evolution (IFREE), and the Institute of Biogeosciences (Biogeos), many research results have been

obtained since the first year and have been published in numerous prominent academic journals.

Moreover, technological development, which serves as one of the two driving wheels of JAMSTEC along with research, yielded many results to develop various forms of exploration technology for seabed resources. Each achievement of these research projects and technological developments shall be introduced in sections of this report.

The operations and maintenance of various research facilities, such as stable operation of the Earth Simulator, whose performance was improved at the end of 2008, success on the first riser scientific drilling by the deep-sea drilling vessel *Chikyu*, installation of a submarine cable for the Dense Ocean floor Network System for Earthquakes and Tsunamis in the Sea of Kumano off the Kii Peninsula, are going well. We shall make further efforts to obtain data contributing to raising the precision and speed of earthquake early warning and tsunami warning as well as advancing earthquake prediction models, which are directly connected to our lives and contribute to disaster prevention and reduction.

Conditions surrounding JAMSTEC are difficult these days. The government as a whole is about to perform a review of Incorporated Administrative Agency from the ground up. Taking this into consideration, we shall further improve streamlining and efficiency of our operations and make efforts on yielding results to 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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## 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 and contributes to resolving various problems crucial to the survival of humanity by applying obtained results to securing the global environment, as well as by tackling fundamental ocean research and technological development and elucidation of the global system centering on the ocean.

JAMSTEC performs activities along with the mid-term plan it implements, based on mid-term objectives goals set by the Ministry of Education, Culture, Sports, Science and Technology, every five years. In order to contribute to achieving the nation's policy goals outlined in the Basic Plan on Ocean Policy and other policies in fiscal 2009, the start of our second mid-term plan and the sixth anniversary of JAMSTEC becoming an Independent Administrative Institution, we have set up the following important research and development institutes:

#### (i) Research on Global Change

The objectives are to conduct comprehensive research on phenomena and processes concerning global changes, including observation of the ocean, land, and atmosphere as well as construction of a numerical model on the global environment to contribute to resolving environmental problems such as global warming; and, through these research projects, to contribute to planning the fifth Assessment Report evaluation report for the Intergovernmental Panel on Climate Change (IPCC).

#### (ii) Research on Earth Evolution

The objectives are to diagnose the cause of ocean-originating natural disasters, including trench-type massive earthquakes and tsunamis, by understanding dynamics of Earth evolution; and to provide findings and information that contribute to protecting people's lives and property from these disasters.

#### (iii) Research on Biogeosciences

The objectives are to explore biotic communities, including

microbes living under extreme conditions such as the deep seabed, and to do research on them to elucidate behavior, function, and interaction with the global environment; and to search for applications of marine biological resources to contribute to socioeconomic development.

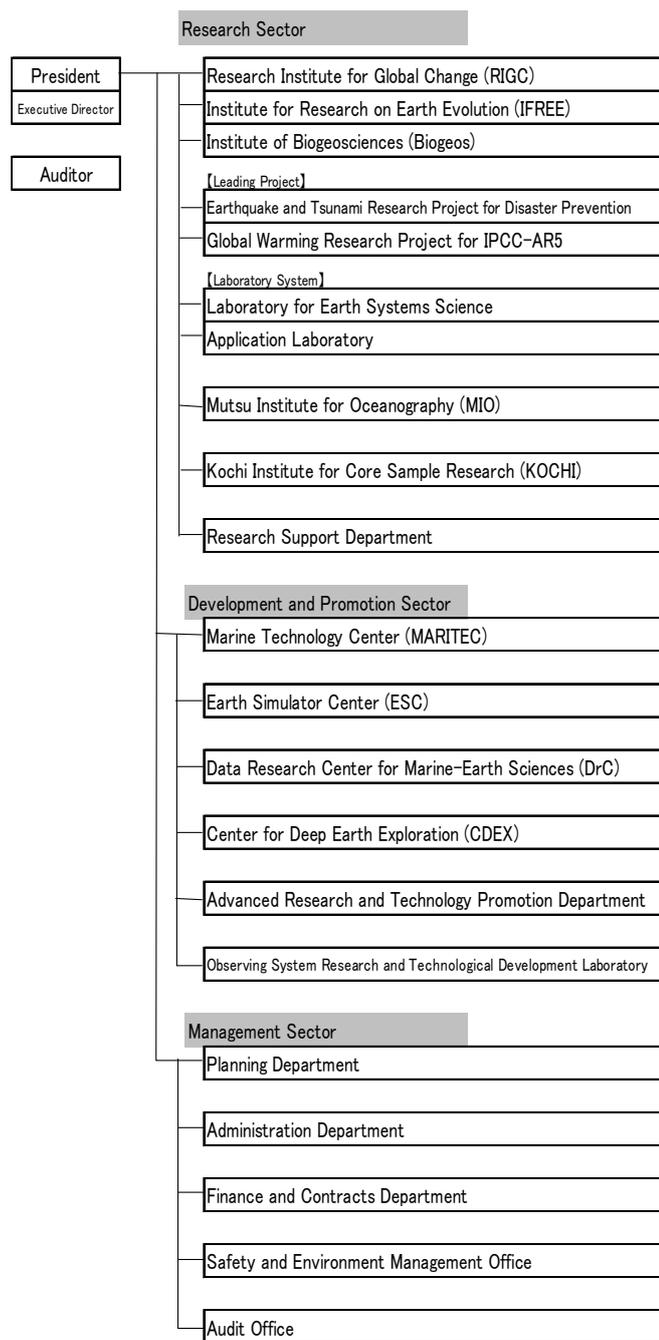
#### (iv) Development of Fundamental Technology on the Ocean

The objectives are to urge development of fundamental technology to promote innovative research on the ocean; and to contribute to domestic industry and life through its use.

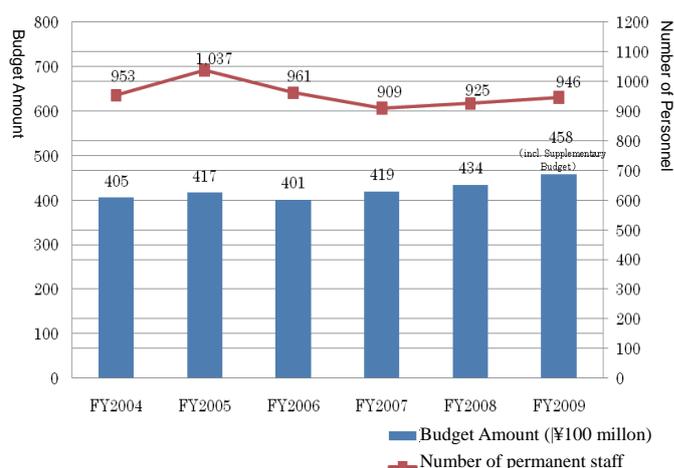
At the beginning of the second mid-term plan, we have concentrated on "establishing a structure" to enhance research and development, mainly by restructuring of the organization by promoting more efficient administration and management, based on JAMSTEC's long-term vision planned in February 2008, namely "New challenges to the frontier of the ocean Earth." The organization was restructured into the Research Sector, the Development and Promotion Sector, and the Management Sector, according to their features. The Research Sector further changed into three research Institutes, the Mutsu Institute for Oceanography, the Kochi Institute for Core Sample Research, and Leading Projects and Laboratory Systems; and it has improved its system to support these research institutes effectively for conducting flexible research and development.

Additionally, we are making efforts on disseminating the results obtained by research and development, on application of the results, and trying to achieve a higher level of marine science and technology by efforts including cooperation for academic research concerning oceans as well as human resources development to support a new ocean-oriented nation.

Organization Chart (As of March 31, 2010)



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



(3) Offices and Institutes

Name	Location
Yokosuka Headquarters	Yokosuka-shi, Kanagawa, Japan
Yokohama Institute for Earth Science	Yokohama-shi, Kanagawa, Japan
Mutsu Institute for Oceanography	Mutsu-shi, Aomori, Japan
Kochi Institute for Core Sample Research	Nankoku-shi, Kochi, Japan
Washington, D.C., Office	Washington, D.C., United States
Tokyo Office	Minato-ku, Tokyo, Japan
Global Oceanographic Data Center	Nago-shi, Okinawa, Japan

As of March 31, 2010

(4) Research Facilities

**Vessels**

**Chikyu**



Deep-sea drilling vessel  
 Length: 210 m  
 Beam: 38 m  
 Height from hull: 130 m  
 Complement: 200 persons  
 Gross tonnage: 56,752 tons  
 Maximum drilling depth: 2,500 m  
 Length of drill strings: 10,000 m  
 Commissioned: 2005

**Mirai**



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

**Kairei**



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

**Yokosuka**



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

**Hakuho-maru**



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

**Kaiyo**



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

**Natsushima**



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

**Tansei-maru**



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

**Submersibles and ROVs**

**Shinkai 6500**



Manned research submersible  
 Depth capability: 6,500 m  
 Complement: 3persons  
 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: 10.6 m  
 Dry weight: 9.7 tons

**Hyper Dolphin**



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

**Kaiko 7000 II**



7,000m 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:4,000-6,000 m  
 Length: approx. 3.5 m  
 Dry weight: approx. 1.0 ton

**Other Facilities**

**Earth Simulator**



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

**Training pool**



**Ultrasonic tank**



**Hyperbaric chamber**



## (5) International Collaboration

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

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

### (i) Contribution to Multilateral Framework for International Collaboration

JAMSTEC sends experts to various task forces in 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. In January 2008, in order to strengthen the Japanese promotion system for the IOC's relevant projects and meetings, the Japan Group of Experts to Advance IOC Programs was established within JAMSTEC, and experts can exchange views and review international research projects. In 2009 members exchanged views at five Subgroups of Experts established in this group, and in May 2009 the group held its second meeting and held a discussion, based on the views expressed at each Subgroup of Experts, about 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, which is one of its major observation and research areas. On request, JAMSTEC sends researchers to other international oceanographic organizations to contribute to their research activities.

### (ii) 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 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)
- North Pacific Marine Science Organization (PICES)
- Global Earth Observation System of Systems (GEOSS)

### (iii) Cooperation under the Intergovernmental Cooperative Agreement

JAMSTEC conducts cooperative research based on the Intergovernmental Cooperative Agreement concluded 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 2009 were:

- the 4th Japan-Sweden joint science and technology committee meeting, April 2009
- the 23rd Japan-France ocean development expert group meeting, October 2009
- the 3rd Japan-Norway joint science and technology committee meeting, November 2009
- the 20th Japan-Germany joint science and technology committee meeting, November 2009
- the 13th meeting of the Japan-China committee on cooperation in science and technology, February 2010
- the 10th meeting of the Japan-Russia committee on cooperation in science and technology, March 2010

### (iv) Cooperation with Foreign Institutions

Under the memorandums 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. During its 10th annual meeting, POGO-11, held in Moscow January 26–28, 2010, an executive director of JAMSTEC served as chair.

(v) Other International Collaborations

Visitors from overseas governments and research institutions came to see JAMSTEC facilities and exchange views, and those visitors included Environmental Adviser with Rank of Minister of the President of the Republic of Nicaragua Jaime Incer, science and technology counsellor Jean-Luc Devenon of the French Research Institute for Exploration of the Sea (IFREMER), President Jose Luis Jesus of the International Tribunal for the Law of the Sea (ITLOS), President Kang Jung-Keuk of the Korea Ocean Research and Development Institute (KORDI), Deputy Chairman Marzan Aziz Iskandar of the Indonesia Agency for the Assessment and Application of Technology (BPPT), and others.

As part of its international activities, JAMSTEC participated in exhibitions at the 6th plenary session of the Group on Earth Observations (GEO) in November 2009 in Washington, D.C., the 10th annual meeting of American Association for the Advancement of Science (AAAS) in February 2010 in San Diego, USA, the 4th GEOSS-AP Symposium in March 2010 in Bali, Indonesia, along with other opportunities.

## 2. Outline and Major Achievements of Each Section

### (1) Research Institute for Global Change (RIGC)

#### 1) Ocean Climate Change Research Program

The oceans store a large amount of heat and dissolved chemical substances. Their circulation in the oceans has a large impact on the global climate. The purpose of this research program is to elucidate the distribution and temporal changes in heat and chemical materials such as carbon dioxide in the oceans. For this purpose we deploy Argo floats, which drift in the mid-layer of the ocean and surface periodically, to measure and automatically transmit oceanographic data. We also conduct basin-scale repeat hydrography using research vessels, to obtain high-quality physical and chemical parameters along trans-oceanic sections. We also deploy mooring buoys, to measure heat flux between atmosphere and ocean in the Kuroshio Extension region. Research is also in progress on a dynamically consistent data assimilation technique that integrates these observational data with the results of numerical simulations.

#### Global Salinity Change Detected by the Argo Float Array

The aim of the international Argo program is to monitor global oceanic temperature and salinity in real time. To achieve that goal, Argo floats are deployed over the global ice-free ocean through international collaboration involving more than 20 countries. The floats observe temperature, salinity, and pressure automatically from the surface to 2,000 dbar each 10 days. The observed data are sent to us via satellites, quality controlled in real time, and released to the public immediately. Anyone can use the Argo data freely. Currently, over 3,000 floats cover the world's oceans (Fig. 1).

The ocean plays an important role in climate change and global warming because the heat and water capacities of the ocean are much larger than those of the atmosphere. Recent global warming is causing an increase in upper water temperature due to heat absorption. This water temperature increase brings not only sea level rise through thermal expansion of seawater but also activation of tropical cyclones. Salinity in the surface layer of the ocean also changes along with changes in freshwater exchange at the sea surface; that is, an increase or decrease in precipitation and evaporation. In other words, the surface layer of the ocean records

the changes of freshwater exchange between the atmosphere and the ocean associated with global-scale climate change.

Argo float data clearly shows the global change in surface layer salinity in the last 30 years (Fig. 2); seawater in the high-salinity area became more saline and that in the low-salinity area became fresher. Since the salinity of seawater is strongly influenced by changes in precipitation and evaporation at the sea surface, this indicates that the distribution and strength of precipitation and evaporation also varied.

A typical negative salinity trend is observed in the North Pacific subpolar region (north of 40° N), where the surface ocean condition strongly influences the climate of Japan. The amount of freshwater exchange (precipitation minus evaporation) is 700 mm/year climatologically. The observed salinity change implies an increase of 12 mm/year in precipitation, which is equivalent to 2% of annual mean freshwater exchange. This means that the global hydrological cycle is becoming strengthened in relation to the change of distribution and strength of precipitation and evaporation, which is possibly associated with global warming.



Figure1. Distribution of Argo floats in May 2010. The number of floats exceeded 3,100, operated by 27 countries and the EU. Japan is one of the leaders in the Argo program; the number of floats operated by Japan is the second largest in the world (287). (From the Web site of the Argo Information Center)

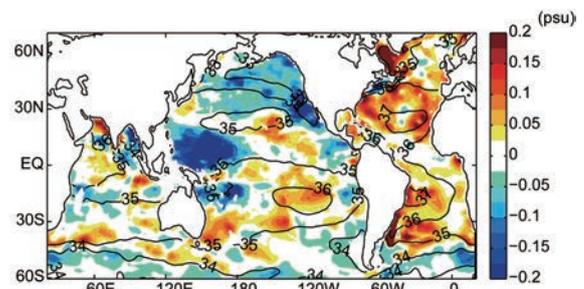


Figure2. Global surface layer salinity anomaly calculated from Argo float data (color; averaged 2003–2007) based on historical salinity data (contour; averaged 1960–1989). Cold colors mean that the salinity decreased from the climatological value in the last 30 years. The salinity in the North Pacific subpolar region is generally negative (Hosoda et al. 2009).

## Acidification of the Subtropical South Pacific Ocean Detected by Transpacific Observation

Transpacific observation was conducted from April through July 2009 with the oceanographic research vessel *Mirai* along an observation line on the 17° south latitude (Fig. 3). The observation project obtained high-precision physical data on water temperature, salinity, current and other parameters along with chemical data on nutrients, dissolved oxygen, total carbon dioxide, total alkalinity, etc.

High-precision data were also obtained in 1994 along this observation line under an international program titled the World Ocean Circulation Experiment (WOCE). The objectives of the 2009 observation program included verifying changes in the ocean environment by comparing two sets of high-precision data on the same line obtained in 2009 and 15 years earlier.

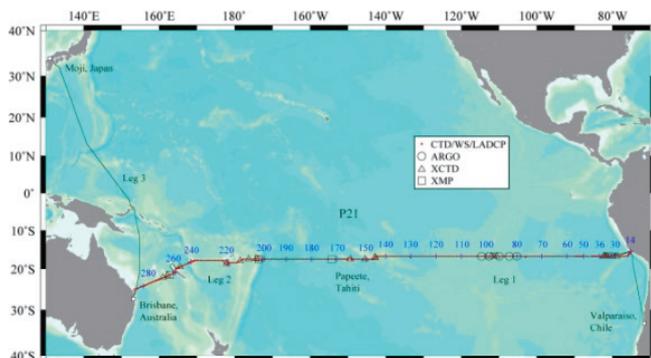


Figure 3. Observation line (WOCE P21 line) provided along latitude 17° south. Water was sampled at 260 points from a maximum 36 layers from the surface to the bottom of the ocean.

Figure 4 illustrates the distribution of degrees of aragonite saturation calculated from total carbon dioxide and total alkalinity data obtained in the 2009 observation. Aragonite is a kind of calcium carbonate ( $\text{CaCO}_3$ ) mineral that makes up the shells and bones of marine organisms. Degree 1 of saturation denotes that sea water is saturated with aragonite, while degrees larger than 1 (the brown area in the Figure) indicate oversaturation, and those less than 1 (the green area) indicate under saturation. As this Figure shows, seawater at depths of less than 200 m is oversaturated in almost the entire area.

Saturation levels in 1994 were calculated from the data of that year in the same manner. Figure 5 shows changes in saturation from 1994 to 2009. Negative values (blue in the Figure) indicate that saturation decreased during this period. It is shown that the saturation of seawater at depths of less than 400 m decreased in almost the entire area. As the area accords with the layer where anthropogenic  $\text{CO}_2$  has accumulated, it is assumed that acidification due to an increase in anthropogenic  $\text{CO}_2$  has caused the decrease in saturation.

In the 2009 observation, temperature increase ( $0.005^\circ\text{C}$ ) and oxygen decrease ( $-2.1 \mu\text{mol kg}^{-1}$ ) are detected in a water mass flowing northward near the southwest Pacific ocean bottom (Lower Circumpolar Deep Water). The flow rate decreased 16% from 13.5 Sv in 1994 to 11.4 Sv in 2009.

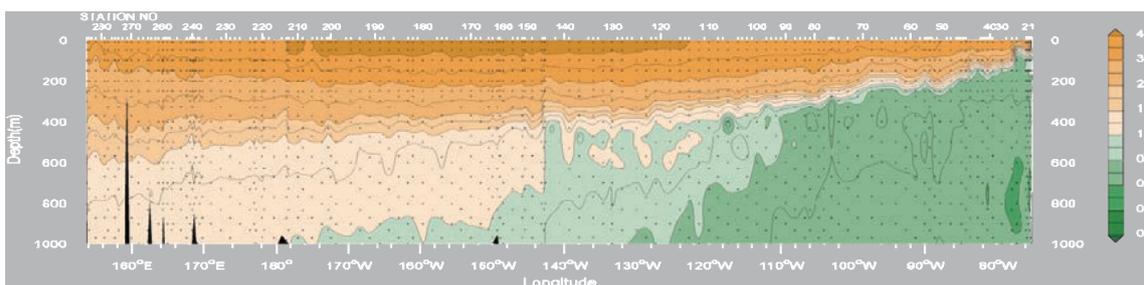


Figure 4. Aragonite saturation distribution calculated from observation data along latitude 17° south

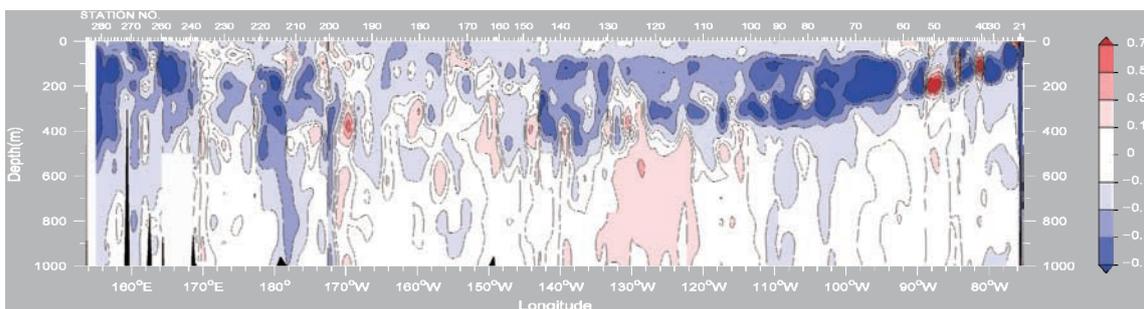


Figure 5. Time change in aragonite saturation along latitude 17° south (1994–2009)

## Factors That Determine Annual Variability of the Ocean Mixed Layer in Winter

In winter, deep convection occur in oceans chilled by cold seasonal winds, resulting in a thickened ocean mixed layer in which water temperature and salt content are vertically even. As depth and water temperature of the ocean mixed layer are factors in variations of oceanic circulation and climate, their long-term fluctuations attract attention. The depth and water temperature of the winter ocean mixed layer are determined by winter seasonal winds by ocean and air conditions in summer and autumn and by the middle-scale oceanic eddies. However, (only) a scant observational studies of these processes have been done.

Using isolines and colors, Figure 6 shows potential density and stratification strength observed with sea-surface moored buoys down to 500 m below the surface layer. The Figure indicates the stratification strength near the surface (< 100 m) was particularly large in 2005 and smaller in 2004 and 2006. It has been verified that variations in solar radiation flux associated with typhoons and depressions in summer and autumn are important for the seasonal stratification strength near the surface (< 100 m).

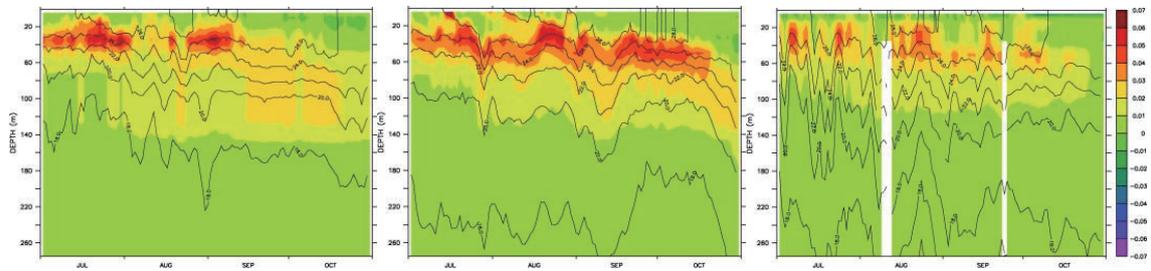


Figure 6. Potential density (isolines) and stratification strength (colors) observed from July through October with sea-surface moored buoys at KEO site (latitude 32.3° north and longitude 144.5° east)—from left to right, in 2004, 2005, and 2006

## 2) Tropical Climate Variability Research Program

The Indo-Pacific tropical area has unique ocean and atmospheric variability that affects the global climate. El Niño, the Indian Ocean Dipole mode phenomenon (IOD), the Monsoon and Madden-Julian Oscillation (MJO; a typical equatorial atmospheric variation) are closely connected with each other and have strong impacts on socioeconomic activities. This program studies these phenomena and their interactions and contributes to the improvement of their predictability. Specifically, the program aims to reveal the mechanisms of fluctuation in El Niño and the IOD based on an observation network of moored buoys. In the western Pacific Ocean and the Indian Ocean, including the Indonesian and Southeast Asian regions, the program also aims to construct high-precision observation networks of the ocean, atmosphere, and land to reveal the water cycling mechanism related to the monsoons, from diurnal to annual variability, as well as the mechanism of the MJO and its effects. An example of recent results of our studies in terms of the mechanism of IOD development is shown.

### a. Indian Ocean Dipole Mode phenomenon

In the Indian Ocean, the IOD event occurs at intervals of several years. Once the event occurs, the sea surface temperature is low in the eastern equatorial area (off Sumatra) and high in the western equatorial area (off the east coast of Africa).

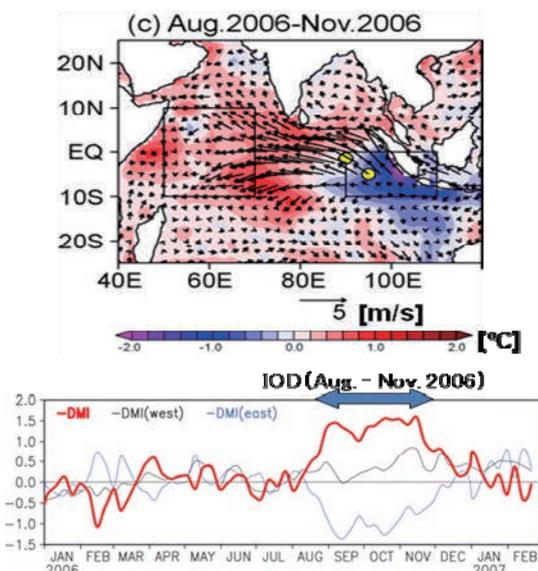


Figure 1. Top: Anomaly of sea surface temperature and sea surface wind vectors during the IOD (August–November 2006). Two yellow dots denote positions of mooring buoy locations. Bottom: The red line shows the change in the IOD index; values larger than 1 indicate a positive IOD condition (January 2006–February 2007). The index is from the difference of averaged sea surface temperature between the western and eastern square boxes areas shown in the upper panel.

This event typically appears in summer, develops into its peak in October, and disappears in December (Fig. 1). The IOD has a strong impact on the world climate, causing abnormal weather in various places with floods or droughts. East Asia, including Japan, tends to have severe summers during the IOD period. In reality, the IOD in 2006 caused serious flood damage in the coastal area of Africa and also severe drought in Australia.

### b. Observed IOD event and its developing mechanism

In recent years, we have been observing subsurface water temperature and current in the eastern tropical Indian Ocean using a mooring buoy array, and we detected an IOD event in 2006 (Fig. 2). This is the first mooring buoy observation to detect an IOD event in the world; we also detected another IOD event in 2007. These events showed a common nature in their thermal structure change. In both events, cooling started near the thermocline in May long before the appearance of the IOD at the surface in August. This cooling is possibly the preconditioning of an IOD event. Moreover, we calculated the heat balance of the surface mixed layer. It revealed that surface temperature change is caused by surface heat flux between the ocean and the atmosphere (short/long wave radiation and latent/sensible heat exchange) under normal conditions.

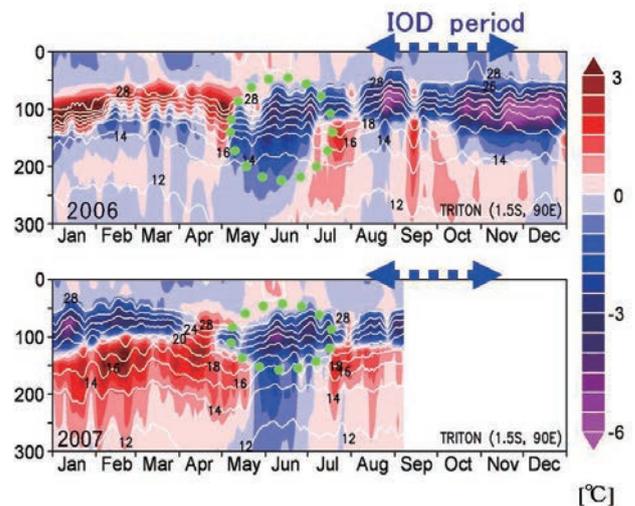


Figure 2. Top: Time/depth section of thermal field (surface to 300 m depth) in 2006 observed by a mooring buoy at 1.5°S, 90°E. Contour interval is 1°C, and anomalies are shown by color level. Bottom: Same as the upper image but in 2007 (white area is an unobserved period). Dotted blue arrows denote the IOD period. Note that subsurface cooling near the thermocline depths appeared in May–June before the IOD in both years.

On the other hand, horizontal heat advection plays a main role in sea surface temperature change during an IOD event. It indicates that cool surface water is transported from other places, i.e. upwelled cool water along the Sumatra coast spreads westward at the surface to the buoy location. In the Pacific Ocean, sea surface temperature in the eastern equatorial area is cooled by upwelling directly in the La Niña condition. It is shown that the surface cooling mechanism of the IOD is quite different from La Niña.

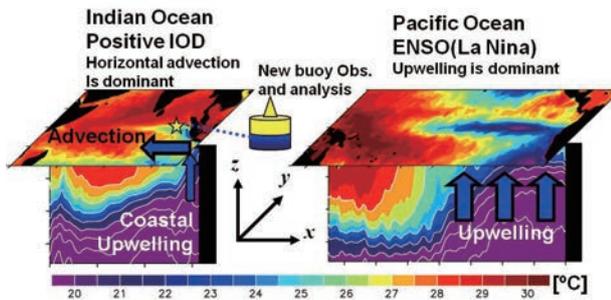


Figure 3. Sketch of the different cooling mechanisms near the surface between ENSO (La Niña) and the IOD (+). In La Niña event, eastern cool water near surface is widely brought by upwelling from deeper depths along the equator (upper right panel). On the other hand, surface cool water is transported from a confined coastal upwelling area in IOD (+) event.

### 3) Northern Hemisphere Cryosphere Research Program

The aim of this research is to reveal past and present conditions and processes of the ocean, snow/ice, atmosphere, and land systems of the northern hemisphere cryosphere. This is achieved through a combination of in situ observation under international collaboration, integrated data analysis based on satellite and archival data, and numerical experiments. Evaluating the impact of global warming on the cryosphere and clarifying the role of this region on the global scale contributes to better future predictions. The primary observation system is described in Figure 1.

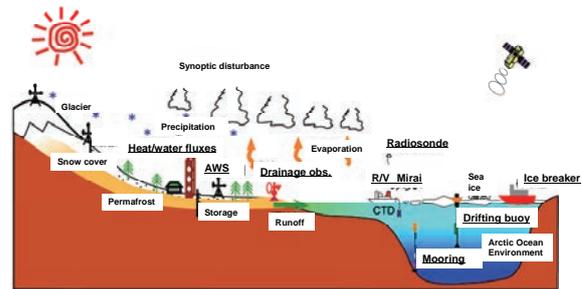


Figure 1. Primary observation structure in the Arctic region and Eurasia.

The main research results are as follows.

(a) Arctic Ocean Study: From collaborative field experiments under the International Polar Year (IPY) program, the first observational evidence of aragonite undersaturation in the deep basins of the world's oceans was found in the Canada Basin of the Arctic Ocean in 2008 (Yamamoto-Kawai et al. 2009). Nishino et al. (2009) indicated that, on the Siberian side of the Arctic Ocean, the loss of sea ice intensifies underwater irradiance and photosynthesis and can thus enhance the biological pump by which carbon dioxide (CO<sub>2</sub>), fixed by photosynthesis into organic matter, is transferred to deeper ocean layers as sinking particulate material (Fig. 2).

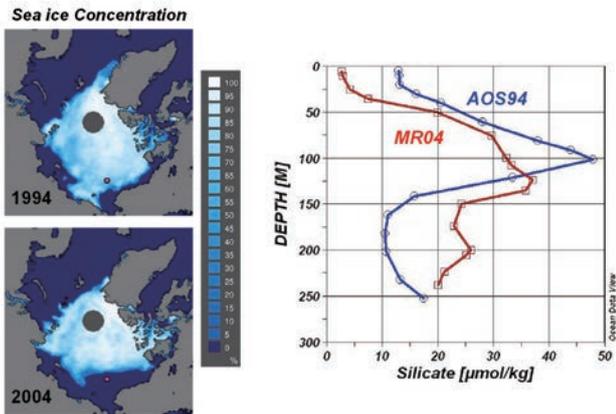


Figure 2. Sea ice concentrations in September 1994 (upper left) and 2004 (lower left) obtained from the National Snow and Ice Data Center, and (right) vertical profiles of nitrate obtained from the Arctic Ocean Section cruise in 1994 (depicted by open circles) and the R/V Mirai cruise in 2004 (open squares). The positions where the profiles were obtained are almost the same, as indicated by dots in the left panels.

(b) Snow and ice variation study: The mass balance of the largest glacier, Potanin, on Altai Mountain was obtained for two years, as -1.03 m for the 2007–2008 budget year and -0.58 for 2004–2005. These negative values for two years show the progress of strong ablation in recent years in this region.

(c) Land hydrology study: From long-term analysis, it was clarified that due to the increase in precipitation and snow fall, moisture and temperature in the active layer radically and simultaneously increased since 2004 in the area of Lena River Basin (Iijima et al. 2009) (Figs. 3 and 4).

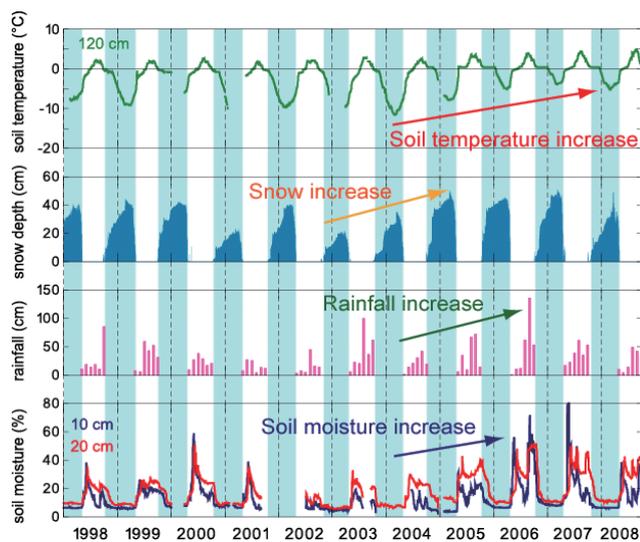


Figure 3. Long-term change in soil temperature, snow depth, precipitation, and soil moisture at Spasskaya Pad (Yakutsk) from 1998 to 2008. Increase in all of the elements since 2004 can be seen (Iijima et al. 2009).

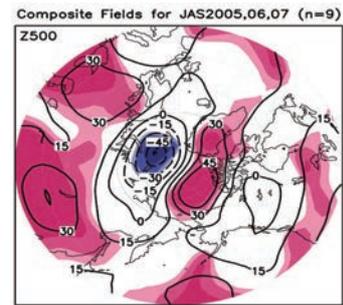


Figure 4. Anomaly of the 5,000 hPa isobar around the Arctic in summer (2005–2007). Blue shows the cyclonic and red shows the anticyclonic tendency. Strong cyclonic activity can be seen in the Siberian side of the Arctic Ocean (Iijima et al. 2009).

(d) Climate study: It was shown that a decrease in the sea-ice meteorological observation buoys in Arctic strongly affects the result of atmosphere reanalysis data (Inoue et al. 2009), and a press release was prepared on this. Also, it became clear that the recent decrease in Arctic sea ice develops an extremely cold winter climate on the Eurasian continent (Honda et al. 2010).

#### 4) Environmental Biogeochemical Cycle Research Program

The importance of understanding the function and change of ecosystems in oceans and land surface has been well recognized for a long time. It also became evident that the “biogeochemical cycle feedback” is one of the major sources of uncertainty in the integrated global scale climate models for future projection. Hence understanding the ecosystem response and feedback to climate and environmental change is urgently requested.

Based on such recognition, we will study how marine and land-surface ecosystem respond and cause feedback to environmental change, aiming to acquire mechanistic understanding to construct better process models. Our study will be based on time-series observation by in situ field observation, satellite remote sensing, and instrumental telemetry in ocean, land and atmosphere as well as model analyses using regional and global scale models. Another aim is to build comprehensive data sets for integrated analyses and for validation of global scale climate models. We also conduct paleoceanographic research for verification of ecosystem and biogeochemical cycle change due to global climate and environmental change.

#### Biogeochemical Study in the Northwestern North Pacific Ocean: Comparison of Subtropical and Subarctic Areas

We positioned two time-series stations for biogeochemical observation in a subtropical (S1: 30°N, 145°E) and a subarctic (K2: 47°N, 160°E) gyres in the northwestern North Pacific Ocean and carried out field observation and installation of time-series mooring systems for ascertaining seasonal changes in sinking particles, etc. The K2, maintained since the early 2000s, has accumulated a large amount of biogeochemical data, and is expected to contribute to the analysis of a long-term trend in time-series change. We carried out a kickoff observation in January–February by research vessel *Mirai*.

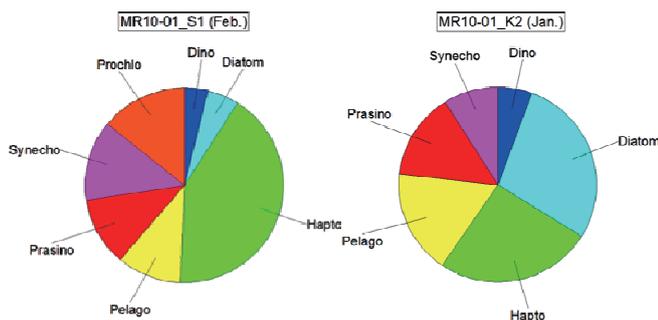


Figure 1. Community structure of phytoplankton observed in January–February 2010. Left: subtropical fixed point S1; right: subarctic fixed point K2

The preliminary result revealed large differences between the subtropical and subarctic zones in the community structures of the primary and secondary producers as well as in the partial pressure of carbon dioxide in the sea surface (Fig. 1).

#### Effects of Mesoscale Eddies on the Ecosystem in the Kuroshio Extension

Aiming to clarify the response of chlorophyll to the change and meandering of the ocean fronts or mesoscale eddies in the Kuroshio extension, we integrated a marine ecosystem model into the eddy resolving Ocean General Circulation Model that can reproduce mesoscale eddies, and we carried out a simulation. As a result, we were able to ascertain the distribution of high-chlorophyll responding to the low sea surface height anomaly area in the northern part of the extension, and the movement of high-chlorophyll water mass along with the westward movement of cyclonic eddies cut off from the Kuroshio extension around 150° and 158° East longitude (Fig. 2). In a cyclonic eddy, along with the vertical convection in the eddy in winter, water of higher nutrients concentration is taken into the mixed layer, accelerates biological productivity, and as a result the chlorophyll concentration in the mixed layer becomes higher. This process was reproduced. In summer, in the west-going eddies, water of high nutrients concentration was lifted up close to the photic layer and maintained high chlorophyll.

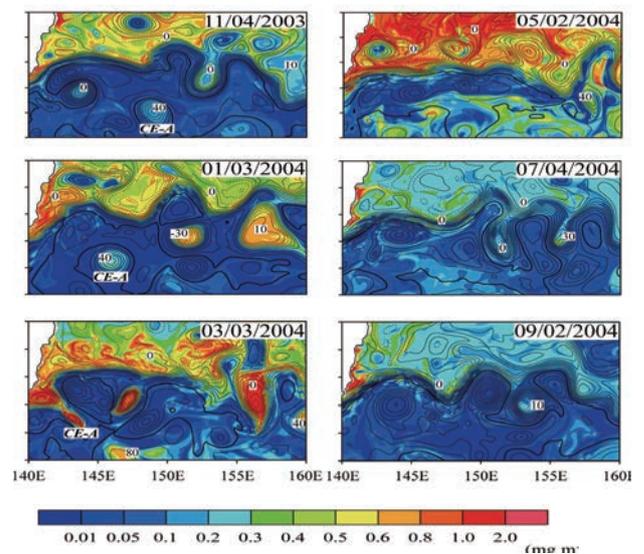


Figure 2. Changes in chlorophyll concentration (color bar) and sea surface height (contour) by simulation (November 2003–September 2004)

## Estimation of the Distribution and Supply Source of Land-originating Debris on the Bering Sea Continental Shelf Area

This study uses a paleoceanologic technique—proxy indicator—and aims to understand amount of material transport from the land area to the ocean at the coastal area, and to estimate its origin. By making the proxy more precise and combining it with model analysis of estimating the mass and origin of the aeolian transport, we also intend to have intraprogram cooperation with the Marine Biogeochemical Cycle Research Team to contribute to the assessment of effects on the marine ecosystem of land-originating material. We investigated the grain size of land-originating debris in bottom sediment of the eastern Bering Sea continental shelf area (Fig. 3) and carried out electron spin resonance and crystallinity analysis of quartz grains. The results showed that even grains larger than 100  $\mu\text{m}$  had been transported to the MC-25 continental shelf area, which is several hundred kilometers away from the Yukon River's mouth near MC-7. The river mouth area probably came close to MC-25 in a glacial period 20,000 years ago when the sea level was about 100 m lower than at present. The median grain size of the several tens of  $\mu\text{m}$ –size grains becomes smaller from the southern part (MC-31, 33) to the western part (MC-22, 26) of the continental shelf, which suggests that the ocean current flowing from the western part toward the southern part over the continental shelf contributes to the transportation and sedimentation of the 10–100  $\mu\text{m}$  size grains. In a wider sea area, except in the southern part of the continental shelf, grains from Cenozoic rocks that exist in the

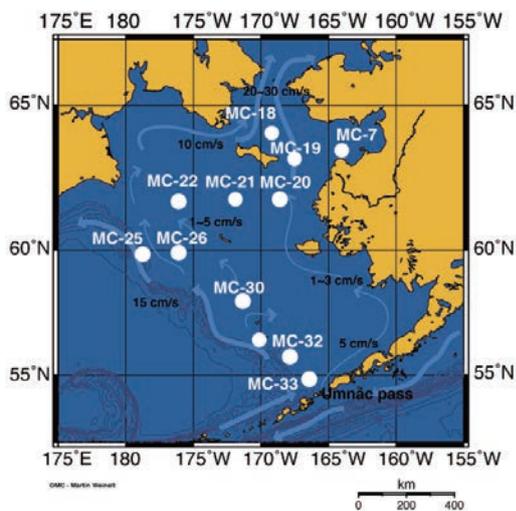


Figure 3. Bottom sediment sampling points in the eastern Bering Sea continental shelf area

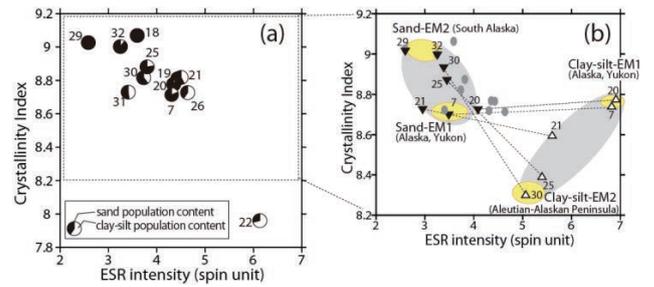


Figure 4. X-Y plots of ESR signal intensity and crystallinity index. They show the sand and clay-silt populations in bulk debris (a) and debris (b) contained in multiple core surface layer samples. Figure (b) also shows the end member of each population. Numbers show the sediment sampling points mapped in figure 3.

middle to lower reaches of the Yukon River were distributed. In the southern part, grains from Mesozoic rocks that exist in the Alaska Peninsula and the southern Aleutian Islands were distributed. At Point MC-22 in the northern part of the continental shelf, we found that a large contribution is by debris grains supplied from the Anadyr River of Siberia.

## Coupling of a Dynamic Global Vegetation Model with an Atmospheric General Circulation Model, and Future Projection

By coupling a dynamic global vegetation model with an atmospheric general circulation model, we took climate and carbon cycle feedback into consideration and carried out a projection experiment using the IPCC emissions scenario A2. If the influence of plants is only on the atmospheric  $\text{CO}_2$  concentration, then the distribution of vegetation is not significantly affected. However, if the climate changes due to the atmospheric  $\text{CO}_2$  concentration changes, then the distribution of vegetation is affected, in particular the northern limit of northern forests moves to a higher latitude (Fig. 5). With this expansion of the northern limit, these areas become carbon dioxide-absorbing areas. This trend coincides with the increasing trend of the recent vegetation index captured by satellite observations.

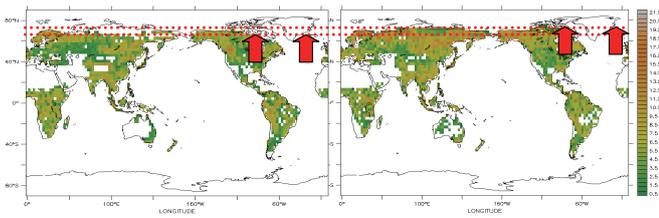


Figure 5. Distribution of carbon bio mass ( $\text{kgC m}^{-2}$ ) in tree trunks and branches. Left, in 2000; right, in 2100

### Advancement of a Regional-Scale Vegetation Change Model with Incorporation of Climate Change and Human Activities

We advanced a mathematical model of vegetation change in Mongolia, incorporating such influences as climate change and human activities. Based on Landsat satellite data, we estimated future vegetation changes in the transitional zones of forests and grasslands in northern Mongolia (Fig. 6).

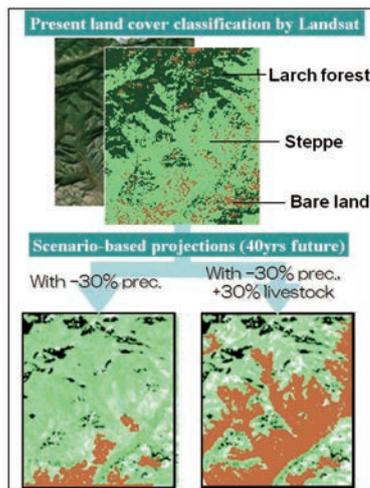


Figure 6. Future estimates in 40 years of vegetation changes, by a mathematical model based on Landsat satellite data, in the transitional zones of forests and grasslands in northern Mongolia

By considering soil water content and plant-eating pressure from livestock, we were able to estimate future vegetation along with change scenarios of climate and human activities. In particular, it was indicated that a sharp increase in livestock could significantly accelerate the denudation of grasslands. We also installed multiple automatic weather stations at important sampling sites in the field, which we used to prove that summer soil moisture variation significantly differs for each type of vegetation, and that positive feedback works between vegetation development and soil moisture.

### Construction of a Data Assimilation System for Atmospheric Trace Components

We completed the first version of a global four-dimensional data assimilation system that uses a local ensemble Kalman filter for atmospheric trace components. This system can be used for chemical transportation models, such as CHASER and ACTM, based on the MIROC global coupled atmospheric chemistry model. As an example, the result of its application to hypothetical carbon dioxide observation data is shown in Figure 7. In a free run, where no data assimilation is done for carbon dioxide and weather parameters, the ensemble experiment does not reduce the error with observed data because of uncertainty derived from the bias within the model itself. When we assimilated only carbon dioxide data to observation data, the error was reduced to about 40%.

When we added assimilation of the weather parameters (wind velocity, temperature, and ground atmospheric pressure), a synergic improvement was seen, and the error became even smaller, to one-third of the original figure. To improve the reproducibility of changes in the distribution of concentrations of atmospheric trace components, it is important to improve the reproducibility of the transportation process by data assimilation of the weather parameters, as well as direct assimilation of observation data on trace components.

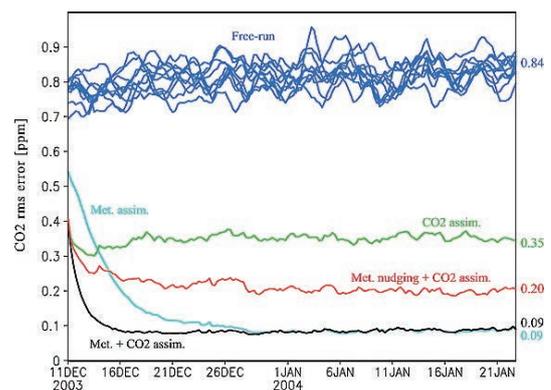


Figure 7. Time series graph of global means of estimated errors for distribution of carbon dioxide concentrations by model. Colors show different experiments; blue: no assimilation; green: carbon dioxide assimilated; red: weather field nudged, carbon dioxide data assimilated; light blue: only weather field data assimilated; black: both weather field and carbon dioxide concentration data assimilated (Miyazaki 2009).

### Assessment of the Influence of Fires on Air Quality on the North China Plain

In June 2006, at Taishan, China, we carried out intensive

observations of ozone, ozone precursor gases and aerosols, etc. to ascertain the situation where air pollutant concentrations reach their maximum and to clarify the mechanism. In particular, the monthly mean ozone concentration at this time of year (June) is reported to exceed 60 ppbv, and the highest hourly value reaches 150 ppbv. However, so far our model simulation and similar model experiments have not easily been able to reproduce this high concentration. June is harvest time for wheat around this area, and high concentrations of air pollution have been observed. The cause is thought to be the large-scale burning of agricultural residue in the fields. This time, therefore, we estimated emissions from agricultural residue using the bottom-up emission estimation method of Yan et al (AE, 2006). In addition, compared with the latter half of June when the impact of biomass burning is small, it became 2–2.5 times as great, namely 200–250 kmol/s.

#### Analysis of Changes in Atmospheric Nitrogen Dioxide Concentrations on the North China Plain

We analyzed temporal change in the NO<sub>2</sub> column concentration

observed over East Asia using the OMI sensor aboard NASA's *Aura* satellite. As a result, we revealed that the atmospheric concentration of NO<sub>2</sub> on the North China Plain has continued to rise since 1996 and reached a record high in 2007–2008 (Fig. 9). First, we verified the OMI data by using the observation data with the multi-axis differential optical absorption spectroscopy (MAX-DOAS) method, which we carried out in the 2005–2008 period. Based on this, we estimated the change in NO<sub>2</sub> concentration from 2005 to 2008 for each grid area of 0.5 degrees of latitude and longitude (approximately 50 km). We detected that some areas had significantly higher rates of increase: 10–15% per year, for example, in Shenyang and its environs compared with Beijing and its environs. In the same period in Japan, a nationwide increase in photochemical oxidants was noticed, while its cause, NO<sub>2</sub> concentration, showed a decreasing or leveling-off trend in Japan. Therefore, we found that not only measures within Japan but also measures beyond national borders must be taken urgently.

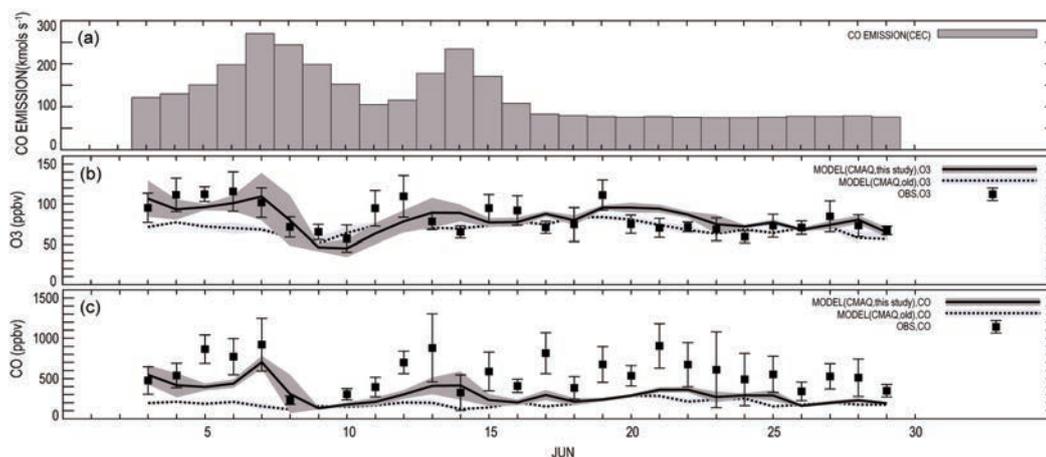


Figure 8. Daily CO emissions in central east China (a), observed and model ozone concentrations (b), and CO concentrations at the mountaintop in Taishan.

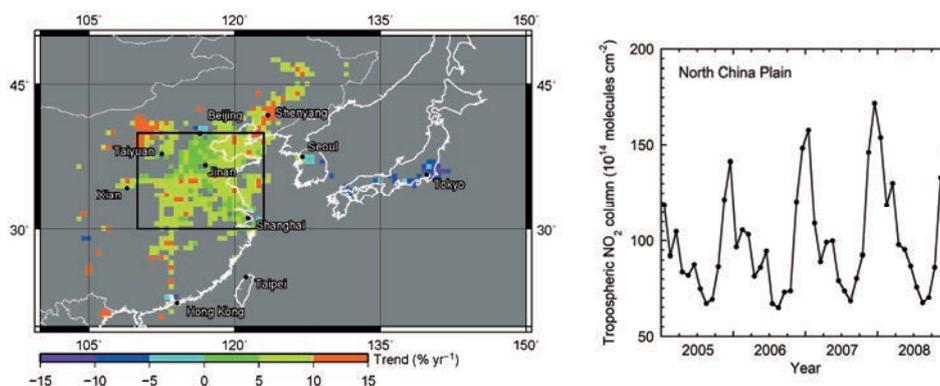


Figure 9. Geographical distribution of the annual increase rate of tropospheric NO<sub>2</sub> column concentrations observed by OMI during the 2005–2008 period (left). Change in the monthly mean of NO<sub>2</sub> in the portion of the North China Plain outlined by the black border (right). (Irie et al. press release, August 7, 2009)

## 5) Global Change Projection Research Program

Projections of global change are investigated by developing an integrated earth system model that includes explicit representations of biogeochemistry, such as carbon-cycle feedback among the ocean, air, and land, and interactions between aerosols and atmospheric chemistry. Mechanisms of climate change and variation are also studied by using paleoclimate simulations and data analyses to clarify how global change, especially global warming, proceeds under the influence of natural variability. Some results from the latter studies are shown below.

### (a) The role of equatorial waves and gravity waves in driving the quasi-biennial oscillation

The roles of equatorial waves (EQWs) and internal gravity waves (GWs) in driving the quasi-biennial oscillation (QBO) are investigated using a high-resolution AGCM with T213L256 resolution (60 km horizontal and 300 m vertical resolution). In the westerly shear of the QBO, EQWs contribute up to ~25–50%. On the other hand, EQWs contribute up to ~10% in the easterly shear phase and GWs with zonal wavelength  $\leq 1,000$  km are the main contributors (Fig. 1). This study provides critical information about the effects of QBO on troposphere-stratosphere changes in the global warming climate.

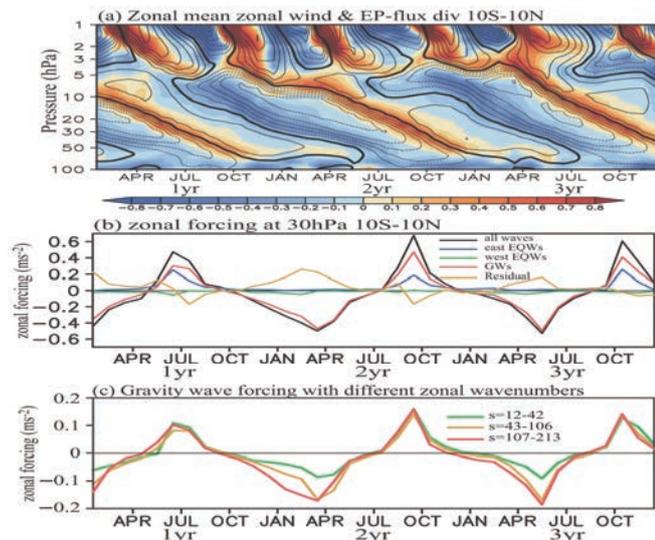


Figure 1. (a) Time–height cross-section of monthly mean zonal–mean zonal wind (contour) and monthly mean EP-flux divergence (colors) at 10°S–10°N. (b) Time variation of EP-flux divergence due to all waves (black), eastward EQWs (blue), westward EQWs (green), and gravity waves (red) at 30 hPa; (c) EP-flux divergence due to  $12 \leq s \leq 42$  (green),  $43 \leq s \leq 106$  (yellow), and  $107 \leq s \leq 213$  (red) (Kawatani et al., JAS 2010).

### (b) Influence of winter and summer surface wind anomalies on summer Arctic sea ice extent

Sea ice in the Arctic in summer has declined during recent decades. In this study, we consider how the winds force changes in Arctic sea ice extent from one year to the next and how they might have contributed to the observed multidecadal decline in ice extent. In both winter and summer seasons, meridional wind anomalies to the north and east of Greenland are correlated with sea-ice extent, presumably because they modulate the export of ice through Fram Strait (Fig. 2). Anticyclonic wind anomalies over the Beaufort Sea during summer favor low sea ice extent (Fig. 2b). The combined effect of winter and summer wind forcing explains roughly one-third of the downward linear trend of sea ice extent. The summer wind forcing has contributed to the record-low values in recent summers. The paper was reported as “Research Highlights” in *Nature*.

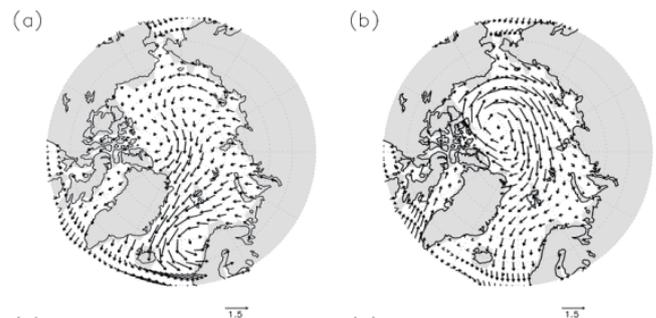


Figure 2. (a) Wind at 925 hPa in winter regressed on the inverted September Arctic sea ice extent. (b) As in (a), but in summer (Ogi et al., GRL 2010).

### (c) Contribution to the global sea level by changes in ice-sheet volumes simulated by a paleoclimate model

Global sea level reconstructions show that the sea level at the last glacial maximum (LGM, around 20,000 years ago) was lower than the present day by about 120 m. In order to estimate the contribution from the Antarctic ice sheet from the LGM to the present day, the maximum possible influence on the ice volume is evaluated by assuming the areas of grounded-ice regions. Sensitivity experiments are performed to separate the effects of changes in ice-grounded areas in major ice-shelf areas (Fig. 3).

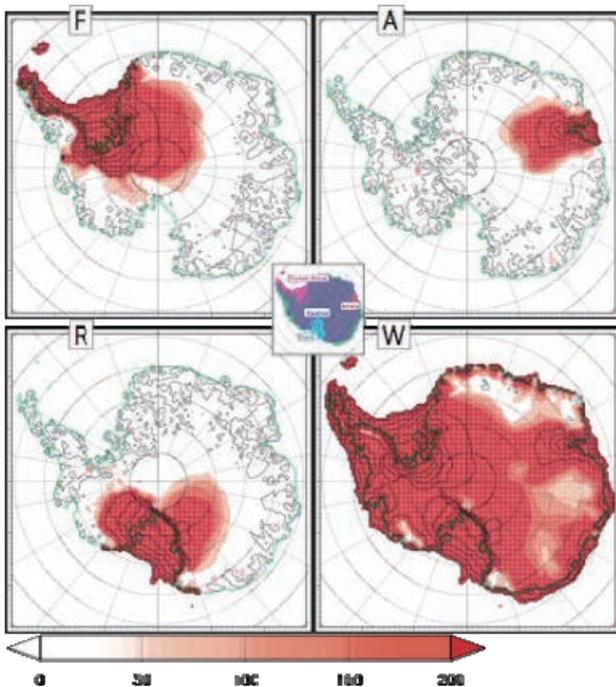


Figure 3. Differences in simulated thickness (m) obtained by sensitivity experiments of advance in the grounded-area A, F, R, and W, relative to the thickness obtained by the control experiment for the present day. The prescribed areas of experiments A, F, and R are Amery + Control, Filchner-Ronne + Control, and Ross + Control, respectively. The areas of experiment W is the entire surroundings (Saito and Abe-Ouchi, *Ann. Geology* 2010).

## 6) Climate Variation Predictability and Applicability Research Program

Our everyday life and socio-economic activities are strongly affected by natural variability in the ocean and atmosphere, such as short-term climate variations, including El Niño and Indian Ocean Dipole events, significant seasonal variability associated with the Asian monsoon, and variations of the Kuroshio Current south of Japan. We explore mechanisms of such climate and ocean variability over time periods ranging from months to years, and conduct experimental predictions, using numerical models with various complexities, to improve prediction skills of the variations. Validation of the predicted results and feedbacks therefrom are our fundamental and key approach to accomplish the objectives. Basic research on how to apply the predicted results to the societal benefit is also our important research theme.

### Low-latitude Climate Prediction Research

We continued to study the predictability and causal links of climate variation modes in the tropics, including the El Niño–Southern Oscillation (ENSO), and found that, among others, the Indian Ocean Dipole (IOD) index helps to improve empirical predictions of ENSO; this was published in *Nature Geoscience*. In addition, we investigated the mutual influence between ENSO and the IOD together with the effect of global warming on natural climate variability through SINTEX-F coupled model numerical experiments. Results indicated that the global SST trend, if predicted correctly, would improve predictability of short-term climate variations. We also studied the unique ENSO event in 2009, in which warm SST anomalies were seen even in the western Pacific, and found that the unusually warm central Pacific in this event negatively affected the Indian summer monsoon rainfall.

One of our important activities is to conduct real-time monthly climate prediction experiments and to continue to post the results on the JAMSTEC website. The SINTEX-F model correctly predicted the evolution and early termination of the 2009 El Niño (Fig. 1), and owing to its world-leading achievements so far, our prediction output received the considerable attention of such international media outlets as *The Weekly Times* in Australia, *The Hindu Business Line* in India, as well as several domestic newspapers and television channels.

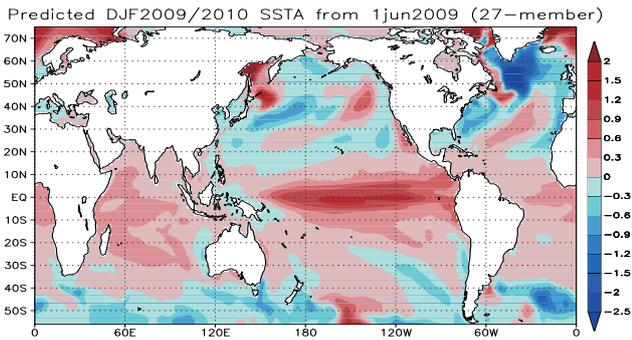


Figure 1. Predictions of the El Niño condition averaged over 3 months (December 2009–February 2010) made in June 2009. The contour indicates the SST anomaly.

### Mid- and High-latitude Climate Predictability Research

Although the importance of a possible feedback mechanism from the ocean to the atmosphere in the midlatitudes is now actively being investigated from the viewpoint of climate dynamics, our understanding of the processes involved is still limited. In order to find a way to understand them, we focused on a couple of important processes: one is the influences of oceanic frontal zones on the distribution of sea surface heat flux, and the other is how atmospheric storm track activities are influenced by that.

Looking into the oceanic frontal zone in the South Indian Ocean simulated in a high-resolution integration of CFES (coupled GCM for the Earth Simulator), we found that oceanic frontal structure can induce distinct cross-frontal contrast of heat release from the ocean to the atmosphere. Also, we showed the mechanism for maintenance of a frontal surface air temperature (SAT) gradient against the relaxing effect of atmospheric disturbances. Collaborating with a research team at the Earth Simulator Center, we further showed that this mechanism is also operative in the Kuroshio-Oyashio Extension region and that the maintained SAT gradient is important for recurrent development of atmospheric disturbances.

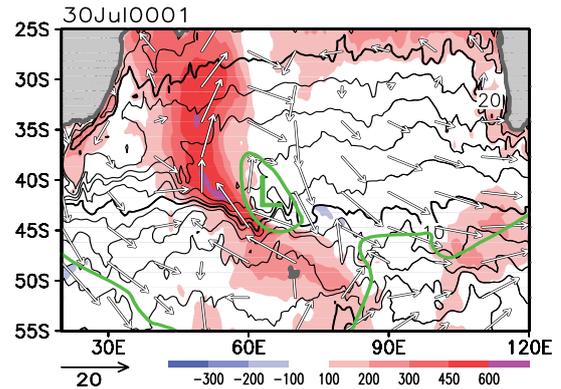


Figure 2. Equator-bound winds (vectors) to the west of a low-pressure system (green L) advect cold air onto the warmer side of the SST front (dense black contour region), and this results in strong heat release from the ocean to the atmosphere (shaded areas). We showed the process through which this heat can maintain a strong meridional SAT gradient. This SAT gradient makes it possible for atmospheric disturbances to develop recurrently over the SST front. Green and black contours are for sea level pressure (1,000 hPa) and SST ( $^{\circ}\text{C}$ ), respectively. Vectors are for sea surface wind ( $\text{ms}^{-1}$ ), and shaded areas indicate the sum of upward latent and sensible heat fluxes ( $\text{Wm}^{-2}$ ).

### Ocean Downscaled Prediction Research

We are conducting comprehensive studies of three-way interactions among ocean currents, tides, and wind-waves for the first time under coupling conditions. For example, our operational high-resolution Kuroshio forecasting system coupled with explicit tidal forcing under quite realistic ocean conditions is the first attempt to do so in the world oceanic community. Another model that couples ocean currents with wind-waves can reproduce more realistic sea surface temperature variations compared with noncoupling models, due to enhancement of vertical mixing in the upper layer.

In this fiscal year, we have also started to produce long-term ocean reanalysis data in Japan's coastal areas and to distribute them to the research community as possible research infrastructure. These results and activity help to improve the skill of our operational ocean forecasting models and to return profits to the various users of the forecasting model outputs.

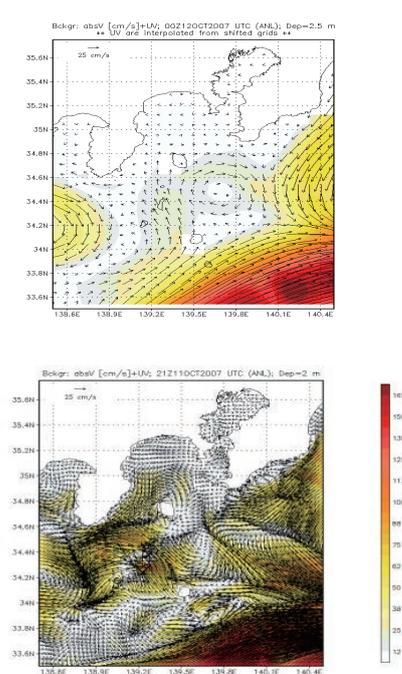


Figure 3. Snapshots of our ocean forecasting models. Top: without tides. Bottom: with tides. Coupling the ocean current and tide results in better representation of detailed features of the surface flow field.

### Climate Variation Informatics Research

The main goals of this research activity are twofold: one is to accelerate application studies using short-term climate prediction, and the other is to study basic dynamical processes of the atmosphere and oceans that may play key roles for the predictability of the coupled system. For the first theme, we are actively involved in the application study parts of the SATREPS–South Africa project, supported by JICA–JST, under collaboration with the Application Laboratory, in addition to submission of a new joint proposal with the International Rice Research Institute on using short-term climate prediction data for rain-fed rice production activities in Southeast Asia.

For the second theme, we continued to develop a high-resolution nonhydrostatic oceanic model that can be run either for stand-alone use or as a coupled one, while we summarized our study on the energetic properties of oceans. In addition, collaborating with the mid- and high-latitude climate predictability team, we discovered noticeable oceanic effects of the Kuroshio-Oyashio Extension as well as the Japan Sea on the summertime climate around Japan, briefly explained in Figure 4.

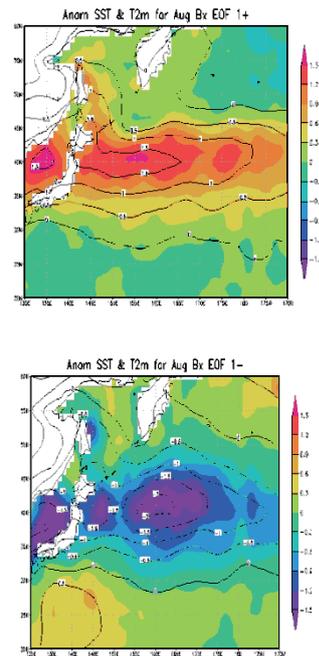


Figure 4. Past climate data during summer shows that the SST anomaly in the Kuroshio-Oyashio Extension and the Japan Sea affected the position of the upper atmospheric jet. The northward shift of the jet causes warmer surface temperatures (top) while the southward shift causes colder temperatures (bottom).

## 7) Advanced Atmosphere-Ocean-Land Modeling Program

There still remains considerable uncertainty in weather forecasting more than one week ahead, as well as in predictions of climate change. It is difficult for present-day computers to achieve significantly higher precision on these issues. Fortunately, their performance is expected to be better in future. Anticipating future performance of computers in approximately 5 to 10 years, we shall develop numerical models with drastically higher precision than present ones for the purpose of contributing to predicting changes in the global environment from a medium or long-term view. For this purpose, we are progressing our research to reproduce various processes in the atmosphere, ocean, and land, etc., in detail and with precision by numerical models, and we are checking them with observed facts.

### Introduction of a New Sea Ice Model

In climate models, sea ice plays an important role. The condition of polar sea ice affects climate change and vice versa. The recent decrease in sea ice in the Arctic Ocean during summer is a good example of this. Therefore, computing sea ice values more precisely than ever plays an essential role in developing a climate model with higher precision.

We have introduced a new sea ice model to compute sea ice values with higher precision. In the conventional model, we assumed that the thickness of sea ice contained in a computation grid was uniform. However, in reality, ice of different thickness is known to exist within the grid scale of the model resolution in use at present. Moreover, heat exchange between the ocean and the

atmosphere significantly depends on the thickness of the sea ice. This means that heat exchange between the ocean and the atmosphere was not correctly computed in the conventional model, in which the thickness of sea ice within a grid was assumed to be uniform. Instead, a distribution of thickness can be reflected in the newly introduced sea ice model. Thanks to this additional effort, heat exchange between the ocean and the atmosphere can be computed with higher precision.

Figure 1(a) shows the result computed in the new sea ice model. This model has approximately 50 km of horizontal resolution and 50 vertical layers in the Arctic Ocean and is driven by daily changing wind. Giving observed values to temperature and salt in the model, we computed, via integration with respect to time for 170 years from the static initial condition, the distribution of sea ice in March of the final year. It accurately reproduces the range of existing sea ice and distribution of thickness and other factors. For the purpose of comparison, Figure 1(b) provides a conventional example computing heat exchange between the ocean and the atmosphere under the assumption that the thickness of sea ice within a grid is uniform. Compared with Figure 1(a), thick sea ice does not appear to form, which results in underestimation of the thickness of sea ice in the conventional computing method.

Thanks to the new sea ice model, we have increased the means to verify model precision. Distribution of sea ice by thickness exists as observed quantities. Thus model-computed distribution of sea ice by thickness can be compared with observations. This enables us to investigate climate reproduction in a model in more detail, and it seems to be useful to construct a model with even higher precision.

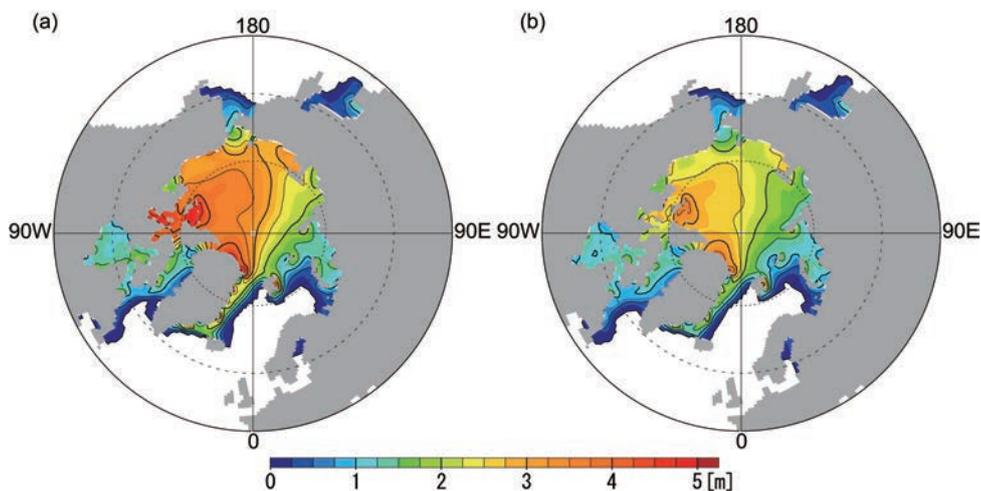


Figure 1. Distribution of sea ice in March computed in the model. (a) The computed result when distribution of sea ice thickness within a grid is considered. (b) The computed result when sea ice thickness within a grid is assumed to be uniform. Compared with Figure 1(a), thick sea ice does not form.

## (2) Institute for Research on Earth Evolution (IFREE)

### Outline of IFREE

IFREE comprises two programs: the Basic Research Program and the Advanced Research Program. The Basic Research Program aims to understand the dynamics and the evolution of the earth system and interactions between its subsystems of interplanetary space, atmosphere, ocean, crust, mantle, and core by using geophysical and geological observations, computer simulations, chemical analyses, high pressure and temperature experiments, and other laboratory experiments. JAMSTEC's big facilities such as research vessels (with submersibles), the Earth Simulator supercomputer, the deep-sea drilling vessel *Chikyu*, and the ocean-bottom observation network are fully utilized. One final goal of IFREE is to comprehensively understand earth's evolution via multidisciplinary research. To achieve this, the Advanced Research Program of IFREE is integrating and further developing the results of the Basic Research Program and conducting cutting-edge, comprehensive, and challenging projects. Research work at IFREE covers lithosphere dynamics, deep-earth dynamics, geochemical evolution, integrated study of the earth system, megathrust earthquake research, the ocean-bottom network, studies linked to the Integrated Ocean Drilling Program (IODP), and various exploratory research projects.

### Tearing of Stagnant Slab

The Pacific plate, the largest plate on the globe, moves WNW at a speed of 8–10 cm per year and is subducted under the Japanese islands (Fig. 1). Among the slabs subducted from the Kurile, Japan, Izu-Bonin, and Mariana arcs, the northern Kurile and Mariana slabs penetrate the 660-km seismic discontinuity into the lower mantle down to depths of ~900 km. On the other hand, the southern Kurile, Japan, and Izu-Bonin slabs bend sharply and flatten over the 660-km discontinuity. Their shape remains slablike, implying that the slab behaves as a thin elastic plate undergoing deformation only by bending or tearing, not by internal shearing. Here, we show that slab tearing occurs as a consequence of slab flattening.

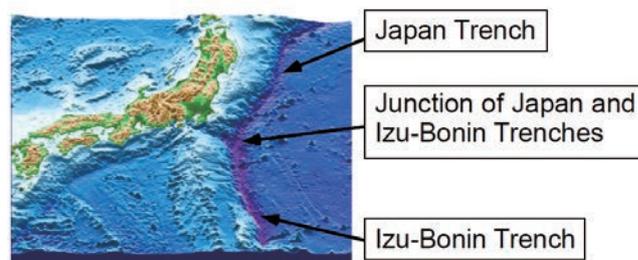


Figure 1. Map of the Japanese islands. The Japan and Izu-Bonin trenches are connected off Kanto with an L-shaped junction.

The idea is schematically illustrated in Figure 2, which shows the Japan and the Izu-Bonin slabs meeting to form a cusp-like junction. Bending the two slabs to the horizontal requires a separation of their horizontal parts with a gap in between (Fig. 2A). The resultant stress concentration at the tip of the slab gap allows back-propagation of the slab gap to shallower depths along the junction (Fig. 2B).

We present three lines of evidence to show this slab gap. The first is the absence of both deep seismicity and slab-related velocity anomalies in a place corresponding to the slab gap. The second is the occurrence of lateral tension-type earthquakes near the tip of the slab gap. The third is the finding of a near vertical plane that may correspond to a side wall of the slab gap. We obtained a three-dimensional P wave velocity model for the whole mantle by inverting more than 8 million first arrival times from the bulletins of the International Seismological Centre and manually chosen P and PP arrival times. The fast P wave speed anomalies near Japan (Fig. 2) reveal laterally continuous subducting slabs along the Kurile, Japan, and Izu-Bonin arcs to depths of 300 km (Fig. 3A). The Japan and Izu-Bonin slab images are, however, disconnected from each other at their junction (~35°N) just below 300 km (Fig. 3B), indicating a slab gap. The gap persists to depths of more than 600 km and westward to the Yellow Sea across the Korean peninsula. As shown in Figure 3, many slab earthquakes around 35°N have occurred at depths shallower than ~300 km, whereas deeper activity is sparse below 410 km. The second piece of evidence is focal mechanisms of events near the gap. A small cluster of hypocenters is seen within the slab gap at depths of 350–410 km (Fig. 3C). Focal mechanisms for the clustered events are different from the typical down-dip compression mechanisms for neighboring events. Instead, they have lateral-tension axes parallel to the strike of the slab (Fig. 2). These events have been interpreted as hinge-faulting that may be responsible for the small but abrupt change in the strike and dip of the deep seismic zone across the arc-arc junction.

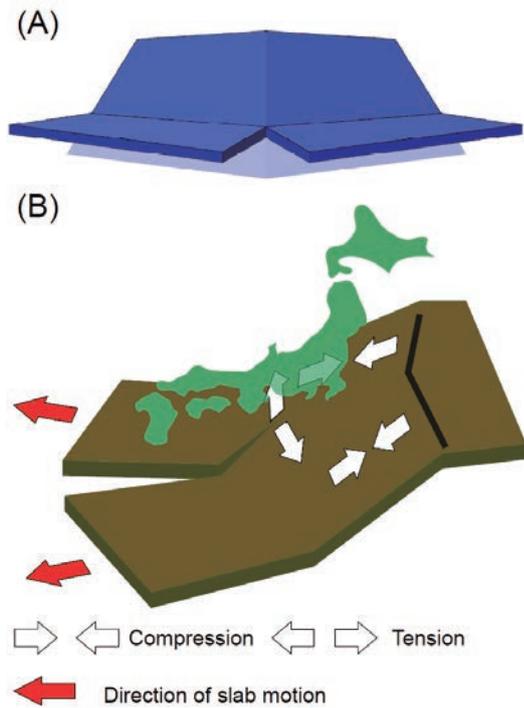


Figure 2. A schematic illustration of the tearing slab. (A) The slab must tear before it lies horizontally in the mantle transition zone. (B) A schematic image of the tearing slab beneath Japan.

The third piece of evidence is a seismic waves generated by a slab edge. Tearing at the junction creates the southern edge surfaces of the Japan slab and the northern edge surface of the Izu-Bonin slab with the slab gap in between. We observed an unknown phase between the P and S arrivals for the 398-km-depth earthquake of 2003 on the Hi-net seismograms only in central Japan. The X phase arrives about 20 s after the direct P wave with an apparent velocity that is slightly higher than that of the direct P wave. We interpret the X-phase as an S-to-P converted phase and found the S-to-P conversion plane that coincides with the northern edge of the Izu-Bonin slab.

Deep slab gaps have been observed in various regions. Most of them are associated with detachment of a deeper part of the slab from the shallower part. For the first time we are reporting the slab tear and consequent slab gap associated with slab stagnation.

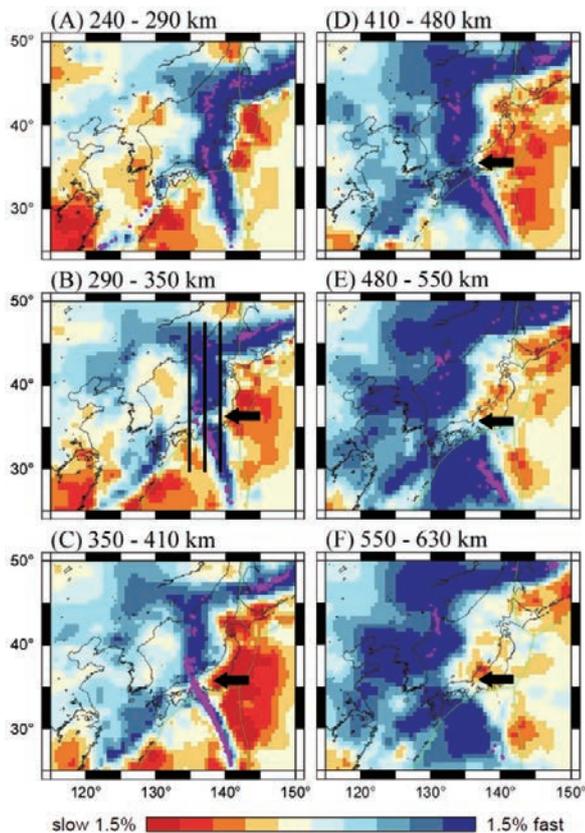


Figure 3. P-velocity anomalies beneath Japan and its vicinity. Red and blue colors represent slower and faster velocities than average, respectively. The cold subducted slab is represented by blue color. Violet dots represent epicenters of earthquakes in the subducted slab. Arrows indicate the tearing part of the slab found in the present study.

IODP NanTroSEIZE Drilling Research: Progress Report and Future Perspectives

The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) program is designed to investigate fault mechanics and seismogenesis along subduction megathrusts through direct sampling, in situ measurements, and long-term monitoring in conjunction with allied laboratory and numerical modeling studies.

In 2007 and 2008, IODP Expeditions 314, 315, and 316 were carried out as NanTroSEIZE Stage 1. A transect of eight sites was selected for riserless drilling to target the frontal thrust region, the midslope megasplay fault region, and the Kumano forearc basin region (Fig. 4). Most excitingly, we found several lines of evidence that indicate recent and present activity of the megasplay and frontal thrust faults, although all drill sites were considered to be in the aseismic portion. Also, many observations, such as borehole breakout images or core fractures, suggest a complex history and spatial variation in the stress field around the drill sites (Fig. 5).

In 2009, the second stage of NanTroSEIZE was carried out,

including IODP Expeditions 319 and 322. Expedition 319 included riser drilling, analyses of cuttings and core samples, downhole measurements and logging, and casing at Site C0009 in the Kumano forearc basin as well as riserless drilling, logging while drilling (LWD), casing, and observatory operations at Site C0010 across a major splay fault that bounds the seaward edge of the forearc basin near its updip terminus. Site C0009 marked the first riser drilling in IODP history. This allowed several scientific operations unprecedented for the IODP, including carefully controlled measurements of in situ pore pressure, permeability and minimum principal stress magnitude, real-time mud gas analysis, and laboratory analyses of cuttings throughout the entire riser-drilled depth range. We conducted a leak-off test at one depth interval and successfully deployed the wireline Modular Formation Dynamics Tester 12 times to directly measure in situ stress magnitude, formation pore pressure, and permeability. After casing the borehole, a long-offset (up to 30 km) two-ship active seismic experiment (offset VSP; Fig. 6) was carried out, recording shots

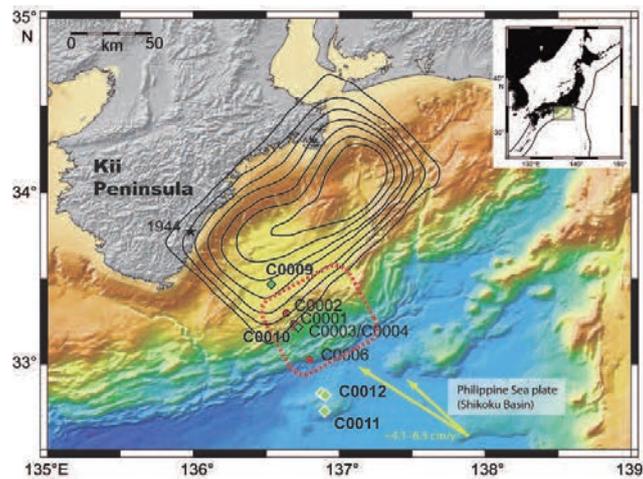


Figure 4. Index map showing the location of NanTroSEIZE drillsites C0001 to C0012 in the Nankai seismogenic zone off Kii Peninsula. [Solid contours are the asperity of Tonankai earthquake. Shallow very-low-frequency events occur in dashed region.]

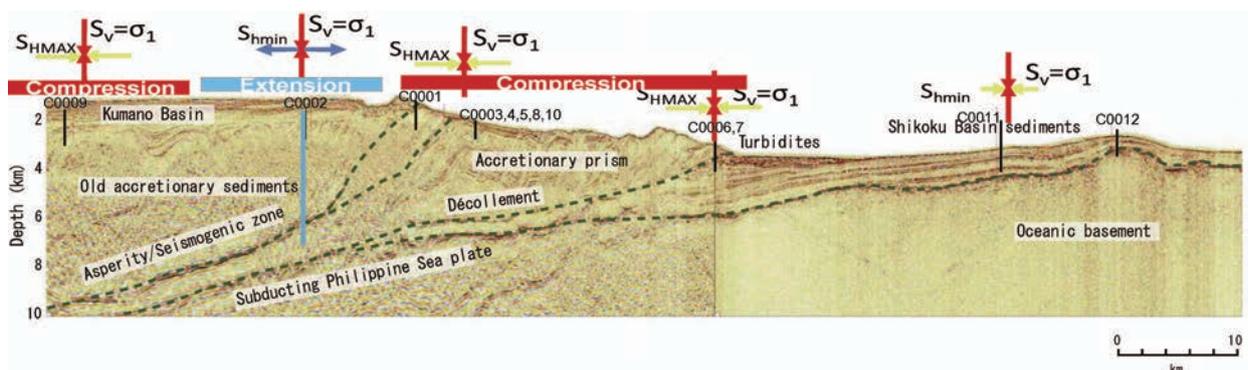


Figure 5. Seismic reflection profile across Nankai Seismogenic zone. Interpreted faults are shown as broken lines. Stress fields inferred from logging and core data at some drill sites are shown as colored arrows.

within the borehole to image the megasplay and master décollement beneath the borehole, and to evaluate seismic velocity and anisotropy of the forearc basin and accretionary prism sediments around the borehole.

At riserless Site C0010, operations included drilling with measurement while drilling (MWD) and LWD across the megasplay fault to 555 m below the seafloor (mbsf), casing the borehole with screens at the depth of the fault, conducting an observatory dummy run, and installing temporary pore pressure and temperature monitoring.

Expedition 322 (Subduction Inputs) was designed to document characteristics of incoming sedimentary strata and igneous basement prior to their arrival at the subduction front. Coring was conducted at two sites in the Shikoku Basin on the subducting Philippine Sea plate. Site C0011 is located on the northwest flank of the Kashinosaki Knoll, whereas Site C0012 is located near the crest of the knoll. Coring at Site C0011 failed to reach the total depth target. Coring at Site C0012, however, penetrated 33 m into igneous basement and recovered the sediment-basalt interface intact at ~540 mbsf. Site C0012 finally provides a reliable geochemical reference site for the subduction zone.

In 2010, IODP Expedition 326 is planned as Stage 3 of NanTroSEIZE, in order to begin drilling of the main ultradeep borehole with “top hole” operations, casing deployment to ~860 mbsf, and installation of the wellhead to be used in later deep riser drilling at Site C0002. Expeditions 332 and 333 are also planned for 2010 *Chikyu* operations for riserless borehole observatory installation and complementary drilling in the subduction input sites. We plan to drill through the seismogenic portion of the plate boundary fault at ~7,000 mbsf by 2013.

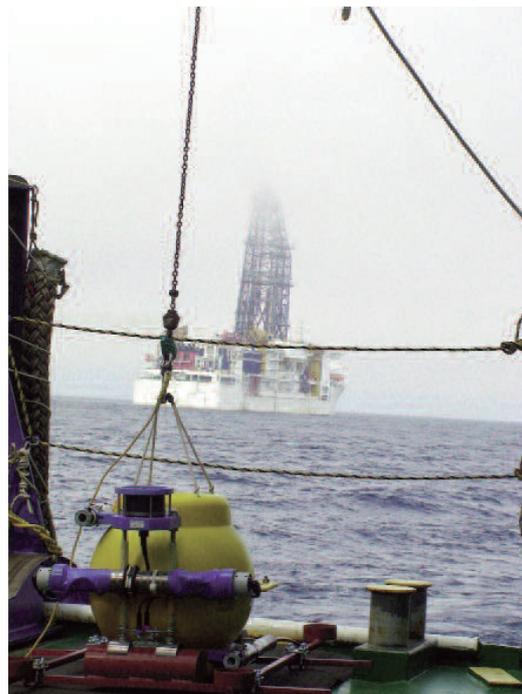


Figure 6. Ocean-bottom seismograph onboard R/V *Kairei* (front) and D/V *Chikyu*. Preparing for offset vertical seismic profiling (VSP) during IODP Expedition 319 in 2009.

## New Insights into Andesite Genesis

How andesite is generated has long been a central question of igneous petrology. The reason for this is twofold. First, andesite erupts in more than 80% of arc volcanoes, typifies subduction zone magmatism that creates over 20% of current terrestrial magmatic products, and is the most dominant volcanic rock in mature continental arcs. Second, the continental crust, the most differentiated end-member among components within the solid earth, is overall andesitic or intermediate in composition (e.g., Taylor 1995, Rudnick 1995, Rudnick and Gao 2003). Knowledge of andesite genesis should therefore provide key constraints on the origin of continental crust and differentiation processes during the evolution of the solid earth.

Two distinctive differentiation trends, tholeiitic and calc-alkalic, are recognized in the Zao volcano, which is located immediately behind the volcanic front of the NE Japan arc. The genetic relation between these two magma series is critical for a better understanding of andesite genesis because they often coexist in close spatial and temporal proximity in arc volcanoes. Petrographic features indicative of “disequilibrium,” such as reversely zoned pyroxene phenocrysts, the wide and bimodal compositional distribution in Ca/(Ca+Na) of plagioclase phenocrysts, honeycomb textures and dusty zones that these plagioclase phenocrysts often exhibit, and the presence of olivine-pyroxene pairs with different Mg/Fe, are observed exclusively in calc-alkalic rocks. In tholeiitic rocks the Sr isotopic ratios of plagioclase phenocrysts, determined both by micromilling combined with thermal ionization mass spectrometry as well as laser-ablation inductively coupled plasma mass spectrometry techniques, are constant at 0.7042–0.7044. On the other hand, those in calc-alkalic rocks (0.7033–0.7042) show more complex characteristics, which can best be understood if at least three end-member components, a calc-alkalic basaltic melt, a tholeiitic basaltic melt, and a tholeiitic felsic melt, contribute to the production of mixed calc-alkalic magmas.  $^{87}\text{Sr}/^{86}\text{Sr}$  and trace element compositions of the least-differentiated basalt magmas, which are inferred from the composition of the calcic plagioclase (Ca/(Ca+Na) > 0.9), suggest that two types of basaltic magma, calc-alkalic and tholeiitic, exist beneath the volcano. The tholeiitic basalt magma possesses higher  $^{87}\text{Sr}/^{86}\text{Sr}$  than the calc-alkalic magma (0.7042 versus 0.7038) and shows characteristic trace element signatures consistent with the presence of plagioclase and

amphibole as melting residues (Fig. 7). This suggests that the tholeiitic magmas are produced via anatexis of amphibolitic crust caused by underplating and/or intrusion of mantle-derived calc-alkalic basalt magmas into the sub-Zao crust (Fig. 8) The mantle-derived calc-alkalic basalt magma mixes with crust-derived tholeiitic melts to form calc-alkalic andesite magmas (Fig. 8). The hypothesis proposed here requires the general consensus that calc-alkalic magmas are produced with greater contributions of crustal component than tholeiitic magmas to be revised and even discarded.

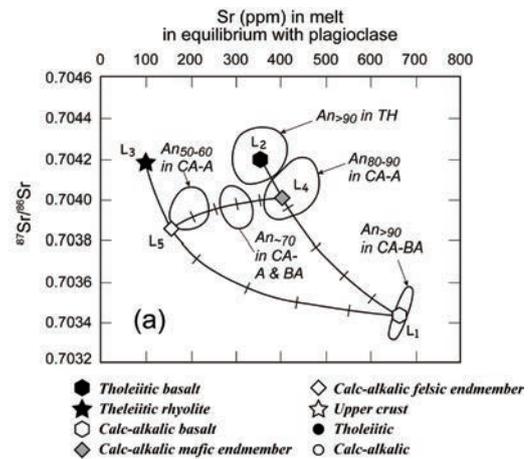


Figure 7. Variations in  $^{87}\text{Sr}/^{86}\text{Sr}$  and Sr concentrations for the melt components inferred from the plagioclase compositions. Three principal end-member components (L1, L2, and L3) are required to explain the calc-alkalic melt components, L4 and L5, which further mix to produce calc-alkalic melts that are able to crystallize An-poor plagioclase. TH: tholeiitic; CA: calc-alkalic; BA: basaltic andesite; A: andesite.

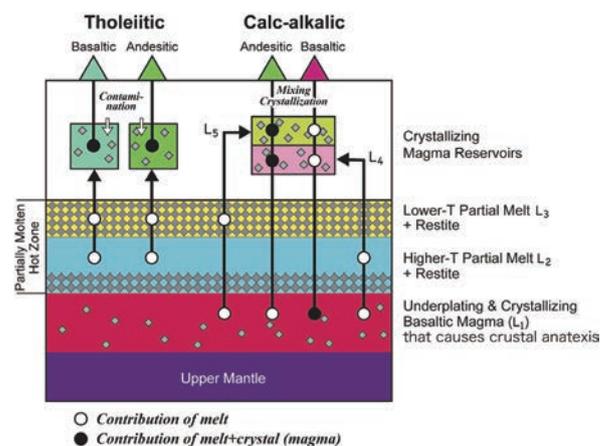


Figure 8. A schematic model for the magma plumbing system and the magma differentiation process in the Zao volcano. For the compositional characteristics of melts (L1 to L5) contributing to tholeiitic and calc-alkalic magmas refer to Fig. 7.

### (3) Institute of Biogeosciences (Biogeos)

#### Marine Biodiversity Research Program

We, the people of planet earth, are facing a big problem: global change in natural environments. If we think about the future of the planet, its biodiversity and its ecosystems, it is important for us to address many questions: How do living organisms interact with each other and with their environments? How do they change their habitats? How are their distributions determined and changed? How is their evolution affected by their environments? In the Marine Biodiversity Research Program, we are studying various marine organisms, especially deep-sea organisms, to understand their diversity, distribution, and the mechanisms underlying how diversity and distribution have been produced and evolved. We are also searching for useful enzymes and bioactive substances hidden in this biodiversity to contribute to betterment of human societies moving into the future. This research program comprises 7 research teams.

#### Biodiversity in the Mesopelagic: the Effects of Global Environmental Change

The larvae of the jellyfish *Pandea rubra* attach to the shell of a species of planktonic snail (Fig. 1, pteropod snail), and *P. rubra* jellyfish in turn act as a substrate for other jellyfish larvae and crustaceans. Ocean acidification will impact pteropods through working to dissolve their calcareous shells and cause a chain of effects throughout this ecosystem. Such species-species interactions are also important in chemosynthetic ecosystems and are one mechanism through which biodiversity in the deep ocean is formed and maintained. We plan to explain the importance of oceanic ecosystems at events such as CBD / COP10.

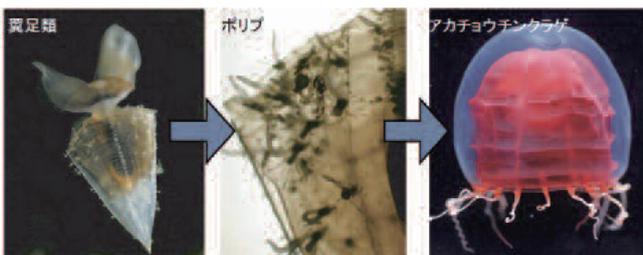


Figure 1. Life cycle of the jellyfish *Pandea rubra* (right). Its larvae (polyps, middle) grow on shells of pteropods (left).

#### An Evolutionary Process of Symbioses between Chemoautotrophic Bacteria and Deep-sea Invertebrates

A large number of invertebrates living at deep-sea hydrothermal vents and seeps harbor chemoautotrophic bacteria as their symbionts and nutritionally rely on the bacteria. Molecular phylogenetic, morphological, and stable isotopic analyses indicate that asymbiotic ancestors of symbiont-harboring mussels might have adapted to moderate biogenic reducing environments as filter feeders, and the symbiotic relationship between mussels and chemoautotrophic bacteria was established afterwards. Finally, mussel species living in present-day vents and seeps have been derived from the biogenic reducing environments such as animal falls and sunken wood (Fig. 2).

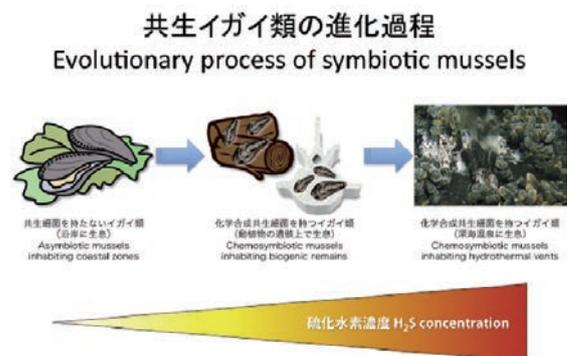


Figure 2. Evolutionary process of symbiotic mussels

#### Understanding the Origin of Eukaryotes through Studying Symbioses in the Deep-sea

Eukaryotic organelles are thought to be derived from prokaryotic cells that made symbiotic associations with the ancestral eukaryotic cells. From genome analysis of the chemoautotrophic symbiotic bacteria in *Calyptogena* clams, genome reduction of symbiotic bacteria has been shown to occur in this intracellular symbiosis. The mechanism underlying this genome reductive evolution is similar to the evolutionary process of eukaryotic organelles.

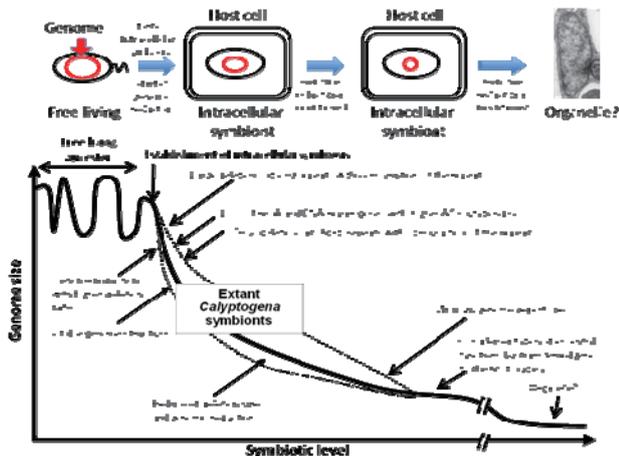


Figure 3. Genome reductive processes in intracellular symbionts

### Probing into Membrane Dynamics to Understand Piezo-adaptation

We investigated the dynamic property of the microbial membrane, focusing on the difference between piezophiles from the deep sea and their shallow-sea relatives. While the membrane of shallow-sea species was highly compressive and was disturbed by high-pressure treatment, that of piezophiles was little affected. The result suggests that the stability of membrane structure is important for piezo-adaptation in microorganisms (Fig. 4).

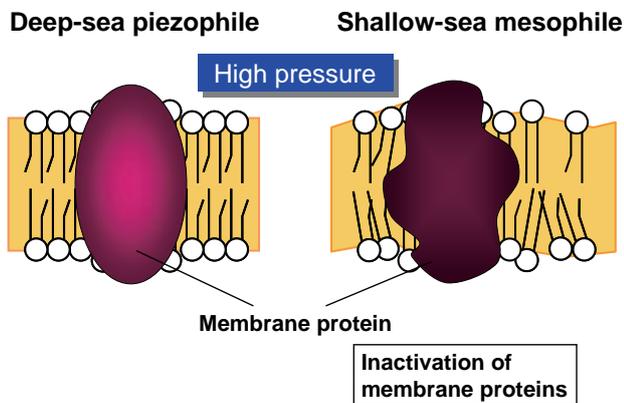


Figure 4. Adaptation of the dynamic property of membranes to high-pressure environments

### Extreme Biotechnological Engineering Research

The purpose of this study was to develop controlling methods for the attachment and detachment of specifically positioned adhesive animal cells cultured on an electrode surface with the application of a weak electrical potential. A patterned indium tin oxide (ITO) optically transparent working electrode was placed on the bottom of a chamber slide with a counter-(Pt) and reference (Ag/AgCl) electrode. We succeeded in controlling the attachment and detachment of animal cells on the working electrode surface.

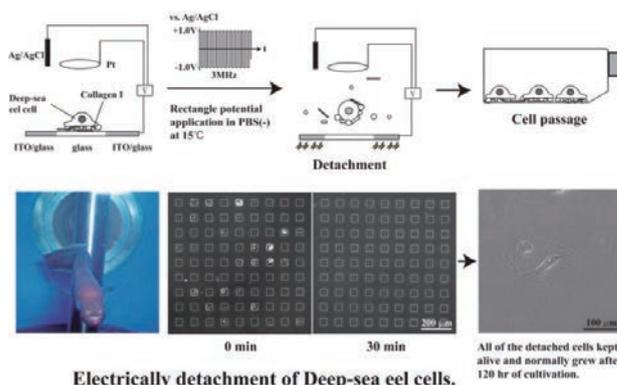


Figure 5. Electrical detachment of deep-sea eel cells

### The Deep Sea: A Treasure Trove of Useful Enzymes

From deep-sea microorganisms, we have found various useful new enzymes, such as lambda-carragenase, agarases, trehalose-synthetic enzymes, and a highly active transglycosylation enzyme. We are developing these enzymes to be commercialized in collaboration with companies. The thermostable deep-sea agarase was launched as a new powerful tool for biotechnology (Fig. 6).

0.5 μm

Producer  
*Microbulbifer thermotolerans* JAMB-A94  
(Suruga Bay, Japan, at a depth of 2,406m)

## Thermostable agarase

Highly effective to recover high molecular weight DNA from agarose gels.

The structure of thermostable agarase

Thermostable β-Agarase  
Code No. 311-07121  
試薬 Lot No. 01009E Size 300 units  
Store at 2-8°C  
For Research Use Only  
販売/和光純薬工業株式会社  
(製造)株式会社ニッポンジーン

Figure 6. Thermostable agarase is on the market.

## United Biogeoresource Exploration

The goal of the UBE team is to develop new techniques to maintain living organisms from various marine environments, such as the deep-sea, in the laboratory. By recreating hydrostatic pressure and chemical conditions prevailing in deep-sea environments in specifically designed culture systems, we are developing new experimental approaches that will allow us to better understand adaptation mechanisms of organisms to their sometimes inhospitable environments, and to reveal new life strategies (Fig. 7).

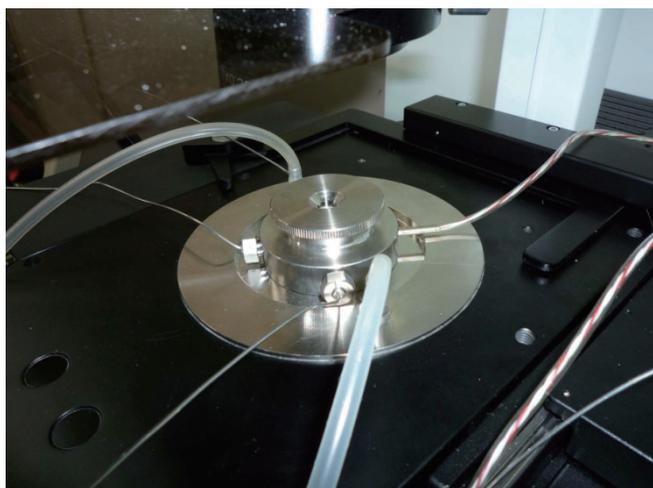


Figure 7. Pressure vessel developed for biological microscopic observation.

## Extremobiosphere Research Program

### Program Goal

How did the Earth become such a rich planet full of life? And who can answer this simple yet hard-to-explain question? We, the members of Extremobiosphere Research Program take a head-on approach to this difficult topic, being ambitious enough to be the world's first group of scientists to prove and answer this fundamental question.

Our Program focuses on the long unseen "earth-life" interactive system independent from sunlight that exists deep down in the Earth's interior. Compared to the lush biosphere on the Earth's surface, this sunlight-independent biosphere may be called the "dark ecosystem." We promote interdisciplinary researches on this dark ecosystem to clarify its mechanisms still wrapped in mystery. The dark ecosystem also possesses undisclosed organisms, chemical reactions, and biological functions beyond our imagination. We also search for and study new organisms in order to promote efficient use of those newly found biological resources.

## Outline of Research Achievements 2009

### Subsurface Geobiology and Advanced Research (SUGAR) Project

(i) Since the discovery of deep-sea hydrothermal activities in the East Pacific Ocean Rise in 1977, the deep-sea hydrothermal system has been considered a great part of the Earth's most active biosphere; the dark ecosystem.

As the research progressed, more facts about the deep-sea hydrothermal fluid system were revealed, and the results showed the existence of an amazingly diverse microbial and biological ecosystem in the hydrothermal systems. However, no scientist knew what the driving forces of such an ecosystem were or how to find them.

We, the Subsurface Geobiology and Advanced Research (SUGAR) Project, boldly attempted to give a general principle to this mystery by collaborating with the Precambrian Ecosystem Laboratory of JAMSTEC. We have successfully proved by analyses and data that the primary factor that decides the ecosystem's biomass and components in a hydrothermal system is the energy potential in the mixing zones of inorganic reducing substances and oxidized substances contained in the hydrothermal fluids and seawater, respectively.

(ii) On the other hand, sampling and culturing of microorganisms from the dark ecosystem has been difficult for most scientists, and very few organisms were kept alive after sampling.

In 2009, we succeeded in culturing microorganisms found in the deep seafloor sediments, including methanogens in a flow reactor culturing method, which was invented after two years of trial and error (Fig. 1). It is well known that a considerable volume of an energy resource, methane hydrate, exists in seafloor sediments. Most methane in methane hydrate was produced by seafloor methanogens. However, which kinds of methanogens are producing methane remains a question unless we succeed in culturing them. Our endeavor to this analysis will surely be a great breakthrough discovery for the world when it succeeds.

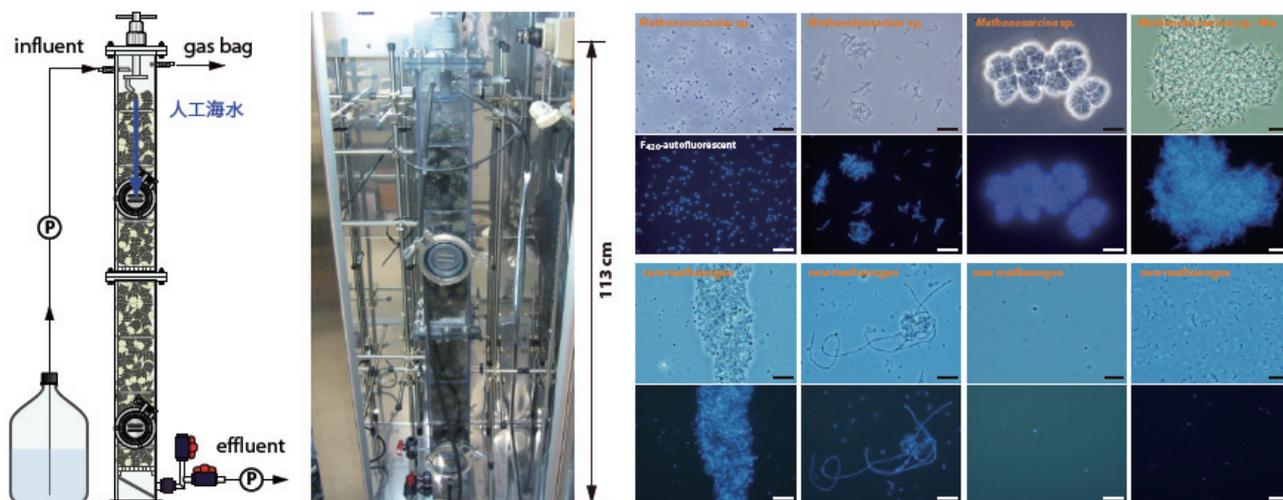


Figure 1. Methanogens isolated from sub-seafloor environment by the new environmental engineering reactor culture method.

### Environmental Metagenomics Research Project

The word *metagenomics* has become more popular in these days. Metagenomics is a methodology to analyze any microbial genome obtained from the natural environment. In the Environmental Metagenomics Research Project, we have overcome perplexities one by one with our enthusiasm to achieve better genome analysis results in order to understand subseafloor microorganisms that were difficult to culture in live condition and are low in activity level.

In 2009 we successfully established a bioinformatic analysis method for mining and outputting the important principles obtained from the massive amount of sequence information. By following this scheme, we conducted environmental metagenomics of sediments from the subseafloor off Shimokita and discovered genomic characteristics that are particular to subseafloor microbial communities.

### Applied Soft Matter Research Project

The dark ecosystem possesses massive amounts of organisms, chemical reactions, and biological functions that are beyond our imagination. The Applied Soft Matter Research Project is a team that promotes the search for and development of these organisms and proposes better ways to use them for our daily lives.

In 2009 we moved ahead with soft matter research on cellulose, the useful untapped resource existing in the most massive volume on the Earth, and developed a nanofibrous culture medium (Fig. 2). The major reason why the cellulose is not being used is its

substantial chemical property, but also due to its structure. It is the same mechanism that allows straw to decay quickly while a log can stay solid for a longer period of time.

A nanofibrous culture medium chemically turns a log into straw. This culture medium made us understand the process of most of the noble cellulose-degrading microorganisms being isolated from the dark ecosystem. This achievement was a breakthrough in applied science; cellulose could be turned into bioethanol, and its potential for industrial use was highly evaluated. We eventually began collaborative product development with a private company.

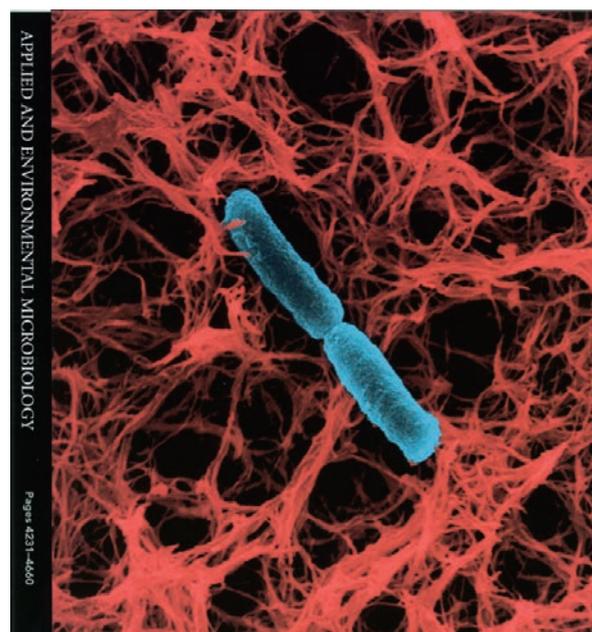


Figure 2. An electron microscope photograph of microorganism multiplying on a nanofibrous culture medium, published as the front cover of *Applied and Environmental Microbiology*.

## Earth and Life History Research Program

### Biogeochemistry Research Team

This team investigates Earth's environment using biomarkers, organic compounds derived from specific source organisms. Specifically, those observed in the sedimentary record provide profound insight into the paleoenvironment when the sediments were formed (Fig. 1). However, we still know very little among the numerous kinds of organic molecules buried in the sediment, and thus the methodology has broad potential for earth science in the future. This science crosses over other fields, including biochemistry and physiology, and is still in a developing stage. Currently, this team is studying (1) the surface water environment in the geological past with light-harvesting plant pigment and their sedimentary derivatives, (2) microbial activity in the deep earth with archaeal lipids and enzymes, and (3) carbon and nitrogen cycles in the aquatic environment with compound-specific isotope analyses that include  $^{13}\text{C}$ ,  $^{14}\text{C}$ , and  $^{15}\text{N}$ .

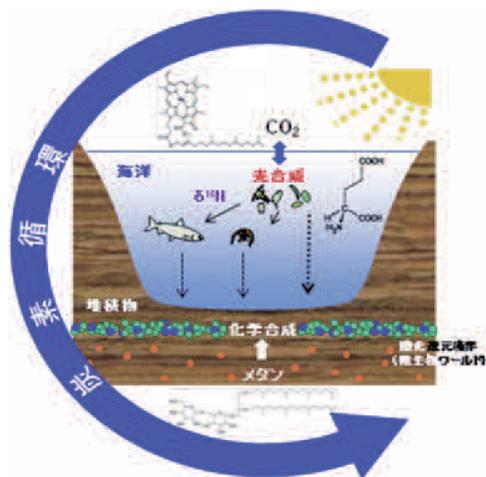


Figure 1. A schematic diagram showing the marine biogeochemical process with some examples of biomarkers

### Geobiosphere Evolution Research Team

This team promotes new, innovative scientific research beyond a traditional earth science approach through developing unique high-resolution analytical technology for studying sediment core samples obtained by the Integrated Ocean Drilling Program (IODP) and the International Continental Drilling Program (ICDP). In fiscal 2009, they developed unique research technology such as nondestructive core scanners, called the TATSCAN series, which

enabled acquisition of high-resolution environmental information at the micrometer scale while keeping sedimentary structure, and Geomill326, a high-precision micromilling instrument to allow taking powder samples at micrometer resolution from rock and fossil materials for discrete chemical analysis (Fig. 2). Application of the Geomill326 provides a valuable contribution to the research activities of JAMSTEC. The technology is expected to meet needs in today's earth science field.



Figure 2. Geomill326, a newly developed micromilling system

### Geobiology Research Team

To elucidate interactions between bioelemental cycling and activities of benthic organisms, this team has developed a two-dimensional oxygen sensor called a planar optode to measure time-lapse oxygen profiles at the sediment-water interface (SWI). Using the planar optode system, they carried out long-term measurement of oxygen profiles with the support of the ROV *Hyperdolphin* in Sagami Bay and found that oxygen profiles at the SWI constantly fluctuate due to physical and biological effects. The pumping of polychaeta was especially prominent to introduce oxygenated water below the oxygen penetration depth (OPD) in a short time (Fig. 3). Interestingly, activities of meiobenthic organisms were observed even below the OPD. Their observation indicated that there exists a sharp chemical gradient at the SWI, but biological activity may tabulate this gradient, and meiobenthic organisms have adapted to live in such chemical environments. They will further investigate redox conditions and relevant biological activities across the sediment-water interface.

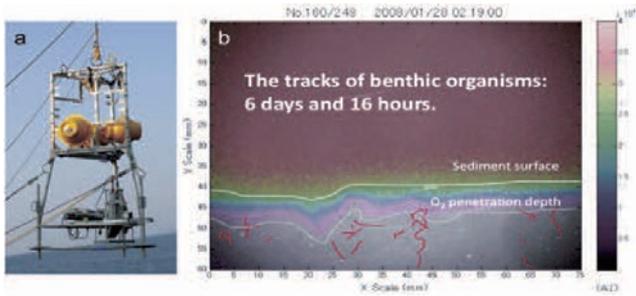


Figure 3. (a) A lander system with a handmade planar optode system installed. This system can measure long-term (~1 year) changes of two-dimensional oxygen profiles at the SWI with a power supply from a deep-sea station. (b) Composite image of oxygen concentration and the corresponding sediment profile obtained from measurement at 1,170 m, close to the Hatsushima deep sea station in Sagami bay. Red lines represent tracks of meiobenthic organisms observed during 6 days of measurement.

### Stable Isotope Ecology Research Team

This team has estimated the trophic level of various types of marine organisms with the nitrogen isotope ratios of amino acids, a newly developed method for solving complex prey-predator interactions. Analyses of marine ecosystems based on nitrogen isotope ratios of amino acids can provide information on the energy flow of prey-predator interactions. Estimation of the trophic level also has the potential to elucidate problems that include host-symbiont interactions and energetic interactions between chemosynthesis-based and photosynthesis-based organisms. The interdisciplinary research team includes ecologists, biochemists, molecular ecologists, and others. It carries out analysis of both chemosynthetic and photosynthetic organisms by using nitrogen isotopes of amino acids for both marine organisms and host-symbionts. Furthermore, it is investigating carbon and nitrogen cycles in the ocean.

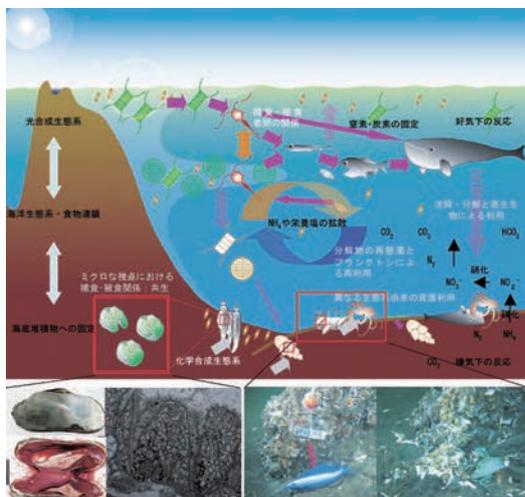


Figure 4. A simplified schematic of marine ecosystems and typical organisms living in chemosynthetic ecosystems.

#### (4) Earthquake and Tsunami Research Project for Disaster Prevention

The Ministry of Education, Culture, Sports, Science, and Technology (MEXT) announced that the probabilities of a massive earthquake measuring magnitude 8 class occurring within 30 years are 87% in the Tokai seismic area, 60–70% in the Tonankai seismic area, and 50% in the Nankai seismic area, respectively. And it estimated that if earthquakes in these areas occur together, damage will be 81 trillion yen, which is close to Japan’s annual national budget. How to prepare for trench-type huge 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 carrying out development of a system for early detection of earthquakes and tsunamis, elucidation of detailed crust structures of hypocentral regions, computer simulation research on earthquake occurrence, and so on. In the following sections, we outline these research and development projects.

#### Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET)

Since fiscal 2006, as a project entrusted by MEXT, we have been carrying out research and development of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (Fig.1) to enhance observation functions in the sea that contribute to disaster prevention and reduction. We deployed high-precision earthquake and tsunami observation equipments at 20 sites that are connected to land station via submarine cables on the seafloor of the Kumano Basin off Kii Peninsula, which is the theorized hypocenter of a future Tonankai Earthquake (Fig. 2).

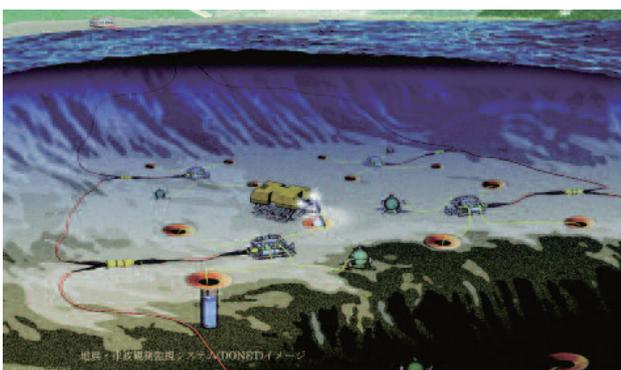


Figure 1. Concept of the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET)

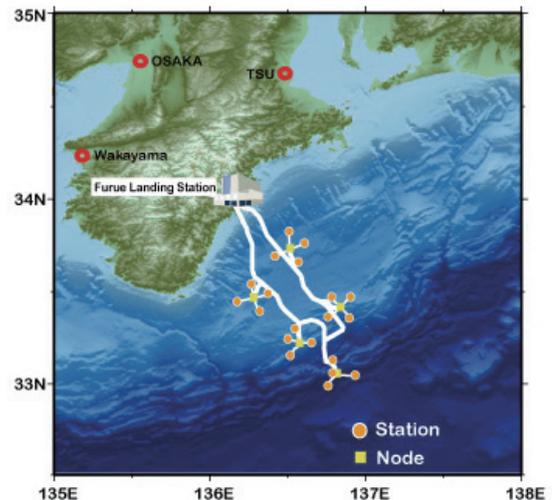


Figure 2. Deployment of the Oceanfloor network (DONET) at the Kumano Basin.

In January 2010 we started installation of a total length of 250 km of a submarine cable and installation of sensors by a remotely operated vehicle. At the end of March we started trial operations. In fiscal 2010 we will continue deployment of observatories.

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

In addition, as the second stage in 2010, we are planning to start construction of the Dense Oceanfloor Network System for Earthquakes and Tsunamis for the Nankai earthquake hypocenter area.

#### Research to Assess Linkage of Tokai, Tonankai, and Nankai Earthquakes

In fiscal 2008, commissioned by MEXT, a research project aiming to assess the possibility of a linked occurrence of a Tokai earthquake, a Tonankai earthquake, and a Nankai earthquake 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 (Fig. 3).

This project aims to deploy ocean-bottom seismometers (Fig. 4) widely and densely in the entire Nankai Trough area from the Sea

of Hyuga to the Tokai area, to carry out survey observation of detailed crust structure, to model the Nankai Trough's crust structure, and to reproduce large-scale earthquake occurrences computer simulations with high precision. In addition, we are doing research to predict tsunamis that occur with earthquakes.

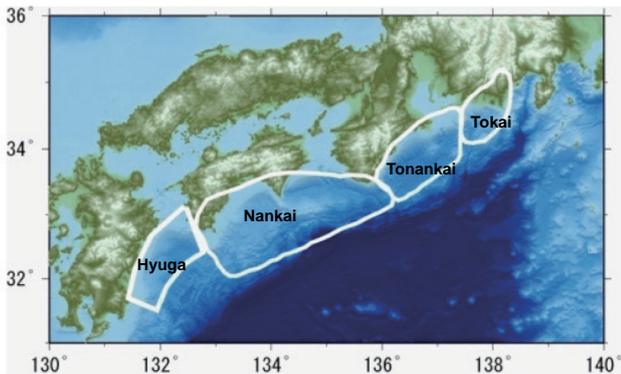


Figure 3. The Nankai Trough trench-type massive earthquake hypocentral region



Figure 4. Ocean-bottom seismometer, deployed on the seafloor, recording natural earthquakes and Seismic waves generated by an air gun over several months

One of this year's research achievements is that the discovery of heterogeneity at the southwestern edge of the Nankai Trough suggested the possibility of a Sea of Hyuga earthquake occurring together with a Nankai earthquake. In the Sea of Hyuga, a sudden-change zone in the crustal structure was identified. An investigation of the crustal structure revealed that the thick crust corresponding to the sunken Kyushu-Palau Ridge exists from the western edge of the hypocentral region of the Hyuga Earthquake (1968). It also revealed that ultralow-frequency events distribute as if they correspond to the sudden-change zone of this crustal structure.

In this project, we organize regional workshops with the Japanese government, local administration, essential-services companies, and others participating. We are actively using these workshops as a forum where we put the latest knowledge from research into practical use in measures for disaster prevention and reduction, and we also take into account regional demand and need for earthquake research.

### Intensive Investigation, Observation, and Research on Crustal Strain Concentration Zones

On the Japan Sea side and inland of northeastern Japan, there are regions called "crustal strain concentration zones" where crustal deformations locally concentrate. In these zones, the Niigata Chuetsu Earthquake (2004), the Noto Peninsula Earthquake (2007), the Niigata Chuetsu Oki Earthquake (2007), and other earthquakes occurred and caused extensive damage (Fig. 5). For this, MEXT started a project in 2008 to clarify the whole picture of active structures in crustal strain concentration zones and to construct a hypocentral fault model. Among these projects, JAMSTEC is in charge of research on the crust structure of the eastern edge of the Japan Sea. In 2009 we carried out artificial seismic prospecting using a multichannel seismic survey system and ocean-bottom seismometers in an area of the sea off the Noto Peninsula to off Sado

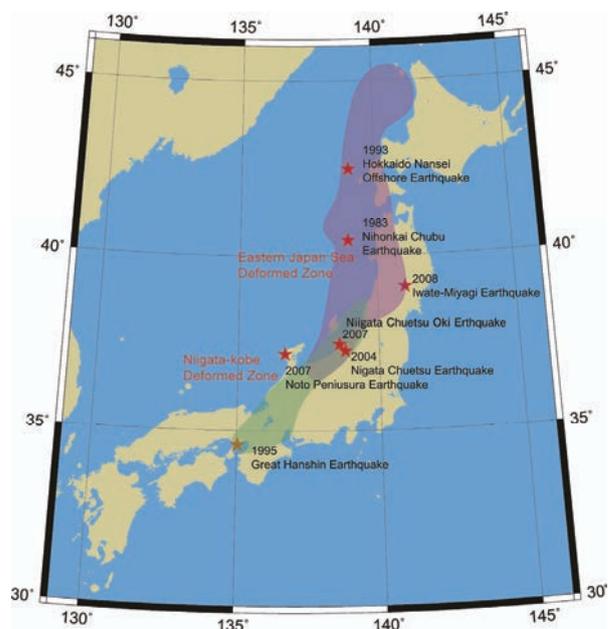


Figure 5. Crustal strain concentration zones of the Japanese Islands

Island (Fig. 6). We have found that Hakusan Shoal and Sado Island, which geographically connect with the Noto Peninsula, have continental crust characteristics, and that in the Toyama Trough between Hakusan Shoal and Sado Island, the crust received reformation by expansion of the Japan Sea and later received deformation by a compression field (Fig. 7).

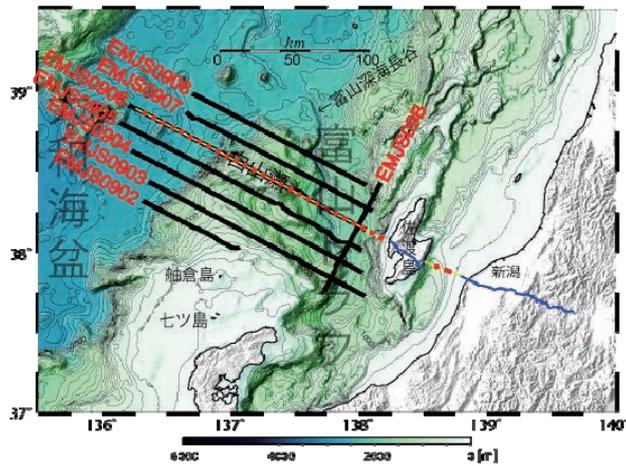


Figure 6. Black lines and red dots, respectively, indicate positions of the multichannel seismic survey measuring lines and ocean-bottom seismometers.

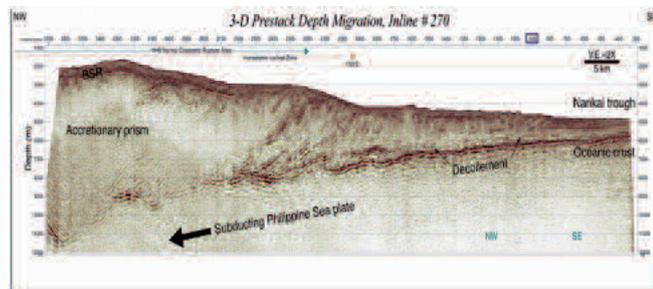


Figure 7. Example of a crust structure prospecting result

## Development of Long-term Borehole Measurement Technology

By installing seismometers, clinometers, strain gauges, thermometers, and other sensors in drilling holes of the deep-sea drilling vessel *Chikyu* and connecting them to the DONET network, we can monitor long-term changes in plate boundaries under the seafloor that cause massive earthquakes, and we can quickly obtain detailed information on an earthquake when it occurs. For this, we must develop sensors and data transmission techniques that can realize stable observation for a long period of time even in the severe environment of pressure a thousand and several hundred times as high as on the ground and a temperature of 170–180°C. As this year's achievement, we developed sensors for riserless borehole use (Fig. 8). Each sensor developed was tested for long-term stability in the Japan Meteorological Agency's cave in Matsushiro. The long-term stability test analyzed each sensor's behavior, confirmed how the sensor fluctuates over the long term, and prepared it for installation in the seabed in fiscal 2010.



Figure 8. Concept of a long-term borehole measuring system

### Real-time Deep Seafloor Observatory

In 2003, we deployed a comprehensive seafloor observatory to monitor earthquakes, tsunamis, sea water temperature, and visual changes in appearance of the sea bottom off Hatsushima Island in Sagami Bay (Fig. 9), which is on the boundary between the Philippine Sea Plate and the North American Plate. Since then, we have deployed observatories off Muroto in Kochi Prefecture, off Kushiro and Tokachi in Hokkaido, and other places. And we have been distributing earthquake and tsunami data in real time to the Japan Meteorological Agency, the National Research Institute for Earth Science and Disaster Prevention, and other relevant organizations. These observation data are available to the general public on the Web; see [www.jamstec.go.jp/scdc/](http://www.jamstec.go.jp/scdc/).

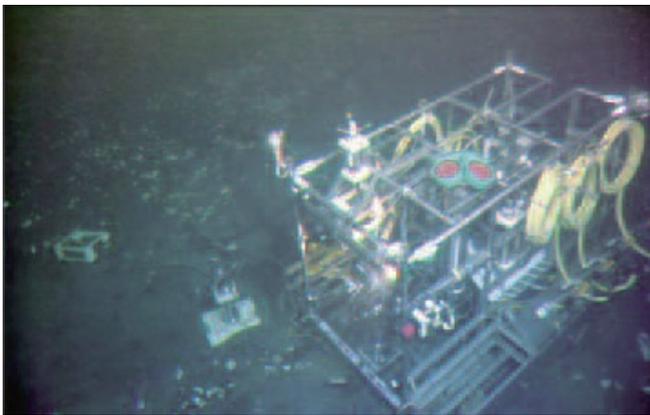


Figure 9. Comprehensive oceanfloor observatory Hatsushima, at a depth of about 1,175 m

## (5) Global Warming Research Project for IPCC-AR5

The global warming research project for the IPCC is dedicated to work on the Innovative Program of Climate Change Projection for the 21st Century project, performed by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), and the Integrated Research on Climate Change Scenarios to Increase Public Awareness and Contribute to the Policy Process project, funded by the Ministry of Environment (MOE). Major research objectives of this leading project are development of an improved earth system model for global warming projection and reduction of the uncertainty associated with the projection. Outcome of the project will contribute to the coming 5th assessment report of the IPCC on one hand, and on the other to the policymaking process for major steps on global warming through providing scientific projections. Among the research outcome of fiscal 2009, three topics are briefly presented below.

### Global Warming Projection Using an Integrated Earth System Model

An international collaborative research framework, titled Coupled Model Intercomparison Project, Phase 5 (CMIP5), prescribes an experimental protocol for the 5th Assessment Report of the IPCC due in 2013. The Long-term Global Change Projection Group has started global warming projection based on the CMIP5 protocol using its integrated earth system model, which is a coupled climate model with biological and chemical processes such as the carbon cycle.

Figure 1 shows sample results from an experiment based on a scenario called RCP4.5, in which CO<sub>2</sub> concentration reaches 540 ppm in 2100. It can be seen, among other things, that global mean surface temperature in 2100 rises by 2.8°C relative to the 1980–1990 period and that anthropogenic CO<sub>2</sub> emission has to be reduced to one-quarter of its current value even under the RCP4.5 scenario in which CO<sub>2</sub> concentration almost doubles relative to the preindustrial era.

In order to complete the CMIP5 protocol, numerous experiments have to be performed in addition to the one depicted in Figure 1. Results from those experiments will be analyzed in various aspects, including impacts of human land use on the global carbon cycle, ocean acidification, and changes in stratospheric circulation under global warming.

### Near-term Climate Prediction Experiments

A global warming projection with prescribed future changes in global-warming gas concentrations has been made to understand future climatic states 100 years from the present. Responding to socioeconomic requirements for global warming predictions detailed in space and time for 30 years ahead, we have introduced data assimilation and ensemble climate prediction methods to the climate model used so far. With the data assimilation, the model is able to produce physical states close to the actual climate by relaxing the model fields toward those observed during model integration. On given dates, the model starts climate predictions in which the model is free from observational constraints. By doing this, it is expected to obtain more reliable products of near-term prediction than ever. The uncertainty of the predictions is evaluated statistically by conducting multiple predictions from perturbed initial climate states, that is, ensemble prediction.

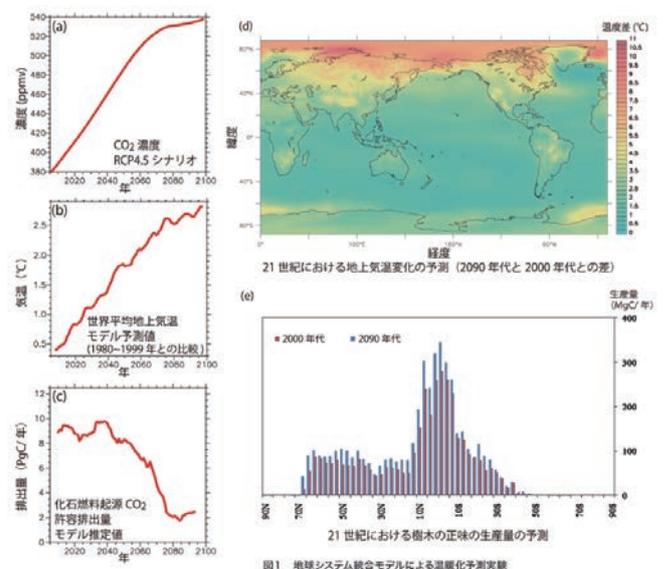


Figure 1. Sample results from global-warming experiments using the integrated earth system model

The data assimilation and ensemble prediction experiments were performed with a climate model of medium resolution as a first step toward detecting predictability of 30-year-lead climate states. Here we focus on decadal climate variations seen in the climate system, particularly on the Pacific decadal oscillation (PDO), which may greatly affect Japan's climate. The PDO is a phenomenon that is characterized as a pattern that takes climatic anomalies with mutually different signs between the equatorial region and the North Pacific, as shown in Figure 2. It is a variation

with periodicity of about 20 years, and it is confirmed plainly in the ocean temperature and sea-level pressure fields.

After a series of failures, we finally succeeded in predictions of PDO for the first time in the world (Fig. 2). According to our experiment, the PDO seems predictable for five to eight years after the prediction starts. This is a prominent outcome of this study, although PDO predictions obtained currently are not sufficient to be used for practical purposes. As shown in Figure 2, the predictability is relatively large in areas where the PDO signals appear strongly.

Research will be conducted continuously to find a physical mechanism behind the predictability of the PDO. In addition, methods of data assimilation and ensemble forecasting will be improved for a higher prediction skill of decadal climate prediction than ever.

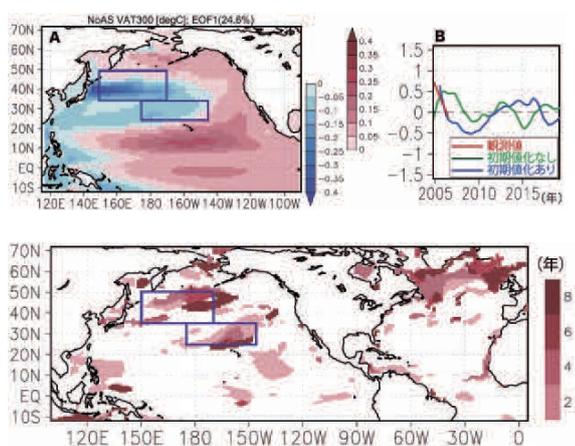


Figure 2. Upper left: PDO signals in ocean subsurface temperature. Upper right: Predicted changes in PDO phase for the coming decades. The PDO phase might change from positive to negative after 2005. Bottom: The durations of PDO predictability seen in ocean subsurface temperatures. Areas of high predictability are highlighted. Areas indicated by two blue rectangles correspond to those where the amplitudes of subsurface temperature anomalies related to the PDO are large and where the PDO is predictable for 5–8 years ahead.

### Global Warming Studies Using NICAM, a Global Cloud-resolving Model

Tropical clouds are one of the important elements in the global environmental system. They drive global atmospheric circulation and affect the global climate condition. They form a multiscale structure, such as individual cumulus, cloud clusters, and monsoon circulations. Tropical cyclones, which cause serious disasters around the world, are generated from organized tropical cloud systems. Tropical clouds also directly affect weather in Japan through heavy rainfall, especially in the boreal summer season.

Existing climate models cannot directly resolve tropical clouds,

since their resolution is about 100 km, much coarser than the scale of cumulus convection, 10 km. Instead, a semiempirical method called cumulus parameterization is used in climate models to represent tropical convective systems. However, it is known that the use of cumulus parameterization is one of the major causes of the uncertainties in climate models. To overcome this difficulty, we developed a global cloud-resolving model, called NICAM, which can be run with a mesh size of about a few kilometers. This new model directly resolves tropical convective systems without using cumulus parameterization.

NICAM enables us to represent tropical clouds almost comparable to cloud images recorded by geostationary meteorological satellites. As shown in Figure 3, NICAM captures the multiscale structure of tropical clouds associated with the Madden-Julian Oscillation, whose realistic simulation has been difficult in present climate models. NICAM also reproduces the tropical cyclogenesis in realistic timing and, in this case, at almost the precise location.

We expect that NICAM will contribute to more reliable projections of future global warming. NICAM will clarify problems in current climate models and will help reduce the uncertainties in simulations of tropical clouds. Particularly, NICAM will promote studies of future changes in tropical cyclones.

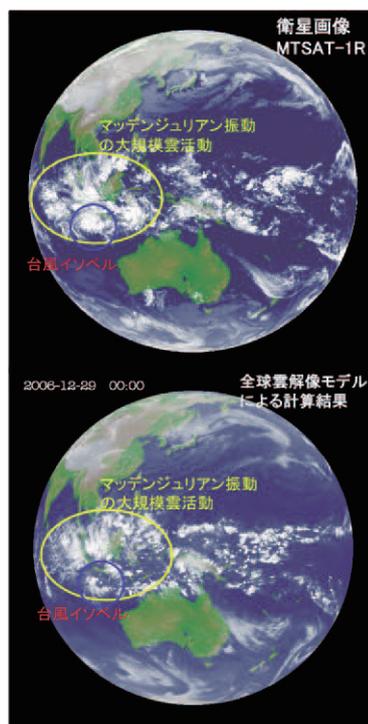


Figure 3. Top: Satellite image at 0:00 JST on 29 December 2006. Bottom: results simulated with NICAM for the same time. Cloud activity associated with the Madden-Julian Oscillation and tropical cyclone Isobel are simulated well in the bottom Figure.

## (6) Laboratory for Earth Systems Science

### Precambrian Ecosystem Laboratory Unit

#### Unit Goal

Understanding the principle of how the Earth has become a rare planet of life has been one of the biggest and most fundamental subjects of liberal arts and a seed of intellectual curiosity for human beings.

One fact we already know in answer to this question is that the interactive system between the Earth and life occurred at the moment of the Earth's formation, and this system has played a major role in the coevolution of different forms of life. In fact, the mantle, crust, ocean, continent, atmosphere, and all the organisms that inhabit them have developed, functioned, and evolved as a whole interactive system entity.

The primary evolution of the primitive Earth-Life interactive system is a dramatic history of the Earth's trial and error in metabolic and energy acquisition systems that supported changes and the organisms in primitive Earth's environment.

Recent research shows that the major mechanism of Earth-Life interactive systems had already been established long before 600 million years ago, in the Precambrian era. The mechanism's evolution was the major cause of why the Earth became a rare planet of life, and it has been dubbed the Precambrian Explosion, a remarkable event in Earth's history.

The Precambrian Ecosystem Laboratory's research goal is to elucidate the primary evolution of the primitive Earth-Life interactive system, the Precambrian Explosion. Our project also aims to make the best use of JAMSTEC's research potential to get a larger picture of the whole story, the UltraH<sup>3</sup> Linkage that began in limited areas of the ocean, and how the ocean environment evolved and propagated the process of photosynthesis and diversification of energy metabolisms on a planetary scale.

#### Outline of Research Achievements in 2009

In 2004, HyperSLiME (hyperthermophilic subsurface lithoautotrophic microbial ecosystem), the most ancient of ecosystems on Earth that still exists today in the Kairei Field in the Indian Ocean, was discovered and described in an article by Dr. Ken Takai and his colleagues. After this announcement, the members of the Precambrian Ecosystem Laboratory continued to have heated

discussions on why it could survive particularly in the Kairei Field.

One of the most convincing hypotheses they reached was that HyperSLiME needed an ultramafics-hydrothermalism-hydrogenogenesis- HyperSLiME (UltraH<sup>3</sup>) linkage system in order to survive. This hypothesis was announced in 2006, and it included two models: "Hadean and early Archean model," which described the most ancient part of the ecosystem's birth and prosperity four billion years ago, and "modern linkage," which described a model of the present age and explained how it could survive until today.

In 2009, the modern linkage model was proved in the Kairei Field. With more detailed geological seafloor observations and core samplings, it became clear that in the Kairei Field, highly concentrated hydrogen was being supplied to hydrothermal fluid produced by olivine-rich gabbro hydrothermal alteration. Therefore, it could be said that the HyperSLiME was being sustained by this hydrogen since hyperthermophilic methanogen was its primary producer. This was proved by both geological-petrological and hydrothermal chemistry simulations (Fig. 1). This was the first proof of the present age's UltraH<sup>3</sup> Linkage.

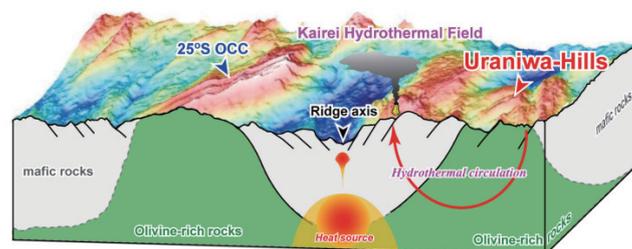


Figure 1. Geological structures and circulation of hydrothermal fluid in the Kairei Field in the Central Indian Ridge, showing the UltraH<sup>3</sup> Linkage. The Kairei Field seemed to be an ordinary ridge-type hydrothermal site; however, it turned out to be an UltraH<sup>3</sup> Linkage that exists due to complex tectonic systems. This was proved by both geological and hydrothermal chemistry and thermodynamic calculation of rock alteration.

On the other hand, the Hadean and early Archean model, which refers to the birth and prosperity of the ecosystem four billion years ago, has described the possibility of komatiite, which may have been distributed widely on the ocean crust, sustaining the hydrogenesis. This idea was new since it was thought to be ultramafics such as peridotite, peridot-gabbro extant in today's deepest part of the crust or upper mantle sustaining the hydrogenogenesis. Even though the hydrogenogenesis by komatiite was theoretically possible, no research had been done by actually using komatiite.

At the Precambrian Ecosystem Laboratory, we have constructed an experiment apparatus capable of withstanding up to 500°C and 600 atmospheres of pressure with hydrothermal fluid (Fig. 2), and we carried out a regeneration of komatiite artificially, just like the newly formed natural komatiite three billion years ago. We then observed an experiment by altering komatiite for more than three months at 300°C and 50 atmospheres.

During the reaction process we measured the hydrogen concentration, and one month after the beginning of the experiment, the result exceeded 1 mM, which was supposedly the threshold value for HyperSLiME formation. Eventually, it generated approximately 3 mM of hydrogen, which is sufficient for sustaining the HyperSLiME. This is a remarkable research achievement to prove the validity of the Hadean and early Archean UltraH<sup>3</sup> Linkage.

In addition to these achievements, in 2009 our guest researcher Yuichiro Ueno's article "Geological Sulfur Isotopes Indicate Elevated OCS in the Archean Atmosphere, Solving the Faint Young Sun Paradox" was published in the *Proceedings of the National Academy of Sciences of the USA*. In 2009 the team also discovered the 3rd and 4th new active hydrothermal fields in Indian Ocean during expeditions by the *Shinkai 6500*.

We are also proud of having excellent scientists in our unit: our research scientist Kentaro Nakamura was awarded an honorable-mention prize, and our visiting PhD student Motoko Yoshizaki was also awarded a poster-presentation prize by the Geochemical Society of Japan.

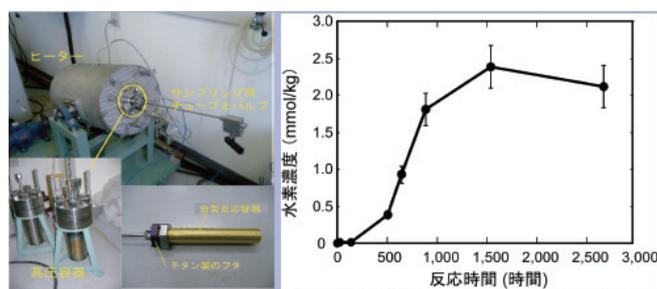


Figure 2. Left: An apparatus constructed by PEL for an experiment, creating a 500°C, 600 atmospheres pressure environment. Right: A graph showing hydrogen concentration produced by komatiite during the reaction under high temperature and pressure. It was proved that it generated approximately 3 mM of hydrogen, which is sufficient for sustaining the HyperSLiME. This is a definitive proof obtained from the experiment, emphasizing the importance of the Hadean and early Archean UltraH<sup>3</sup> Linkage.

## Space and Earth System Modeling Research Laboratory Unit

In December 2009, JAMSTEC started the interdisciplinary research organization called the Space and Earth System Modeling Research Lab Unit, in which we aim to understand from the Earth's interior out to the universe as a system and elucidating the mechanism of the global environment's evolution and large-scale changes. The lab unit's goal is to explore the future Earth by quantitatively ascertaining the complex multisphere interactions that include the space, the Earth's surface, and the Earth's interior through numerical simulation along with experimental and observational research, and to clarify the mechanism of large-scale global environmental changes in the Earth's history. In such research, it is absolutely necessary for the researchers in many fields to cooperate in order to advance the research. The current unit members include JAMSTEC researchers from fields such as ; plasma physics, solar-terrestrial physics, solid earth science, and computer science as well as invited researchers from Nagoya University, the Tokyo Institute of Technology, and the University of Tokyo.

The unit started research on coupled models of the space–Earth surface layer, Earth surface layer–mantle interior, and mantle–core, and the following achievements were obtained:

**The coupled space–Earth surface layer model:** We developed a new computing method, the Super Droplet Method, which can precisely simulate cloud particles and raindrops. By coupling it with an atmospheric fluid model, we successfully reproduced cloud formation, growth, precipitation, and other complicated processes using the Earth Simulator.

The Super Droplet Method uniformly calculates the movement and changes of water drops that make up a cloud or rain by using a particle method. It can calculate changes in the state of water drops based on fundamental physical laws without using empirical parameters. In addition, the Super Droplet Method treats many water drops that have similar characteristics in terms of water-drop size, cloud condensation nucleus, and so on as hypothetical particles. This made calculation efficient, and thus we succeeded in cloud particle simulation, which had been impossible in the past. Furthermore, by carrying on calculation of the super droplet model for cloud microphysics and the fluid model for atmospheric movement complementarily while exchanging information on heat, water vapor mass, and other factors between the two models, we

made it possible to calculate the process from formation of a cloud to rainfall and disappearance of the cloud.

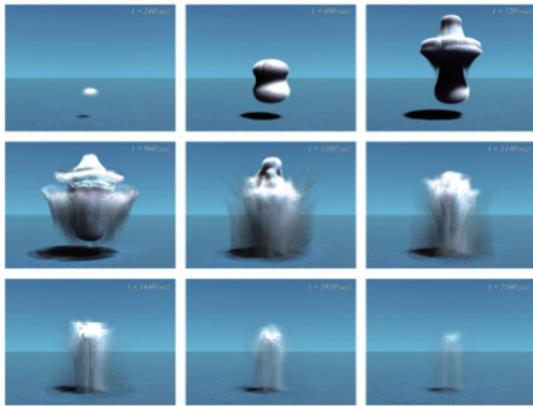


Figure 1. Result of simulation using the super droplet model for the process from formation of a cloud to its disappearance through rainfall

The Earth surface layer–Earth interior coupling model: We developed a three-dimensional spherical shell simulation model of mantle convection, considering a continental lithosphere that has uneven composition and rheology and can transform and move. In this model, we considered a “supercontinent” to be a collection of continents whose density is low and whose viscosity is high. We preset some low-viscosity regions within the supercontinent. We placed this supercontinent on the surface layer of mantle convection that had reached a stationary state and simulated its development after that. A preliminary simulation result showed realization of the continental split and drift similar to the actual Earth, and a characteristic thermal interaction between the mantle and continents was observed.

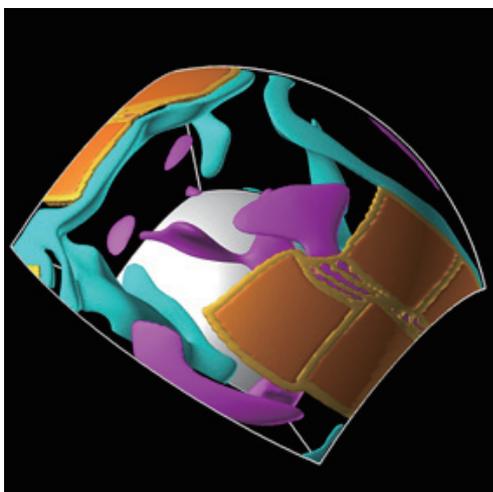


Figure 2. Arrangement of continents when they reassembled and drifted after the supercontinent split

The Earth surface layer–earth interior coupling model: We carried out a simulation of mantle convection with igneous activity and examined how water volume taken into the mantle changes as the interior heat source mass changes along the Earth’s evolution process. In the early Earth, hot matter frequently erupts from the deep part of the mantle and causes large-scale volcanic activity. Because of this, water soaked into the lithosphere is released into the atmosphere, and little water gets into the mantle. In contrast, in the mantle today, plates sink steadily. We found that these sinking slabs carry a large amount of water into the deep part of the mantle.

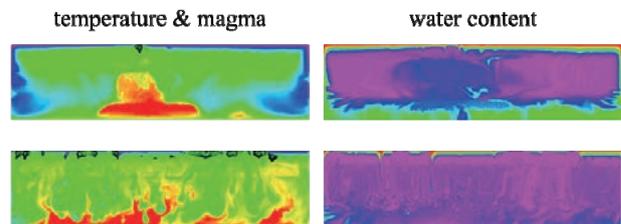


Figure 3. Temperature distribution and water content in the mantle of the present Earth (above) and the early Earth (below)

The coupled mantle–core coupling model: seismological observation of the unevenness and topography of the core-mantle boundary (CMB). We examined the validity of P4KP-PcP travel time difference as new data for estimating the topography of the Earth’s core surface and obtained a preliminary result. A characteristic pattern is that the core is depressed under the Pacific Rim region, the central Pacific Ocean, and Africa.

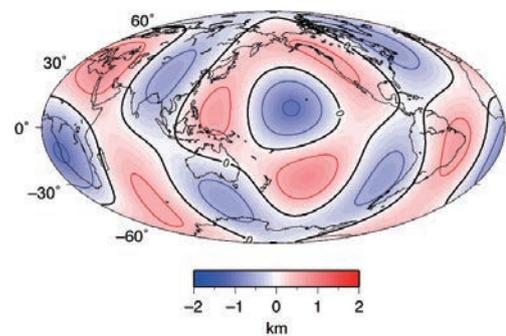


Figure 4. Unevenness of the core-mantle boundary obtained by a new method

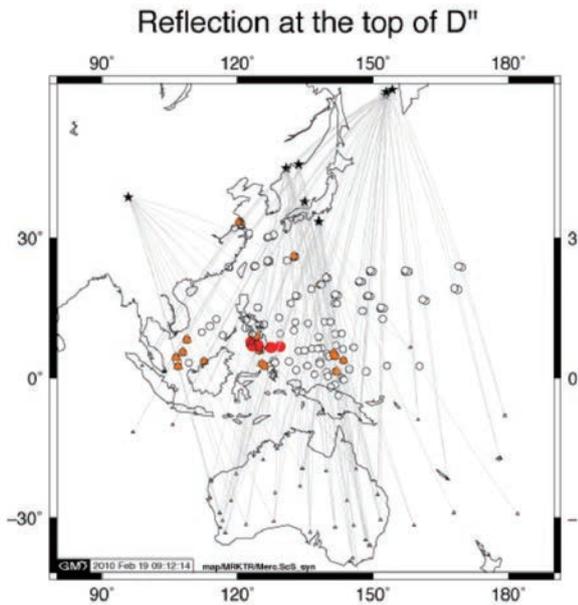


Figure 5. The postperovskite layer of the CMB under the western Pacific Ocean. Red dots show places where significant signals were detected.

The mantle–core coupling model: To clarify unevenness in CMB heat transport, we started investigating the distribution of postperovskite layers in the western Pacific region, where seismological data is so far scarce. The result is revealing an uneven distribution of  $D''$  discontinuities, which are considered as corresponding to postperovskite layers.

The mantle–core coupling model: To estimate thermal flow from the core to the mantle, it is essential to know the thermal conductivity of matter in the lowermost part of the mantle. However, previously there had been no direct measurement under high pressure of thermal diffusivity of minerals in the lower mantle. This lab unit applied a measuring method called the thermoreflectance method (Fig. 6) and succeeded in measuring under 300,000–1,100,000 atm the thermal diffusivity of the  $\text{MgSiO}_3$  perovskite phase, which is the main mineral of the lower mantle. The measurement result showed a large pressure effect, and the thermal conductivity of the CMB under pressure was found to be about 50% higher than previously estimated.

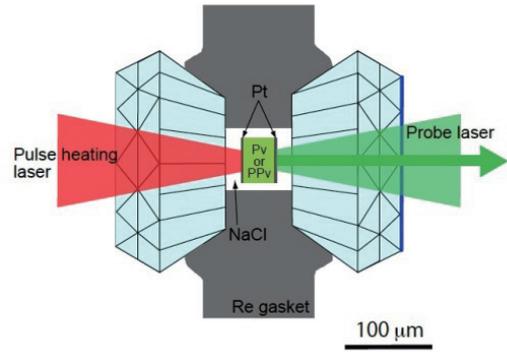


Figure 6. Measurement of thermal diffusivity at high temperature and pressure

## (7) Application Laboratory

### Climate Change Application Lab Unit

The Application Lab (APL) started in fiscal 2009 with the purpose of realizing innovation by mutual enlightenment and sustained cooperation with society so that research results are widely and actively used in societies. At present, we specialize in the atmosphere-ocean coupled system, and we have set out the following three researches and their development goals:

1. At the Climate Change Application Lab Unit—aiming to construct an epoch-making global-scale observation, prediction, and verification system—we carry out application research on climate change and ocean current prediction as well as information provision and verification.

2. By using a global cloud-resolving model, we carry out provision and verification of weather prediction and application information in the tropics and the East Asia region.

3. Using a tropospheric ozone diffusion model, etc., we carry out atmospheric chemistry change prediction, provision, and verification of application information.

With results obtained from these researches and developments, we aim to widely open up application areas and utilization fields domestically and abroad.

In fiscal 2009, researches and developments on a project titled “Prediction of Climate Variations and its Application in the Southern African Region” were adopted as JST-JICA Science and Technology Research Partnership for Sustainable Development (SATREPS) project. It was decided that this joint research with the Republic of South Africa was planned to start in fiscal 2010. The project aims to “promote international joint research which 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 solve global problems and improve the levels of both science and technology” (excerpt from [www.jst.go.jp/global/index.html](http://www.jst.go.jp/global/index.html)).

In this project, we promote research and development of community-based weather and climate change prediction models which are applicable to West Cape State and Limpopo State in

South Africa, and also promote research and development of state-of-the-art models using Earth Simulator and cooperating with local researchers. With local agricultural experiment stations and other facilities, we can obtain detailed observation data and improve prediction accuracy. We will distribute our predictions on local climate change to local residents, people concerning with agriculture, etc., by mobile phone and the internet (Fig. 1). We also plan to cooperate with Pretoria University and Cape Town University on academic joint research including enlightenment lecture series for students and close mutual exchange of researchers. We will deploy aggressive activities to support human resource development for climate change prediction and its application.

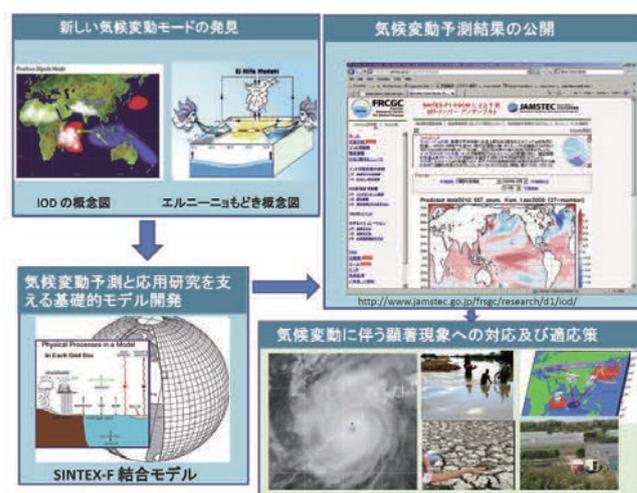


Figure 1. Flow from the discovery of a basic model of climate change and its prediction to providing data to society

At the Climate Change Application Lab Unit, we examine applicability of prediction models such as SINTEX-F1, MSSG, and WRF. At the same time, we continually distribute data on three-month seasonal predictions by SINTEX-F1 inside and outside Japan every month, along with data on sea current predictions by the Japan Coastal Ocean Predictability Experiment (JCOPE). International demand for seasonal predictions by SINTEX-F1 is high, thus particularly in Australia, not only end users such as farm owners but also the parliament at a public are highly interested in this lab’s activities and came to discuss the importance of seasonal predictions (Fig. 2). We will further strengthen our role as Japan’s flagship in seasonal prediction research.



Figure 2. Predictions by SINTEX-F1, periodically taken up by an Australian paper (*Weekly Times*)

Along with international deployment, we actively promoted domestic joint research. We prepared to conclude an agreement with the Japan International Research Center for Agricultural Sciences and the International Rice Research Institute (IRRI) for joint research to improve rainwater rice farming in the Southeast Asia based on seasonal climate change predictions. In addition, we worked toward joint research with the Aizu University Consortium, Kuriyama Town in Hokkaido and Hokkaido University. We are planning to establish a new cooperative relationship with administrative bodies, and deploy aggressive activities toward outreach.

We have shown our international leadership in climate change research; for example, we were invited by Nature magazine to explain the “El Niño Modoki,” which internationally attracted attention as the cause of abnormal weather in 2009. El Niño Modoki makes a climate change pattern different from El Niño that is considered to emerge with ocean warming accompanying global warming (Fig. 3). In addition, we clarified that the Indian Ocean Dipole (IOD), which is called the Indian Ocean’s El Niño, frequently occurs along with ocean warming. These discoveries will play essential and important roles in prediction of abnormal weather.

From now on, we will continue aggressive deployment of activities toward outreach, such as promotion of domestic joint research and establishment of a new cooperative relationship with administrators. At the same time, we will aggressively develop new value in the use of resources and new applicable fields.

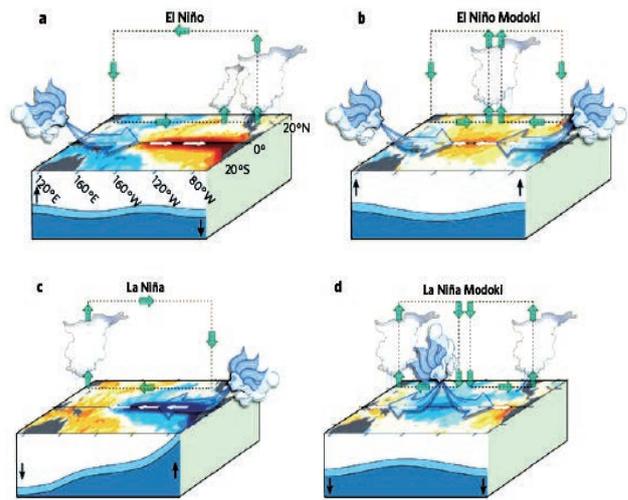


Figure 3. Above: El Niño (left) and El Niño Modoki (right). Below: La Niña (left) and La Niña Modoki (right). They show their respective abnormalities in wind systems and sea surface water temperatures.

## (8) Mutsu Institute for Oceanography (MIO)

The Mutsu Institute for Oceanography (Fig. 1) is on the Tsugaru Strait side of the Shimokita Peninsula. We are conducting the North Pacific Time-series Observation Research project and supporting port entry and departure of the oceanographic research vessel *Mirai* as well as supporting its observation activities, along with hosting various events to promote understanding of marine science and technology around the Shimokita area.



Figure 1. Mutsu Institute with the *Mirai* in port

### (a) Research Activities of the Mutsu Institute

At a time series observing station in the subarctic zone of the northwestern North Pacific Ocean (Station K2, latitude 47°N, longitude 160°E), we are conducting the North Pacific Time-series Observation Research project to understand environmental changes in the ocean. In fiscal 2009 we carried out the *Mirai* MR10-01 Observation Cruise and occupied at the time-series observing station, K2. We also set up the new one in the subtropical zone. This cruise was carried out in the coldest period in winter, in which no observation had been done previously. By comparing detailed changes in nutrients on one surface layer obtained by automatic water samplers, we can now reproduce seasonal variation more accurately. We also began compiling the observation data so far to create a database.

We are also developing autonomous drifting buoy system with a grant for the Japan Earth Observing System Promotion Program, the Ministry of Education, Culture, Sports, Science, and Technology. By fiscal 2007 we had almost completed a small and lightweight autonomous drifting buoy system. In fiscal 2008 and

2009 we tested that field observations were possible in the Labrador Sea, the Antarctic Ocean, and other places.

### North Pacific Time-series Observation Research

Similarly to plants on land, phytoplankton in the ocean surface layer fix carbon dioxide together with nutrients by photosynthesis. Phytoplankton are eaten by zooplankton and their carcasses become particles (marine snow). In this way, carbon is slowly transported toward the sea bottom (Fig. 3a). Various automatic measuring devices from the ocean surface layer to the deep sea revealed that the western North Pacific has a higher ratio of export production to primary production (export rate) than other sea areas, and that carbon dioxide fixed in the surface layer is moved vertically (Fig. 2b).

Analysis of dissolved total carbon dioxide concentrations obtained from time series observation revealed that dissolved total carbon dioxide concentrations are increasing year by year in the deepest part of the surface mixed layer (the temperature minimum layer) to the middle layer. If this increase rate continues, the carbon dioxide partial pressure at the deepest part of the surface mixed layer, which is estimated to be the partial pressure at the surface contacting with the atmosphere in winter, is predicted to become about 420  $\mu\text{atm}$  in about 2020, which would be equal to the partial pressure of carbon dioxide in the atmosphere if it increased at the present rate (Fig. 3b). In addition, analysis of precipitating particles transported from the surface layer to the middle and deep layers that were collected in the sediment trap moored at the time series observing station K2 revealed a tendency that the ratio of silicate (opal) to calcium carbonate is decreasing year by year.

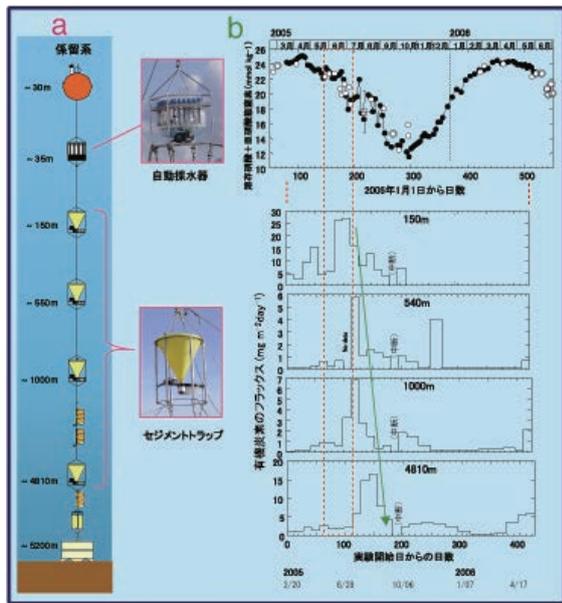


Figure 2. Automatic water sampler and sediment trap installed at the time-series observation point K2 and the seasonal fluctuation of nitrate+nitrite nitrogen at a depth of about 30 m. (a): Time-series observation mooring system; (b): Seasonal fluctuation of nitrite nitrogen at a depth of 35 m, and seasonal fluctuation of organic carbon flux collected in the sediment trap.

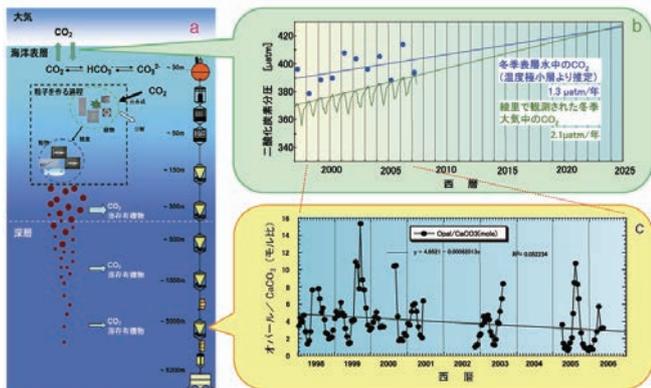


Figure 3. Interannual change of opal/calcium carbonate ( $\text{CaCO}_3$ ) in precipitating particles and partial pressure of carbon dioxide in winter seawater calculated from the temperature minimum layer at the time-series observing station point (Wakita et al., submitted, and Honda et al., prepared for submission). (a): Carbon transport process in seawater; (b): Interannual changes of  $\text{pCO}_2$  in the atmosphere and in seawater in winter, (c): Opal/calcium carbonate ratio in precipitating particles.

### Development of an Efficient Observation Technique

We developed a drifting carbon dioxide sensor (Fig. 4a) that can observe automatically for one year in order to reveal the global carbon dioxide balance. In May 2008 we released the developed instrument in the Labrador Sea and obtained data on partial pressure of carbon for about half a year. This indicated the possibility of future global direct observation (Fig. 4b). In addition, in the second half of fiscal 2008, in cooperation with the National Institute of Polar Research, we released the instrument into the Kerguelen

Plateau area of the Antarctic Ocean and obtained data until the sea ice extension period. The result of analysis almost coincided with previous reports.

We evaluated the instrument's performance by using a simple indoor water pool with a capacity of about 5 tons. The instrument's sensitivity was  $1 \mu\text{atm}$  or better, and the deviation from the on-board observing system was  $2 \mu\text{atm}$  or better. This indicated that the instrument can be used sufficiently for observation.



Figure 4. Drifting autonomous carbon dioxide measuring device developed by the Mutsu Institute, and the results of measurement in the Labrador Sea. (a): The developed drifting carbon dioxide partial-pressure measuring device; (b): Results of measurement in the Labrador Sea



### (b) Support for Ocean Observation Research

We supported the Oceanographic Research Vessel *Mirai*'s port entry and departure three times, and supported TRITON, Argo, and other instruments used for observation, treated collected samples, and so on.

### (c) Promotion of the Understanding of Marine Science and Technology (Promotion and Public Relations)

Under the cooperation from the Mutsu radio station FM AZUR, researchers in the Mutsu Institute sent the latest basic knowledge, titled *Message from the Sea*, to the local community for 15 minutes every week to promote a better understanding of marine science, technology, and research. The program was broadcast 52 times in this fiscal year and 192 times in total. Also, by hosting lectures and other events for people in the Shimokita area, we promoted understanding of marine science, technology, and research and introduced their activities.

In August 2009, with the main theme "the carbon cycle," we

opened the oceanographic research vessel *Kairei* and the facilities of the Mutsu Institute to the public. The workings of the *Kirei* along with the research activities of the Japan Agency for Marine-Earth Science and Technology and the Mutsu Institute for Oceanography were introduced widely to local residents, and about 941 people came. We asked nearby elementary schoolchildren to write message on two real Argo floats, which were on display. Also, commemorating the city's 50th anniversary of incorporation and 5th anniversary of merger, we had Mutsu City's character, "Monsieur Muchuran the First," painted on a real TRITON buoy and put on display (Fig. 5). These measuring devices have actually been deployed in the sea and are conducting observations.

In addition, we measured seawater temperatures in the surrounding area at Sekinehama and Noushi. At the third Marine Environment Monitor reporting session, which had about 79 attendees, we explained the fluctuation shown in the temperature data obtained to the people engaged in fishing around the Mutsu Institute. We are also providing the data to UODAS, issued by the Aomori Prefectural Fisheries Research Center.

Furthermore, in cooperation with the Mutsu City Board of Education, we held classes on the ocean and the environment at elementary and junior high schools in Mutsu City, as was done in fiscal 2008 (Fig. 6).



Figure 5. "Monsieur Muchuran," Mutsu City's character

Hosting a symposium and open houses:

- Oceanographic research vessel *Kairei* and Mutsu Institute facilities open to the public (August)
- Mutsu Marine and Environment Science Symposium (December)
- Cooking class taught by the chef of the oceanographic research vessel *Mirai*—"Let's make the ship's popular dry curry pilaf together!" (December)
- Marine Environment Monitor reporting session (March)



Figure 6. Visiting class held at Mutsu Municipal Ohminato Elementary School.

Other projects:

- FM radio programs, broadcast every week (52 broadcasts in this fiscal year, 192 in total)
- "My school's Argo float, made with our writing"—visiting class at an elementary school in the Sekine District of Mutsu City (July)
- Visiting classes at an elementary school and a junior high school in Mutsu City (December)
- Accepting junior high students for job experience (five students in November)
- Accepting senior high students for job experience (three students in September)
- Accepting university students for internship (August 24–September 4)
- Workplace visit and interview by Tanabu High School students (nine students in July)
- In cooperation with Aomori Prefecture, Marine Environment Monitor measurements were conducted at Sekinehama and Noushi.

## (9) Kochi Institute for Core Sample Research (KOCHI)

### (a) Outline of Activities

The Kochi Institute for Core Sample Research was established in October 2005 at the same time as the start of international operations of the deep-sea drilling vessel *Chikyū*. It is a research institute with a refrigerated repository for drilled core samples and acts as a central place for conducting analyses of core samples as well as their storage and curation. At present, the institute consists of three research groups, a science services group, and a general affairs division.

### (b) Research Activities

#### Physical Property Research Group

This group is advancing research related to earthquake faults through the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) and other scientific drilling projects targeting earthquake faults; measuring the physical and chemical properties, stress, and strain of core samples that include fault rocks; and aiming at a comprehensive understanding of earthquake faults from the viewpoint of material science.

In fiscal 2009 we actively participated in the NanTroSEIZE Stage 2 expeditions, and continued various postcruise research activities using the core samples obtained in Stage 1. In this fiscal year, we published a total of 16 refereed papers in English in international journals.

Regarding the stress state in the Kumano Forearc Basin in the Nankai Trough area, the three-dimensional principal stress direction obtained from anelastic strain recovery (ASR) measurements using drilled cores agreed well with the results of structural analysis and the results of breakout by logging while drilling (LWD) in the two-dimensional plane (Fig. 1). Also, it was revealed that stress in the vertical direction is the largest principal stress. Thus we were able to interpret the deformation pattern that was observed from the seismic profile. Such a stress state had not been anticipated, so it became one of the most remarkable results of the Nankai Drilling project. In Nankai Drilling Stage 2, we also carried out on-board research in riser drilling, which was a world's first in the domain of scientific ocean drilling, and we started research to clarify the stress state at the center of the Kumano Basin.

In experiments using fault model samples, we considered dynamic change in the permeability of fault materials. The results showed that the change in permeability occurring with a high-speed fault movement depends strongly on the mother rock's permeability, slip velocity, and slip displacement. From this result, we estimated that the Nankai Trough massive earthquake fault would increase permeability with earthquake slip. In addition, with friction experiment research using fault samples, we were able to obtain important knowledge on various factors such as water and minerals that affect velocity changes in slip strength, the recovery process of fault strength, the appearance of rare gases, and so on.

In order to advance experimental techniques toward Nankai Drilling Stage 3 ultradeep drilling, which is scheduled to begin in fiscal 2011, this group is working on development and improvement of a machine to precisely and easily measure various basic physical properties (thermal conductivity, fluid movement characteristics, the kinetic friction coefficient) of the soft rock samples.

By agreement with Kochi University and Hiroshima University, two members of this group are doing research and education as visiting professors in their graduate schools.

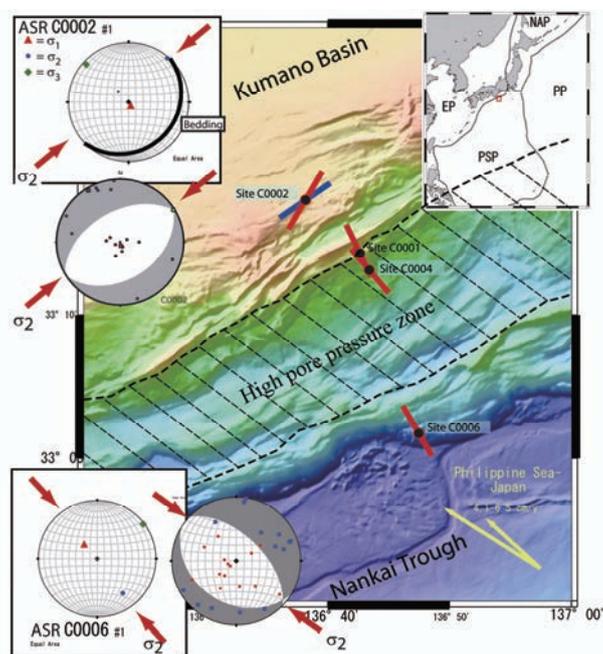


Figure 1. Present three-dimensional stress field as measured by anelastic strain recovery (ASR) method in Nankai Drilling Stage 1 (lower hemisphere projection with frame). It agrees with the present two-dimensional stress field measured by logging while drilling (the principal stress direction in the largest horizontal plane indicated by a color bar at each site) and the past stress field by structure analysis (projection with no frame). Another result obtained was that the largest principal stress in this depth range is vertical.

## Geochemical Research Group

This group is conducting fundamental research to understand material cycles within the earth's surface layer as well as global environmental changes based on metal trace-element concentrations and isotopic ratios in drilled samples. Along with this purpose, developing new techniques to analyze core samples is a part of this group's research activities.

In fiscal 2009, a high-precision, high-accuracy boron isotope analysis technique was newly developed. By improving surface ionization mass spectrometry using metaboric acid ions ( $\text{Cs}_2\text{BO}_2^+$ ), it became possible to measure the boron isotope ratio in carbonate such as coral with a world's top level reproducibility of  $\pm 0.1\%$ . This is expected to become a tool for precisely assessing past pH changes in seawater as recorded in carbonates. We are still doing research on the ocean magnesium cycle by examining the magnesium isotope ratio. In addition to analysis of carbonates, we started analysis of interstitial water collected during IODP Expedition 317. To understand the behavior of antimony in sediment, a method of measurement of antimony isotopes using a multicollector ICP mass spectrometer was also developed.

Excellent results were also obtained from research on fluid form deep underground. Following last year's discovery of hot fluid-rock interaction ( $>350^\circ\text{C}$ ) in an earthquake at the Taiwan Chelungpu Fault, similar geochemical analysis was attempted on past fault zones seen in the accretionary prisms at Shimanto and Emi. As a result, it became clear that such high-temperature fluid-rock interactions seem to occur frequently in earthquake faults in accretionary prisms. On the other hand, from analysis of the core samples taken during the IODP Expedition 316, it was shown that no fluid-rock interaction over  $300^\circ\text{C}$  occurred in the shallow part ( $<300$  m) of the megasplay fault that has grown in the present Nankai accretionary prism near Kumano Basin. From the geological and geochemical comprehensive investigation at a methane-hydrate-bearing area off Joetsu, on the eastern margin of the Japan Sea, it was revealed that sea-level lowering during the last glacial epoch was related to the massive breakdown of methane hydrate and the formation of pockmarks, and that the migration route of deep methane fluid to the surface layer of the sea bottom is very local. Estimation of the source materials of underground fluids in the shallow part of a subduction zone using lithium isotopes is also in progress.

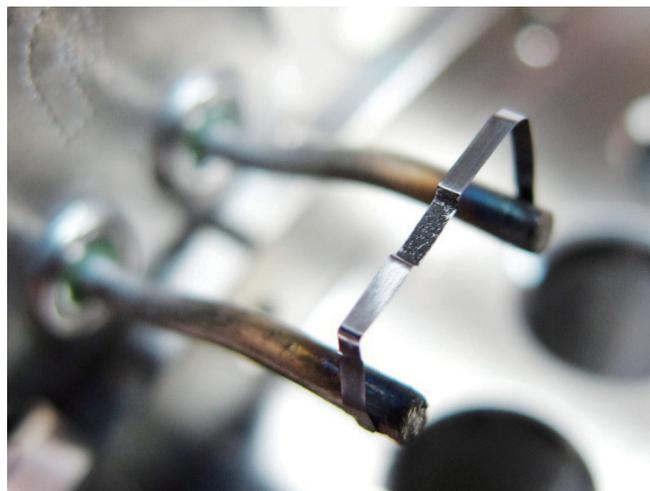


Figure 2. Sample for measurement of boron isotopes. It is applied on a tantalum ribbon 0.75 mm wide with high-purity graphite. The world's top-level boron isotope measurement technique is expected to be used for research on ocean acidification in the past, etc.

## Geomicrobiology Group

Using sediment core samples taken from the Nankai Trough and east off Shimokita Peninsula by the deep-sea drilling vessel *Chikyu*, the Geomicrobiology Group is developing analytical techniques for speedy and precise estimation of biomass distribution, phylogenetic community structure, metabolic activity rates, physiological characteristics, etc. of the microbial communities living in the deep seafloor as well as deploying geoscience-bioscience fusion research.

We used sediment core samples taken from about 365 m under the seafloor east of the Shimokita Peninsula during the training cruise of the *Chikyu* in 2006, added carbon and nitrogen source substrate labeled with stable isotope under anaerobic conditions, and used a high-resolution secondary ion mass spectrometer (NanoSIMS) to measure the substrate-assimilation characteristics and rate of the seafloor microbial community. As a carbon source, we added  $^{13}\text{C}$ -labeled glucose, formic acid, acetic acid, pyruvic acid, amino acid, carbonic acid, and methane. As a nitrogen source, we added  $^{15}\text{N}$ -labeled ammonia or amino acid. In sediment to which glucose, pyruvic acid, and amino acid was added, which can acquire energy substrate for growth, an increase in the number of cells was recognized. In other carbon source substrate, uptake of the substrate was recognized, but no increase in the number of cells was observed (Fig. 3). No substrate assimilation activity of methane or cell growth with methane as an energy substrate was recognized. These results indicate that most of the microbial cells existing in

deep seafloor maintain life functions, and store in cells a minimum necessary amount of life-sustaining energy that enables their growth under certain energy-supply conditions. Interestingly, it was revealed that the assimilation efficiency of ammonia that was added at the same time as a carbon source is uniformly higher than the substrate assimilation efficiency of the carbon source. In the seafloor sediments off Shimokita, large amount of ammonia, mainly from degraded organic matter, and acetic acid from deep organic-bearing layers is produced. Therefore, it can be said that microorganisms under the seafloor are not lacking in carbon and nitrogen sources, but their physiological conditions are lacking in energy sources necessary for metabolism related to assimilation, and that they have characteristics to give priority to accumulation of energy for sustaining life functions that allow survival on a geological time scale, rather than to assimilation metabolism. On the other hand, from the ratio of the initial value of cells that assimilated heterotrophic substrate such as glucose and pyruvic acid to the autotrophic cells that assimilated carbonic acid, it was revealed that the microbial community under the seafloor off Shimokita is dominated by heterotrophic cells.

The Geomicrobiology Group is developing techniques to detect and measure microbial cells in sediment core samples more quickly and precisely. In the last fiscal year, we successfully constructed an automated system that acquires a fluorescent microscope image, finds differences between characteristic wavelengths of fluorochrome of SYBR Green I adsorbed on intracellular DNA and on other non-life mineral particles, analyzes the image, and accurately detects and counts only the microbial cells that contain DNA. In this fiscal year, by applying the principle of this detection system to a flow cytometer, we constructed a system that quickly measures biomass in cell solution stripped and concentrated from sediment through ultrasound treatment, density gradient centrifugation, etc. (Fig. 4). This system can be used for on-board analysis using a general-purpose small-flow cytometer. It will be used in the Integrated Ocean Drilling Program (IODP) during the South Pacific Gyre Underground Biosphere Drilling Cruise (Expedition 329), in which this group participates as a leading player, as well as during the Off-Shimokita Coal Bed Biosphere Drilling Cruise of the *Chikyu* (Expedition 337), and on other expeditions for on-board routine analysis for the first time in the history of scientific drilling.

Using multiple sediment core samples taken by the *Chikyu* from the shallow structure of the seismic zone of the Nankai Trough, this research group is conducting continuously and jointly with Bremen University fundamental research on the size and characteristics of the subseafloor biosphere. In this fiscal year, we extracted DNA from the core samples of all sites that were taken in the IODP Expeditions 315 and 316; decoded with a pyrosequencer a large quantity of PCR products of about 400bp, which were amplified by using tagged primers containing sequences specific to the genealogical domains of bacteria and Archaea; and carried out statistical assessment on these samples' genealogical microbial community structures as well as their similarity and diversity. The result showed that in microbial communities under the seafloor, bacteria uniformly have higher diversity than Archaea, and that diversity and uniformity tend to decrease as the depth increases from the surface layer. In addition, from the vertical profile and other aspects of microbial community structure of core sample at Site C0004, which contains a shallow part of a splay fault, it was suggested that microorganisms in seafloor sediments partly repeat selection and adaptive multiplication along with the activities of the earthquake fault. This research result suggests that the geobiosphere under a dynamic geological environment has sensitivity to the fault zone's physical destruction and fluid movement, the accompanying temperature changes, generation and supply of nutrition and energy substrate, etc., and that an evolutionary process by natural selection and environmental adaptation along Darwin's theory of evolution is going on.

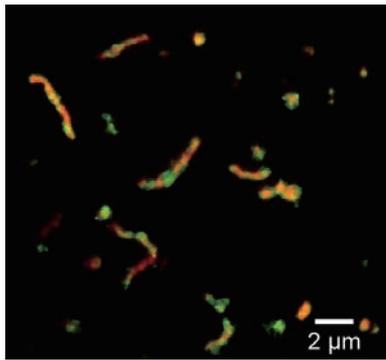


Figure 3. Mapping image to show intracellular assimilation characteristics of various stable carbon and nitrogen isotope substrates by a high-resolution secondary ion mass spectrometer (NanoSIMS) (red:  $^{13}\text{C}$ -glucose, blue:  $^{15}\text{N}$ -ammonia). For analysis, we used microbial cells contained in a core sample taken from about 220 m under the seafloor east off Shimokita Peninsula. Mild cell proliferation using glucose as a carbon source and an energy source was recognized, but the cell's substrate assimilation varied site-specifically, which indicates that the cells that recovered and grew after a long period of energy deficiency are not necessarily in a healthy condition.

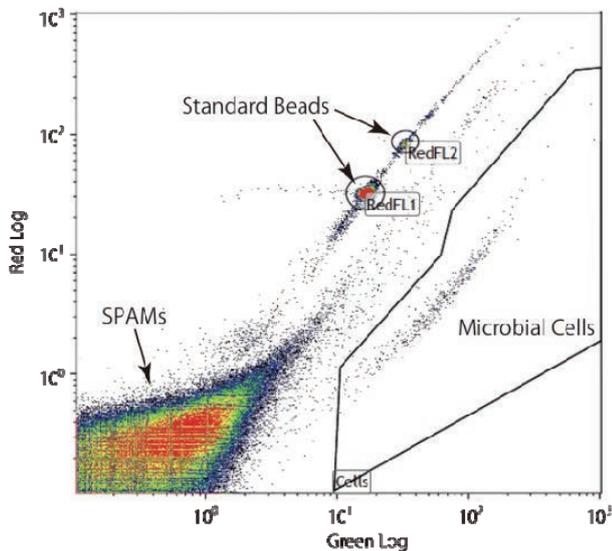


Figure 4. Pattern of detection of microbial cells using a flow cytometry. Compared with conventional methods, faster and more precise cell counting is possible. However, we still need technical improvement, such as higher detection sensitivity of the flow cytometer, to count very small cells under 200 nm in diameter or under a low intensity of fluorescence.

### (c) Curation Activities

#### IODP Core Curation

##### Drilling Cruise

In connection with the NanTroSEIZE Stage 2 cruises (Expeditions 319 and 322) of the deep-sea drilling vessel *Chikyu*, we received, assessed, and coordinated requests for drilled core samples. On Expedition 319, which began in May, we did not take core samples but took cutting samples every few meters. We sieved these into a few particle sizes, packed them separately in plastic bottles, and kept them in cold storage. On Expedition 322, which began in September, we managed core samples taken from the Nankai Trough area, assessed requests, and shipped samples.

##### Sampling Party

In September, the U.S. deep-sea drilling vessel *JOIDES Resolution* ended its Bering Sea cruise (Expedition 323) and visited Yokohama. The cores collected during this expedition were transported to Kochi in accordance with the sample distribution and storage rules set for each oceanic area. For sampling of these cores, a sampling party was organized for 10 days, from November 30 to December 9, at KCC. Thirty-seven researchers came from Japan and other countries and took about 35,000 samples. The remaining samples were taken by 12 Japanese researchers at the second sampling party in February, and by the repository staff in early April. This was the first case of on-land sampling of cores obtained by a drilling vessel belonging to another Implementing Organization. At the same time, the 53,000 samples taken at the repository set a record as the largest number of samples taken by on-land sampling party.



Figure 5. A scene from the sampling party for Bering samples.

## Sample Requests

By March 2010 we had received sample requests for 84 cases of legacy cores, including 1 case of withdrawal, 7 cases of cancellation, 3 cases of rejection, and 1 case of waiting. There were also 138 cases of NanTroSEIZE cores, including reception after moratorium, assessment, sampling for requests that were permitted, and sending the samples to researchers.

## Pilot Study for Curation of Routine Microbiological Sample (RMS)

The existence of the biosphere under the seafloor is attracting attention from many fields. Research on the biosphere under the seafloor is one of the main scientific objectives of the IODP. For such research needs, routine microbiological sample (RMS) sampling is being started, in which IODP cruises routinely collect and store seafloor drilling core samples for microbiological and biogeochemical analysis. The Kochi Institute for Core Sample Research has been preparing facilities that can store and manage RMS in optimum conditions (very low temperature, germfree), such as liquid nitrogen tanks that can store samples at  $-160^{\circ}\text{C}$  and band-saw that can cut frozen samples in semigermsfree conditions. However, there had been no prior case that compared multiple options for sample storage. For uniform and high-quality RMS curation, it was necessary to discuss various matters, including creating a practical work protocol. The Institute participated in the Chikyu training cruises Expedition 904 and 905, carried out in November and December 2009, and collected core samples similar to RMS (Figs. 6 and 7). Using the core samples collected, the institute is doing quality assessment of core samples under multiple storage conditions by using microbiological methods that include measurement of total germ numbers, comparison of DNA composition, etc.



Figure 6. Core samples freeze-preserved for the pilot study.

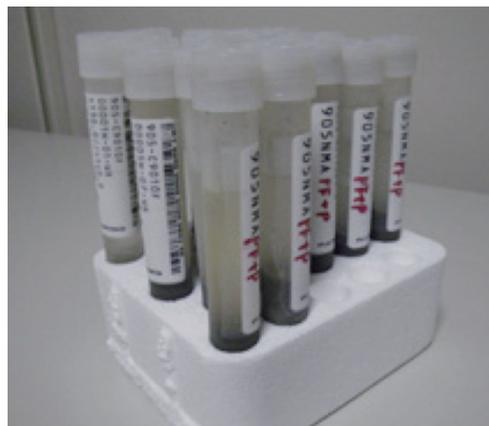


Figure 7. Core samples treated with chemicals for QA/QC.

## The INVEST Conference, a Next-generation Scientific Program Conference

We participated in the international conference to define the IODP scientific program beyond 2013, called the IODP New Ventures in Exploring Scientific Targets (INVEST), which was held at the University of Bremen in Germany on September 23–25. The conference was divided into categories by field of specializations, such as lithology and microbiology, and participants summed up discussion on each category's proposed scientific exploration program and necessary technological innovation. The IODP curation staff submitted opinions on a method for distributing 3D images of IODP cores, for maintaining quality of cores, and added that they need scientists' feedback and cooperation in these matters.

## JAMSTEC Core Samples

In cooperation with the Data Management and Engineering Department of the Data Research Center for Marine-Earth Sciences, the core samples taken during the cruises of the *Kairei*, KR02-01, KR03-10, and KR05-15; the *Yokosuka*, YK04-08 Leg 1; and the *Kaiyo*, KY09-04, were made accessible to science community. We also accepted core samples from this fiscal year's cruises: one cruise by the *Mirai*, two cruises by the *Kairei*, two cruises by the *Kaiyo*, and three test cruises by the *Chikyu* as well as existing samples that had been stored at the Mutsu Institute for Oceanography and the Yokosuka Headquarters.

We also accepted 10 sample requests from outreach-related people such as domestic researchers, elementary school teachers, and the Public Relations Division, and we dealt with four cases of sampling, support for core treatment, and physical property

measurements during moratorium period or after a cruise (two cases for the *Chikyu*, 1 case for the *Mirai*, and 1 case for the *Kairei*).

In addition, as in the last fiscal year, we closely cooperated with domestic projects such as Lake Biwa drilling and Ryukyu coral reef drilling as well as International Continental Scientific Drilling Program (ICDP) projects.



Figure 8. A work scene showing the JAMSTEC core management.

#### (d) Outreach Activities

##### Pre-cruise Training

In late April, we introduced on-board equipment and database to on-board researchers, who were to participate in IODP Expeditions 319 and 320 in NanTroSEIZE Stage 2, and carried out a short training session for them to learn how to request samples, how to take samples, and how to use various softwares. In June, we held a similar training session for participants of Expedition 324 to Shatsky Rise.

##### Exchange with Tongji University, China

In late June, we visited the Tongji University in Shanghai to talk about their loan request for a large quantity of legacy core samples and to introduce educational activities for students as well as IODP activities. We examined a local core repository and equipment for core measurement, and we exchanged information and opinions about research methods.

In addition, we discussed about IODP related information dissemination and education activities, feasibility, and matters to be resolved with the university and Shanghai city staff.

##### Lecture for students

In September, we lectured first-year students of the Komatsushima Municipal Sakano Junior High School in Tokushima Prefecture. This school is located in the southeastern part of the city, where tsunami damage from the Nankai earthquake is anticipated. We introduced the mechanisms of earthquake occurrence as well as the scientific research being done by using IODP cores.

##### The 11th Sand for Students Outdoor Class (Kagawa)

We organized an outreach program, titled Sand for Students and led by CDEX in Shikoku, for the first time. In this program, the Kochi Institute for Core Sample Research cooperated in preparation of study material, and conducted a field survey, coordinated with the school and various procedures necessary for the event. About 30 participants came from the Kagawa Prefectural Marugame High School, Kagawa Prefectural Kanonji Daiichi High School and Kagawa Prefectural Takamatsu Kogei High School, including teachers.

In the program, we carried out field work and observations at the Sekigawa riverside in Shikokuchuo City, Ehime Prefecture, and

at Kotohiki Park in Kanonji City, Kagawa Prefecture, and had an indoor class about sand samples and geology at the Kanonji Daiichi High School.



Figure 9. A scene from Sand for Students field work.

#### J-DESC Core School

In March 2010, a Core School was held by the J-DESC, as it is held every year, for those who hoped to board the ship and work with core samples. We participated in a core analysis basic course as lecturers, and in cooperation with Kochi University staff, gave training on how to treat and record core samples and log initial physical property measurements.

## (10) Marine Technology Center (MARITEC)

The Marine Technology Center does research and development in advanced technology relating to the ocean; research support, such as the operation, administration, and functional improvement of ships, marine observation systems, and research facilities; and activities for training technical experts.

### Technological Development

#### (a) Future Autonomous Underwater Vehicle system

We are developing a Future Autonomous Underwater Vehicle system that can cruise autonomously for a long time and a long distance, search for mineral resources such as hydrothermal deposits, and carry resource exploration devices. In fiscal 2009, for development of a power system, we succeeded in long-term electricity generation of 1,000 hours with highly reliable, highly efficient fuel cells. For communication technology, we succeeded in conducting long-range under water acoustic communication for 300 km horizontally using the time reversal acoustic communication. In addition, for observation technology, we developed synthetic-aperture sonar that can precisely observe a wide area using sound waves. We put it on the autonomous underwater vehicle “*Urashima*” probe and captured clear acoustic images of the deep-sea bottom. Now, by applying the developed underlying technology, we aim to build a demonstration vehicle of the Future Autonomous Underwater Vehicle system.

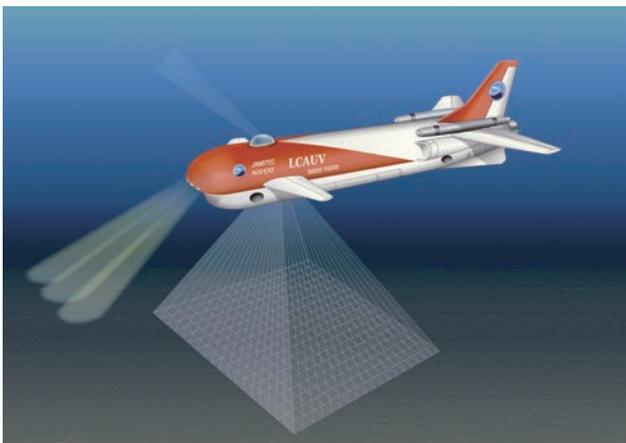


Figure 1. Future Autonomous Underwater Vehicle system

#### (b) Hyper Remotely Operated Vehicle

We are developing a next-generation great-depth highly functional unmanned probe that can do high-precision heavy work such as seabed investigation at great water depths of 7,000 m or more. In fiscal 2009, as a development for great-depth diving, we carried out trial manufacture of a high-strength buoyancy material, trial manufacture of high-strength lightweight cable to connect the vehicle and its support vessel, and assessment of a rotary joint for optical fiber communication to be used for rotating the cable drum in the water. In addition, we carried out a model test of a crawler system for vehicles having movability on slopes, structural model design of a new mechanical hand for work-manipulator technology, and a performance characteristic test of an all-around image system for imaging technology. By applying the underlying technology we have developed, we now aim to build a demonstration vehicle of the Hyper Remotely Operated Vehicle.

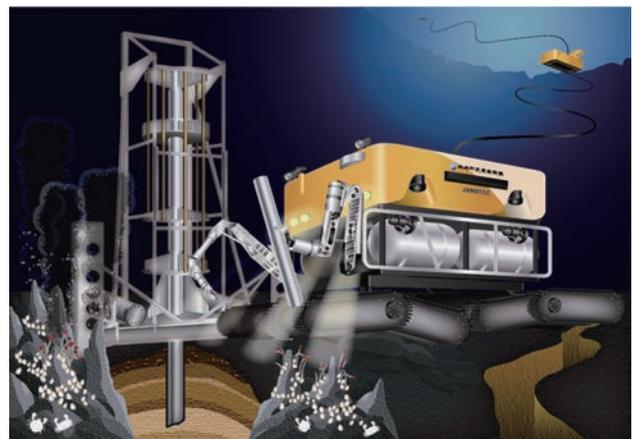


Figure 2. Hyper Remotely Operated Vehicle.

#### (c) Research and Development of Advanced Marine Technology

We are doing research and development of advanced fundamental technology necessary for marine observation and investigation of the next generation. In fiscal 2009 we carried out: trial manufacture of a lightweight high-strength pressure vessel using a composite material, made of carbon-fiber reinforced plastic and metal, as structural material for the next-generation ocean platform; development of a ceramic pressure sphere for OBS capable of reaching a water depth of 11,000 m; research and development of high-speed communication, positioning, and telemetry that connect land and sea seamlessly and enable

high-level remote observation; experiments on short-range high-speed acoustic communication using acoustic signals to communicate over a distance of 700 m at a speed of 80 kbps; experiments on transmission by ships at sea, in which images in the sea taken by the Plankton Investigatory Collaborating Autonomous Suvey System Operon “PICASSO” are relayed in real time using the wideband internetworking satellite “Kizuna”; basic research on underwater communication using lasers; research to significantly improve the ability to observe the surroundings by using around-view cameras; and so on.



Figure 3. Camera images from “PICASSO” transmitted via *Kizuna* from the sea to the JAXA Tsukuba Space Center and the JAMSTEC Yokohama Institute.

#### Cooperation in Operating Ships for Academic Research, Etc.

We are operating and managing the research vessels *Hakuho-Maru* and *Tansei-Maru*, which were transferred from the University of Tokyo Ocean Research Institute in 2004, based on the plans made by the Cooperative Research Vessel Steering Committee. In fiscal 2009, the *Hakuho-Maru* carried out 258 days of cruises, including cruises in the Bering Sea and through the Indian Ocean to Cape Town. The *Tansei-Maru* carried out 273 days of cruises. We also supported observations and other work on both research vessels by placing marine technicians aboard.

#### Providing Research Vessels and Deep-sea Investigation Systems

##### (a) Research Vessels

We are operating and managing the research vessels *Natsushima*, *Kaiyo*, *Yokosuka*, *Kairei*, and *Mirai* based on the plans for research and development to be carried out by JAMSTEC and the plans for research topics collected from the public by the Ocean

Research Promotion Committee of external experts. For operations, we are carrying out the necessary coordination with people involved in fisheries, and also the coordination to acquire permission to do research within other countries’ exclusive economic zones. Furthermore, we are conducting commissioned cruises with external funds, and providing open house events and the educational experience cruises for outreach. We also hold achievement report meetings every year. This year, we held “Blue Earth ’10” at Tokyo University of Marine Science and Technology for two days from March 2, 2010. In fiscal year 2009, the R/V “*Natsushima*” carried out 283 days of cruises, the “*Kaiyo*” 275 days, the “*Yokosuka*” 261 days, the “*Kairei*” 300 days, and the “*Mirai*” 245 days, including cruises to Chile and the Arctic Ocean.

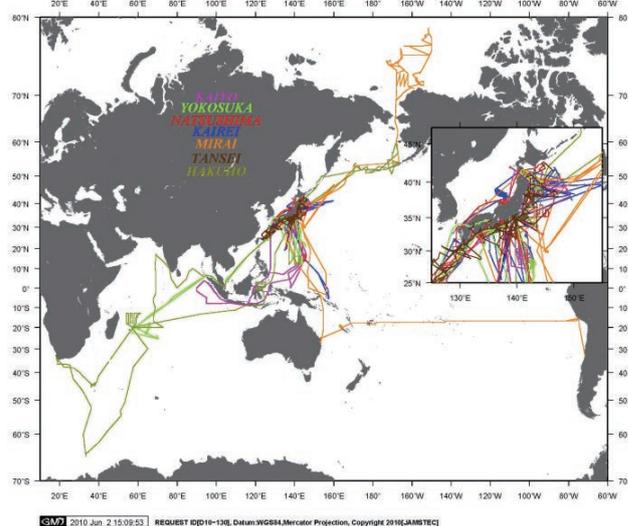


Figure 4. Cruise tracks in fiscal year 2009.

##### (b) Deep-sea Investigation Systems

We are working on functional improvement of manned research submersibles and unmanned vehicle. In fiscal 2009, for the manned research submersible vessel “*Shinkai 6500*”, we equipped and tested a photoelectric combined connector for signal cables in and out of the pressure hull and improved responsiveness of the propulsion system. We prepared the remotely operated vehicle *Hyper-Dolphin* for extension of cables of the Dense Ocean-floor Network System for Earthquakes and Tsunamis. We started operation of *Urashima* for cruises inviting the public, following the *Shinkai 6500* and the *Hyper-Dolphin*.

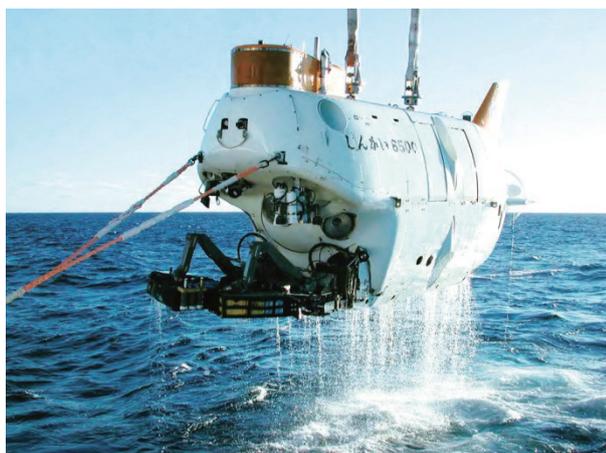


Figure 5. “Shinkai 6500”



Figure 6. “Urashima”

(c) Operation of the international surface buoy array

To monitor and study the ENSO (El Niño/Southern Oscillation) JAMSTEC operate the 15(fifteen) TRITON buoys for TAO/TRITON buoy array for the western Pacific Ocean, and to understand mechanism of the Indian Ocean’s variation and importance of the Indian Ocean for global climate system we operate the 3 (three) m-TRITON buoys for RAMA array for the Indian ocean. These data are published on the Internet web site and GTS (Global telecommunications system). In fiscal 2009, we also started development of buoys to be operated in the Southern Ocean near the Antarctic.

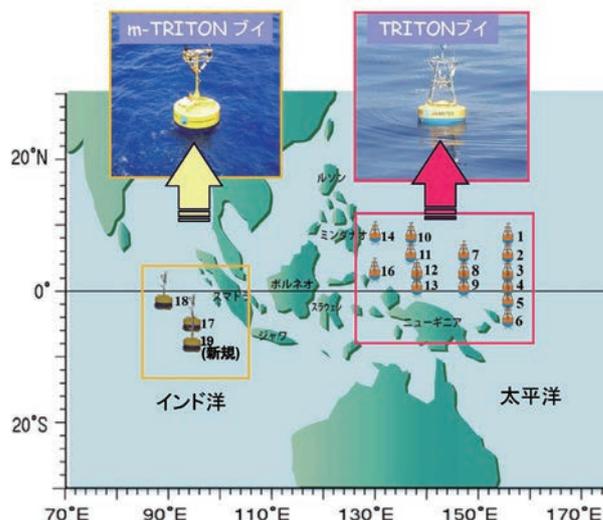


Figure 7. State of operation of oceanographic observation buoys. Upper left: photo of an m-TRITON buoy; upper right: photo of a TRITON buoy.

Training and Quality Improvement of Researchers and Technicians

In fiscal 2009 we carried out divers training for external, water-escape training by helicopter for people on board the deep-sea drilling vessel *Chikyu*, technical training for support technicians at the KAIYOGIJUKU, and other sea safety trainings for on-board researchers.

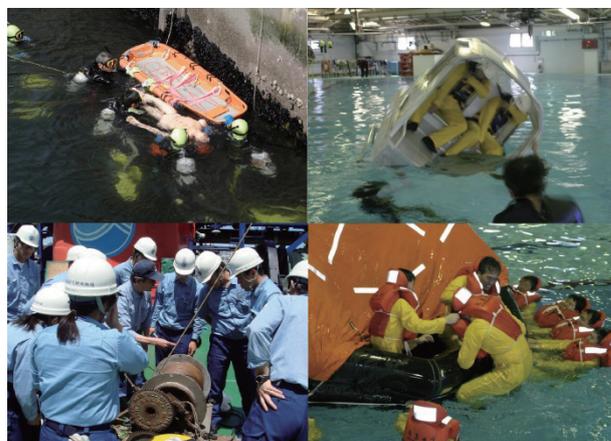


Figure 8. Training for researchers and technicians. Upper left: diving training using a dummy; upper right: water-escape training by helicopter; lower left: KAIYOGIJUKU; lower right: sea safety training.

## (11) Earth Simulator Center (ESC)

The Earth Simulator Center started up in April 2009 as a single organization combining the former Earth Simulator Center, a research sector working with the Earth Simulator, and the former Supercomputer System Planning and Operations. It is a department manages and operates the Earth Simulator, other supercomputers, and the administrative systems and basic networks of JAMSTEC, along with promoting use of the Earth Simulator.

### The Earth Simulator

The Earth Simulator was rated at 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 teraFLOPS (1 teraFLOP is one trillion 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 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.

The Earth Simulator won third place in two of the four categories of the HPC Challenge Awards, Class 1, in 2009: the EP STREAM (Triad) per system section and the Global FFT section; performance was evaluated in programs similar to actual simulation computations.



Figure 1. The new system Earth Simulator

	地球シミュレータ (ES) (2009年3月運用停止)	地球シミュレータ (ES2)
総CPU数	5120CPU	1280CPU
総メモリ容量	10TB	20TB
理論性能	40TFlops	131TFlops
総ストレージ容量	940TB	2.0PB
テープアーカイブ 容量	1.8PB	-
導入時期	2002年3月	2009年3月

Table 1. Comparison of the original and the new system

### Multi-scale Simulation and Modeling Research

Global weather and climate consist of the natural environment and include the atmosphere, the oceans, land, sea ice, and the ecosystem along with chemical substances emitted from human activities and their complex interactions. The Multi-scale Modeling Research Group is working on development of a model to view such complex mechanisms at various space-time scales, which will enable us to predict seamlessly a range of phenomena from the weather to climate change. In order to clarify how global climate change affects the Japan region or urban regions within Japan, we need to simulate globally and by on the city scale all at once. Thus we also develop algorithms and parallel computation techniques to make the most of the Earth Simulator. This prediction simulation model, named the Multi-scale Simulator for the Geoenvironment (MSSG, pronounced “message”), is a nonstatic coupled atmosphere, ocean, land, and sea ice model. It is being further developed toward higher precision for the purpose of predicting very detailed weather by downscaling and climate variation, and for applying adjustment steps for climate change.

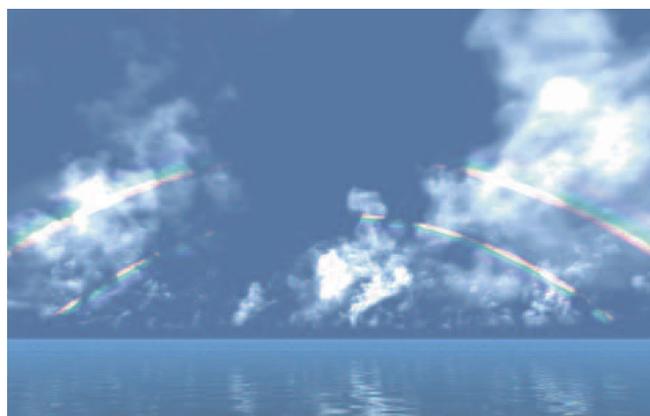


Figure 2. Clouds reproduced by simulation in which each droplet making up the clouds, the collisions of droplets, and their phase changes are taken into consideration; a detailed cloud model affects rainfall processes.

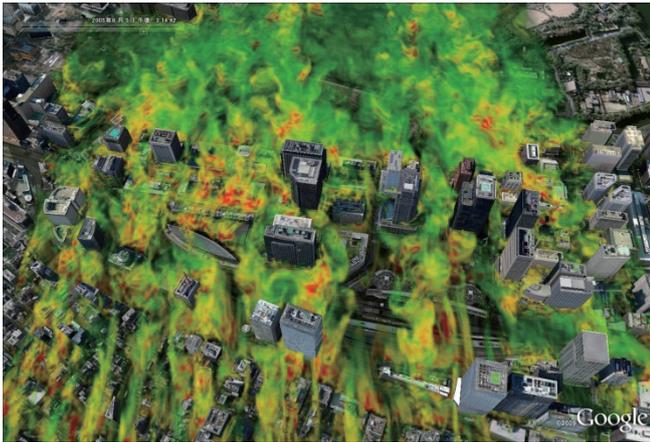


Figure 3. Three-dimensional temperature distribution in a simulation by MSSG with a 5 m computational grid of the conditions of the atmosphere on the periphery of Yuraku-cho, Tokyo, at 3 p.m. on August 5, 2005.

### Advanced Visualization and Perception Research

Scientific visualization that represents simulation data graphically is an essential means to grasp a simulation visually. Visualization techniques are required to make progress to keep pace with simulation techniques as two wheels working together.

The Advanced 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 intelligent 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 retrieve useful information from them.

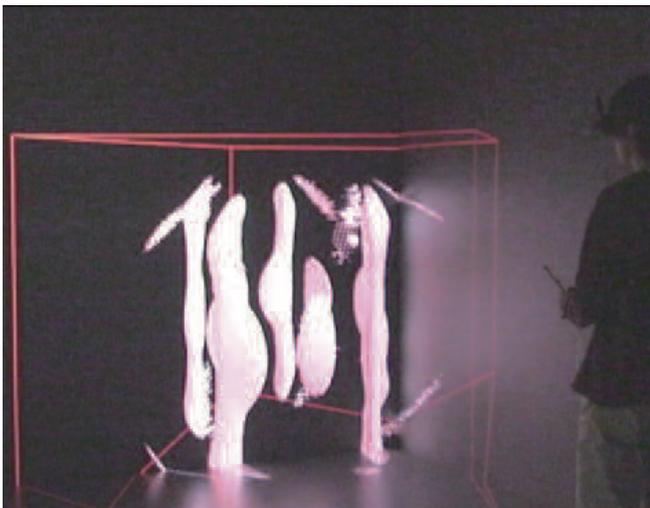


Figure 4. Three-dimensional visualization in a geodynamo simulation by the BRAVE virtual reality visualization equipment: Faster processing for realizing real-time isosurface reconstruction was accomplished by combination with general-purpose graphics processing unit (GPGPU).

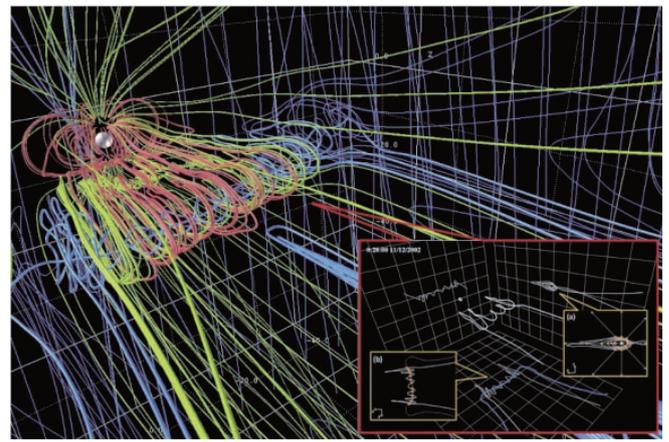


Figure 5. A visualization of a magnetic field computed in a magnetosphere magnetohydrodynamics (MHD) simulation: Visual data mining, which is one of typical intelligent visualization techniques, implements automatic extraction of distinctive magnetic lines of force affecting magnetosphere dynamics and classification of three-dimensional topology.

### 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. Here we shall introduce a simulation result obtained in an atmosphere-ocean coupled model computing with a resolution so high that the storm activities of cyclones and anticyclones and minute eddies in the ocean are represented. Simulation results become useful in the study of each phenomenon only after they have been carefully compared to observational results and their accuracy and features are clarified.

As shown in Figure 6, the model successfully reproduced the North Pacific decadal-scale climate variability, which is one of the typical climate variations. It is characterized by a large scale seesaw pattern in sea surface temperature alternating every 10 years. In other words, when the northwestern Pacific Ocean east of Japan is cold (blue areas), the sea area off west coast of North America from Alaska Bay to the eastern tropical Pacific Ocean becomes warm (red to yellow). Such deviation in sea surface temperature weakens the Aleutian Low. A good coincidence between the model and observations indicates that this atmosphere-ocean coupled model is a useful tool for climate research. At present, vigorous analyses are ongoing in collaboration with JAMSTEC's Research Institute for Global Change as well as universities.

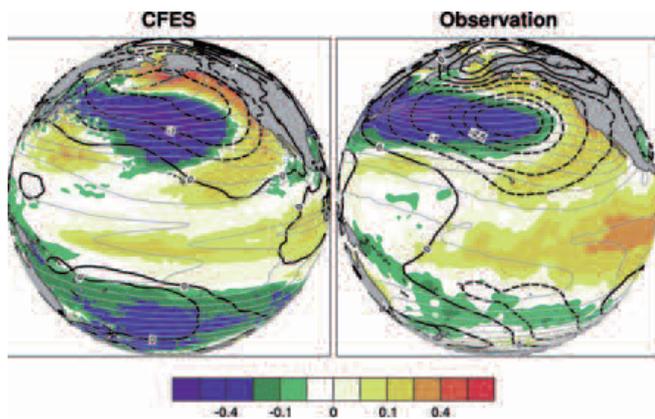


Figure 6. Comparison between a simulation result (left) and an observation result (right) of the North Pacific decadal-scale climate variability.

### Observing System Research and Ensemble Data Assimilation

The team develops an advanced ensemble analysis system fusing observations and simulations and use these system for predictability studies observing system evaluation. The team is composed not only of researchers at ESC but also of those from several programs at the Research Institute for Global Change. The research is ongoing in collaboration with researchers from the University of Maryland in the United States and Doshisha University in Kyoto.

Figure 7 shows Typhoon Haitang in ALERA, an experimental ensemble reanalysis error not only reflects observation density but also varies with the state of the atmosphere. Such error information has never been available in existing techniques, and can be applied to observational system design in order to locate places for effective observation.

This fiscal year, an optimized system, composed of AFES (atmospheric general circulation model for the Earth Simulator) and LETKF (local ensemble transform Kalman Filter) by the University of Maryland, was constructed on the updated Earth Simulator.

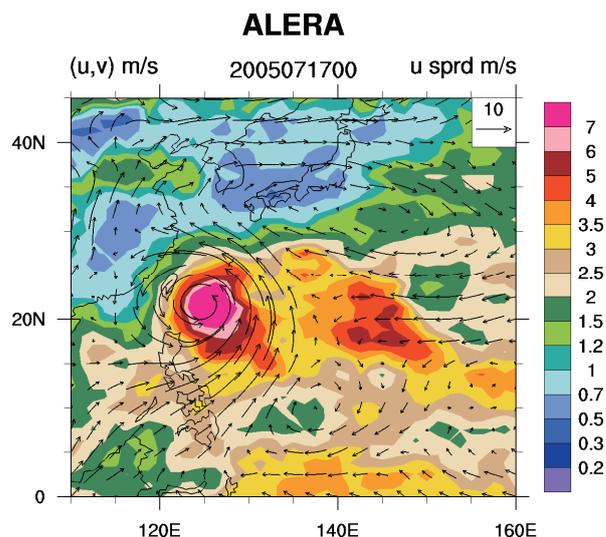


Figure 7. Winds (arrows) and analysis error estimates of zonal wind (colors) at 850 hPa (approximately 1,500 m altitude) at 0 UTC (9 JST) on 17 July 2005.

### Simulation Technology Application Research

We are conducting research to promote application of the world's best-class Earth Simulator to research and development as well as design and production in industry, funded by the Ministry of Education, Culture, Sports, Science, and Technology under the Program for Promoting by Sharing Advanced Research Facilities. In fiscal 2009 we selected 14 projects—including 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. Ltd. Rotating machines—motors—are said to account for more than 50% of national electrical power consumption. Improving the efficiency of rotating machines is one of the important and inevitable themes in environmental issues. On this theme, the company, in cooperation with the University of Gifu and JAMSTEC, succeeded in parallelizing magnetic-field analysis programs by a 3-D finite element method and implementing fast, large-scale analysis of the magnetic field. Figures 8 and 9 show an analysis model of an interior permanent magnet (IPM) motor and eddy current density in the permanent magnet of an eccentric rotorator, respectively (quoted from reports on results of the Earth Simulator Strategic Industrial Use Program). Hopefully, implementation of fast operating-characteristic analysis with higher precision will contribute to shortening the period for design and development of highly efficient rotating machines.

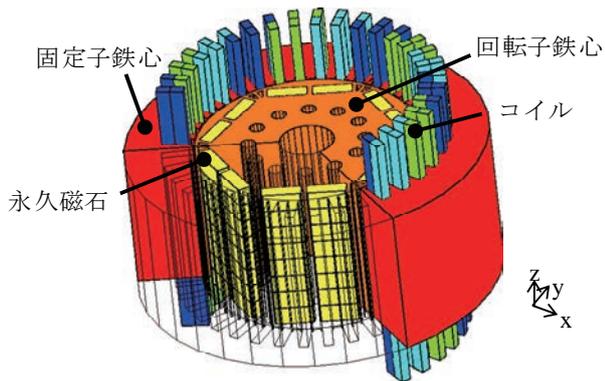


Figure 8. An analysis model of an IPM motor

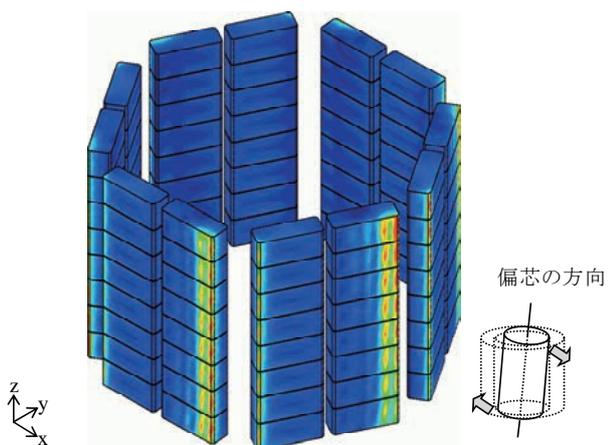


Figure 9. An eddy current density in a permanent magnet (with eccentricity)

### 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. Ltd. (formerly Inctec Inc.) for a technique to reproduce the complex movement of the ink on a computer since fiscal 2005 and has recently developed of a prototype for the ink simulation software.

This prototype enables us to simulate ink's complex behavior, which was essentially impossible to deal with using conventional numerical hydrodynamic techniques, and hopefully it will be used to improve the quality control in printing and also have a wide variety of other applications, such as simulation of the earth's crust and mantle.

### Earth Simulator Confidential-type Use

In principle, information of the Earth Simulator user and their results should be opened to public. However, we have established a fee-based use system in which open of above information and

results is not required. In this system, called as Confidential-type use, we support users in the development of programs and technicalities such as tuning. We also provide a free advance evaluation system (trial use) before making an onerous contract so users can try simulations using the Earth Simulator.

## (12) Data Research Center for Marine-Earth Sciences (DrC)

The Data Research Center for Marine-Earth Sciences has been established in April 2009 with the goal of developing and providing data with new added value produced by integrating various data along with practically useful products in response to needs in research as well as socioeconomy. The center has also prepared a function to manage and open data and sample information obtained by JAMSTEC (fig. 1) to the public. 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, at Nago City in Okinawa Prefecture, opens various data and video information to the public and also conducts activities to increase understanding.

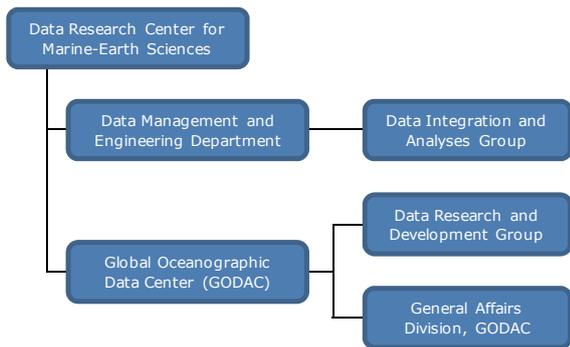


Figure 1. Organization Chart of DrC

### Data Management and Engineering Department

### Data Integration and Analyses Group

### Management and Release of Oceanic Data

In accordance with the Basic Policies on the Handling of Data and Samples (Data Policy) established in 2007, management and lending service of data and samples obtained from vessels and deep-submersible research vehicles proceeded steadily. We prepared a Quick Reference for researchers on vessels to explain the handling rules of data and samples comprehensively (fig. 2).

As for data obtained from vessels, we opened quality-controlled data on oceanic primary production, newly released water temperature and salinity data and track charts obtained by deep-submersible research vehicles (fig. 3). Moreover, we have successively released cruise reports of the past cruises on our Web site.

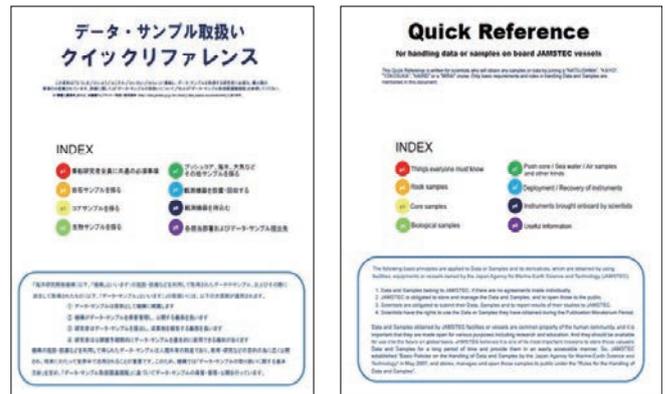


Figure 2. The Quick Reference in Japanese (left) and in English (right)

Dive No.	Lat	Lon	Date(Local)	Dive Scientist	Dive Track	Data	Video	Photo	Sampl.
969	6.3350	133.9550	2006/08/21	Kantaro Fujioka	▶ PNG PDF	CTD		Show	
970	6.3333	134.0650	2006/08/22	Hiroshi Kitazato	▶ PNG PDF	CTD		Show	
971	6.3367	133.9550	2006/08/23	Hideki Wada	▶ PNG PDF	CTD		Show	
972	6.3317	134.0717	2006/08/24	Kazumasa Oguri	▶ PNG PDF	CTD		Show	

Legend: Seawater Sample (blue), Rock Sample (green), Biological Sample (orange), Core (red)

Figure 3. Track charts and CTD data obtained by deep-submersible research vehicles on our Web site.

In addition to the management and lending service of rock samples, we operate the GANSEKI database to open information on its sampling data and analysis data on rock samples, and it started to collaborate with an international portal site. As for sediment core samples, we have released analysis data in collaboration with the Kochi Institute for Core Sample Research, and renewed the Core Data Site. In 2009 we have started implementation of the detailed regulations on the handling of biological samples and started to open metadata obtained from JAMSTEC cruises on the newly constructed Marine Biological Sample Database (fig. 4).



Figure 4. From left: the GANSEKI sample database, the Core Data Site, and the Marine Biological Sample database

As for images obtained by submersibles, a search function “search by index” service had started due to an upgrade of the Deep-sea Image database (fig. 5). On the Data Search Portal Site, where data and samples opened on various JAMSTEC data sites and databases can be searched together, a new search function combining the observation period, the cruise ID, and the type of observation became available as well as search the area chosen by the user (fig. 6).



Figure 5. The “search-by-index” page of the Deep-sea Image database

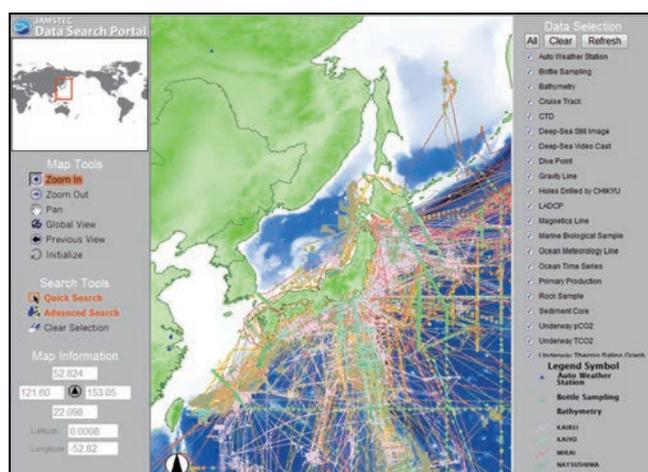


Figure 6. The top page of JAMSTEC’s Data Search Portal Site

## Construction of the Biological Information System for Marine Life

In collaboration with the Marine Biodiversity Research Program of the Institute of Biosciences, we have launched an integrated data provision site for handling diversity and distribution information on marine biology, called the Biological Information System for Marine Life (BISMaL). It is preparing data cooperation with the Oceanic Biogeographic Information System (OBIS) in an international joint project called Census of Marine Life (CoML). BISMaL is also working on cooperation between the Marine Biological Sample database.

## 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 fused. At present, we have developed integrated products for viewing the ocean, atmosphere, and conditions of the ecosystem on a global scale with their applications for management of living aquatic resources, and have constructed a fused database for submarine observation network data and land global observation data.

## Data Integration and Analysis System

The Data Integration and Analysis Group is operating contract services for the Data Integration and Analysis System from the University of Tokyo. We are making exploratory data sets such as ocean reanalysis data, glacier inventory, Asia-area lattice point precipitation data sets, a map tied to the ecosystem, etc., and working on opening and providing data in response to users’ needs reflecting surveys of users. Moreover, we are jointly developing a document metadata constructing tool so that metadata are easily registered by using this tool on the Data Integration and Analysis System introduced by the University of Tokyo as well as preparing data sets to import.

Specifically, as a part of preparation for climate change data, we have developed combination reanalysis data obtained from observation data from 1980 to 2000 and a numerical model (fig. 7), while bearing in mind applications for management of living aquatic resources, we have examined the predictability of the Pacific Decadal Oscillation and other phenomena.

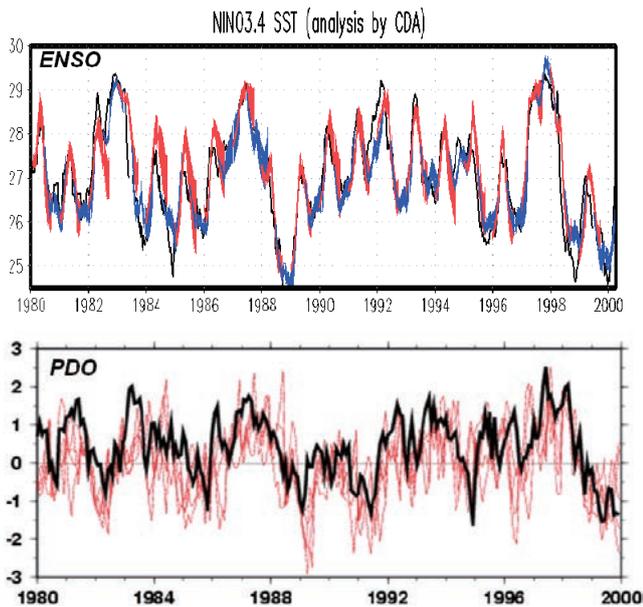


Figure 7. The El Niño index and a time series of the Pacific Decadal Oscillation (PDO) reproduced by 4D-VAR atmosphere/ocean combination reanalysis (surface temperature of the sea in the NINO3.4 region). The black and colored (red and blue) lines indicate the observation values and the results of reanalysis data, respectively

## Global Oceanographic Data Center (GODAC)

GODAC digitalizes, sorts, stores (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. GODAC exterior

## 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 opened to 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 *BlueEarth*, cruise reports, and track charts of the submersibles.

Since its opening in 2001, GODAC has encoded approximately 13,000 deep-sea videos and stored them as video archives. Approximately 21,000 video clips have been indexed and have been open (fig. 9). GODAC also digitalized and released about 87,000 pages of document information.



Figure 9. Videos in the deep-sea video database

GODAC has started to register marine biological information in the Biological Information System for Marine Life (fig. 10) and moved a part of its data to the Marine Biological Sample Database, launched this fiscal year, which releases biological samples obtained by JAMSTEC. GODAC also improved the function of the rock-sample database, which releases sampling information and chemical analysis data on rock samples obtained by JAMSTEC from the deep sea.



Figure 10. An example of biological information on BISMAL

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 (fig. 11) along with its lecture rooms and video system. GODAC also has held 33 seminars since its opening to increase understanding of marine science and technology.

As of the end of 2009, the number of visitors reached 94,704 since the facility opened on November 24, 2001.



Figure 11. Facilities open to the general public

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 10 times—four times in fiscal 2009—and 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.

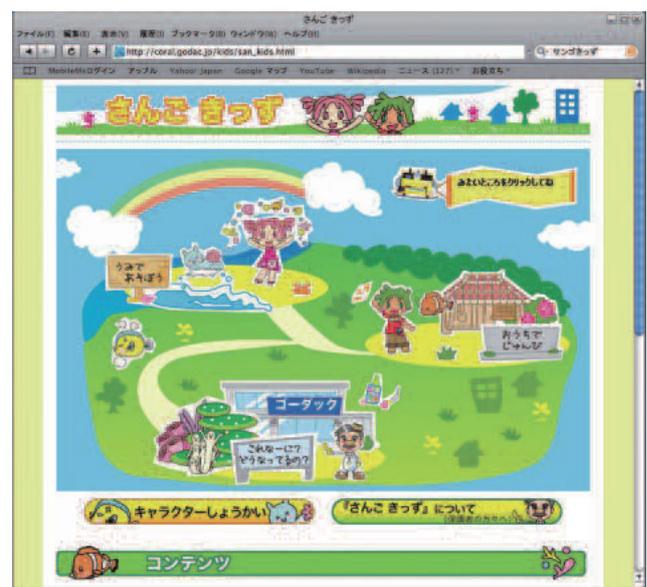


Figure 12. Sango (Coral) Kids

By the end of fiscal 2009, GODAC had also released approximately 580 photographs and videos, taken by the underwater video camera robot, of everyday forms of coral reefs in the Okinawa sea area on the Coral Reef Network Web system (<http://coral.godac.jp>), which helps not only researchers but also the general public understand coral reefs. It also released a new web site, the Sango Kids (fig. 12), which is a page to introduce coral reefs to children, and Investigation and Research at Sekisei Lagoon, a page for JAMSTEC research results (fig. 13).



Figure 13. Investigation and Research at Sekisei Lagoon

In fiscal 2009, GODAC accepted 27 members of 10 entities for work-experience study and internship and participated in the Children's Scientific Ability Training School Program in Okinawa, sponsored by the Cabinet Office, for the purpose of encouraging the adults surrounding children as well as training children's scientific abilities.

### (13) Center for Deep Earth Exploration (CDEX)

As Japan's implementing organization for the Integrated Ocean Drilling Program (IODP), The Center for Deep Earth Exploration (CDEX) operate of the *Chikyū* safely and efficiently and provides scientific and technical support for scientists on board, among other duties. In this way, CDEX is managing and supporting research projects as part of the international scientific program. As part of Japanese National Project, fundamental-technology Integrated Marine Exploration and Earth Observation System, we are also developing the world's best ultra-deep water Riser Drilling Technology.

#### Integrated Ocean Drilling Program

##### Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE)

The deep-sea drilling vessel *Chikyū* has been carrying out the scientific research cruises of Nankai Trough Seismogenic Zone Experiment since September 2007 as part of the Integrated Ocean Drilling Program (IODP). This project has been drilling at several sites in the seismogenic zone in the southwest Japan (Kii Peninsula), which is predicted to cause mega earthquakes such as the Tonankai Earthquake. Geological samples are collected and boreholes are measured. Through this work, the project aims to clarify the conditions of earthquake occurrence at a plate boundary fault and the process of earthquake and tsunami occurrence. This project is divided into four stages. Stage 1 was carried out from September 21, 2007 to February 5, 2008. The Nankai Trough Seismogenic Zone Experiment Stage 2 in fiscal 2009 made two expeditions: Expedition 319 from May 10 to August 31, 2009, and Expedition 322 from September 1 to October 10, 2009.

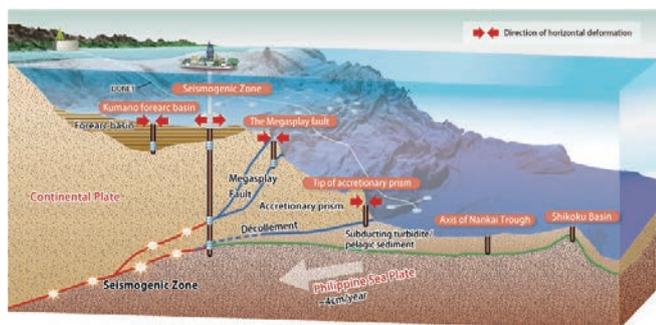


Figure 1. Drill sites of NanTroSEIZE

#### Main Research Achievements in Fiscal 2009

##### • Activity of a mega splay faults

In the Nankai Trough we probed a fault that caused trench-type massive earthquakes and tsunamis and revealed the history of the fault. It is estimated that the fault began its activities 1.95 million years ago and since then has been intermittently active, causing earthquakes and tsunamis. It is strongly indicated that this mega splay faults will be active in future Tonankai and Nankai earthquakes.

##### • Crustal Stress Below the Sea Floor

In the Nankai drilling region, the Philippine Sea Plate is subducting under a Eurasian plate. That is why we expected that the maximum compressional stress would be in the same direction as the plate motion. Among the four drill sites in Stage 1, three sites showed the expected results, but one site, in the upper part of the megasplay, contrary to expectations, showed that an elongation is occurring in the direction of plate subduction, and a normal fault is developing (Fig. 1).

This result, together with model simulations, would help explain the mechanisms that cause Great Earthquakes.

#### Achievements of Stage 2 Expeditions

In the Nankai Trough Seismogenic Zone Experiment Stage 2, which was carried out in fiscal 2009, we drilled at four sites, as shown in Figure 1: the Kumano Forearc Basin, the Megasplay fault, the axis of Nankai Trough axis, and Shikoku Basin. We conducted two expeditions—Expedition 319 from May 10 to August 31, 2009, and Expedition 322 from September 1 to October 10, 2009—and obtained the following achievements.

##### 1. IODP Expedition 319

We conducted drilling operations at three sites: the Kumano Forearc Basin, which is the upper most portion of the seismogenic zone for great earthquakes; the megasplay fault; and the axis of Nankai Trough (Fig. 1). The operations of expedition saw a collection of core sample (a cylindrical geological sample) and geophysical data obtained by Logging While Drilling.

##### • Success in the first riser drilling in the history of scientific drilling

In the Kumano Forearc Basin, which is directly above the

massive earthquake generation zone, we successfully drilled down to 1,603.7 m below the seafloor at a water depth of 2,054.0 m using riser drilling for the first time in the history of scientific drilling.

A variety of new measurements taking advantage of riser drilling capability were also conducted in the Kumano Forearc Basin. Real-time analyses of gas and cuttings recovered from circulated drilling fluid were conducted in the shipboard laboratory. This expedition allowed to measure a stress and pore fluid pressure in the borehole. These data are critical to understanding the mechanics of active tectonic fault zones. The results are expected to help provide deeper insights into subduction zone earthquakes.

We also measured specific resistance, formation density, porosity, velocity of formation, natural gamma ray, fluid pressure, borehole gradient in the megasplay Fault exit and the axis of Nankai Trough. Logging While Drilling is a technique to measure formation properties. With this technique, core is not sampled; however, geophysical data at the drill bit can be obtained almost in real time through continuous in-situ measurement during drilling.

- Success in two-ship subsea geological structure investigation

We carried out vertical seismic profiling (VSP) using two ships, the *Chikyū* and the deep-sea research vessel *Kairei* (Figs. 2 and 3). VSP obtained accurate details of the geological structure of the plate boundary system and the accretionary prism. An air-gun array on the JAMSTEC research vessel *KAIREI* generated elastic waves, which traveled through the formation to be recorded on the borehole and seafloor instruments.

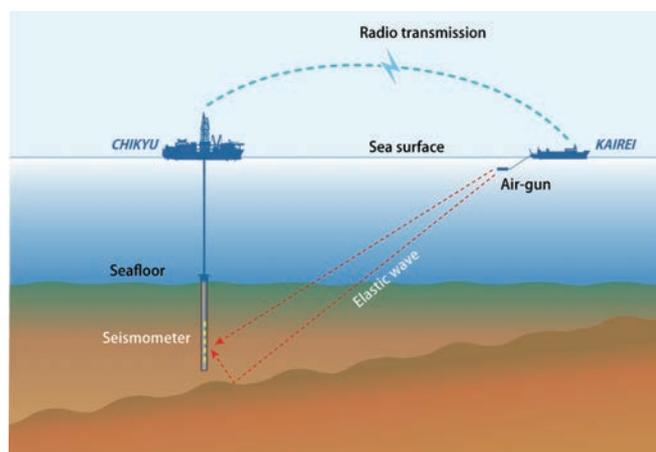


Figure 2. Investigation of subsea geological structures using two ships



Figure 3. R/V KAIREI shoots the air gun for the vertical seismic profiling experiment with the CHIKYU.

- Drilling and monitoring of a mega splay fault

At megasplay fault exit, drilling crossed one of the major faults in the plate boundary, known as the megasplay fault at a depth of about 400 meters below the seafloor. This fault is a prime candidate for tsunami generation, and may have slipped in historical great earthquakes. The borehole was then cased and utilized for observatory operations for the future long-term borehole monitoring. During the drilling operation, scientists documented rock physical properties by Logging-While-Drilling and gain information about stresses in the formation. In the drill holes of Nankai drilling, seismometers and other long-term borehole measuring instruments will be installed to be used together with the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) for real time observation of the trench-type massive-earthquake hypocentral region.

Following these operations, scientists made preparations for the future installation of a Long-Term Borehole Monitoring System (LTBMS).

## 2. IODP Expedition 322

Expedition 322 conducted riserless drilling to investigate input material before being transported to the seismogenic zone for large earthquakes. The drilling operations were carried out at two sites in the Shikoku Basin, the back-arc basin of the IZU-Bonin volcanic chain, where the Philippine Sea plate dives down at Nankai Trough.

Scientists observed, measured, and analyzed cores collected at these two sites in onboard laboratories to characterize sediments and basement rock before being transported to the seismogenic zone at the Nankai Trough by the subduction of the Philippine Sea plate, as follows:

- Two types of groundwater running beneath the seafloor

The analysis of pore water retrieved from the formation confirmed two types of groundwater indicating the multiple sources and migration paths of fluids. These results have important implications for understanding the properties of fluids within the seismogenic zone.

- Volcanic material supply from the Izu-Bonin Arc

In the formations of 5 to 11 million years old, coarse volcanic sediments were confirmed in large quantity (Fig. 4b). Architecture and composition of these sediments suggests that these sediments may have been transported from the easterly located volcanic chain (Izu-Bonin Arc) to the westward, via submarine canyons or alluvial fans spreading on the seafloor.

- Sediment supply from southwestern Japan

Sandstones found in formations up to 1.1 to 1.6 million years old contained abundant minerals derived from land, implying the extensive supply of sand to the Shikoku Basin from the Japanese islands (Fig. 4c). Such sedimentary features suggest a wide distribution of volcanic sediments originated from Japanese Islands.

- Identification of sediment /basement interface, and the collection of basement samples

It is important to investigate input material before being transported to the seismogenic zone for large earthquakes. We identified an interface of early Miocene sediment (approximately 1.6 to 2.3 million years ago) and basement rock at 540 meters below the seafloor at a water depth of 3,510.7m and successfully sampled basaltic pillow lava rocks that make up the basement (Fig. 4a). These rocks are considered to form a sticking (asperities) after they are transported to the seismogenic zone. Studying their petrological, mineralogical and geotechnical properties prior to subduction is expected to contribute significantly to the understanding of rupture dynamics in the seismogenic zone.

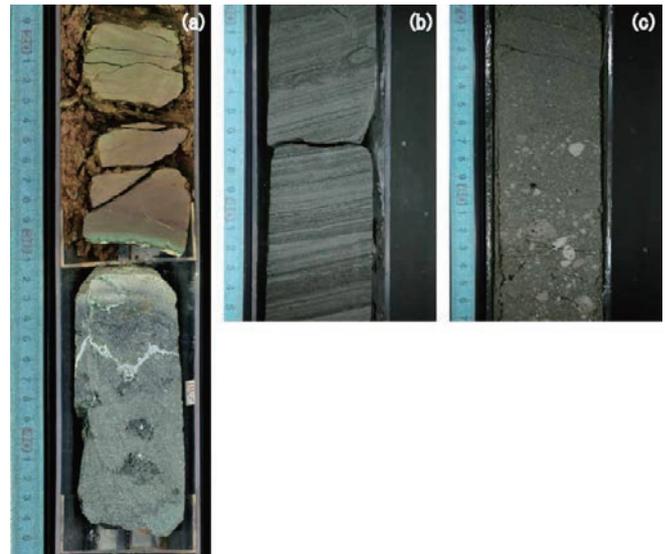


Figure 4. Pillar-shaped geological samples (cores) obtained by drilling near the Shikoku Basin. (a) Boundary of sedimentary rock (upper half) and basaltic basement (lower half) obtained near the Shikoku Basin. (b) Tuff of about 8 million years ago. Tuff core containing pumice and amphibole from the Izu-Bonin Volcanic Zone. (c) Volcanic sandstone of 14 million years ago. The core is of the sandstone layer containing volcanic sediments piled up on the seafloor in the period when there was strong volcanic activity in the central Kii Peninsula.

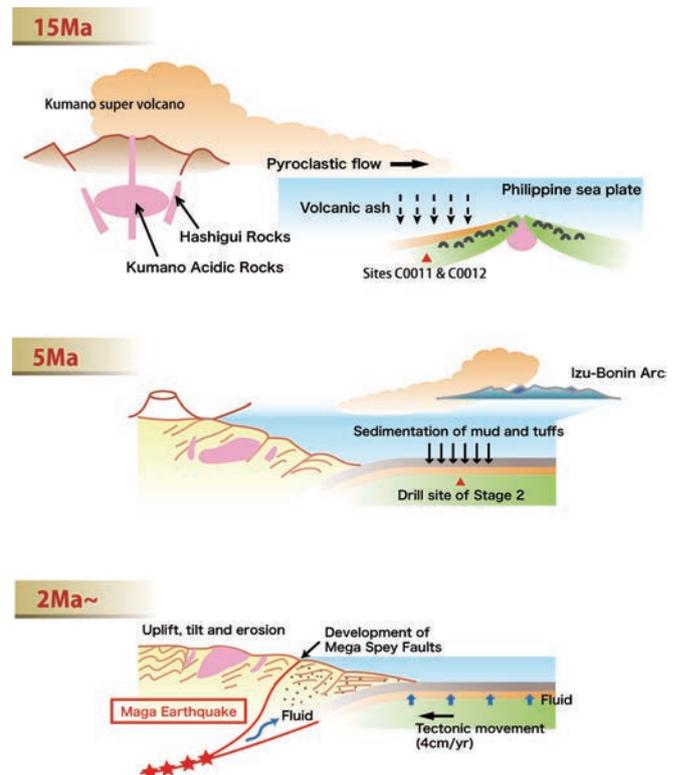


Figure 5. History of the drilling sites.

## (14) Observing System Research and Technological Development Laboratory

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 is conducting the following research and development projects:

### Southern Ocean Buoy Laboratory Unit

At the Southern Ocean Surface Buoy Lab Unit, we are developing the Southern Ocean Surface Buoy Observation System, which can be operated in the Southern Ocean under strong winds and waves and low temperatures, by applying the ocean buoy technology we have accumulated so far.

In fiscal 2009, as measures against strong winds and waves, we developed a program for dynamic behavior analysis to understand the behavior of the upper floating part and the mooring cable of an observation system, taking into account the influence of waves. Also, for measures against low temperatures, we are exposing samples of upper-part materials to low temperatures for extended periods and examining how material properties change (Fig. 1). Furthermore, we carried out icing tests on the upper structures (Fig. 2), weather sensors, and anti-icing paint surfaces to know whether and how icing occurs, and we examined how to prevent icing. From now on, we will further carry out basic tests, develop technologies for strong winds and waves and low temperatures, and aim to install observation systems in the Southern Ocean.



Figure 1. Low-temperature exposure test



Figure 2. Icing test on structures above the sea surface

### Autonomous Profiling Shuttle Development Laboratory Unit

At the Autonomous Profiling Shuttle Development Laboratory Unit, we are doing research and development on a underwater vehicle that carries out oceanographic observation between the sea bottom and the sea surface within a fixed area over a long period of time.

The vehicle 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. Figure 3 depicts the image of its operation. When floating on the surface, it measures its position by 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 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.

In fiscal 2009 we carried out concept design of methods of motion control, maximum depth, power consumption, weight, buoyancy, shape, and so on. At the same time, we started development of the buoyancy engine control unit, which is an important underlying technology. As for the buoyancy engine, we will make good use of the buoyancy engine developed for the great-depth profiling float by the Research Institute for Global Change.

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 of such hydrodynamic characteristics, we started simulation on movement characteristics and started making a half-scale model for hydrodynamic experiments using a towing tank.

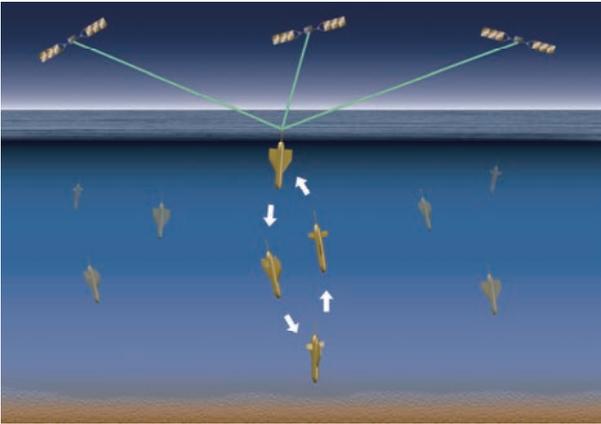


Figure 3. Image of the Autonomous Profiling Shuttle



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

Research Advancement Division  
Advanced Research and Technology Promotion Department  
Headquarters  
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)  
2-15, Natsushima-cho, Yokosuka, 237-0061, Japan